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Quantification and Costing of Domestic Electricity Generation for Armidale, New South Wales, Australia Utilising Micro Wind Turbines

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ABSTRACT: In this study, a general overview of energy and renewable energy sources available in Australia was introduced, household's electricity situation in Australia was presented, and focus wind energy was conducted. A theoretical methodology for quantification and costing of selected micro wind turbines was introduced. This methodology was applied to Armidale city, New South Wales (NSW), Australia as a case study. The methodology involved utilisation of spread sheet application and HOMER software. Such methodology dealt with hourly household electric load in Armidale and hourly wind speed in Armidale as inputs and provided hourly power outputs from selected micro wind turbine as an output. As well, a sample of payback period calculations for the said selected wind turbines is calculated versus various wind speeds. This methodology can be applied to any other cities or towns. Undoubtedly, the ability of quantifying micro electricity generation resultant from micro wind turbines for a specific city or town and evaluating the share of households' electric consumption at that city or town associated with the relevant payback periods opens the gate for further studies of feasibility and visibility of micro wind turbines.

Keywords: Renewable energy in Australia; micro wind turbines; micro electricity generation; Household electricity consumption; Armidale city.
JEL Classifications: C1; C2; C3; C6; C9

1. Introduction

Energy is the keystone of nature and society. All life on earth is made possible by incident solar energy captured and stored by plants and passed through ecosystems. Human civilization was spawned by innovation in acquiring and using diverse sources of energy, first by cultivating plants and domesticating animals and eventually by building machines that could use energy stored if fossil fuels. In fact, each phase of development of civilization was triggered by changes in energy use that provided opportunities for growth of human populations and economic systems (Randolph and Masters, 2008).

Today society is in unprecedented growth period. Since 1850 and the dawn of Industrial Revolution, the population, the economy, and energy use have surged, fuelled by oil, natural gas, and coal. This growth will be limited by diminishing availability of oil and gas and environmental constraints of fossil fuel use, probably sooner that most realize.

Rapid worldwide population growth results in a continuous and rapid increase in energy demand. To maintain a high living standard in industrialized countries, as well, to improve the living standards in developing countries, energy consumption that cannot be avoided.

There is an intergenerational imperative to secure energy resources for the present time and for future generations. To achieve this goal, energy can be utilized much more efficiently. As well, there is need to explore new energy resources away from the traditional, but unsustainable fossil fuel-based energy sources of coal, oil, gas and petrol. Nowadays, renewable energy resources are booming as a sustainable clean energy alternative. Renewable energy sources such as solar, wind, bioenergy, geothermal, hydropower and ocean (wave, tidal and thermal) are versatile, particularly in combination (Australia's renewable future, 2009).

Nowadays, renewable energy sources have probable potential to contribute to fulfil partially to the energy increasing demands worldwide as such sources are reliable and inexhaustible to a great extent. Recent researches show an increasingly evident that renewable energy technologies do have a strategic role to play in the achievement of the goals of sustainable economic development and environmental protection (Sayish, 1999; Wrixon, 1993).

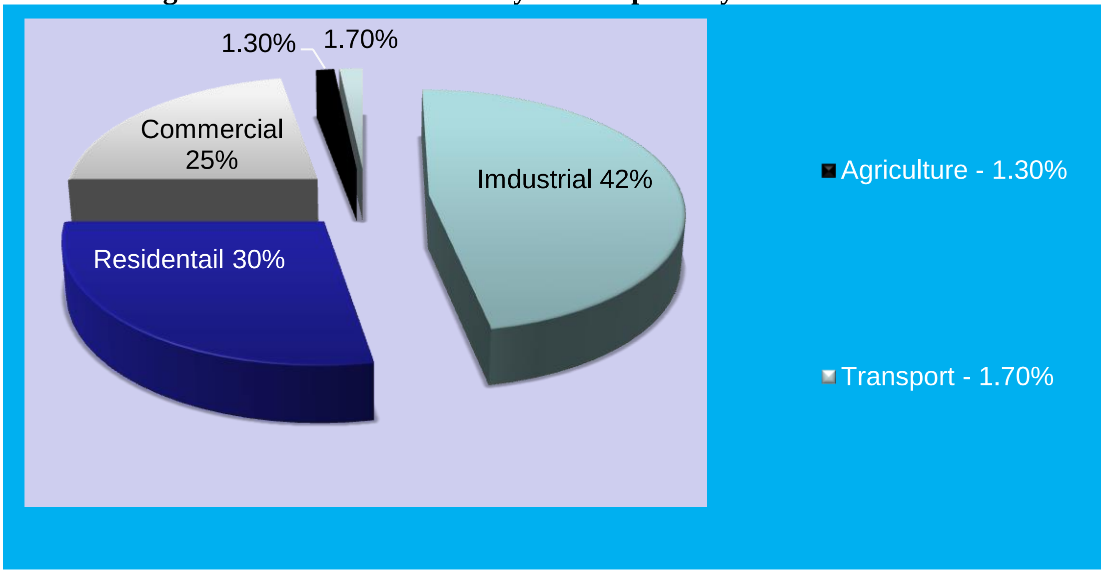
Fortunately, wind is an inexhaustible renewable energy source, which could be used to provide significant amounts of energy to support the needs of continuous and growing energy demand. Wind speed is a crucial factor of in determining wind potential wind speed is strongly dependent on specific site topography and characteristics (Sahin and Aksakal, 1998), such as altitude, latitude, climate, etc.

Australia is the world's 17th largest consumer of non-renewable energy resources and ranks 18th on a per capita basis. Australia's energy consumption primarily is composed of non-renewable energy resources (coal, oil, gas and related products), which represent 96% of total energy consumption. Renewables, the majority of which is bioenergy (wood and wood waste, biomass and biogas), account for the remaining 4 per cent of consumption. Renewable energy consumption, while low, has been growing strongly in recent years (Energy in Australia, 2013).

2. Electricity in Australia

Energy consumption varies in Australia by sector. As Australia is one of the developed countries, it can be easily derived that the industrial sector has the largest share of consumption followed by the commercial sector. Figure 1 shows that industrial sector the largest share, followed by residential sector and commercial sector, ending with a minor shares for transport and agriculture (Australian Energy News, 2010). The real important observation that the residential sector has such a large share of electricity consumption.

Figure 1. Australian Electricity consumption by sector - 2009/2010

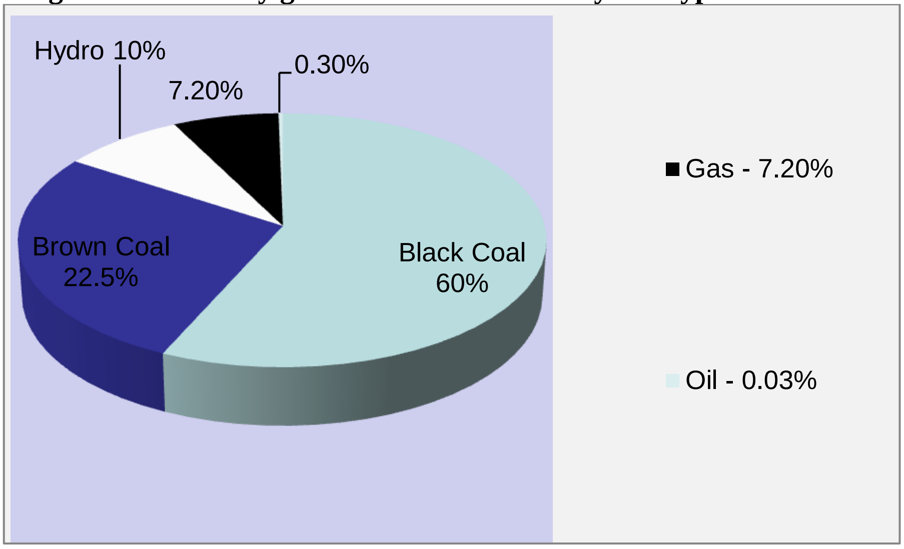


Source: (Australian Energy News, 2010)

Electricity is generated in Australia mostly based on burning fossil fuel. Figure 2 clearly shows that more than almost 85% of the electricity is generated by burning coal either black or brown followed by very minor share of gas and hydro (Australian Energy News, 2010). This implies that the utilisation of renewable energy sources to generate electricity is almost null Australia wide.

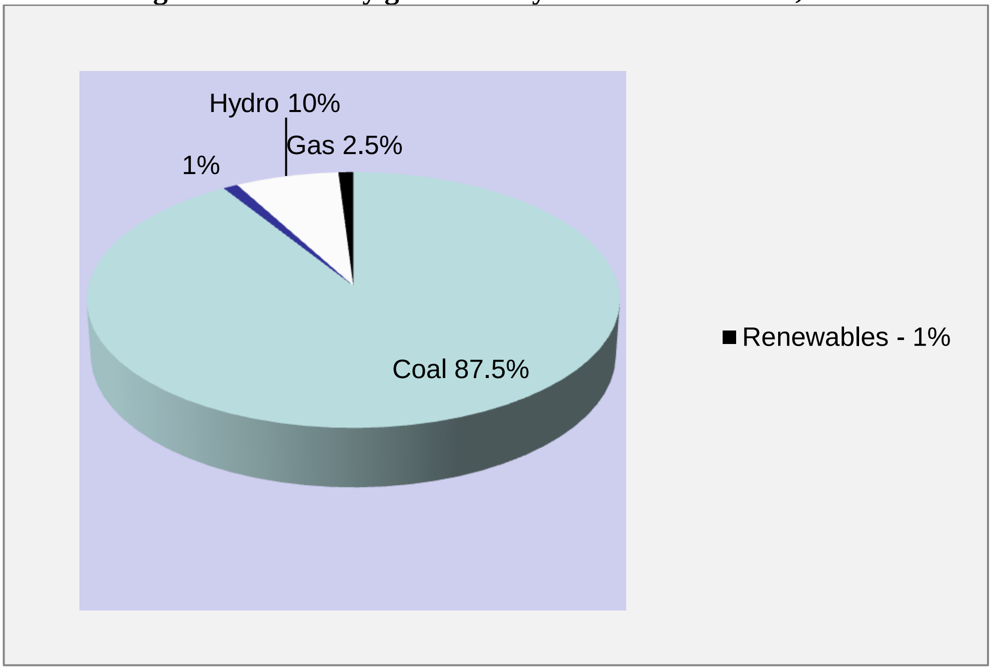
While considering New South Wales (NSW) which is the oldest Australian state and the largest population and cities, as shown in Figure 3 again coal burning has the largest share of electricity generation, followed by a minor share of Hydro. Other renewable energy sources such as wind, photovoltaic, biomass and geothermal, are almost negligible in NSW.

Figure 2. Electricity generation in Australia by fuel type - 2009/2010



Source: (Australian Energy News, 2010)

Figure 3. Electricity generated by fuel source in NSW, 2011



Source: (Environment and Energy NSW, 2011)

3. Armidale, NSW, Australia

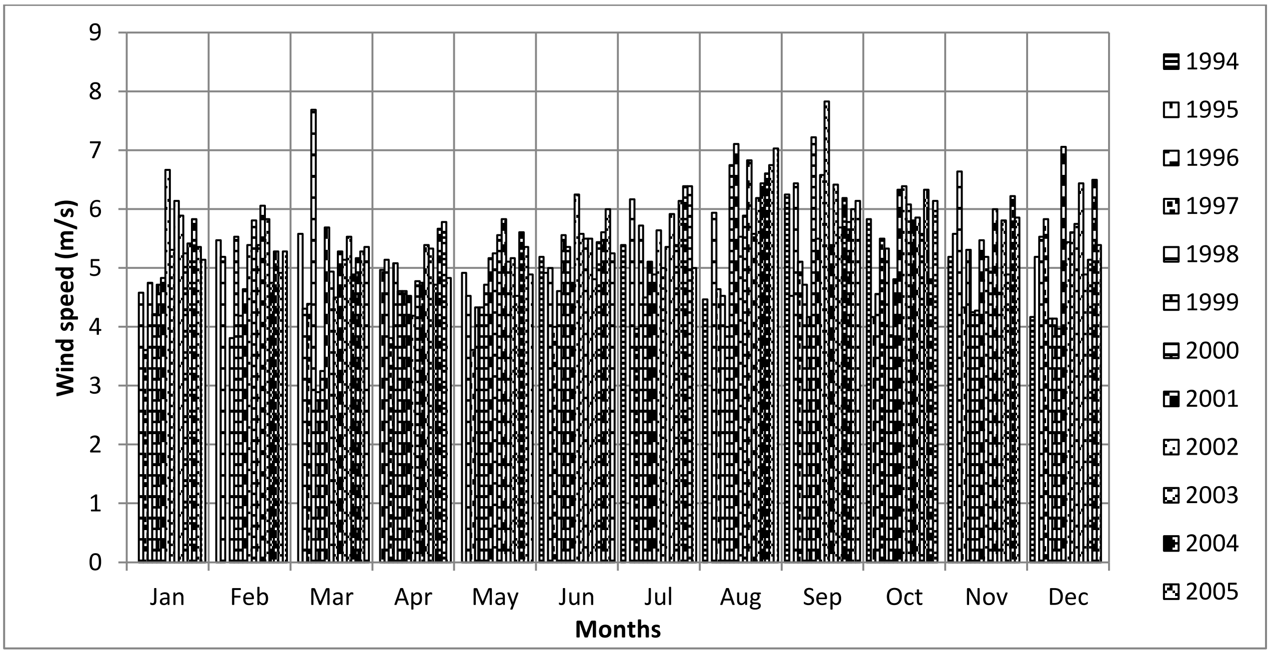
Armidale (30°30′S 151°39′E/ 30.500°S) is a city in the Northern Tablelands, New South Wales, Australia (Burr, 2002). Armidale is located on the Northern Tablelands in the New England region about midway between Sydney and Brisbane at an altitude ranging from 970 metre at the floor of the valley to 1,110 metres above sea level at the crests of the hills (Burr, 2002). Armidale has a cool temperate climate with the majority of rain falling in the summer months. Armidale's elevation results in a mild climate, with pleasant warm summers, extended spring and autumn seasons, and a long cold winter with some frosty nights. Figure 4 shows the location of Armidale. Generally, rural/regional Australia are rich of the following renewable energy sources such as solar, wind, geothermal, biomass and hydropower, however, further works needs to be done to prove the above findings feasibility against existing traditional electricity generation based on fossil fuel (Maklad, 2014a).

Figure 4. Location of Armidale in New South Wales

Source: Google Maps

In this study, mean wind speed data was measured daily by Armidale Airport Automatic Weather Station under the authority of the Australian Bureau of Meteorology (BoM). Observed wind speed data during the period (1994-2010) were obtained at 10 metres above ground level with an anemometer. These data were used to investigate the wind power potential of this region. Figure 5 shows the monthly mean wind speed in Armidale region during the period 1994 to 2014. The highest monthly mean wind speed of 7.83 m/s occurred in September 2003, while the lowest mean wind speed of 2.89 m/s occurred in March 1999. The mean annual wind speed in the period from 1994 to 2010 was 5.30 m/s.

Figure 5. Monthly mean wind speed in Armidale, NSW during (1994-2010)



Source: Maklad and Glencross-Grant (2014)

Figure 6. Selected three micro wind turbines
Skystream3.7 Wind Turbine 2.4Kw

Source: http://www.windenergy.com/products/skystream, 2014

Siliken4.1 Wind Turbine 5kW	**Proven11 Wind Turbine 6Kw**
 Source: http://silikenwind.com/products/, 2014	 Source: http://www.bettergeneration.co.uk/wind-turbine-reviews/proven-11-wind-turbine.html, 2014

4. Theoretical Quantification Methodology

This methodology is previously used by some researchers (Li and Reynolds, 2012), it targets quantifying the electricity generation of micro wind turbines (figure 6); it is implemented by using HOMER software and any spread sheet application such as Lotus or Microsoft Excel or Open Office, etc., methodology consists of three steps as follows:
1) Generation of the household hourly electrical load consumption by HOMER or spread sheet application;
2) Generation of the hourly wind speed by HOMER;
3) Determination of the hourly power output to be generated from micro wind turbines by HOMER.

HOMER (Hybrid Optimisation Model for Electric Renewables) version 2.81-February 8, 2012 is a simulation and optimisation software tool. HOMER is developed by the US National Renewable Energy Laboratory (NREL). HOMER includes a number of renewable energy component models and evaluates suitable technologies options based on the cost and availability of resources (Khan and Iqbal, 2005). Information about resources, control methods and constraints as well as inputs on component types, numbers, costs, efficiency and longevity is required before performing a simulation over a full year and an analysis by HOMER. Sensitivity analysis can also be conducted by replacing a specific number by variables having a range of values. This allows determining the effects of change in a certain parameter on the overall system.

4.1. Generation of the hourly household electrical load

In the methodology the hourly household electrical load is fundamental. However, exact hourly household electrical load over a complete year for Armidale is never available. Therefore, a procedure is established to generate the hourly household electrical load. This procedure, implemented in spread sheet, requires two pieces of information:

- A sort of average household electrical load consumption, Table 1 (Maklad, 2014b) shows average seasonal electrical consumption in Armidale for houses of different occupancies. In regards to this study, average seasonal household electrical load consumption for an average house (a 4 occupants house) in Armidale was 3160kWh in winter, 2020kWh in Spring, while it is 2280kW in summer and 1930kWh in Autumn with average daily kwh 32,22,25 and 21 kWh respectively as calculated by (Maklad, 2014b).
- An average annualised electrical load profile (ratio of hourly to yearly electricity consumption). (Proof of Concept Residential Energy Monitoring Program, 2012) provided average annualised electrical load profile for households is used to account for seasonal factors and it represents the closest to realistic house electricity consumption in Australia.

Table 1. Average electric load consumption seasonally for households in Armidale

Season	Months	1 Occupant		2 Occupants		4 Occupants		6 Occupants	
		Total kWh	Avg. Daily kWh	Total kWh	Avg. Daily kWh	Total kWh	Avg. Daily kWh	Total kWh	Avg. Daily kWh
Winter	Jun–Jul-Aug	1700	18	2255	23	3160	32	4070	42
Spring	Sept-Oct-Nov	1150	13	1440	16	2020	22	2600	29
Summer	Dec-Jan-Feb	1300	15	1630	18	2280	25	2940	33
Autumn	Mar-Apr-May	1100	12	1380	15	1930	21	2490	27

Note: Extracted from Maklad (2014b).

The yearly 8760 hourly household electricity load values, in kWh, could be calculated by using the average annual household electricity load and the average annualised electrical load profile in a complete year for an average house (4 occupants) in Armidale. Examples of generated daily household electricity load profiles are shown in Figure 7 produced by a spread sheet application. Alternatively, hour-by-hour household electrical loads can be artificially generated by HOMER. An hourly electrical load profile for one day (one set) in a year is the minimum requirement. Then, HOMER is capable of synthesizing 8760 hourly electrical load values for an entire year by using this hourly electrical load profile and adding random variability parameters (day-to-day, time step to-time step). HOMER is able to take a maximum of 24 sets of hourly electrical load values consisting of two sets of values for a weekday and a weekend for each month from January to December. Figures (8, 9 & 10) are produced by HOMER shows average daily electric load consumption for seasons in Armidale, graphical intensity electrical consumption for time of day over the year in Armidale and daily electrical consumption hourly profile of months for households in Armidale for households, respectively. Apparently, on average, electricity consumption is significantly higher in winter than summer due to heating requirements and additional lighting which is easily justified considering Armidale sever coldness in winter. As well, the highest electric load consumption is always at 0.8:00am when household are preparing to go to work or school and 00:06pm when household are coming back home to prepare lunch, watching TV, washing, other several activities in addition to heating mainly, it is worth mentioning that cooling in summer also counts for a significant portion of electric load consumption as can be derived from figures (7, 8, 9 & 10).

Figure 7. Typical daily hourly electrical consumption load pattern for the four seasons in Armidale

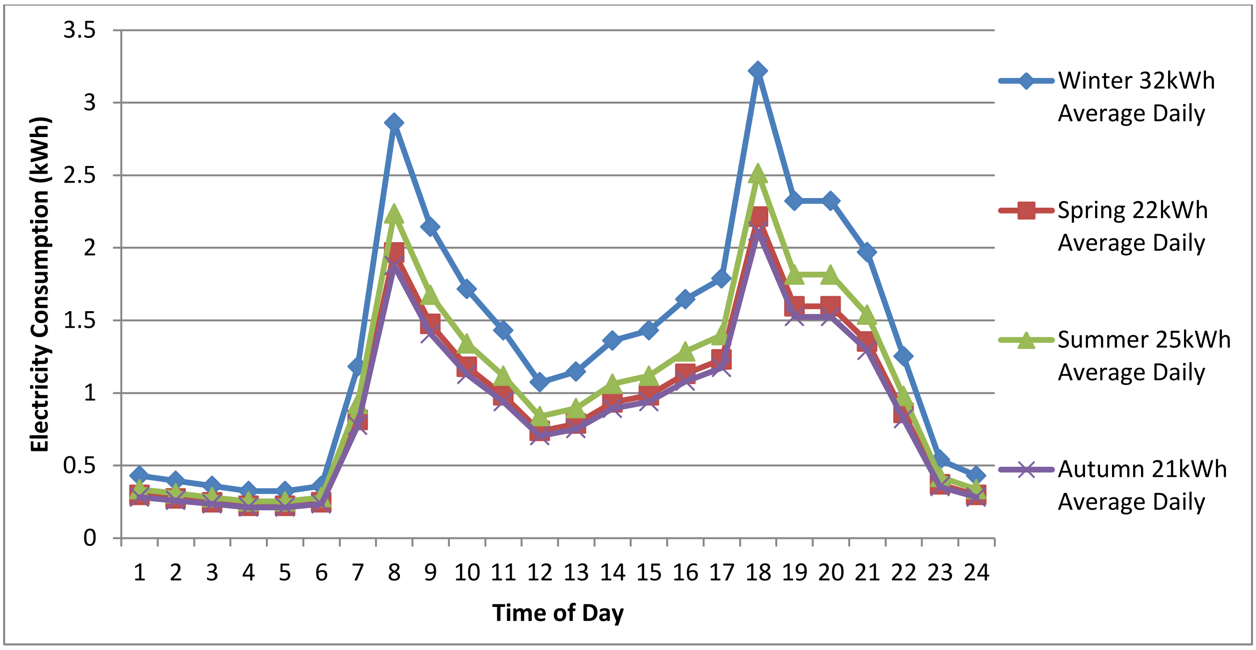
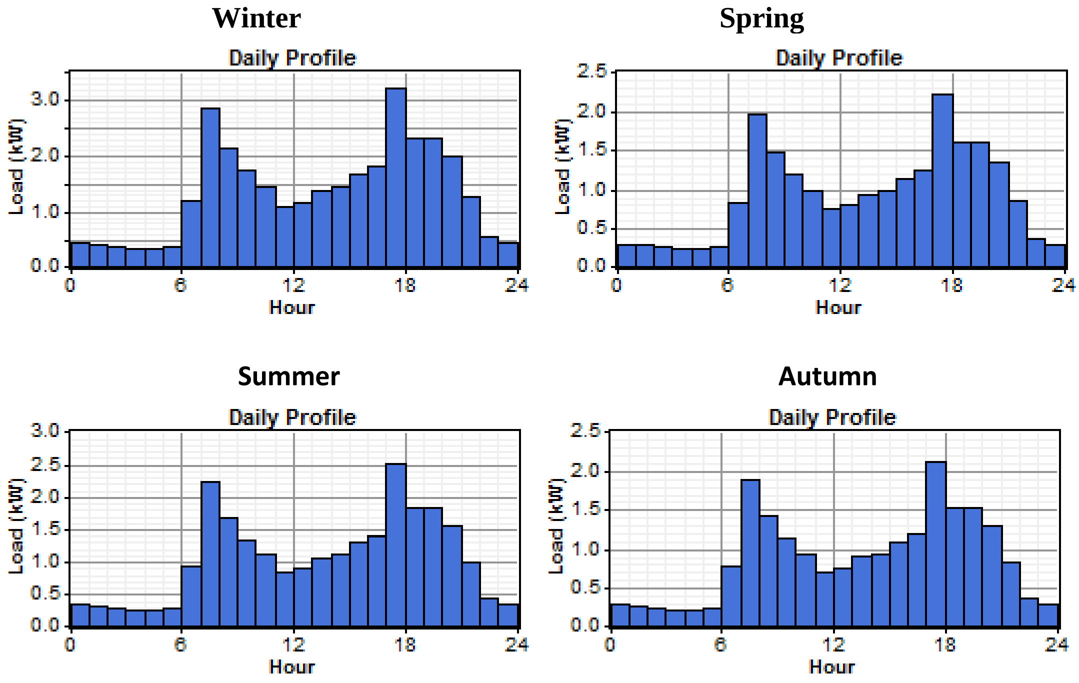


Figure 8. HOMER's daily electrical consumption hourly profile of geographical seasons for household in Armidale


Winter

Spring

Summer

Autumn

Figure 9. HOMER's graphical intensity electrical consumption for time of day over the year in Armidale for households

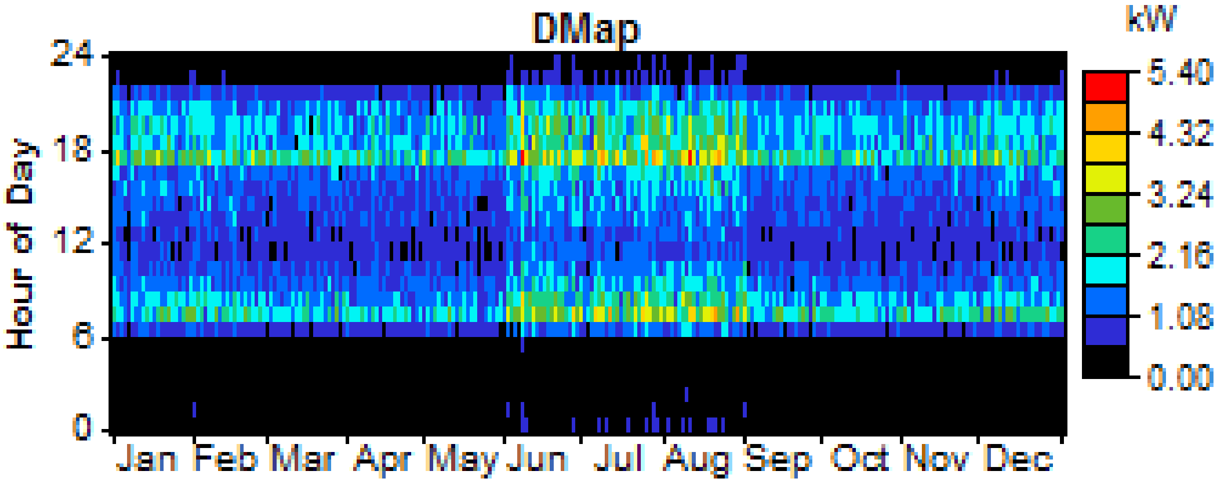
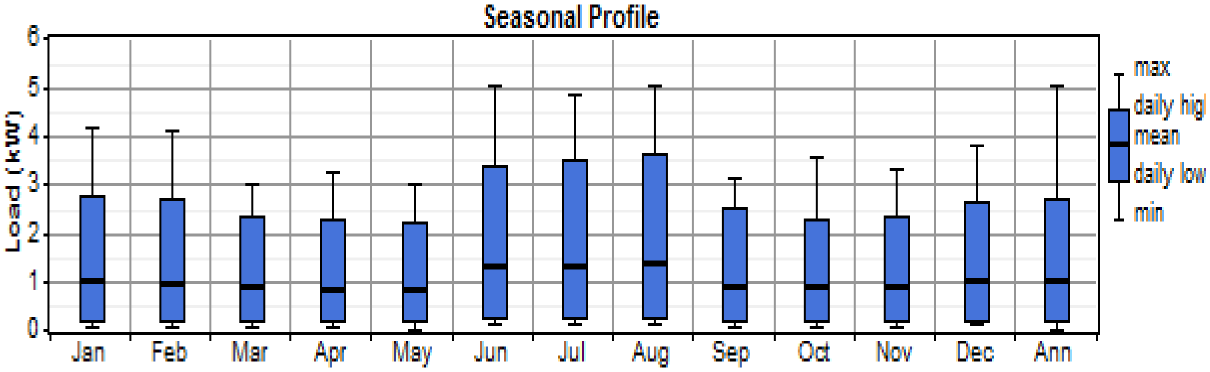


Figure 10. HOMER's daily electrical consumption hourly profile of months for household in Armidale for households



In this case, the seasonal variation can be seen from the generated 8760 hourly electrical load values. However, there is no recognition of any special events, such as holiday periods in Armidale. As well, weekdays and weekdays are considered have the same electrical consumption for facilitation purpose.

4.2. Generation of hourly wind speed

The hourly wind speed data for an entire year at many locations are usually unavailable or too expensive to procure. In order to achieve best accuracy, artificial but statistically reasonable hourly wind speed data can be generated using HOMER's synthetic wind speed data synthesis algorithm. This algorithm can produce data which mimic the characteristics of real wind speed, including strong and sustained gusts, long lulls between windy periods, and seasonal and diurnal patterns.

In this methodology, the monthly average wind speed at the turbine height for a year at the location at which the turbine is to be installed is required. If the monthly average wind speed is not available, the annual average wind speed is used (for each month); the use of an annual average wind speed shows no realistic seasonal variation however. A logarithmic wind speed profile is used for calculating the wind speed at the micro wind turbine hub height if the turbine hub height differs from the height at which the measurements are taken. This accounts for the fact that wind speed tends to increase with height above ground, as the effect of obstacles (buildings and vegetation) decreases with height. A logarithmic wind speed profile uses a surface roughness coefficient length in its calculation. The surface roughness coefficient length is to characterise the landscape condition; in this research a value 0.1 is used to represent a landscape condition of an open field.

The hourly wind speed data is generated by performing complex statistical calculations. Figures (11 & 12) show the HOMER display for generating the hourly wind speed data at Armidale airport. The calculation is based on the average monthly wind speed data at the micro wind turbine hub height and adding four random variability parameters. These four parameters can accurately reflect the wind condition for a particular location ensuring the most realistic hourly wind speed data are generated. The four parameters are: Weibull k factor, autocorrelation factor, diurnal pattern strength and hour of peak wind speed; those factors are calculated with HOMER and will not be presented at this study as it will not serve the purpose of this paper.

Figure 11. HOMER's Average hourly wind speed data for months at Armidale airport

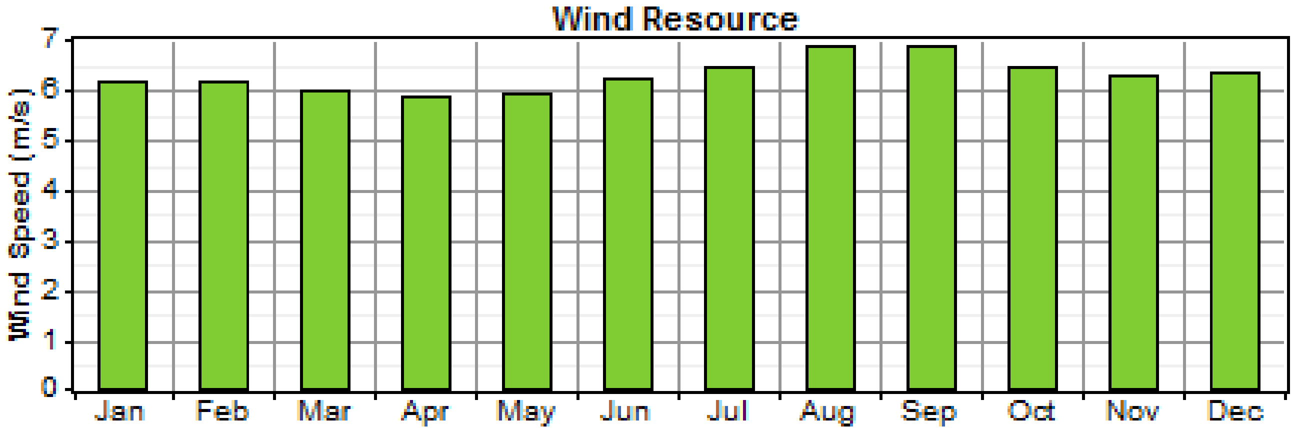
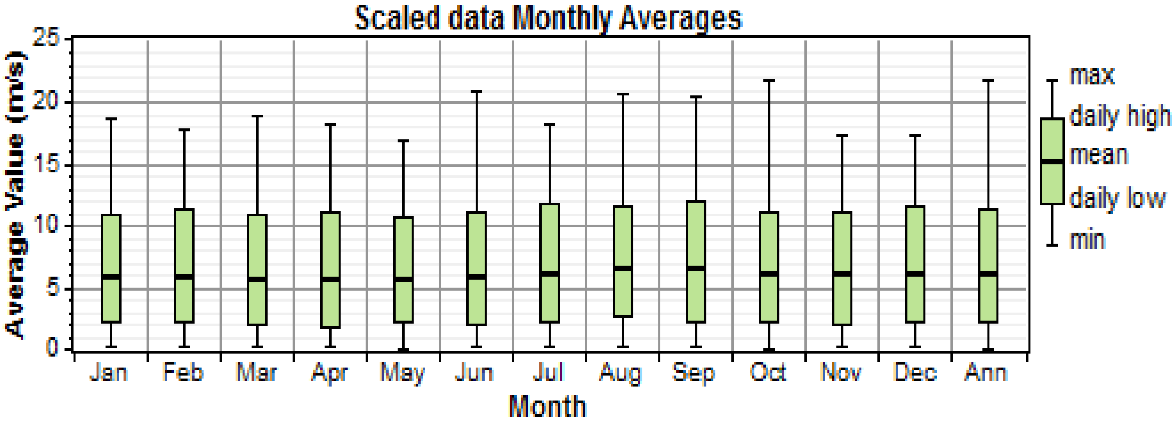


Figure 12. HOMER's monthly wind speed data for at Armidale airport



4.3. Determination of the power output from a micro wind turbine

Micro wind turbines are characterised by its power curve. The power curve provides the power output, in kilowatts (kW), for a given wind speed, in m/s, and takes into account all relevant factors including blade aerodynamics and auto-furling/stall effects, electrical generator, any gearing and the power electronics associated with turbine itself (Kelleher and Ringwood, 2009).

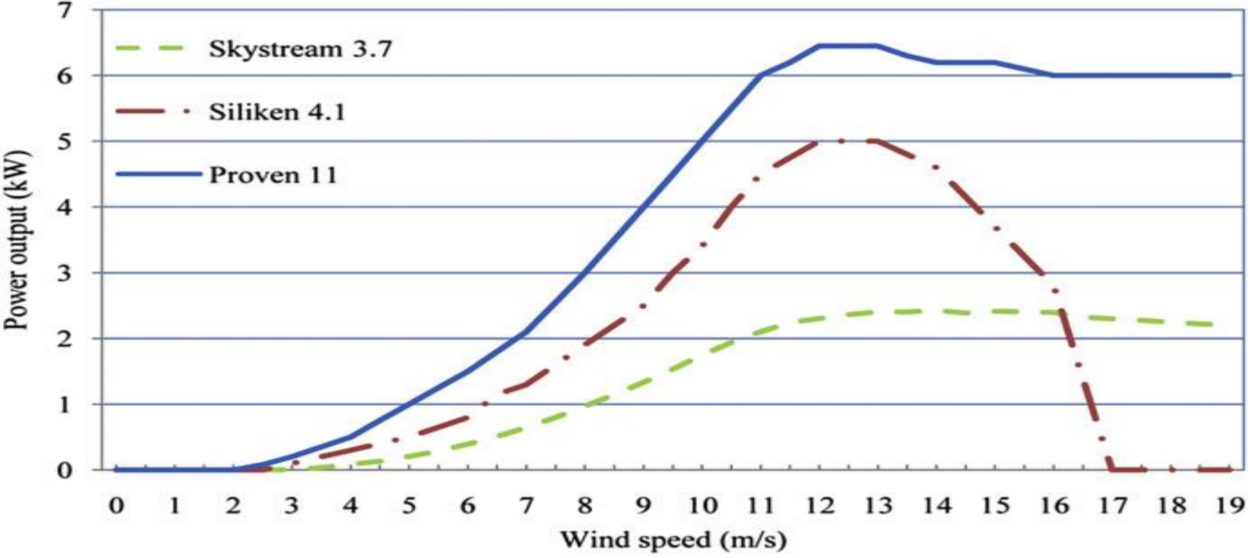
Figure 13 shows the power curves for the Skystream 3.7, the Siliken 4.1 and the Proven 11 micro wind turbines. Three wind speeds on the power curve are used to describe the operation of a particular turbine, and are:

- Cut-in wind speed. This is the minimum wind speed that a wind turbine can generate usable power. Typically the cut-in wind speed is ranges between 2.5m/s to 3.5m/s. for micro wind turbines.
- Rated wind speed. This is the wind speed that a wind turbine can generate its specified rated power by the manufacturer.
- Cut-out wind speed. This is the wind speed that a wind turbine ceases electricity generation and shuts down rotation in order to prevent mechanical damage or fatigue due to excessive

kinetic energy which its parts cannot sustain. Most micro wind turbines are designed to prevent the blades rotating when the wind speed exceeds the cut-out speed. However, newly-designed micro wind turbines like the Proven 11 (one of the selected models in this study) can regulate to their rated power and continuously generate power at high wind speeds.

The power output of a micro wind turbine for a specific hour can be obtained by applying the artificial wind speed generated by HOMER for this hour to the power curve. The same procedure is applied by HOMER for each corresponding hourly wind speed for a year. Hence, there are a total of 8760 hourly/yearly power outputs generated for a micro wind turbine. Every hourly power output of the micro wind turbine is then compared with the corresponding hourly electrical load. In case the hourly power output exceeds the hourly electrical load demand by the household, the surplus electricity could be fed into to the grid (a grid tied system). If the hourly power output is less than the hourly electrical load demand needed by the household, then the grid is used to supply the additional power to satisfy the electrical demand in the hour, and no power is fed into the grid. However, this won’t happen in case it is a standalone power generation system at remote areas, other sources of power generation can be sought such as solar power or diesel generators.

Figure 13. Power curves for three selected micro wind turbines [21-23].



4.4. Calculation of the payback period

The payback period is chosen to perform a comparative cost/benefit analysis. The payback period, calculated in Microsoft Excel 2007, can be used to compare different micro wind turbines when they are installed in the same conditions. In the economic analysis, the assumption is made that the entire capital cost of a micro wind turbine (including the cost of installation) is funded from a loan. The annual repayment is calculated from the money saved by replacing the imported electricity and the profit made from the exported electricity to the grid. The standard formula for calculating the payback period is given by (Malik and Al-Badi, 2009).:

$$n = log(1+i)^{\left(1-\frac{i*C}{R}\right)} \qquad (1)$$

where n is the payback period (number of years), R is the annual repayment on the loan, C is the capital cost, and *i* is the loan rate also called the annual percentage rate (APR).

Table 2 shows the three selected micro wind turbines technical aspects, capital cost as in (2013), operation and maintenance cost, knowing that the life time of three turbines are 20 years. It is meant to select several rated powers in order to provide variety of sections. Assuming a loan rate (5%) and considering the dominating feed in tariffs in Armidale which is 6 cents/kWh, Table 3 shows the relevant payback periods for the three selected models at different mean wind speeds.

Table 2. Technical and financial information for selected three six micro wind turbines

Wind Turbine	Rated Power	Cut-in Wind	Cut-out Wind Speed (m/s)	Hub Height	Capital Cost	Operation and Maintenance Costs	Life Time

	(kW)	Speed (m/s)		(m)	(AUD)	(AUD/year)	(Years)
Skystream 3.7	2.4	3.5	25	14	16,850	160	20
Siliken 4.1	5	3.5	17	11	30,000	230	20
Proven 11	6	2.5	None-Regulating	15	45,500	230	20

Table 3. Payback period (in years) for three sample micro wind turbines for three annual mean wind speeds in Armidale.

Wind Turbine	5m/s	5.5m/s	6m/s
Skystream 3.7	Not Achievable	34 Years	25 Years
Siliken 4.1	Not Achievable	32 Years	23 Years
Proven 11	50 Years	25 Years	20 Years

By all means, the payback period calculations involves many factors, however, the major factor is the capital cost and the funding options, both factors are greatly dynamic changing with time rapidly. Additionally, higher wind speeds and gusts are decreasing the payback period, as well, the option of energy storage can change the payback period far, however, and investigating such aspects is not within this study scope.

6. Conclusion

Three selected micro wind turbines' models to sample the domestic electricity generation in Armidale have been investigated in this paper. The specialized computer software HOMER along with relevant economic calculations are utilised to examine the possible varieties of technical and economic aspects. This is done to ensure a relatively accurate analysis to perform for a specific location, under current technical and cost conditions (Dalton et al., 2009). The paper's goal is not to provide a firm or an exact answer in regards with regard to the economic viability of micro wind turbines in Armidale. However, it targets providing some broad conclusions regarding with technical and economic parameters of micro wind turbines for domestic electricity generation applications by micro wind turbines in Armidale. It has been found that the utilization of micro wind turbine, under current weather conditions technically and financially in Armidale, would be promising performance/generation wise if it is installed in locations with average wind speed (≥ 5 m/s).

Eventually, each and every householder should always conduct a thorough study to decide, in their individual case, if utilising micro wind turbines is the right option for them taking into consideration the local climate condition, the micro wind turbines available in the market at the time of procurement, the funding options might be available. Nevertheless, the micro wind turbine market is a very dynamic market, continuously influenced by improvements in micro wind turbine technology and prices reduction. The economic analysis described in this paper can be used by householders to determine the viability of micro wind turbine installation in their case, although, it is a real difficult mission for ordinary households to decide alone without technical support of manufactures, specialised suppliers and installers, such support is still far lacking due to the lagging commercialisation of micro wind turbines in Australia, in general. Hence, this paper is intended to be a direct help to provide a broad picture for Armidale's households to find their way in the micro wind turbines world.

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