ERCOT MARKET COLD WEATHER FAILURE FEBRUARY 10-19, 2021: EXAGGERATED WIND ENERGY LOSSES AND CORRECTIVE ACTIONS

Summary of Study

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As a result of the ERCOT operational crisis caused by cold weather 10-19 February 2021, the wind farms in ERCOT sustained financial impacts of more than $4 billion – more than twice their annual gross revenues.

Since February, a great deal has been written about the enormous financial impacts of the ERCOT's order to set its settlement hub electricity price at $9,000/MWh, but this is only part of the story.

Wind Farm Financial Hedge Risk Asymmetry

The wind industry has been using financing structures that exacerbated the magnitude of the potential losses during the cold weather event. Hedges used to finance 50% of ERCOT wind projects have several different variations. All wind farm hedges in ERCOT share one important characteristic that has been poorly appreciated until now: they have a highly asymmetric risk that can cause enormous losses in very short periods of time. This exposure jeopardizes the financial stability of the underlying assets. Many wind farms in ERCOT are now experiencing such effects.

We did a study to quantify these asymmetric risks and to provide some practical guidance for wind farm owners and their contractual counterparties about how to structure similar deals to reduce the risks to more acceptable levels. Based on an in-depth, time-series data analysis of wind energy project site-specific wind speed, net capacity factor, and hub settlement pricing, we found that:

- The overall financial impact of icing outages and maximum electricity prices on ERCOT wind farms was 4.2B.
- The average financial impact across all wind projects was determined to be $44.4 million; the maximum financial impact for a single project was found to be $172.5 million.
- The magnitude of losses is many times a wind farm's annual net income, and depending on the type of financial hedge, could negate a large fraction of the project's lifetime return.

A combination of meteorological conditions during the February storm – multiple icing events, prolonged cold temperatures, and high air density – led to downtime for over 87% of the ERCOT wind turbine fleet. When a sufficient amount of ice forms on wind turbine blades, the turbines become inoperable. This combination of conditions, while unusually long, has been inaccurately described as rare and low-probability. They are not. The meteorological record suggests similar events will occur several times during the 30-year useful life of a wind farm in much of Texas.

These climatic realities need to be properly reflected in the risk assessment of the hedged financial products where a wind farm owner has an obligation to deliver potential production (proxy generation) or long-term mean hourly electricity production (fixed shape) to a financial counterparty. The February ERCOT crisis revealed that most wind farm owners had not properly appreciated the asymmetry in value between the benefits of the fixed revenue stream on the one hand and the enormous potential liabilities from weather and regulatory events on the other.

Our analysis has resulted in some data-driven, quantitative tools that provide wind farm owners and their hedge counterparties the ability to quantify and understand these asymmetric risks. Specifically, we recommend three (3) immediate corrective actions:

- Hedged financial structures in ERCOT need to properly reflect realistic meteorological conditions, extreme weather stress tests, and, therefore, more realistic production assurances.
- Hedged products need to recalibrate their strike prices to reflect the asymmetric risks presented by the availability of different resources during extreme electricity demand, ERCOT minimum and maximum prices, and market interventions by regulators.
- Wind farm owners and their hedge counterparties need to partner with turbine OEMs to develop reliable, cost-effective weatherization technologies to reduce the asymmetric risks from future icing events.

Methodology and Pricing/Repricing Results in Brief

In this study, the production and financial impact results are based on an in-depth time series analysis of site-specific wind energy project data: key variables are wind speed, net capacity factor, and hub settlement pricing. Results are categorized into wind energy projects with hedge financing structures and those without. The focus of the study is on wind farm outages reported by the Electrical Reliability Council of Texas (ERCOT) for the period of 14-19 February 2021. Three repricing scenarios are evaluated using market pricing prior to the imposition of $9000/MWh prices by ERCOT.

21,888 Megawatts (MW) of wind farm nameplate capacity, 87 percent of the 25,121 MW ERCOT wind capacity, are evaluated. 12,495 MW, or 57 percent, of the 21,888-MW total, is estimated to be subject to a hedged financial structure. There are 191 wind farm ERCOT Units and 114 wind farms or 94 wind farm clusters. Individual wind farm results are not presented in this report. We estimate the uncertainty of the financial impact dollar values presented herein, based on proprietary information from owner/operators, for the downtime periods studied, to be approximately 15 percent.

While wind farm downtime was primarily caused by icing weather conditions, other lesser sources of downtime were grid outages and cold temperature shutdown. Depending on wind farm location, between one and several icing events occurred, from thick coatings of ice caused by freezing rain to rime ice in freezing fog. Exacerbating the problem was an unprecedented period of air temperatures below freezing, which lingered over Texas for several days and prevented ice melt.

Average icing event air density values were 8-10 percent above long-term average air density during the event, which increased proxy energy production. Site-specific wind speeds and direction have been derived from ERA5 weather-reanalysis hourly wind time series, adjusted to site hub height using validation sources. In turn, based on wind energy resource assessment practice and turbine and wind plant specifications, we estimated the hourly proxy net capacity factor and production for all wind farms with reported outages.

We find that the lost energy production from wind farms that would have otherwise operated, were it not for the icing event, was 629,700 Megawatt hours (MWh). The average wind speed and net capacity factor during the downtime period, aggregated across all wind farms, were found to be 6.3 m/s and 30.6 percent, respectively.

The financial impact of this lost production, whether the financial loss to the owner or gain by others, for the 14-19 February outage periods studied, was $4.18B. The maximum financial impact for a project was found to be $172.5M. The average financial impact across all projects was determined to be $44.4M.

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For hedged projects, the financial impact of this lost proxy production is $2.59B. The maximum financial impact for any wind farm cluster was found to be $172.5M. The average financial impact on any wind farm cluster is found to be $45.4M.

Repricing Scenarios

Given that the market demand was decreased by ERCOT with blackouts, so that production balanced that reduced demand, market prices may have been high but not near the $9000/MWh imposed value. It is not possible to predict power prices had ERCOT not mandated maximum pricing. Three repricing scenarios show reduced financial impacts from the $4.2B baseline value:

- based on the $1826/MWh average electricity price during the 24 hours before 0800 14 February 2021, we find that the overall financial impact drops by 75.9 percent to $1.01B,
- based on the $2186/MWh average electricity price during the 24 hours before ERCOT began load shedding (0125 15 February), we find that the overall financial impact drops by 61.8 percent to $1.60B, and
- based on the $6007/MWh average electricity price during the 24 hours before 1700 15 February, when ERCOT imposed the $9000/MWh pricing mandate, we find that the overall financial impact drops by 26.3 percent to $3.08B.

Further Considerations of Hedge Risk Asymmetry

We have observed that the estimated average financial impact, $45M, of the February 2021 Texas icing and cold weather event on an individual Texas wind farm, without icing mitigation capability and based on common net capacity factors of Texas wind farms, exceeds its typical nominal annual revenue by more than two times. The financial impact is many times a wind farm's annual net income, and, therefore, depending on the wind farm's financial structure, negates a large fraction of a project's lifetime return and creates a significant risk of default.

Climatologically speaking, similar, if most likely shorter, icing and cold weather events will occur several times during the 30-year useful life of a wind farm in much of Texas. (These conditions are less likely for Gulf Coast wind farms, but these producers are more likely to be affected by a different extreme weather event, hurricanes.). For example, after the 2011 cold weather event, which also caused rolling blackouts, FERC and NERC (2011) reported that similar events had occurred in 1983, 1989, 2003, 2006, 2008, and 2010. Therefore, especially if icing mitigation capability is not present, such risks must be accounted for in financial modeling, and pricing should be adjusted upward to account for this risk, lest the project is unable to meet its obligations in time of a production crisis.

The financial structures that require this risk assessment are those where potential production (proxy generation) or long-term mean hourly electricity production (fixed-shape) must be delivered to the financier by operator purchase should the project be unable to operate for any reason. This pricing risk is highly asymmetric. In Texas, the hedge provider price risk is limited to the strike price (up to $20/MWh, or more if prior to 2019) plus the value of the production tax credit, for a value near $40/MWh; asymmetrically, project owner price risk is the maximum possible hub settled price minus the strike price, near $9000/MWh. In ERCOT, unmitigated proxy or fixed-shape hedged price risk for project owners is 225 times larger than that of the hedge provider. We conclude that all such hedges, from a realistic atmospheric science perspective, without turbine icing mitigation, are fundamentally misdiagnosed, with previously unaccounted-for risks and highly asymmetric windfall advantages to the hedge provider. Business interruption insurance, per-megawatt daily caps, to limit risk asymmetry, and/or avoiding fixed-volume hedges and using only as-generated hedges are all possible solutions.

Average wholesale 2020 electricity prices in ERCOT are near $20/MWh, and that ERCOT 2020 energy consumption was 381,000,000 MWh; wholesale electricity purchases in 2020 were $7.6B. The energy purchases during the ERCOT winter event totaled $46B, or six times higher than the 2020 annual total. We conclude, assuming one such event per decade and 2020 average pricing, that the effective realized decadal average ERCOT electricity price is $30/MWh, 50 percent higher than reflected in the 2020 annual average. According to Energy Information Administration (EIA) wholesale pricing data (https://www.eia.gov/electricity/wholesale/#history), ERCOT prices have averaged between $20/MWh and $40/MWh since 2014. If structural changes are not made to the ERCOT grid and market operation, future Texas contracts should reflect a price, likely between $30/MWh and $40/MWh, that accounts for icing events and the very highest ERCOT pricing possible for a few days per year. As-generated production hedges remove the asymmetric risk, although the lost opportunity to sell electricity in icing conditions remains a risk.

Considering Wind Farm Weatherization

Weatherization packages are available from wind turbine manufacturers and from third-party after-market suppliers. These can take the form of cold-weather packages, including heaters and special lubricants to allow operation at colder temperatures. These cold-weather packages are commonly purchased, and many wind farms in Texas have done so. In addition, anti-icing and de-icing packages are available from wind turbine manufacturers as options or from third-party providers as after-market retrofits. The use of such systems is common in Nordic countries, and other locales where icing is frequent and generation must be assured. Anti-icing and de-icing systems take the form of coatings applied to the exterior of blades to discourage ice from sticking, mats with resistive heating applied to critical locations on the blades, or heaters and fans in the blade roots with air chambers that direct heated air through the blades. One company in Canada outfitted a helicopter with an aerial cleaning and de-icing system that can be used to clear ice off of wind turbine blades.

Texas currently has 25,121 MW of wind capacity, mostly unprotected from icing events. Costs of anti-icing and de-icing systems are not widely published, but one publication (Moran 2021) estimates that icing mitigation adds approximately 5-10 percent to turbine price or $50,000 to $100,000 per MW at $1,000,000 per MW at purchase. Thus, upfront icing mitigation of all wind turbines in Texas would have cost $1.25B to $2.50B. The cost of icing mitigation, therefore, would have been less than the $4.18b impacts of the icing event. In hindsight, many project owners likely wish they had purchased an ice mitigation option for their wind turbines. However, that is only because market prices were artificially elevated to $9000/MWh. For most wind farms with fixed-price PPAs, or those that do not experience such unusual market conditions, selection of an ice mitigation option often does not make sense. When a developer is bidding for an offtake agreement, the added cost of an anti-icing or de-icing system harms the competitiveness of a project.

As the penetration of renewables increases over time, it will be more important for system operators to rely on wind energy generation during cold weather ice events such as that experienced in Texas in February 2021. However, project economics do not incentivize developers to install such systems. Installation of additional weatherization equipment may be incentivized if wind farms received capacity credits and capacity payments. These payments could potentially be tied to a requirement that ice mitigation equipment is installed. With sufficiently high penetration of renewables, it might even become necessary for regulators to require weatherization packages, much as aviation lighting is currently mandated. With the widespread use of weatherization packages, perhaps encouraged by the need for resilience in wind energy generation during extreme cold weather events, there would likely be more competition in the market, and prices would likely drop far below the less attractive current rate of 5% to 10% of turbine price.

Appropriate *force majeure* clauses in hedge agreements could potentially mitigate this asymmetric price risk, but that would not help the physical availability of wind generation as renewables continue to penetrate energy markets.

Regarding Weather-Driven Electricity Production and ERCOT Planning

We believe the ERCOT winter weather event and the frailties it revealed in its electricity system planning and operation is a clear mandate that such planning for the ERCOT balancing authority must now more stringently apply atmospheric science-based risk assessment, particularly with regard to extreme weather and peak demand operational scenarios.

ERCOT has more installed wind energy capacity than any state in the United States. It is projected that its renewable energy capacity will exceed 60 gigawatts (GW) within three years and will dominate regular ERCOT generating (not storage or peaker) capacity within a decade.

Electricity production is accelerating toward predominantly wind and solar energy sources, whose fuel, wind, and solar radiation, are governed by the weather at any particular power plant location. Electricity usage, in particular, extreme electricity usage, is similarly governed primarily by changing weather conditions, such as high and low-temperature events. Weather-driven peak electricity demand is clearly understood.

These two statements plainly indicate the need to restructure electricity system resilience and reliability to account for weather-driven production and weather-driven demand, concomitant with the pace of the transition to renewable-energy-dominated production.

Based on atmospheric science principles, we know how solar radiation and wind vary, both temporally and spatially. For example, as relevant to ERCOT, extreme synoptic-scale weather events that persist for one to two weeks over areas the size of Texas can be predicted in advance. We also know that there are always sufficient supplies of electricity produced by wind and solar available across the contiguous United States; with sufficient transmission, this electricity may be transported to any location experiencing a local or regional shortage. We also know that at any given time at a particular wind and solar power plant location, the resource may be zero.

Weather-driven electricity production is inevitable as economically advantaged renewable energy comes to dominate generation capacity in ERCOT. ArcVera's analysis and observations, taken together, clearly describe a condition where, with greater attention to atmospheric science details when assessing the risks of weather-driven electricity production and demand, an adequately resilient and interconnected ERCOT electricity system can be created. ERCOT planning should consider that cold-weather events worse than the recent February 10-19, 2021 event are possible.