The Spatial Planning of Australia's Energy Landscape: An Assessment of Solar, Wind and Biomass Potential at the National Level

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Abstract: Spatially explicit assessment of renewable energy resources is critical for large scale landscape planning and design to maintain energy supply so that economic development and social advancement can be sustained. Renewable energy planning at the national level is pivotal to a nation's socio-economic sustainability in the context of the oil crisis, anthropogenic climate change and the social and economic impacts of globalisation resulting in the international dispersal of energy supply and ownership. Using a case study from Australia, we investigate the annual spatial heterogeneity of solar energy potential across the country towards identifying the strengths and appropriate uses of spatial modelling for regional decision making in energy planning. The case study explores solar radiation distribution in Australia and its potential to supply energy at national, utility and household levels. This study demonstrates the usefulness for integrating these models in the design and planning process for carbon-neutral energy supply. It is also clear that the adoption of spatial modelling systems for solar supply also requires modelling of the political and social opportunities and limitations inherent in the solar landscape. This research advocates a holistic approach enabled by spatial planning through geodesign principles. We conclude with recommendations and guidance for future renewable energy planning as a useful practice for carbon emission reduction to climate change mitigation.

Keywords: Geodesign, climate change, energy modelling, solar energy, Australia

1 Introduction

For centuries humans have modified terrestrial systems to meet basic energy needs, often with profound impact on the landscape systems that support biodiversity and healthy human existence. Human societal use of carbon-intensive and non-renewable energy is regarded as a major driver of climate change, challenging our ability to live sustainably through promotion of human well-being, environmental protection, and equitable economic development of benefit to all. Human lifestyles have evolved from prehistory to the present day, from huts to villages, towns, and cities, with an attendant explosion in consumption of energy and resources. Today, approximately half of the global population lives in urban areas and are responsible for about 70 % of the world's energy demand, and more than 80 % of global greenhouse gases emissions (EILPERIN 2007). Additionally, future population growth is expected to occur predominantly in cities so therefore the issues related to carbon emission reduction in urban areas are now pressing. Urban areas tend to offer easier access to more energy-intensive fuels, such as oil and gas, as well as demands for reliable electricity generation throughout all seasons of the year. Modern cities are characterised by high rates of energy consumption and resource exploitation, which in turn pose concerns of carbon emissions and climate change, exacerbated by our existing system of energy supply and consumption associated with the urban life style which is rarely exposed to the industrial mechanisms required to provide stable yet resource intensive systems.

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Among the most pressing of urban challenges facing human society in the 21st century, energy supply, distribution and consumption could arguably be the most urgent, as energy consumption of urban residents is about four times that of rural residents (HUBACEK et al. 2009, ZHANG et al. 2015). In the same way that energy and mass are linked in Einstein's formula $E = mc^2$, energy and space should also be seen as in a symbiotic relationship., This is particularly apt for low-carbon-city development where decisions regarding energy supply and distribution could be better informed by the opportunities afforded through improved understanding of the source of energy supply – the regional (energy) landscapes. To provide a bridge between energy modelling and spatial planning of the energy landscape, this research seeks to provide a bridge between energy modelling and spatial planning across Australia. A geodesign approach encompassing GIS, remote sensing, spatial aggregation, optimization, and visualisation techniques is used to explore the feasibility of harnessing solar energy to fuel cities and towns in Australia. In this case study landscape is deployed as a medium for the design and planning of new energy infrastructure. This paper aims to present an assessment of solar energy potential in Australia, which will be fundamental for Australia's future energy planning using renewable energy sources. This study will strengthen our research into carbon emission reduction practices; and provide a greater understanding of clean energy and green urbanism concepts, which are important when the international community is currently seeking an agreement on climate change mitigation policy to succeed the Kyoto Protocol agreement.

2 Methods

2.1 The Simplified Geodesign Framework

Since the first Geodesign Summit in 2010, numerous definitions of geodesign have emerged (FLAXMAN 2010, GOODCHILD 2010, STEINITZ 2012, MILLER 2012). Though different, these definitions are built upon McHarg's vision of integrating geospatial techniques into the design process with the goal of living in more environmentally friendly ways – the essence of the contemporary concept of geodesign. The intention of this paper is not to discuss the definition of geodesign, but rather to promote a simplified geodesign approach encompassing GIS, remote sensing, spatial aggregation, and visualisation techniques to explore broad scale landscape planning for harnessing solar energy to fuel Australia's towns and cities (Figure 1). The most challenging component of the workflow is the calculation of global solar radiation fundamental to the construct of the solar energy landscape.

2.2 Solar Radiation Modelling

Solar radiation is intercepted at the Earth's surface as direct, diffused, and reflected components (DUBAYAH & RICH 1995). On a global scale the controlling variables for solar radiation calculation are the latitude, distance from the sun, and time of year. At the local level elevation, local climate, slope and aspect are major factors in determining the amount of energy available, due to the fact that incoming solar radiation is modified as it travels through the atmosphere; is further modified by topography and surface features; and is intercepted at the earth's surface as direct, diffuse, and reflected components. The sum of the direct, diffuse, and reflected radiation is called total or global solar radiation. Generally, direct radiation is the largest component of total radiation, and diffuse radiation is the second largest component. Reflected radiation generally constitutes only a small proportion of total solar radiation, except for locations surrounded by highly reflective surfaces such as snow cover (ESRI 2014).

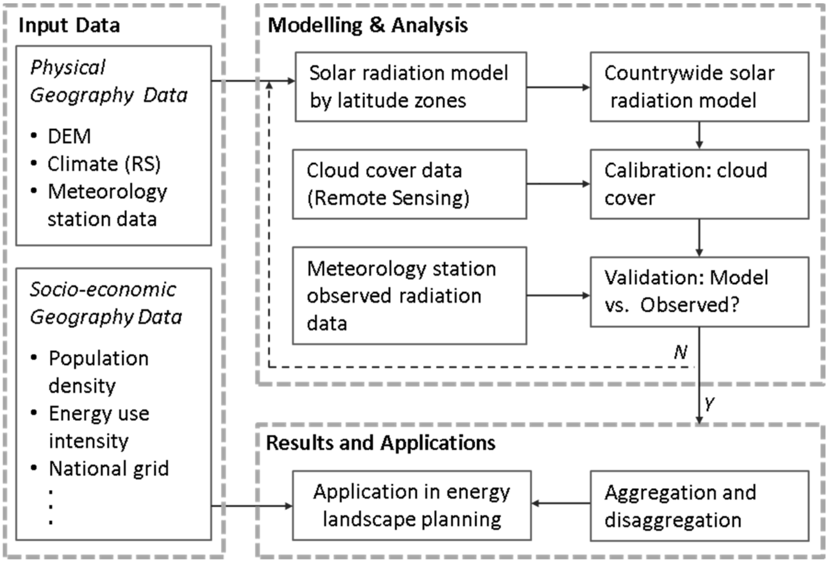

Fig. 1: The simplified geodesign framework integrating GIS, remote sensing and modelling used in this study

The solar radiation toolset from ArcGIS Spatial Analyst extension (DUBAYAH & RICH 1995, ESRI 2014) is used to calculate solar radiation in this study. The solar radiation analysis tools calculate insolation across a landscape or for specific locations, based on the methods from the hemispherical viewshed algorithm (FU & RICH 2002). The tools can perform calculations for point locations or for entire geographic areas. This involves four steps: 1) The calculation of an upward-looking hemispherical viewshed based on topography; 2) Overlay of the viewshed on a direct sunmap to estimate direct radiation; 3) Overlay of the viewshed on a diffuse skymap to estimate diffuse radiation; and 4) Repeating the process for every location of interest to produce an insolation map. The total amount of radiation calculated for a particular location or area is given as global radiation. The calculation is repeated for each feature location or every location on the topographic surface, producing insolation maps for an entire geographic area. Global radiation is calculated as the sum of direct and diffuse radiation of all sun map and sky map sectors, respectively.

In this study, both direction radiation and diffuse radiation are calculated based on the image processing of the raster models of the geography and topography of Australia. The raw ASCII elevation data is downloaded from NASA Shuttle Radar Topography Mission (SRTM) at http://vterrain.org/Elevation/SRTM/. The 1km SRTM elevation data covers the entire terrain of Australia. The downloaded DEM is originally in a geographic coordinate system and is re-projected to the GDA94 Geoscience Australia Lambert projection (Figure 2) to facilitate overlay with other data used for this study.

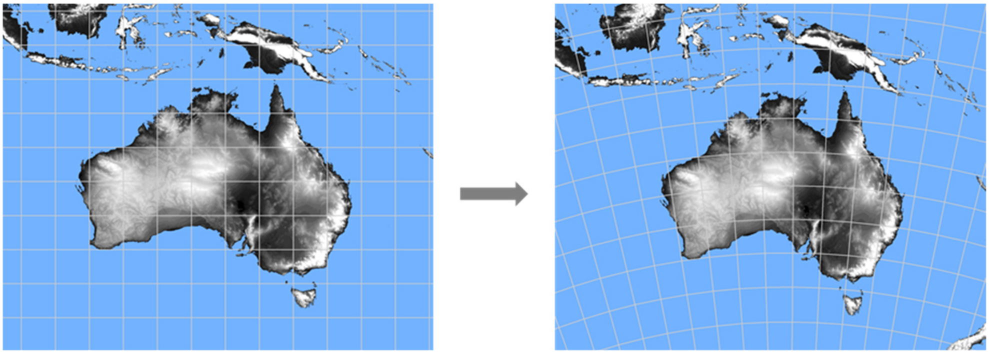

Fig. 2: DEM for Australia in geographic coordinate system (left) and projected coordinate system (right)

To minimize the distortion and disparities in solar radiation modelling, the DEM for Australia is divided into 5 by 5 degree tiles. Theoretically, the finer the tile size is, the smaller the distortion will be. However, solar radiation calculation is very time-consuming and requires high computing power using GIS software on computers. To balance the two, the 5 by 5 degree tiles are used (Figure 3). Solar radiation for each tile is then calculated using the approach described above. Finally, the radiation raster layers for all tiles are merged together so that one single solar radiation raster is produced for the entire country.

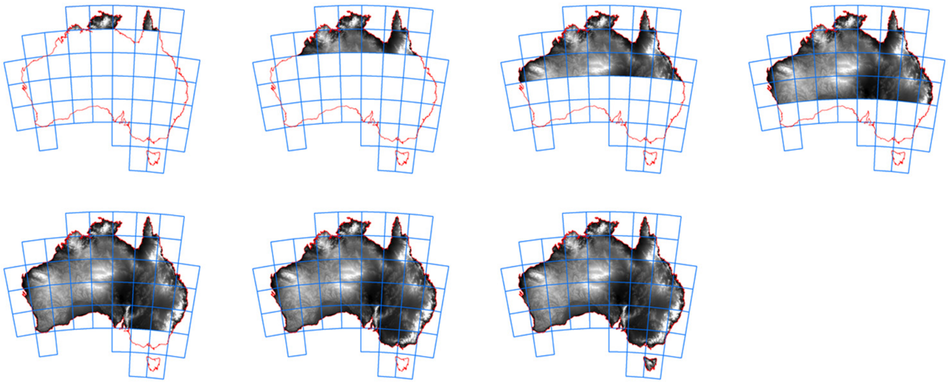

Fig. 3: DEM tiles (46 tiles in total) for tile-by-tile solar radiation calculation (tile size = 5 by 5 degrees before projection transformation)

3 Results

3.1 Australia's Solar Energy Potential

To provide a more reliable assessment of the solar energy potential for countrywide energy planning, additional ancillary datasets such as annual cloud cover, terrestrial biome composition, remotely sensed land cover data, and observed solar radiation from meteorological stations are needed to calibrate the calculation from GIS-based solar radiation modelling. A final composite showing the solar energy potentials for Australia is derived (Figure 4). According to the result, the highest solar radiation in Australia is 1,541 kwh/m^2/yr which is located in the eastern part of Victoria and New South Wales, while the lowest solar radiation is 917kwh/m^2/yr which is located in the Northeastern part of South Australia. A comparison with other similar studies reveals that the result from this study (917-1,541 kwh/m^2/yr) is slightly lower than the estimations by NASA (975-1,600 kwh/m^2/yr, NASA, 2010). It is worth noting that the solar radiation modelling tools in Esri ArcGIS package do not include reflected radiation in the calculation of total radiation and the total radiation is calculated as the sum of the direct and diffuse radiation (ESRI 2014). This could result in the solar radiation in this study being underestimated. Even though, the spatial patterns of solar radiation distribution from both studies are very similar.

From a regional design perspective, the simulation results can be aggregated into two zones; namely the Central-Western Australia (CWA) solar zone and the Eastern Australia (EA) solar zone (Figure 4 B); both zones display high solar radition capacity. This particular spatial pattern of solar radiation in Australia actually provides useful information for nationwide energy landscape planning considering the EA zone has been highly intensively used for agriculture and forestry activities in the country and it is unlikely to use the land for solar energy production in the EA zone. On the contrary, the feasiblity for the construction of large scale solar farms and solar plants in the CWA zone is higher, due to the higher solar radiation potential in this region, as well as the fact that the population density in CWA is much lower and the land is not intensively used for productivity. More thorough discussion integrating ecological and socio-economic concerns is provided in the the next section with regard to energy landscape planning and carbon neutral urbanism.

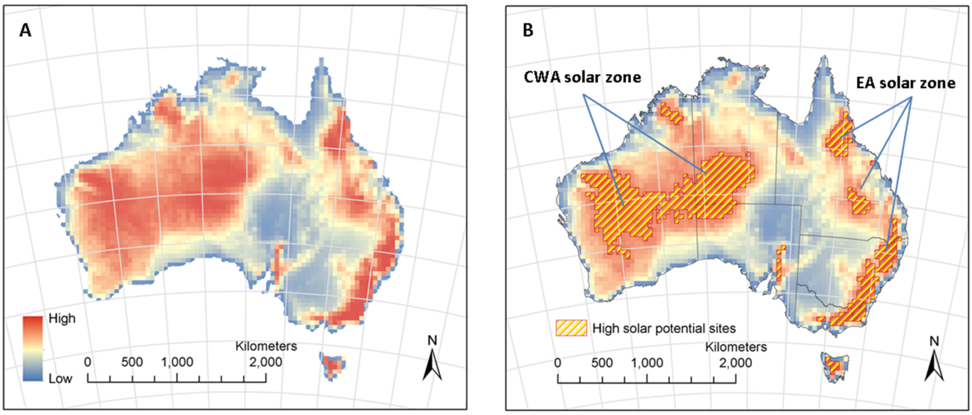

Fig. 4: Spatial pattern of the solar energy potential in Australia

3.2 Primary Solar Energy Zones

One one hand, Australia's current energy mix is dominated by non-renewable fossil energy, which is becoming increasingly limited. On the other hand, the solar energy stock is literally unlimited. Therefore the potential to harvest solar energy and use it for conventional energy supply is tremendously promising. Interestingly, the spatial distribution of solar energy stock with higher 'density' assembles the pattern of lower land use intensity (desert and sparsely vegetated land) in central-western Australia (Figure 5) which makes it more rational to harness solar energy without displacing many important and ongoing agricultural or urban land use activities such as those in the eastern coast of the country. In addition, critical biological/ecological functions of the terrestrial biomes should also be considered in developing solar energy plans.

By overlaying the solar radiation map with the terrestrial biomes map, some primary and secondary solar energy development regions are identified. The primary solar energy development region is located in the eastern part of the CWA solar zone, where the dominate terrestrial biome is the Central Range Desert (Figure 5C). The primary solar development region includes areas in the eastern part of Western Australia, the northwestern part of South Australia and the southeastern part of North Territory. In addition, three secondary solar development regions are also identified. The secondary solar development regions include one region in Western Australia (adjacent to the primary solar energy zone) and two relatively small areas in Queensland. (Figure 5C).

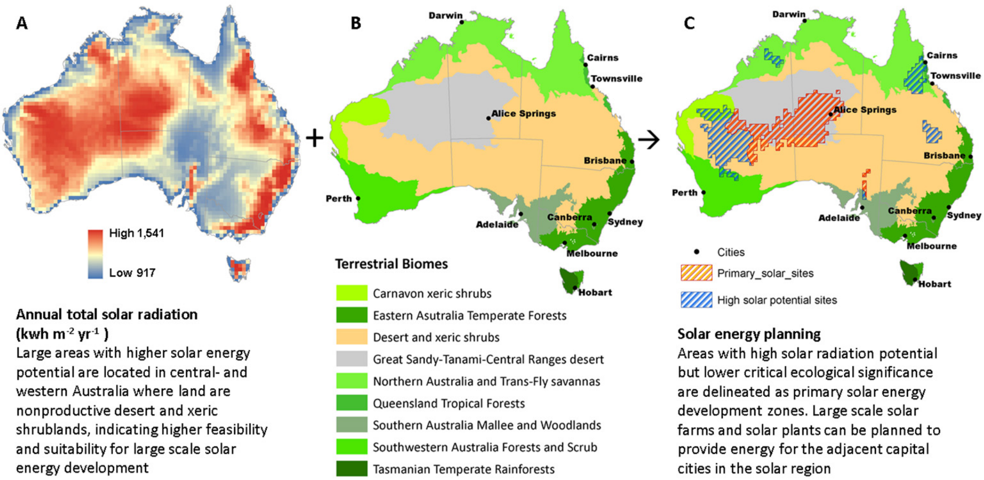

Fig. 5: Sketching primary areas for solar energy development in Australia based on solar energy potential assessment and critical terrestrial biome regions

4 Discussion

The age of petroleum and natural gas is rapidly becoming history. Their fossil replacement, coal, presents serious environmental problems which may significantly undermine the quality of life. Nuclear power includes an unwelcome combination of environmental, safety, and national security dilemmas, exacerbated by nuclear disasters that have occurred in many countries in the world. In such a setting, solar energy, rather than being a visionary exercise for the twenty-first century, is an attractive, renewable, almost nonpolluting source that can be tapped in a variety of ways, especially in Australia – a country with an astonishingly rate of energy consumption and the highest per capita carbon emissions (OECD 2013). Using a scaled system thinking approach (CHEN & LEE 2015), solar energy harvesting and utilisation at three different levels are proposed (grid-connected or off-grid).

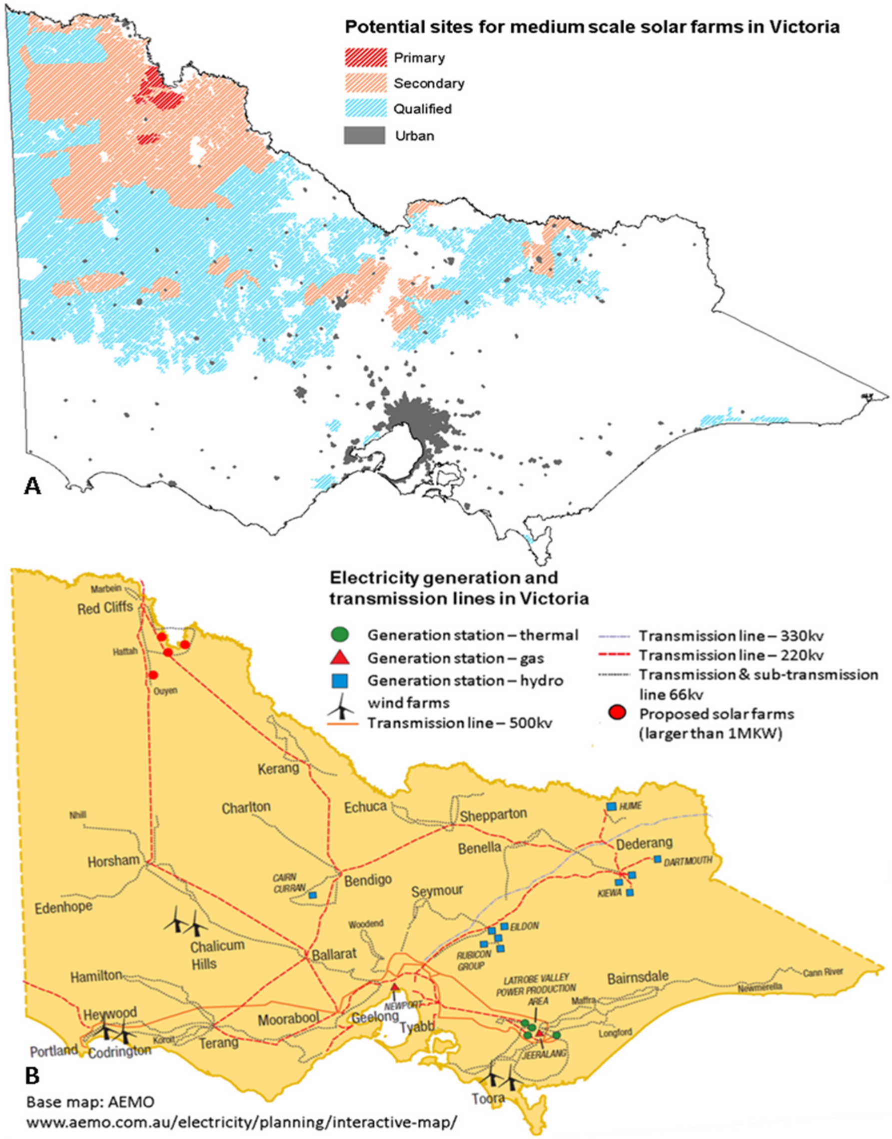

Fig. 6: Scaled system thinking applied to Victoria for solar energy planning

- Large scale solar farms
  - Off-grid to supply power for remote mining industries, etc.
  - Grid connected
  - Example in the APY Lands of north western SA

- Medium scale solar farms
  - Off-grid to supply power for major or minor commercial operations
  - Grid connected
  - Example at Parachilna in central SA – we could look further
- Small scale solar farms
  - Off-grid: remote settlement
  - Grid connected: households
  - Example – at Blinman area of the Flinders Ranges

Suitable sites for national level large scale solar farms are identified in Fig. 5C. For state level or medium scale solar farms a similary regional suitability analysis could be used to identify primary sites. For example, three primary sites for medium scale solar farm development are identified for Victoria (Figure 6A), although Victoria is not considered a solar development priority based on the national level assessment (Figure 5C). Small scale solar farms can be developed in remote settlements or at the individual household level which is a very common practice in Australia. Combining all three levels from large scale solar farms, to municipal level utility-scale solar energy facilities, to household level solar panel functionality with other forms of renewable energy, and connecting them to the national grid (Figure 6B) provide a greater chance for 100% clean and green energy supply for carbon neutral urbanisation and development in the future.

Depsite the technological challenges that lie in the harnessment, conversion, storage, transmission of solar energy which have attracted plenty of attention in both the academic and the industrial world, it must be noted that the increasing in the use of land-based renewable energies, like solar energy and wind farms, can cause new challenges for landscape planning and management. For example, the installation and use of utility-scale solar energy represent an important form of landscape transformation (MCDONALD et al. 2009) and involves a complex set of environmental trade-offs throughout the lifespan (construction, operation and decommissioning) of the project (HERNANDEZ et al. 2014). The ultimate benefits of such projects must be thoroughly investigated and carefully accounted before it is implemented, particularly its carbon footprint implications

5 Conclusion and Outlook

This study has investigated the solar potential in Australia's future energy planning through a preliminary assessment of using solar energy to replace fossil fuel for the country' urbanisation and development. Different from traditional thermal power generation systems, the renewable energy power generation systems can operate under very low or near-zero emissions given the rapid advance of power generation technologies. Currently in Australia several national- or state-level wind power development projects have been completed. Unlike wind power, large scale solar power development and implementation at project level has not started yet. Thus studies like this research are essential to promote solar energy development and implementation in Australia. Albeit possessing great logistic and technical challenges, the benefits of harnessing solar energy at national, regional, municipal and household level are potentially remarkable. This paper presents a perspective towards carbon neutral urbanism using 100% green and clean energy to cope with urgent issues such energy crisis, climate change, and environmental pollution.

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