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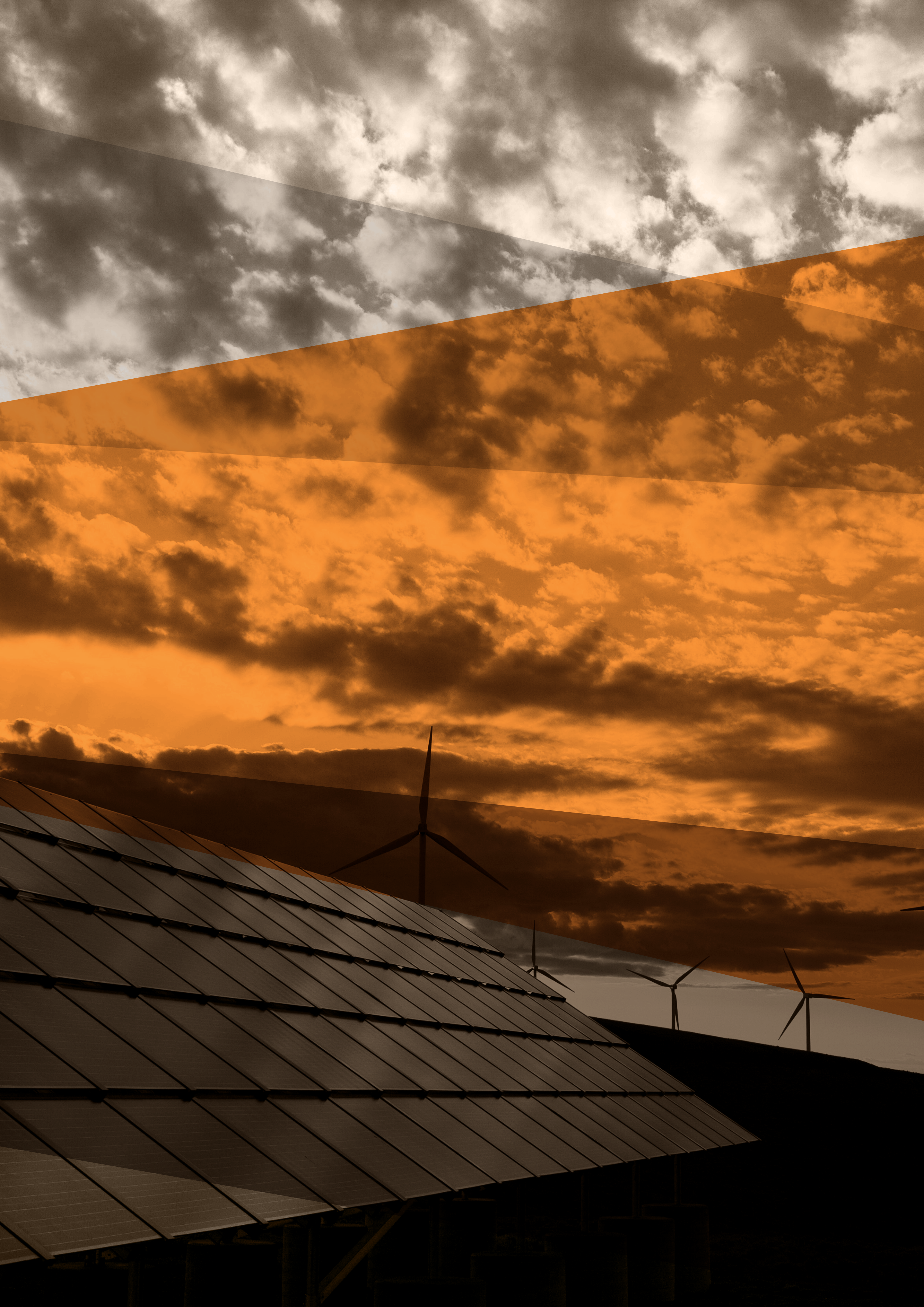
CO-LOCATION INVESTIGATION

A study into the potential for co-locating wind and solar farms in Australia

ARENA

Australian Government
Australian Renewable Energy Agency



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A study into the potential for co-locating wind and solar farms in Australia

Client: Australian Renewable Energy Agency

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Executive Summary

This report provides a summary of the current and prospective opportunity for co-location of wind and solar farms in Australia. The purpose of the report is twofold, firstly to provide ARENA and Government a deeper appreciation of the business case considerations and co-location potential in Australia; and secondly, to provide useful information to developers who are considering co-location developments.

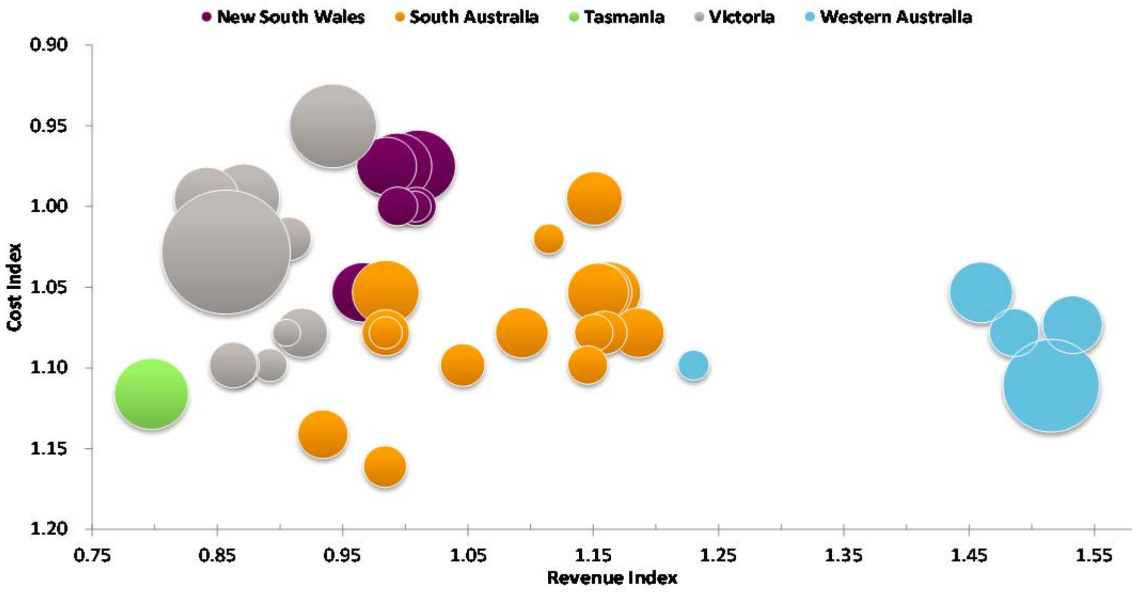
The opportunity to retrofit existing wind farms with solar farms has significant potential not only in Australia but globally. With over 370 GW of large scale wind farms globally and 4 GW installed in Australia there are numerous locations where the two renewable resources are highly complementary. As the renewable industry matures, becoming less dependent on subsidies and cost reductions plateau, the industry must contemplate innovative ways of improving its competitiveness.

It is well known that the development costs and timescales for renewable projects in Australia can be significant barriers for renewable projects, placing pressure on the upfront investment requirements of developers. By co-locating wind and solar farms, synergistic gains can be achieved to help reduce overall cost. Each co-location project must balance the interplay between generation profile to maximise long term energy yield (and minimise curtailment), whilst simultaneously exploiting commercial synergies found in the development, design, construction and operation of developing co-located solar and wind plants. AECOM found that major savings can be achieved, particularly in the grid connection infrastructure. Total cost savings were estimated to be between 3 to 13 percent for CAPEX and 3 to 16 percent for OPEX.

Two types of development for a wind and solar co-location have been considered in this report. The first is retrofitting a solar farm at an existing wind farm (‘brownfield project’). The second is developing a site for both wind and solar farm simultaneously as a ‘greenfield project’. Using historical data, AECOM analysed 10 existing wind farms in Australia. The analysis demonstrated that a solar farm with a size between 25 per cent and 50 per cent of each wind farm’s capacity would only result in 5 per cent curtailment. The analysis also highlights that time of day and seasonal “anti-correlation” (generation of wind at night and solar during the day) of the generation profiles of wind and solar occur at some of the wind farms, with notable anti correlation observed in Western Australia. The technical capacity of wind farms to accommodate co-located solar farms appears substantial. Of the 10 wind farms analysed, 414 MW of solar capacity could be co-located without exceeding 5 per cent curtailment.

AECOM also analysed the financial merit for solar plants at each existing wind farm site by indexes that represent the costs and revenues of each site relative to a benchmark site. The results are shown in Figure 1, in this chart it is preferable to have a low cost index (<1) and a high revenue index. The size of each bubble represents the potential size of a co-located solar plant (Queensland is excluded due to missing data from existing wind farms).

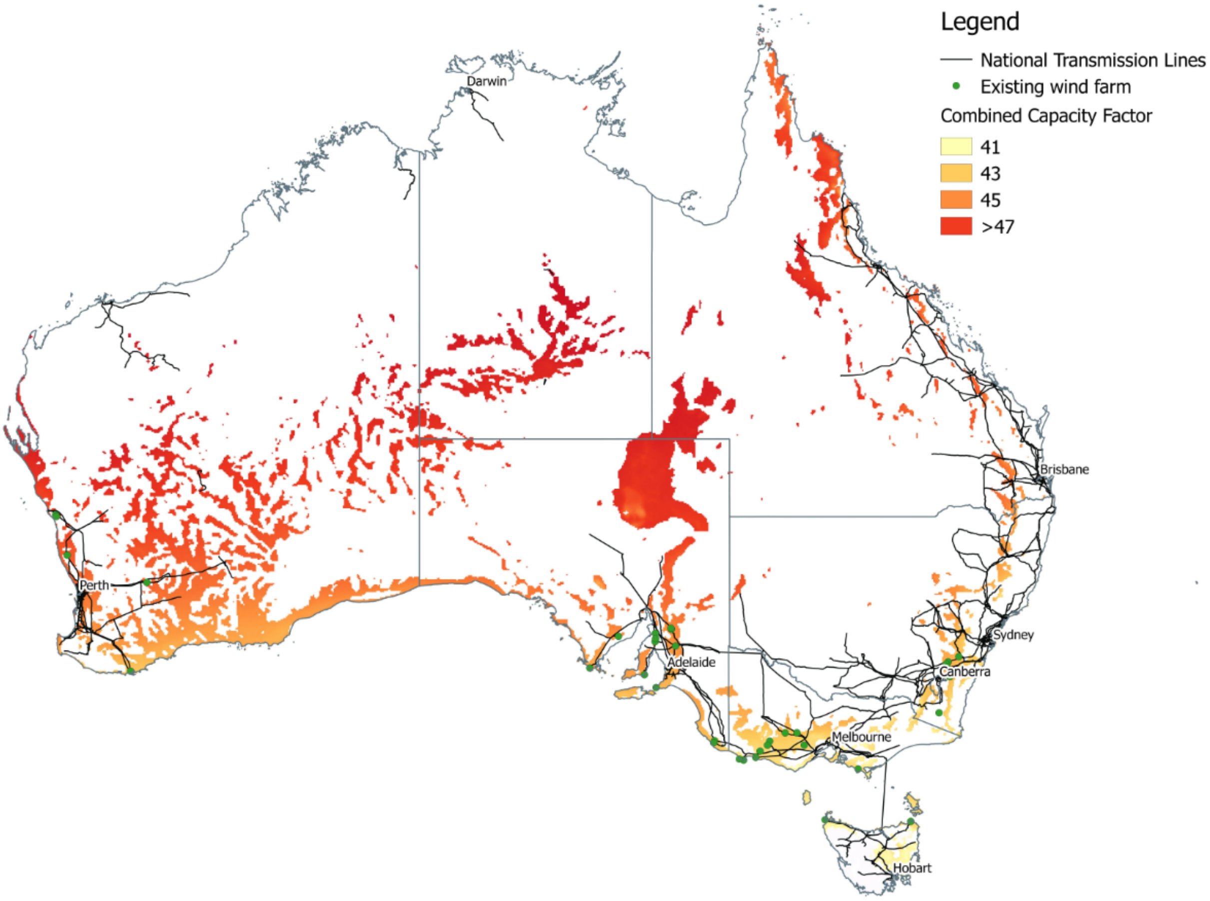
Figure 1 **Graphical representation of cost and revenue indexes for each existing wind farm; bubble size equates to the relative size of a co-located solar plant for each wind farm**



Western Australian wind farms appear more attractive than NEM-connected wind farms. This can be attributed to their superior revenue inputs, which is due to both a superior solar resource and substantially higher wholesale market prices (measured over only 12 months). South Australia and New South Wales are the next best performing state, followed by Victoria and Tasmania, due to the progressively poorer solar resource in these states.

Expanding on this analysis, AECOM has developed combined wind-solar resource heat maps to identify and rate the combined renewable resource at greenfield locations across Australia (see Figure 2 below). The heat maps developed are intended to direct developers to suitable co-location regions and educate interested stakeholders on the co-location opportunity.

Figure 2 Heat map highlighting the best combined wind + solar resource locations (poor wind (<35% CF) and poor solar resource (<16% CF) locations removed)



This study has highlighted some key co-location learnings, summarised below:

- **Cost savings:** Major savings can be obtained in the grid connection equipment and installation, operation and maintenance and development costs (including land costs, development approvals and studies). These savings are estimated at 3 to 13 percent for CAPEX and 3 to 16 percent for OPEX.
- **Prospective regions:** The greatest brownfield co-location opportunities are currently in Western Australia and South Australia, where there is good solar resource, a complementary generation profile and higher wholesale market prices. The best greenfield opportunities for wind-solar co-location are also found in South Australia and Western Australia, as well as parts (non-cyclonic) of Queensland and small parts of New South Wales.
- **Importance of network access;** Many of the greenfield sites are not close to the network, or are adjacent to weak parts of the network. While this creates a challenge for developers, there may be an opportunity for NSPs and policy makers to intervene by opening up regions of high natural wind and solar resource through new network assets.

- **Co-location potential:** The technical capacity of existing wind farms to accommodate co-located solar farms is estimated at over 1 GW. Growth in renewables driven by the Renewable Energy Target is expected to open up technical capacity for an additional 1.5 GW of solar PV to be co-located at new wind farms built by 2020. However, the relative financial competitiveness of these opportunities (combined with relevant policy) may limit the uptake of the full technical potential of co-location.
- **Firming effect:** Given the intermittent nature of renewable technologies, pairing resources in regions dominated by one particularly technology will likely have a “firming” effect. This reduction in the overall facility’s degree of intermittency results in an improved capacity factor at the connection point and can mitigate associated network constraints in regions dominated by a single generation type.

Whilst AECOM is of the opinion that co-location will not dramatically accelerate the uptake of solar or wind alone, we do believe it warrants greater attention as we plan our future low carbon electricity system. AECOM expects as Australia strives to meet the Renewable Energy Target that further benefits and regions will be developed which will also be suitable for co-location. AECOM notes that each project should be analysed on its own merits and that the feasibility will highly depend on government policy as well as local site and market conditions (e.g. availability of offtake agreements). This study does demonstrate that co-location is worth the consideration of developers (both wind and solar) and existing wind farm owners/operators.

Table of Acronyms

Table 1 Table of Acronyms

Acronym	Definition
AC	Alternating Current
ABS	Australian Bureau of Statistics
ARENA	Australian Renewable Energy Agency
AREMI	Australian Renewable Energy Mapping Infrastructure
CAPEX	Capital Expenditure
CEC	Clean Energy Council
CAPAD	Collaborative Australian Protected Area Database
EPC	Engineering, Procurement and Construction
GIS	Geographic Information System
GW	Gigawatt
GHI	Global Horizontal Irradiation
GTI	Global Tilted Irradiation
HV	High Voltage
IMO	Independent Market Operator
LRET	Large-scale Renewable Energy Target
LCOE	Levelised Cost of Energy
MLF	Marginal Loss Factor
MW	Megawatt
NEM	National Electricity Market
NICTA	National Information Communication Technology Australia
OPEX	Operational Expenditure
PV	Photovoltaics
PPA	Power Purchase Agreement
SWIS	South West Interconnected System

1.0 Introduction

1.1 Background

AECOM was commissioned by the Australian Renewable Energy Agency (ARENA) to undertake a study highlighting opportunities for the construction of solar farms at existing wind farm locations around Australia. The particular focus is flat plate photovoltaic (PV) technology which is currently the most cost effective and widely deployed solar technology at a utility scale.

To date, the wind and solar market have worked largely independently of each other. This is the result of a number of factors including, but not limited to:

- Differences in the required scale of energy production
- Relative cost in terms of levelised cost of energy (LCOE)
- Different sources of funding and subsidies (Renewable Energy Target, ARENA, Feed-in-Tariffs)
- Location preferences (rural vs. urban).

Recently, more wind farm developers globally are considering adding significant amounts of solar PV farms to their wind farms. This is occurring for plants that are both in development and those that are in operation, which appears to indicate a new trend in the renewables industry. This trend has been prompted by notable cost efficiencies in sharing sites, grid connection and HV transmission lines. In addition, by merging wind and solar power technologies, generators can increase their capacity factor and decrease their intermittency at the connection point.

With over 4,000 MW of installed wind generation across Australia and multiple gigawatts of wind generation in development, it is worthwhile looking into the benefits, challenges and potential for co-location of solar and wind farms in Australia. As we move towards higher penetrations of renewables on our networks it will be important to characterise the wind and solar resource in Australia, including the quality, variability, and potential complementary nature of the resources.

1.2 Objectives

The objective of this exercise is to examine the potential for wind and solar PV co-location in Australia and to share learnings regarding the benefits and challenges of integrating solar PV into wind farms. ARENA intends to utilise the findings from this report to further promote awareness and understanding of the opportunity for renewable energy developers.

1.3 Scope of investigation

AECOM’s scope has been broken into the following key steps:

1) Profiling the wind output from a sample of existing wind farms in the NEM and SWIS using generation data available from AEMO, Global-Roam and IMO.
2) Consider the extent to which wind and solar generation are correlated at selected locations and undertake a solar farm sizing assessment to ascertain the relationship between the solar-to-wind ratio and curtailment. This analysis utilised historical wind farm generation and historical solar irradiation combined with an assumed connection capacity.
3) Conduct a coarse GIS based screening analysis to assess land suitability for solar at existing wind farms in the NEM and SWIS. Key factors include land zoning, topography and other constraints such heritage agreements and national parks. Information from this analysis will be used to develop a high-level assessment of the relative appropriateness of existing wind farms for co-locating of solar farms.
4) Publish findings in a report and integrate relevant GIS information into the NICTA Australian Renewable Energy Mapping Infrastructure (AREMI) portal
5) Consider the future prospective regions for new greenfield co-location developments.

1.4 Report Structure

A summary of the report structure is provided below.

Figure 3 Report structure

Section 2: **The case for co-location**	• This section summarises the financial drivers that incentivise co-location as well as the commercial and technical challenges that can be experienced.
Section 3: **Generation profile analysis**	• This section completes analysis of profiles at 10 existing wind farms • Combining this with historical solar data, AECOM investigates the correlations of solar and wind generation at each site and estimates sizing of solar farms at each site
Section 4: **Evaluation and site ranking**	• This section gathers high level information on each site such as irradiance, temperature, wholesale price, remoteness index and topography. • Based on this data, AECOM conducts an evaluation process to rank the sites in order of most economic to least economic
Section 5: **Prospective Locations**	• Looking beyond existing wind farms, AECOM investigates the broader potential for co-location in Australia
Section 6: **Conclusions**	• AECOM brings together the findings t into a guide for stakeholders interested in co-location of wind and solar farms

1.5 Limitations

- This study is based on a desktop assessment only, as such it only represents preliminary analysis and consequently each project will require its own individual investigation to completely assess the actual feasibility for each location. For this report not all wind farms in Australia have been assessed, only a select number of wind farms representing the regions where they have been installed with a suitable operating history.
- While AECOM has attempted to locate the connection point for each wind farm via a desktop analysis, AECOM was not able to verify the actual connection locations. As such, the selected areas may not be in the most ideal locations. Nonetheless, this study should provide high level indications of suitable and available land in the region.
- The connection capacity at each wind farm is unknown therefore AECOM has assumed that it is equal to the name plate capacity of the wind farm only.
- Only high level factors have been considered for the appropriateness of land. The willingness of land owners to lease/sell land for use as a solar farm has not been considered.
- Data used for characterising wind farms, siting solar farms and ranking potential locations (i.e. price information, generation profiles, marginal loss factors) are sourced for either current or historical data

sources. AECOM has not attempted to forecast or project future trends such as price, generator performance, generation profiles, etc. Readers should consider this in their interpretation of the report. In addition, wind turbine performance amongst the selected wind farms varies due to technology age, development and site specific characteristics such as wind resource and as such may provide alternate outcomes when compared on a like for like basis.

- The curtailment analysis outlined in Section 2.4 has only considered energy optimisation and hasn't factored any possible commercial revenue or offtake benefits which may vary the results.
- No consideration has been given for outages or other external factors affecting wind farm generation in the analysis.

1.6 Disclaimer

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Any opinion expressed by AECOM concerning predictions are provided on the basis of the company's experience as a consultant and represent AECOM's best judgement based upon its understanding of the commercial and contractual setting in which the study was undertaken and information that has been supplied to AECOM. AECOM does not warrant or guarantee the accuracy of any opinion expressed by AECOM.

2.0 The case for co-location

This section outlines the benefits and challenges for co-locating wind and solar farms in Australia. Many of the benefits and challenges are common and are explained to provide context for evaluating the merits and feasibility of future projects. The opportunity to co-locate is already being considered by a number of renewable energy developers, some of which were consulted in undertaking this study to provide a basis to our findings.

2.1 Context

The concept of co-location is not new and multiple parties have explored, researched and constructed co-located wind and solar farms across the globe. However, co-location opportunities generally remain unexploited. Two clear types of opportunities for wind-solar co-location arise:

1) Retrofitting solar on existing wind farms (called “brownfield” in this report)

2) Developing new co-located wind-solar generation assets (called “greenfield” in this report)

The sections below focus on the national and international context of these opportunities.

2.1.1 National

Australia’s Renewable Energy Target has driven the uptake of over 4 GW of wind generation assets in Australia. This growth is expected to continue, with the Renewable Energy Target driving construction of an addition 6 GW of wind and solar capacity by 2020 (CEC, 2015).

The opportunity to retrofit existing wind farms with solar farms has significant potential not only in Australia but globally. With over 370 GW of large scale wind farms globally and 4 GW installed in Australia there a numerous locations where the two renewable resources are highly complementary. As the renewable industry matures and become less dependent on subsidies, and cost reductions plateau, it must contemplate innovative ways of improving its competitiveness. Also, it is well known that the development costs and timescales for renewable projects in Australia can be a significant barrier for solar projects (particularly given the relative scale and cost of solar compared to wind), which puts pressure on the upfront investment requirements of developers. By co-locating wind and solar farms, synergistic gains can be achieved to help reduce overall cost.

Previously some Australian governments and regulators have attempted to develop precincts where renewables could be co-located with the aim of streamlining approvals, maximise the use of the electricity infrastructure, facilitate innovation, as well as improve community consultation and regional employment opportunities. Such programs have included the NSW’s Renewable Energy Precincts Program, AER’s Scale Efficient Network Extensions, ACT’s Wind and Solar Auctions, the South East Region Renewable Energy Excellence Initiative, and NSW and QLD Renewable Hubs previously promoted together with the Clinton Foundation, among others.

2.1.2 International

A study investigating the benefits of co-location in Europe *(Characterization of the Solar Power Resource in Europe and Assessing Benefits of Co-Location with Wind Power Installations* by Cedric Bozonnat and C. Adam Schlosser) concluded that wind and solar potentials for Europe are anti-correlated at seasonal and monthly timescales. They found that through co-location, renewable power generation would be available more than 70 per cent of the time in southern Europe, and more than 50 per cent of the time in the intermediate latitudes of Europe.

The Mojave Desert in California USA has several large-scale co-located solar and wind farms. An example is the 140 MW Catalina Solar Project and the multiple wind projects ranging from 20 – 170 MW that are connected amongst the solar arrays. For projects that require these multimillion dollar investments to be made the combination of suitable land, a grid connection and a high solar and wind resource would be required. The Mojave Desert (Tehachapi, California) appears to be an ideal place for this combination.

China has one of the largest integrated solar and wind farms in the world, with one of the most significant located at the Zhangbei National Energy Storage and Transmission Demonstration Project. The project was put into operation in 2011 and includes 100 MW of wind generation, 40 MW of solar PV and 20 – 36 MW of battery storage. The project reported to have significantly smoothed and balanced power production, although the use of large scale power storage may well have contributed to this claim rather than the complementary nature of the solar and wind resources.

2.2 Benefits

Two types of development for a wind and solar co-location have been considered in this report. The first is retrofitting a solar farm at an existing wind farm (‘brownfield project’). The second is developing a site for both wind and solar farm simultaneously as a ‘greenfield project’. A third potential scenario is the co-location of a wind farm adjacent to an existing solar farm; this scenario has not been considered in this report. The below section describes the benefits of co-location identified during our research and consultations. For consistency, the above described “brownfield” and “greenfield” are used throughout the description of the benefits.

2.2.1 Benefits during development

- **Site appreciation:** For brownfield developments, the appreciation and understanding of the site is one of the main advantages is, particularly knowing its constraints and current infrastructure will be of benefit for co-location development. Wind farms typically take many years to develop where a detailed understanding of environmental constraints, the community and surrounding infrastructure is developed over time. The time and cost savings through this prior knowledge were noted as material by developers consulted. Relative to a standalone solar farm, the brownfield development is expected to save time and related costs as many site related studies, approvals and design considerations have been completed during the development of the wind farm, and may only require updates. As part of the development approval, an environmental impact statement/assessment or the equivalent would have been carried out which typically include areas such as aboriginal and cultural heritage, flora and fauna studies, noise assessments, visual studies, traffic and transport etc. There is expected to be substantial savings in leveraging these previous studies, which would usually be carried out without any significant background knowledge of the site. In addition to environmental site appreciation, there is meteorological site appreciation. A wind farm will require a lengthy monitoring period to analyse the potential wind resource for the site. Simultaneously, the solar irradiance can also be measured during this period. Having this information available will help with de-risking of the project and will be a benefit to finding a suitable financing outcome.

- **Development efficiencies:** When developing a wind and solar farm site in parallel (greenfield project), the fixed costs of any studies can be shared between the two projects. These shared costs include items such as mobilisation for any site visits, geotechnical studies, ecological and heritage investigations, site topography surveys, etc. Similarly, meetings with relevant stakeholders could also be duplicated. For greenfield sites the expectation is that by considering the co-location of both projects at the outset, the solar farm development cost could be somewhat absorbed in the development budget of the wind farm, which often being much larger projects, can often justify a more considerable upfront investment. Brownfield sites have a strong potential to gain advantage through the ease of obtaining development approvals as site studies and certain approvals (zoning, landscape management, heritage etc.) will have likely been obtained for the site (or neighbouring sites). The previously submitted documents may require only slight adjustments to the layout and amendments to few specific items related to solar PV only.

- **Community understanding:** Community engagement is a crucial element in any infrastructure project, particularly in regional communities where infrastructure projects can offer both disruption and economic growth, and may present itself as either positive or negative depending on the community. For brownfield sites which have an existing understanding of the community’s perceptions, co-location will allow for a more streamlined community engagement approach. This streamlined approach is seen through an existing understanding of the responsiveness of the community to different mediums i.e. some communities may be more receptive to newsletters, town meetings or open days. For greenfield sites, the community engagement requirements would also likely benefit from co-development as the meetings and stakeholder engagement communications would not need to be duplicated. In addition, wind farms can be somewhat polarising and the addition of a technology which is typically more socially acceptable may provide some balance that would not be gained otherwise. The community may also benefit from increased employment and training, as well as greater local investment and further infrastructure upgrades as a result of a more significant investment in two technologies as opposed to one.

- **Availability of land:** Contractual negotiations with landowners and surrounding neighbours would likely benefit in a number of ways for co-location projects. Negotiations with landowners can become protracted however for brownfield projects, the existing terms and factors which are important to a particular landowner have already been identified and the extension of the existing contractual relationship will likely be streamlined. For both greenfield and brownfield sites, the comparatively larger co-location project particularly in terms of land area usage will likely warrant a greater commercial and financial consideration by the developer to benefit the landowners when compared to an individual wind or solar farm.

- **Renewable firming and Power Purchase Agreements:** Given the intermittent nature of renewable technologies, pairing resources in regions dominated by one particularly technology (i.e. wind farms in South Australia) will likely have a “firming” effect. This reduction in the overall facility’s degree of intermittency results in an improved capacity factor at the connection point and can mitigate associated network constraints in regions dominated by a single generation type. The reduced intermittency may make the generation asset more attractive to off-takers and developers due to reduced volume risk. This would likely result in an improved Power Purchase Agreement (PPA) offering or alternatively possibly provide more certainty to the asset owner to take on merchant wholesale price risk.
- **Grid Connection Agreement benefits:** For generators with an existing Grid Connection Agreement there is the added benefit of understanding the capacity limitation of the transmission/distribution network which can be used for the sizing of the solar system. In some instances grid connection agreements will only likely require minor amendments which provide major cost and schedule advantages to co-location developments.
- **Finance, legal and technical advisor cost savings:** There is potential for direct cost savings on professional services such as the use of legal services, accounting and financial advisory services. Additionally there will likely be cost savings in technical areas such as environmental and grid connection studies.

2.2.2 Benefits during design and construction

The primary benefits of constructing a solar farm on an existing wind farm are the large time and cost savings associated with utilising the existing grid connection infrastructure and connection agreements. This reduces both the cost and risk associated with the project especially as grid connection is a significant project risk for many developments. Benefits of co-location during design and construction are highlighted below:

- **Grid Connection equipment benefits:** Rather than building a new connection substation, a project proponent is able to modify the existing substation or switching station depending on the connection configuration. Suitable equipment such as transformers may be present at the grid connection point that may significantly reduce the cost of equipment that would otherwise be required for a separate connection. For brownfield applications additional works such as roads, drainage, lightning protection, earthing, fencing and buildings around the substations will likely be installed for the wind farm and as such is unlikely to require significantly change upon the addition of a solar farm. When planning a greenfield project, allowance within the substation can be made to accommodate both technologies. AECOM estimates the potential saving in regards to equipment and labour for the grid connection to save a project between 2 to 5 per cent of costs (see Section 2.4 for further costs saving considerations).
- **Utilisation of existing infrastructure:** For brownfield applications access roads, drainage, operation and maintenance buildings, warehousing and potentially laydown areas may already be present at the site. These items all have a slight decrease on mobilisation and construction costs. Other items that may be considered to reduce project costs are phone, communications, auxiliary power and security.
- **Engineering:** For greenfield sites, the engineers can consider shared services, infrastructure and equipment to minimise costs for the complete co-located farms. Areas that should be considered are transformers, AC cabling, roads, fencing, monitoring systems for the wind farm and solar farm as well as the O&M building location.
- **Labour:** Local labour in Australia is in some cases challenging to source. For greenfield projects, a multifunctional labour force can be considered to maximise the efficiencies associated during construction. One example noted through the consultation process was that construction delays associated with high winds for turbine construction could be complemented by redeploying these otherwise idle resources onto the solar farm construction.

2.2.3 Benefits during Operation & Maintenance

Sharing operation and maintenance resources, infrastructure and equipment is an additional benefit. The wind farm will require maintenance equipment and staff on site which would be available for the solar plant. However, this can be commercially complicated if different O&M providers are utilised for the solar and wind farms. The items below are considered the most likely benefits of co-location during operation and maintenance:

- **Specialist expertise:** For brownfield sites, the onsite operation and maintenance staff would be able to perform a significant amount of scheduled maintenance which won’t require specialist solar PV knowledge such as panel cleaning, landscaping, civil maintenance, monitoring, security etc. For these common maintenance requirements personnel across the wind farm and solar farm can be used. Specific equipment maintenance such as transformers and inverters will require expertise on which specialists will have to attend site.

- **Joint Labour:** For brownfield systems the wind farm operator will have to be trained in the operation of the solar farms; however the use of a single workforce for minor maintenance activities such as civil maintenance, cleaning, security and system monitoring/testing will provide benefits during operation. AECOM estimated the value of this benefit over time to be around 2 per cent of the OPEX.
- **Administration:** There are efficiencies to be found in the administration associated with running a combined generation asset. These efficiencies can be found in consent compliances, licensing, legal and accounting costs, human resourcing, energy forecasting/planning department and general management of the asset.

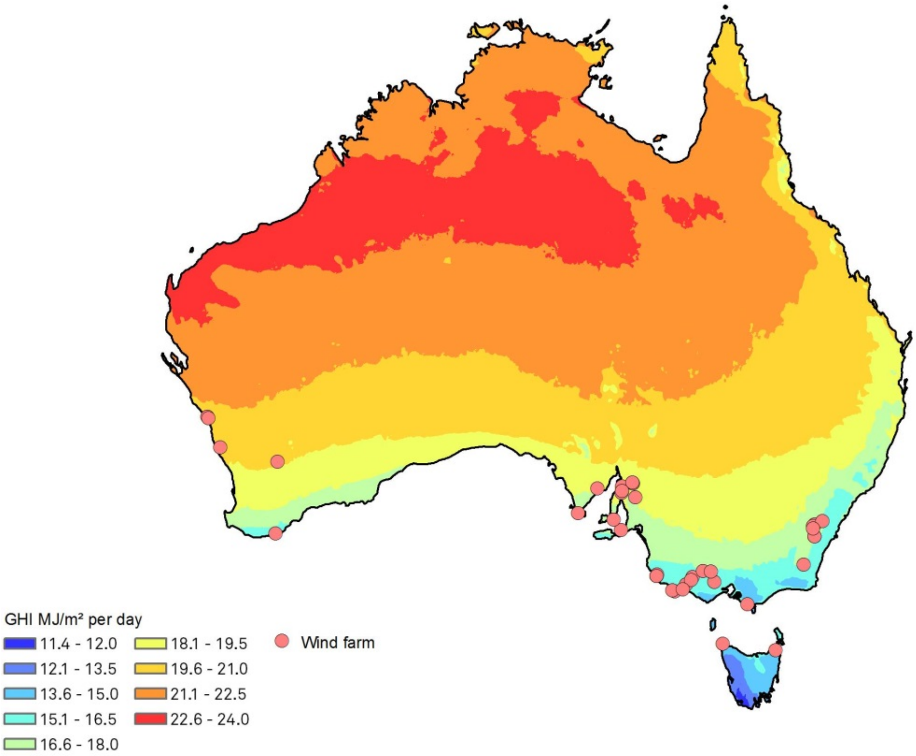
2.3 Challenges

The co-location of wind and solar also brings along some challenges that can limit the benefits described above. The section below describes the potential challenges during development, design and construction (D&C) and the operation and maintenance (O&M) period.

2.3.1 Challenges during development

- **Re-negotiation of agreements:** For brownfield sites, agreements with landowners, off-takers, O&M providers and potentially financiers will likely require amendment.
- **Use of the land:** For wind turbines, co-location will require a material land use change associated with the introduction of solar, which may cause shared agriculture land use challenges. Consideration will need to be given to complementing the needs of the landowners under a shared land use structure. Typically many wind farms require the infrastructure to be located on the ridges at higher elevations to capture the wind resource, whereas solar is optimal in cleared more level land areas which are often closer to water resources. Often, good solar sites are also suitable for agricultural use.
- **Community:** Whilst the community may have been consulted for a wind farm development this does not imply that the development of a solar farm will be openly accepted by the community. Proper community engagement and consultation will be required to make the community familiar with the new plans, technology and benefits of the addition of solar PV.
- **Curtailment:** The network connection agreement often defines an agreed transfer capacity, which restricts the facility’s export. This could lead to curtailment of excess generation if both wind and solar assets are generating simultaneously. Similarly, technical constraints such as transformer or switchgear rating could lead to curtailment. Analysis of the quantity of expected curtailment is required to determine how curtailment will affect the revenue stream and this relationship is fundamental to determining the optimal size of the solar farm relative to the wind farm. An additional important consideration is the technical management of curtailment and whether additional equipment would be required to make this connection possible. The dispatch priority for the wind or solar farm will also need to be considered. From the consultations it is clear that the choice of curtailing the solar PV over the wind is the preferred option for brownfield projects.
- **Warranties:** Warranties provided by the wind farm or solar farm EPC contractor will require additional review and clear responsibility matrices will need to be set-up to avoid confusion if warranty issues occur. This will also be dependent on the interfaces that will be designed between the wind and solar farm equipment.
- **Financiers:** Financiers may have reservations regarding the integration risk of wind and solar farms as well as curtailment risk. The availability of reliable forecasting methods and data will be crucial in this respect.
- **Site suitability:** The location of wind farms across Australia are clustered towards the southern regions due to the strong wind resource, load and electrical infrastructure. Coincidentally some of these areas are of lower solar resource, particularly in the South Eastern states. Figure 4 highlights this poor correlation between existing wind farms and favourable solar resource. For greenfield projects, the challenge will be to find sites with both favourable solar and wind resources, as well as determining suitable compromises between the level of wind and solar resources (Chapter 4.0 elaborates on this). In addition, consideration has to be given to the trade-off between the cost savings of co-location against alternative single-technology sites with more favourable individual resources (e.g. sacrificing co-location cost benefits for improved solar resource at an alternative site).

Figure 4 Major wind farms locations with respect to solar irradiation (red points represent wind farms)



Source: (AECOM, BOM)

2.3.2 Challenges during design and construction

- **Grid connection:** While the grid connection aspects appear to provide a significant benefit to the co-location it is important to review the grid connection agreement and current installed equipment in great detail while considerations are being made on where to connect the generation asset.
- **Shading and land topography**: Choosing suitable sites can be challenging as each site will have different merits and challenges. Shading may become an issue when there is insufficient land available (preferably north of the wind turbines) that is unshaded. Shading by existing transmission lines, wind turbines or hills may have a significant impact on the expect revenues for a solar farm.
- **Plant operating protocol**: Should the wind and solar system be located as an integrated system, the plant's operating protocols will need updates and amendments, which has the potential to be a long process to align all parties.

2.3.3 Challenges during operation

- **Availability:** The design should consider the impact of faults and grid outages for both systems. The probability of a fault occurring on the combined system has increased due to the potential “knock on” effect of the other generator.
- **Monitoring and control:** Plant control and monitoring will require alignment with the current operation of the wind farm in the case of brownfield sites. This will require training of personnel as well as the grid operator.

2.4 Cost saving summary

Given the benefits described above, AECOM has performed a high level estimate of the cost savings possible through co-locating a solar farm on an operating wind farm. The bar graphs in Figure 5, Figure 6 and Figure 7 present the estimates which are based on the cost breakdown of a typical 20-50 MW solar PV farm. Savings are calculated relative to an equivalent solar farm being connected to a pre-existing substation. While these figures have been based on our market experience of utility scale solar project costs, AECOM notes that costs are subject to change on a project-specific basis. In addition, technology and industry expertise are constantly improving, which will also likely impact the cost breakdown in the future.

Figure 5 Estimate of total CAPEX savings that can be realised through co-locating a solar farm on an existing wind farm

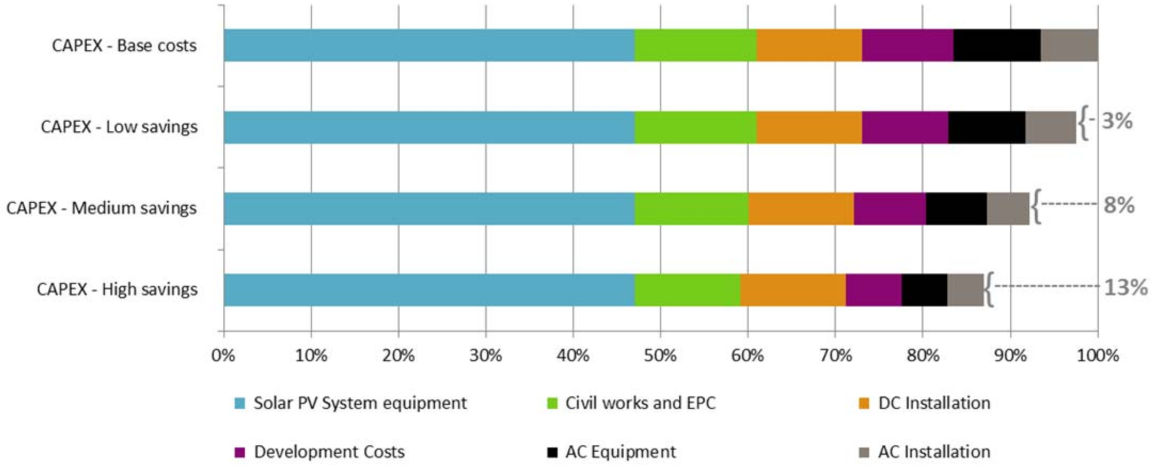


Figure 6 Estimate of CAPEX savings through co-locating a solar farm on an existing wind farm

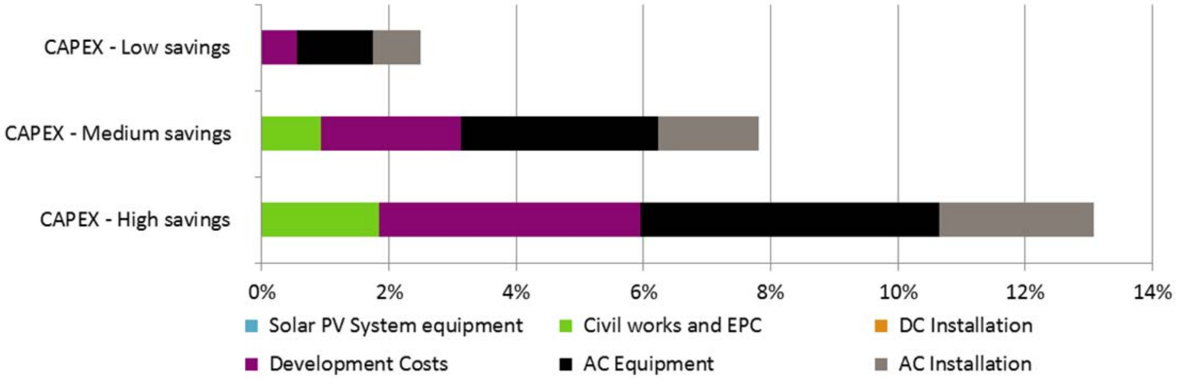


Figure 7 Estimate of total OPEX savings that can be realised through co-locating a solar farm on an existing wind farm

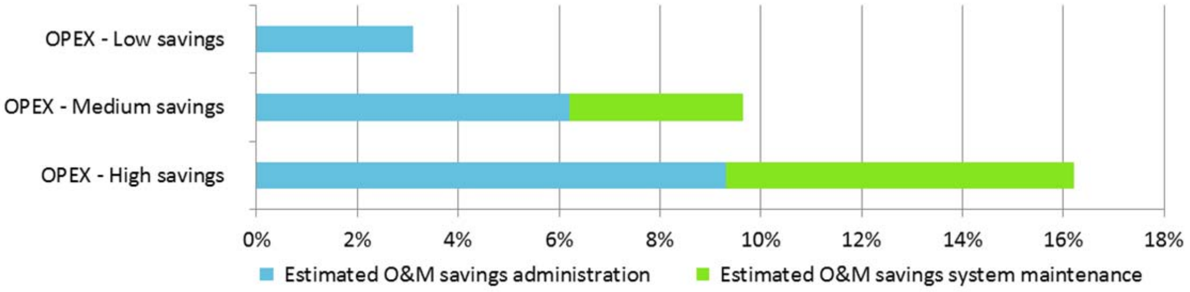


Figure 5 indicates that costs for the actual solar PV equipment required for the solar farm will not change as per the base case. Major savings can be obtained in the grid connection infrastructure and installation as well as the development costs, which are achieved through savings in land costs, development approvals and studies.

Figure 6 shows a breakdown of the estimated savings in more detail for CAPEX.

Additional savings can be obtained via a reduction in operation and maintenance costs. Figure 7 shows a breakdown of the estimated savings in more detail for the operation and maintenance period. It is estimated that the main saving can be found in the administration and reporting costs. AECOM estimates a saving between 3 and 16 per cent for operation and maintenance costs for the solar farm.

3.0 Generation Profile Analysis

3.1 Overview

AECOM has completed analysis of the historical generation profiles of a selection of existing wind farms in the NEM and SWIS using data provided by AEMO, IMO and Global-Roam. This section illustrates high level trends present in wind farm output from the projects chosen. From these trends, insight can be gained regarding the potential correlation of solar with the wind output. In particular, AECOM has investigated the relationship between the penetration of solar at each wind farm and the curtailment that might be experienced had a solar farm been co-located at each wind farm. This is undertaken using coincident historical solar irradiance data to match the wind profiles. The analysis provides a framework to estimate appropriate sizing of potential solar farms at each wind farm.

AECOM selected 10 wind farms for analysis. The selections were based on geographic diversity, as well as prioritising larger wind farms with at least three full years of generation data. Four years of generation data was used for all wind farms except for Hallett 1, Gunning and Oaklands Hill. Wind farms from Tasmania were not analysed due to the relatively poor solar resource. The analysed wind farms are listed below in Table 2.

Table 2 Wind farms selected for generation profile analysis

State	Wind Farm	Capacity
Western Australia	Alinta	89 MW
	Emu Downs	80 MW
	Collgar	206 MW
South Australia	Hallett 1	95 MW
	Snowtown	99 MW
	Waterloo	111 MW
New South Wales	Capital	140 MW
	Gunning	47 MW
Victoria	Waubra	192 MW
	Oaklands Hill	67 MW

3.2 Wind farm generation profile analysis

3.2.1 Western Australia results

Figure 8 Average diurnal generation profile for each year (2011 to 2014) at Alinta (Walkaway) Wind Farm

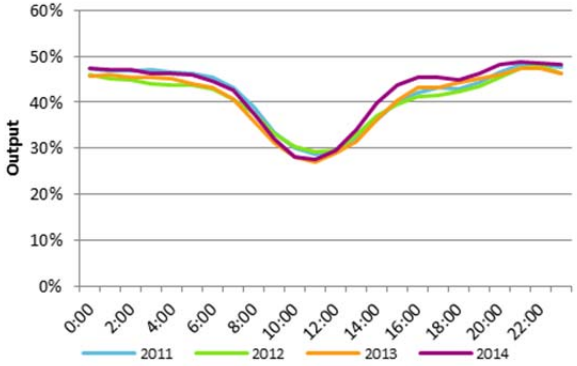


Figure 9 Average diurnal generation profile for each year (2011 to 2014) at Emu Downs Wind Farm

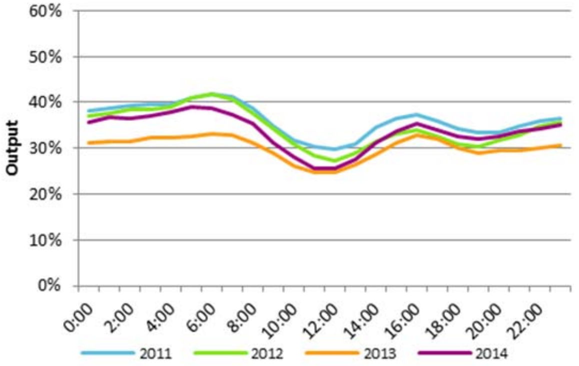


Figure 10 Average diurnal generation profile for each year (2011 to 2014) at Collgar Wind Farm

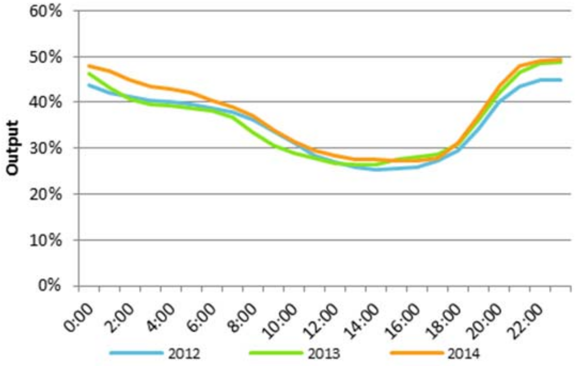


Figure 11 Average diurnal generation profile for each season at Alinta (Walkaway) Wind Farm (data from 2011 to 2014)

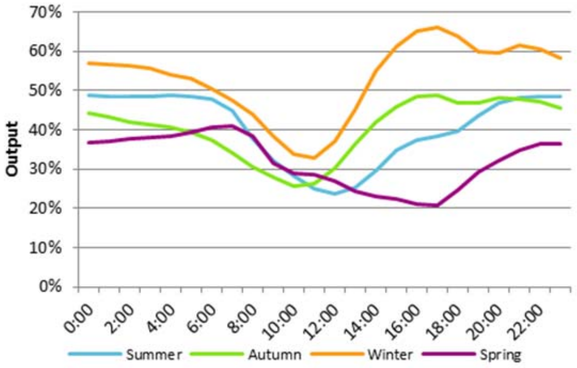


Figure 12 Average diurnal generation profile for each season at Emu Downs Wind Farm (data from 2011 to 2014)

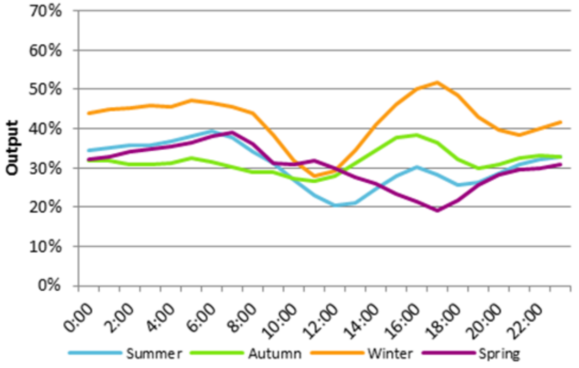
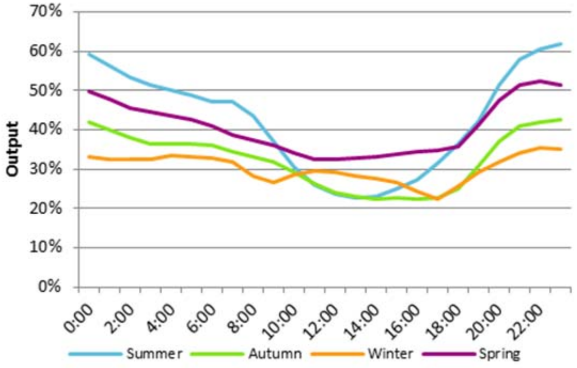


Figure 13 Average diurnal generation profile for each season at Collgar Wind Farm (data from 2012 to 2014)



3.2.2 South Australia results

Figure 14 Average diurnal generation profile for each year (2011 to 2014) at Waterloo Wind Farm

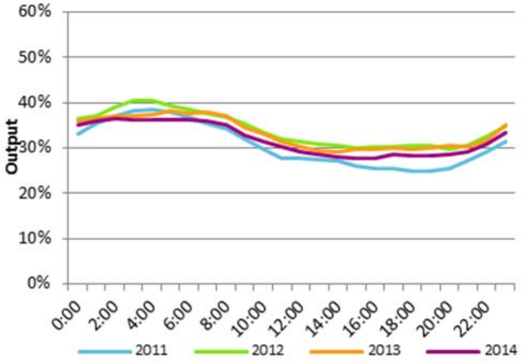


Figure 15 Average diurnal generation profile for each year (2012 to 2014) at Hallett Wind Farm

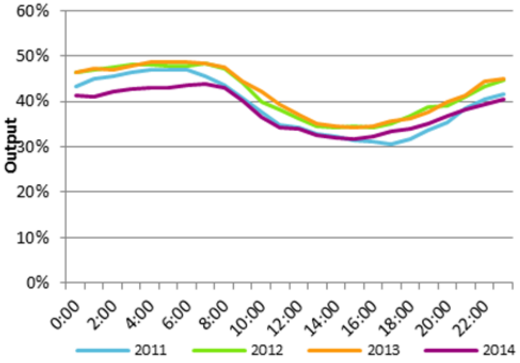


Figure 16 Average diurnal generation profile for each year (2011 to 2014) at Snowtown Wind Farm

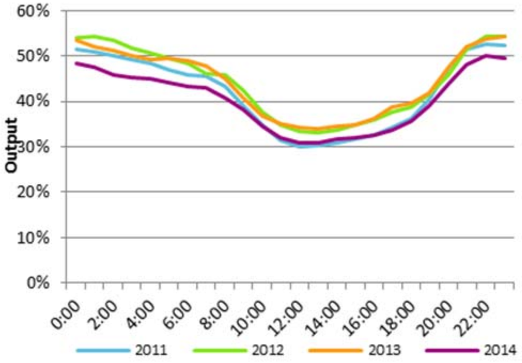


Figure 17 Average diurnal generation profile for each season at Waterloo Wind Farm (data from 2011 to 2014)

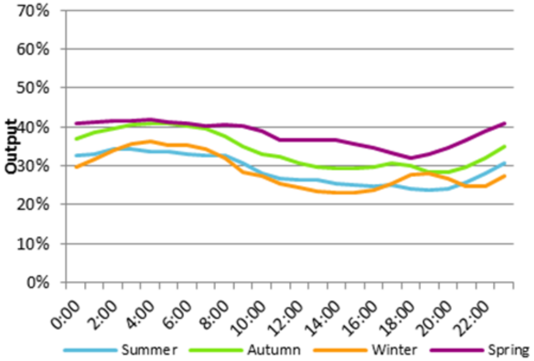


Figure 18 Average diurnal generation profile for each season at Hallett Wind Farm (data from 2012 to 2014)

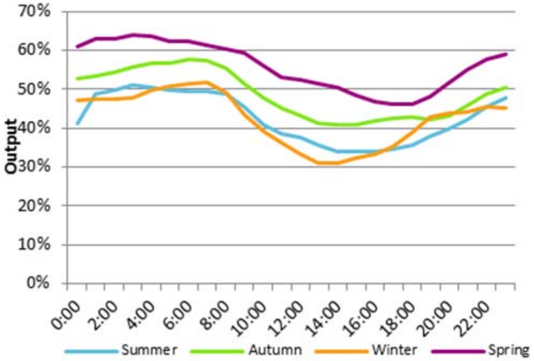
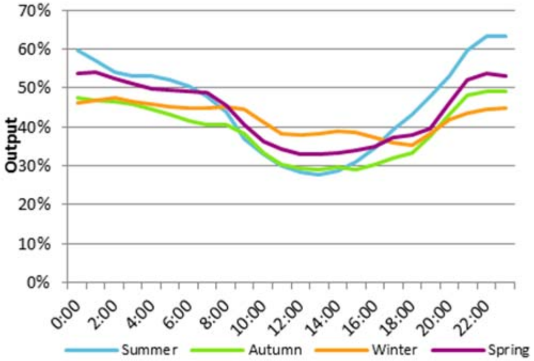


Figure 19 Average diurnal generation profile for each season at Snowtown Wind Farm (data from 2011 to 2014)



3.2.3 New South Wales results

Figure 20 **Average diurnal generation profile for each year (2011 to 2014) at Capital Wind Farm**

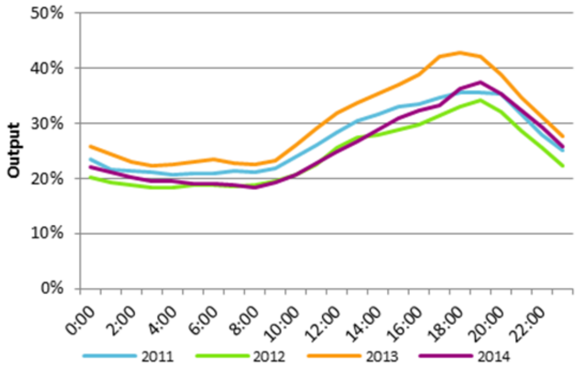


Figure 21 **Average diurnal generation profile for each year (2012 to 2014) at Gunning Wind Farm**

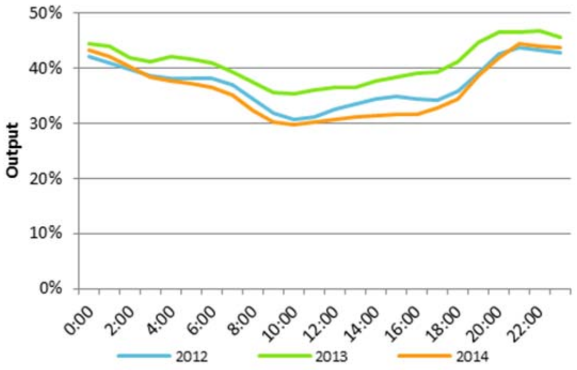


Figure 22 **Average diurnal generation profile for each season at Capital Wind Farm (data from 2011 to 2014)**

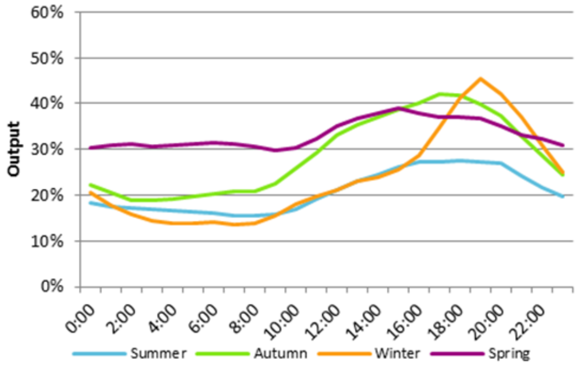
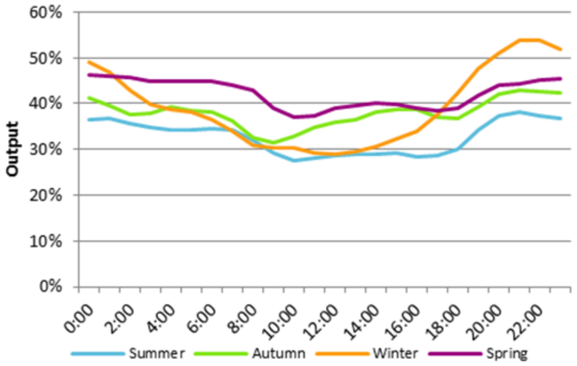


Figure 23 **Average diurnal generation profile for each season at Gunning Wind Farm (data from 2012 to 2014)**



3.2.4 Victoria results

Figure 24 **Average diurnal generation profile for each year (2011 to 2014) at Waubra Wind Farm**

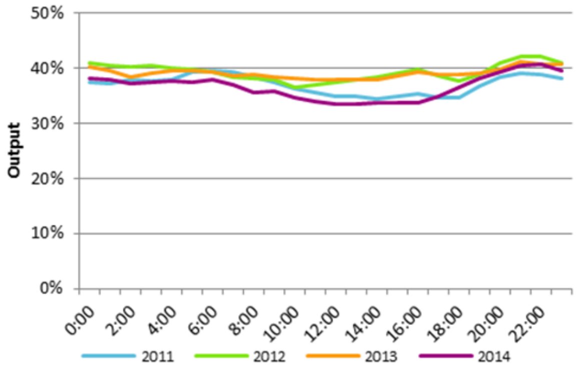


Figure 25 **Average diurnal generation profile for each year (2012 to 2014) at Oaklands Hill Wind Farm**

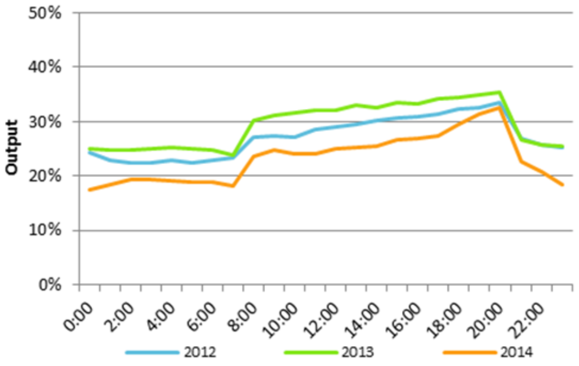


Figure 26 **Average diurnal generation profile for each season at Waubra Wind Farm (data from 2011 to 2014)**

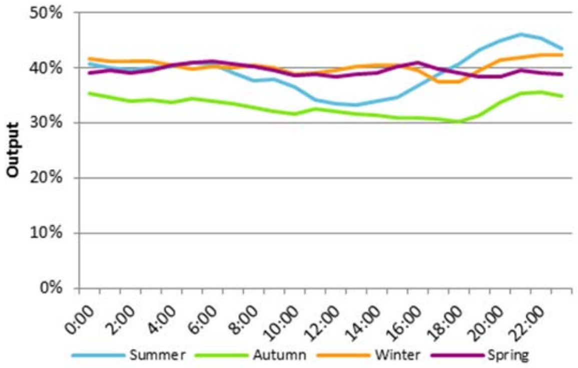
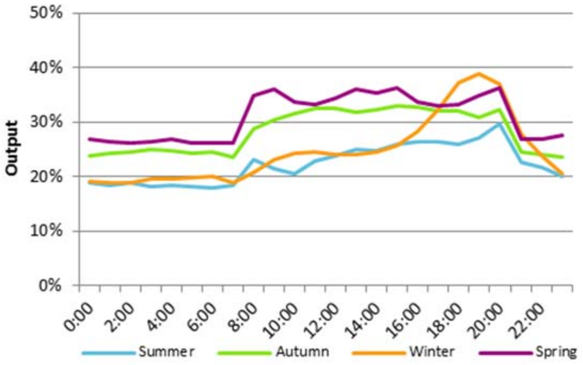


Figure 27 **Average diurnal generation profile for each season at Oaklands Hill Wind Farm (2012 to 2014)**



3.2.5 Summary of findings

Western Australia is characterised by lower average daytime generation across all three analysed wind farms. This characteristic is particularly pronounced at Collgar and Alinta wind farms, which provides more headroom for daytime solar generation.

Similar patterns of low day-time generation were observed at the South Australian wind farms, although to a lesser extent. Wind farms in NSW and Victoria did not consistently follow this pattern.

It was also observed that the wind generation profiles were very consistent from year-to-year. This pattern was observed at all analysed wind farms, although to a greater extent in Western Australia. Other wind farms typically produced the same output profile in each year, although the total output varied, indicating that it is common for a wind farm to have a characteristic diurnal generation profile.

Whilst the analysis clearly demonstrated that each wind farm has a distinct generation profile, it also highlighted a high degree of seasonality at many wind farms. Seasonality manifested itself either by changing the magnitude of energy (with the same profile; e.g. Waterloo and Hallett 1), or by a complete change in the shape of the profile (e.g. Alinta and Emu Downs).

It is also worth noting that some wind farms in close proximity displayed significantly different generation profiles. For example, Gunning and Capital wind farm are only separated by 55 km, yet their generation profiles were substantially different. The difference in generation profiles will likely be caused by numerous factors such as: the frequency distribution profile of the wind for that specific region which is often summarised as difference in Weibull characteristics, and the impact of shear and turbulence.

3.3 Correlation of wind and solar generation

3.3.1 Profile comparison

The wind farm generation profile has been overlayed against the estimated solar farm generation profile in each figure from Figure 28 to Figure 37 for the selected wind farms. The figures indicate the times of the day for which there is potential for the solar farm to impact the combined generation profile at the connection point. The relationship between the wind and solar profiles impacts upon the curtailment analysis in the following section.

3.3.2 Western Australia results

Figure 28 Alinta Wind Farm: Wind and solar (average diurnal generation profile)

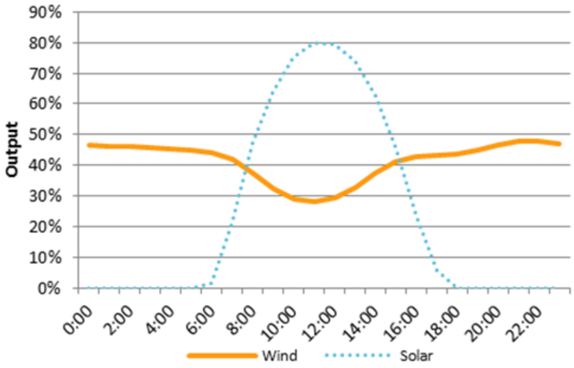


Figure 29 Emu Downs Wind Farm: Wind and solar (average diurnal generation profile)

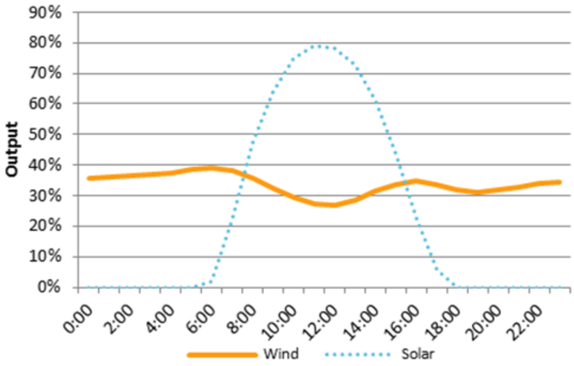
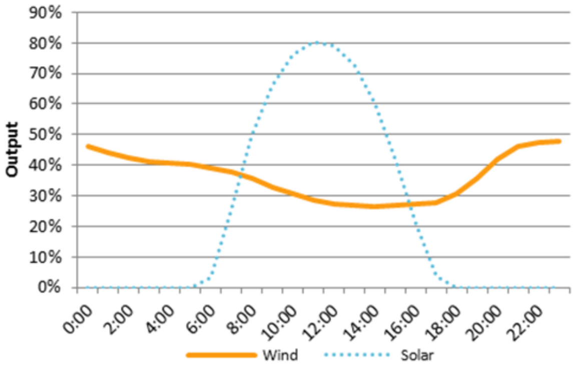


Figure 30 Collgar Wind Farm: Wind and solar (average diurnal generation profile)



3.3.3 South Australia Results

Figure 31 Snowtown Wind Farm: Wind and solar (average diurnal generation profile)

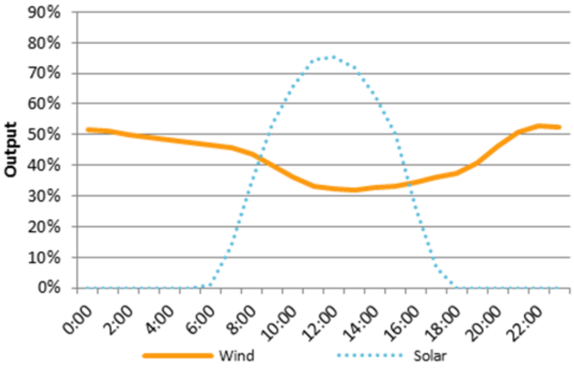


Figure 32 Waterloo Wind Farm: Wind and solar (average diurnal generation profile)

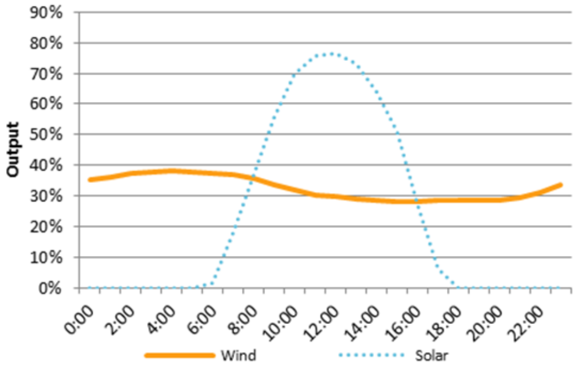
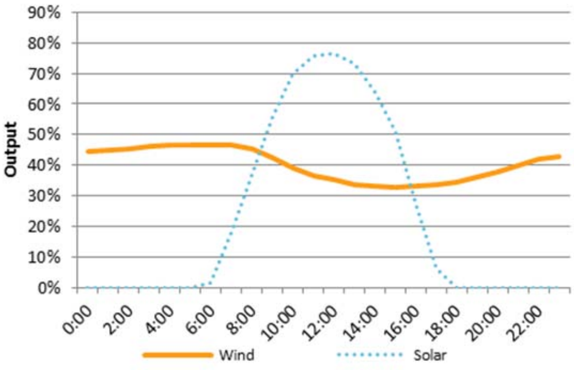


Figure 33 Hallett Wind Farm: Wind and solar (average diurnal generation profile)



3.3.4 New South Wales results

Figure 34 Capital Wind Farm: Wind and solar (average diurnal generation profile)

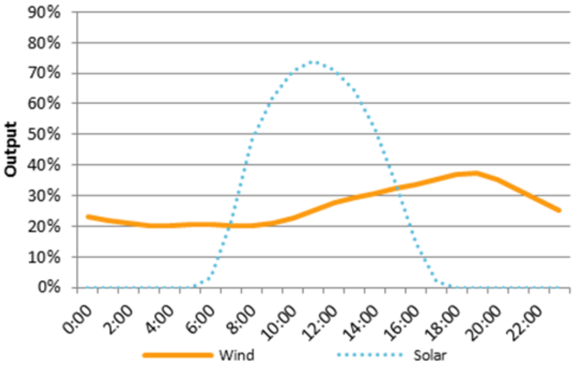
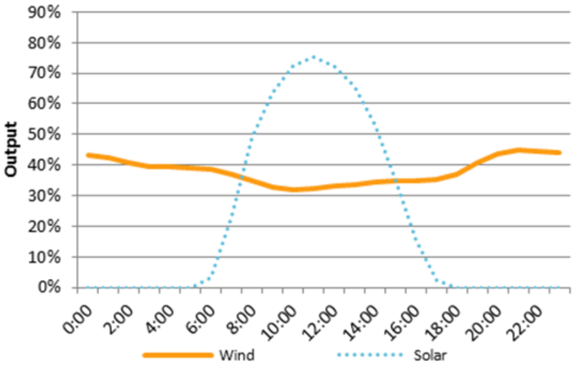


Figure 35 Gunning Wind Farm: Wind and solar (average diurnal generation profile)



3.3.5 Victoria results

Figure 36 **Waubra Wind Farm: Wind and solar (average diurnal generation profile)**

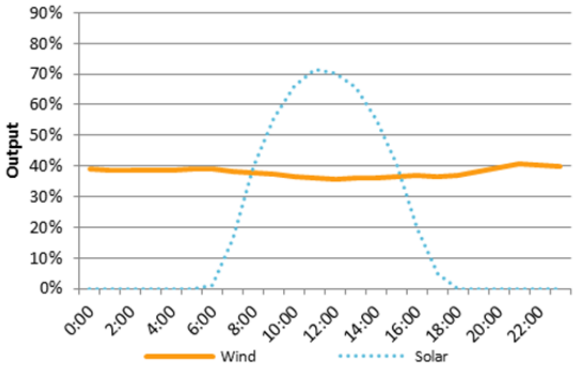
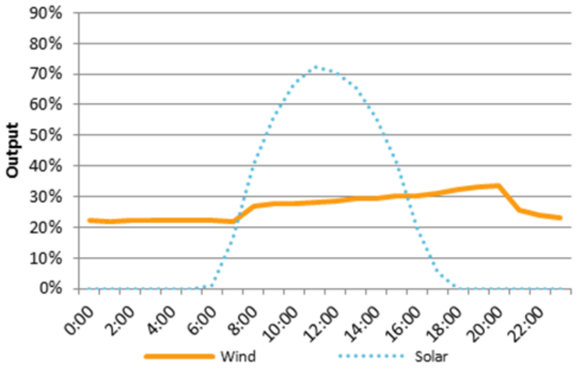


Figure 37 **Oaklands Hill Wind Farm: Wind and solar (average diurnal generation profile)**



3.4 Curtailment analysis

When solar PV is installed at a pre-existing wind farm, the capacity limitations of the connection infrastructure may require excess generation to be curtailed during periods of high co-incident wind and solar generation. AECOM has investigated the relationship between the size of hypothetical solar farms at each wind farm, and the curtailment that could be expected. As expected, with increasing levels of solar capacity, the level of curtailment increases.

In this analysis, AECOM has combined the historical output generation profiles of existing wind farms with hypothetical co-located solar farm output profiles (using modelled coincidence data analysis) to determine the level of correlation between the two profiles. There are two objectives to this analysis:

1) To gain an understanding of the compromises between the relative sizes of co-located solar farms and the potential curtailment that may occur due to capacity constraints at the existing connection points, and

2) To estimate appropriate optimal solar farms capacity at each wind farm location.

In this analysis, AECOM has focused on established wind farms (with at least 3 years historical generation data) and sought to investigate a diverse range of geographies to better understand any geographic trends. The analysis is limited by a number of assumptions:

- Solar generation profiles are based on PVsyst modelling using a typical fixed tilt mounting structure system.
- No specific site by site system optimisation has been conducted. The PVsyst modelling has utilised the same loss assumptions across all factors in the solar farm except for input weather data. Input weather data used in the model is global horizontal irradiation and temperature. Global horizontal irradiation data was sourced from the Bureau of Meteorology (Gridded Hourly Global Horizontal Irradiance 1990 to 2015) for the concurrent time interval. The data set from Bureau of Meteorology is satellite based and covers all of Australia in 5 km grids. Temperature data was sourced from Meteonorm V7.1 which provided an hourly time series for a typical year derived from interpolation from the closest weather stations in its database. The temperature data was then applied for each and every year and hence the temperature data is not for concurrent time periods. This is considered a reasonable approach as the solar farm generation is almost linear with solar irradiation whereas changes in temperature impacts the power generation by a level equivalent to a temperature coefficient of the solar module.
- Outputs are limited by data quality for wind farm generation and solar irradiation, sourced from:
  - Wind farm generation data has been sourced from AEMO, IMO and Global Roam
  - Solar irradiation satellite data has been sourced from the Bureau of Meteorology
  - Temperature data sourced from Meteonorm V7.1
  - Accuracy of the PVsyst model itself which includes assumptions and loss factors used

- It is assumed that the solar farm can connect into the existing grid connection and that the capacity of that grid connection is equal to the capacity of the wind farm as registered with AEMO or IMO
- It is assumed that the connection point capacity constraints lead to curtailment of solar generation only (not wind)

Figure 38 **Solar generation curtailment at each in WA**

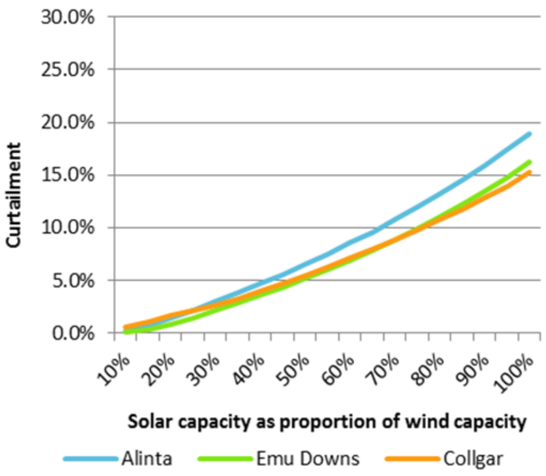


Figure 39 **Solar generation curtailment at each in SA**

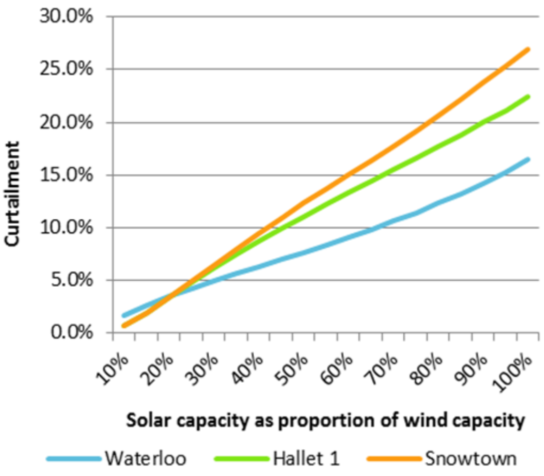


Figure 40 **Solar generation curtailment at each in NSW**

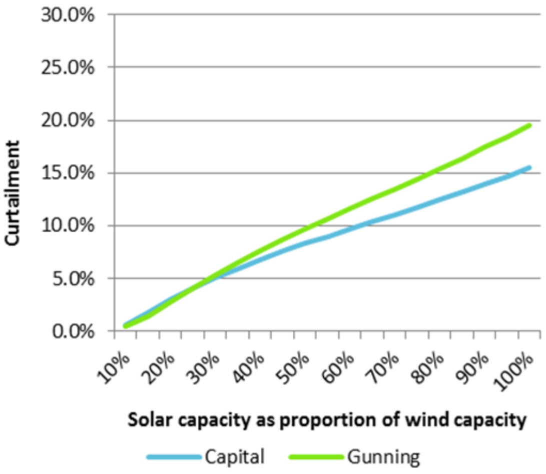
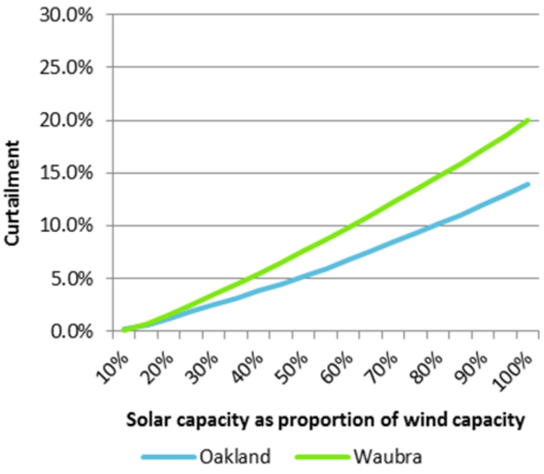


Figure 41 **Solar generation curtailment at each in Vic**



The analysis presented above provides an intriguing snapshot into the complex correlation between wind and solar generation. Some interesting observations are listed below:

- There is often a non-linear relationship between curtailment and capacity of solar. In addition, the concavity of the curtailment curves is inconsistent and unpredictable. The Western Australian wind farms are concave up, while NSW wind farms are concave down. South Australian wind farms appear relatively linear.
- Some locations (e.g. Capital Wind Farm) start with relatively higher curtailment at low penetration but have relatively lower curtailment at higher penetration.
- Oaklands Hill Wind Farm appears to be able to host a large solar farm (relative to its capacity); however this is due to its low existing capacity factor during the modelling period (rather than a beneficial anti-correlation between wind and solar profiles). This effect is exacerbated by the relatively lower solar resource, which reduces the curtailment for a given solar capacity. This illustrates how the correlation and curtailment results presented above should be considered within the context of each wind farm's existing capacity factor and solar resource.

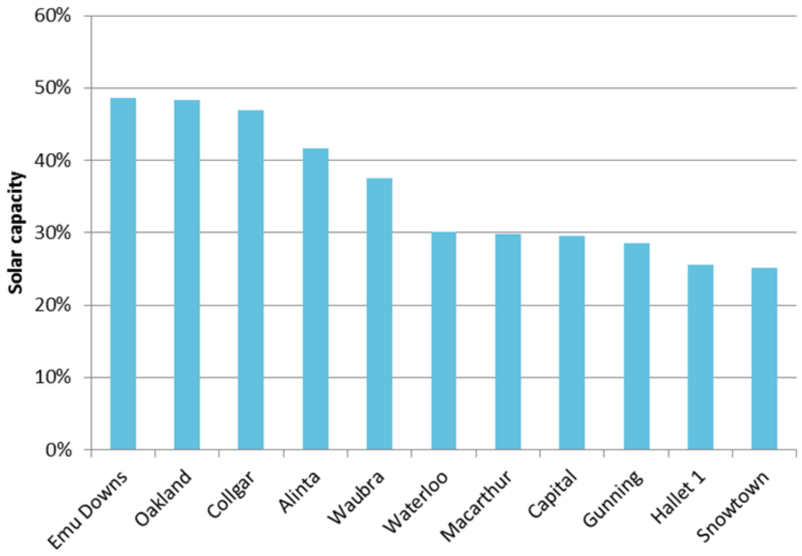
In order to conduct some deeper analysis, AECOM has assumed that interested developers would maximise the size of solar farms co-located at wind farms without exceeding 5 per cent curtailment of the solar output. 5 per cent was chosen as it allows the construction of larger solar farms without exceeding the levelised cost savings that can be achieved through because of co-location (estimated at between 3 – 13 per cent (excluding OPEX savings).

Using the curtailment curves shown above, AECOM has estimated the maximum solar penetration at each wind farm when curtailment does not exceed 5 per cent. The low daytime utilisation of Western Australian wind farms, allows for much larger solar farms than the eastern states, with allowable sizes ranging from 42-49 per cent of the wind farm capacity. Other wind farms range from solar farm sizes between 25 per cent and 30 per cent (of the wind farm capacity), with the exceptions of the two Victorian wind farms, Waubra and Oaklands Hill, accommodate achieve 38 per cent and 48 per cent respectively. The Victorian examples are not a result of a positive wind-solar correlation. Rather, they are a result of the lower solar resource in Victoria, which allows more solar capacity to be installed without resulting in increased curtailment. In addition, the pre-existing low capacity factor at Oaklands Hill Wind Farm provides additional headroom for solar.

Table 3 Summary of recommended size of solar farms at each wind farm (based on 5 per cent allowable curtailment assumption)

State	Wind Farm	Wind farm capacity	Maximum solar penetration (5% curtailment)	Solar farm size
Western Australia	Alinta	89 MW	42%	37 MW
	Emu Downs	80 MW	49%	39 MW
	Collgar	206 MW	47%	97 MW
South Australia	Hallett 1	95 MW	25%	24 MW
	Snowtown	99 MW	25%	25 MW
	Waterloo	111 MW	30%	33 MW
New South Wales	Capital	140 MW	30%	41 MW
	Gunning	47 MW	29%	13 MW
Victoria	Waubra	192 MW	38%	72 MW
	Oaklands Hill	67 MW	48%	32 MW

Figure 42 Solar capacity (proportion of wind capacity) at each wind farm that would result in 5 per cent curtailment



3.4.1 Capacity factor analysis

Using the solar farm sizing methodology described above (i.e. 5 per cent allowable curtailment), AECOM has re-evaluated the diurnal profiles from Section 3.2, showing the impact of a co-located solar plant on the average output.

Figure 43 Alinta Wind Farm: Combined wind and solar (average diurnal generation profile)

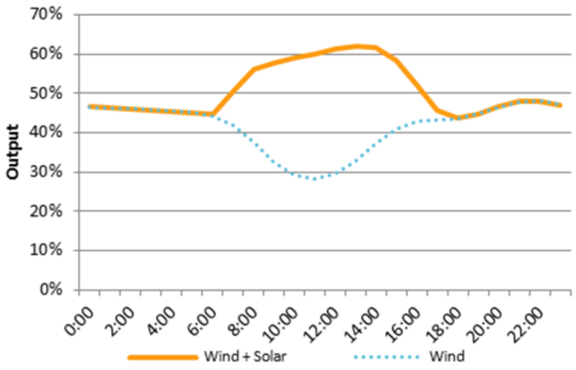


Figure 44 Emu Downs Wind Farm: Combined wind and solar (average diurnal generation profile)

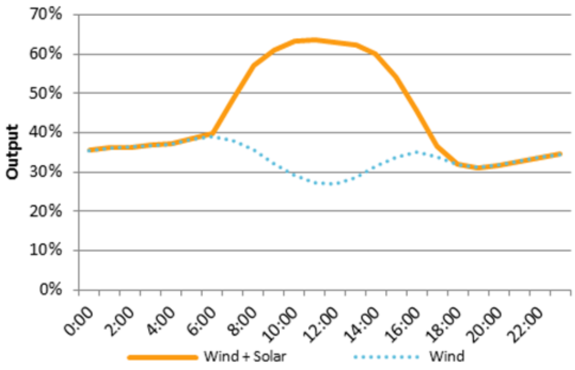


Figure 45 Collgar Wind Farm: Combined wind and solar (average diurnal generation profile)

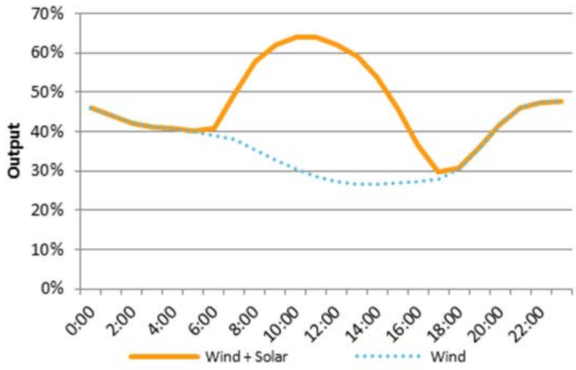


Figure 46 Waterloo Wind Farm: Combined wind and solar (average diurnal generation profile)

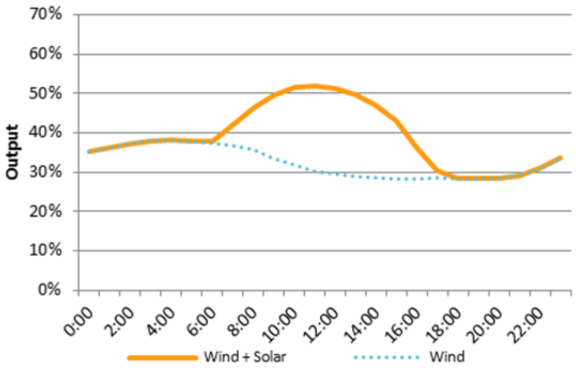


Figure 47 Hallett Wind Farm: Combined wind and solar (average diurnal generation profile)

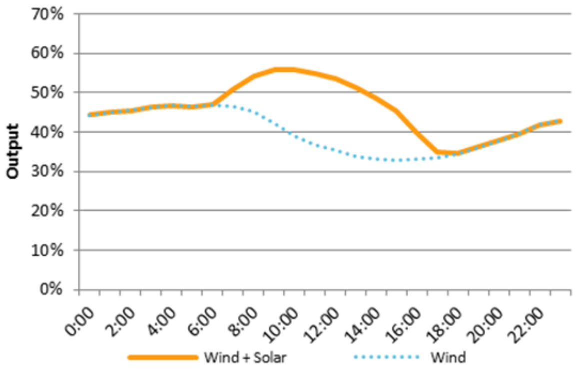


Figure 48 Snowtown Wind Farm: Combined wind and solar (average diurnal generation profile)

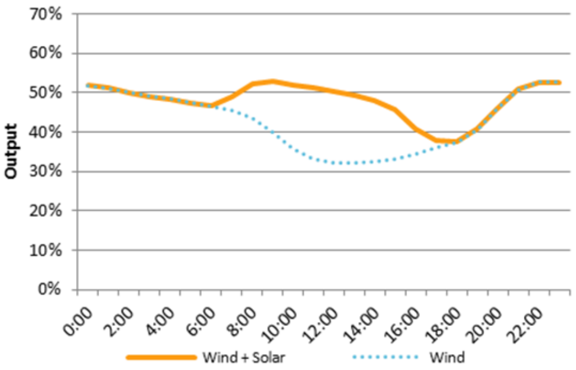


Figure 49 Capital Wind Farm: Combined wind and solar (average diurnal generation profile)

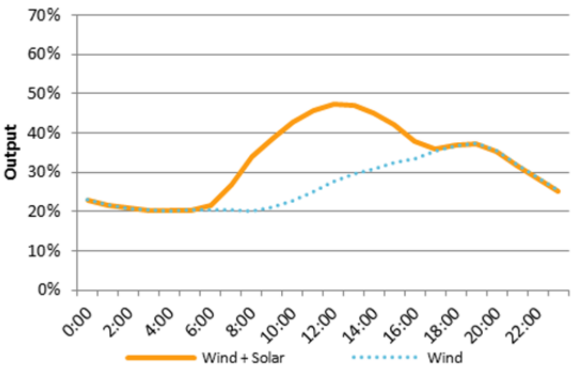


Figure 50 Gunning Wind Farm: Combined wind and solar (average diurnal generation profile)

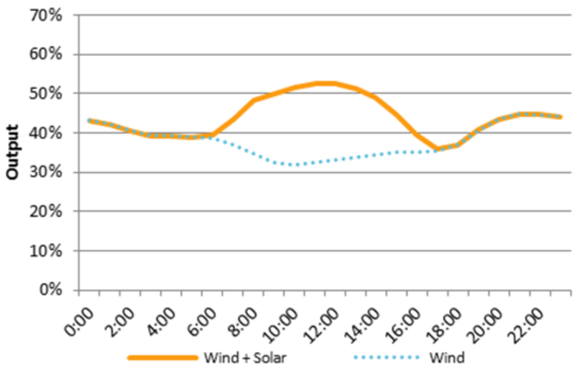


Figure 51 Waubra Wind Farm: Combined wind and solar (average diurnal generation profile)

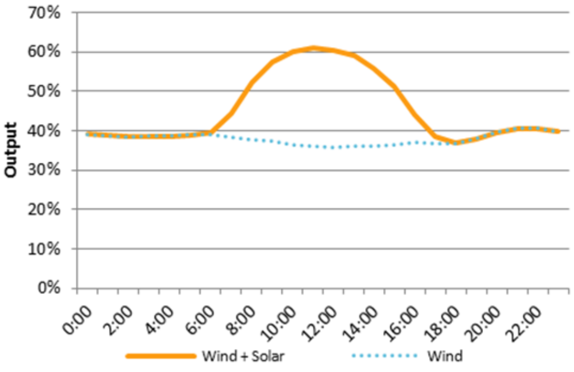
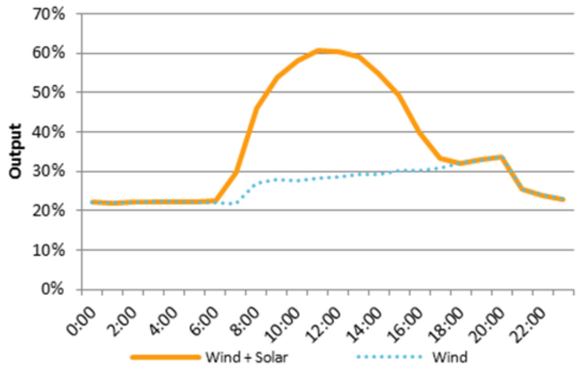


Figure 52 Oaklands Hill Wind Farm: Combined wind and solar (average diurnal generation profile)



3.4.2 Summary

The analysis presented above provides an intriguing snapshot into the complex correlation between wind and solar generation. Using historical data, AECOM was able to demonstrate that solar farms sized between 25 per cent and 49 per cent of each wind farm’s capacity would only result in 5 per cent curtailment.

Table 4 Summary of solar co-location properties at each wind farm

	Wind farm capacity	Maximum solar penetration (5% curtailment)	Solar farm size	Capacity Factor (pre solar)	Capacity Factor (post solar @ 5% curtailment)	Capacity Factor (post solar @ 1:1)
Alinta	89 MW	42%	37 MW	41%	51%	61%
Capital	140 MW	30%	41 MW	27%	33%	45%
Collgar	206 MW	47%	97 MW	36%	47%	57%
Emu Downs	80 MW	49%	39 MW	34%	45%	54%
Gunning	47 MW	29%	13 MW	38%	44%	56%
Hallett 1	95 MW	25%	24 MW	40%	46%	58%
Oaklands	67 MW	48%	32 MW	27%	36%	45%
Snowtown	99 MW	25%	25 MW	43%	48%	60%
Waterloo	111 MW	30%	33 MW	32%	39%	52%
Waubra	192 MW	38%	72 MW	38%	44%	53%

The technical capacity of wind farms to accommodate co-located solar farms appears substantial. Of the 10 wind farms analysed, 414 MW of solar capacity could be co-located without exceeding 5 per cent curtailment. Based on the minimum level of penetration for the selected sites of 25 per cent, it could be estimated that over 1GW of solar could be co-located at existing wind farms in Australia. The results are limited by the assumptions used to derive these figures. The limitations are detailed in Section 1.5.

The above analysis focuses only on the correlation of wind and solar resources, resulting in an estimate of the most appropriate size solar plant at each location. It is very important to note that these results do not facilitate direct comparison of the merits of co-location at each wind farm. This is because it does not consider the relative economic feasibility of any particular project. Other factors such as the local solar resource, wholesale electricity price and construction cost have a direct influence on the relative merits of each project.

Having sized the solar farms in this chapter, Section 5.0 conducts a high level evaluation of the relative economic attractiveness of each co-location project and ranks the potential projects.

4.0 Greenfield co-location opportunities

AECOM has created wind and solar heat maps to help developers identify suitable greenfield wind-solar colocation sites. The heat maps provide high level perspective of regions which are suitable for co-locations sites. AECOM notes the heat maps are indicative tools only and should only be used for high-level analysis. Each site will inevitably have its own characteristics that need to be considered through more detailed research and analysis.

4.1 Methodology

AECOM has considered two methodologies for rating the co-location potential of greenfield locations. The first heat map identifies the locations with the best combined wind and solar resource (Figure 55) while the second map (Figure 56) filters for sites with a “sufficient” wind resource and ranks the remaining sites according to the attractiveness of the solar resource.

The first method is intended to identify the best co-location sites. However, in our analysis, AECOM noticed that the dominance of the wind-resource often outweighs the contribution of the solar resource. Hence, the second method was created to highlight potential wind locations with the best solar resource. A key idea behind the second method was that co-location projects may often be staged, particularly given the current economics of the respective technologies. Currently, large scale wind projects are generally more commercially viable under the LRET scheme (due to having a lower levelised cost of energy), whereas solar PV projects are typically reliant on other funding sources to become commercially viable (even if cost savings are achieved through co-location). Consequently, splitting a co-location project into separate wind and solar stages may be preferred by developers and it will be important to consider the individual commercial viability of each technology.

The heat maps rate locations based on predicted capacity factor. Capacity factor was chosen as a suitable unit as it represents the resultant power available from each technology based on the renewable resource. As such, this choice of unit allows the wind resource (meters per second) and the solar resource (kWh/m^2) to be aggregated.

The heat maps utilise the following input data:

Table 5 Input data - co-location resource maps

Data	Description	Source
Wind	5 km mesoscale grid cell average wind speed at 100 m hub height	Provided by DNV GL to AREMI (noted as draft data)
Ambient temperature	5 km grid average annual temperature data	Bureau of Meteorology (BOM)
Solar	Global Tilted Irradiation (GTI)	AECOM based on BOM GHI data

4.1.1 Wind farm capacity factor estimation

AECOM has estimated greenfield wind farm capacity factors using the DNV GL average wind speed data. This was done using Windographer wind resource assessment software, which generated a distribution of capacity factors for different wind speeds. AECOM has used this relationship to estimate capacity factor at the different wind speeds across the 5 km grid provided by DNV GL. A summary of the Windographer inputs and assumptions is provided below:

Table 6 Input data for co-location resource maps

Input	Value
Overall loss factor	15% (includes availability losses, wake effects, turbine performance and electrical losses)
Distribution type	Rayleigh distribution (k=2)
Air density	1.225 kg/m^3
Turbine	GE 2.5-100

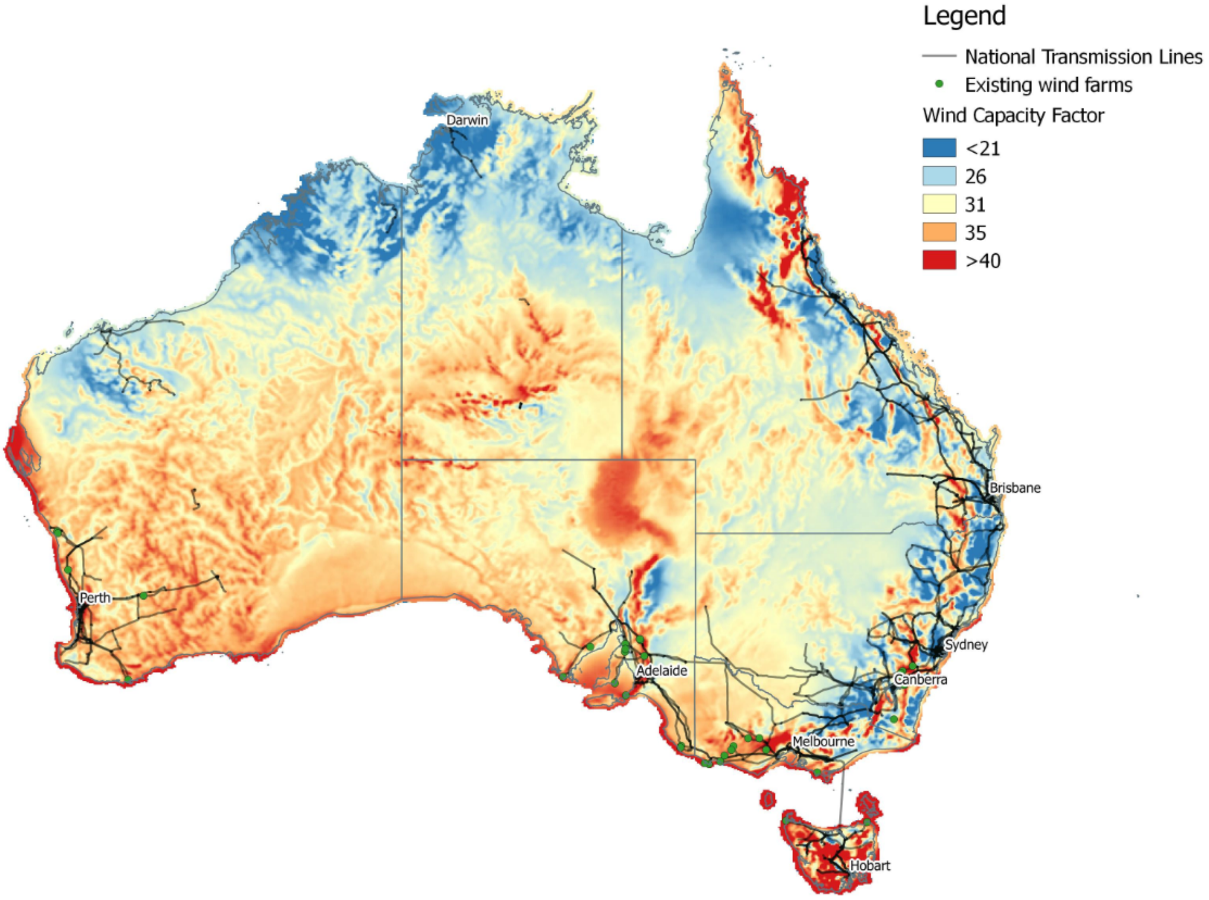
AECOM notes that there are inaccuracies to estimating wind farm capacity factors based on average speed figures (and without consideration for site specific Weibull parameters); however average wind speed was the extent of the data available across Australia. To test the accuracy of this methodology, AECOM compared its results with measured capacity factors at existing wind farms. As shown in Table 7, there is reasonable correlation between the predicted and measured results. The estimated capacity factor is typically within 5% of the actual (6 of 9); however the inherent variability is a clear limitation on this analysis.

Table 7 Existing wind farm capacity factors calculated by AECOM from AEMO generation data compared with capacity factors calculated from DNV GL average wind speed data

Wind farm	Wind farm capacity	Capacity Factor (AEMO data)	Capacity Factor (DNV GL average wind speed)	Comment
Alinta	89 MW	41%	36%	-5% underestimate
Capital	140 MW	27%	34%	+7% overestimate
Collgar	206 MW	36%	36%	Equal
Emu Downs	80 MW	34%	36%	+2% overestimate
Gunning	47 MW	38%	41%	+3% overestimate
Hallett 1	95 MW	40%	38%	-2% underestimate
Snowtown	99 MW	43%	35%	-8% underestimate
Waterloo	111 MW	32%	39%	+7% overestimate
Waubra	192 MW	38%	39%	+1% overestimate

Figure 53 shows the result of AECOM’s wind farm capacity factor estimations across Australia, which is indicative of the relative wind resource.

Figure 53 Wind resource across Australia as the estimated capacity factor of greenfield sites



Source: AECOM (using DNV GL wind resource data)

4.1.2 Solar farm capacity factor estimation

As per the wind methodology above, there are data limitations that restrict the accuracy of estimating capacity factor based on simplified inputs. Nonetheless, the methodology used is considered appropriate for high level estimation and presentation of learnings.

AECOM has also estimated the greenfield solar farm capacity, using GHI data and temperature data from the Bureau of Meteorology and the below formula for capacity factor.

$$CF_{SF} = \frac{(GTI \times PR \times TCF \times DC\!:\!AC\ ratio)}{8760}$$

CF_{SF} = solar farm capacity factor (relative to inverter's AC rating)

GTI = Global Tilted Irradiation (kWh/m^2 estimated empirically from GHI input data)

PR = performance ratio of generic solar farm (80% used; representative of year 1)

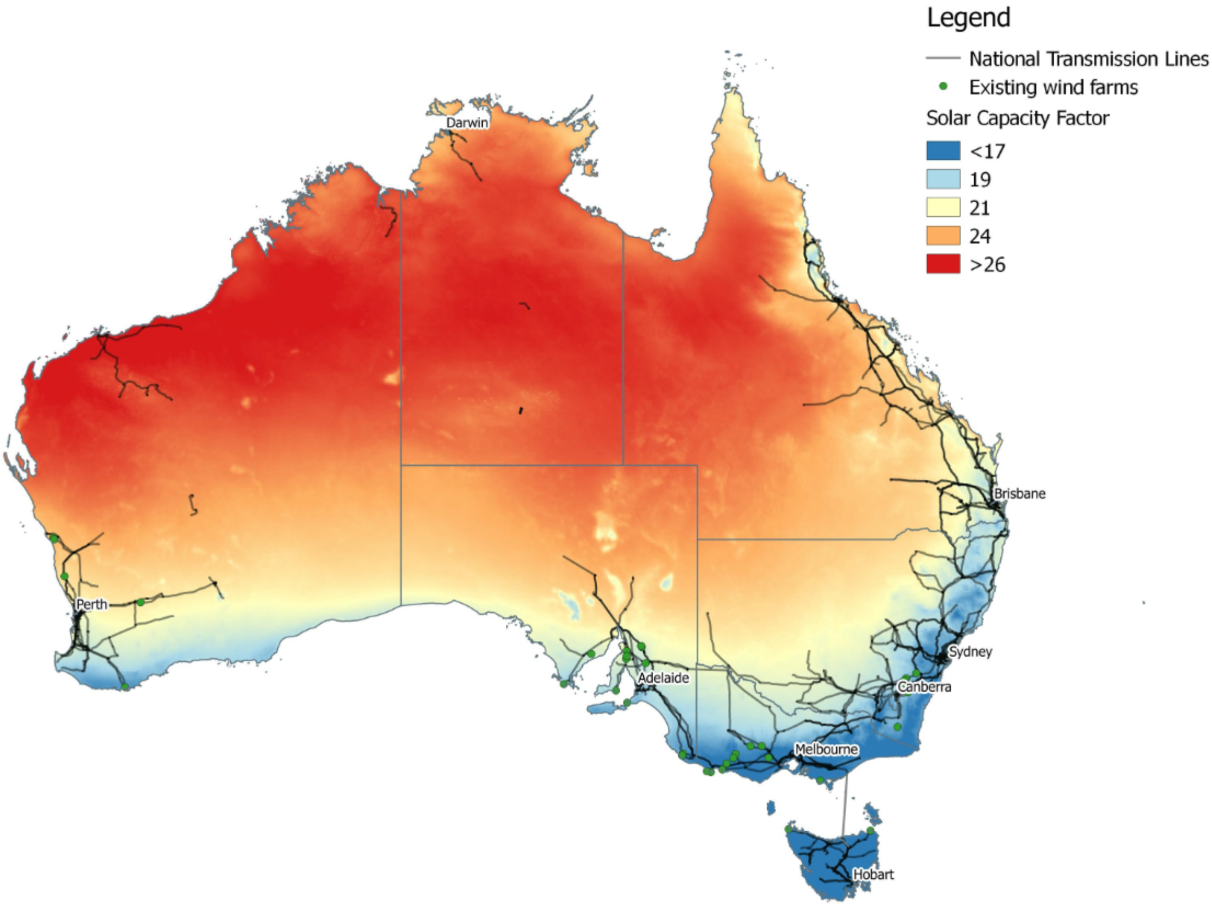
TCF = temperature correction factor (estimated empirically; function of average ambient temperature (BOM)

DC:AC ratio = 1.14 (for generic plant)

8,760 = hours in a year

Figure 54 shows the result of AECOM's solar farm capacity factor estimations across Australia, which is indicative of the relative solar resource.

Figure 54 Solar resource across Australia based on estimated capacity factor of greenfield sites



Source: AECOM (using BOM GHI data)

4.2 Method 1: Combined wind and solar resource

In order to sum the wind and solar resources into a combined resource, AECOM has weighted the relative resources to reflect an appropriate combined design. Based on results from Section 3.0, better utilisation of the connection infrastructure can be gained by sizing the wind farm approximately 2-4 times larger than the solar farm. This is largely because solar farm generation profiles are more concentrated (i.e. more peaky during daylight hours) than wind farm's generation profiles. For the purpose of this combined resource assessment, AECOM has assumed the solar farms are sized at 35 per cent of the size of the wind farm.

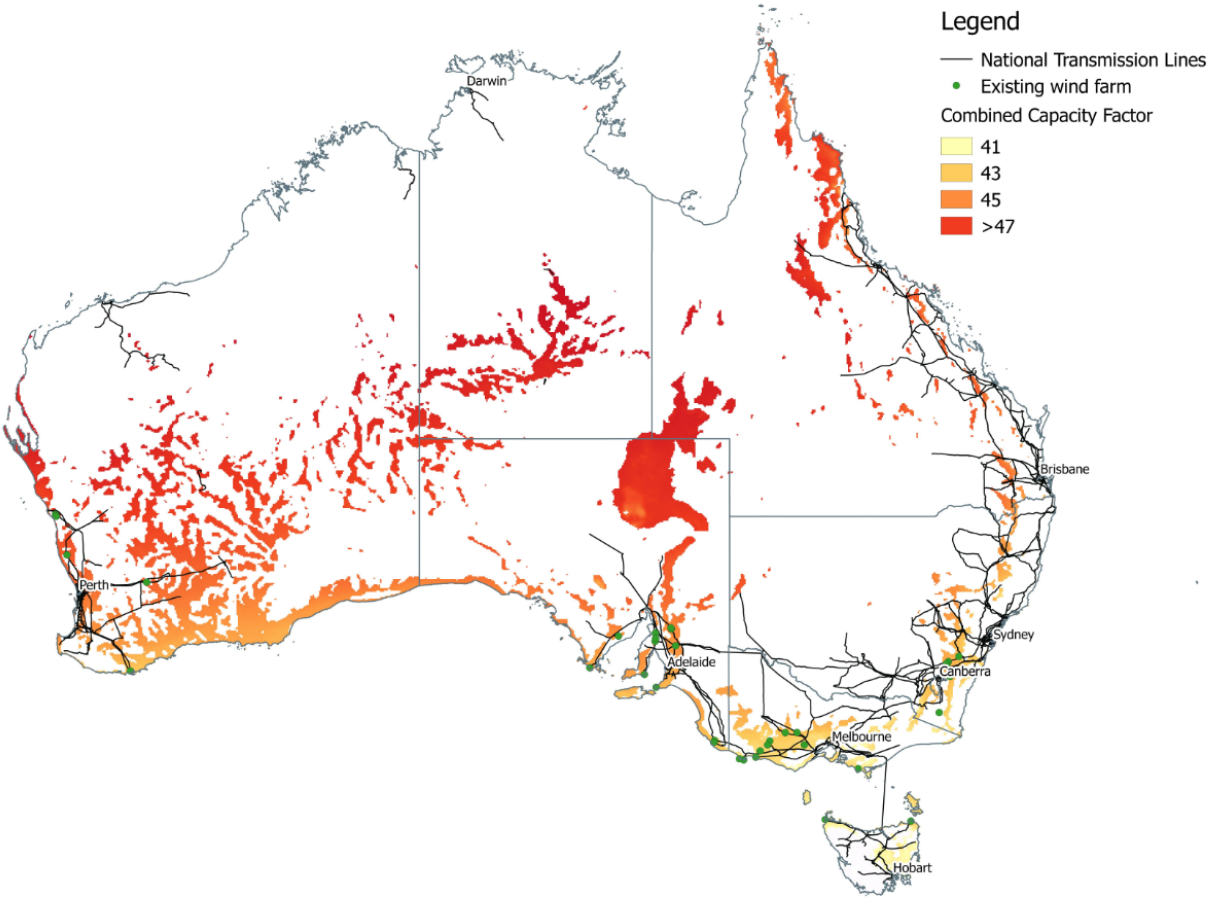
Consequently, the wind resource is dominant in the method of assessing the combined co-location resource (an alternative perspective is presented in Method 2). In addition, the wind resource is highly location dependent and considerably more variable than solar resource. Considering this, one could conclude that all wind farm developers should consider co-locating solar farms. Conversely, solar farm developers would rarely encounter good opportunities to add wind farms to solar farm sites.

Given the dominance of wind resource in the calculation of the combined resource, preliminary analysis revealed that many site with unfavourable solar resources were rated highly. While this wasn't considered an incorrect result (in terms of relative evaluation of co-location sites), it does not allow for the possibility that developers looking at such a site would choose to only construct a wind farm (i.e. without a co-located solar farm due to the poor sola resource). To better reflect this in our results, AECOM implemented a filter which removed sites that had poor solar resources. AECOM acknowledges that there is a large element of subjectiveness in determining what a "poor" solar resource is. Nonetheless, the filter is considered to be a necessary step.

Consequently, AECOM considered it wise to implement a minimum performance standard for both wind and solar resources to remove sites that have favourable resources in only one (wind or solar).

1) Sites with wind capacity factors less than 35 per cent removed
2) Sites with solar capacity factors less than 20 per cent removed
3) Combined capacity factor calculated
    a) Equal to (WF CF) + 0.35 x (SF CF)
    b) Some curtailment (~2% of total output) would be expected (if connection sizing is equal to wind farm nameplate rating), but has been omitted for simplicity
4) The resultant heat map displays the combined capacity factor for a greenfield co-located plant

Figure 55 Heat map highlighting the best combined wind + solar resource locations (poor wind and poor solar resource locations removed)



Source: AECOM (using DNV GL wind resource data and BOM GHI data)

Appendix b provides a State by State overview of the above figure.

4.3 Method 2: Solar resource rating for suitable wind sites

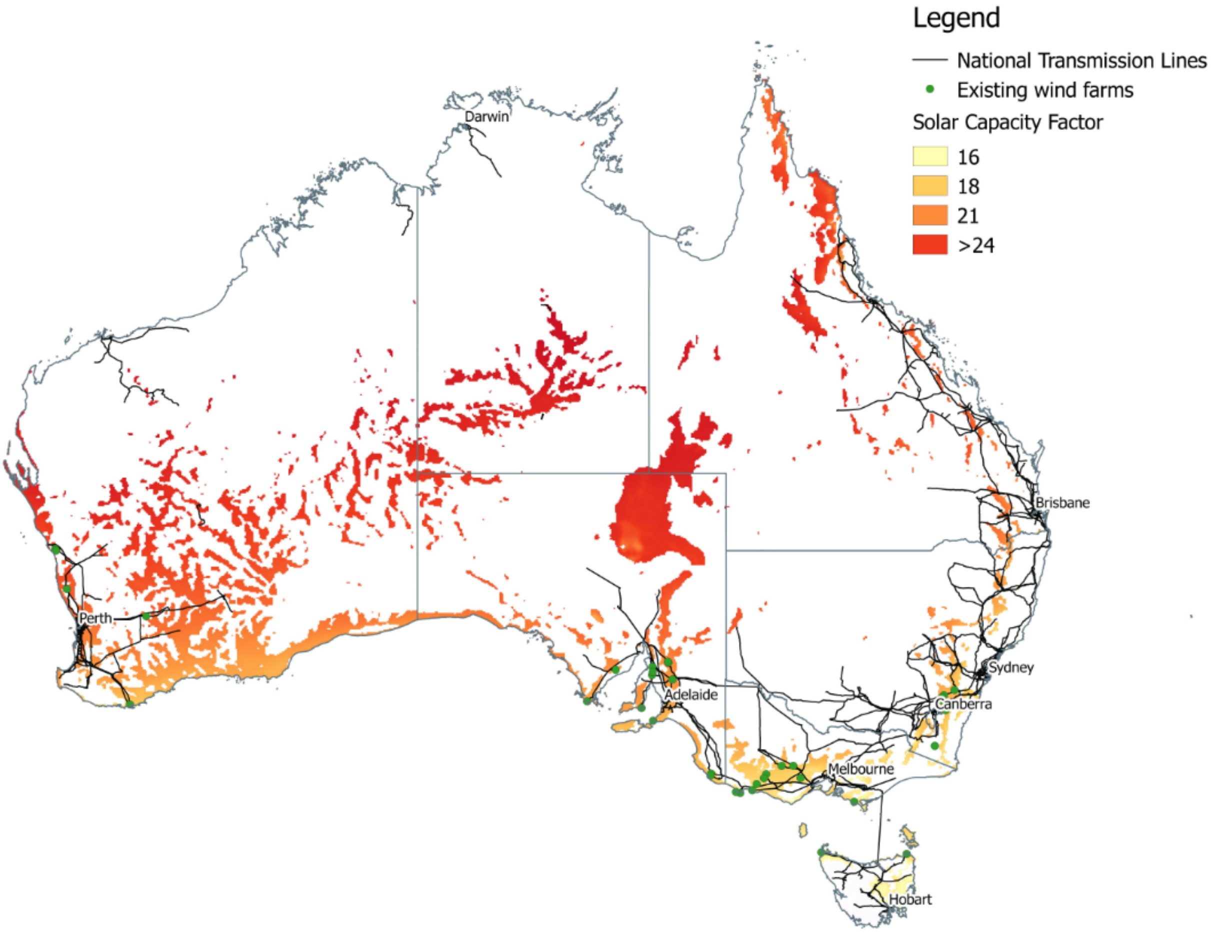
An alternative method of reviewing the opportunity for co-location is to consider the viability of wind and solar individually. Given that wind is currently more economically attractive than solar, AECOM has devised Method 2 to assist wind developers consider the opportunity for installing a future solar farm. The idea behind this methodology is that all the highlighted sites could be considered to have a suitable wind resource. Of these sites, Figure 56 identifies those with the best solar resource.

The below heat map follows the following methodology.

1) Sites with wind capacity factors less than 35% removed
2) Heat map shows solar capacity factor only (at all sites considered to have a “good” wind resource)

a) Some curtailment (~5% of solar output) would be expected (if connection sizing is equal to wind farm nameplate rating), but has been omitted for simplicity

Figure 56 Heat map highlighting the best solar resource locations (poor wind resource sites removed)



Source: AECOM (using DNV GL wind resource data and BOM GHI data)

Appendix b provides a state by state overview of the above figure.

4.4 Limitations

AECOM notes that a key limitation of this analysis is the use of average wind speed as a proxy for wind capacity factor. Average wind speed can be distorted by short periods of very strong wind (e.g. cyclones) and during periods of very high winds, wind turbines are forced to stop generating. Some of these locations are observed in Far North Queensland’s coastal areas.

Other notable limitations include input data accuracy, use of average data (rather than time series data), capacity factor calculations are approximate only (multiple simplifications), site availability and land owner constraints, environmental constraints and grid connection constraints.

The heat maps are only intended to be used as a high level introduction to co-location. AECOM recommends that developers conduct their own analysis to determine the suitability of each site on its own merit.

5.0 Evaluation and Site Ranking

5.1 Overview

Building on the sizing exercise completed in Section 2.4, this chapter seeks to evaluate the relative financial potential of each potential co-location site listed in Table 8. Due to the high-level nature of this financial analysis, it is inherently limited in its accuracy. Nonetheless, it provides some valuable insights into the high level financial drivers for co-location as well as providing guidance to ARENA, Government and developers as to where the greatest opportunities might lie.

The resultant trends are also intended to be insightful for stakeholders interested in prospecting for new co-location sites.

Table 8 Summary of major wind farms in the NEM and SWIS

Wind farm	State	Capacity*
Boco Rock	NSW	113.2 MW
Capital	NSW	140 MW
Cullerin Range	NSW	30 MW
Gullen Range	NSW	165.5 MW
Gunning	NSW	47 MW
Taralga	NSW	106.8 MW
Woodlawn	NSW	48 MW
Bluff	SA	52.5 MW
Canunda	SA	46 MW
Cathedral Rocks	SA	66 MW
Clements Gap	SA	57 MW
Hallett WF 1	SA	94.5 MW
Hallett WF 2	SA	71.4 MW
Lake Bonney 1	SA	80.5 MW
Lake Bonney 2	SA	159 MW
Lake Bonney 3	SA	39 MW
Mt Millar	SA	70 MW
North Brown Hill	SA	132.3 MW
Snowtown North	SA	144 MW
Snowtown South	SA	126 MW
Snowtown	SA	99 MW
Starfish Hill	SA	34.5 MW
Waterloo	SA	111 MW
Wattle Point	SA	90.75 MW
Musselroe	Tas	168 MW
Woolnorth Studland Bay	Tas	140 MW
Challicum Hills	Vic	52.5 MW
Macarthur	Vic	420 MW
Mortons Lane	Vic	20 MW
Mt Mercer	Vic	131 MW
Oaklands Hill	Vic	67 MW
Portland	Vic	148 MW
Waubra	Vic	192 MW
Yambuk	Vic	30 MW
Bald Hills	Vic	106.6 MW
Albany	WA	21.6 MW
Alinta (Walkaway)	WA	89.1 MW
Collgar	WA	206 MW
Emu Downs	WA	80 MW
Mumbida	WA	55 MW

*Source: AEMO Registered Generators list (21 August 2015): IMO Facility Information; AEMO Transmission Loss Factors 2015-16; IMO Transmission Loss Factors 2015-16

5.2 Methodology

AECOM has evaluated the relative financial viability of each co-location opportunity using high-level indicators of potential revenue and project cost. The indicators are summarised in Table 9 below.

Table 9 Indicators of solar farm financial viability

Revenue indicators	Cost indicators
Plant performance (MWh/MW_p) – based on historical irradiation, temperature and latitude	Remoteness index
Marginal Loss Factor	Known development constraints (e.g. heritage listed areas, National Parks)
Historical wholesale market price (state-based)	Economies of scale

The indicators were selected based on access to data, replicability across all sites, and their materiality. Each of the revenue indicators were combined to form a *Revenue Index* and, similarly, each of the cost indicators were combined to form a *Cost Index*. The two indexes were then combined using a scaling factor, which was sized to balance the two indexes, and results in a *Combined Index*. The *Combined Index* directly translates into a relatively ranking of the financial viability of co-location opportunity at each wind farm listed in .

$$\text{Combined Index} = \text{Revenue Index} - (\text{Cost Index} \times \text{Scaling Factor})$$

5.2.1 Revenue Index

The *Revenue Index* represents the relative revenue which might be expected from each proposed solar farm relative to a generic solar farm.

The *Revenue Index* is essentially a function of two factors: output and price. The average pricing is taken from historical spot market prices and is considered a proxy for PPA prices that a wind farm generator might receive. We note that this may be different in reality as the average pricing may not be achievable with PPA's. Average pricing is used in lieu of actual PPA prices due to lack of available data due to commercial confidential information. AECOM has estimated the output of each solar farm as a function of Global Tilted Irradiance (GTI), average temperature and Marginal Loss Factor (MLF). GTI was derived from Global Horizontal Irradiation (GHI) data using an empirical relationship with latitude, derived from a series of PVsyst simulations for several locations. It was assumed that GTI scales linearly with plant output. Similarly, average ambient temperature reduces revenue by approximately 0.5 per cent per degree Celsius.

MLF has been assumed to be equal to the existing MLF for each wind farm. AECOM notes that MLF is subject to change annually as the power system changes. In addition, installing a large generation facility will reduce the observed MLF in an area.

The formula for *Revenue index* is provided below.

$$\text{Revenue index} = GTI \times [1 - (T_{amb\_avg} - T_{ref}) \times 0.5]/100 \times MLF$$

Where:

GTI = *Global Tilted Irradiance*

T_{amb_avg} = *average ambient temperature of site*

T_{ref} = *generic site average ambient temperature 20°C*

MLF = *Marginal Loss Factor*

More detail on the data sources is provided in Appendix A.

5.2.2 Cost index

The *Cost Index* represents the relative levelised cost of each proposed solar farm relative to a generic solar farm. The cost savings from co-location are assumed to be uniform across all sites, and have consequently been disregarded in this analysis.

The cost of constructing a solar farm is very difficult to predict using a generic formula. Nonetheless, AECOM has attempted to project cost estimates by considering the impact of the site's remoteness, potential development hurdles, and the size of the hypothetical plant.

For estimating the cost of remoteness, AECOM used the ABS classifications of remoteness index, and estimated the cost impact using our experience and industry knowledge of existing solar farm costs. Estimating the cost impact of remoteness on each cost component (including equipment supply, construction and operational costs), AECOM developed the following relationship between remoteness and cost.

Table 10 Impact of remoteness of the levelised cost of solar farms

Remoteness Index (as per ABS)	Cost premium
Inner regional Australia	0%
Outer regional Australia	8%
Remote Australia	14%
Very remote Australia	20%

To identify potential development hurdles, AECOM has used the Collaborative Australian Protected Area Database (CAPAD) to complete a preliminary check for potential constraints such as National Park, Conservation Covenant, and Indigenous Protected Areas within the proposed development area. While it is not possible to immediately determine materiality of these constraints on a proposed project, AECOM has elected to impose a 2 per cent cost premium if these constraints are observed in the development area. This cost premium is caused by increased development costs through the associated additional environmental studies, stakeholder negotiations and approval processes. This increase in development costs also captures compliance costs associated with construction and monitoring when protected areas are either on-site or adjacent to the generating asset.

AECOM has also applied an economies-of-scale benefit for locations that have more potential to host larger solar farms. Using the results of the sizing analysis from Section 3.0, AECOM has applied the following cost savings.

Table 11 Cost savings associated with economies of scale

Solar farm size	Cost savings
Smaller than 25 MW	0%
25 MW to 50 MW	2.5%
Larger than 50 MW	5.0%

More detail on the data sources is provided in Appendix A.

5.2.3 Combined Index

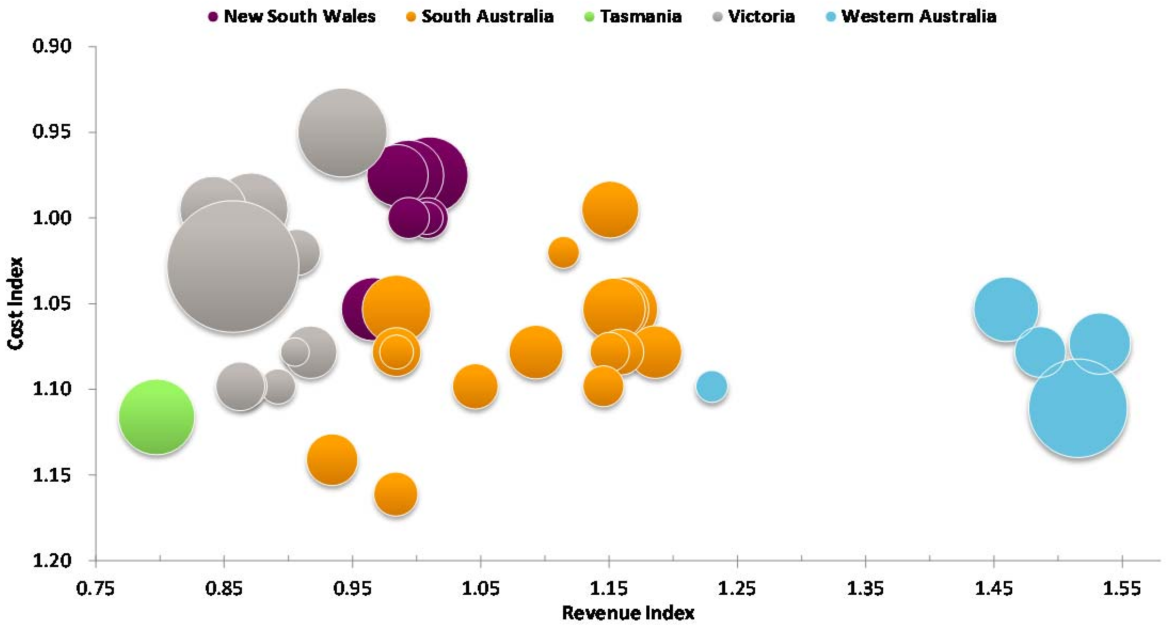
Currently, with solar projects, the present value of costs exceeds the present value of revenue. Consequently, AECOM has scaled-up the cost index by 20 per cent, which is reflective of the imbalance between cost and revenue (as per AECOM's experience with favourable co-location projects).

After the imbalance has been accounted for, the C*ost Index* was combined with the *Revenue Index* to arrive at a final score for each lot.

5.3 Results

The results are represented in Figure 57, where the relative cost and revenue indexes are graphed on separate axes. On this chart, it is preferable to have a low cost index and a high revenue index – this corresponds to the top right hand corner of the chart. Figure 57 highlights a large revenue advantage for the Western Australian sites compared to other states (this is indicative of higher wholesale prices observed recently in WA, combined with a strong solar resource). It also highlights the much larger spread in revenue relative to cost. Note that the size of each bubble represents the potential size of a co-located solar plant. The ratings of each wind farm are shown in Appendix c where the combined index is presented.

Figure 57 Graphical representation of cost and revenue indexes for each wind farm; bubble size equates to potential size of a co-located solar plant for each analysed wind farm



Source: AECOM (using publically available data such as wholesale prices, wind /solar data, GIS data)

It is clear that the Western Australian wind farms appear more attractive than NEM-connected wind farms. This can be attributed to their superior revenue inputs, which is due to both a superior solar resource and substantially higher wholesale market prices (measured over only 12 months, ending August 2015). The next best performing sites are based in South Australia. Once again, the high ratings are attributable to the high solar resource as well as higher wholesale market prices than other NEM states. The ranking of sites within each state are differentiated by small differences in both the revenue and cost indexes. NSW is the next best performing state, followed by Victoria and Tasmania, due to the progressively poorer solar resource in these states.

While this ranking process provides some insight into the economics of co-location, there are many limitations to this analysis, which are detailed in Section 5.4.

5.4 Evaluation limitations

This ranking exercise is intended to identify potential project sites. However, the methodology has its limitations that include:

- *Limitations of scope;* many factors have not been considered due to data availability and practicality of incorporating into the analysis. An example of this is that there is no GIS data to represent vegetation density and site specific environmental constraints (which increases development and construction costs). Other areas include community issues which may increase development costs or completely rule out an area for development, localised terrain which may either impact shading and thus generation potential or increase construction costs due to site specific complexities. As such, this could not be incorporated into the analysis.
- Wholesale electricity prices have largely influenced the evaluation results; wholesale revenue is only based on current market prices. Wholesale market prices are inherently volatile and subject to significant change, particularly as developers respond to price signals.
- *Data accuracy;* while AECOM has completed high level “sense-checks” on the GIS data, no robust verification has been completed and it will inevitably contain some inaccuracies. In addition, approximations have been made, such as the incorporation of MLF. In addition AECOM has located the connection points manually to determine substation locations and hence this is subject to human error but is a best estimate based on the lack of public information in this regard.

- *Fields output interpretation;* there are limitations in the ability to meaningfully interpret GIS data in relation to the lot. For example, within a lot there can be a mixture of suitable land and unsuitable land. The location / distribution of these subsets across the lot can materially impact whether the site is usable. The GIS tabular output is limited to noting the presence of say high gradient, regulated vegetation, water bodies on the lot but the spatial distribution is not ascertainable without manual review.
- *Connection capability and grid constraints;* the ranking has been completed with the assumption that the capacity to connect is equal to the current capacity of the wind farm, this is a generalisation to allow a comparison across sites to be made. Grid constraints and limitations or alternatively availability is site specific information such as the age and capacity of assets, which can only be known through formal discussions with network service providers or discussing directly with generator owners.
- The cost breakdown and impact should not be used for project costing exercises. These considerations were used to relate constructability and maintainability factors, not to arrive at a project cost.
- The above analysis has limited ability to consider the availability and appropriateness of the adjacent land for installing a solar farm. Therefore, it is essential to investigate each site on an individual basis.

5.5 Other considerations

5.5.1 Land suitability

AECOM has investigated the suitability of the land adjacent to existing wind farm connections. This investigation utilised high level GIS information to review potential limitations of the adjacent land for the development of solar PV projects. Appendix a provides an overview of the constraints used and the source data.

AECOM notes that these maps are indicative tools only and should only be used for high-level analysis. Each site will inevitably have its own characteristics that need to be considered through more detailed research and analysis.

The GIS maps serve two purposes:

1) Highlighting land that is potentially suitable for solar using a single GIS layer

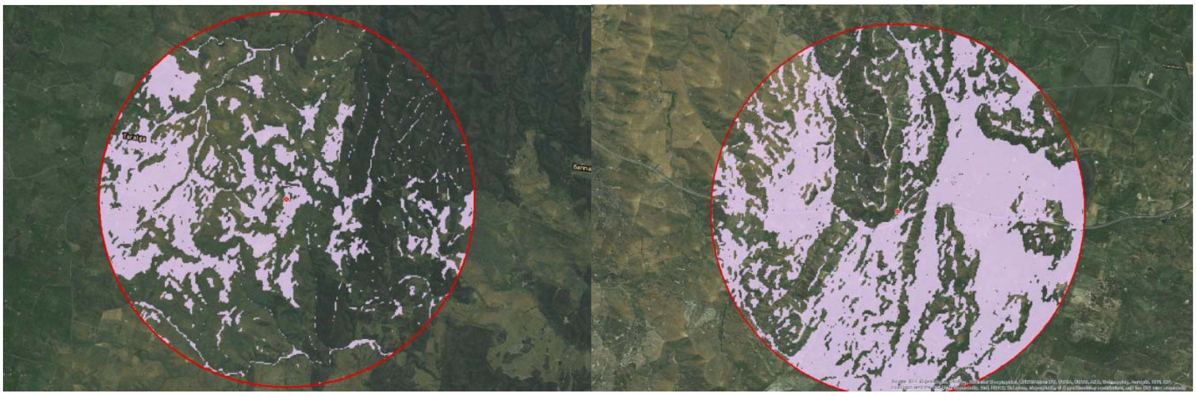
   The suitable land includes areas within a 5km radius of the connection point. It excludes any land deemed too steep (i.e. greater than 5 per cent North, or 4 per cent in other aspects), or land with heritage or national park constraints.

2) Quick reference of site characteristics

   Site characteristics include wind farm details (location, capacity, MLF etc.), and the proposed solar farm characteristics such as sizing (as per Section 3.0), size of suitable land (hectares), cost and revenue indexes, rank and data that informed the ranking process (e.g. remoteness index, potential development constraints etc.).

Wind farms are often located on ridge lines (particularly in-land wind farms), which may be unsuitable for solar due to the steep terrain. An example of the GIS map's depiction of suitable land is provided for two wind farm sites below. The shaded area indicates potentially suitable land within a 5km radius of the wind farm's connection point. In the first example (Taralga), the total suitable area is likely to be easily sufficient to install a solar farm (1904m^2 total suitable land), however the suitable land is very disperse, leaving minimal options for site selection of a continuous land. Conversely, the Cullerin Range site has much more land that appears suitable for solar.

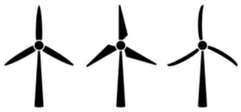
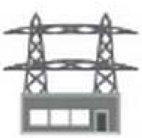
Figure 58 Example ranking results for Taralga (left) and Cullerin Range (right) wind farms (available solar farm area is shaded)



5.5.2 Grid connection options

When co-locating wind and solar generation plant, multiple connection permutations can be considered. These include connecting the solar PV plant to wind turbine strings, or connecting at the substation. Table 12 provides a summary of these options, including the respective advantages and disadvantages. Generally for solar farms in Australia AECOM is of the opinion that Option 3 (substation connection) is the preferred option.

Table 12 Grid connection options for co-location of solar PV with existing wind farms.

	1	2	3 (PREFERRED OPTION)	4
Electrical inter-connection options				
	Wind turbines (11-33 kV)	Distribution level (11-33 kV)	Substation (11-132 kV)	Transmission level (>132 kV)
Connection Option Description	Multiple "smaller" distributed generation units spread out throughout the wind farm connected through a combined stringing configuration.	Larger units to connect into surrounding MV distribution grid through a separate connection.	Connecting into a combined solar and wind substation.	Connecting into a combined solar and wind substation at the transmission level HV.
Typical solar system size	 1-3 MW	 5 – 15 MW	 > 10 MW	 > 50 MW
Advantages	- Use of existing reticulation of the wind farm - use of existing transformers for solar and wind stringing.	- Use of existing reticulation - Flexibility on system location - ease of connection	- use of existing substation of the wind farm - Potential for large solar farm connection - Simple metering arrangement possible - Separate ownerships for the	- see option 3 - Suitable for large (>50mw) solar farms

	1	2	3 (PREFERRED OPTION)	4
			two plants can be structured through shared infrastructure agreements - Clear separation of connection points	
Dis-advantages	- Multiple landowners - Possibly higher probability of curtailment - Likely higher costs for installation - Challenging metering arrangement required - Possible impact on cross warranties of existing reticulation and assets - Difficult to enable separate ownerships structure for the two plants.	- Reticulation may be at capacity - Limited by line capacity	- Restricted to land surrounding the substation - Substation may be at capacity - Addition mv lines may be required	- High substation cost and connection equipment required - Only suitable for large solar farms

6.0 Conclusion

This study is intended to aid developers and policy makers who are considering the merits of co-location of wind and solar generation assets. There are clearly a number of cost and time efficiencies associated with co-location. However, these efficiencies are highly site specific with multiple factors impacting the relative sizing of solar and wind plants, cost savings, and potential revenue. It is essential that developers consider the merits of each opportunity on a site-by-site basis.

Some of the study's key learnings are summarised below:

- **Cost savings:** Major savings can be obtained in the grid connection infrastructure and installation, operation and maintenance and development costs (including land costs, development approvals and studies). These savings are estimated at 3 to 13 % for CAPEX and 3 to 16 % for OPEX. Whilst each project should be evaluated on its own merits, the cost reduction opportunities (CAPEX and OPEX) will increase competitiveness of any project.
- **Prospective regions:** The greatest brownfield co-location opportunities are currently in Western Australia and South Australia, where there is good solar resource, complementary generation profiles, and more attractive wholesale market prices. The best greenfield opportunities for wind-solar co-location are found in Western Australia, South Australia and parts of Queensland (non-cyclonic).
- **Importance of network access;** Many of the greenfield sites are not close to the network, or are adjacent to weak parts of the network. While this creates a challenge for developers, there may be an opportunity for NSPs and policy makers to intervene by opening up regions of high natural wind and solar resource through new network assets.
- **Curtailment:** Using historical data, AECOM was able to demonstrate that for 10 existing wind farms, solar farms sized between 25 % and 49 % of the relevant wind farm's capacity would result in no more than 5 % curtailment.
- **Co-location potential:** The technical capacity of wind farms to accommodate co-located solar farms at existing wind farms is estimated at over 1 GW (without causing more than 5 % curtailment). Growth in renewables driven by the Large-scale Renewable Energy Target is expected to open up technical capacity for an additional 1.5 GW of solar PV to be co-located at new wind farms by 2020.
- **Firming effect:** Given the intermittent nature of renewable technologies, pairing resources in regions dominated by one particular technology will likely have a “firming” effect. This reduction in the overall facility's degree of intermittency results in an improved capacity factor at the connection point and can mitigate associated network constraints in regions dominated by a single generation type. Further firming in the future may also be achieved through the use of energy storage.

While AECOM is of the opinion that the solar co-location will not dramatically accelerate the uptake of solar or wind alone, we do believe it warrants greater attention as the cost of utility scale solar falls and we plan our future low carbon electricity system. As Australia strives to meet the Renewable Energy Target, AECOM expects that further regions will be developed which will also be suitable for co-location. In particular, policy makers may consider the potential to create renewable energy hubs, where various technologies are co-located to take advantage of potential cost reductions.

AECOM notes that each project should be analysed on its own merits and that the feasibility will highly depend on government policy as well as local site and market conditions (e.g. availability of offtake agreements). This study does demonstrate that co-location is worth the consideration of developers (both wind and solar) and existing wind farm owners/operators as there are some clear benefits to be gained.

Note that there are limitations in the high level nature of AECOM's analysis as pointed out throughout the report. Consequently AECOM strongly recommends that all future developments be assessed through a detailed project-specific feasibility study. Also, whilst this report highlights there is a high technical potential for the integration of solar on to existing and future wind farms, the viability of future projects will be dependent on future market conditions, including wholesale market prices, renewable energy policy, and renewable technology costs. AECOM has not attempted to forecast these factors and, as such, they have not been addressed in this report.

Appendix A

GIS Data Sources

Appendix A GIS Data Sources

This Appendix summarises the data sources used by AECOM in its GIS analysis.

Each wind farm's location represents the location of the substation that connects it to the transmission network. These substations were manually located using Google Earth, combined with Geoscience Australia's datasets for substation and transmission network location. This method is prone to human error and AECOM recommends that readers complete their own investigations.

AECOM selected the connection substation as a central point of reference as it was considered the most economic and technically appropriate place to connect a solar farm. In essence, the location of the wind turbines is not particularly relevant except for the potential shading impact; although AECOM acknowledges that different approaches to connection are possible.

AECOM set the wind farm registered capacity (sourced from either AEMO or IMO) as the transfer capacity at each wind farm's connection point. This is intended to be representative of both the existing network Connection Agreement as well as the technical capacity of the connection.

Marginal Loss Factors (MLF) were taken from AEMO and IMO's respective Transmission Loss Factors 2015-16 publications. It is noted that these are subject to future change as the energy system evolves. They are also subject to change following the installation of a solar farm. Nonetheless, the values are used in AECOM's analysis as the most appropriate proxy for future MLF.

A summary of each wind farm's location, transfer capacity and MLF is provided in Table 13 below.

Table 13 Summary of major wind farms in the NEM and SWIS (source: AEMO, IMO)

Wind farm	State	Capacity*	Latitude	Longitude	MLF
Boco Rock WF	NSW	113	-36.583	149.105	0.96
Capital WF	NSW	140	-35.187	149.524	0.97
Cullerin Range WF	NSW	30	-34.818	149.405	0.97
Gullen Range WF	NSW	166	-34.615	149.458	0.98
Gunning WF	NSW	47	-34.696	149.383	0.97
Taralga WF	NSW	107	-34.411	149.868	0.98
Woodlawn WF	NSW	48	-35.187	149.524	0.97
Bluff WF	SA	53	-33.349	138.750	0.98
Canunda WF	SA	46	-37.664	140.416	0.94
Cathedral Rocks WF	SA	66	-34.850	135.594	0.88
Clements Gap WF	SA	57	-33.508	138.131	0.97
Hallett WF (1)	SA	95	-33.349	138.750	0.98
Hallett WF (2)	SA	71	-33.309	138.727	0.98
Lake Bonney WF (1)	SA	81	-37.738	140.388	0.94
Lake Bonney WF (2)	SA	159	-37.738	140.388	0.94
Lake Bonney WF (3)	SA	39	-37.738	140.388	0.94
Mt Millar WF	SA	70	-33.625	136.704	0.90
North Brown Hill WF	SA	132	-33.309	138.727	0.98
Snowtown North WF	SA	99	-33.714	138.140	0.92
Snowtown South WF	SA	144	-33.714	138.140	0.98
Snowtown WF	SA	126	-33.830	138.118	0.98

Wind farm	State	Capacity*	Latitude	Longitude	MLF
Starfish Hill WF	SA	35	-35.604	138.159	1.01
Waterloo WF	SA	111	-34.002	138.911	0.98
Wattle Point WF	SA	91	-35.110	137.706	0.82
Musselroe WF	Tas	168	-40.781	148.011	0.90
Woolnorth Studland Bay	Tas	140	-40.719	144.698	0.89
Bald Hills WF	Vic	107	-38.756	145.974	0.98
Challicum Hills WF	Vic	53	-37.359	143.152	1.00
Macarthur WF (1)	Vic	420	-38.065	142.183	0.99
Mortons Lane WF	Vic	20	-37.836	142.466	1.03
Mt Mercer WF (1)	Vic	131	-37.832	143.888	1.00
Oaklands Hill WF	Vic	67	-37.681	142.552	1.03
Portland (Bridgewater) WF	Vic	58	-38.372	141.379	1.00
Portland (Cape Nelson) WF	Vic	44	-38.412	141.543	1.00
Waubra WF	Vic	192	-37.356	143.606	1.01
Yambuk WF	Vic	30	-38.307	142.012	1.03
Albany WF	WA	22	-34.976	117.832	0.98
Alinta (Walkaway) WF	WA	89	-28.923	114.928	0.94
Collgar WF	WA	206	-31.542	118.457	1.00
Emu Downs WF	WA	80	-30.488	115.377	1.01
Mumbida WF	WA	55	-28.992	114.960	0.96

*Source: AEMO Registered Generators list (21 August 2015): IMO Facility Information; AEMO Transmission Loss Factors 2015-16; IMO Transmission Loss Factors 2015-16

** MLF for Challicum Hills Wind Farm not found in AEMO data. The value has been estimated based on proximity to Oaklands Hill Wind Farm.

*** Portland Wind Farm is directly connected to an end user (Alcoa) – as such it does not have a MLF published by AEMO

The full list of data sets and sources used in the GIS analysis is provided in Table 14 below. It includes both public and user defined data sets.

Table 14 Data set summary

Data set	Source	Description	Criteria/use
Wind farm connection locations	Manually via Google Earth	Estimated location of substation where wind farms connect to the electricity grid	Identifying suitable land (potential sites are located within a 5km radius of the substation)
National transmission lines	2015, Geoscience Australia	Spatial location of all known high voltage electricity transmission lines what make up the electricity transmission networks within Australia	N/A
Global Horizontal Irradiation (GHI)	2015, Bureau of Meteorology (BOM)	Map of average conditions for Australia, 5km grids	N/A
Global Tilted Irradiation (GTI)	AECOM based on BOM GHI data	AECOM has estimated the GTI at each location based on an empirical formula derived from PVsyst analysis	Revenue index and greenfield prospecting heat maps.

Data set	Source	Description	Criteria/use
Ambient temperature	2015, Bureau of Meteorology	Map of average conditions for Australia, 2.5km grids	Revenue index
Wind resource	DNV GL	5 km mesoscale grid cell average wind speed at 100m hub height. This data was developed by DNV GL in a study for AREMI. AECOM has used draft data, which is believed to be suitably accurate for the high level purposes of this study. DNV GL provided this data with significant disclaimers, viewable on the AREMI website.	Used for greenfield prospecting heat maps.
Slope	2015, NASA SRTM elevation data	Slope is defined as increase or decrease in elevation over a distance. This provides a high level guidance to eliminate lower quality sites.	Filtering suitable land; if met slope is <5 per cent North or <4 per cent East/West/South
Remoteness index	2011, Australian Bureau of Statistics	The Remoteness Areas (RAs) divide Australia into broad geographic regions that share common characteristics of remoteness for statistical purposes	Cost index; more remote locations will be more expensive to build solar farms
Collaborate Australian Protected Area Database (CAPAD)	2014, Australian Government, Department of the Environment	State and territory protected areas such as heritage listed areas and National Parks	Cost index

Appendix B

Greenfield Co-Location Heat Maps

Appendix B Greenfield Co-Location Heat Maps (more detail)

Figure 59 Solar resource across Australia based on estimated capacity factor of greenfield sites

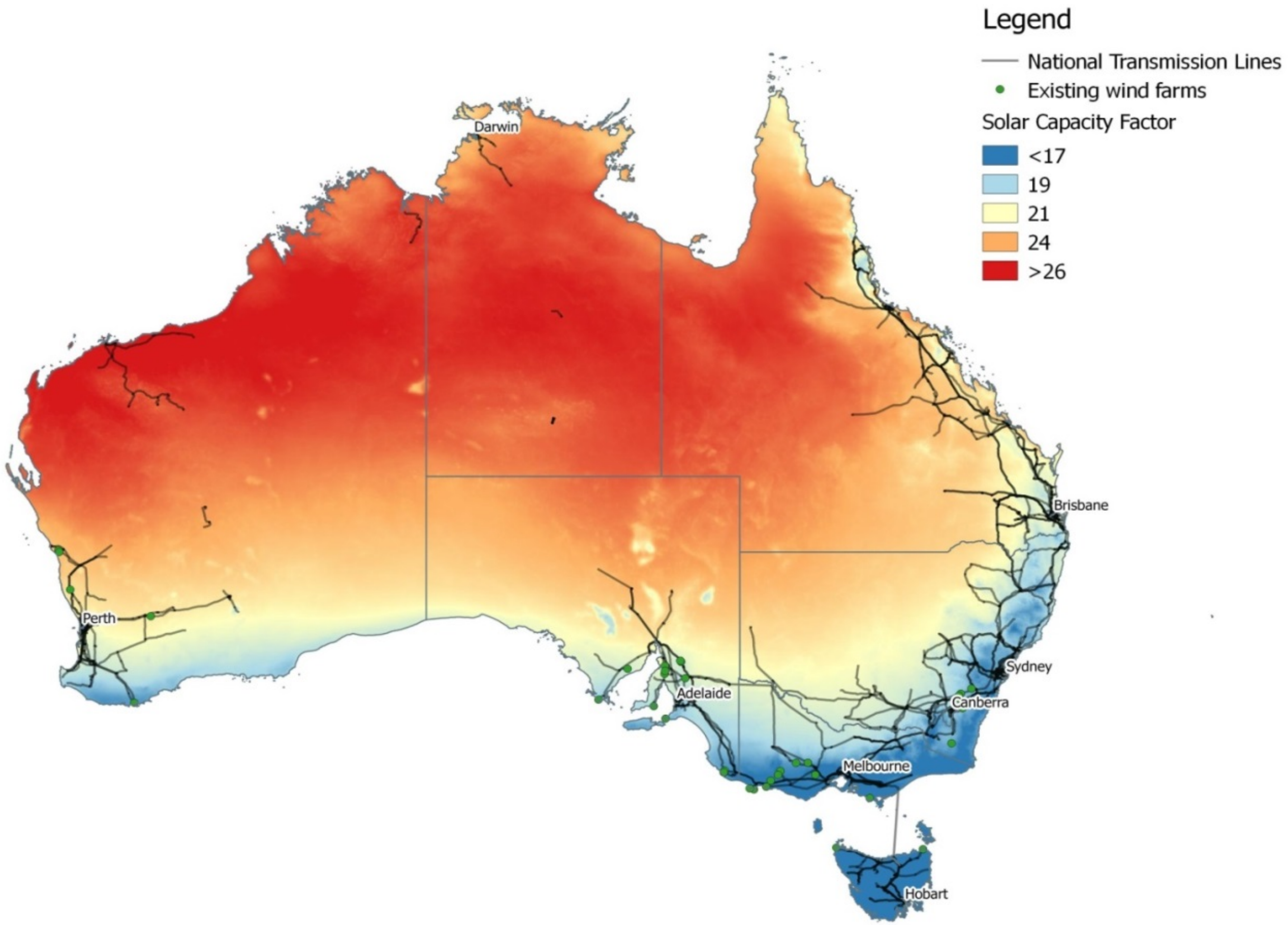


Figure 60 Wind resource across Australia based on estimated capacity factor of greenfield sites

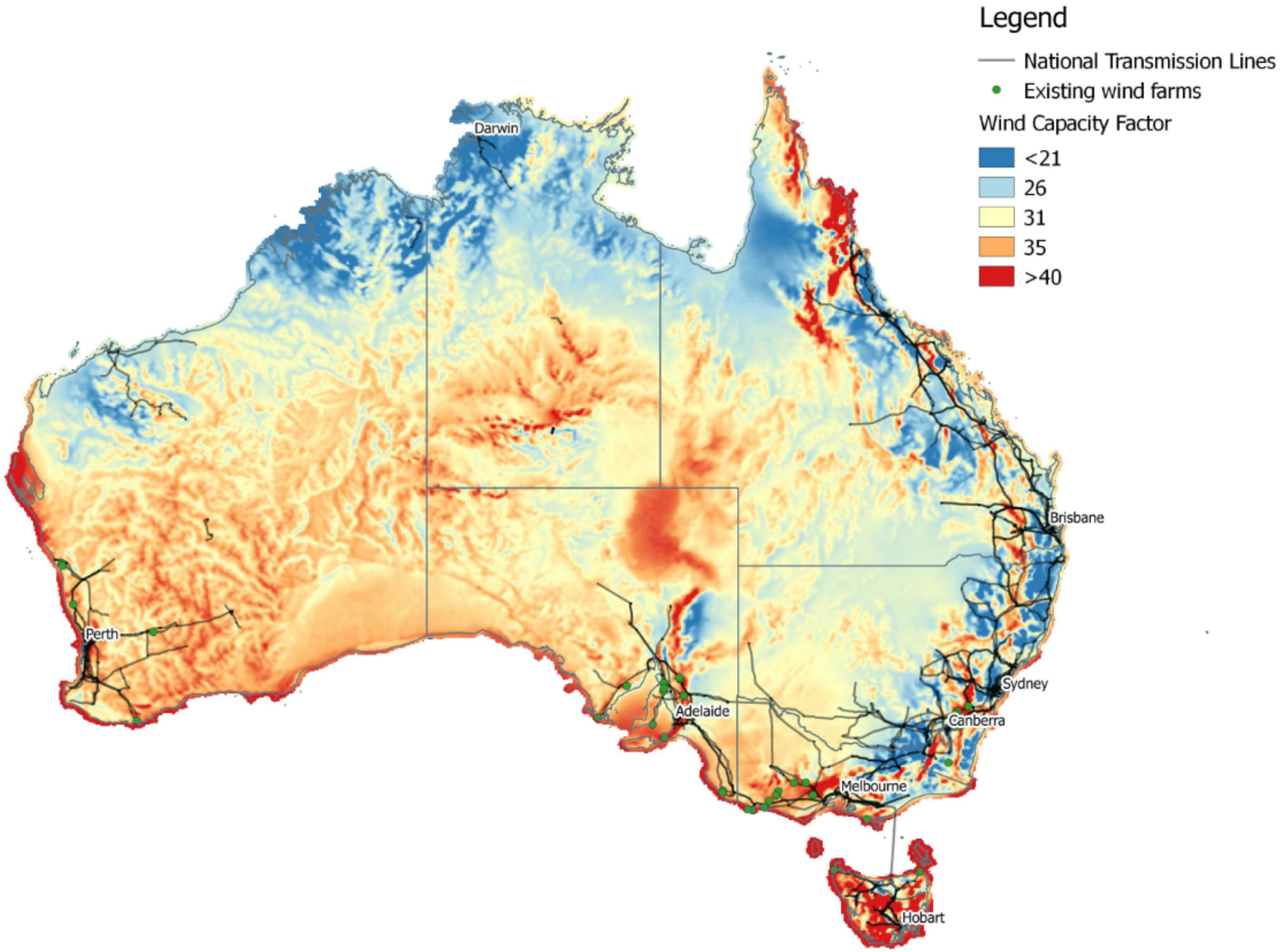


Figure 61 South eastern Australia: combined wind + solar capacity factor (Method 1; poor wind and poor solar resource locations removed)

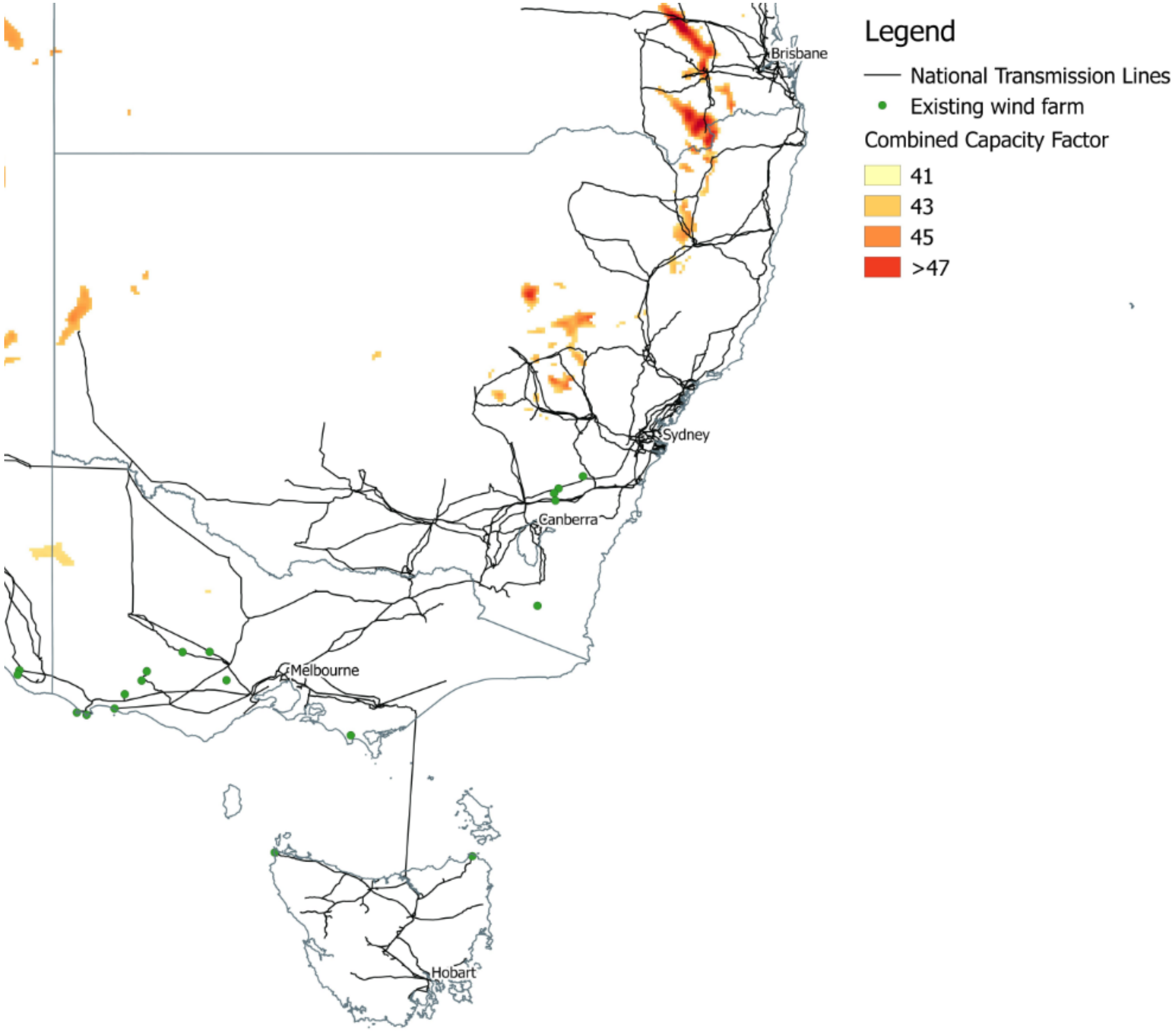


Figure 62 Queensland combined wind + solar capacity factor (Method 1; poor wind and poor solar resource locations removed)

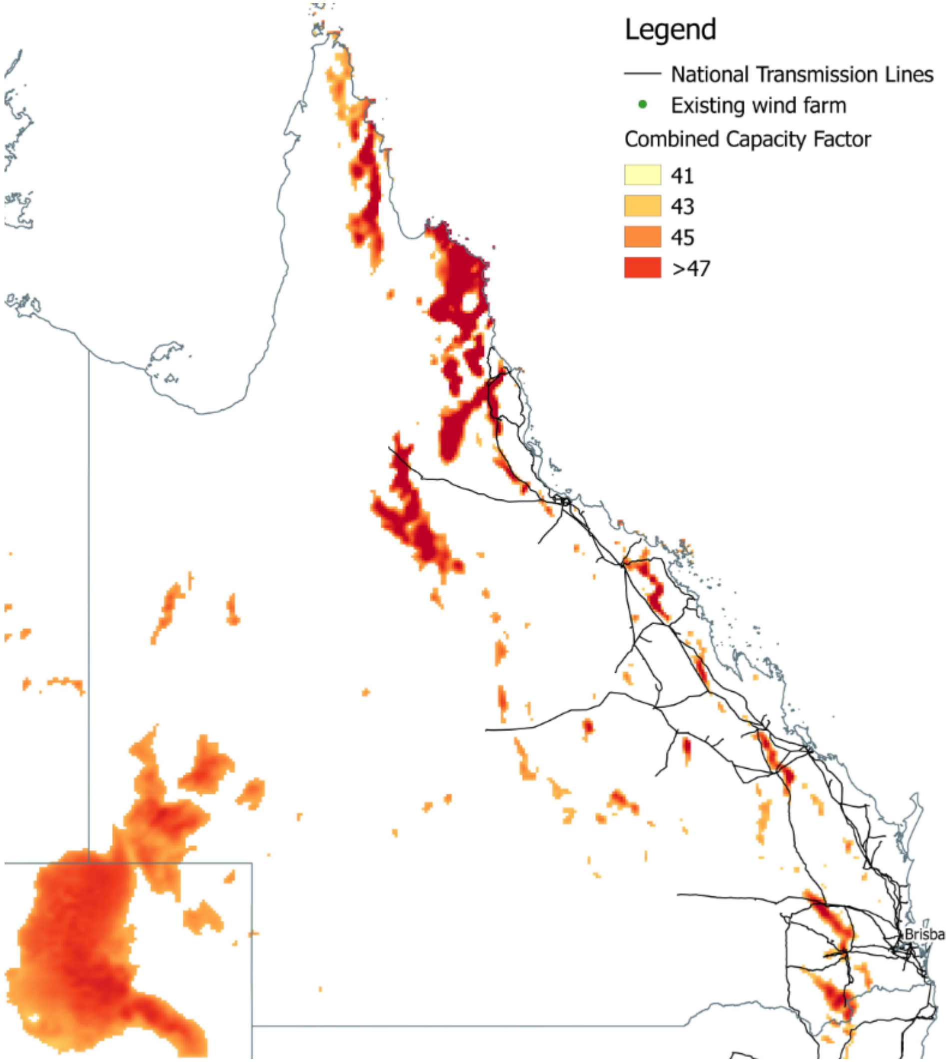


Figure 63 **South Australia combined wind + solar capacity factor (Method 1; poor wind and poor solar resource locations removed)**

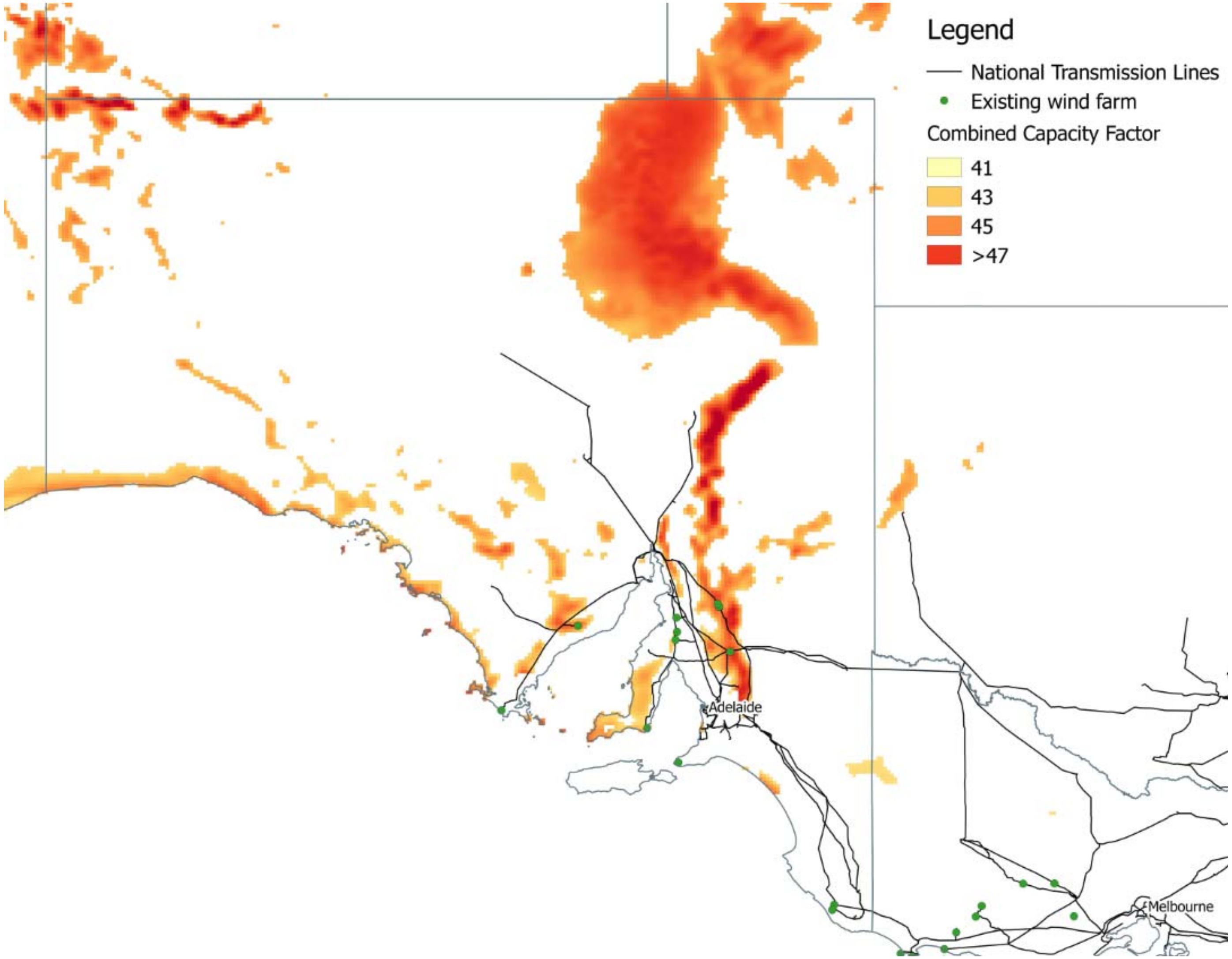


Figure 64 Western Australia combined wind + solar capacity factor (Method 1; poor wind and poor solar resource locations removed)

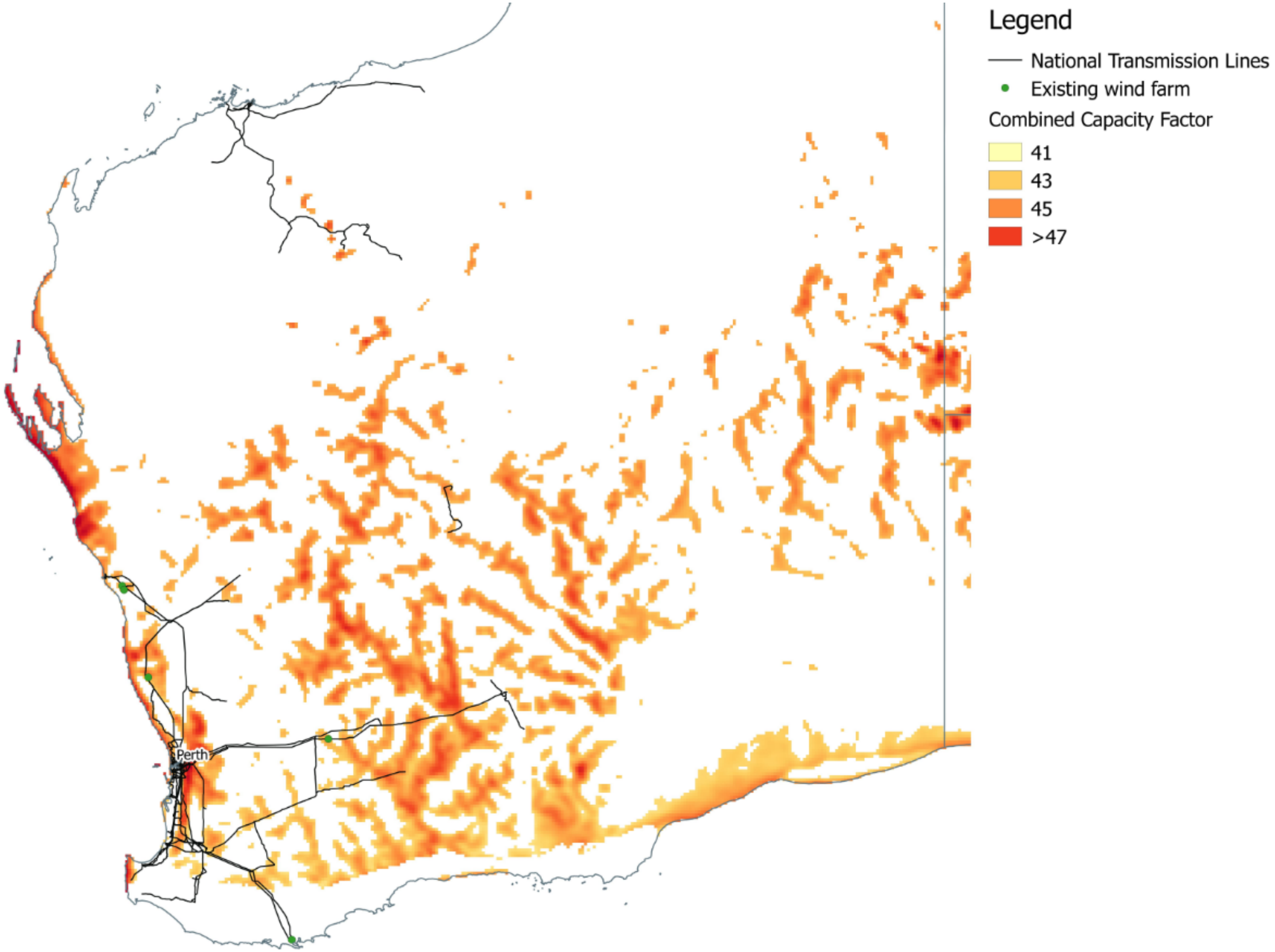


Figure 65 South eastern Australia solar capacity factor (Method 2; poor wind resource locations removed)

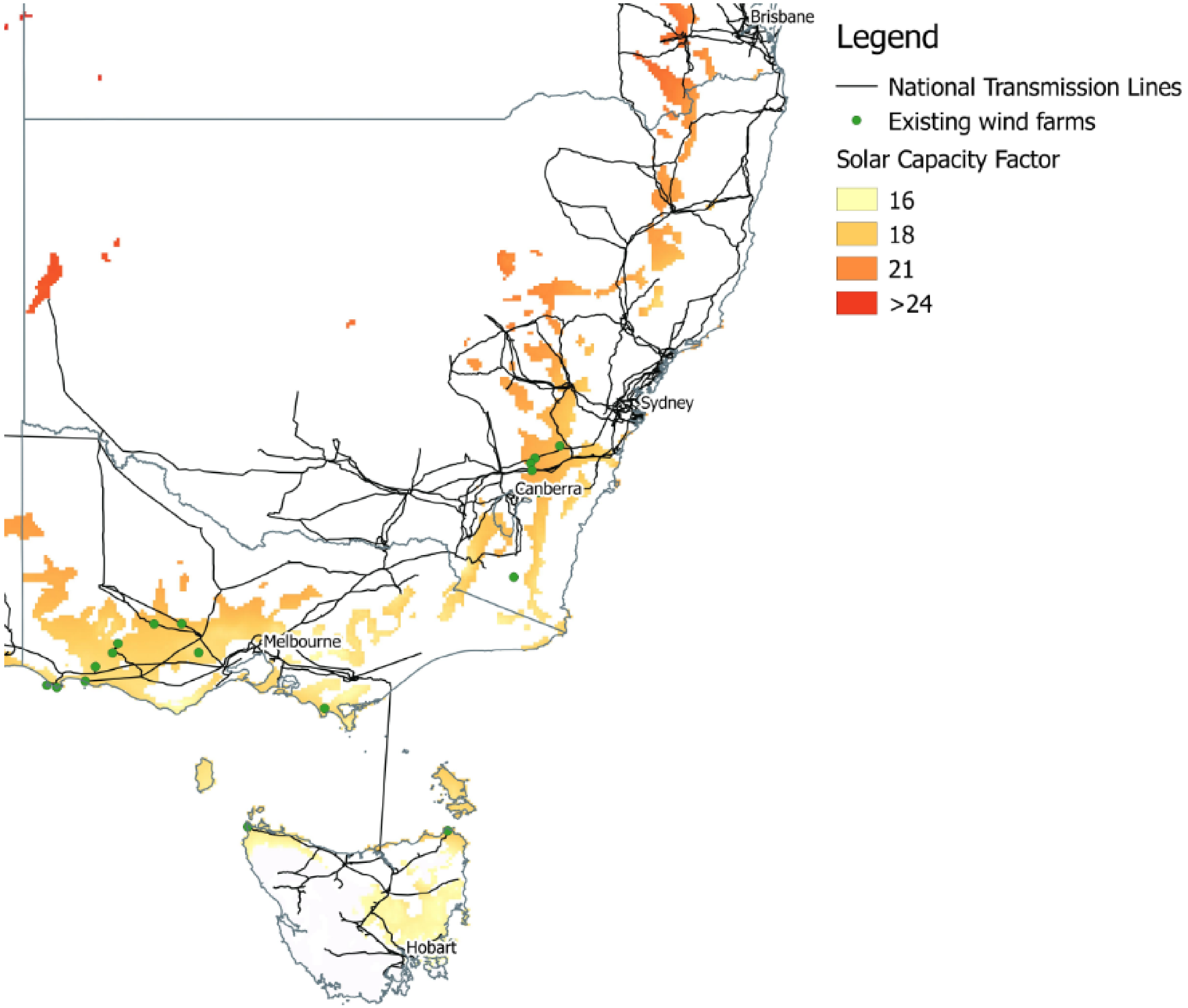


Figure 66 Queensland solar capacity factor (Method 2; poor wind resource locations removed)

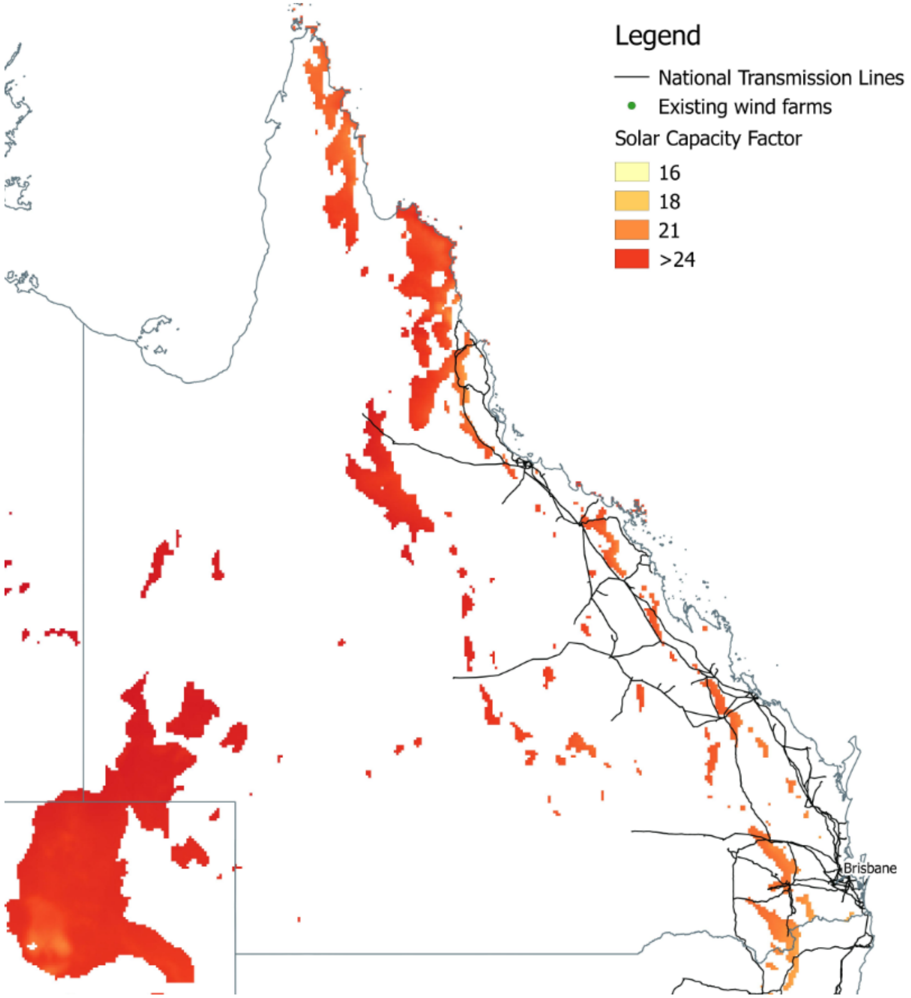


Figure 67 **South Australia solar capacity factor (Method 2; poor wind resource locations removed)**

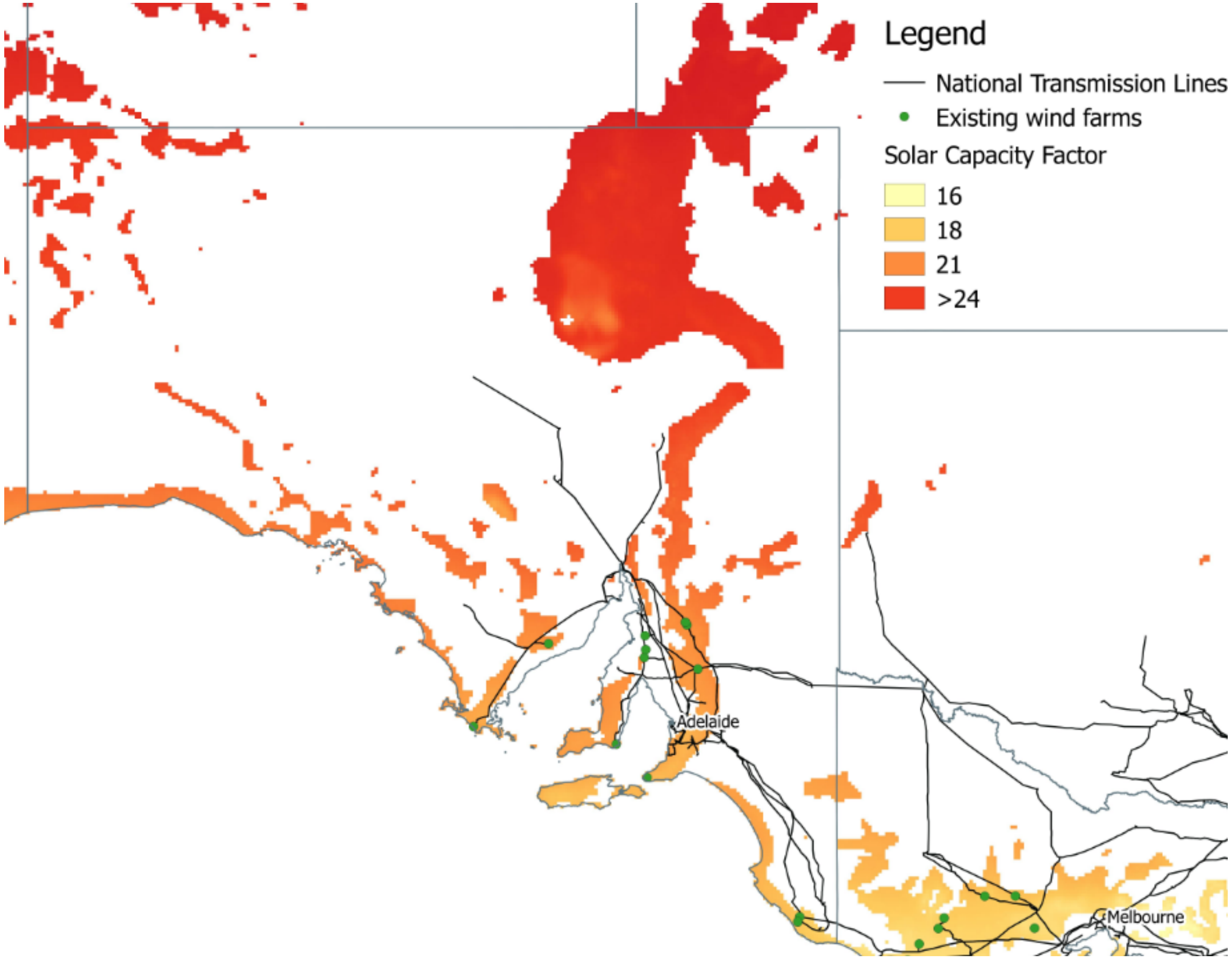
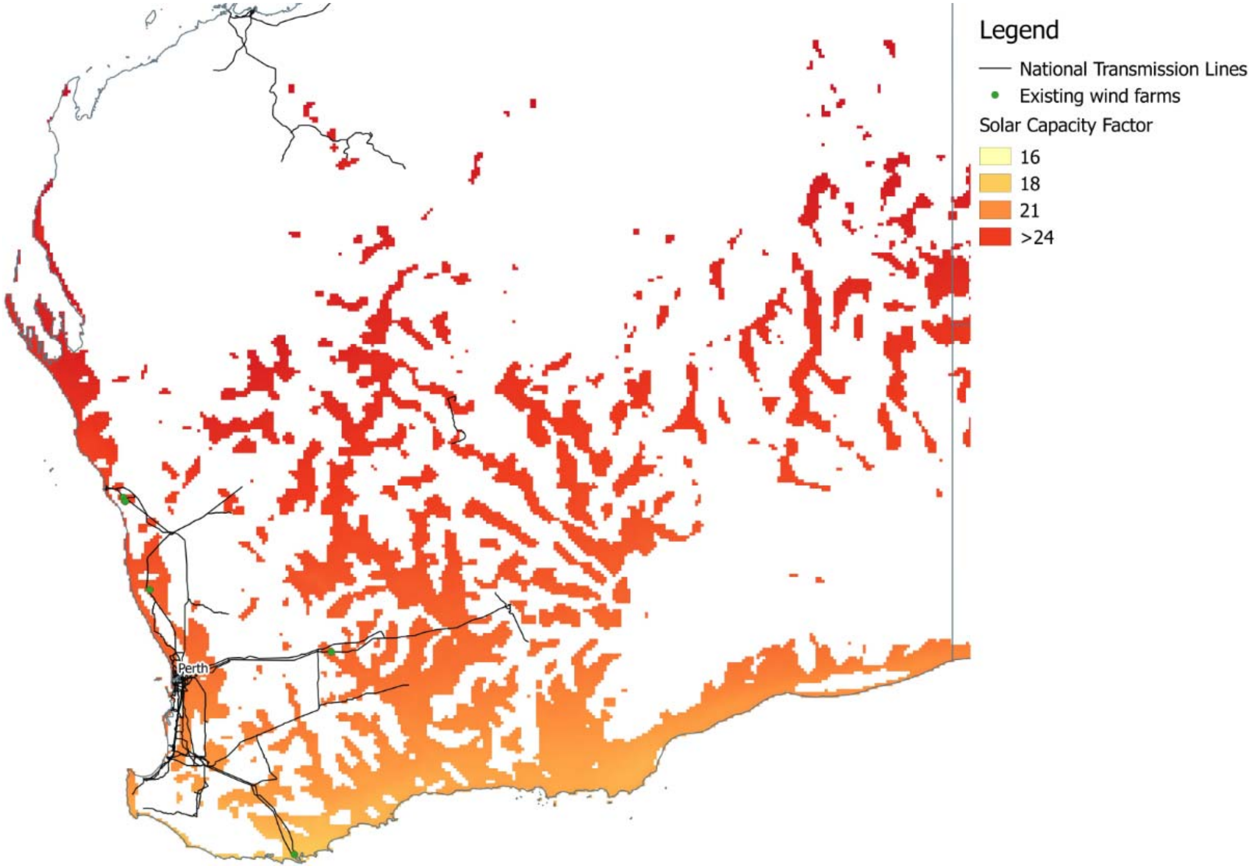


Figure 68 **Western Australia solar capacity factor (Method 2; poor wind resource locations removed)**



Appendix C

Ranked Existing Wind Farms

Appendix C Ranked Existing Wind Farms

The *Combined Index* was calculated for each of the largest wind farms in the NEM and SWIS resulting in a ranking of the relative financial performance of each co-location opportunity. A summary of the results is shown below.

Note that the indexes are calculated relative to a generic plant and the positive/negative outcome of the *Combined Index* is only intended to indicate relative financial performance (not absolute financial viability).

A positive or negative combined index does not indicate whether the project would be suitable or not. It should only be interpreted as a relative ranking of the suitability of the sites (subject to the limitations discussed in 5.4).

Table 15 Summary of co-location evaluation

Rank	Wind Farm	State	Revenue Index (rank)	Scaled Cost Index (rank)	Combined Index
1	Emu Downs	WA	1.53 (1)	-1.29 (21)	0.24
2	Alinta Walkaway	WA	1.46 (4)	-1.26 (15)	0.20
3	Mumbida	WA	1.49 (3)	-1.29 (22)	0.19
4	Collgar	WA	1.52 (2)	-1.33 (38)	0.18
5	Waterloo	SA	1.15 (11)	-1.19 (5)	-0.04
6	Albany	WA	1.23 (5)	-1.32 (32)	-0.09
7	Snowtown North	SA	1.16 (7)	-1.26 (15)	-0.10
8	Snowtown South	SA	1.16 (9)	-1.26 (15)	-0.11
9	Hallett 1	SA	1.19 (6)	-1.29 (22)	-0.11
10	Starfish Hill	SA	1.11 (14)	-1.22 (11)	-0.11
11	North Brown Hill	SA	1.15 (10)	-1.26 (15)	-0.11
12	Hallett 2	SA	1.16 (8)	-1.29 (22)	-0.13
13	Bluff	SA	1.15 (12)	-1.29 (22)	-0.14
14	Gullen Range	NSW	1.01 (17)	-1.17 (2)	-0.16
15	Clements Gap	SA	1.15 (13)	-1.32 (32)	-0.17
16	Capital	NSW	0.99 (20)	-1.17 (2)	-0.18
17	Taralga	NSW	0.99 (23)	-1.17 (2)	-0.18
18	Gunning	NSW	1.01 (18)	-1.2 (8)	-0.19
19	Cullerin Range	NSW	1.01 (19)	-1.2 (8)	-0.19
20	Waubra	Vic	0.94 (29)	-1.14 (1)	-0.20
21	Snowtown	SA	1.09 (15)	-1.29 (22)	-0.20
22	Woodlawn	NSW	0.99 (20)	-1.2 (8)	-0.21
23	Mt Millar	SA	1.05 (16)	-1.32 (32)	-0.27
24	Lake Bonney 2	SA	0.98 (24)	-1.26 (15)	-0.28
25	Boco Rock	NSW	0.97 (28)	-1.26 (15)	-0.30
26	Canunda	SA	0.99 (22)	-1.29 (22)	-0.31
27	Lake Bonney 1	SA	0.98 (24)	-1.29 (22)	-0.31
28	Lake Bonney 3	SA	0.98 (24)	-1.29 (22)	-0.31

Rank	Wind Farm	State	Revenue Index (rank)	Scaled Cost Index (rank)	Combined Index
29	Challicum Hills	Vic	0.91 (32)	-1.22 (11)	-0.32
30	Mt Mercer	Vic	0.87 (35)	-1.19 (5)	-0.32
31	Bald Hills	Vic	0.84 (40)	-1.19 (5)	-0.35
32	Oaklands Hill	Vic	0.92 (31)	-1.29 (22)	-0.38
33	Macarthur 1	Vic	0.86 (38)	-1.23 (13)	-0.38
34	Mortons Lane	Vic	0.91 (33)	-1.29 (22)	-0.39
35	Musselroe	Tas	0.84 (39)	-1.23 (13)	-0.39
36	Cathedral Rocks	SA	0.98 (27)	-1.39 (41)	-0.41
37	Yambuk	Vic	0.89 (34)	-1.32 (32)	-0.43
38	Wattle Point	SA	0.93 (30)	-1.37 (40)	-0.44
39	Portland Cape Nelson	Vic	0.87 (36)	-1.32 (32)	-0.45
40	Portland Bridgewater	Vic	0.86 (37)	-1.32 (32)	-0.46
41	Woolnorth Studland Bay	Tas	0.8 (41)	-1.34 (39)	-0.54

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