the influence of Information Technology on the Energy Mix in Texas

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EXECUTIVE SUMMARY

This report examines the impacts of information technologies (IT) on carbon emissions and electricity price in electricity markets. Specifically, this report focuses on the role IT played in enabling the Electric Reliability Council of Texas' (ERCOT) transition to a nodal market, the subsequent impacts on the penetration of renewable energy, and the resulting effects on carbon emissions and electricity prices. In summary, IT and data have been core enablers in this transition.

About ERCOT

- Electricity markets have been evolving since their inception and now constitute one of, if not the most complex machine(s) on earth. ERCOT covers 75% of Texas land area and about 85% of the electric load within the state.
- The ERCOT grid connects more than 43,000 miles of transmission lines and more than 570 utility-scale generation units.
- ERCOT underwent a major transition in 2010 from zonal to nodal operation that enabled more efficient market performance.
- The percentage of electricity provided by wind in ERCOT has increased from 2% in 2006 to about 18% in 2017 while total electricity use has increased in parallel.

The Role of IT

- ERCOT operates multiple markets for energy and reliability that require quickly processing large volumes of data on electricity demand, supply, and transmission characteristics
- Real-time data-driven grid insight and assessment tools have helped facilitate the continued increase in wind and solar deployments in ERCOT.
- Accurate wind and solar forecasts benefit grids with high levels of renewable energy.
- ERCOT has developed a new IT-driven Reliability Risk Desk on the operation room floor to better incorporate data from and about wind and solar operations to grid operators.

OUTCOMES

Market efficiencies, increased wind generation, and the lower price of natural gas in ERCOT have all resulted in:

- **Lower carbon intensity of electricity**
- **Lower wholesale market costs of electricity**

Average retail rates for electricity in Texas have fallen 18% in the past 10 years

Direct investments by major corporations in Texas wind exceed $6.5 billion dollars, with wind-inspired investments likely in the tens of billions

IT-enabled efficiency improvements of the ERCOT market helped decarbonize the grid while lowering prices for consumers

guidance/future

- Any grid looking to incorporate large amounts of variable, renewable generation into their system can learn lessons from the Texas grid.
- Higher penetrations of renewables in any grid can benefit from faster IT and controls.
- It would be beneficial to develop fast-response control systems that allow for synthetic inertia to provide grid frequency response in real time.
- Distribution edge pricing will exponentially increase the amount of data the grid needs and generates.
- More research is needed to determine the benefit of block chain technologies to the grid.

Introduction & Background

This report looks at the role of IT in ERCOT as a case study for the role it might play in modern power markets elsewhere. Power markets are at a transition, with some stakeholder groups pushing towards deregulation to encourage more competition, some pushing for re-regulation to protect conventional generators such as nuclear and coal, and some pushing for mandates that include storage, demand response, distributed energy resources, or renewable energy. In all of these instances, the increasing information intensity of the power sector is driving a growing role for IT.[1] Understanding the recent ERCOT example is instructive of the increasing IT demands in a modern electric market.

A Very Brief History & Overview of Electricity Markets in the US

The first centralized utility model was built by Thomas Edison in 1882 as a DC power grid.[2] Within a couple of decades, the beginnings of the modern AC power grid were refined by Westinghouse and Tesla. Samuel Insull created the modern natural monopoly utility in 1932.[3] FDR created the Rural Electrification Administration in 1935 and by 1945 almost 90% of rural homes were electrified.[4] The sector began a process of deregulation after the energy crises in the 1970s and today some areas have been opened up to competition in the wholesale and retail sectors. Through the years, mergers between many smaller grids have allowed for a more reliable supply of electricity. In the U.S. there are 10 major grid-balancing regions and 3 major grid interconnections; the Eastern Interconnection, the Western Interconnection, and ERCOT. The structure of the interconnections helps maintain the reliability of the power system by providing multiple routes for electricity to flow. It also enables generators to supply electricity to many load centers. This redundancy helps prevent transmission line or power plant failures from causing interruptions in service. The grid-balancing regions match supply and demand in real time, adjusting operations as needed.

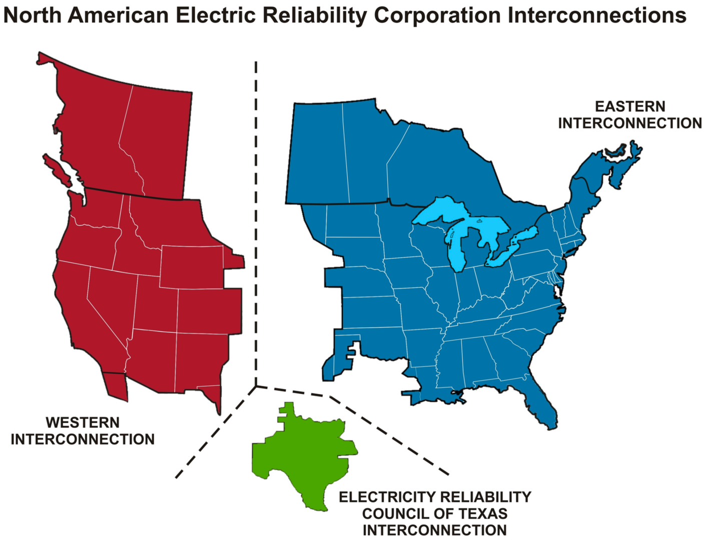

Figure 1: The US (and most of Canada) consist of three synchronous interconnections. Figure from the US Department of Energy . [5]

A Very Brief History of ERCOT[6]

The Electric Reliability Council of Texas (ERCOT) facilitates multiple levels of markets that are designed to provide reliable and secure electricity within its borders. ERCOT covers 75% of Texas land area and about 85% of the electric load within the state. The ERCOT grid connects more than 43,000 miles of transmission lines and more than 570 utility-scale generation units, or power plants larger than 1 megawatt. ERCOT is a 501(c)(4) membership-based nonprofit that is overseen by the Public Utility Commission of Texas and the Texas Legislature. ERCOT is not a market participant and does not own generation or transmission/distribution wires.

The genesis of the ERCOT began in 1941 when multiple electric utilities merged as the Texas Interconnected System (TIS) to support the US war effort by sending power to aluminum smelters on the Gulf Coast. The utilities, realizing the benefits of being connected, remained so after the war. TIS created ERCOT in 1970 to comply with the North American Electric Reliability Corporation (NERC) requirements. By 1981, TIS transferred all operations to ERCOT. In 1995, the Texas Legislature began deregulation in the wholesale generation sector and the first commercial wind farm began operation in ERCOT.

In 1996, ERCOT became an Independent System Operator (ISO) and in 1999 the Texas Legislature voted to deregulate the retail electricity sector. In 2001, ten separate ERCOT control centers were concentrated into a single control center for the entire grid.

In 2002, the retail electricity market opened to about 75% of ERCOT load and by 2005 25% of retail customers had switched from their incumbent provider. In 2006, Texas surpassed California in wind power and continues to set wind records every year. In 2010, the first utility scale solar farm connected to the ERCOT grid and the wholesale market shifted from zonal to nodal, significantly changing power plant dispatch and data fidelity. In 2013, the Competitive Renewable Energy Zones were connected by about 3,600 miles of transmission lines from wind rich West Texas to Central Texas load centers. The next year wind power output from West Texas exceeded 10,000 MW.

By the end of 2017, ERCOT had connected more than 20,000 MW of wind and 1,000 MW of utility-scale solar to the grid with expectations for 30,000 MW of wind and 3,000 MW of solar installed by 2020.

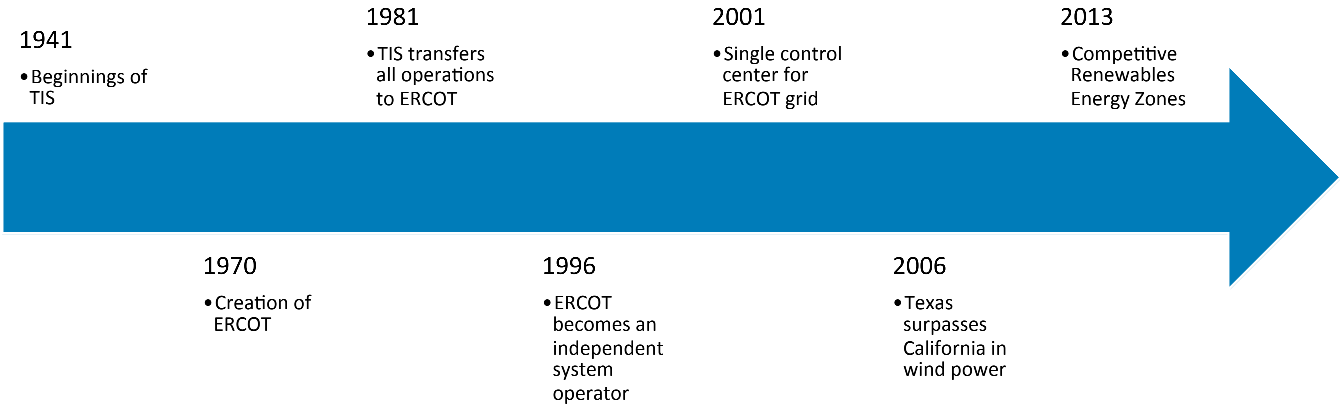

Figure 2

How ERCOT Dispatches Power

ERCOT has multiple mechanisms for ensuring sufficient power plants are online to match demand in any given interval, including the Long Term System Assessments (LTSA) (which spans years and decades) to sub-second frequency response. However, the bulk of the energy managed by ERCOT is managed through the Security Constrained Economic Dispatch (SCED) of power plants.

One can think of SCED as an energy auction that ERCOT holds every five minutes. Participating power plants bid how much power and at what price they are willing to sell into the market. ERCOT takes all the bids and sorts them from lowest to highest price. This sorted arrangement is often called a “bid-stack”. Then ERCOT sums the power plants’ capacities, stopping at the amount needed to meet demand. The most expensive dispatched generator is referred to as the *marginal generator* and its bid is the *marginal clearing price of energy* (mcpe). All the power plants at this threshold and below are awarded the right to put their power into the system and everyone is paid the marginal clearing price set by the marginal generator in that interval. The remaining power plants that bid higher than the marginal price are not dispatched, are not allowed to put power into the system, and are not paid.

Figure 3 illustrates an example bid-stack for ERCOT sorted from lowest-to-highest price (in $/MWh along the y-axis) with the power plants’ capacities denoted by each bid’s width (in GW along the x-axis). At the time represented in Figure 1, ERCOT system-wide demand is about 40 GW, represented by the vertical black line in the figure. Thus, everything to the left of the black line (a mix of renewables, nuclear, coal, and natural gas) is sending power to the grid while everything to the right of the line is not. This auction is re-run every five minutes and the whole process starts over.

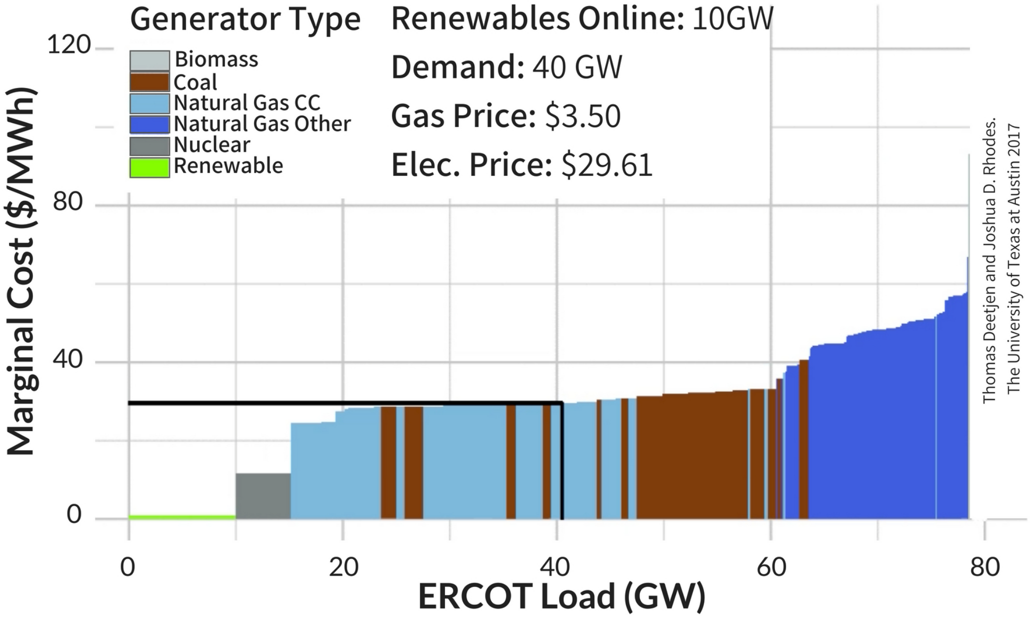

Figure 3: Example bid-stack for ERCOT[7]

Changes to ERCOT

There have been some significant changes to ERCOT's market that have changed the dispatch and operations of the market. ERCOT incorporates changes to its protocols through a stakeholder committee-driven Nodal Protocol Revision Requests (NPRR) process. Summarized below are a few of the recent changes that have directly affected ERCOT's ability to leverage data and incorporate more wind and solar into the grid mix.

One significant change was ERCOT's transition from a zonal to a nodal market. ERCOT's previous Zonal market only allowed ERCOT to balance supply and demand between four zones (West, North, South, and Houston), but not within each zone. Under this system, it was not always guaranteed that the cheapest generation source would be dispatched.

The Nodal market divided the four zones into thousands of nodes and, because Nodal allowed for congestion pricing, power plant dispatch became more efficient. [8]

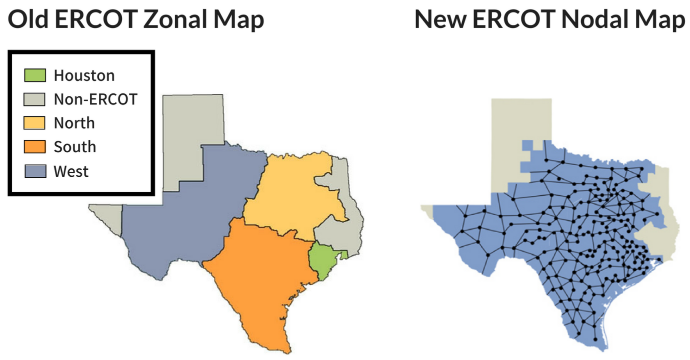

Figure 4: Figure showing the difference in the fidelity of power generation dispatch before and after the switch from a zonal to nodal market in ERCOT. [9]

Beyond ERCOT's energy market, there are ancillary service markets that provide critical services for grid operations. These services, defined by FERC,[10] include Scheduling, System Control and Dispatch, Reactive Supply and Voltage Control, Regulation and Frequency Response, Energy Imbalance; and Operational Reserves.[11] Each of these services meets a specific need and has a different response time ranging from seconds to hours. Because reliable operation of a power system means that no component should function outside its safe operating range, even in the event of disturbances,[12] and because of recent increases in variable renewable generators, the roles of ancillary services and operational reserves are receiving more scrutiny. Table 1 shows a summary of selected grid services, including longer planning assessments.

Time-Scale	Service	Notes/Comments
Seconds	Regulation, frequency, response, reactive supply, voltage control	Real-time control of deviations in grid operations to maintain stability
Minutes	Security Constrained Economic Dispatch TSAT, VSAT	Real-time dispatch of power plants and assessment of system conditions
Hours to Days	Wind and solar forecasts	Provided on a rolling basis from 3rd party vendors
Weeks to Months	Seasonal Assessment of Resource Adequacy (SARA)	The SARA reflects near-term weather forecasts, generator outage trends, and updates to the generation fleet
Years to Decades	Long-Term System Assessments, Capacity, Demand and Reserves Report, Regional Transmission Plan	Assessment of trends that could affect grid operations in the long term

Table 1

Dispatch of power plants was also reduced from 15 to 5-minute intervals allowing for more precise matching of load to generation. Because more changes in the market could be met with energy dispatch (turning power plants up and down every 5 instead of 15 min), lower levels of ancillary services (power plants on quick standby to make up for differences in load and generation) were needed. Having access to more data and computing ability enabled these rule changes that made the grid more finely-resolved in place and time. Because of the grid's higher fidelity, it was easier to accommodate increasing levels of variable renewables without driving up reliability costs. Figure 5 (below) shows this reduction in Regulation-Up requirements (blue line) even as wind capacity (red line) continued to increase, with a big step-down in costs in 2010 when ERCOT's methodology changed.

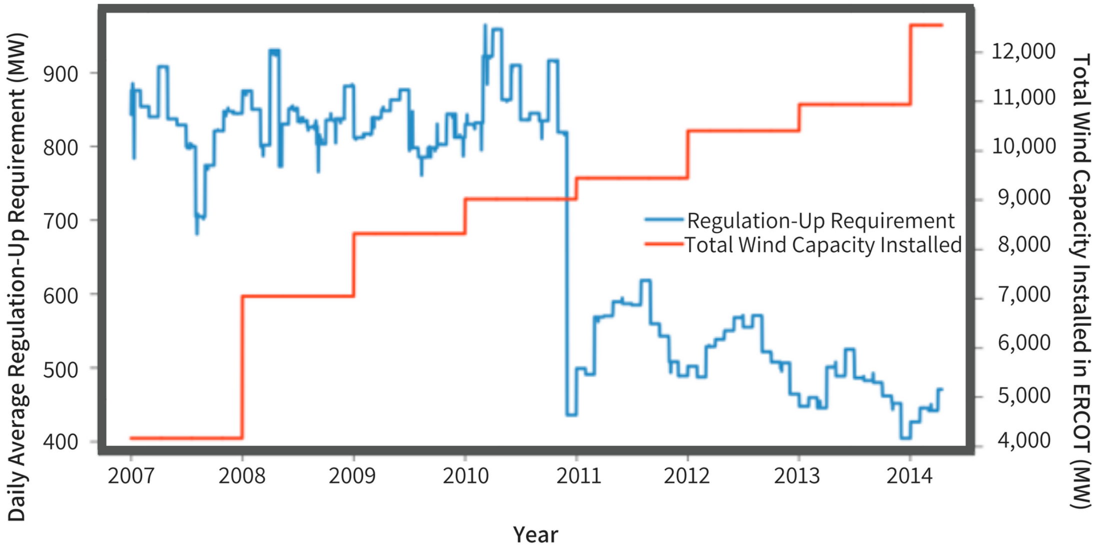

Figure 5: The amount of daily average Regulation-Up Requirements (MW) have decreased even as more wind capacity has been added to the grid in ERCOT.

Regulation reserves (Regulation-Up and Regulation-Down) are quick-responding (seconds to minutes) resources that fill in the gaps between the continuously changing generation and load. They are the most finely-resolved balancing that is part of normal operations. Increased market efficiencies, enabled by more data flow and computing power, allow the market to function at a finer resolution (5-min. vs. 15-min.), thus reducing the need for quick-responding regulation serves, even with increasing wind capacity.

While Regulation-Up and Regulation-Down requirements were reduced, there were other ancillary services that did increase in the same time-period. However, these increases were slower responding resources, and thus less expensive to procure. Thus, even with increased variability from wind, the increases in market efficiencies, driven by IT, reduced the cost of reliability.

Other changes in ERCOT's protocols have also reduced costs and fostered the integration of more wind.

NPRR 352 included improvements in the methods for prediction of the maximum sustained energy production for wind farms after curtailment. This change allowed entities scheduling wind farms to be more flexible when curtailment was lifted on those wind farms, reducing regulation requirements and allowing for more wind generation to enter the system.

NPRR 361 increased the frequency and granularity of wind forecasts. Before NPRR 361, wind forecasts were posted every hour, but the change required five-minute wind forecasts for the next hour to be posted every five minutes. This change gave near-real-time insight into how wind power is operating on the grid by requiring higher time-resolved forecasts and simulations.

> **“ERCOT'S protocols reduced costs and fostered integration of more wind”**

NPRR 460 increased the ramp rate for wind generators in ERCOT. Before passage of NPRR 460, wind generators were only allowed to ramp up to 10% per minute of their nameplate capacity, but now they are able to ramp it up to a five minute average of 20% of their capacity. This change allowed more wind power to come online faster, but required better forecasts of wind power conditions as mandated in NPRR 361.

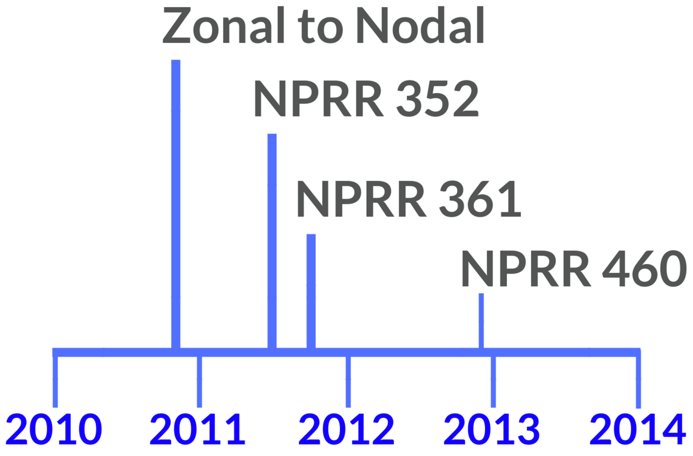

Figure 6: Timeline of ERCOT market rule changes

Generation Trends in ERCOT

Electricity markets in the US and Texas have been decentralizing, digitizing, and decarbonizing over the past decade. On that last point, much success has been achieved. In the United States, the transportation sector recently overtook the electricity sector as the largest source of carbon emissions. In ERCOT, the amount of electricity consumed increased by about 15% from 2006-2016, while the amount of wind energy produced increased 727% in the same time period. Figure 7 shows some of these trends.

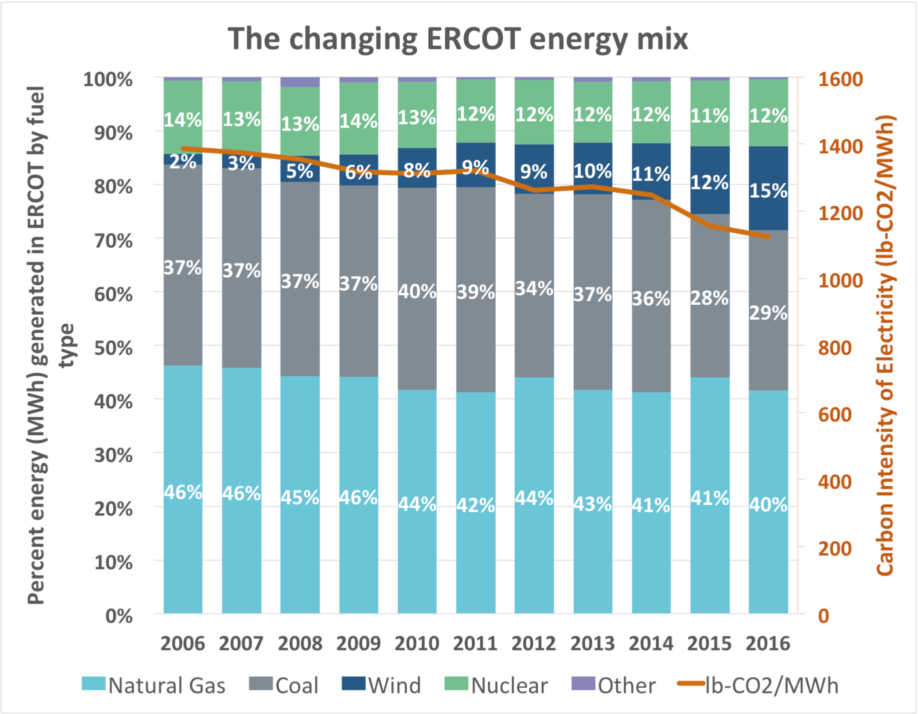

Figure 7: Texas' energy mix has been changing with the recent additions of renewables and the decreasing cost of natural gas. Both of these changes have driven down the carbon intensity and price of electricity in Texas.

Figure 7 also shows the decline in the carbon intensity of electricity generation in ERCOT, denoted by the burnt orange line. As wind power has increased in ERCOT, the carbon intensity of electricity has fallen by about 24% since 2006. In ERCOT, the total amount of carbon emissions associated with electricity peaked in 2011 at about 238 million metric tons and has fallen to about 209 million metric tons as of 2016 – the lowest level of carbon emissions associated with the electricity sector in Texas since 1998.[13]

Solar & Wind are Associated with a Lower Carbon Intensity of Electricity

Over the past 15 years in ERCOT, wind has increased from less than 1 GW in 2002 to almost 18 GW in 2016 and solar is expected to increase from 15 MW (2010) to 556 MW (2016). During this span, the carbon intensity of all electricity generated in ERCOT has fallen from 1,438 lb-CO2/MWh (2002) to 1,124 lb-CO2/MWh (2016).

A regression analysis of the data indicates that adding both wind and solar to the ERCOT grid reduce the carbon intensity of electricity in ERCOT (see Appendix for details). The analysis indicates that if wind and solar had not been built in ERCOT, there would be about 58 million more tons of CO_2 emitted in ERCOT in 2016 than actually were emitted.

Costs of Electricity in ERCOT

The switch from zonal to nodal has been correlated with a lower cost of electricity in the ERCOT market. Zarnikau et al,[14] show that “zonal averages of locational marginal prices under the nodal market are about 2% lower than the balancing energy prices that would occur under the previous zonal market structure in ERCOT.”

A regression analysis of the effect of wind and solar capacity on the cost of electricity in ERCOT (similar to the above analysis for carbon intensity, see Appendix) also indicates that increasing levels of wind and solar are correlated with lower electricity prices.

Lower wholesale market prices have also translated to lower retail prices in some parts of Texas.[15] A comparison of retail rates available from the Texas Public Utility Commission indicates that consumers are paying about 18% less for electricity today than they were 10 years ago.[16] In other words, IT-enabled efficiency improvements of the ERCOT market helped decarbonize the grid while lowering prices for consumers.

IT’s Enabling Role in ERCOT

IT’s role has continued to grow in electricity markets as sensing has become more ubiquitous and as computing costs have dropped, matching trends in other sectors such as manufacturing and healthcare. In particular, IT’s role in electricity markets falls into roughly three categories: 1) operations, 2) planning and modeling, and 3) forecasting.

Operations

Grid operations include making decisions at the control room level that keep the grid stable. ERCOT contains over 570 generators, each reporting their status every 2 seconds. ERCOT’s few dozen of synchrophasors[18] send time-stamped and geo-located[17] voltage and current information 30-60 times per second. Almost 10 million smart meters (customers) send data on consumption every 15 minutes (about 50GB/day of readings) to ERCOT to be stored and acted upon. Overall, that means ERCOT is growing more data-intensive with time. As more stochastic generation assets (wind and solar) come online, even more data and faster control will be needed to make operational decisions at timescales needed for balancing supply and demand.[19]

“Today there is a lot of excitement about electricity because people see that this is a space that is transforming so rapidly and the foundation of that transformation is … data.” – Brian Janous, Microsoft’s general manager of energy (Interview given to Shayle Kann on The Interchange podcast[20])

ERCOT’s real-time tools allow for more dynamic control of the market. Particularly the Transient Security Assessment Tool, or TSAT. The TSAT runs every 15 minutes and updates the operating limits of the transmission system to more accurately reflect real-time conditions. Before 2014, the TSAT was a yearly simulation[21] that was referenced for real-time grid operations. With only a yearly simulation, even if the transmission capacity were available, sometimes wind generation was still curtailed because grid operators did not have the necessary insight into the real-time conditions of the grid and used the conservative scenario instead. After 2014, the TSAT was updated to run in real-time (every 15 minutes) and has reduced curtailment of wind in real-time that would have otherwise occurred with the yearly analysis.[22] Thus, faster deployment of data has directly enabled higher levels of wind generation. The TSAT, along with the Voltage Security Assessment Tool (VSAT), both parts of the Transmission Constraint Manager tool, were estimated to have saved the grid $27 million in congestion management costs alone in 2011.[23] The TSAT and VSAT interface with ERCOT’s Energy Management System (EMS) through the DSAManager.

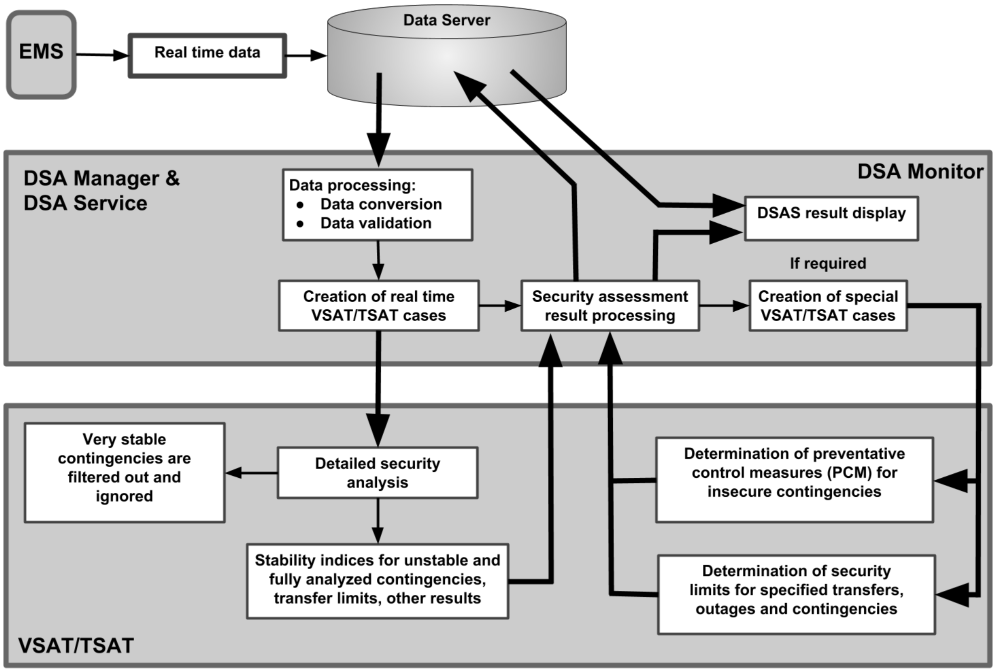

Figure 8: The components of ERCOT's DSATools. Figure from Chen et al. [24]

Though these real-time models allow for more precise operation of the grid, the very nature of transient model calculations requires significant computing resources. The original TSAT was only run yearly because of its IT resource burden.[25] Further improvements, such as reducing the TSAT runtime from 15-minute to 5-minute intervals might offer additional benefits in terms of improved grid operations and reduced curtailments. In other words, as simulations approach real-time to match the actual conditions of the grid, integration levels of variable renewables are likely to increase further.

In total, ERCOT utilizes a significant suite of IT technologies and tools that allow the grid to function with a high degree of reliability. While it is beyond the scope of this paper to analyze each tool, some of the other major tools used for operations are listed here:[26]

1. Energy Management System (EMS) – The EMS is a software suite that monitors and manages the operations of the power system.
2. Market Management System (MMS) – The MMS is the software suite that monitors and manages the market side of the power system.
3. State Estimator (SE) – SE is an application that analyzes the current system conditions, using a network model and available SCADA data, to estimate the flows on all transmission elements in a system. This tool runs in real-time.
4. Security Constraint Economic Dispatch (SCED) – Optimized unit-specific dispatch minimizing costs while mitigating congestion. This tool runs every five minutes.
5. Real-Time Contingency Analysis (RTCA) – RTCA is an application that performs contingency analysis for the real-time power system and reports all post contingent violations.
6. Transmission Constraint Manager (TCM) - a real-time application that collects and maintains information related to constraints from the real-time contingency analysis.

The Reliability Risk Desk

ERCOT recently added an additional chair to its control room, the Reliability Risk Desk .[27] This new desk serves three functions: 1) monitor the real-time performance of wind and solar generators, 2) monitor inertia and responsive reserves, and 3) monitor and identify forecast error risk, including intra-hour risk.[28] In particular, ERCOT sees the necessity of the Reliability Risk Desk to get ready for the coming solar boom in Texas.

[The] reason we think we are going to have the Reliability Risk Desk is because of the growth of solar.[29] – Joel Koepke, Supervisor of Grid Applications Development, ERCOT

One of the main functions of the Reliability Risk Desk, formerly known as the "Renewables Desk," is to visualize curtailed wind generation in real time. This display allows for operators to assess whether the imposed constraints on wind farms by ERCOT are valid, or if they could possibly be eased. The system also allows operators to quickly see which wind generators are up to date with telemetry information, thus allowing operators to judge how accurate the forecast models for individual generators might be. The more stale the data, the lower the confidence in the modeled future output.

"The PI [data infrastructure and operations intelligence] System provides a passive copy of all data in real-time, within business context allowing for "what if" scenarios and future modeling in order to support decisions made in the ERCOT EMS" – David Thomason, Industry Principal Global Power Generation, OSIsoft

The models are updated with any new grid infrastructure every week, and the desk receives 10-second status updates comparing the actual, total available, and projected output from each wind generator. These data are crucial because wind forecasts are updated hourly, but grid operations are conducted on the order of seconds.

The ERCOT Large Ramp Alert System (ELRAS) is part of the Reliability Risk Desk and is designed to monitor the probability of large wind output ramps in the ERCOT region and provide ERCOT Operators with further situational awareness.[30] This tool alerts operators to the probability that there will be a sudden decrease of wind generation in the near future and allows operators time to preemptively schedule ancillary services to maintain reliability.

While the bulk of the current workload of the Reliability Risk Desk is focused on wind, the techniques developed will also be applied to solar as more is built in ERCOT's territory.

The Reliability Risk Desk relies on multiple layers of IT to fulfill its mission, a mission that is expected to grow in importance as more wind and solar are deployed in ERCOT.

Planning & Modeling

ERCOT completes both short-term (6-year)[31] and long term (15-year) system adequacy assessments. The long-term system assessments[32] allow ERCOT to identify locations where additional transmission or generation resources might be necessary to meet future demand. Given the increasing share of renewables located far from load centers, these planning exercises become more critical and computationally intensive. For instance, ERCOT is estimating that by 2031 there will be between 15,000 and 30,000 MW of solar PV added to the system, potentially a 3,000% increase over 2017 solar PV levels. Most of ERCOT's long term scenarios estimate that there will be significant increases in solar and wind generation in the western part of ERCOT while generation resources in the central and eastern parts of the state are reduced. This imbalance will result in a large increase in the amount of west-to-east power transfer over long-distance transmission lines, which will require significant amounts of real-time modeling and data analytics to keep the system stable. That means future grid interconnection studies will require even more detailed simulations.[33]

In the 2016 Long-Term System Assessment,[34] ERCOT indicated that there might not be adequate resources to meet peak demand under a high-renewables scenario indicating that other dispatchable grid resources (including firm capacity, load as a resource, demand reduction, etc.) will be needed to keep the grid stable. This future is one of the reasons that ERCOT has developed the Reliability Risk Desk.

Forecasting

The importance of wind forecasting over the last decade has grown. Investment in better wind forecasting has had an instrumental impact for enabling higher levels of renewable integration.

ERCOT currently purchases wind forecasts from AWS Truepower, but has recently taken on a more active role in forecast validation with the recent Reliability Risk Desk.

ERCOT receives detailed, 168-hour, forward-looking wind and solar forecasts from AWS Truepower updated hourly for the location of every wind and solar farm connected to the system. These forecasts are used by the Reliability Risk Desk to estimate the expected output from these plants to ensure that adequate resources are available to match supply with demand. The forecasts have continued to improve and recent work shows that modern forecasts can have average errors of about 8-10% for individual wind farms and 4% for entire systems.[35]

Each forecast for each wind farm location requires tens of gigabytes of data that are reprocessed every 5 minutes. Wind forecast training datasets are petabytes in size and, given the decreasing margins and competition in the forecasting business they have had to continuously invest in faster networks and massively parallel compute resources, all in an effort to keep refining their machine learning capabilities.

"Accurate forecasts allow for more renewable energy integration because they make the system more predictable on short time frames. Greater confidence and reliability also reduce the need for extra capacity and reserves, reducing overall system costs."
— Bruce Bailey, PhD, VP Renewable Energy, UL (AWS Truepower)[36]

Grid service or application	Function	Where service should be considered.
Energy Management System (EMS)	Manages suite of tools that operate the grid	Complex grids
Market Management System (MMS)	Runs financial aspects of grid operations	Grids with independent buyers and sellers
State Estimator (SE)	Analyzes current grid conditions	Complex grids
Security Constraint Economic Dispatch (SCED)	Min-cost dispatch of power plants to reliably meet demand	Grids with multiple generators.
Real-Time Contingency Analysis (RTCA)	Tool constantly running what-if scenarios on current grid conditions	Grids with independent supply and demand
Transmission Constraint Manager (TCM)	Tool that automatically updates transmission constraints	Grids with long transmission lines connecting load
Reliability Risk Desk	ERCOT desk that validates wind and solar forecasts	Grids with large amounts of renewable energy
Solar/wind forecasting	Provides near-time predictions of renewable energy availability	Grids with large amounts of renewable energy
ERCOT Large Ramp Alert System (ELRAS)	System that predicts large changes in wind generation	Grids with large amounts of renewable energy
Seasonal Assessment of Resource Adequacy (SARA)	Seasonal assessment of near-term capacities and weather patterns	Grids with high dependence on weather
Regional Transmission Plan	Short-term (6-year) look at system resources and trends	Complex grids
Long-Term System Assessments	Long-term (15-year) look at system resources and trends	Complex grids

Table 2: Summary of selected grid applications and services.

Economic Activity

A regression analysis using data for the past decade indicates that lower electricity prices in ERCOT are associated with higher levels of gross state product (GSP) in Texas (see Appendix for details). This result is consistent with other parts of the country[37] and the world.[38] Lower electricity prices can drive development because they reduce costs for consumers.
J. Garen, C. Jepsen, and J. Saunoris, “The Relationship between Electricity Prices and Electricity Demand, Economic Growth, and Employment,” 127 1000000441, 2011.

Economic Development from Wind in Texas

Texas leads the nation for corporate off-site renewable development.[39] Industry leaders such as AT&T,[40] Facebook,[41] Akamai,[42] Amazon[43] (whose owner Jeff Bezos personally christened their project atop a 300 foot tall wind turbine),[44] Microsoft,[45] Apple,[46] Google,[47] Salesforce,[48] HP,[49] Walmart,[50] Home Depot,[51] IKEA,[52] 3M,[53] Dow,[54] Owens Corning,[55] Equinix,[56] Target,[57] General Motors,[58] Procter & Gamble,[59] Mars,[60] Nike,[61] Whole Foods,[62] Johnson & Johnson,[63] Unilever,[64] and General Mills[65] have all signed power purchase agreements with or invested directly into wind farms in Texas to meet employees’ and customers’ expectations of good corporate stewardship. Many others, such as Dell (the sponsor of this report), have long procured clean energy through local utility arrangements.[66]

These companies alone represent about $6.4 billion worth of power purchase agreements (PPAs) for about 3,500 MW of clean energy projects in Texas. Long-term contracts with stable corporate partners make it easier for developers to get financing at favorable rates, allowing for lower cost PPAs for offtakers.

“We put a lot of effort into choosing where to locate a facility like this, …there are a lot of things we look for — everything from a shovel-ready site, to access to renewable energy…”[67] -- Ken Patchett, director of data center operations for Facebook’s West Region

“This agreement represents the latest step we are taking on HP’s journey to reduce our carbon footprint across our entire value chain, while creating a stronger, more resilient company and a sustainable world.”[68] -- Gabi Zedlmayer, VP and CPO, Corporate Affairs, HP

Renewable energy projects also bring economic benefits to the communities where they are built. Solar Photovoltaic Installer and wind turbine technician are currently the two fastest growing jobs in the U.S.[69]. Wind Turbine Technicians make, on average $52,000 per year and up to $90,000 with experience and overtime.[70] These middle to upper-middle class jobs provide economic stability in mostly rural regions where there are few alternatives.

Renewable energy projects also increase local tax bases and provide needed funding for rural school districts. Nolan County, which includes the city of Sweetwater, TX and nine utility-scale wind farms, has seen its tax base increase from $500 million to $3 billion since 2000, mostly due to wind development.[71] From these tax base increases, some school districts have been able to spend “tens of millions of dollars” upgrading and building new schools.[72]
RILA and ITI, “Corporate Clean Energy Procurement Index: State Leadership & Rankings,” 2017.

Other Grids That Could Benefit from ERCOT's Experience

ERCOT has become a leader in integrating variable renewables into its electricity grid. In 2017, ERCOT ranked seventh in the world for major power markets for highest percentage of electricity generated from wind and solar. The system is still evolving and that percentage is expected to increase in the coming years, but IT has been a key enabling technology for integrating higher levels of variable renewables.

Forecasting, planning, real-time grid operations, and reliability assessments all become more complex with increasing variable renewable generation. When that generation is also far from load, as in ERCOT, the challenges are compounded further because of the need to manage transmission congestion and location-specific supply.

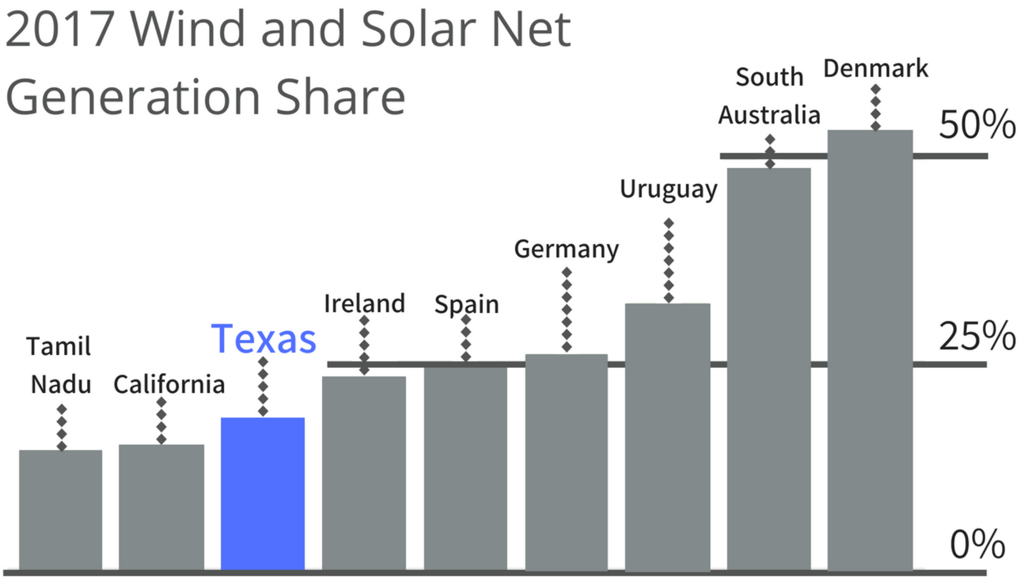

Figure 9: As a grid, Texas ranks 7th in the world for the share of electricity coming from wind and/or solar.[73]

While other grids can learn from ERCOT's experience, each will be different in its approach. Location matters when choosing a suite of technologies to power the grid as some locations will have better access to renewable resources than others. However, they will have various commonalities, such as the need for better forecasting, firm capacity to match supply and demand, and the role IT plays for maintaining grid stability. These challenges are particularly acute for grids that have their best resources far from load. A few examples include WECC, Germany, and Australia.

WECC: The Western Electricity Coordinating Council is an interconnected North American Electric Reliability Corporation (NERC) region that comprises the western half of the U.S. (and Canadian) grid. While the vast majority of the population lives in the western part of WECC, most of the wind resource lies to the east and the solar to the south. Recent studies[74] have indicated that high levels of renewable penetration will require significant increases in transmission capacity and low levels of friction between different markets within WECC. Transmission management over large disperse areas will require information and accurate forecasts.

GERMANY: The *Energiewende* (energy transition) is Germany's attempt to transition to a low carbon, low cost, reliable energy system. Germany has made progress, but their carbon emissions have not decreased as desired despite increasing levels of wind and solar because of nuclear phase-outs. Delayed coal plant retirements,[75] and difficulties in siting new power lines from the wind rich northern part of Germany to the population centers in the south have resulted in periods of negative pricing, which have slowed the adoption of more renewables.

AUSTRALIA: In 2016 the South Australian grid experienced a weather-related transmission line failure that resulted in the islanding and almost total blackout of the South Australian grid. Subsequent assessments and reports indicate that improving the ability of the South Australian grid to forecast conditions that could lead to islanding and improving the ability of the grid to operate as an island could alleviate some of the risks associated with weather-driven outages. Wind constitutes a significant amount of generation capacity in South Australia, so plant level control of wind farms' change in output and coordination across the generation fleet will be critical in maintaining stability.

Recommendations on Future Efforts

For a sector that has typically operated on multi-decade timescales, today's technologies and markets operate on sub-minute, sub-hourly timescales. This evolution opens up opportunities for new solutions to the challenges of maintaining grid reliability while decarbonizing.

Using IT to Enable Synthetic Inertia

One major hurdle for incorporating larger shares of renewables into the grid are the rotational inertial requirements used to maintain control of the grid frequency in the case of a generator failure or power line disruption. If a large power plant trips offline, the frequency of the grid will start to fall. The inertia of the rotating mass of shafts inside other power plants will resist the frequency fall and give primary frequency response time to come online. Grids typically set a minimum amount of inertia that must be available at all times. For ERCOT this threshold is about 100 gigawatt-seconds (GW-s). Different types of power plants contribute different amounts in inertia, but because wind and solar operate asynchronously by convention they are considered to be non-contributors to total inertia. This constraint could eventually lead to more wind and solar curtailments as other generators will be forced to stay online to meet the inertial requirements. Additional research is needed to develop the controls that could allow wind and solar to provide this type of grid support.

Expanded Ancillary Services and Batteries

Implementing operational and economic changes to the way that solar and wind resources are deployed could alleviate some grid stability concerns. First Solar recently demonstrated the ability to provide fast frequency response in California by self-curtailing total generation and using the extra power available to follow frequency regulation commands.[76] ERCOT also requires that all wind turbines set aside 5% of their maximum power output so that it can be used for primary frequency response (response within 12 to 14 seconds) in the event of a frequency excursion. The latest wind turbines are also capable of supplying synthetic inertia (response in ~1 second) to the grid, but these abilities have not been enabled in ERCOT.

Battery adoptions are growing as different business cases arise. FERC recently passed rules to allow batteries to buy and sell in the wholesale markets. While this decision will benefit battery technologies in the grid.[77] it will introduce more variables for grid operators as now they will have units that can act as both supply and demand, with various multi-directional bidding structures. While batteries can allow for more renewable energy into the grid, the operational characteristics are more complex, and they do not always guarantee a reduction in carbon emissions.[78] IT will play a key role for managing their operations.

Transactive Energy & Blockchain

Traditional grid structure is very hierarchical, or top down. Large generators generate electricity which flows through grid infrastructure and is purchased by end users. The traditional vertically-integrated utility has a similar structure, with a single entity owning most or all aspects of generation, conveyance, and billing of electricity.

A transactive energy system is an energy grid that is more nodal. End points (including throughout the distribution grid) can be both consumers and producers, commonly called "prosumers." For instance, technology can enable neighbors to sell their rooftop solar electricity to one another directly and automatically. Enabling this, however, will require significant IT infrastructure investments to operate successfully. This change would vastly increase the number of controllable points and prices on the grid. Because basic physics are still required to keep the grid stable, this type of grid will require exponentially more control and data analytics.

Blockchain is a secure, linked, and distributed ledger technology that can manage and support the very large number of transactions that are required for a transactive grid.[79] Because there are multiple (every node participating) copies of the ledger constantly being appended to and checked, fraud becomes much more difficult. The technology is designed to allow different users who might not know or trust each other to participate in a trusted transaction, such as buying and selling energy. Recent concerns over the energy intensity[80] of blockchain and the services they support have resulted in movements to less energy-intensive ledger methods.[81] While using blockchain technologies could allow peer-to-peer energy transactions to take place between any two untrusted parties, more research is needed into the effect of having very large numbers of bilateral contracts on overall grid transaction efficiency.

IT as a Direct Energy Enabler

As energy, IT hardware, and data processing and storage become cheaper, their interactions can help promote each other. Data centers currently consume about 2% of the total electricity used in the U.S.[82] Cheap, consistent power has long been a selling point for datacenter locations because of their expensive cooling loads.[83] Locations such as Washington state and Nevada have attracted investment because of their low industrial power costs. However, the price-depressing effects of large amounts of co-located renewables might be attractive to future data center developments even in locations that have typically had higher power costs, such as California. Data centers themselves can act as flexible load by running redundant locations and only utilizing certain locations when local renewable generation is high, and thus prices are low. This type of operation can save money and energy because it is oftentimes less energy intensive to move data than energy.

Conclusions

Information technologies have been and will continue to be crucial in allowing ERCOT and other grids to decarbonize by more efficient market operation and inclusion of variable, low carbon sources such as wind and solar without compromising grid reliability. Increased computing power has allowed real-time grid architecture and simulation tools to be utilized more often, allowing for a more consistent use of existing resources. More efficient market design has allowed the grid to remain stable with fewer backup resources. More accurately resolved, temporally and spatially, wind- and solar-resource forecasts have also allowed more confidence at the grid management level for greater levels of renewable energy penetration. Wind and solar, along with natural gas, have driven down both the total amount of CO_2 emissions and the carbon intensity of electricity in ERCOT. These low-priced resources have reduced the wholesale market costs of electricity, which has also resulted in a lower retail cost of electricity for consumers.

Underlying all of these changes are more data, and the information technologies that allow the data to be used in a coherent and actionable way.

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