Differentiating between context and hot air – with consideration to *Sustainable Energy - without the hot air* by David JC MacKay

Submitted by Paul Michael Robins to the University of Exeter as a dissertation towards the degree of Master of Science by advanced study in Energy Policy and Sustainability

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I certify that all material in this dissertation **which is not my own work** has been identified with appropriate acknowledgement and referencing and I also certify that no material is included for which a degree has previously been conferred upon me

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Abstract

Sustainable Energy – without the hot air by Professor David MacKay is a new take on estimating the potential of non-fossil fuel energy sources for the United Kingdom. The main aim of the book has been to try to answer important questions, such as whether it is possible to live on our own renewables. In doing so, MacKay has also tried to make the book as bias-free and as easy to understand as possible, which would enable the general public to partake in informed debates on energy policy. With public opposition often a roadblock on a path to change, it is a good idea if more people are aware of the details of technologies and the overarching rationale for them. Studying the physics behind our demands and potential sources, MacKay has even created his own set of units to evaluate, in a fair manner, what is required and what is possible.

For the large part, MacKay has been successful at making energy simple to understand, and for those new to energy policy, the book makes an excellent introduction. However, the process of simplification has led to errors, unfairness and a restriction on the usefulness of the book. His analysis on wind energy seems unfair and to have underplayed its potential, and despite his insistence on numbers, his descriptions regarding nuclear neglect some of the same drawbacks that other renewables face. Reducing each technology to a single number lacks the context regarding how difficult it would be to implement any of his or anyone's 'plans', how long they would take, how suitable each technology is to different locations, and so on. Ultimately his decision to generally ignore social, economic and environmental factors means his comparisons of the technologies have little use, as present day decisions take into account these factors and we also do not know for certain what the conditions will be in the future.

However, the book itself does still have some use. It clearly describes the need for change and highlighting some of the difficulties change faces, as well as concisely explaining each technology, setting straight some misconceptions and suggesting the better ways to reduce your energy usage. But those looking for a guide on what should or will be built now, would be better off looking elsewhere for the necessary context.

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Acknowledgements

I would like to thank Catherine Mitchell for her support as dissertation supervisor.

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Abbreviations

BWEA – British Wind Energy Agency

REF – Renewable Energy Foundation

SEWTHA – Sustainable Energy – without the hot air

1

Introduction

Generally speaking, simple is regarded as easier to understand (as it is the first definition in the Oxford English Dictionary[1]). Simple can also be more reliable, cheaper, quicker etc than an equivalent complex solution with more parts to it (either moving parts or criteria it has to satisfy). It is therefore no surprise we might favour simple over complex, and something that is easy to understand can be a powerful force. Simple instructions like "*Mirror, Signal, Manoeuvre"* and *"Stop, Look, Listen*" can be considered to have proven themselves over time as effective learning instruments, and the traffic light colours - red, amber and green - are a simple way of giving advice to either motorists or even food shoppers. Indeed, even in science simple has its followers: "Ockham's razor" is the name given to the belief that the simplest answer is usually the right one (although it is certainly not always true and holds no scientific weight by itself). There are in actual fact, a wide variety of meanings of simple, from clear and understandable to ordinary and stupid. Because simple is almost never an objective term, different people will have different opinions on what can be called a simple energy system, for example.

1.1 Background

In December 2008, Professor David JC MacKay of Cambridge University published his book: "*Sustainable Energy – Without the Hot A*ir" (SEWTHA). His desire to write the book stemmed from his belief that the energy policy debate was clouded with myths, emotions, propaganda and so forth. The result of these was that progression towards a sustainable energy system - and successfully mitigating climate change - was hindered, to the detriment of everyone. In taking a general overview of current energy demand and future energy supply, he decided to ignore the economic and environmental concerns that would add complexity and arguments. In other words: making it simple.

As he mentions in his book, the economic and environmental concerns don't affect the *theoretical potential* of a source, only what is later realised. But the value of that potential relative to current demands, gives an indication of the shape of future energy policy. If the current demand outweighs future potential, we have to consider serious changes to society and our lifestyles, vice versa and we might not have to.

By sidestepping the discussions over what percentage can be realised and simply giving numbers for pure potential, he aims to give people a neutral source of information on each energy source. This would allow people to have a better estimate how much energy they currently use and see what might be required of non-fossil fuel sources in the future, to provide the same levels of service.

From seemingly out of nowhere, the book has been a success (it reached a sales rank height of 47th in the Amazon books section[2]) and so brought informed energy policy discussions closer to the general public. It also brought Professor MacKay publicity and admiration[3, 4]. This success arguably provides evidence for the case that people want - or maybe even need - simple in regards to energy policy, and that there are those willing to provide it.

Another definition of simple is that it is free from deceit - in this case without the misinformation and propaganda as mentioned earlier. So if the numbers are accurate and portrayed in a fair manner, then in one way, MacKay has definitively made energy policy simple. But can energy policy be simple according to a definition of being easy to understand? Making something easier to understand increases the chances and number of people understanding it, and as public perception can sometimes play a decisive role in determining the success or failure of projects and applications - for example the suspension of a planned Eden Project wind turbine[5] and Vestas' vice president Peter Kruse saying:

"*You have some of the best onshore sites on the planet but they are strong, the faceless Nimbys [not in my back yards]*," [6]

Then there is a clear importance of making something easy to understand so as to widen the audience.

This ease of understanding requirement explains the estimation nature of the book, numbers to 5 significant figures or without real world comparisons might be too abstract or off-putting for the casual reader. Being presented with a single figure for a technology (e.g. 40kWh/d/p for using a car) is quicker and easier to comprehend than having to estimate the number yourself, even if multipliers or online calculators are given to you. That single estimated figure won't be exactly correct, but it should be within an order of magnitude, and making that number increasingly accurate would require more effort for disproportionately less knowledge (or other benefits) gained. For example, estimating my car mileage at 47.34km per day, rather than 50km per day, requires more effort but changes the situation very little – especially when many reduction measures are percentage based, not absolute (e.g. properly inflated tyres could save upwards of 1% of fuel consumption[7]). The finer details might be more important for companies or governments who operate on larger scales and with finer margins, but for individuals, simple is good and easy.

Understanding is also part of the reasoning behind MacKay's creation of a new unit of measurement, the 'kilowatt hours per day per person' (kWh/d/p). This unit not only tries to compare all sources on an equal footing, but to also allow people to better understand their relationship with energy. So in the same way that 1 kilogram is a bag of sugar, 2 metres is about the height of a door or 2 litres is a bottle of coke, 1kWh/d/p is approximately a 40W light bulb left on continuously. Thus readers who don't know the difference between a megawatt and a gigawatt, or what a load factor is, can compare the numbers a lot easier.

However the problem with the 'easy to understand' definition of simple, is not just the lack of objectivity as mentioned earlier, but also that a large number of variables are an argument for inherent complexity. For example, guessing which side a coin will land on is simple - heads or tails - but correctly guessing all 6 numbers out of 49 in the lottery is a lot harder. It can be argued that it is still simple – the basic premise is easy to understand – but being successful is quite a different matter. Indeed with energy policy, there are a large number of variables involved: the technology and their characteristics (e.g. energy security worries, requires fuelling), the locations (e.g. windy areas, source of cooling water needed), the demands of each and every energy user and when (e.g. is it dispatchable, can it load follow) and so on. So could there be a successful, simple answer to any energy related problem?

A simple solution could mean either having only significant sources (for example, the Severn Barrage generating 5% of UK's electricity by itself[8] despite protests that there are better alternatives that generate less[9]) or a one-size-fits-all approach (a single technology represents an arbitrary majority of generation). However this approach may not be the best solution in every case. Even if this one-size-fits-all solution is the optimal one (following consideration of build speed, energy payback time, generation efficiency, cost, lifespan and so forth), it still misses the benefits of a diverse range of energy sources. This diversity can bring energy security advantages - notably reliance on gas wasn't such a big problem until the North Sea output started falling and the lack of gas storage added to price volatility[10, 11] - but would a diverse solution still be 'simple'?

With electricity generation capacity in the UK split into one-third gas, one-third coal and one-third nuclear and renewables[12] it could be argued the UK has a diverse electricity generation mix. Granted the total energy mix may be different and not all of the capacity was built since the market was liberalised in the 90's, but companies seeking to diversify their portfolio (e.g. Centrica – mainly a gas company – buying part of British energy[13] – a nuclear one) suggest that in the real world, a 'complex' set of solutions that reduce a company's exposure to risks, might be preferable. Economies of scale might favour a single, simple solution, but having diversity wouldn't inherently impede achieving economies of scale as well.

The general public currently may be largely unaware of how or where their electricity has come from (instead focusing on the services that energy provides), indicating that while public understanding might have benefits, it has not been necessary for a working energy system. Resource depletion and climate change mean the requirements for a successful energy system might change, not just to a low carbon version, but to a more publicly involved one - as the emergence of the 'Not In My Backyard' (NIMBY) phenomenon may support and benefitting from energy efficiency may require. Deference of decisions on energy matters may or may not remain the common stance for the general public, but greater understanding is never a bad thing.

This is where MacKay comes in. Books that explain things simply – such as SEWTHA – could help provide this understanding and would therefore be important cogs in the energy policy machine.

1.2 Aims and Objectives

The aims and objectives of this dissertation are:

Considering the only objective definition of simple is '*free of deceit*', has MacKay presented his data and analysed it in a clear and unbiased manner?

Ease of understanding was mentioned as a potentially vital important characteristic for a book on energy policy, so does SEWTHA make energy policy easy to understand?

Simplifying things to make them easier to understand might mean making compromises, so has any context been lost or misconstrued by simplification?

Finally, are the numbers MacKay has used reasonably accurate?

1.3 Structure of the Study

Due to time and word count limits, not all of SEWTHA will be covered in this dissertation. Focus will be primarily on MacKay's estimations of the sources of production (rather than demand), because the aim of the book is to consider if renewables are able to meet our current demand (demand also has official figures for comparison).

The sources of production looked at will be wind and nuclear, because both are relatively mature technologies so not only is there data available for discussion and comparison, but also because they are considered important at the present time due to efforts to meet carbon dioxide targets.

MacKay's analysis of how production and demand stack up will also be looked at to see if his interpretation gives a balanced viewpoint to the reader.

Each chapter will also be considered separately and in the same order as SEWTHA for consistency.

2

Cars

2.1 Introduction

We start with the first source of demand in *Sustainable Energy*, cars. MacKay assumes the average car user travels 50km per day with a car capable of doing 33 miles per gallon and that therefore the energy requirement is 40kWh/d/p. How true are these numbers and how fair is the context in which they are set?

2.2 Average versus Average

MacKay has estimated the energy usage for the average car user, not average car use per UK citizen - which would include non car users. This is to prevent the average car user from reading a figure that would give them the sense that their energy requirements are lower than is actually true. The reverse of this is that non car users - who haven't read the notes at the end of the chapter - might believe their personal energy requirements are higher due to assuming that 40kWh/d was their 'share of the burden'.

Out of interest, the disparity between the mileage of average person (30km/day) and average car user (50km/day) is almost a factor of two, and in the notes MacKay states a figure of 24kWh/d/p as the per person average, based on that ratio. But clarification from his wiki site confirms 13kWh/d/p as the average energy use of car driving per person, rather than 24kWh/d/p which would be average road transport per person[14]. Using 13kWh/d/p instead of 40kWh/d means MacKay's final total estimate would go from 195kWh/d to 168kWh/d, which can be considered acceptable as it doesn't change the magnitude of the total. Regardless, not every demand category has been divided by 60 million citizens either and MacKay provides a total averaged-per-person figure of 125kWh/d/p, so as MacKay has also stated his conditions in the notes section, the use of calculating for an average car user can be considered a fair decision.

2.3 Fuel Economy

What about the fuel economy? MacKay notes the average figures from a Department for Transport document from 2007 are in the 30-40mpg bracket. Have vehicles improved much since 2007? Well - to follow in the footsteps of MacKay and estimate - the most popular car in the UK is the Ford Focus[15] and a mid-range (1.8 litres), post 2009 model has a combined miles per gallon of 40.4[16], well within considered tolerance.

2.4 Conclusion

It is considered that MacKay has estimated cars in a fair manner due to the validity of his estimates and his stating of what group his estimates apply to. Miles per gallon and distance are concepts generally well understood by the general public, so there isn't any trouble regarding understanding, as MacKay has kept to these units.

3

Onshore Wind

3.1 Introduction

This chapter looks at how MacKay has studied onshore wind in chapter 4 of his book. He estimates that wind turbines covering 10% of the UK land area would generate 20kWh/d/p - or half of what an average car driver uses - and that this is based upon an average wind speed of 6m/s which equates to a power per unit area of 2W/m2. So are these numbers a fair reflection?

3.2 Average Wind Speed

In the chapter on cars, MacKay estimated energy usage for the average car user, not the average car use per person, because of the affect non-car users would have on the figure. However for wind he uses an average UK wind speed, rather than a figure for the areas where wind farms would likely be placed (a figure that wouldn't be affected by areas of lower wind speed with no wind farms). MacKay states that he's not interested in 5% increases, rather factors of 2 or 10 (MacKay, p.17) as the aim of the book was to give a clear and general overview. That's completely understandable, so does a small change in the wind speed used, change the potential extractable energy by an equally small amount?

Well, the energy in the wind varies with the cube of the wind speed, so small discrepancies in assumptions are magnified as higher speeds hold disproportionately more energy. This means that although 6m/s might be the average figure, the figure for the weighted average – and thus a truer potential of wind - will be higher. Table 3.1 has been constructed using the formulae MacKay has used (MacKay, pp. 264-265), but for a range of wind speeds from 3m/s to 12m/s. Figure 3.1 has also been included to graphically show the data from Table 3.1, highlighting the cubic increase in power density as wind speed increases.

Wind Speed (m/s)	Power in Wind (W/m^2)	Power per unit area (W/m^2)
3	17.6	0.3
4	41.6	0.7
5	81.3	1.3
6	140.4	2.2
7	223.0	3.5
8	332.8	5.2
9	473.9	7.4
10	650.0	10.2
11	865.2	13.6
12	1123.2	17.6

Table 3.1

Power varies according to the cube of the wind speed

Source: Author

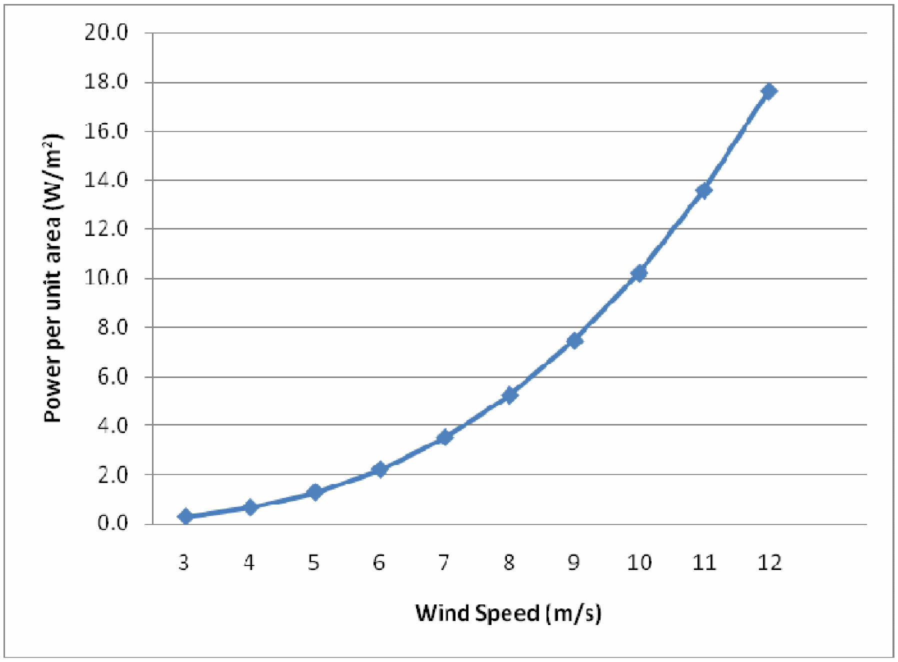

Figure 3.1

Power-per-unit-area against wind speed

Source: Author

MacKay does mention that it would be best practise to use the average of the cube and not the cube of the average, but says this is complicated because wind turbines are designed to be more efficient at certain wind speeds than others (MacKay, p.266). He also mentions that some sites have average speeds lower than 6m/s (MacKay, Figure B.6, p.265), in effect offsetting those with higher speeds. However this still seems slightly unfair, as MacKay even mentions that 33% of UK land area has mean speeds of 7m/s (MacKay, p.268) but still uses a mean speed of 6m/s when:

"*covering the windiest 10% of the country with windmills*" (MacKay, p.33)

The use of 6m/s is even more contentious because this appears to be at a 10m height (MacKay, Figure B.6, p.265). MacKay does cover wind shear formulas and the topic of height affecting wind speeds (MacKay, p.266) and states that doubling the height increases the power of the wind by 30%, but doesn't incorporate this information into his estimation of wind power.

To take an example, High Volts wind farm - built in 2004 - is one of E.ON's most recent onshore wind farms and uses 2.6MW turbines that have a hub height of 60m[17]. Using MacKay's graph of height versus wind speed (Figure 3.2) shows that 60m corresponds to (depending which formulae you use) either side of 8m/s. Table 1.1 indicates that 8m/s would give a power per unit area of 5.2W/m2 – two and a half times the power MacKay estimated using 6m/s at a height of 10 metres.

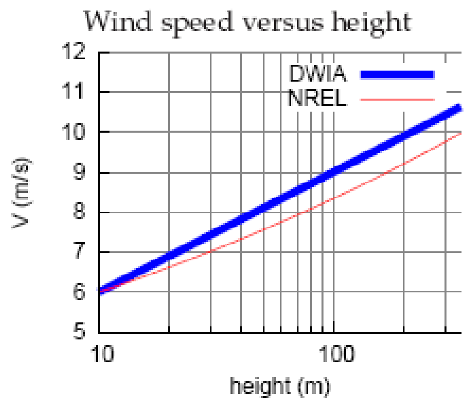

Figure 3.2

Wind speed versus height according to two separate formulae for wind shear

Source: MacKay, D. 2008, p.266
DWIA = Danish Wind Industry Association;
NREL = National Renewable Energy Laboratory.

3.3 Real World Data

However following the criticism that he has portrayed wind unfairly, MacKay has written a number of blog posts on the subject of what current wind turbines are actually delivering using real world data[18].

Figure 3.3 shows power-per-unit-area (taking into account load factors) against rotor diameter for around 75 wind farms (with 7 or more turbines and at least a year of data at full operation), with the range between 2 and 3 W/m2 highlighted. The graph shows the data also split according to the country it is based in and includes a few offshore points as well. Across all the data points there appears to be a positive trend for increasing power as rotor diameter increases, however this is because the data points with greater power-per-unit-area are predominately from Scottish hilltops which likely have better wind resources.

Looking at the locations individually shows the three offshore farms are almost completely unaffected by increasing rotor diameter, while Welsh hilltops and English fenland also have very little power variation. As MacKay states (MacKay, p.265), larger diameter turbines need to be placed further apart from each other - because of wake effects among other reasons - so this will cancel out the benefits of increasing rotor diameter. English coastal & hilltops do show a possible positive trend, but since this relies on only a couple of data points for at larger rotor diameters, this is inconclusive until they are looked at in greater detail.

We move on to Figure 3.4, where power-per-unit-area is compared to wind farm area, and the 2 to 3W/m2 band has been highlighted as before. What is again clear is the lack of correlation with the power per unit area. Offshore, Welsh hilltops and Scottish hilltops all have near constant power per unit areas as the wind farm area increases. English coastal & hilltops is again different, spread vertically rather than horizontally, however this doesn’t indicate any correlation between wind farm area and power per unit area.

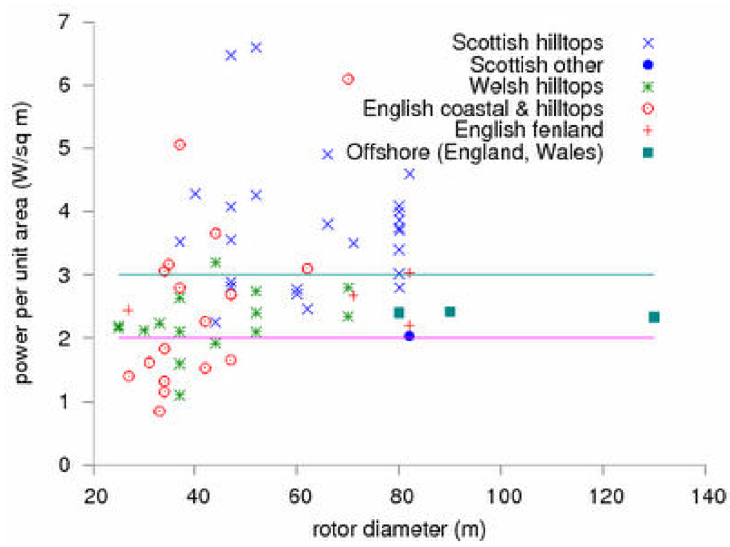

Figure 3.3

Power per unit area plotted against rotor diameter for 75 wind farms. MacKay uses this to validate his estimate of 2W/sq m as a good average.

Source: David MacKay, 2009. *Wind farm power-per-unit-area data complete.* [Online] Available at: http://withouthotair.blogspot.com/2009/05/wind-farm-power-per-unit-area-data.html [Accessed 27 August 2009].

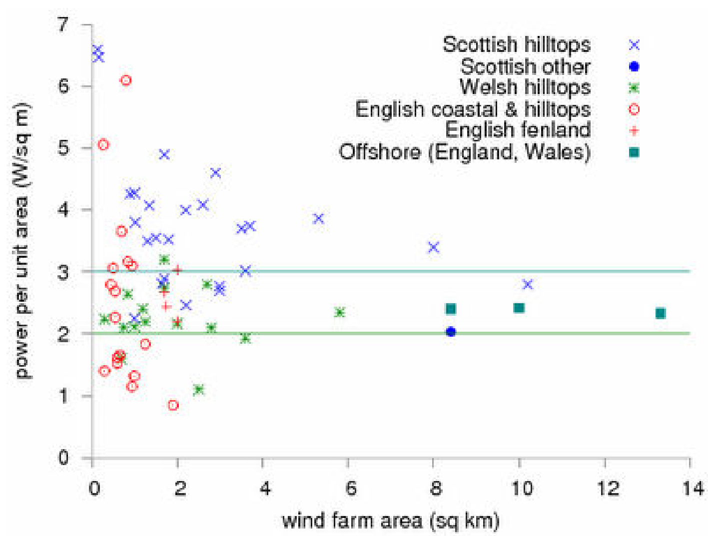

Figure 3.4

Power per unit area plotted against wind farm area for 75 wind farms. MacKay uses this to validate his estimate of 2W/sq m as a good average.

Source: David MacKay, 2009. *Wind farm power-per-unit-area data complete.* [Online] Available at: http://withouthotair.blogspot.com/2009/05/wind-farm-power-per-unit-area-data.html [Accessed 27 August 2009].

Although there is no data for wind farms above 2 sq km, the variation in power output suggests a wide variation in the wind speeds between English coastal & hilltop wind farms. As such, it can be assumed that any possible positive correlation in Figure 3.3 could be explained by a number of factors:

- Variations in local wind speeds. As we know from Figure 3.1, wind can speeds have a large impact on power output, so the natural variation could artificially be creating any sense of correlation even with 20-plus data points for the 3 main locations.
- Different turbine sizes. Larger rotor diameters might not be important, but higher hub heights can access stronger winds.

- Some sites have a stronger and more focused prevailing wind than others, allowing turbines perpendicular to the wind to be spaced closer together. For example, the English wind farm with a high power per unit area of $5W/m^2$, is Royd Farm, and has been circled in Figure 3.5. The rotor diameter for these turbines is 37m, but the distance between turbines within the two columns is estimated to be around 80m, much less than the rule of thumb that states 5 times the rotor diameter is appropriate.

These factors could be exaggerated by the small scale of (at least some of) the wind farms covered where high winds are concentrated over a small area, although MacKay's decision to consider wind farms of at least 7 turbines was presumably expected to significantly reduce this affect.

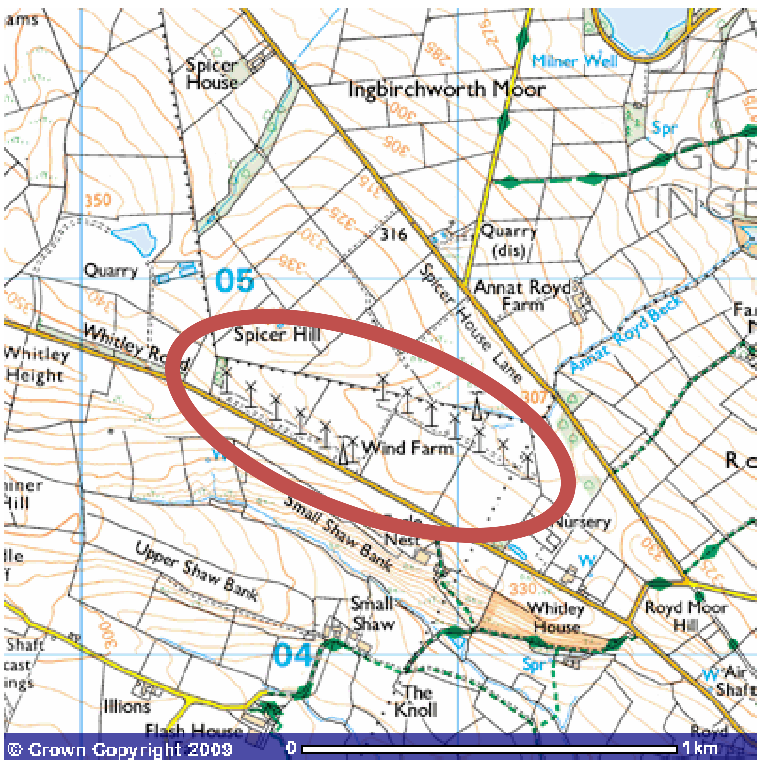

Figure 3.5

Ordnance Survey Map of Royd Moor wind farm (circled), showing the close proximity of turbines within each row.

Source: Ordnance Survey, 2008. *Get-a-map, 1:25000* scale

Figure 3.6 is from MacKay and shows the averages for each location category from Figure 3.4. They tend to support his conclusion that wind farms provide around $2W/m^2$, although it should be noted that while MacKay is sceptical about wind's potential, $2W/m^2$ appears to be a minimum from an average site in any location in the UK.

"*I fear 6m/s was an overestimate of the typical speed in most of Britain*"

(MacKay, p.265)

Indeed, Scottish hilltops average over $3W/m^2$ which is 50% greater than the power-per-unit-area estimate from MacKay. Figure 3.7 is from the British Wind Energy Association, and charts the wind speeds at 25m heights. It shows how Scotland (particularly the hilltops) has strong winds far in excess of 6m/s, so if 10% of the country was required to be covered with wind, Scotland would likely have a significant proportion of that. However there will no doubt be difficulties involving public opposition and grid access due to the remoteness and natural beauty of large areas of Scotland.

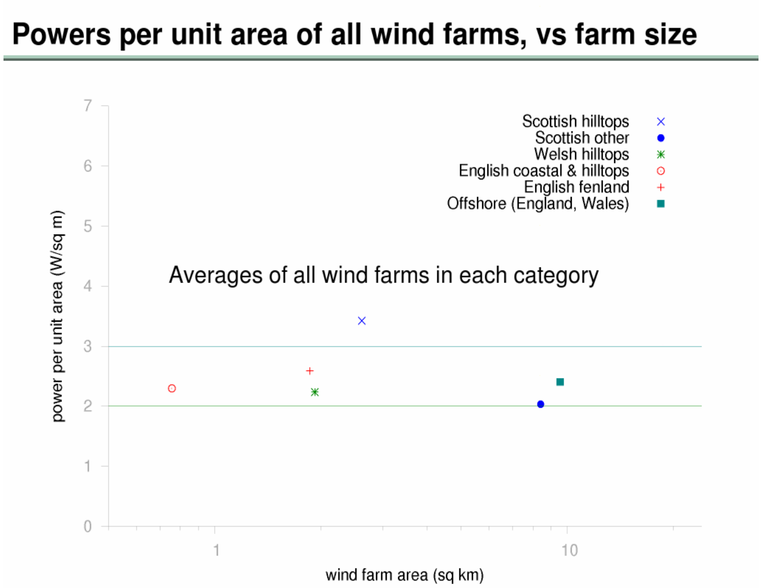

Figure 3.6

Power per unit area plotted against the average wind farm area for each category. MacKay uses this to validate his estimate of 2W/sq m as a good average.

Source: David MacKay, 2009. *Wind farm power-per-unit-area data complete.* [Online] Available at: http://withouthotair.blogspot.com/2009/05/wind-farm-power-per-unit-area-data.html [Accessed 27 August 2009].

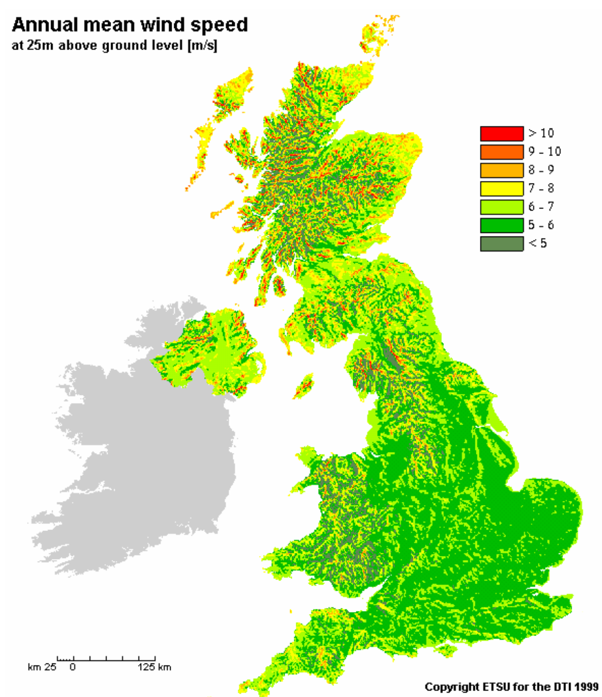

Figure 3.7

Annual mean wind speed at 25m

Source: British Wind Energy Association. Available at: http://www.bwea.com/noabl/ [Accessed 27 August 2009].

For evidence that Scotland is likely to bare the majority of wind expansion, Figure 3.8 is from the British Wind Energy Association and shows wind farms currently under construction. 21 out of 28 onshore wind farms are being built in Scotland, or 741.2MW out of a total of 832.7MW. This implies that the majority of onshore wind power added in the UK in the near future will be around the 3.4W/m^2 average that MacKay showed in Figure 1.6.

Wind farms currently under construction

Onshore

England	1	26.00 MW
Northern Ireland	1	20.00 MW
Scotland	21	741.20 MW
Wales	5	45.50 MW
	28	**832.70 MW**

Figure 3.8

Wind farms currently under construction

Source: British Wind Energy Association: *UK Wind Energy Database Statistics*. Available at http://www.bwea.com/statistics/

3.4 Discrepancy

But why is there the discrepancy between MacKay's figures and the figure estimated here of two and a half times greater? It could be a few things:

- Turbines were assumed to be 50% efficient (just shy of the theoretical limit of 59%) at turning wind speed into electrical power. Each turbine model has a different efficiency and Figure 1.8 shows an example of one. The efficiency actually varies with wind speed (up to a maximum of 44% in this case) and demonstrates why MacKay said a thorough analysis of wind was too complicated. Simply put, different wind speeds hold different amounts of power that are converted at different efficiencies to electrical energy.

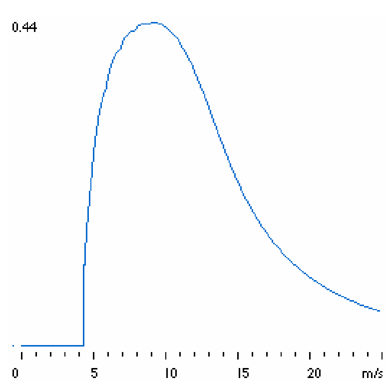

Figure 3.9

Example of Turbine Efficiency

Source: Danish Wind Energy Association http://www.windpower.org/en/tour/wres/cp.htm

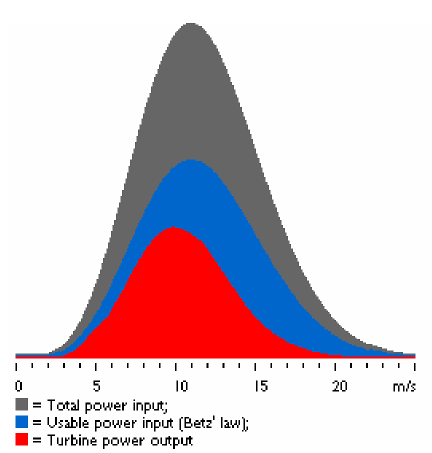

Figure 3.10

Comparison of total power outputs

Source: Danish Wind Energy Association http://www.windpower.org/en/tour/wres/powdensi.htm

As you can see in Figure 3.9, the turbines aren't very efficient at very low speeds (if at all) or very high speeds so their *average* efficiency might be a low figure, but they are designed to be at their most efficient at fairly common, but fairly powerful wind speeds. Figure 3.10 shows the relationship between the amount of wind power at an average site and how much is usable. Note the way that the efficiency of a turbine is designed, alters the peak of the red curve compared to the total power. As economics are the primary focus, not extracting the maximum amount of wind power per unit area, this could contribute to the discrepancy.

- Most of the turbines MacKay surveyed in Figure 3.3 and 3.4 were older models that have hub heights insufficiently high to avoid wind speed penalties from wind shear.
- Companies have put them where they can get permission, not where the best winds are.

3.5 Potential Answers

To help answer these questions, and some of the previous ones raised in this chapter (does hub height have an effect, are the best spots are already taken and so on), a table has been created using the power-per-unit-areas MacKay worked out in Figure 3.3 and 3.4, along with additional criteria from his source – the Renewable Energy Foundation (REF) [19] - and the British Wind Energy Association (BWEA) [20].

Table A, located in the appendix, covers 55 wind farms from England, Scotland and Wales. Some of the wind farms in MacKay's graphs aren't included, as power-per-unit-area data wasn't given for them on MacKay's online presentation slides.

The first graph resulting from Table A is Figure 3.11. Hub height is compared to power-per-unit-area and for comparison; two theoretical power-per-unit-area lines have been plotted based upon 6m/s and 5m/s wind speeds at a 10m height. The graph indicates that (perhaps unsurprisingly) average power-per-unit-area is related to hub height and in proportion to the theoretical values. Welsh wind farms in particular, are closely spread along the theoretical line based upon 5m/s wind speed at a 10m height, while English and Scottish wind farms show greater variation, but still generally increasing in power as hub height increases. Some English and Scottish sites are above the expected values for 6m/s at a 10m height, suggesting either a windier site, or closer packed turbines - as in the case of Royd Moor, the English wind farm at $5W/m^2$.

The next graph is Figure 3.12 and compares the date of wind farm completion against power per unit area. Some early wind farms have been repowered with upgraded turbines and effort has been taken to use the date of 'repowerment' rather than the original date, although a very small number might be incorrect. For some wind farms there was a difference between the commission date used by the Renewable Energy Foundation and the online date stated by the British Wind Energy Association.

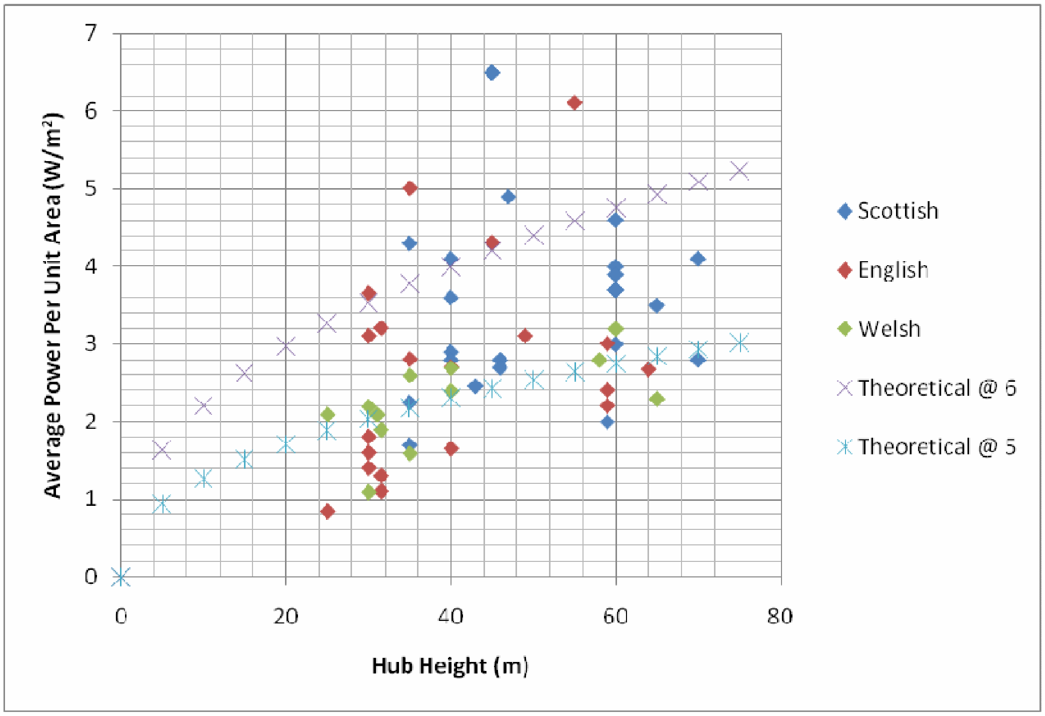

Figure 3.11
Power per unit area against hub height. Theoretical values based upon 6m/s at 10m and 5m/s at 10m have been included.

Source: Table A

It is believed the difference is due to when the first few wind turbines are installed and generating (REF), and the whole wind farm installed and generating (BWEA). Therefore the BWEA dates were used for consistency, although it is not expected to have a significant impact on the results.

MacKay says:

"*Obviously most of these early wind farms are located in excellent hilltop spots. We might thus expect the power densities of future farms to be lower.*" [21]

You can understand this view point, as it makes economic sense to site your farm in the best locations and so they would be built upon first. Whether in reality wind farms have so far been built primarily at the best locations, or at the locations where they could get permission and grid access, is a matter for debate. But it is unlikely that as a technology develops and the supporting structures grow up with it (public acceptance/grid access/regulatory rulings/planning/detailed wind speed maps and so forth) that sites that were originally not known or off-limits become accessible.

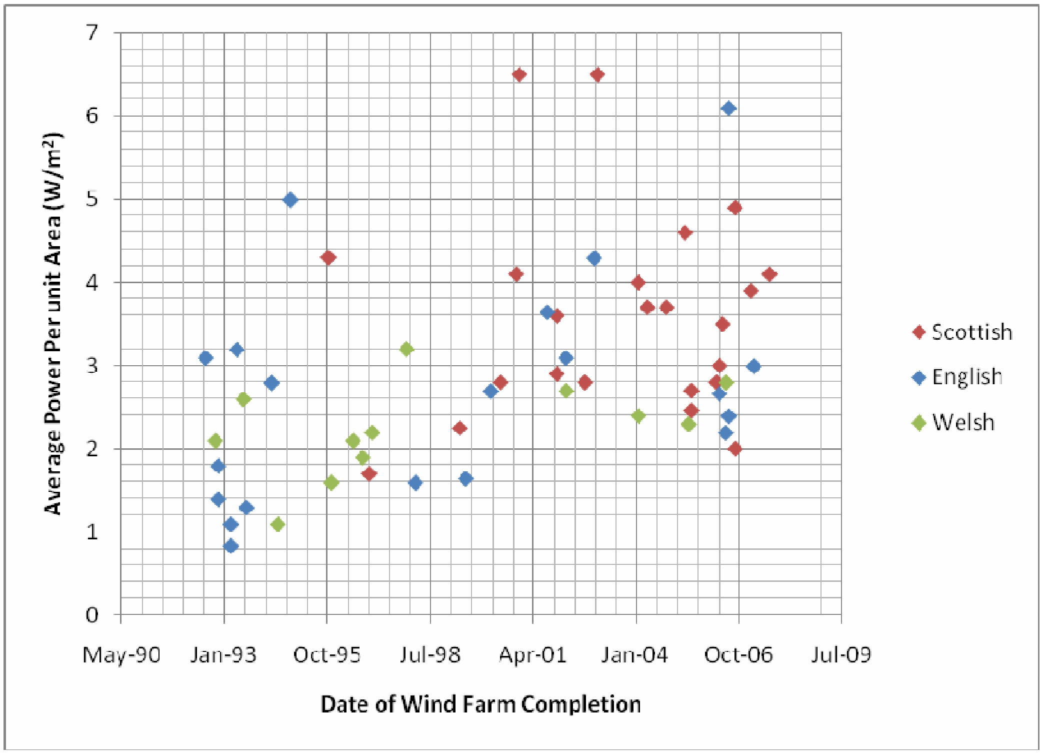

Figure 3.12

Power per unit area against date of wind farm completion.

Source: Table A

Contrary to MacKay's statement though, Figure 3.12 shows a reasonable correlation between newer wind farms and greater power-per-unit-areas, particularly the minimum power-per-unit-area. Whether this trend will continue in the future is uncertain, however:

Positive factors for increasing power density are:

- Increasing turbine hub height allows higher wind speeds to be accessed.
- Increasing turbine efficiency can reduce costs but also increase the percentage of the power in the wind that is converted into electricity.
- Improved grid access increases the number of sites available to be developed. If more pylons are built and upgraded in Scotland, better quality sites are available as well.

Negative factors are:

- Sites with the highest wind speeds could already have been built upon forcing future farms to be located in calmer areas, reducing potential power output
- Turbine hub height increases eventually lead to a levelling out of wind speeds (according to the wind shear formulae) as well as potentially greater public opposition due to greater visual impacts.

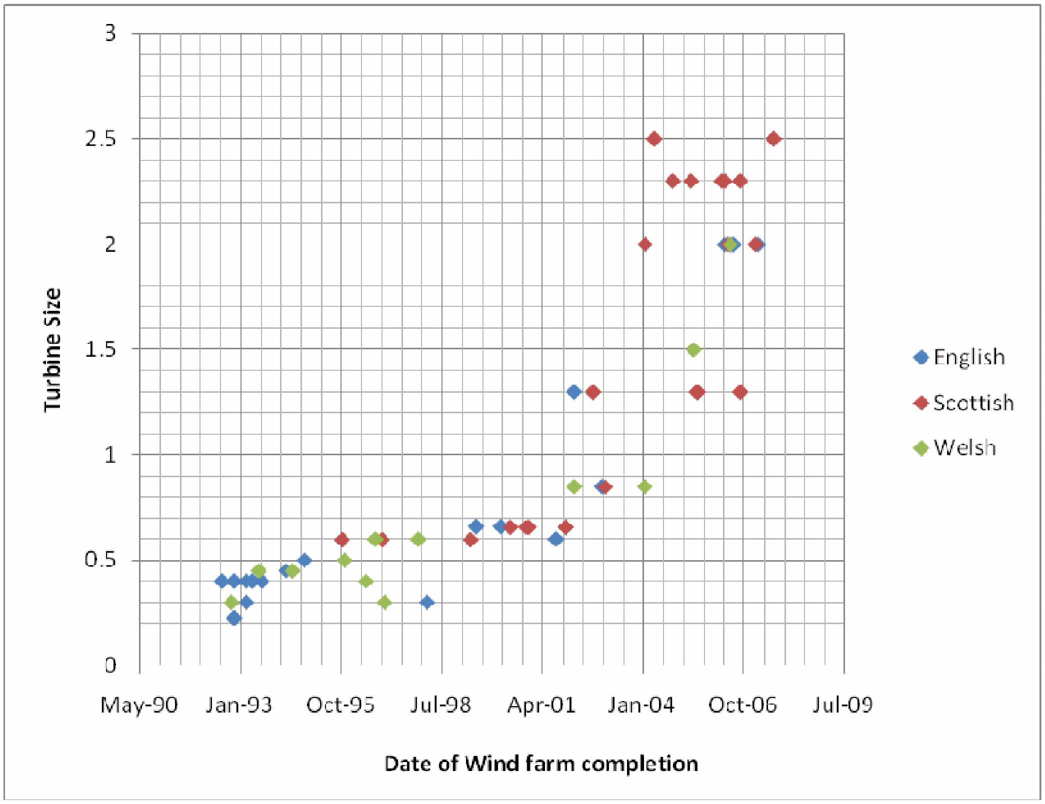

Figure 3.13

Turbine size against date of wind farm completion

Source: Data obtained from Renewable Energy Foundation, British Wind Energy Association

More powerful wind turbines generally have higher hub heights, and to reinforce the suggestion of 'Increasing turbine hub height allows higher wind speeds to be accessed' as a positive factor for increases in future power density, Figure 3.13 has been shown. It shows turbine size against the date of wind farm completion and shows a very strong correlation that newer wind farms use more powerful turbines, especially in Scotland where the majority of future farms are being constructed. With turbines in excess of 3MW currently available for onshore farms, it can be said that the trend in Figure 1.13 hasn't reached a limit yet, although increasing hub heights draws diminishing returns.

3.6 Comparison with Denmark

If we want to imagine what could be a realistic short term target for the amount of onshore wind power in the UK, we could extrapolate from countries with more prevalent wind energy already. Denmark has around 5000 onshore turbines with a capacity of 2700MW[22]. The UK has about 5.5 times the land area of Denmark, which means an equivalent of 27500 turbines and a potential capacity of 15000MW. Figure 3.14 shows the distribution of turbine sizes in Denmark (including around 200 offshore turbines with a capacity of around 400MW) and shows that the majority are of the sub-MW size. If the UK was to approach the same number of turbines as Denmark, they would likely be newer, higher and more efficient models, meaning the total capacity would be higher than 15000MW. However assuming the 15000MW figure, and a 33% load factor, 5000MW would be around 10% of the UK's electricity requirements – a respectable amount. This equates to 2kWh/d/p and assuming 2W/m^2 as the power per unit area; this would occupy 1% of the UK land area. This is 10% of the estimation MacKay made which might not seem a great deal, but Denmark stopped building more wind turbines in recent years as it replaced some of its older turbines with more modern ones (Figure 3.15)

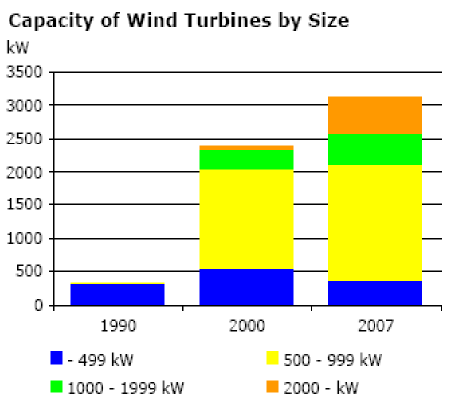

Figure 3.14

Danish Wind Turbines by Size

Source Danish Energy Agency, 2007. *Energy Statistics 2007* p.9.
Available at:
http://www.ens.dk/graphics/UK_Facts_Figures/Statistics/yearly_statistics/2007/energy%20statistics%202007%20uk.pdf [Accessed 27 August 2009]

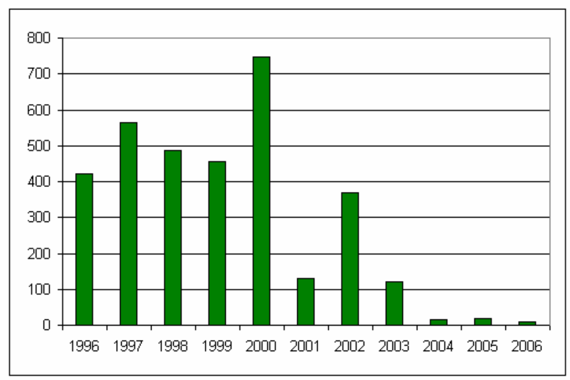

Figure 3.15

Yearly Installed Wind Turbines in Denmark

Source: Danish Wind Industry Association, 2007.
Available at:
http://www.windpower.org/composite-1459.html
[Accessed 27 August 2009]

Granted this is by no means a perfect comparison, as the conditions between the two countries will be different slightly; public attitude, population density and wind speeds and so forth, but Denmark shows that significant amounts of wind – relative to electricity demand - are possible.

3.7 Conclusion

As it currently stands, the more recent wind farms are in excess of the 2W/m^2 estimate of MacKay and for Scottish wind farms, often 4W/m^2 or more. His statements that not everywhere even has wind speeds of 6m/s, gives readers the impression that 2W/m^2 is a maximum, rather than a minimum as Figure 3.11 suggests. While the numbers MacKay has presented might be correct for what they are (e.g. at a 10m height), they aren't fair numbers for calculating the power in the wind and thus the potential of wind power. His response using real world data did not compare the affect of hub height nor historical trends in increasing hub height and turbine power, instead suggesting that power densities were likely to go down. Analysis here shows that power-per-unit-area has generally increased and as future farms are to be mainly built in windier Scotland, may possibly continue increasing. This suggests that MacKay has been deceitful over the potential of onshore wind power.

The difficulty of calculating and understanding wind power is quite high, but although MacKay has tried to simplify it for the average reader, there is a discrepancy between a simple analysis and a fuller, complex one, upwards of a factor of two. This implies that simplicity has lost accuracy to too great a degree and has become misleading.

So although MacKay may have made wind easy to understand (by saying it is power density times area covered), it appears to that context has been lost, future potential misconstrued and an unfairness in the numbers shown against onshore wind power.

4

Offshore Wind

4.1 Introduction

Offshore wind is likely to play a crucial role in creating a sustainable energy system for the UK. A target of 15% of energy to come from renewable sources by 2020 (the electricity sector is expected to make up the majority of this) means that as one of the more mature renewable technologies, wind is set to play a very important role. Indeed the government hopes for 25GW of offshore wind capacity by 2020, in addition to the 8GW already planned or built[23].

MacKay has split offshore wind into shallow and deep classifications, both assumed to have average power-per-unit-areas of 3W/m^2, 50% greater than onshore wind. He estimates using a third of shallow British territorial waters (about 13000km^2) provides 16kWh/d/p (40GW) and deep water (about 27000km^2) provides 32kWh/d/p (80GW). How realistic are these assumptions?

Well offshore wind is not as mature as onshore wind, so an analysis of real wind farm data, in the same manner as what was used for onshore, will not be used due to too small a number of offshore wind farms running for too few years (there are 6 offshore wind farms compared to around 200 onshore farms on the Renewable Energy Foundation: UK Energy Renewable Data database). Therefore questions such as: what will the average real wind farm produce, will the power density increase over time, and so on, will either have to be skipped or come down to subjective extrapolations and assessments on the wind farms that have been built, approved or mid-construction.

4.2 Current Offshore Wind Farms

The 6 operating offshore farms on the REF database are listed below:

- **Barrow** occupies 10km^2 and has a capacity of 90MW. They were predicted to have an average power-per-unit-area of 3.5W/m^2 (38.6% load factor[24]) but in one full year achieved 2.25W/m^2 (25% load factor).
- **Blyth** was only 1 turbine (1 broke) and data effectively stops after April 2005.
- **Burbo** occupies 10km^2 and has a capacity of 90MW. They were predicted to have an average power-per-unit-area of 3.6W/m^2 (40% load factor[25]) but a full year of data is unavailable.
- **Kentish Flats** occupies 10km^2 and has a capacity of 90MW. As MacKay says, they were predicted to have an average power-per-unit-area of 3.2W/m^2 (36% load factor), but in operation achieved 2.6W/m^2 (29% load factor).

- **North Hoyle** occupies 8.5km^2 and has a capacity of 60MW. They have a load factor of 36%[19] and an average power-per-unit-area of 2.6W/m^2.
- **Scroby Sands** occupies 8.5km^2 and has a capacity of 60MW. They have a load factor of 28%[19] and an average power-per-unit-area of 2W/m^2.

And one Round 1 site that isn't on the Renewable Energy Foundation database:

- **Lynn and Inner Dowsing** occupies 20km^2 and has a capacity of 194MW[26]. Assuming a load factor of 33%, that equates to an average-power-per-unit area of 3.2W/m^2

These are all Round 1 wind farms - essentially testbeds – and limited to an area of 10km^2 and 30 turbines. Their load factors appear to be generally lower than expected, at just under 30%, and power densities around the same value as MacKay estimated – 3W/m^2.

Out of interest, the first Round 2 offshore wind farm has just started exporting electricity to the grid, albeit from only a couple of turbines:

- **Gunfleet Sands** will eventually occupy 17.5km^2 and have a capacity of 172MW[27]. This equates to an average power-per-unit-area of 3.5W/m^2 (36% load factor).

While construction work at another offshore wind farm begins:

- **Sheringham Shoal** will eventually occupy 35km^2 and have a capacity of 315MW[28]. This equates to an average power-per-unit-area of 3.6W/m^2 (40% load factor).

So offshore wind farms have typically been estimated with load factors around the near 40% mark, but the few that are currently operating aren't quite reaching those figures (the load factor does vary year-on-year - often by several percent - mainly because of natural wind variations).

Whether future offshore wind farms will have higher power densities - due to higher/more efficient turbines, windier sites further offshore, or other learning effects - remains to be seen, because of the small data sample. Offshore winds are supposed to be stronger and steadier than onshore, and therefore their power densities should be greater as well. Hilltops act as concentrators for well placed onshore wind farms, so offshore farms might average near the power density of Scottish hilltops at around 4W/m^2 although this would only be an increase of 25% of MacKay's estimate. However this might be countered by considering that offshore farms already use 2MW and 3MW turbines with their associated higher hub heights. The flatness of the sea also means none of the local geography that allows some small onshore sites to have extremely high power densities, due to either better wind speeds or having the turbines placed closer together. So given the lack of historic data, like onshore wind has, with which to argue higher power densities, the figure of $3W/m^2$ is a fair one.

4.3 Area Coverage

Regarding the potential fraction of offshore land used, deep offshore is very much subjective, as the economics will change and the technology improve, as the offshore industry develops and expands. Shallow offshore is more likely to also be areas of wildlife/shipping/military use, but various methods to alleviate these problems exist, such as radar algorithms or more radar stations, the understanding that turbines provide artificial reefs for wildlife to inhabit[29], and consideration of greater threats to bird life (MacKay, p.64). For these reasons, at this time there appears to be no long term insurmountable engineering problem that would stop the use of a third of the offshore area.

4.4 Building and Costs

MacKay predicts that the building materials required to build the thousands of requires turbines would be a stretch for the UK and on a par with the building of Liberty ships during the Second World War. The UK's manufacturing base has changed since the 1940's, so perhaps a fairer comparison would be considering the UK's current car manufacturing capability, as it is UK based and the structure of the UK economy and skills of the workforce are near to what we might see if such a turbine building program were started today. Pre-recession, the UK produced around 1.5 million vehicles and 200,000 commercial vehicles[30]. Assuming one tonne of steel per car and two tonnes for commercial vehicles, that is nearly 2 million tonnes of steel per year. Compared to MacKay's estimate of 60 million tons of steel and concrete required, it would of course take a number of years at that rate to build all of the wind turbines. However years aren't a major problem, as it would take numerous years for sources of demand to switch to electricity (for example: cars and heating) for that level of wind power to be required. This is not to mention that we currently import almost all of our turbines, so it is unlikely that in the future we will be building all of them.

MacKay briefly covers the costs of offshore wind at around £3 million per MW capacity. Current cost estimates from the BWEA (Figure 4.1) are in line with this estimate, at £3.1 million per MW. However this figure would include the cost of jack-up barges, which MacKay added on.

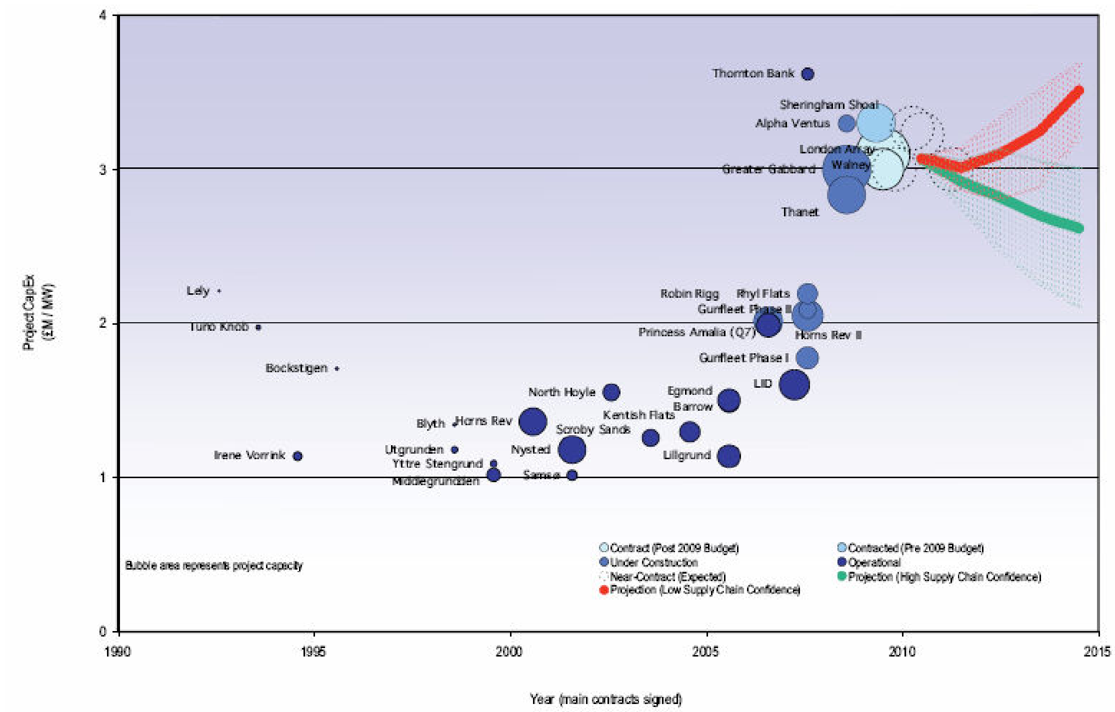

Figure 4.1

Historical, current and projected future capital costs for offshore wind projects

Source: British Wind Energy Association, 2009. *UK Offshore Wind: Charting the Right Course*.
http://www.bwea.com/pdf/publications/ChartingtheRightCourse.pdf

4.5 Conclusion

As historical data is in short supply, MacKay's analysis of offshore wind speeds and its potential - based upon the few Round 1 farms that are operating - is considered to be fair. This also means it has been relatively simple to discuss and context has not been missed, although uncertainty remains over long term accuracy.

5

Can we live on renewables?

5.1 Introduction

Chapter 18 in *SEWTHA* is titled: 'Can we live on renewables?' and is where MacKay looks back over his completed 'stacks' of demand and supply. Total demand for a moderately affluent person has been estimated at 195kWh/d/p and potential production of renewables at 180kWh/d/p and their respective breakdown is shown in Figure 5.1.

MacKay duly mentions that while it might appear a close race, both stacks have different ratios of the different forms of energy (thermal/chemical/electrical) and assumptions about economics and environmental problems were ignored when estimating the production stack. This means that in the real world, production is likely to be only a fraction of the value that has been calculated and so by themselves would not support our current demands.

5.2 Demand

He then seeks to validate his estimates of both stacks; demand is compared to official figures and production to numerous other estimates from respectable organisations. Official demand figures equate to 125kWh/d/p, less than MacKay estimated, but this is due to accounting for the average person, rather than the typical moderately-affluent person and not including for the energy in imported goods or food. Despite MacKay mentioning it several times later on, it is obviously acceptable to ignore the energy in imported goods (around 40kWh/d/p) as we do not need to produce energy for goods made overseas. Part of food (12kWh/d/p) also does not need to be accounted for, as we import around 40% of our food[31].

So it seems that the demand column MacKay has estimated is only really useful for giving 'moderately affluent' people a rough idea of what proportions

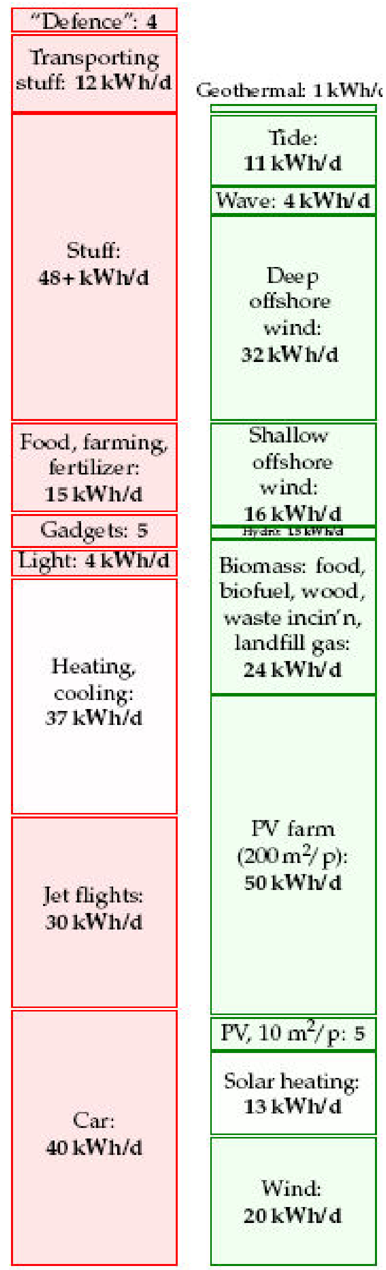

Figure 5.1

Demand versus Production

Source: MacKay, D., 2008, p.103

their energy use is broken into, while the official primary energy use figures give us a broad 'target' to reach. MacKay also equates thermal, chemical and electrical energy as equal, rather than taking into account the efficiencies at which they are typically converted within our society. Considering that the aim was to see whether Britain can live on its own renewables, the efficiency factor between the different forms of energy perhaps shouldn't be 1:1, as this ratio suggests that renewables need to produce electricity for 'conversion to electricity' losses as well. As renewables generate electricity directly, this gives the impression that renewables need to meet a higher level of demand than is actually necessary.

Although MacKay says that we don't know what technologies will be predominate in the future and what they run on (which is fair enough), he does later estimate that electrification and efficiency improvements see a reduction in demand from 125kWh/d/p to 68kWh/d/p (as shown in Figure 5.2) and uses this lower number in his series of 'energy plans'. However, this figure is only mentioned once in the entire book, on page 231, compared to countless times for 125kWh/d/p. True, 125kWh/d/p is the figure for current consumption, but for a book about theoretical potentials in the future, and which also examines areas of potential large improvements in energy use (electric cars/heat pumps), surely a theoretical demand level would be fairer and better suited and so deserved to be highlighted better.

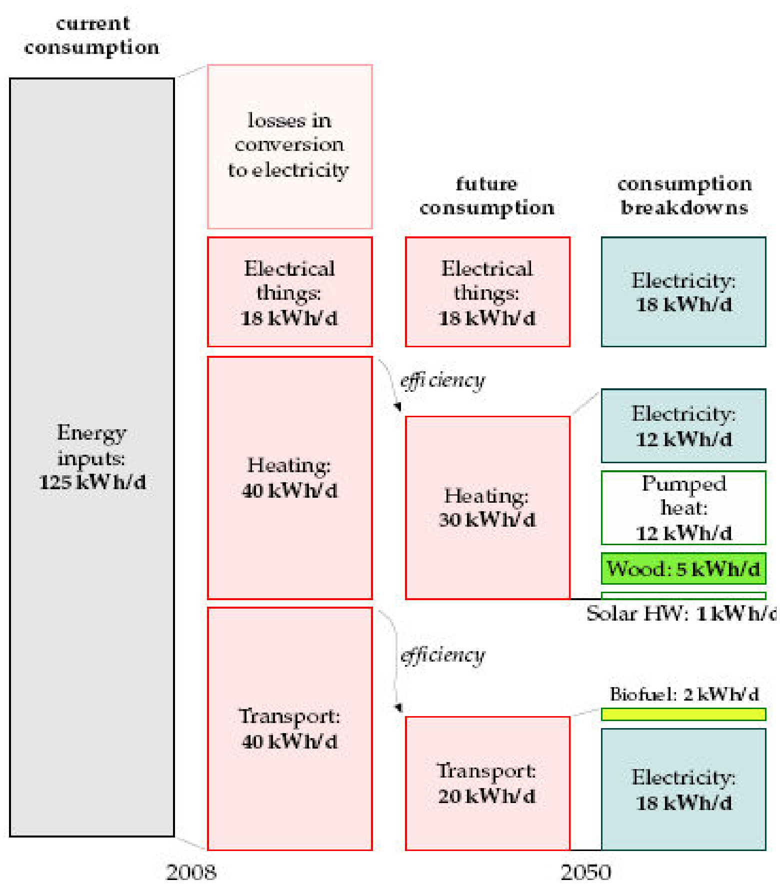

Figure 5.2

Current and possible future demand breakdowns

Source: MacKay, D., 2008. p.204

The production stack is compared to four different reports that have considered the theoretical or practical estimates of various renewable technologies, and with few exceptions, they are significantly smaller than estimated by MacKay. This isn't too surprising as the majority of sources are practical estimates, which would obviously be lower than theoretical estimates and due to many renewables being in the relative early stages of development, it is likely that these practical estimates will improve over time. (Notably, one source considers 7p/kWh economic constraints as well as practical, while the others were published in 2001, 2002 and 2007).

MacKay's thoughts on what will actually be realised 'after the public consultation' seem slightly superfluous, given that he stated he was not going to consider economic or environmental constraints. The figures seem to be subjective guesses (although they might have been based upon the four other publication's estimates) and they add little to the discussion, other than potentially reinforcing an opinion that renewables simply can't and won't match our demands.

Next MacKay shows what renewables actually supplied in 2006, 1.05kWh/d (MacKay, p.111) compared to nuclear (3.4kWh/d). It's worth noting that renewable energy targets foresee around a 10 fold increase on current renewable levels by 2020[32] so although they may be challenging targets, they are considered possible. Additionally, gas-fired power stations went from nothing, to over a third of the total electricity generated in the UK, within a decade, so large scale change is not unprecedented[33].

5.4 Conclusion

This chapter has seen mixed outcomes from MacKay. The official demand figures support his estimates in rough magnitude and distribution so the numbers he has used are accurate. However, his estimates have assumed including areas such as imports (energy for which, does not need to be produced domestically) and conversion to electricity losses (which would not present in a renewable energy system) that implies unfair analysis from MacKay. To his credit, MacKay does estimate a future demand scenario incorporating improvements in efficiency and electrification, but the figure is mentioned once and several chapters after his comparison of demand and production. His predictions of what renewables might contribute in reality does not appear to have been stated as based upon anything particular, and so it has little use except to show how tough change might be or to semi-validate critics of renewables. Overall, MacKay's comparison of production to demand is slightly misconstrued in places, although it is debatable whether they are significant enough to deflect from his underlying message that theoretical production of renewables is not magnitudes higher than our current demand.

6

Nuclear

6.1 Introduction

Following the trouble of renewable energy sources meeting current demands, MacKay decides to consider the potential of nuclear power. Depending on which reserves are considered, he estimates that traditional reactors using uranium from the ground would provide 0.55kWh/d/p over 1000 years and using uranium from the oceans would provide 7kWh/d/p. If fast breeder reactors were used these figures would be multiplied by sixty to 33 and 420kWh/d/p respectively.

6.2 Discussion

Certainly nuclear power has been given a hard time, sometimes unfairly, and MacKay snuffs out various myths about it. He presents data to show nuclear power has a relatively low death rate compared to fossil fuels, although this underplays the extremely dangerous but extremely low probability events, as well as other health risks that aren't deadly.

MacKay's consideration of nuclear power has been as fair as renewables while discussing potential limits, however he seems to have been unfair regarding the finer details. He believes renewables are never going to reach their potential in the UK because of public opposition, cost, the rate of scaling up required and so on. However these same issues for nuclear are given less negativity, such as a 100,000 times scaling up of uranium extraction for a single 1GW reactor is prefaced 'simply'. Although MacKay stated economics weren't going to be considered, comparing costs between the real costs of renewables to potential costs of nuclear fuel seems unfair, and although the Olkiluoto plant from Finland is mentioned on page 216, it is at a cost of £1.3billion per GW despite estimates that it is over £3 billion[34]. No mention is given to potential public opposition of nuclear power stations occupying 2 of every 100 kilometres of shoreline, nor consideration to the load balancing that would be required if nuclear power were to supply a significant amount of the UK's energy - as while new and current nuclear power plants are capable of load following, they would likely be run as baseload due to the affect on their economics[35].

But one of the biggest issues of MacKay's treatment of nuclear power is due to the simplification and creation of a single, comparable unit of measurement. It was mentioned earlier that the demand and production 'stacks' give the impression that there is a fixed target to be reached, and reducing every technology to a single number can lead people to believe that the biggest number will be the best technology and implicitly 'the answer'. This ignores any potential benefits of having a diverse mix, the time and effort it would take as well as the social, economic and environmental factors. Indeed saying there is 1000 years of power at whatever level of production holds little usefulness because of the timeframe decisions are actually made in. The lifespan of power plants, knowledge of risks, finances, competitors, political legislation, market structure and so on, means that even though power plants might last 60 years, work on replacing it may only start 10 or 15 years before it retires and there is little requirement to continue with the same technology unless economics still favour it. In a liberalised energy market, costs are almost everything and companies are unlikely to consider return on investments that are decades away unless risks are known or reduced.

Reducing the number of years a fuel is to be drawn out over would increase the rate at which you could use it, and so improve the chances of a single source meeting our demand level, but again, it comes down to the economics at the time rather than a large kWh/d/p figure. Similarly, MacKay's estimate of UK coal power is 0.7kWh/d/p over 1000 years (MacKay, p.158) but if coal power is relatively economic, then it will be used at a far greater rate in less time.

6.3 Conclusion

It seems that this chapter on nuclear power has highlighted that simplification has serious drawbacks in understanding energy policy. While knowing the potential of a technology has its uses, present day decisions must consider the social, environmental and economic aspects. Despite MacKay's assertion to focus on numbers not words, the context MacKay has given to his numbers has suggested bias towards nuclear power, although assessing the theoretical potential has been fair.

7

Conclusion

In conclusion, *Sustainable Energy - without the hot air* is a useful book for anyone to read as an introduction to energy policy. It succinctly explains the reasoning behind climate change, highlights equity issues on energy usage, dispels commonly held myths and explains in detail how various technologies work.

7.1 Free of Deceit

At the start of this dissertation, it was mentioned that the only definition of simple that can be regarded as objective, was *"free of deceit".* MacKay's methodology of examining theoretical potential only, is one that can achieve that criterion but MacKay has only been partly successful at this. In simplifying as much as possible, inaccuracies have slipped in – above the amounts MacKay considered not worthwhile - and context also seems to have been lost or underplayed. Onshore wind appears to have more potential regarding power density than MacKay has envisaged, although this difference is countered by his estimation to cover 10% of the UK land area. A country with more established wind, Denmark, may have around the order of 1% coverage, so it does remain to be seen whether the UK can match or improve on this in the future. Meanwhile, his consideration of all forms of energy being equal, while fair in theory, is unfair to future electricity production that would be without conversion losses, and his repeated remarks that the energy embedded in imports should be domestically produced are misguided. Nuclear power also appears to have not been worded as difficult as other renewables.

However, his fundamental message to the reader remains: getting off fossil fuels will be hard. Renewables could power the UK completely, but only if we import them from other countries, accept a lot of nuclear power, reduce demand significantly or industrialise most of the countryside.

7.2 Ease of Understanding

The other primary definition of simple: *"easy to understand"*, has also generally been satisfied. MacKay has reduced evaluations to (figuratively speaking) the lowest common denominator in hope that people will understand the problem better, some examples are:

- Estimating per person. This means the reader will be able to empathise better with the number, rather than think about large, national numbers.
- Having single production and demand stacks side-by-side. This creates a single target that total production must meet.

- Giving a single value for the power densities of renewables. This tends be an average and thus ignore the potential for areas to exceed this figure, but it allows people to simply multiply the figure by the amount of land they consider useable.

Certainly such methods make the final figures easy to understand, but such an aim has the potential to compromise the accuracy of the figures and lack an appreciation for what was or wasn't required. For example, cumulative emissions and a potential 'energy gap' are rather important factors, so differences between the various technologies for the time it takes to deploy a certain number of gigawatts can be crucial, not to mention the effects that skill requirements, supply chains and capital expenditure costs can have.

7.3 Context

There are some cases where presentation of that data has suffered from lack of context. One of the major points has been creating a set of units to compare all the energy sources and demands. While this is indeed a useful measure, readers could focus on a belief that bigger is simply better and advocate the choice of a single energy source as 'the answer' to energy related problems. A simplistic analysis and an instruction to make a plan that adds up gives the impression that once we have gone through the difficulties of deciding what energy mix we want, that time, economic and environmental issues won't play a role in building that plan.

Ultimately MacKay wasn't aiming for exact perfection with the numbers – something both supporters and critics of the book might miss. As he says in his Motivations chapter on page 17, the book is not about 5% here or there, because the big question is whether sustainable sources have a chance of mitigating climate change and providing a continuation of our lifestyles. As our ability to harness energy from the various resources is limited to only a fraction of the total - because of theoretical limits, real world impracticalities and economics - the potential discrepancies on his numbers are overshadowed.

For example, if we could extract 25% of all the available resources for our use, those resources would need to total at least 4 times the size of our current demands (for comparison, extraction rates from oil wells is typically 10-60%[36]) . As MacKay has shown, the potential production total is not multiples of our demand, unless we accept imports/nuclear/countrywide renewables. Debating an error of 20 or 30% on one technology doesn't change the overriding concern that decisions will be difficult – hence MacKay's chapter on saying yes (p250).

Whereas if the potential from sustainable sources were say, 100 times current demand, then you could look at the social, environmental and economic factors for each technology and consider which could be the best or most useful. That's not to say that any errors found shouldn't be corrected in later prints (MacKay has a wiki set up for people to comment on the book[37]) but that the finer details aren't the point of the book.

However, this does mean the book is restricted in its usefulness. Certainly it is useful by way of highlighting to the reader the scale of challenge we face and what options are available, but when companies and governments plan and invest, discussions move from theoretical 'could' to those of practical 'can' and ethical 'should'. This shift requires knowledge of the economic, social and environmental aspects of the technologies that numbers alone does not provide. Numbers are an important part of a debate on energy, but context is equally important, otherwise discussions among readers could be based around arguments solutions that contribute only a small fraction of the total are not helpful. No two country's demands are equal and nor are their resources and population spread equally within the country, so any solution could find niche areas that represent a high percentage of energy generation for people in that area, but much less when averaged across the total population. His unit, the kWh per day per person, while suitable to compare different countries, is subject to population shifts over time. Although the population of a developed country tends to be fairly steady, the future is inherently uncertain and numerous reasons could see large population movements. So the kWh/d/p figure could improve or worsen depending on the shift, while the generation capacity remains constant, however this remains a minor issue.

7.4 Summation

Essentially MacKay has devised an 'energy budget' for the UK and calculated its upper limit. But while that does have its uses, potential means nothing unless it is realised and very little in the real world is done without consideration for the details. Compare this with a financial budget: a person might know the total amount of money they will earn in their lifetime and could use that information to make rational decisions to secure and optimise their quality of life. But most people are likely to regard their earnings in ten or twenty years time as having no affect on how they live today because of the restrictions of their quality of life that saving might require, as well as uncertainties such as what they would have to buy in the future. Likewise with technologies that we ration to last 1000 years, is it right – or even possible due to human nature – that we restrict its usage in favour of something perhaps more expensive or cumbersome? Not only do people have the potential to act irrationally, selfishly or prioritise the short term but we also don't know what conditions will exist in the future and if they would permit the continued use of a particular technology. Financial collapses, social upheaval, trade restrictions, wars, natural disasters and so on, are things that, while having a low chance of happening, would have an effect on what we could build – depending on whether it relies on imports, domestic infrastructure or large sums of capital investment and so on. Setting aside for future generations at the possible expense of today's people, is as much a moral question as it is about numbers.

Additionally, MacKay's desire for an interactive piece of software for users to design their own energy scenario is an interesting one. Assuming that it wouldn't be a case of merely changing the ratios of each source, but was actually in depth and fully descriptive, so as to include (editable) budgets, costs, demand levels, land usage and so forth, it would be useful as a means to visually demonstrate what it might take to create a sustainable energy system, and the challenges it faces. It could even provide a use for professionals in the energy policy industry to highlight the potential of their product or findings. There is a game based on a similar concept from the BBC[38] that is less specific but considers food, water and public opinion as well as energy.

Sustainable Energy – without the hot air contains many areas of good, clear information, but sadly it has been let down in other areas by fundamental problems in simplifying something as complex as energy. While it contains little new information within the energy policy field, its simple approach has at least attracted more attention to energy policy, and hopefully this book is the beginning rather than the end of their learning.

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Bibliography

MacKay, D. (2008) *Sustainable Energy – Without the hot air*. Version 3.5.2. Cambridge: UIT. Available at www.withouthotair.com

Introduction

1. *Compact Oxford English Dictionary*, 2009. Oxford University Press. [Online] Available at: http://www.askoxford.com/concise_oed/simple [Accessed 27 August 2009].
2. David MacKay, 2009. *Better than BS 7671 2008 IEE wiring regulations 17th edition*. [Online] May 16. Available at: http://withouthotair.blogspot.com/2009/05/better-than-bs-7671-2008-iee-wiring.html [Accessed 27 August 2009].
3. The Guardian, 2009. *Power to the people*. [Online] 30 April. Available at: http://www.guardian.co.uk/environment/2009/apr/30/david-mckay-sustainable-energy [Accessed 27 August 2009].
4. The Guardian, 2009. *In Praise of..David MacKay*. [Online] 1 May. Available at: http://www.guardian.co.uk/commentisfree/2009/may/01/climate-change-debate-david-mackay [Accessed 27 August 2009].
5. The BBC, 2009. *Eden suspends giant turbine plan*. [Online] 27 January. Available at: http://news.bbc.co.uk/1/hi/england/cornwall/7853269.stm [Accessed 27 August 2009].
6. The BBC, 2009. *Green energy hit by 'faceless Nimbys'*. [Online] 20 August. Available at: http://news.bbc.co.uk/1/hi/sci/tech/8207802.stm [Accessed 27 August 2009].
7. National Energy Foundation, 2009. *Act on CO2 when travelling*. [Online] Available at: http://www.nef.org.uk/actonCO2/caremissions.asp [Accessed 27 August 2009].
8. The Guardian, 2009. *Environmentally friendlier options on Severn Estuary sidelined in favour of big projects that threaten biodiversity, say campaigners.* [Online] 26 January. Available at: http://www.guardian.co.uk/environment/2009/jan/26/barrage-tidal-severn [Accessed 27 August 2009].
9. RSBP et al, 2009. *Severn Tidal Power: Review of "Interim Options Analysis Report"*. [Online] London: Atkins. Available at: http://www.rspb.org.uk/Images/Atkins_review_tcm9-216760.pdf [Accessed 27 August 2009].
10. Select Committee on Business and Enterprise, 2008. *Eleventh Report: Energy Prices, fuel poverty and Ofgem*. [Online]

Available at: http://www.parliament.the-stationery-office.co.uk/pa/cm200708/cmselect/cmberr/293/29305.htm [Accessed 27 August 2009].

11. The Times, 2009. *Threat from lack of gas capacity, expert says*. [Online] 19 July. Available at: http://business.timesonline.co.uk/tol/business/industry_sectors/utilities/article4359781.ece [Accessed 27 August 2009].
12. Ernst & Young, 2006. *The European Generation Mix*. [Online] Available at: http://www.euractiv.com/ndbtext/general/EY_EU_Generation.pdf
13. The Guardian, 2009. *Centrica to buy 20% stake in British Energy from EDF*. [Online] 10 May. Available at: http://www.guardian.co.uk/business/2009/may/10/centrica-buys-british-energy-stake-edf [Accessed 27 August 2009].

Cars

14. MacKay, D., 2009. Chapter 3 – Sustainable Energy. [Online] Available at: http://www.inference.phy.cam.ac.uk/wiki/sustainable/en/index.php/Chapter_3 [Accessed 27 August 2009].
15. Auto Trader, 2009. *The UK's most popular cars revealed*. [Online] 7 January. Available at: http://www.autotrader.co.uk/EDITORIAL/CARS/news/NEWCARS/49771.html [Accessed 27 August 2009].
16. Vehicle Certification Agency, 2009**.** *Vehicle details for Focus 1.8 Duratec (125PS) 3/5 Door Saloon M5.* [Online] Available at: http://www.vcacarfueldata.org.uk/search/vehicleDetails.asp?id=22646 [Accessed 27 August 2009].

Wind

17. E.on, 2009. *Holmside* [Online] Available at: http://www.eon-uk.com/generation/holmside.aspx [Accessed 27 August 2009].
18. MacKay, D., 2009. *Is David MacKay "trying to make wind sound useless"? Let's look at more data.* [Online] 8 May. Available at: http://withouthotair.blogspot.com/2009/05/is-david-mackay-trying-to-make-wind.html [Accessed 27 August 2009].
19. Renewable Energy Foundation, 2009. *UK Renewable Energy Data: Issue 8, Wind Monthly Generation Statistics*. [Online] Available at: http://www.ref.org.uk/Files/ref.reds.wind.30.03.09.pdf [Accessed 27 August 2009].

20. British Wind Energy Association, 2009. UK wind energy database: Operational Wind Farms. [Online]
Available at: http://www.bwea.com/ukwed/operational.asp [Accessed 27 August 2009].
21. MacKay, D., May 2009 Presentation, *Power per unit area of most wind farms in Britain*. [Online] Available at: http://www.inference.phy.cam.ac.uk/mackay/presentations/WIND2/mgp00002.html [Accessed 27 August 2009].
22. Danish Wind Industry Association, 2004. *Turbines in Denmark*. [Online] Available at: http://www.windpower.org/composite-1458.htm or http://www.talentfactory.dk/composite-1458.htm [Accessed 27 August 2009].

Offshore Wind

23. DECC, 2009. *Offshore Energy Strategic Environmental Assessment – Post consultation report*. [Online] Available at: http://www.offshore-sea.org.uk/consultations/Offshore_Energy_SEA/OES_Post_Consultation_Report.pdf [Accessed 27 August 2009].
24. BOWind, 2008. *Key Facts*. [Online]
Available at: http://www.bowind.co.uk/keyfacts.shtml [Accessed 27 August 2009].
25. Dong Energy, 2008. *Burbo Bank Offshore Wind Farm*. [Online] Available at: http://www.dongenergy.com/SiteCollectionDocuments/NEW%20Corporate/Burbo/BurboBankLeaflet.pdf [Accessed 27 August 2009].
26. Centrica Energy, 2009. *Lynn and Inner Dowsing: Project Development*. [Online] Available at: http://www.centricaenergy.com/index.asp?pageid=21&area=lynn&sub=project [Accessed 27 August 2009].
27. New Energy Focus, 2009. *"First" Round Two wind farm starts generating electricity.* [Online] 21 August.
Available at: http://www.newenergyfocus.com/do/ecco.py/view_item?listid=1&listcatid=129&listitemid=2944&section=Wind [Accessed 27 August 2009].
28. New Energy Focus, 2009. Onshore construction begins for Sheringham Shoal wind farm. [Online] 7 September. Available at: http://www.newenergyfocus.com/do/ecco.py/view_item?listid=1&listcatid=32&listitemid=2978&section=Wind [Accessed 7 September 2009].
29. Vella, G., 2002. *The Environmental Implications of Offshore Wind Generation*. [Online] Available at: http://offshorewind.net/Other_Pages/Links%20Library/The%20Environmental%20Implications%20of%20Offshore%20Wind%20Generation.pdf?grID=117&d_ID=880 [Accessed 27 August 2009].

30. The Society of Motor Manufacturers and Traders Limited, 2008. *Record breaking figures for 2007 UK vehicle production*. [Online] 25 January. Available at: http://www.smmt.co.uk/articles/article.cfm?articleid=16852 [Accessed 27 August 2009].

Can we live on renewables?

31. DEFRA, 2008. *Ensuring UK Food Security in a changing world*. [Online] Available at: http://www.ifr.ac.uk/waste/Reports/DEFRA-Ensuring-UK-Food-Security-in-a-changing-world-170708.pdf [Accessed 27 August 2009].
32. DECC, 2009. The UK Renewable Energy Strategy.
33. Energy Information Administration, 2009. *Country Analysis Brief: United Kingdom – Electricity*. [Online] Available at: http://www.eia.doe.gov/emeu/cabs/United_Kingdom/Electricity.html [Accessed 27 August 2009].

Nuclear

34. The Guardian, 2009. *Nuclear power around the world*. [Online] 14 August Available at: http://www.guardian.co.uk/environment/datablog/2009/aug/14/nuclear-power-world [Accessed 27 August 2009]
35. Nuttel, W., Pouret, L., 2008. Can Nuclear Power Be Flexible? [Online] Available at: http://www.eprg.group.cam.ac.uk/wp-content/uploads/2008/11/eprg0710.pdf [Accessed 27 August 2009].

Conclusion

36. Energy Information Administration, 2008. *International Energy Outlook 2008: Defining the Limits of Oil Production.* [Online] Available at: http://www.eia.doe.gov/oiaf/archive/ieo08/index.html [Accessed 27 August 2009].
37. MacKay, D. 2009. *Sustainable Energy - without the hot air wiki: main page*. [Online] Available at: http://www.inference.phy.cam.ac.uk/wiki/sustainable/en/index.php/Main_Page) [Accessed 27 August 2009].
38. The BBC, 2006. *"Climate Challenge"*. [Online] Available at: http://www.bbc.co.uk/sn/hottopics/climatechange/climate_challenge/ [Accessed 27 August 2009].