# ON-SHORE WIND AND SOLAR POWER PLANTS AS ALTERNATIVE ENERGY SOURCES FOR VICTORIA

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**ABSTRACT:**

This study investigates alternative energy scenarios for Victoria to minimise carbon-emissions. There are many renewable energy options for Victoria; however, the visual impact on the State's landscape is unknown. This project illustrates a Victoria powered solely by renewable energy: namely on-shore wind and solar power plants. Areas suitable for such power sources were identified using data analysis via geographic information systems. The visualisation of energy landscapes was produced using digital globe technologies. Landscape scale visualisation enables the State to be perceived in its totality. This will benefit decision-makers considering sustainable energy mixes by assisting with site selection and policy development.

## 1. INTRODUCTION

Due to heavy reliance on brown coal, green house gas emissions for Victoria are among the highest in the world per capita (State of the Environment Report, 2008). Sustainable energy options, such as solar and wind power, provide alternatives to reduce Victoria's carbon-footprint. Appropriate siting of alternative power options requires social, environmental and economic concerns to be addressed. Spatial analysis and visualisation assist with the selection of alternative energy options and understanding of their effect on the State's landscape. Visual portrayal of information further enables ideas to be widely shared.

### 1.1 Wind and Solar Power Potential and Feasibility for Victoria

The Victorian Wind Atlas (2003) indicates Victoria has world-class opportunities for wind farm sites; both inland and along the coastline. In addition, the Sustainability Victoria Website (2009) highlights solar energy as a potential option in Victoria. Manufacturing advances, in both wind turbine and solar cell development, have increased output potentials (Hoffmann, 2006; Edwards, 2008).

### 1.2 Environmental Concerns

Wind power uses kinetic energy from the wind to produce a clean form of energy without directly producing harmful emissions. Nonetheless, many concerns are raised regarding environmental effects. For instance, sites with high wind speeds may coincide with migratory paths of birds (Welch and Venkateswaran, 2009). No wind farm should be sited directly in an avian migratory path. Also, according to the United State's Federal Aviation Administration (FAA) analysis, the movement of the turbines can cause electromagnetic interference with radar that may result in blind spots for air traffic controllers. Ten kilometres is an acceptable distance to ensure wind farms are not a hazard to aircraft in flight (MTC, 2009).

Furthermore, wind turbines lead to concerns regarding noise. The Danish Wind Industry association reports that new technology has resulted in wind turbines becoming increasingly quiet (DWIA, 2003). It is generally recommended that a distance of 1km is sufficient to eliminate noise disturbance (Pedersen and Persson Waye, 2007).

Solar energy does not produce any direct emissions, pollutants, bi-products or noise. Nonetheless, both these renewable energy resources have a visual impact on the surrounding landscape.

### 1.3 Visual Impacts

Both wind and solar sources affect the aesthetics of the landscape. Wind farms, in particular, have been widely studied for their visual impact and met considerable local opposition in a number of locations. A variety of variables determine the extent and nature of the impact. Torres-Sibille et al. (2009a, 2009b) have devised indicators to quantify the visual impact of both solar and wind farms on the landscape. They identify factors which contribute to a person's perception of these power plants are: visibility, colour, fractality and movement. Consequently, it is necessary to consider the distribution, configuration and placement of such power plants across the Victorian landscape. Solar plants, on the other hand, are considered 'unobtrusive' (Renewable Energy Sources, 2009) although there has been very little research on the impact of their widespread use.

### 1.4 Objectives

This study identifies a sustainable energy scenario for Victoria, by determining a mix of on-shore wind farms and solar plants. The mix of resources generates sufficient power to meet current and projected electricity needs for the year 2030. Issues of power storage to cope with variations in production and demand are however not addressed here. Also, our research does not address economic considerations. Overall this study had three objectives:

1) To determine an appropriate energy mix scenario for on-shore wind and solar power plants to address the electricity demands for Victoria.
2) To identify optimal site locations for wind and solar plants under environmental and social constraints.

3) To present visual aids that illustrate the impact on the State's landscape in its entirety should this energy scenario be realised. Visualisations are intended to communicate a general understanding of the extent of the impact (rather than provide an in situ experience).

## 2. METHOD

### 2.1 Determine Energy Scenarios and Corresponding Energy Demand

The energy consumption for Victoria for 2008/2009 and the projected consumption in the year 2030 were provided by the Australian Bureau of Agricultural and Resource Economics (ABARE, 2008). Additionally, the prospect of vehicles being solely powered by electricity by the year 2030, rather than other fuels, was considered. Calculations were based on figures provided by the Australia Bureau of Statistics (ABS, 2003), the Victorian Planning Provisions (VPP, 2008), and General Motors (2006). We defined two renewable production scenarios, with associate storage for load distribution, based on generation potential equivalent to 100% of current and projected (2030) energy demand:

Scenario 1: 7.2 GW
Scenario 2: 12.5 GW (including electric vehicles)

If all existing, approved and proposed solar and wind farms in Victoria were realised then they would generate 71% of estimated energy requirements for scenario 1 and 41% for scenario 2 (Department of Primary Industries, 2009). An additional power capacity of 2GW for 2009 levels and 7.5GW for 2030 levels is required under these scenarios.

Given necessary energy storage, this remaining demand is assumed to be met with 50% wind and 50% solar.

### 2.2 Identify Suitable Site Locations

Using ESRI's ArcGIS geographic information system (GIS), suitable site locations for wind and solar farms were determined by considering all concerns raised by the literature.

**Sufficient Energy Resources:** Only areas with an average annual wind speed greater or equal to 6m/s are considered suitable for wind farms. Similarly, only areas of the State which benefit from 21 MJ/sq. m of solar exposure annually were selected as potential solar plant locations.

**Planning Zone Considerations:** The potential site locations were limited to the following planning zones: Farming Zone (FZ), Green Wedge Zone (GWZ), Rural Conservation Zone (RCZ), Rural Activity Zone (RAZ), Mixed Use Zone (MUZ) and Industrial Zones (IN*). Additionally, the identified areas were not located in national parks or areas of environmental, heritage or cultural significance. This was achieved by eliminating potential sites with the following planning overlays: Environmental Significance Overlay (ESO), Significant Landscape Overlay (SLO), Heritage Overlay (HO), Erosion Management Overlay (EMO), or Vegetation Protection Overlay (VPO).

**Land Use – Protection of Flora:** It was necessary to ensure that the proposed sites were not located in areas of dense vegetation. All areas of dense vegetation including native bush and commercial plantation land use areas were eliminated.

**Distance from Townships:** A one kilometre buffer was placed around towns to minimise aesthetic disturbance to communities.

**Threatened Fauna:** Point data revealing sightings of threatened fauna was examined. Potential site areas were then limited to areas more than five kilometres from sightings.

**Airports:** To avoid interference to aircraft, potential sites were limited to greater than ten kilometres from any airport.

**High Voltage Power lines:** To facilitate the connection of power plants to the State electricity grid, potential sites were preferred within 15 kilometres of high voltage power lines. This was feasible in the case of wind farms because of the large suitable area. Solar sites are more restricted and this preference was not applied.

This process resulted in a single mapping of optimal areas for solar plants. Available wind farm sites were divided into four classes according to wind speed (6-6.5m/s, 6.5-7m/s, 7-7.5m/s, 7.5-8m/s).

The site analysis addresses continuous factors in a binary inclusion/exclusion process; a comprehensive spatial analysis would use a weighted factor combination method. The focus of this study was to illustrate a potential impact of the transition to renewable power rather than provide precise spatial planning.

### 2.3 Identify New Sites

In order to visualise the energy mix, it was necessary to determine the final sites to be used from the potential sites previously identified. Selected sites were dispersed across the State. (Thus minimising the effect on any one community's environment). Wind farm sites were limited to 20 km², resulting in 180 turbines. Solar plant sites were restricted to 10 km².

Polygons were created in ArcGIS to represent these sites' size, shape and location. Additionally, the centroid of these polygons was used to create a point shapefile to depict the location of the sites.

### 2.4 Visualisation of the Energy Scenarios

The final objective was to visually represent the overall impact on the landscape of Victoria. The two scenarios were visualised using the Google Earth digital globe and Google Sketch-Up software packages, to produce a landscape scale depiction. These visualisations were reproduced in the form of maps and still images although flyovers were also created.

Wind turbines or solar panels are highly visible from ground level but tend to disappear rapidly at distance. Therefore two different approaches to infrastructure visualisation were followed.

- Three-dimensional (3D) polygons were created in Google Sketch-Up to illustrate the space occupied by solar and wind plants. The 3D polygons representing wind farms occupy 20km² and are 120 metres high; these are blue. 3D polygons representing solar plants occupy 10km² and are 20 metres high; these are coloured yellow. Bright colours were selected to maximise the visibility of the polygons. The polygons created in ArcGIS, of required dimensions and exact location of the power plants, were converted into KML (Keyhole Modelling Language) files. These were then imported into Google Earth to be used as guides. The 3D models were then manually placed over each of the 2D polygons.

- Using Google Sketch-Up, solar plant and wind farm realistic 3D models were created. The models were built to scale using the dimensions previously determined. The 3D models were exported as COLLADA (COLLAborative Design Activity) files. These files were then imported into Google Earth. The previously imported polygon KML files enabled the solar plant and wind farm models to be situated in locations determined as suitable through the spatial overlay method described above.

Each process was repeated until the entire Victorian landscape in Google Earth was populated with existing, approved and proposed wind farms and solar plants for both scenarios (1) and (2). Still images were taken in Google Earth at different locations and heights.

## 3. RESULTS

### 3.1 Optimal Site Locations for Wind and Solar Plants

The optimal sites for wind farm development were mainly distributed across western and southern Victoria (Figure 1). The optimal positions for solar plants were identified in the north-west of the State (Figure 2). Figures 3 and 4 show the complete distribution, including those currently existing or proposed, of power plants needed to produce the output levels of the two scenarios.

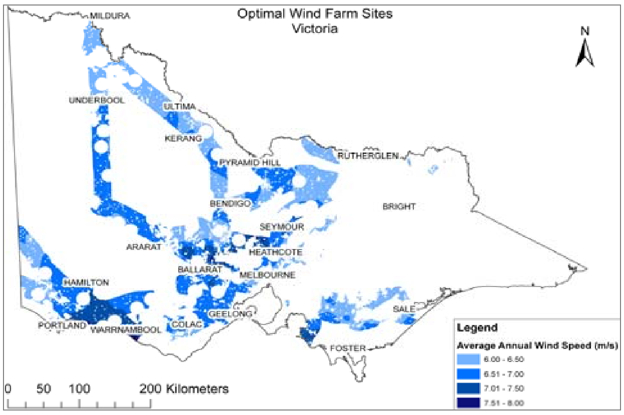


Figure 1: The optimal sites for wind farms across the State of Victoria

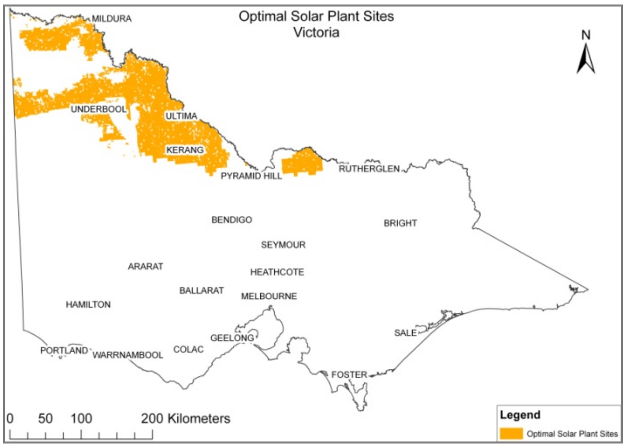


Figure 2: The optimal locations for solar plants across Victoria

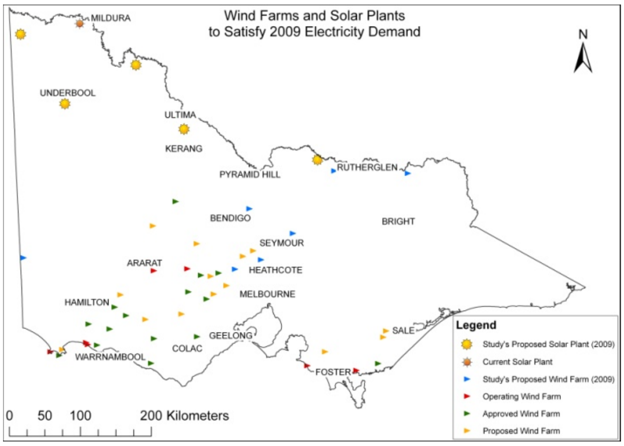


Figure 3: The number, distribution and location of the required solar and wind power plants to meet electricity demand for 2009

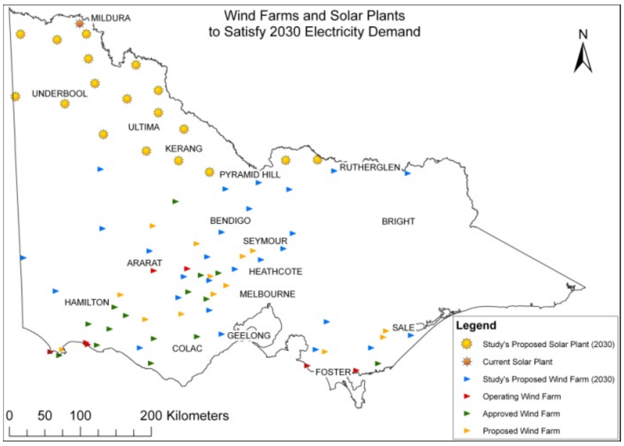


Figure 4: The number, distribution and location of the required solar and wind power plants to meet electricity demand for 2030

### 3.2 Visualising the Impact on the State's Landscape

Assuming solar and wind plants are visible from a distance of 20 kilometres and no greater, Figures 5 and 6 show how much of the State is visually affected by the developments. A more comprehensive analysis would take account of the hiding effect of the terrain. The analysis could also generate visibility mapping from the road network or other significant vantage points.

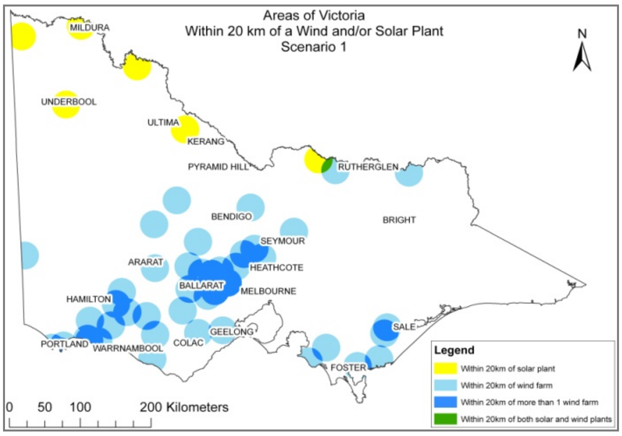


Figure 5: Regions of Victoria where a solar plant or wind farm are considered to be visible for scenario 1

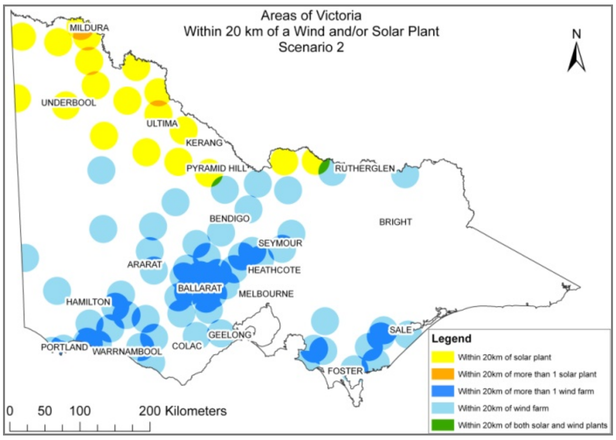

Figure 6: Regions of Victoria where a solar plant or wind farm are considered to be visible for scenario 2

While maps provide an overview of likely affected areas they give no impression of either the visual impact of a 180 turbine wind farm (20 km²) or a 10 $km^2$ solar plant. They also give little idea of the overall degree of impact on the broader Victorian landscape. Figures 7 to 10 endeavour to address these issues.

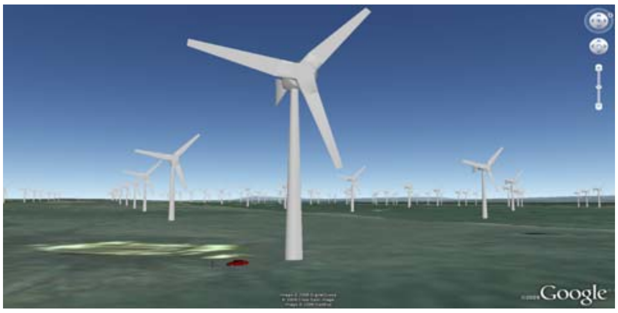
Figure 7: A 180 turbine wind farm on the immediate landscape. A car (5m in length) and a person (1.8m in height) show scale


Figure 8: 180 turbine wind farm; eye altitude of 500m

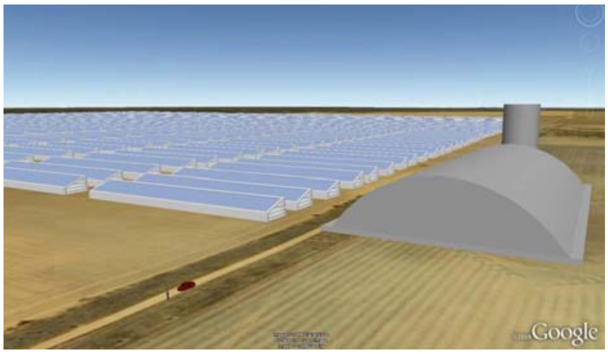
Figure 9: A close-up of a 10 square kilometre solar plant. A car (5m in length) and a person (1.8m in height) show the scale

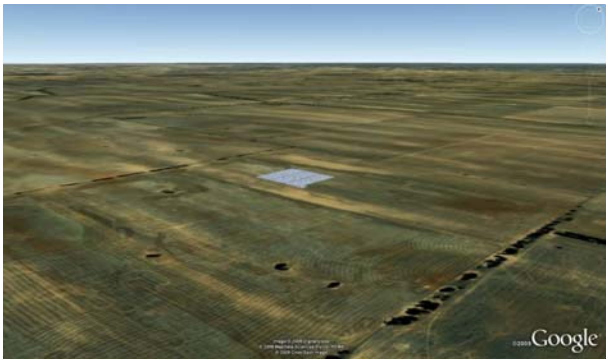
Figure 10: A 10 km² solar plant in north-west Victoria; eye altitude of 500m

If the camera is moved still higher to give a view of the relative distribution of plants, the individual turbines are no longer visible. Figure 11 shows the use of coloured 3D blocks to represent the location and dimensions of the wind and solar installations.

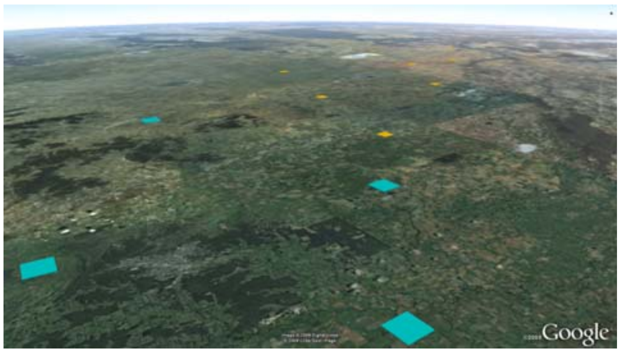
Figure 11: Image illustrating the distribution, size, shape and location of wind farms (blue) and solar plants (yellow); eye altitude of 40km

## 4. DISCUSSION

This study presents renewable energy mix scenarios to provide for Victoria's current (2009) and projected future (2030) electricity demands. The proposed scenarios consist of a combination of wind and solar. Landscape scale visualisations illustrate the impact on the State's landscape in its entirety.

### 4.1 Site Suitability and Energy Mix

In order to satisfy the two scenarios, suitable site locations were determined. Analysis of geographic information revealed that 9.8% of the State is optimal for solar plant development. In contrast, 30% of Victoria is appropriate for wind farms. The optimal positions for solar plants were identified in the north-westerly part of the State where the average annual solar exposure is 21 MJ/sq. m. Moreover, the average annual wind speeds available in suitable locations for wind farms range from six metres per second to eight metres per second. The windiest areas are situated along the coastline near Portland and Warrnambool and inland near Ballarat.

The existing, approved and currently proposed plants were also considered. Currently the only solar plant development in Victoria is estimated to have an installed capacity of 154 MW. In contrast, the estimated capacity of operating and planned wind farms in the State is 4 957 MW. Thus, 3% of the energy generated by these two sources is solar and the remaining 97% is wind. The extensive wind resources in Victoria are already being used to a far greater extent than solar power.

In general, wind farms are considered more intrusive to the landscape than solar plants (Renewable Energy Sources, 2009). This suggests that from a visual viewpoint it would be beneficial to maximise use of solar plants. However, as suitable sites for solar plants are restricted to the north-west corner of the State, this would result in a large number of solar plants in a limited region; such grouping is visually undesirable.

By satisfying the electricity demand with 50% solar resources and 50% wind resources, it was calculated that overall, for 2009 levels, solar plants would contribute 17% and wind farms the remaining 83%. This dramatically reduces the current discrepancy of distribution. For 2030 levels, solar plants would contribute 31% and wind farms the remaining 69%. This energy mix coincides with the availability of the respective resources and enables dispersion of the plants to reduce the visual impact.

### 4.2 Final Site Selection for Wind Farms and Solar Plants

Stanton (1996) highlights that the intrusiveness of a wind farm is not directly proportional to the number of turbines in an array, but rather is attributable to design aspects. For example, large wind plants may appear less dominating than a smaller development when the large wind plant is presented in a visually comprehensible method. For this study, it was decided to use fewer large sites for wind farms and solar plants to minimise visual interference; rather than a greater number of smaller plants more frequently distributed across the State.

To satisfy current electricity demands an additional eight wind farms and five solar plants would be required. To meet the projected electricity demand for the year 2030, an additional 27 wind farms and 18 solar plants are needed. The land area required for scenario 1 is 210 km² and for scenario 2 is 720 km².

Among the environmental and social concerns raised by the literature our mapping indicated that the dominant constraint was the visual impact on the environment; primarily to minimise the visual impact on any one community. This objective was achieved by dispersing the wind farms and solar plants across the State in the potential areas identified.

The most suitable locations for wind farms in Victoria cover an area from the coast near Portland, moving inland in a north-easterly direction, to Seymour. Despite the considerable number of current existing developments or projects in different stages of completion in this region, a number of additional developments were proposed within this zone (figures 3 and 4). Sites chosen aim to keep the density within reasonable limits.

Furthermore, in order to minimise the visual impact of wind farms, this study selected no sites in coastal regions (within 15km of the coastline), despite the rich wind resources available. Research reveals that the impact on the landscape is significantly higher in areas of natural beauty, primarily coastal regions. In contrast, in areas of low natural beauty, wind farms actually improve the visual aesthetics (Lothian, 2008).

### 4.3 Visibility Analysis

Using the simplistic assumption that solar and wind plants are visible to the human eye from a distance of 20 kilometres and no greater; analysis was performed to identify the proportion of the State where a solar and/or wind farm could be seen. Figures 5 and 6 illustrate the areas where the power plants may be visible for each scenario.

For scenario 1, only 3% of the State is within visible range of a solar plant and 20% is within range of a wind farm. For scenario 2, 9% of the State can ‘see’ a solar plant and 27% can ‘see’ a wind farm. Unsurprisingly, the proportion of the State that can ‘see’ a solar plant in 2030 increases approximately three times, in accordance with the increase in the number of solar plants. However, the area where wind farms are visible only increases by 37% despite the number of additional turbines proposed by the study increasing by 237%. There are 56 wind farms in different stages of development in Victoria (Wind Projects in Victoria, 2009). This study proposes a further 27 wind farms in scenario 2: a 48% increase. However at 180 turbines each, these farms are considerably bigger than many of the existing farms which typically have 20 to 50 turbines. The area where wind farms may be visible increases more than the percentage of additional wind farms; this is because the wind farms proposed by this study are more dispersed than the existing developments. Whether this is the best strategy is an open question. Figure 6 shows that large areas are within viewing distance of more than one wind farm. A traveller from Portland to Seymour may never be out of sight of wind turbines.

### 4.4 Landscape Scale Visualisation Techniques

Three-dimensional models, created in Google Sketch-Up and then imported into Google Earth, provided a realistic illustration of the impact on the State’s landscape. The size of 3D models and their impact on the surrounding environment has been visualised. Still images were taken of the 3D models in Google Earth at different proximities and elevations. Figures 7 and 9 indicate the visual effect of a power plant on the landscape for a nearby person. These images give the viewer a sense of the extent of each power plant.

In contrast, figures 8 and 10 are images taken of the power plants from 500 metres altitude. These images are effective in illustrating the impact of individual power plants across the broader landscape. However, no two power plants were closer than 30 kilometres. Thus when visualising the landscape it was not possible to easily see the next closest power plant. Hence the viewer would be unable to perceive the visual impact of all the power plants on the Victorian landscape in their entirety from the still images. A secondary form of visualisation was required.

To provide a more representative visualisation of proximity of power plants to one another, 3D polygons built to scale highlight the size, shape, position and distribution of the plants (figure 11). These brightly coloured polygons are easier to see on the landscape compared to the wind turbines and solar cells.

The polygons clearly and accurately depict the distribution of power plants on the landscape. The bright colours of the models however, do not give a representative idea of the visual impact of power plants. These models have a greater impact on the landscape than the actual power plants would from the same viewpoint. Thus, the polygons are appropriate for highlighting the distribution of power plants on the landscape and their proximity to one another; the realistic 3D models are more representative of the actual visual impact as perceived from the viewpoint of a person travelling through the landscape.

## 5. CONCLUSION

This research examined an alternative renewable energy mix for Victoria. It identified optimal site locations for wind and solar power plants across the State of Victoria. In addition, a suitable energy mix of solar and wind resources was established to satisfy two energy demand scenarios. Scenario (1) satisfied 100% of current energy demands and scenario (2) satisfied 100% of projected energy demands for 2030.

The study employed landscape scale visualisation to convey the visual impact of the scenarios on the Victorian landscape. Maps and still images sought to illustrate the impact on the landscape in its entirety should these energy scenarios be realised. The success of the visualisation approach has not been tested. The ideal, in terms of providing a viewer with an accurate sense of the visual effects on the Victorian landscape would be to enable the viewer to take unrestricted virtual journeys through and over the landscape. A number of flyovers were produced but even these distance the viewer from the full impact of a landscape with frequent and substantial energy infrastructure. Another visualisation option would be to generate animations showing continuous views from major highways since these would give the best sense of the frequency of occurrence of the new power plants. Further exploration of these issues, in light of the demands arising from greenhouse mitigation strategies, is clearly warranted. Nevertheless, our simple approach could benefit decision-makers considering renewable energy mixes; assisting with appropriate site selection and policy development.

## 6. REFERENCES

ABARE, 2008. Australian Consumption of Electricity, by State, The Australian Bureau of Agricultural and Resource Economics (ABARE), Australia. http://www.abare.gov.au/interactive/energyUPDATE08/excel/Table_I_08.xls (accessed 20 Mar. 2009)

Australian Bureau of Statistics, 2003. Survey of Motor Vehicle Use, Australian Bureau of Statistics (ABS), Australia. http://www.abs.gov.au/ausstats/abs@.nsf/ProductsbyReleaseDate/3EAAB384EF8D2F62CA2570800072002D?OpenDocument (accessed 20 Mar. 2009)

DPCD, 2008. Victoria in Future 2008, Department of Planning and Community Development, Victoria, Australia. http://www.dse.vic.gov.au/DSE/dsenres.nsf/LinkView/B9023E3BAACA5A6ACA256EF60019E55806C7DF80826B65674A256DEA002C0DCA (accessed 22 Aug. 2009)

DWIA, 2003. Danish Wind Energy Association, Denmark. www.windpower.org/en/core.htm (accessed 10 May 2009)

Edwards, R., 2008. When it comes to turbines, bigger is accepted as better, *New Scientist*, 200(2677), p. 35.

General Motors, 1999. Performance Statistics - 1999 General Motors EV1 w/NiMH. United States Department of Energy Office of Energy Efficiency and Renewable Energy, USA. http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/fsev/eva_results/ev1_eva.pdf (accessed 25 Apr. 2009)

Gipe, P. and Wiley, J.,1995. Wind energy comes of age. *Energy Policy*, 19(8), pp. 756-767.

Hoffmann, W., 2006. PV solar electricity industry: Market growth and perspective. *Solar Energy Materials and Solar Cells*, 90, pp. 3285-3311.

Lothian, A., 2008. Scenic Perceptions of the Visual Effects of Wind Farms on South Australian Landscapes. *Geographical Research*, 46(2), pp. 196 -207

MTC, 2009. Airspace Issues in Wind Turbine Siting, Massachusetts Technology Collaborative, Massachusetts, USA. http://www.masstech.org/rebates/Community_Wind/faaairspace.html (accessed 1 May 2009)

Pedersen, E. and Persson Waye, K., 2007. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. *Occupational and Environmental Medicine*, 64, pp. 480-486.

Renewable Energy Sources, 2009. Technology Comparison, World Press, USA. http://www.renewable-energy-sources.com/2008/11/28/comparison-of-energy-sources/ (accessed 24 Sep. 2009)

Stanton, C.,1996. The Landscape Impact and Visual Design of Windfarms, School of Landscape Architecture, Heriot-Watt University, Scotland, United Kingdom. pp. 1-52.

State of the Environment Report, 2008. Commissioner Environmental Sustainability Victoria, Victoria, Australia. www.ces.vic.gov.au/CES/wcmn301.nsf/childdocs/-FCB9B8E076BEBA07CA2574F100040358?open (accessed 28 May 2009)

Sustainability Victoria Website, 2006. Sustainability Victoria, Victoria, Australia. www.sustainability.vic.gov.au/www/html/2119-interactive-maps.asp (accessed 20 May 2009)

Torres Sibille, A.d.C., Cloquell-Ballester, V.-A., Cloquell-Ballester, V.-A. and Darton, R., 2009b. Development and validation of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms. *Renewable and Sustainable Energy Reviews*, 13(1), pp. 40-66.

Torres-Sibille, A.d.C., Cloquell-Ballester, V.-A., Cloquell-Ballester, V.-A. and Artacho Ramírez, M.Á., 2009a. Aesthetic impact assessment of solar power plants: An objective and a subjective approach. *Renewable and Sustainable Energy Reviews*, 13(5), pp. 986-999.

Victoria Planning Provisions, 2009. Department of Planning and Communtiy Development, Victoria, Australia. http://www.dse.vic.gov.au/planningschemes/VPPs/combinedPDFs/VPPs_All_Clauses.pdf (accessed 20 Aug. 2009)

Victorian Wind Atlas, 2003. Sustainable Energy Authority, Victoria, Australia.

Welch, J. and Venkateswaran, A., 2009. The dual sustainability of wind energy. *Renewable and Sustainable Energy Reviews*, 13(5), pp. 1121-1126.

Wind Projects in Victoria, 2009. Department of Primary Industries, Victoria, Australia. http://www.dpi.vic.gov.au/dpi/dpinenergy.nsf/childdocs/-384C1AC0F3D5716CCA25729D00102547-FD29EA297F0AB66DCA2573540007C7D6?open (accessed 24 Apr. 2009)