PEMBINA Institute

I'll Have What They're Having

Lessons learned from six jurisdictions leading in wind and solar deployment

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Summary

Decreasing costs of wind and solar have driven a wave of renewable energy integration across the globe. Six jurisdictions — California, Texas, Ireland, Germany, South Australia, and Denmark — have surfed the leading edge of this wave and demonstrated how renewables can contribute to a modern grid. We compare the jurisdictions to the Alberta grid, because of its growing fleet of wind and solar. Despite the different pathways taken by each jurisdiction, our analysis has uncovered several key findings that could help advance wind and solar deployment across Canada:

1. High penetration of wind and solar has already been achieved in both hot and cold climates, and across various sizes of electricity grids.
2. Successful jurisdictions have deployed both wind and solar — including rooftop solar.
3. Improving grid flexibility through energy storage, transmission interties, and demand response is a key factor in enabling renewable development. Many of these technologies can also provide the important ancillary grid services that have traditionally been served by natural gas, coal and hydroelectric generation.
4. Increased development of wind and solar does not correlate with higher energy prices or decreased system reliability. Factors such as market design, transmission system planning, and regulations will play an important role in ensuring a smooth transition.

Together, these findings show that wind and solar can be an integral part of reliable, affordable grids, and that higher levels of renewables development is achievable across all jurisdictions in Canada with long-term planning.

Introduction

For nearly a decade, renewable electricity — wind and solar — has been the lowest-cost option for electricity production.[1] Renewables development continues to break records across the globe, with solar investments surpassing all other power generation technologies combined last year.[2] As a result, electricity grids around the world are now reaching high levels of wind and solar penetration, sparking the questions: how much renewable capacity can existing grid infrastructure handle, and how do we modernize our grids to integrate even more? These questions are especially relevant in Alberta, a province that currently leads the country in new wind and solar installations despite high levels of regulatory and market uncertainty pushing developers to invest in other markets.[3]

To try and answer these questions, we can look around the world to countries and subnational electricity grids that are leading in deployment of wind and solar energy. Here we assess a diverse set of electricity grids: California, Texas, Ireland, Germany, South Australia, and Denmark. Renewable penetration — the proportion of annual electricity generated by wind and solar — in these jurisdictions this year are two to four times as high as in Alberta (Figure 1).

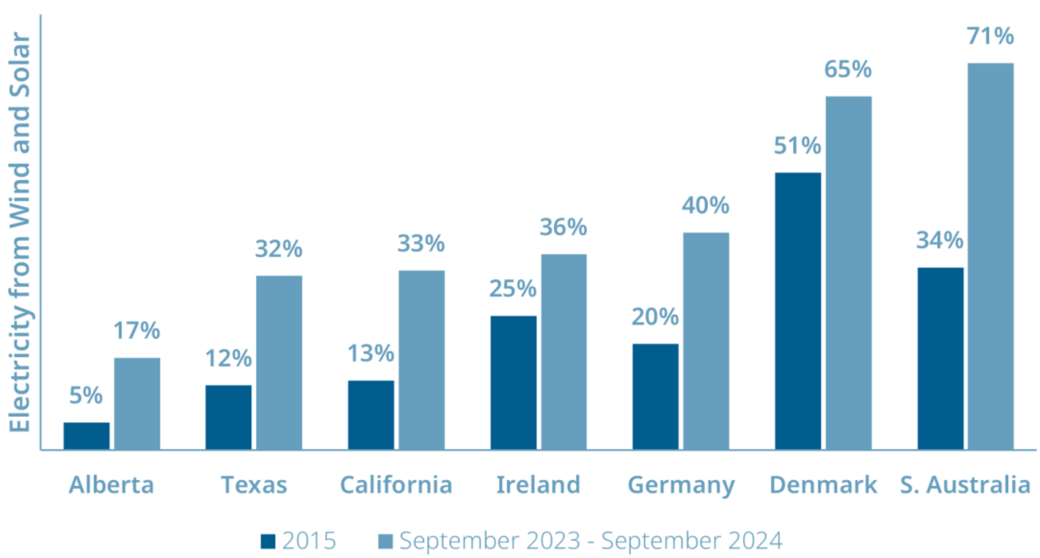

Figure 1. Growth in electricity from wind and solar for selected jurisdictions, 2015 and 2024

Data sources: Alberta Electric System Operator,[4] GridStatus.io,[5] Australian Energy Market Operator,[6] Ember[7]

Key findings

No two electricity grids are exactly alike. Each jurisdiction will have its own unique benefits and challenges in decarbonizing its electricity sector. There are, however, common themes among the leading jurisdictions that we've surveyed that other systems can look to. These findings are discussed below.

Finding 1: Grid size and local climate are not a reason for low renewable penetration.

The jurisdictions studied range in size from small states like South Australia, with a population of 1.8 million and a peak demand of 3,000 MW, to large states like Texas with 80,000+ MW demand peaks. Germany is the largest jurisdiction studied with a population of 83 million. In comparison, Alberta's population is 4.9 million and its peak demand is 12,000 MW.

Temperature-wise, jurisdictions like Texas, California, and South Australia have hot climates and summer peaking systems. Germany and Ireland have milder year-round temperatures, while winter-peaking Denmark is the coldest jurisdiction studied. Although Alberta's winters are harsher than those in the studied jurisdictions, Texas, California and South Australia face summer heat that provides a parallel case study of how high renewable penetration is possible in extreme climates. Integrating renewables into grids in hot climates comes with a different set of challenges, such as navigating peaks during high temperatures when thermal generation facilities must derate. But these challenges are arguably just as difficult as those experienced in colder climates, where winter peaks may occur during or after sunset.

Finding 2: Jurisdictions benefit from developing both solar and wind.

Solar and wind generation are typically complementary, in that the wind blows most often when the sun isn't shining. This is true both on a diurnal timescale — i.e. it is typically windier overnight when the sun has set — and seasonally, where solar dominates summer months but is overtaken by wind during the winter. This phenomenon (for example, see Figure 2) is more prevalent in some jurisdictions but appears to exist in some capacity everywhere.

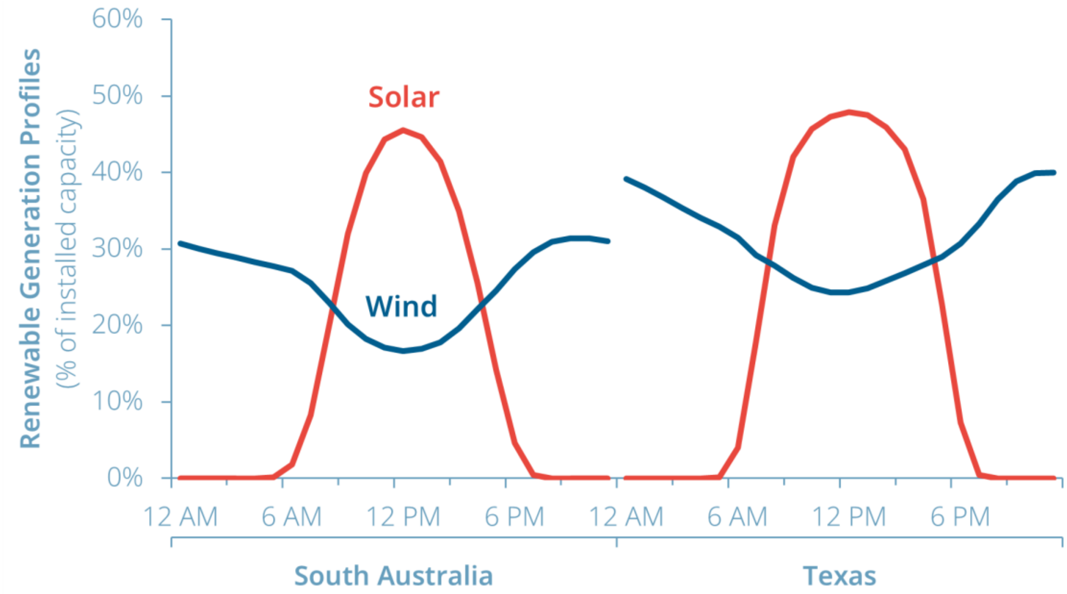

Figure 2. Complement of wind and solar generation profiles on a typical day in South Australia and Texas

Data sources: Australian Energy Market Operator,[8] GridStatus.io[9]

Finding 3: Rooftop solar can play a significant role in reducing electricity sector emissions.

In 2023, 40% of homes in South Australia had rooftop solar panels, totalling over 2,000 MW of capacity.[10] These rooftop solar panels have met nearly 20% of the state's demand in 2024 to date, providing significant power during peak hours, even in the winter (Figure 3). South Australia's success with rooftop solar shows how consumers can play an important role in grid decarbonization. It also shows that integrating high volumes of distribution-connected generation is both possible and effective. Rooftop solar has additional grid benefits beyond producing power: because rooftop solar generates electricity right where it will be used, it can also help reduce line losses, congestion, and transmission costs without new land or transmission development. Homeowners can receive benefits from rooftop solar such as increased home resale value and added resilience during power outages if they opt to pair their solar panels with battery storage. Rooftop solar panels will also reduce the proprietor's electricity bills, though the cost savings depend on several region- and install-specific factors, including the rate and structure of residential electricity plans, number of panels installed and the amount of sunlight that the house receives.

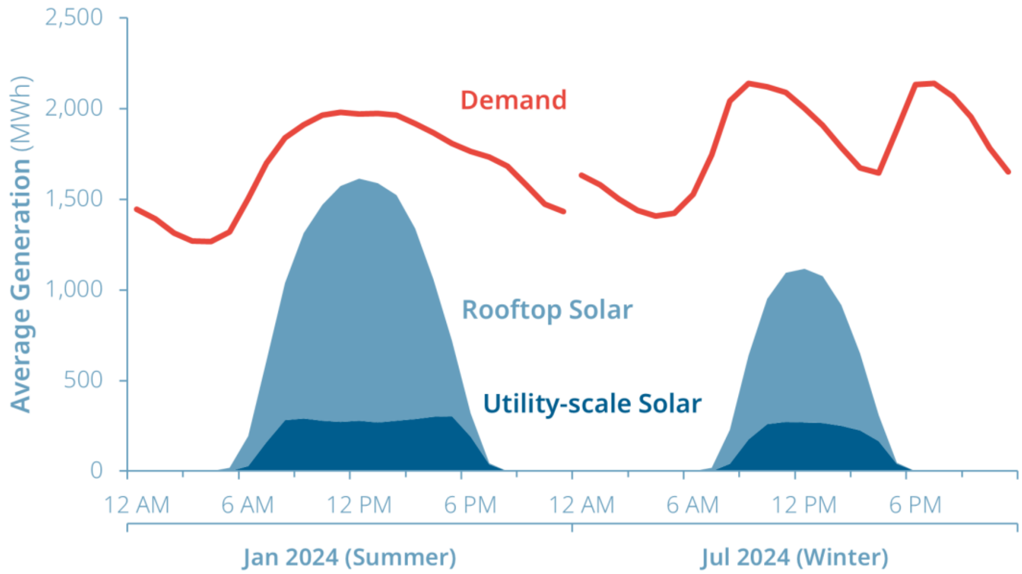

Figure 3. Solar generation relative to demand in South Australia, January 2024 and July 2024

Data source: Australian Energy Market Operator[11]

Finding 4: Energy storage, strong interconnections, and demand response are key enablers of renewable penetration and utilization.

Wind and solar are inherently not dispatchable — that is, their output cannot increase on demand but is instead subject to the local weather conditions. Energy storage, including short duration (e.g. batteries) and long duration (e.g. pumped hydro) allow time- and location-shifting of wind and solar generation, moving electricity from when and where the generators operate to when and where that power is needed. Inter-regional transmission lines connecting jurisdictions (interties) provide a similar benefit in that they allow jurisdictions to trade low-cost wind or solar when it is abundant with their neighbors in exchange for imported power later (typically hydroelectric, nuclear or gas) when wind and solar generation are lower. All the jurisdictions we've scanned have some balance of energy storage, interties, or both (Figure 4), contributing to grid flexibility and allowing for higher penetration of renewables. For example, the European Union announced an electricity interconnection target of 15% by 2030, meaning all member countries should have enough intertie capacity to transport 15% of the electricity they produce to neighbouring countries.[12]

California's management of this summer's heatwave is an example of how these factors support a reliable grid. In previous years, Californians were asked to conserve electricity during heatwaves because the grid was unable to keep up with demand. This year, by adding clean generation capacity alongside increased battery storage and improved coordination between the system operator and government, California's grid was able to handle record-breaking demand while also exporting excess electricity to support its neighbours.[13] Texas has also implemented a demand-response program, discussed in the following section, that uses price signals to encourage reduced consumption during peak events when renewable generation cannot meet demand.

Based on the jurisdictions scanned, there does not seem to be a simple relationship between the mix and amount of flexibility boosting technologies and level of renewable penetration achieved. For example, California and Texas met around 32-33% of their electricity demand with wind and solar over the past 12 months (Figure 1) but have significant differences in intertie, energy storage, and demand-response capabilities (Figure 4). Rather, we find that there are a range of pathways through which an electricity grid can increase flexibility to enable a higher build out of renewables. If Alberta intends to achieve a high percentage of wind and solar energy use (e.g. 30% or more) it should be looking to increase its proportion of intertie, demand response, and/or storage capacity to be more in line with jurisdictions in Figure 4 that have already achieved this milestone. Though Denmark is an edge case in that its extensive interties allow it to go without storage and demand response as a means of incorporating significant wind and solar.

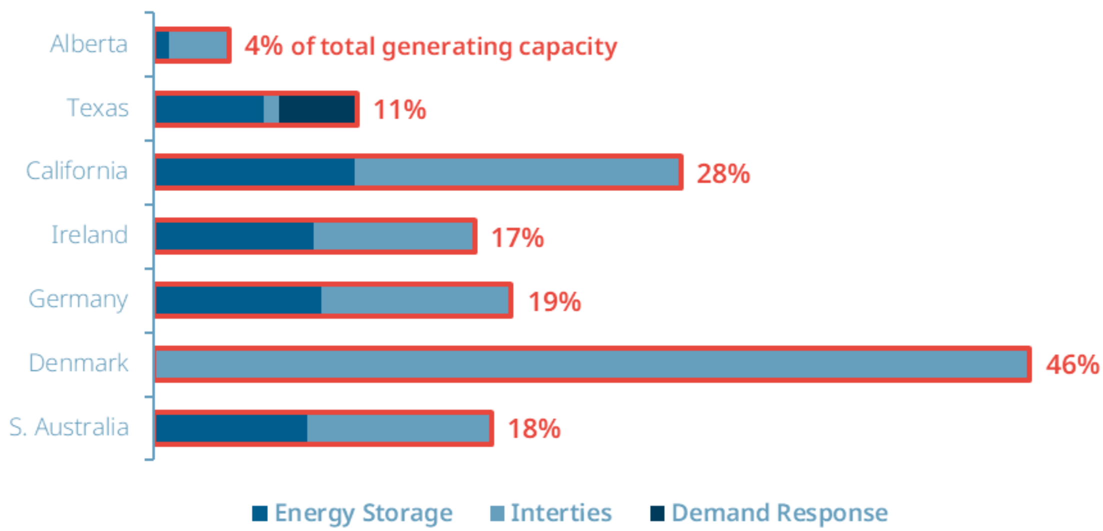

Figure 4. Energy storage, interties (import), and demand-response capacity in selected jurisdictions

Data sources: Alberta Electric System Operator,[14] California Independent System Operator,[15] Electric Reliability Council of Texas,[16] Grid United,[17] EirGrid,[18] Energy Storage Ireland,[19] Power Technology,[20] Energy Charts,[21] Ember,[22] Australian Energy Market Operator,[23] Government of South Australia[24]

Finding 5: Ancillary services can be provided by more than just gas plants.

Ancillary services are used by electricity system operators to ensure reliable operation of the electricity grid, such as correcting for supply imbalances and helping avoid power outages in the event of a disturbance. In most jurisdictions, ancillary services are (currently and historically) provided by large mechanical systems, such as coal, natural gas, and hydroelectric power plants, as their large spinning turbines are capable of balancing grid operations and providing reserve power. However, as a grid incorporates more wind and solar, the quantity and type of ancillary services required to maintain system stability will change, favouring more flexible and agile resources than have been traditionally used. As such, leading jurisdictions are turning to smaller distributed resources such as energy storage (e.g. batteries) and demand-response programs to cost-effectively meet their changing ancillary service needs.

For example, integration of battery energy storage in Australia has been shown to decrease the cost of ancillary services when replacing fossil fuel generators.[25] Texas, on top of extensive and growing energy storage capacity, has also developed several demand-response programs — including energy efficiency measures and options for demand-side market participation — to help balance supply and demand. Through these programs, over 9,000 MW (shown in Figure 4) of demand participate in its ancillary services market.[26] In 2016, the European Union established new requirements for power generators that would allow system operators to require synthetic inertia capabilities from wind farms,[27] the benefits of which have been demonstrated in Quebec since 2006.[28] Ireland has taken a unique approach to bolster grid stability, deploying a 130-tonne flywheel as short-duration energy storage in the form of a rotating mass. The flywheel is large enough that, should the ocean cable between Ireland and Great Britain fail, even while supplying its full 500 MW of capacity, it could provide grid operators with an eight-second buffer (a long time, in terms of electricity grid operations) to remedy the situation.[29]

Finding 6: Increasing renewable penetration does not correlate to higher power prices.

Wholesale power prices are determined by a wide range of factors, including but not limited to electricity market structures, regulations, weather conditions, fuel costs, variations in electricity demand and power plant availability. In most electricity markets, hourly (or sub hourly) price is set by more expensive dispatchable generators, typically natural gas. As a result, the price of natural gas is a major influence on the price of power, even in renewables rich grids (Figure 5), since dispatchable generators most often set the marginal price paid for power.[30] This phenomenon is most prevalent in Europe, where geopolitical instability caused a sharp rise in natural gas prices, and consequently electricity prices, in 2021 and 2022. And, while prices in Ireland, Germany, and Denmark have fallen drastically in the past two years, due to a combination of decreased gas prices and increased supply (mostly wind and solar), they have yet to recover to pre-2021 levels.

California, Texas, and South Australia, on the other hand, have all experienced a decline in wholesale electricity prices relative to 2017, or no change. South Australia is notable because its electricity price declined despite a clear increase in its gas prices, while Texas and California demonstrate that even in jurisdictions with low gas prices, substantial increases in wind and solar generation are compatible with lowering power prices.

Alberta is unique in that it has low gas prices and high (albeit decreasing) electricity prices. A study by the School of Public Policy at the University of Calgary found that between 2020 and 2021, 61% of the increase in power prices can be attributed to a lack of competition.[31] In recent years, a small number of incumbent gas-fired generators have controlled 80 percent of dispatchable power in Alberta, giving them an outsized influence on electricity prices.[32] However, recent decreases in electricity prices have been attributed to increased competition driven by two large, new gas-fired units, and several new solar and wind facilities coming online.[33]

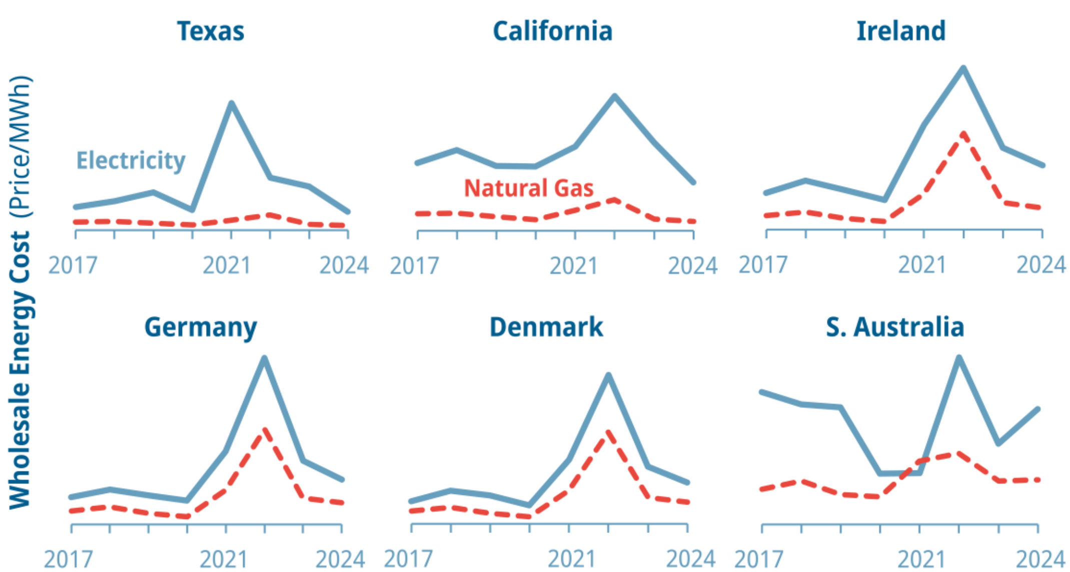

Figure 5. Wholesale electricity and natural gas prices in selected jurisdictions, adjusted for inflation

Data sources: California Independent System Operator,[34] U.S. Energy Information Administration,[35] Potomac Economics,[36] Ember,[37] Trading Economics,[38] Australian Energy Market Operator,[39] Australian Energy Regulator,[40] Triami Media BV[41]

Finding 7: Reliability can be achieved in high renewable penetration grids, particularly in regions that prioritize interconnections and innovation.

The European countries studied have integrated high volumes of renewables onto their grids without sacrificing reliability. In terms of system disruptions, Denmark, Germany and Ireland all performed better than the European and Central Asian average from 2014 to 2019, the most recent data available.[42] In Denmark, where wind generation has been prevalent for decades, the probability that electricity is available on consumer demand was measured at 99.9% in 2015. That 0.1% unavailability was the result of distribution grid issues, not a shortage of supply.[43]

The success of Denmark, Germany, and Ireland is in part due to their interconnection capacities, but also due to their continued learning and innovation. Germany has experienced fewer system disruptions since 2019.[44] In the past three years, Ireland has seen improvements in its winter reliability forecasts, reducing its expectation of system disruption from 51 hours to 3.6.[45] While this is still 0.6 hours outside Ireland's standard, there is no risk of a full system blackout caused by insufficient generation this coming winter.[46] Ireland's improved forecasts are due in part to the procurement of a new 190 MW gas peaking plant and 270 MW of new batteries.[47] Small amounts of gas generation can improve reliability, but they are required only during periods of peak demand.

South Australia also uses gas plants as a security measure. The Australian Energy Market Operator (AEMO) requires a minimum of two gas, coal or hydroelectric generators to be online at any given time to help maintain grid frequency.[48] The AEMO is in the process of reducing dependence on these resources for reliability so that they can bring more renewables online. A recent AEMO study has found that batteries, wind and solar generation, plus frequency and voltage management devices installed in 2021, can maintain grid frequency without needing backup gas, coal or hydroelectric.[49]

The U.S. has the worst grid reliability among advanced economies, largely due to its aging infrastructure and extreme weather.[50, 51] Despite this, California's grid reliability has been on an upward trend. Over the past two years, it added over 11,000 MW of clean energy to the grid, bolstered its battery fleet to nearly 10,000 MW, and added no gas-fired generation. These new clean energy and storage resources, combined with increased collaboration between system actors and a well-connected regional electricity market that balances supply and demand, helped California weather three weeks of extreme heat in the summer of 2024 without mandating conservation, as noted above.

Texas showed significant improvement in reducing its system disruptions between 2021[52] and 2022[53] but remains an outlier in several ways. One challenge is that the Texas electricity grid is one of the only grids in the U.S. that operates in isolation, and therefore cannot share resources with its neighbours like the other jurisdictions in this analysis. Extreme weather has also exposed the weaknesses of its aging grid infrastructure and has increased the risk of their gas system freezing. It is not a coincidence that Texas has had the most power outages of any U.S. state since 2019.[54]

In the past few years, Alberta has seen a sharp rise in emergency grid alerts, with 16 level three (the highest level) alerts between 2022 and April 2024, largely caused by unexpected outages of large gas plants during high demand and low wind generation events. For context, the province saw only two level three alerts in the 2010s and a single level three alert in the 2000s.[55] In a modern and reliable grid, these alerts should not be so common. Improving the province's interconnection capacity would improve its reliability. The importance of interconnection and energy storage was experienced firsthand on January 13, 2024, when the province narrowly missed brownouts by leaning on its neighbours and small fleet of batteries.[56] As shown in Figure 4, Alberta's intertie and storage capacity is only 4% of total generation capacity, though in this instance it was enough to avoid the worst impacts of that grid alert. Interconnection capacity as well as dependable transmission and distribution networks within a jurisdiction are necessary to reliable grid systems — with high renewable penetration or without.

Conclusion

As the cost of deploying wind and solar continues to decline, countries and sub-national electricity grids around the world continue to push the envelope on renewable energy integration. Through a scan of six leading jurisdictions — California, Texas, Ireland, Germany, South Australia, and Denmark — we've identified some common characteristics and pathways through which other electricity grids could increase wind and solar development while maintaining affordability and reliability.

The Pembina Institute acknowledges that the work we steward and those we serve span across many Nations. We respectfully acknowledge the space our organization is headquartered in as the traditional and ancestral territories of the Blackfoot Confederacy, comprised of the bands Siksika, Piikani, and Kainai, the Îyârhe Nakoda Nations, including the bands of Goodstoney, Chiniki, and Bearspaw, and the Tsuut'ina Dené. These Lands are also home to the Otipemisiwak Métis Government (Districts 5 and 6) whose Peoples have deep relationships with the Land.

These acknowledgements are some of the beginning steps on a journey of several generations. We share them in the spirit of truth, justice, reconciliation, and to contribute to a more equitable and inclusive future for all of society.

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