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Abstract

The goal of this study is to review the technology for wind energy generation and to then apply previously uncovered statistics to measure the feasibility of applying the technology to a specific location, in this case the continent and country of Australia. Aside from a purely numerical analysis, an assessment of sustainability impact will also be considered. Based on findings, the potential for capitalizing on wind energy the world over is enormous with Australia being one of the most suitable locations on the earth. A long term renewable energy implementation plan must be instituted for nations to achieve their own goals and those of the rest of the world. Once accepted as just another commercially viable way to produce electrical energy (but without the release of hydrocarbons), it becomes easy for society to rely more on wind power to support its lifestyle.

1. Introduction

Wind energy has been used by mankind for centuries if not millennia. And although past technologies served their creators well, it was at a relatively rudimentary level. Today's level of technical sophistication has pushed the field of wind energy to incredible heights, both literally and figuratively. There is considerable interest worldwide in capitalizing on this technology because of its simple, even pure nature that can greatly reduce dependence on fossil fuels. This paper endeavors to explore the potential penetration of wind energy by using Australia as a case study. The fact that Australia is a discrete land area may help to make this analysis more pronounced.

Substantial research has been done on the viability of wind energy as a primary renewable resource. The world's total wind capacity has been quantified and the level of intensity has been mapped for virtually every continent. The results show that the potential is a generous multiple of the world's annual consumption. [1] It is now a matter for governments to decide if the technology is viable for their particular situation and if so, to what extent it becomes part of their overall energy portfolio.

This paper will present a framework for decision making that could be applied in a wide range of situations. Like the technology itself, this can range from an entire country to a single home owner. Essentially it will present a metric for evaluating technical feasibility and a "checklist" for the social, economic, and environmental parameters that must be considered. This should prove valuable to individuals at all levels interested in applying wind energy technology to modern needs and thereby helping to reduce global carbon emissions.

2. Wind Technology

Unequal heating of the earth's surface causes wind patterns on earth as do predominantly westerly moving air masses or weather fronts. These winds are not only continuous but often quite substantial in their magnitude. One must look at locations where wind energy is significant and at the same time overlays with human activity such that transmission is minimized.

2.1 Worldwide suitable locations

While wind energy may be found all around the earth, and it's potential enormous, there are constraining factors that must be considered. When these factors are weighed, one finds that some locations are quite promising and others not.

Both wind speed and its constancy are primary considerations. A constant, robust wind close to the earth's surface would be ideal but this situation does not exist. In general, areas in the path of unequally heated portions of the earth's surface tend to have the greatest potential.

Not surprising then, shorelines where major land masses meet the oceans provide the best opportunities. Locations just off shore are even more attractive providing 90% more wind speed than nearby land locations. [1] Figure 1 is a sample wind map showing suitable locations where wind power may be exploitable. In this case the best locations in Europe are along the English Channel up into Scandinavia. [1]

2.2 Potential capacity

In evaluating wind strength globally, scientists place wind potential into categories ranging from Class 1, the weakest to Class 7 the strongest. This system and the accompanying wind speeds may be seen in the legend found in Figure 1.

This particular legend and map illustrate wind at a height of 80 meters above the surface.

Generally, wind is not only stronger the higher one rises above the earth's surface but it is also more constant. However the higher one goes the more costly is the structure necessary to support the wind generation equipment - the turbines. Thus, depending on location, an optimal height may be ascertained with regards to cost/output. Today's technology supports wind towers in excess of 100 meters.

Given the current state of technological development, the total amount of available wind energy based on the 80 meter wind speed, has been calculated to be 72 TW per year. This amount is equivalent to five times the amount of energy consumed by the entire world in the year 2000. [1] Clearly there is tremendous potential for wind to become a major source of energy well into the future.

2.3 Examples of technology use

The classic Dutch windmill and farm windmills seen in rural areas illustrate that capturing energy from the wind is not new. In the past few decades however there has been explosive growth in the development and use of wind capturing technology.

Early windmills converted wind energy directly to mechanical energy. In most cases windmills, as the name implies, turned a mill to grind grain or to pump water from a well. Once electrification spread throughout the world it didn't take long for wind to be converted directly to electricity via a generator. Windmills became wind turbines.

One of the most compelling aspects of wind technology is that it is feasible at a wide range of scales. In the tradition of the farm windmills that served rural areas too far from the grid system, today there are wind turbines that are capable of supporting a single household and be entirely off of the public grid.

At the other end of the spectrum are governments that have and continue to construct large wind farms of multiple turbines arrays. These installations can support the electrical needs of large, populated regions.

While there has been much experimentation with design, the configuration that has become the standard to date is a three-blade (rotor), horizontal-axis turbine mounted on a single pole structure.

Small residential type turbines produce electricity up to about 20 kilowatt hours and are installed at heights less than 50 meters. Larger units that often serve business or commercial applications can achieve MW level and are installed upwards of 100 meters.

But it is the multi-MW wind turbines where much of the current development is focused. Experimental units are reaching upwards of 150 meters (the rotors themselves measuring over 100 meters) and are generating in excess of 3.5 MW. Figure 2 shows this incredible range of available wind turbines. [2]

2.4 Storage and distribution

Unlike fossil fuel power generation which is controllable at the generation station, wind generated electricity can obviously only occur when the wind blows. The location and occurrence of the wind rarely matches the need for electricity to support human activity. Once generated however, wind produced electricity can easily be added to an existing grid

The critical element then is location, the nearer wind turbines are to the grid and/or its point of use, the less is lost in

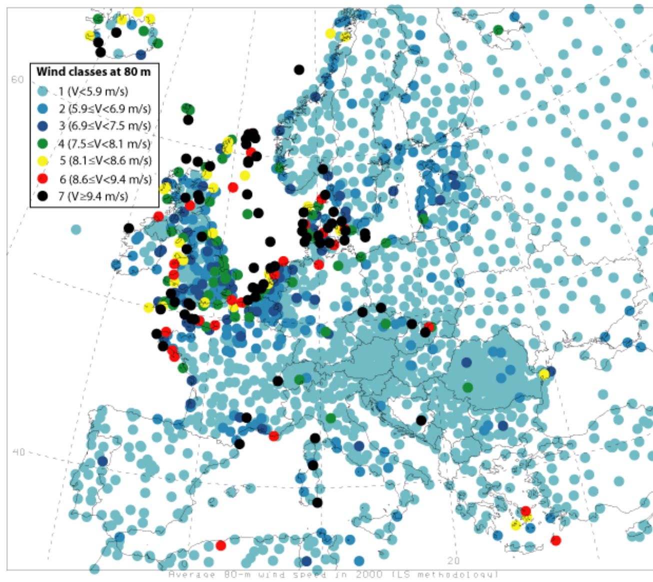

Figure 1. Wind map of Europe. [1]

transmission. For residential and small commercial applications transmission is not an issue. The only issue is if a site is able to produce all that it needs.

Since the demand for power is in no way related to when the wind blows, wind energy does not serve as a good source of base load power at this time. Thus wind power needs to be used when it is being produced with other generation methods used to fill the voids. What remains for wind energy to become most viable then is a method of storage.

For small scale generation such as at the residential level, supplying the grid with excess power becomes a form of storage. In this way the grid needs to generate less power from its base when small scale generation is contributing and in turn it sells back to the small scale generators/users when they need supplemental power.

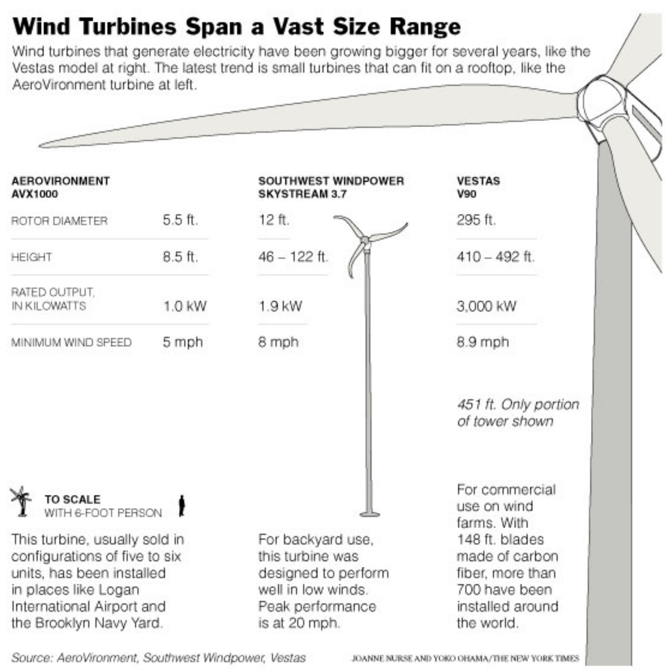

Figure 2. The range of available wind turbines. [2]

Aside from this arrangement, batteries are the logical form of storage. But because battery technology is currently limited and there are environmental issues with their production, only smaller installations can take advantage of them. Utility scaled turbines are such that they must feed directly into the grid and their production used when available. Battery use at this scale is still experimental.

Indirect forms of storage have been considered. These methods primarily attempt to utilize power when not needed in order to physically transform another medium. These methods include using the power to:

- move water to a higher location to be released later to turn a turbine
- compress air to be released later to turn a turbine
- perform electrolysis on water thereby producing hydrogen to be used as a fuel for multiple purposes.

2.5 Research development

To improve the overall effectiveness of wind technology, research and development is focusing on two areas; storage capability, and leveling out production.

As noted above, a variety of storage options are at the research stage. Other research has been conducted however which shows that leveling out of production is a possibility, perhaps making storage a minimal need.

A single wind farm, as one would expect, displays the inconstancy of wind patterns. If one were to look at a dozen or so wind farms at different locations this inconstancy dissipates, i.e. each location would be experiencing different wind conditions at any given moment in time. Thus if multiple wind farms were interconnected, their combined production of power would much more resemble the baseline need.

Research has shown that an average of 33% (and a maximum of 47%) of wind generated electricity can be used as baseline power if wind farms were to be interconnected. [3]

The study was based on theoretically interconnecting 19 wind farms in the mid-western United States with data collected for a year. Wind speeds were evaluated at a height of 80 meters. Furthermore, the study also showed that there appeared to be no saturation point or degradation with the leveling effect by adding more sites to the “wind grid”.

This research may very well show that as more wind farms are constructed and added to the overall power grid, the need for storage can be greatly diminished and wind power depended upon as a part of the baseline load production.

3. Location

To examine the future potential of wind power as a sustainable energy source Australia emerges as a location worthy of a case study. It is a modern industrialized nation, it has discrete borders, and it has a wide range of geophysical features.

3.1 Energy profile

Australia is not a densely populated nation but since it is an industrialized country its energy needs are not small. In fact, as shown in Figure 3, only Canada and the United States consume more electricity per capita than does Australia. [4]

On the other hand Australia is energy rich to the point that it exports a significant portion of its energy production. In 2006/07 it produced in excess of 17,000 PJ, used only 5,770 of it and exported the remaining 12,975. It leads the world in coal exports but also ranks high in exporting liquefied natural gas (LNG) and uranium. [5]

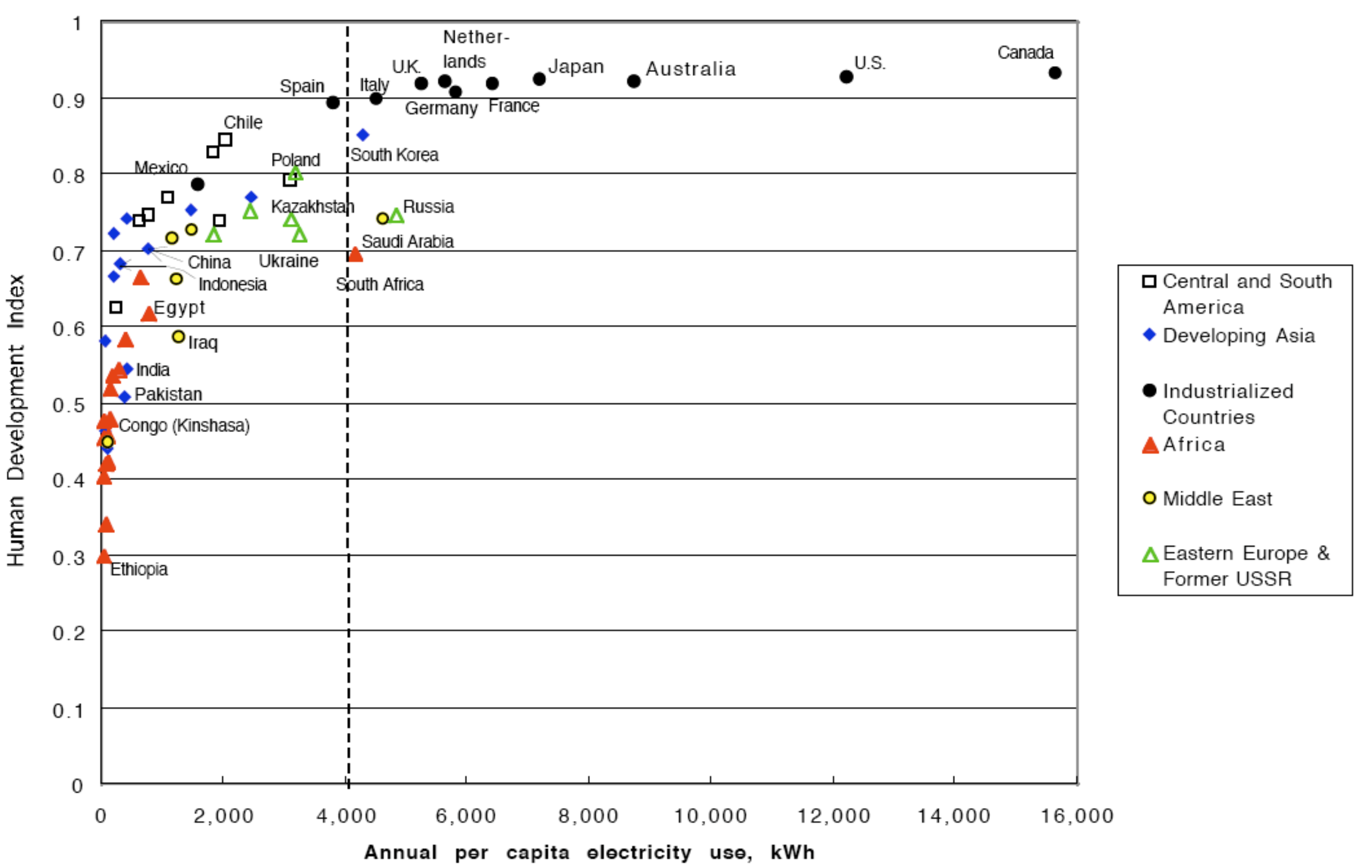

Figure 3. A comparison of electrical usage by countries listed by Human Development Index. [4]

Despite its heavy use of energy per capita, its abundance of natural resources would allow Australia to support itself from an energy standpoint for quite some time. Its only vulnerability lies in the petroleum needed to support the transportation sector. While the continent has good petroleum reserves, growth in transportation use has pushed liquid hydrocarbon fuel imports to over 1000 PJ annually. [5]

The obvious difficulty for Australia then is how readily will they be able to abandon the rich carbon based energy supply they now possess in favor of a more sustainable and less polluting energy supply.

3.2 Population and lifestyle

Australia is home to about 21 million inhabitants with 90% of them living primarily along the southern and eastern coasts of the continent where urban development has occurred. The remaining 10% live a very rural life sprinkled about the more than 7.5 million sq. km. of land area. [6]

The geographic extremes found on the continent have forced development to follow a very rigid pattern. These same features will also force further development long into the future especially with regards to energy production.

The vast interior of the continent is a dry and harsh landscape well known as the "Outback." Because of its severe nature it is very sparsely populated and not well suited for almost any kind of development.

The northern and southwestern coasts are more hospitable and support moderately sized urban areas. The northern coast, known as the "top end" lies in the tropical monsoon belt and tends to be either dry or very wet. Because of the remoteness of these two areas however, they tend to be regions unto themselves, i.e. there is little in the way of infrastructure connecting them to the rest of the country.

It is along the southeastern and eastern coastline that the greatest concentration of people live. This land is fertile, temperate, and contains the variety of resources needed to support modern human activity. Figure 4 illustrates Australia's geography and population pattern. [7]

The lifestyle of Australians is decidedly contemporary and in tune with inhabitants from developed countries around the world. Australians enjoy the conveniences of modern living and like the rest of the world are only now beginning

Figure 4.
Geophysical map of Australia. [7]

to address the ecological price this lifestyle brings with it. For inhabitants of the sparsely populated regions of the country, the lifestyle is entirely different. Independent, rugged, and natural might all be ways of describing this culture within a culture. Wind energy technology is such that it should appeal to both of these groups.

3.3 Current consumption

Current consumption is the starting point for any energy need analysis. Consumption for all energy needs for Australia for 2006/07 were as follows: [8]

Fuel	Energy (PJ)	Share (%)
Coal	2324	40
Oil	1990	35
Gas	1158	20
Renewables	298	5
Total	**5770**	

Renewables	Energy (PJ)	Share (%)
Biogas/Liquids	13	4
Hydro	52	18
Solar/Wind	28	9
Biomass	205	69
Total	**298**	

Clearly Australia is heavily dependent on fossil fuels to support its energy needs. The world's total energy production includes 13.7% from renewable sources [4] making Australia's 5% competitively weak. And given that hydro, solar, and wind energy are just over 1% of the total, Australia finds itself in a difficult decision making position. Its production is much more than what it needs, but it's almost all the wrong kind of energy by global warming standards.

3.4 Replacement with new technology

Based on these consumption statistics there is no question that Australia needs to improve its carbon footprint. The country ratified the Kyoto Protocol in December of 2007 so it has formally made the decision to address its problem. The target is to limit emissions to 108% of its 1990 level during the 2008-2012 time frame. [9]

With almost all of its electricity currently coming from fossil fuels and with the demand projected to increase from 254 TWh to 416 TWh by 2029/30. [8] Australia must begin to add renewables to its national energy portfolio in order to meet demand and its Kyoto target. It would appear that the country is headed in the right direction. While current wind farm capacity is only 818 MW there are another 2925 MW proposed. [8]

Solar can certainly be part of the growth mix but this paper will focus on the potential of wind. Hydro power is not viable in the long run as this is a relatively dry continent who's water supply is proving to be fragile. From 2005-06 to 2006-07 hydropower decreased 10% continuing a downward trend that started in 1992-93. [5]

A look at Figure 5 reveals that Australia has a range of renewable power plants. [8] Their locations not only match population centers but the geographic transition areas (mountains to coastal, coastal to ocean) where renewable resources are frequently found. The only exception is solar in the outback where the potential would be excellent but where population is the least.

Figure 6 illustrates wind potential for the continent. [1] As one can readily see, the wind potential for Australia is excellent. It more than makes up for the unsuitability of solar and hydro. Some of the best readings on earth are clustered along the shores of Australia exactly where the population is concentrated.

There are no less than 23 class 7 wind locations, 21 at class 6, 12 at class 5, and 12 at class 3, or 68 locations at class 3 or better. In fact Oceania has the highest percentage of stations (21%) that have strong wind power potential outside of Antarctica. [1]

Furthermore, since these locations coincide almost exactly with population concentrations, proximity to the existing electrical grid is insured. Figure 7 illustrates the existing grid showing the excellent match with wind farm potential. [8]

4. Sustainability Impact

As with any sustainable energy system, its design and implementation must strike a balance between making economic sense, serving society as a whole, and causing as little environmental disruption as possible in the long term.

4.1 Economics

Australia is unique among major industrialized nations in that it is overwhelmingly an energy exporter. This is so much the case that energy related industries account for a A$16 billion trade surplus. [8] For Australia to begin to devalue this industry (which is almost entirely fossil fuel based) in order to shift to more renewable power can be viewed as an economic hardship.

By entering the wind market relatively late, however, the cost of the technology is proving to be very competitive as the industry is now well in the commercial stage. Of the 67 proposed power plants in the country, the highest number (21) are wind based. The number of gas plants is second at 20, whereas solar and hydro account for only 1 each. [8] This would tend to confirm the infeasibility of these other two renewables as previously noted.

A basic check of costs would be in order so as to confirm this perceived competitive cost of wind power generation. One of the newest wind farm proposals is a massive project in Silverton, New South Wales. The pertinent data is as follows:

Installation cost	A$2 billion [10]
Output	825 MW [10]
Current electric rate	.055 per kWh [4]
Utilization rate	60% (average of existing wind plants) [4]

If one assumes an operation and maintenance factor of 1.5%, and a CAF rate of 7.3% the levelized cost of electricity (LCOE) is estimated to be \$0.0406 per kWh. This obviously compares well with the current electrical rate of \$0.055 per kWh. At the early stages of a project this size it is understood that this is a rough estimate, however even with the inevitable increase in costs as the project unfolds, this shows that wind power is indeed economically viable.

4.2 Social

Like inhabitants of other industrialized nations, Australians are accepting the need to convert their energy supply from

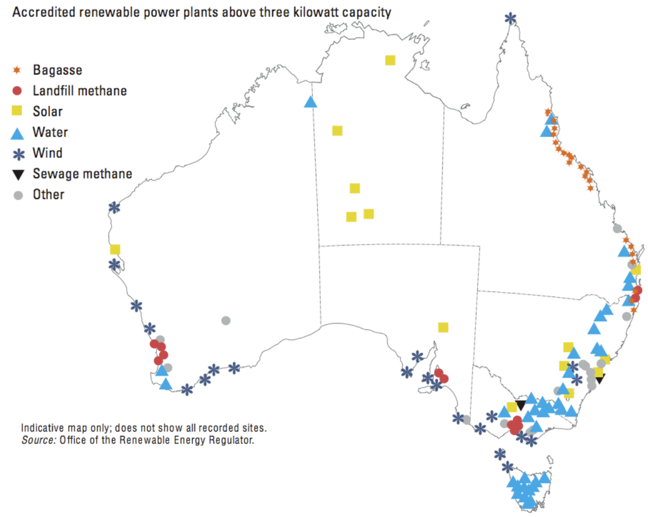

Figure 5.
Location and number of renewable energy power plants in Australia. [8]

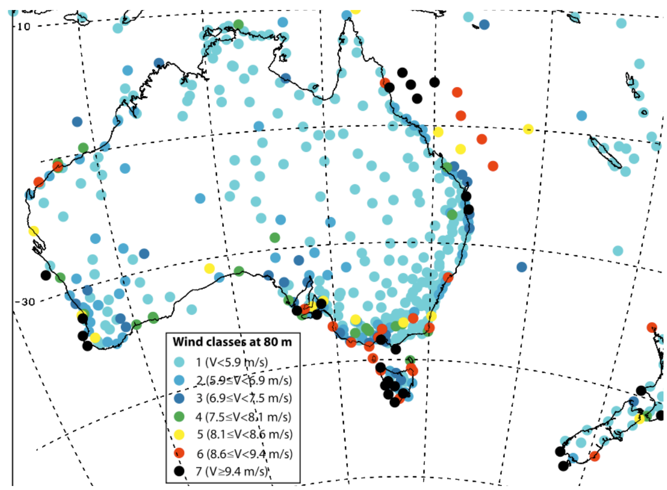

Figure 6.
Wind power potential for Australia. [1]

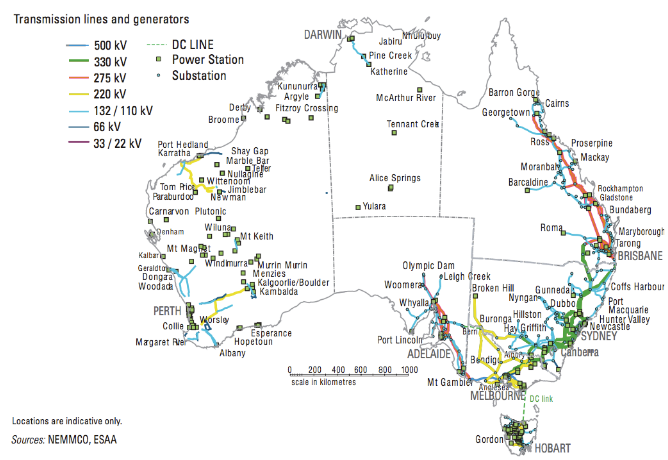

Figure 7.
Australia's power grid. [8]

fossil based to renewable based. And like their counterparts in other countries the change is being imposed on them anyway.

As previously noted, Australia ratified the Kyoto Protocol in 2007 thereby assuring its commitment to reducing carbon emissions. [9] To meet this commitment the government has instituted a range of policy measures, most significant among them the Mandatory Renewable Energy Target (MRET. This legislation requires large energy consumers to purchase renewable energy certificates (RECs) from accredited renewable energy suppliers. In this way the market for renewable energy will be guaranteed. Furthermore, the government also revised its renewable energy target to be 20% by 2020. [8]

4.3 Environmental

The installation of wind energy systems would have little effect on the environment in Australia, certainly less globally when one considers the carbon emissions that would be eliminated. The case could be made that wind systems would actually improve the environment in Australia.

The lack of abundant water is becoming a serious concern on the continent and wind energy is the only renewable that requires no water. The addition of wind power plants would also ease the strain on and maybe eliminate the need for the hydro power plants currently on line. By their very function they often affect the water supply adversely.

A second concern would be the conflict between off shore wind generators and the highly prized and sensitive Great Barrier Reef which lies along the eastern shore - exactly where prime wind occurs. The potential energy from wind is so strong on shore however that there is no need whatsoever to go off shore and conflict with the surrounding oceans.

Lastly, since the locations of wind energy are found at the same locations as the energy demand, the infrastructure required, i.e. the existing power grid, already exists. While there would still be some additional construction work required it would be minimal in comparison to similar projects found elsewhere in the world.

The great but environmentally sensitive Outback would be left literally untouched except for small wind turbines installed in applicable areas. These have no more environmental impact than the traditional windmills that have been used there for generations.

5.0 Conclusion

In this study, a major renewable energy resource (wind) was surveyed with the intention of evaluating it for feasibility at any given location on the earth. Australia was chosen as a case study because of its unique characteristics. Technical aspects of wind technology were weighed against conditions on the Australian continent. Economic, social, and environmental issues of were also evaluated.

In this case study it was found that Australia is very well suited for wind energy generation. Accurate wind power data is available, is found to be greatest where the population and the existing power grid exists, and the technology is already at the commercial stage. This is a critical finding since it is also suggested that solar and hydro power are particularly incompatible and the country's per capita demand is one of the highest on earth. The Australian government has just recently come to the same conclusions since the uptake of wind energy is very pronounce now and planned for the future.

The evaluation methodology used here can be applied at almost any scale. One checks the technology against what the land will allow and then confirms the fit with the parameters set by the inhabitants, e.g. legislation, lifestyle needs, and other entrapments of human activity.

Further studies might quantify to a more precise level the wind generation capacity at locations around the globe to the point of predicting optimum generator size and height. Other studies could focus on the choice/selection of renewable sources at a given site, i.e. selecting one technology over another or potentially combining more than one.

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