Reevaluating Texas Energy Market Forecasts in The Wake of Recent Extreme Weather Events

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**Abstract.** This paper provides updated forecasts on the adoption of sustainable energy in the state of Texas and the Electric Reliability Council of Texas. It is important that the forecasts of the adoption of sustainable energy are reexamined after Winter Storm Uri crippled the Texas power grid and left many without power. This storm highlighted the issues the Texas power grid had and has continued to struggle with in supplying the state with energy since Winter Storm Uri. The literature review will offer an overview of the relevant literature on the adoption of sustainable energy and relevant events that have occurred in the state of Texas that will give the reader the necessary background and context needed to understand the need for this study as well as its implications. The text will offer the reader updated forecasts on the adoption of renewable energy in the state of Texas. Methodologies will be addressed as the researchers used three different forecasting techniques in an endeavor to produce the most accurate model for forecasting the future adoption of sustainable energy in the state of Texas. The discussion will review the findings of the forecasting methods used, the significance of the findings, and the implications of the results for the future of the Texas energy economy.

1 Introduction

Over the previous three decades climate change has become a more commonly discussed topic both in the public space and the academic space. This growth can be attributed to rising global temperatures and ever more frequent climate-related natural disasters. As one observes the world around them it quickly becomes apparent that examples are becoming more and more numerous. Whether it be the wildfires that devastated California, Australia, and more recently Canada causing not only destruction due to the flames but also high levels of pollution to the point of needing face coverings when walking outside in some locales, the record high temperatures in Paris during the summer of 2019 which caused discomfort for many due to the general lack of air conditioning in European houses, or more close to home Winter Storm Uri, which posed a significant challenge to Texas residents when many lost power due to the extreme cold temperatures. These events highlight the need to address the effects of climate change and the dangerous implications if the issue is not resolved.

The climate-related natural disasters and rising temperatures have caused many to look for solutions to reduce the role human civilization plays in climate change. One of the common solutions put forward is a switch to sustainable energy sources, away from polluting fossil fuels. As the detrimental consequences of climate change become increasingly evident, it's critical that human civilization transition wholesale away from fossil fuels and towards clean and renewable energy sources. The adoption of green energy technologies, such as solar photovoltaic panels, wind turbines, and novel energy storage systems, has grown exponentially in recent years. These technologies hold the promise of significantly reducing greenhouse gas emissions, mitigating climate change, and fostering energy independence.

Often when green energy is discussed by politicians and citizens of their respective countries, two questions are commonly asked. The first regards the practicality of relying primarily on sustainable energy sources as the main sources of power for the power grid, and the second concerns how long it will take to transition over to relying mostly on renewable energy sources. It is integral that accurate forecasts are available to the public so that they can be cited as reliable sources of information. These forecasts need to be updated after significant events to ensure that up-to-date and accurate information on such an important issue is available to the public. It is also important that policy makers have reliable forecasts available to them as legislation is drafted on the subject of sustainable energy. For these reasons the researchers involved in this study believe that the need for updated forecasts is ever present when dealing with an issue as important as sustainable energy and the combatting of the negative effects of climate change.

Much research has been done in the past across many aspects of renewable energy and many researchers have dedicated their careers to the pursuit of such an important goal. In particular, many excellent academic journal articles have been published in an attempt to forecast the cost, timeframe, and viability of the switch from traditional fossil fuels to renewable energy. Due to the size of Texas, its population, the place it holds in the United States, and the availability of data, the Electric Reliability Council of Texas (ERCOT) and the Texas power grid are often the subject of these journal articles. However, as the environment that humans inhabit continuously moves in the direction of extreme climate disasters, the researchers involved in this study believe that a reexamination is necessary to account for recent events.

The aforementioned climate disasters each have posed different challenges. In particular, winter storm Uri caused considerable strain on the Texas power grid. ERCOT drew significant criticism from citizens of the state of Texas for the lack of reliability of the power grid, leaving many without power for a significant period of time and rolling blackouts taking effect. The researchers involved in this study believe that winter storm Uri, and the events that followed it, demand a reexamination of the forecasting studies already done.

In addition to environmental factors, advancements in the field of computer science and statistics have seen machine learning and neural networks become increasingly popular. The researchers believe that new methods may be conducive to finding updated results and moving the discussion on green energy forward.

This paper aims to forecast the adoption of sustainable energy in the state of Texas and how Winter Storm Uri may have affected the prior trends. In addition to forecasting the adoption of sustainable energy, the researchers will compare the current forecasting calculated in this paper to those done in prior studies to see how the forecasts have developed and evaluate how Winter Storm Uri and the following events have affected the prior calculations.

Start of Literature review.

* 1. On the Need to Reevaluate Forecasts So Soon

At the time of the research for and writing of Mann’s team’s 2017 paper (Mann, N., et al. 2017), Winter Storm Uri wouldn’t happen for another 2-3 years. Occurring in February of the second year of a global pandemic, Uri’s frigid low temperature of 6º F (in Texas, specifically) and the same number of inches of snow that broke the “record for consecutive days of snow on the ground in Austin” (Year in Review - Winter Storm Uri, n.d.) blindsided Texans in that way for the first time in several years, and for the last time ever for 210 of those people. Over 60% of Texans had no power for the six days spanning February 14th to the 20th (Texas Comptroller of Public Accounts, n.d.). In Germany just five months later, part of a castle erected in the 1800s was washed away by a nearby river flooded by astonishing rainfall in the region (Eddy, 2021). In the summer of 2023, residents of North America either sneezed, coughed, or choked on the smoke of unprecedented wildfires across much of Canada (Stanier, n.d.), and in the historical community of Lahaina on the Hawaiian motu (island) of Maui, high winds gusting up to hurricane velocity were whipped up by an actual hurricane passing the archipelago to the south. These winds tore down power transmission lines onto dry lawns and began a surprising and horrific wildfire that destroyed the town (“How Fire Turned Lahaina Into a Death Trap,” 2023) and the lives (fully destroyed, i.e., ended) of over ninety residents. In the same late summer months, ERCOT struggled to keep the Texas power grid from failing again, this time not for extreme cold but rather extreme heat (Foxhall, 2023). It can go without saying that these recent developments in the Earth’s weather have motivated a sense of urgency in some about the timeline and coming effects of climate change, and that the performance of ERCOT over the past few years has shaken Texas residents’ confidence in its ability to maintain grid integrity (Jones, 2022). It is because of this urgency that, despite Mann et al. 2017 giving forecasts through 2030 (Figs. 22-35, Table 10, etc.), this study goes, to quote Shakespeare, *“once more unto the breach”* of the issue to reevaluate such forecasts with the most recent data on grid conditions, assuming those conditions are affected by climate change-related weather patterns and phenomena, by the ability of renewables (most notably those affected by weather and/or celestial conditions, namely, wind and solar) to support the demand placed on the grid, and by forces of economic and governmental policy conditions and decisions.

* + 1. The Effects of Climate Change and Heating Technology Changes on ERCOT’s Grid Conditions

Fortunately for researchers investigating this topic, summer peak demands on ERCOT’s grid are relatively stable compared to a linear regression, with actuals visibly closer to their regression line than the same for winter peak demands (Skiles et al., 2023). Skiles’ team finds this to be a result of a handful of reasons, including summer demands being influenced by notable efficiency in electric cooling and winter demands being volatile on account of, in part, the transition of home heating from natural gas furnaces to electric heat pumps and the like. Axiomatically, the use of natural gas *furnaces* in homes, while common for heating, makes little sense applied to cooling, so the home-heating appliance transition would not be reflected in summer demand data.

With this winter demand variability and the possibility of more century storms like Uri happening on the order of decades or shorter (recall the 2011 blackouts in Texas also caused by winter storms), ERCOT has clear cause to cultivate versatile power generation solutions to address the need for easily-dispatched generators or energy storage units that are robust in near-zero-Fahrenheit weather that may include dangerous and/or damaging precipitation like freezing rain.

Winter weather, however, does not and will likely not maintain a monopoly on ERCOT’s struggle to avoid capacity-deficit blackouts. Markham Watson refers to an announcement from ERCOT stating that despite “that there will be sufficient installed generating capacity available to serve the system-wide forecasted peak load for the upcoming summer season, June-September 2023”, “for the first … time the peak demand for electricity this summer will exceed the amount we can generate from on-demand dispatchable power”; Public Utility Commission of Texas (PUCT) Chairman Peter Lake warned that Texas “’faces a new reality’ in the summer of 2023”. Lake further indicated that renewable energy would be crucial, nay, truly indispensable to the Texas grid for summer 2023. Emily Foxhall’s article in the Texas Tribune relates the stress the grid indeed faced, discussing in the article summary that ERCOT’s conservation requests were at least as frequent at one point as three requests in a single week.

* + 1. How Texas Energy [Un]Reliability Affects ERCOT and the Energy Technology Market

During the February 2021 Texas energy crisis, natural gas prices spiked so extremely that the state government was forced to place price caps and utilize other market controls to prevent said market from suffering a meltdown from the sheer volatility caused by a perfect storm of gas plant and wind turbine failures; some of the gas plant failures were accidents, occurring when electricity transmission providers were asked to suppress transmission to avoid damage to the heavily in-use grid. This action “pulled the rug out from under” the gas supply chain installations on those providers’ grid subdivisions, causing them to fail by starvation of their operational electricity requirements for getting the natural gas through the supply chain to the plants that would do the actual power generating using the gas. In a grimly amusing way, the Texas natural gas infrastructure was essentially asphyxiated (Cai et al., 2022). Solar power, on the other hand, performed as well as could be expected (Sweeney, 2022), giving hope to the notion that it can be the MVP (Most Valuable Producer, if you will) of winter demand satisfaction in a renewable energy future, whereas the delay of summer daily demand ramping down later than solar production ramps down (Duquiatan & Horwath, 2023) precludes that advantage in summer months.

For virtually any American citizen, Twitter user, and foreigner paying close attention to American politics, the Republican Party (GOP) as a whole is well known for their dogged support for fossil fuels, support that may at times verge on belligerence toward both renewable energy sources and the people who campaign for an end to fossil fuel use. The governor of Texas at the time of this paper’s writing, and at the time of Winter Storm Uri’s aftermath, is Greg Abbott, a leading politician of the GOP as the governor of a state long associated within & beyond U.S. borders with American conservative & right-wing politics. It is no surprise, then, that under his guidance, initiatives begun immediately following the energy disaster caused by Uri gave priority to natural gas generation. Keep in mind how various segments of the Texas energy supply performed during the crisis, i.e., recall that both gas generation *and* gas infrastructure failed during Uri’s wintery wrath, while of solar and wind only the latter saw significant failures; according to Mann et al. (2017), current natural gas generation as of 2015 contributes well over thrice the amount of electricity to the ERCOT grid that wind does. That being said, solar contributes such a small amount that much investment in it is needed to allow it to come in handy to a mathematically significant extent. A year after Uri, the majority of the Texas public polled by the Texas Politics Project were unsatisfied with their state government’s response to the energy disaster (Reader, 2023) and investor interest in fossil fuel power generation has fallen well behind renewables and other clean energy forms such as the Comanche Peak nuclear fission reactor (Duquiatan & Horwath, 2023)—ERCOT’s reputation as custodian of the Texas electric grid and an extension of the state’s government does not stand to benefit from such action not in line with the desires of the people and the prevailing winds of the energy economy. Measurably counterproductive decisions such as this coming from places of power are a notable detractor to the successful implementation and maintenance of new and existing renewable and clean energy generators. Hope for the transition of energy generation away from fossil fuels remains, however, in the aforementioned investor interest in renewable/clean energy. ERCOT and the State of Texas would be more helpful to those ends if they encouraged and facilitated such investment.

Nevertheless, the renewables economy already benefits from government encouragement for new technologies and infrastructure types: at the federal level, for example, standalone storage facilities (no generation, only storage), which in today’s economy benefit from significant strides in battery technology in recent years and from other novel energy storage means, benefit from a whopping 30% investment tax credit (ITC) specifically for such facilities (Duquiatan & Horwath, 2023). As gas- and especially coal-fired power plants age less than gracefully and are gradually left behind by the economy, a total of 18.3 gigawatts (GW) of renewable energy capacity is in development for the Texas grid, driven strongly by these federal tax credits.

* + 1. Risk Factors Post-Uri and in the Current Economy in General

As of October of 2022, experts in the energy field had reason to believe that ERCOT would not be ready for another Uri. The executive director of Commission Shift, Virginia Palacios, is referenced in Justin Horwath’s 2021 article that the Texas Railroad Commission (TRC) had not physically inspected (i.e., with TRC representatives physically on-site for the inspections) most of the gas supply chain installations under its jurisdiction, despite the TRC stating that nearly all inspected facilities were sufficiently winterized (Horwath, 2021). At best it can be inferred that the TRC suffers from lax standards of inspection and frustrating budgets; at worst TRC’s statements can be viewed as purposive platitudes, dispensed to lull the public into the belief that the Texas government is doing its job to ensure grid reliability when in fact little more than lip-service is being done. However, as mentioned in the previous section (§1.1.2) of this paper, if the statements discussed were indeed meant as platitudes, they haven’t convinced Texans (Reader, 2023). This is not to say that the Texas grid has not been improved. Energy industry consultant Alison Silverstein relates in Horwath’s article that the standards placed on power plants for their weatherization have been made more stringent and that policy changes have been implemented to prevent the sort of severe price spikes that, along with ice and snow, were precipitated by Winter Storm Uri.

It may be more worrying, or perhaps disheartening, that the State of Texas is pursuing cryptocurrency mining to the tune of between three and five additional *gigawatts* of electricity consumption. Cryptocurrency is not known for being a reliable investment. Besides the fact that cryptocurrencies have known utility to criminal enterprises by way of pseudonymity, the historic volatility of some of the most well-known cryptocurrencies such as Bitcoin make for a foolish investment (Frankenfield, 2023). Horwath mentions that both U.S. Senator for Texas Ted Cruz and Governor Abbott both support cryptocurrency mining, and it should be noted that both Cruz and Abbott are Republicans—it has been noted by Aaron Mak that the GOP has developed a fondness for cryptocurrency, a fondness that is depicted in referenced Tweets from Josh Mandel (R-Ohio), for example, to bizarrely veer into an appeal to nationalist sentiment, with the apparent goal to be to cement cryptocurrency as a conservative/right-wing American value (Mak, 2022). The most disturbing detail in this phenomenon is that one of the draws of cryptocurrency for the right wing is the priority of financial independence from the current world economy’s major banks and national reserves such as the U.S. Federal Reserve Bank. The narrative implicates a faceless group of political and economic elites—Karl Marx (in)famously referred to the group using the term “bourgeoisie”—in economic, political, and social decisions that the lower socioeconomic classes either don’t understand, dislike on ideological grounds, or both, at least in the perception of those on the right. The danger of this narrative in right-wing spaces is a century or so old at least: irrational conceptualization of this obscure elite society “dovetail[s] with a legacy of far-right thought that spans back to foundational anti-Semitic texts” (Mak, 2022), notably, *The Protocols of the Elders of Zion*, a propaganda story framing Jews as masterminds of economic exploitation of the common man. This dark movement within the American right is understandably (within the purview of American politics) galvanized by the fact that Democrats in general show skepticism of cryptocurrency’s benefits and a stalwart willingness to regulate it, contrasting over time with the GOP’s gradual cozying up to, and now staunch embrace of, the new system, particularly in its capacity to exist apart from a government that the right wing both distrusts and explicitly (see Mandel’s Tweets in Mak’s article) hopes to shrink.

The combination of a hazardous push to invest more in fossil fuel combustion for generating power for Texas’ grid, an inadequate response to patent faults in ERCOT’s management of the grid and the natural gas supply chain laid bare by Winter Storm Uri, and ideologically disturbing fascination of the state leadership with a use of up to 5,000 MW of electricity pursuing an investment fraught with financial risk show that there is good cause for concern regarding the integrity of the Texas power grid in the near future and the effects its provision, use, and management may have on the global climate and the safety of the vast majority of Texans. The scientific community and the public cannot afford to be complacent with forecasts of grid conditions and climate perils made even five years ago: the situation has changed and with it so must the schedule of analysis.

2 Literature Review

The transition from fossil fuels to clean and renewable energy sources has emerged as a promising solution to mitigate climate change's detrimental consequences. As the effects of climate change become increasingly apparent, the imperative of Texas to shift away from traditional energy sources towards sustainable alternatives grows ever more pressing. This review delves into the multi-faceted landscape of sustainable energy in Texas, encompassing renewable energy assessment, policy dynamics, infrastructure resilience, grid reliability, and the integration of cutting-edge technologies. It sheds light on the state's remarkable potential to lead the way in building cleaner, more reliable, and accessible energy systems for a sustainable future.

In this comprehensive exploration, this paper discusses the harnessing of Texas' abundant solar and wind resources, examine the resilience of its energy infrastructure in the face of extreme weather events, investigate the catalytic role of government policies and incentives in the transition to sustainable energy, analyze the intricate balance between energy supply and demand, and delve into the latest advancements in sustainable energy technologies. By probing these diverse facets of sustainable energy, Texas seeks not only to safeguard its energy future but also to contribute to a global movement toward a more sustainable and resilient world. Let's dive into the detailed sections that elaborate on each of these key points.

**2.1 Sustainable Energy Assessment: Harnessing Solar and Wind Resources**

Texas, recognized for its vast solar and wind resources, stands as a prominent player in the transition to sustainable energy sources. Akhadov's research in 2023 delves into the performance characteristics of solar concentrators, shedding light on the potential of solar thermal energy production (Akhadov, 2023). By examining the efficiency and effectiveness of solar concentrators, this study contributes to harnessing solar energy in Texas, a state that enjoys abundant sunlight throughout the year. The findings emphasize the importance of improving and optimizing solar energy technologies to make the best use of Texas' solar potential (Akhadov, 2023).

Al-Aboosi (2019) introduces hierarchical methodologies for evaluating solar energy availability under different sky conditions, with Texas as a significant case study (Al-Aboosi, 2019). This research illuminates the dynamic nature of solar energy generation due to Texas' diverse climate. By studying how solar energy varies under various sky conditions, this work provides insights into optimizing the use of solar panels and ensuring a consistent energy supply, even in challenging weather scenarios. It highlights the significance of understanding the factors that affect solar energy availability for better energy planning and infrastructure (Al-Aboosi, 2019).

Amonkar et al. (2022) introduce a k-nearest-neighbor space-time simulator for wind and solar power modeling, contributing to the integration of renewable energy sources on a large scale (Amonkar et al. 2022). The innovative approach presented here facilitates a more accurate prediction of wind and solar energy generation. By using space-time simulation, researchers can make precise forecasts, which are crucial for optimizing energy grid management. It provides a foundation for understanding when and where renewable energy sources will be most productive, aligning supply with demand more effectively (Amonkar et al. 2022).

Slattery et al. (2011) emphasize the state and local economic impacts of wind energy projects, providing valuable insights into Texas' wind energy potential and economic benefits (Slattery et al., 2011). Texas, with its extensive land area and favorable wind conditions, holds significant promise for wind energy. This research not only highlights the economic advantages of investing in wind energy but also showcases the positive environmental impact by reducing greenhouse gas emissions (Slattery et al., 2011). By understanding the local economic benefits, policymakers can make informed decisions to support the growth of wind energy in Texas.

**2.2 Energy Storage and Grid Integration**

While Texas possesses vast solar and wind resources, the variability of these renewable energy sources necessitates efficient energy storage solutions. Energy storage is a crucial aspect of sustainable energy infrastructure. Researchers like Zhang et al. (2022) focus on the complexities of energy grid failures, but it's equally vital to explore how energy storage can mitigate such failures (Zhang et al., 2022). Texas must invest in grid-scale energy storage technologies such as advanced batteries, pumped hydro storage, and compressed air energy storage. Systems such as these store energy in a variety of chemical and mechanical ways, holding in reserve electrical power to supplant power being generated in real time when the latter is incapable of supporting consumer demand with a safe margin (Zhang et al., 2022).

The integration of energy storage solutions into Texas' grid is pivotal. It ensures a consistent energy supply even during severe weather events or when renewable energy generation is insufficient. Policymakers and energy providers need to collaborate on creating incentives for the development and deployment of energy storage systems, as this is essential for achieving a reliable and resilient sustainable energy infrastructure.

**2.3 Infrastructure and Resilience: Preparing for Severe Weather Events**

Texas' energy infrastructure faces resilience challenges, as demonstrated by the severe disruption caused by the 2021 Winter Storm Uri. The Texas Comptroller of Public Accounts conducted a comprehensive economic assessment of the storm's impact, revealing vulnerabilities in the state's energy infrastructure (Texas Comptroller of Public Accounts, n.d.). The study provides a comprehensive analysis of the economic consequences of severe weather events on energy infrastructure. It underscores the need for proactive measures to enhance grid resilience, as disruptions like Winter Storm Uri expose vulnerabilities in the system (Texas Comptroller of Public Accounts, n.d.). This research is instrumental in guiding infrastructure investments and improvements to withstand extreme weather conditions.

Zhang et al. (2022) conducted a detailed analysis of the causes and consequences of the 2021 Texas blackouts, elucidating the complexities of energy grid failures and their mitigation (Zhang et al, 2022). By analyzing the root causes and the subsequent impacts of the Texas blackouts, this research provides valuable insights into grid management and disaster response. Understanding the intricacies of energy grid failures is essential for designing effective mitigation strategies and improving overall grid reliability (Zhang et al., 2022).

**2.4 Policy & Incentives: Catalysts for Sustainable Energy Transition**

Government policies and incentives play a pivotal role in Texas' transition towards sustainable energy. Hanke et al. (2020) explore empowering vulnerable consumers to participate in renewable energy communities. Their research highlights the inclusive design of the Clean Energy Package, a policy framework that makes sustainable energy accessible to a broader population. By focusing on inclusivity, this study promotes the idea that sustainable energy should be accessible to all, irrespective of socioeconomic factors. It underlines the importance of supportive policies to drive the transition to sustainable energy in Texas (Hanke et al., 2020).

Rudolph et al. (2023) investigate the impact of renewable energy tax incentives on electricity pricing, demonstrating the intricate relationship between policy measures and energy costs. Their research showcases how government incentives can significantly affect the affordability of sustainable energy for consumers. By analyzing the effects of tax incentives, this study offers valuable insights into the interplay between policy decisions and the economic aspects of sustainable energy adoption (Rudolph et al., 2023). It highlights the significance of well-structured policies in making sustainable energy an attractive choice for consumers (Rudolph et al., 2023).

**2.5 Balancing Energy Supply and Demand**

Balancing energy supply and demand is vital for a resilient energy grid. Bixler et al. (2019) developed an observatory framework for understanding urban social-ecological-technical systems. This framework enhances comprehension of the dynamics between energy supply and demand, providing valuable data for policymakers and energy providers. By studying the interplay between various factors in urban systems, this research offers insights into managing energy supply and demand efficiently. It contributes to the development of strategies for maintaining a stable and reliable energy grid (Bixler et al., 2019).

**2.6 Modeling Energy Forecasting and Demand**

Amonkar (2022) KNN space-time simulator research showcased assessing the severity, duration, and frequency of energy droughts in the Texas Interconnection. His research incorporates the spatial structure and wind-solar dependence in simulations, providing a tool for estimating the regional long-duration storage capacity. The research highlights the significance of correctly representing space-time dependence in simulations to ensure accurate estimations in the context of wind and solar generation configurations (Amonkar et al.2022).

Utilizing Random Forest Regression (RFR) and Long Short-Term Memory (LSTM) models Balal’s (2023) research focused on forecasting solar photovoltaic (PV) power generation in Lubbock, Texas, these models exhibit the capability to capture intricate patterns and complex relationships in solar power generation data, providing valuable insights for solar PV investors in improving planning and production processes. Their study emphasizes the suitability of machine learning models, particularly ensemble methods for accurate solar PV power generation forecasting (Balal et al., 2023).

Employing ARIMA, Multiple Linear Regression, and Seasonality models, Ruthford’s (2021) time series-focused study forecasts electric energy demand. The study does a robust job highlighting notable deviations from a simple sinusoidal pattern due to various factors by combining ERCOT demand with weather data. The time-series models were developed to account for these seasonal factors, utilizing one-hot encoded variables for month, day, and hour, along with the compiled temperature data (Ruthford et al., 2021).

**2.7 New Technologies for Sustainable Energy**

Technological advancements are driving the sustainable energy transition in Texas. Mekhilef et al.'s comprehensive review in 2011 of solar energy use in industries highlights the role of technology in the industrial sector. Their findings emphasize the importance of adopting advanced technologies to enhance the integration of solar energy into various industrial processes. This research showcases the potential for technology to revolutionize industrial energy usage in Texas (Mekhilef et al., 2011).

Woo et al. (2023) explore regional revenues from solar and wind generation, emphasizing the economic potential of new technologies, including advanced weather modeling and improved solar and wind technologies. Their research provides a detailed economic perspective on the adoption of these technologies in Texas (Woo et al., 2023). By highlighting the economic benefits, it underlines the promising outlook for sustainable energy technologies in the state. This research also signifies the role of advanced weather modeling in optimizing the use of solar and wind energy, making it more reliable and efficient (Woo et al., 2023).

3 Methods

The demand for electricity is a pivotal driver of modern society, underpinning a wide range of essential activities, from powering homes and industries to supporting technological advancements and environmental sustainability. Accurate and reliable models of electricity demand are paramount for grid management, resource allocation, and the development of sustainable energy policies. In this literature review, this study embarks on a comprehensive exploration of methodologies used to model electricity demand, with a specific focus on data sourced from the Electric Reliability Council of Texas (ERCOT) spanning the years 2007 to 2023.

Electricity demand modeling has gained substantial importance in recent years due to the increasing complexity of energy markets, the integration of renewable energy sources, and the need for efficient resource management. ERCOT, as the independent system operator for the Texas electricity grid, offers a rich dataset that encapsulates diverse and dynamic factors influencing electricity consumption.

The primary intent of this review is to explore and analyze the diverse modeling approaches that researchers have employed to understand and predict electricity demand within the ERCOT region. Three major modeling paradigms are considered in detail: Linear Modeling, Time Series Models, and Neural Network Models. Each of these approaches offers unique advantages and exhibits limitations in its capacity to capture the nuanced behavior of electricity demand data. The overarching goal is to evaluate the suitability of these modeling techniques in the context of ERCOT data and, by extension, contribute to the body of knowledge surrounding energy demand modeling.

Throughout this review, the discussion will delve into the strengths and weaknesses of each modeling approach, highlighting their ability to account for temporal dependencies, capture non-linear patterns, and provide interpretable insights. Moreover, it will examine how these models handle the intrinsic complexities associated with electricity demand forecasting, such as seasonality, volatility, and unforeseeable external factors. In doing so, this paper aims to guide future research endeavors, inform policy decisions, and assist energy stakeholders in their efforts to optimize resource allocation and grid management within the ERCOT region.

As electricity demand continues to evolve and adapt to an ever-changing landscape, it is essential to harness advanced modeling techniques that can respond to the multifaceted challenges of the energy sector. This literature review serves as a comprehensive reference for researchers, policymakers, and industry professionals seeking to gain deeper insights into the modeling of electricity demand, with the goal of enhancing the sustainability and efficiency of energy systems in the ERCOT region.

3.1 Data Preprocessing

Before modeling, the data is to go through extensive preprocessing, including data cleaning, missing data imputation, and outlier handling. Specific preprocessing steps are to follow:

* Removal of missing data points.
* Detection and handling of outliers.
* Aggregation of data into appropriate time intervals (e.g., hourly, daily, monthly) as per the modeling requirements.
* Data normalization and scaling to ensure consistency and comparability.
* EDA

3.2 Linear Modeling

Linear models are commonly used in the analysis of electricity demand due to their simplicity and interpretability. This section describes the linear modeling approach applied to the ERCOT data.

Advantages:

* Interpretability: Linear models are straightforward to interpret, making it easy to understand the relationships between independent variables (predictors) and the dependent variable (electricity demand).
* Simplicity: Linear models are simple and computationally efficient, making them a good starting point for modeling tasks.
* Stability: They tend to work well when the relationship between variables is approximately linear.

Disadvantages:

* Assumption of Linearity: Linear models assume that the relationships are linear. In reality, electricity demand may have complex, non-linear patterns.
* Limited Expressiveness: They may not capture the seasonality and temporal dependencies found in time series data effectively.

**Model Selection**

The choice of linear model(s) was based on an extensive review of the literature, considering models such as:

* Simple Linear Regression: A straightforward model that assumes a linear relationship between a single predictor and electricity demand.
* Multiple Linear Regression: Extends simple linear regression to incorporate multiple predictors to capture more complex relationships.
* Generalized Linear Models (GLMs): Useful when dealing with non-normal distribution of data or when modeling electricity demand in terms of its predictors with a non-linear link function.

**Model Evaluation**

The performance of the selected linear models was assessed using standard metrics, including:

* Mean Absolute Error (MAE)
* Mean Squared Error (MSE)
* Root Mean Squared Error (RMSE)
* R-squared (R²) for goodness of fit

3.3 Time Series Modeling

Time series models are essential for capturing the temporal dependencies and patterns in electricity demand data. This section describes the various time series models used in the analysis.

**Advantages:**

* **Temporal Dependencies**: Time series models are specifically designed to capture temporal dependencies and seasonal patterns present in electricity demand data.
* **Forecasting Capabilities**: They excel at making short-term and long-term forecasts based on historical data.

**Disadvantages:**

* **Complexity**: Some time series models can be complex and computationally intensive, requiring careful tuning.
* **Sensitivity to Hyperparameters**: Selection of appropriate hyperparameters is crucial, and poor choices can lead to inaccurate forecasts.

**Model Selection**

The choice of time series models was made based on the unique characteristics of the ERCOT data. Models considered include:

* **Autoregressive Integrated Moving Average (ARIMA)**: Combines autoregressive and moving average components to model stationary time series data.
* **Seasonal Decomposition of Time Series (STL)**: Decomposes time series data into seasonal, trend, and residual components for analysis.
* **Exponential Smoothing**: Uses weighted averages of past observations to make forecasts, with various methods like Holt-Winters.
* **Long Short-Term Memory (LSTM) Networks**: A type of recurrent neural network (RNN) that can capture long-range dependencies and is suitable for sequence data.

**Model Evaluation**

The performance of the selected time series models was assessed using time series-specific evaluation metrics, such as:

* Mean Absolute Percentage Error (MAPE)
* AIC/BIC for model selection
* Forecast accuracy and precision
* Visual inspection of forecast plots and residuals

3.4 Neural Network Modeling

Neural network models have gained popularity in recent years for modeling complex and non-linear relationships in electricity demand data. This section describes the neural network modeling approach.

**Advantages:**

* **Non-linearity**: Neural networks can capture non-linear relationships in electricity demand, making them suitable for complex and dynamic patterns.
* **Deep Learning**: Deep neural networks can learn hierarchical features and complex dependencies in data, allowing for more accurate predictions.

**Disadvantages:**

* **Data and Computation Demands:** Training deep neural networks often requires a large amount of data and substantial computational resources.
* **Black Box nature**: Neural networks are often less interpretable compared to linear models.

**Model Selection**

The choice of neural network architectures was guided by the specific characteristics of the ERCOT data and included models such as:

* **Feedforward Neural Networks (FNN)**: Standard neural networks with one or more hidden layers that can approximate complex functions.
* **Recurrent Neural Networks (RNN)**: Suitable for sequential data, they can capture short-term dependencies but may suffer from vanishing gradient problems.
* **Long Short-Term Memory (LSTM) Networks**: A type of RNN with specialized memory cells, capable of capturing long-term dependencies.
* **Gated Recurrent Unit (GRU) Networks**: Another type of RNN with similar capabilities to LSTM but with fewer parameters.
* **Convolutional Neural Networks (CNN) for 1D data**: Utilizes 1D convolutions to capture local patterns and is effective for some time series data.

**Model Training**

The neural network models were trained on the preprocessed data, and hyperparameters were tuned to optimize model performance.

**Model Evaluation**

The performance of the neural network models was assessed using various evaluation metrics, such as:

* Mean Absolute Error (MAE)
* Mean Squared Error (MSE)
* Root Mean Squared Error (RMSE)
* Mean Absolute Percentage Error (MAPE)
* Time series-specific metrics for forecasting accuracy

4 Results

“The correct BibTeX entries for the Lecture Notes in Computer Science volumes can be found at the following website shortly after the publication of the book: <http://www.informatik.uni-trier.de/~ley/db/journals/lncs.html>”  
LNEE Paper Template | PDF | Portable Document Format | Typefaces - Scribd, https://www.scribd.com/document/272800381/LNEE-Paper-Template.

5 Discussion

“The Lecture Notes in Computer Science volumes are sent to ISI for inclusion in their Science Citation Index Expanded.”   
—LNEE Paper Template | PDF | Portable Document Format | Typefaces - Scribd, https://www.scribd.com/document/272800381/LNEE-Paper-Template.

6 Conclusion

“The Lecture Notes in Computer Science volumes are sent to ISI for inclusion in their Science Citation Index Expanded.”

—LNEE Paper Template | PDF | Portable Document Format | Typefaces - Scribd, https://www.scribd.com/document/272800381/LNEE-Paper-Template.

Acknowledgments. “The heading should be treated as a 3rd level heading and should not be assigned a number.”  
Introduction - AHFE Conference, https://ahfe.org/files/AHFE\_Template\_LastName\_FirstName\_PaperID.docx.

~~Notes. we are aware that our problem statement and the state of our paper are not aligned presently. We are presently redirecting our approach in the efforts of fully reproducing a study and expanding upon it.~~ Adjustments made

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Appendix.