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Permitting best use of wind resource for small wind-turbines in rural New Zealand: A micro-scale CFD examination

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ABSTRACT

To maximize uptake of micro renewable-energy generation, specifically small wind-turbines, it is crucial to permit for tower heights which allow maximum utilization of the available wind resource. Within New Zealand, municipal governments have authority to place limitations on the height of built structures in rural areas, including wind turbines.

Numerical simulations using Computational Fluid Dynamics (CFD) are used to examine the effects of simple house shapes and heights on the characteristics of the air flow reaching wind turbines. Within New Zealand, municipal governments have authority to place limitations on the height of built structures in rural areas, including wind turbines. However at present they have insufficient information to understand which height limitations may decrease wind-resource utilisation by small wind-turbines installed in these areas. This research finds that current permitted structure heights are not sufficiently high, necessitating either lengthy planning consent processes or acceptance of sub-optimal turbine output. Municipal councils in New Zealand could reduce barriers to small wind-turbine installations by considering taller towers, in the 15–20 m range, acceptable. This 15–20 m range is transferrable to all rural areas, in other developed or developing countries, where a lone small turbine or small number of small wind-turbines are being considered for installation near dwellings.

Introduction

New Zealand has a high quality wind resource (Reuther and Thull, 2011), however complications due to the scale and visual impact of large wind farms have prevented some developments from proceeding as planned (Kempen, 2012). Small wind turbines, with a target market of rural landowners, are less visually imposing and as a form of distributed generation offer myriad benefits associated with using energy close to its point of generation. These benefits include postponement of electricity grid upgrades and reductions in losses during transmission (Nair and Zhang, 2009).

At present there are several barriers to the uptake of small wind-turbines in New Zealand. Not only do rural landowners see the capital cost of the turbines as a significant barrier, particularly as there are no government policies financially supporting renewable energy generated electricity or guaranteeing its long-term purchase or purchase price, but also the process of gaining municipal government consent to install the turbine is seen as extremely daunting (Barry and Chapman, 2009).

Municipal governments set limits on accepted land use within their jurisdictions, including the height of built structures. Land-owners wishing to build structures, including wind turbines, on their land must meet the requirements set by the relevant municipal governments. This process, known as “resource consent”, is governed by the Resource Management Act 1991 (RMA) (Parliamentary Counsel Office, 1991). This act delineates a range of environmental, economic, and societal values which regional and municipal governments should seek to preserve (Parliamentary Counsel Office, 1991), and the vehicle through which these governments do this is their District Plans. Municipal governments may, within their District Plans, label activities as permitted, various types of discretionary, or prohibited (Parliamentary Counsel Office, 1991). Permitted activities do not require resource consent, thus are cheaper and faster to undertake (Parliamentary Counsel Office, 1991). If wind turbines exceed the “permitted” height in a district, considerably more paperwork and time will be required for their installation.

It has been suggested that there is a case for national government intervention to streamline the resource consent process for small wind-turbines (Barry and Chapman, 2009), but as of 2012 the process still remains less than transparent to potential wind turbine installers (Schaefer et al., 2012). Removing legislative barriers may prove an effective way to stimulate installations in the absence of financial support (American Wind Energy Association, 2008; Barry and Chapman, 2009).

Most District Plans do not yet have specific provisions for small wind turbines (Energy Efficiency and Conservation Authority, 2010a). The

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situation in New Zealand is complicated by the need to comply with height restrictions set individually by each city council's District Plan, as has been noted by New Zealand's Energy Efficiency and Conservation Authority (Energy Efficiency and Conservation Authority, 2010b). To determine typical permitted heights for structures such as turbines, a sample of maximum heights set by district councils in areas with high wind resources and significant populations was taken (Table 1). It was considered that where plans only specified permitted heights for buildings, as opposed to all structures, any other structure including a wind turbine would need to be at least below this height to remain unchallenged.

If permitted heights for structures in rural zones are not sufficient to maximise electricity generation from a turbine at any given site, then rural landowners wishing to install turbines at a greater height must either go through the resource consent process which they view as a significant barrier and disproportionately expensive (Barry and Chapman, 2009), or install a shorter turbine tower resulting in sub-optimal electricity output and a lengthier payback period. These can both be seen as disincentives for rural landowners to install small wind-turbines. Though the use here is to consider alignment of New Zealand District Plan structure height limitations with optimal turbine tower heights, the optimal heights found will be transferrable to all rural areas, in developed and developing countries, where the turbine will be located near sparse buildings.

A more informed approach that quantifies to some extent the effect that a permitted maximum tower height could have on energy generation potential could offer useful insights into the impact such legislation could have. The use of numerical simulation tools to optimise design parameters without the need for comprehensive site specific physical measurements has been demonstrated in a range of other situations to inform planning and design (Shaw, 1992; Wakes et al., 2010). Computational Fluid Dynamics (CFD) could therefore provide an effective simulation tool for comparing the proportional reduction in wind quality, and thus in electricity generation potential, at any given tower height.

In a ‘real world’ situation there are an infinite variety of house shapes, other existing obstructions to wind flow, and variations caused by topography and ground cover roughness. Initially a highly simplified and thus highly transferrable model of the effects of a simple house shape on airflow will be examined. It is assumed that almost all small rural wind turbines in New Zealand will be located near (within 100 m) the buildings they supply power to, in an attempt to limit cabling costs which must be borne by the homeowner (Electricity Authority, 2010). It is also assumed that only a lone or small number of small wind turbines would be installed, such that they will not affect each other's electricity output by formation of downstream wakes.

Optimal tower height is defined, for each house, as the height at which wind velocity is not lower than the maximum observable velocity in the absence of near ground effects and if the wind had passed no obstruction. At this height it will be considered that best use is being made of the wind resource, and any legislative restrictions not permitting this height are considered to present barriers to effective utilisation of wind resource. Initial CFD simulations will determine the range of optimal tower heights, for turbines placed next to houses of varying shapes and heights. These generalised cases do not account for site-specific optimisation but this comparative study allows insights into general issues that will inform the process of turbine siting.

The aim of this research is to determine the proportional reduction in utilisation of wind resource caused by tower height limitations, for a small wind turbine sited a maximum of 100 m from a house in a rural area.

Method

Modelling was conducted, using FLUENT software offered by ANSYS (ANSYS Inc., 2009), for several scenarios where the house presents maximum obstruction to the air flow, with wind having to pass over the house to reach the turbine (Fig. 1). These represent the worst case scenarios. It is likely that turbine installers would attempt to install the turbine such that the house was only an obstruction for less common wind directions in the area, but installers may be constrained by other obstructions, considerations such as views, layout of land, or existing features such as vegetable gardens. It was considered that the turbine would not be placed on the house for structural reasons. Some 40 simulations were run to build a picture of the effects on wind flow of ground roughness, inlet velocity, house roof shape, and house height.

Turbine output

The concern is the effect the house will have on the flow approaching normal to the turbine, with downstream effects of the turbine considered irrelevant to its optimal tower height. Therefore the pole and turbine were not modelled in the simulations. Frequently the simplification of not modelling the turbine is made, as in the case of Balduzzi et al. (2012) examining building mounted micro-turbines, Ledo et al. (2011) when examining the effect of different roof shapes on wind turbines in urban environments, and Palma et al. (2008) when modelling complex terrain and the effect this would have on wind turbines placed in the region.

This work seeks to determine the effects of built objects alone on the utilisation of wind resources by small wind-turbines. Though significant variation in performance of turbines will exist depending on the optimisations performed by each turbine manufacturer, a more general understanding of wind resource utilisation can be gained by considering the fundamental equation describing limitations on extracting energy from wind (see Eq. (1)). Reduction of potential electricity output of the turbine is considered entirely in relation to the velocity approaching

Table 1
Permitted structure heights in rural zones, for selected districts with high wind resources.

City	Population	Average wind speed (m/s)	Permitted height (m)
Wellington (Wellington City Council, 2011)	200,000	>7	8[a]
(Lower) Hutt (Hutt City Council, 2006)	103,000	4–8	8[a]
Southland (Southland District Council, 2001)	29,600	2–8	12[a]
Far North (Far North District Council, 2011)	58,500	2–8	12
Queenstown Lakes (Queenstown Lakes District Council, 2011)	28,700	2–8	8[a]
Masterton (Masterton District Council, 2011)	23,500	4–9	15[a]
Palmerston North (Palmerston North City Council, 2006)	82,100	4–7	9[a]
Ashburton (Ashburton District Council, 2010)	30,100	3–7	10[a]
Manawatu (Manawatu District Council, 2007)	30,000	4–7	20[a]
Waitaki (Waitaki District Council, 2010)	20,900	2–8	10[a]
Dunedin (Dunedin City Council, 2005)	126,000	2–5	10

[a] These plans specified heights for buildings and accessory buildings, but not “structures”.