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MSc Program
Renewable Energy in Central and Eastern Europe

Analysis of the Australian wind energy potential - Historical development and future prospects

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Dipl.-Ing. Carlo Obersteiner

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Vienna, 14.09.2009

Affidavit

I Mag. (FH) Konstantin Tsoukanas, hereby declare

1. that I am the sole author of the present Master Thesis "DEVELOPMENT AND FUTURE POTENTIALS OF WIND ENERGY IN AUSTRALIA, and that I have not used any source or tool other than those referenced or any other illicit aid or tool and,
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, ____________________ ____________________________

Date Signature

Abstract

"After so many years of neglect under the previous Government we are sending a clear signal to the world that Australia is taking responsibility on climate change."[1]

Australian electricity sector is responsible for more than one third of Australian Greenhouse Gas emissions. Yearly continuous rise in electricity consumption and thereby caused Greenhouse Gase emissions are not compatible with Australian Policies to target climate change and to reach its CO2 reduction targets up to the year 2020. Policies for combatting climate change have been implemented to supply electricity generation from renewable energy sources and targets have been set to built a legal framework in setting renewable energy goals.

As Australian wind energy industry is in strong competition with traditional energy sources as from coal, it is investigated how current and future wind potentials develop under these circumstances. An insight into current development of wind projects and future wind farms is given where an evaluation of new wind traces visualizes future wind bubbles over Australia.
Additionally, to show not only development of wind farms on the map, a screening of five wind farm sites under different preconditions is done to show if requirements for future wind farms are given.

Despite challenging economic and technical premises for wind energy, it is shown that Australian wind energy seems to increase rapidly its commitment to green energy by implementing a large number of new wind farms into the national electricity market.

Main conclusions are that Australian wind industry will face an upturn within the next years based on a number of positive signals given not only by the Australian Government who supports renewable energy by implementing the Renewable Energy Target Scheme (RET) and the Mandatory Renewable Energy Target (MRET), but also by international investors who are sweeping into the Australian wind energy market.

[1] Senator for South Australia,Member of the Labour Party: Mr.Hon Penny Wong

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Acronyms

AUD	Australian Dollar
AWS	Automatic Weather Stations
CPRS	Carbon Pollution Reduction Scheme
DKIS	Darwin-Katherine Interconnected System Grid
GDP	Gross Domestic Product
GWh	Gigawatthour
MRET	Mandatory Renewable Energy Target
MMA	McLennan Magasanik Associates
Mtoe	Million Tonnes of Oil Equivalent
NEM	National Electricity Market
NEMMCO	National Electricity Market Management Company
ODF	Other Domestic Fuel
OECD	Organisation for Economic Co-operation and Development
REC	Renewable Energy Certificate
RET	Renwable Energy Target Scheme
SWIS	South West Interconnected System
Sq km	Square kilometres
TPES	Total Primary Energy Supply
USD	United States Dollar
WA	Western Australia

1 Introduction

Historically, Australian energy mirrors shows that energy demand has increased within decades. At the same in time, energy intensive production and electricity generation which is based on the use of coal has become a major reason for Australian Greenhouse Gas emissions.

Natural resources have ever since been used to cover energy demand although Australian landscape offers excellent conditions for multiple usage of renewables. As the usage of renewable energy sources has become one of the major topics for Australian environmental protection, wind energy as a renewable energy source shows excellent opportunities in Australia.

Australian commitment to combat climate change is underlined by the Renewable Energy Target Scheme and the Expandet Renewable Energy Target, which both of them secure an increasing demand of renewables for electricity generation within the next decade. These governmental programs built the baseline for current and future developments in the Australian wind energy branch.
Hence, wind energy seems to have considerable advantages compared to historical energy sources. Low emissions techonology, high availablility of excellent wind conditions, governmental support through mandatory renewable energy targets and an increasing list of proposed wind parks for the next decade gives Australian wind energy branch strong up-wind.

European countries, who are always confronted with limited space for wind farming, would be jealous by keeping an eye on Australian wind energy projects which are planned for the next years. Not only Australian landscape with its unique coastline offers unequaled opportunities, but also wind conditions as shown on the Australian Wind Atlas are outstanding indicators.
Supported by the National Electricity Authority, which enlarges its electricity grid within proposed wind development areas, future wind farm development areas fulfill besides excellent wind conditions also the electricity grid requirements. These facts underline that Australian wind energy branch has greceived strong signals for growth.

1.1 Core Question

The core objective of this Master Thesis is to highlight current and future development in Australian wind energy branch in contrast to historically used non-renewable energy sources.

Derived objectives are:

- to *mirror* Australian energy profile on the supply and demand side.
- to *screen* the baseline for current and future wind energy development by identifying Australian Governmental Support Schemes to increase the usage of renewables for electricity.
- to *analyse* if development of wind energy in Australia is compatible with the capacity of its electricity grid and to check up planned extensions within the electricity grid to support the integrations of wind farms into the Australian Electricity Market.
- to evaluate if proposed wind energy development areas, also called wind bubbles, fulfill significant requirements concerning wind speed and grid connetion.

It should be mentioned that Australian Renewable Energy Target Profile shows steady increase in the usage of renewables up to the year 2020 whereas it is nowadays not predictable which direction wind energy will take.

1.2 Main literature

While the topic of the present Master Thesis is a subject area that needs latest information from relieable sources, most useful sources have been given by governmental publications or international organisations.
To name only a few of them the International Energy Agency is publishing
a multiplicity of useful informations through the yearly review on its member states. In-depth data for every aspect of energy related information, including renewable energy and policies on them, can be found in the Australian Review on Energy Policies 2005, as well as in the Environmental Performance Review of Australia.

Besides that, Australian officials offer a wide range of latest information on energy policies and development in renewable energy generation. Additionally this information is underlined by a number of renewable energy maps which visualize development in this sector.

Unluckily, during the process of the writing this Master Thesis, some governmental web sites or lobbyist groups like the Australian Wind Energy Association have merged and therefore useful data concerning development of renewables has been taken aside or swept into other areas of competence. Additionally key data of current operating wind farms are kept unpublished so that a reliable analysis of different data sources can only done on a basis of governmental publications.

Luckily, the Australian Bureau of Meteorology offers a wide range of climate informations, which some of them with a data track of more than fifty years. These data sets made it possible to analyse Australian wind conditions on several spots and to calculate different preconditions for wind energy development on various locations.
Thanks to the Australian National Electricity Management Company, useful information concerning development within the Australian electricity grid has been provided.

1.3 Structure of the Work

This present work gives the reader at the beginning of chapter 2 general information of Australia. To understand later approach of this Master Thesis an overview of Australian climate zones is given to bundle general facts of Australia with an overview of its economy.

Afterwards, a deep insight into Australian Energy Mirror shows besides the conspicuous energy production and energy consumption facts also Australian-wide electricity supply and demand. This information in chapter 2 gives the reader a good overview of electricity-supply and electricity-demand to understand in the following subsection the given overview of Australian Greenhouse Gas emmittants in connection with electricity generation. After that, an insight into Australian Renewable Energy Targets is shown besides data concerning the share of renewables for electricity generation. Additionally an overview of the Australian electricity network and the integration of wind farms into the national electricity system provides additional background information.

In chapter 4, wind conditions over the country are shown by a visualisation done with the Australian Wind Atlas. With this information, the reader can understand following subsection which covers the distribution of wind zones over the country. It is highlighted that wind zones differ from state to state and that wind speed is an important point for future development of wind energy in Australia. It is illustrated how cyclone affected areas are targeted by strong and dangerous winds, which gives the understanding of wind energy development beyond these zones.

Next, historical development of wind energy in Australia is presented, followed by data of current operating wind farms spread over Australia and an analysis of greatest wind farms per State.

Chapter 4 is closed by a stunning analysis of proposed wind energy projects, given per state and region, and shown on the Australian Wind Map. With this knowledge the reader gets an understanding of the ambitious Australian wind energy roadmap.

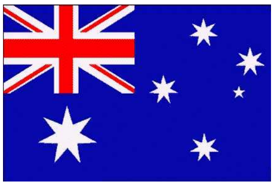
Chapter five goes more into detail of wind farm siting and shows in the beginning in subchapter 5.1 Australian most challenging wind project namely Silverton 1000 Megawatt Wind Farm. An overview of the circumstances of the project as financial aspects and electricity grid facts lead to an analysis of Silverton Wind Farm concerning its capacity factor. Bevore going more into detail, a study done by the Australian National Electricity Management Company shows future wind energy connection points in the electricity grid, also called wind bubbles.

In the following subsection one of these wind development points can be identified as it is located in the surrounding of Silverton Wind Farm. With this information and with the given yearly energy output of this stunning wind park, a recalculation from energy output and wind turbine information allows a nearly calculation of the capacity factor of this wind park.

This calculation is necessary to understand, how wind speed can influence not only energy output of a wind turbine but also influence long term financial feasibility of a wind park project. For this reason four possible wind park sites are analysed concerning their possible electricity grid connection point and their wind speed capacity.

Results of this analysis are summarised in chapter 6, which shows how capacity factor and electricity grid availability are indicators for future development in wind farm development.

2 General Facts of Australia



2.1 Position and area

Australia as the world´s sixth largest country with land mass of more than 7.6 million km^2 or to say 80% larger than the combined countries of the European Union is as great as the continental United States of America. Australia has no land boundaries to other countries and is a federal country consisting of six states[2] and two territories[3]

2.2 Governmental facts

Australia`s official name is the *Commonwealth of Australia* and the government is described by a Constitutional Monarchy which means that its power is based on a written constitution. Australian Head of State is Queen Elisabeth II and therefore it is named a Constitutional Monarchy.

2.3 Population

Australian population stands now at about 21,7 Million people. Because of its geographical position, Australian population is concentrated in main coastal regions which are the south east, east and the south west. In the arid red centre which is located in the middle of Australia, few people have settled down because of its extreme climate conditions.

With a population density of 2.7 people per square kilometre (sq km) over the whole country, the highest density can be found at the Australian Capital Territory´s with approximately 142 people living in the city of Canberra which is the Capital of Australia.[4]

Areas of high population can be found in coastal areas with relatively moderate climate conditions which are Sydney, Melbourne, Adelaide, Perth, Broome, Brisbane and around Cairns.

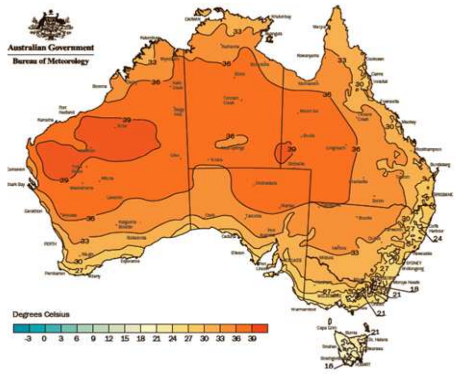
[2] Queensland,South Australia, New South Wales, Victoria, Western Australia and Tasmania

[3] The Northern Territory and the Australian Capital Territory

2.4 Australian climate zones

Australia´s island continent offers a wide range of climate zones, starting from the tropical in the north, to the dry and arid climate in the middle, to the tempered regions in the south .

Australian climate is caracterised by the world´s second driest continent with average summer temperatures (January) exceeding 30 degrees Celsius over most of the country. More than 40% of the land mass is covered by sand dunes and most of Australian desert is semi-arid. Following images show the distribution of annual heat in comparison to annual rainfall over the country.



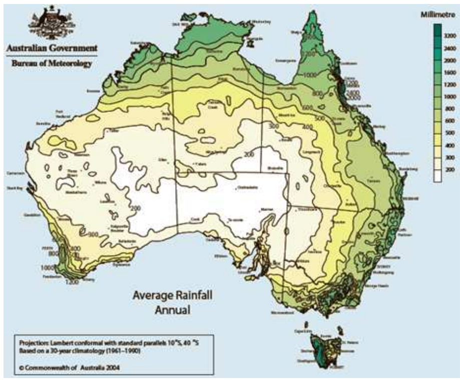


Figure 2.4.1 Comparison of annual heat distribution to annual rainfall areas

Source: Australian Bureau of Meteorology

Northern Australia has a tropical climate with rainforests, grasslands and desert, only in the south and south east where the Great Barrier Reef is located, a tempered climate with fertile soil can be found. Australia has many of natures extremes which include floods,droughts,tropical cyclones,bushfires, storms and also tornados.

Climatic factors influences people´s desire for settling down in areas with moderate climate conditions which can mostly be found in Australian coastal areas. (International Energy Agency: Energy Policies of IEA Countries, Australia,2005 Review, p.23)

2.5 Economic Overview

Australian Economy is characterized by an average economy growth of 3 per cent since the year 2000 which benefits from the global commodities boom. (OECD Science, Technology and Industrial Outlook 2008).

As one of the strongest economies in the world it shows constantly fallen unemployment rate with the lowest in 2008 (5 per cent) since the 1970s and a gross domestic product (GDP) growth since the year 2000 above 3 per cent each year. The following figure shows Australian GDP development since the 1960 where a significant decrease in the 1980ies and 1990ies can be recognised.

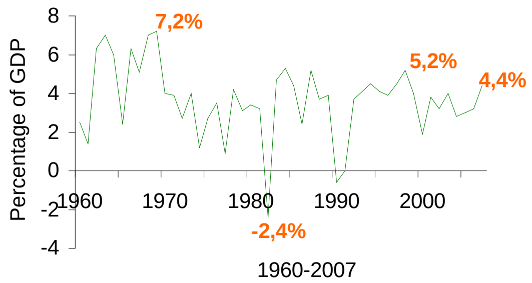


Figure 2.5.1: Australian Real GDP Growth in Percentage

Source: OECD Factbook 2009, Macroeconomic Trends, Evolution of GDP; own calculation

Australian financial markets have been ranked by the *2007-08 World Economic Forum Global Competitiveness Report* as the worlds seventh advanced financial market in the world.

Australian trade mirror shows an export of goods and services at about 215 billion USD in the year 2006 to 2007 which makes around 21 per cent of Australian total GDP. High ranking trading partners are Japan, China, USA, Singapore and the United Kingdom. Main exporting goods are agricultural products, energy goods and minerals.

As an attractive angle for international investors and companies, Australia benefits from its closeness to the Asian-Pacific market as well as from its highly developed domestic market. Advantages can also be seen in the growing partnership with the European-American business market besides its excellent political and economic stability and an privileged time zone.

Australia has been ranked by the World Bank as the fastest place in the world to start up a business with authorities procedures of just two days. (Australian Department of Forreign Affairs and Trade, Australian Economy 2008, p. 2)

2.6 Australian Energy Mirror

2.6.1 Energy Production

Australia, as the world eight largest energy producer, supplies 2.4 per cent of total world energy demand. Continuous growth rate in energy production show an average increase of 4.3 per cent a year since 1997 until now.

Global demand for energy and steadily increasing need of economy growth rates can be seen as key drivers for this trend. As a net exporter of its energy goods, Australia is exporting nearly two thirds of its domestic energy commodities with coal as the largest export energy earnings. (Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 1)

Following image shows a spreading of Australian energy exports starting from the 1980ies until 2008, projected in billion United States Dollar (USD).

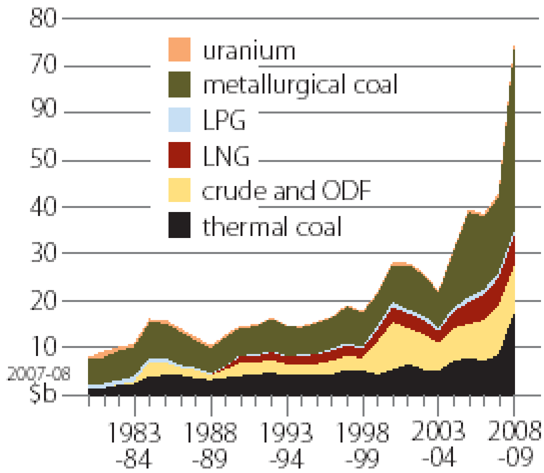


Figure 2.6.1: Energy exports, 1980ies until 2008 shown in commodities[5]

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 2

Autralian energy sector is characterized on the one hand by a high level of energy security as it is rich in mineral sources including coal, natural gas and oil.

[5] ODF: other domestic fuel

On the other hand, due to its emission intense energy production, Australian emission of Greenhouse Gas from fuel combustion per Unit of GDP is the second highest of the International Energy Agency average. This is caused by the common use of coal for electricity generation[6]. (International Energy Agancy: Energy Policies of IEA Countries, Australia, 2005 Review, p.26).

The following image shows sources of energy production from the 1970ies until the year 2007.

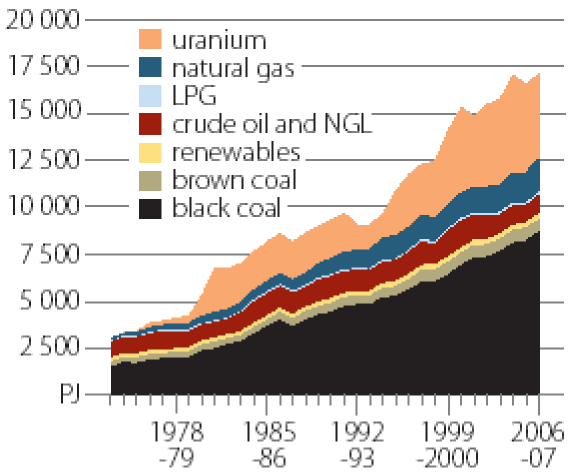


Figure 2.6.2: Australian energy production by source 1970ies to 2007

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 1

More than 42.6 % of Australian total primary energy supply (TPES) is dominated by coal, which makes an yearly production of 185 Millions tonnes oil equivalent (Mtoe) of which more than 73 % are exported into foreign countries.

2.6.2 Energy Consumption

Usage of oil makes 39% of the total primary energy consumption and natural gas about 19.7% (International Energy Agancy: Energy Policies of IEA Countries, Australia,2005 Review, p.23)

Energy Consumption can be localized by three major sectors which are:

- Electricity generation
- Transport sector
- Manufacturing

[6] In 2003, 77% of all electricity generation was produced by coal.

All three industry sectors counted within the last 25 years for approximately 80 per cent of Australian total energy demand. (Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 2)
Following image gives an overview of Australian states and shows its different population facts in relation to its GDP and energy consumption whereas it is recognizable that areas with high population consume more energy .

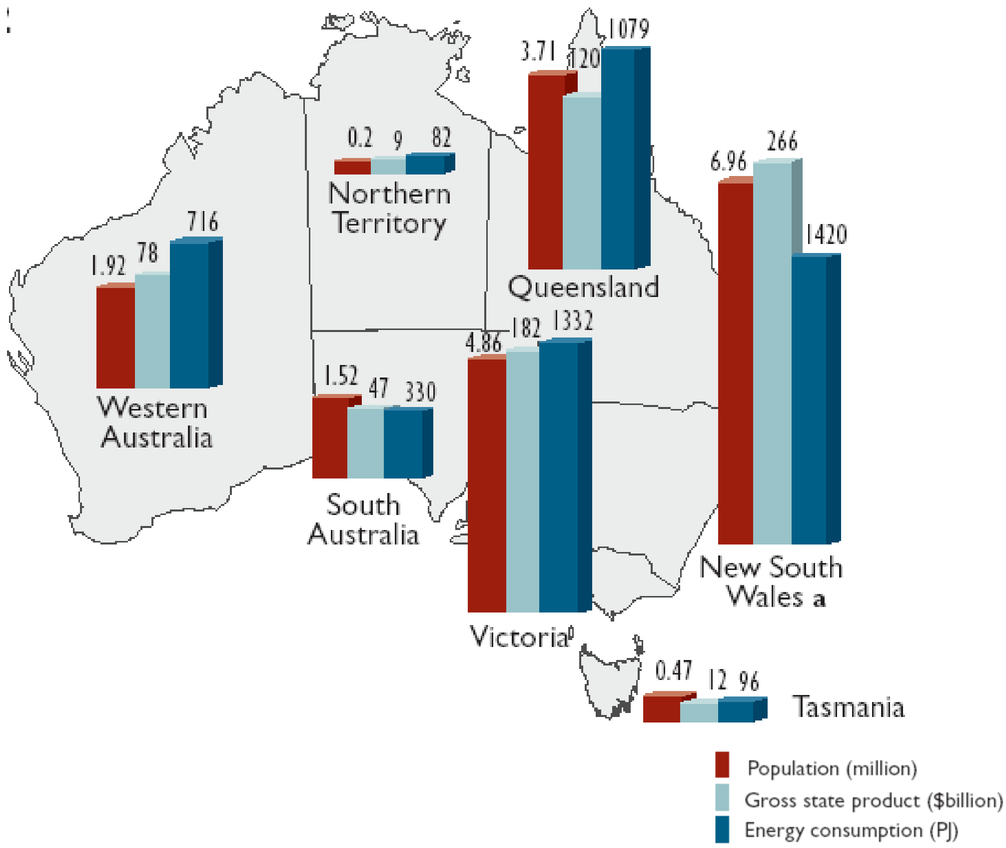


Figure 2.6.3: Overview of Australian population,GDP and energy consumption
Department of Industry,Tourism and Resources, Energy in Australia, 2004, p.1

2.6.3 Electricity Supply and Demand

Australian electricity market is one of its largest industries which makes nearly 1.5 per cent of the total gross domestic product. Consumption of electricity has steadily increased since the 1970ies with an average increase rate of 3.3 per cent during the last decade. Electricity generation rose within the last years up to 10 per cent whereas the number of electricity customers increased up to 7 per cent.

Following figure mirrors increasing generation of electricity which is nowadays five times higher than in the 1970ies. (Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 19)

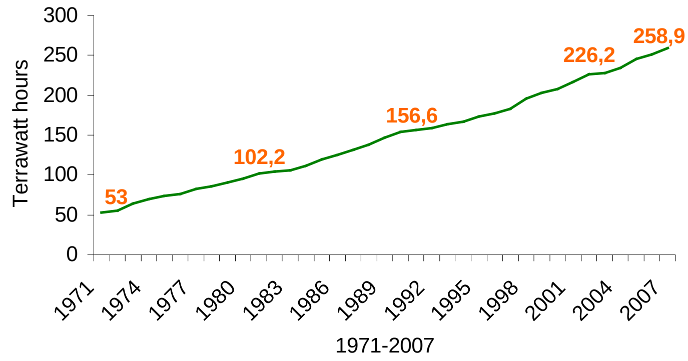


Figure 2.6.4: Electricity Generation 1971 to 2007 in Terrawatt hours

Source: OECD Factbook 2009, Energy Supply, Electricity generation

About 84 per cent of Australian electricity generation is generated by coal because of its low costs and high availability. One of Australias leading electricity sector modellers McLennan Magasanik Associates (MMA) suggest that in 2030 electricity generation could be Australias number one source of emissions. (McLennan Magasanik Associates: A comparison of emission pathways and policy mixes to achieve major reductions in Australia´s electricity sector greenhouse emissions, 2008, page 1)

The following chart shows the spreading of energy type, used to generate electricity where coal accounts for more than the half of total electricity production.

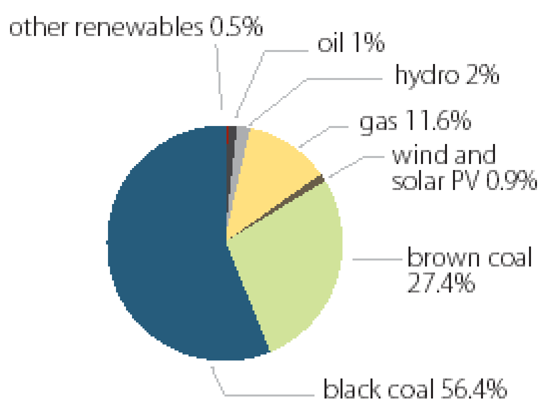


Figure 2.6.5: Fuel inputs into Australian electricity generation 2006-2007

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 19

Due to the usage of coal for electricity generation, Australian electricity prices are between the lowest in the world. Electricity price was increasing constantly until the year 2007 where average electricity prices increased due to strong demand and marginal supply. Following charts shows household- and business- electricity price development in Australia starting from the 1980ies until 2008. Until the mid 1990ies both consumers enjoyed nearly the same price but in 1994 prices have developed seperately.

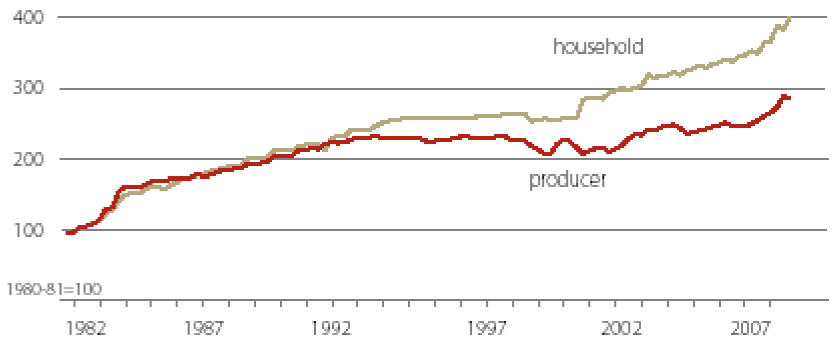


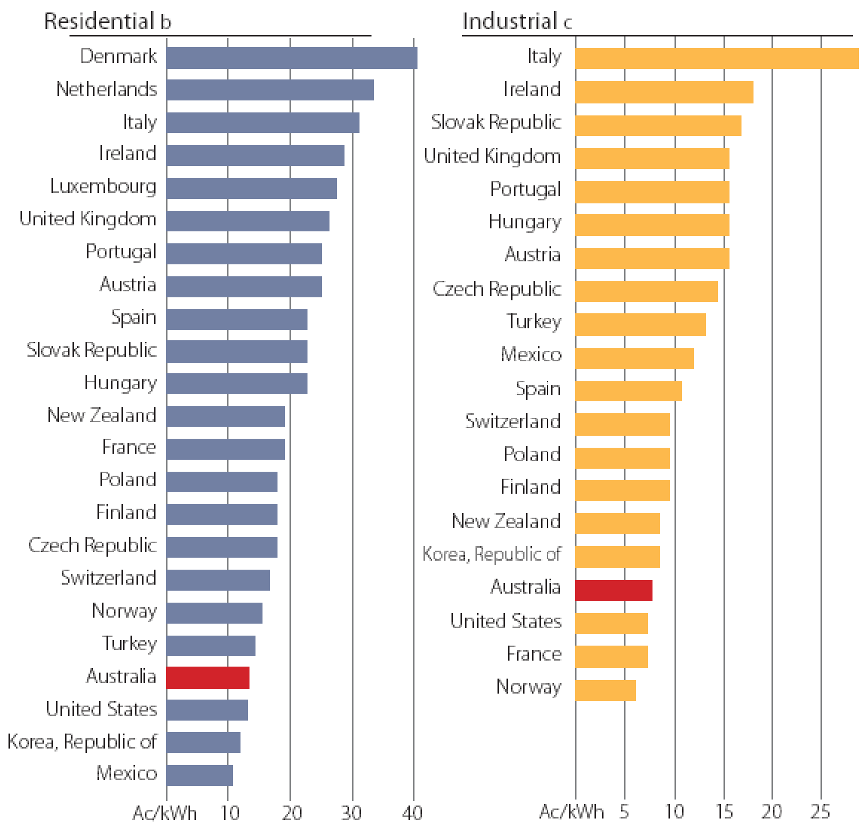
Figure 2.6.6: Electricity prices for households and businesses 1980-2008

Souce: Australian Bureau of Statistics,Producer price Index cat.no. 6427, Consumer price Index cat. no. 6401, 2008

Following table shows a comparison of residental to industrial electricity prices in selected OECD countries whereas Australian electricity prices can be found in the lowest electricity-price category.

Table 2.6.1: Electricity Price comparison in 2007-selected OECD countries

Source: International Energy Agency, Energy prices and taxes, 2008



2.6.4 Share of Renewables for Electricity Generation

Due to its various climatic conditions, Australia has access to higly accessable renewable energy sources which are nowadays used not only for electricity production but also for heating and transportation.

Renewable energy production increased from 2000 to 2005 by 16 per cent, where in 2006 to 2007 an increase of 10 per cent in renewable energy production was recognized. Following table gives an overview of Australian renewable energy production starting from the year 2001 until 2007.

Table 2.6.2: Australian production of renewable energy, including electricity and heat

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 29

	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07
	PJ	PJ	PJ	PJ	PJ	PJ
Bagasse	91.7	95.1	96.8	108.3	109.1	110.8
Other biofuels b	10.1	10.7	10.6	10.4	12.3	12.8
Hydroelectricity	57.5	58.7	58.0	56.2	57.7	52.0
Solar hot water	2.7	2.8	2.6	2.6	2.4	5.9
Wind c	0.6	1.0	1.6	3.2	6.2	22.5
Wood and woodwaste	95.0	99.2	96.9	91.5	82.3	93.8
Total	257.6	267.5	266.5	272.2	270.0	297.8

a Electricity and heat. b Includes biogas, black liquor, crop and municipal waste. c Includes solar photovoltaic.

Highest increase in electricity production by renewable energy sources can be seen by wind energy and photovoltaic, which rose from 0.6 petajoules in 2001 to 23 petajoules in 2006-07. Hydro Energy for electricity production decreased from 2006 to 2007 at about 10%.

Australian renewable energy share contributes about 6.5 per cent of total electricity supply whereas more than two-thirds of it is supplied by hydroelectricity.
Because of various climate conditions in Australia, renewable energy production is spread into different locations all over the country.

Whereas hydoenergy is generated in Queensland, Victoria, New South Wales and Tasmania, wind farms can be found in South Australia, Western Australia and Victoria, mostly in coastal areas. (Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 34)
Following table shows Australian renewable energy capacity split into the regions. It can be recognised that the Northern Territory and Tasmania stand at the bottom of renewable energy production in 2007.

Table 2.6.3: Capacity of electricity generation from renewables in Australia, 2007.

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 34

	biogas MW	bagasse MW	wood-waste MW	other renewables b MW	hydro MW	wind MW	solar MW	other c MW	total MW
NSW a	68	16	42	36	4 275	18	4.0	0.5	4 459
VIC	78	0	0	34	566	134	0.7	0.0	813
QLD	17	359	15	4	659	13	0.4	0.1	1 066
SA	22	0	10	0	5	740	0.7	0.0	778
WA	27	6	6	63	32	201	0.7	0.0	336
TAS	5	0	0	0	2 276	144	0.0	0.0	2 425
NT	1	0	0	0	0	0	1.6	0.0	3
Other d							63		63
Aust	218	380	73	137	7 814	1 249	71	1	9 942

a Includes the ACT. b Black liquor, crop waste, municipal waste and biodiesel. c Oceanwave and geothermal.
d Domestic, recreational and remote installations.

2.7 Mandatory Renewable Energy Target and Renewables

Australian answer for reduction of greenhouse gases is called the Mandatory Renewable Energy Target (MRET). Australian Government concluded in 2007 that by 2020, 20 per cent of total electricity production will be generated by renewable energy sources whereas in 2010, 9500 gigawatt hours of electricity will be generated by renewable energy sources. The national renewable energy target will be increased therefore after 2010 from 9500 gigawatt hours of electricity production from renewables to 45 000 gigawatt hours. (Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 34)

A single renwable energy target scheme (RET) will expand the MRET and combine State and Territory renewable energy targets into a national scheme. (Australian Government, Department of Climate Change, Design of the Renewable Energy Target (RET) scheme, Fact sheet, 2008, p. 1)

Following chart shows the steady increase of renewable energy generation up to 2020.

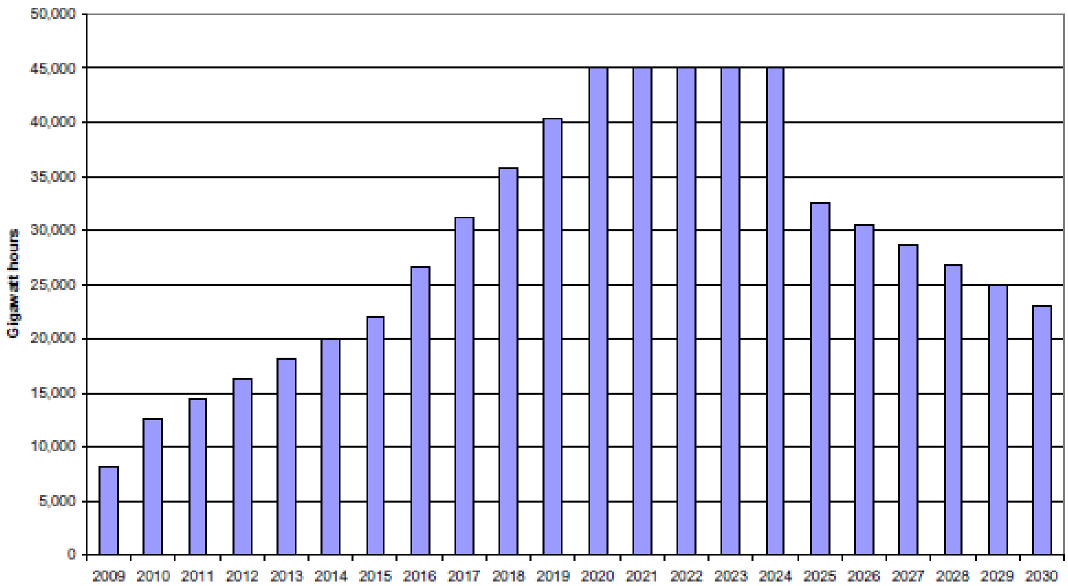


Figure 2.7.1: Renewable Energy Target profile from 2009 to 2030

Source: www.climatechange.gov.au/renewabletarget/pubs/RET-scheme-design.pdf, p.2

It can be recognised that annual targets ramps up moderately up to the year 2015 from which on it increases more steeply up until the year 2020. Annual targets will decrease from 2024 on and will phase out in 2030.

2.7.1 Development of Renewables under the MRET

Australian renewables for electricity generation have experienced a steady increase within the last decade. Measured from the most increasing renewable energy source, wind energy has developed most within the last ten years. Wind energy increased at about 37.8% or 2330 GWh since 1997, solar water heater with 24.6% or 1515 GWh and Hydro with 11.5% or 711 GWh of total renewable energy production.

Following table shows values of renewable energy sources contributing to total electricity generation whereas wind energy developed most since 1997.

Table 2.7.1: Increase in renewables since 1997 under the MRET

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 35

	increase		baseline generation
	GWh	share %	GWh
Bagasse	516	8.4	513
Black liquor	113	1.8	154
Hydro	711	11.5	15 604
Landfill gas	576	9.3	264
Sewage gas	66	1.1	5
Photovoltaic	109	1.8	0
Solar water heater	1 515	24.6	0
Wind	2 330	37.8	5
Wood waste	150	2.4	63
Other b	83	1.4	4
Total	6 169	100	16 614

a Reported generation under the Mandatory Renewable Energy Target scheme, above baseline levels in 1997.
b Includes municipal solid waste combustion and food and agricultural wet waste.

The RET will be discontinued between 2020 and 2030 when the Carbon Pollution Reduction Scheme (CPRS) will support renewable energy technologies for a longer time.(Source:www.climatechange.gov.au/renewabletarget/pubs/RET-scheme-design.pdf, p.2). The CPRS will support renewable energy techniques to enter the market and will mature between 2020 and 2030 as the Renewable Energy Target scheme develops.

2.7.2 Impacts of the Renewable Energy Target to the Electricity Market

Due to the Renewable Energy Target and the Carbon Pollution Reduction Scheme, renewable energy generation will expand. Even without the expanded RET scheme the amount of Renewables, contributing total electricity supply, will be at about 7000GWh with the Mandatory Renewable Energy Target scheme.

Generation of wind energy is expected to raise in all States especially in Victoria and New South Wales because of its excellent wind resources. Western Australian level of renewables is also expected to increase but limited, because of its inability to transport excess renewable energy generation into other electricity markets. The

Northern Territory expects no increase in Renewabe Energy generation from wind energy prior to 2020 but shows increase in Photovoltaic and solar thermal generation.
(McLennan Magasanik Associates: Benefits and Costs of the Expanded Renewable Energy Target, 2009, p. 32)

2.7.3 Renewable Energy Certificate prices under the RET scheme

Renewable energy certificate (REC) prices which are shown in the following figure reflect continuous price development until the year 2030.

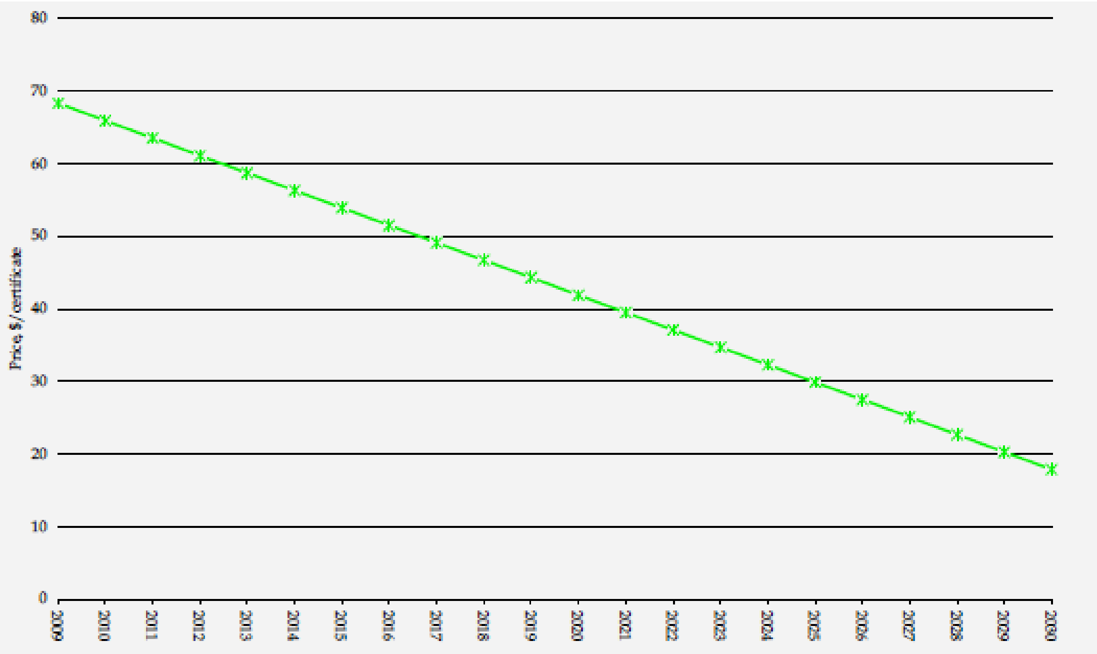


Figure 2.7.2: Renewable Energy Certificate Price development 2009 to 2030.

Source:McLennan Magasanik Associates: benefits and Costs of the Expanded Renewable Energy Target, 2009, p. 32

Price in each year reflects long term contract prices for certificate which support the renewable energy, entering the market each year.
The price level starts under the MRET at about AUD70/MWh and will decrease until 2030 whereas electricity prices will increase over time. (Source:McLennan Magasanik Associates: Benefits and Costs of the Expanded Renewable Energy Target, 2009, p. 34)
Current Governmental policy is to phase out the MRET scheme as emission price increases. From 2020 to 2024 the amount of Renewable Energy Certificates will be kept constantly at 45 million REC´s per year but will fast decline after that period.

(Carbon Market Economies Pty. Ltd.: Renewable generation projections 2009 to 2028, Revised Final Report, 2009, p. 14)

2.8 Integrating Wind Farms into the Australian Electricity System

Currently there are three major electricity markets in Australia:

- National Electricity Market (NEM) which is responsible for the grid integration in Queensland, New South Wales, Victoria, South Australia and Tasmania (Electricity Supply Industry Planning Council: Wind report to Essential Services Commision of SA, 2005, page 8)

- The South West Interconnected System (SWIS) which is responsible for grid connection in Western Australa (WA).

- The Darwin-Katherine Interconnected System Grid (DKIS) in the Northern Territory (McLennan Magasanik Associates: A comparison of emission pathways and policy mixes to achieve major reductionsin Australia´s electricity sector greenhouse emissions, 2008, p.4)

Australian electricity grids have historically been designed near to large scaled fossil fuel generators with a continuous and controllable output of electricity.

Contrary to the fossil fuel energy production, the generation of renewable energy from wind power needs improved infrastructure and market integration measures to adapt a greater supply of clean renewable energy sources. (Wind Energy Technical Advisory Group: Integrating wind farms into the National Electricity Market, January 2005, page ii). To get an imagination of the Australian electricity network, following figure shows Australian-wide distribution of electricity networks and lines.

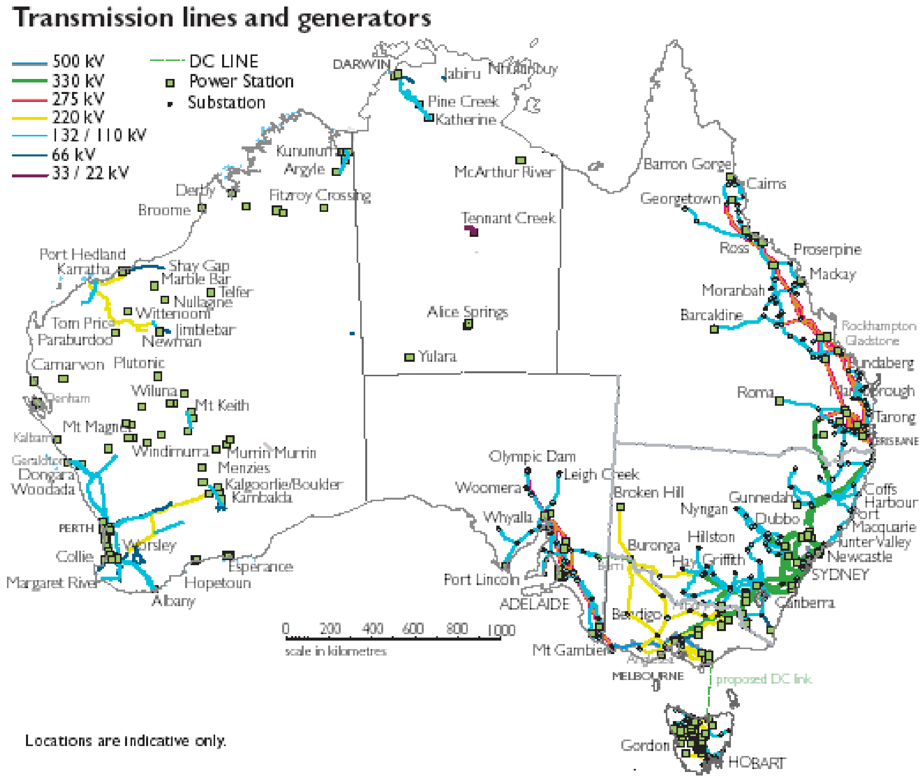


Figure 2.8.1: Australian Electricity Transmission lines and Generators

Source: Australian Department of Resources, Energy and Tourism, Energy in Australia 2009, p. 1

The eastern Australian electricity System, also called National Electricity Market, operates a single interconnected electricity grid system and provides more than 7.7 Million Australian customers with electricty. The Northern Territory and Western Australian electricity supply is guaranteed by a number of small remote electricity grids, apart from the South West Interconnected System (SWIS) which supplies the south west of Western Australia with Electricity.

South Australia, Victoria, New South Wales, Queensland and Tasmania are along the way Australian top locations for current and future wind parks and play therefore a major role for integrating wind energy into the Australian Electricity System.

The National Electricity Management Company is ensuring a stable electricity system and manages supply of electricity through a cycle of bidding and dispatch. Electricity Generators dress the volume of electricity they can provide and for what price they will sell it. These bids are pooled in a list with the cheapest price at the bottom and the highest price at the top of it.

Not all generators sell electricity to the market as it is explained above, as it is common that electricity generators and electricity retailers have a contractual arrangement for the supply of electricity. These arrangements guarantee generators a fixed price schedule over a certain period of time so that project-development companies can calculate returns gained from wind turbines over a certain period of time. These electricity trading scheme is also called „off market“ trading. These off market trades are „bids“ into the trading pool but are placed with zero dollars so that they are located at the bottom of the price range for electricity.

Generators who are bidding in this way are called price takers because they take every price that is set by the pool, whereas the wind farm company does not care about this price because they have arranged long term price contracts with the electricity retailer. Nowadays, all Australian wind farms have fixed long term of market contracts with one or more electricity retailers. (Australian Government; Australian Greenhouse Office, Wind Farming and the Australian Electricity System, 2004, p. 6)

All current Australian wind farms are classified as „embedded generators“ which means that the electricity output is sold only into the distribution system and not into the larger transmission system.

The electricity network can be divided into two parts namely the transmission and distribution network. Distribution network is part of the system which delivers electricity from the larger transmission points to the electricity consumer. The transmission system delivers large volumes of electricity to specific points of the electricity network. This means that the output of current wind farms is small enough to be consumed by local electricity demand.

It should be noticed that some local Australian electricity distribution networks are large and can cover in some cases thousands square kilometres and reach ten of thousands of customers.

Large wind farms which are proposed to be built within the next years will have to be connected into the transmission system and will operate like a traditionall large generator in the electricity system. (Australian Government; Australian Greenhouse Office, Wind Farming and the Australian Electricity System, 2004, p.18)

3 Method of Approach

3.1 Introduction

At the beginning of the following analysis of wind potentials in Australia, a review of previous development of the renewable energy sector, including tariffs for electricity and Australian Renewable Energy Support Schemes should be kept in mind from previous chapters to understand the complex relation between the relative small usage of green energy in contrast to Australian usage of fossil fuels to generate electricity.

Firstly a screening of winds, blowing continuously on Australian coastal areas, will be given to understand and in a later stage to linken wind strenghts to potentials of wind development in certain locations all over Australia. Geographic distribution of wind zones and a screenshot of daily and annual variability of winds gives a first insight into possible locations for future wind parks.

With the knowledge gained from chapter 2, which gives an overview of current electricity transmission lines all over the country, in a second step current and proposed wind park sites will be opposed to compare if current and future locations differ from each other in terms of positioning.

Additionally, an analysis done by the Australian National Electricity Market Management Company shows if the extension of the electricity grid is done in wind energy development areas.

To investigate, if these wind energy developing zones are located within the electricity grid extensions points (also called wind bubbles), an analysis of wind speed, based on data provided by the Australian Bureau of Meteorology, and a scoring of capacity factors will be done.

Finally, to round out the following analysis of wind energy development, Australian largest wind project, namely Silverton 1000 MW wind park will be presented.

4 Wind Energy in Australia

4.1 Wind conditions over the country

Australia´s climate is strongly characterized by its latitude which is between 10 degrees south and 39 degrees south with Tasmania extending to 44 degrees south. This location is strongly influended by a sub-tropical high pressure belt causing different wind conditions all over the country.

4.1.1 Geographic Distribution of Wind Zones

As winds have „*counter clockwise circulation around anticyclones in the Southern Hemisphere*“ (Australian Bureau of Statistics, Year Book Australia 2005, p.16), the direction on the southern side of the sub-tropical zone tends to be westerly.

This weather section in the south of Australia is also known as the roaring 40´s[7] and reaches its strongest winds in the Bass Strait which is located between the city of Melbourne and Tasmania. Tasmania is mostly influenced by this westerly flow whereas Northern Australia is influenced by monsoon and southeast trade winds. (CSIRO Wind Energy Research Unit, Wind Resource Assessment in Australia-A Planners Guide, 2003, p.9)

Position and strength of the air circulation cause the direction of the weather system. Strong weather systems can therefore expand deep into the southern mainland of Australia, whereas weaker air circulations touch the southern coasts. These wind circulations can be seen on the wind atlas of Australia where coastal areas reach yearly mean wind speed up to 10 metres per second whereas winds reach the inner mainland with yearly mean wind speed at about 5.6 to 6.7metres per second. (Source: www.bom.gov.au, Bureau of Meteorology, World Wide Web based Cyclone Information Paper).

Following image shows distribution of wind zones over Australia.It can be recognized that areas of strong wind zones accur on coastal areas. Blue areas show yearly mean wind speed of 5.6 to 6.2 metres per second and can be classified as

[7] Roaring 40´s: Named after the latitude zone it assigns

zones of lower wind activity. Yellow areas show moderate wind zones with yearly mean wind speed between 6.3 and 6.5 metres per second. Best wind conditions can be found in red marked areas with yearly mean wind speed between 6.6 and 10 metres per second.

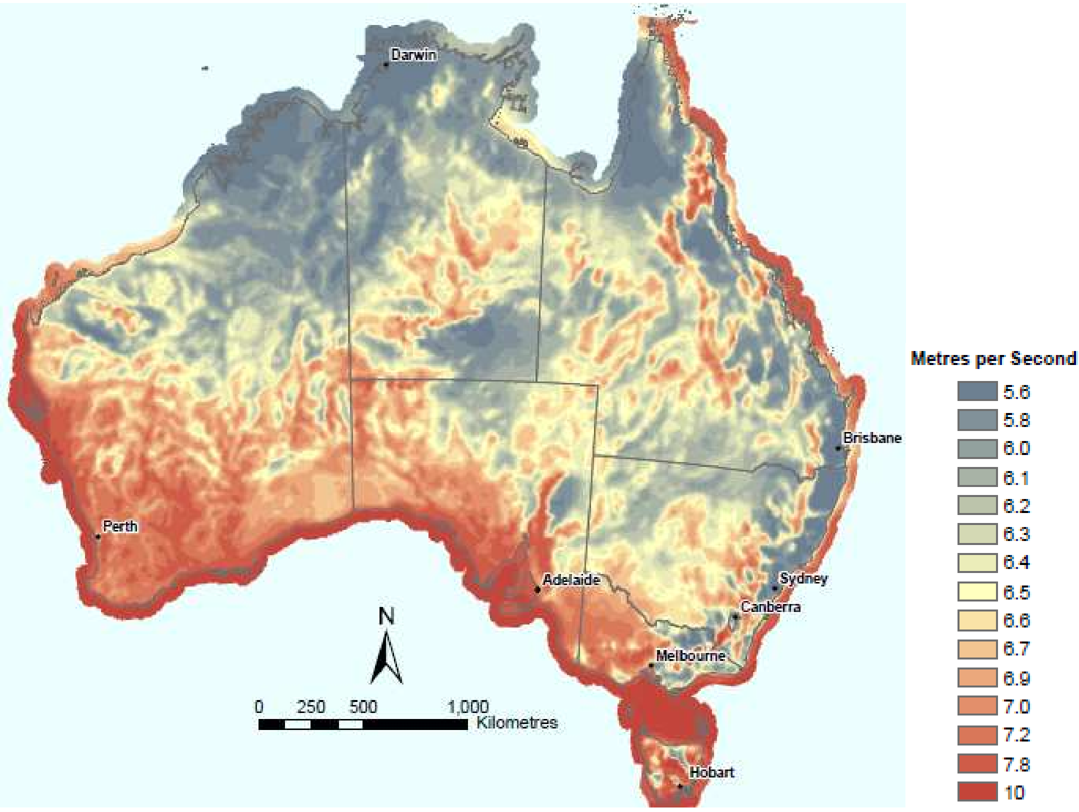


Figure 4.1.1: Mean Wind Speed over Australia measured at 80metres above ground level

Source: Commonwealth of Australia, Department of the Environment, Water heritage and the Arts, Renewable Energy Altas of Australia

Figure 4.1.1 illustrates that wind rich areas can be found on the southern half of Australia in coastal areas and around Tasmania. An analysis of selected wind spots will be done later on in this work.

4.1.2 Daily and annual wind speed variability

As wind occurs through the year with seasonal distinctions in southern regions of Australia, winter and spring have the windiest conditions.

Additionally to seasonal wind speed distinctions, monthly and daily variation can be recognized. Daily cycle in wind speeds occur usually in the afternoon where wind speeds-up because of a higher atmospheric air flow, where high speed air comes down from higher air zones. High seasonal and daily variability in wind speed are of strong importance for measuring wind capacity in conection with possible wind energy generation.

One of Australia´s most known sea breeze is the Fremantle Doctor which occurs in summer months near the Western Australian Coast and is caused by temperature difference between land and sea. The Mean Wind Speed of the Fremantle Doctor can refresh up to 10 metres per second.

Following figures show variability of wind at selected area at 9am and 3pm. In comparison to that, inner annual wind speed variation compared to inner annual wind speed variability between the year1971 and 200 is shown. While these figures give an impression of various intra-day wind conditions and of availability of these data to the public, project-development companies can benefit from these informations for selection of possible wind park sites.

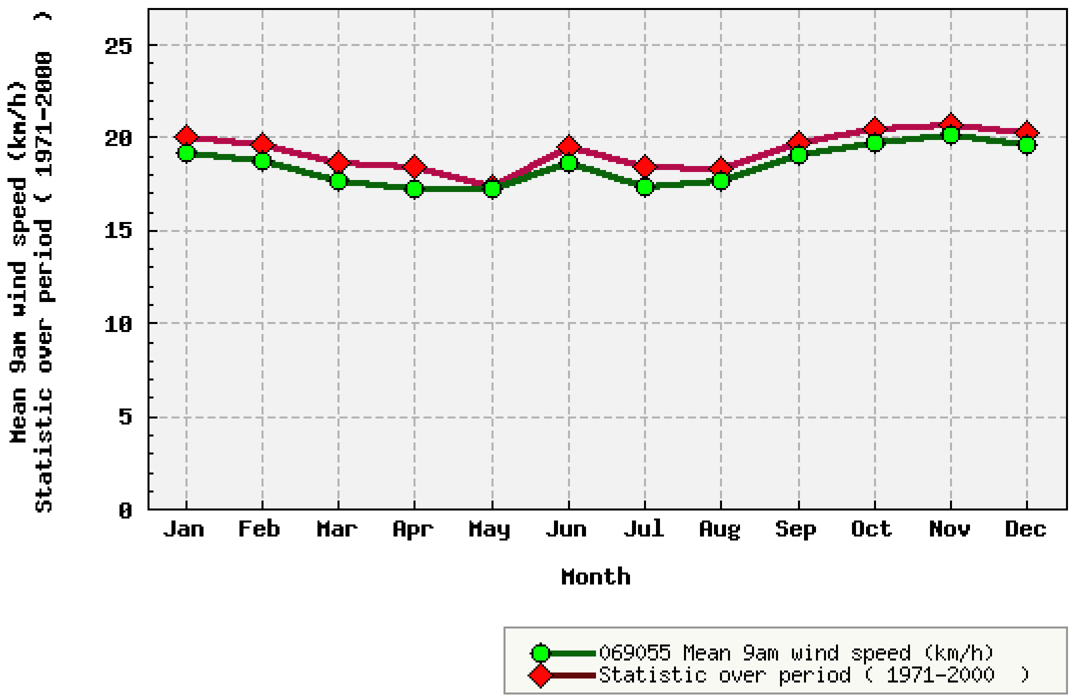


Figure 4.1.2: Comparison of wind speed on Green Cape Lighthouse inner annual and from 1971-2000 at 9am.[8]

Source: Bureau of Meteorology, Climate Statistics for Australian locations

[8] Green Cape Lighthouse is located at: Latitude 37.26 South and Longitude 150.05 East /Site Nr.069055

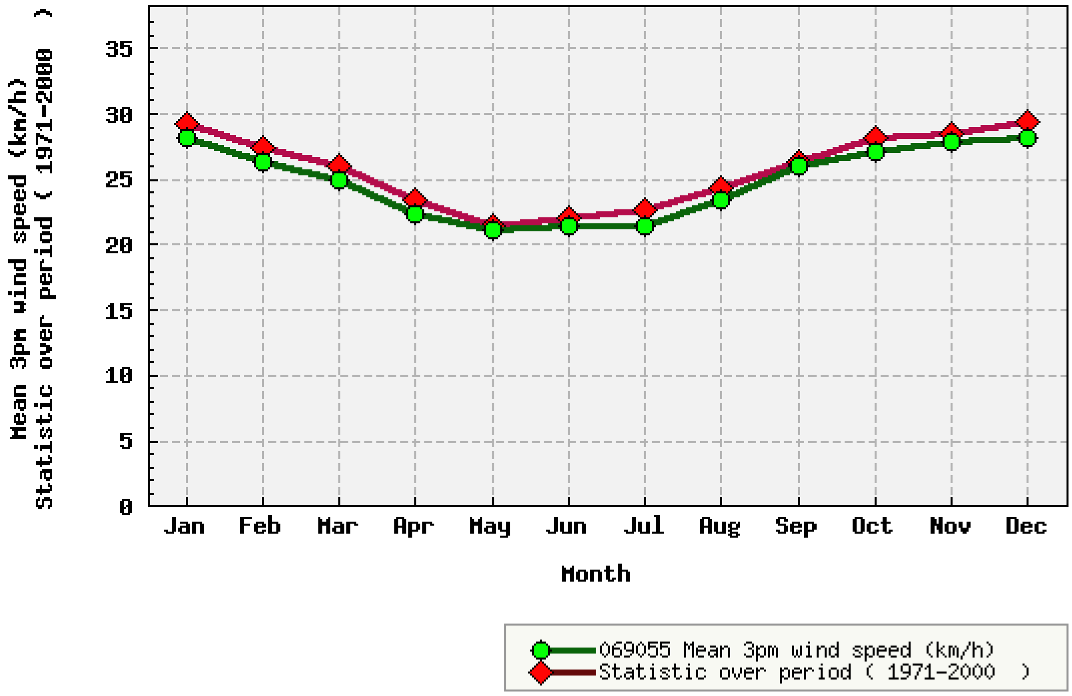


Figure 4.1.3: Comparison of wind speed on Green Cape Lighthouse inner annual and from 1971-2000 at 3am.

Source: Bureau of Meteorology, Climate Statistics for Australian locations

It can be recognized that at this selected measurement point wind speed ist higher in the afternoon higher than at 9am in the morning. At forenoon, mean wind speed is measured between 15km/h and 20 km/h whereas in the afternoon mean wind speed can be found between 20 km/h and 30 km/h.

In a later chapter a deeper analysis of selected sites will be done to estimate possible potentials for new wind farms. For calculating the capacity factor[9] data sets will be used, provided by the Australian Bureau of Meteorology.

4.1.3 Cyclone affected areas

Australian coastal areas in the North, especially between Broome and Exmouth are highly cyclone affected areas. In the tropical cyclone season which can be located between November and April about five cyclones cross this area on an average, causing severe damages.

Black spots show in the following figure non severe cyclones , red spots are marked for severe tropical cyclones.

[9] The capacity factor of a power plant is the current output over a period of time and its possible output if it had operated at full capacity the entire time. For calculating the capacita factor, the total energy produced by a plant over a time is divided by the energy the plant would have produced at full capacity.

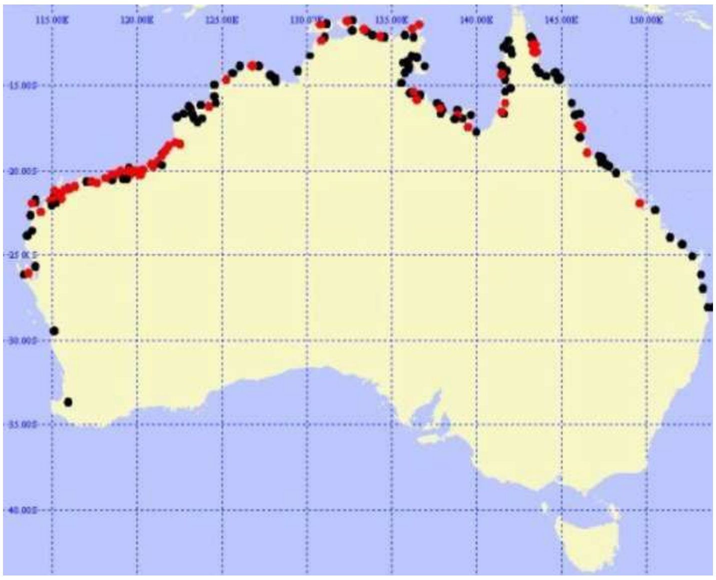


Figure 4.1.4: Cyclone affected areas in Australia

Source: Bureau of Meteorology,World Wide Web based Cyclone Information Paper

Areas with high risk of cyclone can be seen as less favourble for wind park projects because of the high destructive power of strong winds caused by cyclones. These areas can be found in the North and the North East of Australia. (Source:www.bom.gov.au, Bureau of Meteorology, World Wide Web based Cyclone Information Paper).

4.2 Wind Measurement Data

The Australian Bureau of Meteorology offers a wide range of public available climatic data sets which, in some cases, go back to the 1950ies. With more than 500 installed Automatic Weather Stations (AWS), wind speed data is recorded mainly on a hourly basis and is tracking not only wind speed but also wind direction.

Although these AWS are not often located in possible wind farm areas, the recorded data can be important to create long term statistics for wind maps.

Following figure shows selected Wind Measurement spots across Australia which delivers data sets to the Australian Bureau of Meteorology.

Figure 4.2.1: Wind measurement spots across Australia

Source: Australian Bureau of Meteorology

Accessorily, the Australian Bureau of Meteorology offers wind speed and wind direction measurements which are made on a daily basis at 9am and 3 pm in spring, summer, autumn and winter.

Some locations in Australia (airports and cities) have more extendet observation programs. These wind measurement data is accessible for everyone on the website of the Australian Bureau of Meteorology[10] and can be of importance for wind farm siting and pre-selection of their position. In the following, an example of these visualization in form of wind roses is given. Wind roses display wind direction, strenght and frequency at selected times and seasons.[11]

[10] See: www.bom.gov.au

[11] How to interprete this wind rose: The percentage of calm conditions is represented by the size of the centre circle-the bigger the circle, the higher the frequency of the calm. North is located at 12 o clock of the wind rose circle whereas eight directions are used. The length of each segment within the wind rose is proportional to the frequency of winds blowing from that direction.

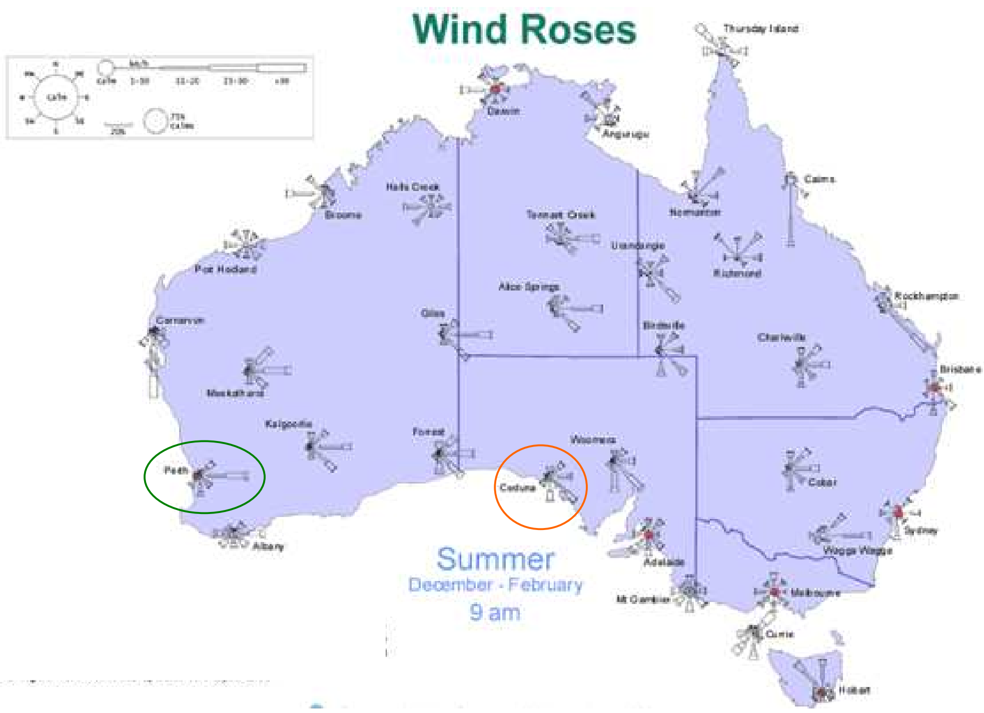


Figure 4.2.2: Wind roses over Australia for summer time measured at 9am

Source: Australian Bureau of Meteorology

In comparison to wind measurement in the moring at 9am following image shows wind rose measurement at 3pm. Green and red marked areas give good examples of intra-day variability of wind speed.

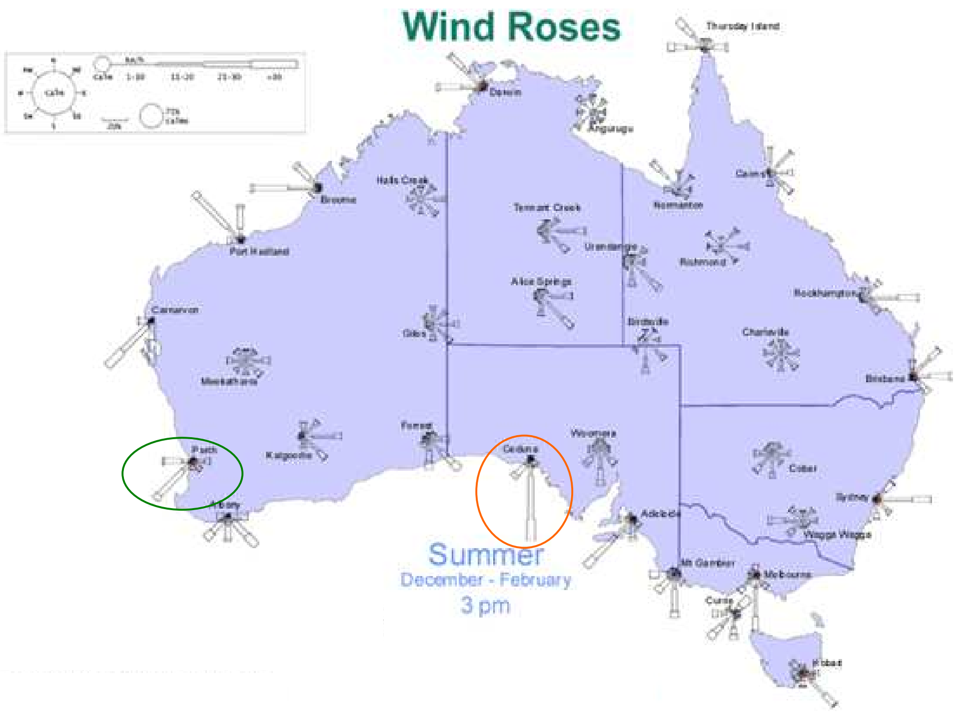


Figure 4.2.3: Wind roses over Australia for summer time measured at 3pm

Source: Australian Bureau of Meteorology

Luckily, areas of high population density can be found in Australian coastal areas so that wind farm siting can be located in coastal regions and in range of large cities.

Aditionally to that, the Australian Sustainable Energy Development Authority of New South Wales has publises wind maps reflecting infrastructural and constraint overlays. (CSIRO Wind Energy Research Unit, Wind Resource Assessment in Australia-A Planners Guide, 2003, p.19)

Following figure shows a wind atlas of New South Wales where dark-green to bright-green marked areas are marked as wind rich regions.

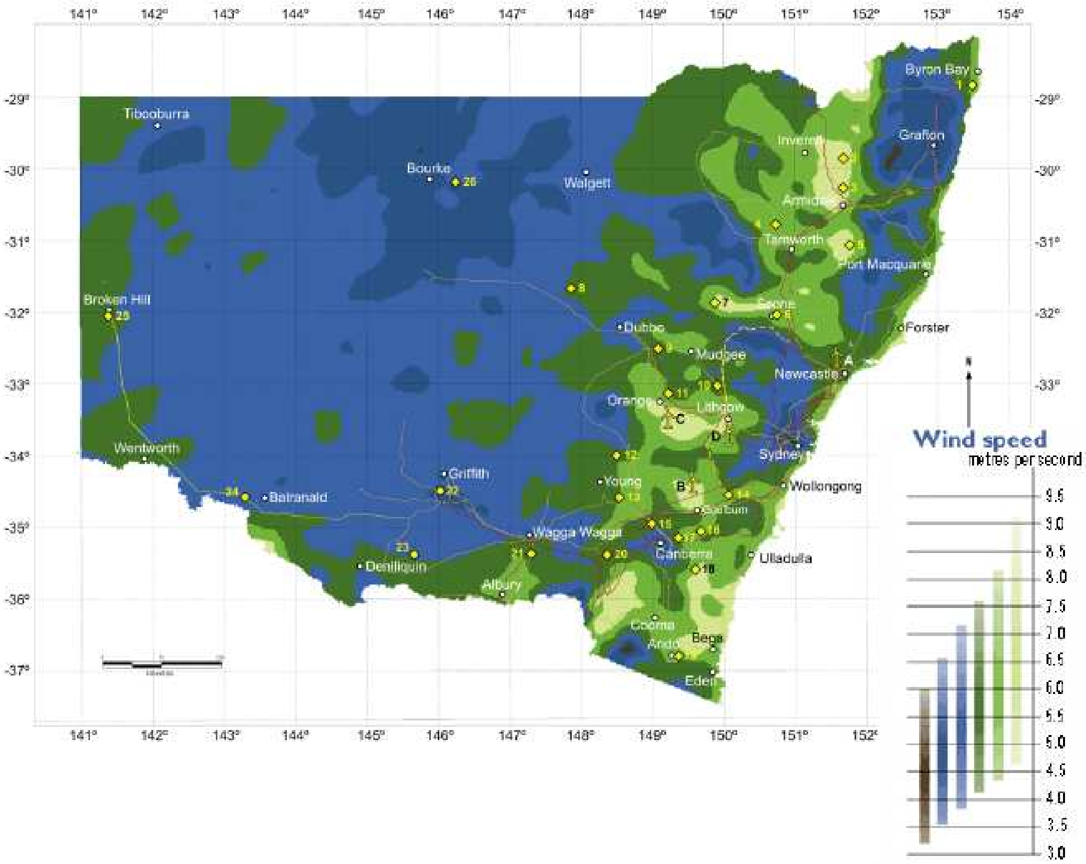


Figure 4.2.4: Wind Atlas of New South Wales

Source: CSIRO Wind Energy Research Unit, Wind Resource Assessment in Australia-A Planners Guide, 2003, p.19

New South Wales Government offers also 100m high resolution wind maps including wind reports with two ore more years of data records. Based on these wind maps, wind farm-planners have access to first data sets for rough site selections and analyis of possible wind farm placing.

As good wind conditions are the most important pre-condition for converting wind energy via wind turbines into energy, wind measurement can be seen as the top criteria for selecting possible sites for wind farms.

4.3 Wind Energy development in Australia

Australias first wind farm which was connected to the grid stands at Salmon Beach, Esperance, in Western Australia where the longest operating windfarm (commissioned in 1992) stands only a few kilometres away at 9 Mile Beach.

First grid connected turbine was positioned in Victoria in 1987 with a 20kW Westwind windmill.

Following figure gives an impresssion on Australias development in wind energy installations over the last 20 years.

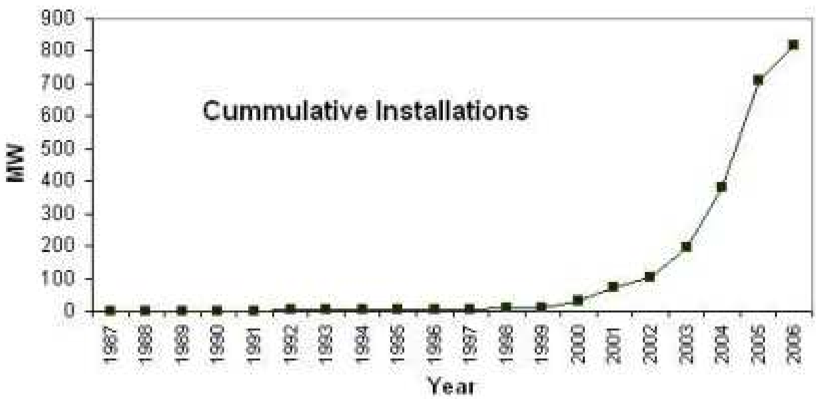


Figure 4.3.1: Cummulative Installations of Electricity gained from Wind Energy

Soure: http://www.auswind.org/downloads/factsheets/WindEnergyInAustralia.pdf

It can be recognized that strong upwinds in the wind energy sector have started up from the year 2000 with constant trend upwards.

Australias wind energy sector has increased within the last two decades with the result that wind energy is one of the fastest growing renewable energy source in the country.

4.3.1 Current Wind Farms

Due to different preconditions for wind energy over Australia, wind farms have been placed as shown on the following map. Purple coloured spots stand for a wind energy site whereas the single spot in the sea north of Western Australia is located on an island and is not an offshore operating find farm.

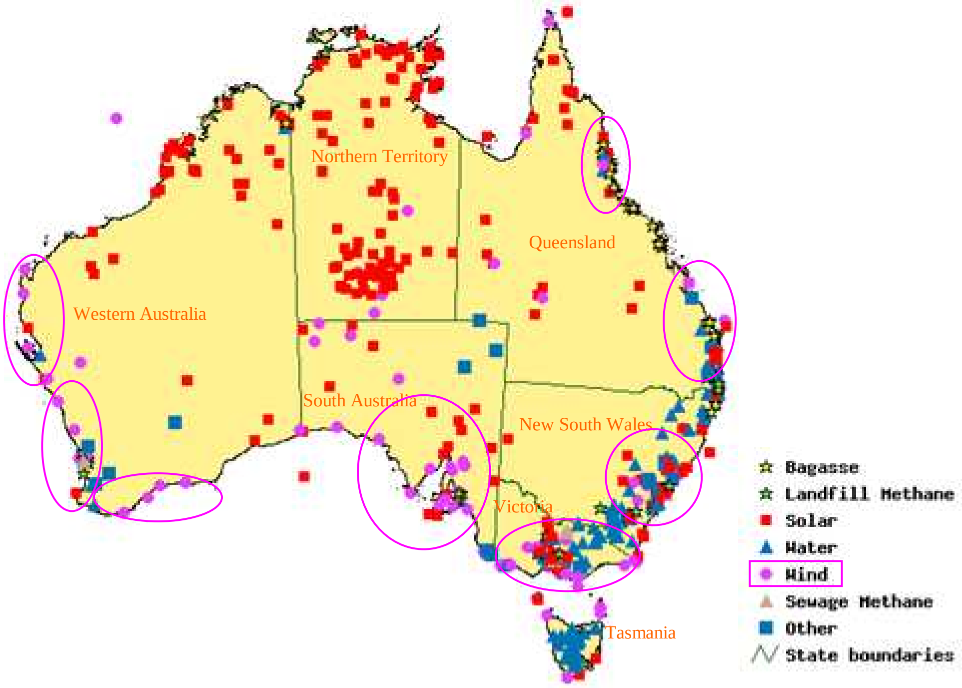


Figure 4.3.2: Current operating Wind Farms in Australia

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts

The majority of wind parks can be found in coastal areas near towns. Spots in the center of Australia stand for small wind turbines, supplying small commuities.

To underline Figure 4.3.2 which shows distribution of current wird farms over Australia, following table gives an overview of its number per state. As there arose during the past years multiple projects in areas nearby, current installed wind parks have built the guideline for future settlements of wind farms.

Table 4.3.1: Total current installations of wind energy – per State

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts, self calculated

State	**Installed**
South Australia	1.040 MW
Victoria	450 MW
Western Australia	204 MW
New South Wales	150 MW
Tasmania	144 MW
Queensland	13 MW
Northern Territory	1 MW
Total	**2.002 MW**

Australia nowadays accounts for about 2000 Megawatt of installed capacity of wind energy whereas data quality concerning all installed wind turbines variies between data sources. The Australian Government of the Environment, Water, Heritage and the Arts published a data set concerning all licenced wind turbines installed over Australia so that the Number shown in table above includes also small wind turbines which are used in remote areas.

On the top of Australian Wind Farm development, South Australia is outperforming all other states followed by Victoria and Western Australia. The tail-light in wind farm-development is given by the Northern Territory, which has only about 1 Megawatt of installed wind energy. The Epenarra Wind turbine in the Northern Territory supplies an air landing strip and a small community with electricity. Reason for underdeveloping in wind energy can be seen in the cyclone affected coasts, its extension, weak wind conditions and rarely populated landscape.

Following figure mirrors the percentage of distributed wind energy by state wheras South Australia accounts for more than 50% of Australias total wind energy supply, followed by Victoria with 22,48% and Western Australia with 10,19 %.

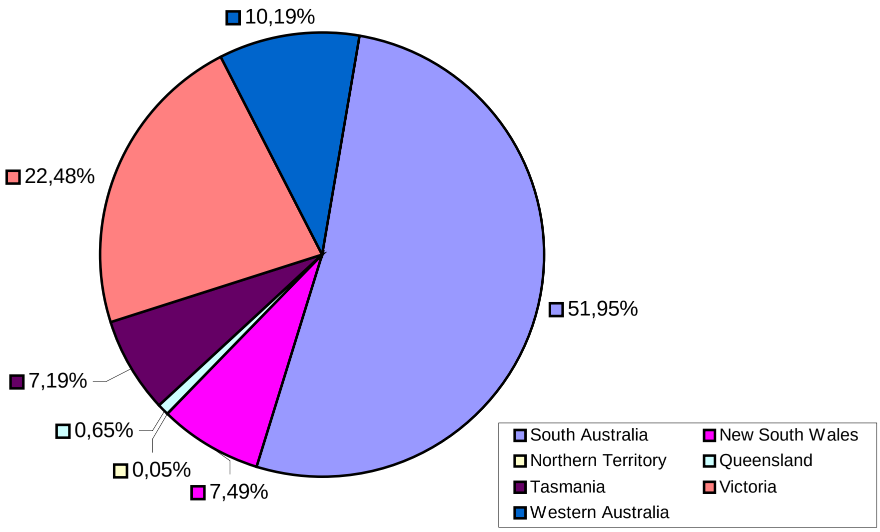


Figure 4.3.3: Percentage of current wind parks spread over Australia

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts

In this context an analysis of Australian largest wind farms spread over all states is shown in the following figure.

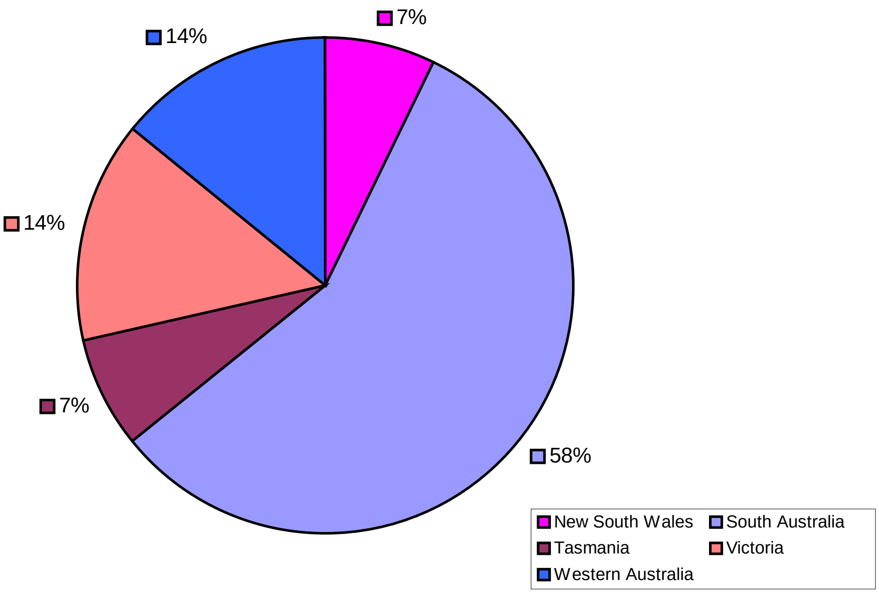


Figure 4.3.4: Percentage of major Wind Farms given per Australian State

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts,self calculated

It can be recognized that also in Figure 4.3.3 as well in Figure 4.3.4 South Australia and Victoria harbour not only Australias highest amount of large wind parks, but also have highest amount of installed wind turbines. Following table names Australian biggest wind farms.

Table 4.3.2: Largest Wind Farms in Australia assorted by state

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts,self calculated

Name	MW	Location
Bungendore	132	New South Wales
Lake Bonney 2	159	South Australia
Hallett 4	132	South Australia
Snowtown	99	South Australia
Hallett 1	95	South Australia
Wattle Point	91	South Australia
Lake Bonney 1	80	South Australia
Hallett 2	71	South Australia
Mount Millar	70	South Australia
Cathedral Rocks	66	South Australia
Woolnorth	140	Tasmania
Waubra	192	Victoria
Cape Nelson	66	Victoria
Walkaway – Alinta	90	Western Australia
Emu Downs	79	Western Australia

Largest current operating wind power plant is Waubura with a capacity of 192 MW which is located in Victoria, followed by Lake Bonney 2 (159MW) in South Australia and Woolnorth (140 MW) which has been built in Tasmania as shown on figure above.

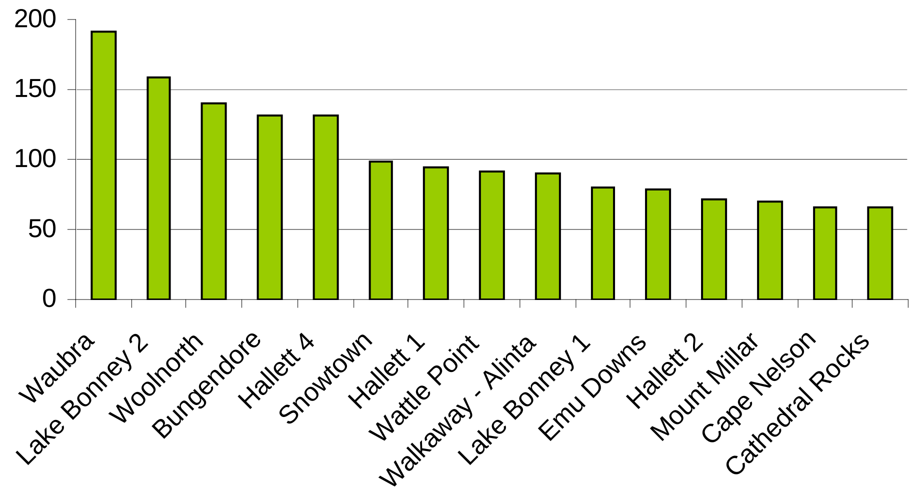


Figure 4.3.5: Largest Wind Farms in Australia assorted by name

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts,self calculated

For the analysis of future wind projects, which will be done in an later stage of this work, it is essential to know the distribution of current projects over the country. As seen in the tables and charts above, South Australia and Victoria are leading states regarding current installation of wind energy. To get an insight into wind energy development in Australia and an imagination of possible future developing areas, next chapter will show projects which will be realized within the following years.

4.4 Proposed wind energy projects

As Australia underlines its commitment to reduction of Greenhouse Gases by generating electricity from renewables, fairly an increasing number of wind energy projects are in progress for the next years.

A map, created by the Australian Department of Environment ,Water, Heritage and the Arts shows the distribution of proposed wind farms over the country which are marked in purple colour.

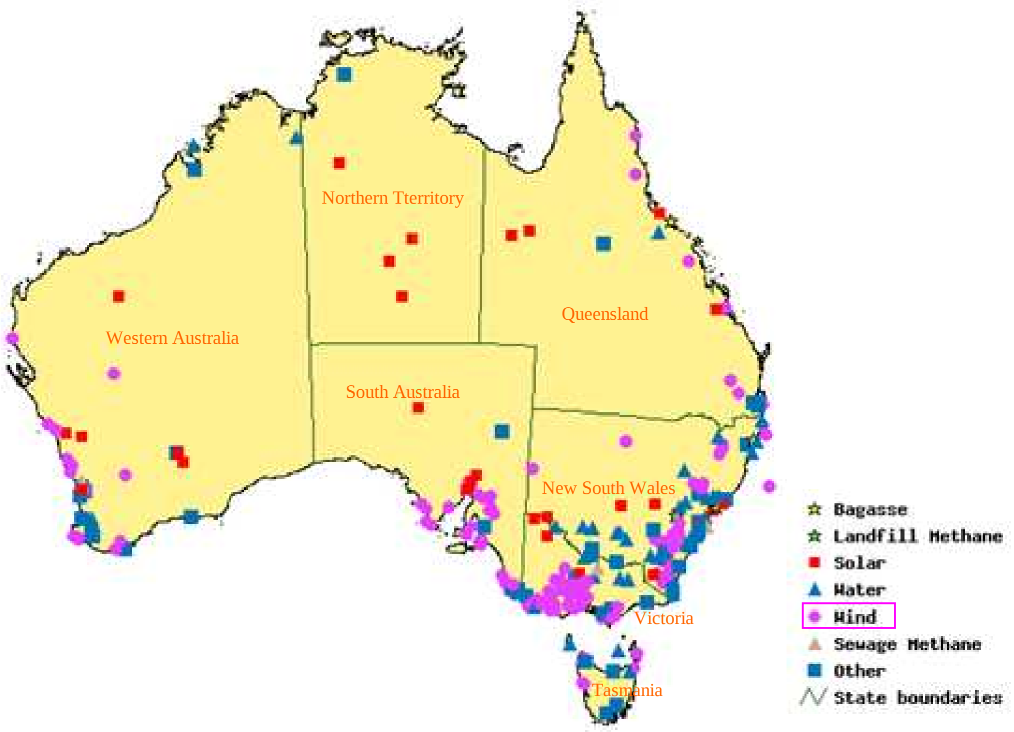


Figure 4.4.1: Proposed wind energy projects in Australia

Source: Source: Australian Government:Department of the Environment, Water, Heritage and the Arts

Due to excellent wind conditions in the southern coastline, the southwest of Western Australia, southern South Australia, south-western Victoria , northern Tasmania and some areas in New South Wales and Queensland, it is not wondering that new projects are expected to settle down in these areas.

Comparing spots from current operating wind farms (See Figure 4.3.2) with proposed wind parks, it can be recognised that a multiplicity of new wind farms integrate into the wind bubble of current operating wind parks.

Following table gives an overview of 15 selected projects, split in states and its owner.

Table 4.4.1: Proposed Wind Farms per State

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts,self calculated

Name	Location	Proposed	Owner
Silverton	New South Wales	1000MW	Epuron
Boco Rock	New South Wales	254MW	Wind Prospect
Yass Project	New South Wales	200MW	Epuron Pty Ltd
Carmodies Hill	New South Wales	175MW	Pacific Hydro
Coopers Gap	Queensland	630MW	Investec Bank/Windlab Systems
Macarthur	Victoria	350MW	Southern Hydro
Mortlake 1&2	Victoria	264MW	TME Australia Pty Ltd
Mount Gellibrand	Victoria	232MW	Wind Hydrogen Ltd
Baynton	Victoria	200MW	Windlab Systems
Pyrenees	Victoria	200MW	Wind Power Pty Ltd
Stockyard Hill	Victoria	200MW	Wind Power Pty Ltd
Worlds End	South Australia	180MW	AGL Energy Ltd
Uley Station	South Australia	160MW	Babcock and Brown
Heemskirk	Tasmania	160MW	Roaring 40s/Hydro Tasmania
Collgar	Western Australia	270MW	Investec Bank

In comparison to Table 4.3.2 where current biggest Australian Wind Farm has a capacity of about 200 Megawatt, least proposed project starts with a capacity of 160 Megawatt. This shows that future projects show a significant increase in installed wind turbines per project.

Largest and most challenging project is Silverton Wind Park with a capacity of more than 1000Megawatt.

Following chart gives an overview of current and proposed wind projects selected per state.

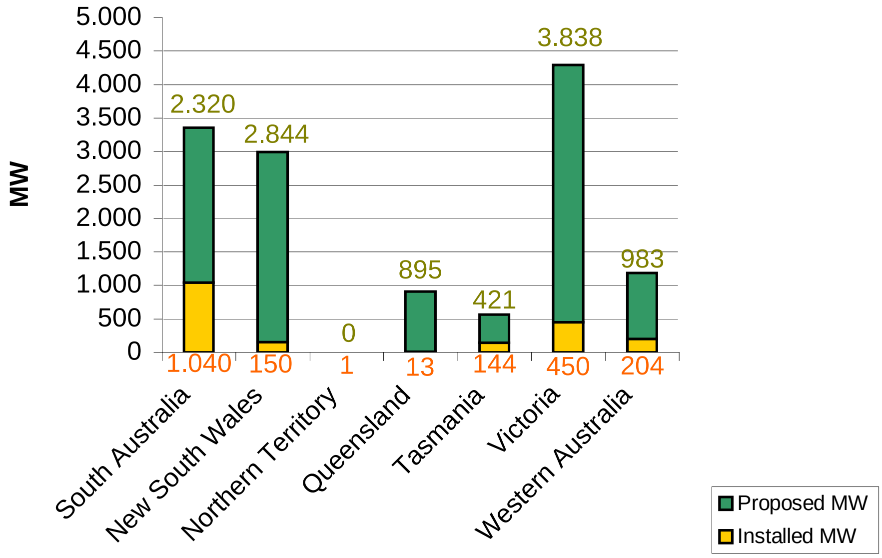


Figure 4.4.2: Current and proposed installations of wind energy per state

Source: Australian Government:Department of the Environment, Water, Heritage and the Arts,self calculated

Distribution of future wind farms over Australia shows that some states are developing faster than others, whereas Northern Territory has nearly no commitment to wind energy within the next years. Highest amount of proposed wind projects can be found in Victoria, followed by South Australia and New South Wales.

5 Analysis of future developments of wind energy projects

For pointing out future potentials for wind energy in Australia, a simulation for proposed wind bubbles in the National Electricity Market (NEM) has been done by the National Electricity Market Management Company (NEMMCO).
These wind rich areas, also called wind traces, have been defined by wind speed data supplied by the Australian Bureau of Meteorology where:

- Wind speed data from proposed wind parks have been averaged to create one single mean wind speed data for each wind bubble and exixting wind farms have been assigned to their individual wind speed trace.

- Turbine characteristics from well known turbine manufacturers have been taken into account by generating a relationship between wind speed data and the power generator output and additionally a power curve was developed.

- Wind bubbles shown in the map have sufficient wind quality to be a precondition for future development of wind farms in this area. (National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.88)

Following figure shows the result of future wind development areas, where it is recognizeable that all proposed wind bubbles are located in areas with high wind speed and in the near of towns or greater communities. As there are no relieable informations for development of wind bubbles in Western Australia it is assumed that due to its excellent wind conditions on the South West coast, wind energy will develop equal to South Eastern States.

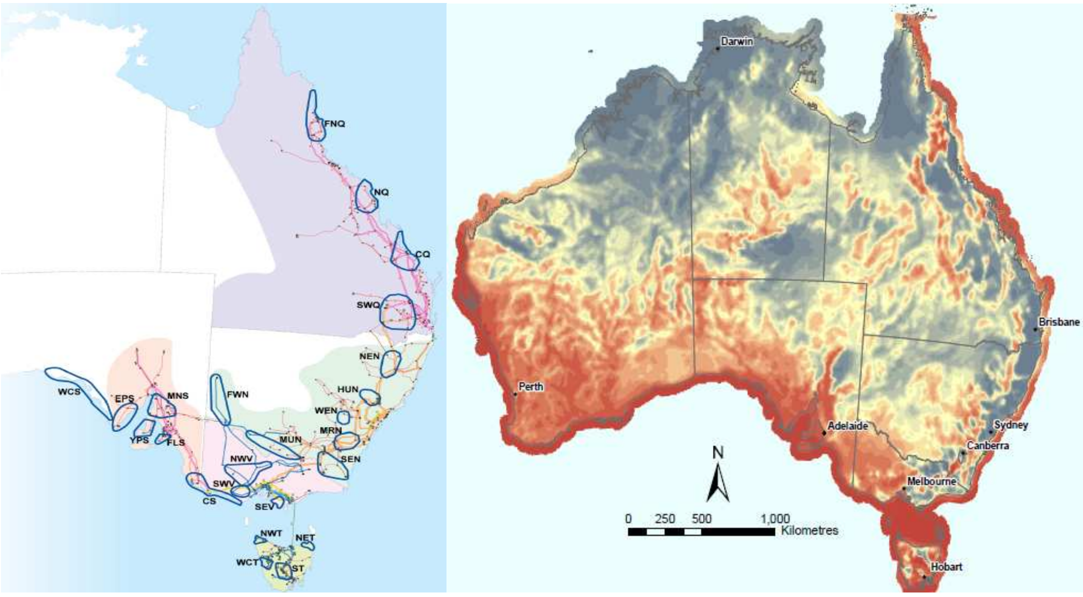


Figure 4.4.1: Future wind bubbles within the National Electricity Market in comparison to Australian Wind Atlas

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.90

Table 4.4.1 provides a summary of the wind energy development zones in the National Electricity Market with their location and the Bubble code.

Table 4.4.1: Proposed Wind Bubbles in the National Electricity Market

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.88

Region	NTS Zone	Description	Bubble Code
Queensland	NQ	Far North QLD	FNQ
		North QLD	NQ
	CQ	Central QLD	CQ
	SWQ	South West QLD	SWQ
New South Wales	SWNSW	Far West NSW	FWN
		Murray NSW	MUN
	Can	South West NSW	SEN
		Marulan NSW	WRN
	NCEN	West NSW	WEN
		Hunter NSW	HUN
	NNS	New England NSW	NEN
Victoria	LV	South East VIC	SEV
	CVIC	North West Victoria	NWV
		South West Victoria	SWV
	Mel	Central South	CS
South Australia	NSA	West Coast SA	WCS
		Eyre Peninsula SA	EPS
		Yorke Peninsula SA	YPS
		Mid North SA	MNS
	ADE	Fleurieu Peninsula SA	FLS
	SESA	Central South	CS

Tasmania	TAS	North West TAS	NWT
		North East TAS	NET
		West Coast TAS	WCT
		South TAS	ST

Aditionally to this, the National Electricity Market Management Company has published proposed wind farm connection points which can be found in the Annex of this document.

5.1 Assessment of proposed and future Wind Park sites

Australian wind energy branch is facing some challenging wind energy projects in the following years. To gain insight into specifications of wind park siting, Australian largest wind energy project has been selected and will be screened for a comparison to four other sites. All projects, including Silverton Wind Farm are located in the proposed wind energy bubble which are assumed by the National Electricity Market Management Company to develop within the next years.

In the following, Silverton Wind Farm will be screened in regard to its energy output in relation to the calculated capacity factor. Financial aspects of the project and benefits for the local communities in respect of electricity supply will be highlighted.
In addition to this, possible wind park sites all over Australia will be selected. This screening will outline if future development can take place under the proposed expansion within the electricity network and under given wind conditions.

5.1.1 Silverton 1000 MW wind farm

One of Australian most challenging wind project, the biggest wind park on the southern hemisphere and one of the largest wind park of the world, is Silverton Wind Farm located in New South Wales.
Silverton Wind Farm is placed about five kilometres north of the town of Silverton and 25km north west of Broken Hill, which is famous for its mining history.

The Project:
Silverton Wind Farm has a forecasted electricity capacity of more than 1000MW and will have up to 598 turbines in operation. The yearly average renewable energy output is estimated with 3,500,000 MWh which is sufficient for supporting 430,000 homes in New South Wales.

Figure 5.1.1: Silverton wind farm location near Broken Hill

Source: Google Earth, web screenshot

Site Location:

Silverton Wind Farm is located about 25 km near the town of Broken Hill.

Due to the high electricity output of the wind park of about 1000 MW, the project company has to do major investments into the electricity network.

In the first stage of construction, a 25km transmission line will link the electricity directly into the Transgrid substation located in Broken Hill.

Second stage of construction includes a transmission line from Broken Hill to Red Cliffs substation in Victoria which is about 300km away. This construction stage would also include a new backup supply capacity for the town of Broken Hill which is currently connected by a single transmission line. Following figure shows the location of the wind park in the north west of the town.

Figure 5.1.2: Location of Silverton Wind Farm north-west of Broken Hill

Source: Silverton Wind Farm, project Development Company: wwwsilvertonwindfarm.com

With calculated construction costs of about AUD 2 Billion, Silverton Wind Farm provides, besides energy coming from renewable sources, also an AUD 701 million injection into the regional community.

Table 5.1.1: Summary of key informations-Silverton Wind Farm

Source: Silverton Wind Farm, project Development Company: wwwsilvertonwindfarm.com

Summary of key information

Capacity	1,000MW
Date of completion	Phase 1 in 2011
Location	New South Wales
Number of Turbines	598
Greenhouse Gas savings	3,500,000 p.a.
Homes supplied	over 430,000
Yearly Electricity output	3,500,000 MWh

As mentioned above, for positioning of Silverton Wind Farm additional construction of transmission lines will be necessary to transport electricity gained from Silverton Wind Farm into the National Electricity Market. Following figure shows Wind Bubble FWN , which takes into consideration future lining within the electricity network.

Figure 5.1.3: Location of Wind Bubble FWN-Silverton Wind Farm

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.90

Electricity Network Connection Points:

Within wind bubble FWN following wind energy connection points will be developed within the next years.

Table 5.1.2: Electricity Network Connection Points-Wind Bubble FWN

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.91

Code	Connection Point	(kV)	Code
FWN	Broken Hill	220	FWN BH 220
	Buronga	220	FWN BUR 220

Silverton Wind Farm project company calculated an energy output of about 5853 MW/h per year and turbine or an annual energy output of 3,500 000MW/h for 598 turbines.

This capacity assumes that under certain circumstances a capacity factor of 33 per cent is given with an annual mean wind speed of about 6,784m/s. Following figure shows a screenshot of assumed parameters for this counted back data.

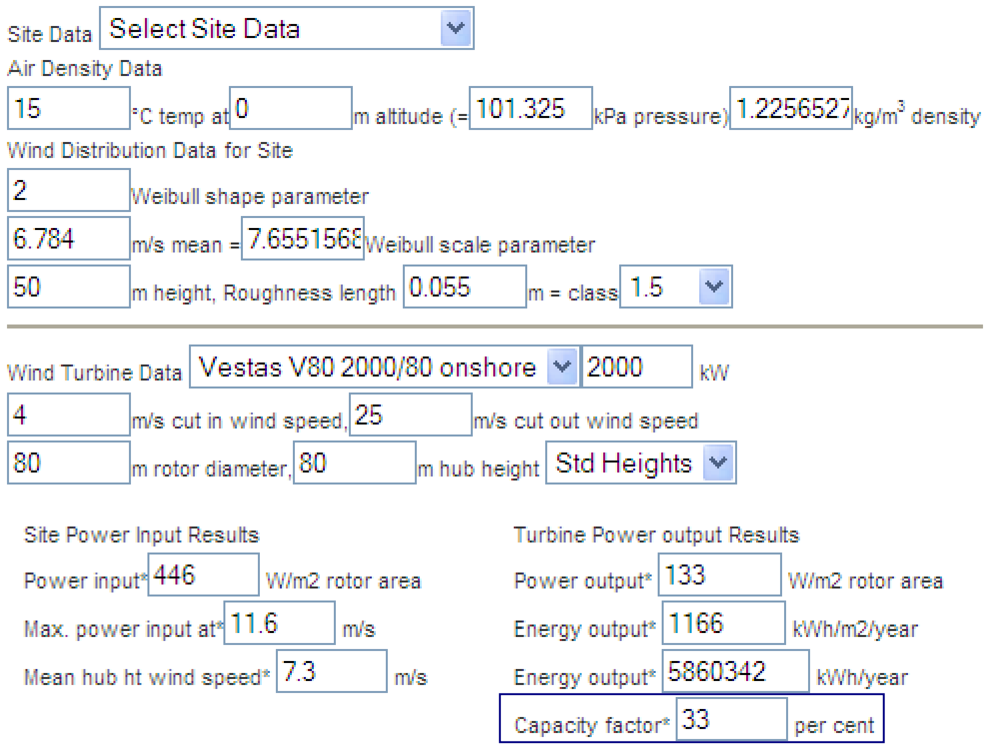


Figure 5.1.4: Calculation of capacity factor for Silverton Wind Farm

Source: Danish Wind Industry Association, www.windpower.org, self calculated

Silverton Wind Farm is located in an area with good wind speed as it can be seen on the Australian Wind Atlas, therefore this project with a financial size of about AUD 2,4 Billion will be realized within the next two years.

By looking forward to future developments in Australian wind energy branch, in the following chapter four sites, which are located within future wind bubbles, will be selected and analysed concerning their wind speed and calculated capacity factor.

5.1.2 Showcase wind farm I-South Australia

For analysing preconditions for future siting of wind parks, an analysis of four sites will be done.

As mentioned in chapter 5, the National Electricity Market Authority of Australia has calculated several possible wind development points, also called wind bubbles. These wind bubbles have proposed wind connection points (see Annex 7.1) so that it can be assumed that electricity, gained from new built wind parks can be delivered into the distribution or transmission network.

For analysis of showcase wind farm I, wind bubble code MNS, located in South Australia, near the city of Adelaide has been chosen.

Following data has been selected to specify location of wind siting analysis point:

Location of Wind Bubble MNS:

Wind Bubble MNS is located in the North-West of Adelaide, which is the capital of South Australia.

Figure 5.1.5: Location of Wind Bubble MNS-Showcase I

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.90

Electricity Network Connection Points:

Following wind energy connection points within wind bubble MNS will be developed within the next years.

Table 5.1.3: Electricity Network Connection Points-Wind Bubble MNS

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.91

Code	Connection Point	(kV)	Code
MNS	BRT	132	MNS BRT 132
	BGT	132	MNS BGT 132
	BRT	275	MNS BRT 275
	BGT	275	MNS BGT 275
	Robertstown	132	MNS ROB 132
	Robertstown	275	MNS ROB 275

Wind Data:

Wind tracking point: Edithburgh: 35.11 South / 137.74 East

Following wind data, provided by the Australian Bureau of Meteorology, shows recorded wind speed data from the past 16 years.

Table 5.1.4: Annual Wind Speed at Wind Bubble MNS,1993 to 2009

Source: Australian Bureau of Meteorology, self calculation

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
wind speed km/h	27,4	26,7	23,7	22,2	21,3	23,3	23,6	23,7	24,8	25,3	26,7	26,9	24,6 km/h
													6,83/s

Calculation of capacity factor:

With an annual mean wind speed of 6,83m/s and under following assumptions a capacity factor of 34 per cent can be calculated:

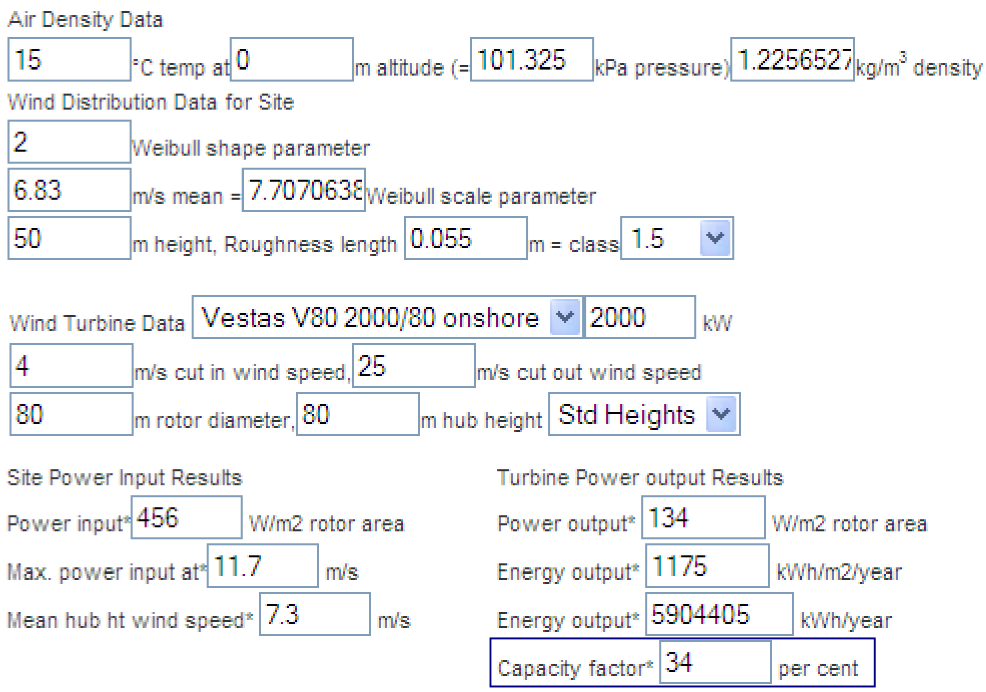


Figure 5.1.6: Calculation of capacity factor-Showcase wind farm I

Source: Danish Wind Industry Association, www.windpower.org, self calculated

With a capacity factor of 34 per cent and a yearly estimated energy output of 5904MW/h, wind bubble MNS offers excellent preconditions for new wind farm siting.

5.1.3 Showcase wind farm II-Victoria

For analysis of showcase wind farm II, wind bubble code NWV, located in the back-country of Victoria, has been chosen.

Location of Wind Bubble NWV:

Figure 5.1.7: Location of Wind Bubble NWV-Showcase II

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.90

Electricity Network Connection Points:

Following wind energy connection points within wind bubble NWV will be developed within the next years.

Table 5.1.5: Electricity Network Connection Points-Wind Bubble NWV

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.91

Code	Connection Point	(kV)	Code
NWV	Ballarat	220	NWV BLR 20
	Bendigo	220	NWV BEN 220
	Ballarat-Bendigo 200 kV	220	NWV BLR-BEN 220
	Ballarat Horsham 220kV	220	NWV BLR-HOR 220
	Horsham	220	NWV HOR 220

Wind Data:

Wind tracking point: Ballarat Aerodrome: 37.51 South / 143.79 East

Following wind data, provided by the Australian Bureau of Meteorology, shows recorded wind speed data from the past 47 years.

Table 5.1.6: Annual Wind Speed at Wind Bubble NWV

Source: Australian Bureau of Meteorology, self calculation

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
wind speed km/h	21,4	20,9	20,0	19,6	18,6	19,9	20,6	21,7	22,1	21,3	20,6	20,8	20,6
													5.72m/s

Calculation of capacity factor:

With an annual wind speed of 5,72m/s and under following assumptions a capacity factor of 23 per cent can be calculated:

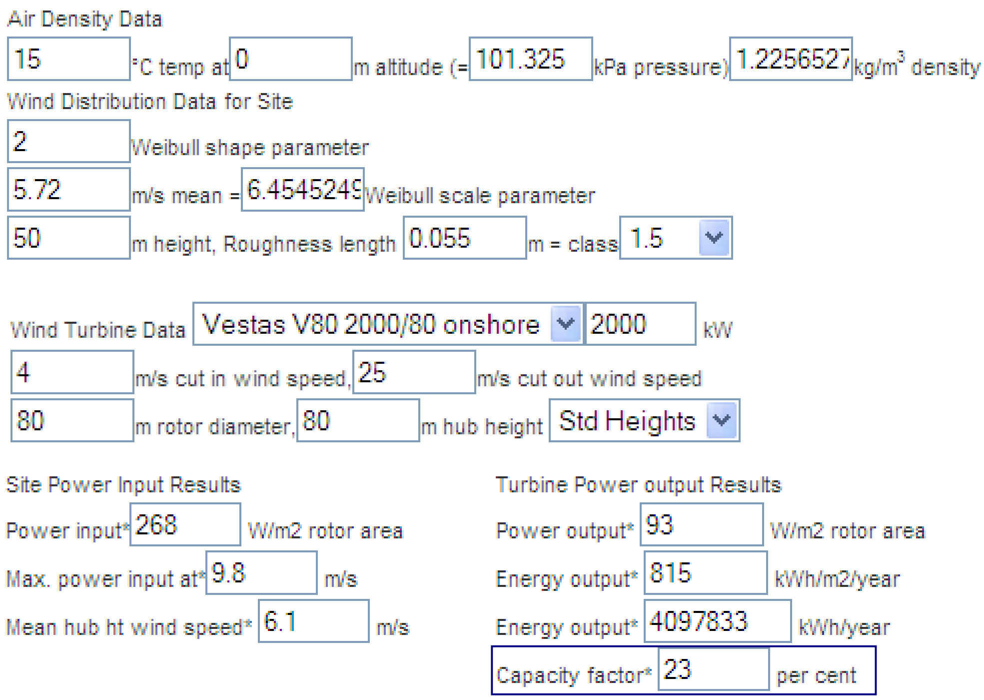


Figure 5.1.8: Calculation of capacity factor-Showcase wind farm II

Source: Danish Wind Industry Association, www.windpower.org, self calculated

With a capacity factor of 23 per cent and a yearly estimated energy output of 4097MW/h, wind bubble NWV offers good wind conditions for future developments.

5.1.4 Showcase wind farm III-Queensland

For analysis of capacity factor in showcase wind farm III, wind bubble code SWQ, located off the coastal area in Queensland, has been chosen.

Location of Wind Bubble SWQ:

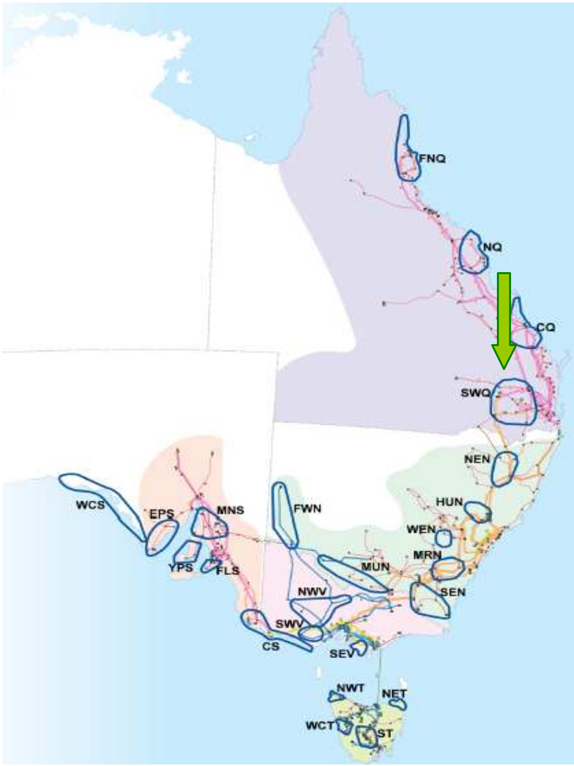


Figure 5.1.9: Location of Wind Bubble SWQ-Showcase III

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.90

Electricity Network Connection Points:

Following wind energy connection points within wind bubble SWQ will be developed within the next years.

Table 5.1.7: Electricity Network Connection Points-Wind Bubble SWQ

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.91

Code	Connection Point	(kV)	Code
SWQ	Tarong	275	SWQ 275

Wind Data:

Wind tracking point: Oakey Aero: 27.40 South / 151.74 East

Following wind data, provided by the Australian Bureau of Meteorology, shows recorded wind speed data from the past 31 years.

Table 5.1.8: Annual Wind Speed at Wind Bubble SWQ

Source: Australian Bureau of Meteorology, self calculated

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
wind speed km/h	18,5	17,5	17,0	16,3	16,1	17,1	17,1	17,7	17,9	17,6	17,6	17,4	17,3
													4,80m/s

Calculation of capacity factor:

With an annual mean wind speed of 4,80m/s, and under following assumptions, a capacity factor of 15 per cent can be calculated:

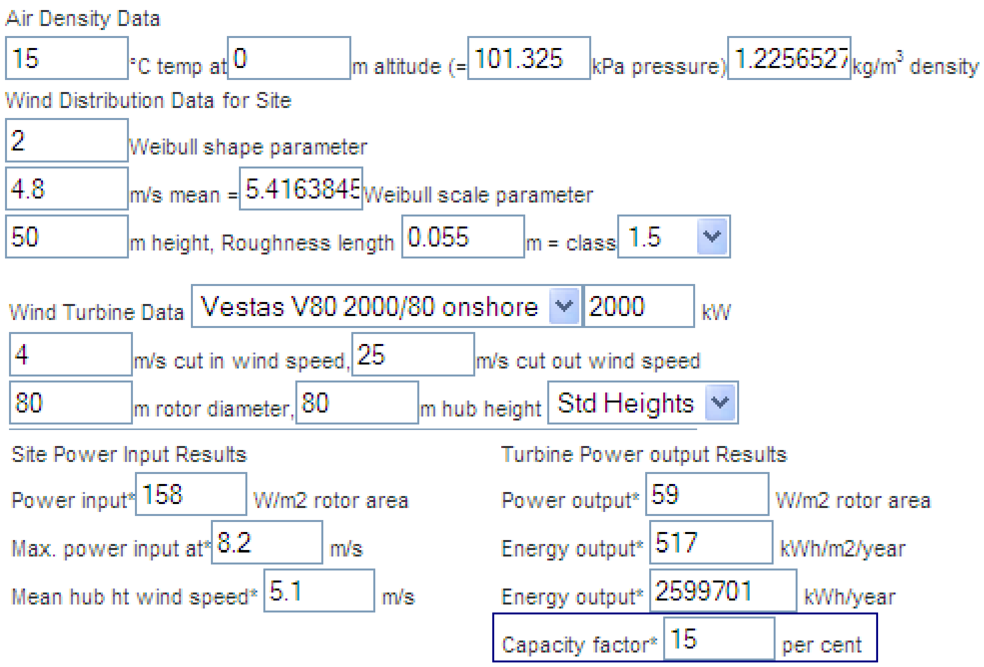


Figure 5.1.10: Calculation of capacity factor-Showcase wind farm III

Source: Danish Wind Industry Association, www.windpower.org, self calculated

With a capacity factor of 15 per cent and a yearly estimated energy output of 2599 MW/h, wind bubble NWV offers fair wind conditions for future developments.

5.1.5 Showcase Wind Farm IV-Western Australia

Due to the lack of accurate information concerning future developments within the Western Australian Electricity Network, for an analysis of the capacity factor a wind site near a proposed wind park has been chosen.

Location of Wind Measurement Point:

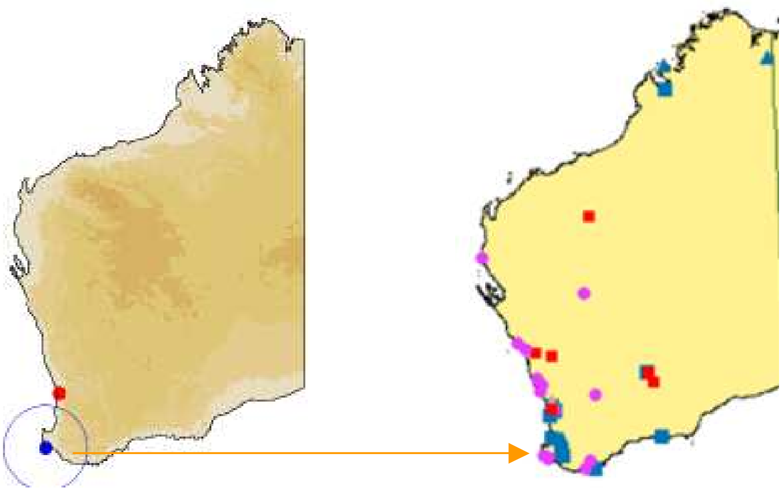


Figure 5.1.11: Cape Leeuvin Wind Tracking point vs. proposed wind park sites in Western Australia

Source: Australian Bureau of Meteorology / Australian Government: Department of the Environment, Water, Heritage and the Arts

Wind Data:

Wind tracking point: Cape Leeuwin: 34.37 South / 115.14 East

Following wind data, provided by the Australian Bureau of Meteorology, shows recorded wind speed data from the past 30 years.

Table 5.1.9: Annual Wind Speed at Cape Leeuwin wind site

Source: Australian Bureau of Meteorology, self calculated

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
wind speed km/h	31,4	32,4	30,3	27,1	29,0	32,3	33,5	32,5	31,7	30,7	30,9	30,1	31,0
													8,61m/s

Calculation of capacity factor:

With an annual mean wind speed of 8,61m/s, and under following assumptions, a capacity factor of 43 per cent can be calculated:

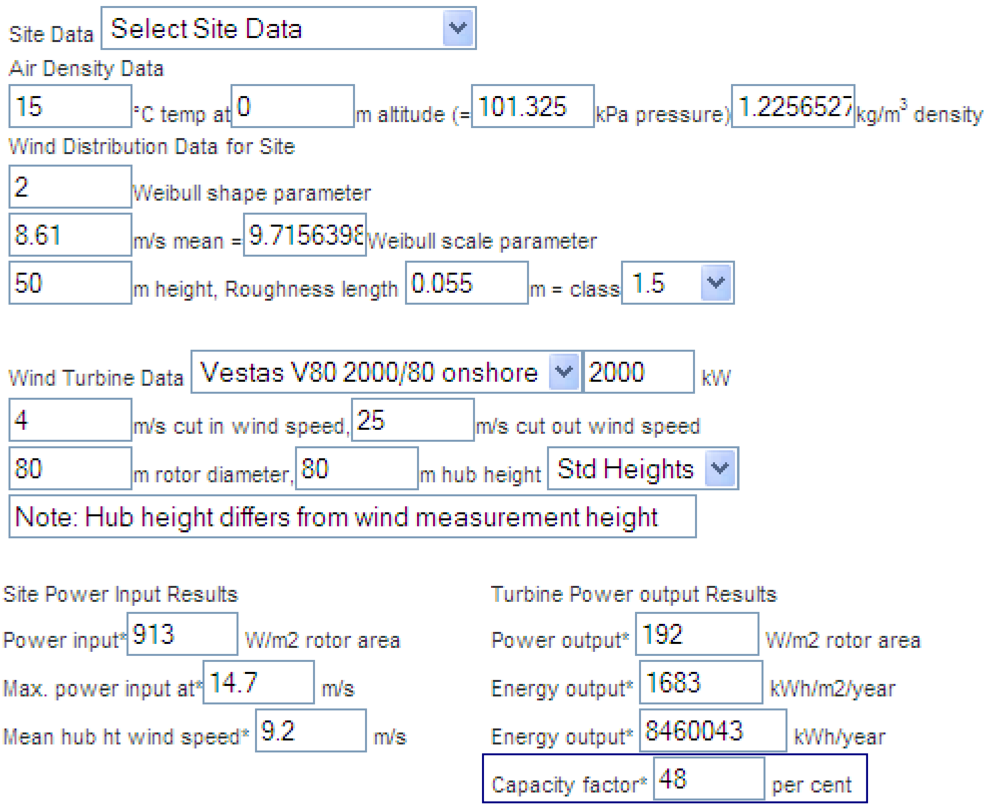


Figure 5.1.12: Calculation of capacity factor-Showcase wind farm IV

Source: Danish Wind Industry Association, www.windpower.org, self calculated

With a capacity factor of 48 per cent and a yearly estimated energy output of 8460 MW/h, wind bubble NWV offers excellent wind conditions for future developments in wind energy on this spot in Western Australia.

6 Conclusion

Following conclusion is linked to a couple of points as highlighted in this thesis. For getting a betten overview, these aspects are treated now in a seperate paragraph.
The aim of the present work was to analyse in detail how wind energy has developed in the past, to detect possible competitors and to find indicators for future growth.
To underline the importance of Australian electricity industry for its economy, it has to be pointed out that, as mentioned in chapter 2, Australian electricity market is one of its largest industry. Continuous growth rates in electricity demand with a current electricity generation five times higher than in the 1970ies, reflects the importance of electricity generation for this country. Nowadays, still 84 per cent of Australian electricity supply is generated by coal. Hence, Australian emission of Greenhouse Gas from fuel combustion per Unit of GDP is the second highest of the International Energy Agency member states. Australian richness in natural resources, its accessibility and the usage of coal now for decades are the main counterparty to wind energy when it comes to satisfy rising electricity demand.

On the one hand, Australia has a strong history by using fossil fuels for electricity generation. On the other hand, Australian Government shows its strong committment to combat climate warming by reducing its Greenhouse Gas emissions with national laws. This comittment is agreed in the concluded Mandatory Renewable Energy Target, which assigns that by 2020, 20 per cent of total electricity production will be generated by renewable energy sources. In section 2.6.4 a steady increase of the share of renewables for electricity generation can be noticed still now. Figure 2.7.1 in chapter 2.7 reflects Australian Renewable Energy Target Profile from the year 2009 up to the year 2030 and shows a steady increase in the usage of renewables for energy generation.
As illustrated in chapter 4, Australia offers excellent wind condition on the Eastern, Southern and Western coastline. With more than 500 installed Automatic Weather Stations, the Australian Bureau of Meteorology offers a wide range of climate data which includes also wind speed tracking. This data is public available and supports therefore companies by pre-selecting sites for proposed wind parks.
Continuous rise in wind energy projects, as mentioned in chapter 4.3 show that since the year 2000 a steady increase in new projects can be seen. A comparison of current operating wind farms and an analysis of future proposed wind farms, as it is mentioned in subchapter 4.3.1 and chapter 4.4 come to the following conclusion.

States, who had a strong commitment to wind energy in the past show a large number of wind parks which are in planning-status or will be realised within the next years. It can be recognised that the size of future wind farms exceeds current operating wind parks by a multiple.

For this reason, in chapter 5 it is investigated how the Australian National Electricity Market Management Company (NEMMCO) responds to this increasing need of electricity grid expansion and the following conclusion are of importance. Due to the rising number of wind farms, NEMMCO has done a screening of locations all over Australia to find out best sites for wind parks. In this site-analysis, wind speed of current wind farms and an analysis of areas with good wind conditions have been done to simulate future growth within these wind energy development zones, also called wind bubbles. As a result of this simulation, a comparison of the wind bubble-map to the Australian Wind Atlas is done in Figure 4.4.1. Areas with high wind speed and with closeness to an existing electricity grid will expand grid capacity. A full list of all proposed wind park connection points and the grid expansion is provided in the Annex of this document to show that Australian commitment to future development of wind energy is promising.

To get an insight into different preconditions within these wind bubbles, chapter 5.1 provides a screening of five wind parks which four of them are assumed to be built inside these areas. Last project, namely Silverton 1000MW Wind Park is also located in one of these zones. A comparison of these five locations by evaluating historical wind speed data and calculating their capacity factor brings the present work to the following final conclusion.
Due to different wind speed within these proposed wind bubbles, different capacity factors have been calculated. At the head of the analysis excellent capacity factors guarantee high electricity output and a high feasibility in realizing new wind farms within these zones. Hence it can therefore be assumed that areas of high wind speed within these zones will develop first than areas with a lower capacity factor.

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7 Annex

7.1 Proposed wind connection points in the National Electricity Market

Region	Code	Connection Point Summary	(kV)	Code
QLD	FNQ	Turkinje	132	FNQ 132
	FNQ	Woree	275	FNQ 275
	NQ	Bowen North	132	NQ 132
	NQ	Strathmore	275	NQ 275
	CQ	Gladstone	132	CQ 132
	CQ	Gladstone	275	CQ 275
	SWQ	Tarong	275	SWQ 275
NSW	FWN	Broken Hill	220	FWN BH 220
	FWN	Buronga	220	FWN BUR 220
	MUN	Jindera	330	MUN 330
	MUN	Deniliquin	132	MUN 132
	SEN	Cooma	132	SEN 132
	MRN	Marulan	132	MRN 132
	MRN	Bannaby	330	MRN 330
	WEN	Wallerawang	132	WEN 132
	WEN	Wallerawang	330	WEN 330
	HUN	Liddell	330	HUN 330
	NEN	Armidale	132	NEN 132
	NEN	Armidale	330	NEN 330
VIC	SEV	Foster	66	SEV FOS 66
	SEV	Leongatha	66	SEV LEO 66
	SEV	Wonthaggi	66	SEV WON 66
	SEV	Hazelwood - Cranbourne 500 kV line	500	SEV HZ-CRA 500
	SEV	Hazelwood - Rowville 500 kV line	500	SEV HZ-ROW 500
	SEV	Hazelwood - Rowville 220 kV line	220	SEV HZ-ROW 220
	SEV	Yalloum - Rowville 220 kV line	220	SEV YAL-ROW 220
	NWV	Ballarat	220	NWV BLR 220
	NWV	Bendigo	220	NWV BEN 220
	NWV	Ballarat - Bendigo 220 kV line	220	NWV BLR-BEN 220
	NWV	Ballarat - Horsham 220 kV line	220	NWV BLR-HOR 220
	NWV	Horsham	220	NWV HOR 220
	SWV	Terang	220	SWV TER 220
	SWV	Terang - Ballarat 220 kV line	220	SWV TER-BLR 220
	SWV	Terang - Moorabool 220 kV line	220	SWV TER-MBL 220
	SWV	Moorabool - Heywood 500 kV lines	500	SWV MBL-HY 500
	CS	Moorabool - Heywood 500 kV lines	500	CS MBL-HY 500
	CS	Heywood	275	CS HY 275
	CS	Heywood	500	CS HY 500
	CS	Heywood - APD 500 kV lines	500	CS HY-APD 500
	CS	APD	220	CS APD 220
	CS	APD	500	CS APD 500
SA	WCS	WC	11	WCS CULT 275
	EPS	Pt Lincoln	132	EPS PTL 132
	EPS	Yadnarie	132	EPS YAD 132
	YPS	PV	132	YPS PV ARDW 132
	YPS	Dalrymple	132	YPS DAL 132
	FLS	MY	66	FLS MY 66

	FLS	VH	66	FLS VH 66
	FLS	KI	33	FLS KI 33
	FLS	Cape Jervis	66	FLS CJ 66
	MNS	BRT	132	MNS BRT 132
	MNS	BGT	132	MNS BGT 132
	MNS	BRT	275	MNS BRT 275
	MNS	BGT	275	MNS BGT 275
	MNS	Robertstown	132	MNS ROB 132
	MNS	Robertstown	275	MNS ROB 275
	CS	Snuggery	132	CS SNUG 132
	CS	Snuggery	275	CS SNUG 275
	CS	South East	132	CS SE 132
	CS	South East	275	CS SE 275
TAS	NWT	Burnie	110	NWT 110
	NWT	Burnie	220	NWT 220
	NET	Hadspen	110	NET 110
	NET	Hadspen	220	NET 220
	WCT	Farrell	110	WCT 110
	WCT	Farrell	220	WCT 220
	ST	Chapel Street	110	ST CHA 110
	ST	Chapel Street	220	ST CHA 220
	ST	Liapootah	220	ST LIA 220
	ST	Waddamana	220	ST WAD 220
	ST	Waddamana	110	ST WAD 110

Figure 7.1.1: Proposed Wind connection points in the NEM

Source: National Electricity Market Management Company, 2009 NTS Consultation: Final report, 2009, p.91