Developing a GIS-Based Decision Support Tool For Evaluating Potential Wind Farm Sites

by

Xiao Mark Xu

A thesis submitted in
fulfilment of the requirements for the degree
of Master of Social Sciences at
The University of Waikato

2007

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Abstract

In recent years, the popularity of wind energy has grown. It is starting to play a large role in generating renewable, clean energy around the world. In New Zealand, there is increasing recognition and awareness of global warming and the pollution caused by burning fossil fuels, as well as the increased difficulty of obtaining oil from foreign sources, and the fluctuating price of non-renewable energy products. This makes wind energy a very attractive alternative to keep New Zealand clean and green.

There are many issues involved in wind farm development. These issues can be grouped into two categories - economic issues and environmental issues. Wind farm developers often use site selection process to minimise the impact of these issues. This thesis aims to develop GIS based models that provide effective decision support tool for evaluating, at a regional scale, potential wind farm locations. This thesis firstly identifies common issues involved in wind farm development. Then, by reviewing previous research on wind farm site selection, methods and models used by academic and corporate sector to solve issues are listed. Criteria for an effective decision support tool are also discussed. In this case, an effective decision support tool needs to be flexible, easy to implement and easy to use. More specifically, an effective decision support tool needs to provide users the ability to identify areas that are suitable for wind farm development based on different criteria. Having established the structure and criteria for a wind farm analysis model, a GIS based tool was implemented using AML code using a Boolean logic model approach. This method uses binary maps for the final analysis. There are a total of 3645 output maps produced based on different combination of criteria. These maps can be used to conduct sensitivity analysis. This research concludes that an effective GIS analysis tool can be developed for provide effective decision support for evaluating wind farm sites.

Keywords: Wind farm site selection, GIS, Boolean logic model, Binary classification, Multi-criteria decision support, sensitivity analysis.

Acknowledgements

I would like to thank all those people who made this thesis possible and an enjoyable experience for me.

First of all, I would like to thank University of Waikato and the Department of Geography, Tourism and Environmental Planning. In particular, my supervisors, Dr. Lars Brabyn and Dr. Lex Chalmers for their understanding, continuous support, unlimited trust, supervision and patience throughout the study. Their intervention on crucial points rendered the thesis a worthwhile work.

I wish to express my sincere gratitude to Frank Bailey, for his encouragement, and contributions for the improvement of the document.

I gratefully acknowledge my dear friends Joe Zhang and Tao Xu for their motivations and sympathy throughout the hard days.

I would especially express my thanks to my parents in-law who always support and motivate me.

I would like to express my deepest gratitude for the constant support, understanding and love that I received from my wife Ivy. Thank you for always being there for me throughout this exciting, sometimes stressful, long and gratifying journey. Your support and understanding have led to this becoming a reality.

Finally, I would like to express my special thanks to my parents who always support and motivate me and who truly merit the dedication of this thesis.

Table of Contents

Developing a
GIS-Based Decision Support Tool
For
Evaluating Potential Wind Farm Sites

by

Xiao Mark Xu

A thesis submitted in
fulfilment of the requirements for the degree
of Master of Social Sciences at
The University of Waikato

2007

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Abstract

In recent years, the popularity of wind energy has grown. It is starting to play a large role in generating renewable, clean energy around the world. In New Zealand, there is increasing recognition and awareness of global warming and the pollution caused by burning fossil fuels, as well as the increased difficulty of obtaining oil from foreign sources, and the fluctuating price of non-renewable energy products. This makes wind energy a very attractive alternative to keep New Zealand clean and green.

There are many issues involved in wind farm development. These issues can be grouped into two categories - economic issues and environmental issues. Wind farm developers often use site selection process to minimise the impact of these issues. This thesis aims to develop GIS based models that provide effective decision support tool for evaluating, at a regional scale, potential wind farm locations. This thesis firstly identifies common issues involved in wind farm development. Then, by reviewing previous research on wind farm site selection, methods and models used by academic and corporate sector to solve issues are listed. Criteria for an effective decision support tool are also discussed. In this case, an effective decision support tool needs to be flexible, easy to implement and easy to use. More specifically, an effective decision support tool needs to provide users the ability to identify areas that are suitable for wind farm development based on different criteria. Having established the structure and criteria for a wind farm analysis model, a GIS based tool was implemented using AML code using a Boolean logic model approach. This method uses binary maps for the final analysis. There are a total of 3645 output maps produced based on different combination of criteria. These maps can be used to conduct sensitivity analysis. This research concludes that an effective GIS analysis tool can be developed for provide effective decision support for evaluating wind farm sites.

Keywords: Wind farm site selection, GIS, Boolean logic model, Binary classification, Multi-criteria decision support, sensitivity analysis.

Acknowledgements

I would like to thank all those people who made this thesis possible and an enjoyable experience for me.

First of all, I would like to thank University of Waikato and the Department of Geography, Tourism and Environmental Planning. In particular, my supervisors, Dr. Lars Brabyn and Dr. Lex Chalmers for their understanding, continuous support, unlimited trust, supervision and patience throughout the study. Their intervention on crucial points rendered the thesis a worthwhile work.

I wish to express my sincere gratitude to Frank Bailey, for his encouragement, and contributions for the improvement of the document.

I gratefully acknowledge my dear friends Joe Zhang and Tao Xu for their motivations and sympathy throughout the hard days.

I would especially express my thanks to my parents in-law who always support and motivate me.

I would like to express my deepest gratitude for the constant support, understanding and love that I received from my wife Ivy. Thank you for always being there for me throughout this exciting, sometimes stressful, long and gratifying journey. Your support and understanding have led to this becoming a reality.

Finally, I would like to express my special thanks to my parents who always support and motivate me and who truly merit the dedication of this thesis.

Table of Contents

Chapter 1

Introduction

Area of interest of the study

This research focuses on GIS models and the development of an analytical methodology that can be used to evaluate site suitability for wind farms. Within a GIS framework, the research goal is to develop a multi-attribute trade-off analysis tool for assessing potential wind farm locations. The study uses established principles and methods, but makes an original contribution to both GIS methodologies and wind farm locational studies.

In the evaluation of potential wind farm locations, many factors could be considered. While the obvious importance of wind strength, direction and consistency need to be taken into account, and biological and environmental factors are important, social and economic also have to be considered. The project initially focused on physical factors and on the environment impacts. To make the research process more complete, however, social and economic impacts are also considered in this analysis.

The use of one set of criteria for identifying appropriate wind farm sites is problematic because the criteria will vary in different spatially contexts. Also planners/developers may be prepared to trade-off one criterion if there are significant benefits in other criteria. For example, developers may be prepared to spend considerable costs on road access to a site if the potential wind power at this site is particularly favourable. A GIS model therefore needs to be flexible so that planners/developers can explore the effects of different criterion on site selection and evaluate a number of different sets of criteria. This thesis argues for, and develops an exploratory site selection GIS tool. This is different to an optimisation tool that works with a single set of criteria or an additive weighting tool.

The tool developed in this thesis is intended for generalised site selection analysis that can be applied at a regional or national scale. The tool is also designed so that it can be easily used by a non GIS person.

The thesis will first look at what kinds of factors are involved in harnessing wind energy and how these factors are measured or given value in the models that are used to evaluate potential locations for wind farms. For example, is it necessary to include multiple variables that describe a site's wind environment? Are wind speed and an assessment of daily variability an adequate set of variables, or are direction and seasonable variability also important in the evaluation of sites? The study will conduct an analysis of international research on wind farm locations, and this survey of the literature and modelling practice will then be related to the research literature available in New Zealand. The importance of redundancy in data and the use of surrogate variables are issues of particular significance.

Significance of this research

Global warming, caused by burning fossil fuels, is one of the most challenging environmental problems facing the world’s population today. The results of global warming are expected to be disastrous (U.S. Environmental Protection Agency, 2007). The world needs to phase out the burning of fossil fuels such as oil, coal and gas and phase in renewable energy sources such as wind and solar generated power. These factors make the utilisation of wind energy the fastest growing energy source in the world. According to the Global Wind Energy Outlook (Greenpeace and Global Wind Energy Council, 2006), the global wind capacity grew from 4,800 megawatts in 1995 to over 59,000 megawatts by the end of 2005.

In New Zealand, there is increasing recognition and awareness of the pollution caused by burning fossil fuels, as well as the increased difficulty of obtaining oil from foreign sources, and the fluctuating price of non-renewable energy products (New Zealand Wind Energy Association, 2007). New Zealand has one of the most under-utilised wind resources for power generation in the world. The Review of New Zealand’s wind energy potential to 2015 (Energy Efficiency and Conservation Authority, 2001, p8) states that New Zealand can conservatively produce 3,070 MW using wind; currently we produce only 36 MW. Thus, wind energy is a very attractive alternative in New Zealand with reference to retention of a ‘clean and green’ image.

There are lots of issues involved with wind farm development and they can be grouped into two categories: environment issues and economic issues. There has been an ongoing effort internationally to solve these issues. Researchers in social and environmental science have developed models to predict the impacts of these issues and they use these models as assessment tools to analyze and evaluate wind farm projects before their construction. These models have different characteristics. Some of them focus on regional scale (e.g. a geographic analysis of wind turbine placement in Northern California (Rodman et al., 2005)). Some of them focus on national scale (e.g. wind farm analysis and site selection analysis for the Philippines (National Renewable Energy Laboratory, 2003). Some of them narrowly focus on one aspect of wind farm development (e.g. Spanish methods of visual impact evaluation in wind farms (Hurtado et al., 2003)), while some of them work with aspects of wind farm development (Short-cut design of wind farms (Kiranoudis et al., 2000)). Through good modelling and the adaptive construction and operating procedures, the environmental impact of wind farm can be minimised. Lessening the impact increases the chance of gaining resource consents and maximising the profitability of wind farms.

This research is informed by New Zealand’s *national* energy policy and the industry-based research carried out by wind harvesting energy producers. However, largely for data access, handling and interpretation purposes, the key analytical processes focus on the *regional* scale. The choice of the regional rather than national scale is to keep data collection and analysis at a manageable level. This research uses the Wanganui region to develop and test a GIS model. This region was chosen because it already has successful wind farm development and this can be used to calibrate and verify a model. This model could be applied to other regions with some modification to comply with varying trade-off formats to reflect the variability in regional plans.

Central argument and statement of research question

The specific question this research attempts to address may be formulated as: is it possible to devise GIS based models that will provide effective decision support frameworks for evaluating wind farm sites?

The research process of this thesis requires the evaluation of the environmental, economic and social issues involved in wind farm site selection and investigates the ability of GIS modelling to resolve selection issues. The following sub question assist in addressing the research goal:

- What can previous research on wind farm site selection tell us?
- What are the environmental, economic and social issues involved in wind farm location selection?
- How do these issues impact on wind farm location selection?
- How can GIS models help to solve the wind farm site selection issues?

This research will explore and investigate the potential of applying GIS based modelling to provide effective decision support for people to evaluate wind farm sites.

Thesis outline

Chapter two establishes the global importance of alternative energy sources such as wind farms in an era of increasing pressure on non-renewable energy resources. Current planning issues and the processes involved with wind farm site selection are also discussed. This part of the thesis provides the energy context and planning issues surrounding the development of the wind farms.

The theoretical issues surrounding data, models and methodologies are presented in chapter three. This review focuses on the purpose of GIS models, their processing approach and data. This chapter also explores the site selection criteria for wind farms and how these criteria are modelled. This includes an assessment of trade-off analysis and classification methods. This chapter will underpin the development of the modelling methodology used in this research.

Chapter four describes the model that was developed in this research. Questions around the choice of wind parameters and terrain criteria are addressed as well as other aspects of the model such as access to road and power lines, land use conflict and visibility.

The original contribution of this study is also found in chapter four. Here, I construct an application prototype that present a concrete example illustrating how the model works. The prototype includes two parts. The first part is a set of AML codes to produce maps that are useful for the planning and general community information. These maps show areas suitable for wind farm development for a given set of criteria. These maps are exported from the modelling process to jpeg image files using ArcPlot (Environmental System Research Institute). The second part of the prototype shows a GUI to perform the trade-off analysis function. The GUI prototype is produced using HTML with JavaScript. The final product is delivered in web page format and is included in the DVD attached at the back of this thesis. The cartographic outcomes of different modules are also discussed in this section. Existing wind turbine placements in the study area are used to verify this model.

The second to last chapter evaluates the wind farm site selection tool developed in this study. The main focus in this chapter is the comparison of static binary map methods used in this study with other methods such as dynamic ArcIMS approach and desktop approaches. The advantages and disadvantages of these different approaches are presented. The potential use of the site selection tool developed in this study is also discussed including the potential to scale at the national level. Lastly, this chapter compares this tool with an existing wind farm planning tool called WindPro.

The concluding chapter of this thesis summarises the main findings of this study, critically evaluates the limitations, and presents ideas for future research.

Chapter 2

The Context for Wind farm Modelling

In this chapter, the broad set of issues that underpin climate change and their relationship to sustainable energy provide a platform for a discussion of renewable energy resources, particular wind. The second section of the chapter looks at emergent interest in wind power generation before putting this discussion in a New Zealand context. The development of wind farms has local and regional impacts, and the literature assessing these impacts and their management is examined in the third section of this chapter. The seminal set of guidelines for establishing wind farm in New Zealand is reviewed in the concluding count of the chapter

Climate change and the emerging importance of wind farms

Global warming

The Earth's climate has changed many times during the Earth's history. Climate has been affected by factors such as volcanic eruptions, changes in the Earth's orbit and the amount of energy released from the Sun. Beginning late in the 18th century, human activities associated with the industrial revolution began to change the composition of the atmosphere and influenced the Earth's climate. Over the past 200 years, the burning of fossil fuels and deforestation has caused the concentration of heat-trapping "greenhouse gases" to increase significantly in the atmosphere. These gases prevent heat from escaping, thus increase earth's temperature (U.S. Environmental Protection Agency, 2007).

There are four main greenhouse gases involved. They are carbon dioxide, methane, nitrous oxide and fluorocarbons. Figure 2.1 shows the distribution of greenhouse gases in the Earth's atmosphere and carbon dioxide is clearly the majority with 76%.

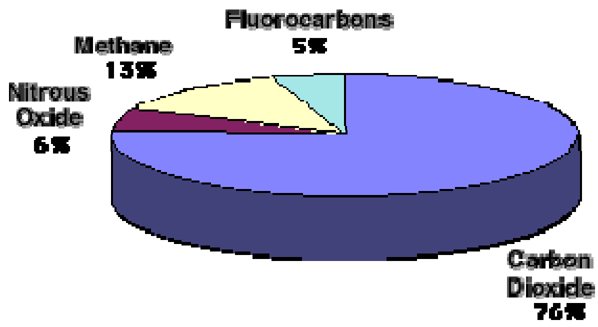


Figure 2.1: Greenhouse gases distribution in Earth's atmosphere

Source: **http://www.umich.edu/~gs265/society/greenhouse.htm**

There are three major ways that carbon dioxide is emitted into the air. They are human exhalation, burning of fossil fuels for energy, and deforestation of the planet (Hopwood and Cohen, 2006). The Figure 2.2 shows that the carbon dioxide concentration has been increased thirty percent since 1750.

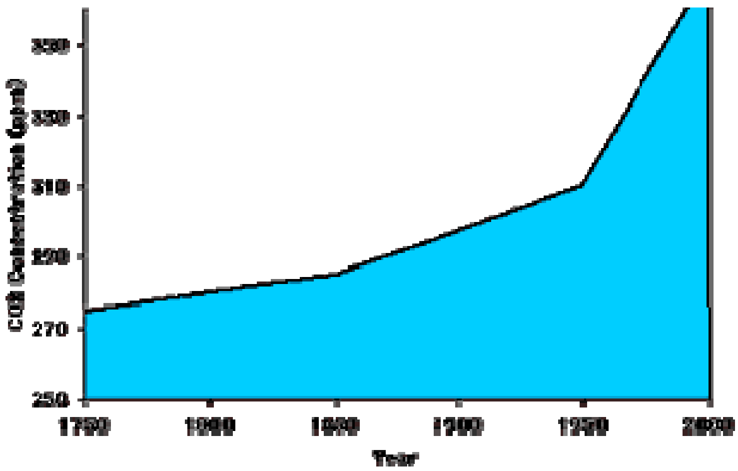


Figure 2.2: Increase of CO_2 since 1750

Source: http://www.umich.edu/~gs265/society/greenhouse.htm

The burning of fossil fuels is the largest contributor to the increase in CO_2; fossil fuels include coal, oil and natural gas. Our societies use these fuels in power plants to generate electricity, heat homes and run cars. Power plants and factories are the biggest contributor of CO_2, emitting 33% each, with cars and trucks contributing 22% and major transportation 12% (see Figure 2.3).

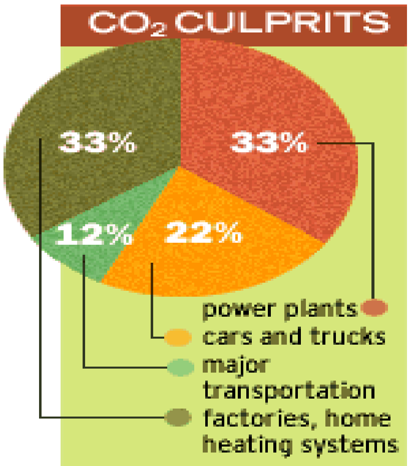


Figure 2.3: CO_2 culprits.

Source: http://www.umich.edu/~gs265/society/greenhouse.htm

The greenhouse gas inventory shows that New Zealand's emissions are increasing, with carbon dioxide emissions in 2004 about 37% higher than they were in 1990, as shown in Figure 2.4 (Ministry for the Environment, 2007).

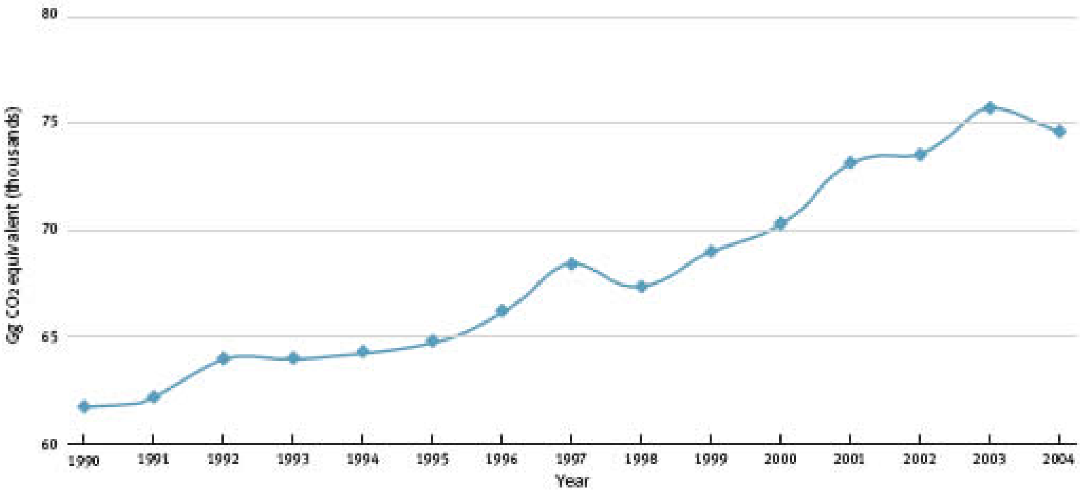


Fig 2.4: New Zealand Total CO_2 emission 1990-2004

Source: http://www.climatechange.govt.nz/resources/reports/nir-apr06/html/figures/figure-2-1-1.html

The energy sector produced 31,647.91 Gg CO_2 equivalents in 2004 and represented 42.4 percent of New Zealand's total greenhouse gas emissions. The sources contributing most to this increase are emissions from road transportation (increase of 62.7%) and public electricity and heat production (increase of 73.6%).

Global warming will have serious impacts on the environment and on our society (U.S. Environmental Protection Agency, 2007). The rise of the temperatures will not only cause the ice in Antarctica to melt and accelerate the rise of sea level, but they also may reduce water resources due to rainfall decreases. There changes will cause irreversible changes to ecosystems and threaten animals and plants, especially in the cold seas and polar areas. As average temperature increases, optimum habitat for many species will decrease dramatically, and this will force species to move higher up mountains or further towards the poles. If there is no higher ground or where changes are taking place too quickly for ecosystems and species to adjust, local losses or even global extinctions will occur (WWF, 2007). More pests and diseases may benefit from higher temperatures, indirectly affecting human health. There may be more heat-related illnesses in hotter summers and increased breathing problems as higher temperatures increase air pollution in cities, reducing air quality.

Kyoto Protocol and carbon tax

To address global warming and delay climate change, the Kyoto Protocol was introduced in 1997. The purpose of Kyoto Protocol is to reduce the total greenhouse gas emissions of developed countries (and countries with economies in transition) to 5 percent below the level they were in 1990 (United Nations, 1998). It sets targets for the greenhouse gas emissions of developed countries for the period 2008 to 2012. Different countries have different targets. For New Zealand, the target is to reduce greenhouse gas emissions to the level they were in 1990, or take responsibility for excess emissions. New Zealand Government will also introduce carbon tax scheme. The carbon charge will be payable from 2007 / 2008, at a level of no more than $25 per tonne of CO_2. As mentioned before, New Zealand’s emissions are increasing; with carbon dioxide emissions in 2003 about 37% higher than they were in 1990 and 42.4 percent of total greenhouse gas emissions were produced by the energy sector. The emission unit constrain and tax scheme may well encourage energy generators to invest in wind farm development. For instance, Genesis has proposed an approximately 19MW wind farm at Awhitu. They estimate that the wind farm could save 37,100 tonnes CO_2 per year. This could save them $927,500 in carbon tax, and this must be a clear incentive for investment in sustainable energy production to limit the impact of emissions from existing generating plant. Genesis has the ability to reduce the carbon tax on its coal fired operations by investing in wind power that receives a carbon credit.

Wind energy development

International wind energy development

Increased interest in wind energy sustained the dynamic growth worldwide in generator capacity in the year 2006 (World Wind Energy Association, 2006). By the end of December 2006, 14,900 MW were added. The currently installed wind power capacity generates more than 1 percent of the global electricity consumption (See Figure 2.5).

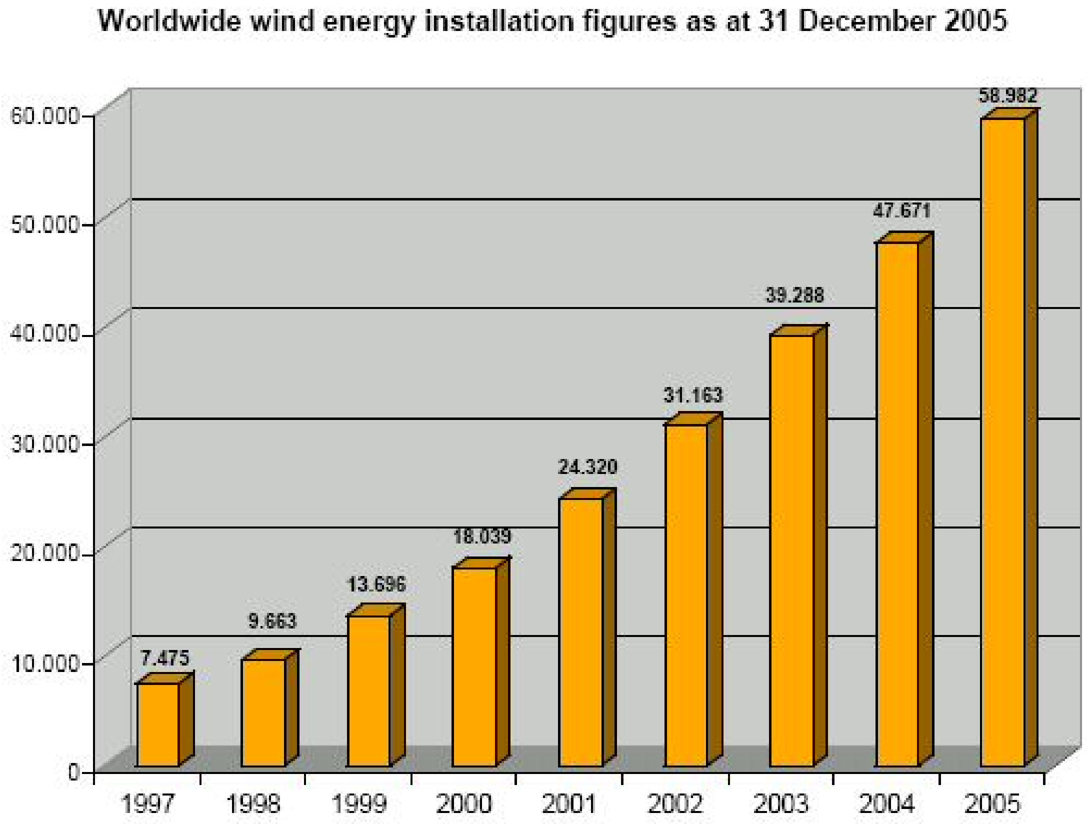


Figure 2.5: Worldwide wind energy installation figures

Source: http://www.wwindea.org/home/index.php?option=com_content&task=view&id=13&Itemid=2

Europe retains leadership in terms of overall capacity (40,932MW), and also has expressed interest in additional capacity. The European market showed a growth rate of 18% in 2005. More growth is expected as the EU countries have an increasing awareness of the contributions of wind power to energy security. America extended its capacity greatly in 2005 and represents 17% of global wind energy capacity. Asia became the most dynamic world region in the year 2005, with growth rate of 48%. The major drivers are India and China. China made a big step forward from position 10 in 2004 (764 MW) to number 8 in global ranking in 2005 (1260 MW). The major reason behind the excellent growth is the new renewable energy law adopted by Chinese government in early 2005. It increased the official target for the year 2020 from 20 GW to 30 GW (see Figure 2.6 and Table 2.1 and Table 2.2).

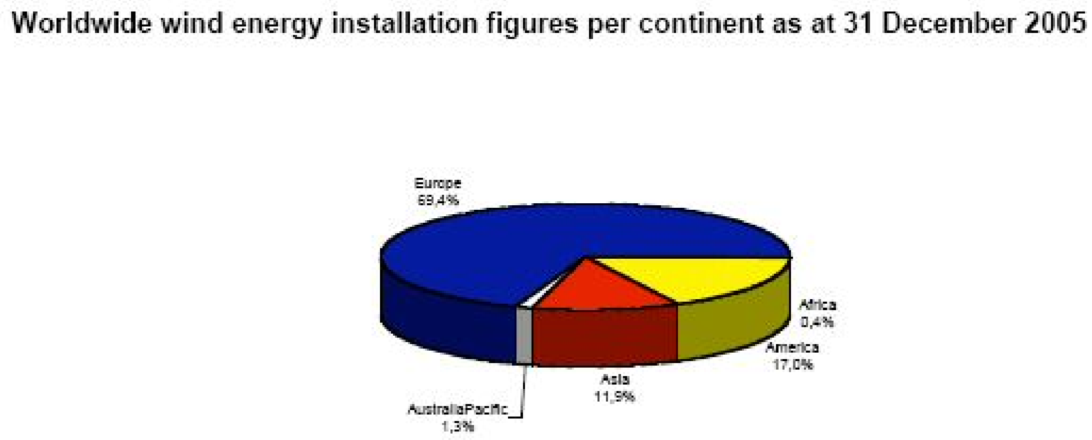


Figure 2.6: Worldwide wind energy installation per continent.

Source: http://www.wwindea.org/home/index.php?option=com_content&task=view&id=13&Itemid=2

	Installed Capacity 2005 (MW)	2005 in %	Installed Capacity 2004 (MW)	2004 in %
Europe	40.932	69,4	34.758	72,9
Africa	252	0,4	240	0,5
America	10.036	17,0	7.367	15,5
Asia	7.022	11,9	4.759	10,0
Australia-Pacific	740	1,3	547	1,1
World	**58.982**	**100,0**	**47.671**	**100,0**

Table 2.1: Worldwide wind energy growth

Source: http://www.wwindea.org/home/index.php?option=com_content&task=view&id=13&Itemid=2

Country/region	Additional capacity in 2005 (MW)	Rate of growth 2005 (%)	Total capacity installed end 2005 (MW)
Germany	1798,8	10,8	18.427,5
Spain	1764,0	21,3	10.027,0
USA	2424,0	36,0	9.149,0
India	1430,0	47,7	4.430,0
Denmark	4,0	0,1	3.128,0
Italy	452,4	35,8	1.717,4
United Kingdom	465,0	52,4	1.353,0
China	496,0	64,9	1.260,0
The Netherlands	141,0	13,1	1.219,0
Japan	143,8	16,0	1.040,0

Table 2.2: World wide wind energy top 10

Source: http://www.wwindea.org/home/index.php?option=com_content&task=view&id=13&Itemid=2

New Zealand wind energy development

As an island nation located in the Southwest Pacific, New Zealand is exposed predominantly to north-westerly winds travelling across the ocean, uninterrupted by other land forms. This geographical position results in consistent and relatively strong winds throughout much of the year (New Zealand Wind Energy Association, 2007).

There is strong public support for wind energy in New Zealand (EECA, 2004). In May, 2004, EECA appointed the UMR Research to conduct a nation-wide omnibus survey. This survey was a telephone survey of a nationally representative sample of 750 New Zealanders 18 years of age and over. The results showed that wind power recorded the highest approval ratings across the five electricity generation methods tested with 40.9% (Table 2.3). The results also showed that the main benefits of wind power were perceived to be that it was environmentally friendly (59%) and its installation and running costs are low (46%). Other advantages identified were that it is a renewable resource (25%) and a natural resource (22%) (Table 2.4). More than

35% of respondents were strongly in favour of having a wind farm built in their local area, 25% were moderately in favour, 18% were against the idea and 20% offered a neutral view (Table 2.5). The main concerns about wind power identified by respondents were that is an unreliable source of power (26%) and that the turbines are ugly and unsightly (25%) (Energy Efficiency and Conservation Authority, 2004, see Table 2.6).

MOST PREFERRED TYPE OF ELECTRICITY GENERATION *Which one of the following types of electricity generation would you MOST prefer to meet future electricity needs?*	
	May 2004 %
Wind power	40.9
Hydro electricity	40.7
Geothermal	5.0
Coal fire plants	3.9
Gas fired plants	3.3
Other	2.9
Unsure	3.3

Table 2.3: Most preferred type of generation

MAIN BENEFITS OF WIND POWER *What do you think are the main benefits of wind power?*	May 2004 %
ENVIRONMENTALLY FRIENDLY Environmentally friendly (44.9%), Won't damage the waterways /rivers /lakes (5.2%), Won't damage the land (5.1%), Clean (1.1%), Less pollution (0.9%), Saves water (0.7%), Decreasing noise pollution (0.5%), Won't damage land / displace people (0.4%), Could use areas that can't be used for farming (0.1%).	58.9
LOW COST Low cost (16.3%), Cheaper running costs (15.3%), Resource doesn't cost anything (8.7%), Cheaper installation and set up cost (4.9%), Efficient (0.5%).	45.7
RENEWABLE RESOURCE Renewable resource (24%), Constant supply (0.9%).	24.9
NATURAL RESOURCE Natural resource (21.9%).	21.9
WELL SUITED TO NEW ZEALAND Well suited to the environment and climate (0.7%)	0.7
GOOD BACKUP SYSTEM	0.3
EMPLOYMENT OPPORTUNITIES Could provide a tourist attraction (0.1%), Employment opportunities (0.1%).	0.2
DON'T INFRINGE ON PEOPLES CULTURAL RIGHTS	0
NOT DANGEROUS	0.1
WORKED WELL OVERSEAS	0.1
PREFERABLE TO NUCLEAR POWER	0.1
WON'T TAKE UP TOO MUCH ROOM	0.1
THEY LOOK NICE	0.1
NO BENEFITS	0.7

NB: This is a multiple response question and hence percentages do not add to 100%.

Table 2.4: Main benefit.

SUPPORT FOR A WIND FARM IN LOCAL AREA *Using a 1 to 5 scale where 1 means you are strongly in favour and 5 means you are strongly against – how would you feel about a wind farm being built in your local area?*	May 04 %
1, Strongly in favour	35
2	25
TOTAL 1 + 2	**60**
3	**20**
4	6
5, Strongly against	12
TOTAL 4 + 5	**18**
Unsure	2

Table 2.5: Support for a wind farm in local area

MAIN DISADVANTAGES OF WIND POWER *What do you think are the main disadvantages of wind power?*	May 2004 %
UNRELIABLE Not reliable / unpredictable (22.8%), Can't guarantee source (1.9%), Isn't enough wind (0.7%), Strong winds may damage the turbines (0.1%).	25.5
UGLY / UNSIGHTLY	24.8
NOISE POLLUTION Noisy / noise pollution	14.7
HIGH COST Cost involved in set up / establishment (14.4%), Too much money will be put into it (0.1%), High maintenance costs (0.1%).	14.6
INEFFICIENT Inefficient / don't generate enough electricity	10.7
REQUIRE TOO MUCH SPACE	7.3
LOCATION Finding appropriate sites (5.2%), Not accessible to everyone (0.1%).	5.3
DISADVANTAGES TO WILDLIFE May be harmful to birds / wildlife (0.7%).	0.7
TECHNOLOGY HASN'T ADVANCED ENOUGH	0.4
WON'T CREATE JOBS	0.3
THEY WON'T BE PROFITABLE ENOUGH	0.1
WE DON'T KNOW ENOUGH ABOUT THEM	0.1
NO DISADVANTAGES	4
NB: This is a multiple response question and hence percentages do not add to 100%.	

Table 2.6: Main disadvantages.

In 2007 there are six operating wind farms in New Zealand with total capacity of 168 MW. According to the report written by EECA, wind energy currently provides approximately 150 gigawatt hours per year of electricity, or under 0.5 percent of New Zealand's electricity generated. If economic and resource consent conditions were favourable, it is estimated that wind resources could provide approximately 23% or 7,900 gigawatt hours per year of the country's present electricity needs at costs of up to 10 c/kWh within 10-15 years (Energy Efficiency and Conservation Authority, 2001). The EECA report also identified thirteen general areas for land based wind farm development throughout New Zealand, on the basis of available wind and distance to load centres. They are: Far North, West Coast Auckland, Coromandel/Kaimai Ranges, Cape Egmont/Taranaki Coast, North Island East Coast Hills and Coast, Manawatu Gorge, Wairarapa Hills and Coast, Marlborough Sounds Hills, Wellington Hills and Coast, Banks Peninsula, Canterbury River Gorges, Inland

Otago, and Foveaux Strait and SE Hills (See Figure 2.7 and Table 2.7 for more details).

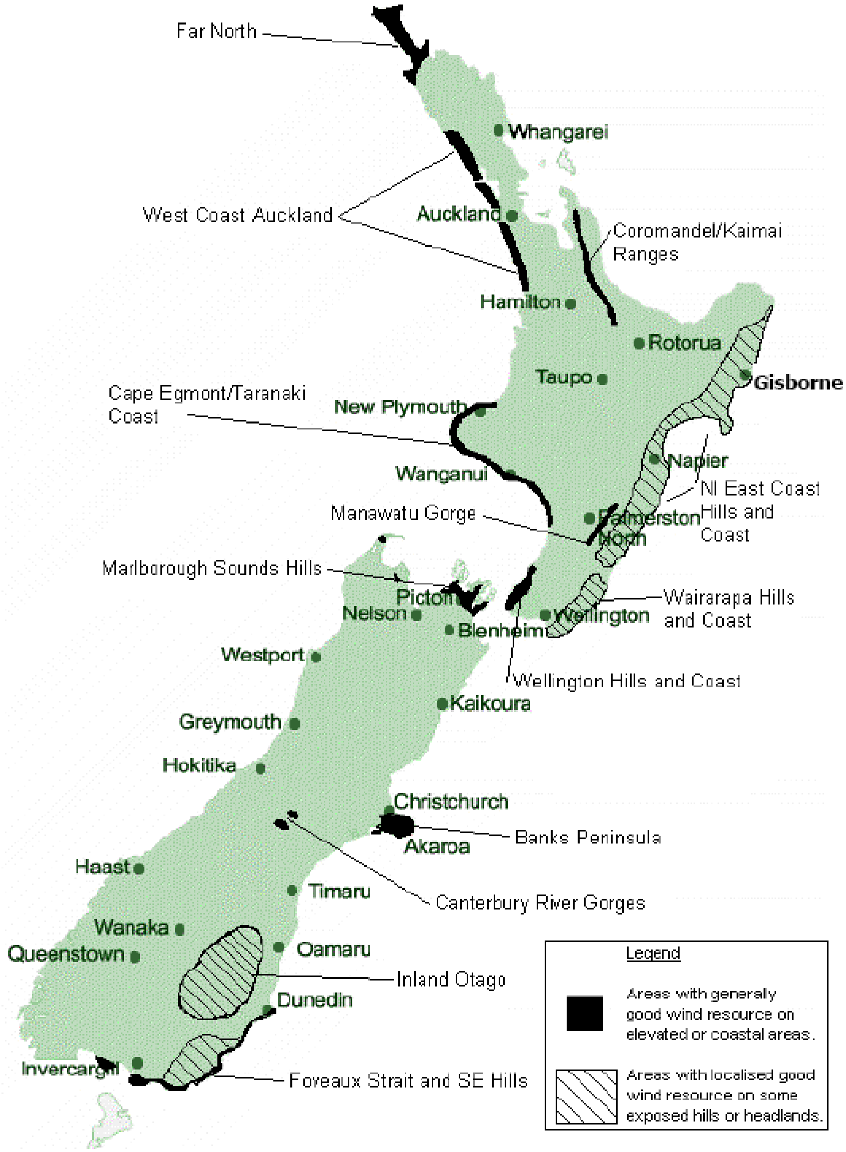


Figure 2.7: Suitable locations for wind farm.

Source: EECA

Region	Estimate Resource (typical wind speed in m/s at 50 mAGL)	Base Case Area (km^2)	Base Case MW	Base Case GWh/y
1. Far North	8	35	350	1,070
2. West Coast Auckland	8	8	80	250
3. Coromandel/Kaimai Ranges	9	4	40	140
4. Cape Egmont/Taranaki Cost	7	30	300	710
5. Manawatu Gorge	10	10	100	410
6. NI East Coast Hills and Coast	8	30	300	920
7. Wellington Hills and Coast	10	25	250	1,030
8. Wairarapa Hills and Coast	9	30	300	1,080
9. Marlborough Sounds Hills	8	8	80	250
10. Banks Peninsula	8	10	100	310
11. Canterbury River Gorges	7	12	120	280
12. Inland Otago	7	30	300	710
13. Foveaux Strait and SE Hills	9	35	350	1,260
14. Distributed	7	40	400	950
Total		**307**	**3,070**	9,370

Table 2.7: Wind resource information for potential regions

Issues involved with wind power development

Issues involved with wind development are almost universal. These matters have impacts on three main sets of conditions, environmental impacts, social impacts and economic impacts. The European Best Practice Guidelines for wind farm development listed the following assessments that a developer should consider during the wind farm development (European Wind Energy Association, 2004):

- Visual and landscape assessment
- Noise assessment
- Ecology assessment
- Archaeological and historical assessment
- Hydrological assessment
- Interference with telecommunications systems
- Aircraft safety
- Safety assessment (structural integrity, transportation safety)
- Traffic management and construction
- Electrical connection (impacts of new infrastructure such as overhead lines and substations)

- Effects on the local economy
- Global environmental effects
- Tourism and recreational effects
- Decommissioning

The Western Australian Planning Commission grouped issues into three categories, technical issues, planning issues and environmental issues. The guidelines for wind farm development created by Western Australian Planning commission listed following issues that may involved in wind farm development (Western Australian Planning Commission, 2004):

- Land use.
- Public health and Aircraft safety.
- Socio-economic benefits.
- Landscape and Visual impact.
- Noise.
- Other possible amenity effects.
- Vegetation and fauna

While in Ireland, the Department of the Environment, Heritage and Local Government listed following issues in their wind farm planning guidelines (the Department of the Environment, Heritage and Local Government, 2007):

- Natural heritage.
- Ground conditions.
- Archaeology.
- Noise.
- Safety aspects.
- Proximity to roads and railways.
- Proximity to power lines.
- Interference with communications systems.
- Aircraft safety.
- Wind prospecting.
- Decommissioning and reinstatement.

In New Zealand context, the report written by Mark Ashby (Ashby, 2004) listed eleven wind farm development issues. They are: visual impact, noise, birds, infrastructure, property values, public attitudes, CO_2 release, offshore development, tourism, wind prospecting and life of consent.

Visual impact

Due to the size of the wind turbines, visual impact becomes the most difficult issue to deal with of all the issues associated with wind farm development. Often the public attitudes towards the wind turbines are divided. People tend to find them either interesting or ugly.

Maori cultural heritage also could become another potential issue. It is common for iwi identity to be expressed in the relationship to specific geographic features. If a wind farm visually intrudes on the views of an ancestral mountain, this might be considered to be an adverse effect.

Noise

According to the white paper prepared by the Renewable Energy Research Laboratory, wind farms could produce two types of noise, mechanical noise and aerodynamic noise (Rogers et al., 2006). The mechanical noise is from the motion of mechanical components, and aerodynamic noise is from the flow of air around the blades. To protect nearby residents, wind farm proposals must comply with a national New Zealand Standard which states that sound levels “measured at the boundary of any residential site must not exceed the greater of 40 decibels or background noise plus 5 decibels” (New Zealand Standard NZS 6808, 1998).

Birds

Wind turbines present a collision risk to birds and have adverse effects on bird-life, but the effect is minimal compared with other man-made structures such as communications towers (New Zealand Wind Energy, 2007). There are also some adverse effects during the wind farm construction and operation. The construction process may damage bird habitats and the motion of the turbine blades may drive birds that are sensitive to the motion away from their habitats.

Infrastructure

During wind farm development, there are two main infrastructure issues involved. The first one is roading. Road access needs to be suited to the transport of large pieces of equipment to the site. Normally, a minimum 6-10 metre wide access way is needed to allow safe passage of large cranes and transporters carrying turbine blades and towers. The gradients and radius of corners also need to be considered as some of the equipment has significant length. The impact of road access is different depending on the wind farm location. For example, compare the Canterbury Plains with the North Island hill country, the North Island hill country requires significant earthworks and upgrading local roads leading to a site to allow passage of large loads.

The second issue is the electricity transmission. After the wind farm has been built, it needs to be connected to existing electrical networks. This requires upgrading existing lines or building new ones. A wind farm needs either an on-site substation before connection to a line, or a line connecting it to an existing substation. Normally, a megawatt (MW) size of wind farm needs to be less than the kilovolt (kV) level of the electricity line that transports its power. The transitional provisions of Resource Management Act made lines up to 110kV a permitted activity. This may become a problem for rural areas with low capacity lines. In those areas, there may be a mismatch between line size and the desire of developers to build large-scale wind farms. The local grid system may not match the area’s wind energy potential, and new high voltage electricity lines face difficulty gaining consent.

Property Values

In 2003, a USA Government funded agency conducted an extensive and scientific property value effects study. The study found that in 26 out of 30 analyses, property values near the wind farm performed better than in the comparable communities without a wind farm. In New Zealand, there is no evidence of property values been devalued by the Tararua or Hau Nui wind farms, or by the Brooklyn wind turbine. In fact, a significant subdivision of high value housing has been built in close proximity (as close as 700m) to the Brooklyn turbine since it was constructed.

Public Attitudes

Public attitudes to wind energy are complex and dynamic, but it is very important that there be fully canvassed during the consultation process for the wind farm development. As mentioned before, the survey carried out by EECA showed that wind power was the preferred means of generation. However, public attitudes vary from region to region. For example, the Te Apiti wind farm application received 20 submissions with 11 of those being in support. Consent was granted without any appeals being lodged. In contrast, the Awhitu wind farm near Waiuku received about 260 submissions, with 21 supporting and the rest opposed. The consent authority also received a petition of 750 signatures in opposition. Public attitudes can never be taken for granted.

Wind Prospecting

The energy production of a wind farm is heavily dependent on wind speed. Therefore, an accurate estimate of long-term mean wind speed at a site is essential. To make sure that a site has a good wind resource, wind farm developers have to make an initial assessment. The assessment will be based on the topography and broad-scale wind data. Currently in New Zealand, the best wind data uses a 10 Kilometre grid, and this coarse spatial resolution is one of the main drivers for a refined on-site measurement programme. On-site measurement normally takes 1 to 3 years, and uses one or more anemometer towers. In some district plans in New Zealand, specific activity of building an anemometer tower is not clearly addressed, thus, lead to uncertainty, additional coasts and delays in obtaining site specific data.

Any of the above issues may constrain the design of the wind farm or even stop a development altogether. Thus, it is necessary for developers to consider those issues at early stage. The site selection process is widely used to make sure that there is a sufficient resource to make the project viable, at the same time, minimise the adverse effects of the issues. The National Renewable Energy Laboratory used site selection analysis to rank and prioritize potential wind energy sites in Philippines (National Renewable Energy Laboratory, 2001). In New Zealand, any wind farm development needs to get a land use consent.

The consent authorities are generally regional and territorial local authorities. They require the developer to conduct an extensive range of environmental assessments and to provide an environmental management plan before the consent can be granted. By using the site selection process, developers could avoid those “dangers” area and foresee the potential adverse effects of the wind farm development. Therefore, enables them to create a detailed development plan and solution to avoid, minimise or mitigate the adverse effect. This will make the resource consent much easier to get.

This chapter has introduced the issues that have driven the interest in wind farms. Discussions about sustainable energy have indicated wind farms as a good option, although the management issues sometimes lead to implementation debate. The discussion provides a platform for an exploration of modelling round wind farm development, particular site selection.

Chapter 3

Theoretical Considerations Relating to Wind Farm Site Selection

This part of thesis focuses on theoretical considerations revealed in literature on wind farm site selection. It is broken down into two parts. The first part reviews the broad field of research and commentary on criteria used in wind farm site selection processes and the data used for site selection models. This review includes work published in the corporate and academic press. The second part of the chapter is more specific; it discusses some of the algorithms and processes developed by researchers to handle site data, focusing on modelling processes used in data analysis and the structure of different models.

The research and commentaries reviewed draw heavily on quantitative data about the real world, and embed these discussions in various forms of spatial analysis. Geography has an historic and substantial involvement in the evaluation of sites for a wide range of activities (Abler et al., 1972, Berry et al., 1968, Taylor 1977 and Smith 1971) and the review points to a number of contemporary works that reference and use geographical commentaries in their work. Spatial analysis, be it in physical geography, economic geography or environmental geography remains a strong field of interest in applied science and this chapter locates the thesis in this research field. The chapter identifies New Zealand contribution to wind farm site selection, but notes the limited amount of reported work as a justification for this project. The chapter also provides the platform for the development of the particular New Zealand research methodology developed in the following chapter. The methodology will focus on the physical, economic and social conditions that influence site selection in this country.

Literature review of past work on wind farm site selection

There are many issues involved with industrial wind farm development but they can be grouped into two broad categories: economic issues and environment issues. As noted above, it is clear that virtually all of the major contributions in science and in social science are written from a scientific standpoint, and the implicit theoretic approaches are those of positivism and the scientific method. As Johnston et al (2004, 606-608, 727-729) note, despite the rise of 'new' geographies, the methods of science and positivistic theoretical approaches continue to be widely practiced in contemporary geography. The scientific modelling of wind farm site selection process that draws on environmental and economic data are modelled in the corporate sector and universities around the world.

Economic issues

The economic issues associated with wind farm site selection have been addressed in terms of maximizing economic benefit derived from a range of potential sites (for example, Kiranoudis et al., 2000). This makes the wind speed a priority during the site selection process. A good wind speed can generate more power; thus making the wind farm more profitable. For the wind resource, researchers often used wind speed or wind power density when ranking or prioritizing potential wind farm sites (Rodman et al., 2006, National Renewable Energy Laboratory, 2001). An economic scoring mechanism is commonly used; different wind farm sites are given a different score based on their wind speed and ranking for the economic potential of the sites.

In the analysis of potential wind farm site selections in the Philippines and Sri Lanka an NREL wind atlas (National Renewable Energy Laboratory, 2003), and local meteorological data were used to rank and eliminate areas that did not have a good economic wind power density. In these cases, wind power density less than 300 W/m^2 at 30m height for the Philippines and less than 400 W/m^2 at 50m height for Sri Lanka were used in the economic assessment. The potential sites were assigned a value from 1 to 5 depending on their economic wind resource. In this assessment process, scores for different sites can be compared and sites that receive high scores can be picked as more favourable locations for wind farm development.

Other than the wind speed, obstacles and terrain characteristics may also influence the economic efficiency of wind power generation. Tall obstacles such as buildings and trees can block or obstruct the wind flow (Rodman et al., 2006). In New Zealand there are no plans to build a wind farm in the middle of urban areas, so the forest and land covers are the major focus in local assessments (Ashby 2004).

Terrain characteristics are also theorised to have some influence on the economics of wind flow, too. Normally, ridge crests or other high ground are preferred for wind turbine placement but flat valleys may also be suitable if they act as a wind channel. In the geographic analysis of wind turbine placement in Northern California (Rodman et al., 2006), the wind resource in relation to obstacles and terrain characteristic was used in a physical suitability model to determine the economic site suitability of sites for wind farms. In Rodman's research, the obstacle used was the forest density. The densities were determined from the primary and secondary vegetation types at the potential wind farm site.

The terrain characteristic criterion used in Rodman's research was based on either its close proximity to a ridge or placement on a relatively flat valley. The slopes assessment used for the valleys was based on the majority of slopes over a 150m × 150m area. Again, a score system was developed to give each site a score, with range from 0 (unsuitable economic potential) to 4 (excellent economic potential). The assessment is summarised in Table 3.1.

Score	Wind speed (large turbine) m/s	Wind speed (small turbine, grid-connected) m/s	Wind speed (small turbine, off-grid) m/s	Obstacles	Valley	Distance to ridge (m)
Excellent (4)	>7	>4.5	>3	No forest	0-7°	<10
Good (3)				Low density	7-16°	10-30
Fair (2)				Medium density	16-30°	30-50
Poor (1)					30-40°	50-100
Unsuitablie	<7	<4.5	<3	High density	>40°	>100

Table 3.1: Physical suitability model scores for wind speed, obstacles and terrain. Source: The Geographic Analysis of Wind Turbine Placement in Northern California (Rodman et al., 2006).

Environmental issue

The impact of wind farms on surrounding environment and population has a direct influence on the resource consent application, and these issues are often important in the evaluation of potential sites (New Zealand Wind Energy Association, 2007). Potential wind farm sites that attract heavy opposition and have a huge environmental impact will become harder or sometimes impossible for developers to gain resource consent for the development of a site that may be economically viable (Ashby, 2004). Thus, during the wind farm planning process, developers of potential site models need to foresee the environmental and human impact factors and avoid or mitigate them. By predicting these effects in their models, analysts can avoid sites where there may be heavy opposition due to environmental and human impact concerns, thus reducing the public opposition to the wind farms. The environmental and human impact factors include: visual impact, land use conflict, damage to vegetation and the impact on sensitive environmental areas. These impacts are summarised in the paragraphs below.

Visual impact

Visual impact is the most difficult one to deal with. Often the public attitude towards the wind turbines is divided. People tend to find them either interesting or ugly. To predict and quantify the visual impact of a wind farm on neighbouring population, a method called visual impact evaluation matrix (VIEM) was developed (Hurtado et al., 2003). There are four main criteria associated with visual impact evaluation matrix. They are: visibility of wind turbines from near by town, visibility of wind farm from different viewing position, distance between wind farm and town and town population. In Hurtado's definitive paper, each of these criteria can be represented by a coefficient that shows their level of impact. Hurtado's abstractions or theoretical models have been widely adopted in site selection analysis.

To find out the visibility of wind turbines from a proximal town (**a**), a town is split into several areas, and assessed using the following expression:

$$a = \frac{\sum_{i=1}^{n} X_i / WM}{n}$$

Where **n** is the number of areas inside the town with different views of the wind farm, **Xi** is the number of wind turbines visible from area **i**, and **WM** is the total number of wind turbines in the wind farm.

To find out the visibility of a wind farm from different viewing positions, two coefficients have been theorised. The first one is the viewing position coefficient **v**. Wind farms are considered be visualized inside cuboids of regular shape. This enables the model to allow for the wind farm being seen from the front, diagonally or longitudinally. The wind farm has different impact level on surrounding town, depending on the viewing position, thus, coefficient **v** can be determined based on the viewing position (Hurtado et al., 2003). The model is summarised in Figure 3.1 and Table 3.2. The **v** coefficient is between 1.00 and 0.00 where 1.00 has maximum impact.

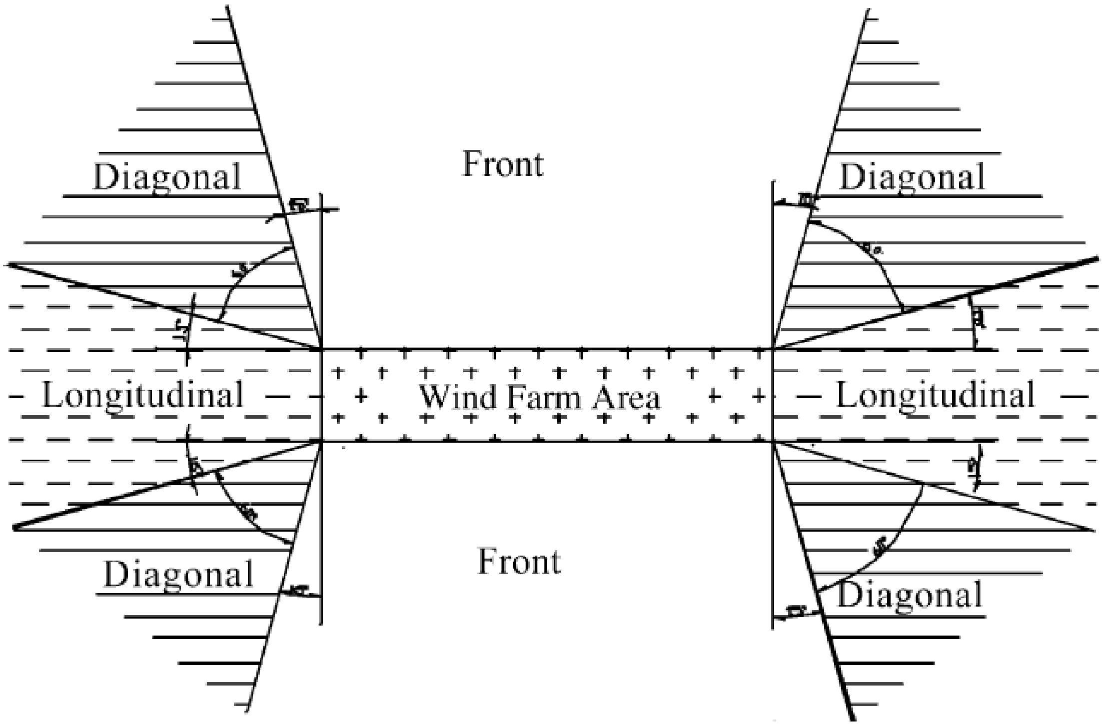


Figure 3.1: Viewing position

Viewing position	V coefficient
Frontal	1.00
Diagonal	0.5
Longitudinal	0.2

Table 3.2: V coefficient from different viewing position

The second coefficient used to determine the visibility of a wind farm from a different viewing position is the number of wind turbines belonging to the wind farm. This is because analysing three turbines is not the same as analysing 25. Thus, a quantity coefficient **n** is added (see Table 3.3).

Number of wind turbines	n coefficient
1 - 3	0.5
4 - 10	0.9
11 - 20	1.00
21 - 30	1.05
>30	1.1

Table 3.3: Quantity Coefficient

Once these two coefficients have been determined, the impact of visibility of a wind farm from different viewing position can be calculated by using the expression:

c=**v**×**n** (Hurtado et al., 2003 489)

For distance between wind farm and town coefficient (**d**), it takes into account the distance between the wind farm and the town. The distance to each town or its proximity to the wind farm is directly proportional to *alteration* in the landscape. For distance within 500 m, the coefficient will be maximum (1.00), and for distance between 500 m and 6000 m, the expression 1.05-0.0002×**X** was used (**X** is the distance between wind farm and town). For distances greater than 6000 m, and while the wind farm is still visible, the associated impact will be minimal; the wind farm could be considered as part of the background landscape (see Table 3.4).

X distance	d Coefficient
X<500m	1.00
500 < X < 6000m	1.05-0.0002×X
6000m < X (if wind farm visible)	0.10

Table 3.4: Distance Coefficient

The town population coefficient (**e**) is the last coefficient. Visual impact increases when the number of people increases. In highly populated areas, this coefficient will be at the maximum and in low population areas it will be minimized (see Table 3.5).

Population	**e coefficient**
>300	1.00
100-300	0.9
50-100	0.6
20-50	0.45
5-20	0.35
1-5	0.02
0	0.00

Table 3.5: Population Coefficient

After obtaining these coefficients, a total could be calculated by using the expression:

T = a×c×d×e

The total (T) is a number between 1.00 and 0.00. It represents the visual impact level on a surrounding town (See Table 3.6).

Total	Impact level
0.00-0.10	Minimum
0.10-0.30	Light
0.30-0.50	Medium
0.50-0.70	Serious
0.70-0.90	Very serious
09.0-1.00	Maximum

Table 3.6: Impact level.

Other environmental impacts

Other than the visual impact, wind farm site assessment also has to evaluate the impact on other aspects of environment. Those aspects include land use, vegetation, wild life, and environmentally sensitive areas. To predict those impacts, wind site selection analysts usually use a weight and score system. Different criteria can be added into the score system, and different weights can be assigned to those criteria based on their importance. The geographic analysis of wind turbine placement in Northern California (Rodman et al, 2005) is a good example. In that research, five criteria were taken into consideration. They are: vegetation/land use (weight = 3), presence of endangered plant species (weight = 2), presence of wetlands (weight = 1), presence of populated area (weight = 1), and presence of recreational parkland (weight = 1). Those criteria were scored and weighted by an expert (See Table 3.7).

Score	**Vegetation/land use (w=3)**	**Endangered plant species (w=2)**	**Wetlands (w=1)**	**Urban areas (w=1)**	**Recreation areas (w=1)**
Excellent (4)	Farmland barren	No endangered species	Not wetlands	Not urban	No public parkland
Good (3)					
Fair (2)	Grass				
Poor (1)	Shrubs/chaparral				
Unsuitable (0)	Forest wetlands	Endangered species	Wetlands present	Urban	Public parkland

Table 3.7: Environmental suitability score system.

The wind farm and site selection analysis for the Philippines and Sri Lanka (National Renewable Energy Laboratory, 2003) developed a theoretical model using a similar approach to predict the environmental effects of wind farms. They devised the scoring system as a tool to rank and prioritize potential wind farm sites at a national level. The environmental issues were put into a preliminary spreadsheet and a score was assigned to them (see Table 3.8 and Table 3.9). The cumulative scores for different sites were compared. Sites that received high scores were theorised to have more favourable conditions for wind farm development.

	Points Assigned (Score)					
Criteria	**0**	**1**	**2**	**3**	**4**	**5**
Wind resource density based on NREL atlas (W/m^2)	< 300	-	300-400	400-600	600-800	800-1200
On-site wind measurements to confirm wind resource	None	Local Opinion	< 1 Year		1-2 years	> 2 years
Quality of on-site measured wind speed data	None	Low		Moderate		High
Correlation of on-site wind speed data with wind atlas estimates	None	Low		Moderate		Strong
Quality and availability of correlated long-term data	None	Low		Moderate		High
Proximity to transmission lines		>20 km	10-20 km	5-10 km	1-5 km	< 1 km
Upgrades required to existing transmission lines		Extensive	Moderate		Minor	None
Terrain		Rugged	Complex		Rolling	Flat
Accessibility		Poor	Marginal		Good	Excellent
Security		Poor	Satisfactory	Excellent		
Terrain orientation to prevailing wind		Poor	Marginal		Good	Excellent
Landowner concerns		High		Moderate		Low
Social acceptability		Poor		Satisfactory		Excellent
Land costs		High		Moderate		Low
Vegetation over 10 m		Significant		Scattered		None
Soil conditions		Solid Rock	Fractured Rock		Soil/Rock	All Soil
PAGASA rank in frequency of typhoon passages over province	1 - 11	12 - 23	24 - 35	36 - 47	48 - 59	60 - 71
Other environmental issues (corrosion, humidity)		Extensive	Moderate		Minor	None
Insects		Many	Moderate	Few		
Cultural or environmental concerns		Extensive	Moderate		Minor	None
Site capacity, MW		<25		25-50		> 50
Aviation and telecommunications conflicts		Extensive	Moderate		Minor	None

Table 3.8: Site ranking criteria and score system for Philippines

Source: National Renewable Energy Laboratory

	Points Assigned (Score)				
Criteria	1	2	3	4	5
Wind resource density at 50 m based on NREL atlas	<400	400-500	500-600	600-800	>800
Proximity to transmission lines	>20 km	10-20 km	5-10 km	1-5 km	< 1 km
Transmission/interconnection capacity & grid stability	Poor	Marginal	Satisfactory	Good	Excellent
Terrain	Rugged	Complex	Moderate	Rolling	Flat
Accessibility	Poor	Marginal	Upgradeable	Good	Excellent
Terrain orientation to prevailing wind	Poor	Marginal	Satisfactory	Good	Excellent
Neighbor or community concerns	High		Moderate		Low
Social acceptability	Poor		Satisfactory		Excellent
Land costs	High		Moderate		Low
Vegetation over 10 m	Significant		Scattered		None
Soil conditions	Solid Rock	Fractured Rock	Rock/Soil	Soil/Rock	All Soil
Site environment issues (corrosion, humidity)	Extensive	Moderate	Average	Minor	None
Cultural or environmental concerns	Extensive		Moderate		None
Aviation and telecommunications conflicts	Extensive		Moderate		None

Table 3.9: Site ranking criteria and score system for Sri Lanka

To summarise the scientific approach to model site selection for wind farms, there are many issues that need to be modelled in an assessment of wind farm site assessment. Environmental and economical issues that influence development have been modelled in an abstract way by both academic researchers and commercial wind farm developers world wide. There are lots of methods available to predict the effects of those issues and many ways to determine sites based on those issues (See Table 3.10). By using those issues as criteria of site selection, the environmental impact of wind farm can be minimised, thus increasing the chance of gaining the resource consent and maximising the profitability of wind farms.

As this discussion indicates, wind farm modelling considers relevant issues, but handles them in a way that assigns numerical values to effects for the purpose of computer-based modelling. Where there are a very large number of potential sites, and sound data underpinning the creation of assessments, this positivist scientific approach is appropriate. Once potential sites are reduced to a workable set, more complex analyses and negotiations are carried out to determine the final site choice. The commentary has drawn heavily on the National Renewable Energy Laboratory's Philippine wind farm site selection process as an example, because this group first identified relevant issues involved in wind farm.

Based on those approaches, numerical score were assigned to large number of potential sites and a preliminary site ranking process was conducted based on the site scores. In this process, six top ranking sites were selected as favourable for wind farm development and rest of sites have been taken out of consideration. After potential sites were reduced to a workable set, more detailed economic analysis and site visiting and evaluation were conducted to find the optimal site (National Renewable Energy Laboratory, 2001).

	Spanish methods of visual impact evaluation in wind farms (Hurtado et al., 2003)	**Short-cut design of wind farms** (Kiranoudis et al., 2000)	**A geographic analysis of wind turbine placement in Northern California** (Rodman et al, 2005)	**Wind farm analysis and site selection analysis for Philippine and Sri Lanka** (National Renewable Energy Laboratory, 2003)
Scale	Regional scale	Regional scale	Regional scale	National scale
Research focus	Narrowly focused, in-depth analysis on the visual impact of wind farm	Narrowly focused, in-depth analysis on the economic profitability of wind farm	Broadly focused on physical requirements, environmental requirements and human impact factors	Broadly focused on wind resource and environmental issues involved with wind farm development
Objective	Predicts the visual impact of a wind farm	Predict and optimize the economic benefits of wind farm	Use GIS to evaluate site suitability and predict the locations for wind farm development in Northern California	Ranking and prioritizing potential wind farm site in Philippines and Sri Lanka
Methods	Visual impact evaluation matrix (VIEM) used. Based on five coefficients which represent different affected types in town	Mathematical models of wind turbines and empirical design equation were used based on the construction characteristics and operational performance to describe optimal farm size for a wide range of site characteristics, farm sizes and different wind turbines	Weighting and scoring system combined with mathematical equations to give site a range from Unsuitable (0) to excellent (4)	Weighting and scoring system for factors affecting site suitability. And cumulative scores for different sites were compared for preliminary site ranking

Out come	Quantify the visual impact generated by a wind farm in the affected neighbouring population. Help regional planners to assess the visual effect of setting up wind farms	Help regional planners to automatically determine the optimum number of wind turbines installed, the amount of energy recovered and reasonable estimation of the plant cost	Help planners to determine where future wind turbines may feasibly be located and to identify how much land availability is lost due to environmental and human impact factors. Reduce public controversy over wind turbines by avoid sites where there may be heavy opposition due to environmental and human impact concerns	Eliminate land that not suitable for wind farm and find sites receive high socres.
Rule based			√	
Site screening and ranking method				√
Multiple attribute		√	√	√
Visibility analysis	√			
Wind speed analysis		√	√	√
Economic analysis		√		
Terrain analysis			√	√
Land use conflict			√	√
Land cover			√	√
Land cost		√		√
Endangered species			√	
Population analysis	√		√	

Environmental impact assessment			√	√

Table 3.10: Methods used on wind farm site selection.

Specific algorithms, process and models used in wind farm site selection

Multiple attribute site selection models

Multiple attribute modelling/selection is also know as multiple criteria decision making. It refers to making decisions in the presence of multiple, usually conflicting criteria. It is commonly theorised as continuous or discrete, depending on the domain of alternatives (Zanakis et al., 1997). It is generally assumed in multiple attribute analysis, decision makers have to choose an alternative among several options. Selecting an alternative from set of options depends on many, often contradictory characteristics. Accordingly, analysts will generally have to content with a compromise solution (Chakhar, 2003).

In wind farm development, developers often face two challenges. First of all, they must maintain an ecological equilibrium but nevertheless contribute to economic growth. Secondly, they must try to avoid opposition and reduce objections (Hansen, 2005). Traditionally, overlaying and buffering of variables mapped in geographic space have been used in site location studies. However, when handling multiple conflicting criteria this kind of vector-based geo-processing is of limited use. Some scholars argue that overlays are difficult to handle when there are many underlying variables (Hansen 2005 and Jansen 1990). Next, the overlay procedure does not take into account the fact that the different variables are not of equal importance. Finally, it is difficult to handle threshold values, and a transformation of a continuous variable to a nominal basis will inevitable lead to substantial losses of information (Janssen et al., 1990). By combining the multiple criteria decision making methods with GIS, there is a prospect that a system can be devised to handle the complexity, uncertainty, multiple and sometimes conflicting management objectives.

Multiple attribute site selection models can be theorised in two phases: determination of attributes or factors, and evaluation and site selection (Hoffman et al., 1993). In the determination of attributes or factors phase, attributes or factors that may operate in the site selection process will be determined and they frequently vary in different industrial sectors. For example, in tree planting site selection model, the factors may be identified as the socio-economic and environmental factors that allow planting trees in a way that maximizes environmental, social, and health benefits to communities that need them most (The Department of Geography, Indiana University Purdue University Indianapolis, 2006). In the transportation sectors land use factors, transport demand factors, dynamic traffic assignment factors and environmental impact factors were identified (Strauch et al., 2007).

After the attributes have been identified, they can be evaluated. A classification can be based on the site selection requirements. The classification methods could use binary (0 or 1) or ranking systems (0 to 5, for example). The Department of Geography at Purdue University, Indianapolis used binary classification methods to identify locations suitable or not suitable for tree planting on the basis of multiple attributes, while Van der Merwe ranked the land potential for different land development from ‘not suitable’ to ‘very high potential’ (Merwe et al., 1997). Another way to evaluate multiple attributes is to evaluate each individual attribute in different modules and then integrate those modules into a standardised programme. The data communication within the programme system link via the manipulation of input and output data files. As Figure 3.2 shows, the coordination of the programme can be directed by a control programme (Strauch et al., 2007).

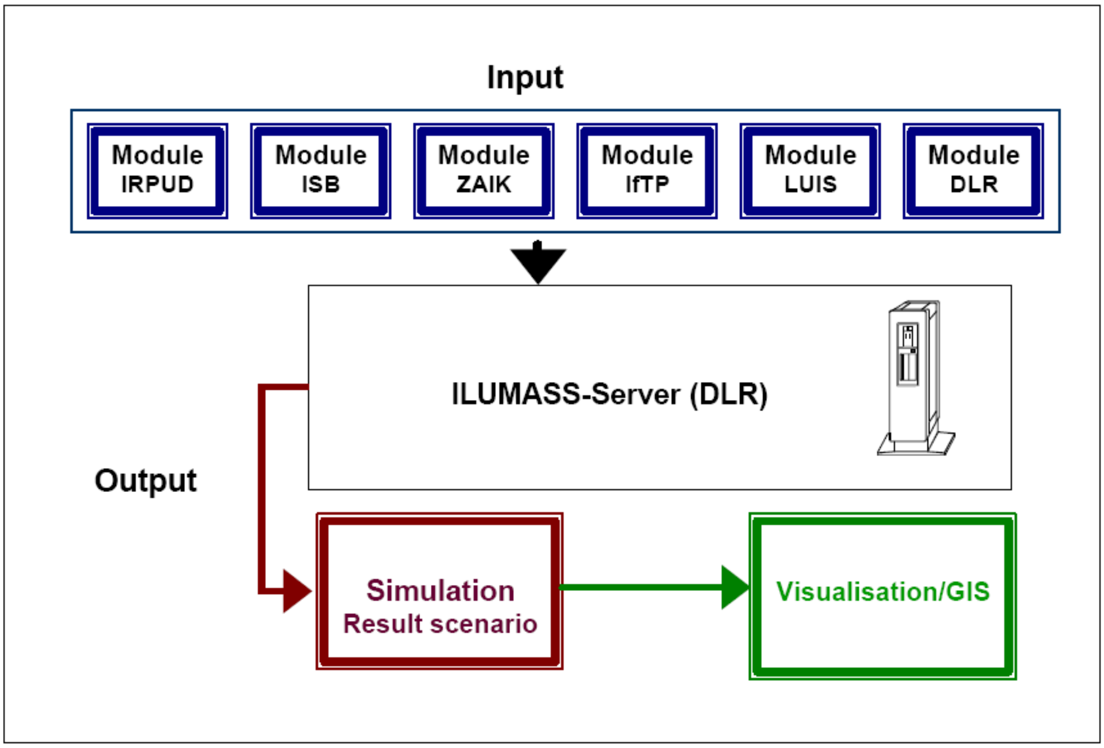


Figure 3.2: Integration and module structure in ILUMASS

Boolean integration method

Boolean integration involves the logical combination of binary maps. In GIS applications, binary maps are usually prepared to indicate favourable and unfavourable areas for particular analysis. Using binary maps is generally in raster format, with only two values, 1 and 0 to be processed. The pixels having value of “1” are the favourable areas, while the pixels having value of “0” are the unfavourable ones. To superimpose those binary maps, Boolean operators are used. Normally, there are two types of operator used in GIS, “AND” (intersect) and “OR” (union). In “AND” statements, processing requires that all conditions must be present for the statement to be true. In “OR” statements, any presents of conditions will make the statement true. The statement can be represented in a final map to show areas that meet those conditions.

The GIS-based geothermal potential assessment for western Anatolia (Nesrin, 2006) used this method to find areas favourable for geothermal development. First of all, the requirements for geothermal potential were displayed in binary maps. These maps were then combined with Boolean operators. The resultant map showed sites which meet those requirements.

The community tree planting research conducted by Purdue University (noted above) also used an alternative method to combine the binary maps. In their research, they identified nine socio-economic and environmental criteria for tree planting. Each criterion was represented as an individual layer in GIS and recoded to a binary map. These binary maps were then combined. The values in the resultant map ranged between 0 (no criteria met) to 9 (all criteria met).

Rule based methods

Rule based GIS models can provide a method to weight the different features according to their effects on site development. The first step is to identify factors that will have effects on site development and/or influence the decision making process. The factors are then represented as data layers and can subdivided into multiple sub-classes. The second step is to use expert input to score and weight the individual layers identified in step one. Each data layer is given a weight that represents its significance to the overall suitability measurement and a score is assigned to sub-classes according to their suitability. The last step is to develop models to evaluate the factors. In Rodman's study on wind turbine placement in Northern California (Rodman et al., 2005), a rule based GIS model was used to evaluate and target suitable wind power sites in Northern California.

The study carried out by Rodman et al. first, they identified three factors theorised to influence the wind farm site selection. The first factor is physical features required for successful wind turbine operation. This factor was broken down into four sub-classes: wind speed, obstacles, valley and distance to ridge. The second factor is the environmental influences on wind farm site selection. The factor is theorised to break down into vegetation, endangered plant species and wetland sub-classes. The third factor is human impact which breaks down to urban and recreational land sub-classes.

In the second step, a score system was developed by experts for these sub-classes. In the Rodman et al. model, these scores ranged from 4 (excellent) to 0 (unsuitable) depending on the suitability of the sub-classes.

In the third step, individual GIS models were developed to evaluate the factors identified in step two. Those models create maps that represent the factors with scores for different locations. Last, a combined model was developed to combine scores from individual models. If any location had an unsuitable (0) score from any individual model, then that location was considered to be unsuitable.

Site screening and ranking method

The objective of a site screening and ranking method is to provide a mechanism for ranking and prioritizing potential sites. The first step of this method is to identify the screening or ranking criteria that influence site selection. In wind farm site selection, the screening criteria usually involved in assessments are wind resource, land suitability and site suitability. The second step is to assign a relative score to screening criteria. Normally, a preliminary spreadsheet was used to present the criteria and their relative scores. Sometimes, a weighting system is also used to reflect the relative importance of some of the screening criteria. In the case of wind farm, the score assigned to wind resource is often weighted (multiplied) by a number to reflect its importance in selecting a wind energy site. The last step is to add the scores together and rank the site based on their cumulative scores. Sites that receive high scores will have more favourable conditions for development.

The National Renewable Energy Laboratory (National Renewable Energy Laboratory, 2003) used a similar approach to single out suitable wind farm development site for the Philippines. First all, they identified screening criteria that influenced the wind farm site selection. They then developed a scoring and weighting system. A weight factor 4 was assigned to the wind resource score. Last, they ranked sites based on their scores. The difference here was that there is an elimination process involved in their research due to the large number of potential sites. The first elimination process is based on wind resource. Sites that have wind density less than 300 W/m^2 will be eliminated. Then, land availability was used for secondary elimination. Sites that are not available for wind farm development were eliminated. The rest of the potential sites were ranked based on their cumulative scores (See table 3.11).

	Pantabangan	Carranglan (Valley)	Digdig (Mountain)	Sual	Caliraya	Sampioc
Wind resource density based on NREL map	0	3	5	3	2	3
Weighted Score (multiplier = 4)	0	12	20	12	8	12
Duration of on-site wind measurements to confirm wind resource	0	1	1	0	1	0
Quality of on-site measured wind speed data	0	0	0	0	0	0
Correlation of on-site wind speed data with wind atlas estimates	0	0	0	0	0	0
Quality and availability of correlated long-term data	0	0	0	0	0	1
Wind Resource Subtotal	0	13	21	12	9	13
Proximity to transmission lines	4	4	2	4	5	2
Upgrades required to existing transmission lines	4	4	4	5	5	1
Terrain	2	4	2	4	4	4
Accessibility	5	5	1	4	4	4
Security	3	2	3	2	2	2
Terrain orientation to prevailing wind	2	5	5	4	5	4
Landowner concerns	3	3	3	3	1	3
Social acceptability	3	3	3	3	1	3
Land costs	3	3	3	3	1	3
Vegetation over 10 m	1	3	1	3	3	3
Soil conditions	5	5	5	5	5	5
Rank in frequency of typhoon cyclone passage over provinces	1	1	1	2	4	4
Other environmental issues (corrosion, humidity)	4	4	4	4	4	4
Insects	3	3	3	3	3	3
Cultural or environment concerns	4	4	2	4	2	4
Site capacity, MW	1	5	5	5	3	3
Aviation and telecomm conflicts	5	5	5	5	5	5
Site Related Subtotal	53	63	52	63	57	57
TOTAL SCORE	53	76	73	75	66	70

Table 3.10: Final scores for different sites in the Philippines.

Source: Source: National Renewable Energy Laboratory

Summary

The review of site selection literature relevant to wind farms has shown that the increased focus on scarce energy identified in Chapter Two has lead to a new application of the various theories of analysis. The aim is generally to seek an effective decision support framework for evaluating potential wind farm sites.

The primary aim is to identify an effective decision support framework for evaluating wind farm site. The process involves providing a method that can be used by developers to solve issues involved in wind farm development (economic issues and environmental issues). Often the economic issues are identified as the key factors; these include factors such as energy output and construction cost that influence the economic benefits of wind farm developments (Ashby, 2004). The environmental issues identified as factors (such as impact on vegetation, visual impact and land use conflicts that have impact on environment) have been identified by Rodman et al, (2006), and these issues need to be clearly considered.

The first section of this chapter discussed the almost universal set of criteria used by the corporate sector and universities in their site selection models to. This discussion illustrated data used for those criteria and how those data can be categorised, and it provides clear lines of investigation for the methodological considerations of the next chapter. The key variables are listed here to summarise the review chapter and to provide a link to the next chapter.

The following sets of criteria were considered to be central in the development of the site selection model developed in the next chapter:

- Wind speed
- Visibility
    - Distance to urban areas
    - Visibility analysis from urban areas
- Environmental issues
    - Indigenous vegetation
- Land use conflict
    - Archaeology sites
- Accessibility
    - Road network
    - Power grid connection
- Terrain analysis
    - Closeness to ridge tops
    - Flatness of the land

- Minimum area criteria
    - Clustered patches
    - Contiguous areas

An effective decision support framework for evaluating wind farm site should be very flexible. The second section of this chapter discussed some common algorithm and modelling methods used by developers. It revealed process involved in the analysis of data and structure of different models. By reviewing and comparing different algorithms and models, it becomes clear that the proposed model in this study will be similar to the model created by Strauch. The rational behind this is the flexibility of the model. The main characteristic of Strauch's model is each individual criterion will be represented by different modules which will be integrated into a standardised programme (Strauch 2007).

Lastly, an effective decision support framework for evaluating wind farm site should be easy to implement yet can provide effective results that easy for developers to understand and easy to reach wide audiences. For these reasons, the binary categorization method will be used to show areas that not suitable (0) or suitable (1) for wind farms based on the criteria and variables. For example, for wind speed module, the input data layer will be the mean wind speed data, and variable will be the desired wind speed. The output result maps will show the areas that are suitable for wind farms (1) and not suitable for wind farm (0). This type of categorization method is easy to implement and it is a simple, yet effect way to show the results. The result maps also can put online for public's interests.

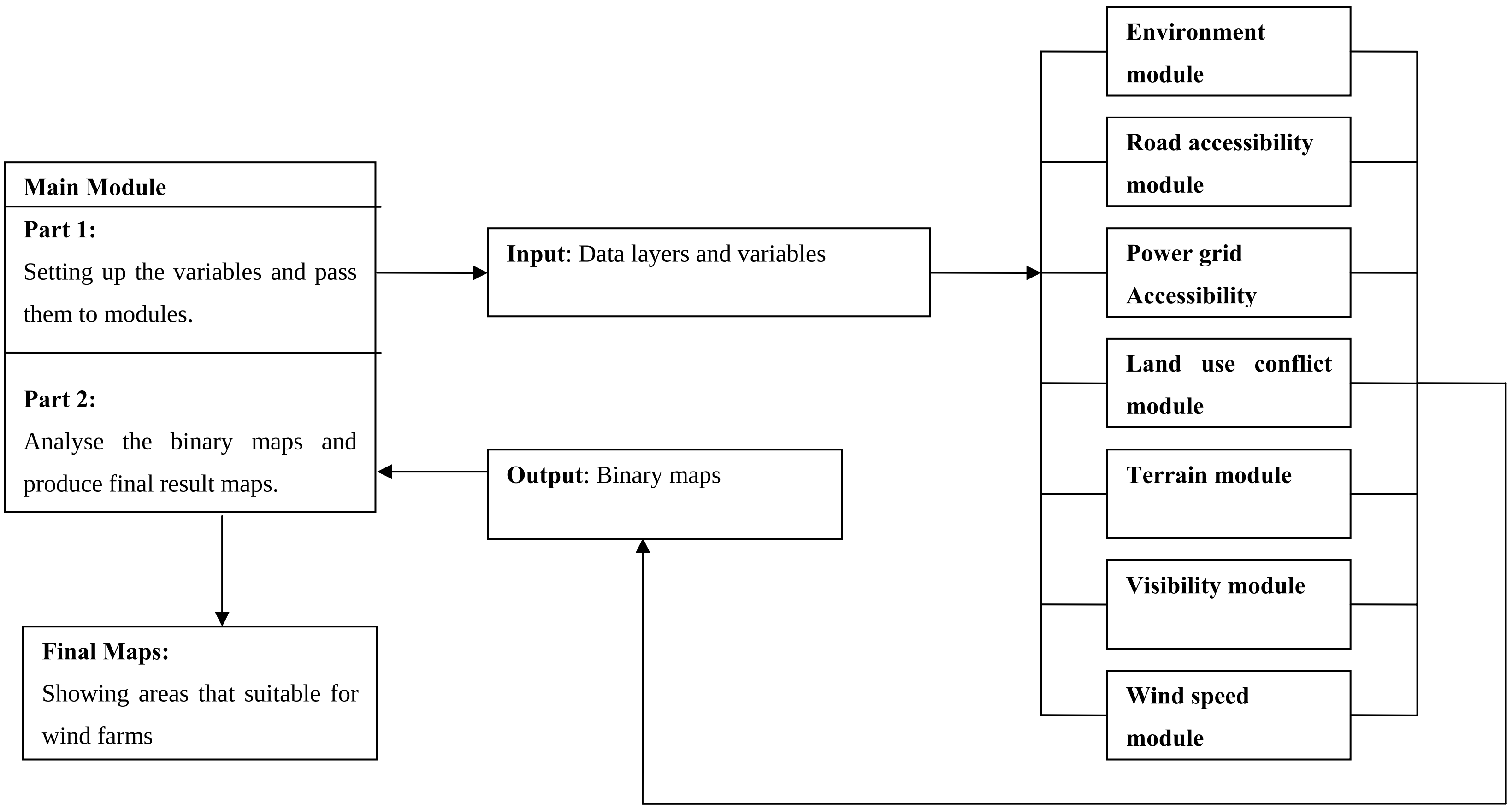


Figure 3.3: Model structure.

Chapter 4

Methodology

This chapter focuses on the methods used to implement the proposed GIS based site evaluation tool for wind farms. It begins with a discussion of scale considerations and the issues of selection an appropriate case study area. National and regional scale will be compared, and reasons for choosing a particular region as the study area will be discussed. A section on components of the analytical model and model implementation will follow. The main purpose of this section is to identify and describe the GIS tools and algorithms used to implement the individual modules within the site evaluation tool. The graphics outputs from different modules are also discussed in this section.

Scale consideration and study area selection

For wind farm site selection, researchers often focus on two contrasting scales: the national scale (National Renewable Energy Laboratory, 2001) or the regional scale (Rodman et al, 2006). At the national scale, the aim is to set broad guidelines and all the wind farm planning processes will be based on that guideline. For example, in National Renewable Energy Laboratory's research in the Philippines, the study introduced standard guidelines for selecting wind farm site in the Philippines and the planning processes of wind farm in different regions were based on these guidelines. Compared with the national scale, the regional scale is much more flexible; it allows developers to treat regions differently.

The purpose of this study is to develop a method that can be used to evaluate wind farm locations on the basis of localised criteria. Thus, a small case study area was considered to allow a variety of local effects to be considered and to minimise the amount of data to be processed. There is a second point to be considered with reference to regional studies.

There councils determine the planning frameworks within which developers can propose wind farm development.

The case study area also needs to have existing wind farm sites that can be used to verify the model. The Wanganui region has been identified by Energy Efficiency and Conservation Authority as one of the favourable areas for wind farm development on the basis of available wind and distance to load centres (EECA, 2001). It also has existing wind farms that are known to have good conditions for wind farm development, and they could be used to validate the predictive model. This regional scale approach used data from Wanganui region as the study area (see Figure 4.1).

The purpose of the case study approach is the grounds the model building in data sets of manageable size and planning contexts that were sub-national. Once the predictive model been built and verified, with some alternation of the model and use of national level data, there is significant potential to extend the model to a national level.

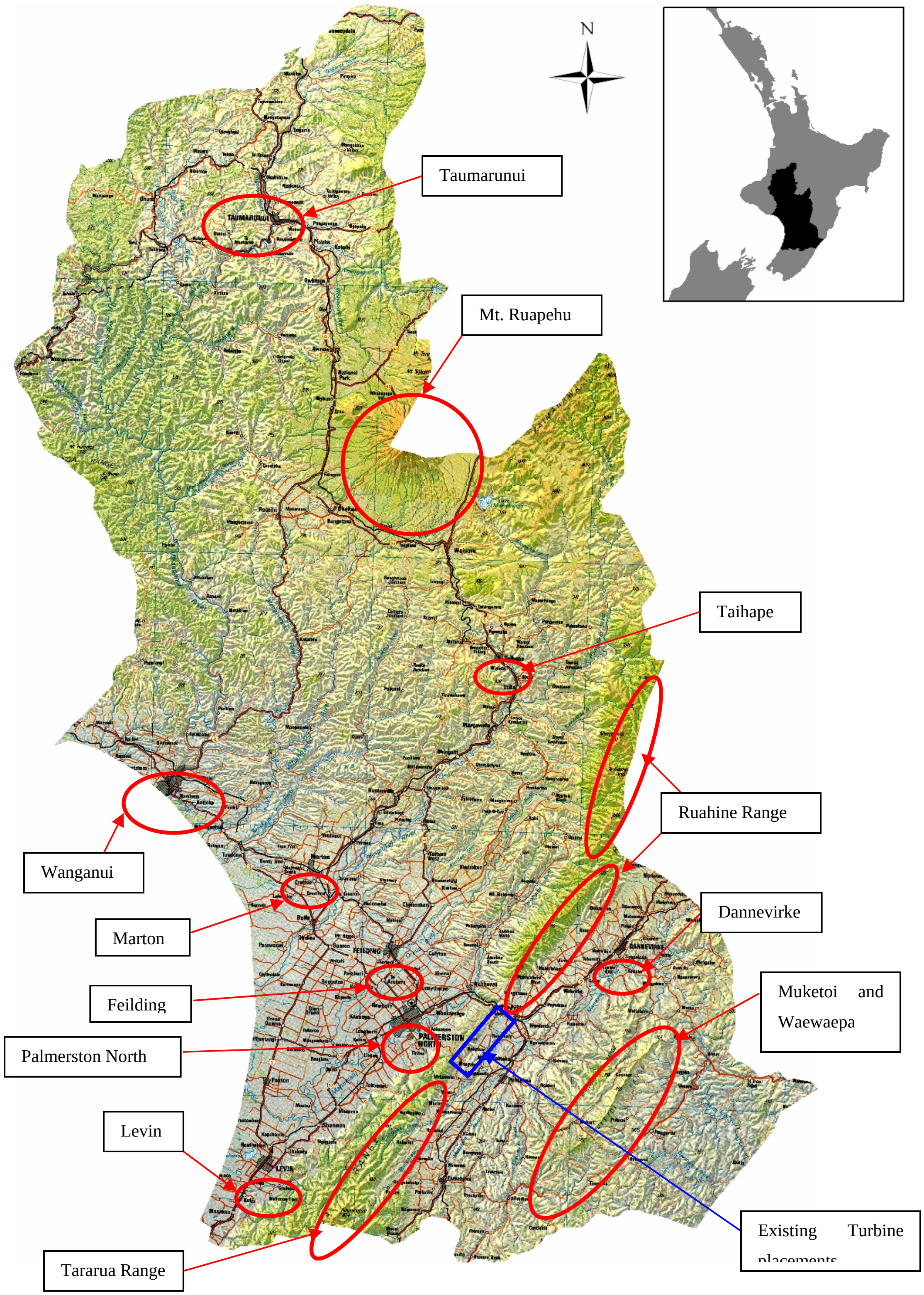


Figure 4.1: Wanganui-Manawatu region locations.

Source: University of Waikato GIS data.

Data preparation

The data that are required for running the various modules in the site evaluation model are obtained from different sources. All sources are at the New Zealand national scale and the Wanganui regional shape file was used to clip these data, so they can be used for Wanganui region. The AML grid function used by the modules required the data type to be coverage format. Thus, before the data can be used by the modules, they were converted into raster format (see Table 4.1 for more details). To decrease the run time of AML model, a raster analysis mask is needed. The raster analyst mask will limit the analysis only to the Wanganui region.

Raw data	Source	Raw data format	Derived data format	Usage
National mean wind raster	Landcare Climate Rasters 1998.	Raster layer with 500 m cell size	Raster layer with 50 m cell size	Used in wind module to find out areas have suitable wind speed
National road network shape file	LINZ.	Line shape file	Raster layer with 50 m cell size	Used in road accessibility module to identify areas within certain distance to road
National Power line shape file	TransPower NZ	Line shape file	Raster layer with 50 m cell size	Used in power line accessibility module to identify areas within certain distance to power lines
North Island Landcover coverage file	Terralink	Polygon coverage	Raster layer with 50 m cell size	Used in environmental module to exclude all the indigenous forest areas
National Archaeology shape file	Doc and NZAA	Point shape file	Raster layer with 50 m cell size	Used in land use conflict module to exclude areas that close to the archaeology site
North Island DEM	Landcare	Raster layer with cell size 100 m	Raster layer with 100 m cell size	Used in Terrain module to find out areas that above mean elevation. Also used in visibility module as z-value.
National urban coverage	LINZ	Polygon coverage	Raster layer with 200 m cell size	Used as observation point in visibility module

Table 4.1: Data used in the wind farm site evaluation modules

Components of the analytical model and Model implementation

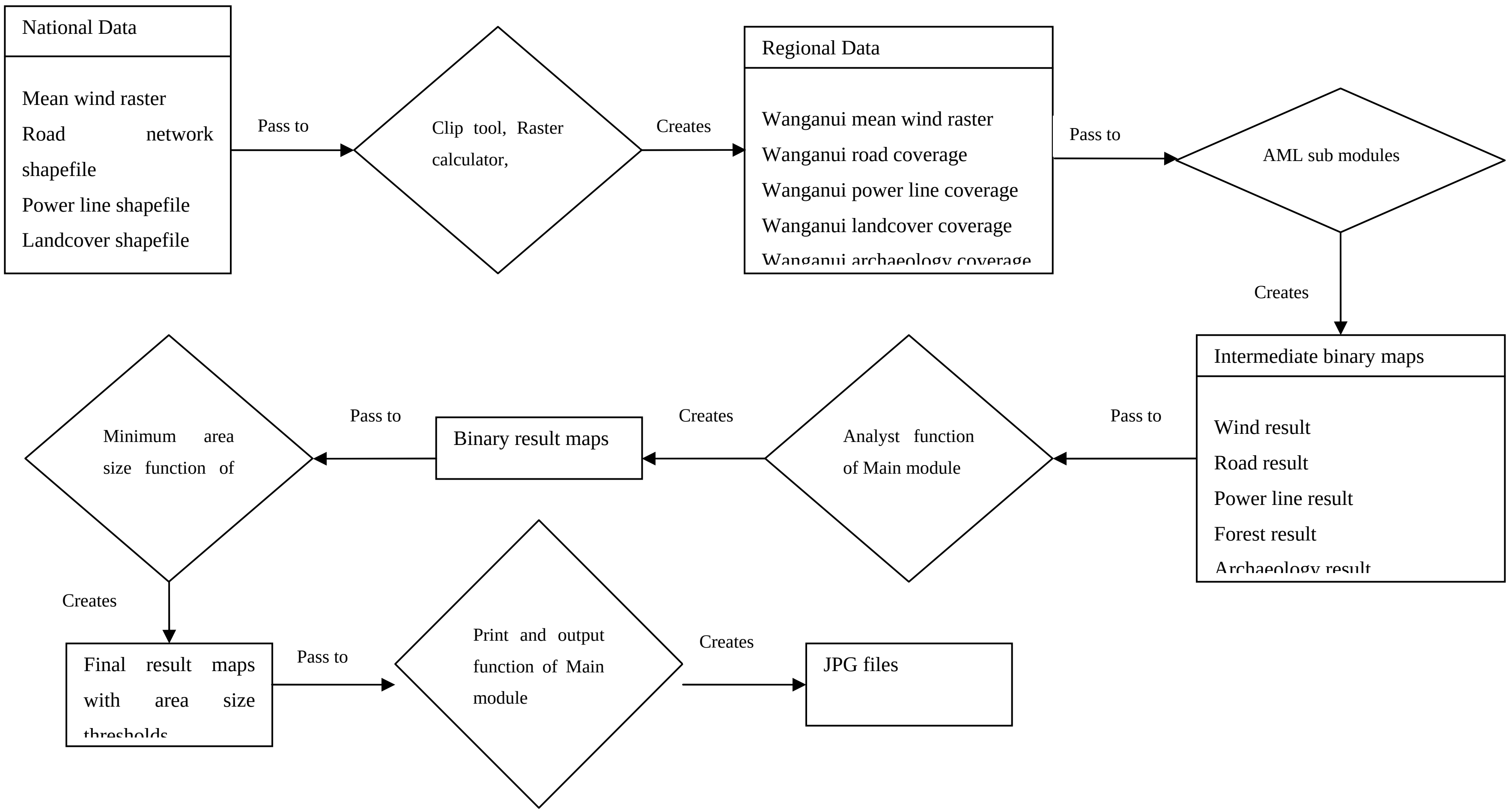
The proposed model for this research consists of eight modules. They are the main module, wind speed module, road accessibility module, power grid accessibility module, environmental module, land use conflict module, terrain module, and visibility module. All the modules were written in Arc Macro Language (AML) using ArcInfo work station. The detailed AML codes are included in the Appendix section. Each module can be viewed as an independent program with a distinct role or responsibility and they are capable of receiving data and variables, processing data, and sending data to other modules (see Table 4.2 and data flow diagram for more information). This section of the thesis will discuss the data used in these modules, the role of the modules, the GIS tools used to implement the modules and output maps from the modules.

Module name	**Function**	**Criteria used for sensitivity analysis**
Wind speed module	Process the mean wind speed data. Conduct sensitivity analysis on suitable wind speed range. Create wind speed result binary maps which identify areas within the wind speed range.	1. Not considered 2. Mean wind speed between 10 – 25 m/s 3. Mean wind speed between 10 – 30 m/s
Road accessibility module	Analyse the accessibility of areas to the road network based on the distance to road network. Identify areas that within certain distance of road network at same time, exclude the road network areas. Create binary road accessibility result maps.	1. Not considered 2. Within 5 Km of road network 3. Within 10 Km of road network
Power grid accessibility module	Analyse the accessibility of areas to the power line network based on the distance to power line network. Identify areas that within certain distance of power line network at same time, exclude the power line network areas. Create binary power grid accessibility result maps.	1. Not considered 2. Within 5 Km of power line network 3. Within 10 Km of power line network
Environmental module	Exclude all the indigenous vegetation areas. Create a binary map that shows areas that outside the indigenous vegetation areas.	Away from indigenous vegetation
Land use conflict module	Exclude possible and use conflict areas. Create binary maps that show areas that are certain distance away from possible conflict locations	500m away from conflict locations

Terrain module	Identify areas that high up the ridge or areas that are flat. Process the elevation data and the slope data. Create binary maps that within the criteria.	For elevation: 1. Not considered 2. Above 50% of relative elevation 3. Above 75% of relative elevation For slope 1. Not considered 2. Less than 10 degree 3. Less than 15 degree
Visibility module	Analyse the visibility impact of wind farm on nearby urban areas based on how many times an areas can be seen by the observation point and distance from urban areas. Process the urban polygon so it can be used as observation point. Create binary visibility result map shows areas that have minimum visual impact on urban areas.	1. Not considered 2. Areas can't be seen from any urban areas. 3. Areas can be seen less than 40 hectares of urban areas.
Main module	Control the coordination of the entire model by setting up all necessary variables used in modules and run the individual modules. It also conducts the final analysis based on the binary result maps created by sub modules. Conduct block functions to show blocks that have certain number of cells that suitable for wind farm.	1. Not consiered Clustered patches 2. More than 100 ha. Within 400 ha. 3. More than 200 ha. Within 400 ha. Contiguous 4. Larger than 200 ha. 5. Larger than 400 ha.

Table 4.2: Modules and their functions

Data flow diagram



Main module: coordination function

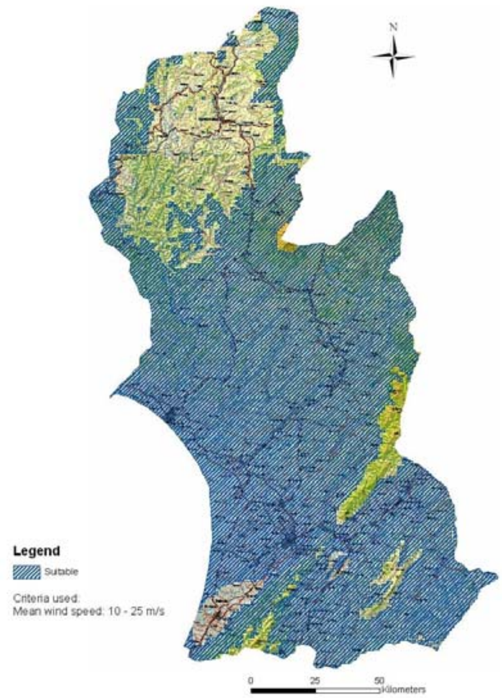
The main module has four functions, and only the first function is described here, with the other three explained in the later section of this chapter. The first function is to control the coordination of the entire model. It consists of two routines. The first routine is called "&routine setvariables". This routine will set up all necessary variables (such as cell size) and pass them to the other modules. The reason behind this is to make the model flexible. In New Zealand, different regions have different criteria for the wind farm development; thus, variables need to be changed to suit the requirement of different regions. Rather than go to the individual modules and change variables in them, the set variable routine in the main module allows planners to change the variables in the main module, thus making it easier for planners to change the variables. The second routine is called "&routine run". In this routine, AML function "&r" will be used to run the sub-modules.

Wind speed module

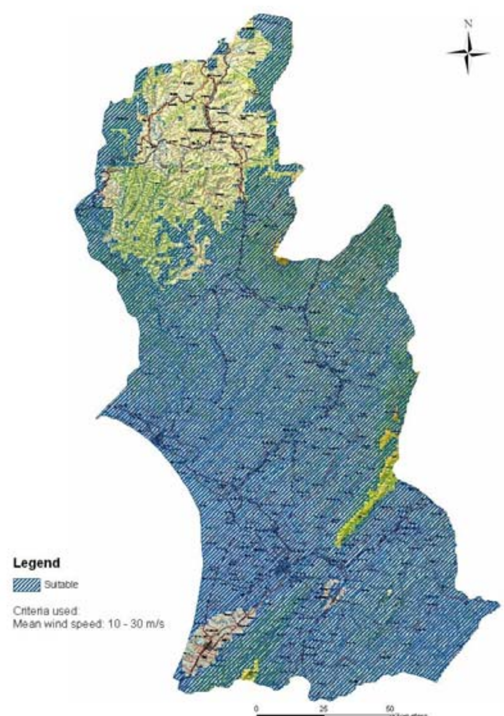
The wind speed module works with the wind speed parameters relevant to wind farm development. Raster data of mean wind speed from Landcare was used. The coverage has a cell size of 500m. According to the metadata provided with the data, the cell values have been interpolated from climate stations throughout the country, using wind speed at 10 m above the ground recorded during the period 1971–2000. At each station, the average wind speed (based on hourly observations) for each month and year during the 30-year period were calculated. Some stations have data for the full period, while others have data for only a few years. Stations with at least two years of data were selected. The estimated data accuracy for most of the country is approximately ± 1 m/s. High elevation areas, where climate stations are sparse and wind data are generally of short duration, have more uncertainty and hence the estimated data accuracy is probably nearer ± 2 m/s. Because the coverage has a cell size of 500m, AML resample function was used to resize it to 50m to comply with other data.

There are two variables passed into this module from main module. They are minimum wind speed and maximum wind speed. These variables allow users to set up a desired wind speed range thresholds for wind farm site evaluation. There are two derived binary result maps produced in this module: w_1 and w_2. The first selected suitable areas with mean wind speed between 10 m/s to 25 m/s and the second w_2, selected areas with mean wind speed between 10 m/s to 30 m/s (see Map 4.1 and Map 4.2 for more details).

In the output Map w_1, there are total of 1,643,444 hectares of land area within the mean wind speed range. The module clearly identified six areas outside the wind speed range. They are areas around the township of Taumarunui, areas near Levin, part of the Ruahine Waewaepa and Puketoi ranges, part of the Tararua range and areas surrounding Mt Ruapehu. Areas near Taumarunui and Levin had a mean wind speed less than 10 m/s while the Ruahine range, Waewaepa and Puketoi range and at the foot of Mt Ruapehu has wind speed over the 25 m/s threshold. In the second output map w_2, there is a significant increase of land area compared with w_1 (a total of 1,711,050 hectares of land are within the mean wind speed range). The changes occurred in the Waewaeoa and Puketoi ranges and the areas at the foot of Mt Ruapehu where mean wind speeds between 25 m/s to 30 m/s are now included.



Map 4.1: w_1 binary result map with main wind speed 10-25 m/s.



Map 4.2: w_2 binary result map wind main wind speed 10-30 m/s

Road accessibility module

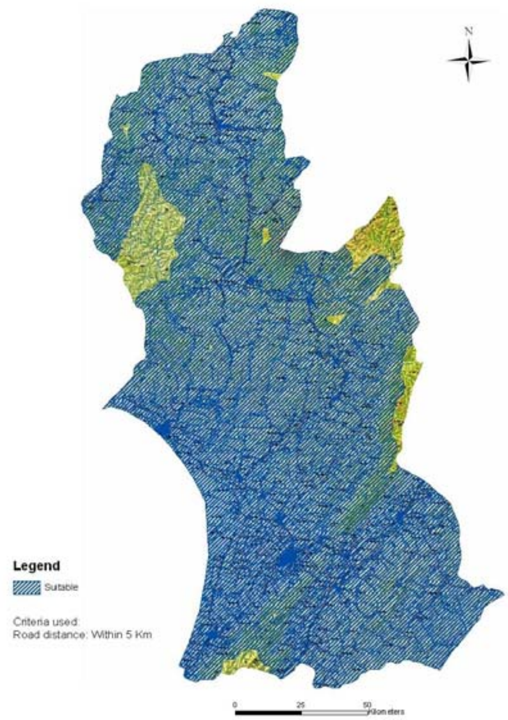
The purpose of the road accessibility module is to analyse the accessibility of areas to the road network based on the distance from a road network. This module has two functions. The first function is to identify areas that are close to the road network. The second function is to exclude the roading areas.

A road network coverage of the study area was used in this module. The coverage it was obtained from the LINZ topographic data set. The AML "linegrid" function was used to convert the coverage file into a grid file. After that, "eucdistance" function was used to calculate the Euclidean distance from each cell to the closest source, i.e., the road network. The output raster (road_dist50) has floating-point distance values. A variable called %.road_max% was passed here from the main module. This variable was used to set up the threshold of the desired distance to the road network.

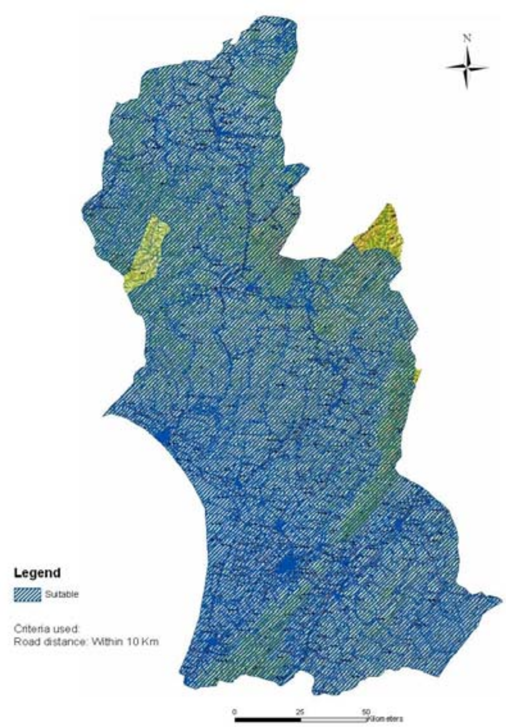
In a real life situation, wind farms cannot be built on road and in some regional plans, it is clearly stated that high structures such as wind turbines should be a certain distance away from the road network. To exclude the road areas, the road network raster (road50a) was used in the "CON" statement. The "CON" statement will output a raster layer that identifies areas that fall within the desirable distance from road network, and at the same time, outside the roading areas.

There were two binary maps created in this module: r_1 and r_2. r_1 identified areas that within 5 km of the road network and r_2 identified areas that within 10 km (see Map 4.3 and Map 4.4 for more details). For binary result Map r_1, most of the areas in the Wanganui region were with in the 5 km road buffer (total of 1,952,234 hectares). Areas that outsides the road buffers were located near the Matemateaonga Range, the Kaimanawa Mountains and Mt Ruapehu. In this situation, those areas were occupied by national parks and indigenous vegetation, and no road network exists in these areas. For the binary result map r_2, the criteria of within 10 km of road network were used. There are total of 2,058,331 hectares inside the buffer. The difference between r_1 and r_2 were not significant (about a 5% change of area size).

Other than the road buffer, the road accessibility module also identifies the road surface as not being suitable for wind farm because practically, wind turbines cannot be built on the road. It clearly showed that the module methodology had identified the road network as unsuitable for a wind farm site and all the turbines were placed outside the roading surface.



Map 4.3: r_1 binary result map with distance to road < 5 km.



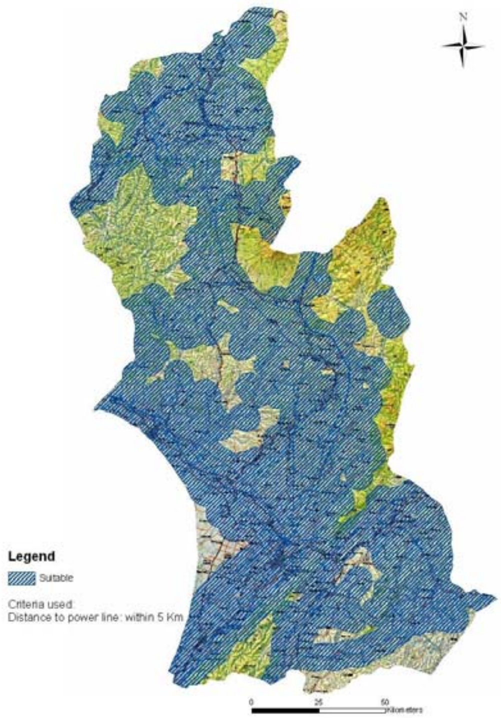
Map 4.4: r_2 binary result map with distance to road < 10 km.

Power grid accessibility module

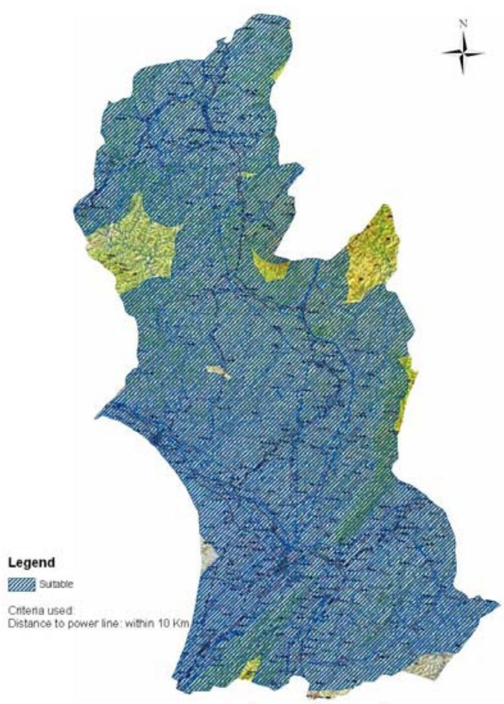
The power grid accessibility module has the purpose of analysing the accessibility of the site to the national power grid. The working principle of this module is the same as the road accessibility module, but with different input data and variables. For this module, the local power line coverage was used, as it includes high voltage power lines and other lines.

This module produced two binary result maps. The first one is p_1, which identifies areas that within 5 km of the national power grid (Map 4.5). The second map p_2, identifies areas that lie within 10 km of the national power grid (Map 4.6). In p_1, areas near the Matemateaonga Range, Kaimanawa Mountains and Mt Ruapehu were identified as not being suitable for wind farms because of lack of power gird access. The area that lies within the power grid buffer is about 1,576,598 hectares. Compared with p_1, p_2 has a total of 1,976,873 hectares within the power line buffer. The area size difference between those two criteria is about 25%.

The output suggest that most of the existing wind turbine placements are inside the buffer and at the same time, outside the area occupied by the power line themselves. There were 3 or 4 exceptions for wind turbines placed within the area occupied by power lines. The reason is that during the conversion from power grid line feature file format to raster file format, cell size of 50 m were used. Thus, the raster power grid has a width of 50 m. Practically, the power line only has a width of about 5 m, so as long as the turbines not placed in the middle of the power line area, it should be acceptable.



Map 4.5: p_1 binary result map with distance to power line < 5 km



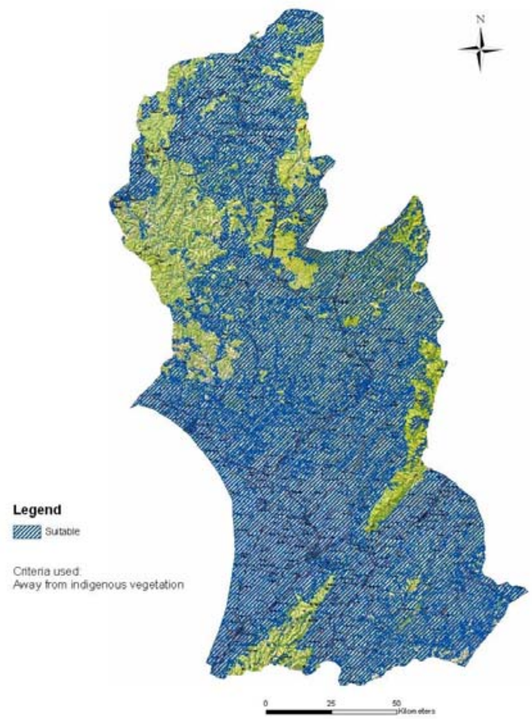
Map 4.6: p_2 binary result map with distance to power line < 10 km

Environmental module

The environmental module was used to deal with environmental aspects of wind farm site evaluation. At this stage, only indigenous vegetation was considered. The purpose here is to exclude all the areas that are covered with indigenous vegetation. The indigenous vegetation identified here is indigenous forest and scrub. Data used for this module is the local Landcover coverage obtained from TerraLink. According to the documentation, it was derived mainly from satellite imagery but also ancillary data. The minimum mapping unit is one hectare and the target classification accuracy is greater than 90%. The positional accuracy is ± 25 m.

To be able to exclude indigenous vegetation areas, the PAT file of landcover coverage was edited and converted to raster layer with 50m cell size. This module created one binary result map called Forest (Map 4.7). The total area size that is suitable for wind farm is 1,529,322 hectares, which is about 70% of the total area. There are three significant areas that stand out as not being suitable for wind farms: two are the Matemateaonga Range and Tararua Range, both of which are covered in indigenous forest, and one is in the Ruahine Range. This area is covered in scrub.

The existing turbine placements clearly showed that most of the turbines were placed in the areas that are not covered with indigenous vegetation. There are still one or two exceptions. Again, the conversion process may cause this kind of error.



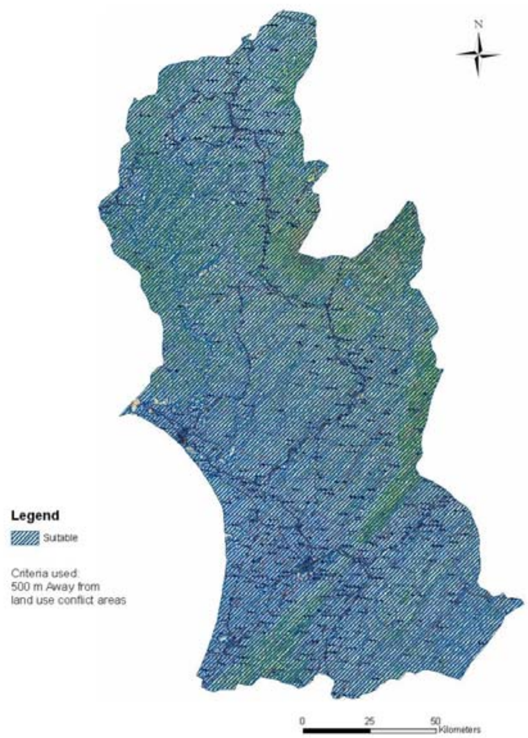
Map 4.7: Forest binary result map with area away from indigenous vegetation

Land use conflict module

This module is focused on the land availability. Areas such as defence areas, Pa sites, and archaeology sites etc should be excluded due to possible land use conflict. The data used for this module is the local archaeology coverage. It was obtained from the Doc and New Zealand Archaeology Association. It is in point format. The location of sites is usually recorded only to within about 100m. The grid reference gives the location of a site, but it does not delimit its extent. This may affect the accuracy of the data.

A variable called %.archaeology_b% was passed into this module from main module. This variable enables the module to create a buffer around archaeology sites. This variable could be altered to meet different regional councils' requirements. In this study, a 500m buffer was used.

This module created a binary result map is called a_result binary map (see Map 4.8). In this binary output map, there are total of 2119517 hectare of land were identified as suitable for wind farms. The map shows that all the existing turbines were located in the suitable areas. The closest turbine placements were about 700m away from the 500m buffer.



Map 4.8: a_ result map with 500 m away from land use conflict areas

Terrain module

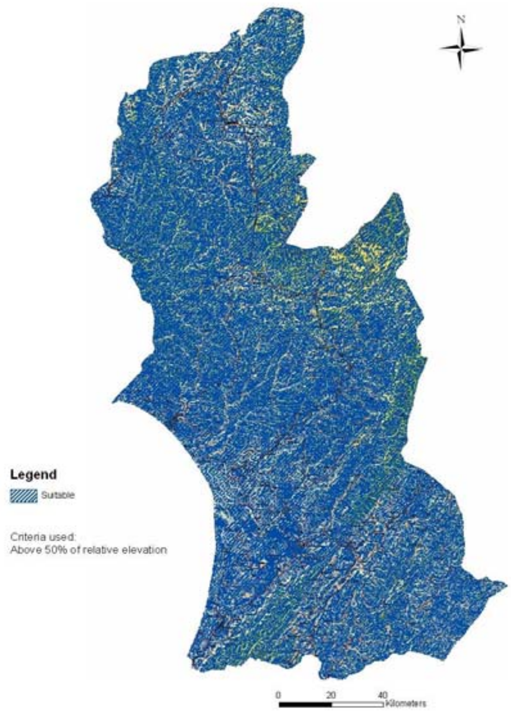
The purpose of the terrain module is to identify areas that are near the crest of ridges and areas that are flat. The module consists of two functions: a relative elevation function and a slope function. Data used for this module are in the form of a local DEM, clipped from the Landcare coverage with 100m cell size.

In this research, the relative elevation describes the relationship between the cell elevation and minimum elevation within a given area. The function will return a raster layer which indicates how far away the cell is positioned relative to the minimum elevation within the search area. It is a percentage value. Imagine that a ridge has maximum elevation of 100m and minimum elevation of 0m. If a cell has an elevation of 50m, it will be 50% away from lowest point. If a cell has an elevation of 95m, it will be 95% away from lowest point. Thus, if a cell had a higher percentage, it will be positioned closer to the top of ridge.

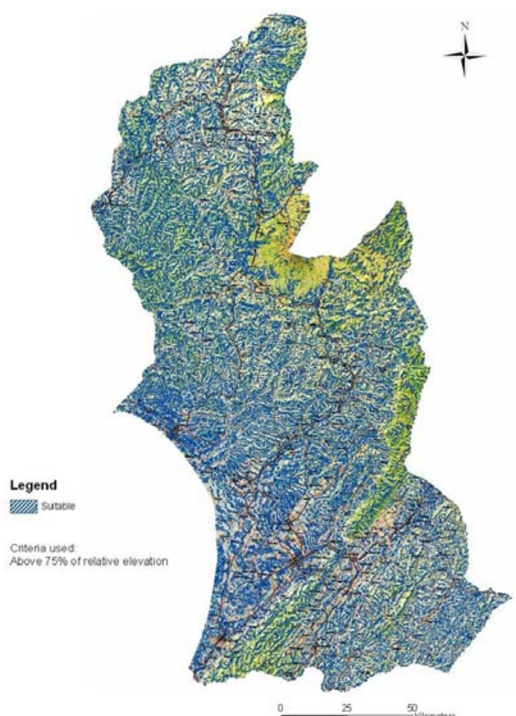
In this function, "focalrange" and "focalmin" were used to calculate the elevation range and minimum elevation within a given search area. After that, the DEM was used to subtract the minimum elevation to find out the elevation difference between cell elevation and lowest elevation. Then, the elevation difference was divided by the elevation range to find out the position relative to the minimum elevation. The output raster has a percentage value between 0% (lowest point in the area) and 100% (highest point of a ridge).

There were two relative elevation thresholds variables used in this module: above 50% and above 75% of relative elevation. It produced two binary result maps, e_1 and e_2 (see Map 4.9 and Map 4.10). In the output map e_1, thresholds of above 50% were used. In this map, the suitable area size is 963,979 hectares, which is about 45% of total area. Compared with e_1, the e_2 result map used threshold of above 75%. It has area size of 288,921 hectares or about 13% of total area. The most significant changes occurred in Mt Ruapehu, the Tararua Range and the Ruahine Range.

The output maps clearly show that a large number of the existing turbines are above 50% of relative elevation, but there are large numbers of turbines that are not above 75% of relative elevation. This indicates that the most of the existing wind turbines in Wanganui region were placed in the 50% to 75% relative elevation range.



Map 4.9: e_1 binary result map with above 50% of relative elevation

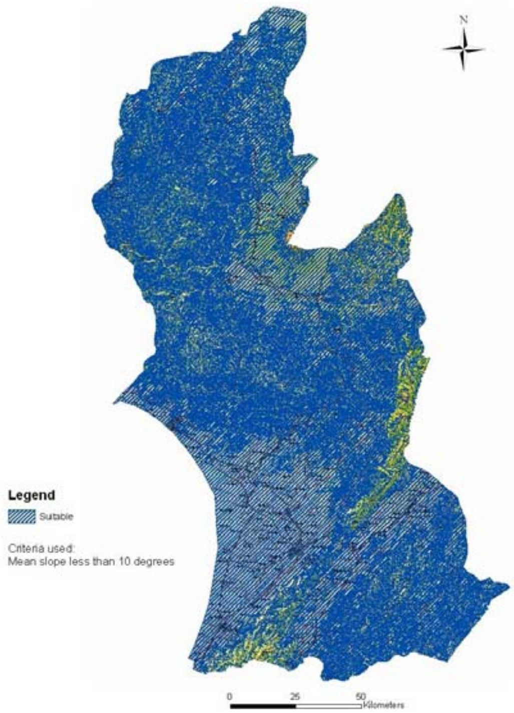


Map 4.10: e_2 binary result map with above 75% of relative elevation

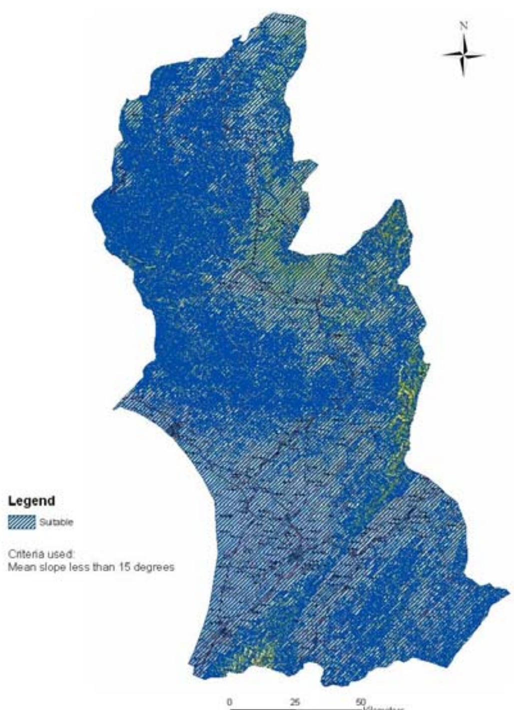
The second function of this module is slope function. The module used the AML function called “SLOPE” to identify areas that are suitable for wind farms, based on the flatness of the area. The “SLOPE” function calculates the maximum rate of change in elevation value from each DEM cell to its neighbours. The output slope grid can be calculated either as percentage or degree. In this case, the degree option was used.

There are two slope thresholds used here. They are mean slope less than 10 degrees or mean slope less than 15 degrees. Two binary output maps were produced, s_1 and s_2 (see Map 4.11 and Map 4.12).

Result map s_1 used thresholds of mean slope less than 10 degrees. There are total of 1,227,760 hectare identified as suitable. There are large areas that were identified as not beingsuitable in the Tararua and Ruahine Ranges. This is due to the steepness of those ranges. Result map s_2 used thresholds of mean slope less than 15 degrees. There are total of 1,633,456 hectares identified as suitable.



Map 4.11: s_1 binary result map with mean slope < 10 degrees



Map 4.12: s_2 binary result map with mean slope < 15 degrees

Visibility module

The visibility module deals with the visibility impact of wind farm from nearby urban areas. The module used a visibility function to perform visibility analysis on a grid by determining how many observation points can be seen from each cell location of the input grid, or which cell locations can be seen by each observation point. The function has two options. The frequency option creates a grid file recording the number of times each area can be seen from the observation points. This value is recorded in the value item in the VAT file. The observer's option stores the binary-encoded information about which observation points can be seen from the input grid cell. This information is stored in the value item. In this study, the frequency option was used.

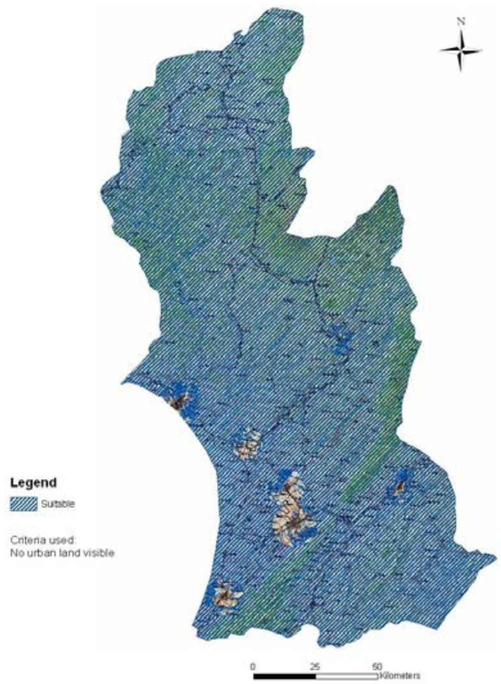
The visibility function requires two forms of input data for visibility calculation and analysis, an input grid to define the z-values and a point or line features coverage to be used as observation points. In this study, the local DEM with 200m cell size was used to define the z-values and local urban coverage was converted into a point file to use as observation points. In this study, each point is equivalent of four hectares of urban land. The reason for using DEM with 200 m cell size and one point for every four hectare of urban land is because determining visibility is a computer-intensive process and the processing time is highly dependent on the grid resolution and number of observation points. Although high grid resolution and a high number of observation points increase the accuracy of visibility analysis, it requires a much longer processing time. Thus, 200 meter grid resolution and a point for every four hectares were used to decrease the processing time and at the same time, not compromise the accuracy of visibility analysis.

In this module, the distance factor also been taken into consideration. This is because, for distances greater than 6000 m, and while the wind farm is still visible, the associated impact will be minimal; the wind farm could be considered as part of the background landscape (Hurtado et al., 2003).

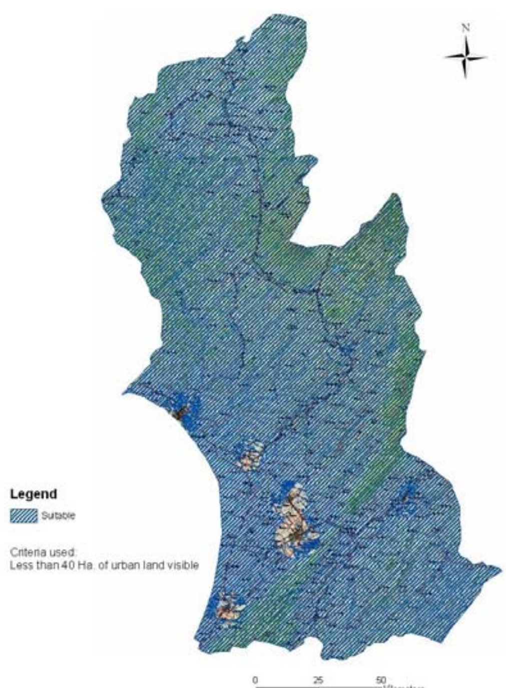
This module produced two binary output maps: v_1 and v_2 (see Map 4.13 and Map 4.14). The v_1 map indicates areas that cannot be seen from any urban land or at lest 6 km away from urban areas. The v_2 map indicates areas that can be seen from less than 40 hectare of urban land or at lest 6 km away from urban areas.

In output Map v_1, there are seven major urban areas in the Wanganui region that stand out as not suitable for wind farms. They are Wanganui, Marton, Feilding, Palmerston North, Levin, Taihape and Dannevirke. The area size suitable for wind farm is 2,088,362 hectares. In result Map v_2, there is a total of 2,095,475 hectares suitable for wind farm. Although the change of thresholds did not have a huge impact on big urban centres such as Wanganui, Marton, Feilding, Palmerston North and Levin, the most significant changes occurred in the small urban centres. The new threshold now includes many of areas in the small urban centres such as Taihape and Dannevirke due to the small size of the urban land areas.

The output maps verify that all the existing wind turbine placements were well hidden from the urban centres. In fact, the closest distance between wind turbine and urban centre is about 10 km. At that distance, the turbines were barely visible.



Map 4.13: v_1 binary result map with no urban land visible



Map 4.14: v_2 binary result map with < 40 ha of urban land visible

Main module: analysis function

The second function of the main module is to analyse the binary maps created by modules. The AML function “CON” will be used to combine those binary maps into one map showing locations that are either suitable or not suitable for wind farms. For sensitivity analysis purposes, all the different combinations of binary maps should be considered. A loop in the analysis function was used to produce maps showing suitable wind farm location based on different criteria. For example, the v1p1r1w1e1s1 map will show areas suitable for wind farm with criteria where no urban land is visible, the site is within 5 km of power lines and road networks have mean wind speed between 10 to 25 m/s. The site also has above 50% of relative elevation and have mean slope less than 10 degree. In contrast, v2p2r2w2e2s2 map shows areas suitable for wind farms with criteria where less than 40 hectare of urban land is visible, the site is within 10 km of power lines and road networks, and it has a mean wind speed between 10 to 30 m/s. It is also above 75% of relative elevation and have mean slope less than 15 degree.

These resulting binary maps will show areas that are suitable for wind farm with value of “1” and are in 100m by 100m areas (i.e. 1 ha). In terms of the overall land area required for a wind farm, a single square kilometre of land (100 hectare) can support 10 to 15 MW of wind power (New Zealand Wind Energy Association, 2005). In New Zealand, the capacity of wind farm ranged from 8.65 MW to 90.75MW. Thus, the reasonable wind farm size should be more than 100 ha. For this reason, a minimum area size threshold was introduced in the third function of main module.

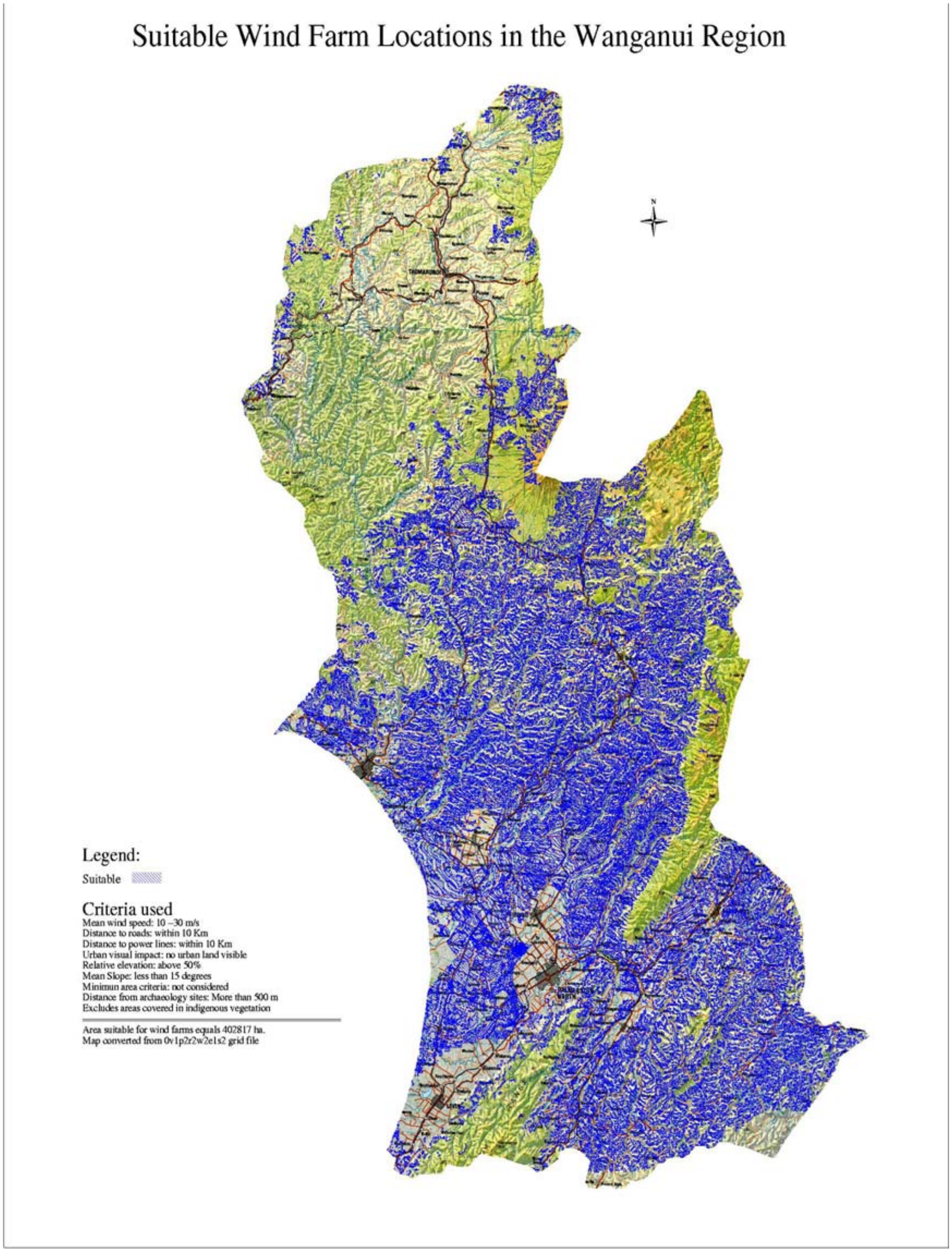
Main module: minimum area size function

This part of the main module was used to exclude areas that were suitable for wind farm but having an area less than the minimum size threshold. There are two categories involved in this function.

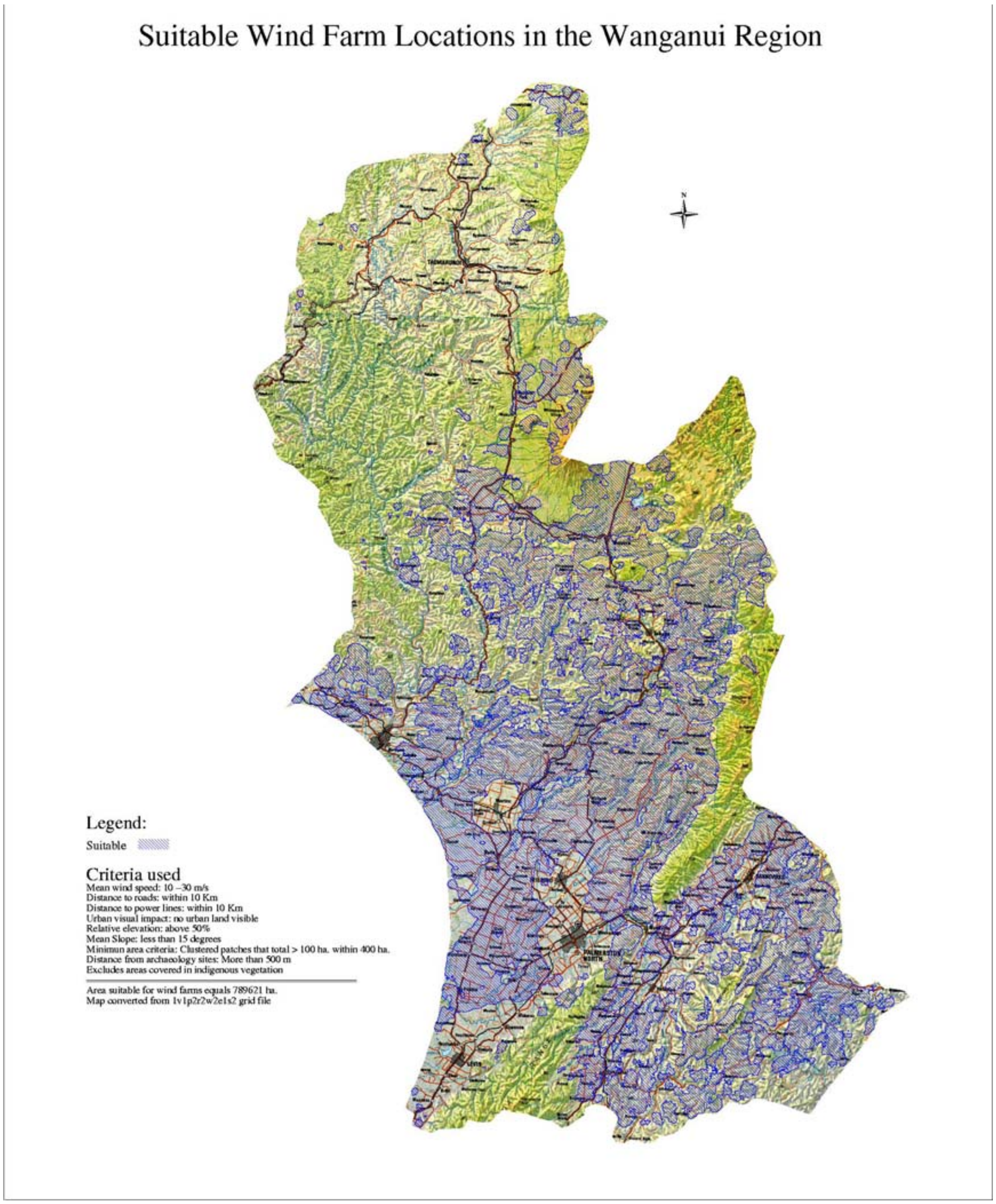
The first category is clustered patches within a certain block area. According to the New Zealand Wind Energy Association, land area that is physically taken up by the wind farm structure is typically in the region of three to four percent of the total area of the entire wind farm. The remaining land area can continue to be used for its original activities (New Zealand Wind Energy Association, 2005). This means that within the proposed wind farm site, it is not necessary to have entire areas suitable for wind farm. As long as the suitable areas occupy higher percentage of total land area, that site will be considered as acceptable.

In this study, a block area of 400 hectare was considered and two minimum clustered patch size threshold used: larger than 100 hectare (25%) or larger than 200 hectare (50%). In AML, the function focalsum was used to find out how many suitable areas lie within 400 hectare block. Then, the CON function was used to exclude block areas below the minimum clustered patch size threshold (see Map 4.15 and Map 4.16).

Map 4.15 includes all cells that are suitable for wind farm and the smallest cell is one hectare. With the clustered patches larger than 100 hectare in a 400 hectare function switched on, Map 4.16 not only excludes areas that did not meet the size requirement, it also joins small patches of cells if they are close together. The significant changes occurred in the central and south west region where lots of individual cells were excluded.



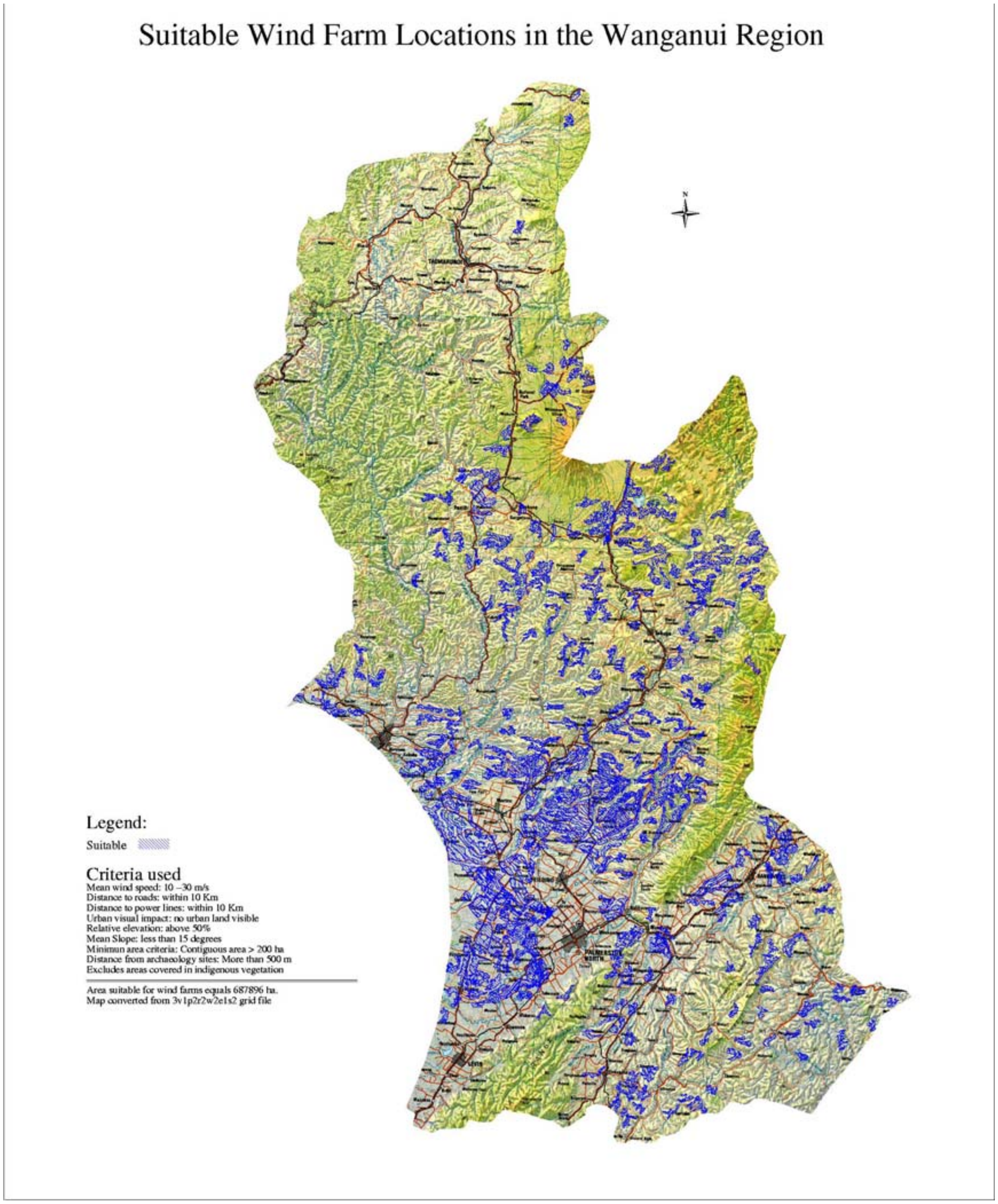
Map 4.15: 0v1p2r2w2e1s2 result map.



Map 4.16: 1v1p2r2w2e1s2 result map with clustered patches larger than 100 hectare in a 400 hectare block.

The second category is contiguous area size. It used contiguous areas size threshold to exclude areas below the threshold. Two thresholds were used here: 200 hectares and 400 hectares. In AML, the result grid file was firstly converted into polygon coverage. Then, the PAT file of the polygon coverage was edited. The select function was used to select areas that were suitable for wind farm where at the same time; the size is larger than the minimum area threshold. After that, the calculate function was used to assign value of 1 to those selected areas and 0 to the rest of the areas. The last step was to convert the edited polygon file back to grid file (see Map 4.17).

Comparing with Map 4.16 and Map 4.17, it can be seen that Map 4.17 only included areas with contiguous area sizes of more than 200 hectares.



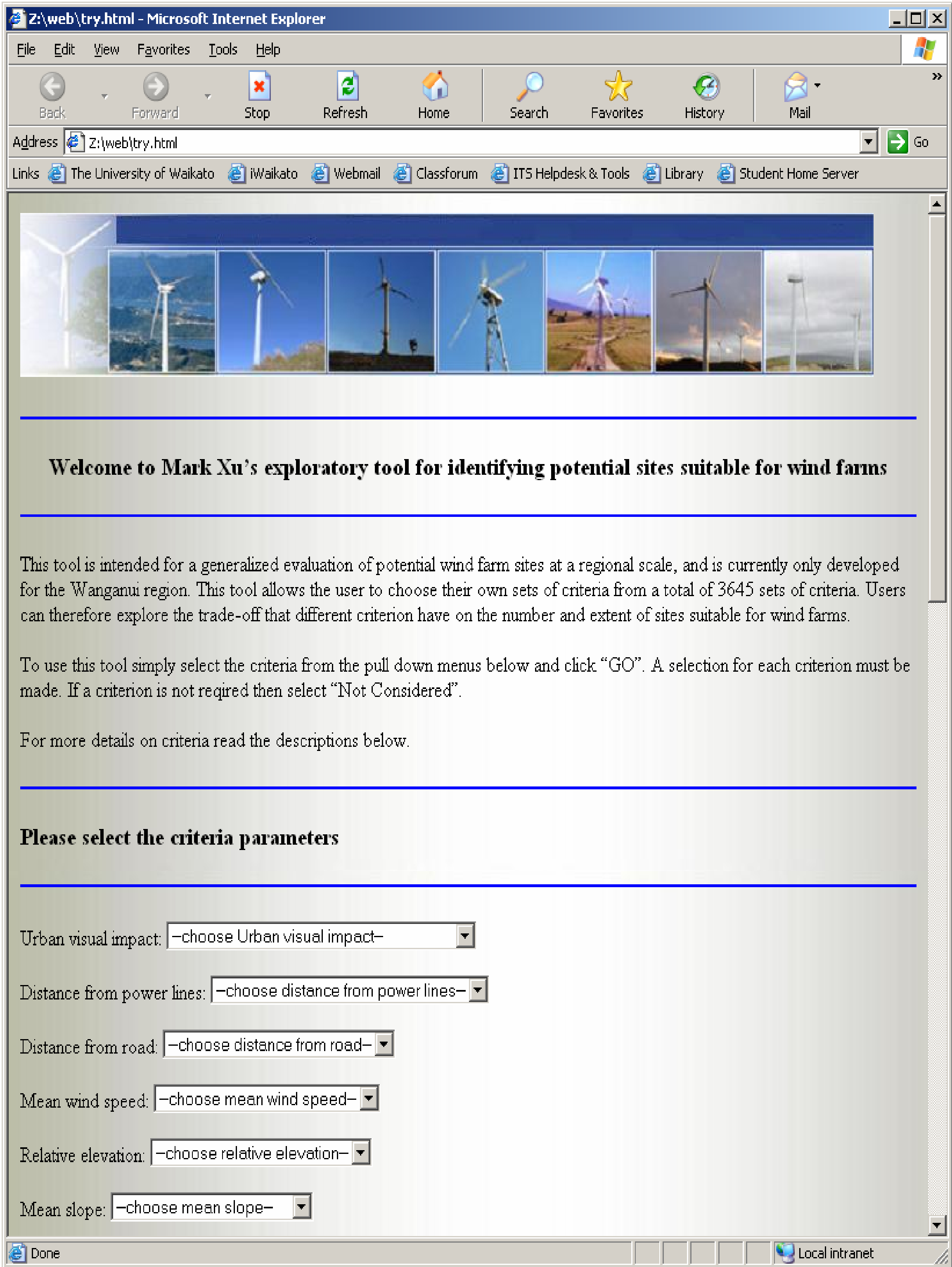
Map 4.17: 3v1p2r2w2e1s2 result map with contiguous area larger than 200 hectare.

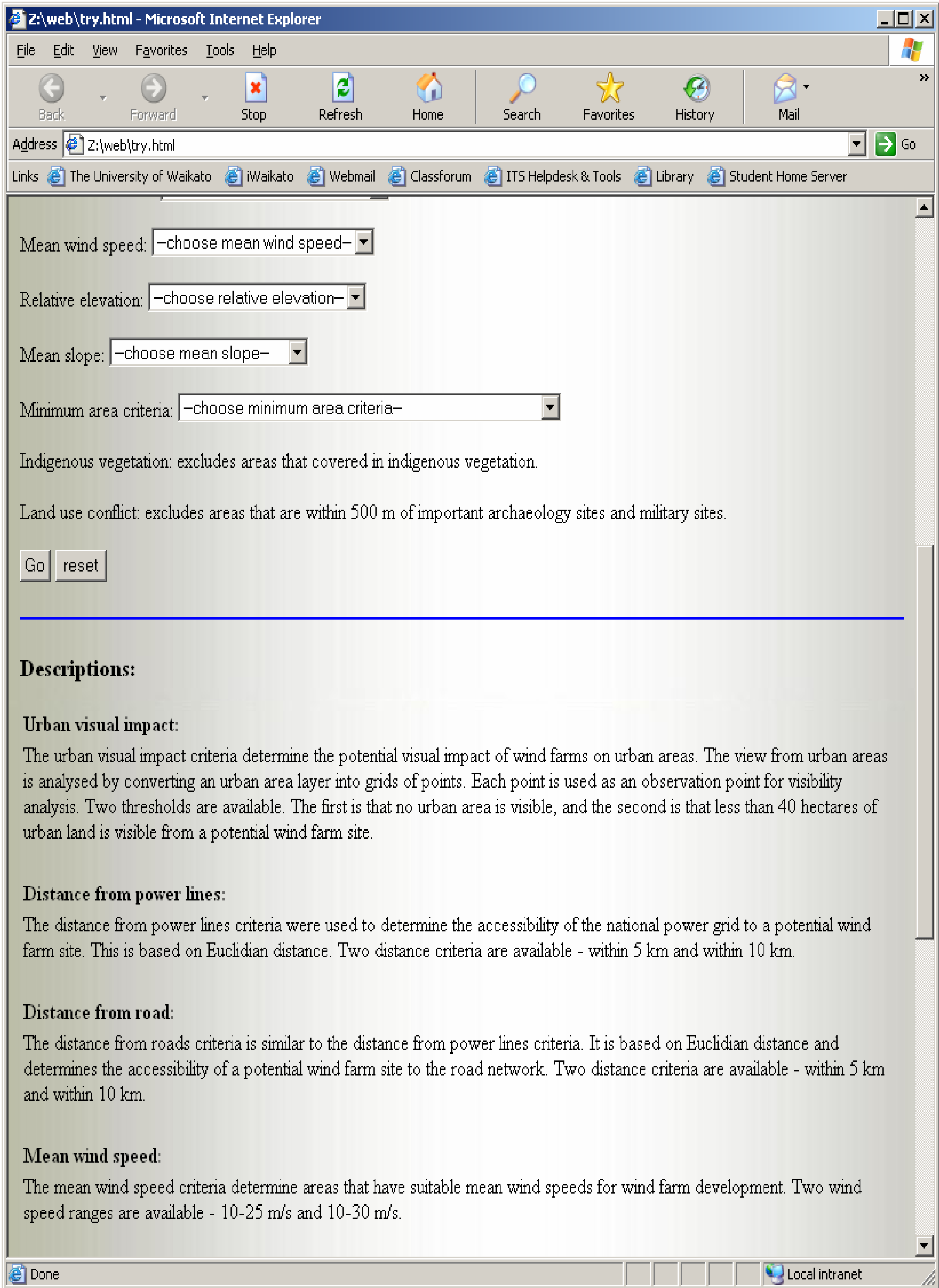
Main module: Print and output function

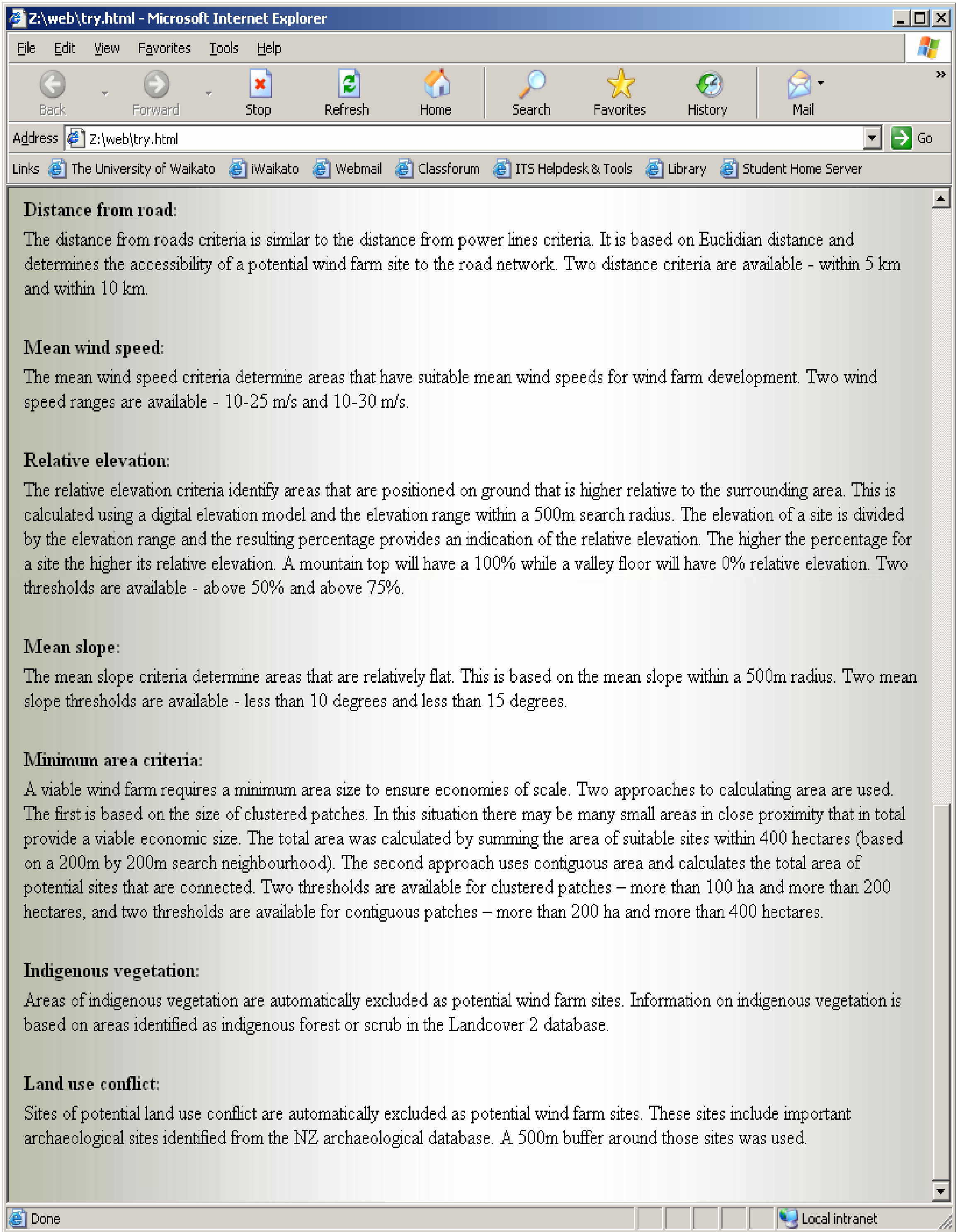
The last function of the main module is the print and output function. This function focused on using ArcPlot to put the results binary map into a map component using ArcPress to export the map component into JPG file. Due to large numbers of different combinations of output maps, this function was used to automate map production. For sensitivity analysis purpose, a web site was built using JavaScript. It requires the JPG file to be able to run successfully. Thus, the output function was used to export all the result maps into JPG file format.

Web site

Once the AML processed all the data and produced all the JPG files, a web site was built for potential users to obtain result maps for different criteria. This web site has been built by using HTML and JavaScript (see Figure 4.2). In this web site, drop down selection boxes are included for users to select different criteria parameters. Once they click on the "Go" button, the JavaScript will automatically acquires the user's input information and open the matching JPG file in a new window.


Z:\web\try.html - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History Mail
Address Z:\web\try.html
Go
Links The University of Waikato iWaikato Webmail Classforum ITS Helpdesk & Tools Library Student Home Server
Welcome to Mark Xu's exploratory tool for identifying potential sites suitable for wind farms
This tool is intended for a generalized evaluation of potential wind farm sites at a regional scale, and is currently only developed for the Wanganui region. This tool allows the user to choose their own sets of criteria from a total of 3645 sets of criteria. Users can therefore explore the trade-off that different criterion have on the number and extent of sites suitable for wind farms.
To use this tool simply select the criteria from the pull down menus below and click "GO". A selection for each criterion must be made. If a criterion is not reqired then select "Not Considered".
For more details on criteria read the descriptions below.
Please select the criteria parameters
Urban visual impact: --choose Urban visual impact--
Distance from power lines: --choose distance from power lines--
Distance from road: --choose distance from road--
Mean wind speed: --choose mean wind speed--
Relative elevation: --choose relative elevation--
Mean slope: --choose mean slope--
Done
Local intranet


Z:\web\try.html - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Forward Stop Refresh Home Search Favorites History Mail
Address Z:\web\try.html Go
Links The University of Waikato iWaikato Webmail Classforum ITS Helpdesk & Tools Library Student Home Server
Mean wind speed: --choose mean wind speed--
Relative elevation: --choose relative elevation--
Mean slope: --choose mean slope--
Minimum area criteria: --choose minimum area criteria--
Indigenous vegetation: excludes areas that covered in indigenous vegetation.
Land use conflict: excludes areas that are within 500 m of important archaeology sites and military sites.
Go reset
Descriptions:
Urban visual impact:
The urban visual impact criteria determine the potential visual impact of wind farms on urban areas. The view from urban areas is analysed by converting an urban area layer into grids of points. Each point is used as an observation point for visibility analysis. Two thresholds are available. The first is that no urban area is visible, and the second is that less than 40 hectares of urban land is visible from a potential wind farm site.
Distance from power lines:
The distance from power lines criteria were used to determine the accessibility of the national power grid to a potential wind farm site. This is based on Euclidian distance. Two distance criteria are available - within 5 km and within 10 km.
Distance from road:
The distance from roads criteria is similar to the distance from power lines criteria. It is based on Euclidian distance and determines the accessibility of a potential wind farm site to the road network. Two distance criteria are available - within 5 km and within 10 km.
Mean wind speed:
The mean wind speed criteria determine areas that have suitable mean wind speeds for wind farm development. Two wind speed ranges are available - 10-25 m/s and 10-30 m/s.
Done
Local intranet



Distance from road:

The distance from roads criteria is similar to the distance from power lines criteria. It is based on Euclidian distance and determines the accessibility of a potential wind farm site to the road network. Two distance criteria are available - within 5 km and within 10 km.

Mean wind speed:

The mean wind speed criteria determine areas that have suitable mean wind speeds for wind farm development. Two wind speed ranges are available - 10-25 m/s and 10-30 m/s.

Relative elevation:

The relative elevation criteria identify areas that are positioned on ground that is higher relative to the surrounding area. This is calculated using a digital elevation model and the elevation range within a 500m search radius. The elevation of a site is divided by the elevation range and the resulting percentage provides an indication of the relative elevation. The higher the percentage for a site the higher its relative elevation. A mountain top will have a 100% while a valley floor will have 0% relative elevation. Two thresholds are available - above 50% and above 75%.

Mean slope:

The mean slope criteria determine areas that are relatively flat. This is based on the mean slope within a 500m radius. Two mean slope thresholds are available - less than 10 degrees and less than 15 degrees.

Minimum area criteria:

A viable wind farm requires a minimum area size to ensure economies of scale. Two approaches to calculating area are used. The first is based on the size of clustered patches. In this situation there may be many small areas in close proximity that in total provide a viable economic size. The total area was calculated by summing the area of suitable sites within 400 hectares (based on a 200m by 200m search neighbourhood). The second approach uses contiguous area and calculates the total area of potential sites that are connected. Two thresholds are available for clustered patches – more than 100 ha and more than 200 hectares, and two thresholds are available for contiguous patches – more than 200 ha and more than 400 hectares.

Indigenous vegetation:

Areas of indigenous vegetation are automatically excluded as potential wind farm sites. Information on indigenous vegetation is based on areas identified as indigenous forest or scrub in the Landcover 2 database.

Land use conflict:

Sites of potential land use conflict are automatically excluded as potential wind farm sites. These sites include important archaeological sites identified from the NZ archaeological database. A 500m buffer around those sites was used.

Figure 4.2: Website interface.

This chapter has described the underlying methodology for wind farm site evaluation that was developed to use the available data. There are total of nine wind farm site evaluation criteria considered. They are wind speed criteria, road network and national power grid accessibility criteria, environmental criteria, land use conflict criteria, relative elevation criteria, slope criteria, visual impact criteria and minimum area size criteria. The description of the model and its various components (called modules) is provided. Numbers of GIS functions such as Focalmean and visibility function etc were used to implement these modules. Some of the key map outputs are shown and they provide the platform for evaluating the effectiveness and accuracy of this model.

Chapter 5

Evaluation and Application

This chapter discusses the evaluation of the wind farm site selection tool produced in this study. It first discusses the binary map methods used, focusing on its advantages and disadvantages. The processing time of this methods and ways to shorten the processing time are also considered. Then, an evaluation of the modules section will be presented to discuss the limitations involved in some of the module. Different approaches to implement this tool will be compared followed by the potential use of this site selection tool. The possibility of applying this model at a national level will be discussed, focusing on data required and a possible modification to the model and processing time needed. Lastly, the tool developed in this study will be compared with WindPRO, an existing wind farm planning tool.

Evaluation of binary map methods

The site selection tool produced in this study used binary map methods to predict suitable wind farm locations in the Wanganui region. It first created different binary maps based on different criteria. Then, map algebra (using Boolean operator "and") was used to combine all the binary maps to create the final suitability map. This approach is also known as "multiply", where all the criteria must be met to be able to derive the value of 1 (Davis, 2001). The final suitability map is expressed only in suitable (1) or not suitable (0) with no possibility of "maybe" (Bonham-Carter, 1994).

The advantage of the binary map approach is its simplicity. In the wind farm site selection case where rules for site selection are set up by requirements, binary combinations are practical and easily applied. However this approach gives equal importance to each criteria being combined. In practice, different criteria need to be weighted so that their relative importance is considered. For example, mean wind speed is a more important indicator than road accessibility. But in the binary map approach, both of them were treated equally.

As mentioned before, the binary map methods are expressed only as suitable (1) or not suitable (0) with no possibility of “maybe”. Sometimes, this could be problematical. For example, what happens if one area meets all the important criteria for a wind farm except for one less important criteria? The tool developed in this study will definitely identify this area as not suitable due to the multiply approach. However, in practice, this area maybe selected as suitable because the criteria that did not meet is not as important as other criteria that did. Thus, the unmatched criteria could be ignored. To deal with this problem, a different approach called binary rating model could be used. The difference between those two approaches is the map algebra used. In the binary rating approach, different binary maps are combined using map algebra operation “Add” instead of “Multiply” (Davis, 2001). By doing so, the final suitability map will contain the score of different areas. Users can set up thresholds that can be used in this method to select areas that are above a certain score. For example, if there are 7 criteria used for wind farm site selection, the rating approach could assign scores to different areas ranging from 7 (all of the criteria are met) to 0 (none of the criteria are met). With this score, user can set up a threshold, say, 5 and selecting areas that meet more than 5 criteria as suitable for wind farm development.

Processing time

The running time for process data and overlaying of different combinations of binary result maps is about eleven days. Most of the running time was spent on visibility analysis and binary map overlay (see Table 5.1). The estimated processing time for using this tool at national level also included and it is discussed in the later section. For visibility analysis, there is a total of more than 5000 observation points. Thus, it took about three days to conduct the analysis. The binary map overlay took about six days. This is because many different combinations need to be pre-processed (a total of 3645 combinations). After all the combinations have been processed, the system took about two days to produce maps (JPEG files) of each combination. The total size of JPG files are about 3 G. The running time of this approach depends on the performance of the computer. But it could be significantly reduced by using high performance computers. The input data quality also has an effect on the running time. In this study, 50 m and 100 m cell size were used. With more resolution such as 10 m or 25 m cell size, the analysis time will increase. One more way to decrease the running time is to run the model on separate computers. With some alternation of the AML code, the model could be running simultaneously on different computers.

Module and process	Processing time (Regional)	Estimated processing time (National)
Wind speed module	10 minutes.	2 hours
Road accessibility module	10 minutes	2 hours
Power grid accessibility module	10 minutes	2 hours
Environmental module	10 minutes	2 hours
Land use conflict module	10 minutes	2 hours
Terrain module	30 minutes	6 hours
Visibility module	3 days	37.5 days
Binary map overlay	6 days	75 days
JPG output	2 days	25 days

Table 5.1: Module, process and processing times.

Module evaluation

This section will focus on evaluation of some of the modules developed in this study. It will discuss some limitations involved in those modules.

Wind speed module

The wind speed module developed in this study focused on selecting a suitable wind speed range for wind farm development. The wind speed data used here were mean wind speed data. The consistence and direction factor were ignored at this stage. In practice, these factors need to be considered carefully. For example, imagine an area with very high wind speed for 2 or 3 months, but slow wind speed for the remaining time. The mean wind speed data will average out the wind speed, thus making this area suitable for a wind farm. This may be problematic due to the factor that for most of the time, energy production rates in that area are very low.

Road and power grid accessibility module

In the road and power grid accessibility module, the Euclidian distance between area and road or power lines were used to determine the accessibility. In real life situation, factors such as terrain characteristic should also be taken into consideration. For example, in this study, the Ruahine Range was identified as suitable because it was within a 5 km road buffer. In practice, it is very difficult to place wind turbines in those places because of the ragged terrain characteristic.

Land use conflict module

In the land use conflict module, it set up a 500 m buffer around all the protect sites such as archeology sites and military bases etc. The major disadvantage of this module is that this module used points shape file to represents the location of the protected sites. The actual area extents of those sites were ignored. This may decrease the accuracy of the output binary map. For example, if a military base is larger than a 500 m buffer, the area outside the buffer will be considered as suitable for wind farms. In this case, these areas shouldn't be selected.

Environmental module

The environmental module only considered the impact on indigenous vegetation covers. The impacts on endangered bird species and other animal species were not considered. This may be problematic sometimes, especially when the wind turbine placed near the migration path of bird species. It may increase the birds' fatality risk. Another limitation of this module is that the wetland and other protected nature land form were ignored.

Visibility module

The visibility module in this study used urban land area as an indicator of visual impact analysis. This means that if the urban land area increases, the visual impact will increase accordingly. In practice, visual impact has direct link with population effected by the wind farm development. This means that the more people can see the wind turbine, the greater the visual impact on them. Thus, urban populations also contribute to the visual impact. In this study, the urban population was ignored. It may cause some problem in practice. For example, town A and town B might have a similar area, but town A has a population twice that of town B. In this study, the visual impact on these two towns will be similar. But in practice, the visual impact in town A should be much more severe compared with town B, thus, turbine placements should be further away from town A.

Terrain module

In this study, the terrain module identified the area near the mountain top as more suitable than the area near the foot. In theory, this is a very good idea because the area on the mountain top will have uninterrupted wind. In practice, the construction cost will increase as it is harder to transport those turbines up the mountain.

Comparing different methods for delivering results

Static map approach

The wind farm site selection tool developed in this study used the static approach. This means that all the data and binary result maps have been pre-produced. This approach allows the end user to access fixed map data and they do not require ArcGIS tools to conduct any analysis. Figure 5.1 shows the steps involved in the static map approach.

The advantage of this static approach is that the end user does not need expensive ArcGIS software or internet map server (IMS) to conduct analysis and the result JPG files could be shared around. It also created the opportunities to put this site selection tool online for public interest. It is also easy to implement. The major disadvantage is that this approach required a large amount of time to pre-process data and it is less flexible. All the requirements have to be pre determined. The end users only have limited options to select from; they also cannot directly interact with static maps

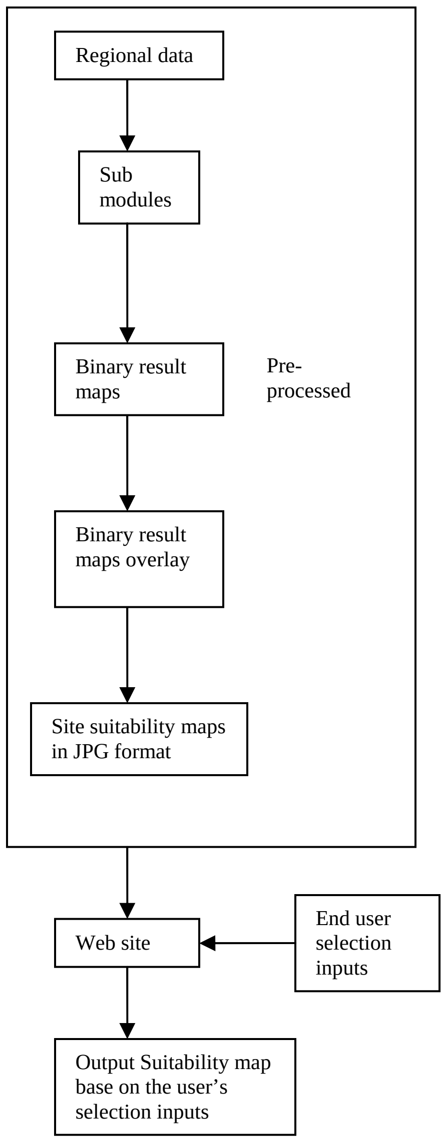


Figure 5.1: Static map approach components and steps.

Dynamic ArcIMS approach

An alternative way to develop this tool is to use the dynamic ArcIMS approach. This approach gives the end user the ability to choose what information they want to display and allows users to set up whatever criteria parameters they desired. There are four main components in ArcIMS: ArcIMS spatial server, ArcIMS application server, ArcIMS connectors and web server (ESRI Development Network, 2007). ArcIMS spatial server provides the capabilities for accessing the GIS data, rendering the map and sending the responses back to other components. ArcIMS application server handles the load distribution of incoming requests. ArcIMS connectors connect the web server to the ArcIMS application server. Web server provides communication with map services using the HTTP protocol. They can be grouped into client side components and server side components (see Figure 5.2 for more details). Compared with a static map approach, it is much more flexible and more dynamic. However, the major disadvantage of this approach is that it is hard to implement. The programmer needs sound knowledge in database programming, website programming and ArcIMS software programming. This approach needs a web server to host the website and ArcIMS components to conduct analysis. They are not cheap to obtain. The price for ArcIMS is $7,500 USD for the first CPU and $5,000 for each additional CPU. Web server costs about $150 annually. One more weakness of this approach is that there is constant maintenance work involved with the server side components once it has been developed, including system maintenance, web server maintenance and data updating.

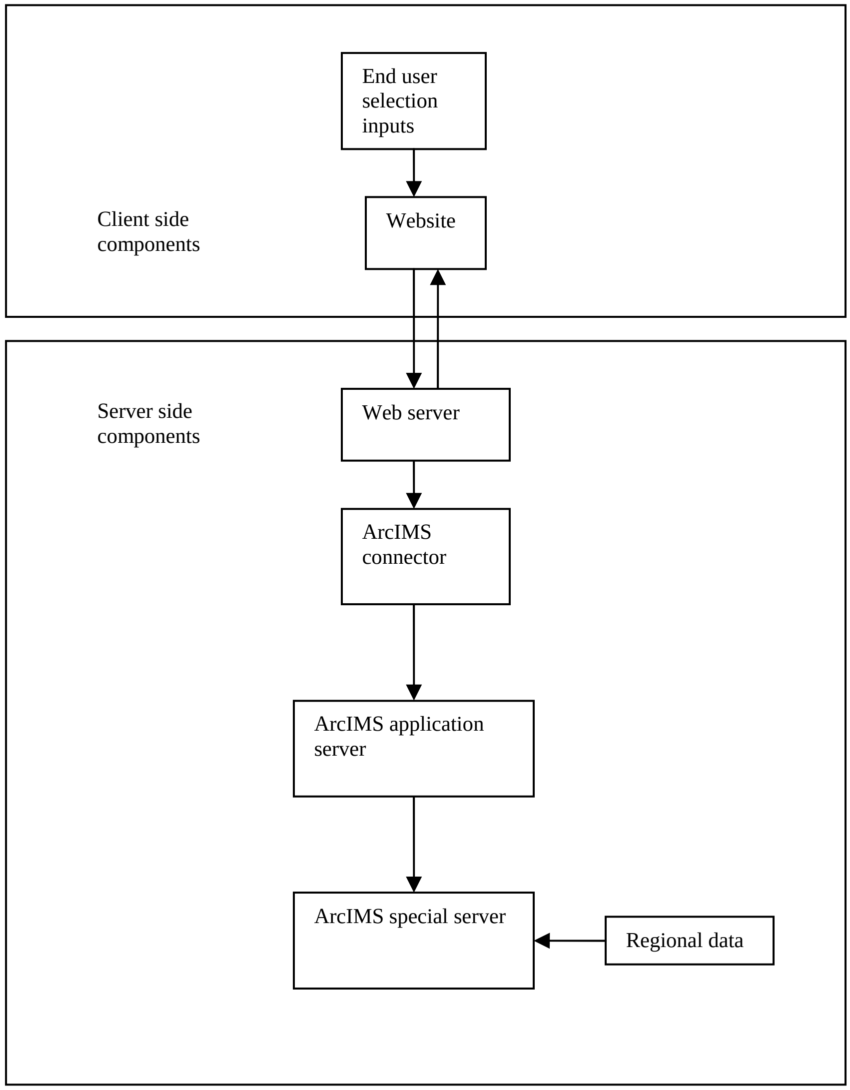


Figure 5.2: ArcIMS approach components and steps.

Desktop approach

Another alternative method to develop the wind farm site selection tool is to use the desktop approach. In this approach, desktop software could be developed using programming languages such as AML. The desktop software consists of two parts: Graphics user interface (GUI) and analysis modules. The GUI interface provides the function for users to set up their own desired parameters. After that, the parameters will pass to analysis modules. The analysis modules will produce suitability maps based on the user's parameters inputs (see Figure 5.3). The difference is that for this approach, the end user must have ArcInfo to be able to run the site selection tool interface (if the interface is developed in AML). The end user inputs criteria at an early stage and the site selection tool will then produce a site suitability map based on the inputs criteria. The advantage of this approach is its flexibility. The end user can input what they want. The entire process only needs to run once to output the suitability map, thus, less run time is required. The disadvantage is the end user must have ArcInfo and necessary data on their computer, thus making it harder for the public to access this tool.

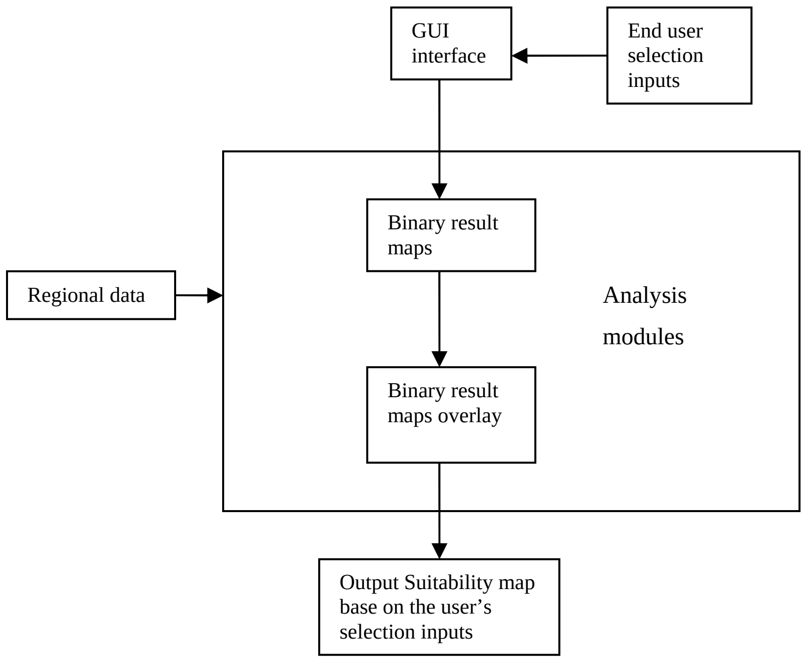


Figure 5.3: Desktop application approach components and steps.

Potential use of wind farm site selection tool

The initial scoping of this study is to design a GIS based site selection tool for energy companies that identifies range of suitable sites available for wind farm development. During the wind farm planning process, developers and planners can use this tool to identify suitable areas for wind farms. Once the suitable areas have been identified, they can conduct more detailed analysis on those areas and choose the optimal one. Because this tool does not need an ArcInfo installed, it can be accessed anywhere (i.e. during public hearings to show that proposed wind farm will have minimum visual impact on the local population). This tool also could be put online for the public's interests.

The main focus of this tool is to give the regional planners or developer from corporate sector the ability to minimize the risks involved in wind farm development by identify areas that less effected by development risks.

There are two types of risks existing in wind farm development: economic risks and environmental risks. The planner can use this selection tool to select areas that are not exposed to those risks by setting up the desired criteria parameters (see Table 5.2). Normally, highly restrictive criteria parameters will be used to identify areas have low risks.

The economic risks include wind farm construction costs and potential energy output. To maximize the profit of wind farms, planners need to minimize the construction costs and maximize the energy output. To minimize the construction costs, the wind farms should be placed close to a road in order to decrease the transportation cost and close to the power gird to minimize the amount of power line needed to connect wind farms to the grid. The slope also may contribute to the transportation cost. Higher slope means that it is harder to transport the turbines thus increasing the costs. The wind turbines also need to be placed on high ground and in a high wind speed area to maximize the energy output. The selection tool can give planners the ability to alter the criteria parameters to locate areas that have low economic risks (i.e. using criteria parameters such as less than 5 km from road, less than 5 km form power grid, less than 10 degrees of mean slope, above 75% of relative elevation and wind speeds between 10-30 m/s).

The environmental risks include impact on indigenous vegetation, visual impact on nearby urban areas and possible land use conflict. With the site selection tool, planners can set up desired criteria parameters to exclude areas that are exposed to those risks (i.e. using criteria parameters such as being away from indigenous vegetation, minimum urban visual impact and greater distance from possible land use conflict locations).

As mentioned before, wind farm developments are controlled by regional councils and attitudes towards their development differ between regions to regions. Some regions think that economic needs are more important than the environment protection, whilst others think that environment protection is more important; others think they are equally important. This selection tool gives planners the ability to select wind farm locations based on the region's needs. For example, if a region thinks environment is more important than economy, planners can use highly restrictive environmental criteria parameters combined with less restrictive economic criteria parameters (see Table 5.3). Thus, this site selection tool gives the planners the ability to conduct the trade-off analysis between the environment protection and economic benefits.

Risk Types	High risk	Low risk
Economic risks	Low wind speed, greater distance away from road and power grid, high mean slope, low relative elevation	High wind speed, less distance away from road and power grid, low mean slope, high relative elevation.
Environmental risks	Indigenous vegetation exists, high urban visual impact, possible land use conflict exists.	Away from indigenous vegetation, minimum urban visual impact, greater distance from possible land use conflict areas.

Table 5.2: Level of risks and correspondent criteria parameters.

Regions' needs	Environmental criteria parameters	Economic criteria parameters
Economic needs more important than environmental protection	Less restrictive	Highly restrictive
Environmental protection more important than economic needs	Highly restrictive	Less restrictive
Both important	Highly restrictive	Highly restrictive
Both not important	Less restrictive	Less restrictive

Table 5.3: Regions' needs and correspondent criteria parameter restrictiveness

Another potential use of this selection tool is to conduct sensitivity analysis. The sensitivity analysis defined as a procedure to determine how changes to each parameters impact on the outcomes. If a small change in a parameter results in relatively large changes in the outcome, the outcomes are said to be sensitive to that parameter (Web Dictionary of Cybernetics and systems 2007). This tool could be used by developers to determine how changes to some of criteria impact on the actual wind farm site selection outcomes. For example, if developers want to analysis the impact of wind speeds on wind farm site selection, they can change the wind speed criteria and compare the total suitable areas size for different wind speeds. In this study, the relative elevation criteria have most impact on the outcomes. Above 50% and above 75% of relative elevation were used in this study. For above 50%, there are total of 963,979 hectares were identified as suitable for wind farm. For above 75%, the total area size was decreased dramatically to 288,921 hectares. Thus, the wind farm site selection is sensitive to relative elevation.

Possibility to model whole of New Zealand

At this stage, the main focus of this study is to develop a predictive tool at a regional level. In the future, there is a potential for applying this tool at a national scale. This would require a few modifications to this tool. Firstly, the data used for national scale needs to be reconsidered. All the data used for national scale prediction must be at a national scale. The cell size for national data cell size needs to be reconsidered. For regional scale, the cell size of 100 meters was used. For national scale, cell size needs to be altered to decrease the processing time. Secondly, masks used in regional scale prediction must be changed to regional scale. In regional scale, Wanganui region shape file were used as analysis mask to limit the analysis only on the Wanganui region. For national scale, the analysis masks needs to be set to the whole of New Zealand. Since the cell size and analysis masks were set up in the AML code, the AML code needs to be changed too.

The Wanganui region occupies about 8% of the total New Zealand land area size. Thus, we can estimate processing time at national level, which is about 138 days (see Table 5.1). The processing time may decrease with change of data cell size. However, some modules may take longer time to run. Using the visibility module as an example; it converted urban land into point to use as observation point. The numbers of points are dependent on urban land area size. Compare with the Wanganui region, the Auckland region has a much larger urban land area. Thus, the estimated processing time for visibility module will increase dramatically. As mentioned in processing time section, the running time could be decreased by break down the model and run the modules simultaneously on different computers.

Comparison of existing wind farm planning tool

There are many wind farm planning tools available, but the most frequently used tool is WindPRO. WindPRO is a Windows modular based software. The different modules in WindPRO are fully integrated, which means that a change in input data in one of the modules will automatically been recorded on all other modules and calculations will be revised accordingly.

The WindPRO software package consists of several modules, each with a specific purpose (EMD international, 2007). Those modules can be grouped into two parts: wind farm site designing and wind farm site selection. The focus here is to compare the wind farm site selection part. For site selection, the WindPRO used environmental impact assessment module and grid and planning module to select desired sites. The environment impact assessment focused on calculation of visual impact for a specified area, calculation of shadow impact, noise calculations and land use conflict calculations. The planning module focused on site finding based on GIS data. Figure 5.4 shows an example result map produced by land use conflict calculations and Figure 5.5 shows an example result map produced by visual impact module. Compare with result maps from site selection tool developed from this study, result maps from WindPRO used multi-class categorization, where result maps from this study used binary categorization. The multi-class categorization has the advantage of showing more details on the result map but sometimes it is harder for user to interoperate. The binary categorization is easy to implement and very simple yet effective to show the result.

Because WindPRO is a desktop software suit, it requires the user to buy a license to use it and it is also very expensive. Compared with WindPRO, the tool developed in this study used a similar programming approach (modular based). The difference is that the main focus of this tool is to explore suitable wind farm areas and it used the static map approach to display the result. It is much easier to implement and it is very convenient for public to access it.

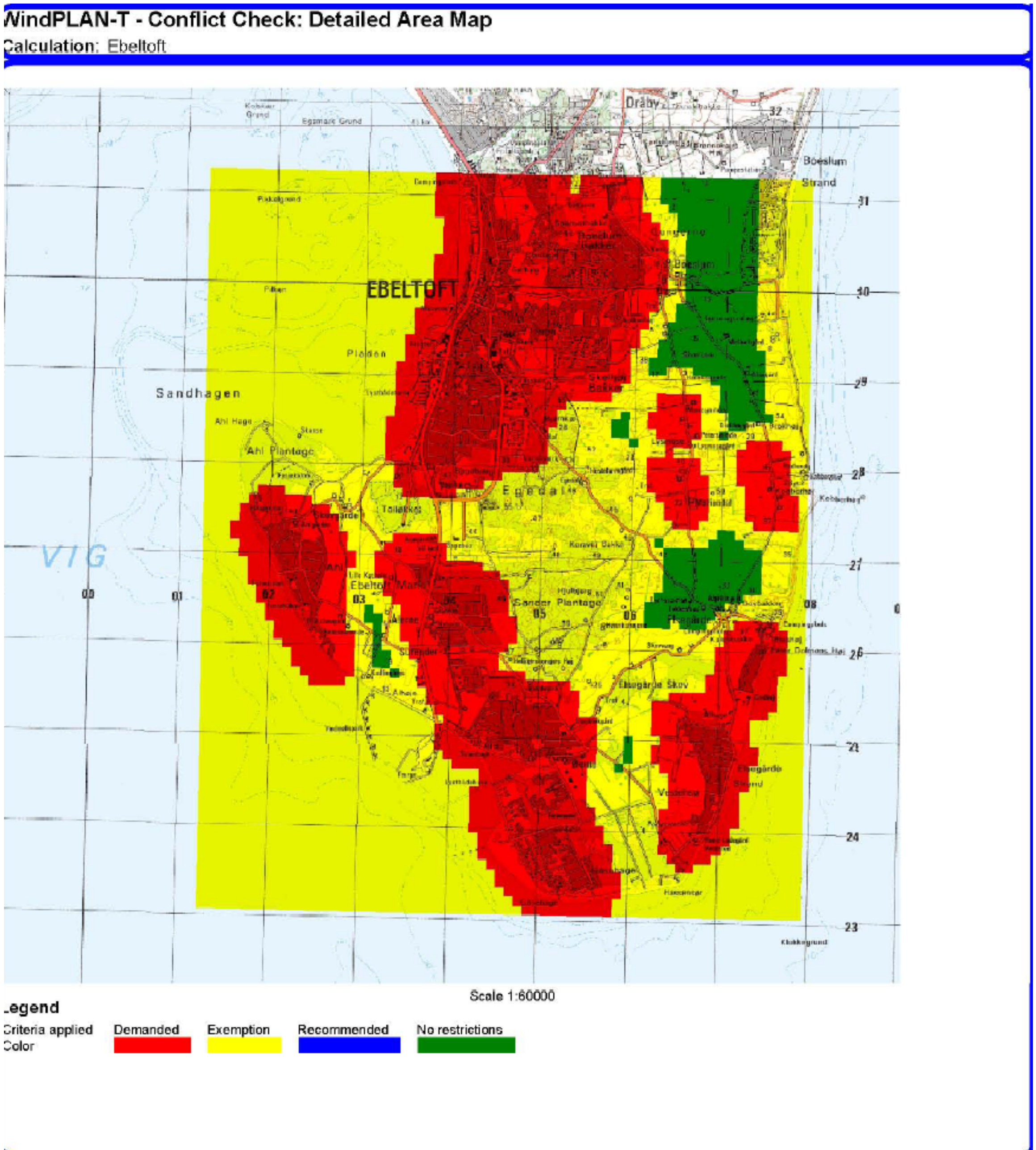


Figure 5.4: Land use conflict result map from WindPRO

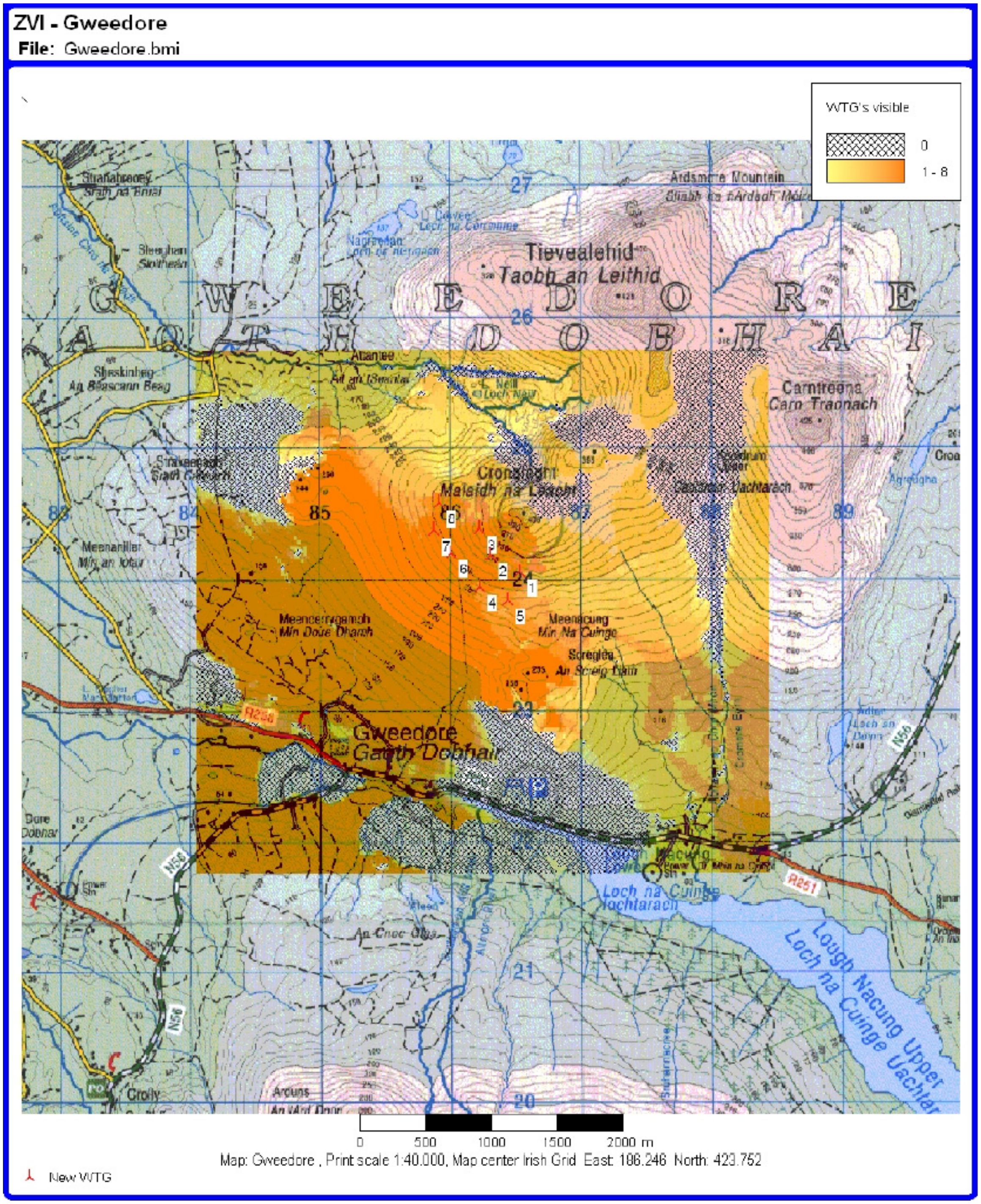


Figure 5.5: Visual impact result map from WindPRO

Chapter 6

Conclusion

Overview

The question this thesis attempts to address is whether it possible to devise GIS based models that will provide effective decision support frameworks for evaluating wind farm sites. In this concluding chapter I argue that, on the basis of the evidence provided, GIS based models can provide effective decision support frameworks for wind farm site selection. The following paragraphs review the evidence and the processes carried out in the analysis.

I begin by introducing the broad set of issues that underpin climate change. A review of these issues provides a platform for a discussion of emergent interest in wind power as an alternative renewable energy resource. The discussion led to an awareness of the interest in a set of guidelines for establishing wind farms in both international and New Zealand contexts. In the context of site evaluation there is a requirement for clear explanations of what are the effective decision support frameworks for evaluating wind farm sites. The critical matter is that an effective decision support framework should help developers to identify suitable wind farm sites which minimise the environmental impact and maximise the economic benefit.

Chapter three illustrates the theoretical considerations revealed in the literature on wind farm site selection. I have organised this chapter in two parts. The first part discusses criteria used to solve problems involved in the wind farm site selection process. I focus on the evaluation of different theoretical and applied criteria developers used in their wind farm site selection tools and the data used in their applications. The second part focuses more closely on algorithms and processes wind farm site modellers used to handle the data. I compare the different methods used to implement the various site selection tools. Based on this review of the theory and applications in site selection, a set of criteria for a wind farm site evaluation tool is devised and a method to apply this tool is introduced. The literature review is an essential part of the study as it provides the grounds for criteria selection and some guidance on the way the proposed model structure can be developed.

In the methodology chapter, I describe how the GIS based site selection tool is developed. I first discuss scale considerations and the study area selection. In the comments I illustrate the rationale behind choosing a regional scale rather than a national scale. I also explain the reasons for choosing the Wanganui region as study area. The section that follows this discussion describes the data preparation for the site selection process; the data need to be configured for effective use in the site selection tool. I outline the preparation of raw data, explain the work done on derived data and the way I use the data in the model. A summary data flow diagram is presented to illustrate how data flows within the model. After that, components of the analytical model and model implementation are presented to explain in detail what kinds of GIS tools were used to implement the analytical modules. In the chapter I also include a graphic description of results derived from different modules.

Chapter five provides an extensive evaluation section. In the chapter, I discuss the various performance criteria used in the evaluation of the site selection tool. I first discuss the binary map methods used in this study, focussing on the fundamental principles, the algorithms involved and the processing time required. The advantages and disadvantages of various approaches are discussed. Following this, I present a module evaluation to illustrate the limitations in some of the modules. Then, different ways of delivering the analytical results are compared: the static map approach used in this study is compared first with the dynamic ArcIMS approach and then the desktop approach to illustrate the advantages and disadvantages involved with these different approaches. I also consider the site specificity of the work undertaken in this study and the potential use of this tool at a national scale. In my view it would be necessary to modify the data and model structure of the prototype tool to have national value. In the final section of the chapter, I compare the tool developed in the study with an existing wind farm planning tool called WindPro. In this section I discuss the advantages and disadvantages of these two tool sets.

Summary of main findings and limitations of the analysis

The main finding of this study is that GIS based models can provide effective decision support frameworks for evaluating wind farm sites. In the study I identify environmental and economic issues involved in wind farm site selection and the impact those issues have on wind farm site selection. By relating these findings to previous research on wind farm site selection, I throw new light on the criteria needed for decision support frameworks to be effective. Environmental impacts can be shown to be at least as significant as the physical site parameters. My model allows the user to trade-off, removing the impact of one criterion if it is considered to be an effect that can be mitigated.

The sub question of how GIS models can help to solve wind farm site selection issues is answered by analysing and comparing different approaches and models used to implement site selection tools. Based on those findings, I develop a GIS-based model and implement a site selection tool. By using this site selection tool in the Wanganui region study area, I identify suitable wind farm sites, and these outcomes are tested against the real world sites selected for wind farm development. The existing wind farm placements in the study area verify that this tool can provide an effective decision support to select suitable wind farm locations.

The emphasis in this research is on the exploration of method, and the testing of available data within the model developed. The data quality is clearly a matter that needs to be considered. Regional data used in this study were clipped from national data. In practice, corporate developers often develop their own datasets of physical, environmental and economic data for each site. These data have higher quality and accuracy than the ‘proxy’ data I was able to access for this analysis.

A second limitation was the analytical power available to run the models. The ArcGIS platform has many attractive features, but it is a generic GIS and many of the major corporate developers doing this work have more powerful computing resources, and access to industry packages.

Despite these limitations, the thesis claims some success in the exploration of site selection modelling.

Future research

In the evaluation chapter, I identify a number of opportunities for further research. These opportunities could address some of the matters unresolved in this study because of time constraints, the limitations of processing power and the need to use secondary data at a sub-national rather than site-specific level.

A future research agenda could work to build on this research in the following ways, with the aim of improving the performance of the wind farm site selection tool with reference to:

- Consideration of consistency and direction factors for the wind speed module. The mean wind speeds used in this study did not include the wind speed consistency information that would be required for evaluation of potential wind farm sites. Direction and consistency data could be included in the wind speed module to improve the accuracy of this module.

- Consideration of terrain characteristics in the road and power grid accessibility module. This work could include terrain characteristics such as slope in the accessibility module. The aim would be to exclude areas that lay within the desired road or power line distance, but which would create difficulty for the transportation of materials and turbines to sites due to terrain constraints.

- Consideration of endangered bird species and other animal species in the environmental module. The locations of habitats and migration paths of endangered bird species could be used in the environmental module to create buffers around these locations. By placing wind turbines outside those buffers, the habitats and migration paths of bird species would be protected.

- Consideration of population density in the visibility module. The Census data for urban population could be used in the visibility module to include population factors more explicitly. Incorporating Census data will improve the reliability of visibility module.

- Use of the actual area extent for archaeology sites and military sites. Due to the data availability, a point shape file was used to represent locations of potential land use conflict sites. The points shape file did not show the actual areal extent of those sites, thus the accuracy of this module was compromised. In the future, the polygon shape files rather then a points shape file could be used to improve the accuracy.

- Expansion of the environmental module. In this study, only the indigenous vegetation and scrub have been considered. In future developments, other environment factors such as noise, wet land and conservation areas could be considered to make this module more comprehensive.

The thesis in the context of national energy issues

This work is not just of interest to geographers, GIS scientists, modellers and engineers. As the opening paragraphs of this thesis indicate, concerns like sustainability are increasingly debated in the public domain. With the rising awareness of climate change (Stern Report, 2006) and depletion of non-renewable resources, renewable energy has become more important globally. New Zealand, with over 70% of its energy generation being from renewable sources, and the capacity to increase energy generation from sources such as wind power, is in a relatively good position. However, the country is still vulnerable to the declining global stocks of fossil fuels like oil, and recent government initiatives associated with the signing of the Kyoto protocol (New Zealand Treasury, 2007) have significant positive impact on the renewable energy sector.

In terms of renewable energy resources, wind farms do not always have wide appeal, nor are they free from environmental impact. But, in the contemporary debate about energy policy in New Zealand, and the widely publicised case for carbon neutrality, energy from renewable sources has become increasing important for environmental and economic reasons. Ways of assessing the suitability of different sites can contribute to the identification of the best sites meeting both environmental and economic criteria. While the physical sciences, environmental sciences and economics all contribute to site evaluation, the key processes and the data that report the operation of this process all have to be seen and understood spatially. Traditionally this spatial analysis has been carried out in Geography, and the development of GIS in the last 15 years has greatly increased the capacity of geographers to carry out this work.

More recently our ability to build models in GIS has increased the value of the contribution geographers can make. My aim was to build a model of the wind farm site evaluation process based on assessing multiple criteria, and to test this against a known spatial distribution of wind farm sites. As the evaluation carried out in chapter five indicates, the process worked well enough with the case study site in Wanganui that further development of this approach should be encouraged.

References

Ashby, M., 2004: *Wind's up - Planning the future now*. Retrieved 21 Oct 2006 from: http://www.eeca.govt.nz/eeca-library/renewable-energy/wind/report/winds-up-planning-the-future-now-report-04.pdf

Abler, R., Adams, J.S. and Gould, P., 1972: *Spatial organisation: The geographer's view of the world*. London: Prentice-Hall International.

Berry, B.J.L. and Marble, D.F. (eds.) 1968: *Spatial analysis: A reader in statistical geography*. London: Prentice-Hall International.

Bonham-Carter, G.F., 1994: Tools for Map Analysis: Multiple Maps. In Merriam, D.F., (ed.), *Geographic Information Systems for Geoscientists: Modelling with GIS*, Pergamon, 267-337.

Chakhar, S., 2003: Enhancing Geographical Information Systems Capabilities with Multi-Criteria Evaluation Functions. *Journal of Geographic Information and Decision Analysis* 7 (2) 47-71.

Davis, B.E., 2001: Site Suitability and Models. In Clark, S., (ed.), *GIS: A Visual Approach*, Onword Press, 317-348.

EMD International, 2007: *WindPRO Modules*. Retrieved 12 May 2007 from: http://www.emd.dk/WindPRO/Modules/

Energy Efficiency and Conservation Authority, 2001: *Review of New Zealand's wind energy potential to 2015*. Retrieved 10 Nov 2006 from: http://www.windenergy.org.nz/documents/Pre04/

Energy Efficiency and Conservation Authority, 2004: *UMR wind research report*. Retrieved 12 Jan 2007 from: http://www.eeca.govt.nz/renewable-energy/wind/index.html

ESRI Development Network, 2007: *Introduction to the ArcIMS API*. Retrieved 19 July 2007, from: http://edndoc.esri.com/arcobjects/9.2/Java/java/ArcIMS/arcims_apis_ovw.htm

European Wind Energy Association, 2004: *European best practice guidelines for wind energy development*. Retrieved 6 Jan 2007 from: http://ec.europa.eu/energy/res/sectors/doc/wind_energy/best_practice.pdf

Greenpeace and Global Wind Energy Council, 2006: *Global wind energy outlook*. Retrieved 2 Jan 2007 from: http://www.greenpeace.org/international/press/reports/globalwindenergyoutlook

Hansen, H.S., 2005: GIS-based Multi-Criteria Analysis of Wind Farm Development. Retrieved 3 Feb 2007 from: http://www.scangis.org/scangis2005/papers/hansen.pdf

Hopwood, N. and Cohen, J., 2006: *Greenhouse Gases and Society*. Retrieved 12 Nov 2006 from: http://www.umich.edu/~gs265/society/greenhouse.htm

Hoffman, J.J. and Schniederjans, M.J., 1994: A Two-stage Model for Structuring Global Facility Site Selection Decisions: The Case of the Brewing Industry. *International Journal of Operations & Production Management*, 14 (4), 79-96.

Hurtado, J.P., Fernandez, J., Parrondo, J.L. and Blanco, E., 2003: Spanish method of visual impact evaluation in wind farms. *Renewable and sustainable energy reviews* 8, 483-491.

Jansen, R. and Rietveld, P., 1990: Multi-criteria Analysis and Geographical Information Systems: an Application to Agricultural Land Use in the Netherlands. In Scholten, H.J. and Stillwell, J.C.H., (eds.), *Geographical Information Systems for Urban and Regional Planning*. 129-139.

Johnston, R.J., Gregory, D., Pratt, G. and Watts, M. editors, 2000: *The Dictionary of Human Geography*. Oxford, UK: Blackwell.

Kiranoudis, C.T., Voros, N.G. and Maroulis, Z.B., 2001: Short-cut design of wind farms. *Energy policy* 29: 567-578.

Merwe, V. and Hendrik, J., 1997: GIS-aided land evaluation and decision-making for regulating urban expansion: A South African case study. *GeoJournal* 43: 135-151.

Ministry for the Environment, 2007: *New Zealand's greenhouse gas inventory 1990-2005: an overview*. Retrieved 12 Jan 2007 from: http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-overview-jul07/index.html

National Renewable Energy Laboratory, 2001: *Philippine wind farm analysis and site selection analysis*. NREL/SR-500-30934.

National Renewable Energy Laboratory, 2001: *Sri Lanka wind farm analysis and site selection assistance*. NREL/SR-710-34646.

Nesrin, T., 2006: GIS Based Geothermal Potential Assessment for Western Anatolia. M.Sc. Thesis, The Graduate School of Natural and Applied Sciences, Middle East Technical University.

New Zealand Wind Energy Association, 2007: *Climate change and the environment*. Retrieved 3 Jan 2007 from: http://www.windenergy.org.nz/FAQ/factsheet3climate.htm

New Zealand Wind Energy Association, 2007: *Wind resource of New Zealand*. Retrieved 3 Jan 2007 from: http://www.windenergy.org.nz/FAQ/resource.htm

New Zealand Wind Energy Association, 2007: *Wind farm basics*. Retrieved 3 Jan 2007 from: http://www.windenergy.org.nz/FAQ/factsheet1basics.htm

New Zealand Wind Energy Association, 2007: *Wind turbine sitting*. Retrieved 3 Jan 2007 from: http://www.windenergy.org.nz/FAQ/factsheet5siting.htm

New Zealand Wind Energy Association, 2007: *Birds and Bats*. Retrieved 3 Jan 2007 from: http://www.windenergy.org.nz/FAQ/factsheet8birds.htm

New Zealand Wind Energy Association, 2007: *Siting*. Retrieved 3 Jan 2007 from: http://www.windenergy.org.nz/FAQ/factsheet5siting.htm

New Zealand Standard NZS 6808, 1998: Acoustics – The assessment and measurement of sound from wind turbine generators, *New Zealand Standards*.

Rodman, L.C. and Meentemeyer, R.K., 2006: A geographic ananlysis of wind turbine placement in Northern California. *Energy Policy* 34: 2137-2149.

Rogers, A.L., Manwell, J.F. and Wright, S., 2006: *Wind turbine acoustic noise*. Retrieved 20 Oct 2006 from: http://www.ceere.org/rerl/publications/whitepapers/Wind_Turbine_Acoustic_Noise_Rev2006.pdf

Smith, D.M., 1971: *Industrial location: An economic geographical analysis*. New York: Wiley.

Store, R. and Jokimaki, Jukka., 2003: A GIS-based Multi-scale Approach to Habitat Suitability Modeling. *Ecological Modelling.* 169: 1-15.

Strauch, D., Moeckel, R., Wegener, M., Grafe, J., Muhlhans, H., Rindsfuser, G. and Beckmann, K.J., 2007: *Linking Transport and Land Use Planning: The Microscopic Dynamic Simulation Model ILUMASS.* Retrieved 13 Jan 2007 from: http://www.geocomputation.org/2003/Papers/Strauch_Paper.pdf

Taylor, P., 1977: *Quantitative methods in Geography: An introduction to Spatial Analysis.* Boston: Houghton-Mifflin.

The Department of Geography, Indiana University Purdue University Indianapolis, 2006: *Tree Planting Site selection Model in Addressing Social and Environmental Needs through Community Tree Planting.* Retrieved 10 Jan 2007 from: http://www.iupui.edu/%7Egeospace/kibi_web/model.html

The Department of the Environment, Heritage and Local Government, 2007: *Wind Farm Planning Guidelines*. Retrieved 12 Jan 2007 from: http://www.sei.ie/index.asp?locID=276&docID=-1

United Nations, 1998: Kyoto protocol to the United Nations framework convention on climate change. Retrieved 12 Nov 2006 from: http://unfccc.int/kyoto_protocol/items/2830.php

U.S. Environmental Protection Agency, 2007: *Climate Change*. Retrieved 2 Jan 2007 from: http://www.epa.gov/climatechange/

Vatalis, K. and Manoliadis, O., 2002: A Two-level Multicriteria DSS for Landfill Site Selection Using GIS: Case Study in Western Macedonia, Greece. *Journal of Geographic Information and Decision Analysis*. 6 (1) 49-56.

Web Dictionary of Cybernetics and System 2007: *Sensitivity Analysis*. Retrieved 13 March 2007 from
http://pespmc1.vub.ac.be/asc/SENSIT_ANALY.html

Western Australian Planning Commission, 2004: *Guidelines for Wind Farm Development*. Retrieved 12 May 2007 from:
http://www.wapc.wa.gov.au/Publications/210.aspx

White, G.,Garrad, A. and Tindal, A., 1997: Integrated Design Methodology of Wind Farms. *IPENZ Transactions*, 24 (1) GEN 62-68.

World wind energy association, 2006: *Worldwide wind energy boom in 2005*. Retrieved 12 Nov 2006 from:
http://www.wwindea.org/home/index.php?option=com_content&task=view&id=13&Itemid=2

WWF, 2007: *Nature at risk – the impacts of global warming*. Retrieved 10 Nov 2007 from:
http://www.panda.org/about_wwf/what_we_do/climate_change/problems/impacts/index.cfm

Zanakis, S.H., Solomom, A., Wishart, N. and Dublish, S., 1997: Multi-attribute decision making: A simulation comparison of select methods. *European Journal of Operational Research* 107: 507-529.

Appendix I

AML code

Main module

```
/* File name main.txt

/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

&call setvariables      /* used to set up variables
&call run               /* call sub modules
&call analysis          /* call the analysis functions

&return

/***********************************************************
&routine setvariables
&type set_variables
/***********************************************************

/*setting up the variables for different modules

/*==========variables for wind module===========================
/*set number of sensitivity analysis
```

```
&setvar .w_sensitivity = 2
/*set min_wind and max_wind
&setvar .min_wind = 10
&setvar .max_wind = 25

/*=========variables for archaeology module=================
/*set number of sensitivity analysis
&setvar .a_sensitivity = 1
/*set archaeology site buffer
&setvar .archaeology_b = 10


/*==========variables for land cover module=================
/*set land cover type
&setvar .landtype = 'INDIGENOUS_FOREST'
&type new land cover type %.landtype%


/*==========variables for road module======================
/*set number of sensitivity analysis
&setvar .r_sensitivity = 2
/*set road buffer
&setvar .road_b = 1
/*set maxmum distance from road
&setvar .road_max = 5000
&setvar .rcount = 1

/*==========variables for p_line module====================
/*set number of sensitivity analysis
&setvar .p_sensitivity = 2
/*set power line buffer
```

```
&setvar .pline_b = 1
/*set maxmum distance from power line
&setvar .pline_max = 5000


/*=========variables for visibility module====================
/*set number of sensitivity analysis
&setvar .v_sensitivity = 2
/*set vis requirement
&setvar .vis_req = 0


/*=========variables for terrain module======================
/*set number of sensitivity analysis
&setvar .e_sensitivity = 2
&setvar .s_sensitivity = 3
/*set elevation requirement
&setvar .e_req = 50
/*set slope requirement
&setvar .s_req = 10


/*=========variables for loops=============================

&setvar .p_count1 = 0
&setvar .r_count1 = 0
&setvar .v_count1 = 0
&setvar .w_count1 = 0
&setvar .e_count1 = 0
&setvar .s_count1 = 0
&setvar .t_count1 = 0
```

```
&setvar .c_count1 = 0



&setvar .p_count = 3
&setvar .r_count = 3
&setvar .v_count = 3
&setvar .w_count = 3
&setvar .e_count = 3
&setvar .s_count = 3
&setvar .c_count = 5

/*=========variables for minimum area size function=========
&setvar .cell_req = 100                    /* area of 1 ha.
&setvar .areasize = 2000000



&setvar .f_count1 = 1



/*set cell size
&setvar .cellsize = 100



/*set analysis mask area
&setvar .area = 'wanganui_r'



/*specify the search radius of the focal neighborhood functions in metres
&setvar .searchradius = 500

/* convert search area to cells
```

```
&setvar .searchcells = [TRUNC [CALC ( %.searchradius% / 100 ) + 0.5]]

&return

/**********************************************************************
&routine run

/* run the sub modules

&r wind.txt           /* wind module
&r archaeology.txt    /* land use conflict module
&r forest.txt         /* environmental module
&r road.txt           /* road accessibility module
&r p_line.txt         /* power grid accessibility module
&r visibility.txt     /* urban visual impact module
&r terrain.txt        /* terrain module

&return

/**********************************************************************
&routine analysis
&type analysis

/* set the analyst mask
setwindow %.area%
setmask %.area%

&DO &WHILE %.v_count1% < %.v_count%

&DO &WHILE %.p_count1% < %.p_count%
```

```
&DO &WHILE %.r_count1% < %.r_count%

&DO &WHILE %.w_count1% < %.w_count%

&DO &WHILE %.e_count1% < %.e_count%

&DO &WHILE %.s_count1% < %.s_count%

&DO &WHILE %.c_count1% < %.c_count%

&type %.f_count1%=%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w
%.w_count1%e%.e_count1%s%.s_count1%

&if [exist %.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e
%.e_count1%s%.s_count1% -grid]
&then kill %.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e
%.e_count1%s%.s_count1% all


        &if %.c_count1% = 0 &then
        &call c_0

        &if %.c_count1% = 1 &then
        &call c_1

        &if %.c_count1% = 2 &then
        &call c_1

        &if %.c_count1% = 3 &then
        &call c_2
```

```
        &if %.c_count1% = 4 &then
        &call c_2

        &type output map%.f_count1%
        &call print
        &call output



        &setvar .f_count1 = %.f_count1% + 1
        &setvar .c_count1 = %.c_count1% + 1

        &end

        &setvar .cell_req = 100
        &setvar .areasize = 2000000
        &setvar .c_count1 = 0
        &setvar .m_c_req = 25
        &setvar .s_count1 = %.s_count1% + 1
        &setvar .m_s_req = %.m_s_req% + 5
  &end

  &setvar .s_count1 = 0
  &setvar .m_s_req = 10
  &setvar .e_count1 = %.e_count1% + 1
  &setvar .m_e_req = %.m_e_req% + 25
&end

  &setvar .e_count1 = 0
  &setvar .m_e_req = 50
  &setvar .w_count1 = %.w_count1% + 1
  &setvar .m_max_wind = %.m_max_wind% + 5
```

```
      &end

      &setvar .w_count1 = 0
      &setvar .m_max_wind = 25
      &setvar .r_count1 = %.r_count1% + 1
      &setvar .m_road_max = %.m_road_max% + 5000
     &end

    &setvar .r_count1 = 0
    &setvar .m_road_max = 5000
    &setvar .p_count1 = %.p_count1% + 1
    &setvar .m_pline_max = %.m_pline_max% + 5000
  &end

&setvar .p_count1 = 0
&setvar .m_pline_max = 5000
&setvar .v_count1 = %.v_count1% + 1
&setvar .m_vis_req = %.m_vis_req% + 40
&end

&return

/*******************************************************
/* no minimum area size considered
&routine c_0

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end
```

```
setwindow %.area%
setmask %.area%


&if [exist f_temp -grid] &then kill f_temp all
f_temp = con(e_%.e_count1% eq 1 and s_%.s_count1% eq 1 and v_%.v_count1% eq 1
and a_result eq 1 and forest_result eq 1 and p_%.p_count1% eq 1 and r_%.r_count1% eq
1 and w_%.w_count1% eq 1, 1, 0)

&if [exist
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% -grid] &then kill
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% all
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% = f_temp


&return

/*********************************************************
/*minimum area size with clustered patches

&routine c_1

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

setwindow %.area%
```

```
setmask %.area%

&type %.f_count1%=
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1%

&if [exist f_temp -grid] &then kill f_temp all
f_temp = con(e_%.e_count1% eq 1 and s_%.s_count1% eq 1 and v_%.v_count1% eq 1
and a_result eq 1 and forest_result eq 1 and p_%.p_count1% eq 1 and r_%.r_count1% eq
1 and w_%.w_count1% eq 1, 1, 0)

&if [exist b_temp -grid] &then kill b_temp all
b_temp = focalsum(f_temp, RECTANGLE, 20, 20, DATA)

&if [exist
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% -grid] &then kill
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% all
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% = con(b_temp >= %.cell_req%, 1, 0)


&setvar .cell_req = %.cell_req% + 100

&return


/*********************************************************
/*minimum area size with contiguous area size
```

```
&routine c_2

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

setwindow %.area%
setmask %.area%

/*&type %.f_count1%=
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1%

&if [exist f_temp -grid] &then kill f_temp all
/*f_temp = con(e%.e_count1%s%.s_count1% eq 1 and v_%.v_count1% eq 1 and a_result
eq 1 and forest_result eq 1 and p_%.p_count1% eq 1 and r_%.r_count1% eq 1 and
w_%.w_count1% eq 1, 1, 0)
f_temp = con(e_%.e_count1% eq 1 and s_%.s_count1% eq 1 and v_%.v_count1% eq 1
and a_result eq 1 and forest_result eq 1 and p_%.p_count1% eq 1 and r_%.r_count1% eq
1 and w_%.w_count1% eq 1, 1, 0)



&if [exist f_p_temp -poly] &then kill f_p_temp all
f_p_temp = gridpoly (f_temp)

&if [exist f_p_temp_a -cover] &then kill f_p_temp_a all
copy f_p_temp  f_p_temp_a
```

```
arc additem f_p_temp_a.pat f_p_temp_a.pat yes 3 3 i

&if [show program] ne ARCEDIT &then &do
&if [show program] ne ARC &then quit
arcedit
&end

ec f_p_temp_a
ef poly
select all
calculate yes = 0
select for GRID-CODE = 1 and AREA > %.areasize%
calculate yes = 1
save
q

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

&if [exist
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% -grid] &then kill
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% all
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% = polygrid(f_p_temp_a, yes, #, #, %.cellsize%)


&setvar .areasize = %.areasize% + 2000000
```

```
&return

/*******************************************************
/* out put maps into jpg file
&routine print


&if [exist temp -grid] &then kill temp all
temp = select
(%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1%, 'VALUE = 1')

/* use the cursor to get the total area size

cursor temp_c declare temp.vat info rw
cursor temp_c open

&setvar .total_cell = %:temp_c.count%

cursor temp_c close

&if [exist poly1 -poly] &then kill poly1 all
poly1 = GRIDPOLY(temp)

&if [show program] ne ARCPLOT &then &do
&if [show program] ne ARC &then quit
ap

&end
```

```
/* Start the map composition

&if [exist map%.f_count1% -directory] &then killmap map%.f_count1%
clear

map map%.f_count1%

/*Specify the basic page size, units and map extent
clearselect
mapextent clip
mapunits meters
pageunits cm
pagesize 50 60.5
maplimits page
mapposition lr lr
image wanganui_tif
clearselect

/*****************Write the title
textfont times
textquality proportional
textsize 1.5
move 8.5 58
text 'Suitable Wind Farm Locations in the Wanganui Region'



/***************draw the frame
linesymbol 1
box 2 2 50 60
```

```
/*************** Shade the polygon features

reselect poly1 poly grid-code = 1
arclines poly1 4
clearselect

reselect poly1 poly grid-code = 1
polygonshades poly1 32
clearselect

/*******insert north point
markerset north2.mrk
markersymbol 1
/*markercolor 4
markersize 2.5
marker 35 50

/*******insert legend

textsize 0.9
move 6 20 /*2 11
textfont times
text 'Legend:'

textsize 0.6
move 6 19    /*2 10
text Suitable
/*shadetype color
/*shadecolor green
shadesymbol 32
```

```
patch 8.5 19 10 19.5  /*4.5 10 6 10.5


&sv .wt0  [quote Mean wind speed: not considered]
&sv .wt1  [quote Mean wind speed: 10 - 25 m/s]
&sv .wt2  [quote Mean wind speed: 10 - 30 m/s]

&sv .rt0  [quote Distance to roads: not considered]
&sv .rt1  [quote Distance to roads: within 5 Km]
&sv .rt2  [quote Distance to roads: within 10 Km]

&sv .pt0  [quote Distance to power lines: not considered]
&sv .pt1  [quote Distance to power lines: within 5 Km]
&sv .pt2  [quote Distance to power lines: within 10 Km]

&sv .vt0  [quote Urban visual impact: not considered]
&sv .vt1  [quote Urban visual impact: no urban land visible]
&sv .vt2  [quote Urban visual impact: < 40 hectares of urban land visible]

&sv .et0  [quote Relative elevation: not considered]

&sv .st0  [quote Mean Slope: not considered]
&sv .st1  [quote Mean Slope: less than 10 degrees]
&sv .st2  [quote Mean Slope: less than 15 degrees]

&sv .ct0  [quote Minimun area criteria: not considered]
&sv .ct3  [quote Minimun area criteria: Contiguous area > 200 ha]
&sv .ct4  [quote Minimun area criteria: Contiguous area > 400 ha]
```

```
textsize 0.9
move 6 17.5    /*2 8.5
text 'Criteria used'

textsize 0.5

move 6 17       /*2 8
&if %.w_count1% = 0 &then
text %.wt0%
&if %.w_count1% = 1 &then
text %.wt1%
&if %.w_count1% = 2 &then
text %.wt2%


move 6 16.5
&if %.r_count1% = 0 &then
text %.rt0%
&if %.r_count1% = 1 &then
text %.rt1%
&if %.r_count1% = 2 &then
text %.rt2%


move 6 16
&if %.p_count1% = 0 &then
text %.pt0%
&if %.p_count1% = 1 &then
text %.pt1%
&if %.p_count1% = 2 &then
text %.pt2%
```

```
move 6 15.5
&if %.v_count1% = 0 &then
text %.vt0%
&if %.v_count1% = 1 &then
text %.vt1%
&if %.v_count1% = 2 &then
text %.vt2%


move 6 15
&if %.e_count1% = 0 &then
text %.et0%
&if %.e_count1% = 1 &then
~text 'Relative elevation: above 50%'
&if %.e_count1% = 2 &then
~text 'Relative elevation: above 75%'


move 6 14.5
&if %.s_count1% = 0 &then
text %.st0%
&if %.s_count1% = 1 &then
text %.st1%
&if %.s_count1% = 2 &then
text %.st2%

move 6 14
&if %.c_count1% = 0 &then
text %.ct0%
```

```
&if %.c_count1% = 1 &then
~text 'Minimun area criteria: Clustered patches that total > 100 ha. within 400 ha.'
&if %.c_count1% = 2 &then
~text 'Minimun area criteria: Clustered patches that total > 200 ha. within 400 ha.'
&if %.c_count1% = 3 &then
text %.ct3%
&if %.c_count1% = 4 &then
text %.ct4%

move 6 13.5
&sv .a_text  [quote Distance from archaeology sites: More than 500 m]
text %.a_text%

move 6 13
text 'Excludes areas covered in indigenous vegetation'

move 6 12.5
text '=============================================='

move 6 12
&sv .total [quote Area suitable for wind farms equals %.total_cell% ha.]
text %.total%

move 6 11.5
&sv .text [quote Map converted from
%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%w%.w_count1%e%.e_count1
%s%.s_count1% grid file]
text %.text%

/* Close the map composition file
map end
```

```
/*&call output

q

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

&return

/************************************************************
&routine output

&if [show program] ne ARCPLOT &then &do
&if [show program] ne ARC &then quit
ap
&end

&sys arcpress map%.f_count1% -djpg_24 -R100 -
oD:\wanganui_data\0a_image\%.c_count1%v%.v_count1%p%.p_count1%r%.r_count1%
w%.w_count1%e%.e_count1%s%.s_count1%.jpg

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

&return
```

Land use conflict module

```
/* File name &r archaeology.txt
/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/****************Routines*********************
&call coverage-grid
&call analysis

&return

/********************************************
&routine coverage-grid

/*convert point coverage to grid file
&if [exist archa50 -grid] &then kill archa50 all
archa50 = pointgrid(archaeology, #, #, #, %.cellsize%)
&return
/*********************************************
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%

&if [exist archa50a -grid] &then kill archa50a all
```

```
archa50a = con(isnull(archa50), 0, 1)

/*create a 500m buffer around archaeology sites
&if [exist archaexp -grid] &then kill archaexp all
archaexp = expand(archa50a, %.archaeology_b%, LIST, 1)

/*create a_result map showing areas outside the buffer
&if [exist a_result -grid] &then kill a_result all
a_result = con(archaexp_%.count% eq 0, 1, 0)


&return
```

Environmental impact module

```
/* File name &r forest.txt

/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/* Routines

&call coverage-grid
&call analysis

&return

/*****************************************************************
&routine coverage-grid

/*convert coverage to grid file
&if [exist landcover1 -cover] &then kill landcover1 all
copy landcover landcover1

/*add an field to land cover call forest
arc additem landcover1.pat landcover1.pat forest 3 3 i

&if [show program] ne ARCEDIT &then &do
&if [show program] ne ARC &then quit
arcedit
```

```
&end

/*start editing the land cover
ec landcover1
ef poly
select all
calculate forest = 0
/*assign value 1 if area covered by indigenous forest or scrub
select CLASS_NAME = 'INDIGENOUS_FOREST'
calculate forest = 1
select CLASS_NAME = 'SCRUB'
calculate forest = 1
save
q

&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

&if [exist forest50 -grid] &then kill forest50 all
forest50 = polygrid(landcover1, forest, #, #, %.cellsize%)

&return

/***********************************************************************
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%
```

```
/*select areas that not cover by indigenous forest and scrub
&if [exist forest_result -grid] &then kill forest_result all
forest_result = con(forest50 eq 1, 0, 1)


&return
```

Power grid accessibility module

```
/* File name &r p_line.txt

/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/* Routines

/*&call coverage-grid
/*&call analysis
&call analysis2
&return

/*********************************************************************
&routine coverage-grid
/*convert line coverage to grid file

setwindow %.area%
setmask %.area%

&if [exist pline50 -grid] &then kill pline50 all
pline50 = linegrid(powerline, #, #, #, %.cellsize%)

&return

/*********************************************************************
```

```
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%

&if [exist p_0 -grid] &then kill p_0 all
p_0 = con((pline_dist50 >= 0), 1, 0)

&return

/*********************************************************************
&routine analysis2
&type analysis

setwindow %.area%
setmask %.area%

&setvar .count = 1

&if [exist pline50a -grid] &then kill pline50a all
pline50a = con(isnull(pline50), 0, 1)

/*calculate the eucdistance from area to power lines
&if [exist pline_dist50 -grid] &then kill pline_dist50 all
pline_dist50 = eucdistance(pline50)

&DO &WHILE %.p_sensitivity% > 0

/* select areas with in the power line buffer
&if [exist p_%.count% -grid] &then kill p_%.count% all
```

```
p_%.count% = con((pline_dist50 < %.pline_max% & pline50a eq 0), 1, 0)

&setvar .count = %.count% + 1
&setvar .p_sensitivity = %.p_sensitivity% - 1
&setvar .pline_max = %.pline_max% + 5000

&end

&setvar .p_count = %.count%
&return
```

Road accessibility module

```
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/* Routines

&call coverage-grid
&call analysis
&call analysis2
&return

/*********************************************************************
&routine coverage-grid

/*convert line coverage to grid file
&if [exist road50 -grid] &then kill road50 all
road50 = linegrid(roads, #, #, #, 50)

&return

/*********************************************************************
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%

&setvar .count = 1
```

```
&if [exist road10a -grid] &then kill road50a all
road50a = con(isnull(road50), 0, 1)

/*calculates eucdistance from areas to road network
&if [exist road_dist50 -grid] &then kill road_dist50 all
road_dist50 = eucdistance(road50)

&DO &WHILE %.r_sensitivity% > 0

/*select areas that within the road buffer
&if [exist r_%.count% -grid] &then kill r_%.count% all
r_%.count% = con((road_dist50 < %.road_max% & road50a eq 0), 1, 0)

&setvar .count = %.count% + 1
&setvar .r_sensitivity = %.r_sensitivity% - 1
&setvar .road_max = %.road_max% + 5000

&end

&setvar .r_count = %.count%
&return

/*********************************************************************
&routine analysis2
&type analysis

&if [exist r_0 -grid] &then kill r_0 all
r_0 = con((road_dist50 >= 0), 1, 0)

&return
```

Terrain module

```
/* File name &r terrain.txt

/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/* Routines

&call r_elevation
&call slope
&call analysis

&return

/*************************************************************

&routine r_elevation

/*calculates the elevation range within a given area
&if [exist ele_range -grid] &then kill ele_range all
ele_range = focalrange (dem100, circle, %.searchcells%, data)

/*calculates the minimum elevation within a given area
&if [exist ele_min -grid] &then kill ele_min all
ele_min = focalmin (dem100, circle, %.searchcells%, data)
```

```
/*calculates the r_elevation
&if [exist ele_diff -grid] &then kill ele_diff all
ele_diff = dem100 - ele_min

/*calculates elevation difference in percentage
&if [exist ele_percent -grid] &then kill ele_percent all
ele_percent = ele_diff * 100 / ele_range

&return
/*********************************************************************
&routine slope

/*calculates mean slope
&if [exist slope -grid] &then kill slope all
slope = slope (dem100, degree)

&return

/*********************************************************************
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%

/*select areas above 50% or 75% of r_elevation
&if [exist e_0 -grid] &then kill e_0 all
e_0 = con( ele_percent >= 0, 1, 0)
&if [exist e_1 -grid] &then kill e_1 all
e_1 = con( ele_percent >= 50, 1, 0)
```

```
&if [exist e_2 -grid] &then kill e_2 all
e_2 = con( ele_percent >= 75, 1, 0)

/*select areas have mean slope less than 10 or 15 degrees
&if [exist s_0 -grid] &then kill s_0 all
s_0 = con( slope >= 0, 1, 0)
&if [exist s_1 -grid] &then kill s_1 all
s_1 = con( slope <= 10, 1, 0)
&if [exist s_2 -grid] &then kill s_2 all
s_2 = con( slope <= 15, 1, 0)

&return
```

Visual impact module

```
/* File name &r visibility.txt

/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/* Routines
&call coverage-grid
&call grid-points
&call visibility
&call analysis
&call analysis2

&return

/**********************************************************************
&routine coverage-grid
/*convert polygon coverage to grid file
&if [exist urban200 -grid] &then kill urban200 all
urban200 = polygrid(urban, #, #, #, 200)

/*resize the DEM to 200 meters cell size
&if [exist dem200 -grid] &then kill dem200 all
dem200 = resample (dem100, 200, search)

&return
```

```
/******************************************************************
&routine grid-points
/*convert grid file to point coverage
&if [exist urbanpt_200 -cover] &then kill urbanpt_200
urbanpt_200 = gridpoint(urban200)

&return

/******************************************************************
&routine visibility
&type visibility

setwindow %.area%
setmask %.area%

/*conduct visibility analysis using urban point as observation points with frequency
options
&if [exist vis_200 -grid] &then arc kill vis_200 all
vis_200 = visibility(dem200, urbanpt_200, POINT, frequency)

&if [exist vis_100 -grid] &then arc kill vis_100 all
vis_100 = resample (vis_200, 100, search)

&return
/**********************************************************************
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%
```

```
&if [exist v_0 -grid] &then kill v_0 all
v_0 = con(vis_100 >= 0, 1, 0)

&return
/*********************************************************************
&routine analysis2
&type analysis

setwindow %.area%
setmask %.area%

&setvar .count = 1

&if [exist urban_dist -grid] &then kill urban_dist all
urban_dist = eucdistance(urban50)

&DO &WHILE %.v_sensitivity% > 0
&if [exist v_%.count% -grid] &then kill v_%.count% all
v_%.count% = con(vis_100 <= %.vis_req% or urban_dist >= 6000, 1, 0)

&setvar .v_sensitivity = %.v_sensitivity% - 1
&setvar .vis_req = %.vis_req% + 10
&setvar .count = %.count% + 1

&end

&setvar .v_count = %.count%

&return
```

Wind speed module

```
/* File name &r wind.txt

/* Starts in Grid
&type coverage-grid
&if [show program] ne GRID &then &do
&if [show program] ne ARC &then quit
grid
&end

/* Routines
&call analysis
&return
/***********************************************************************
&routine analysis
&type analysis

setwindow %.area%
setmask %.area%

&setvar .count = 1

/*resize the mean wind data
&if [exist mean_wind1 -grid] &then kill mean_wind1 all
mean_wind1 = resample (mean_wind, 50, search)

&if [exist w_0 -grid] &then kill w_0 all
w_0 = con((mean_wind1 >= 0), 1, 0)

/*select areas have wind speed within the desired wind speed range
```

```
0&DO &WHILE %.w_sensitivity% > 0
&if [exist w_temp -grid] &then kill w_temp all
w_temp = con((mean_wind1 >= %.min_wind% & mean_wind1 <= %.max_wind%), 1, 0)
&if [exist w_%.count% -grid] &then kill w_%.count% all
w_%.count% = resample (w_temp, 100, search)

&setvar .w_sensitivity = %.w_sensitivity% - 1
&setvar .max_wind = %.max_wind% + 5
&setvar .count = %.count% + 1

&end
&setvar .w_count = %.count%

&return
```