Applied Energy 190 (2017) 354–367

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Assessment of solar and wind resource synergy in Australia

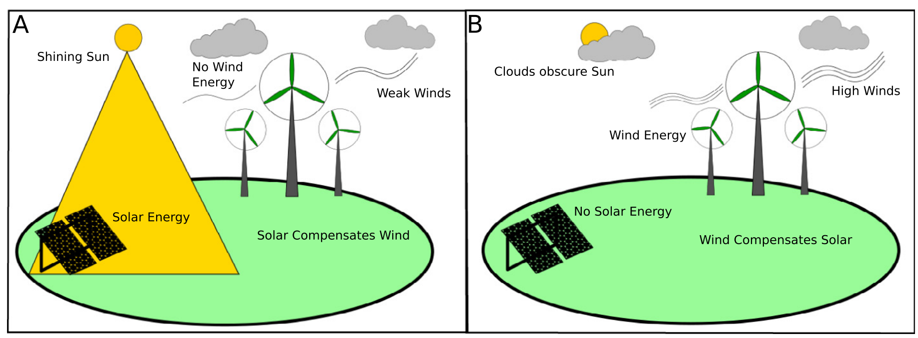
Abhnil A. Prasad [a,*], Robert A. Taylor [b,c], Merlinde Kay [b]

[a] Climate Change Research Centre, University of New South Wales, Sydney, Australia
[b] School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, Australia
[c] School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, Australia

HIGHLIGHTS

- Strong temporal synergy of solar and wind resource exists in Australia.
- Temporal synergy enhanced by 10% with an increase in spatial extent to 465 km.
- Greater synergy characteristics were in close proximity to established transmissions lines.
- South-eastern regions show great potential for future development of solar/wind hybrid systems.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form 19 November 2016
Accepted 27 December 2016
Available online 6 January 2017

Keywords:
Intermittency
Synergy
Solar
Wind
MERRA data

ABSTRACT

Solar and wind generated power is expected to increase drastically in the future. Unlike fossil fuels, however, solar and wind resource extraction introduces challenges of variability and intermittency. Several recent studies around the world have shown that since dissimilar climatological factors are responsible for wind and solar resources, they can often operate in tandem to offset lulls in each other. While most research on solar and wind resource interaction has been undertaken over the Northern Hemisphere (America, Europe and China), there is a lack of understanding on how much (or even if) solar and wind resources complement one another in other parts of the world. To partially address this issue in the Southern Hemisphere, this study provides a systematic quantitative analysis of the complementary characteristics of solar and wind resources on the Australian continent. As such, wind power density and surface incident shortwave flux are derived from the hourly Modern Era Retrospective Analysis for Research and Applications (MERRA) product for the entire continent for the period from 1979 to 2014. It was found that the temporal synergy between solar and wind resource is maximum along the western and southern coast of Australia. Tasmania, south-eastern (parallel to eastern Great Dividing Range), and northern regions (Cairns and Kimberley Plateau) of the continent also showed significant synergy (≈40% within a distance of 93 km), which was mostly influenced by hours of daylight when the solar resource is available. Increasing the spatial extent increased the occurrence of synergy characteristics to 50% within a distance of 465 km. These findings are significant because most of the synergy (and intermittency) in solar and wind resources was found in proximity to transmission lines – locations where renewables are likely to be cited going forward. Amongst current large-scale solar and wind farms operating in south-eastern Australia, this study also finds that increased power production is possible by balancing existing assets with complementary solar and wind farms. While these results are limited to a single continent, the

* Corresponding author at: Climate Change Research Centre (CCRC), Level 4, Mathews Building, University of New South Wales, Sydney, NSW 2052, Australia.
E-mail address: abhnil.prasad@unsw.edu.au (A.A. Prasad).

http://dx.doi.org/10.1016/j.apenergy.2016.12.135

proposed *approach* (e.g. using similar metrics) can be readily applied to investigate synergies between solar and wind resource in other parts of the world using the global MERRA product.

1. Introduction

Motivated by current carbon emissions causing climate change, worldwide efforts have significantly grown for decarbonisation by increasing the penetration of renewables globally [1,2]. The total renewable energy share in the power generation sector worldwide is therefore expected to grow rapidly based on additional renewable energy targets set by each country on top of the current policies and growth trajectories. According to a recent report by IRENA [3], in 2014 the total renewable energy share (excluding hydropower) in the worldwide power generation sector was 8%, which included the wind having a share of 3% of total power generation and solar photovoltaic < 1%. However, wind's share of worldwide power generation is expected to increase to 14% whereas solar photovoltaic can increase to 7% by 2030 [1]. The top-five renewable energy producing regions by 2030 are expected to include China, USA, the EU, India and Brazil [1]. The EU has already committed to obtaining 35% of gross power consumption from renewables by 2020 and this is expected to increase to 80% by 2050 – with wind and solar photovoltaic generated power as their top priorities [4].

As is the case in many countries [5], solar and wind–derived electrical generation has become increasingly important in the Australian power grid. Over the past five years, solar (including large and small scale) and wind power generation has increased by 128% and 18% per year respectively [6]. With a Renewable Energy Target (RET) scheme designed to ensure that 20% of Australia's electricity comes from renewable sources by 2020 (from ~4.5% today) [6,7], solar and wind power generating systems are being deployed at a rapidly accelerating scale [8].

While engineering and installation firms typically focus on stand-alone solar or wind projects, their intermittency (caused by stochastic climatic and weather conditions) can hinder the performance of these systems [9]. The overall annual quality of both solar and wind resources is largely dictated by fixed (local and global) climate and geographic features. On shorter time-scales, however, solar power is negatively impacted by the movement of clouds [10–12], while wind power benefits from moving weather fronts [13,14]. These variations result in corresponding variations to power generation, and can significantly affect grid scheduling and transmission operations [15,16]. Australia has six climate zones [17] with vast variety of weather conditions affecting solar [12] and wind [18] resources. These climate zones are most commonly represented globally [19], thus the Australian context is indicative of solar and wind resource coupling at a global scale.

1.1. Solar/wind hybridisation

Recent studies show that co-located solar/wind power generation systems represent highly reliable sources of power in comparison to stand-alone systems [20–22]. However, true solar/wind hybrid systems are not well-developed and require more planning and testing [23] than traditional stand-alone systems. Nema, et al. [23] reviewed the design, operation and control requirements of a solar-wind hybrid energy system. They showed that a pre-feasibility analysis and proper sizing of units for optimized performance through simulations is crucial in setting up a solar/wind hybrid system. Although, there are several studies centred on the optimum sizing of hybrid solar/wind power generating systems [9,24–36], relatively little work to date has gone into pre-feasibility studies of the wind and solar resources globally.

Pre-feasibility studies are crucial to predict the performance of how solar and wind will interact at (and across) potential sites using high quality long-term weather data. Several studies conducted in regional locations around the globe have investigated the feasibility of hybrid solar/wind power generating systems through assessments of irradiance and wind speed data [37–42]. Most of these studies show that the extent to which variability in solar and wind resources balance each other is dependent on local climate and weather conditions at various spatial and temporal scales. However, it is clear that enhanced stability (and minimised intermittency) is possible when both wind and solar resources are used in concert [43]. This only does not apply to co-located solar/wind power generation systems, but spatially aggregated solar and wind farms are designed to optimise intermittency resulting from different locations [44].

1.2. Complementary solar and wind resources

Numerous papers have explored the complementary, combined characteristics of wind and solar resources. An extensive review based on analytical techniques used to determine the ability of intermittent renewables like wind and solar power has been reported by Hart et al. [45]. In 1979, Takle and Shaw [46] provided one of the first analyses on the complementary behaviour of solar and wind energy records. Takle and Shaw found higher complementary behaviour on a daily and seasonal scale than on an annual basis. They also found an optimum mix of solar and wind technologies was possible if spatial variability is designed into the system to create a balancing effect on the localised intermittency caused by single sources [46]. Sahin [47] demonstrated the strong anti-correlation between the available solar and wind power potential over a year in north-eastern part of the Arabian Peninsula. In particular, Sahin found strong anti-correlations (≈ -0.75) between the two power potentials on a monthly scale. Heide et al. [48] used meteorological model estimates of a 100% renewable Europe scenario to show that the optimal seasonal mix was 55% wind and 45% solar power generation. Widen [13] assessed correlations between solar and wind energy in a future scenario for Sweden using climatic data of 8 years with hourly resolution. He found negative correlations between solar and wind power from hourly to annual scales, but stronger correlations on a monthly scale. Nikolakakis and Fthenakis [49] showed that by optimising the synergy between solar and wind resources, a maximum penetration of 30% solar and wind energy can be achieved in New York state without adding storage and without having to dump > 3% energy. Li et al. [50] developed an approach to quantify and investigate the impacts of diverse geographical factors on the complementarity of solar and wind using station data over Oklahoma. Li et al. showed that 57% of all sites had an above average complementarity index of wind and solar radiation. Santos-Alamillos et al. [51] looked at the spatiotemporal balancing between solar and wind energy resources in the Southern Iberian Peninsula using daily-integrated solar and wind energy estimates produced from the Weather Research and Forecasting (WRF) mesoscale model. They showed interesting complementary characteristics with anti-correlations of 0.56 (balancing patterns occurred 71% of the time) of solar and wind at marked seasonal and spatial scales in the