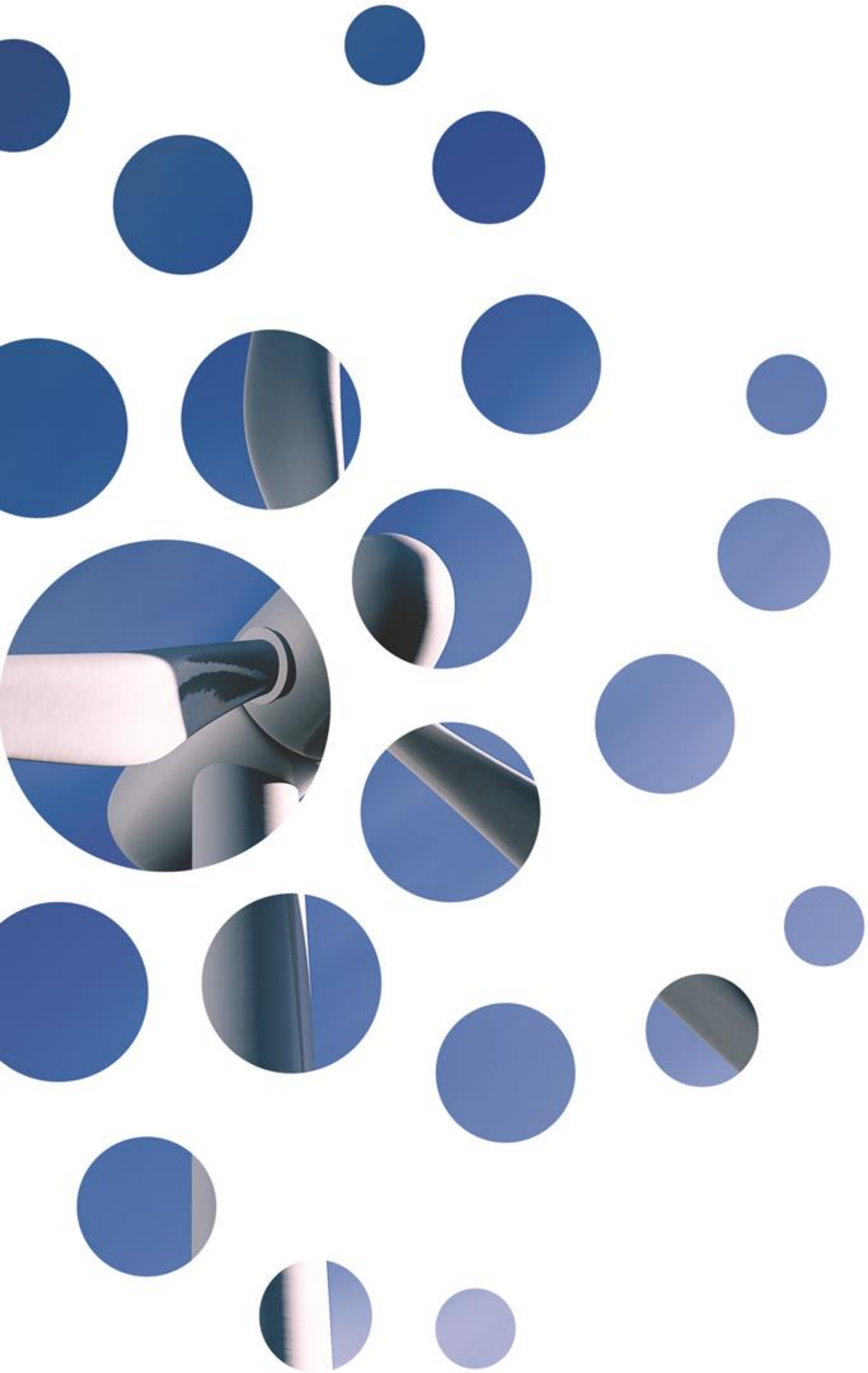

AWS TRUEPOWER

PREPARED FOR

ALBERTA ELECTRIC SYSTEM OPERATOR

WIND AND SOLAR ASSESSMENT

Alberta
Canada

13 June 2018

CLASSIFICATION

CLIENT'S DISCRETION

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463 NEW KARNER ROAD | ALBANY, NY 12205 | USA
www.awstruepower.com | contactus@awstruepower.com

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DOCUMENT CONTRIBUTORS

ANALYSTS	REPORT & REVIEW
Scott Haynes Senior Renewable Energy Analyst **Jeff Long** Senior Renewable Energy Analyst **Kate Rojowsky** Research Scientist	**Kate Morphis-Berg** Senior Project Manager **Peter Johnson** Project Manager **Victoria Alpaugh** Project Coordinator

DOCUMENT HISTORY

Issue	Date	Summary
A	06 April 2018	Draft Report
B	31 May 2018	Updated to Incorporate Additional Discussion
C	13 June 2018	Updated to Incorporate Additional Discussion

TABLE OF CONTENTS

1. INTRODUCTION

AWS Truepower, LLC (AWST), a UL Company, was retained by Alberta Electric System Operator (AESO) to assess the wind speed and solar resource intensity, expected capacity factors, correlations between production profiles and the levelized cost of energy for the province of Alberta, Canada. This report outlines the methodology and results of the study.

Modeled datasets were used to estimate the solar and wind resource magnitude and distribution across the province.

A GIS-based approach was taken to identify constraints and exclusion areas to determine which areas in the province would be suitable for future wind or solar development.

AESO identified 42 planning areas, which divide the province into development regions for wind and solar expansion. The energy capacity factor maps, based on the modeled resources, were utilized along with the constraint map layers to estimate the energy production potential for each planning area.

Finally, a correlation study was completed which compared the simulated wind and solar production timeseries prepared for each planning areas against the profile for each of the other areas, as well as comparing the wind and solar profiles for each planning area to each other.

An average levelized cost of energy (LCOE) value was also calculated for each planning area using the input from the resource analysis, constraints mapping and technology expected to be available and utilized in three future time periods. The inputs and LCOE estimates are presented under separate cover.

2. WIND AND SOLAR RESOURCE ASSESSMENT

2.1 Wind Resource Assessment

The wind resource was characterized at a height of 100 m above ground surface using data developed by AWST, at a spatial resolution of 200 m. These data were simulated using the MesoMap system.[1] The *MesoMap* system creates a wind resource map in several steps – first through running a mesoscale model, then using the mesoscale model results as input into a microscale model.

The mesoscale model used for this analysis was the Mesoscale Atmospheric Simulation System (MASS[2]), a weather model used in commercial and research applications. MASS was run in a series of nested grids, with the innermost grid having a spatial resolution of 1.2 km. Using regional weather data, MASS

[1] Available at https://dashboards.awstruepower.com/

[2] Developed for NASA, the US Air Force, and commercial and research applications, MASS is similar to and has been verified against other mesoscale weather models such as MM5 and WRF. For further information, see http://www.meso.com/mass.html.

simulated historical weather conditions for a representative sample of days. The MASS output was then coupled to WindMap – a mass-conserving model – which was run on a grid scale of 200 m.

AWST has developed a method of adjusting its wind maps using a wide array of wind resource measurements to ensure accuracy. The Alberta data was modeled as part of a larger effort to map the resource across all of Canada. The Canada map was validated using a total of 368 validation points, which consist of available publically available reference stations and proprietary tall tower datasets used with owner's permission. The estimated standard error of the wind speed maps is 0.35 m/s.

The wind resource map is shown in Figure 2.1 and the corresponding GIS files have been provided to AESO.

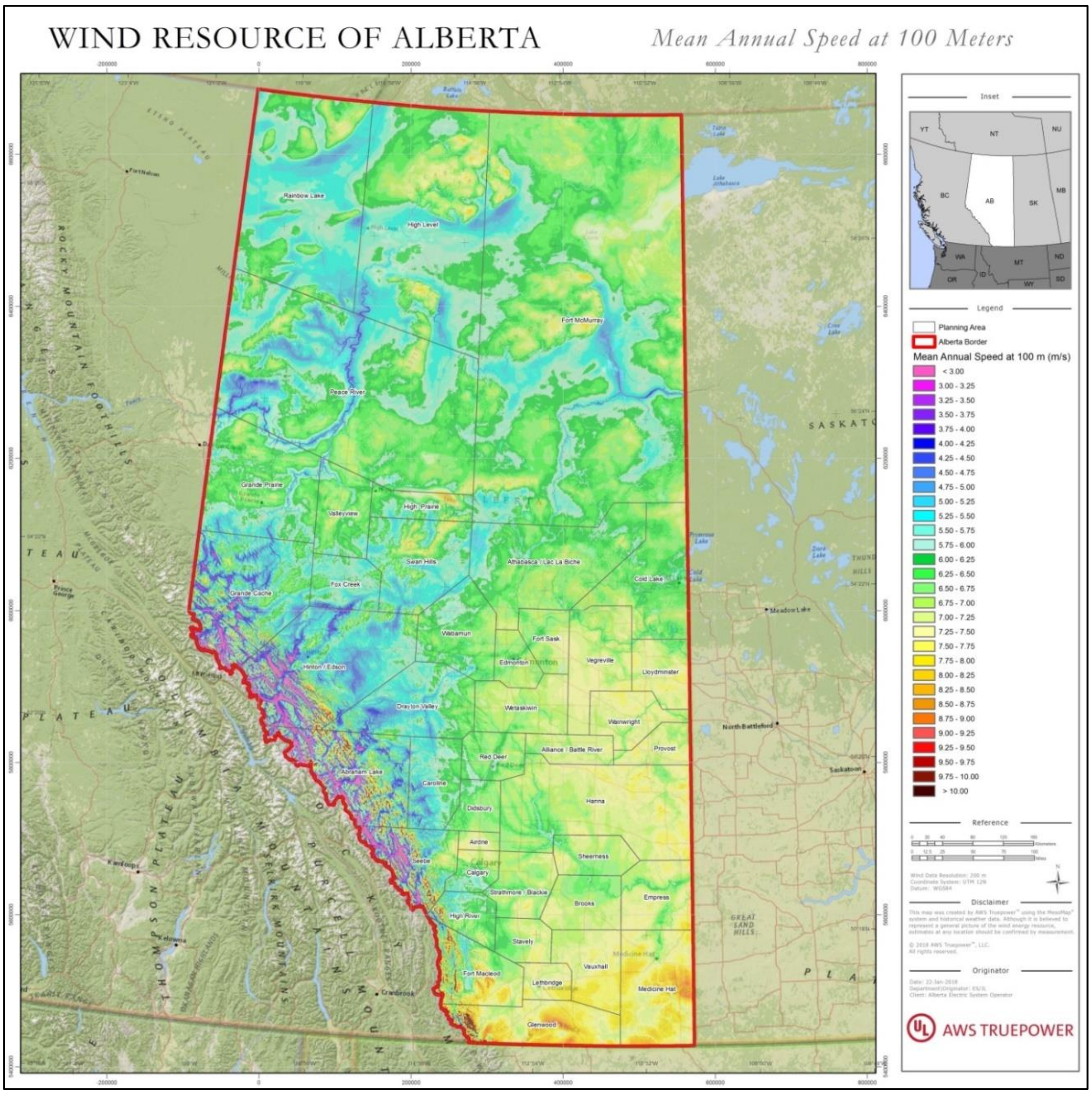

Figure 2.1: Wind Resource Map of Alberta

2.2 Solar Resource Assessment

For the solar resource map, the Physical Solar Model (PSM) dataset was used. PSM is a publicly-available solar data set provided by the National Renewable Energy Laboratory (NREL) as part of the National Solar Radiation Database (NSRDB). The data set features half-hour records at a spatial resolution of 4 km across the United States and Southern Canada, with a period of record from 1998-2016. The model estimates global horizontal irradiance (GHI), direct normal irradiance (DNI), diffuse horizontal irradiance (DHI), ambient temperature, and wind speed, and other parameters such as surface albedo. AWST expects this data set to have a long-term GHI uncertainty of approximately 6%.

The solar resource map is shown in Figure 1.2 and the corresponding GIS files have been provided to AESO.

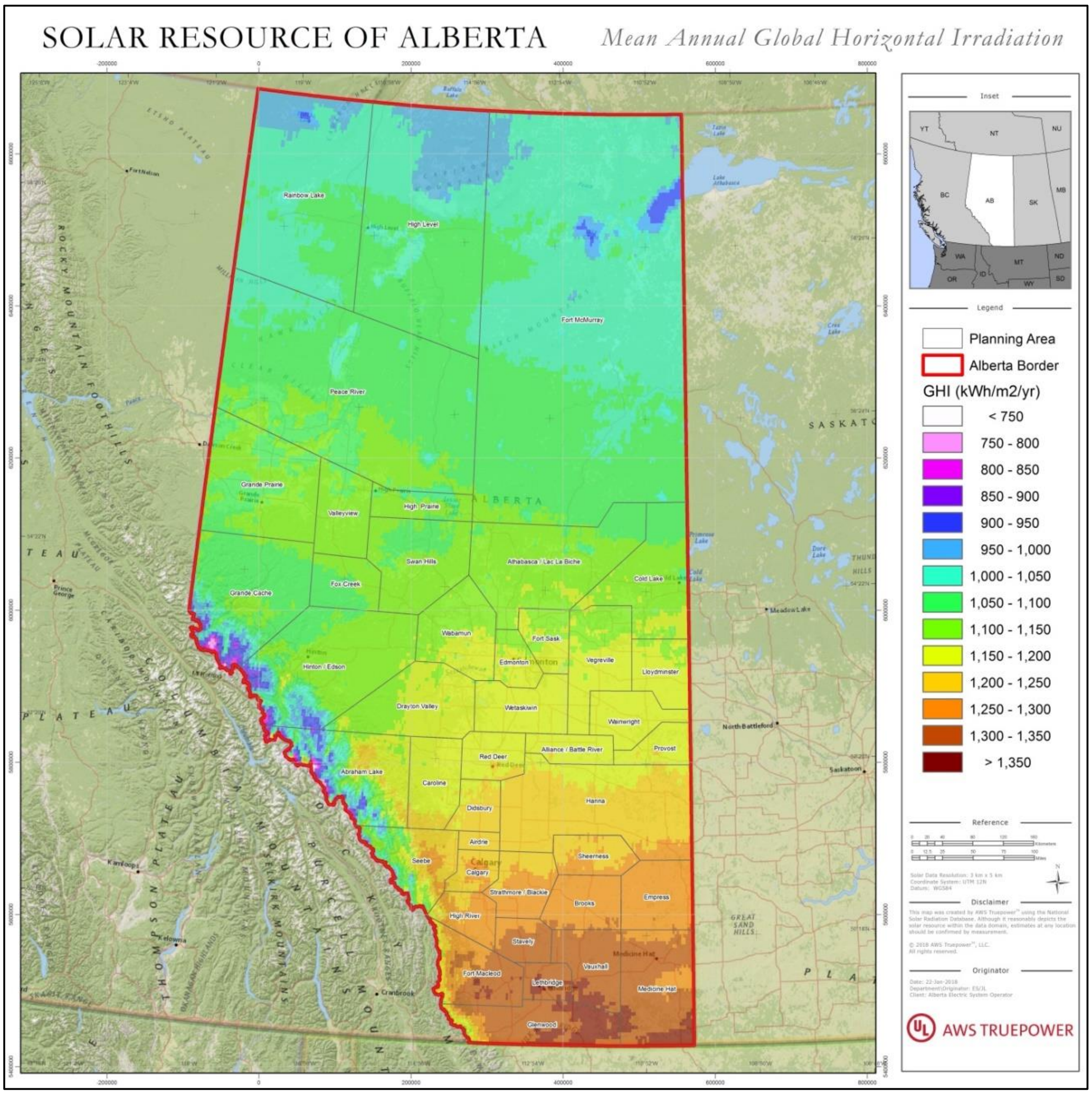

Figure 2.2: Solar Resource Map of Alberta

3. CONSTRAINTS AND EXCLUSIONS

3.1 GIS Constraints Mapping

A set of exclusions was defined where future wind and solar development would be effectively removed from consideration due to conflicting land uses, park designations, environmental restrictions and terrain slope.

For wind exclusions based on structure height of a turbine, a hub height of 100-m and a rotor diameter of 150-m were assumed, resulting in an exclusion distance of 175-m. The exclusion factors, together with buffer distances from the borders of the designated areas, are identified in Table 3.1. All exclusion areas are depicted in the map in Figure 3.1 for wind and Figure 3.2 for solar, and amount to 72.5% of the province's total area for wind and 69% of the province's total area for solar.

Table 3.1: Excluded Areas

Exclusion	Setback Distance - Wind	Setback Distance - Solar	Data Source
Caribou Range	175 m	100 m	Alberta Wildlife Directive[34]
Greater Sage Grouse Range	3200 m	3200 m	Alberta Wildlife Directive
Mountain Goat and Sheep Areas	175 m	100 m	Alberta Wildlife Directive
Piping Plover Waterbodies	200 m	200 m	Alberta Wildlife Directive
Trumpeter Swan Waterbodies & Watercourse	800 m	800 m	Alberta Wildlife Directive
Named Lakes	1000 m	1000 m	ESRI Database
Wetlands and Water Bodies	100 m	100 m	ESRI Database
Airports – Large	6,095 m	500 m	AESO[5]
Airports - Small / Medium	3,050 m	500 m	AESO
Wind Farms - Existing	2,000 m	500 m	Ventyx Database
Wind Farms - Proposed	2,000 m	500 m	Ventyx Database
Slope	> 15%	> 5%	DEM Data
Alberta Provincial Border	175 m	30 m	ESRI
Landmarks	500 m	30 m	ESRI
Railroads	175 m	30 m	ESRI
Roads - Major	175 m	30 m	ESRI
Transmission Lines	175 m	60 m	AESO
Urban Areas	500 m	30 m	Roughness of 0.5 & ESRI
Military Bases	175 m	30 m	AESO

[3] Wildlife Directive for Alberta Wind Energy Projects. AEP Fish and Wildlife 2016 No. 6. Fish and Wildlife Policy, Alberta Environment and Parks. April 7, 2017.

[4] Wildlife Directive for Alberta Solar Energy Projects. AEP Fish and Wildlife 2017 No. 5. Fish and Wildlife Policy, Alberta Environment and Parks. October 4, 2017.

[5] "AWS Truepower simulated historic renewable profiles", email communication, Adam Gaffney, 24 January 2018.

Exclusion	Setback Distance - Wind	Setback Distance - Solar	Data Source
Radar Stations	50 km	60 m	AESO
Ecological Reserves	175 m	30 m	AESO
Heritage Rangeland	175 m	30 m	AESO
National Parks	175 m	30 m	AESO
Natural Areas	175 m	30 m	AESO
Protected Areas	175 m	30 m	ESRI
Provincial Parks	175 m	30 m	AESO
Provincial Recreation Areas	175 m	30 m	AESO
Wildland Provincial Parks	175 m	30 m	AESO

The wind and solar exclusions are shown in Figures 3.1 and 3.2, overlaid on the wind and solar resource maps, respectively.

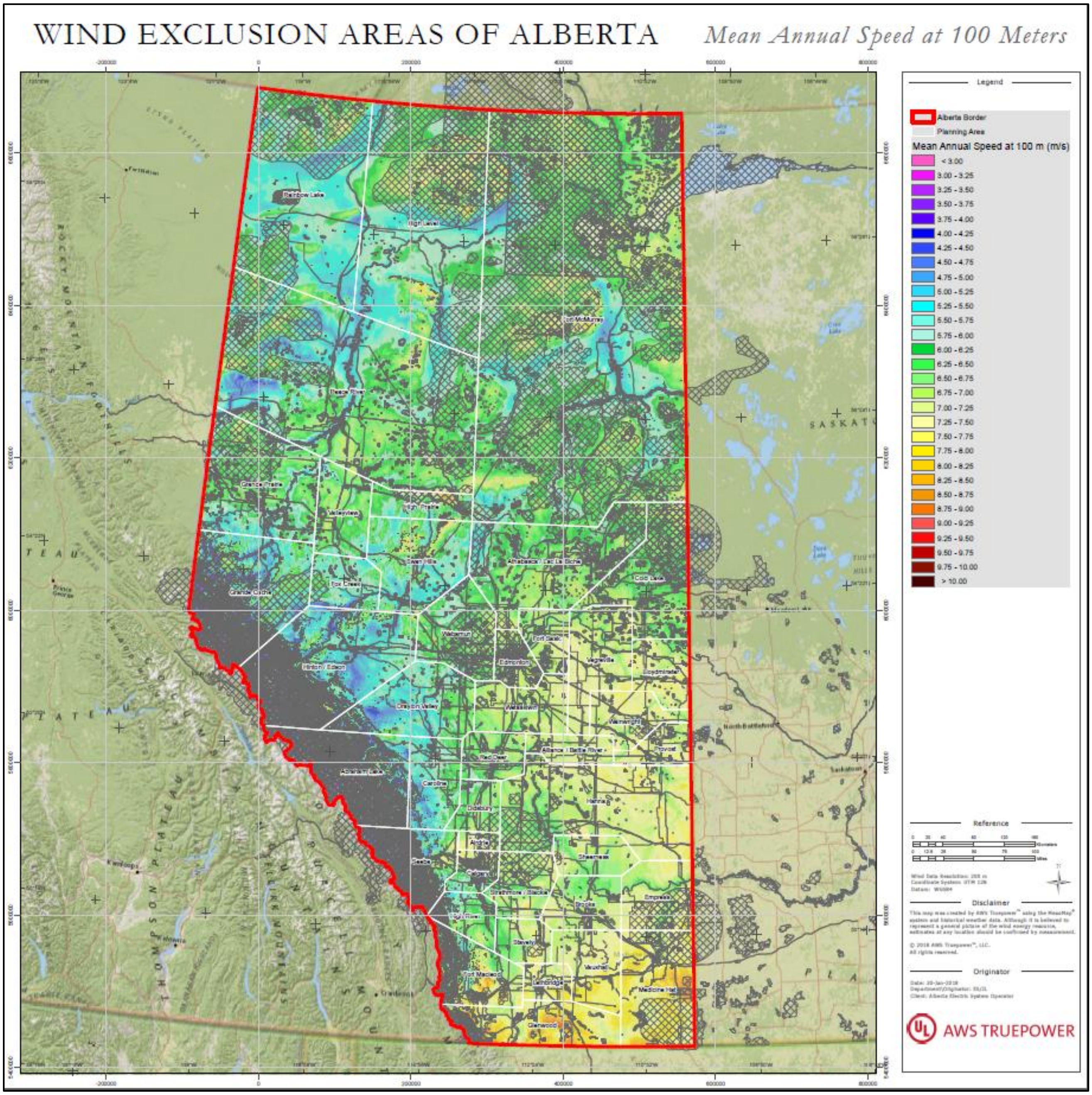

Figure 3.1: Exclusion Areas of Wind Development

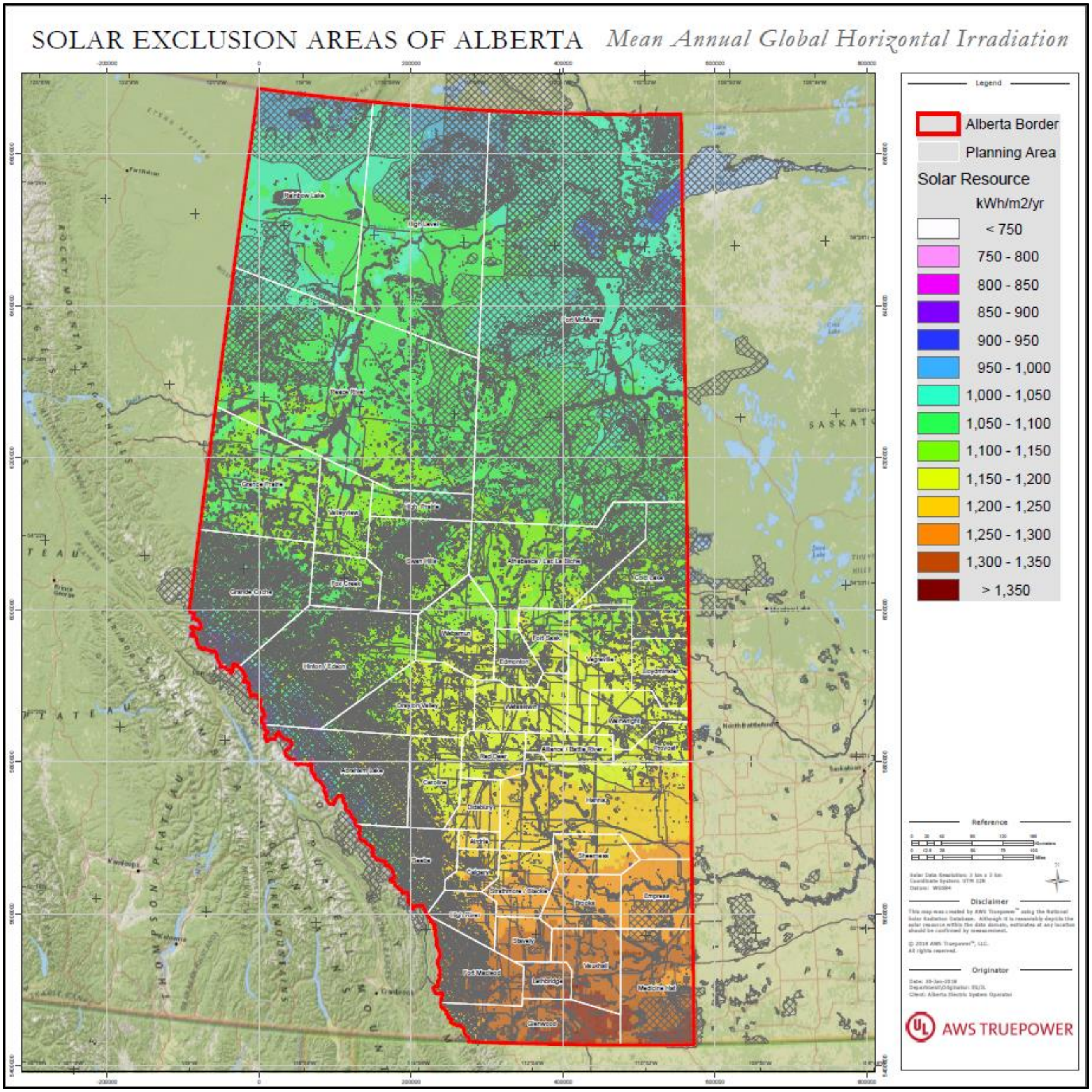

Figure 3.2: Exclusion Areas of Solar Development

3.2 Stakeholder Considerations

3.2.1 Wind

Typical landowner and stakeholder concerns regarding wind projects include visual and noise impacts, safety impacts, impacts to wildlife and sensitive species and impacts to air navigation and radar communication systems. In terms of concerns specific to landowners, UL often finds noise and visual impacts to be the most common concerns arising in the development process. Additionally, non-participating landowners and other stakeholders often are concerned about their ability to participate in the planning process and often feel disenfranchised during development of large scale energy projects when there is not a clear, open public outreach process.

In Alberta, wind projects are permitted by the Alberta Utility Commission and there is a clear process for application and evaluation of project impacts. Sponsors are required to submit environmental impact studies evaluating potential impacts. The Alberta Utility Commission prescribes noise emissions limits and requires developers to demonstrate compliance with the noise standards and also often requires post-construction monitoring to validate pre-construction estimates. Noise complaints are registered and reported to the AUC and mitigation can be required if noise limits are exceeded. Visual impacts are much harder to regulate in that individuals view turbines differently and often landowners who are not benefiting from royalty payments but that are subject to view impacts are the most vocal about their concern for impacts. It is most beneficial to run pre-construction visual simulations and ensure that all stakeholders have the opportunity to evaluate them prior to approval of a project. This can help alleviate fears of visual impacts as well as set expectations. Impacts related to shadow flicker often arise, which is the effect of the turbine blades spinning in front of sun light, creating a flicker effect. These impacts are most prevalent in flat areas where limited trees or other obstructions help to obstruct the view of turbines. Simulations can be run during development of a project to estimate the amount of shadow flicker that sensitive receptors will experience and mitigation often includes planting trees, installing blinds or other shading methods. Wind farm safety concerns typically arise from the potential for ice throw and turbine or component fall. These fears can be alleviated by ensuring that adequate set-backs from structures, public roads and right of ways are established.

Wildlife impacts are another typical concern for wind project stakeholders. Alberta Environment has published guidelines for developers which include pre-construction survey requirements as well as post-construction monitoring guidelines. In Alberta wildlife agencies are involved in the review of project applications and developers are required to consult with agencies regarding the findings of their studies and proposed mitigation plans. Environmental NGOs and other environmental stakeholders often feel the process for evaluating impacts to wildlife and sensitive species does not take a broad enough view of the cumulative impacts. Site specific studies tend to focus mostly on immediate threat at the local level and potential threat to migratory species passing through a project; however wildlife advocates often argue that the cumulative impacts of several wind energy projects across North America is having a larger impact on avian and bat species than is being reported at the local level.

Other regions in Canada and North America have seen wind energy development constraints in areas where impacts to radar communication systems, department of defense flight paths and other air navigation routes are anticipated. Unlike site specific environmental impacts, many times impacts to air navigation and radar communication cannot be mitigated without significant expense. Developers are encouraged to evaluate the potential for impacts to air navigation and radar communication as early in the planning process as possible to avoid significant investment in projects with fatal flaws.

3.2.2 Solar

Similar to wind energy project, PV solar projects are often challenged regarding the potential for noise and visual impacts. In terms of visual impacts, while solar panels are within a few meters of ground level and therefore not as visible from far distances like wind turbines, the footprint and land cover/use for a solar plant is much larger on a per MW basis. Solar projects cover between 30-70 percent of the project's land area and are typically proposed in relatively flat locations where the traditional land use is agricultural. Stakeholders often voice concerns over the change of the use of the land and a switch from agricultural uses to more industrial uses. Visual simulations are beneficial in areas where concerns over visual impacts and the change of land use exist. Landowners and other stakeholders such as those in the private and jurisdictional aviation industry sometimes also share concerns over glare and safety regarding passing vehicles and air traffic. Modern PV panels are designed with anti-reflective coating to absorb light and are therefore manufactured to reduce as much glare as possible. At most angles of incidence, PV panels are expected to absorb between 95-99 percent of incoming light, minimizing reflection and glare. Solar inverters do emit a small amount of operating noise in the form of a hum associated with HVAC activities and electrical operation, though the noise, ranging from 50-90 dBA at one meter when operating, is typically not audible from outside the boundary of the project area which is fenced off.

Other stakeholder concerns over solar projects include impacts to wildlife and sensitive species. Solar projects tend to cover large areas of land, which can disturb habitat areas and migratory routes for land mammals. Additionally, impacts to sensitive plant species are a concern considering the large areas of land that can be covered by panels. The AUC requires that developers evaluate impacts to wildlife and plant species prior to submittal of an application and wildlife agencies are involved in the review process. Impacts to avian species have been evaluated at solar projects in North America. Stakeholders are often concerned that waterfowl confuse large solar projects with water bodies and some collision impacts have been documented; however these are relatively minimal compared to the collision impacts encountered with other structures such as homes, office buildings and wind turbines.

Impacts to water drainage systems and soil erosion are common issues evaluated at commercial scale PV solar projects. In areas where flooding or extreme erosion events naturally occur due to poor drainage and flash flooding, custom drainage systems and erosion control methods have been implemented as mitigation. These issues most typically occur in desert areas where solar projects may affect the way water is distributed across the landscape and concentrate erosion in specific areas across a site.

3.2.3 Decommissioning

All energy projects typically cause concern over what happens at the end of a project's life. Stakeholders prefer to see plans for the decommissioning of projects, including financial security posting to ensure that a developer does not abandon a project and avoid removal and restoration. Decommissioning plans can be developed which assess the decommissioning cost of a project and outline the measures a developer is to take to restore the area upon the end of a project life.

3.2.4 Stakeholder Engagement

Developers can avoid schedule delays and lengthy permitting process by engaging stakeholders early in the process. Prior to submittal of development applications there should be opportunities for stakeholders to evaluate project development plans and identify potential concerns. Developers can incorporate stakeholder concerns in the initial project design as well as project impact studies.

4. NET CAPACITY FACTORS AND ENERGY PRODUCTION POTENTIAL

4.1 Wind Capacity Factor Map

A wind gross capacity factor map was developed using wind speed frequency distribution data simulated via the MesoMap system and a composite wind turbine power curve. The net capacity factor was estimated using a regionally-representative wind turbine with the characteristics described in Table 4.2.

Table 4.1: Characteristics of Hypothetical Sites Modeled

Plant Type	Capacity (MW)	Turbine Hub Height	Turbine Rated Power	Turbine Rotor Diameter	Turbine IEC Class
Utility-Scale	100	100 m	3.0 MW	150 m	III

The composite power curve (3.0 MW nameplate rating, IEC class III) represents current, commercially-available technologies. The 3.0 MW turbine size was recommended by AWST and is in the middle of the size range of currently available turbine technology (which is currently approximately 2.5 to 3.5 MW).

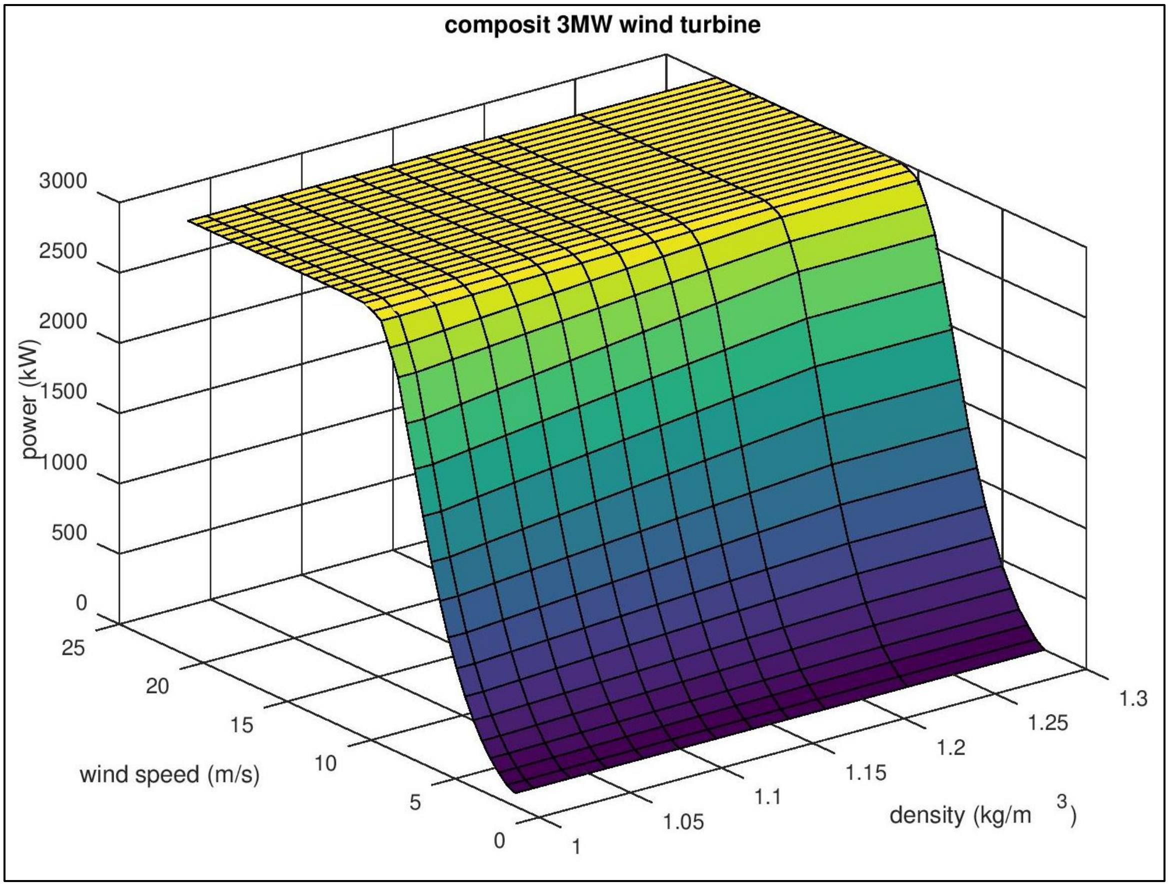

Figure 4 .1: Composite 3MW wind turbine power curve.

An energy loss factor of 18% was uniformly applied to the gross capacity factor map to calculate the net capacity factor. This loss value is an approximate average for land-based wind projects in Alberta. The energy loss factor is a composite of multiple loss sources primarily consisting of wake losses, electrical losses, project downtime/availability losses, suboptimal turbine performance, and environmental losses due to blade soiling and degradation, icing, lightning, and extreme temperatures. It is important to note that loss values can vary significant between projects. Examples of the variability of individual categories include, but are not limited to:

- Icing and site access losses change per site and are largely based on the temperature and precipitation conditions experienced by a project location.
- Wake losses can vary significant based on the project layout and orientation.
- Environmental curtailments could be required based on specific wildlife or other considerations at a project. No environmental curtailment losses were considered in the representative loss value applied.

Based on the modeled resource data and assumptions regarding wind plant design and loss values, the estimated uncertainty in the wind capacity factor values is approximately 20% on average across the developable land in the planning regions.

The wind capacity factor map is shown in Figure 4.2 and the corresponding GIS files have been provided to AESO.

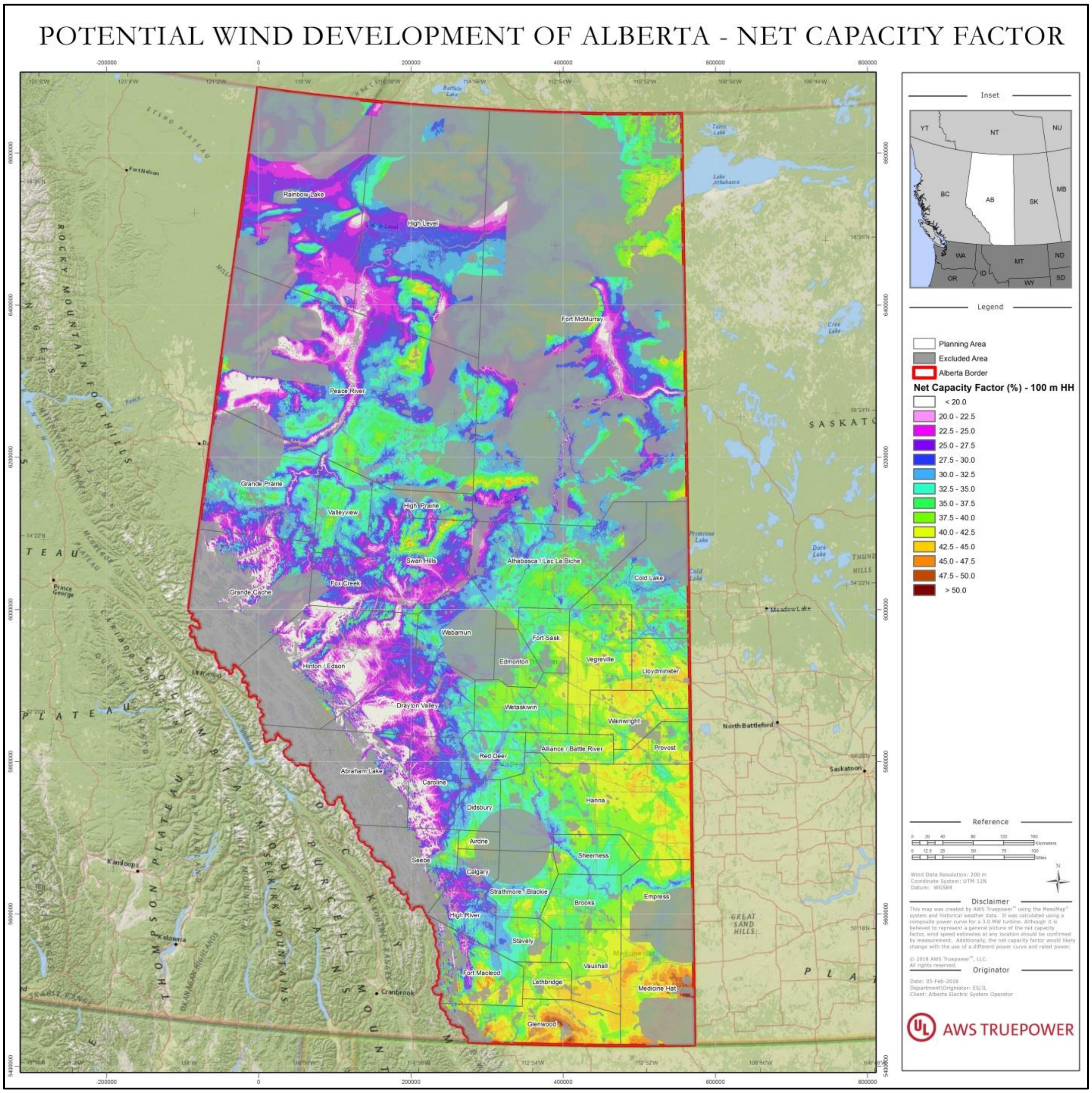

Figure 4.2: Wind Net Capacity Factor Map of Alberta

4.2 Solar Capacity Factor Map

A solar capacity factor map was developed by AWST using an ensemble approach. First, energy production estimates and net capacity factors were computed for each study area centroid using AWST's TS2Solar energy model. These estimates were adjusted to minimize potential bias in the energy model by comparing to an equivalent energy estimate from PVsyst. The adjusted net capacity factors were then correlated to their corresponding annual GHI estimates to develop a relationship between GHI and net capacity factor for the province. This relationship was then used to estimate the net-capacity factor for every grid cell in the province, and depicted in a graphical map-based format.

4.2.1 Generation of Energy Estimates and Profiles for Each Study Area

PSM time series data, the same data source that was used to prepare the solar resource map, was downloaded for the centroid of each of the 42 study areas. These data served as input to AWST's power conversion software to estimate first-year energy and net capacity factor, and to synthesize solar photovoltaic (PV) generation profiles for the correlation analysis, which is described in Section 6. The energy estimates and profiles were modeled for a regionally-representative solar plant with the characteristics described in Table 4.2. A composite utility-scale module was developed to reflect projected installations in the near future. The module characteristics and estimated loss factors were developed by AWST to be representative of the expected installed solar fleet technologies for the years 2017-2030. Specifications for this module are given in Table 4.3.

Table 4.2: Characteristics of Hypothetical Sites Modeled

Plant Type	Capacity (MW)	Tracking System	Tracking Type	Tilt (°)	Azimuth(s)	DC:AC ratio
Utility	50	Fixed	NA	30	0	1.4

Table 4.3: Module Specifications

Module Parameter	Utility Scale
Rated Capacity (W)	375
Efficiency (%)	22
Temperature Coefficient of Power (%)	-0.4
Area (m^2)	1.96

The power conversion process proceeded with the following steps:

- Modeled irradiance was translated into plane-of-array values (irradiance incident on the tilted modules) using solar geometry for the direct components and the Perez algorithm.[6]
- Gross power output was obtained by multiplying the PV area by the plane-of-array global irradiance and the module efficiency.

6 R. Perez, P. Ineichen, R. Seals, J. Michalsky, and R. Stewart, 1990: Modeling daylight availability and irradiance components from direct and global irradiance. Solar Energy, 44, 271–289.

- The wind speed and temperature from the PSM dataset was used to calculate the PV module temperature. The PV temperature was used to calculate the reduction in module efficiency due to thermal factors.
- Loss assumptions consistent with those relevant for Alberta were applied to calculate the net energy at each site.
- Soiling and snow loss assumptions were applied to calculate net energy based on AWST's soiling and snow model and available weather data from a typical location within Albert. Monthly loss factors were applied.
- Row-to-row shading loss assumptions were applied to calculate net energy. Row-to-row shading losses were varied by time of day based on typical module spacing.[7] Neither horizon shading nor east-west shading were considered

4.2.2 Adjustment of Energy Results

Half-hour net solar PV profiles (1998-2016) were simulated for all sites using the approach described above. The resulting energy estimates were calibrated to minimize potential energy model bias by adjusting the energy and net capacity factor estimates based on a comparable energy estimate from PVsyst.

4.2.3 Creation of Net Capacity Factor Map

Using the GHI estimates from PSM and the adjusted energy results, AWST created a relationship between GHI and net capacity factor for the 42 study area centroids. The relationship showed a strong correlation of 98%, as depicted in Figure 4.3 below. The relationship between GHI and net capacity factor was then applied to the GHI estimates in the solar resource map to calculate the capacity factors across the province.

7 The modeled plants were designed to reduce row-to-row shading, thus this loss is expected to be less than 1%.

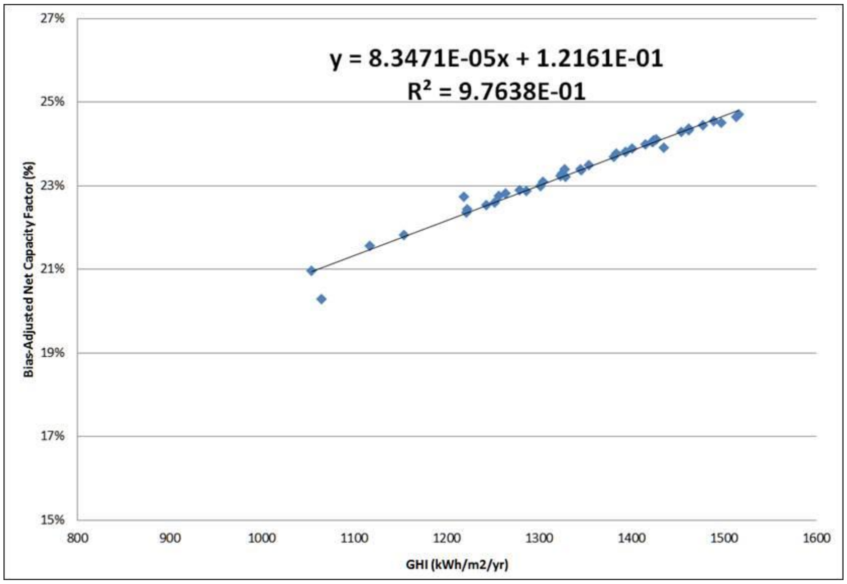

Figure 4.3: Relationship between GHI and Adjusted AC Net Capacity Factor

Based on the modeled resource data and assumptions regarding wind plant design and loss values, the estimated uncertainty in the solar capacity factor values is approximately 10% on average across the province.

The solar capacity map is shown in Figure 1.4 and the corresponding GIS files have been provided to AESO.

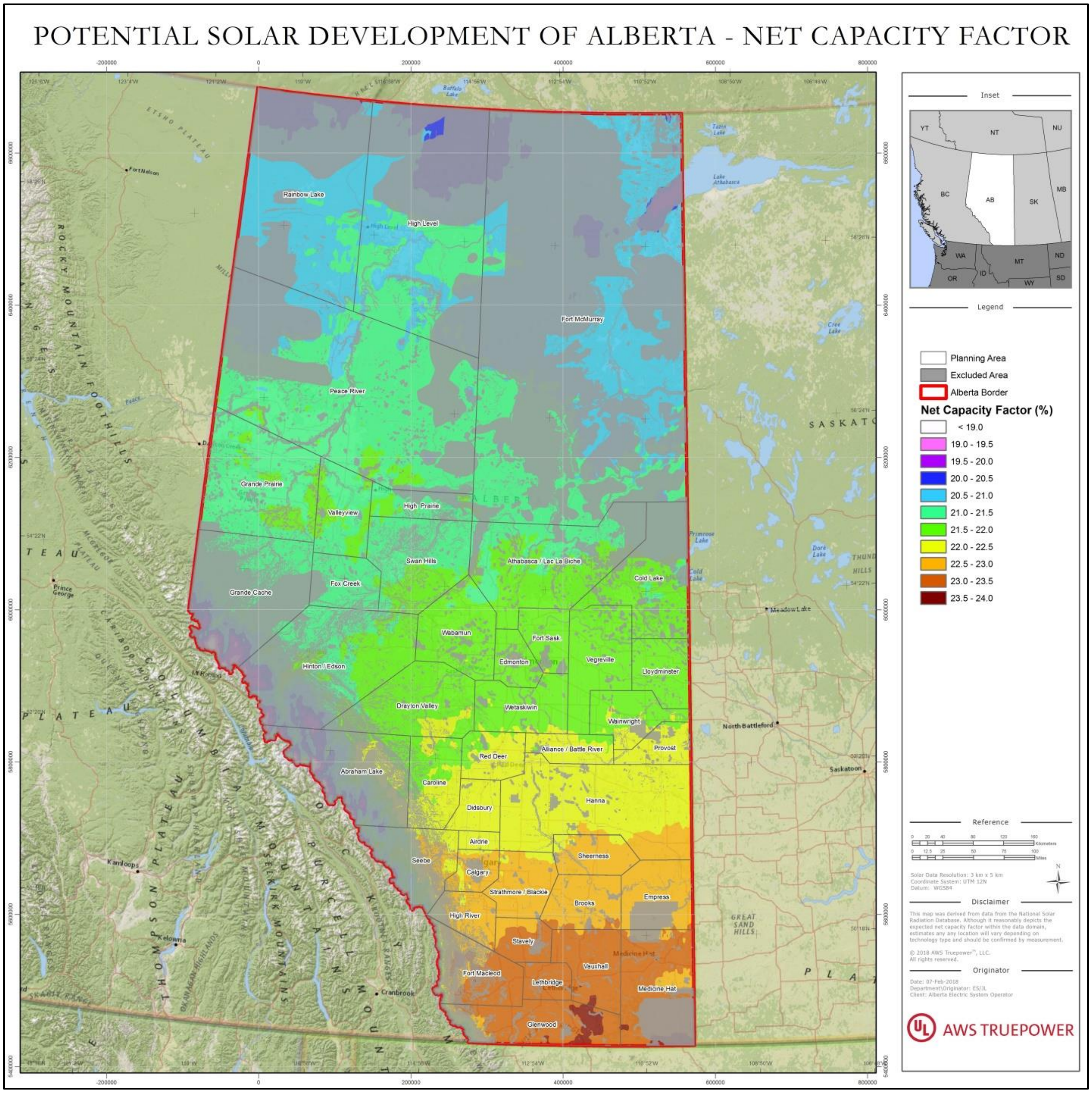

Figure 4.4: Solar Net Capacity Factor Map of Alberta

5. ENERGY PRODUCTION POTENTIAL

AWST used the net capacity factor and constraints maps described above to estimate the 100% area build out potential of each planning zone. A table was prepared to summarize the available developable area within each zone, as well as the mean, minimum and maximum net capacity factor values. The production build-out potential was then calculated by multiplying the developable area (sq km) by MW density assumptions for solar (40 MWAC per sq km) and wind (10 MW per sq km) based on AWST's regional experience.

The 100% area case potential annual energy output was calculated by multiplying the planning area build out potential by the average estimated net capacity factor for the area and the average number of hours in a calendar year (8766 hours).

The results of these calculations, along with other summary statistics for each planning area that can be used to understand the buildout potential were provided to AESO in two sets of tables. The tables were provided for two scenarios, with and without a constraint limiting build out to areas within 20 km of a 115 kV or greater substation.

The tables below summarize the maximum development potential for the entire Alberta province, as well as for the five planning areas with the largest solar and wind development potentials. These figures represent a maximum build-out scenario based on (1) the transmission-constrained land area, (2) the assumption that 100% of the non-excluded area is suitable for development, and (3) locations with a net capacity factor above thresholds established in the study. Based on these assumptions, the area with the most available developable area have the most production potential.

It should be noted that both wind and solar categories include the overlapping area. This area is broken out in the spreadsheets provided separately and should be deducted from any combinations of resource values.

Table 5.1: Total Potential Solar and Wind Production – Transmission Constrained – 100% Area Case

Resource	Area Greater than 20% (Solar) or 30% (Wind) NCF AND Developable (sq km)	Mean NCF on Developable Land (with Solar NCF >20% AND Wind NCF >30%)	Potential Rated/Peak Production (GW)	Potential Total Annual Energy Output (GWh/yr)
Solar	193,307	21.9%	7,732	14,868,346
Wind	124,418	36.7%	1,244	3,998,512

Table 5.2: Five Planning Areas with Largest Potential Solar Production – Transmission Constrained – 100% Area Case

Name	Region	Area Greater than 20% NCF AND Developable (sq km)	Mean NCF on Developable Land (with Solar NCF >20%)	Solar Potential Rated/Peak Production (GW)	Solar Potential Total Annual Energy Output (GWh/yr)
Hanna	Central	12,545	22.3%	501.79	980,798
Peace River	Northwest	12,536	21.2%	501.45	931,998
Fort McMurray	Northeast	10,644	20.9%	425.75	781,102
Athabasca / Lac La Biche	Northeast	9,412	21.5%	376.49	710,537
Grande Prairie	Northwest	9,192	21.4%	367.68	688,393

Table 5.3: Five Planning Areas with Largest Potential Wind Production – Transmission Constrained – 100% Area Case

Name	Region	Area Greater than 30% NCF AND Developable (sq km)	Mean NCF on Developable Land (with Wind NCF >30%)	Wind Potential Rated/Peak Production (GW)	Wind Potential Total Annual Energy Output (GWh/yr)
Hanna	Central	10,548	38.9%	105.48	359,449
Peace River	Northwest	8,148	33.7%	81.48	240,696
Athabasca / Lac La Biche	Northeast	7,861	34.4%	78.61	237,049
Vauxhall	South	6,132	40.4%	61.32	217,078
Wetaskiwin	Edmonton	5,782	37.2%	57.82	188,390

6. CORRELATION OF EACH PLANNING AREA

AWST estimated the correlation of the wind and solar production hourly profiles estimated for each AESO planning area to each other, as well as to the production profiles for each of the other planning areas. Wind speed, solar irradiance, and other atmospheric variables were simulated at potential wind and solar locations in each planning area using modeled resource data. The meteorological parameter time series were converted to production for the correlation analysis.

The following correlation scenarios were evaluated once the time series were prepared:

- The wind production potential correlation between AESO planning areas
- The solar production potential correlation between AESO planning areas
- The correlations between wind and solar production within AESO planning areas

Matrices were provided to AESO summarizing the correlation coefficient (Pearson coefficient) of wind/solar/combined generation between and within each planning area.

6.1 Preparation of Solar Energy Time Series

The solar energy time series were developed using AWST's energy modelling tool TS2Solar, as described in Section 4.2. The resource input time series for these profiles was the PSM data set. For the purpose of the comparison, the solar time series were scaled to be representative of a 3 MW project size.

6.2 Preparation of Wind Energy Time Series

AWST used the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) reanalysis datasets to prepare the wind energy time series. MERRA-2, which was developed by the National Aeronautics and Space Administration (NASA), utilizes a variety of observing systems which have been assimilated into a global three-dimensional grid by numerical atmospheric models at a horizontal resolution of 1/2° latitude and 2/3° longitude. The datasets were interpolated to the locations specified in Figure 5.1, representative of a 50 m measurement height. These locations differ from the planning area centroids as they were chosen to be more representative of areas likely to experience future wind power development.

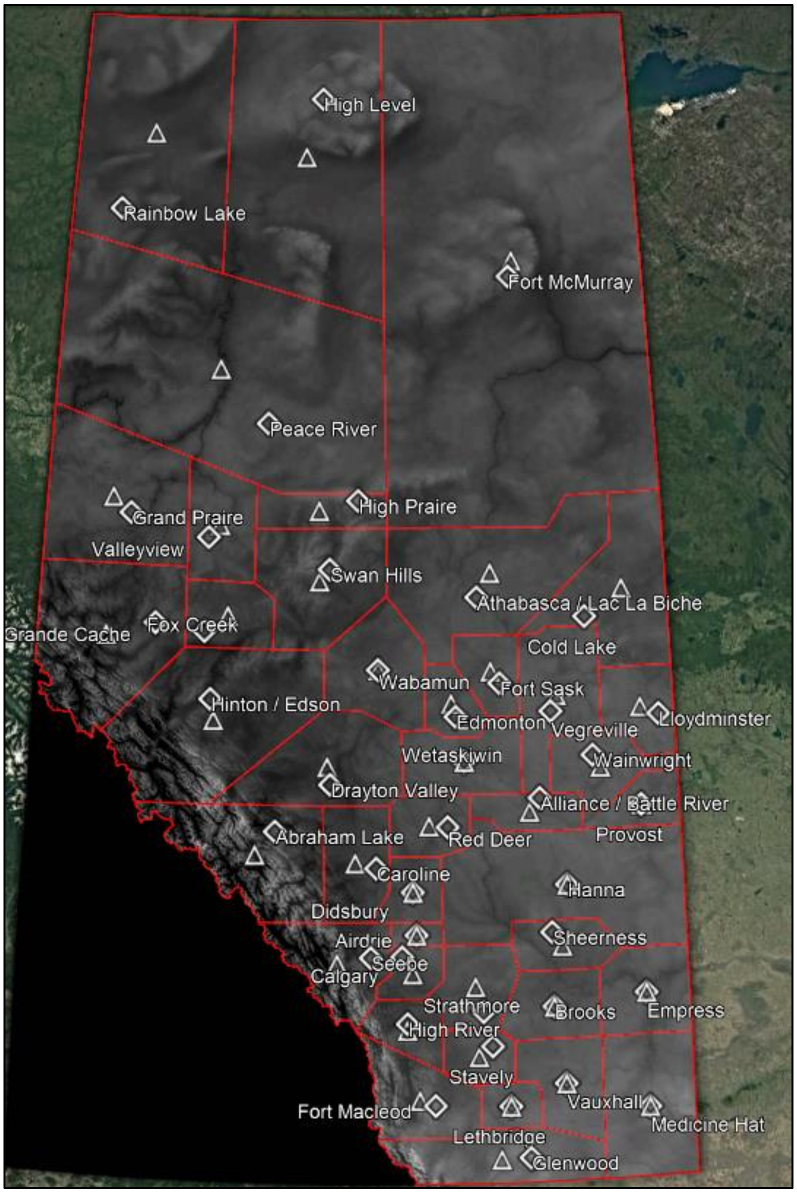

Figure 5.1: Location of zone Centroids (triangles) and MERRA extract points (diamonds) for each zone in Alberta.

The MERRA-2 time series data was extrapolated to a hub height of 100 meters using the shear values calculated from the wind speeds at the 10 and 50 m levels. The 100 m time series of wind speed was then scaled to the long term modeled mean (LTMM). The air density was calculated from MERRA data using surface temperature and pressure variables and the idea gas law. The resulting representative time series of wind speed and air density were used to calculate gross power from a composite 3MW turbine which is described in Section 4.1. Each record in the hourly time series was multiplied by a loss factor to calculate the net production dataset.

6.3 Correlation Analysis

Both Pearson's linear correlation coefficient and R-squared were used to gauge the strength of the correlation between the solar and wind production profiles for each planning area (R-squared being defined as the square of Pearson's product moment correlation coefficient). Pearson's correlation coefficient varies between -1 and 1, where negative numbers indicate the slope of the correlation between two variables is negative (i.e. they are anti-correlated) and positive numbers indicate the slope of the correlation between two variables is positive. The results presented below are for the hourly correlations; however daily and monthly correlation results have also been provided to AESO.

6.4 Correlation Results

Pearson correlation coefficient matrices are shown below between zones for the wind and solar simulations for the following scenarios:

- The wind production potential correlation between AESO planning areas
- The solar production potential correlation between AESO planning areas
- The correlations between wind and solar production within AESO planning areas

While the wind profiles for a few areas are fairly well correlated, the correlations between the wind profiles for most areas are weak on an hourly basis (Figure 6.1). Regarding the solar profiles, all areas show correlation coefficients of near 1.0 on an hourly basis (Figure 6.2).

There is little to no correlation between wind and solar within any of the zones (Figure 6.3).

The correlation results help determine which zones had the likelihood of producing renewable energy at the same time. These correlations are useful to help characterize the diversity of renewable resources across Alberta. High correlations between zones suggest more susceptibility to ramp events and intermittency, while low correlations suggest less vulnerability to resource ramp events. In general, the wind-to-wind correlations were weak-to-moderate, ranging from 0.XX to 0.XX, while the solar-to-solar correlations were strong, ranging from 0.XX to 0.XX. Wind-to-solar correlations were weak, ranging from 0.XX to 0.XX. This suggests that, while some susceptibility exists within a particular resource type, a combination of wind and solar development may help to mitigate ramp and intermittency risk across the province.

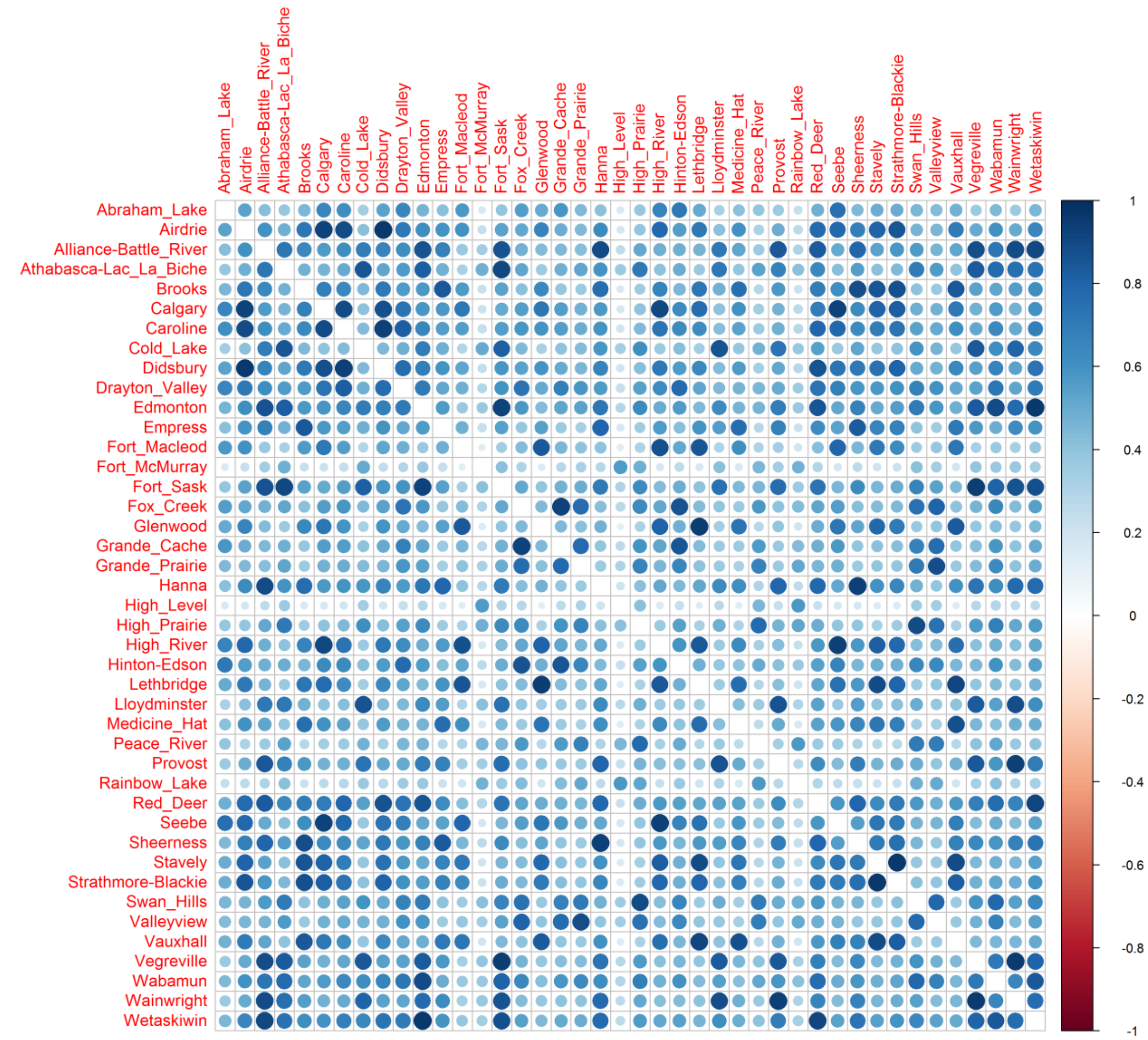

Figure 6.1: Hourly Wind Correlations Between Zones

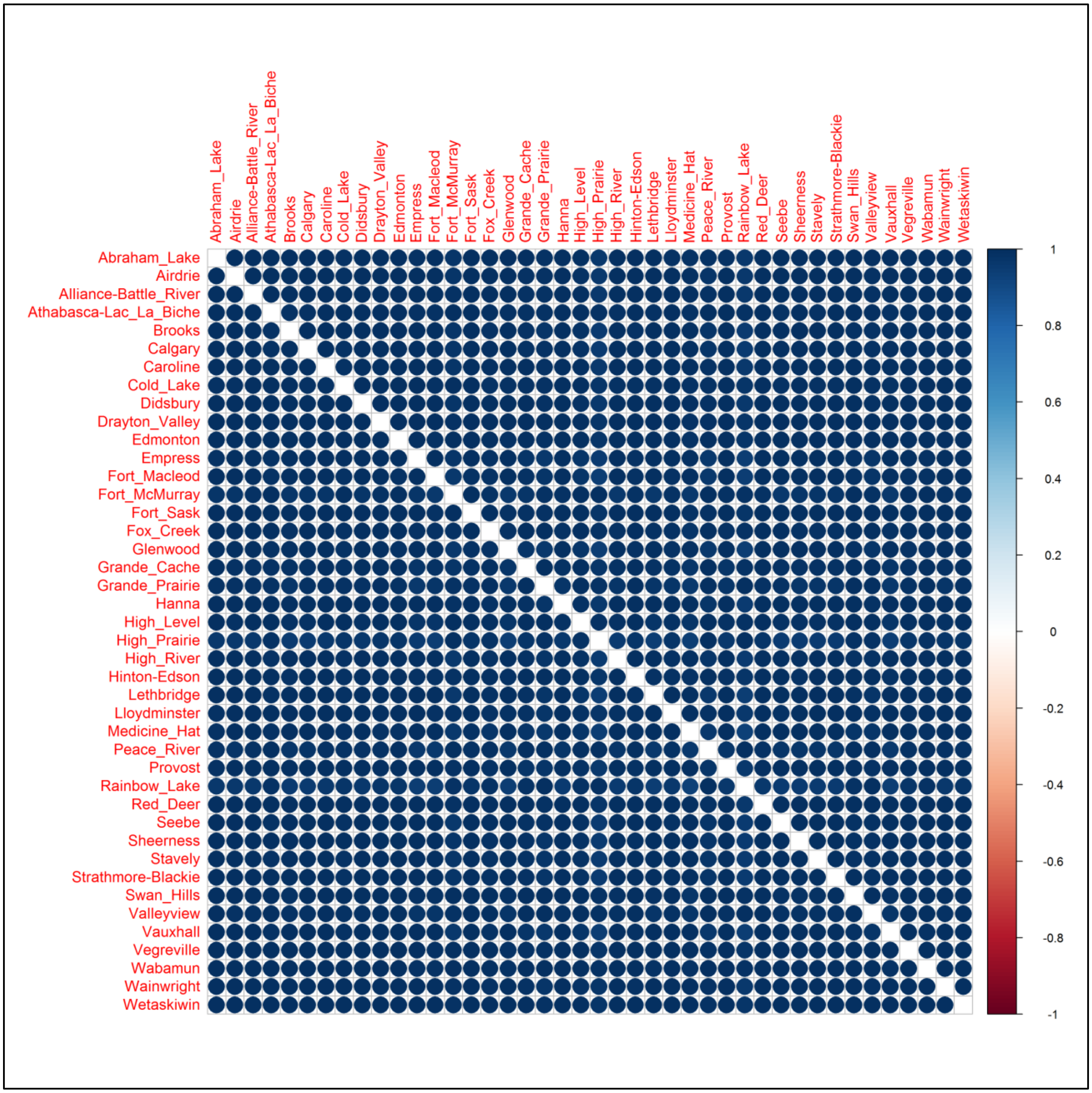

Figure 6.2: Hourly Solar Correlations Between Zones

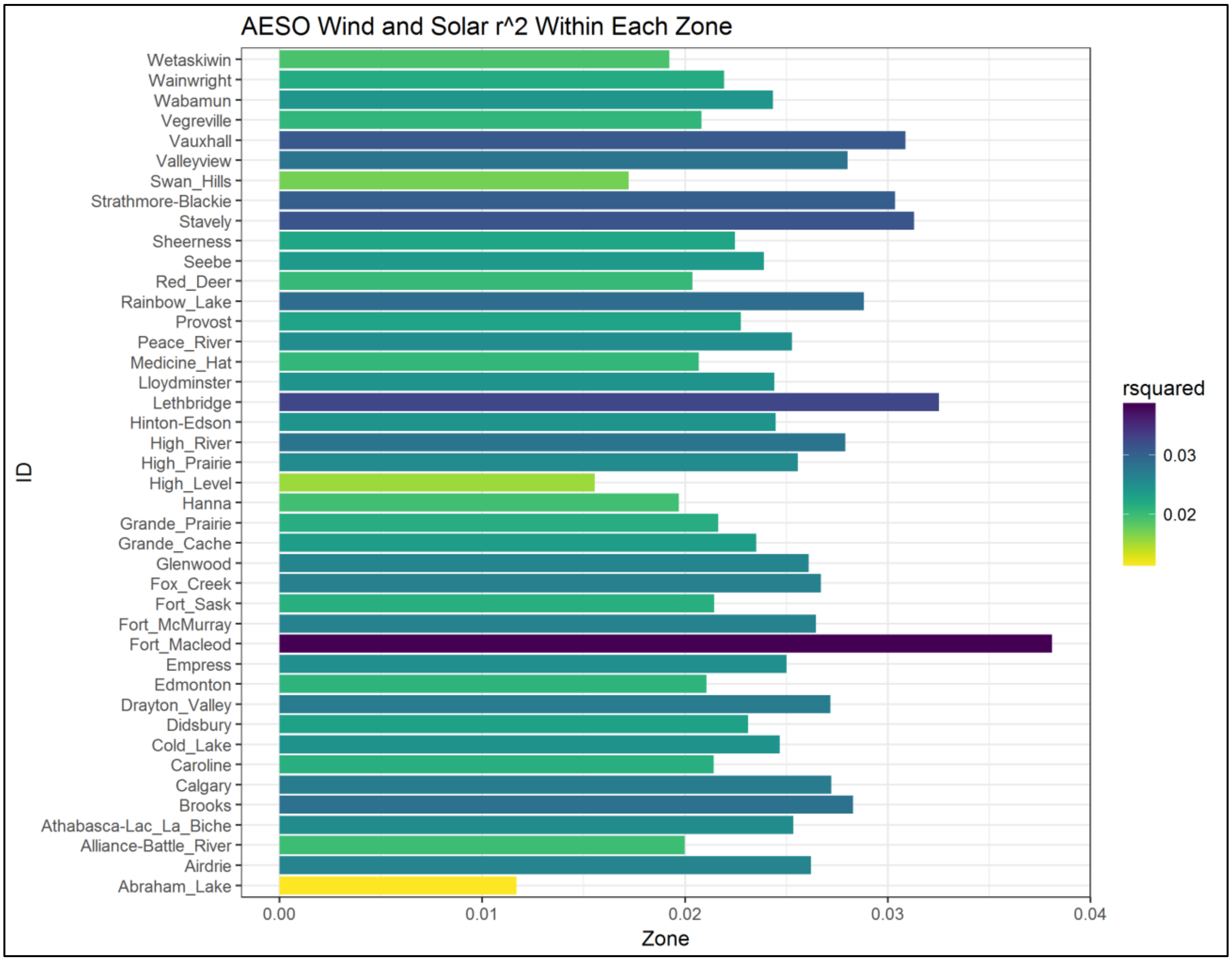

Figure 6.3: Wind and Solar Hourly r^2 Within Each Zone

6.4.1 Network Plots

To help demonstrate the strength of correlations between zones, network analyses plots were generated. These plots use color profiles to show the relative correlation between zones, and the number of significant connections between a particular zone and others included in the study. While the colors in the network analysis are significant, the physical location of each node (representing a zone) in the network plot is not meant to convey any relationship between the points. Rather, the location of each node has been assigned to allow for spacing to assist with a clear graphical display of all the data, minimizing the amount of convolution and overlapping lines as much as possible.

For the purposes of graphical display (not intended to suggest key values for grid integration planning) and to better illustrate the zones with the highest correlations (and therefore most likely to be impacted by regional resource intermittency), a minimum threshold filter was applied to the inter-zonal correlation coefficients (i.e. correlation coefficients between zones were not included in the plots if they did not meet a certain threshold). Table 6.1 provides the filtering threshold values used for the hourly, monthly and daily aggregation periods. Note that filter threshold values increase with aggregating time period. While the choice of filter values is subjective, the reason for the increase is simply that correlations between zones improve as the aggregating period increases. For the hourly aggregation period, the sun-up/sun-down diurnal cycle is clearly a dominant feature for both wind and solar. For the monthly and daily aggregation periods, the seasonal cycle is dominant.

Values Below Threshold Removed	Hourly	Daily	Monthly
Solar Threshold	0.99900	0.99945	0.99990
Wind Threshold	0.8500	0.8905	0.9350

Figure 6.1: Filter Threshold Values for Different Aggregation Periods

Figures 6.4, 6.5 and 6.6 show the solar network plots using hourly, daily and monthly aggregation periods respectively at the threshold values given in Table 6.1. Figures 6.7, 6.8 and 6.9 show the wind network plots using hourly, daily and monthly aggregation periods respectively as given in Table 6.1. The network plots can be interpreted according to three parameters:

- Number of unfiltered correlations: the greater the number of connections one zone has with others is an indication of how strongly the resource in that zone correlates to other study areas.
- Correlation strength: stronger correlations are represented with blue, while weaker correlations are represented with yellow.
- Clustering of correlations: clear clusters of nodes indicate zones that are part of the same correlation family.

Zones with nodes with five or more connections to others and blue (stronger) correlations show the highest correlations with others and should be considered the most susceptible to regional intermittency and ramp events. Alternatively, sites with less connections and yellow (weaker) correlations have a resource that is comparatively less correlated with others.

For solar, the most correlation-sensitive zones on an hourly basis were Calgary, Airdrie, Lethbridge. On a daily basis, the most correlation-sensitive zones were Edmonton, Fort Sask, Vegreville, and Lloydminster. On a monthly basis, the most correlation-sensitive zones were Fort Sask, Vegreville, Wabamun, Edmonton, and Lloydminster. In each case, the shapes of the plots do not suggest extreme zonal clustering, graphically demonstrating that solar correlations are consistently high for all zones in the analysis.

For wind, the most correlation-sensitive zones on an hourly basis were Airdrie, Didsbury, Stavely, Edmonton, and Strathmore-Blackie. On a daily basis, two predominant clusters emerged, indicating that there are two predominant correlation clusters: the cluster surrounding Fort Sask represents comparatively weaker correlations than the highly correlated region around High Level, Fort McMurray, Lethbridge, and Strathmore-Blackie. On a monthly basis, the wind sites showed even more dense clustering, suggesting quite high correlations centered around zones such as Fort McMurray, High Level, Strathmore-Blackies, and Calgary; an additional cluster also emerged around Fort Sask, Vegreville, Wainwright, and Edmonton.

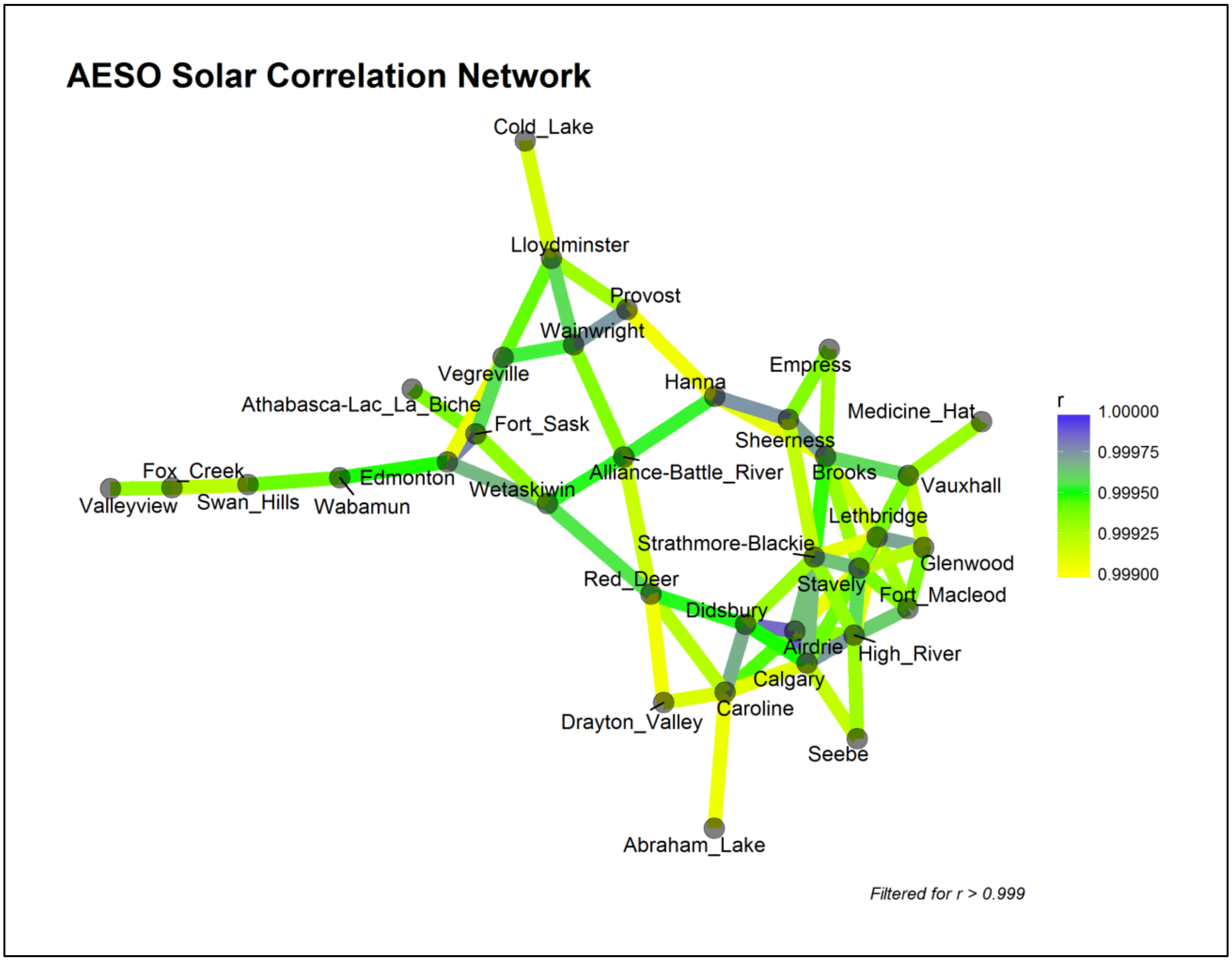

Figure 6.4: Hourly Solar Zonal Correlations

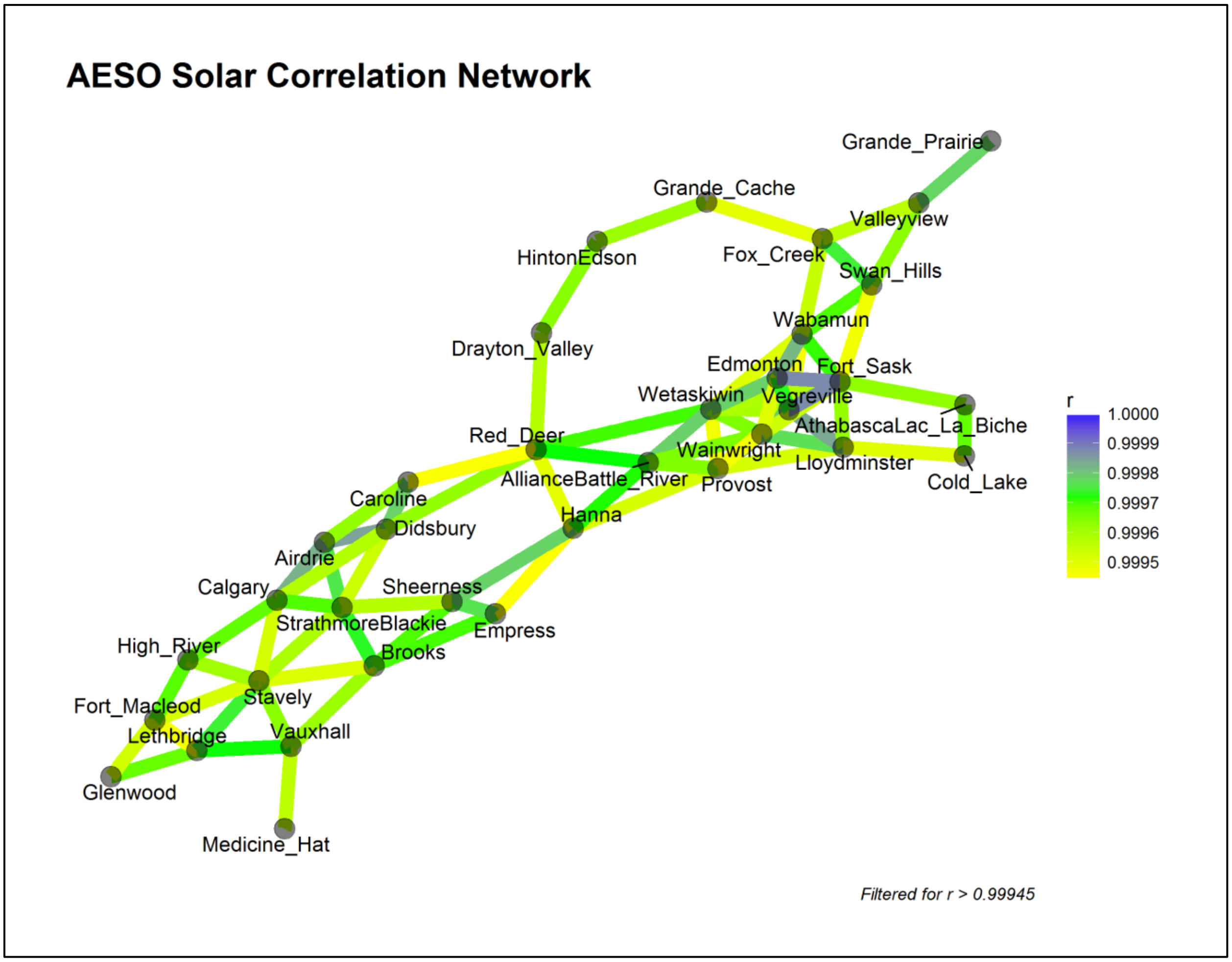

Figure 6.5: Daily Solar Zonal Correlations

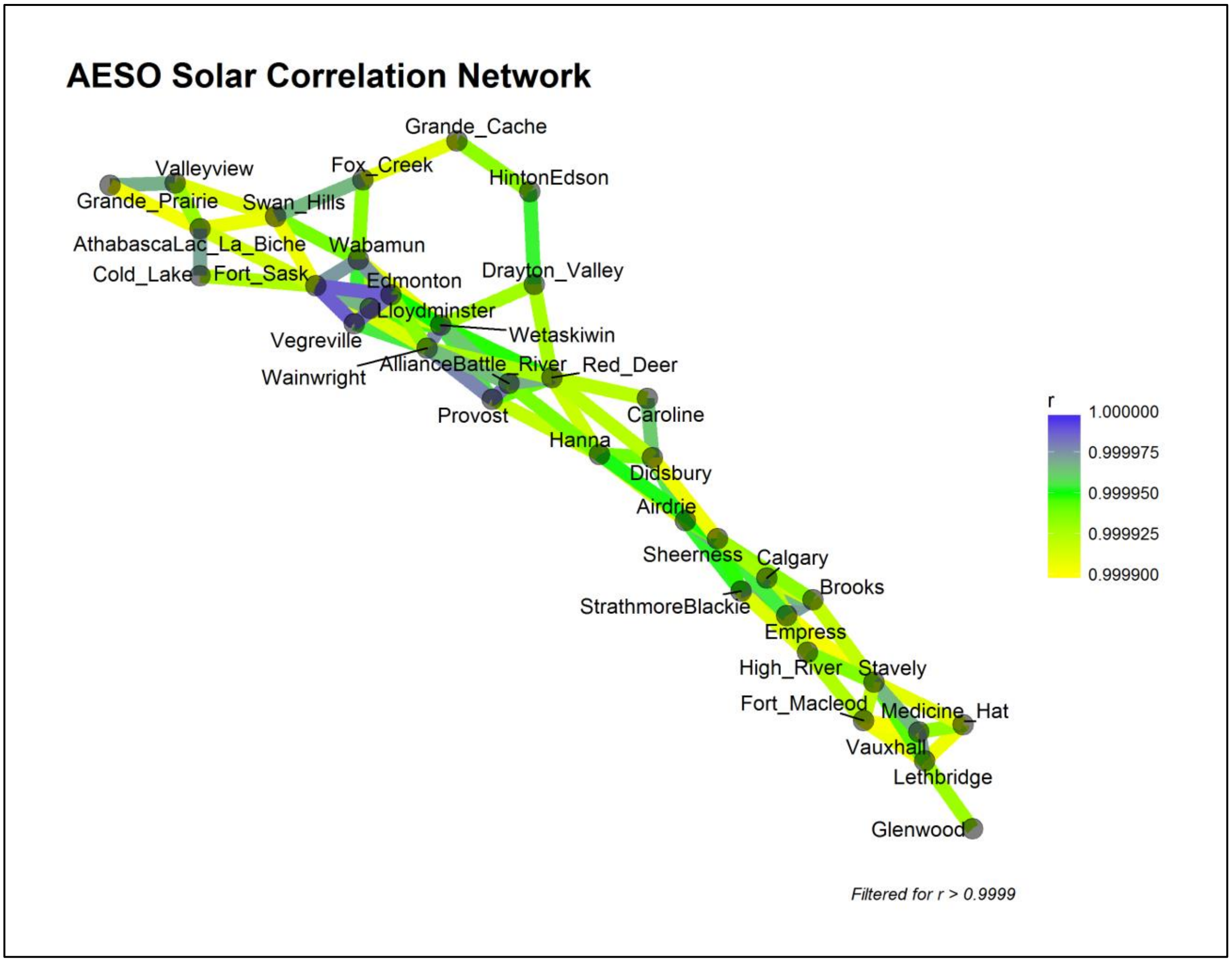

Figure 6.6: Monthly Solar Zonal Correlations

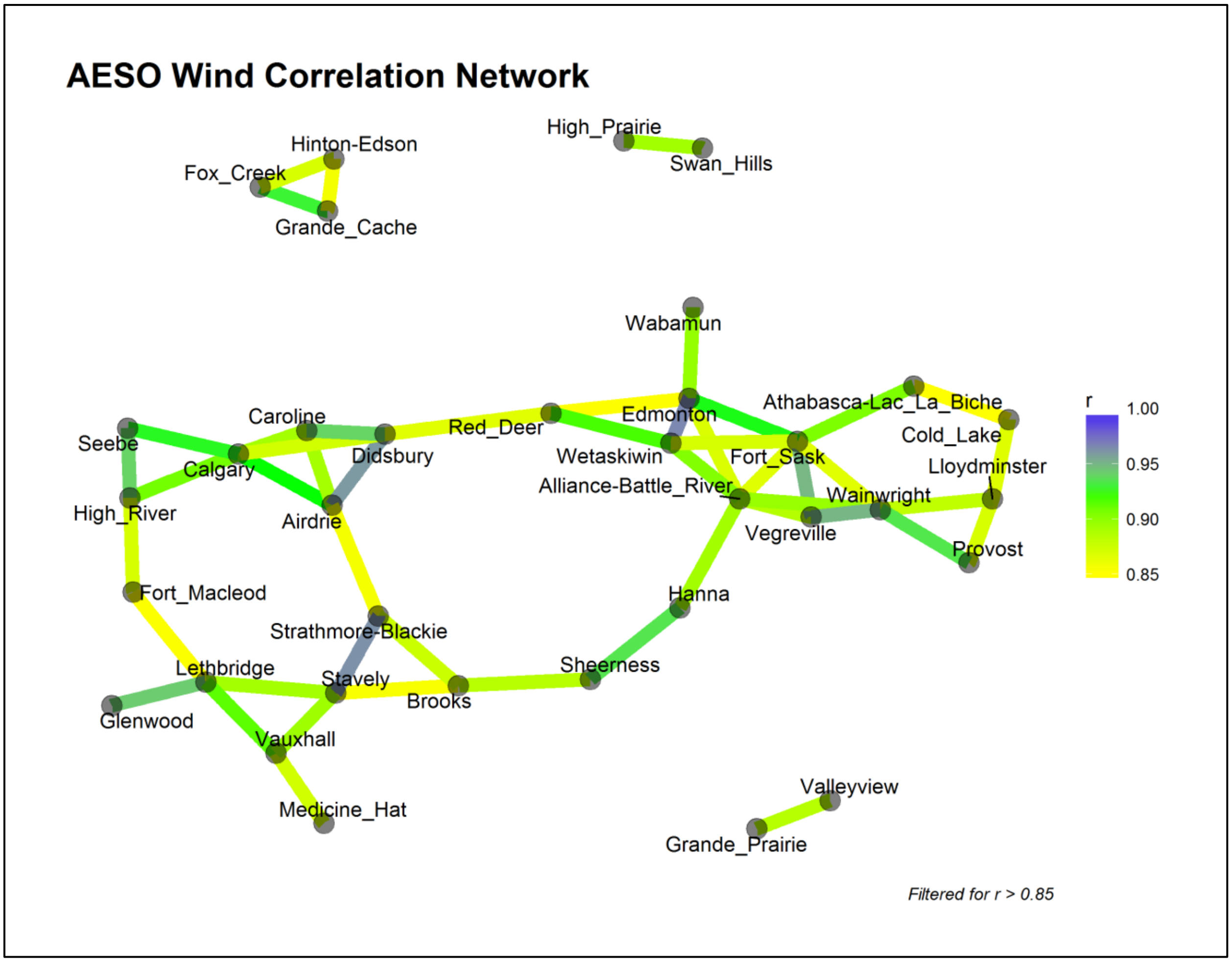

Figure 6.7 Hourly Wind Zonal Correlations

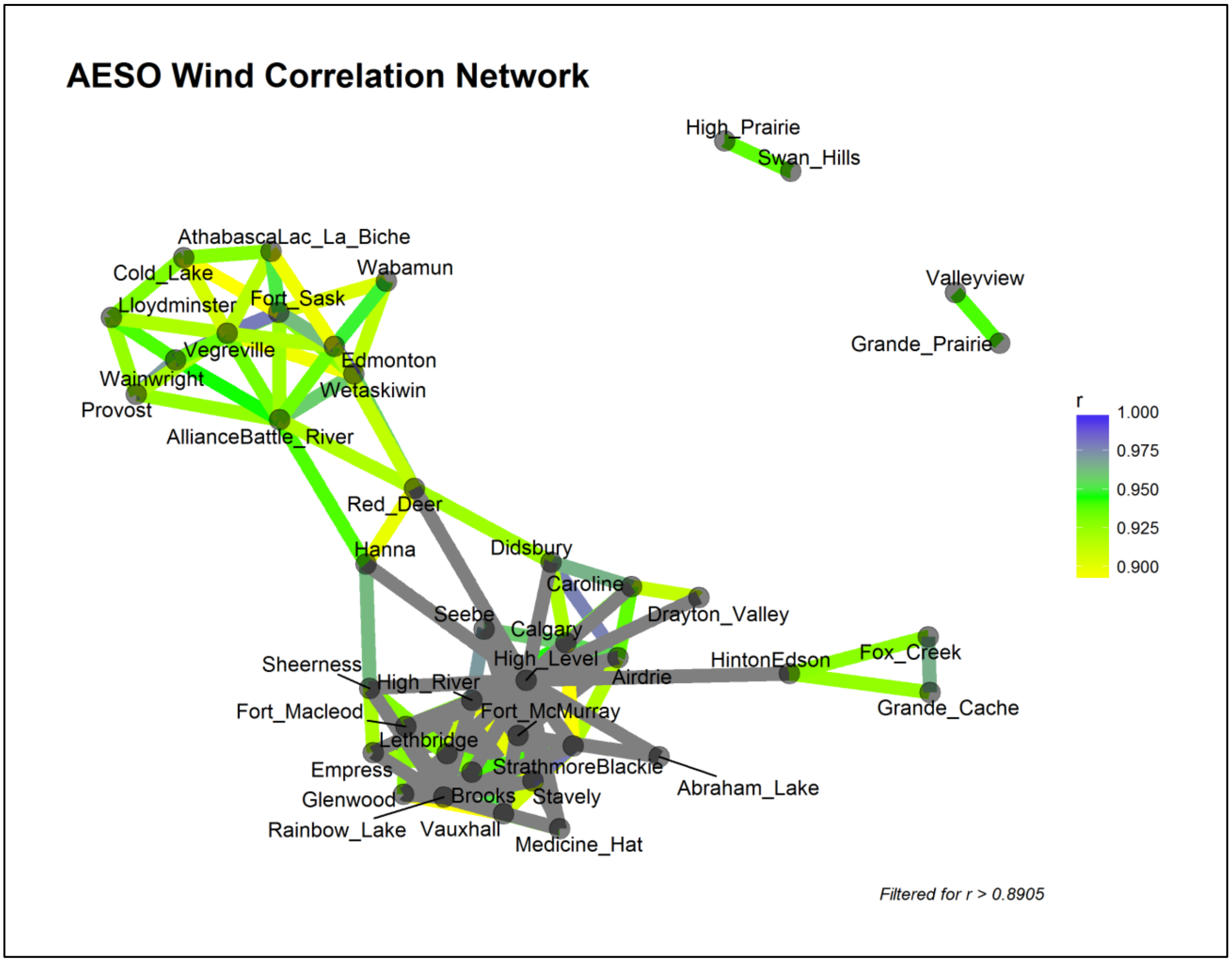

Figure 6.8: Daily Wind Zonal Correlations

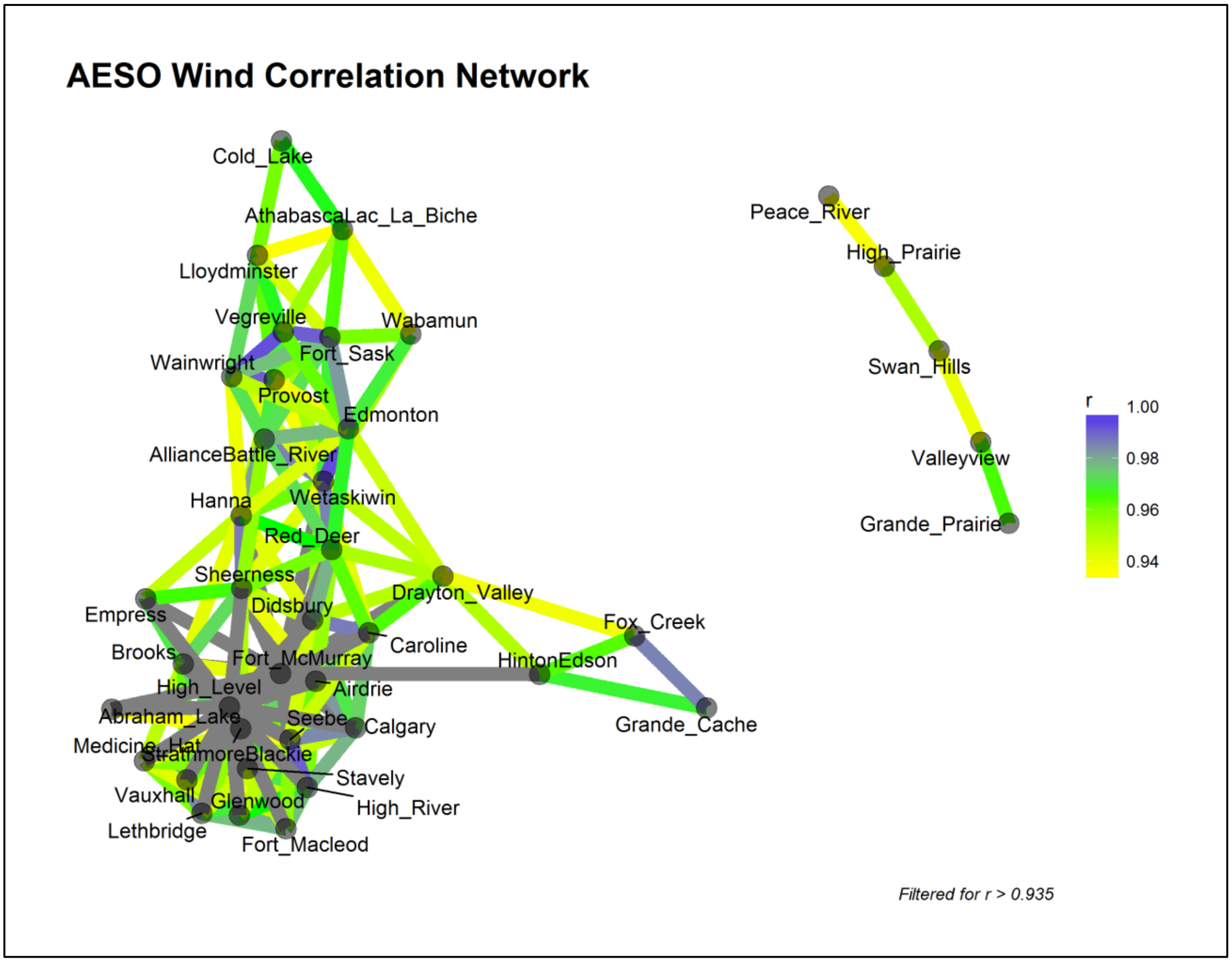

Figure 6.9: Monthly Wind Zonal Correlations

Figures 6.10, 6.11 and 6.12 show the interconnection between highly correlated geographic solar zones for hourly, daily and monthly aggregation periods as given in table 6.1. Figures 6.13, 6.14 and 6.15 show the interconnection between highly correlated geographic wind zones for hourly, daily and monthly aggregation periods as given in table 6.1. These figures differ from the network plots in that they represent the geographical relationship between highly-correlated zones, while the network plots were focused on correlation families (strong/multiple correlations), independent of geography.

In Figures 6.10, 6.11, and 6.12 (solar), it is apparent that all zones in the study are strongly correlated. This is indicated by the numerous connections with neighboring zones. This is especially obvious in the daily and monthly geographic correlation maps. The hourly correlation plot shows similar agreement, but with less correlations in the east-to-west direction. This is expected, as the sun’s trajectory across the sky is expected to weaken correlations on an hourly basis due to different sunrise/sun-peak/sunset times at different longitudes and when considering the impact of horizon shading from the Rocky Mountains in the morning.

In Figures 6.13, 6.14 and 6.15 (wind), it is apparent that the geographic isolation of High Prairie, Swan Hills, Valley View and Grand Prairie leads to few correlations with other zones. Satellite imagery shows this area to be relatively flat, while the Rocky Mountains to the west are approximately 4,000 feet in elevation, and mountains to the north and south are approximately 6,000 feet higher. In figures 6.13 and 6.13 is there is another less obvious group of zones which is isolated from the bulk of the zones on an hourly and daily aggregation period. These zones are Grand Cache, Hinton Edson and Fox Creek. These zones are in the western-wind lee of a very mountainous region that includes Kakwa Provincial Park and the Willmore Wilderness Park (approximately 11,000 feet in elevation).

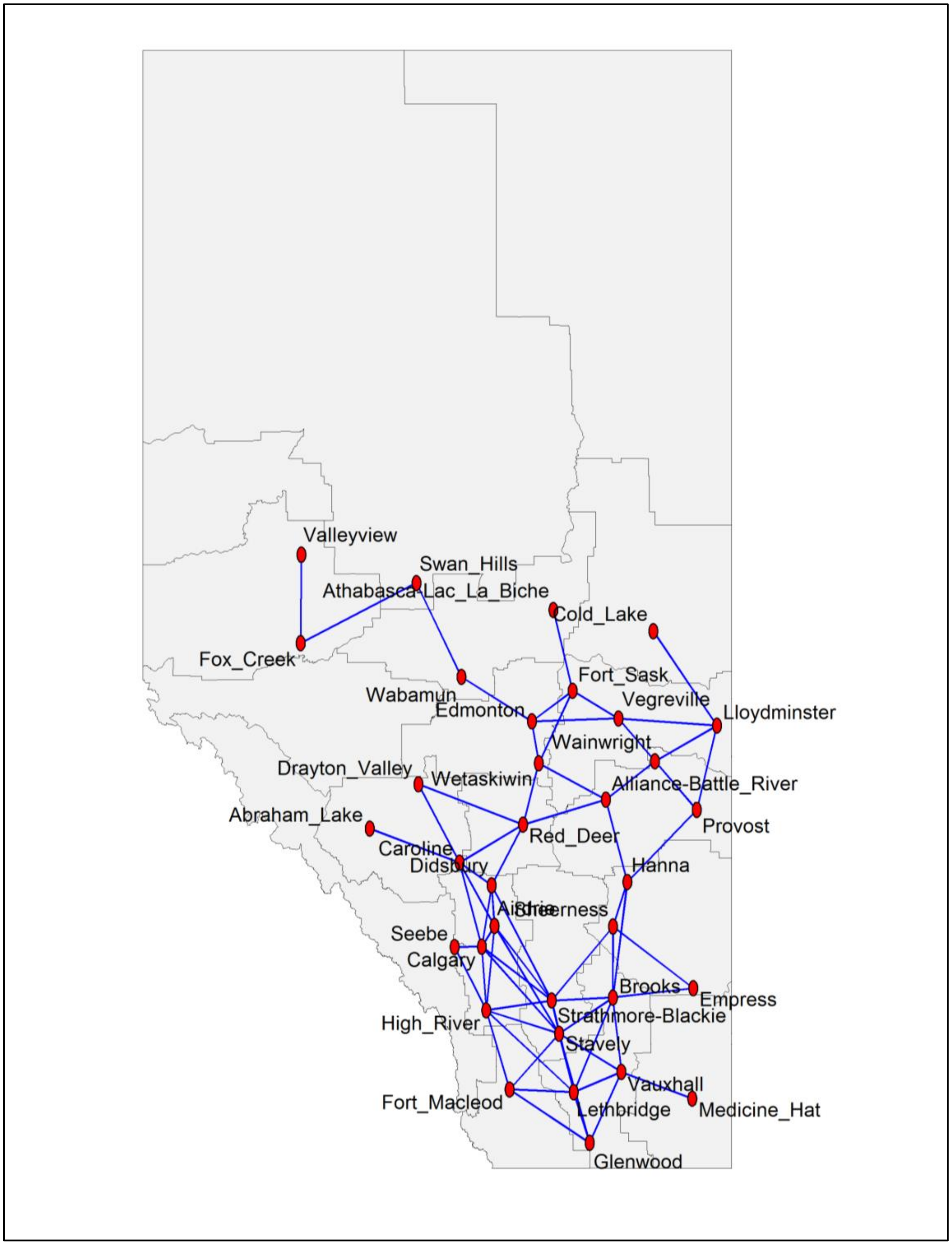

Figure 6.10: Hourly Solar Highly Correlating Zones (Filtered for r>0.999)

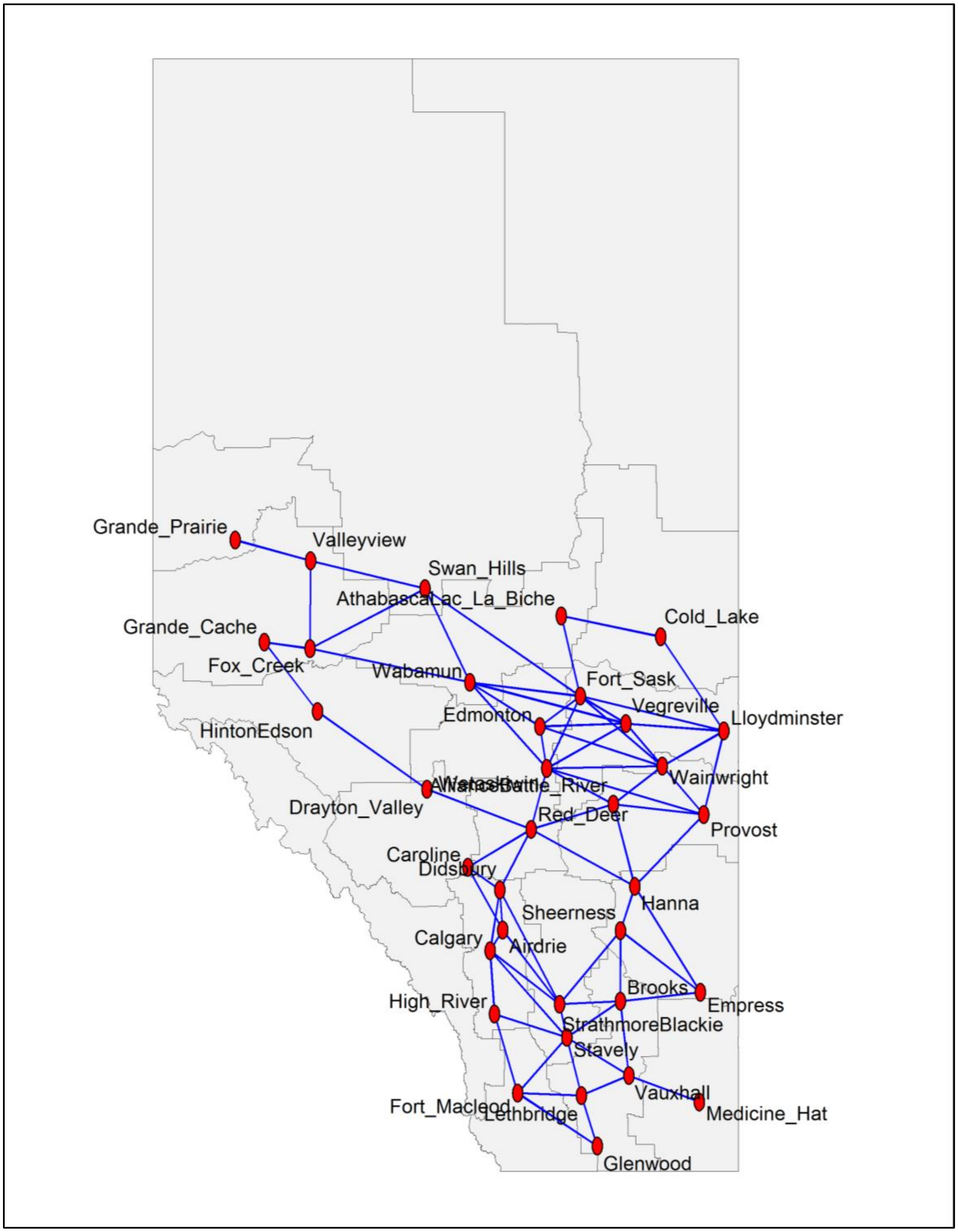

Figure 6.11: Daily Solar Highly Correlating Zones (Filtered for r>0.99945)

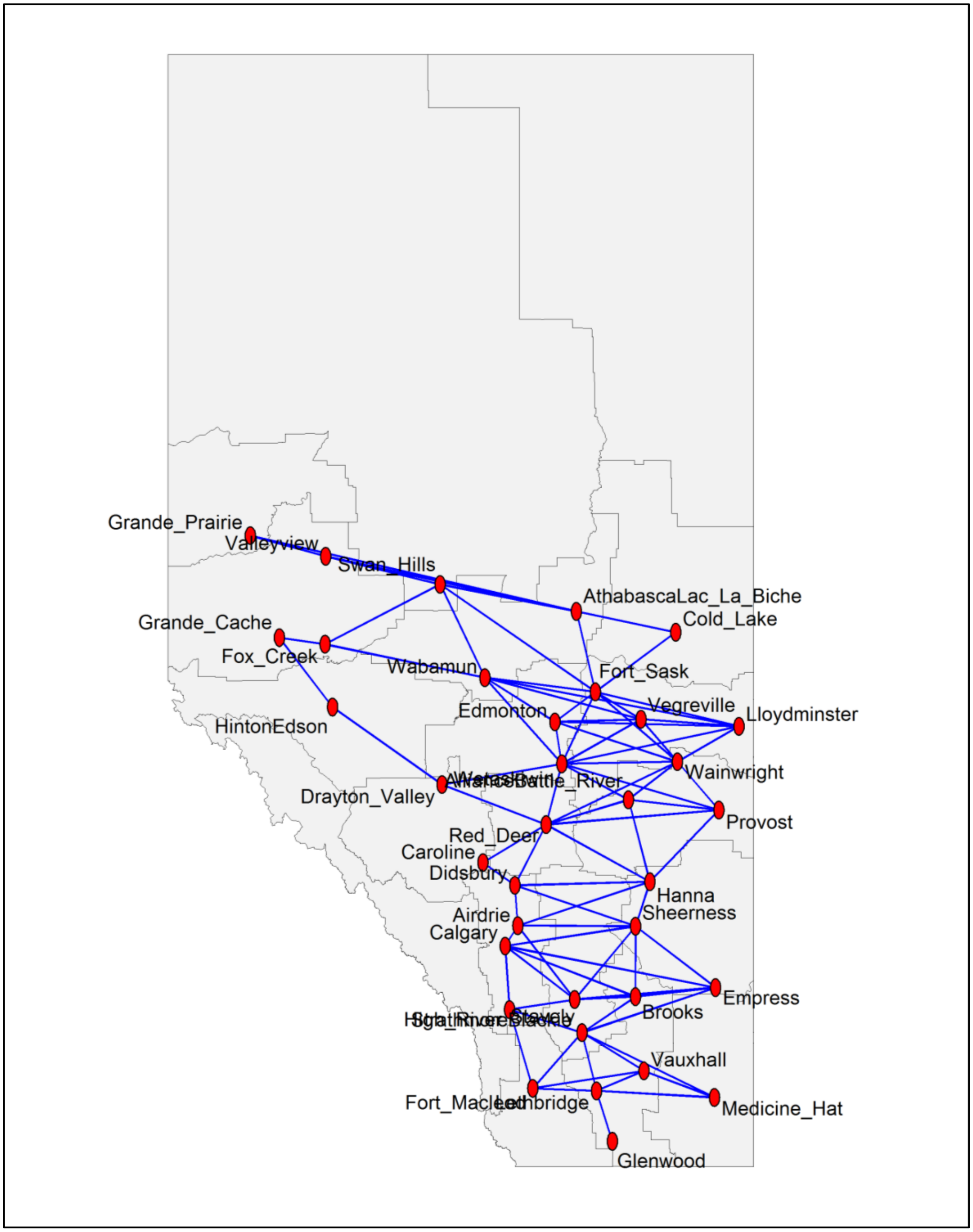

Figure 6.12: Monthly Solar Highly Correlating Zones (Filtered for r>0.9999)

Figure 6.13: Hourly Wind Highly Correlating Zones (Filtered for r>0.85)

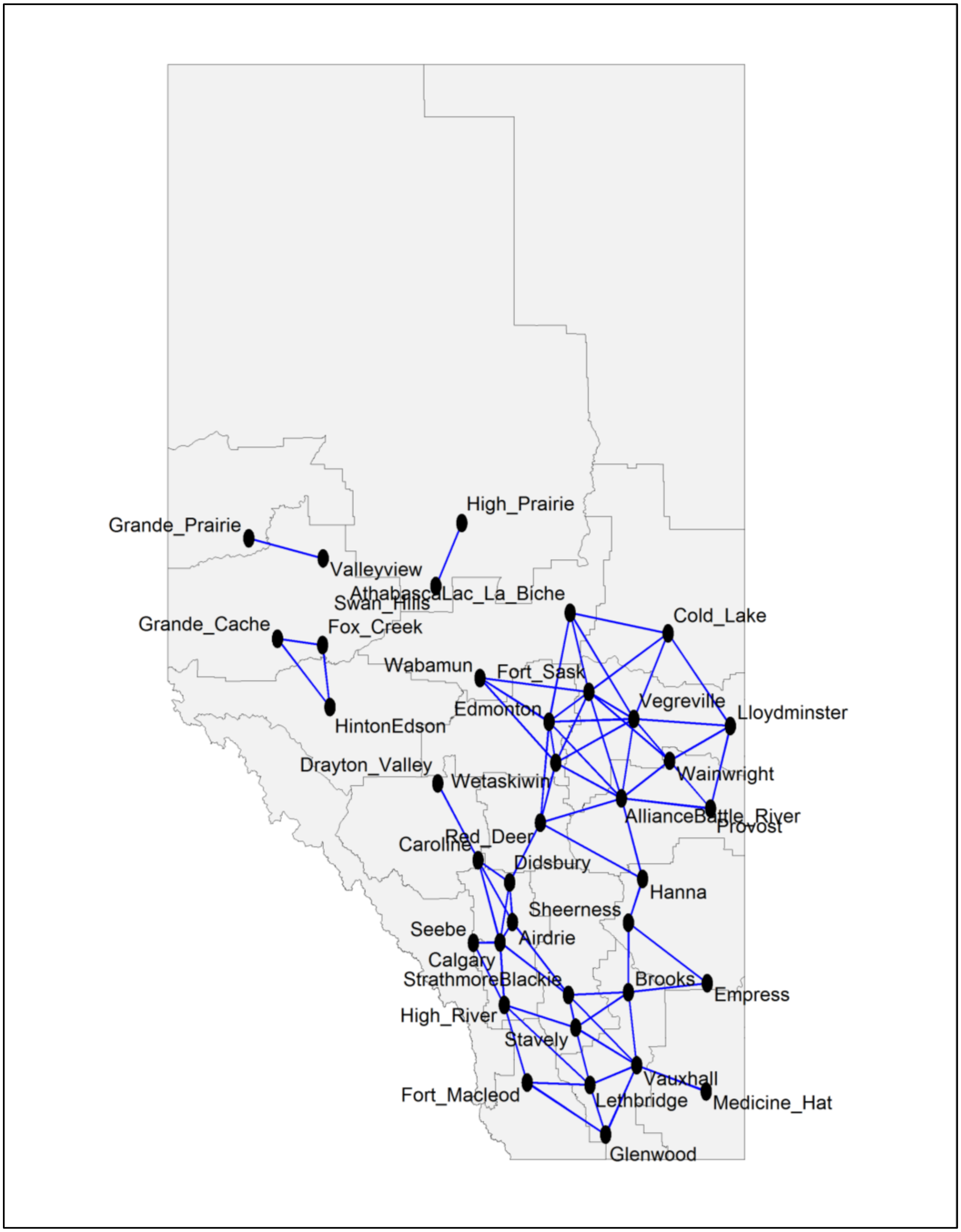

Figure 6.14: Daily Wind Highly Correlating Zones (Filtered for r>0.89)

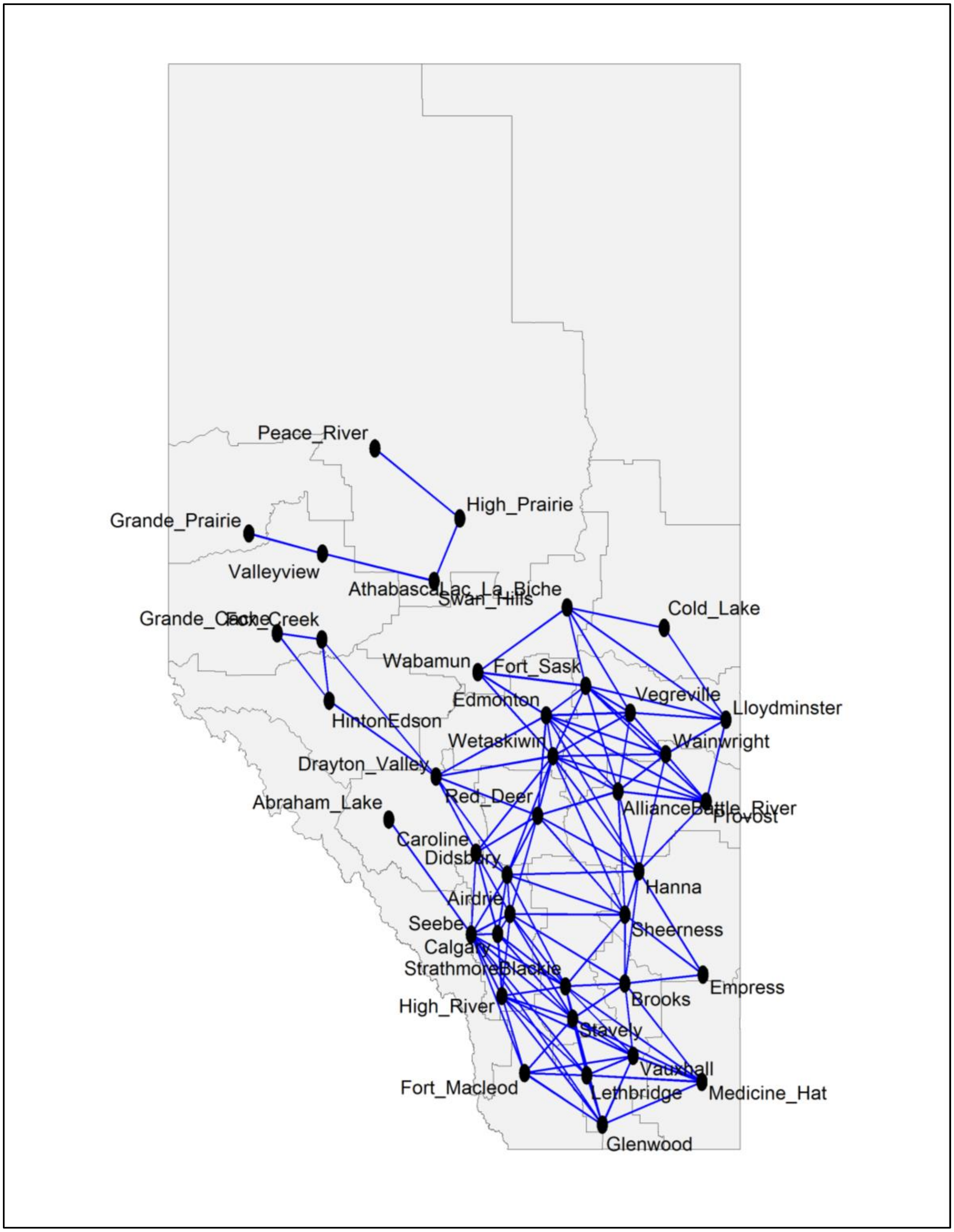

Figure 6.14: Monthly Wind Highly Correlating Zones (Filtered for r>0.94)

7. SUMMARY

A review of Alberta's wind resource shows that the highest wind speeds are expected in the southern and eastern portions of the province. Similarly, the most abundant solar resource potential is located along the southern border of the province. An evaluation of the developable area of Alberta revealed that most of the southwestern area is less suitable for development due to complex terrain. Areas in the north of the province are also less suitable due to the abundance of lakes and wetlands in those areas.

Despite these exclusions, a significant amount of potentially developable area is available in the southern half and eastern portions of Alberta. Assuming that all available area was used for wind or solar development, AWST has calculated the maximum wind and solar capacity build out and energy production potential for 42 planning areas.

AWST estimated the maximum development potential for the entire Alberta province, as well as the individual specified planning areas. The table below summarizes the energy statistics for a maximum build-out scenario based on (1) the land area with and without transmission constraints (constrained and unconstrained, respectively), (2) the assumption that 100% of the non-excluded area is suitable for development, and (3) locations with a net capacity factor above thresholds established in the study.[8]

Table 7.1: Total Potential Solar and Wind Production – Transmission Constrained – 100% Area Case[9]

Resource	Area Greater than 20% (Solar) or 30% (Wind) NCF AND Developable (sq km)	Mean NCF on Developable Land (with Solar NCF >20% AND Wind NCF >30%)	Potential Rated/Peak Hourly Production (GW)	Potential Total Annual Energy Output (GWh/yr)
Solar - Unconstrained	367,645	21.8%	14,705	28,033,103
Solar - Constrained	193,307	21.9%	7,732	14,868,346
Wind - Unconstrained	234,373	36.5%	2,344	7,496,296
Wind - Constrained	124,418	36.7%	1,244	3,998,512

An evaluation of correlation factors showed that there is little correlation in the wind resource between study areas on an hourly basis. Wind and solar are also not strongly correlated within the same study area. Solar production is expected to be well correlated when compared to other planning areas on an hourly basis.

[8], [9] Transmission constrain refers to proximity of existing transmission of 115 kV or greater. For the purpose of this study, it is assumed that projects beyond 20 km from transmission infrastructure are uneconomic.

APPENDIX – LEVELIZED COST OF ENERGY SUMMARY

AWS TRUEPOWER

To: Alberta Electric System Operator
From: Kate Morphis-Berg, AWS Truepower, LLC
Email: Kmorphis-berg@awstruepower.com
Cc: Peter Johnson, AWS Truepower, LLC
Date: June 13, 2018
Re: Levelized Cost of Energy Estimates for Comparison of Alberta Planning Areas

INTRODUCTION

AWS Truepower, LLC, a UL company (AWST), was retained by Alberta Electric System Operator (AESO) to prepare a wind and solar energy assessment to support transmission planning efforts. As part of this work, AWST has calculated the leveled cost of energy (LCOE) for each planning area using the estimated average net capacity factor for each area, along with cost assumptions based on AWST's experience with projects in North America. LCOE estimates are provided using cost assumptions for three future timeframes: 2018 – 2020, 2021 – 2025 and 2026 – 2030.

The other tasks associated with this work including resource and net capacity factor assessment, constraints mapping and production correlation analysis are described in a separate report.

LEVELIZED COST OF ENERGY CALCULATION

AWST assessed a range of levelized costs for solar and wind energy production systems in three timeframes for each AESO planning area: 2018-2020, 2021-2025 and for 2026-2030.

For each time period, AWST will use the following calculation to provide a high-level cost of electricity values.

$$COE = \frac{FCR \cdot (CC \cdot P + IC)}{8760 \cdot CF \cdot P} + OP$$

where:

- FCR = fixed charge rate = 12.8%
- CC = capital cost (individual wind and solar assumptions for each time period)
- IC = interconnection cost – assumed same for wind and solar, assumed standardized distance to the nearest substation (US$200,000 per km) and cost to interconnect (US$1,000,000 to interconnect to existing substation)
- CF = net average plant AC capacity factor (calculated for wind and solar by planning area)
- P = plant nameplate AC capacity (assumed based on regional experience for wind and solar projects)
- OP = operating cost, including O&M expenditures and plant overhead expenditures (individual wind and solar assumptions for each time period)

Wind Cost of Energy Assumptions

The following values were used for the wind LCOE calculations based on the assumptions presented below.

Wind Cost Input Assumptions

Cost Category	Cost (US$/MW – 2017 Real Dollars)		
	2018 - 2020	**2021 – 2025**	**2026 - 2030**
Capital Cost – Turbine	$920,000	$710,000	$390,000
Capital Cost – BOP	$530,000	$480,000	$430,000
Capital Cost - Total	$1,450,000	$1,190,000	$820,000
Operating (O&M) Cost Per Year	$27,950	$25,000	$22,500

Capital Costs

- The turbine capital cost values based on AWST's internal database of turbine costs are adjusted to the representative project's specific turbine and project assumptions based upon AWST's empirical cost relationships with turbine nameplate, hub height, number of turbines, and year of commercial operation.[1]
  - The following assumptions regarding the turbine technology were considered for the different time periods:

	2018 - 2020	**2021 – 2025**	**2026 - 2030**
Hub Height	100 m	110 m	120 m
Turbine Rated Power	3.0 MW	4.0 MW	5.0 MW

- The Balance of Plant (BOP) cost is defined, in this case, to include everything except the turbine.
- A decrease of the BOP cost of 10% every 5 years is assumed[1].

Net Capacity Factor

- The capacity factor used for the planning area calculations are taken from the energy statistics spreadsheets, "Mean NCF on Developable Land NCF >30%" column. Both the transmission constrained and unconstrained cases are presented.

Plant Nameplate AC Capacity

- AWST assumed a 100 MW project size for a representative wind project.

Operating and Maintenance (O&M) Costs

- O&M costs are based on a dataset inclusive of 150+ farm-years of operational data (actual operating costs) and O&M cost projections (financial model assumptions).
- O&M and capital cost data are sourced from different databases.
- Similar to BOP capital cost reductions, we are assuming 10% cost reduction every 5 years for the operating costs.
- An average cost over a 20 year project life is assumed.

1 Colin Tareila. Technology Trends Infocast Presentation. Version 1. February 2018.

Solar Cost of Energy Assumptions

Solar Cost Input Assumptions

Cost Category	Cost (US$/MW – 2017 Real Dollars)		
	2018 - 2020	2021 – 2025	2026 - 2030
Capital Cost	1,000,000	860,000	720,000
Operating (O&M) Cost Per Year	$18,500	$17,500	$17,500

Capital Costs

- The solar cost input assumptions are based on AWST's internal solar project database and are adjusted to the representative project's specific location and project assumptions based upon AWST's empirical cost models and year of commercial operation;
- System equipment and installation costs will continue to decline over time as installation efficiencies increase; however a minimum system cost for existing established technologies will be reached in the near future;
- System soft costs will decrease over time as all involved parties become more familiar with large utility scale PV systems and system designs, and equipment and energy assessments become more standardized;
- Year-to-year reductions in module costs will begin to slow down in the near future as the design and fabrication of the modules are both optimized for production, shipping, durability and reliability. Module costs will become more commodity-driven and will be primarily influenced by raw material and assembly costs. New module technologies may have the ability to further lower costs; however raw materials such as glass, silver and aluminum will still be cost drivers in the manufacturing of PV modules;
- The cost of inverters will begin to level off and may increase slightly as the designs become more mature, new switching components and algorithms are introduced and grid support functions become more integrated into the inverter design; and
- Labor costs are anticipated to drop slightly as system installations become more streamlined; however labor costs will reach a minimum and eventually begin to increase with inflation and general economic growth.

Net Capacity Factor

- The capacity factor used for the planning area calculations are taken from the energy statistics spreadsheets, "Mean NCF on Developable Land NCF >20%" column. Both the transmission constrained and unconstrained cases are presented.

Plant Nameplate Capacity

- AWST assumed a 50 MWAC/70 MWDC project size for a representative solar project.

Operating and Maintenance (O&M) Costs

- O&M costs and cost projections are based on AWST's database of O&M contracts for over 100 systems that are operating and currently under construction and from various national and international databases of operating system costs;
- O&M costs will depend heavily the quality of equipment used, the quality of the installation and the environment (arid, snowy agricultural, etc.) where the system is installed;
- O&M costs are primarily driven by the cost of labor and will not decrease significantly over time;
- Enhanced system monitoring, data analytics and just in time maintenance all have the potential to streamline the O&M process and keep the O&M costs from increasing dramatically; and
- As more experience is obtained from operating systems, the O&M cost models will get more refined however, as new equipment and technologies are deployed, there will be a small increase in O&M costs as providers become familiar with the new technology.

Results

The results of this analysis are presented in an Excel file provided separately to AESO. The calculations are included in the spreadsheet so that AESO can adjust the assumptions as desired to understand the sensitivity of the calculations to the input values.

All of the costs presented in the Excel spreadsheet are in 2017 real dollars (USD and CAD). An assumed USD to CAD exchange rate is included but it is recommended that this be reviewed and updated with the most current information at the time the spreadsheet is used. The costs are presented in $/MWh.