Geographical Information Systems for Strategic Wind Energy Site Selection

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ABSTRACT

Wind resources alone are not sufficient to support wind energy development. Neither is the technical feasibility of a wind energy facility enough to make it sustainable. Internationally, countries are establishing guidelines for selecting sites for wind energy development and recognising the need to plan strategically as the size and number of wind energy applications makes them consequential for spatial and environmental planning.

Given not only the size of the wind energy facility, but the size of the wind turbines themselves, the impacts of wind energy facilities are mainly landscape and visual. Sites for wind energy facilities are assessed relative to their impact on human settlements, flora and fauna as well as scenic routes and recreational areas.

The cumulative impacts of wind energy developments cannot be adequately addressed at the project specific or Environmental Impact Assessment level. Alternatively, environmental and spatial issues can be addressed early in the siting process through the Strategic Environmental Assessment. Identifying and designating areas of suitability for wind energy developments at this level aids implementation and enhances integration with other land uses. Geographic Information Systems (GIS) are a particularly useful tool in identifying areas suitable for wind energy development as they can draw together and analyse data from disparate sources.

A GIS for wind energy site suitability analysis must be able to integrate a variety of criteria (including environmental and technical) which can be both quantitative as well as qualitative. Layers of environmental and technical criteria are combined using the overlay function in GIS to produce a constraints map showing the most and least suitable areas for locating wind energy facilities. With GIS, decision makers are able to assign weights to each criterion according to its significance to the overall assessment. It is then possible to model and compare different scenarios based on the criteria chosen, determine the effect that each criterion has on the outcome and choose the best option where there is little constraint and little impact.

A GIS is particularly helpful as a decision support tool for locating suitable wind energy development sites where it is able to handle and simulate the physical, economic and environmental constraints.

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DISCLAIMER

The results presented in this dissertation are based on my own research at the Vrije Universiteit Amsterdam.

All assistance received from other individuals and organisations has been acknowledged and full reference is made to all published and unpublished sources used.

This thesis has not been submitted previously for a degree at any Institution.

Signed:

Birgit Moiloa
at Cape Town, SOUTH AFRICA on 30 November 2009

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1 INTRODUCTION

1.1 History of Wind Energy Projects in South Africa

Wind energy development is a relatively new phenomenon in South Africa. The Darling Wind Energy Facility is the first independent power producer (IPP) for energy derived from wind in South Africa. The facility has a design capacity of 5.2MW of electricity and started generating in May 2008.

In previous decades, South Africa generated some of the lowest cost electricity in the world (DME, 2008). The electricity was and continues to be generated mostly from coal. A public policy of extending electrification to more segments of society as well as rising demand from industry has whittled down the traditional excess supply. Figure 1 below shows how the national utility Eskom's reserve margin, that is the gap between how much electricity the system should be able to provide against how much electricity is demanded from it, set ideally at 15%, has been compromised by the rise in demand which has put South Africa's electricity generating capacity under pressure (ABSA Capital, 2008). This has lead to an increasing interest in both electricity conservation measures and additional ways of generating electricity.

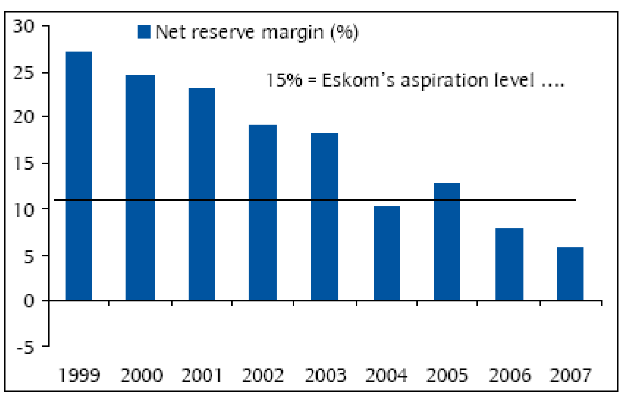


Figure 1 **South African Historic Net Electricity Reserve Margin**

***Source*: ABSA Capital, 2008**

Furthermore, in a world that has become increasingly concerned about climate change caused by the increase of carbon dioxide (CO_2) emissions from burning fossil fuels, a particular emphasis has been placed on renewable sources.

South Africa has an abundance of wind and solar resources (DME, 2003). However, because South Africa produces some of the cheapest electricity from coal in the world, generating electricity from renewable sources has until now not been an economically viable option. Given the global move towards cleaner, greener electricity and the escalating cost of electricity in South Africa, developers are looking more favourably at renewable energy projects in South Africa, especially wind energy.

South Africa's national government has set a target of 10 000 GWhs of energy from renewable sources by 2013 (DME, 2003) but generally lacks a comprehensive plan to achieve this target and a framework in which to maximize the socio-economic benefits from wind energy whilst at the same time ensuring that there is little to no impact on the environment.

Given South Africa's relative inexperience with wind energy development, the cumulative impact of these projects is not known. Currently wind energy developments are subject to an Environmental Impact Assessment (EIA) which evaluates project applications on a site-specific level. However, during this process implications for the region are also raised. One of the main concerns with the EIA regulations since their inception in 1997 was that they provided project specific solutions without addressing strategic issues.

European land planners, on the other hand, have the benefit of hindsight. In a report titled 'Development of an Ecological Strategy for Onshore and Offshore Wind Power Use' commissioned by the German Federal Environmental Agency in March 2007, a strategy to "clean up the landscape" by rectifying scattered sites is proposed (Klinski *et al*, 2007). Given the lessons learned from the 1990s, regional planners are approaching wind energy development more strategically.

Strategic planning is necessary to predetermine the acceptable location of wind energy facilities as well as their respective number, size and design. Internationally, scenarios are modelled for numbers, scale and distribution of developments using Geographical Information Systems (GIS).

1.2 Aims and Objectives

Designating areas of suitability for wind energy developments enhances implementation and promotes integration with other land uses. Environmental and spatial issues can be addressed early in the siting process by introducing them strategically at the regional level. Geographic Information Systems (GIS) are a useful tool in identifying areas suitable for wind energy development as GIS can draw together and analyse data from disparate sources.

The implementation of criteria (including technical and environmental) for the identification of areas suitable to the establishment of wind energy facilities is likely to promote greater pursuance of wind energy development in those regions while balancing national interests of promoting alternative energy generation with local strategic environmental objectives. This will also avoid conflict between local, national and other interest groups through an integrated environmental planning process.

The deployment of a GIS is particularly advantageous in collating and parsing the data from at least four interested spheres: project sponsors, the public, the regulatory authority, and nominally independent experts. The thesis will posit that multi-criteria analysis with GIS enables the decision maker to evaluate different alternatives to make the most appropriate or best choice.

We seek to examine therefore, how GIS can support spatial decision making for strategically locating areas for wind energy development at a regional level. More specifically, we analyse what South Africa can learn from previous studies which applied GIS to support strategic decision making for wind energy site selection. This will be analysed through a literature review and an in-depth review of three case studies. From the analyses, recommendations for South Africa will be made on the implementation of GIS for wind energy site suitability analysis at a strategic level based on international best practice.

1.3 Methodology

South Africa is challenged by the threat to energy security due to the growing demand for electricity outstripping supply. Additional challenges such as the impacts of climate change compel South Africa to meet the increase in demand for energy with the supply of energy from cleaner and renewable sources. The first chapter introduces the conundrum faced by South African environmental authorities with regards to increasing the amount of renewable energy in the energy mix and simultaneously mitigating the impact of renewable energy developments, such as wind energy facilities, on the environment. From an environmental perspective, wind energy development impacts are predominantly visual as well as having a potential threat to endangered species.

Chapter 2 considers strategically planning for wind energy development by designating no-go areas and pre-determining suitable sites or zones for wind energy development using assessment criteria with parameter values. Strategic planning not only aids authorities in making decisions that are in line with development priorities for the region but also guides the developer in pursuing feasible options. Strategic planning for wind energy development is a global practice and the United Kingdom, Denmark, Germany, and the USA are given as examples where strategic approaches have been taken.

It is important to understand the legislative framework conditions for strategic environmental planning and assessments in South Africa before determining the best approach to strategically selecting sites for wind energy development and at which level, regionally or nationally this should take place. Chapter 3 describes the Environmental Impact Assessment (EIA) which every application for a wind energy facility is subject to in South Africa and introduces the Strategic Environmental Assessment (SEA) to address issues raised in the EIA that have implications for the region.

Chapter 4 gives a brief overview of the changing perspectives in planning and the development of GIS which have in turn influenced the methods and approaches used for spatial planning. A consequence of GIS becoming part of a more open and inclusive process which includes public participation and conflict resolution, is that both hard (quantitative) and soft (qualitative) data representing the views of all stakeholders must therefore be incorporated into a decision support system with GIS. Chapter 4 further describes the uses and requirements of GIS for wind energy site suitability analysis, which amongst others the GIS must have the ability to integrate a variety of criteria (including environmental and technical) which can be both quantitative as well as qualitative. A number of methods exist to combine map layers using constraints or criteria which result in an output map. Criteria differ in significance to the overall assessment and the GIS must therefore be able to assign weights to each. It is then possible to model and compare different scenarios based on the criteria chosen, determine the effect that each criterion has on the outcome and choose the best option where there is little constraint and little impact. Examples of such methodologies taken from literature are given in the thesis.

Chapter 5 includes three case studies of GIS based models for wind energy facility site selection used in the USA, England and South Africa, respectively, selected to illustrate how GIS has been applied by planners and decision-makers in different geographic locations and contexts. A description of each GIS based model is given, taking into account the different assessment criteria used and approach taken to determining site suitability. These GIS based models were assessed on their strengths and weaknesses in locating suitable sites for wind energy development and to show the overall support GIS provides for decision making.

In Chapter 6, the case studies were analysed according to the following questions relating to the functions and capabilities of GIS which would support decision making:

- Did the process include diverse multi-disciplinary data?
- Were alternative scenarios created to evaluate the effects of input criteria and parameters?
- Were the criteria inputs participatory?
- Was the purpose of the study fulfilled?
- Can these models be replicated elsewhere?

Based on the findings from the case studies, recommendations are made in the final chapter for an improved strategy for locating suitable sites for wind energy development in the Western Cape, South Africa using GIS.

2 WIND ENERGY PLANNING

2.1 Wind Energy Policy and Planning

In December 2008, the European Union agreed on a 20% renewable energy target by 2020 which means a 20% contribution of renewable energy resources to total energy demand and a 20% reduction in greenhouse gas emissions by 2020, otherwise known as the so-called 20:20:20 plan (RenewableEnergyWorld.com, 2008).

"If renewable energy targets are to be met, a positive and innovative approach will be required. The planning system can only deliver sufficient additional renewable energy schemes to meet the shortfall if positive planning policies are in place. They need to be backed up by strong leadership, the integration of planning for renewable energy with other more mainstream planning activities and communications between planners, the renewable industry, interest groups and the wider public" (Office of the Deputy Prime Minister of the United Kingdom, Planning Policy Statement 22: Renewable Energy, 2004).

Experience has shown that wind resources alone are not sufficient to support wind energy development. It suggests that neither is the technical feasibility of a wind energy project enough to sustain it. Only countries that have set up an “adequate enabling environment and long-term stable comprehensive public policies, with strong political commitment”, have succeeded in developing wind power (Schwartz, 2008).

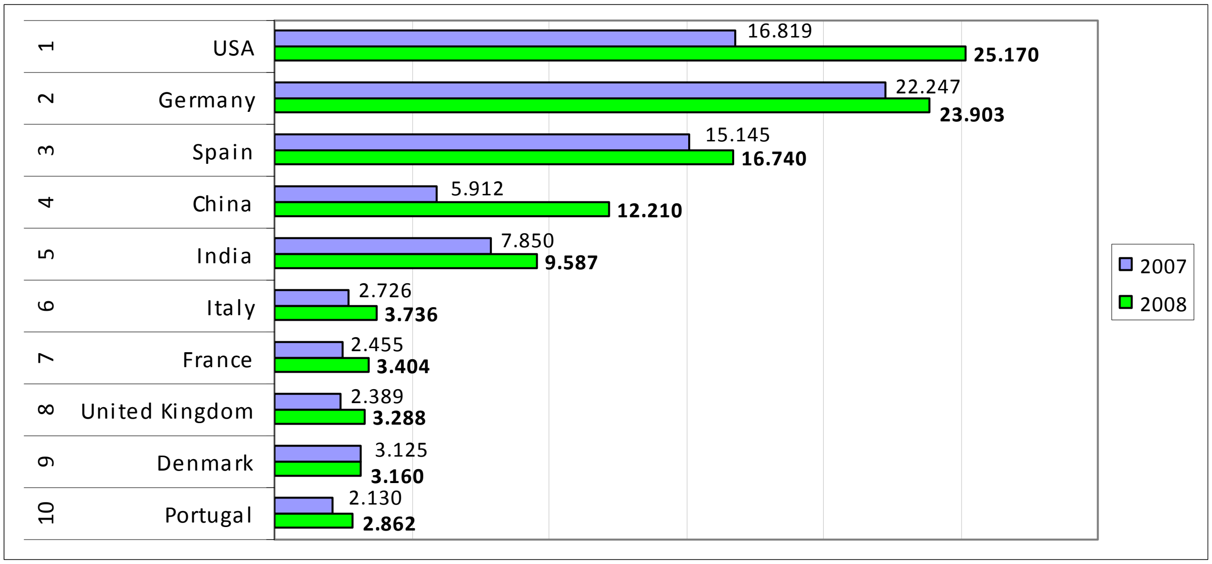
Insert 1 Leading Wind Energy Countries

***Source*: WWEA, 2009**

Globally, the USA and China took the lead in generating *additional* megawatt capacity in 2008, compared with 2007 (See Table 1 below). In 2007 Germany held the world top ranking position for installed capacity but was overtaken by the USA in 2008, with China having taken the lead in Asia over India. According to the World Wind Energy Report (2008), the USA accounted for 50.8% of the wind turbine sales in 2008. The pioneer country Denmark fell back to rank 9th in terms of total capacity, whilst until four years ago it remained in 4th position for several years. Denmark remains a world leader given the relative geographic size of the USA compared to Denmark, where Denmark has 20% of its electricity supply coming from wind energy.

Table 1 **Top Ten Countries for Installed MW of Wind Energy**

***Source*: WWEA, 2009**



There is considerable literature available regarding policy and planning for wind energy development internationally. The United Kingdom's Policy Planning Statement 22 is an example of a comprehensive and contemporary report guiding the planning and development of renewable energy. There are also a number of 'Best Practice Guidelines' for wind energy development developed by organizations such as the American Wind Energy Association (AWEA, 2008); the British Wind Energy Association (BWEA, 1994); and the European Wind Energy Association (EWEA, 2002) amongst others.

Clear guidelines on the assessment of environmental impact of wind energy development are beneficial to wind energy developments. Visual impact is cited as one of the senior objections to wind energy. Furthermore, guidelines can help avoid the kind of environmentally negative projects that give wind energy a bad reputation, but can also help avoid rejection of projects on purely subjective criteria as is often the case when visual impact and the degradation of the landscapes are overlooked (Schwartz, 2008).

The only related guideline in South Africa is a document entitled 'Strategic Initiative to Introduce Commercial Land Based Wind Energy Development to the Western Cape - Towards a Regional Methodology for Wind Energy Site Selection' developed by a provincial agency. The Department of Environmental Affairs and Development Planning (DEADP) in the Western Cape produced the document in 2006. The purpose of the document was to establish a policy on the implementation of a methodology to be used for the identification of areas suitable for the establishment of wind energy projects. The DEADP received much criticism for this document and was perceived as a barrier to investment in wind energy in the province. The planning criteria for wind energy development were viewed as too conservative and restrictive to development. Moreover, the planning criteria included environmental criteria only.

The experience of the South African environmental authorities appears to be that they are under pressure to approve clean energy projects in the light of the country's energy supply challenge as well as the political desire to mitigate global climate change. The South African environmental authorities must strike a balance between promoting alternative energy and at the same time ensure that there is little to no impact on the environment.

A brief description is given below of policy and planning processes followed for wind energy development in the United Kingdom, Denmark, Germany and the USA.

2.1.1 United Kingdom

Each country within the UK has adopted, or is in the process of drafting its own guidance on the development of renewable energy. These are listed in Table 2 below:

Table 2 UK Planning Policies

***Source*: IEEP, 2009**

Planning Policy	Country
Planning Policy Statement (PPS) 22 on renewable energy	England
Scottish Planning Policy (SPP) 6 on renewable energy development and Planning Advice Note (PAN) 45 on good practice in renewable energy technologies	Scotland
Technical Advice Note (TAN) 8 on planning for renewable energy	Wales
Draft Planning Policy Statement (PPS) 18	Northern Ireland

In the UK 50MW developments are used as a threshold between local and regional decision-making as stipulated in Section 36 of the 1989 UK Electricity Act. For developments below 50MW the local authority will determine whether an Environmental Impact Assessment (EIA) is required. Above 50MW, decision-making is centralised. Decisions are currently taken by the Department of Energy and Climate Change for England and Wales, and by the Scottish Executive for Scotland. In future, with the adoption of the Planning Act 2008, decisions over 50MW in England and Wales will be taken by the centrally appointed Infrastructure Planning Commission rather than a government department (IEEP, 2009).

Planning approaches to wind energy development in the UK vary from one another and range from the highly stratified selection of indicative zones for development in Wales under TAN8; to a system in Scotland of local development plans setting out localities favourable to and sensitive to wind development to a more ad hoc approach in England based on local and regional criteria with limited central coordination. Each approach has its benefits but data appears to show that England receives the highest number of individual planning applications for onshore wind energy facilities for mainly small-scale developments. When looking at delivery of potential capacity compared to England and Wales, Scotland is leading the way by having received and approved applications for the highest level of onshore wind (IEEP, 2009).

2.1.2 Denmark

A report on 'Danish Wind Energy Planning and Development' (Fraser, 2002), shows that in 1995 Denmark developed a wind energy plan for its 14 regions which translated into local plans for 275 local municipalities. These county-level efforts and corresponding local efforts targeting areas considered suitable for wind energy development, resulted in the original national target of 1500 MW being met several years before the 2005 deadline (Committee on Environmental Impacts of Wind Energy Projects & National Research Council, 2007). Denmark shows that it is beneficial to have an explicit target for wind energy and have it translated into a wind energy plan.

The process was started by identifying local wind potential at the scale of 1:25 000, as wind strength has an economic importance. Other criteria identified at regional level include the visual assessment; areas of special landscape designation (areas with conservation and heritage interest); telecommunications, main roads, military areas, density of local housing and airports; and access to the local electricity grid.

Previously in Denmark the size and number of turbines were not considered in cumulative impact assessments. This led to too many small wind energy facilities with different wind technologies. Today an Environmental Impact Assessment (EIA) will be triggered by developments which consist of more than 3 turbines and where turbines exceed the height of 100m. The scale extent of wind energy development is viewed in relation to the scale of its panoramic setting (hill or plain). The cumulative effect is considered to be the perceived effect on the landscape of two or more wind energy developments visible from any one place.

Through the regional plan, policies on the required size and design of wind turbines as well as zones for various scales of development are enforced. Old approvals of wind energy developments may not be considered appropriate today and may not be replaced once the wind energy facility has come to the end of its lifecycle.

The Danes have had to review their regional plans and are now having to plan for the new focal area of offshore wind energy facilities. A scrapping system has been introduced so that wind power is further developed while older, poorly positioned wind turbines are decommissioned. This means that an extra surcharge is paid to new, onshore wind-turbines on the condition that the owner is in possession of a scrapping certificate for a wind turbine with installed power of 450 kW or less which was decommissioned between 15 December 2004 and 15 December 2010 (Danish Energy Authority, 2008).

2.1.3 Germany

Germany has had a Regional Spatial Programme since 1999 showing suitable areas for wind energy developments. This includes a wind potential and technical area analysis. A GIS technique overlaying layers of positive or negative criteria (areas of constraint or lack of constraint) is used to identify areas which would be appropriate or inappropriate for development.

The German Federal Building Code treats wind energy facilities as so called “privileged projects”. It is the responsibility of regional authorities to designate preferred zones for use of wind energy through the use of negative mapping of no-go areas. However, this means that they can also restrict construction in specific areas otherwise known as exclusion zones.

According to Klinski *et al* (2007), the regional governments of Schleswig-Holstein, Lower Saxony, Mecklenburg West Pomerania and the North Rhine Westphalia states are using wind power decrees to assist the officials responsible for making planning and licensing and authorization decisions. The aim of these decrees is to prescribe clearance recommendations or buffers for residential areas (such as a 1 km buffer), nature and landscape conservation zones and transportation routes.

Figure 2 below shows the municipal region of Hannover in Lower Saxony, Germany. Hannover has used the overlay method using GIS. Displayed in green are buffered natural reserves as well as bird protection areas. In red are buffered settlements. Using only these criteria as negative criteria leaves the areas in white as potential sites for wind energy development.

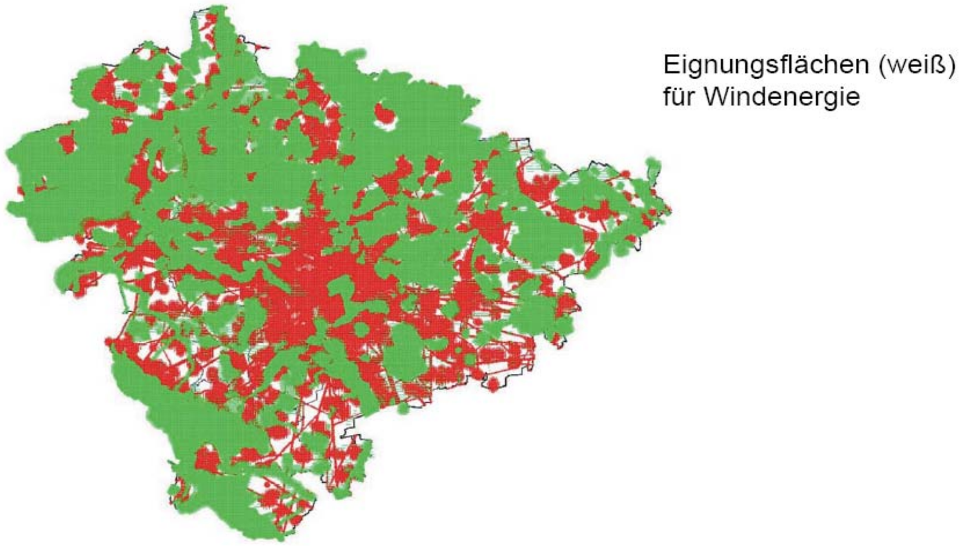


Figure 2 **Potential sites for wind energy development in Hannover state, Germany**

***Source*: BWE, 2005**

Figure 3 below, takes matters a step further by analyzing the amount of land available and thereby determining the limit to the size of a wind energy facility. By using this method, the regional authorities have determined a potential for 300MW or 240 turbine installations.

Figure 3 **Number, scale and size of wind energy developments for Hannover state, Germany**

***Source*: BWE, 2005**

2.1.4 United States of America

In the USA each state is governed by its own laws and will therefore have its own policy regarding renewable energy and environmental planning. Typically, wind energy developers require permits for wind energy development from one or more government agencies. Permitting entities at the federal, state, and local levels may have jurisdiction over a wind energy development (NWCC, 2002).

Some state and local agencies in the USA have geographic based information systems that identify land use and environmental resources, which may include the following: zoning and land use designations; transmission lines, roads and highways including scenic designations; biological resources, parks, and recreation areas. Agencies have discussed using this information to identify in advance geographic areas that have good wind potential for wind energy development; are likely to pose constraints for wind energy developments with regards to permitting requirements; or where wind development will not be permitted. Through this process the USA has designated areas to facilitate permitting and promote development of wind generation in preferred locations.

2.2 The Role of Designating Environmental No-Go Areas

Reasons for objecting wind energy developments typically include the visual and landscape disturbance, threats to bats and birds as well as noise and shadow flicker from wind turbines. The associated impacts of wind energy development will be discussed in more detail in Section 2.3.

European Union governments have used the legislative process to protect the most highly endangered habitats and species across Europe through designating areas for protection. These protected areas are known as Natura 2000 (see Insert 2 below as well as Annexure A map of Natura 2000 areas). Natura 2000 areas together with a landscape sensitivity analysis result in no-go areas for wind energy developments. Most countries are using this method of negative mapping while landscape assessment increasingly plays a role in identifying suitable sites for wind energy development.

Insert 2 **Natura 2000**

***Source*: www.natura.org**

In May 1992 European Union governments adopted legislation designed to protect the most seriously threatened habitats and species across Europe. This legislation is called the Habitats Directive and complements the Birds Directive adopted in 1979. At the heart of both these Directives is the creation of a network of sites called Natura 2000. The Birds Directive requires the establishment of Special Protection Areas (SPAs) for birds. The Habitats Directive similarly requires Special Areas of Conservation (SACs) to be designated for other species, and for habitats. Together, SPAs and SACs make up the Natura 2000 series. All EU Member States contribute to the network of sites in a Europe-wide partnership from the Canaries to Crete and from Sicily to Finnish Lapland.

Special Protection Areas (SPAs) are classified under the Birds Directive to help protect and manage areas which are important for rare and vulnerable birds because they use them for breeding, feeding, wintering or migration. Special Areas of Conservation (SACs) are classified under the Habitats Directive and provide rare and vulnerable animals, plants and habitats with increased protection and management.

The Natura 2000 Networking Programme is funded by the European Commission and managed on their behalf by Eurosite, the European Landowners Organization and the EUROPARC Federation.

In South Africa, proclaiming areas for conservation based on the landscape, heritage or ecological value is provided for in the Protected Areas Act (Act 57 of 2003, section 17) and the National Heritage Resources Act (Act 25 of 1999). However, compared with Europe's Natura 2000 sites, not much land in South Africa has been designated as bearing conservation or cultural value, besides national parks, core areas in biosphere reserves and world heritage sites. In 2007, 2.92% of the total land area was designated to National Parks (DEAT, 2007a). Thus, relatively little land has formally been legislated as sensitive at a national level.

In South Africa, it remains a challenge to classify an area as sensitive in order to preserve the landscape if the conservation, cultural or economic value is not officially defined, nor when there is no agreement on the value of the landscape. Landscape character assessments will be looked at in more detail in Section 2.6.

Insert 3 below illustrates how having designated sites for protection such as "Natura 2000" assisted the Czech Ministry for the Environment in resolving conflicts over wind energy development and nature conservation to achieve their renewable energy target of 1 500 MW.

Insert 3 **Nature conservation and wind energy – the Czech approach**

***Source*: EWEA, 2006**

In a determined attempt to forestall potential conflicts over wind energy facilities and nature conservation interests, the Czech Ministry of the Environment has produced a map showing where the two interests are likely to clash. It is one of the most thorough analyses of the issue among the ten accession states which joined the EU two years ago.

According to the Czech National Energy Strategy, up to 1000 wind turbines of 1.5 MW capacity are needed to meet environmental objectives. So far, less than 30MW has been constructed.

The Ministry's approach was to start with data showing sites with wind speeds of more than 4 m/s taken form regional meteorological stations and physics institutes. On a map of the Czech Republic these areas were then overlaid with details of national parks, protected landscape areas, sites designated under "Natura 2000" and the main bird migration routes.

Although the results show that some of the windiest sites are also in heavily protected mountainous regions, this is not always the case, and there are other large areas with no conservation restrictions.

"Our aim was to show which areas were the most suitable for wind energy facilities and to prevent conflicts which would make our political objective more difficult," says Martina Paskova, who was jointly responsible for the study. "We have to be honest that the Czech Republic is not the best country in Europe for wind energy, but we are still supporting it through our environmental policies. These alternative energy sources are really necessary. At the same time our cultural landscape is part of our heritage and needs to be protected."

The Environment Ministry's aim is that details of its study should be available in the form of guidelines to both conservation bodies and prospective wind investors. The Ministry would also provide developers with a list of environmental aspects whose impact could be negative and a list of documents which would have to be submitted during any application.

- The European Environment Agency has launched a project to examine the technical potential for wind energy, both on land and offshore, in 2020 and 2030, taking into account a number of environmental and other constraints. The aim is to show whether ambitious future renewable energy targets can be met in an environmentally compatible way.

Each of the countries mentioned in the previous section, gave reference to the use of resource criteria for the selection of wind energy development sites or areas. According to Baban (2004) specific siting criteria for the region need to be developed based on user requirements and comply with the guidelines used nationally and internationally.

2.3 Assessment Criteria for Wind Energy Development

In the British Wind Energy Association as well as the American Wind Energy Association best practice guidelines, criteria are categorised as either environmental or technical and are broad in scope (BWEA, 1994; AWEA, 2008). The European Best Practice Guidelines for wind energy development developed from the experience of the British Wind Energy Association and the Dutch Wind Energy Industry in drafting their guidelines, lists the following environmental and technical considerations as initial criteria for assessments:

I Environmental considerations

- Visual Aspect
- Proximity to dwellings
- Ecology
- Archaeological/historical heritage
- Recreational uses (of surrounding land)
- Telecommunications
- Civil and military airports
- Restricted areas

II Technical considerations

- Wind resource
- Existing land uses
- Ground conditions
- Site access
- Electrical connection
- Draft project design including scale, layout and turbine size (EWEA, 2002)

The above mentioned criteria were selected based on the associated impacts of wind energy developments. In general, the environmental criteria include environmental and landscape sensitivity (visual impact, noise, flora and fauna, heritage sites, etc), planning restrictions and public opinion, whereas the technical criteria generally include wind speed, topography conducive to wind velocity, access to the grid and road accessibility.

The DEADP (2006) selected criteria for the Western Cape based on the British Wind Energy Association Best Practice Guidelines (see Table 3). The justifications for the selection of criteria are briefly discussed below.

Table 3 Criteria for Wind Energy Development in the Western Cape Based on International Criteria
***Source*: DEADP, 2006b**

Criteria	Threshold
Noise	
See distance from housing/residential areas and distance from roads and railway lines	
Noise limit during the night	35 dB(A)
Noise limit during the day	50 dB(A)
Ambient noise level	May not be exceeded by more than 7dB
Shadow Flicker	
See distance from housing/ residential areas and distance from roads and railway lines	
Distance between turbines and separate wind farms	
Distance between consecutive turbines	The sum of the height of 2 turbines plus the radius of the two rotor blades
Distance between consecutive wind farms	2.5km
Minimum number of turbines within a wind farm	10
Maximum number of turbines within a wind farm	20
Distance from housing residential areas	
Distance from temporary/seasonal dwellings (e.g.chalets)	350m
Distance from single dwellings	500m
Distances from isolated settlements/hamlets	750m
Distance from urban areas	1km
Distance from a city centre	5km
Distance from transportation routes	
Distance from railway lines	2.5km
Distance from well-known scenic routes and tourist route of significance to local tourism	2.5km
Distance from municipal/secondary roads	500m
Distance from national roads	3km
Distance from well-known scenic routes of major national/international significance to tourism	4km
Distance from high voltage lines	
	250m
Distance from radio communication, radar and navigation beacons	
	500m
Distance to historical sites and buildings	
	500m
Distance to natural reserves and other protected areas	
Distance from provincial nature reserves	500m
Distance from declared mountain catchment areas	500m
Distance from areas designated as Open Space Zone III	500m
Distance from national parks	1km
Distance from provincial nature reserves	1km
Distance from protected natural environments	1km
Distance from Ramsar sites	1km
Distance to water bodies	

Distance from the 1:50 year flood line	200m
Distance from wetlands and water bodies of local importance	300m
Distance from perennial rivers	400m
Distance from wetlands and water bodies of national importance	1km
Distance from the coast	4km
Distance to forests	
Distance to indigenous forests	500m
Protection of fauna and flora (excluding forests) and avian species	
Distance from habitats and nesting areas of protected avian species and fauna	At least 500m
Distance from flight paths of protected species	1km
Defence constaints	
Distance from sites of national security priority	15km (must be confirmed with agency)
Aviation constraints	
Distance from international airports	15km (must be confirmed with agency)
Distance from private airfields	15km (must be confirmed with agency)
Gas transmission and distribution pipes	
	The sum of the height of 2 turbines plus the radius of the two rotor blades
Mountains, hills and other elevated features	
Maximum height of elevated feature in relation to topography	A height 25m above the local topography

Firstly, noise attributed to the motion of the wind turbine's mechanical components and the airflow between the blades has a negative impact on people. Most countries have standards which must be adhered to, for example up to 50dB(A) of noise is permitted during the day.

Secondly, due to the size of a wind energy facility (a 100MW wind energy facility may occupy 20 km^2 of land) and the height of the turbines (up to 150m in height) the visual impact is usually quite significant. Visual impacts such as the flicker of the sun through the turbine blades, known as shadow flicker, and the visibility of turbines can be assessed spatially. Wind energy facilities are usually located outside of urban or residential areas as large populations are generally housed in these areas and there are concerns over safety as well as visual and noise impacts. Setbacks are also given from transportation routes which include all roads, rail or other routes such as hiking trails from where wind energy facilities can be seen.

Thirdly, issues with regards to accessibility include the road accessibility and access to the transmission grid. The type of road which will be used for the transportation of large wind turbine components must be suitable. Access roads which need to be constructed or widened will have an impact on the environment. Gaining access to the transmission grid could entail the upgrade of the existing grid or extending new transmission lines. The wind energy facility might also require an on site substation or a line connecting it to a substation.

Fourthly, areas of national security or operations which require surrounding undeveloped areas to maintain an area of security are referred to as defense constraints. Similarly, wind turbines can interfere with aviation radar signal and would require a significant buffer around areas such as airports.

Fifthly, nature reserves, protected areas and heritage sites are protected for their environmental sensitivity, scenic beauty or may include heritage sites which are of cultural or historic value. Furthermore, coasts and rivers are special habitats and places of recreation. The footprint of towers, roads and associated structures disturbs vegetation and habitat areas. Wind turbines also present a collision risk to birds and may have negative effects on the bird populations, especially migratory birds.

Lastly, topography is a contentious criterion as it can be either positive or negative. Wind speed is affected by slope, aspect and elevation. The most consistently windy sites are typically situated on the coastal plain closest to the coastline or on areas of elevations such as hills and mountains. However, although wind speed and direction are important criteria for wind energy development as they will determine the economic feasibility of a project, visibility increases atop ridgelines and hilltops.

Unlike in Europe and some parts of the USA, where a site suitability analysis includes both the wind potential and the environmental criteria, in South Africa very little good data exists for wind speed and direction and is thus left out of the list of assessment criteria. Internationally, the desired wind speed is above 6.5 m/s, however, improvements in technology create opportunities for utilizing winds at lower wind speeds.

Furthermore, wind energy development is only feasible where there is access to the national electricity grid and whether there is capacity on the grid to handle variable loads from wind power. As the generation of electricity from wind energy is increasing globally, system operators and network planners have to deal more and more with challenges associated with the integration of wind energy generation into the distribution and transmission systems. Smith and Wiese (2002) highlight an important issue regarding interconnection and planning processes in the USA, where in the past transmission systems were designed for large synchronous power plants. Commissioning power plants typically have longer lead times (five years and more), which allows the transmission planners time for an impact analysis on the transmission grid. Over time and in an orderly, step by step fashion, capacity could be added to the grid where needed.

Today the US market has been opened to competition and interconnection applications come from multiple entities operating on relatively unpredictable schedules. Smith and Wiese (2002) also point out that many newer generators are dependent on technologies which may not be adequately represented in traditional transmission system stability models. In addition to this, they require shorter lead times and may feed in incrementally in smaller quantities as opposed to all at once. Similarly, in South Africa, the electricity utility Eskom will need to plan for the load flow from wind energy which differs from the load generated from coal or nuclear power. Eskom will need to be able to give the status of the transmission grid and account for potential grid expansion.

Finally, the importance of public opinion must not be excluded. Public consultation workshops are held during the EIA process where developers have the opportunity to create awareness around wind energy and the benefits and impacts of the proposed project. Early consultation with the public and gauging the acceptability of wind energy developments will avoid Not-In-My-Back-Yard (NIMBY) objections in the EIA phase.

3 LEGISLATIVE FRAMEWORK

3.1 Environmental Impact Assessment in South Africa

With limited experience of wind energy facilities and no clear guidelines in place in South Africa, the only mechanism available to assess the implications of wind energy development is through an Environmental Impact Assessment process required under the aegis of the National Environmental Management Act (NEMA), Act 107 of 1998. Consequently, wind energy developments in South Africa are currently being assessed on an ad hoc basis through either a Basic Assessment or a Full Scoping and Environmental Impact Assessment depending on the nature of the development and the activities which trigger these assessments.

The Environment Impact Assessment (EIA) is a formal process used to understand the potential environmental impacts of a development and provides the decision-making authority with the information to approve, refuse or reject an application based on whether the development is environmentally sound and sustainable or not. The EIA promotes sustainable development through the identification of appropriate enhancement and mitigation measures and to ensure that resources are used effectively and efficiently.

Section 24 of NEMA (1998) provides for the EIA process as well as the promulgation of regulations. In April 2006 regulations in terms of Chapter 5 of NEMA (1998) referred to as Government Notice No. R. 385, R. 386, and R. 387 were promulgated (DEADP, 2006a). Government Notices Nos. R. 386 and R. 387 contain the lists of activities requiring screening and scoping, which may lead to a full EIA. The scoping report, conducted by the environmental assessment practitioner, will determine whether a basic assessment is needed or whether a full scoping report is required.

There will be a number of parallel or integrated applications facing the wind developer, including heritage legislation, namely the Heritage Resources Act (Act 25 of 1999) and planning legislation including rezoning and subdivision required in terms of the Land Use Planning Ordinance (Ordinance 15 of 1985) and the Agricultural Act (Act 70 of 1970). The need for other assessments such as a heritage, visual impact or landscape assessment will be triggered depending on the nature of the proposed development.

Insert 4 below gives a short summary of the legislation governing wind energy developments in South Africa.

Insert 4 Legislation governing wind energy developments

- South Africa's national Department of Minerals and Energy (DME) is the energy controlling authority in terms of the Electricity Act (Act 41 of 1987) and has recently brought out the National Energy Act (Act 34 of 2008).
- The National Energy Regulator of South Africa (NERSA) in addition to approving tariffs also issues licenses to wind developers to generate electricity.
- The South African Department of Environmental Affairs and Tourism (DEAT) is the competent authority spelling out the requirements for the Environmental Impact Assessment in Chapter 5 of the National Environmental Management Act (Act 107 of 1998), triggered by a wind energy development.
- Turbines must also adhere to the specifications of the Civil Aviation Authority.
- Protected Areas Act (Act 57 of 2003, section 17) and the National Heritage Resources Act (Act 25 of 1999) which includes proclaimed protected areas and scenic routes. These areas are proclaimed by national ministers and members of the executive council.
- Other legislation includes the Land Use Planning Ordinance (Ordinance 15 of 1985) and the Agricultural Act (Act 70 of 1970) for rezoning and subdivision.

3.1.1 Basic Assessment

In terms of the list of activities and competent authorities published in Government Notice No. R 386, a wind energy development will trigger a Basic Assessment in the event of the following:

- The construction of facilities or infrastructure (including associated structures and infrastructure) for the generation of electricity, where the output is more than 10 megawatts but less than 20 megawatts (Clause 1(a))

- The transmission and distribution of electricity above ground with a capacity of more than 33 kilovolts and less than 120 kilovolts (Clause 1(c))

- The removal or damaging of indigenous vegetation of more than 10 m^2 within a distance of 100 meters inland of the high water mark of the sea (Clause 5). Given that coastal locations will be a highly sought after location for wind turbines, this Clause will be triggered given the foundation size of a turbine which is on average about 12 to 15 m^2.

- The transformation or removal of indigenous vegetation of 3 hectares or more (Clause 12).

- The construction of masts of any material or type and of any height, including those used for telecommunication broadcasting and radio transmission, but excluding masts of 15 metres and lower exclusively used by radio amateurs or for lighting purposes, as flag poles or as lightning conductor poles (Clause 14). This clause will be triggered by the erection of a temporary wind measuring mast as measuring masts are typically 60 to 80m tall.

- The construction of access roads wider than 4 metres (Clause 15).

- The subdivision of land exceeding 9 hectares in size into portions of 5 hectares or less (Clause 18).

- The decommissioning or recommissioning of existing facilities or infrastructure for electricity generation (Clauses 23 and 24(a)). Note, that this will only apply in the long term as wind energy facilities may be decommissioned.

3.1.2 Full Scoping and EIA

In terms of Government Notice No. R 387, an application for full scoping and EIA is required where:

- The construction of facilities or infrastructure (including associated structures and infrastructure) for the generation of electricity where (i) the output is 20 megawatts or more; or (ii) the facility covers a combined area in excess of 1 hectare (Clause 1(a)).

- The transmission and distribution of above ground electricity with a capacity of 120 kilovolts or more.

- Any development activity, including associated structure and infrastructure where the total developed area exceeds 20 hectares (Clause 2).

3.2 Strategic Environmental Assessment (SEA)

3.2.1 What is SEA?

Given that the primary purpose of the Environmental Impact Assessment (EIA) is to determine and evaluate the environmental implications of development and to inform decision-making at the project level, there are however a number of more strategic decisions that are typically made at the planning, programming and policy level that influence the nature of development. Strategic Environmental Assessment (SEA) has therefore evolved, complementary to EIA, in order to determine the broader implications of policies, plans and programmes. EIA focuses on the positive and negative impacts of a specific development project once it has been formulated. The role of SEA, however, is to allow for the decision-maker to pro-actively determine the most suitable development type for a particular area, ***before*** development proposals are formulated (DEAT, 2004). SEA can further be defined as:

"SEA is a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure that they are fully included and appropriately addressed at the earliest appropriate stage of decision-making on par with economic and social considerations" (Sadler and Verheem, 1996), and as Munasinghe (2007) succinctly puts it, "SEA may be seen as vector for incorporating sustainability". The aim of SEA is therefore to ensure that environmental protection and sustainability is incorporated at **all levels** of decision-making (Therivel, 2004).

The need for SEA arises only when there is a known significant impact of a strategic action. Strategic actions include the following (Therivel and Brown, 1999):

- Legislation on international, national, regional and local level;
- Green and White Papers;
- Economic policies, budgets, fiscal planning;
- Integrated development plans on national, regional or local level including conservation areas and World Heritage sites;
- Sectoral policies, plans and programmes at a wide range of scales;
- Policies, plans and programmes for management of a specific resource at a wide range of scales;
- Policies, plans and programmes to achieve social ends.

From the above it is clear that designating areas for wind energy development or the development of renewable energy policy and wind energy plans would require a SEA.

3.2.2 SEA Internationally

The European Commission issued a directive, the European Union Directive 2001/42/EC, which requires a SEA to be carried out for the preparation of all policies, plans and programmes in Europe. This directive is commonly known as the SEA Directive.

"The objective of [the] Directive is to provide for a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation and adoption of plans and programmes with a view to promoting sustainable development, by ensuring that, in accordance with [the] Directive, an environmental assessment is carried out of certain plans and programmes which are likely to have significant effects on the environment." (The European Parliament and the Council of the European Union, 2001)

Munasinghe (2007) notes that practical experience with SEA of policies, plans and programmes has been limited throughout the world, with critical issues yet to be resolved, such as the proposed scope of the approach, its role and relationship to other policy instruments in decision-making; and the appropriateness of relying on the methods and procedures of project environmental assessments.

3.2.3 SEA in South Africa

The concept of SEA has existed in South Africa since the 1990s and has since been recognized as a valuable tool in environmental management in the country. In 2000 the national Department of Environmental Affairs and Tourism published guidelines for SEA. The guideline defined SEA as "a process of integrating the concept of sustainability into strategic decision-making" (DEAT, 2004).

Although the general principles and basic steps of SEA were widely known, there was less agreement on the tools to be used, techniques to be applied and final outputs of the SEA process. In 2007, DEAT published an Integrated Environmental Assessment Guideline series to provide more practical guidance on the tools, techniques and outputs of SEA to promote the use of SEA in South Africa.

Despite the absence of a formal SEA process, the South African national Department of Minerals and Energy's energy policy for South Africa does require that both environmental and economic merits of all proposed energy sources be fully considered, which would normally be covered by SEA. This is in line with the United Nations sustainable development principles and the national environmental principles found in Chapter 1 of NEMA (1998). It is also congruent with international environmental best practice.

Although South African legislation provides linkages to SEA such as NEMA (1998) which in turn provides for the development of Environmental Management Frameworks (EMFs) complimentary to SEA, successful SEA generally occurs where there is an explicit legal obligation to require it (DEAT, 2007b; CEC Report, 2001).

3.2.4 SEA and South African Spatial Development Frameworks

The DEAT SEA guidelines summarize additional policy and framework legislation. It lists the Municipal Systems Act 32 of 2000 and Municipal Planning and Performance Regulations. In short, the Act requires that local authorities form a policy framework for the municipality through adopting an inclusive plan for the capacity and allocation of resources, which is known as the Integrated Development Plan (IDP). The regulations further state that a strategic assessment must be undertaken of the environmental impact of the Spatial Development Framework (SDF), which is the spatial component of the IDP.

This also has a direct legal link to the land use management scheme under the South African Land Use Bill of 2002 where the Spatial Development Framework should guide and inform all decisions of the Municipality related to the use, development and planning of land.

Government land use policies and plans can shape and promote desired land uses in a macro-economic framework such as the promotion of generating clean energy from the wind through a wind energy plan. Verheye (2008), in his paper 'Land Use Planning for Sustainable Development', cites land evaluation as an example of a practical tool for identifying broad land use zones showing constraints and opportunities for development of priority areas for strategic government or private sector activities.

Ideally then, wind energy planning should be incorporated into the municipal spatial development frameworks as required by the Municipal Systems Act (Act 32 of 2000), but the terms of inclusion need to be guided by a provincial policy. Experience in many countries globally has also shown that to the present, future development of wind energy projects has not been included in land use or spatial plans. The consequence of this is a lengthy process of modifying spatial plans before a wind energy development can be approved in a specific area. Authorities should anticipate future development of wind energy projects and allocate suitable areas in advance (Schwartz, 2008).

3.2.5 SEA Data Needs and Scale

There are two key aspects of scale in SEA, namely, scale as an extent of the assessment, that is, the size of the study area and scale in terms of the level of detail or amount of detail used (João, 2007). João (2007) argues that the choice of data and scale is particularly challenging in SEA. João (2002) notes that spatial scale will always affect assessments that rely strongly on mapped information, such as, very large projects, cumulative effects assessment, and strategic environmental assessment. What is deemed 'significant' will be affected by the data used and scale chosen. Issues that individually might not be considered significant might cumulatively become significant (João, 2007). Such is the case with the placement of wind turbines and wind energy facilities when considered in relation to other installations and developments.

There is no 'one best way' for choosing data and scale in SEA. According to João (2007), there are multiple or a range of scales suitable for the description of a system with some being more ideal than others and some which need to be avoided. Spatial scales range from global, across macro-regions, regions, municipalities to site specific (Partidario, 2007).

Partidario (2007) argues that understanding the context should be the primary step in planning, policy or impact assessment. Saunders (2009) recommends a mapping scale of 1:50 000 as it is well suited to mapping wind energy facilities and for viewing the surrounding geographic context of a proposed development. Not withstanding the potential of Not-In-My-Back-Yard (NIMBY) objections associated wind energy development, Simão et al (2008) recommend that users or stakeholders must be able to explore (using GIS) the impacts of the wind energy facilities at local scale. Whichever scale is selected, the choice of scale should be public and transparent as the chosen scale is often subject to observer bias (João, 2002).

4 GIS METHODS FOR SELECTING WIND ENERGY FACILITY SITES

4.1 GIS and Spatial Decision-Making

Information systems and planning have become “twins” since the 1980s (Scholten and Nijkamp, 1991). Information systems, in particular, GIS in planning has evolved along with the changing perspectives on planning from scientific approaches (1950s – 1970s) through the political process-orientated perspectives (1980s) to focus on communication and public participatory approaches (1990s). This evolution of planning has been paralleled by the increase in accessibility and user-friendliness of GIS technology as GIS has evolved from a ‘closed-expert’ orientated to an ‘open-user’ orientated technology (Malczewski, 2004).

Malczewski (2004) argues that while databases and spatial information systems are important components of planning activities, planners deal with political issues as well as complex urban and regional challenges. He points out that in the past GIS has had a functional use within planning, placing spatial reasoning and scientific analysis at the core. This assumes a direct relationship between the information available and the quality of planning and decision making based on that information. Moving away from this technocratic approach he suggests that, GIS has become part of a more open and inclusive process which includes public participation and conflict resolution. This means that GIS is rather seen as a tool for planning *with* the public as opposed to *for* the public.

Differing and often conflicting views on wind energy development exist between stakeholders and decision makers. In most cases the developer will firstly assess the financial feasibility of developing a wind energy facility by looking at the potential for wind (wind speeds typically above 6.5 m/s), the land availability and the accessibility to the transmission grid. Subsequent to these findings the developer will consider the regulations, environmental and planning concerns, and the influence of public opinion to identify suitable sites for wind energy facilities. For spatial planners, rural areas have traditionally been seen as ideal for wind energy development as these areas have usually been regarded as being of little or insignificant value to the public. This has changed due to the increased value now placed on rural areas, especially wilderness areas, and the need to bring energy closer to the points of primary consumption which are urban areas.

Section 2.3 lists various assessment criteria (environmental and technical) which can be used for site selection of wind energy facilities, however, the importance of each as mentioned before will differ between role players and also the local environment in which they are to be applied (Sparkes and Kidner, 1996). GIS offers a platform for decision support tools to select wind energy sites from initially conflicting positions (Ramirez-Rosado et al, 2007). GIS can draw together and analyze data from disparate sources and produce maps, graphs and reports, all of which are visually appealing and can be easily understood by stakeholders and decision-makers.

Given that planners and environmental authorities need to consider maximising the socio-economic benefit of wind energy facilities whilst minimising the environmental impact, environmental planning must be strategic and will require a multi-criteria spatial decision support system for wind energy site suitability analysis. Multi-criteria analysis (MCA) or evaluation, is a technique used in decision-making to analyse and compare how well different alternatives achieve different objectives and through this process identifying a preferred alternative (Therivel, 2004). Multi-criteria evaluation techniques have been developed to assist decision makers in exploring and finding solutions to problems that require trade offs between multiple and conflicting objectives (Simão et al, 2008). Therivel (2004) explains that multi-criteria analysis involves choosing the relevant assessment criteria or impacts and alternatives, scoring how each alternative affects each criterion; weighting the impact and aggregating the score and weight of each alternative, and finally choosing the best alternative based on these scores.

GIS has capabilities to manage and analyse volumes of diverse multi-disciplinary data needed in the application. GIS also has the functionality to perform "what if" scenarios which can be used either, to evaluate the effects of different planning policies and to select those most suitable or, to find the optimum wind farm site among a number of potential sites. According to Baban and Parry (2000) this is what makes GIS useful for locating wind energy development sites.

However, while GIS is often used to support decision making in planning and land use, the lack of analytical modelling capabilities limits the support to multiple decision making strategies (Simão et al, 2008). According to Malczewski (2004), GIS operations are being extended to statistical, optimization, simulation, and related modeling functions to increase GIS capability for exploratory, explanatory and predictive analysis. Baban and Parry (2002) argue that GIS has the ability to handle and simulate the physical, economic and environmental constraints and is therefore once again a useful decision support tool for locating suitable wind energy development sites. According to Chakhar and Mousseau (2007), GIS and multi-criteria analysis are two complimentary tools, each of which has advantages and some limitations in spatial decision making; their integration permits to avoid these limitations.

The Environmental Impact Assessment (EIA) and Strategic Environmental Assessments (SEA) are regulatory mechanisms, used in conjunction with spatial planning, to control the proliferation of wind energy facilities in areas which are not environmentally suitable for these types of developments. The spatial placement of wind energy facilities will not only be determined by the wind resource or the technical capacity of the grid for connection but by the environmental "go ahead" to do so. GIS for wind energy related impact assessments is thus included in the next section 4.2 for an overview of how GIS is used in impact assessment to assist with determining where wind energy facilities can be placed.

It is important to note that the wind resources as well as other technical data layers are additional layers which need to be considered and can not be excluded from assessing the feasibility and overall suitability for wind energy facilities. Therefore Section 4.3 looks at how these multi criteria are incorporated into a GIS and what methods are used to produce the final output map showing the overall suitability for the placement of wind energy facilities.

4.2 GIS and Wind Energy Related Impact Assessments

Of all the potential impacts related to wind energy facilities, the impact on the landscape is commonly considered the most important (Lejuene and Feltz, 2008). In a case study of wind farm conflict in rural Catalonia, Spain, research showed that the recent opposition to wind farms are not so much due to NIMBY as in earlier cases of wind farm development but is attributed more to the conflict over landscape change (Zografos and Marinez Alier, 2009). Landscape assessment has emerged over the last decade as an integral component of both regional and local planning and in environmental decision-making. According to Wilson (2002), the planning context for landscape assessment in the United Kingdom has evolved to incorporate sustainable development into rural and planning policies. Landscape designations are indicative of landscape value, however landscape features, characteristics and values can also be used as indicators for landscape sensitivity. It is important for landscape assessments to consider the ecological, historical and cultural features which contribute to the character of the landscape. Greater attention is thus given to the value of all landscapes, rather than only designated landscapes.

Qualitative data, in the absence of quantitative data, on the value of the landscape can be collected through questionnaires at public participation workshops and through specialists who are able to give expert input. Expert judgement can be used to develop alternatives, analyze and rank them as well as predict impacts and suggest mitigation measures (Therivel, 2004). Data can be stored, analysed and manipulated with GIS, which is renowned for excellent spatial analysis and making iterative and alternative analyses in impact assessments. See Insert 5 below for further benefits of GIS for impact assessments.

Insert 5 The Benefits of GIS for impact assessments

- GIS is a useful tool to convey and present information by overlaying geographically referenced data.
- GIS can provide a composite picture of the receiving environment (including sensitive areas, resources, pressures, etc (DEAT, 2007b).
- GIS can be used to store and display the environmental baseline data for SEA.
- GIS can be used to sample, analyze, store and visually present indicators (Langaas, 2007).
- GIS can map the cumulative impacts (DEAT, 2007b).
- Alternatives can be modelled with GIS.
- GIS can identify spatial indicators that will facilitate the monitoring of mitigation measures and SEA results (Gonzales, et al, 2005).
- A database of baseline information can be used in future decision-making processes.

Due to the visual impact of wind energy facilities on people and the surrounding areas, a visual impact assessment is required. The assessment is conducted using visual simulation techniques such as photomontage, Viewshed Analysis and Digital Elevation Modelling (DEM). Visibility Analysis, using GIS software, highlights those areas on a map from which the wind turbines would be visible. The visibility map depicts the viewshed of the surface from a particular point and includes all points on the surface that are visible by direct line of sight from that observation point, and vice versa (Worboys, 2001).

4.3 GIS-Based Site Selection

4.3.1 Site Suitability Mapping with GIS

The fundamental analytical functions of a GIS based spatial decision-support system include query analysis, proximity or buffer analysis, overlay analysis, neighborhood analysis, network analysis, and modeling. Various combinations of these functions are commonly used during the geographic data analysis process (BESR, 2002). According to Longley et al (2003), the buffer operation is one of the most important transformations for the GIS user. Given any set of objects, a buffer operation creates a new object by identifying all areas that are found within a specified distance of the initial object (Longley et al, 2003).

Buffering is defined as:

The formation of areas containing locations within a given range of a given set of features. Buffers are commonly circular or rectangular around points, and corridors of constant width about lines and areas (Worboys, 2001).

Where for example, wind energy development is restricted along coastal zones due to the visual disturbance, by using a 4 km buffer, a corridor can be created where it is preferred that no wind energy development should take place. Decision makers are able to set parameters for associated impacts of wind energy facilities to avoid potential or irreversible impacts.

The concept that underpins wind energy site suitability modelling is map algebra (Malczewski, 2004). Map algebra introduced by Tomlin in the 1980's and developed further in the 1990's uses single factor map layers as operands on which spatial operators are applied to generate new map layers (Chakhar and Mousseau, 2007). This can be expressed as follows:

Where three input map layers X,Y and V have the following relationships V(X-Y) = Z, the map Y is first subtracted from map X and then the resulting map is multiplied by V to obtain the output map layer Z (Malczewski, 2004).

The use of two procedures, which are also common map combination or overlay operations in GIS and used with multi-criteria analysis, include Boolean Overlay and Weighted Linear Combination (WLC) (Malczewski, 2004). Eastman (2003) lists a third option for multi-criteria analysis, namely the Ordered Weighted Average (OWA) which is similar to the Weighted Linear Combination but provides a continuum of aggregation procedures. The Boolean Overlay, Weighted Linear Combination and the Ordered Weighted Average procedures can also be applied to other applications for finding suitable locations such as siting municipal solid waste landfill sites (Mahini and Gholamalifard, 2006) and land-use suitability analsis (Malczewski, 2004). The Boolean Overlay and the Weighted Linear Combination, being the most commonly used according to Malczewski (2004), are discussed briefly below. Models are often made up of combined approaches as none of the individual approaches provide a comprehensive method for wind energy site suitability analysis (Eastman, 2003). Proposed GIS-based methodologies for locating suitable sites for wind energy facilities found in literature are given in Section 4.3.3 to illustrate the combination of these procedures.

4.3.2 Boolean Overlay

For wind energy planning, deterministic overlay and buffer functions are used most commonly in site location studies (Hansen, 2005). Ian McHarg first illustrated the use of the overlay method by the use of transparencies in his book 'Design with Nature' in 1969 (Longley et al, 2003), which became the precursor to the overlay technique now used in GIS since the 1970's.

The Boolean Overlay can be defined as:

The combination of one or more layers into a single layer that is the union, intersection, difference, or other Boolean operation applied to the input layers. (Worboys, 2001).

According to Malczewski (2004), when given a set of suitability maps and corresponding threshold values, the Boolean intersection (AND) will result in classifying areas suitable according to the threshold criteria met. The Boolean union (OR) will result in areas suitable which meet at least one threshold criterion. Maps produced using Boolean operations based on threshold criteria are also referred to as constraints or tolerance maps. Hansen (2005) cautions that these functions can be limiting in a GIS when seeking to compare and add weight to different alternatives. Boolean searches are limiting because they provide only "yes" or "no" answers.

4.3.3 Weighted Linear Combination (WLC)

The Weighted Linear Combination (WLC) approach, or otherwise known as Simple Additive Weighting in decision support systems, allows the decision maker to assign weights according to the relative importance of each suitability map and combines the reclassified maps to obtain an overall suitability score (Malczewski, 2004). Suitability can be expressed as (Eastman, 2003):

$$S = \sum W_i X_i$$

where

S	Suitability
W_i	Weight of factor i
X_i	Criterion score of factor i

The result is a continuous mapping of suitability that may be masked by one or more Boolean constraints to accommodate qualitative criteria and given a threshold to produce a final decision (Eastman, 2003). This is described more readily in the examples that follow below.

Ramirez-Rosado et al (2007) present a decision support system developed to assist with the selection of consensual geographic locations for wind energy facilities in La Rioja, Spain where the stakeholder groups initially held opposing positions. The aim of the methodology is the creation of tolerance maps. Described briefly, in the first stage, each stakeholder group defines their criteria maps and attribute sets. Values are given to criteria between 0 and 1, with 0 indicating the least suitable location and 1 indicating the best location. Secondly, the tolerance maps of the stakeholder groups are processed and the described criteria captured in order of preference. During this process criteria are defined, weighted and aggregated as described in the Weighted Linear Combination approach. Pair-wise weights (weights between pairs of criteria) based on expert input are also determined and aggregated resulting in a map of tolerances. The decision support system helps to identify on all the tolerance maps the geographical locations with the value of 1 for the development of wind energy facilities in order to make a final decision.

Baban and Parry (2002) propose two ways of combining constraint layers. Firstly, by assuming that all the layers are of equal importance and therefore carry the same weight and secondly, by allocating weights to constraint layers based on their perceived importance and developing a pair-wise matrix for all layers. In the second method, the principle eigenvector is calculated using GIS software and provides the information used to determine suitability. The integer outputs ranged from 0 to 10, where 0 represents the most suitable locations and 10 the least suitable locations. In comparing the effect of weighting the layers, the results of the study showed that the second method resulted in a slight increase in the geographical extent for the most suitable sites.

In summary, with GIS, map layers corresponding to each constraint criterion are created followed by the allocation of weights to each layer and different scores to each attribute within the layers using reclassification and buffer generation methods. Using the overlay function to combine all the layers will result in the constraints map. The resultant map will show the most and least suitable areas for locating a wind energy facility (Baban, 2004). The uncertainty and fuzziness generally associated with any decision require a sensitivity analysis whereby each input criteria can be evaluated against the impact on the final result and whether this is consistent with a given decision (Chakhar and Mousseau, 2007). If the decision-makers are not satisfied with the outcome of the constraints map, they have the option to modify any subjective parameters (or buffer values), until the result conforms to their point of view (Joerin et al, 1998).

5 CASE STUDIES

5.1 Introduction

In this section, three case studies of GIS based models for wind energy facility site selection used in the USA, England and South Africa respectively have been selected to illustrate how GIS has been applied by planners and decision-makers across the world.

These three models have been selected as they represent different geographic locations and contexts. The three models were also selected because of their use of GIS for constraints mapping and varied use of weighting procedures. A description of each model is given below, taking into account the different assessment criteria used and approach taken to determining site suitability. These models will be assessed on their strengths and weaknesses in relation to their capability and functionality mentioned above which make them "useful" for locating wind energy development sites.

5.2 Northern California Model

5.2.1 Background

Rodman and Meentemeyer (2005) propose a rule based method (based on known processes) using GIS to analyse the suitability of wind energy developments in Northern California. This approach is a geographic analysis of wind energy facilities already developed and sites proposed so that energy planners can use the information to predict the extent to which wind energy can be developed further based on land availability and public perception.

5.2.2 Methodology

The geographic model includes multiple variables to represent the physical, environmental and human impact factors and their effects on wind turbine site suitability. The following criteria were used:

- Physical features such as wind resources, obstacles and terrain;
- Environmental factors including land use, vegetation and sensitive areas such as wetlands or presence of endangered plant species; and
- Human impact factors including proximity to development and public recreational areas.

Data for each of these factors were mapped in the GIS, converted to a raster (grid cell) format, and resampled to 30m x 30m cell size (the scale of the highest resolution data set). These data were converted to 30m resolution for the overlay analysis.

These GIS models were chosen as they provide a method to weight the different features according to their effects on the phenomena studied. According to Rodman and Meentemeyer (2005), they are flexible and allow different inputs to be used to evaluate a variety of scenarios.

The three models were developed (physical, environmental, human) using expert judgement to score and weight the individual layers that influence decisions. Each data layer (such as average wind speed or vegetation) was then assigned a weight that represented its significance to the overall suitability measurement. The most important criterion is assigned the highest weight.

For example in the physical model the average annual wind speed layer was given a weight of 3, obstacles a weight of 2 and terrain a weight of 1. The environmental model consisted of three layers, namely vegetation or land use (weight = 3); presence of endangered plant species (weight = 2) and presence of wetlands (weight = 1). Lastly, for the Human Impact model urban and recreational layers were given equal weights of one.

The layers were also subdivided into multiple classes or values where each of these classes were given a score according to its suitability.

For example, in the physical layer where the average annual wind speed must meet the minimum threshold speed for each class of wind turbine and the wind speed was found to be adequate (≥7 m/s) for large scale wind turbines and (≥ 4.5 m/s) for small scale turbines, a score of 4 = Excellent was given for the site suitability. If the wind speed was not adequate (<7 m/s) for the large scale turbines, the score was 0 = Unsuitable. Similarly, the terrain suitability score was based on the maximum of either the ridge top or valley score.

For the environmental layer, the following classes were derived: crops, barren, grass, shrubs, forest and wetlands and a relative score given to each. The absence of an endangered species was rated as 4 = Excellent and the presence thereof was rated 0 = Unsuitable.

For the human impact layer binary scores were used for both layers to describe the locations where wind turbines were 4 = Excellent or 0 = Unsuitable. If they are situated in an urban area, that would be classified as “unsuitable”, whereas all areas outside of an urban area are deemed “excellent”.

5.2.3 Results

These three models were examined individually and were also combined to compose various overall site suitability models. Each model resulted in a map with scores which range from Poor (1); Fair (2); Good (3) to Excellent (4). Locations with a suitability score of 0 were not considered. If any location had a score of 0, from an individual model, then that location was considered to be unsuitable for any combined model that included the individual model.

The physical and environmental models were combined and compared against the physical model alone, and all three models were combined and compared with the physical and environmental combination. Figure 4, the physical, environmental and human impact model for large-scale wind energy development model compared with Figure 5 below which shows the physical, environmental and human impact model for small-scale wind energy development illustrates how factors such as the threshold for wind speed will influence the overall assessment of site suitability. Figure 4 below shows suitable areas for large scale wind turbines and the proposed areas for the Solano and Altamont wind farms. Figure 5 shows many more suitable areas available for small-scale wind turbines.

Northern California

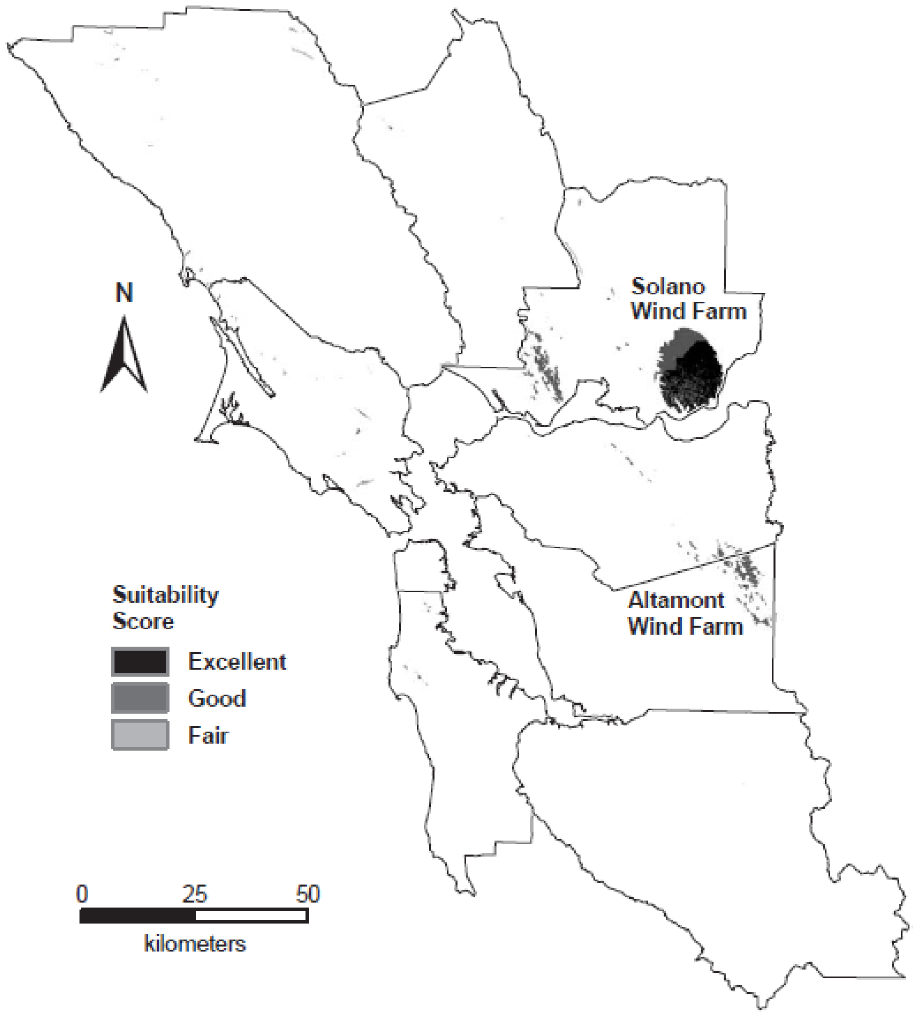


Figure 4 **Suitable Areas for Large-scale Wind Energy Development**

***Source*: Rodman and Meentemeyer, 2005**

Northern California

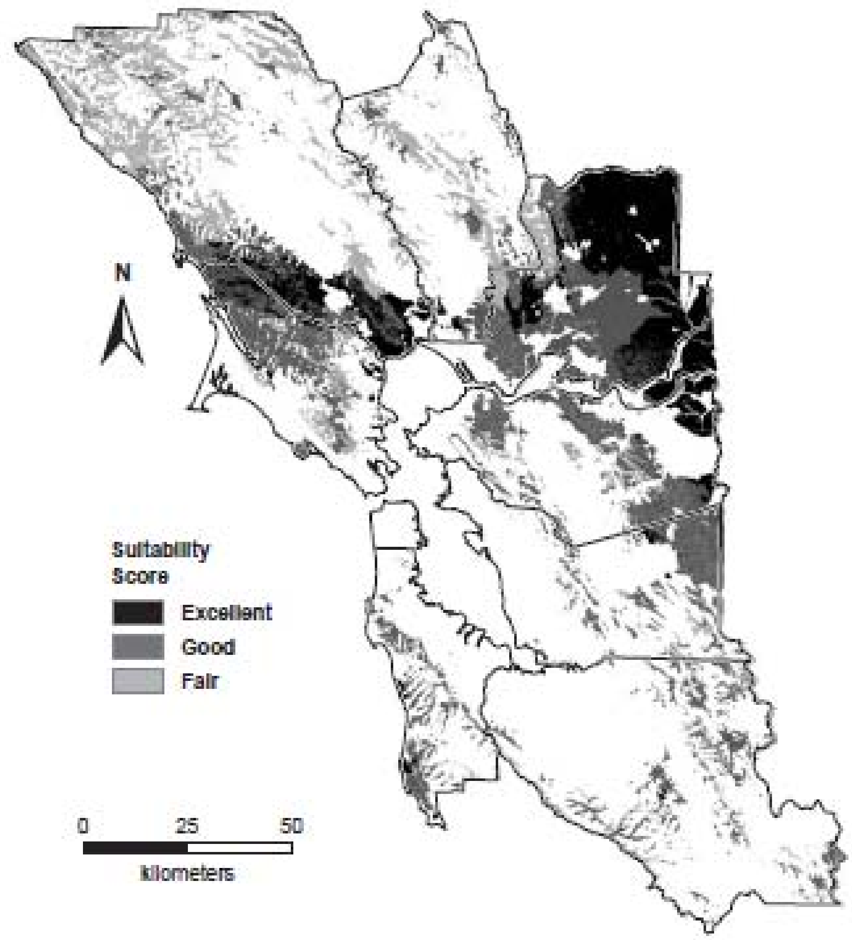


Figure 5 **Suitable Areas for Small-scale Wind Energy Development**

***Source*: Rodman and Meentemeyer, 2005**

The results from the analysis show that the criteria and their respective scores do impact the amount of land available for wind energy development. With regards to existing wind energy facilities in the Solano County and the Altamont Pass, the Solano Wind Energy Facility is located near an urban area and the Altamont wind energy facility is located across a bird migration route. Coincidently, both wind energy facilities face strong opposition from the public. Rodman and Meentemeyer (2005) conclude that the large-scale suitability model could be improved by including additional factors such as visibility analysis and mapping of bird migration corridors.

5.3 Government Office of the North East (GO-NE) Model

5.3.1 Background

Internationally, wind energy developments currently comprise the main issue of planning significance in relation to renewable energy policy. The full potential of wind energy must be determined in order to set realistic targets for renewable energy policy. This potential will be limited by physical features such as topography or environmental constraints such as protected natural areas. Further limitations of wind energy development include the cumulative impact such as the visual impact on the landscape and the capacity of the transmission grid to accommodate additional wind energy facilities. Dunsford et al (2003) developed a regional Geographical Information System (GIS) to support the development of the North East of England Renewable Energy Strategy.

5.3.2 Methodology

A GIS cartographic model was used to create and evaluate options for the location of onshore wind energy facilities using the following input layers:

- Wind speed
- Utilities
- Infrastructure
- Landscape issues
- Radar and Communication
- Military training and operations

According to Dunsford et al (2003), this model was chosen as it allows the Boolean combination of “layers” of information containing data relating to constraints or restrictions on wind energy development with the result being pockets of areas considered suitable for wind energy facilities based on the input criteria.

The cartographic model is divided into three separate models and is discussed briefly below:

1. The GIS Constraints Model;
2. Visibility Analysis; and
3. Landscape Appraisal

The GIS Constraints Model

The GIS constraints model is comprised of eight categories (cultural heritage; landscape; Ministry of Defense (MoD); nature conservation; radar; safety/topple distance; wind speed and visual amenity/noise) which are classified as either an absolute constraint based on specified parameters with defined limits ie. “no-go”, or as zones of consultation which require further consultation.

The specified parameters are described as either a “footprint”, “buffer” or “viewshed”. See Table 4 below for parameter values:

Table 4 Criteria parameters and type of constraint

***Source*: Adapted from Dunsford *et al*, 2003**

Categories	Criteria	Type	Parameters	Constraint
Cultural Heritage	Historic Parks, Gardens and Battlefields	Polygon	700 metre Buffer	Absolute
	Listed Buildings	Point	Footprint	Absolute
	Greenbelt	Polygon	Footprint	Consultation
	World Heritage Site	Polygon	700 metre Buffer	Absolute
	World Heritage Site	Polygon	10 kilometres	Consultation
Landscape	Areas of Outstanding Natural Beauty	Polygon	Footprint	Absolute
	Heritage Coast	Polygon	Footprint	Absolute
	National Park	Polygon	Footprint	Absolute
MoD	Low Flying Area 20	Polygon	Footprint	Consultation
	Low Flying Area 13	Polygon	Footprint	Consultation
Nature Conservation	Special Protection Areas	Polygon	Footprint	Absolute
	Royal Society for the Protection of Birds	Polygon	800 metre Buffer	Absolute
	Special Areas of Conservation	Polygon	Footprint	Absolute
	Sites of Special Scientific Interest	Polygon	Footprint	Absolute
	RAMSAR	Polygon	Footprint	Absolute
	Ancient Woodland	Polygon	Footprint	Absolute
Radar	Airports	Polygon	Viewshed	Absolute
Safety/ Topple Distance	Motorways			
	A roads	Line	150 metre Buffer	Absolute
	B roads	Line	150 metre Buffer	Absolute
	Railways	Line	150 metre Buffer	Consultation
	Electricity Pylons	Line	150 metre Buffer	Absolute
Windspeed	ETSU Windspeed	Polygon	> = 6.4 m/second	Absolute
Visual Amenity/Noise	Residential properties	Point	400 metre Buffer	Absolute
	Residential properties	Point	700m Buffer	Absolute

Visibility Analysis

The wind turbines were classified according to their actual height, the viewing height, the Zone of Theoretical Visibility (ZTV) and the observation point from where they were being viewed. Visibility was calculated by identifying the cells in an input Digital Terrain Model (DTM) which could be seen from one or more observation points, as well as from the subject height and viewing height. Cells are then classed as either a cell that can see the given observer point which is scored as 1 or a cell that cannot see the given observer point which is given a 0. The calculation is repeated for each additional observation point with the resultant visibility surface which contains cells with the value equal to as many other cells which can be seen from each respective point. Visibility analysis is done for the surrounding area, road networks and residential areas. The result is a map showing grid cells with the highest values as the most visible areas.

Landscape Appraisal

The landscape assessment is an "assessment of the capacity of landscapes to accommodate wind developments" (Benson et al, 2003). A distinction is made between landscape character, which refers to landscape features creating a particular sense of place, and landscape sensitivity, which refers to the vulnerability of the landscape to change. A third distinction is landscape value referring to a designation such as Sites of Special Scientific Interest (SSSI) or Areas of Outstanding Natural Beauty (AONB) or degree to which it is valued by the community and other stakeholders, and a final distinction is landscape capacity, referring to the extent to which a landscape can absorb or accommodate development without a fundamental change in character. Landscape character areas such as rounded hills, upland forests and moorland, coastal plateau and so forth were compiled for the GO-NE region and given a sensitivity score. Landscape sensitivity ratings range from low, low-medium, medium, medium–high to high. These ratings were derived using previous landscape assessments, field surveys to validate the assessments and the use of expert judgement. These ratings were applied to each of the following criteria listed below (Benson et al, 2003):

A. Physical Criteria

- Scale and openness
- Landform and shape
- Settlement
- Landscape pattern and foci
- Visual composition
- Physical context - effect on sensitivity from other landscape character types within a viewshed

B. Perceptual Criteria

- How landscape is experienced
- Context
- Sense of remoteness
- Modification
- Naturalness

5.3.3 Results

Scenarios are then modelled by combining the models such as the GIS constraints model and Visibility Analysis. The visual impact and areas preferred for wind energy development are displayed on a map. The combination of the GIS constraints model together with the Landscape Appraisal provides locations where a landscape is less sensitive to wind energy development and where there is little constraint to wind energy developments.

5.4 Western Cape Regional Methodology

5.4.1 Background

Authorities in the Western Cape of South Africa acknowledge that wind energy facilities are going to become a feature in the region and that assessment methods need to be developed to plan and assess wind energy development in the province. The rationale for developing the methodology was so that planning zones could be delineated identifying specific areas for wind energy development.

International precedence, such as the GO-NE study, was chosen as a starting point for selecting the methods of assessment and which were then adapted to suit the local context. The site suitability analysis with GIS below therefore also consists of a GIS constraints model, visibility analysis and landscape appraisal.

5.4.2 Methodology

GIS Constraints Model

The following criteria were selected with parameters in Table 5 below:

Table 5 List of Regional Criteria

***Source*: Adapted from DEADP, 2006b**

	Criteria	**Buffer**
1	**Urban Areas**	800 metres
2	**Residential Areas (Including rural dwellings)**	*400 metres
3	**Transport Routes**	
3a	National Roads	3 kilometres
3b	Local Roads	*500 metres
3c	Provincial Tourist Route	4 kilometres
3d	Local Tourist Route	2.5 kilometres
3e	Railway Lines	250 metres
4	**Transmission Lines**	
4a	Major Power lines	250 metres
4b	Cell Phone Masts and Communication Towers	*500 metres
4c	Radio and Navigation beacons	*250 metres
5	**Key Infrastructure/ Airports**	
5a	Airport with Primary Radar	25 kilometres
5b	Local Airfield	2.5 kilometres
5c	National Security Sites	15 kilometres
6	**National Parks and Provincial Nature Reserves**	2 kilometres
7	**Protected Areas**	
7a	Mountain Catchments	*500 metres
7b	Protected Natural Environment	2 kilometres
7c	Private Nature Reserves	*500 metres
8	**Coast and Rivers**	
8a	Distance to Coastlines of Undisturbed Scenic Value	4 kilometres
8b	Distance to Flood lines	*500 metres
8c	Distance to 1:100 year flood line	*200 metres
9	**Sensitive Areas (Avian)**	
9a	Distance to Major Wetlands (Ramsar sites)	2 kilometres
9b	Distance to Local Wetlands	*500 metres
9c	Distance to Bird Habitats or Avian Flight Paths where known	1 kilometres
10	**Topographical**	
10a	Slope and Elevation	*25 metres
10b	Distance from Ridge Lines	*500 metres
11	**Vegetation**	
	Distance to Important Vegetation/Remnant Vegetation	*unknown

(*) Key Criteria to be mapped at local/project scale

Criteria not included on a regional scale are noise, shadow flicker and wind energy facility layout. These criteria are generally superseded by other criteria such as the distance from urban and residential areas.

In addition to this, in South Africa the following features were not selected due to the lack of reliable data:

- Mobile telephone towers (4b)
- Mountain catchments (7a)
- Private nature reserves (7c)
- Distance to 1:100 year floodline (8c)
- Height above local topography (10a)

Locations which fall within the buffered areas around features were mapped as negative criteria. Parameters developed internationally are considerably less conservative than the proposed criteria for the study area in the Western Cape. This is mainly due to the fact that internationally, landscape assessments using proclaimed areas such as Natura 2000, have already eliminated areas before criteria can be applied. South Africa does not have many proclaimed areas for protection, hence, according to the regional environmental authorities, the need for the stringent application of parameter criteria.

Landscape Appraisal

The aim of the landscape based assessment was to identify sensitive areas based on a qualitative approach, which were not suitable for wind energy developments. The overall goal of the programme was the protection of valuable and sensitive landscapes as well as the mitigation of potential impacts on visual quality (DEADP, 2006b).

The physical and cultural character of the study area landscape was defined by five major components (topography, geology and soils, vegetation, settlement pattern, and cultural significance), combinations of which allow consistent regional landscape types to be recognized. The resultant maps were based on two generic analyses:

A. Land Form (topography patterns) to depict the physical character. The following Land Form components were derived: Hills and mountains, foothills, coastal plains, inland plains, rivers, valleys and estuaries.

B. Land Cover (settlement and agricultural patterns) to depict the cultural character. The following Land Cover components were derived: Urban, urban-industrial, urban-coastal, historic/cultural settlements, rural/agricultural zones and wilderness areas.

A visibility analysis determining the Zone of Visual Influence (ZVI) from road networks was included in the landscape-based method. Based on a composite assessment of visibility, landform types, and land cover types areas were then rated as positive, negative ("restricted"), or intermediate ("negotiable").

Table 6 Positive and Negative Criteria

***Source*: DEADP, 2006b**

Criteria	Positive Criteria	Negative Criteria
Zone of Visual Influence (ZVI) Viewshed Analysis	Areas largely hidden from main transport routes	Areas highly visible from main transport routes, especially scenic routes
(Land Cover) Vegetation	Areas largely transformed by agriculture	Areas of natural vegetation lending a "wilderness" quality or having conservation potential. Historic and cultural landscapes.
(Land Form) Topography	Large inland plains	Mountains and Hills, Coastal plains, Rivers and Estuaries

Table 7 below illustrates a rating system applied to the area under consideration to highlight zones of concern or zones of opportunity.

Table 7 Rating of criteria

***Source*: Scoping Report, September 2007**

No.	Description	Preference
1	Areas with more than 1 negative criteria*	Highly restricted
2	Areas with 1 negative criteria*	Restricted
3	Neutral areas (no positive or negative criteria)	Negotiable
4	Areas with 1 positive criteria (and no negative criteria)	Preferred
5	Areas with more than 1 positive criteria (and no negative criteria)	Highly preferred

*The rating system assumes that criteria rated as negative would always override criteria rated as positive.

Figure 6 below illustrates the process model to develop a wind energy plan using layers such as environmental criteria, planning criteria, infrastructure and landscape criteria, cultural and landscape criteria. The various layers are combined in a "sieve" analysis using GIS. The result of all the criteria above gives a composite map showing areas of preference based on the combinations in Table 7 above.

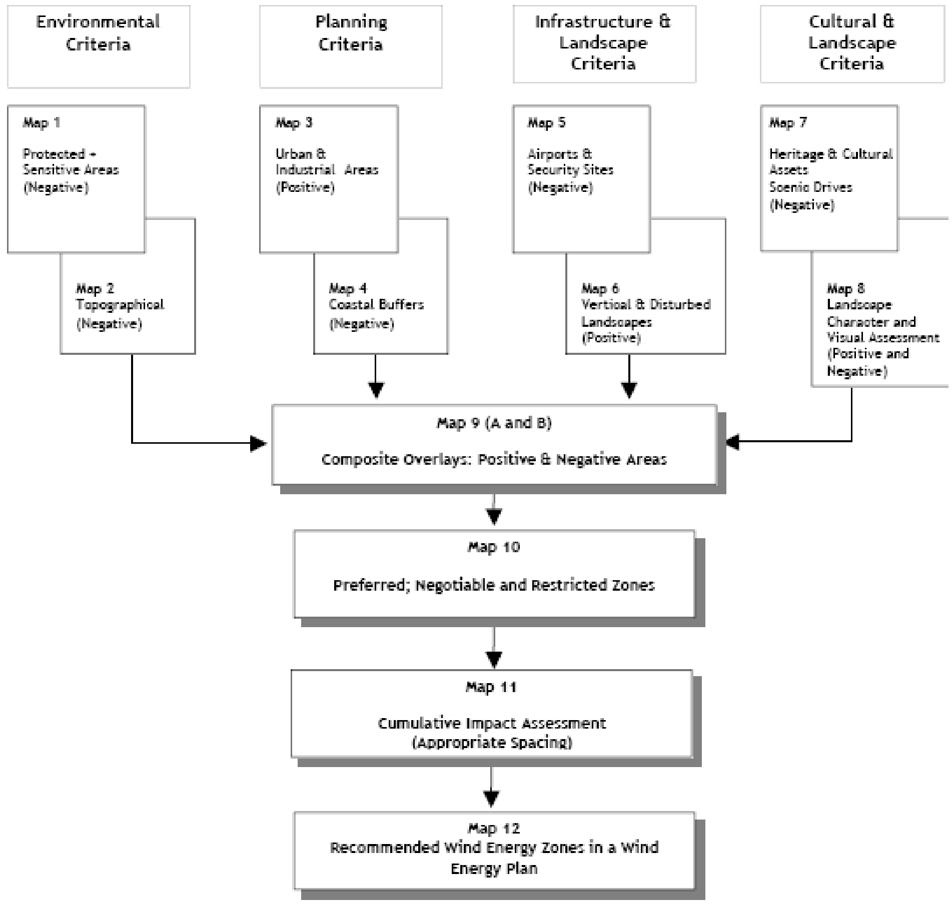


Figure 6 **GIS Model to develop the regional wind energy plan**

***Source*: DEADP, 2006b**

The final output was subjected to a cumulative impact assessment analysis, after which recommended wind energy zones are illustrated in a regional wind energy plan (DEADP, 2006b).

5.4.3 Results

The resultant composite map, based on a rating system related to criteria importance and landscape sensitivity, defines the preferred wind energy zones, see Figure 7 below. The study area for this assessment is largely undeveloped with open landscapes and in order to avoid being able to see one wind energy facility from the next, which would be the cumulative impact, buffers of 30 km or 50 km around wind energy facilities were proposed as an additional layer to the composite map.

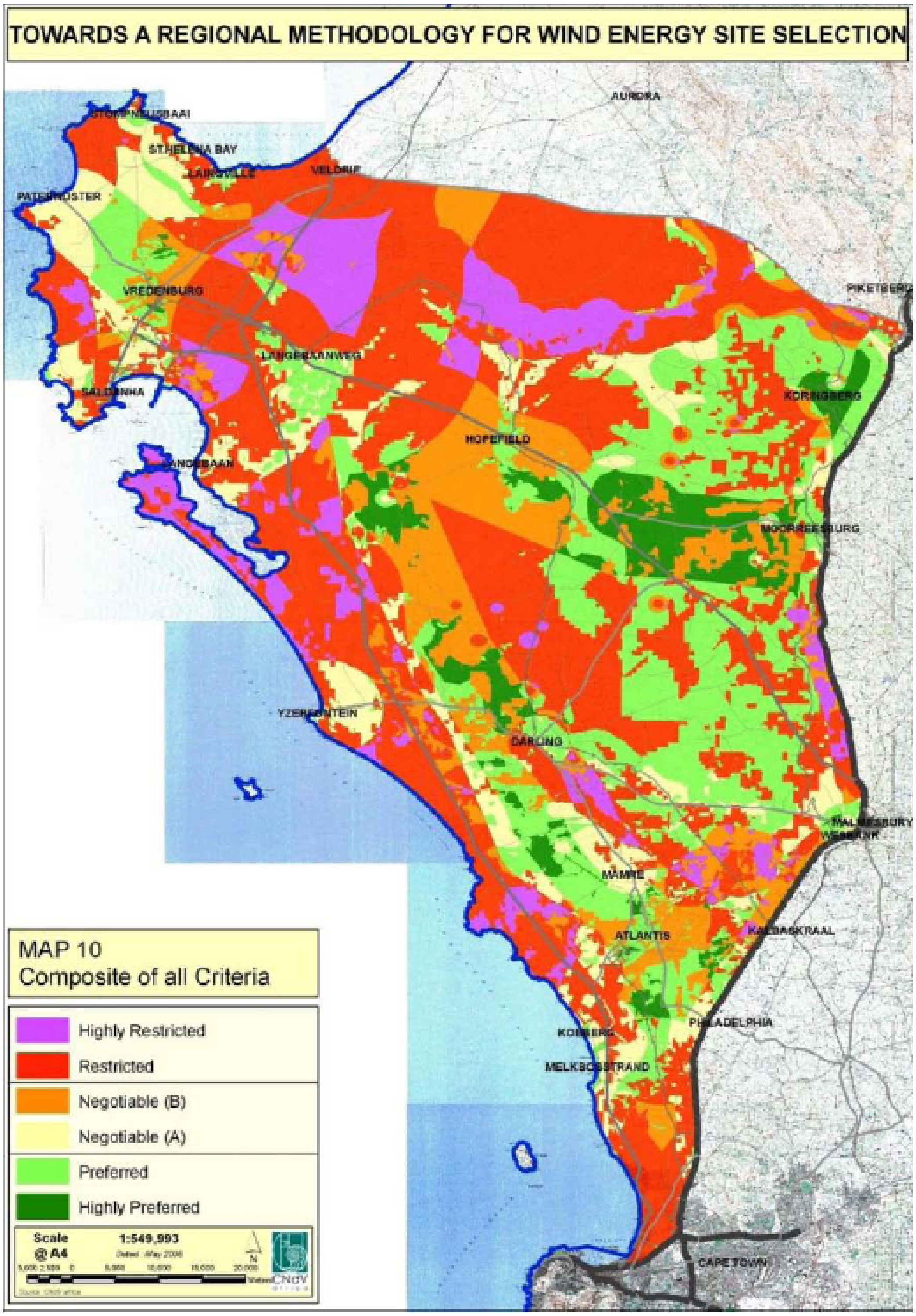


Figure 7 **Composite map of all criteria**

***Source*: DEADP, 2006b**

5.5 Overview of Case Studies

Three case studies have been chosen to illustrate how GIS can be used in varying ways to evaluate or determine suitable sites for the location of wind energy facilities. Below is an overview of each GIS based model.

Table 8 Overview of Case Studies

Model	**Northern California**	**Government of the North East**	**WC Regional Methodology**
Location	USA	UK	South Africa
Scale (geographic extent)	Regional	Regional	Regional
Purpose of the study	Evaluation and validate whether already existing wind energy facilities were indeed located in ideal wind energy development zones to use this information for placing future wind energy facilities more strategically.	Adopted to promote wind energy as part of a renewable energy strategy for the North Eastern region of England by locating potential areas for wind energy development.	A proposed methodology for the strategic site selection of wind energy facilities in the Western Cape province of South Africa in order to preserve the quality of the landscapes whilst promoting wind energy development in the region.
Constraints Model	Physical, environmental and human	Technical and environmental	Technical and environmental
Wind Resource Layer	Yes	Yes	No
Grid Connection Layer	No	Yes	No
Land Appraisal	No	Yes	Yes
Visibility Analysis	No	Yes	Yes
Weighting and Scoring System	Scores were assigned using expert judgement. The scoring ranged from 0 = Unsuitable, 1 = Poor, 2 = Fair, 3 = Good and 4 = Excellent for attributes of the physical, environmental and human models.	Constraints classified either as absolute of zones of consultation; visibility map showing grid cells with the highest values as the most visible areas and landscape appraisal ratings of low (1) to high (5) sensitivity.	Negative criteria result in restricted or highly restricted areas and presence of positive criteria will result in preferred to highly preferred areas. The presence of any negative criteria will result in restriction regardless of any positive criteria.
Sensitivity Analysis	Display of different combinations used to show the effect of each criterion such as physical and environmental impacts versus only physical features and allows the decision maker to draw conclusions on the importance of including more than one criterion	The constraints model was combined with the visibility analysis to determine whether it would be visually acceptable in a preferred area and the combination of the constraints model with the landscape appraisal.	The constraints model was combined with the landscape assessment (including visual assessment) and the final output subjected to a cumulative impact assessment analysis.

6 ANALYSIS

According to Baban and Parry (2002), GIS has the ability to handle and simulate the physical, economic and environmental constraints and is therefore a useful decision support tool for locating suitable wind energy development sites. This section is an analysis of the case studies to look at some of the strengths and weakness of the GIS-based models in locating suitable sites for wind energy development. We sought to examine how GIS can support spatial decision making for strategically locating areas for wind energy development at a regional level and more specifically analyse what South Africa can learn from previous studies which applied GIS to support strategic decision making for wind energy site selection.

Did the process include diverse multi disciplinary data?

All three GIS-based models made use of various technical and environmental criteria as input layers which were suited to the local context. The Northern California Model included physical features such as wind resources, obstacles and terrain; environmental criteria such as land use, vegetation and sensitive areas including wetlands and endangered plant species; as well as impact on humans such as the proximity of the wind energy facility to people and recreational areas. Public opinion and visibility were not included as criteria but were assessed separately based on feedback from the public.

The Government of the North East Model included physical features such as wind resources, technical utilities and infrastructure, radar and communications, military and training operations; and environmental criteria such as landscape issues such as designated protection areas and heritage areas. However, the model uses only urban features in the visibility analysis and does not include rural-residential areas which would also be visually impacted by wind energy facilities.

The Western Cape Regional Methodology included physical features such as urban and industrial; land form and land cover; environmental criteria such as protected areas and topography; infrastructure and landscape features such as airports and security; transformed landscapes from mining and agriculture; and landscape criteria such as heritage and cultural sites as well as scenic drives. However, wind data and technical data such as access to the grid were not included as assessment criteria. The Western Cape Regional Methodology could have very different outcomes if a wind resource and grid capacity layer were added. It is possible that although an area may comply with environmental criteria, that does not mean that it is a suitable site for wind energy development.

Were alternative scenarios created to evaluate the effects of input criteria and parameters?

The advantage of the Northern California Model for the decision maker is the use of expert input to score and weight the individual layers that influence a decision. The decision maker is then able to assess which features work for or against the desired outcomes. This information assists the decision maker in facilitating trade-offs and finding opportunities for exceptions which often help resolve areas of conflict. When comparing the effect of the threshold value chosen for wind resources between what is needed for large scale wind turbines versus small scale wind turbines, very little land was left available for wind energy development for large scale installations. The case study deems all wind less than 7m/s as unsuitable for large scale wind turbines. Given the technological advancements in the wind energy industry, it could be that new technology can operate adequately at lower wind speeds, which means that theoretically areas of 5.5 m/s and above could be considered in future and with that more land would potentially be available for wind energy development.

The Government of the North East Model used combinations of a GIS constraints model with specified parameters which are either no-go or negotiable; a visibility analysis; and a landscape appraisal, which is slightly more subjective and has relative scores for landscape sensitivity. The constraints model was combined with the visibility analysis to determine whether it would be visually acceptable in a preferred area. Also, a combination of the constraints model with the landscape appraisal will result in landscape sensitivity and can be used as a further indicator as to whether it would be acceptable or not.

Similarly to the Government of the North East Model, the Western Cape Regional Methodology uses the inputs from the GIS constraints model, visibility analysis and landscape appraisal to compile composite maps of criteria for suitable wind energy development sites. The difference between the two models is that the Western Cape Regional Methodology added a rating system where negative criteria result in restricted or highly restricted areas and the presence of positive criteria will result in preferred to highly preferred areas. The presence of any negative criteria will result in restriction regardless of any positive criteria. The creation of alternative scenarios was found to be lacking in the Western Cape Regional Methodology. Composite maps were created based on ‘positive’ and ‘negative’ criteria which result in restricted or preferred areas, as mentioned above. Where two negatives occur based on parameter values, the location will be defined as highly restricted. The methodology does not cater for those negatives where they could potentially be ‘negotiable’, or in other words, if they sat on the border of the parameter value.

Furthermore, although a rating system is used for the Western Cape Regional Methodology to produce the final map, both the Government of the North East and the Western Cape Regional Methodology do not weight any of the initial input criteria. It can then be assumed that all criteria were weighted as equally important. Given the conflicts over the definition of location suitability, assigning equal weights to input criteria may not be conducive to yielding consensual results. Furthermore, based on the study of Baban and Parry (2002), assigning equal weights will result in a slight decrease in the geographical extent for the most suitable sites as opposed to assigning different weights based on perceived importance.

Were the criteria inputs participatory?

In each of the case studies, the criterion chosen were based on guidelines and international best practice. The perceived importance of each was based predominantly on expert judgement. However, each case study does give evidence of public participation even if only in the form of questionnaires. Opposition to wind energy facilities are mainly attributed to visibility, landscape change and the impact on birds. The Northern California Model deems all areas outside of urban areas suitable for wind energy development. By not including rural residential areas in the assessment, this increases the risk of potential opposition to wind energy development in the rural area from those living there. On the other hand, where the Western Cape Regional Methodology proposes generating buffers of 30 kilometres to 50 kilometres for open flat areas to avoid any possibility of being able to see one wind energy facility from another, very little land is left available for wind energy development. There are large ‘open flat’ areas in the region and using such parameters can be perceived as authorities arbitrarily curbing wind energy development.

Was the purpose of the study fulfilled?

The advantage of the Northern California model in simulating the consequences of spatial decisions already made, is that much of the uncertainty commonly found in decision-making can be removed. The results of the analysis were compared with actual wind developments in the area and it was shown that opposition to wind energy facilities occurred where areas were mapped as less suitable due to bird migration routes and the proximity to urban areas. This shows that these are important criteria to be included in future studies and the results of the study can be used for future strategic planning.

Both the Government of the North East model and the Western Cape Regional Methodology are useful for strategic planning as they “sieve” through the region to find suitable areas for wind energy development. Assessing the amount of available land for wind energy development has provided policy makers with a spatial framework for renewable energy policy. Targets for renewable energy would be set unrealistically if based soley on the strength of the wind resource or technology used. Also, with a forecast of likely sought after areas for wind energy development as well as areas which are restricted, this analysis can be incorporated into wind energy plans.

Can these GIS based models be replicated elsewhere?

These GIS based models are limited by the amount of GIS data in the correct format available. GIS models are known to be computer and time intensive as several layers need to be standardized, reclassified, overlaid, weighted and so forth. These GIS based models appear to have been simplified and adapted to suit the needs of the local context, but the GIS operations used to produce the suitability maps can be used in other models. Although these GIS based models require skilled professionals in GIS to develop them, once the suitability layers have been created other interested parties could do a basic analysis in a GIS viewer.

7 CONCLUSION AND DISCUSSION

Countries around the globe have developed policies for including renewable energy as part of national energy strategies. The preference for renewable energy sources is the logical outcome of both a desire to increase the reliance on sustainable energy sources as well as the desire to reduce the emissions of carbon dioxide from burning fossil fuels. Identifying areas suitable for wind energy development is a component of sustainable energy planning, as it will determine the extent to which wind energy might be harnessed and developed as part of a renewable energy strategy, taking into account various environmental and technical limitations.

The policy makers and authorities who deal with wind energy development applications need to strike a balance between promoting alternative energy and at the same time ensuring that there is little to no impact on the environment. Best practice guidelines for the placement of wind energy facilities are beneficial to both authorities and developers. Authorities must be able to defend their decisions from criticism and developers should prevent the rejection of projects due to avoidable transgressions of policy regarding the visual impact and the perceived degradation of the landscape.

In South Africa wind energy developments are currently being assessed on an *ad hoc* basis through either a Basic Assessment or a Full Scoping and Environmental Impact Assessment. An EIA focuses on the positive and negative impacts of a specific development project once it has been formulated. Yet where wind energy development is concerned an EIA cannot adequately evaluate the cumulative impacts such as the value gain or loss of being able to see one wind energy facility from another. The size and number of wind energy developments also has implications for spatial planning. These should ideally be addressed at a more strategic level, and it is at this level that geographical information systems are very useful.

Geographical information systems can be used in Strategic Environmental Assessments which are broader in scope than Environmental Impact Assessments, and permit the decision-maker to pro-actively determine the most suitable development type for a particular area, before development proposals are formulated.

With regards to data and scale needs for impact assessments, spatial scale affects assessments that rely strongly on mapped information such as very large projects, cumulative effects assessment as well as strategic environmental assessment. What is deemed significant at a particular scale might not be seen as significant using a different scale. This is important to note when considering the cumulative impact of wind energy facilities which are more noticeable at a regional scale than at a site specific or local scale, or the impact of Not-In-My-Back-Yard (NIMBY) objections to wind energy facilities at local scale where the locations of actual wind energy facilities would be perceived differently at a regional scale. Planners need to take the context into consideration when choosing scale and make this an open and transparent process.

A brief history has been given on the evolution of GIS in parallel with spatial planning. GIS has evolved from a 'closed-expert' orientated to an 'open-user' orientated technology and has become part of a more open and inclusive process which includes public participation and conflict resolution. Given the conflict of interest between wind energy developers, environmental and planning authorities and the public, GIS is useful here as it offers a platform for decision support tools to select wind energy sites from initially conflicting positions and can draw together and analyze data from disparate sources to produce maps, graphs and reports.

GIS can be integrated with multi-criteria analysis techniques which involves choosing the relevant assessment criteria or impacts and alternatives, scoring how each alternative affects each criterion; weighting the impact and aggregating the score and weight of each alternative. With GIS, map layers corresponding to each constraint criterion are created followed by the allocation of weights to each layer and different scores to each attribute within the layers using reclassification and buffer generation methods. The use of the overlay function to combine all the layers results in a constraints map.

A few examples are given of methodologies used for creating constraints maps to find suitable site for wind energy development. These examples from literature show that models are often made up of a combination approaches such as the Boolean Overlay and the Weighted Linear Combination.

Three case studies of GIS based models for wind energy facility site selection used in the USA, England and South Africa respectively were selected to illustrate how GIS has been applied by planners and decision-makers in different geographic locations and contexts. A description of each GIS based model is given, taking into account the different assessment criteria used and approach taken to determining site suitability. These GIS based models were assessed on their strengths and weaknesses in locating suitable sites for wind energy development and to show the overall support GIS provides for decision making.

Each model illustrates how GIS can be tailor-made to become an effective support tool for spatial decision-making. The advantage GIS gives to planning models is that different scenarios can be developed to assess what effects assessment criteria have on one another and whether this meets the desired outcome. Additionally, the advantage of developing and comparing alternatives is that it allows the decision maker to balance the views of authorities, communities and developers by creating a platform from which negotiations can proceed.

Although having quantative threshold criteria based on expert input allows authorities to defend their decisions from criticism, there is a risk of excluding potentially suitable areas with overly stringent criteria. In the Northern California Model, adequate wind speed was given as 7 m/s for wind energy development using large scale turbines. Wind below the threshold was deemed “unsuitable” and wind 7 m/s and above was deemed as “excellent”, with no scores in between such as “good”. Areas with an average wind resource of perhaps 6.5 m/s would therefore not be considered, however it is clear from looking at the assessment done for small scale wind turbines that there would be a lot more land available for wind energy facilities if the threshold criteria for wind were more flexible. The Western Cape Regional Methodology proposes generating buffers of 30 km to 50 km for open flat areas to avoid any possibility of being able to see one wind energy facility from another. The use of conservative parameters such as these do not facilitate consensus on wind energy facility placement, especially where there is good economic potential for wind energy.

Overall, the GIS based models in the case studies showed that diverse multidisciplinary data were included, alternative scenarios to evaluate the effects of input criteria were created (with the exception of the Western Cape Regional Methodology); the criteria input was participatory and that the purpose of each study was fulfilled. The GIS based models were developed according to their purpose, context and available data, however elements of the system are replicable and can be used in other models. These factors contribute to the ‘usefulness’ of the GIS based models for locating suitable sites for wind energy development.

South Africa lags in planning for wind energy development. The country would benefit from having regional wind energy plans as part of the spatial development frameworks and a formalized Strategic Environmental Assessment process. However, while wind energy development applications are still being assessed on an *ad hoc* basis, good wind energy development guidelines, consisting of reasonable absolute and negotiable constraints would greatly assist in implementing sustainable projects. Integrating criteria into a user-friendly GIS would not only assist strategic planners and authorities but developers could also make use of it for their planning and prospecting. Furthermore, it would be in the authorities’ best interests to overlay wind resources and technical constraints such as grid capacity with environmental constraints to gain a realistic view of how much wind energy development could take place in the country.

It is therefore recommended that the authorities in the Western Cape consider the following in the Strategic Environmental Assessment:

1. A GIS based model with flexible parameters to enable trade-offs for conflict resolution comparable to the Government of the North East (GO-NE) model where criteria were not only categorized as absolute constraints but also zones of consultation which makes allowances for negotiable areas and areas of uncertainty;
2. Publish guidelines consisting of reasonable absolute and negotiable constraints;
3. Consider adding a wind resource and a grid connectivity layer to the assessment; and
4. Use the areas identified as 'preferable' and 'highly preferable' for wind energy plans within the spatial development framework.

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