The Generation of Renewable Power and the Need for a Sustainability Evaluation

P Ward February 2006

1. Introduction

Faced with apparently unlimited quantities of "free" energy in the form of wind, wave or solar, commentators often forget that some kind of machine is needed to covert this energy into usable power. Given the overarching objective of reducing greenhouse gas emissions, then some kind of evaluation needs to be made of the effectiveness towards that goal, and the sustainability of the power generation method should be understood; using the definition of sustainability of not compromising the environment for future generations.

It seems that in many cases the renewable energy industry seems to have a momentum of its own, it is often taken as a given that any source of renewable energy will reduce greenhouse gas emissions and hence improve the outlook for the global environment. This short paper will demonstrate that this is not necessarily the case.

Currently the analysis of the sustainability of renewable energy is limited to the evaluation of the embedded energy (and hence CO_2 etc) within the materials used to produce the renewable energy generator. This can be done by Life Cycle Analysis or by the more recent materials embedded energy method. However, this paper will seek to demonstrate that this approach, at best, only gives a partial view of sustainability. **Here we will show that a full analysis of all the economic activity related to a particular form of renewable power generation is essential to understand its impact on the environment.**

2. Materials Based Sustainability Assessments

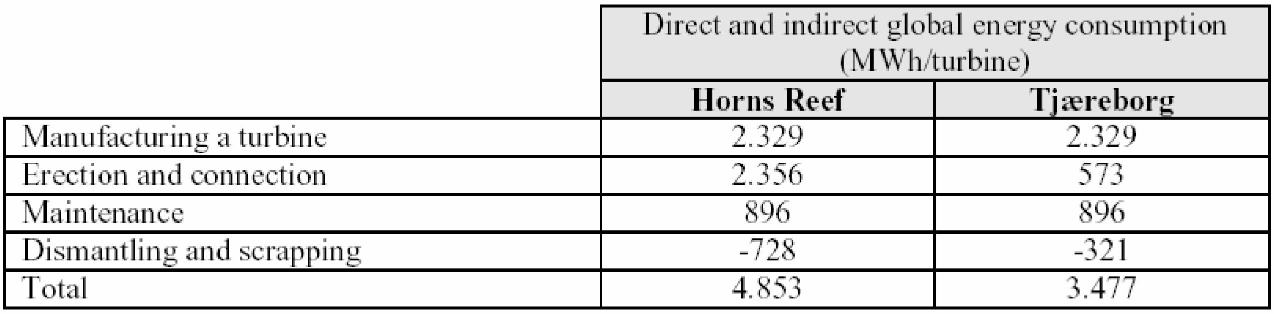
2.1 BWEA Statement

Most of the available material on sustainability refers to wind turbines and there is a very widely quoted article by BWEA Director David Milborrow (1) which was privately circulated in the Wind Stats Newsletter. This asserts that for the turbines of that time the **energy payback period is between 3 and 9 months** depending on the average wind speed.

This analysis used some rather unique methods "*the component parts of the wind turbine are broken down, not by type of material and weight, but by manufacturing sector and then by monetary value within each sector. The associated data on primary energy input, per unit value, come from background studies using standardized methods.*" In reality he then relies on data from a conference, Eurowin **1991**, J Schmid and H P Klein and then calculates the payback period. This does prompt the question as to whether this result is relevant in 2006 given the substantial evolution of wind turbines over the intervening period.

2.2 Vestas/Elsam Report 2004

The other frequently reported reference for wind turbines is the Elsam Engineering (wind generation operators) report (2) which appears on the Vestas web site. This suggests that a life cycle analysis, done according to ISO 14040-14043, gives an **energy payback period of three months**. However, the ISO standards refer to the environmental impact of the materials used, not to the method used in evaluating the energy payback period. The energy payback calculation appears in Appendix 3 of the report where they indicate a very similar method of calculation as Milborrow "*The energy consumption for manufacturing, erection and scrapping of a turbine including the foundation has been calculated by means of a so-called energy multiplier, which indicates the global direct and indirect energy consumption in various trades in comparison with their turnover (TJ/mill. DKK).*" The key numbers in this report are the Direct and Indirect global energy consumption per turbine shown below.



	Direct and indirect global energy consumption (MWh/turbine)	
	Horns Reef	**Tjæreborg**
Manufacturing a turbine	2.329	2.329
Erection and connection	2.356	573
Maintenance	896	896
Dismantling and scrapping	-728	-321
Total	4.853	3.477

It is worth noting that dismantling and scrapping is regarded as a negative consumption hence they are claiming a benefit for the recycling of the materials which should be claimed by the next user of those materials. However, by their calculation the total energy utilized is 3,477 MWh/turbine for the on-shore installation at Tjaereborg. They also suggest that the annual production at that site is 5,634 MWh/turbine; a simple calculation on that basis suggests a **payback period of about 7.4 months**.

There follows a complex calculation which converts the turbine output into the equivalent input to a coal fired power station, ie more than doubles the output, and hence a number for the energy payback of three months is produced.

2.3 Embodied Energy

A concept used in the building industry is **Embodied Energy** (3). "*Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the acquisition of natural resources to product delivery, including mining, manufacturing of materials and equipment, transport and administrative functions*." Luckily the CSIRO (3) in Australia and the Centre for Building Performance Research Victoria University of Wellington, New Zealand (4) publish data on the embodied energy of standard materials. Also the Elsam engineering report (2) includes an inventory of materials and a lot of other useful information like the tower height and weight and the size and weight of the foundations.

All this data has been put together in the Excel file shown in Appendix 1. Here it can be seen that for the Tjaereborg size of turbine the total materials embodied energy comes to 3,900 MWh compared to the 2,329 MWh estimate above. This could be taken as suggesting a more thorough accounting of energy usage. Relating this data to the larger turbines needed for efficient generation in the in-land part of the UK (Ellands Farm, Northants) then we see that the embodied energy becomes 4,550 MWh. Adding the erection and maintenance estimates from section 2.2 of this report and then dividing by a reasonable output for the Ellands Farm site we arrive at a **materials related energy payback time of 16.5 months**. This is rather longer than the proponents of wind energy are suggesting.

2.4 Solar Photovoltaic Panels

Some reasonably reliable data comes from a very interesting book (5) on a building development called the "Beddington Zero (Fossil) Energy Development" where the BioRegional Development Group has done its best to produce low environmental impact housing and business development. There is a detailed description of reusing and recycling building materials and good design for low energy consumption; together with data about the photovoltaic panel system they have installed to produce electricity.

A company called Solartechnologies (6) (quoted by BP as the premier PV Company in the UK) has installed 109 kW of potential generating capacity. This capacity actually produces 108,000 kWh of electricity per year (5); this means that the system is effectively running for 991 hours per year, or 2.7 hours per day, ie a load factor of 11.3%. For comparison the East Midlands RSS8 entry on PV (7, Appendix 6) assumes an average of 2.4 hours of operation per day.

The BedZED book (5) suggests that these panels save 52,000 kg of CO_2 emissions per year, ie. a CO_2 saving of 481g/kWh. This is roughly in line with the "grid average" figure of 430g/kWh. They also declare the embodied energy as 9550 GJ and the embodied CO_2 as 755,100 kg. On this basis the **CO_2 payback period is about 15 years**. Since the embodied energy is 9550 GJ, which is equivalent to 2,650 MWh, divided by an annual output of 108 MWh per year gives an **energy payback period of roughly 24.5 years**.

A CO_2 payback period less than the energy payback period might suggest that some Carbon neutral source of energy has been used. However this seems unlikely since the most of the embodied energy is in the Si crystals themselves which may come from China or Russia, both of which have low cost fossil fuel energy.

The reality is that these calculations are only approximate, it would be better to assume that **both of these payback periods are approximately 20 years**. This is equal to the theoretical design life of the PV panels, assuming they are accessible for routine maintenance (which will involve its own energy and Carbon expenditure). In this case no Carbon neutral energy is produced and so in the context of a developed country with good access to grid-borne electricity no greenhouse gas emissions are saved. However, in remote areas where there the grid connection costs (financial and environmental) may be excessive then solar photovoltaic panels may find an application.

3. Total Economic Activity Sustainability Assessments

3.1 Introduction

This section will introduce the idea of the energy consequences of the total economic activity associated with renewable energy power generation.

3.2 Solar Photovoltaic Panels

Returning to the subject of PV generation, although the data in 2.4 seems quite persuasive, there is another way of looking at the sustainability issue. The DTI pamphlet on the PV Demonstration Programme (8), issued by the Energy Saving Trust in 2004, tells us that the price for a grid-connected PV system is between £4,000 and £8,000 per kWp (kW peak, equivalent to installed capacity). If we take the lower figure of £4,000 and convert that into an equivalent amount of electricity at wholesale prices (say £30/MWh) then the price of **1kWp** (£4,000) would buy some **133 MWh** of energy. But this is **much higher than** the embodied energy declared by **BedZED of 24.3 MWh per kWp**. Why should this be the case?

Obviously there are many reasons why PV panels are expensive; the production is still at relatively low volume, the vendors are selling small numbers so they must charge more to stay in business and the prices also include connection to the grid. These points do not change the embodied energy within the PV panel materials; but they do increase the total economic activity associated with selling each kWp of PV panel capacity.

The key idea here is that these **"peripheral" economic activities also result in energy expenditure**. There are obvious examples; building and heating warehouses and offices or running company vehicles. But even people's wages eventually go into heating their houses and buying other goods which have caused energy to be expended.

This way of looking at the energy related to the whole economic activity was first proposed by Hans Bethe, the Physics Nobel Laureate, when he was looking at the American nuclear power industry proposals in the 1960s. To paraphrase, he said "if you track back far enough in the manufacturing activity then the price of an article reflects **directly** the energy used in producing that article". Indeed this principle has been used in Italy in their analyses of energy sources (9).

Returning to the PV panel example, it may be true that the choice of £30/MWh is a little low to express the average price paid in all the elements of the total economic activity, but a simple Excel program permits a sensitivity analysis to be done, as below.

Cost per kWp	Price of Electricity	Embodied Energy	Energy Payback
£4,000	3p/kWh	133 MWh	135 Years
£4,000	4p/kWh	100 MWh	101 Years
£4,000	5p/kWh	80 MWh	81 Years

On this basis it would seem that the price of PV panels needs to drop by an order of magnitude if they are to make any kind of contribution to the reduction of green house gas emission.

3.3 On-Shore Wind Turbines

A more sophisticated version of the Bethe calculation is shown below for an on-shore wind turbine.

Wind Turbine Total Value Energy Calculations

All figures per MW

Capital Cost per MW of installed capacity (£)	£1,000,000
Annual Maintenance as % of Capital Cost	2.00
Ground Rent per annum per MW (£)	£2,500
Share of initial costs, planning etc, per MW (£)	£50,000
Period of calculation (years)	20
Total Cost (£)	£1,500,000
Wholesale Price of electricity per MW (£)	30
Equivalent Energy Content (MW)	50,000
Load Factor (%)	25
Electricity Produced in one year (MW)	2190
Years to energy payback	**22.8**

Here the capital cost per MW is taken from the Enertrag AG web site (10), the annual maintenance figure is taken from the Finnish study (11), the ground rent is the well-know £5,000 per turbine and the initial costs are assumed to be in the order of £500,000 for a five, 2MW installation. This latter figure is a rough average; the actual figure depends on whether the application goes to appeal. The load factor is also taken from (10).

Again, while many of these figures may be debated, a sensitivity analysis can be done as shown below. Here it is clear that the Carbon neutrality of an on-shore wind turbine varies from 50% in the most extreme best case to zero in the nominal case. In this situation it was pointless to calculate a worst case.

Consequently, when calculated in this manner then the greenhouse gas claims for on-shore wind turbines must be halved for an extreme best case and they may go zero if the nominal case applies.

Capital Cost £	Annual Maint. %	Period years	Price Electricity £/MWh	Energy Payback Years
1M	2	20	30	22.8
1M	2	20	40	17.1
1M	2	25	30	24.5
1M	2	25	40	18.4
1M	1.5	20	40	16.0
600k	2	20	30	14.3
600k	1.5	20	40	10.0

The fact that the energy consequences of the total economic activity associated with the installation of a wind turbine is substantially greater than the energy embodied in the materials should not be a surprise. Indeed it is the basis of the economic model of a manufacturing enterprise to take some materials and then add value by means of manipulating those materials into a new form, adding value by the know-how used and finally using market forces to find an appropriate price.

Indeed there is an example at the moment where the price of wind turbines is increasing due to a high level of demand in the USA. This does not imply any increase in the energy content of the materials, but the total economic activity related to wind turbines is increased by the increased profits of the manufacturers.

3.4 Passive Solar Panels

In this context we mean the simple “black box” heat exchangers used to produce hot water. In the UK it is generally assumed that a solar panel can produce about 25% of the electrical energy requirements of the average family per year, ie about 1.2 MWh per year.

Currently the cost of these panels in the UK is very high, in the region of £3,000, because of the low volumes. At this price level the total economic activity embodied energy is in the region of 100 MWh (£30/MWh) or 75 MWh (£40/MWh). Clearly the energy payback periods at these prices are absurd, more than 60 years at best.

However, since these boxes are very “low tech” it is reasonable to expect that the price should reduce rapidly in the future. If we assume that they become commercially viable when they give a five year economic payback (in a domestic context) then the cost should be somewhere in the region of 6 MWh x £80/MWh, ie about £500.

At £500 the total economic activity embodied energy is 12.5 MWh (£40/MWh) ie a total economic activity embodied energy payback of about 10 years, which could produce some greenhouse gas emission reduction if the design life were 20 years.

4. Conclusions

To repeat, it should not be a surprise that the energy consequences of the total economic activity associated with the installation of a wind turbine is substantially greater than the energy embodied in the materials. This is the basis of the economic model of a manufacturing enterprise which adds value to some materials and then use market forces to find an appropriate price.

This paper has illustrated an alternative method for evaluating the viability of a given renewable energy generation scheme by looking at the total economic activity. Although the individual calculations are only approximate, their simplicity permits a sensitivity analysis versus the input parameters to be done and hence a reasonable view can be taken of the potential for a given renewable energy generation scheme to reduce greenhouse gas emissions.

This kind of analysis must be seen as essential, after all, promoting a renewable energy power generation scheme which is at best ineffectual at reducing global warming, or at worst increases it, is as bad as continuing with fossil fuels.

References

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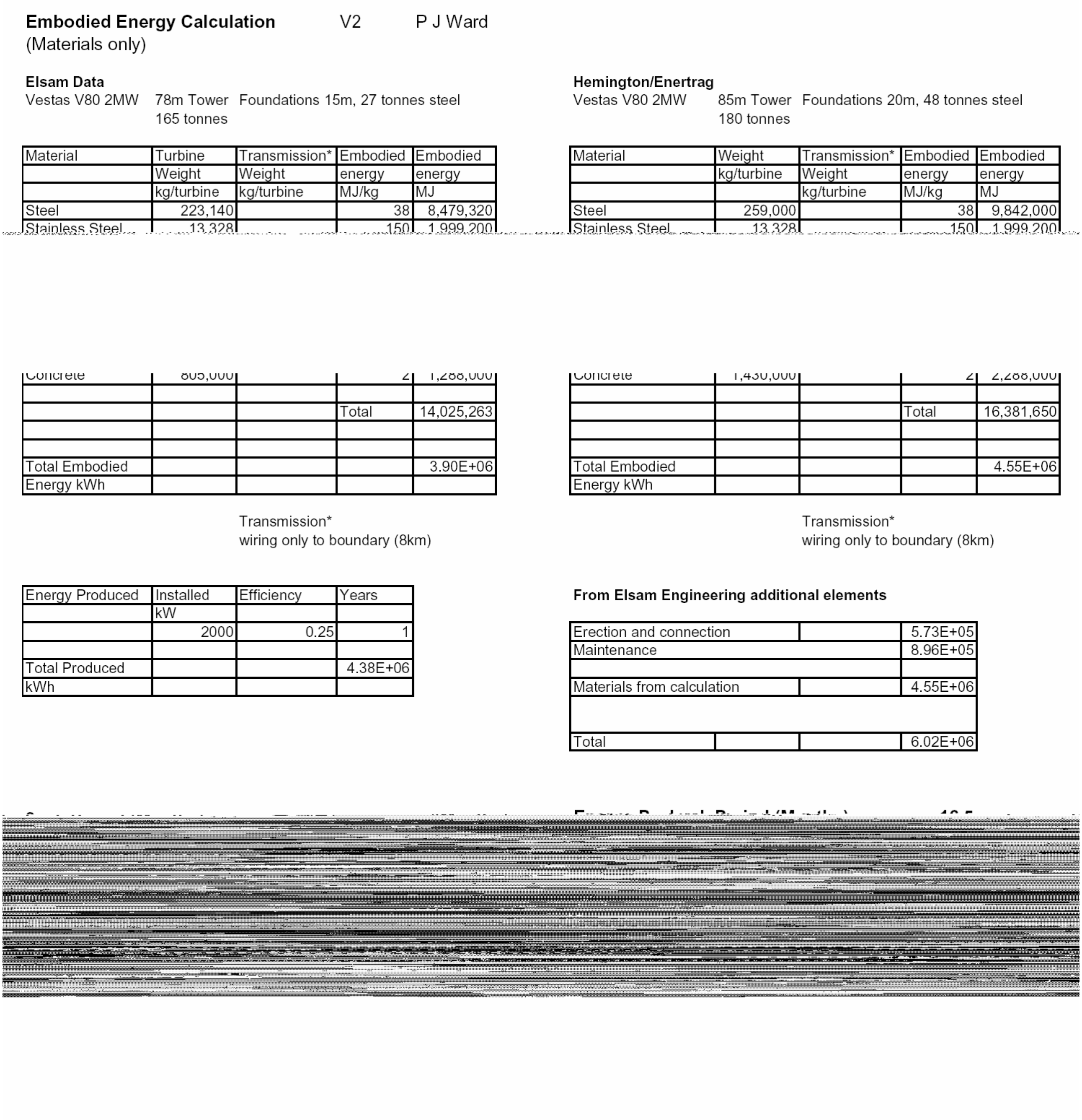
Appendix 1.



Embodied Energy Calculation V2 P J Ward
(Materials only)

Elsam Data
Vestas V80 2MW 78m Tower Foundations 15m, 27 tonnes steel
165 tonnes

Material	Turbine Weight kg/turbine	Transmission* Weight kg/turbine	Embodied energy MJ/kg	Embodied energy MJ
Steel	223,140		38	8,479,320
Stainless Steel	13,328		150	1,999,200
Concrete	805,000		2	1,288,000
			Total	14,025,263
Total Embodied Energy kWh				3.90E+06

Transmission*
wiring only to boundary (8km)

Hemington/Enertrag
Vestas V80 2MW 85m Tower Foundations 20m, 48 tonnes steel
180 tonnes

Material	Weight kg/turbine	Transmission* Weight kg/turbine	Embodied energy MJ/kg	Embodied energy MJ
Steel	259,000		38	9,842,000
Stainless Steel	13,328		150	1,999,200
Concrete	1,430,000		2	2,288,000
			Total	16,381,650
Total Embodied Energy kWh				4.55E+06

Transmission*
wiring only to boundary (8km)

Energy Produced	Installed kW	Efficiency	Years
	2000	0.25	1
Total Produced kWh			4.38E+06

From Elsam Engineering additional elements

Erection and connection		5.73E+05
Maintenance		8.96E+05
Materials from calculation		4.55E+06
Total		6.02E+06

[illegible]