Wind Turbine Electricity Autoproduction to reduce Carbon Footprint

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ABSTRACT

Electrical autoproduction refers to the production of electricity on site for one's own use. The possibility of replacing oil- or gas-generated electricity with wind-generated, autoproduced electricity is examined in this paper. Efficient electrical autoproduction requires understanding of the local load. The electrical load examined here is that of Waterford Institute of Technology. The turbine selection is examined in terms of the characterised load, the displaced CO_2, the amortisation of the invested capital and the local wind resources.

1. INTRODUCTION

The Carbon footprint for the Waterford Institute of Technology (WIT) is calculated from an electrical energy perspective alone (thereby ignoring the Carbon footprints associated with transport, water and space heating).

This paper reports on the potential Carbon footprint reduction, by replacing imported electrical energy with electrical autoproduction through a large (up to 75metre hub height) wind turbine. The technical, environmental and economic grounds are considered in order to assess the viability of such a project.

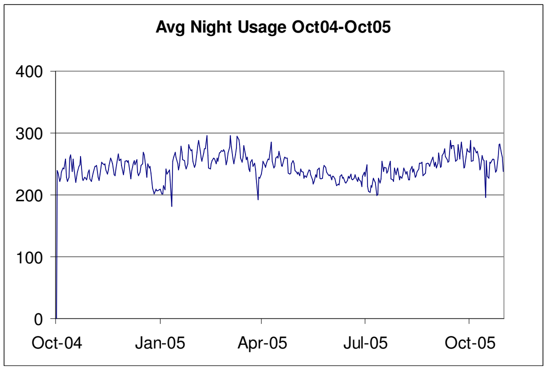
The requirements and viability of siting a wind turbine at WIT is presented, in a context that sees most of the Irish wind energy is generated in remote, hilly areas particularly on the west coast of Ireland, whilst WIT is located in an urban environment in the South East

2. ELECTRICAL LOAD AND ASSOCIATED FOOTPRINT

WIT has increased in size with the addition of new buildings for Health Science, the Walton Building housing the WIT Computer resources and a new two-storey restaurant. The new buildings are bright and include some Building Management Systems to reduce their energy usage. Also, retro-fitting efforts in the existing building stock have attempted to reduce their electrical energy usage, by, for example, replacing fluorescent lighting using magnetic ballasts, with fluorescent lighting using electronic ballast. Nonetheless there has been a gradual increase in the electrical baseload, probably due to increased floor-space and due to increased number of building users.

Electricity in WIT is used primarily for lighting, computing, ventilation and catering. Gas is used for space and water heating.

The electrical measurements presented here were provided by the WIT electricity supplier from readings taken every quarter hour. For the period of these readings, the supplier was An Bord Gais. The graphs in Figure 1(a) and (b) show two overlapping measurement periods, October 2004 to October 2005 and July 2005 to July 2006. The graphs highlight the size of and gradual increase in the electrical baseload (7.5% annual increase in the October 2004 to October 2005 period and 15% annual increase in the July 2005 to 2006 period). The size of the electrical baseload is important in dimensioning the electrical autoproduction, as will be explained later in the article. The upward trend will continue, due to the addition of a new Tourism and Leisure building later this year.



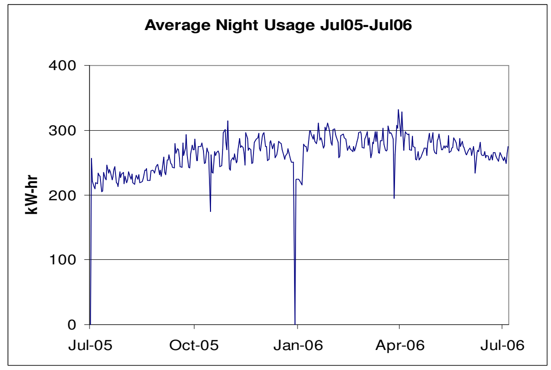


Figure 1(a) and (b): 12-month night measurements October 2004-05 and July 2005-06

This upward trend has been tracked in combined day and night readings from October 2003 to October 2006, shown in Figure 2. The average increase in the total load is 11% per annum. This is approximately the same as the average night increase or average increase in quiet periods, such as Summer months. This uniformity of increase across busy and quiet periods suggests that the floorspace, rather than the number of users, is the dominant parameter influencing usage.

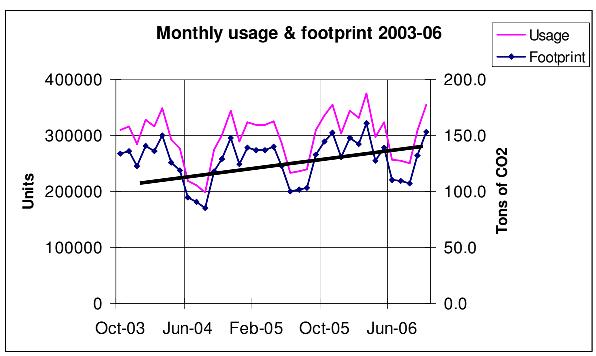


Figure 2: WIT monthly usage and Carbon footprint 2003-06

3. WIND RESOURCE AND ENVIRONMENTAL ASSESSMENT

Preliminary wind resource measurements have already occurred, using a 10-metre high mast. This work was contracted to Wind Prospect Ltd consultants, to assess the viability of the site wind resource. These readings show an average wind speed of about 3.5 m/s at the 10metre measurement height.

The local site is not as windy as sites in the West of Ireland. The Irish Wind Atlas predicts an average wind speed in this area of around 7.5m/s, at 70 metres above sea level [1]. However, wind farms on the West of Ireland are driven exclusively by economic concerns, maximising the energy output to a large energy demand. Paradoxically, this does not undermine the economic argument for wind energy electrical autoproduction in a less windy site, as the price obtained by a private wind farm is much less than the cost of an imported kwHr, which an electrical autoproducer tries to displace with on-site generated electrical energy.

4. ECONOMIC INCLUDING PRICE INFLATION

A characteristic of many renewable systems is the large initial capital investment required. Consequently, the economic consideration prior to purchase tends to focus on the payback or amortisation of cost duration.

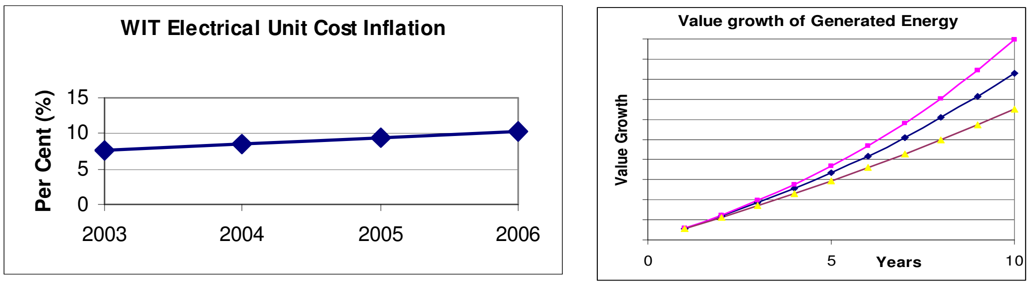


Figure 3: Variation in electrical unit cost inflation and the effect of the variation on the value of the electricity generated.

The Amortisation relationship may be expressed in a simple manner as follows:

$$C_{Init} = \sum_{i=1}^{Y} (W_{generated,annual} C_{unit} (1 + P_{Inf})^{i} - C_{annual})$$

C_{Init} = *Initial Capital Cost*
$W_{generated,annual}$ = *Annual Energy Generated*
C_{unit} = *Actual Cost of electrical energy unit*
P_{Inf} = *Electrical Energy annual average Inflation*
C_{annual} = *Annual running Costs*
Y = *Number of Years*

This expression assumes that little or no energy is exported to the grid, but rather that the generated energy displaces energy that would otherwise have been imported. When supply exceeds demand, the excess is taken up by the National Grid, with a consequent lower value to WIT for that generated unit. The baseload growth does not influence the calculation, other than to make the previous assumption more valid as time passes. The turbine costs are recouped, when the summation on the right equals the initial capital cost, C_{init}, on the left of the expression. The figure of $W_{generated,annual}$ depends on the turbine dimensions and the wind speed at the chosen hub height. Allowing for this uncertainty, the amortisation should lie between 7 and 11 years, based on the above formula. This relatively large spread can be reduced once the wind speed and turbine dimensions have been ascertained. The P_{Inf} parameter highly influences the amortisation as can be seen in Figure 3.

5. WIND GENERATION AND ASSOCIATED CARBON REDUCTION

The Carbon footprint for electricity usage is usually calculated by taking the national weighted average over all electricity generation types. So, for example, in the UK where generation is from gas, oil, coal, nuclear and hydro the weighted average for all usage is 0.43 kg of CO_2 per electrical kWatt-hour generated [3]. This figure is conservative, compared with other published figures [4] and also in an Irish context, due to the absence of nuclear power generation in Ireland, but will be used in this paper.

The amount of Carbon footprint reduction depends on various factors, not least the final selection of the turbine. If the final turbine selection is based on the base load, as presented in a later section, then the turbine would be rated about 850kW. Based on this figure, a 30% of rated value electrical production and a weighted average for all usage is 0.43 kg of CO_2 per electrical kWatt-hour generated [3], it would reduce WIT emissions by about one thousand tonnes of CO_2 annually.

This is approximately equivalent to the amount 320 acres of forest can absorb annually (In [2] Wackemagel & Rees state that a forest absorbs approximately 3 tons of CO_2 per acre of trees per year. This would consequently also reduce the national CO_2 emissions, saving Ireland in emissions penalties due under the Kyoto Agreement.

6. REGULATORY REQUIREMENTS

Electrical autoproduction using a wind generator would offer a number of advantages, once the environmental, regulatory and economic aspects have been met. The advantages include the reduced Carbon footprint and relatively short time for amortisation of capital. The environmental considerations include the measurement of the local wind resource and the selection of appropriate turbine site and dimensions. The regulatory considerations relate to the Planning Permission for the wind monitoring mast as well as the turbine itself [5] and the relevant permissions required from the Commissioner for Energy Regulation (CER). Finally, the economic considerations relate to the return on the large capital investment and the smaller annual recurrent costs.

7. TURBINE DIMENSIONING

The energy in wind is defined by the well-known equation $W=\frac{1}{2}\rho A v^3$, where ρ is the wind density, A is the area of wind being considered *and* v is the wind velocity. Given that ρ is approximately 1kg/m^3, the energy for wind incident on a turbine can be considered as $W=\frac{1}{2}Av^3$, with A being the area described by the turbine blades. The cubic relationship between velocity and energy helps to explain the selection of the West of Ireland and hilly areas for turbine sites. The average velocity increases with increasing hub height. The wind tends also to be less turbulent and more laminar in flow into the turbine, at higher heights. Turbulent wind can limit the turbine lifetime. The final hub height technical selection is, therefore, influenced by the desire to maximise both A and v, while reducing the effect of turbulence. Turbulence after wind passes a building can be up to three times the building height. In the case of WIT, the nearby Tourism and Leisure building will be 18 metres high.

The linear relationship between area and energy helps explain the swept area, A, of turbines (the relationship to turbine blade length is quadratic, so the same wind incident on a 25-metre length blade captures 625 times more energy than a 1-metre blade which helps to explain why small-scale turbines are not appropriate in this context).

Ideally, the turbine should be dimensioned such that most of the generated energy is consumed on-site and very little exported to the National Grid. If the graph of readings for 2003-2006 is examined, the WIT baseload has increased over that period from about a 220 to 260kW. If the latter figure is chosen and if the average output of the turbine is 30% of its rated value (30% is an accepted figure to allow for the variability of wind), the appropriate turbine to meet the baseload would be rated at 870 kilowatts. The rest of WIT's requirements would come from the National Grid.

The turbine swept area for 870kilowatts is 2,100m^2, (assuming the Irish Wind Atlas figure for 70m) and can be achieved by a 26m turbine blade. The hub height should therefore accommodate a 26m turbine blade, if the load is to be matched and the velocity is an average of 7.5m/s.

Taking the comments on load matching, turbulence and the swept area, average wind, the overall height (hub height plus blade length) and wind speed into account, the ideal hub height would be at least 75metres.

8. CONCLUSION

The electrical base load of 260kW and is rising by 11% per annum. If the present 260kW base load is matched and the turbine produces at 30% of its rated value, then this suggests a 26m blade at a hub height of over 70m. However, taking turbulence in the wake of the new Tourism and Leisure building, the ideal hub height would be at least 75metres high. The annual WIT carbon footprint reduction would be 1000 tons per annum.

The work indicates that electrical autoproduction is technically and economically feasible at the WIT site, despite the relatively low wind speeds. However, the significant regulatory requirements must also be fulfilled in order to bring the project to completion. The next steps include measuring the wind speeds at 50m, to get a more exact annual wind average and turbulence for this height and, by extrapolation, heights up to 75m.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Irish Wind Atlas is available on http://esb2.net.weblink.ie/SEI/MapPage.asp

[2] Our Ecological Footprint, Wackemagel & Rees, 1996, Science Press, co-published with Springer-Verlag GmbH.

[3] Carbon Dioxide Emissions from the Generation of Electric Power in the United States, July 2000, US Department of Energy Report.

[4] http://www.asa.org.uk/asa/adjudications/non_broadcast/Adjudication+Details.htm?Adjudication_id=40704

[5] The planning requirements are described in Wind Energy Development Guidelines 2006, which superceded the Wind Farm Development (1996) Guidelines, both available from the Dept of the Environment