Quantifying the Value of Renewable Energy as a Hedge Against the Volatility of Natural Gas Prices in Wisconsin

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Abstract

This research study investigated whether adding renewable energy to the grid in Wisconsin would lower or maintain electricity prices through 2050. Since Wisconsin adopted a plan to become carbon neutral by 2050, this study explored different paths to achieving this goal. This study examined three different paths or scenarios, specifically base case, optimal, and carbon-free, using an Excel-built toolkit. The toolkit allowed the researcher to customize all major assumptions, making it a practical tool that could assist electric utilities in the future in determining whether additional renewable energy would indeed lower and stabilize electricity prices. Applying different statistical tools to the scenarios, the study discovered that the base case scenario would achieve 25 percent renewable energy by 2050 with the projected electricity price of 14.5 cents per kilowatt hour (kWh), the optimal model would create 33 percent renewable energy with the electricity price of 16.9 cents per kWh, and the carbon-free scenario would create 100 percent renewable energy by 2050 with the projected electricity price of 21 cents per kWh. The hedging premium exhibits higher volatility than the natural gas prices as the coefficient of variance (COV) exhibits the volatility of the hedging costs at 883.33, meaning the end users need to pay a 1-cent premium per kWh. Assuming that Wisconsin's grid has a medium capacity to absorb large quantities of renewable energy, this study estimates that under the base case scenario, adding one kilowatt of renewable energy decreases the price of electricity by 1.4 cents per kWh. The optimal scenario keeps the electricity prices almost the same, 0.03 cents per kWh, compared to the no additional renewable energy scenario. Under the carbon-free scenario, the most aggressive scenario in terms of adding renewables, electricity prices are estimated to rise an average of 3 cents per kWh.

Dedication

I dedicate my dissertation work to my family and many friends who have supported me through the process. A special feeling of gratitude goes to my loving wife Amie, and daughters Angelina and Sofijana, who gave me love, space, and time to work on this dissertation. Their words of encouragement and push for tenacity ring in my ears. Even in my ups and downs during the dissertation work, they have never left my side and are very special.

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Thank you to the chair, Dr. Katherine Hyatt, for providing timely and helpful feedback and always being willing to help. Many thanks also to Dr. Nicole Lowes for helping me with my statistical skills. Both of you have been my greatest cheerleaders. I will always appreciate Ms. Amanda Anderson's work, who spent many hours proofreading my work.

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Section 1: Foundation of the Study

Because the United States electric market is so fragmented and each state has its unique generation portfolio, the state authorities need to create strategies to provide affordable electricity to its residents and businesses. Like most states, Wisconsin, and its electric utilities, are constantly weighing whether renewable energy or traditional hedging mechanisms are a better and less expensive option to minimize the impacts of the volatile fuel market, primarily oil and natural gas.

Traditionally, to hedge the future prices of electricity, the electric utilities pay the difference between the spot electricity contracts and the expected future electricity price (Cotter & Hanly, 2015). Additionally, the electricity hedging business practice and the associated costs depend on the extent to which sellers and buyers are risk averse (Billio et al., 2018). The issue arises when utilities do not have effective tools that can be utilized quickly to compare the traditional hedging mechanisms to investing in renewable energy. Some electric utilities, at least in the short term, use financial hedging instruments to manage natural gas prices, assuming that there are no risk aversion factors or other premiums built into the forward price compared to the expected futures price (Alasseur & Feron, 2018)

Alternatively, those electric utilities that are more risk-averse attempt to secure electricity prices in the long term by deploying different types of renewable energy (Ahmad et al., 2018). According to Juntilla et al. (2018), the practice has shown that when electricity buyers are risk-averse and desire to limit their exposure to electricity price fluctuations, the use of financial instruments in the short term is more affordable compared to expensive renewable energy installations.

There are two major reasons why utilities take two opposite approaches to electricity hedging. First, the quantity risk component of hedging creates difficulty in accurately identifying both electricity prices and production levels by the electric utilities. As the electricity demand changes on the utility side, the quantities of electricity being hedged create large swings in the costs of the hedging mechanisms (Bartllet, 2019).

Second, many electric utilities adopted a long-term strategy premised on the belief that renewable energy mitigates the fuel price risk within a resource portfolio (Lucheroni & Mari, 2019). According to Ahmad (2017), in the past few years, to hedge against fuel price volatility, natural gas buyers have paid $0.76 per metric million British thermal unit (MMBtu) over the predicted spot prices to lock in natural gas prices long-term. This additional cost to hedge the natural gas prices is potentially great enough for electric utilities to avoid investments in variable-price hedges, such as traditional hedging mechanisms, and move towards fixed-price investments such as renewable energy (Ahmad et al., 2018). In addition, policymakers and regulators often create other benefits for electric utilities to encourage them to invest in various renewable energy sources.

Background of the Problem

Currently, two key drivers impact the hedging strategies in the electricity market. First, fuel prices are volatile and unpredictable caused by the depletion of fossil fuels, fuel price increases, and the increasing use of fossil fuels resulting in environmental damage... According to Reboredo (2018), this relatively unsustainable situation will not improve in the coming years, given that the existing energy generator will likely be unable to meet the potential electricity demand.

Second, the complexity of the electric markets and the dynamics of the ever-changing power generation portfolios require the electric utilities to constantly research and investigate hedging strategies against the tile fuel prices. Because of this complexity and granularity, electric utilities find themselves in a position where they constantly need to develop new hedging tools and strategies to effectively control electricity prices (Song et al., 2019).

The key question is whether to invest in renewable energy or buy traditional hedging mechanisms to protect against fuel prices. Many authors who ascribe to the electricity hedging position (Bartlett, 2019; Ahmad, 2017; Cotter & Hunley, 2017; Wilson et al., 2019) believe that renewable energy is the best solution for electricity shortages and improving the environment. However, from the electric utility perspective, choosing between traditional hedges and renewable energy is not that simple because the utilities need to control the cost side of the business and, at the same time, ensure price stability long-term (Bush et al., 2012).

Balancing these two very important goals can cause the local electric utilities to either neglect the long-term hedging and environmental benefits or increase the running by paying the traditional hedging mechanisms, forcing utility users to pay inflated electric prices (Saeed et al., 2020). To address these issues in the electricity market, this study attempted to explain the relationship between natural gas prices and electricity prices by quantifying how renewable energy can lower electricity prices in the long-term, if at all.

Problem Statement

The general problem addressed by this study is the lack of appropriate financial tools and developed strategies for electric utilities to effectively evaluate whether to engage in traditional hedging mechanisms, such as futures contracts, or to invest in renewable energy as a hedge against rising natural gas prices. According to Reboredo (2018), unstable fuel prices and each electric market's particular features are required by the electric utilities to perform their hedging analysis, which suggests that future research in this area should be focused on the specifics of each state or market. Hedging against the volatility of fuel prices using an electricity forward contract is likely a more direct approach in some regions, however deploying additional renewable energy has better long-term effects, meaning each electric utility needs to develop its hedging strategy (Juntilla et al., 2018). Ahmad et al. (2018) suggest that future research regarding hedging against the volatile fuel prices by the electric utilities should be based at the state or regional level given the differences in the electric markets and the state regulations.

The specific problem addressed by this study is the lack of appropriate financial tools and developed strategies for Wisconsin electric utilities to effectively evaluate whether to engage in traditional hedging mechanisms, such as futures contracts, or invest in renewable energy as a hedge against rising natural gas prices.

Purpose Statement

The purpose of this study is to assist the electric utilities in Wisconsin to quantify the benefits of renewable energy deployments in their power generation portfolios to minimize the impact of unstable fuel prices. For this study, the researcher created an Excel toolkit that allows the electric utilities to run different hedging scenarios and determine whether the deployment of renewable energy or traditional hedging mechanisms, such as swaps and forward contracts, is better.

Research Questions

The proposed study will have three major research questions.

RQ1: What are the volatility and the costs of the traditional hedging mechanisms, particularly forward contracts or swaps, for the electric utilities in Wisconsin?

RQ2: What is the incremental value of renewable energy for the electric utilities in Wisconsin as a hedge against natural gas price volatility?

RQ2a: What is the methodology to estimate the incremental value of renewable energy?

RQ2b: How much would the electric utilities in Wisconsin need to invest in renewable energy to stabilize the electricity price?

RQ3: What is the relationship between the investments in renewable energy and the electricity costs for the electric utilities in Wisconsin?

Hypotheses

H1 Null: Traditional hedging mechanisms are not significantly more volatile and expensive than renewable energy sources.

H1 Alternative: Traditional hedging mechanisms are significantly more expensive than renewable energy sources.

H2 Null: The incremental value of renewable energy is not statistically significant in terms of lowering electricity prices for the electric utilities in Wisconsin.

H2 Alternative: The incremental value of renewable energy is statistically significant in terms of lowering electricity prices for the electric utilities in Wisconsin.

H3 Null: There is no statistically significant relationship between increased renewable energy installations and electricity prices in Wisconsin.

H3 Alternative: There is a statistically significant relationship between increased renewable energy installations and electricity prices in Wisconsin.

Nature of the Study

The purpose of the proposed study is to assist the electric utilities in Wisconsin to quantify and compare the benefits of renewable energy deployments compared to traditional hedging mechanisms to minimize the impact of unstable fuel prices. For this study, the researcher created an Excel toolkit that allows the electric utilities to run different hedging scenarios to determine which hedging option is better, the deployment of renewable energy or traditional hedging mechanisms, such as swaps and forward contracts.

Discussion of Research Paradigms

This study utilized the post-positivism research paradigm. According to Creswell and Poth (2018), post-positivism includes the subjectivity of reality in the research and moves away from the purely objective stance of a problem. The application of post-positivism helps to achieve the goals of the proposed study because this study examines the hedging options (the objective component of post-positivism) viewed through the lenses of different electric utility companies (the subjective component of post-positivism).

According to Murzi (2007), the post-positivism paradigm aligns well with quantitative research problems. The proposed study is quantitative, and the second and third research questions are quantitative, therefore post-positivism paradigm fits the research objectives well. The post-positivism paradigm is also known as methodological pluralism, meaning that the research involves finding value in a variety of sources of information, rather than supposing that any research method is inherently superior. As such, to answer the research questions, the proposed study will seek numerous data sources to address the general and specific problem statements.

Discussion of Design

There are three major types of research designs, including fixed, flexible, and mixed designs. The fixed design is generally pre-planned and focused on variables that can be measured and compared (Creswell & Poth, 2018). This type of design mostly uses numerical data sets, although qualitative information can be utilized as well.

The flexible design, on the other hand, offers the researcher freedom during the data collection process. The flexible design starts with a researcher exploring a particular idea or problem and, simultaneously, developing the causalities and relationships between the examined variables (Leavy, 2017). In this type of research, the variables are not measured quantitatively, and the theory may not even exist before the research begins. This type of study uses non-numerical data, although numerical information can be utilized in the study to answer the research questions.

The mixed design intentionally combines the elements of fixed and flexible designs to expand the scope of the study. According to Robson and McCartan (2016), the mixed approach expands the study's insights because this approach allows a combination of data sampling, data collection, and different analysis techniques. The main benefit of the mixed design is the triangulation across datasets, which allows the researchers to view problems from multiple perspectives. This approach helps the researcher develop a more complete understanding and a fuller picture of the research problem (Robson & McCartan, 2016).

The proposed study was conducted with a fixed design using quantitative methods. According to De Jonge and Van Der Loo (2018), quantitative research is a formal, objective, systematic process where quantitative data is used to obtain answers to research problems. This research design is used to describe variables and then examine and determine relationships among those variables(Datallo, 2008).

To examine the hypothesis, this study utilized correlational and regression design. Given that the overall task of the study was to collect, compare and analyze the renewable energy generation data in Wisconsin and compare it to the traditional electric hedging costs, the quantitative method is selected as the most adequate.

Discussion of Method

A research method is defined as a well-structured, logical, or standard plan utilized by a researcher to examine the research questions. Quantitative research analyzes the relationships between variables through statistical tools (Campbell et al., 2017). The fixed design uses four types of quantitative methodology, namely descriptive methodology, correlational methodology, quasi-experimental methodology, and experimental methodology (Yilmaz, 2013).

The descriptive methodology describes the current status of a problem, or a variable, and does not insist on defining the hypothesis at the beginning of the study. This type of design is developed only after data collection occurs (Campbell et al., 2017).

The correlational methodology utilizes statistical analysis to determine whether two variables are related and how strong the relationship is (Blocher et el., 2019). A quasi-experimental methodology is considered a true experimental design and is mostly utilized in situations when a standard research design is not applicable or practical. The experimental methodology is built to determine the cause-and-effect relationships between the variables by manipulating or changing the independent variable to observe and record the changes in the dependent variable (Leavy, 2017).

This study was conducted by fixed design using quantitative methods, specifically the regression design. As the overall task of this study was to collect, compare, and analyze renewable energy generation in Wisconsin compared to traditional electric hedging costs, the regression method was the most appropriate. According to Robson and McCartan (2016), correlational research is adequate for analytical approaches, such as variance and correlation analysis, time series analysis, and regression analysis. Cost movements of financial instruments are analyzed by the quantitative approach, specifically by correctional statistical analysis (Mariappanadar & Kairouz, 2017). The correlational analysis provides the basis for the cost trend analysis, which gives an insight into the entity`s cost movements.

A structured correlational research design is a common characteristic of quantitative research (Campbell et al., 2017). This approach is designed to test a theory by using variables that are measured with numbers and analyzed with statistics to determine if the theory explains or predicts the subject of interest (Yilmaz, 2013). Data collection and analysis were based on the entire sample population to satisfy the objectivity criteria of the quantitative method. The selected sample must be sufficient, unbiasedly selected, and representative of the population (Datallo, 2008). Correlation and regression are statistical methods that allow a researcher to explore the relationship between two variables. According to Robson and McCartan (2016), quantitative research offers a generalization of information based on the collected and analyzed data. For most correlation analyses, the 95 percent confidence interval is used to determine the significance of the relationship.

Summary of the Nature of the Study

Numerous theories and models have been developed in theory and practice in an attempt to cope with the uncertainty of fuel prices, and ultimately the volatility of the electricity price. Many practitioners in the field seemingly believe that renewable energy deployments could stabilize electricity prices. However, the complexity and fragmented electric markets offer different opportunities and obstacles for electric utilities to capitalize on this theory. Therefore, each utility is required to assess its hedging position based on its power generation portfolio and determine the amount of renewable energy required in its portfolio to minimize the impact of volatile fuel prices.

To provide electric utilities with a comprehensive approach that would allow them to make their hedging decisions easier and more efficient, many practitioners and researchers agree (Ahmad, 2017; Cotter & Hunley, 2015; Green & Newman, 2017) that the creation of standardized financial instruments and structured transactions in the electricity market would provide numerous tangible benefits to the electric utilities. In addition to providing the utilities with a more simplified approach, the standardization would allow more effective management of the electricity volume risk, create a better synchronization between generation and transmission capacity, and create more efficient service contracts on the market. This approach could therefore reduce the energy transaction costs in the energy market and create greater liquidity for the contractual parties. The standardization of the hedging financial instruments in the energy market would also improve the overall risk management practices utilized in electricity hedging.

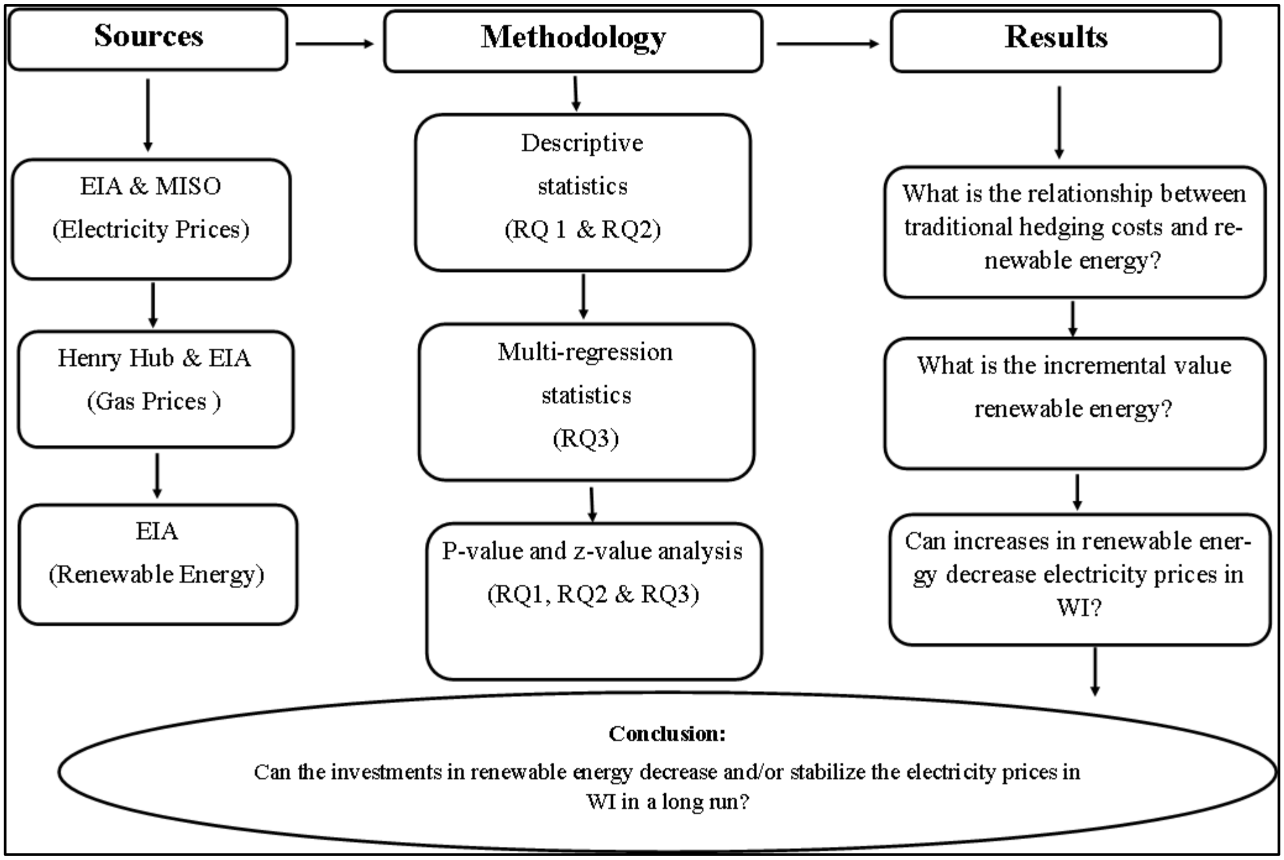
This study is a step toward creating a more standardized approach to hedging against volatile fuel prices in the electricity market. It is an attempt to create a bridge between the existing fragmented theory and the necessity for a more practical standardized model that could be replicated among different electric utilities.

Theoretical Framework

To visually understand the relationships between the major components of this study, see Figure 1 below. The figure shows how the sources, methodology, and main research questions flow together to answer the main question of whether renewable energy is a better hedge compared to traditional hedging mechanisms as protection against volatile fuel prices for the electric utilities in Wisconsin.

Figure 1

Relationships Between Concepts



Theories

The key underlying theory in this study is the merit-order theory. There are secondary theories that will be assessed in the proposed research, including the Mean-Variance Portfolio (MVP) theory, the Levelized Cost of Energy (LCOE) theory, and the Generalized Auto Regressive Conditional Heteroskedasticity (GARCH) theory.

The renewable energy merit-order theory posits that utilizing more renewable energy should decrease the overall costs of electricity because wind and solar energy have very low marginal costs compared to coal and gas-fired generating facilities. Renewable energy facilities often receive feed-in tariff revenues and can then provide power at a lower cost, decreasing the spot electricity prices (Woo et al., 2016).

The MVP theory, also known as modern portfolio theory, implements the value of resource diversification in a portfolio to help investors choose the most profitable portfolio. The theory applies the correlation of outcomes (returns on financial assets) that reduces the risk (measured by the variance of returns) for a particular expected portfolio return (Xia et al., 2019). The MVP analysis is a tool that allows electric utilities to analyze the decision to invest in traditional hedging mechanisms or renewable energy. In this study, the MVP analysis would assist the electric utilities in Wisconsin to estimate the greatest reward at a given level of risk or the least risk at a given level of return. In addition, the MVP analysis would provide insights into the electric utilities' spread returns for different investment options on a daily or weekly basis (Xia et al., 2019). The mean-variance portfolio analysis offers two considerable advantages to electric utilities. First, it simplifies the investment portfolio selection because only the most efficient portfolios are considered, rather than the entire universe of possible portfolios (Bush et al., 2012). Second, it efficiently quantifies how a particular portfolio diversification reduces the investment risk.

The LCOE theory uses a cash flow method to estimate the returns from each power generation alternative. This theory, as suggested by Bush et al. (2012), should be accompanied by the hourly production cost model (PLEXOS). Together, the LCOE and the PLEXOS method allow users to identify the incremental impact of renewable energy generation as a hedging option. For this study, the LCOE would allow the electric utilities to properly determine the costs of renewable energy, including capital, operating, and disposition costs. This would allow a correct cost estimate for each renewable energy option that the electric utility could utilize to compare against traditional hedging mechanisms.

The GARCH theory is a dynamic hedging model used in the energy futures market. The model is built on several simultaneous equations that calculate the returns of the hedged portfolio and the futures (Billio et al., 2018). This model is widely used for portfolio selection and in energy trading transactions. First, the GARCH theory allows monitoring of the entire hedging process as fuel prices undergo volatile stages. Second, the theory uses regime-switching models that allow users to find effective ways to reduce risks associated with their portfolios. These interconnected chain models are more adaptable than single-chain models because they report on sub-movements in the hedging costs during turbulent periods, known as volatile ups and downs (Peura & Bunn, 2021). Finally, the granulated model structure allows users to identify hedging portfolios that have minimum variance and, ultimately, minimum risk exposure (Billio et al., 2018).

Actors

The primary beneficiary of this study would be the electric utilities in Wisconsin. They would benefit from finding accurate information and tools to assess options for hedging against fuel price volatility risks. The main goal of this study is to create a better hedging methodology to assist electric utilities in quickly assessing hedging strategies.

The Public Service Commission (PSC) of Wisconsin, as a governing body in the electric utility arena, would benefit substantially from the study results because it would specify how electric utilities price their electricity. This is very important from the agency`s point of view given that in regulated electric markets, such as Wisconsin, the agency must approve any changes in electricity prices.

The state and local governing agencies could be further prompted to support investments in renewable energy if the deployment of renewable energy provides lower electricity prices in the long term.

This study benefits investors in electric utilities as well. Traditionally, investors have used futures for hedging to manage risk exposure and to estimate an optimal hedge ratio (OHR) for their portfolio, which helps the investors to minimize the risk associated with the portfolio (Reboredo, 2018).

The recent worldwide uncertainty created by the COVID virus and followed by the financial market volatility brought to the forefront risk strategies that can minimize the impacts of large and unexpected market movements. This is particularly important for energy consumers as supply and demand shocks can negatively impact energy commodities and investments (Cotter & Hanly, 2015).

Finally, the local communities would benefit from this study through a cleaner environment and job creation if additional deployment of renewable energy is the best option to hedge against the volatility of fuel prices.

Variables

One of the products of this research is an Excel-based toolkit able to address the relationship between natural gas prices and electricity prices by quantifying whether renewable energy can lower electricity prices long-term.

The deployment of renewable energy measured in mega-watts is set as an independent variable. This variable includes the dominant renewable energy sources in Wisconsin, which are solar, hydro, wind, and biomass. The cost of developing various renewable energy types, as well as the levelized cost of energy for these sources, were found on the Department of Energy`s website.

In this study, the natural gas price is an independent variable used for determining the cost of traditional hedging mechanisms, such as futures contracts. The data for this variable was collected from the Henry Hub database and the EIA. The Henry Hub natural gas spot price measures the price of natural gas in US dollars per 1 million British thermal units (BTU). The futures prices for natural gas were designated as Contracts 1 through 4 in this study, with the month measured from the spot date. For the analysis, Contract 4 data were utilized, which offers hedging prices for natural gas four months ahead.

The electricity price in Wisconsin is set as a dependent variable. This variable includes the electricity prices for the last 10 years. The study analyzed the historical relationship between the deployments of renewable energy and corresponding electricity prices to estimate the impact of additional renewable energy on the stability of electricity prices. The electricity market data was collected and provided by the EIA, updated biweekly. Wisconsin electricity prices were also found under the Midcontinental Independent System Operator (MISO) database, which provides electricity information for the Midwest region of the United States.

The study evaluated multiple relationships between these variables, including the following:

First, the study evaluated the relationship between the volatility of natural gas prices and the hedging mechanism, such as futures contracts. This volatility was then compared to the volatility of the LCOE prices for renewable energy sources. Based on this comparison, the study determined whether futures contracts are more or less expensive and volatile compared to renewable energy and how that impacts the electricity prices paid by the end user.

Second, the study examined the relationship between the levelized costs of renewable energy and electricity prices, assuming that greater deployment of renewable energy creates less demand for fuel, specifically natural gas, which should then stabilize the electricity price. In this case, the study applied the merit-to-order approach to examine whether adding renewable energy has a positive or negative impact on electricity prices in Wisconsin.

Finally, the study assessed the relationship between renewable energy and electricity prices to determine whether increasing renewable energy under different scenarios would stabilize electricity prices by decreasing reliance on natural gas.

Relationships Between Theories, Actors, and Variables

This study also investigated whether the merit-order theory could be applied if additional renewable energy was deployed in the state of Wisconsin. The research is specifically focused on whether the theory could be applied to the first two research questions. The merit-to-order theory was also applied to the actions of Wisconsin`s Energy Department, Public Service Commission, and electric utilities. In particular, the study offers an Excel-based toolkit that could assist these entities in determining whether the merit-to-order theory would apply. If so, the theory could then analyze how adding more renewable energy to the state`s grid would impact electricity prices until 2050. Moreover, the study allows any interested party in any of the states to investigate how the prices of natural gas and the LCOE of different renewables impact the end user of electricity.

Summary of the Research Framework

This study aimed to provide answers to the three main research questions to determine whether the null hypothesis holds: whether Wisconsin investing in renewable energy and generating 100 percent of its energy from renewable sources by 2050 will lower the overall electricity prices. To address such a complex question, the study will conduct multiple statistical analyses comparing the costs of hedging against volatile natural gas prices to additional renewable energy installations. Applying the merit-order theory that additional renewable energy should decrease electricity prices, this study analyzed whether there is a significant relationship between renewable energy installations and electricity prices, and under which conditions the merit-order effect could be achieved in Wisconsin by 2050.

Definition of Terms

Renewable Energy

Renewable energy is the energy generated from renewable resources that are naturally replenished, such as sun, wind, rain, tides, biomass, waves, and geothermal heat. Renewable energy sources are created by natural processes that are replenished at a rate faster than the rate at which they are consumed (Cotter & Hanly, 2017).

Hedging Mechanisms or Derivative Contracts

A derivative contract is a type of financial contract conducted over-the-counter (OTC) between two parties designed to hedge against risks and market fluctuations (Lucheroni & Mari, 2019). The value of this type of financial security is based on an underlying asset or commodity and its associated market fluctuations (Juntilla et al., 2018). In the energy sector, hedging mechanisms include, but are not limited to swaps, forward contracts, options, and futures contracts.

Swaps

A swap is a financial instrument by which two parties exchange cash flows or liabilities from two different financial instruments. This derivative is allowing the contractual parties to swap revenue streams arising from underlying assets held by each party (Bartllet, 2019).

Although the swaps are conducted OTC, they can be customized to meet the needs of the contractual parties.

Forward Contracts

A forward contract is a contractual agreement between two parties that specifies the buying or selling of electricity at a pre-determined price and quantity where the delivery takes place at a future time. Forward contracts allow generators to hedge against low market prices and retailers to hedge against potential financial losses due to high market prices in the spot market (Anderson & Hu, 2008).

Futures Contracts

A futures contract is an agreement between two parties to buy or sell assets and commodities at a fixed price where the assets and commodities can be delivered and paid at a later date (Ahmad, 2017). As with forward contracts, this type of contract allows sellers or buyers to hedge against risk. However, futures are conducted in the exchange-traded setting with standardized contract elements while forward contracts are conducted in customizable OTC contracts (Genc & Reynolds, 2018).

Options Contracts

An options contract grants an owner the right, but not the obligation, to buy or sell electricity at a set price on or before a certain date. More specifically, a call option gives the holder the right to buy electricity and a put option gives the holder the right to sell electricity (Saeed et al., 2020). This type of contract provides more flexibility than a forward contract because the option holder has the choice as to when and whether to exercise his or her option, depending upon the power generation availability or the existing pricing trend on the market, or both (Bartllet, 2019). However, engaging in a forward contract involves no cost, whereas purchasing an options contract requires a non-refundable fee.

Physical Hedge

Whereas financial hedging locks in price risk by utilizing either a futures contract or a swap, physical hedging locks in risk by purchasing a physical amount of fuel to be delivered to a specific location at a specific price (Peura & Bunn, 2021). The benefit of physical hedging is that it locks in both the price and the supply of the fuels necessary to produce electricity.

Risk Aversion

Risk aversion is defined as the ability to undertake or manage the risks associated with certain business activities. According to the prospect theory, gains and losses are perceived differently from a risk standpoint, and the value changes of gains and losses relative to a reference point make some more or less risk-averse (Bell et al., 2017). Therefore, risk aversion is a perception of gains and losses viewed through different risk perspectives.

Spot Market

The spot market is where the electricity market can operate as an instant market where power supply and demand are matched instantaneously. The spot market can be arranged as the day-ahead market or the real-time market (Bartllet, 2019). The day-ahead market is the most prevalent spot market with about 95 percent of energy transactions occurring in this market (Pineda & Conejo, 2013). The day-ahead market occurs on the morning before to allow the electricity generator to prepare sufficient power to meet the demand (Anderson & Hu, 2008). The remaining spot market operates in real-time, which typically runs once every hour and once every five minutes, reacting to load changes in real-time where demand must meet the supply (Xia et al., 2019).

Forward Market

The forward electric markets offer parties the opportunity to engage in longer-term bilateral contracts to hedge against price or quantity risks, or both (Gullìa & LoBalbo, 2015). Bilateral contracting plays an extremely valuable role in wholesale power markets because of the high volatility of electricity prices in the spot markets. Although some of these contracts impose some physical requirements, they are essentially financial hedges against spot prices (Bush et al., 2012).

Assumptions, Limitations, and Delimitations

When a researcher believes that there is a relationship between two variables that can be tested and discovered, that belief is called an assumption. Limitations are elements associated with a particular study that are outside of the researcher`s control. Alternatively, delimitations are those elements that the researcher can control.

Assumptions

The main assumption in this study is that increasing renewable energy generation reduces wholesale electricity prices and benefits electricity consumers. However, the variability of renewable energy generation and the level of risk aversion of electricity market participants can change this underlying assumption significantly.

This study also assumes that electricity is a non-storable commodity, meaning that there are no storage technologies available to manage the peak demand. It is understood that technologies that would offer significant storage capacity would alter the forward and spot prices of electricity, and therefore change the hedging strategies.

This study assumed that the development costs for new distribution and transmission infrastructure would be between 2 and 3.5 cents per kilowatt hour. This is a crucial and very sensitive assumption because it impacts the results of the study substantially.

Limitations

The analysis for this study will include only renewable energy as a hedge against the volatility of fuel prices, although measures to increase energy efficiency decrease power consumption and ultimately electricity demand. The reason for excluding energy efficiency measures from the analysis is the lack of reliable data to quantify the resulting savings.

The analysis will also be limited to electric utilities as the biggest purchases of electricity, although other business entities are also engaged in power purchases, which can impact the supply and demand curve. The reason for excluding other electricity purchases is the lack of reliable and available data for these types of purchases. If the data for this type of purchase were necessary for the analysis, the amount would be calculated by subtracting the purchases from the electric utilities from the total amount of electricity purchases.

Delimitations

This study has two major delimitations. First, the study focused solely on the Wisconsin electricity market in an attempt to determine if the local state markets behave differently because the United States electricity market is fragmented. Second, the study included only major renewable energy sources in Wisconsin, including solar, wind, biomass, and hydro. The other sources of renewable energy are deemed negligent.

Significance of this Study

The results of this study are significant in that they reduced the literature gap in two important ways. First, this study identified critical factors that influence electricity hedging related to particular markets. The existing literature offers general knowledge about individual factors that impact electricity pricing but fails to recognize the practical implications of local factors at the utility level. Second, this study created a practical Excel model that is relatively simple for the electric utilities in other states to modify and apply. The existing literature offers very complex theoretical models that are relatively inapplicable to electric utilities.

Reduction of Gaps in the Literature

This study is a step toward creating a more standardized approach to hedging against volatile natural gas prices in the electricity market. The results of this study created a bridge between the existing fragmented theory and a necessary practical standardized model that can be replicated among different electric utilities.

In doing so, this study reduced the gap between theory and practice in the energy sector. First, this study will identify and quantify critical factors that influence electricity hedging related to particular markets. The existing literature is lacking in practical knowledge of local factors at the utility level, offering only general knowledge about individual factors. Moreover, this study offers a practical and user-friendly Excel model where the analysis can be customized by the utilities based on their knowledge of the inputs. In many instances, utilities have firsthand knowledge about many inputs used in this study, therefore the research would stay current.

Implications for Biblical Integration

Applying a biblical perspective in research requires implementing honesty, integrity, stewardship, and trustworthiness (Wesley, 2019). The honesty principle is well described in the Bible, specifically in this verse: “You shall not commit an unrighteousness in justice, in measures of length, weight, or volume. Just scales, just weights, just dry measures, and just liquid measures you shall have” (Leviticus 19:35–36, NIV). The same principle is stated in

Psalms, which confirms that those who have “clean hands and a pure heart” will be able to climb the “mountain of the Lord and stand in His holy place” (Psalm 24:3–4, NIV).

The stewardship principle is widely referenced in the Bible and is applied to both thinking and learning. The Bible teaches that God is the source of all material things on Earth and entrusted humans with the responsibility for the preservation of material things for the benefit of all. This responsibility should be taken seriously and performed with excellence. “Whatever you do, do it enthusiastically, as something done for the Lord and not for men, knowing that you will receive the reward of an inheritance from the Lord (Colossians 3:23, NIV).

The principle of trustworthiness should be applied to the learning process as well, the meaning of which can be found in the opening verses of the book of Luke where the Bible provides a clear understanding of being trustworthy. “And if you are untrustworthy about worldly wealth, who will trust you with the true riches of heaven?” (Luke 16:11, NLT). According to Fambro (2016), Paul instructed humans to examine everything carefully, thus data gathering, careful analysis, and the formulation of sound conclusions should be utilized to distinguish truth from error.

Benefit of Business Practice and Relationship to Cognate

This study was specifically designed to have practical applications in the energy sector, especially to assist electricity producers in Wisconsin. This study aims to help all affected parties in the energy sector, especially entities such as electric utilities, government agencies, and any other entities interested in comparing the costs of hedging natural gas prices to investing in renewable energy in Wisconsin. As such, the study resulted in an Excel toolkit model, a practical tool that allows users to customize the inputs to create their analysis of how renewable energy impacts electricity prices.

The primary beneficiaries of this study are the electric utilities in Wisconsin. They benefit from finding applicable information and tools about the hedging options against natural gas price volatility risks. The study results, together with the toolkit, will help many electric utilities adopt a long-term strategy for renewable energy to mitigate the fuel price risk within a resource portfolio. The main goal of this study was to create a more effective and practical hedging methodology to assist electric utilities in efficiently identifying hedging strategies.

The results of this study quantify the risk component of hedging for utilities that usually causes difficulty in determining the optimal size of the position for both price and production risk. As the electricity demand changes on the utility side, the quantities of electricity being hedged create significant swings in the hedging mechanisms' costs.

The PSC of Wisconsin, as a governing body in the electric utility arena, will find the study results beneficial because they allow the PSC to quantify how adding renewable energy to the grid would impact overall prices. This is very important from the agency`s point of view because in regulated electric markets, such as in Wisconsin, the agency must approve any changes in the electricity prices. The PSC could utilize the tool to assess the short and long-term impact of adding selected quantities of renewable energy on electricity prices. Finally, the state and local governing agencies could be encouraged to utilize the toolkit model to support investments in renewable energy.

Summary of the Significance of this Study

The significance of this study is that it offers a pragmatic approach to hedging volatile natural gas prices with various renewable energy sources. As such, the research developed a toolkit model that would allow the user to customize the standardized template and generate analysis based on his or her inputs. A practical approach can benefit many actors in the energy sector, including state and public entities, electric utilities, public and private investors, and academia.

A Review of the Professional and Academic Literature

Reducing Risk in Merchant Wind and Solar Projects through Financial Hedges

The study provides a general overview of financial designs for hedging energy risks when wind renewable energy is involved in the generation portfolios (Bartllet, 2019). The author believes that many renewable energy projects chose to participate in the direct market through merchant contracts rather than engaging in long-term power purchase agreements (PPAs). Although the wholesale electricity markets offer higher prices, they also bring higher risks associated with market uncertainties. To attract equity investors, who are generally risk-averse, the renewable energy project owners buy hedges against the price volatilities on the energy market. This impacts the overall hedging costs and the cost of electricity. The study explains the factors that should be included in the analysis to estimate which strategy produces a better hedge, renewable energy or traditional hedging mechanisms. The key takeaway from this study is that differences in project costs, government subventions, size of projects, and generation profiles are the deciding factors. The study identifies renewable energy credits (RECs) and production tax credits (PTC) as factors influencing the electricity market and driving electricity prices.

Furthermore, the study discusses potential future financing challenges associated with renewable energy, such as expiring federal subsidies, and how these challenges could potentially impact hedging strategies. In the end, the author suggests that electricity price modeling depends on the structure of the renewable energy source. The study states solar has three major advantages to wind, including more predictable generation, longer project life, and provision of electricity during a midday heavy load profile. In addition, according to Bartlett (2019), an increase in generation from renewable energy sources could cause local transmission congestion, leading to low nodal prices for renewable energy. Although a general feature of renewable energy is to drive electricity prices down, scarcity events, such as grid congestion and source variability, can cause electric prices to rise. As renewables become a more predominant source of energy, they would lose the hedging role against volatile electricity prices based on the fired generation. The value of renewable energy will imminently decline due to a lack of the following: a sufficient long-term storage solution, flexible electricity demand that smooths out prices over a period, and robust transmission solutions that even out prices of electricity through regions. With the addition of renewable energy to the grid, the risks and uncertainties will exponentially grow to keep pushing electricity prices higher.

How low can it go? The importance of quantifying minimum generation levels for renewable integration

The study discusses significant limitations of large-scale renewable energy deployments based on the fact that renewable energy generation, especially solar and wind, do not offer significant flexibility to meet electricity demand (Denholm et al., 2018). In addition, the limited flexibility of the grid system and the inability of the CHP and hydro plants to turn off or reduce electricity production when wind and solar sources produce a significant amount of power creates a technical and economical limit on large-scale renewable energy integration. The authors believe that to properly analyze adding large amounts of renewable energy to the grid, the grid limitation must be included in the cost analysis, which would impact electricity prices. The authors pointed out that many studies found that grid limitation produces an economic limit and decreases the value of renewable energy generators that create the economic carrying capacity of the power system. The value of the variable generation (VG) depends on many factors, including renewable energy supply timing, electricity demand patterns, transmission capacity constraints, and hydro and thermal generation flexibility. Additionally, to estimate the minimum levels of conventional power generation, the analysis must include predictions of the impact on VG penetration of the supporting technologies, such as storage. To address the above issues, the study introduces the concept of net load, also known as residual load, which is calculated as the normal load minus the electricity generation from variable sources. Under this theory, any generation created by the VG sources must be followed by a decrease in power generation by the hydro and thermal units. Given that these units do not have the flexibility to be turned on and off regularly, this limits the instantaneous penetration of renewable energy. The existing power grid system cannot respond to the high variation of the VG generation. Therefore, understanding grid integration capability and costs are critical for accurate electricity pricing models.

The authors underline that the lack of an existing comprehensive data set, either by the Federal Energy Regulatory Commission (FERC) or Energy International Committee (EIC), of the startup and shutdown parameters for various electricity generators presents a challenge for all decision-makers on whether to incorporate more solar and wind into the power grid. Moreover, from the cost perspective, the authors highlighted that turning on and off different generators could be more costly than the benefit of adding VG to the grid. The study concludes that more investigation is required to discover the true costs of increasing and decreasing power on different generation sources related to the grid capacity before a large amount of VG can be added to the grid.

Renewable Power and Electricity Prices: The Impact of Forward Markets (Bunn & Peura, 2018)

The research assumes that increasing variable renewable power generation in the electric utility portfolios will reduce wholesale electricity prices due to the lower marginal production cost of the renewable resources. This assumption is called the merit-order effect, which was created to investigate how renewable sources affect electricity prices in forward markets, widely used by electric utilities, as a hedge against revenue variability. The study confirms that the merit-order theory creates favor renewable energy due to its low operation costs, but it ignores its high variability. Electricity demand is relatively rigid and large-scale electricity storage options are lacking; thus the existing spot prices are highly volatile, and adding renewal energy creates more volatility in the market. For example, wind generators with an average capacity of 30 percent and a variability of 25 percent, measured by the standard deviation, cause the spot price volatility to further increase. Although most of the electricity is traded using different forms of forward contracts well in advance of the spot prices, the pricing of those forward contracts differs from the spot market pricing. The forward electricity prices, as well as the generation costs, include the hedging costs of the risk exposure to the market. This portion of the forward pricing is called forward premia and fluctuates with the variability of the power supply.

The study confirms that higher renewable energy generation reduces the price when the power is traded in the spot market alone. However, the higher variability of renewable energy sources changes the spot price risk and the volume of hedging through forwarding contracts. This situation causes the existing power producers to sell more on the spot market, which should create lower prices. The variability of renewable energy generation impacts the electricity prices through the direct competition emphasized in the merit-order model and through changing the hedging volumes in the forward market.

In addition, the merit-order effect is fully functional in scenarios where renewable energy resources are deployed in higher quantities and at higher capacities. However, the study concludes that the merit-order effect alone is insufficient to evaluate the price impacts of renewable generation compared to traditional hedging mechanisms, such as forward contracts and swaps. Thus increased forward trading due to the variability of renewable energy sources, even with the low generation costs, may cause the price of electricity to increase. This is because the energy markets are impacted by numerous other variables that need to be included in the analysis, such as government incentives and renewable resource availabilities.

A utility-based approach to energy hedging

The study proposes a new approach to understanding electricity prices by suggesting that optimal energy hedging strategies should be developed using optimal risk aversion ratios (Cotter & Hanly, 2015). The study introduces energy hedging by applying market-based risk aversion coefficients to create optimal hedge strategies. To do so, the study estimates and applies time-varying risk aversion coefficients, primarily focusing on the risk aversion of the energy market participants. Furthermore, the study applies those risk aversion coefficients to different power generation portfolios, including renewable energy, to estimate optimal hedging strategies using utility functions such as quadratic, exponential, and log. This approach allows the utilities to examine the risk impacts on the optimal hedge portfolio when different power generation selections are available.

By comparing utility-based optimal strategies based on the risk aversion of the energy market investors, the study attempts to discover a new methodology that would emphasize the importance of risk attitudes, more specifically those of investors and hedgers in the energy sector. The study found that these risk aversion factors are similar to those produced by the asset pricing models in the equity market. This means that there are no extraordinary risks associated with the energy market, although this could change, particularly as the energy sector experiences significant turbulence.

Strategic Commitment to a production schedule with uncertain supply and Demand: Renewable Energy in Day-Ahead Electricity Markets

In this study, the authors explored the concept of a day-head electricity market to assess the impact of renewable energy on electricity prices (Sunar & Birge, 2017). A day-ahead market is a market that happens one day in advance of the operating day and is divided into 24 hourly blocks. Each generator submits its schedule and commitment for each time block of the day-ahead market, and the generator must produce the committed energy or be subject to a penalty. This flexibility is only offered to variable renewable generators. It is not available to coal and nuclear producers as they are considered base-load generators and must run their products to continue to achieve operational efficiency. The authors observed different competing generators, including renewable energy and conventional power producers, as they committed to their price-contingent generation schedules in a day-ahead market. Once the day-ahead market is cleared, each particular generator chooses commitment for the next day-ahead market. If a producer delivers less power than originally committed, it pays a penalty specific to the undelivered amount of power. The day-ahead market established these penalties to improve the reliability of energy producers and motivate them to produce realistic quantities to reduce the production volatilities. This study tries to identify equilibrium strategies by analyzing the supply function of the electricity market containing different types of producers. One of the reasons why the day-ahead markets increase their trading volumes, especially in the MISO region, is the participation of variable renewable energy. MISO and other regional electricity markets created rules to enable variable generation, such as wind, to sell more power in the day-ahead market.

The price modeling developed by this study is based on three major assumptions. First, the major difference between renewable and non-renewable companies is that renewable companies offer uncertain power supply. Second, renewable energy generation occurs with significant operational costs. Third, a renewable energy company can change its generation schedule and volume for the day-ahead electricity market. Based on the model developed by this study, the data showed that even under the pressure of penalties, the energy companies overcommit electricity production, which can lead to reliability degradation. To avoid these situations, the authors proposed fixed underperforming penalties not connected to the electricity price.

Setting costs targets for zero-emission electricity generation technologies

This study explores how different renewable energy deployment scenarios impact energy pricing across different regions (Mai et al., 2019). Despite higher levels of penetration of renewable technologies, up to more than 50% of the electricity mix, due to falling installation costs, renewable energy is still expected to meet greater challenges. This study uses the LCOE as a measure to determine whether renewable energy can compete against gas-fired generation facilities as natural gas is relatively cheap.

More specifically, this study uses the LCOE concept, together with the Regional Energy Deployment System Model (ReEDS) model to (a) evaluate the required costs for any specific renewable energy technology to compete with other non-renewable sources, and (b) assess how solar, wind and hydro would achieve a specific level of penetration under different scenarios from now until 2050. The model is set to minimize the total system cost and account for existing economic, policy, environmental, and technological constraints. The ReEDS model was developed by the National Renewable Energy Laboratory and includes scenario modeling for all states until 2050 (National Renewable Energy Laboratory, 2022). This model is built as a high spatial resolution model with non-linear algorithms that account for resource variability. One drawback of the model is that it does not include potential local policies and probable technology advancements in building future scenarios.

In conclusion, rather than addressing how much added renewable energy generation would increase electricity prices, this study found a new approach that quantifies how much governments need to provide in subsidies to make the penetration available. More specifically, the study introduces concepts of marginal credit value and required costs. The marginal credit value is defined as the production subsidy required to make the technology competitive at a certain level of penetration. The required costs represent the difference between LCOE from input assumptions and the marginal credit value from the model results. The study concludes that each renewable technology`s attributes affect the relative costs and the value to the system. Therefore, as renewable energy penetration increases, the value of renewable energy sources declines due to ability to be dispatched and transmission limitations.

Electricity sector policy, technological change, and U.S emissions goals: Results from the EMF 32 model intercomparison project

This study analyzes different scenarios regarding the changes in the electric power sector as a result of the United States climate policy changes requiring federal, state, and local utilities to incorporate more renewable energy into their portfolios (Bistline et al., 2018). The study explores six different scenarios, including cap and trade and carbon tax options, to estimate electricity rate trajectories in the short and long term. The study estimated that coal and nuclear power will decline in electricity generation usage and that natural gas, solar, and wind will become dominant sources of power in the future. It also estimated that natural gas generation would increase due to lower natural gas prices. Finally, wind and solar electricity production would increase based on decreasing initial installation costs, positive environmental stipulations, and the carbon tax on coal and oil fire facilities. Based on the EMG32 model utilized in this study, wind and solar energy would reach 60% of the total power generation by 2050. However, the authors recognize that these estimates may differ between regions based on the availability of renewable resources, local regulations and incentives, electric load characteristics, and the existing electricity mix.

This study also analyzed the relationship between wind and solar energy and concluded that wind generation will surpass solar long-term because of increased onshore wind installations spurred by higher wind capacity factors, relative cost declines, and higher marginal values of added capacity.

One of the biggest challenges is to estimate the nuclear production levels in the future given that federal and state environmental policies guide nuclear power generation. Most of the modeled scenarios predict that the price of renewable power will remain relatively the same, and lower-cost nuclear power will then lead to an increase in gas-fired facilities installations, increasing carbon dioxide emissions.

This study suggests that more stringent carbon dioxide emissions policies are required to increase renewable energy deployments because the existing environmental regulations, coupled with the current market trends, are insufficient to achieve the goal of having 100% renewable energy generation by 2050.

The Use of Solar and Wind as a Physical Hedge against Price Variability within a Generation Portfolio

This study provides a framework to estimate the incremental value of renewable energy projects that could serve as a physical hedge against the risks associated with fuel costs (National Renewable Energy Laboratory, 2022). The report emphasizes the value of portfolio diversification in the electric utility field using the LCOE theory and PLEXOS modeling, which allows users to reduce the risk and uncertainty of renewable energy system costs over the project`s lifespan.

More specifically, the study considers different renewable energy penetration scenarios and determines the incremental value of renewable energy under various levels of renewable portfolio standards. To accomplish this task, the study explores different economic dynamics, risk mitigation strategies, and the incremental value that renewable energy could add to the power system.

The study concludes that adding renewable energy can reduce the variability of the overall electric system costs compared to the portfolios that are mostly comprised of natural gas-fired generation facilities. In addition, the authors conclude the following:

a) Solar and wind generation significantly reduce the risk exposure of electricity costs from volatile natural gas prices.

b) Combining wind and solar provides a better hedge against uncertain fuel prices due to anticorrelated daily and seasonal generation profiles.

c) The reduction in the volatility of electricity costs is greater in portfolios dominated by gas-fired facilities than in coal-dominated portfolios.

d) The increasing impact of adding renewable energy decreases as renewable energy deployments are added.

Assessing the impact of renewable energy sources on the electricity price level and variability – A quantile regression approach

This article addresses the influence of wind and solar, energy on the level and variability of electricity spot prices in Germany (Maciejowska, 2019). This study starts by explaining the merit-order effect in the energy sector, which is described as a movement of the electricity price curve due to an increase in low-cost renewable generation. This means that every increase in renewable energy installations is expected to cause electricity prices to fall.

Based on this common assumption, this study uses quantile regression to test the merit order effect for different segments, specifically the quantiles of electricity prices during low, intermediate, and high demands (Maciejowska, 2019). Using the inter-quantile range (IQR) to measure the price volatility in Germany, the study estimated that wind and solar influence price movements differently. Wind generation increases electricity prices during low electricity demand and decreases electricity prices during high electricity demand. Alternatively, the study determined that solar power generation stabilizes electricity prices during normal electricity demand levels. Based on these results, one can conclude that solar and wind, as the dominant renewable energy sources, nematically impact the price levels, approximated by the price median. Therefore, the study suggests that incorporating more renewable energy requires an adequate balance between wind and solar resources, which is largely determined by the grid capacities and demand curves. Policy supporting the development and integration of RES should pursue a balance between wind and solar power.

The results of this study show that both wind and solar have a price-dampening impact on energy prices, meaning they cause oscillations in the electricity market. This aligns with other studies concluding that renewable energy variability increases the volatility of energy prices.

The effect of wind and solar power forecasts on day-ahead and intraday electricity prices in Germany

This study analyzes the effects of wind and solar power generation forecasts on electricity prices (Gürtler & Paulsen, 2018). To do so, the study utilizes the daily prices on a day-ahead and intraday electricity market within 24 hours. The study then analyzes that data using the fixed regression and the Driscoll-Kraay table of standard errors (Gürtler & Paulsen, 2018). Unlike similar previous studies that utilize standard pooled regression analysis, this study deployed a panel data analysis to avoid negative consequences of omitted variables bias, triggered by unobserved heterogeneity. The analysis applies the fixed effects model, which is designed to exclude heterogeneities and replace them with transformations within the population. The day-ahead prices and intraday prices are set as dependent variables. The utilization of the Driscoll and Kraay standard error tables allowed the authors to include heteroscedasticity, autocorrelation, and cross-sectional dependence of the residuals (Gürtler & Paulsen, 2018). This approach identifies time-dependent effects in the results, meaning that the study accounts for different price levels within each hour of a day and their specific effects.

To control power generation heterogeneity and model nonlinear price behavior for a variety of power demands, the authors differentiate between fuel types including coal, gas, and others. This study found that both solar and wind create price-dampening effects on power prices as a result of lower fuel prices. More specifically, the price of electricity is around $1 per megawatt hour (MWh) lower due to solar and wind penetration. However, as the solar and wind penetration increases, coal and natural gas prices decrease and become low and stable.

This study also discovered that reducing errors in the forecasting of wind and solar power generation, as well as smoothing the cyclical demand, leads to price volatility. Different fuel types within specific power generation portfolios impact electricity prices differently. Therefore, the study found that between 2012 and 2013, when the gas and coal prices were relatively low, renewable energy sources had a smaller dampening effect. Alternatively, from 2013 to 2015, renewable energy had a greater effect due to increased natural gas prices.

Does renewable energy generation decrease the volatility of electricity prices? An analysis of Denmark and Germany

This study explores the effect of variable renewable energy (VRE) technologies with zero marginal costs on the decrease of renewable electricity prices in Denmark and Germany (Rintamäk et al., 2017). The main focus of this study was to examine how the shift in energy sector supply curves impacts electricity price volatility. Because renewable energy technologies are unable to flexibility respond to high peak and low off-peak demand and prices, utilities need to properly incorporate renewable energy generation into their portfolios. A thorough understanding of renewable energy demand-response applications is necessary to compensate for the losses of conventional generators caused by increasing and decreasing the generation due to the intermittency of renewable energy sources. There is also a need to understand how the penetration of VRE affects volatility, which the authors in this study explore using distributed lag models with Danish and German data sets.

The authors found that wind generation in Denmark decreases the daily volatility of prices, while wind generation in Germany increases the volatility because of a stronger impact on off-peak prices. The main drivers of this phenomenon are the availability of flexible generation capacities and wind power generation patterns. Solar power generation, however, tends to decrease price volatility, but only in Germany. Solar and wind energy negatively impact weekly electricity prices, meaning they contributed to the electricity prices increase due to their intermittency.

This study suggests that integration policies should be tailored to region-specific sources of renewable energy to create economically significant effects on day-ahead price volatility. To manage electricity price volatility, the hourly, daily, and weekly estimates of renewable power generation play a crucial role. This is because the daily average of renewable energy generation increases the weekly volatility of electricity prices due to the high day-to-day variability of wind and solar power production. One significant conclusion is that higher average weekly wind power generation contributes to higher weekly price volatility.

As a solution, the study offers a few suggestions to help the power authorities to handle intermittent supply and decrease balancing costs, including capacity payments for flexible power generation facilities, spreading wind and solar facilities across wide transmission areas, and coordinating supply and demand with adjacent markets.

Disruptive innovation, stranded assets, and forecasting: the rise and rise of renewable energy

This study explores how disruptive technologies, in this case, solar generation coupled with battery storage, can change the markets and influence the commodity price (Green & Newman, 2017). This paper recognizes that renewable energy with battery storage is a disruptive innovation that can compete with fossil fuel assets and eventually surpass their generation. The authors believe that renewable capacity on a global scale can meet the electricity demand due to the introduction of battery storage and decreasing retail renewable electricity prices. Essentially, battery storage can become a cost-effective solution to store energy and make the final energy consumers independent from unstable grids and volatile energy prices (Green & Newman, 2017).

This study utilizes simple modeling to predict how various levels of GDP and electricity demand influence electricity pricing in different scenarios. The study explores the possibility of energy efficiency and renewable energy generation meeting the global energy demand. The authors model energy demand as a function of GDP growth and the growth of energy consumption and find that growth in GDP drives energy consumption. However, achieving the carbon-free, also called carbon-neutral, energy goal by 2050, will require a significant increase in energy efficiency measures, combined with renewable energy installations.

Structural price model for coupled electricity markets

This paper focuses on developing a structural model able to calculate the electricity spot and forward prices in markets that have limited interconnection options and different fuel types in their portfolios (Alasseur & Feron, 2018). The authors build the model as a multi-commodity pricing model that includes the effects of different power generation technologies and electricity price cross-border interconnection specifics. The proposed model assumes that electricity spot prices are impacted by fuel prices and their production and consumption volumes. Additionally, the model includes an ability to estimate the forward electricity prices and derivatives related to the energy markets.

The authors proposed a multi-commodity electricity price model for two interconnected zones where the technologies used to produce electricity are specific to each zone. In this way, this model represents some peculiarities in the spot prices of the two markets. The study focuses on the Central West Europe (CWE) zone, which includes 19 European countries with 85 percent of the total electricity demand. This interconnected market offers a few crucial advantages to the participating countries. First, it decreases physical risks associated with the energy markets as it allows the pooling and sharing of the production capacities across the member`s area of service. Because electricity demand is inflexible and not perfectly correlated, pooling the electricity supply resources makes the entire grid more robust compared to the individual electricity systems. Furthermore, these types of interconnected systems ensure that the power transmission networks operate safely, reducing the risk of blackouts.

Second, resource pooling allows the participating countries to become more cost-efficient and lower the electric rates for their final users. Under the market coupling model, such as in CWE, the buyer bids on spot markets through electricity auctions without considering the limitations of cross-border capacities. As such, the coupling markets inform buyers about the best purchasing options and optimize the cross-border flow of electricity. In addition to forcing the individual markets to become more efficient, the coupling market grants buyers the advantages associated with neighboring markets, which ensures higher liquidity of the individual markets and better hedge strategies against the risks involved with a particular market.

Revisiting long-run relations in power markets with high-RES penetration

This study investigates how European Union electricity generation from renewable energy resources plays a role in electricity price creation (Gianfreda et al., 2016). It analyzes the long-term relationship between day-ahead electricity prices and fuel prices for natural gas and coal. The study found that coal and gas prices influence power generation less because of increased renewable energy generation. In the energy market, this phenomenon is called a merit-to-order effect. However, this study also discovered that an increase in renewable energy penetration creates integration and interconnection issues, which complicates the management of electricity. The intermittency of renewable energy sources and the lack of significant electricity storage options cause balancing issues with demand and supply, which increases the volatility of electric prices. This occurrence becomes more apparent in territories that have an uneven spread of renewable energy sources, which creates transmission imbalances. The authors suggest that electricity market convergence could help countries to solve some of these issues characteristic of individual markets.

This study showed that support for renewable energy influences the relationship between electricity and fuel prices, meaning that energy policies help renewable energy penetration and weaken the correlation between electricity prices and fuel market movements. Although the study found that coal generation has increased its influence on electricity prices because coal became inexpensive compared to natural gas, the switch from natural gas is not expected to be a new instruction for coal facilities. The authors suggest that an increase in renewable energy generation can lower emission prices and spur coal and oil-fired generation.

This study recognized that switching to renewable energy causes electricity prices to be impacted more by weather conditions and less by fossil fuel volatility. This is especially true as energy integration becomes more prevalent across the European continent. Therefore, the authors believe that integrated energy policies should be directed towards strategies that would enable market coupling and grid unification to balance power generation and consumption.

Optimum bidding strategy for wind and solar power plants in the day-ahead electricity market

This document explores potential strategies for how wind and solar power generating facilities can maximize their profits in day-ahead markets by using joint strategies and existing energy storage technology opportunities (Ozcan et al., 2021). Both strategies are analyzed using different partnering groups with 15 partners in the bidding pool trying to take advantage of a larger power generation reservoir. The proposed model is run based on the installed capacity. The main purpose of using both strategies for solar and wind generating facilities is to balance the power generation from renewable energy sources (Ozcan, et.al., 2021). The secondary purpose of this study is to measure the impact of different regulatory requirements on the income of generating facilities.

This study introduces the joint bidding model (JBM), which allows the bidding of collaboration groups. The study also develops the battery deployment model (BDM) to assess the impact of battery technologies on electricity prices. The impact of each strategy on total income is analyzed. According to the study results, the JBM business strategy is more sensitive to different regulatory requirements. However, it increases the profit of the collaborative participants by up to 0.65%. The BDM strategy on its own is not feasible or financially viable due to high initial costs. On the other hand, pairing wind and storage generating facilities with different storage solutions significantly increases the profit of the collaborative participants. For example, the study estimates that extra income per megawatt (MW) ranges between $218 and $400 per year for solar generating facilities with the storage option. Furthermore, the wind generating facilities could expect an increase ranging between $2,460 and $6,795 per MW per year. Therefore, the deployment of batteries in wind-generating facilities creates additional income more than tenfold that of solar-generating facilities. Thus the BDM strategy is viable provided that the levelized cost of deployment of the battery drops below the extra income values achieved per MW of battery.

Electricity market design under increasing renewable energy penetration: Misalignments observed in the European Union

The main purpose of this document is to discuss whether the European Union (EU) electricity market design can achieve its mission in terms of integrating more renewable energy without significantly impacting electricity prices (Peng & Poudineh, 2019). The study investigates the market design behind just the pricing mechanism. The authors discovered misalignments between the increase of renewable energy deployments and coordination of the different times of market elements, including the wholesale market, retail market, and market regulations.

This study also discovered that in multi-level governance such as the EU power sector, misalignments also occur between different countries in terms of renewable support mechanisms. To advance in terms of deploying more renewable energy, the study suggests that some reforms need to be adopted to eliminate friction between the different levels of governance. The study identifies the main priorities necessary in reform to maintain stable electricity prices, including more efficient renewable energy supporting mechanisms, short-term operation security, grid and infrastructure security and flexibility, and resource management.

The authors noted that in the past the priority was on de-risking renewable investments and making renewable energy more affordable. However, as recent trends show, renewable energy technologies have become more competitive, and regulators should broaden their perspective to involve more renewable energy rather than simply sheltering renewable energy investments from the market risks.

To remove the barriers to further renewable energy expansions, the study proposes a concise and holistic approach that would identify the main issues affecting the EU power market.

Since decarbonization in the energy sector became a global issue, the study believes that a new electricity market design is required that is capable of promoting and integrating different renewable energy sources and increasing overall renewable energy participation in the EU electricity mix. Renewable energy should not exert support solely from tax dollars because increased taxes cause electricity prices on the retail level even though renewable energy has a depressing effect on the wholesale electricity prices.

Alternatively, increases in the retail price of electricity and incentives for renewable energy stimulate consumers to invest in distributed renewable energy because this decreases their energy consumption and power cost. However, this implies that the transmission costs or the network costs must be offset another way given that a shrinking pool of end-users contributes less to these costs, which are recovered on a kWh basis. Therefore, electricity prices must be increased or the consumers need to leave the grid, also referred to as grid defection.

To address these issues, the study suggests that the final users need to receive better information from the regulators about their non-system-optimal consumption and power generation opportunities. These balancing actions on both the supply and demand side of the spectrum, will decrease the volatility of electricity prices caused by adding more renewable energy to the grid.

From energy legislation to investment determination: Shaping future electricity markets with different flexibility options

This study investigates the impact of increasing renewable energy generation on electricity pricing given its highly intermittent generation structure, solar and wind facilities in particular, needing to be incorporated into electricity grids (Landner et al., 2019). The authors acknowledge that new, more optimal approaches need to be implemented to integrate more renewable electricity generation into the existing energy system. These new approaches could include building significant storage facilities, implementing more over-capacities in the transmission network, installing conventional backup power plants, developing a network of local storage facilities, or establishing efficient demand-side management to achieve low-carbon energy goals.

The perpetual necessity for grid flexibility will require regulatory agencies to create laws that will reduce or eliminate current investment obstacles and provide sufficient incentives to attract private sector investors. To meet the demand for more renewable energy, and simultaneously keep the price of energy from escalating, an efficient energy market must be designed to propel efforts to transition to a more effective energy system.

According to the authors of this study, a new legal framework will need to resolve uncertainties associated with energy investments so private investors are more comfortable with the maker risks. These laws must also avoid the unfavorable treatment of certain investors or technologies. Moreover, eliminating the complexities of the existing energy system would improve the system costs and ultimately decrease electricity prices. The authors claim that the most obvious barriers are inefficient regulatory incentives because they create an uneven investment field for all renewable energy technologies.

To be more specific, the study mentions that in Germany zonal price signals may lead investors to commit their resources to inefficient investments and ignore local resource scarcities. Additionally, the authors conclude the German uniform pricing system is inefficient because it is created for the day ahead spot market, so if investors do not notice any price differences between the local networks, the investors do not know to invest in the areas where the investments would produce the most.

The integration of renewable energy sources efficiently into the existing power system will require adequate private sector investments in flexible energy options, not just renewable energy generation. A continuous increase in intermittent renewable energy generation will create an ever-increasing mismatch between the grid capabilities and supply and demand.

This study concludes that keeping the price of electricity stable long-term will require the utilization of flexibility options, including demand flexibility, storage flexibility, conventional generation flexibility, and transportation flexibility.

Hedging Strategies of Green Assets against Dirty Energy Assets

This study takes a slightly different approach to electricity hedging by stating that investments in clean energy stocks and green bonds provide a better hedge compared to the portfolio with dirty assets, such as gas (Saeed et al., 2020). The study examines the hedging effectiveness of the United States volatility index concerning clean energy prices and renewable energy stocks. The evidence suggests that combining clean energy stocks with crude oil provides a profitable hedging prospect.

The study conducted a wide-range literature review to determine how the fuel and renewable energy stocks are related, and whether they have a significant impact on electricity prices. The literature review showed that clean energy stock returns, whether short or long-term, were not impacted by crude oil returns, suggesting that employing more renewable energy would stabilize the electricity prices by nullifying the volatility of the fuel market. The diversification that comes through renewable energy deployment aids electricity prices.

The authors state that the government policies motivated by environmental concerns created a drive towards clean energy, making these investments appealing to environmentally responsible investors. The study used dynamic conditional correlation models to compute optimal hedge ratios and analyze the effectiveness of the hedging strategy. The study found that investors need to utilize a dynamic hedging strategy responsive to changes in the energy market.

Internal hedging of intermittent renewable power generation and optimal portfolio selection

This study introduces a new approach for hedging against the risks associated with volatile generation portfolios that includes dispatchable (oil and natural gas sources) and non-dispatchable (solar and wind sources) power generation sources (Lucheroni & Mari, 2019). The proposed hedging strategy is based on deciding on the total power generation in advance, then "compensating any unpredictable non-dispatchable production with a matching reduction of the dispatchable fossil fuel production." In theory, this approach would allow the electric utilities to have sufficient short-term volume and avoid the costs of financial hedging or storage. To create such optimization, the study uses the LCOE theory, where the CO2 prices, fuel costs, and intermittencies of the generation sources are included as uncertain variables. The study concluded that the production cost risk can be better managed when the dispatchable electricity from fossil fuel sources can be replaced with non-dispatchable electricity generated by renewable sources. It then found that the generation costs can be limited if the utilities find ways to accurately predict the intermittent power generation sources, such as solar and wind.

The value of forecasts: Quantifying the economic gains of accurate quarter-hourly electricity price forecasts

This study attempted to estimate the economic benefits of establishing a forecast model for German quarter-hourly electricity spot markets (Katha & Ziel, 2018). In addition to studying the electricity pricing forecasts, the authors explore the impact of early day-ahead electricity prices on intraday forecasts. The main assumption is that even simple electricity trading strategies, supported by good forecasting techniques, can lead to significant economic impacts.

The German electricity market includes a significant amount of renewable energy installations. However, to grow this trend within the country`s portfolio, a new approach is required to help the market participants to focus on quarter-hourly prices because it would increase residual volumes after hourly day-ahead bidding. This is important because quarter-hourly spot markets would decrease the volatility of the power grid created by intermittent renewable energy sources.

To create such quarter-hourly forecasts, the study applied a modern regression technique called the elastic net estimator that takes into consideration only variables that significantly impact future pricing. The study found that the intraday auction prices are easier to predict than the ongoing trading system as it provides high forecasting accuracy compared to the traditional benchmark models. This approach was verified by the Diebold-Mariano test, which confirmed the quarter-hourly forecasts (Katha & Ziel, 2018, p.418). However, these models proved to be inaccurate for the continuous intraday market since the study`s forecast models revealed only minor increases in performance whereas the Diebold-Mariano statistics suggest better results. The study concludes that market participants that engage in traditional mean-variance strategies to manage the risks associated with the market would find the quarter-hourly forecast beneficial and suitable to estimate investment returns.

The Effect of Wind and solar power generation on wholesale electricity prices in Australia

In Australia, renewable energy deployments were seen as one of the largest drivers of electricity prices, causing concerns about pursuing greater renewable energy integration into the national power system (Csereklyei & Ancev, 2019). Many critics pointed out that increases in the penetration of solar and wind farms triggered an increase in wholesale and retail electricity prices, leading many to believe that there is a significant correlation.

This paper investigates if the increased penetration of renewable energy was correlated with electricity prices. This study found evidence of the merit-order effect, meaning that installations of wind and solar generation resulted in reductions in wholesale electricity prices. Therefore, there is only evidence of a negative correlation between the two.

More specifically, the authors found evidence showing that wind facilities moderately lower electricity prices due to an increase in the average dispatched capacity. In opposition, utility-scale solar operations lower the merit-to-order effect of renewable energy. The authors predict that the renewable installation will continue to have a moderating impact on the merit-to-order effect short-term, while such predictions are hard to establish long term. This study found that the actual increases in wholesale can be attributed to the rise of natural gas prices, establishing a positive relationship between these variables. The study findings could have significant implications for the energy policy in Australia. First, government support for renewable energy, especially wind and solar, should continue because the merit-order effect holds in this case. Second, further expansions of renewable energy installation in the energy policy will likely lead to lower wholesale electricity prices, assuming all else holds equal. Third, existing energy policies and the progress made in decarbonization are consistent with long-term carbon dioxide reductions. Finally, reliance on natural gas just during peak hours could potentially lessen the negative impact of rising natural gas prices.

To rebut the claim that renewable energy increases electricity prices, the authors test the merit-to-order effect in the Australian electricity market. The merit-to-order effect is based upon the assumption that the equilibrium of supply and demand will propel cheaper renewable energy generators to supply more power at cheaper marginal costs, driving the wholesale electricity price down. Therefore, the more energy is produced at zero or close to zero marginal cost, the less expensive the entire power mix should get. To conduct the analysis, the study utilizes solar and wind generation statistics coupled with the wholesale prices from 2010 through 2018. The analysis utilizes 30-minute intervals and daily prices expressed in Australian dollars (AUD) fed through the autoregressive distributed lag models (ARDL). The model showed that every additional gigawatt of installed wind lowers the wholesale electricity price by 11 AUD/MWh. Under the same assumptions, one gigawatt of solar capacity lowers the electricity price by 14 AUD/MWh.

The second question this study addresses is whether the magnitude of this effect has been changing as solar and wind penetration increases. The study found that further renewable energy expansion will likely decrease electricity prices.

Energy planning and modern portfolio theory: A review

This study investigated how the design of a power generation technologies portfolio is important for power generation optimization to provide electricity at the lowest cost possible. The study notes that these questions must be viewed not only from a cost perspective but also from an environmental perspective (Deliano et al., 2017). Furthermore, the optimization process needs to include variables associated with the availability of resources and technologies, energy security, and social and environmental impact. The authors believe that the main goal of each power system is to create a diversified system that includes nonrenewable and renewable energy sources with renewable energy generators and RES plants placed strategically to maximize efficiency.

The methodology used in this study was based on Markowitz's portfolio theory (Deliano et al., 2017, p.641), which tries to find the long-term optimal investments in the energy assets that will provide the best combination of renewable and non-renewable sources available to a certain energy portfolio. To optimize those portfolios, the study takes into account the cost, returns, and economic risks associated with each technology included in a particular portfolio, The main tool the study utilizes is the quadratic optimization approach, which allows the user to either maximize the return on their assets or minimize the generation cost associated with the portfolio.

The study presents a literature review, followed by an analysis of the MPT, which is regarded as the dominant approach when it comes to optimal energy planning. Although the approach seeks to optimize resources at the least amount of cost, the analysis handles numerous constraints associated with different technologies and territories.

Under the MPT approach, the optimization includes the key variables and risks involved in the energy market to find efficient portfolios. As a risk control approach, the MPT seeks to find the most optimal diversification available among the existing options, generally using the standard deviations of net present value (NPV) or the internal rate of return (IRR). These deviations measure the variability of returns viewed through the lens of the private investor. From a risk perspective, the literature considers renewable energy technologies a tool that allows for lowering risks within a certain power generation portfolio, if the local geography and the system capacity allow these technologies to be optimally integrated.

However, the MPT recognizes that incorporating renewable energy is not an infinite process given the grid limitations (i.e., transmission congestion) and source intermittencies, which increase the risks associated with portfolios through imbalances. To model the impact of renewable energy risks on electricity prices, this study compared renewable energy sources to alternatives. For example, nuclear energy has the lowest operating costs because it has a low carbon dioxide footprint. However, technologies that use fossil fuels are considered riskier since they are exposed to market fluctuations and less desirable given their carbon dioxide emissions.

Overall, the study highlights that the technologies with the lowest costs, such as coal, are not desirable from an environmental perspective and that optimal planning requires considering costs, return, and environmental gains as all these variables drive electricity prices.

Multi-agent electricity markets: Retailer portfolio optimization using Markowitz theory

The Markowitz theory is known for the optimization of the energy assets in a specific portfolio by considering the value of each asset and its historical market volatility (Lagarto et al., 2017). The purpose of the theory is to create an optimized investment frontier with multiple points. The points represent different levels of risk and associated gains or returns. For example, risk-averse private investors choose points that have low-risk investments, therefore the returns are smaller. The Markowitz theory could be utilized in the energy market to address the risks associated with renewable and non-renewable technologies and determine the optimal source mix to achieve the highest goals for investors (returns) and final users (wholesale and retail prices).

This study aims to develop an optimized frontier using the Markovitz theory as a risk management tool to optimize energy portfolios in liberalized energy markets. As such, the authors review the literature and practical applications of a multi-variable system for electricity markets simulating the behaviors of the market participants. The results show that an optimal mix of renewable energy sources can keep the prices stable compared to the risk-return ratio.

One main characteristic of the multi-agent system is the simulation of the energy markets based on participant risk-taking and cost variables, whether the simulation is conducted in liberalized electricity markets or regulated markets. The robustness of the model allows the user to utilize day-ahead market data and other electricity markets, or some combination of the above-mentioned markets. As a result, the model computes a matrix of returns for different types of market participants based on their risk aversion. To introduce different levels of risks, the authors use risk characterization, including risk-averse, risk-seeking, and risk-neutral.

Revitalizing the wind power induced merit order effect to reduce wholesale and retail electricity prices in Australia

This study investigates the effect of additional wind power generation on wholesale spot prices in Australia under the existing transmission grid constraints (Bell et al., 2017). To assess such an increase in wind power on the National Electricity Market (NEM), the study focuses on identifying and removing the impediments to such expansion to maximize the merit-order effect.

According to the authors, one of the key benefits of expanding renewable generation is to lower wholesale and retail electricity prices by having power generation sources with very low marginal costs. A competitive dispatch process based on low operational costs, coupled with adequate transmission capability, should allow wind facilities to be dispatched ahead of gas or coal-fired facilities, or both. Such market occurrence would lower electricity prices universally. Further, this study is investigating price islanding effects as a result of transmission congestion in some areas.

This study uses sensitivity analysis to examine how various levels of wind penetration impact electricity prices in different states in Australia. The study found that the additional wind installation impacts differ between states but have similar effects on prices for nodes within the same state. The analysis showed that wind installations decrease wholesale spot prices but increase retail prices in deregulated states such as South Australia, Queensland, and Victoria. One of the potential explanations for this is limited transmission grids in these states.

The study utilized the ANEM model, which is based on an algorithm as opposed to the linear programming used by other similar studies. The ANEM model utilizes quadratic programming to minimize the impact of nodal differences, power generation variable costs, and transmission limitation costs. Unlike quadratic programming, linear programming does not directly capture the impact of transmission congestions on spot prices.

Overall, the study found that the average wholesale spot price at the nodal level falls when additional wind installations are introduced, meaning the economic benefits of the merit-order effect from wind generation are passed on to the final electricity users. To further improve the study results, the authors suggest that grid unification would eliminate coordination and overhead costs, further expanding the merit-to-order effect of renewable energy.

The impact of intermittently renewable energy on Italian wholesale electricity prices: Additional benefits or additional costs?

Although significant renewable energy generation increases positively impact the environment and energy security, government subsidies play an instrumental role (Gullia & Lobalbo, 2015). These subsidies are paid at the taxpayers' and final electricity users' expense. Some studies find that renewable energy expansions significantly increase the price of electricity because they require costly infrastructure additions, as well as backup power costs, conventional generator cycling costs for ramping up and slowing down due to intermittency, and additional balancing expenses.

To address the true costs of these investments, the study applies a hybrid model that allows the authors to evaluate the net cost of the supporting policies for renewable energy. The reason for applying the hybrid model is to provide a more complete picture than shown by either the simulation-based model or the full empirical analysis. The hybrid approach, proposed by this study, introduces the correlation between renewable energy installation and market forces (also called a market effect).

To expand the analysis horizons, this study includes wind and solar generation since each exhibit different generation structures and predictabilities. The study employs a simulation model to measure the merit-order effect and the market power effect, even though they occasionally counterbalance each other.

The hybrid method includes a two-step analysis. First, the study determines the average hourly net price, excluding the average change in fuel prices. Then this study calculates the average hourly net demand (the average net demand for each hour of the year). This step allows the correlation between hourly electricity prices and hourly demand. Second, the regression analysis tool includes the net price as the dependent variable and the net demand as the independent variable. Under this model, there are no other independent variables given that the net demand can accurately explain the differences in the hourly electricity prices.

This analysis confirms that when the market forces are not competitive, the increase in solar simulations does not provide significant evidence of the merit-to-order effect, meaning the spot prices do not decrease. If the solar generators want to offset the decrease in profits during off-peak hours, this is accomplished by increasing the prices, meaning that the average price would stay the same or increase.

The authors state that even when additional solar deployments do not decrease the price of power, the additional renewable energy may have other benefits. Among others, the increased capacity can minimize the market power of dominant companies, with the potential to significantly influence electricity prices. Because solar and wind resources complement each other in terms of dispatch ability during 24 hours, even when they cause an increase during a specific period, prices will decrease significantly long-term.

Risk-based framework for supplying electricity from renewable generation-owning retailers to price-sensitive customers using information gap decision theory

This study investigates how the electricity prices in the retail market are formed and what underlying market forces impact the electricity markets (Nojavan et al., 2017). The study states that pricing structures, including fixed pricing, time-of-use pricing, and real-time pricing are mainly used to maximize the profit of market participants. The determination of the optimal electricity selling price is based on a retailer`s management of uncertainty related to the pool market price and the demand created by the end-user consumers.

This study investigates the electricity price determination process under the different pricing structures mentioned above based on the market and profit opportunities. In the electricity market, the bidding and offering curves for the day-ahead market are generally based on information gap decision theory (IGDT). According to this approach, the optimal bidding and offering strategies are created using the market price uncertainty, which is a function of the market position (positive market conditions bust risk-taking, and vice versa) and the risk aversion of the investor. To incorporate these variables into the analysis, the study utilizes the scenario-based stochastic approach, which responds well to scenarios with uncertain market prices, investor-required rate of return, demand, and variable climate conditions, such as irradiation and wind speed. When the three selling structures are compared, the selling price based on real-time pricing increases the retailer`s profit. Finally, the study suggests that the IGDT model offers retailers the best opportunity to achieve optimal bidding in the day-ahead market based on the risk associated with a certain pool of buyers.

Specifying An Efficient Renewable Energy Feed-in Tariff

This study investigates how feed-in tariffs (FiTs), as a preferred support mechanism for renewable energy sources, impact the market prices of electricity (Farrell et al., 2017). This paper investigates how the most common structure of FiT supports renewable energy deployments and how they affect market price exposure. Commonly employed FiT structures result in either investors or policymakers incurring the full degree of market price exposure. More specifically, the study investigates three common FiTs structures, including constant premium, shared upside and cap, and floor. In terms of methodology, the study uses partial derivatives to quantify the sensitivity of changes in the underlying market variables, followed by numerical examples and quantitative examples of each FiT's structure. The underlying variables that drive electricity price forecasting are the structure around investor risk tolerance, annual volume-weighted average prices, and single-cost scenarios.

The study states that FiTs usually come in two forms, fixed price or constant premium. The fixed price structure allows investors to better control their market risk exposure to low prices, meaning the risk is transferred to policymakers through a higher subsidy cost. Alternatively, a constant premium structure removes the risk by guaranteeing a fixed premium per unit of electricity. However, investors are fully exposed to market volatility risk. To balance risk between policymakers and investors, and to keep the electricity price relatively stable, the authors suggest that feed-in tariffs need to balance risk distribution using the market as a corrective force. One potential solution the authors suggested was applying variants of price floor, shared upside, and cap and floor FiT structures to balance the risks of uncertain market positions. An appropriate theoretical framework is required to adequately characterize the strategic interaction between policymakers and investors when setting a FiT price.

FiT design should incentivize the desired amount of renewable generation, which is a function of the level of FiTs offered by the policymakers and the required rate of return investors set as their price to accept market risks. Therefore, the proposed model includes the following variables: (a) the deployment of QI units of renewable capacity, (b) operational time t, (c) the assumed number n of investors willing to put in service Q units of renewable energy, (d) capital c and operation costs o for the renewable energy systems, and (e) a discount rate r.

Following this convention, along with modeling in the context of an annual timestep, the authors in this study chose GBM to model annual electricity prices. This modeling approach allows incentives to be modified based on the risk variables associated with renewable energy investments and government incentives. In addition, the GBM model allows commodity prices, or financial derivatives, to be modeled with a certain degree of randomization to account for unexpected market fluctuations.

Assessing the Effects of Solar and Wind Prices on the Australian Electricity Spot and Options Markets Using a Vector Autoregression Analysis

Because solar and wind power have recently increased significantly, many believe that renewable power sources impact electricity prices in a meaningful way. The lower marginal cost sources, such as wind and solar, should decrease electricity prices as they displace sources with higher operating costs (Alsaedi et al., 2020).

This study analyzes the impact of solar and wind prices on the spot and options markets in Australia by using a vector autoregression analysis. The study utilizes Granger causality to determine which direction wind and solar generation is influencing electricity prices, as well as the impulse response function and forecast error variance. The authors identify a direct relationship between solar and wind electricity prices and the spot prices in the Australian market, meaning that solar and wind decrease the spot and options of electricity prices. The authors believe these findings should encourage authorities to increase renewable energy deployments because they are more cost-effective and environmentally friendly.

The multivariate analysis presented in this study utilizes multiple statistical tools including (a) a vector autoregression (VAR) model to examine the extent of the relationship between the renewable energy source and the spot energy prices; (b) the causality test to examine the link between two variables; (c) the impulse response analysis measures the duration and strength of the relationship; and (d) the forecast error variance decomposition (FEVD), which determines whether the forecast error variances of the solar, wind, spot, and options prices are influenced by each other.

First, based on the VAR analysis, the spot and option prices in the Australian market are strongly interconnected. Second, the wind electricity price had a medium to strong influence on the options price. The FEVD results indicate that the contribution of the solar electricity price to the spot electricity price was between 3.5% and 8%, depending on the state within Australia. Furthermore, the contribution of the wind electricity price to the spot electricity price was between 3.3% and 7.5%. Fourth, the FEVD indicates that the highest level of volatility for spot and option prices was triggered by their innovations. Fifth, the Granger causality analysis shows that at a 99% confidence interval, there is a significant relationship between solar and wind generation prices and the spot prices across the states in Australia. Last, the study used the VAR model to forecast the spot electricity price for two years and concluded that the electricity prices will drop between 8% and 10% across the territories, with all other conditions remaining unchanged. Similarly, the VAR model estimates that the electricity option price will decrease between 8% and 23%. The authors note that these findings are congruent with previous studies stating that wind and solar penetration decreases wholesale prices, although the retail prices may increase in some instances.

Overall, the analysis indicated that Australia should continue implementing existing energy policies to create a positive impact on the spot and option electricity prices as they significantly contribute to short-term and long-term greenhouse gas emissions goals.

On intermittent renewable generation & the stability of Australia's National Electricity Market

The authors of this study believe that modern energy markets can integrate moderate levels of variable renewable energy. However, they question whether high levels of integration can occur given the electric grid constraints (Simshauser, 2018). The grid markets are volatile due to a high value of lost load (VoLL), even without intermittent renewable energy sources. Therefore, the inherent volatility can throw the power grid off equilibrium for extended periods, becoming even more volatile when variable sources are added. Variable sources cause additional volatility due to the lack of optimization between conventional and renewable energy resources. Therefore, the increase in renewable generation exasperates price volatility. The issue multiplies in imperfectly interconnected areas and where the hedge markets encounter a lack of swaps and caps.

The main purpose of this study was to examine the stability of the Australian electricity market under increased renewable energy generation. Under the base case scenario where VRE reaches 35 percent of the energy mix, the analysis showed that the electric market can maintain a stable equilibrium when the exit and the adjustment of the retired thermal plants happen seamlessly. However, in practice, there is no perfectly smooth transition from conventional to renewable sources. The authors believe that VRE increases create hedge contract shortages, followed by mid-and long-term disequilibrium and significant volatility in the electricity market.

The optimum mix of electricity from wind- and solar sources in conventional power systems: Evaluating the case for New York State

As many states increase their renewable energy targets, the increase in solar and wind generation destabilizes the grid and creates volatility in the electricity market (Nikolakakis & Fthenakis, 2016). Although more stable and predictable, hydroelectric generation is very limited with renewable energy expansions mainly consisting of solar and wind generating facilities. This study considers that solar facilities produce power in a much narrower timeframe than wind, but they produce during peak hours. Conversely, wind-generating facilities produce power for longer periods, but their most productive hours are during off-peak hours, meaning that a certain amount of power is usually wasted because demand is so low.

This study created a model based on software called Matlab to assess how solar and wind generation impacts the supply and demand of electricity in New York. The model includes grid flexibility, solar and wind generating potential, electric load, and excess energy as the main variables in the analysis. To create future projections, the model increased solar and wind generation in 100 MW increments. The calculations are done on an hourly basis where the model deploys maximum renewable energy penetration with minimum electricity dumping within the given constraints. The study did not include any cost analysis as the econometric modeling was beyond the scope of this study. However, the authors acknowledge that economics dictate the most optimal solution in many instances, not only demand and supply curves.

This study ran some simulations based on hourly resources and estimated load data to approximate maximum penetration for solar and wind resources. The optimization of these resources shows that increases in renewable energy generation are possible with higher levels of grid flexibility. The study found that at 80 percent grid flexibility, approximately 30 percent of the energy can originate from wind and solar without requiring significant storage facilities or dumping more than 3 percent of the generated power. The authors believe that additional renewable energy penetration is achievable if energy managing, planning processes, and grid resiliency are improved. However, to fully depend on renewable energy resources without causing a major shift in the electric markets, the authors suggest that either new storage technologies need to be developed, conventional generators need to develop ways to adjust their outputs more efficiently, or the supply-demand characteristics need to change to follow renewable energy generation patterns.

Merit-order effects of renewable energy and price divergence in California's day-ahead and real-time electricity markets

This study addresses two issues associated with the electric market in California. First, the study attempts to identify whether the merit-to-order effect influences electricity prices in day-ahead and real-time markets (Woo et al., 2016). Second, the study investigates the reasons for the divergence between the day-ahead market (DAM) and the real-time market (RTM).

This study used 21,000 hours of data between 2012 and 2015 to determine whether there is significant proof of a correlation between DAMs and RTMs, and if so, what is triggering the price differences. The study applied numerous analytical tools, including regression analysis and descriptive statistics to determine California's electricity price movements. Based on the analysis, the authors concluded that both the DAM and RTM prices depend on two day-ahead forecasts, system loads (demand) and renewable energy generation (supply). The analysis also includes forecasting errors as a variable, expressed as a difference between the actual and forecasted consumption.

The authors find evidence that the merit-order effect exists in the Californian electricity market and that the divergence between DAM and RTM prices depends on the day-ahead forecasted errors and renewable generation variability. Moreover, the results show that increases in natural gas prices, scheduled nuclear plant retirements, and economic growth can cause electricity price increases. One way to address these volatile events is to create an energy policy that emphasizes implementing energy efficiency measures (better control of usage) and creating demand response measures that let energy systems modify energy usage for grid optimization.

Business Practices

To conduct an initial assessment of the impact of adding renewable energy to the grid on electricity prices, many electric utilities either utilize sophisticated software or hire a consultant. In addition, the process of obtaining insight into whether renewable energy is a good hedge option against volatile energy prices takes a significant amount of time and resources. To reduce the time between obtaining the inputs and conducting the analysis, this research attempts to provide electric utilities, and many other entities, tools to conduct these initial assessments before they commit significant resources to a more detailed study.

The Problem

This study addresses the research problem from two perspectives. The general problem is the lack of appropriate financial tools and developed strategies for electric utilities to effectively evaluate whether to engage in traditional hedging mechanisms or invest in renewable energy as a hedge against rising natural gas prices.

The specific problem is the lack of appropriate financial tools and developed strategies for Wisconsin electric utilities to effectively evaluate whether to engage in traditional hedging mechanisms or invest in renewable energy as a hedge against the rising natural gas prices.

Theories

The key underlying theory is the merit-order theory. The secondary theories the proposed research will use include the Mean-Variance Portfolio (MVP) theory, the Levelized Cost of Energy (LCOE) theory, and the Generalized Auto Regressive Conditional Heteroskedasticity (GARCH) theory.

The renewable energy merit-order theory posits that utilizing more renewable energy should decrease the overall costs of electricity because wind and solar energy have very low marginal costs compared to coal and gas-fired generating facilities. Renewable energy facilities often receive feed-in tariff revenues, therefore they can provide power at a lower cost, decreasing the spot electricity prices (Woo et al., 2016).

The MVP theory implements the value of resource diversification in a portfolio to help investors choose the most profitable portfolio. The theory applies the correlation of outcomes (returns on financial assets) that reduces the risk (measured by the variance of returns) for a particular expected portfolio return (Xia et al., 2019). The MVP analysis is a tool that allows electric utilities to analyze the decision to invest in traditional hedging mechanisms or renewable energy. In this study, the MVP analysis would assist Wisconsin electric utilities in estimating the greatest reward at a given level of risk or the least risk at a given level of return. In addition, the MVP analysis would provide insights into the electric utilities' spread returns for different investment options on a daily or weekly basis (Xia et al., 2019). The mean-variance portfolio analysis offers two significant advantages to electric utilities. First, it simplifies the investment portfolio selection because only the most efficient portfolios are considered, rather than the entire universe of possible portfolios (Bush et al., 2012). Second, it efficiently quantifies how a particular portfolio diversification reduces the investment risk.

The LCOE theory uses a cash flow method to estimate the returns from each power generation alternative. This theory, as suggested by Bush et al. (2012), should be accompanied by the hourly production cost model (PLEXOS). Together, the LCOE and the PLEXOS method allow users to identify the incremental impact of renewable energy generation as a hedging option. For this study, the LCOE would allow the electric utilities to properly determine the costs of renewable energy, including capital, operating, and disposition. This would allow a correct cost estimate for each renewable energy option that the electric utility could utilize to compare against traditional hedging mechanisms.

The GARCH theory is a dynamic hedging model used in the energy futures market. The model is built on several simultaneous equations that calculate the returns of the hedged portfolio and the futures (Billio et al., 2018). This model is widely used for portfolio selection and in energy trading transactions. First, the GARCH theory allows monitoring of the entire hedging process as fuel prices undergo volatile stages. Secondly, the theory uses regime-switching models that allow users to find effective ways to reduce risks associated with their portfolios. These interconnected chain models are more adaptable than the single-chain models because they report on sub-movements in the hedging costs during turbulent periods, known as volatile ups and downs (Peura & Bunn, 2021). Finally, the granulated model structure allows users to identify hedging portfolios that have minimum variance and, ultimately, minimum risk exposure (Billio et al., 2018).

Variables

This research study created a toolkit model that examined and explained the relationship between natural gas prices and electricity prices by quantifying whether renewable energy can lower electricity prices long-term.

The deployment of renewable energy in mega-watts is set as an independent variable. This variable includes the dominant renewable energy sources in Wisconsin, including solar, hydro, wind, and biomass. The natural gas price is set as an independent variable and used for determining the cost of traditional hedging mechanisms by calculating the difference between the spot and forward markets. The Wisconsin electricity price is set as a dependent variable and includes electricity prices for the last 10 years. All data sets were collected from the EIA website and verified through other sources, when feasible.

The study evaluated the following relationships:

First, this study evaluated how much the volatility of fuel prices, mostly natural gas, drives the price of traditional hedging mechanisms. This study then estimated whether different futures contracts are effective tools to protect electric utilities from unpredictable fuel prices and how they impact the electricity prices paid by the end-user.

Second, this study examined the relationship between deployments of renewable energy in Wisconsin and electricity prices, assuming that greater deployment of renewable energy creates less demand for fuel, particularly natural gas, which should stabilize electricity prices.

Finally, this study statistically tested the relationship between traditional hedging mechanisms and renewable energy investment costs and electricity prices to determine whether it is feasible for Wisconsin to develop a level of renewable energy that would stabilize electricity prices by relying less on fuels with volatile prices.

Related Studies

The body of literature concerning different states and countries meeting their 100 percent renewable energy goals is vast and colorful. Many of these research studies are dedicated to theoretical, rather than practical, concepts. Some of the studies are difficult to replicate and verify in different business environments. Therefore, this study proposed more practical concepts and resulted in a toolkit allowing users to adjust inputs based on their data sets.

A research study conducted by Denholm et al. (2018), discusses significant limitations of large-scale renewable energy deployments because renewable energy generation, especially solar and wind, does not offer significant flexibility to meet electricity demand. Moreover, the grid system's limited flexibility and the inability of the CHP and hydro plants to turn off or reduce production when wind and solar sources produce significant electricity, create a technical and economical limit on how renewable energy can be integrated large scale.

Bunn & Peura (2018) base their conclusions on the assumption that increasing variable renewable power generation in electric utility portfolios will reduce wholesale electricity prices due to the lower marginal production cost of renewable resources. Mai et al. (2019) explore how various renewable energy deployment scenarios impact energy pricing across different regions. Although higher levels of penetration of renewable technologies are achievable due to falling installation costs, increasing renewable energy to more than 50% of the electricity mix will still face many challenges. Gürtler & Paulsen (2018) concluded that renewables, especially wind and solar, can decrease the cost of energy. However, in some instances, forecasting errors in electricity generation can increase the price of electricity.

Rintamäk et al. (2017) examine how the shift in supply curves in the energy sector impacts electricity price volatility. Because renewable energy technologies have exceptionally low flexibility to respond to high peak and low off-peak demand and prices, it became crucial for utilities to properly incorporate renewable energy generation into their portfolios.

Alasseur & Feron (2018) found that renewable energy generation influences the relationship between electricity and fuel prices, meaning energy policies encourage renewable energy penetration and decrease the correlation between electricity prices and movements in the fuel markets. Ozcan et al. (2021) suggest that energy partnerships (joint bidding systems) require significant battery storage capacity to lower electricity prices when introducing more renewable energy. Landner et al. (2019) suggest that integrating significant renewable energy sources efficiently into the existing power system will require adequate private sector investments in flexible energy options, not just renewable energy generation. A continuous increase in intermittent renewable energy generation will create significant mismatches between grid capabilities and supply and demand.

Lucheroni & Mari (2019) posit that a continuous increase in intermittent renewable energy generation will decrease risk exposure but create significant mismatches between grid capabilities and supply and demand. Therefore, utilities need to find ways to accurately predict intermittent power generation sources, such as solar and wind. Deliano et al. (2017) believe that renewable energy generation can positively impact electricity prices, but power generation technologies portfolio design is important for power generation optimization to provide electricity at the lowest costs possible. Bell et al. (2017) believe that the key benefit of expanding renewable generation is lower wholesale and retail electricity prices as renewables have very low marginal costs. Alsaedi et al. (2020) note that there is a direct relationship between solar and wind electricity prices and the spot prices in the Australian market, meaning that solar and wind electricity prices decrease the spot and options of electricity prices.

Resolving the lack of appropriate financial tools and developed strategies for electric utilities and other entities to effectively evaluate whether to engage in traditional hedging mechanisms or develop renewable energy projects is the main goal of this study. To solve the problem, this study undertook the following tasks:

a) Research the literature and gather information about available tools and approaches that address the problem;
b) Gather the information necessary to conduct such an analysis;
c) Create a toolkit model, detailed but customizable, that would allow users to evaluate different scenarios of adding renewable energy;
d) Provide the methodology to interpret the results; and
e) Suggest further improvements to the model and data collection.

Summary of the Literature Review

The literature offers a variety of theoretical frameworks that deal with states` ability to produce 100% renewable energy. Much of the research was dedicated to exploring pathways for different countries to become carbon-free in the future. The leading approach in the literature was to build new theoretical approaches on a micro-scale and attempt to apply them on a larger level. One of the most common approaches is the merit-to-order theory with some variations, particularly the MVP approach. The literature review also revealed that most of the studies either dealt with the costs of transitioning to the 100% renewable energy goal or tried to examine different portfolio mixes based on local renewable energy resources. Due to the complexity of the topic, most researchers do not attempt to combine both components of achieving the 100 percent renewable energy goal.

Summary of Section 1 and Transition

Because the United States electric market is complex, and the state electric markets are granular, electric utilities continually need to develop new hedging tools and strategies to effectively control fuel costs. Therefore, electric utilities face the question of whether to invest in renewable energy or buy traditional hedging mechanisms to protect against fuel prices. Wisconsin electric utilities, especially those that are small or rural, face the problem of always needing new tools to solve this dilemma.

Research and practice developed numerous theories and models to cope with the uncertainty of fuel prices and the volatility of electricity prices. Many practitioners in the field believe that renewable energy deployments can stabilize electricity prices. However, the complexity of fragmented electric markets offers different opportunities and obstacles for electric utilities to capitalize on this assumption. Therefore, each utility is required to assess its hedging position based on its power generation portfolio and decide on how much renewable energy is required in its portfolio to minimize the impact of volatile fuel prices.

To provide electric utilities with a comprehensive approach that would allow them to make their hedging decisions easier and more efficient, many practitioners and researchers agree (Ahmad, 2017; Cotter & Hunley, 2015; Green & Newman, 2017) that the creation of standardized financial instruments and structured transactions in the electricity market is needed. In addition to providing utilities with a more simplified approach, standardization would allow more effective management of electricity volume risk, create a better synchronization between generation and transmission capacity, and create more efficient service contracts on the market. This approach would reduce energy transaction costs in the energy market and produce greater liquidity for the contractual parties. Standardization of hedging financial instruments in the energy market would improve the overall risk management practices utilized in electricity hedging.

This proposed study would be a step toward creating a more standardized approach to hedging against volatile fuel prices in the electricity market. It would create a bridge between existing fragmented theory and the need for a more practical standardized model that could be replicated among different electric utilities.

The work for this study involved a literature review to define the research problem, the research questions, and the hypothesis. It then consisted of research focused on identifying the relevant hedging approaches and theories in the energy market. The remaining research was implemented using the following steps.

First, this study reviewed all applicable literature to identify relevant factors that influence hedging in the electricity market. As indicated earlier, the literature has been fragmented and does not include a comprehensive approach that could be used in energy hedging. Furthermore, a significant number of approaches cannot be quantified to have any practical implications.

Second, once the key drivers were identified, this study collected the relevant data related to those drivers. In an attempt to provide the highest level of data validity, the study cross-referenced the data sets wherever possible. This step was very important given the fragmentation of the energy market and the different sources of information involved.

Third, as a part of this study, an Excel-based financial model was created which would allow the electric utilities to compare the benefits of the traditional hedging mechanisms to investments in renewable energy. This financial tool will allow utilities to decide at what level renewable energy investments provide greater benefits than hedging mechanisms. Additionally, the model will allow the utilities to adjust their desired renewable generation portfolio by assigning different percentages to renewable energy sources, such as solar, wind, biomass, and hydro.

Last, identifying, understanding, and applying appropriate statistical tools was one of the most important priorities of this study. The correlation and regression analysis were selected as the most appropriate, which could potentially change depending on the completeness of the data sets.

Section 2: The Project

Because the United States electric market is so fragmented and each electric utility has a unique generation portfolio, each electric utility must figure out the best hedging business practices. Like most of the states, Wisconsin utilities are constantly weighing whether renewable energy is a better and less expensive option compared to traditional hedging mechanisms for minimizing the impact of the volatile fuel market, primarily oil and natural gas.

Traditionally, to hedge future prices of electricity, electric utilities pay the difference between the long-term forward electricity contracts and the expected future electricity price (Cotter & Hanly, 2015). The electricity hedging business practice and associated costs also depend on the risk aversion of sellers and buyers (Wilson et al., 2019). The issue arises when utilities do not have effective tools to utilize rather quickly to compare traditional hedging mechanisms with renewable energy investment. Some electric utilities, at least short-term, use financial-hedging instruments to manage fuel prices, assuming that there are no risk factors or other premiums built into the forward price compared to the expected futures price (Cotter & Hanly, 2015).

This study attempted to simplify, while still incorporating, all the main factors influencing the hedging strategies in the electricity market. Therefore, the study included a literature review to identify the main factors and their practical implications and build a practical, Excel-based model to assist utilities in making initial hedging decisions.

Purpose Statement

This study assisted Wisconsin electric utilities by quantifying the benefits of renewable energy deployments in their power generation portfolios to minimize the impact of unstable fuel prices. Specifically, this study created an Excel toolkit that allows electric utilities to run different hedging scenarios to help them to decide which hedging option is better, the deployment of renewable energy or traditional hedging mechanisms, such as swaps and forward contracts.

Role of the Researcher

To achieve the goals of this study, the researcher completed a literature review, data collection, data analysis, and interpretation of the analysis results. A successful research process is often characterized by unhurried, reflective thinking and a thorough review of the literature on a topic of interest (Wesley, 2019).

The first step was gathering information relevant to the study with a focus on triangulation and ensuring the validity and credibility of the data. Although most of the data was collected from free sources, the validation process required access to some subscription databases to gain deeper insights. For example, information about the spot and future prices for electricity and gas is readily available. However, information about swaps and forward contracts ais only available in industry-specific databases owned by private entities.

The second step was selecting the most appropriate tools, including finding and utilizing the most adequate statistical analysis. This study utilized regression analysis and the correlation test to determine the relationships between different variables. While regression analysis aims to determine the relationships between the variables, the correlation test focuses on describing the strengths of those relationships and gaining crucial confidence in the analysis (Creswell & Poth, 2018). In addition, some of the causalities between variables were discovered by descriptive statistics. Once the practical relationships between the variables were established, this study created a theoretical and practical framework, in the form of an Excel spreadsheet, that allows utilities to make initial decisions on whether traditional hedging techniques or investing in renewable energy is more profitable.

The third step included interpreting the analysis and drawing study conclusions. The key element of this step was to answer the research questions and coherently address the hypothesis. Thus, the researcher integrated the literature review and the findings into a final study report.

Overall, the research process involved careful planning and data gathering, paying attention to details, and following closely established procedures and protocols. The research was completed with all diligence and eagerness to determine whether the answers were true. Moreover, it was based on the researcher's faith in the Biblical truth which states that research inquiry leads to truth discovery. In the Bible, Jesus speaks about this relationship by proclaiming, "'Ask and it will be given to you. Seek and you will find'" (New King James Bible, Matthew 7:7). However, the research process cannot be based solely on curiosity but requires the researcher to be fully invested in the study (Wesley, 2019). This type of approach can be found in the Bible when Solomon spoke this truth, "If you seek wisdom as silver, and search for her as for hidden treasures; then you will . . . find the knowledge of God" (New King James Bible, Proverbs 2:4-5).

Research Methodology

This research methodology is often defined as the systematic approach, which addresses the research problem by gathering information about the research hypotheses, conducting an analysis, providing an interpretation of the analysis, and forming a conclusion. The research methodology questions involve determining the most appropriate design and research method.

Discussion of Fixed Design

There are three major types of research designs, including fixed, flexible, and mixed design. Fixed design is generally pre-planned and focused on variables that can be measured and compared (Creswell & Poth, 2018). This type of design mostly uses numerical data sets, although qualitative information can be utilized as well.

Although flexible design can be easily adapted to many research variations, it is not the best approach when numerical variables are selected for a study. The flexible design is more suitable for qualitative studies where variables cannot be easily numerically expressed (Creswell & Poth, 2018). This study was conducted with a fixed design using quantitative methods because it establishes a simple research structure which allows the researcher and readers to follow the research steps.

According to De Jonge and Van Der Loo (2018), quantitative research is based on an objective, formal, and systematic process where the quantitative data is used to obtain answers to the research problems. This type of research design is based on describing the research variables, examining the significance of the relationships among variables, and determining how the relationships between variables address the research questions (De Jonge & Van Der Loo, 2018). The main research questions of this study will be examined through the correlation design. Given that the overall task of the study is to collect, compare, and analyze the costs of renewable energy in Wisconsin and compare them to traditional electric hedging costs, the quantitative method was selected as most appropriate.

Discussion of Quantitative Method

In the literature, a research method is defined as a logical, well-structured, and standard plan utilized by a researcher to examine the research questions. Quantitative research is used by a researcher to analyze the relationships between the variables through different statistical tools (Campbell et al., 2017). Descriptive design describes the status of a problem, or variable, and does not require define the hypothesis at the beginning of the study. This type of design is developed only after data collection occurs (Campbell et al., 2017).

The correlational design utilizes statistical analysis to determine whether two variables are related, and how strong the relationship is between the variables (Blocher et al., 2019). A quasi-experimental design is considered a true experimental design and is mostly utilized when a standard research design is not applicable or practical (Robson & McCartan, 2016). The experimental design is built to determine the cause-and-effect relationships between variables. For this design, the independent variable is manipulated or changed to observe and record the changes of the dependent variable (Leavy, 2017).

This study will be conducted by fixed design using quantitative methods, specifically the correlation design. Given that the overall task of this study is to collect, compare and analyze the investment data for renewable energy in Wisconsin to traditional electric hedging costs, the correlational method is the most appropriate. According to Robson and McCartan (2016), correlational research is adequate for analytical approaches, such as variance and correlation analysis, time series analysis, and regression analysis.

Cost movements of financial instruments are analyzed by the quantitate approach, specifically correctional statistical analysis (Mariappanadar & Kairouz, 2017). The correlational analysis provides the basis for the cost trend analysis, which provides insight into the entity`s cost movements. A structured correlational research design is a common characteristic of quantitative research (Campbell et al., 2017). This approach is designed to test a theory, consisting of variables that are measured with numbers and analyzed with statistics, to determine if the theory explains or predicts the subject of interest (Leavy, 2017).

To satisfy the objectivity criteria of the quantitative method, data collection and analysis was based on the entire population for each variable. The selected sample must be sufficient, unbiasedly selected, and representative of the population (Creswell & Poth, 2018). Correlation and regression are statistical methods that allow a researcher to explore the relationship between two variables. According to Robson and McCartan (2016), quantitative research offers a generalization of information based on the collected and analyzed data. For most correlation analyses, the 95 percent confidence interval is used to determine the significance of the relationship.

Summary of Research Methodology

Based on the nature of this study, fixed design and quantitative method were chosen as the most appropriate. The quantitative method aligned with the goals of this study because this design establishes a simple research structure that allows both researcher and readers to follow the research steps. It also provided the framework to generalize information based on the collected and analyzed data. This study utilized descriptive statistics and multivariance analysis as tools to test the hypothesis. In addition, the study applied p-tests to determine type I and Type II errors. All the statistical analyses were conducted under the 95 percent confidence interval in order to determine the significance of the relationship between different variables.

Participants

Participants are individuals who take part in a certain activity that is the subject of a particular study. This study did not include any individuals as participants, but rather included information about electricity prices, renewable energy generation, and spot and futures prices for natural gas.

Population and Sampling

Discussion of Population

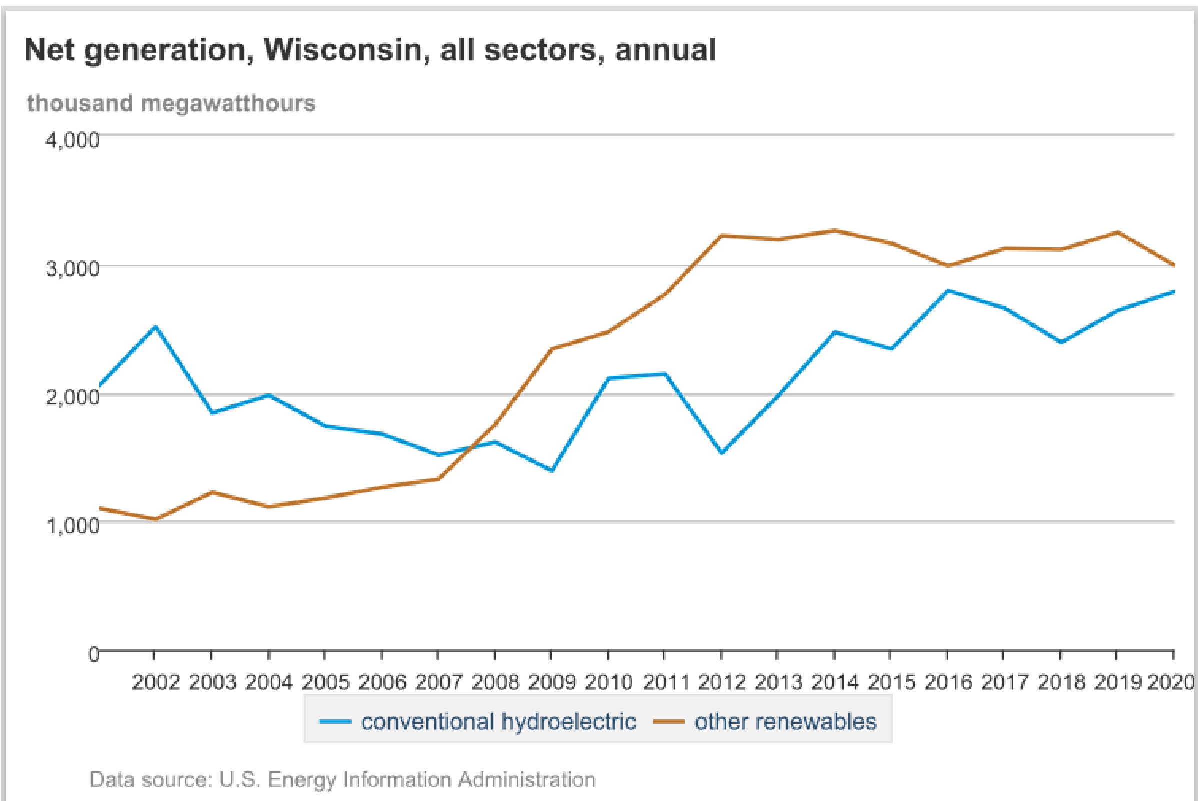
Population is often defined as a complete set of elements, either persons or objects, that have some common characteristics defined by a researcher. The notion of population generally includes two types of populations, the target population and the accessible population (Leavy, 2017). The target population, or universe, includes the entire group of people or objects on which the researcher will base the study findings. The accessible population is the portion of the population to which the researcher has reasonable access (De Jonge & Van Der Loo, 2018).

For this study, given its accessibility, the entire target population for all three variables (electricity prices, renewable energy generations, and spot and futures prices for natural gas) was included in the study. The only sampling for this study was the selection of the time frame for the research population, which is the data from 2013 through 2022, discussed below in more detail.

In general, the sampling frame is defined as the actual set of components from which a population sample is drawn (Creswell & Poth, 2018). The sample frame for this study was variables data for the previous decade because renewable energy installations in Wisconsin started to significantly increase in 2010 after the U.S. government adopted the American Recovery and Reinvestment Act of 2009 (ARRA). This act consisted of a variety of grants and loans for renewable energy installations. The incentives encouraged numerous renewable energy installations, allowing renewable energy to become more competitive with fossil fuel energy. Figure 2 below shows the increase in renewable energy generation in Wisconsin after the ARRA created significant incentives for renewable energy projects.

Figure 2

Wisconsin's Renewable Energy Generation from 2000 to 2020



This study includes the following populations:

The first population consists of the average electricity prices in Wisconsin for all users (residential, commercial, and industrial) in the last decade, on an annual basis.

The second population consists of renewable energy generation in Wisconsin in MWh from 2013 through 2022by all entities (residential, commercial, industrial, and utility installations) on an annual basis.

The third population consists of the natural gas future prices and spot prices for the last decade in Wisconsin. This population contained weekly data at the Henry Hun and Wisconsin city gate prices.

Discussion of Sampling

As mentioned above, the study included the entire population for all three variables, therefore sampling methods were unnecessary and an adequate sample size for each population was selected using statistical analysis methods, including regression and correlation, utilizing the 95 percent confidence level and 5 percent confidence interval.

Summary of Population and Sampling

This study included all data points for each variable, therefore there was no sampling in this study. Each variable included the data sets for 2013 through 2022, and no missing information was found. The data for all three variables was gathered from the same source, the Energy Information Administration, which is the US Department of Energy’s data office.

Data Collection and Organization

Data collection involves creating a method of gathering and analyzing information from different sources in order to obtain complete information about the study`s subject (Arkkelin, 2014). The data process allows the researcher to answer the study`s questions through analysis and forecast future trends. Data organization involves processes that allow a researcher to organize data in a way that will allow efficient data manipulation and analysis (Campbell et al., 2017).

Data Collection Plan

This study includes three major populations.

The first population consists of the electricity prices and total power consumption in Wisconsin for all users (residential, commercial, and industrial) in the last decade. The data set for this population includes the entire population within the sample frame from 2011 through 2021. This variable contains the yearly data, which is then compared to renewable energy production at the same level to correlate how renewable energy generation participates in the total power generation. Wisconsin's yearly electricity prices for all users (residential, commercial, and industrial) were obtained from the Energy Information Administration`s website database on the Electricity Prices web page (Energy Information Administration, 2022).

The second population consists of renewable energy generation in Wisconsin in MWh in the last decade by all entities, including residential, commercial, industrial, and utility installations. The data set includes the entire population within the sample time frame from 2013 through 2022. This population includes the yearly renewable energy generation from all recorded renewable sources, including solar, hydro, wind, geothermal, and biomass. The information was obtained from the Energy Information Administration`s website database, located on the Dashboard web page (Energy Information Administration, 2022).

The third population consists of natural gas future and spot prices for 2013 through 2022 in Wisconsin and at the Henry Hub. The futures prices for natural gas are the prices that buyers are expected to pay for natural gas to hedge against spot price volatilities. The spot prices for natural gas are the prices that buyers pay on the instant market, where power supply and demand are matched instantaneously. The data set includes the entire population for the sample frame from 2013 through 2022. The information was obtained from the Energy Information

Administration`s website database, located on the Natural Gas web page (Energy Information Administration, 2022).

Instruments

The only data collection instrument that was used in this study is the archive database. Most of the information was collected using freely accessible databases created by the Energy Information Administration. Some additional information was collected from database archives created by the Wisconsin Public Service Commission, Wisconsin Energy Office, and Henry Hub. These additional archives were used to verify the primary source of data. The archive data includes the sets of information for 2013 through 2022.

Data Organization Plan

Once the data was downloaded, the data was organized by each variable.

The first population consists of the electricity prices in Wisconsin for all users (residential, commercial, and industrial) from 2013 through 2022 with the corresponding amounts. The data was downloaded at the yearly levels and stored in one sheet in Excel, organized into two rows. The first row contains a specific date or time, and the second row contains a specific electricity price for the corresponding date or time.

The second population or variable consists of renewable energy generation in Wisconsin in MWh from 2013 through 2022by all entities, including residential, commercial, industrial, and utility installations. The data was downloaded from the EIA website at the yearly level. The dataset included renewable energy generation from all recorded renewable sources, including solar, hydro, wind, geothermal, and biomass. This data was organized into two rows, where the first row represented the period (year), and the second row represented the corresponding value in MWh of generated electricity from renewable sources.

The third variable population consists of the natural gas future and spot prices from 2013 to 2022 in Wisconsin and at the Henry Hub. The dataset includes the entire population for the sample frame. Since the other two variables are based on Wisconsin`s prices, a delivery fee was added to both spot and futures prices at the Henry Hub in (LA) to reflect the natural gas prices at the Wisconsin city gate point of purchase. The information was downloaded from the Energy Information Administration`s website database, located on the Natural Gas web page under the Beta data set (Energy Information Administration, 2022).

Summary of Data Collection and Organization

All the data was gathered from the original source, which is the United States Department of Energy. The data were divided into three major categories to match the hypothesis testing goals. Furthermore, the data set was fully verified through other sources, such as Henry Hub and the Wisconsin Department of Energy. All data information was used within each population; therefore, no sampling was necessary. No secondary databases were used either because there was no missing information,

Data Analysis

The data analysis process summarizes how the collected data addresses the research questions. The process involves the interpretation of data gathered through different instruments, and analytical and logical explanations of the results to predict future trends. The analysis conducted for this study involves three major sections, including variable data sets analytics, descriptive statistics, and hypothesis testing.

The Variables

This analysis included three variables, including two independent and one dependent variable shown in the table below. All variables are scale variables and expressed on a yearly basis.

Table 1

The Variable Selection and Characterization

Variable	Variable characteristics	Relationship	Type
Renewable Energy	Quantity (MWh) and Development Price ($/MW)	Independent	Scale
Electricity Price	Future and Spot Prices ($/kWh)	Dependent	Scale
Natural Gas Price	Quantity (MMBtu/year) and Price ($/MMBtu)	Independent	Scale

This study uses renewable energy and natural gas price as independent variables to show their impact on electricity price, which is a dependent variable. This means that the movements in renewable energy quantities and prices, along with the prices of natural gas, drive the prices of electricity. All three variables are scale variables, or measurement variables, meaning that they have numeric values. According to DeJong and Van Der Loo (2018), variables with numeric values can also be labeled as scale variables by default.

Renewable energy is selected as an independent variable because different amounts of renewable generation and pricing drive the electricity markets. In a similar study, Bunn and Peura (2018) identified renewable energy as a driving force that impacts electricity markets across the globe. The authors used renewable energy generation, pricing, and quantities, to determine if the electricity prices change with different levels of renewable energy generation. Similarly, Denholm, et al, (2018) used renewable energy generation data from California and Texas to assess whether renewable energy impacts electricity prices in these markets. In both studies, renewable energy generation was a scale variable, meaning dollar amounts for energy were continuously paired with the year when generation occurred. In this study, renewable energy is a scale variable because it covers data that can be measured with a numeric value.

Natural gas prices are the second independent variable and are organized as a scale variable for the same reasons as renewable energy. Natural gas prices greatly influence electricity prices across different markets in the United States (Bush et al., 2012). According to Juntila et al. (2028), changes in the natural gas markets impact electricity prices and create a need for heading markets. The authors underline how behavioral changes in natural gas prices drive electricity prices differently in different markets. Since natural gas prices impact electricity prices, Maciejowska (2019) suggests that they have a strong relationship based on the quintile regression analysis test.

The electricity prices are a dependent variable in this study, also organized as a scale variable. The movement of electricity prices in different markets can only be assessed by examining the main market drivers, such as fuel costs, and derivative markets, including renewables (Maciejowska, 2019). Woo et al. (2016) examined the relationship between electricity prices and renewable energy and determined that while the direction of the relationship is not always the same, the relationship exists.

Descriptive Statistics

Descriptive statistics are used to describe the characteristics of a particular data set through a variable's mean, standard deviation, or frequency. Descriptive statistics help a researcher to understand the collective characteristics of the data population included in the study (Arkkelin, 2014). All descriptive statistics can either measure central tendency or variability, also called dispersion (Creswell & Poth, 2018). This study utilizes some of the measures of tendency, including mean, minimum, and maximum. These measures analyze the most common patterns of the analyzed data set. This study also performs standard deviations and standard errors. The standard deviation measures the amount of variation or dispersion of values included in the analysis (Robson & McCartan, 2016). This study conducted different normality tests to ensure the data is reliable to allow the researcher to draw accurate and reliable conclusions. Descriptive statistics, together with graphs and tables, are utilized in analyzing how adding renewable energy impacts electricity prices.

In addition, this study deploys the measures of variability which focus on the dispersion of data. The variability descriptive statistics measures assist readers and researchers in better understanding the meaning of the analyzed data by focusing on the frequency of each data point in the distribution and how dispersed a variable is in the distribution of a particular data (Arkkelin, 2014). To estimate how the spot and futures prices of natural gas correlate, this study utilizes the skewness of the data set to test for normality.

Hypotheses Testing

This research study includes three null and alternative hypotheses.

Null Hypothesis: There is no statistically significant relationship between increased renewable energy installations and electricity prices in Wisconsin.

Alternative Hypothesis: There is a statistically significant relationship between renewable energy installations and electricity prices in Wisconsin.

Under hypothesis testing, this study examines a few crucial relationships between natural gas prices, renewable energy installations, and electricity prices in Wisconsin. The first set of tests is an evaluation of how much the volatility of natural gas drives the prices of futures hedging contracts and then electricity prices. Based on that analysis, this study determines whether futures contracts are effective tools to protect electric utilities from unpredictable natural gas prices. This study also explored how that impacts electricity prices paid by the end-user. This analysis addresses the first research question, which addresses the costs of hedging mechanisms relative to the electricity prices.

This study utilizes two statistical tools, multi-linear regression analysis and descriptive statistics, including minimum, maximum, and mean. First, linear regression analysis is utilized to take the last 10 years of real data and extrapolate it to project the cost of futures contracts and renewable energy. Second, after electricity data was projected 27 years into the future, descriptive statistics are used to determine whether there are significant differences between the three examined scenarios.

The scale variable is the most versatile in terms of applying statistical tools. Therefore, the most common parametric tests, such as descriptive statistics, correlation, regression, t-tests, and ANOVA, would apply to this variable (Creswell & Poth, 2018). If descriptive statistics show that capacity costs to manage the variability of renewable energy sources are less than buying electricity futures contracts over the same period for the same amount of power, the study shows that increased renewable energy installations are driven by higher natural gas costs.

The second set of tests examines the relationship between Wisconsin renewable energy installations and electricity prices, assuming that greater deployment of renewable energy creates less demand for fuel, particularly natural gas, which should stabilize or decrease electricity prices, or both. This analysis addresses the second research question, and two sub-questions, that attempt to determine whether and to what degree additional renewable energy impacts electricity prices. Based on the existing data sets for electricity costs and renewable energy deployments from 2013 to 2022, this study applies regression analysis to create a correlation formula that includes variables, slope, and intercept values to estimate how blocks of 100 MW of installed renewable energy will impact the electricity price. Because renewable energy and the electricity price variables are expressed as scale variables, the regression analysis was deemed appropriate for testing this hypothesis.

The third set of tests focuses on whether there is a statistically significant relationship between renewable energy installations and electricity prices currently and long-term, assuming that increases in renewable energy installations significantly lower electricity prices. This addresses the third research question, whether more renewable energy can lower electricity prices and under what conditions. The statistical tests use the current situation as a starting point to estimate future potential, assuming the state will set a goal to produce 100 percent of the power from renewable sources by 2050, as many other states have done (Day, 2021). Correlation analysis is used with a 95 percent confidence interval to determine what the existing and potential future situation is if the state continues developing renewable energy sources. This analysis includes two variables, renewable energy installations and electricity prices. For both variables, this study uses the existing data to project future estimates and make predictions regarding the relationship between these two variables. Because the variables are scaled or measurable, correlation and regression analysis were appropriate statistically (Morgan et al., 2013).

Hypotheses Testing Alternatives

The research statement which is tested for statistical significance is called the null hypothesis. The purpose of testing the significance is to assess the strength of the evidence against the null hypothesis. The statement that is being tested against the null hypothesis is called the alternative hypothesis. If the statistical analysis proves the alternative hypothesis is true, the research data contradicts the null hypothesis. In this study, if the null hypothesis is false, then investing in renewable energy is more expensive than hedging in natural gas and would increase electricity prices long-term.

In case the data does not meet the criteria for the selected statistical test, the alternative is to use ANOVA one-way and ANOVA two-way tests, which are more generalized tests that can be used with different types of data and incomplete data sets. Two of these statistical tools allow the researcher to measure the strength of the relationships between the variables using p-test and t-tests. The p-test and the t-test are part of the ANOVA analysis in the SPSS statistical software (Morgan et al., 2013).

Summary of Data Analysis

The data analysis conducted in this study was based on the tree hypothesis established in this research. There were three major steps involved in this analysis, specifically data organization for each variable, descriptive statistics, and hypothesis testing with statistical analyses such as multi-linear regression, p-test, and t-test. The data for all three variables go through the process of columns to fit the required analysis. The descriptive statistics are mainly involved in the analysis of minimum, maximum, mean and standard deviation values. Finally, the statistical analyses are based on applying the multi-regression analysis to determine the relationship between renewable energy installations and electricity prices.

Reliability and Validity

Reliability

Data reliability means that utilized datasets are complete and accurate, which is a crucial foundation for building trust in the study results (Robson & McCartan, 2016). Ensuring data reliability is one of the main objectives of every research project because building data integrity is building trust in the study results (Arkkelin, 2014). In this study, the data reliability is ensured through the following steps: (a) the validity assessment will ensure that the data is correctly formatted and stored so the statistical software can correctly read and analyze the data; (b) the completeness assessment will ensure that the data set includes values for the all required fields or the data must be provided from other sources; and (c) the uniqueness assessment will ensure that the data is free from duplicates and dummy entries (Leavy, 2017).

One of the ways to ensure data reliability is to identify whether the data was used in similar previous studies, whether the data set came from a primary or secondary source, how the data is transferred from one source to another, and how credible the data transfer procedures are (Campbell et al., 2017). Given that most of the data utilized for this study will be gathered from original and verified sources captured electronically, the confidence in the data is high.

One of the ways to measure the reliability of scale or continuous variable data is to apply a paired t-test. In this study, the paired t-test is utilized to measure the correlation between two independent variables, natural gas prices and renewable energy installations (Arkkelin, 2014). Since the main assumption is that higher natural gas prices drive an increase in renewable energy generations, and vice versa, the paired t-test reveals the strengths of this relationship. Additionally, because linear regression analysis is utilized as a statistical tool in this study, R-squared, t-value, and standard error estimates measure the strength of the relationship between dependent and independent variables.

Validity

The validity of research can be described as the desired level at which the research standards are closely followed during the research process (Leavy, 2017). Because valid data can still be incomplete, the researcher cannot rely only on this measure to ensure the reliability of research findings. To ensure the highest level of research validity, the following measures are undertaken: (a) an appropriate time scale for the data sets are utilized to make sure the data fits the time frame of the research, (b) appropriate methodology is applied to address the characteristics and goals of the study, and (c) the original dataset is utilized in the analysis (Arslan, 2019).

Summary of Reliability and Validity

Researchers must consider the importance of reliability and validity before creating and deciding on a research design. This is particularly true in quantitative research given the importance of having accurate data sets so that reliability and validity issues do not lead to research biases and negatively affect research results. Both reliability and validity are designed to ensure the quality of the research. While reliability measures the consistency of information involved in the study, validity tests the accuracy of that information.

Summary of Section 2 and Transition

To address the impact of adding renewable energy to Wisconsin's energy mix on electricity prices, this study analyzes whether renewable energy sources are a better hedge against volatile natural gas prices than futures contracts. To simplify the overwhelming complexities of hedging strategies in the electricity market, this study developed an Excel-based model using statistical tools such as correlation and regression. The main goal of this study is to assess and quantify how different levels of renewable energy installations impact electricity prices, and whether renewable energy is a less expensive option compared to the futures contracts used by utilities to hedge against volatile natural gas prices.

This study creates a new approach and methodology as a step toward creating a more standardized approach to hedging against volatile fuel prices in the electricity market. This study also creates a bridge between existing fragmented theory and the need for a more practical standardized model that could be replicated among different electric utilities.

Section 3: Application to Professional Practice and Implications for Change

Because the United States electric market is so fragmented and each state has a unique generation portfolio, state utilities must create strategies to provide affordable electricity to its residents and businesses. Like most states, Wisconsin, and its electric utilities, are constantly weighing whether renewable energy or traditional hedging mechanisms are a better and less expensive option to minimize the impact of the volatile natural gas market. Traditionally, to hedge against future natural gas prices for electricity generation, the electric utilities pay the difference between the futures contracts and the spot prices. However, utilities do not have effective tools to deploy quickly to compare traditional hedging mechanisms with investing in renewable energy.

Currently, they are two key drivers impacting renewable energy installations in the electricity market. First, the increasing use of fossil fuels across many industries results in environmental damage and depletion of fossil fuels. The steady increase in fossil fuel use, including natural gas, causes fuel prices to rise and become volatile and unpredictable. Second, because of the harm to the environment caused by fossil fuels, federal, state, and local governments started to create different forms of incentives in renewable energy.

This study examines three major research questions.

RQ1: What are the volatility costs of traditional hedging mechanisms, such as futures contracts, for electric utilities in Wisconsin?

RQ2: What is the incremental value of renewable energy for Wisconsin electric utilities as a hedge against natural gas price volatility?

RQ2a: What methodology can be used to estimate the incremental value of renewable energy?

RQ2b: How much do Wisconsin electric utilities need to develop renewable energy to stabilize electricity prices?

RQ3: What is the relationship between increases in renewable energy generation and electricity prices for Wisconsin electric utilities?

To address the research questions above, this study investigates the following hypotheses:

HP1: Traditional hedging mechanisms, such as futures contracts, are volatile and more expensive than renewable energy for Wisconsin electric utilities.

HP2: The incremental value of renewable energy as a hedge against volatile natural gas prices is significant for electric utilities in Wisconsin.

HP3: There is a significant negative relationship between increases in renewable energy generation and electric prices.

This study was designed using the post-positivism research paradigm where the subjectivity of reality in the research is applicable and moves away from the purely objective stance of a problem. The application of post-positivism helps to achieve the goals of this study because the study of investment options (the objectivity component of post-positivism) was viewed through the lens of different electric utility companies (the subjectivity component of post-positivism).

Additionally, the post-positivism paradigm aligned well with quantitative research problems and methodological pluralism, finding value in a variety of sources of information. As such, this study pursues numerous data sources to answer the research questions and address the problem statements. This study utilizes fixed design and quantitative method, a formal, objective, systematic approach where quantitative data is used to obtain answers to research problems.

The theoretical framework of this study was based on two major concepts, the merit-to-order and LCOE concepts. These two concepts are highly related to the research topic as they examine the role of renewable energy in the electricity mix to impact electricity pricing. The renewable energy merit-order theory states that because wind and solar energy have very low marginal costs compared to coal and gas-fired generating facilities, dispatching more renewable energy should decrease the overall costs of electricity.

LCOE theory uses a cash flow method to estimate the returns for each power generation alternative. For this study, LCOE would allow electric utilities to properly determine the costs of renewable energy, including capital, operating, and disposition costs. This allows a correct cost estimate for each renewable energy option that the electric utility could utilize to compare against traditional hedging mechanisms.

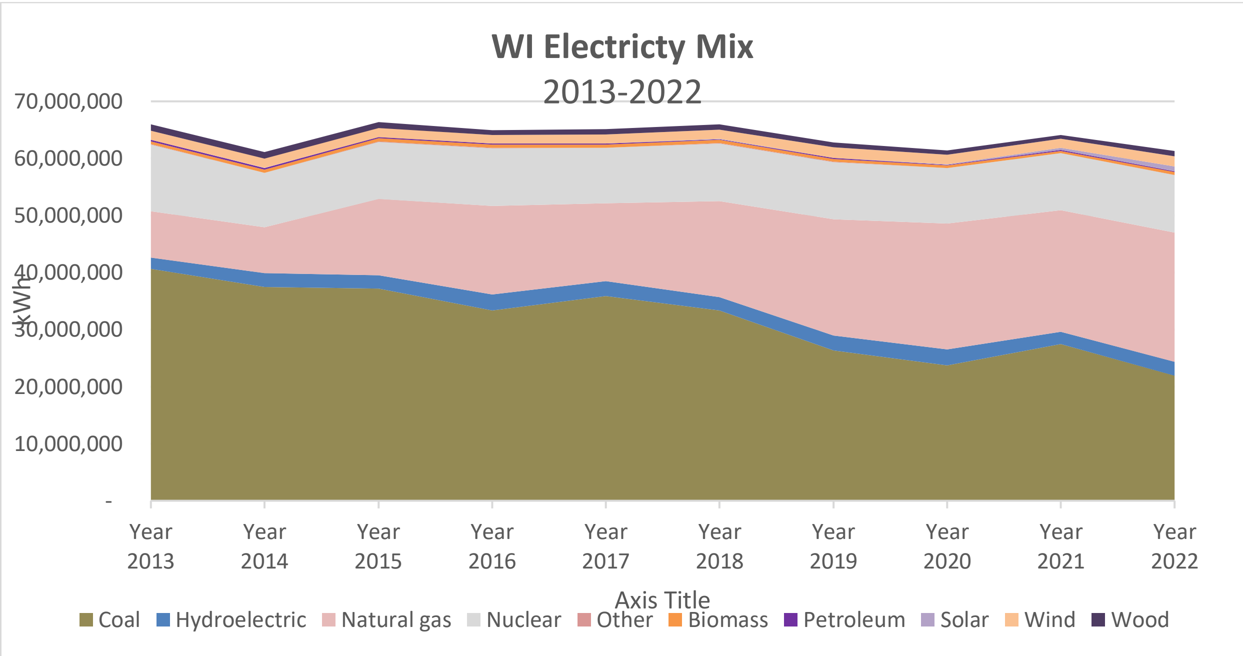
Presentation of the Findings

Wisconsin belongs to the group of states that has a regulated electricity market. In a regulated electricity market, the electric utilities have a monopoly as they control the entire supply chain of the market with oversight from the Public Service Commission. That monopoly allows utilities to make all decisions regarding how the power is generated, transmitted, and distributed to customers. In Wisconsin, electric consumers are not allowed to choose who generates their power as they are bound to the utility that services their area.

Based on the historic and current electricity mix data (Figure 1) collected by the EIA, Wisconsin heavily relies on coal and natural gas as its main electricity sources.

Figure 2

Wisconsin's Electricity Mixes From 2013-2022

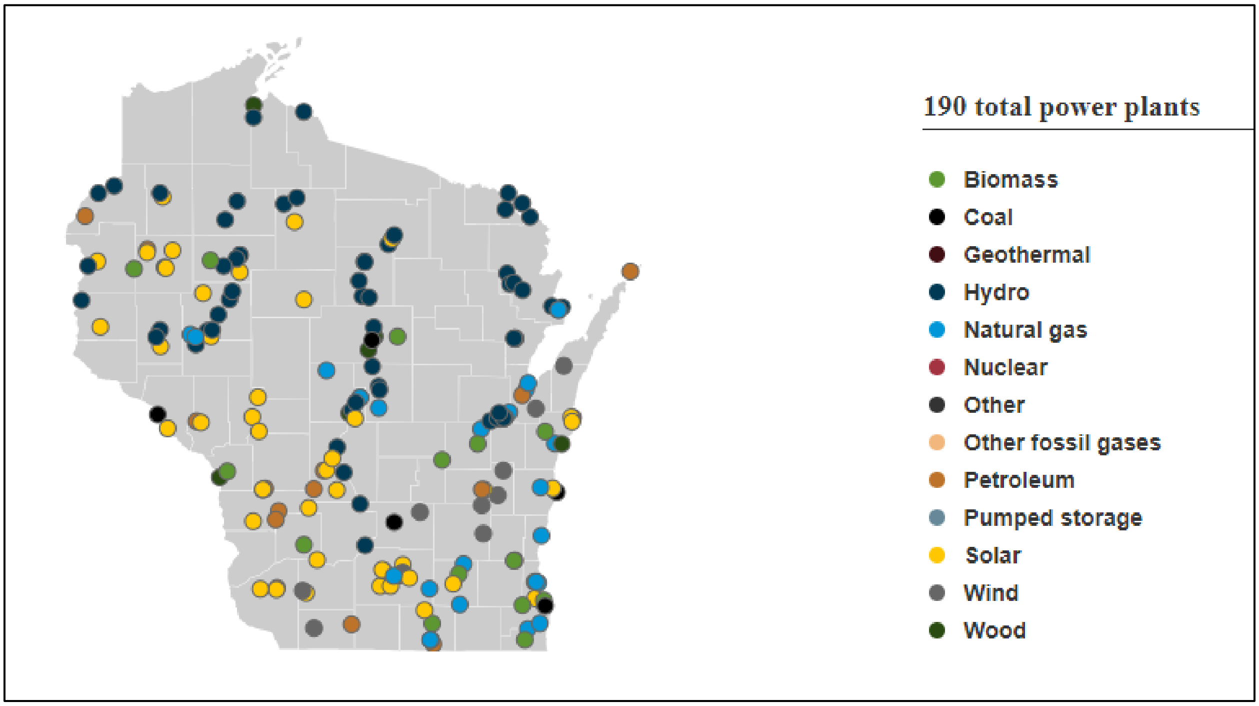


Note. Source: (Energy Information Administration, 2022)

The positive trend is that Wisconsin is becoming less reliant on coal plants as the original goal was to retire coal plants by 2022. However, the supply chain issues created by COVID, as well as rising natural gas prices, made the main electric utilities in Wisconsin extend the closing dates of their coal plants. In addition to the shortage of energy supplies, supply chain issues across the industries delayed the commencement of renewable energy projects in the regulatory and construction stages (Lauber, 2022).

Figure 3

Power Plants in Wisconsin by Location and Source Type



Note. Source: (Energy Information Administration, 2022)

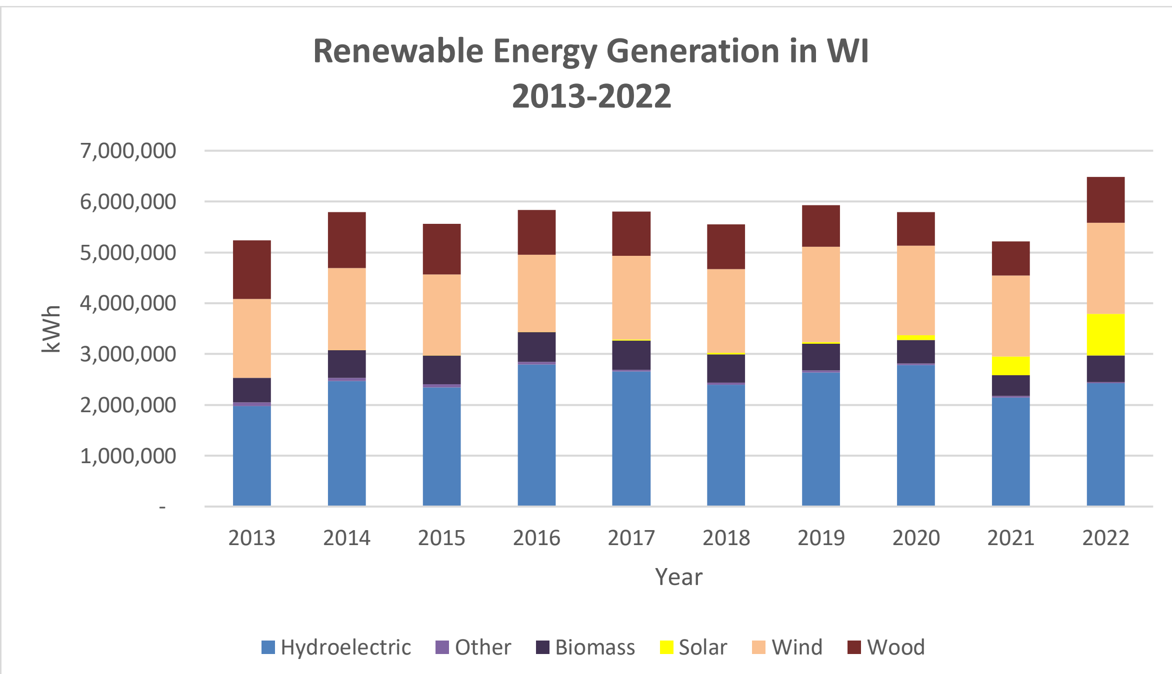
In 2019, Wisconsin's governor Tony Evers signed an executive order to create electricity from carbon-free resources, such as solar, wind, hydro, and biomass. Although renewable energy represents 10.6 percent of the energy mix in Wisconsin, only a small percentage of this renewable energy is produced in the state, creating a deficit of $14.4 billion (Energy, 2023). As a part of the state's effort to produce electricity from renewable energy sources, the state is actively pursuing energy efficiency measures. According to the National Renewable Energy Laboratory, Wisconsin could potentially save 18 percent of its electricity consumption through energy efficiency measures, such as HVAC improvements, lighting, building envelopes, and geothermal pumps for heating and cooling (National Renewable Energy Laboratory, 2020).

Implementing such measures swiftly would help the state of Wisconsin to reach its renewable energy goals more quickly.

To address whether Wisconsin can achieve its renewable energy goals, this section of the study provides a brief overview of the renewable energy sources available in Wisconsin. The study addresses the main renewable energy sources, including biomass, geothermal, hydroelectric, solar, and wind. Figure 4 portrays the power generation from renewable energy sources, excluding natural gas and nuclear, which are not considered renewable energy.

Figure 4

Renewable Energy Sources in Wisconsin in the Last Decade



Source: (Energy Information Administration, 2022)

Based on the renewable energy maps in Appendix 2, the following can be concluded:

1. Wisconsin does not have any significant geothermal resources and no significant projects are developed as of this study. The southern part of the state has some limited potential that has not yet attracted investors.

2. Wisconsin has good biomass resources, including biomass solids, biomass crops, forest and mill residue, urban food waste, and farm manure. Currently, the state produces a half million KWh per year from biomass sources.

3. Wisconsin has good hydro potential, however most of the feasible sites are already developed. Undeveloped sites need to go through stringent regulatory approval, therefore all hydropower estimates, including the EIA`s, do not anticipate this renewable energy source growing significantly. Currently, hydropower generates around 2.5 million KW per year.

4. Other renewable sources in Wisconsin include hydrogen and other relatively new technologies that are not yet fully scalable. Currently, these sources generate a relatively small percentage of renewable energy generation, although they could play a significant role in the future.

5. Wisconsin has decent solar potential in the southern part of the state, but the variability of the sun presents an obstacle for solar investors. Federal and state incentives, as well as low capital and operation costs, however, made solar attractive in Wisconsin. Currently, this source of renewable energy generates around 0.8 million KWh per year and solar is growing.

5. Wisconsin has very good wind potential at a height of around 180 feet. This source currently produces around 0.9 million KWh and is the second-growing source of energy behind solar.

Descriptive Statistics

Descriptive statistics are used to describe the characteristics of a particular data set through a variable's mean, standard deviation, or frequency. This study utilizes mean, minimum, and maximum to address common patterns in the analyzed data set. Additionally, the study examines the standard deviations and standard errors. The standard deviation measures the amount of variation or dispersion of values included in the analysis (Robson & McCartan, 2016). Descriptive statistics, together with graphs and tables, are utilized in analyzing how adding renewable energy impacts electricity prices.

In addition, the study will utilize measures of variability that focus on the dispersion of data. The variability descriptive statistics measures assist readers and researchers in better understanding the meaning of the analyzed data by focusing on the frequency of each data point in the distribution and how dispersed a variable is in the distribution of a particular data (Arkkelin, 2014).

To estimate how spot and futures prices of natural gas correlate, this study will utilize descriptive measures, graphs, and the skewness of the data set. The descriptive statistics are presented by the major variables in the study, starting with the independent variables, natural gas and renewable energy, and ending with the electricity prices as the dependent variable. The data sets for all variables are limited to the last ten years, 2013 through 2022, where all data points are included.

Natural Gas Prices.

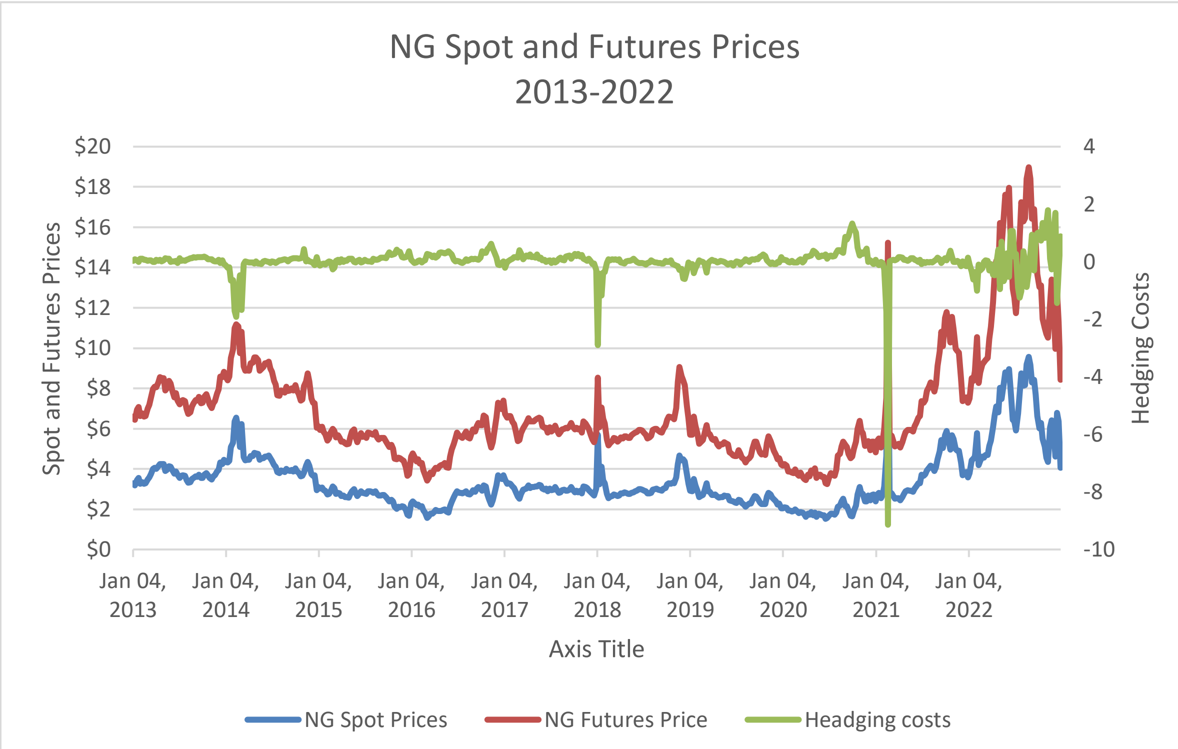
To address the first research question, descriptive statistics are used to analyze the first variable, spot and futures natural gas prices. To determine the volatility and costs of electricity hedging, this study analyzes futures contracts. Since natural gas prices impact electricity prices, Maciejowska (2019) suggests that these variables have a relationship.

Figure 4 presents the spot prices of natural gas in Wisconsin and includes transportation and insurance costs for natural gas delivery to Wisconsin. The spot price is what a buyer is willing to pay for a one-time open market transaction for immediate delivery of a specific quantity of natural gas at a specific location. In contrast, a futures contract determines the price of natural gas to be delivered at a later date. For this analysis, the study utilized data for four futures contracts, which give a buyer more hedging security over gas prices. The Energy Information Administration (EIA) keeps track of four types of futures for natural gas commodities. Futures Contract 1 offer prices expire three business days before the first calendar day of the delivery month. Therefore, Contract 1 represents the delivery month following the trade date.

For Contracts 2 through 4, the delivery month is determined as the successive delivery months following Contract 1. For this study, futures Contract 4 is used as the earmark to estimate hedging costs. The hedging costs, the difference between the spot and the future market, is represented by a gray line in Figure 3. Figure 5 shows that every time the natural gas market increases, the entities that hedged the natural gas on the market achieve a financial gain (negative values on the right-side axis).

Figure 5

Natural Gas Prices, Spot, Futures, and Hedging



Note. Source: (Energy Information Administration, 2022)

Table 1 exhibits the major descriptive statistical measures, underlining that all three sets of data (NG spot prices, NG future prices, and hedging costs) vary significantly statistically. If the data set is deemed to be normally distributed, this study uses standard deviation, which shows the variability of values in a data set (Creswell & Poth, 2018). A standard deviation (or σ) is a measure of how dispersed the data is about the mean. A low standard deviation means data are clustered around the mean, and a high standard deviation indicates data are more spread out (Leavy, 2017). In other words, extreme values occur more frequently with a high standard deviation. The data is normally distributed (portrayed by a bell shape curve) if most of the values in the data set cluster around the mean within one normal distribution. Based on Table 2, futures and spot prices exhibit a certain volatility with 1.46 and 1.36 standard deviations. Similarly, the variance for natural gas spot and futures prices in two of these data sets exhibit volatility with 2.13 and 1.84 standard deviations. The hedging cost variability, measured through standard deviation and variance, does not exhibit significant variability, except when the natural gas market increases and decreases radically. However, the minimum and maximum values portray a different picture of the variability of hedging costs. With a maximum of 1.79 and a minimum of -9.14, the variability of the hedging cost is much more dramatic than even natural gas prices.

Table 2

Descriptive Statistics for Natural Gas Prices, Futures, and Hedging Costs

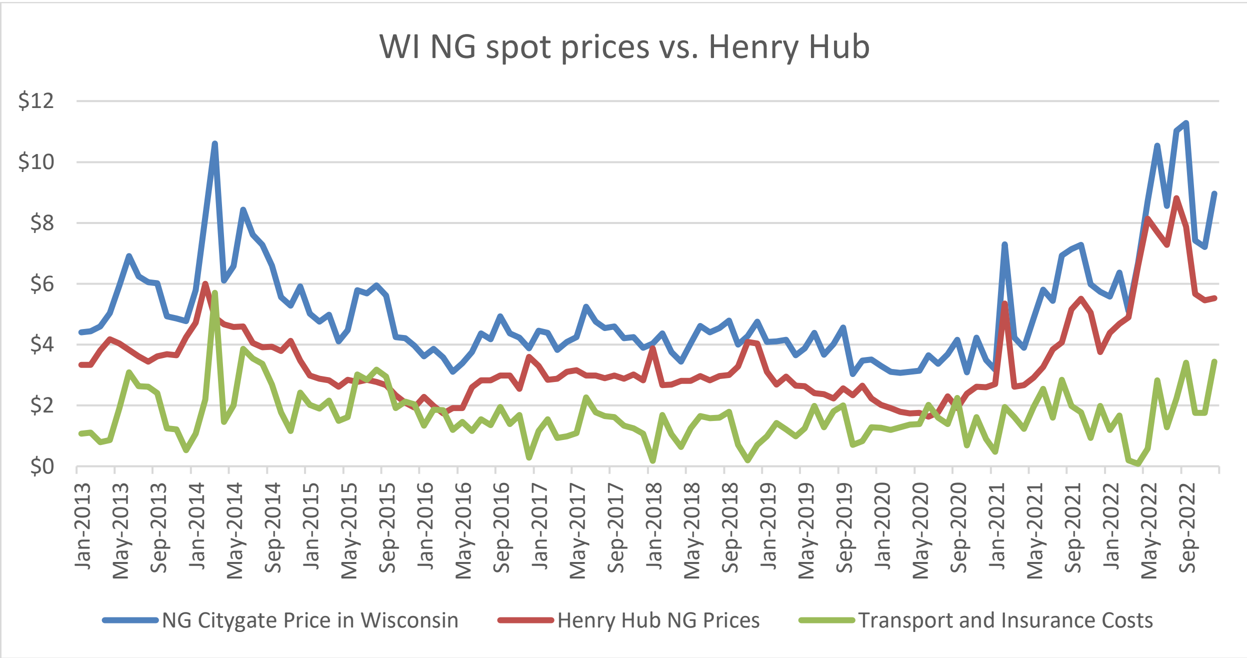
	NG Spot Prices	NG Futures Price	Hedging costs
Minimum	1.52	1.68	-9.14
Maximum	12.18	9.42	1.79
Median	2.97	3.03	0.05
Range	10.16	7.41	1.79
Standard Deviation	1.46	1.36	0.55
Variance	2.13	1.84	0.30

Note. Source: (Energy Information Administration, 2022)

Figure 6 shows the relationship between natural gas prices at the national level (Henry Hub in Louisiana) and spot prices of natural gas in Wisconsin. The difference between the two of these prices includes transportation and issuance costs (depicted by the gray line in Figure 6). This cost is important because Wisconsin utilities' development of renewable energy sources would avoid the transportation from the purchasing point to the delivery point costs and insurance costs for natural gas.

Figure 6

Comparison Between Wisconsin and Henry Hub Natural Gas Prices for the Last Decade



Source: (Energy Information Administration, 2022)

Table 3 compares the descriptive statistics for both national and Wisconsin's natural gas prices, as well as for the transportation and insurance costs. The descriptive statistics show that Wisconsin city gate and Henry Hub natural gas prices can vary significantly, with standard deviations and variance outside of normal distributions. This means that more data points are further from the mean, thus purchasing natural gas can bear some risks. The table also shows that transportation and insurance costs on average stay around 1.59 for MMBtu or 1 cent per kWh. This means that increased power generation from natural gas would further increase the price of electricity.

Table 3

Descriptive Statistics for Natural Gas Prices at the City Gate and Henry Hub

	NG Citygate Price in Wisconsin	Henry Hub NG Prices	Transport and Insurance Costs
Minimum	3.03	1.63	0.08
Maximum	11.28	8.81	5.70
Median	4.51	2.98	1.59
Range	8.25	6.79	3.68
Standard Deviation	1.73	1.38	0.84
Variance	2.98	1.92	0.71

Note. Source: (HenryHub.com, 2023)

Renewable Energy.

Electricity generated from VRE sources, like solar and wind, is weather-dependent and exhibits a certain degree of variability. In contrast, conventional energy sources, such as coal, nuclear, and natural gas, can generate electricity when requested. These variable or intermittent renewable energy sources (IRES) cannot be dispatched when demand is required due to their fluctuating nature. Alternatively, geothermal, biomass, and hydro sources are more controllable and constant sources, therefore they are more desirable by utilities and other electricity producers (Bistline, et al., 2018).

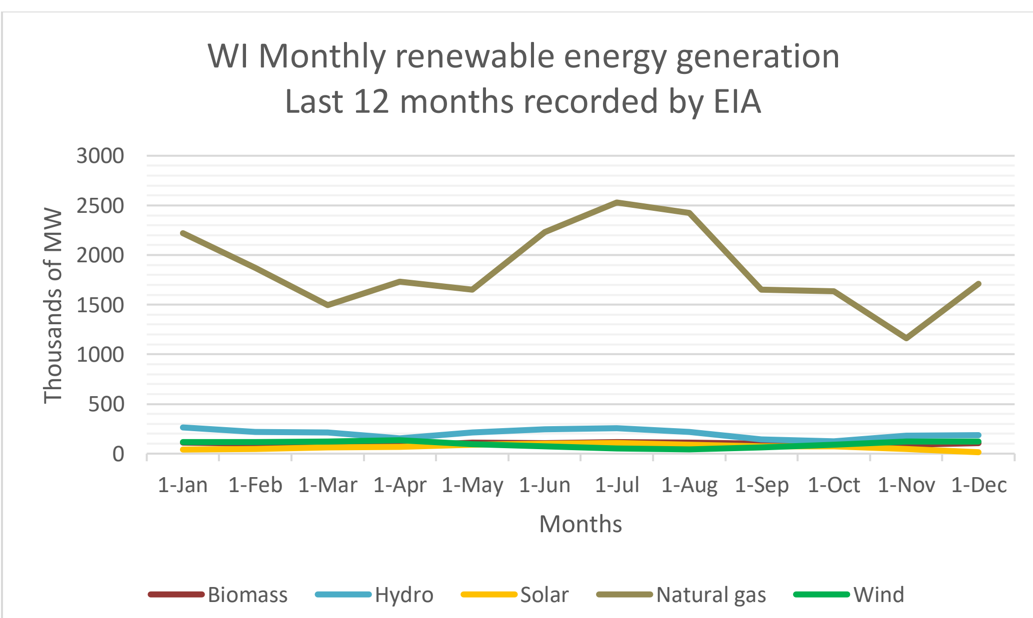
Small amounts of intermittent power have no significant effects on balancing the grid. However, the increased amounts may require utilities to upgrade or even completely redesign their power transmission and distribution to ensure the reliability of the grid (Csereklyei & Ancev, 2019). To absorb large amounts of VRE (see Figure 7), utilities and government entities developed different strategies, including the use of battery storage, pumped hydro projects, improved interconnection between renewable sources and the grid, and having overcapacity to bridge the gaps between demand and supply (Bartllet, 2019).

Matching power demand to supply when small amounts of VRE deploy is feasible if the VRE is built around good interconnection points. However, incorporating huge amounts of renewable energy represents a significant challenge and may require large investments to handle peak demand. The balancing authorities, such as MISO for Wisconsin, have built in a "spinning" reserve that helps to balance the load against uncertainties of power supply and demand. This built-in reserve helps with smaller amounts of renewable energy entering the grid, but it cannot sustain significant increases.

Figure 6 visually represents the generation from different power sources during a typical month in a year. Since renewable energy in Wisconsin represents only 10.6 percent of the total energy mix, balancing the grid is relatively feasible. In this case, natural gas generating facilities (depicted by the gray line in Figure 6) provide electricity during summer and winter peak months, assuring grid reliability. The situation would drastically change if Wisconsin starts retiring coal plants (base load) and natural gas plants (base and peak load).

Figure 7

Monthly Renewable Energy Generation in Wisconsin



Note. Source: (Energy Information Administration, 2022)

Based on the last 10 years of power generation data, the descriptive statistics presented in Table 3 show that natural gas plants that provide peak demand, and solar, wind, and hydro exhibit a relatively large variability.

Table 4

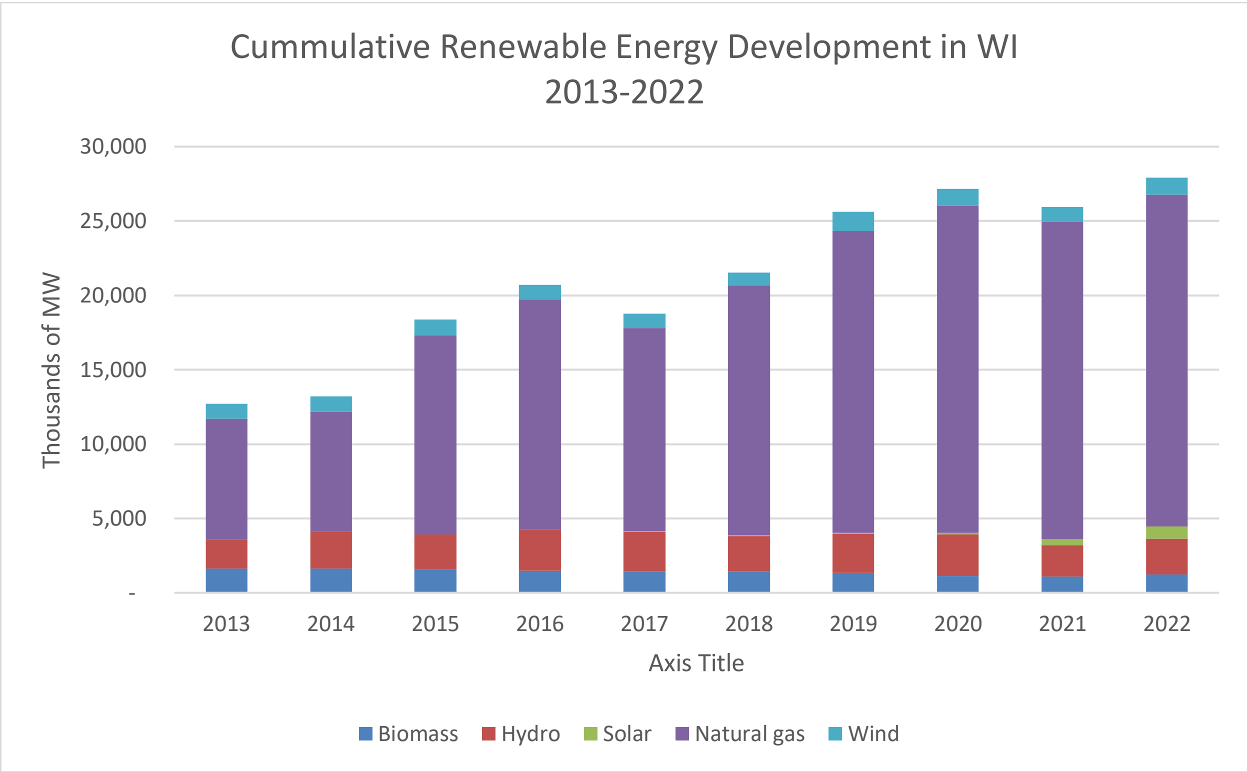
Descriptive Statistics Showing Variability for Different Energy Sources

	Biomass	Hydro	Solar	Natural gas	Wind
Minimum	76.92884	123.8757	14.16838	1161.60114	42.89289
Maximum	116.1851	263.6884	107.1169	2529.23157	135.1687
Median	102.5369	212.4574	70.64175	1721.50047	105.4706
Range	39.25623	139.8127	92.94853	1367.63043	92.27576
Standard deviation	10.49329	42.6848	26.29132	390.404087	29.55363
Variance	110.1091	1821.992	691.2334	152415.351	873.4171

This is because solar and wind renewable sources increased their participation in Wisconsin`s energy mix (Figure 8). The increased balancing need comes from the nature of renewable energy, which changes daily and seasonally. During a typical day, wind facilities peak overnight and during early morning hours, and solar plants peak in the early afternoon. Over the course of a year, wind-generating facilities peak in winter and early spring, with some regional differences. In contrast, solar generators reach maximum generation during the summer months. The above-mentioned generation potential needs to be matched to the demand, where the maximum demand in Wisconsin is during the early evening hours and summer and winter months.

Figure 8

Cumulative Renewable Energy Generation in Wisconsin in the Last Decade



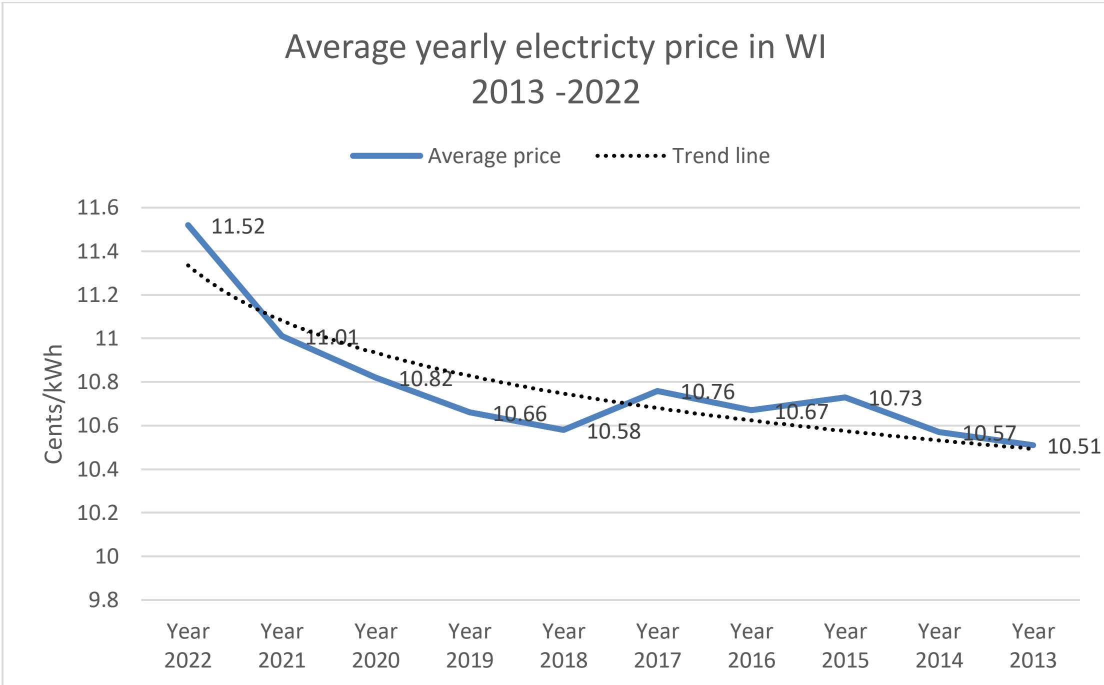
Note. Source: (Energy Information Administration, 2022)

Electricity Prices.

The electricity prices in Wisconsin were relatively stable over the last decade because coal generation provided a huge demand. Electricity prices experienced an increase in the last two years due to volatile natural gas prices and shortages in the supply chains. Figure 9 shows the price movements of electricity in Wisconsin (depicted by the blue line) and the trend line (depicted by the dotted line), which shows that the average electricity prices increased by 1 percent on average every year. However, the recent volatility of natural gas prices in 2022 caused the electricity price to spike by 4.7 percent.

Figure 9

Average Yearly Electricity Prices in Wisconsin from 2013-2022

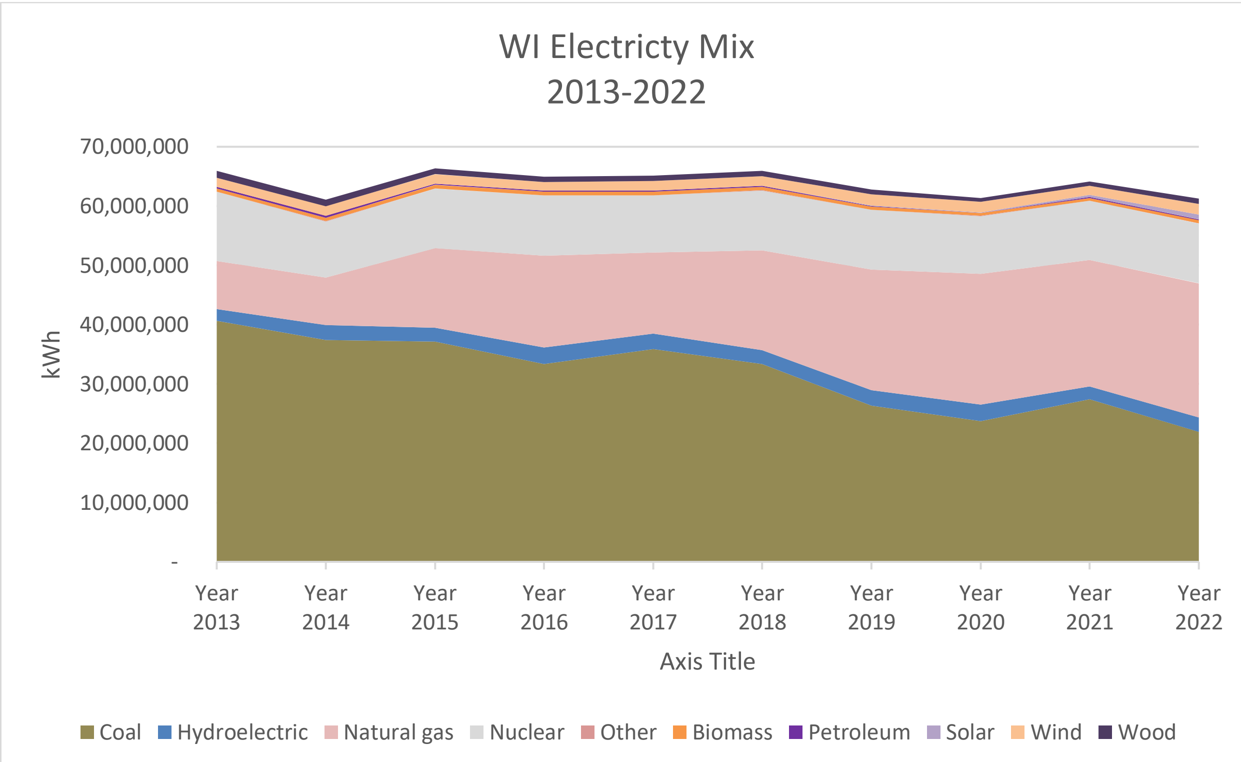


Note. Source: (Energy Information Administration, 2022)

Figure 10 reveals that the electricity mix in Wisconsin changed in the last decade with more energy being generated from renewable sources and natural gas. Both trends would make the average price vulnerable because renewable energy is intermittent and natural gas price volatility is one of the biggest risks on the market.

Figure 10

Wisconsin's Electricity Mixes in the Last Decade



Note. Source: (Energy Information Administration, 2022)

Hypotheses Testing

Over the last decade, there has been a growing interest by many states to create electric systems that can be supplied by 100% renewable energy. The state of Wisconsin expressed a desire to achieve this goal by 2050. Although there is a significant amount of literature examining the benefits and pathways of moving toward a such lofty goal, it is evident that many academic references deal with this issue from a theoretical standpoint, rather than a pragmatic view.

Because a system that utilizes 100% renewable energy does not yet exist, researchers are forced to rely on models to provide better insight. Modeling the penetration of renewable energy is a complex task. This toolkit model is an effort to provide utilities and other entities with a simplistic estimate, not an in-depth and precise projection. The complexity of modeling comes from many directions, including the challenges of heavy reliance on VRE generators, undeveloped storage resources, new technologies, and balancing and transferring unpredictable renewable energy from the generation place to the grid. Also, any modeling effort needs to address the chronology of electricity generation where past data plays a crucial role in forecasting the future.

Toolkit Model.

The toolkit model is an Excel-based spreadsheet that includes historic and projections data about the key variables that drive electricity prices in Wisconsin. The tool is designed to assist Wisconsin electric utilities and other impacted entities to develop long-term strategies to assure the stability of electricity prices. The toolkit is built to be user-friendly but also to allow customization to meet the diverse needs of various entities with the need to ensure stable electricity prices.

The toolkit collects the underlying data from the EIA and allows the users to build an unlimited number of scenarios. For this study, three scenarios are explored based on the amount of renewable energy deployed and the need to keep electricity prices relatively stable.

The first scenario is called a base case scenario, which is based on the EIA`s estimates of future generations for the Midwest, and also follows the trend line of historic data. The second scenario is built around phasing out coal generation by 2030 and natural gas by 2050. This scenario, also called an optimal scenario, develops renewable energy in a way that controls it so that it does not drastically increase electricity prices. The third scenario includes renewable energy that would phase out coal and petroleum generation by 2030, decrease natural gas and nuclear generation significantly by 2040, and phase out natural gas and nuclear by 2050. Under these scenarios, it is assumed that Wisconsin will develop its sources and not import significant amounts of renewable energy.

In all three scenarios, the model considers the following key variables: electricity demand, electricity mix, LCOE for each energy source, energy efficiency measures, transmission and infrastructure costs, and backup costs for renewable energy resources. This study did not include generation estimates for new technologies being developed as their impact on electricity prices is still largely unknown.

Key Variable Inputs for All Scenarios.

The toolkit model used the key variables across all models. To avoid linearity of results, given that no market is linear over a prolonged period, the study divided the research period into three segments, representing each decade within the study period. The model allows users to enter different inputs for the key variables for each of the three planning periods, 2023–2030, 2031–2040, and 2041–2050. To estimate the cost of a 100% renewable goal by 2050, this research analysis makes a series of substantial assumptions.

1. The capacity factor is a measure of how much energy is generated by an electric facility in comparison to the maximum output of the facility. It is a function of the solar panel's efficiency and available solar energy. Given that solar technology keeps improving and solar panels keep increasing in efficiency, the toolkit allows the user to adjust this variable. This is true of wind and biomass energy as well. Therefore, the model allows capacity factor adjustment for all energy sources. The capacity factor improvement estimates are included in the analysis for these reasons. Based on data from the EIA database, solar and wind improved their capacity factors by five points in the last decade. Assuming that research progress continues, this study

uses a conservative estimate that solar will improve by two points and wind by one point each decade until 2050 (Energy Information Administration, 2022).

2. Energy efficiency measures can lower the average energy prices by eliminating the need to install new power-generating facilities or transmission lines. In addition, energy efficiency can reduce the peak demand, allowing flexibility to the balancing authorities. Although energy efficiency measures decrease electricity demand, this study is focused only on savings from the electricity standpoint. Although current electricity energy savings from energy efficiency measures are 1.5%, the NREL projects that Wisconsin could save up to 18% through these measures. To analyze using equal footing, this study kept the energy efficiency measures at 1.5% of the total demand (Cadmus, 2021).

3. The electricity demand is expected to grow by 1 to 2% annually, based on the EIA`s outlook report (Energy Infomation Administration, 2022). Assuming that some demand will be met through energy efficiency measures, this study kept the growth of the electricity demand at 1% annually from 2023 through 2050. Based on the recent study conducted by the NREL, the distribution and transmission costs are estimated at around 6.6 c/KWh, which is within 5% of the estimate in this study.

Based on the historic data between 2012 and 2023 in Table 5, the average annual increase in electricity consumption or demand in Wisconsin was 0.6%.

Table 5

Historic Consumption of Electricity in Wisconsin in the Last Decade

In million kWh	*Year 2013*	*Year 2014*	*Year 2015*	*Year 2016*	*Year 2017*	*Year 2018*	*Year 2019*	*Year 2020*	*Year 2021*	*Year 2022*
Coal	40.65	37.45	37.18	33.36	35.85	33.32	26.34	23.76	27.44	21.91
Hydroelectric	1.98	2.47	2.34	2.80	2.66	2.39	2.64	2.79	2.14	2.43

Natural gas	8.10	8.05	13.40	15.47	13.66	16.80	20.33	22.00	21.34	22.65
Nuclear	11.68	9.45	10.01	10.15	9.65	10.13	10.03	9.77	9.97	10.08
Other	0.07	0.06	0.06	0.05	0.03	0.04	0.04	0.03	0.03	0.02
Biomass	0.48	0.54	0.57	0.59	0.58	0.55	0.52	0.46	0.41	0.52
Petroleum	0.30	0.32	0.21	0.15	0.14	0.14	0.14	0.02	0.17	0.16
Solar	-	0.00	0.00	0.00	0.02	0.04	0.04	0.09	0.37	0.81
Wind	1.56	1.62	1.59	1.52	1.64	1.64	1.88	1.76	1.59	1.80
Wood	1.15	1.10	1.00	0.88	0.88	0.88	0.82	0.66	0.68	0.89
Total demand	**65.96**	**61.06**	**66.36**	**64.97**	**65.11**	**65.94**	**62.77**	**61.35**	**64.14**	**61.29**

Note. Source: (Energy Information Administration, 2022)

4. In this study, the capacity cost, the cost that utilities incur to have backup generation in case some generators go out of commission, is utilized to estimate the cost that entities must incur due to the intermittent or variable nature of renewable energy. The estimate of capacity costs is provided by the EIA in their 2022 outlook report (Energy Infomation Administration, 2022). Table 6 presents the avoided costs of energy, which are used in this study to estimate the backup costs that utilities incur to handle the variability of renewable energy sources.

Table 6

Avoided Costs of Energy for Different Electricity Sources

Energy source	$/MWh
Coal	38.69
Hydroelectric	37.87
Natural gas	39.54
Nuclear	38.42
Other	77.00
Biomass	39.84
Petroleum	107.82

Solar	32.85
Wind	36.00
Wood	45.00

Note. Source: (Energy Information Administration, 2022)

5. The infrastructure and transmission costs are included in this study to reflect the additional costs that utilities must spend to bring renewable energy generators online that are further away from existing infrastructure. Although it is very difficult to estimate these costs, it is recognized by the literature that these costs often make renewable energy projects unrealistic (Bartllet, 2019). Finding accurate information about these costs for Wisconsin proved to be a challenging task, therefore this study utilized the average transmission and distribution costs, escalated for inflation, from existing utility bills in Wisconsin.

In addition, it is assumed that as renewable energy development increases, these costs will increase as well because the most feasible project will be developed first before less attractive projects. Therefore, this study assumes different transmission and infrastructure costs for projects based on the time frame when they come online. For example, for all new renewable projects between 2023 and 2030, this study assigns 2 cents per KWh as additional transmission and distributions costs. For the installations between 2031 and 2040, the study assigns 2.5 cents per KWh. Finally, for each additional kWh that comes online between 2040 and 2050, this study assigns 3 cents per KWh.

6. The renewable energy variability factor portrays the variability of wind and solar on a yearly basis. Based on the historic data recorded by the EIA, wind and solar resources vary between 5% and 10 % annually, therefore 7% is selected as the appropriate estimate for this study. Based on the variability of solar and wind resources, this study estimated the backup costs for generators to come online when wind and solar are underperforming. The backup costs are calculated by multiplying the levelized capacity costs published for each energy source.

7. Inflation is estimated to be 3% annually. Although inflation in the last decade hovered around 2%, the recent inflation of 8% in 2022 is considered short-lived and the estimate of inflation for the next decade is around 3%. Therefore, this study selected 3% inflation, although supply chain issues could increase this rate.

8. The LCOE refers to the estimated revenue required to build and operate an energy generator over a specified cost recovery period. It is a measure of the average net present cost of electricity generation for a generator over its lifetime. The LCOE in electrical energy production is defined as the present value of the produced electrical energy price (usually expressed in cents per KWh), taking into consideration the economic life of the plant, construction costs, operation, maintenance, and fuel costs.

The EIA publishes historic and future projections for the LCOE for each power generation source. The LCOE varies based on the project size as well, therefore the study uses the average project size to calculate the LCOE for each decade until 2050. Table 7 provides the LCOE for different sources projected by EIA for the three next decades.

Table 7

Projections for Levelized Cost of Energy (LCOE)

	2023	**2031**	**2041**
Coal	82.61	81.035	79.46
Hydroelectric	64.27	69.855	75.44
Natural gas	39.94	41.995	44.05
Nuclear	81.71	80.955	80.2
Other	77	76	75
Biomass	90.17	88.35	86.53
Petroleum	117	119.435	121.87
Solar	33.46	32.265	31.07
Wind	40.23	40.155	40.08
Wood	90	88.5	87

Note. Source: (Energy Information Administration, 2022)

9. The demand charges and other fees on electric bills are hard to predict given that different utilities have different rate structures and requirements from local authorities. In addition, renewable energy generation installed by the end user and utilities have different implications on the demand charges. For example, when an end-user installs a renewable energy system and enters into the net metering program, the demand charges will likely decrease. However, if a utility or a third-party producer supplies renewable energy to the grid, the benefit is more likely to be lost. To estimate demand and other charges, this study uses the 2022 charges and escalates them for inflation. However, it is not unreasonable to expect that utilities will increase demand charges as more intermittent power is added to the grid. These peak-generating units are generally natural gas or petroleum-fueled, which are relatively inefficient and costly to run. In some instances, hydroelectric and pumped storage facilities serve as peak-providing units. If the combustion turbines are utilized as the backup capacity, according to the EIA analysis from 2022, the costs would be 6.8 to 13.1 cents per KWh. This study utilizes the medium value of 10.1 cents per KWh as the average number for this range (EIA, 2023).

Base Case Scenario.

The base case scenario attempts to achieve two major goals. The first goal is to phase out fossil fuels (coal and petroleum) gradually by 2050 to lower carbon emissions. The second goal is to ensure that increasing renewable energy generation does not create a disruption in the energy sector and associated markets, including the electricity and natural gas markets, and their associated supply chains. The levels of increased renewable energy generation are based on EIA projections for 2022 through 2050.

After the main assumptions (Appendix II) have been entered into the model, Figure 11 shows that the base case scenario predicts the average electricity price in Wisconsin will rise until 2050 at the rate of 1% annually. Given that this model is a high-level planning tool, the base case scenario was set to keep demand and required generation within +/- 2% to allow the user to freely change the electricity mix. Matching the generation with the required demand was deemed necessary because this tool offers users the option to tailor the key variables to achieve the best possible electricity price.

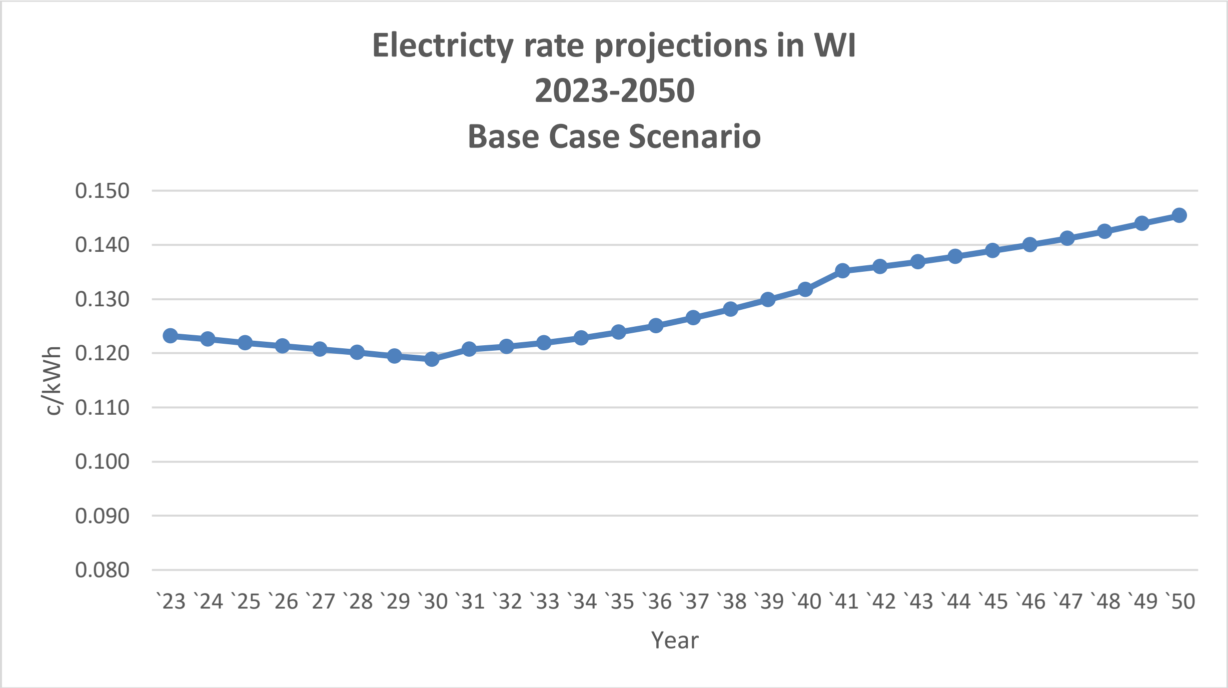
Despite less expensive renewable energy LCOE entering the market, as well as energy efficiency measures and capacity factor improvement that have a positive impact (lowers the price) on the average electricity price, the electricity price is still expected to rise. The main drivers are demand charges and new infrastructure that needs to be installed to bring the new renewable generation online. Additionally, electric prices are expected to drop slightly before 2030 because cheaper renewables will enter the market and the grid will be able to accept them with no significant additional costs and disruptions. It is important to note that the model does not account for sudden economic shifts and further disruptions in energy and related markets. Since the goal of the scenario was to stop using fossil fuels for electricity generation and replace them with renewable energy, the scenario meets that expectation by projecting electricity rates close to the historic data.

A relatively small increase in the electricity price, around 1%, can be attributed to falling LCOE for renewable energy sources, technological developments of renewable generators, and increased energy efficiency measures that lower the entire demand.

The summary of all scenario assumptions can be found in Appendix 1.

Figure 11

Electricity Rate Projection for the Bas-Case Scenario in Wisconsin for 2023 Through 2050

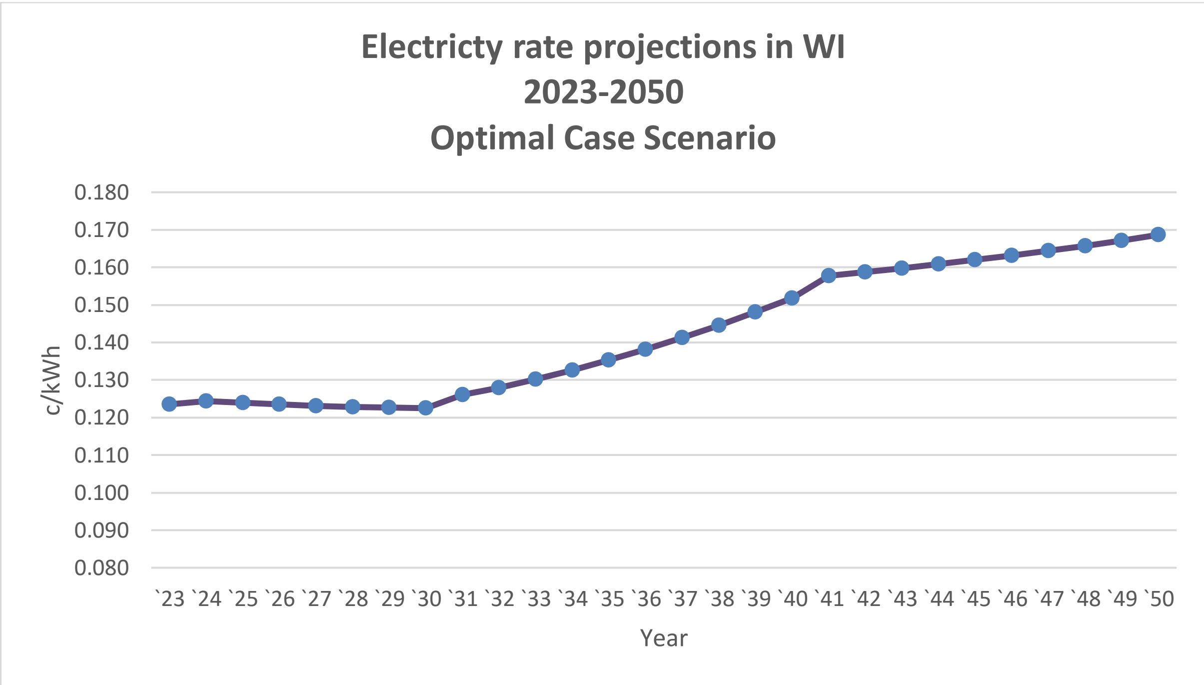


Optimal Scenario.

The optimal case scenario is based on goals similar to the base case scenario, to develop the greatest amount of renewable energy without significantly increasing electricity prices. Under this scenario, the goal is to phase out fossil fuels by 2040 and keep natural gas and nuclear generation at 2022 levels. The main characteristic of this scenario is that as solar and wind generation increase in the first period, 2023 through 2030, the electricity prices increase more than the base case scenario. The same results of higher electricity prices occur in the second period, 2031–2040. In the third forecasted period, 2041–2050, the electricity prices are relatively the same as in the base case scenario.

Figure 12

Electricity Rate Projection for the Optimal Scenario in WI for 2023 through 2050



It is worth mentioning that under the optimal case scenario, the decrease in electricity mix costs almost cancels out the increase in demand, transmission, and generation costs. Therefore, the electricity price between 2023 and 2030 is relatively similar to the electricity price under the base case scenario for the same period. As Figure 12 shows, the main difference from the base case scenario is the increase in electricity prices between 2031 and 2041 as a result of ramped-up renewable energy generation. This scenario shows it is possible to achieve moderately aggressive renewable energy goals without causing the electricity price to jump significantly since the price is projected to move from 14.5 cents (base case) to 16.9 cents (optimal scenario) in 2050.

Carbon-free Scenario.

The carbon-free or zero-emissions scenario assumes that coal plants will retire by 2030 and natural gas and nuclear plants will be phased out by 2050. The main goal of this scenario is to meet the deadlines set by utilities to close the coal plants by 2030 and the deadline set by the state to stop using natural gas and nuclear energy by 2050.

Figure 13

Electricity Rate Projection for the Optimal Scenario in Wisconsin for 2023 Through 2050

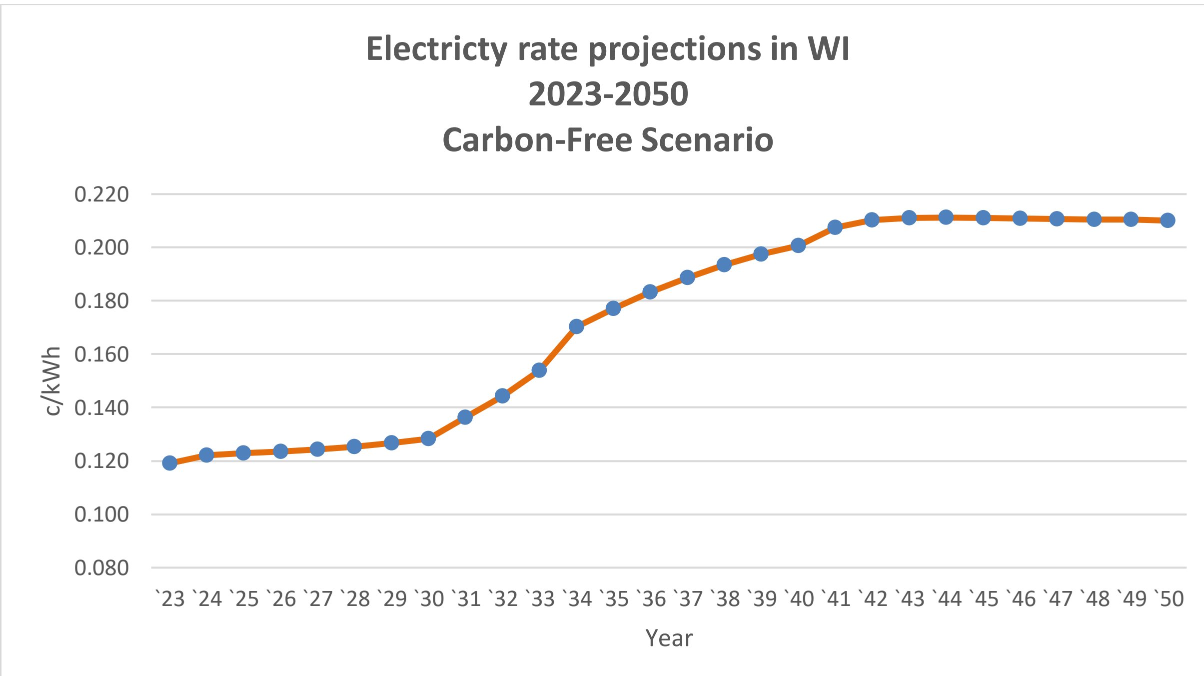


Figure 13 shows how costly for Wisconsin residents it would be to shut down the coal plants by the end of 2030. This would cause the average electricity price to reach 21 cents per KWh, an 82% increase compared to the electricity price in 2022, which was 11.5 cents per KWh. One of the greatest drivers of such a significant price increase is high transmission and distribution costs to develop resources that might not be economically feasible under normal circumstances. It is also questionable whether the state of Wisconsin and investors can feasibly develop that many renewable sources in a relatively short period.

Furthermore, the scenario does not include any estimates of potential market disruptions created by such a high demand for the goods and services that support the energy sector. Wisconsin's renewable energy development could stumble due to its relative inability to compete with southern and western for the same projects given that those states have better solar and wind resources.

Hypothesis Testing

To address the main research questions, this study developed and investigated three hypotheses. Each hypothesis has a null and an alternative statement, as listed below.

H1 Null: Traditional hedging mechanisms are not significantly more volatile and expensive than renewable energy sources.

H1 Alternative: Traditional hedging mechanisms are significantly more expensive than renewable energy sources.

H2 Null: The incremental value of renewable energy is not statistically significant in terms of lowering electricity prices for Wisconsin electric utilities.

H2 Alternative: The incremental value of renewable energy is statistically significant in terms of lowering electricity prices for Wisconsin electric utilities.

H3 Null: There is no statistically significant relationship between increased renewable energy installations and electricity prices in Wisconsin.

H3 Alternative: There is a statistically significant relationship between increased renewable energy installations and electricity prices in Wisconsin.

The first hypothesis investigates whether traditional hedging mechanisms, such as futures contracts, are more volatile and expensive than renewable energy for Wisconsin's electric utilities. Therefore, the null hypothesis states that traditional hedging mechanisms, such as futures, are not statistically more expensive and volatile than renewable energy sources.

Based on the MPT, each investment risk is characterized by the volatility of the prices assigned to a particular commodity (Anderson & Hu, 2008). The MPT states that all investors are rational and knowledgeable and operate in a perfectly efficient market. One of the measures of volatility that investors use is the standard deviation (STDEV). As a fundamental statistical tool, STDEV measures the variation of sample values around the average of the sample (Campbell, Taylor, & McGlade, 2017). Higher levels of STDEV mean that the data set has a higher level of volatility than the population mean. However, the STDEV is an absolute measure of volatility for a particular population, and it may not accurately portray the level of volatility (Bartllet, 2019). To deal with this deficiency of the STDEV, this study will utilize the coefficient of variation (COV), which is capable of comparing two data sets on a relative basis.

Table 5 compares the LCOE projected costs for renewable energy sources with costs of natural gas (spot and futures) and hedging costs. This study selected the LCOE projections over the historic LCOE because renewable energy costs significantly dropped in the last decade, which would not give an accurate comparison between these variables. Based on the data included in Table 7, which includes past and projected LCOE costs, it can be seen that the LCOE for renewable energy sources continues to decline, making it more affordable for electric utilities and other entities to develop renewable energy projects

Table 5 shows that the expected levelized cost of renewable energy, in addition to the decreasing trend, is less volatile than natural gas prices and hedging costs. A low STDEV means data are clustered around the mean, and a high STDEV indicates data are more spread out. In this case, the study utilized the COV concept because it can show the variability between two or more data sets. In instances where the data sets have the same STDEV, the COV utilizes its means to determine their relative variability.

The COV analysis shows that the hedging costs variable has the highest COV at 883.33, whereas the renewable energy sources have a COV ranging from 2.6 to 8.3. The data set below shows that all renewable energy sources have a relatively small COV. This anomaly is because the LCOE for wind is expected to drop dramatically between 2020 and 2030, which causes COV to be more volatile.

Table 8

Volatility Analysis Comparison Between Renewable Energy Sources and NG Prices

	Biopower	PV	Wind	Natural gas	Hydro	Nuclear	NG Spot Prices	NG Futures Price	Hedging costs
Minimum	54.32	40.14	30.74	48.34	25.24	73.8	1.52	1.80	-9.14
Maximum	58.27	53.26	87.47	58.06	30.01	82.6	12.18	9.54	1.68
Median	56.73	46.53	51.91	53.6	29.28	78.8	2.97	3.09	0.10
Average	56.51	46.61	55.50	53.4	28.45	78.5	3.44	3.50	0.07
Standard Deviation	1.50	4.92	21.298	3.535	1.88	3.30	1.46	1.32	0.60
Variance	2.26	24.29	453.59	12.50	3.54	10.89	2.13	1.74	0.35
Coefficient of Variation	2.66	10.57	38.36	6.62	6.61	4.20	42.50	37.64	883.33

The prices of natural gas have doubled in the last few years, mainly due to weather-driven demand and record-breaking exports. The long-term outlook projects that natural gas prices will stabilize; therefore, the electricity prices will remain relatively stable (Energy Information Administration, 2022). However, greater reliance on renewable energy will decrease natural gas prices, which should decrease volatility. The February 2022 30-day historical volatility of United States natural gas prices showed front-month futures prices averaging 179%, measured at Henry Hub. At the same, using the same metrics, the five-year average was 48% (EIA, 2023).

Figure 14

Electricity Price Projections Under Different Scenarios

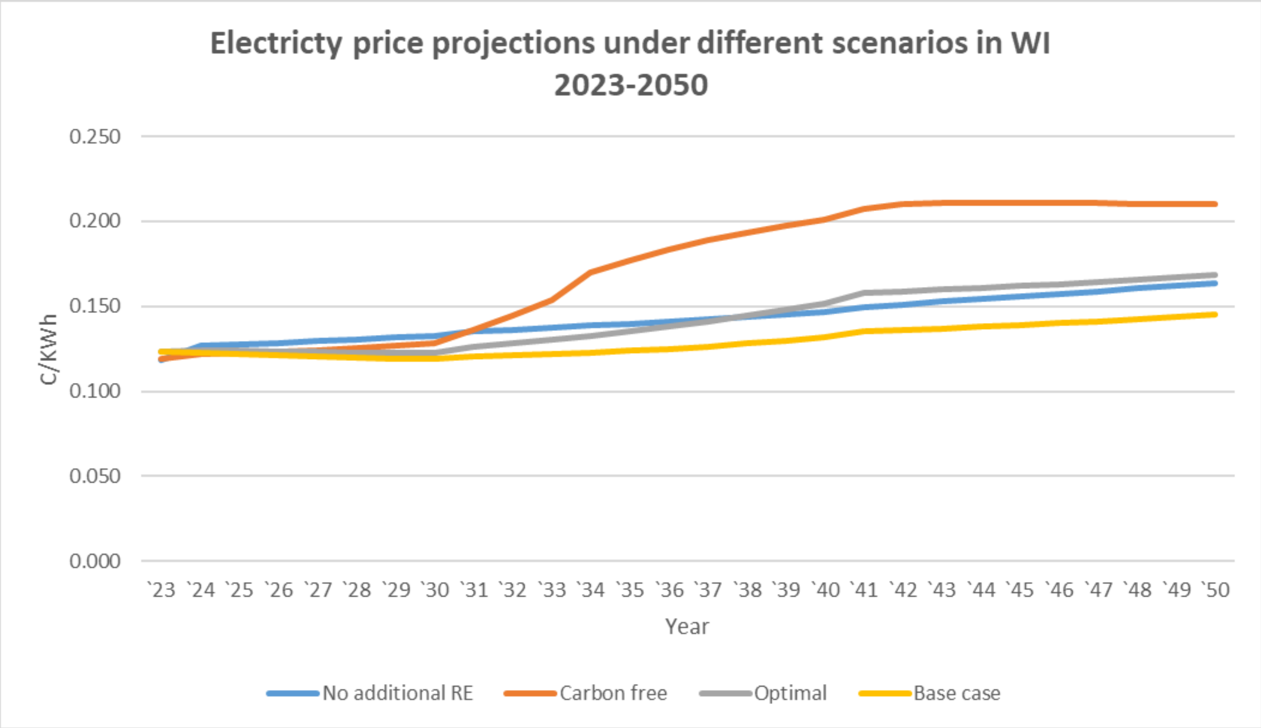


Table 9

Levelized Cost of Energy (LCOE) for Different Resources

	2013	2014	2015	2016	2017	2018	2019	2020	2030	2040	2050
Biopower	82.20	82.38	72.77	71.18	71.07	55.36	63.93	58.27	57.46	56.00	54.32
PV	104.00	91.50	79.00	65.00	55.00	54.80	54.00	53.26	48.89	44.18	40.14
Wind	70.00	65.14	59.00	55.00	47.00	45.00	42.00	41.24	37.18	33.12	30.74
Hydro	42.51	42.46	36.57	48.39	50.72	39.84	41.41	25.24	29.12	29.45	30.01
Renewables (average)	74.68	70.37	61.84	59.89	55.95	48.75	50.34	44.50	43.16	40.69	38.80
Natural Gas	74.00	74.00	65.00	64.00	63.00	58.00	56.00	59.00	54.74	52.46	48.34

Note. Source: (Energy Information Administration, 2022)

The analysis showed that the first null hypothesis is rejected, and the alternative hypothesis is accepted, because hedging against natural gas used for electricity generation is significantly more expensive, measured in terms of the LCOE metric, than renewable energy sources. However, this is only measured on the LCOE basis, not on the electricity cost basis.

Renewable energy sources are less expensive and volatile hedging options only if the grid can absorb the variable renewable energy without significant upgrades and investments. Estimating whether the grid can accept larger amounts of renewable energy is a complex task given that locations of the future renewable projects are completely unknown.

The second null hypothesis to be tested is that the incremental value of renewable energy as a hedge against volatile natural gas prices is not statistically significant in terms of lowering electricity prices for Wisconsin electric utilities. In essence, this means that every MW of additional renewable energy does not lower the average electricity prices in Wisconsin.

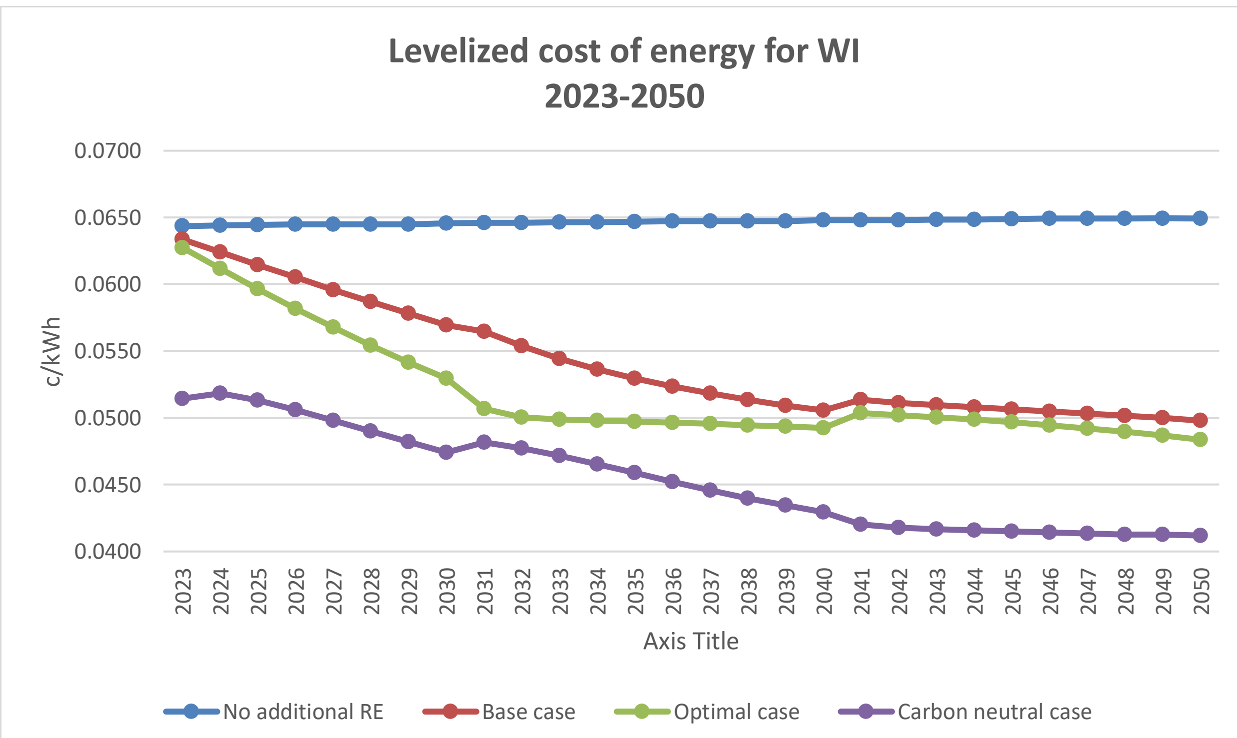
To estimate the value of added renewable energy, this study takes into consideration two facts. First, the renewable energy mix can significantly impact the value of each MW of renewable energy added. Renewable energy sources with lower LCOE, such as wind and solar, will increase the value of added renewable energy. Second, the LCOE estimates can be impacted by federal, state, and local incentives offered to make renewables more competitive than fossil fuel sources.

This study analyzed the impact of adding renewable energy from two angles. First, the simplest approach was to base the analysis on the projected LCOE, using the 2022 energy mix as the starting point. In this case, renewable energy, mostly solar and wind, decreased the overall costs of energy. Figure 15 shows that in three renewable energy scenarios, additional renewable energy lowers the overall LCOE. In the non-renewable energy scenario, LCOE keeps increasing due to expected inflation. Three other scenarios, even with 3% inflation, generate lower LCOE prices because adding less expensive renewable energy has a greater impact, more than 3%, compared to inflation. Under the no additional renewable energy scenario, the LCOE is estimated to grow on average by 1% until 2050. Alternatively, three other scenarios predict a decrease in LCOE, 29% (base case), 33% (optimal case), and 56% (carbon-free case).

Figure 15 demonstrates that adding renewable energy to the grid would significantly lower the overall LCOE for the electricity mix. Under the carbon-free scenario, the LCOE would reach $41.2 per MWh from the current LCOE of $64.4 per MWh. This would be a 56% decrease over 27 years. Either way, the LCOE estimates created by the EIA will greatly impact whether adding renewable energy will decrease the prices of electricity in the future overall.

Figure 15

Overall Levelized Cost of Energy Projections under Different Case Scenarios

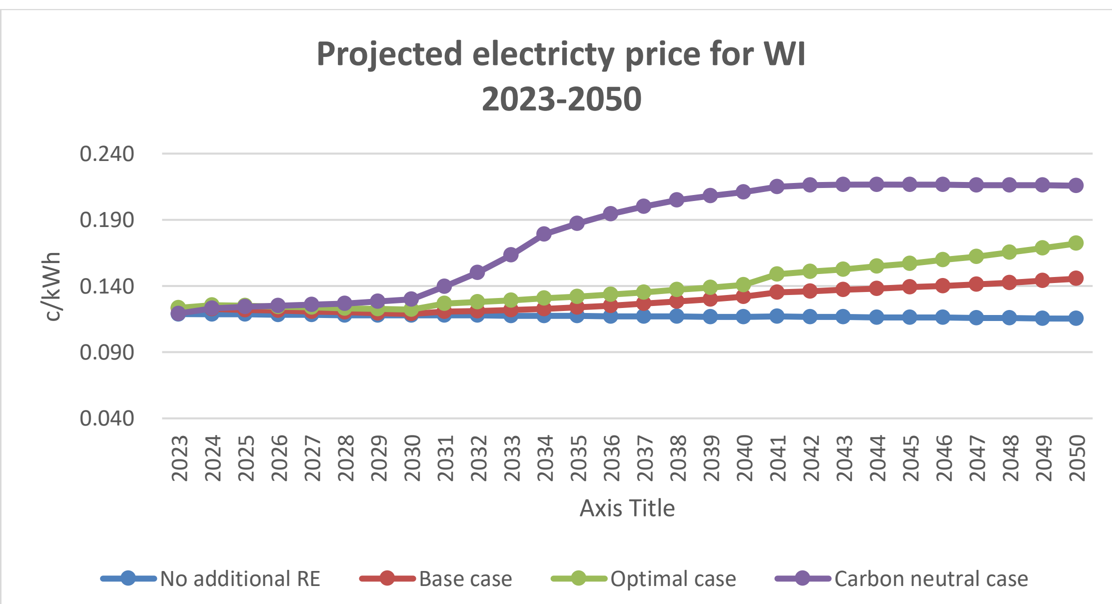


Analyzing the hypothesis from the electricity price standpoint reveals a different picture. The projections suggest that additional renewable energy will increase the price of electricity due to backup costs for intermittency and increased demand charges for installing new transmission and distribution lines. Based on the model developed for this study (Figure 15), the no additional renewable energy scenario could expect a price increase of 9% between 2023 and 2050. However, this scenario assumes that the natural gas prices will stay within the range of $5 per MMBtu, which is a very sensitive assumption. Three other scenarios predict a price increase, 28% for the base case scenario, 39% for the optimal scenario, and 66% for the carbon-free scenario.

In all three cases, the demand costs that utilities could charge to keep the grid system balanced is the most sensitive assumption in the entire analysis. The grid analysis for a renewable energy project can only be conducted if the location of a project is known. In addition, connection costs and incentives for renewable energy installations are the other two variables that could change this analysis significantly.

Figure 16

Average Electricity Price Projections under Different Case Scenarios



Based on the analysis, the null hypothesis failed to be rejected as there is no proof adding renewable energy to the grid will significantly lower the average electricity prices. It is worth noting that even as the overall LCOE value decreases with adding renewables to the electricity mix, potential backup and demand charges are higher than the lower LCOE benefit, when renewables are deployed at a faster rate. Therefore, the study arrives at the same conclusion as under the first hypothesis, which is that adding renewable energy is cost-effective only if the grid can accept that energy without significant investments in the grid and backup assets.

The third hypothesis attempts to determine whether there is a significant negative relationship between renewable energy deployments and electric prices, with the null hypothesis stating that there is no statistically significant relationship between renewable energy increase and electricity price decreases. The key question of this study is whether increasing renewable energy quantities can stabilize or lower the price of electricity in Wisconsin.

To estimate whether there is a correlation between renewable energy and electricity prices, and the strength thereof, this study utilized multi-regression analysis. Multiple linear regression is a statistical tool that assesses the relationship between two or more independent variables (renewable energy and natural gas prices) and a dependent variable (electricity prices). This study utilizes Excel’s function regression analysis where the outcome provides quantitative measures of the precision (accuracy of the estimates) and reliability (the regression reflects actual relationships among the variables). To examine the relationships between the independent and dependent variables, this study uses multilinear regression on two scenarios, the optimal and the carbon-free scenario, to examine whether rapidly (carbon-free scenario) or moderately (optimal scenario) adding renewable energy decreases the average electricity prices in Wisconsin.

The analysis is conducted under 95% of the confidence interval and based on multi-regression analysis (detailed results in Appendix 1), the following characteristics of the relationships exist:

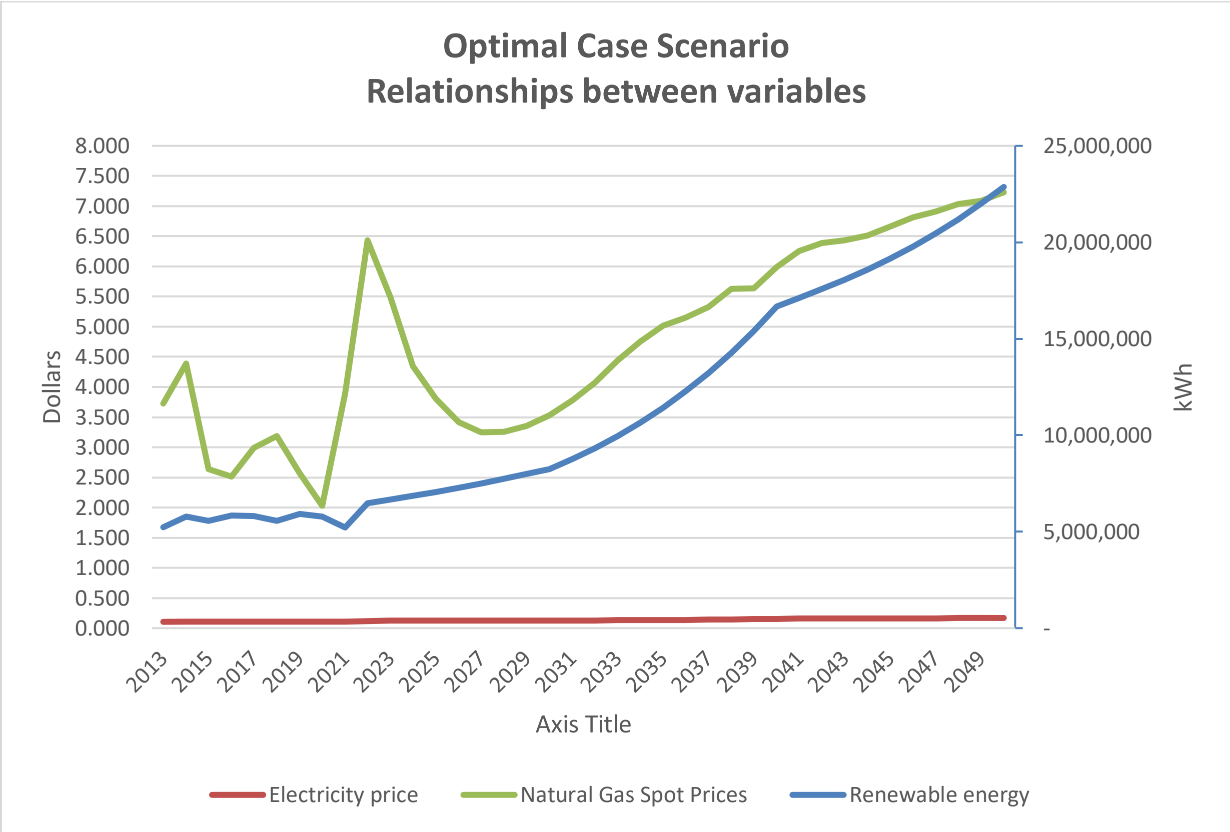
1. The R-square or coefficient of determination is 0.90 in both scenarios, which is relatively large and shows the degree by which changes in the dependent variable (electricity price) can be explained by the changes in the independent variables (renewable energy and natural gas prices). It shows that renewable energy installations and natural gas prices impact the average electricity price in Wisconsin.

The standard error is estimated at 0.03 (optimal scenario) and 0.014 (carbon-free scenario), which measures the dispersion of the observations within the data sets. It also measures the accuracy of the regression estimates by providing the typical distance that the observation points would fall from the regression line. Given that the numbers are relatively small, it means that the chance of regression being wrong in this case is relatively small.

The T-value measures the reliability of each independent variable, meaning the degree to which an independent variable has a valid, stable, and long-term relationship with the dependent variable. A small T-value means that there is little or no relationship between the variables. Under the optimal case scenario, the values of 1.73 for natural gas and 13.38 for renewable energy show that renewable prices have a greater impact on electricity prices than natural gas. Under the carbon-free scenario, the values of 0.78 for natural gas and 8.12 for renewable energy also mean that renewable energy has a greater impact on electricity prices than natural gas prices. The results confirm that by replacing natural gas with renewable energy, renewable energy had a more significant impact on the average electricity price. Therefore, as renewable energy expands, especially under carbon-free scenarios, the relationship gets stronger between renewables and the average electricity prices.

Figure 17

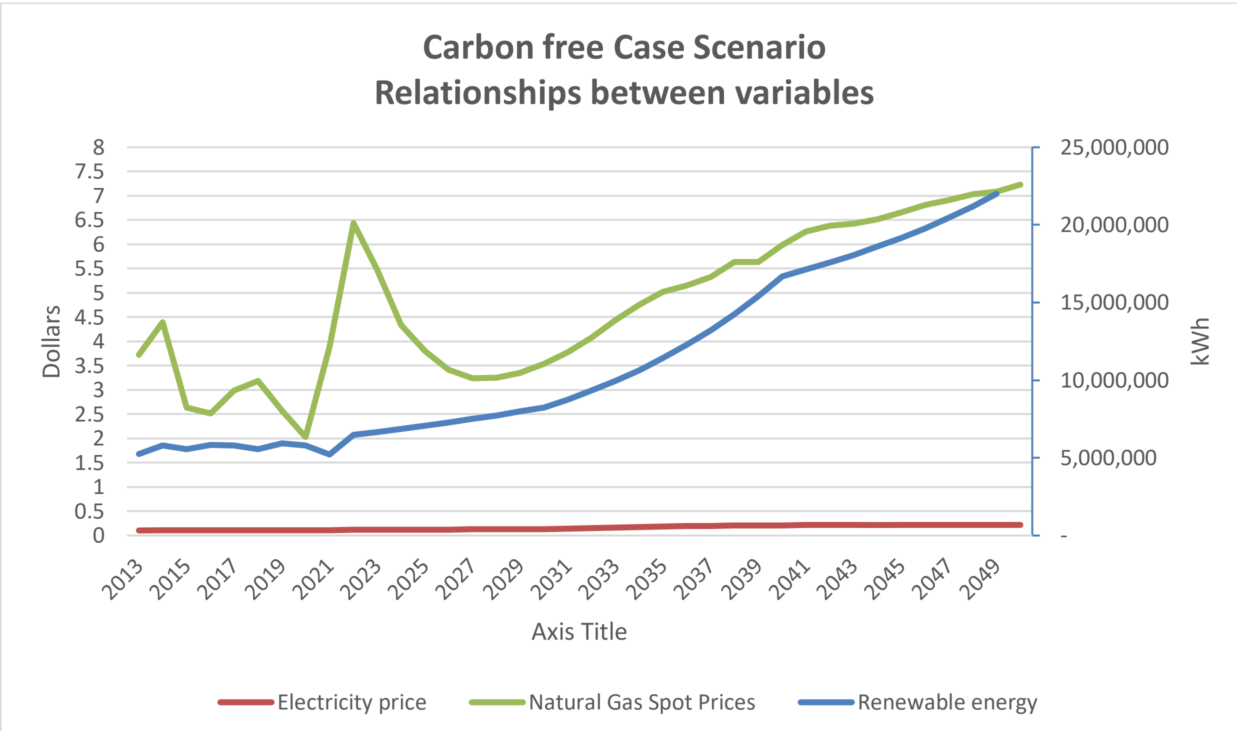
The Relationship between Independent and Dependent Variables under an Optimistic Case Scenario



The p-value in both analyses is larger than the .05 confidence interval. Values of .07 for the optimal scenario and 0.09 for the carbon-free scenario suggest that changes in independent variables are less likely to make a statistically significant change in the dependent variable. Although the p-values are not much further from the significance level, they show the relationship between independent and dependent variables. Even though renewable energy drives the average electricity price, it does not bring the electricity prices down, a negative relationship. Rather, the relationship is positive since adding more renewable energy to the grid drives the average electricity price higher.

Figure 18

The Relationship between Independent and Dependent Variables under Carbon-free Case Scenario



Overall, the F value for the ANOVA test under both analyses exhibits relatively high numbers, 174 for the carbon-free scenario and 500 for the optimal scenario. This value proves that the regression model is not statically significant in the analysis. Since both independent variables do not have a statistically significant impact on the dependent variable, the overall F statistic is also not statistically significant. Based on the multi-linear analysis conducted in this study, the null hypothesis failed to be rejected. No statistically significant evidence supports that increasing renewable energy generation impacts the average electricity price inversely.

The hypothesis testing shows that renewable energy and natural gas prices have an impact on the average electricity prices in Wisconsin, although that impact is not statistically significant. The analysis indicates that renewable energy can be a good hedge against volatile electricity prices only if the grid can accept larger amounts of variable renewable energy without significant investments in transmission and distribution. If the grid can sustain additional renewable energy, the LCOE analysis shows that electricity prices would decrease.

To summarize the hypothesis testing, this study concluded the following:

a) This study rejects the null hypothesis because the natural gas hedging costs are more expensive compared to the levelized cost of renewable energy. Therefore, the study accepts the alternative hypothesis since natural gas prices are more volatile and expensive compared to renewable energy sources. However, this is only true if the grid can absorb variable renewable energy without sizable investments which make renewable energy more costly compared to natural gas.

b) This study failed to reject the second null hypothesis because adding renewable energy does not significantly decrease the average electricity price. The null hypothesis can only be rejected if the value of adding additional renewable energy to the grid is measured in terms of LCOE for the energy mix.

c) The third null hypothesis failed to be rejected, based on the multi-linear analysis conducted in this study, as there is no statistically significant evidence that any of the independent variables impact the dependent variable inversely. Therefore, increased renewable generation does not decrease the average electricity prices on a statistically significant basis. Specifically, adding renewable energy does not decrease the average electricity price for 2023 through 2050.

Type I and Type II Error Analysis

Statistical hypothesis testing means that a study relies on statistically significant results, which are never 100% certain. Although hypothesis tests are designed to be reliable within the range of probabilities (95%in this study), results are still not guaranteed to be true. Statistical testing can cause two types of errors, error I and error II. Error I occurs when a researcher rejects the null hypothesis when it is true. Error II occurs when the null hypothesis is accepted when is false.

Hypothesis I - Error I and II Analysis

The probability of rejecting the null hypothesis when it is true is also known as the alfa (α) error. The probability of a type I error is measured by the significance level (α) of a hypothesis test. The significance level indicates the probability of erroneously rejecting the true null hypothesis (Arkkelin, 2014).

To estimate type 1 error for the first hypothesis, the following null and alternative hypotheses are set:

$N_0: \mu \geq 55$

$N1: \mu \leq 55$

The null hypothesis states that traditional hedging mechanisms are not significantly more expensive than renewable energy sources. In this case, the mean for the levelized costs of renewable energy is 55, meaning that the average LCOE for renewable energy is $55 per MWh. A one-tailed test for the p-value is conducted in Excel using t-Test: Two-Sample Assuming Unequal Variances. The alfa (error 1) value is 0.05 or 5% (Table 10), meaning there is a 5% chance of rejecting the null hypothesis when it is true.

Table 10

Error I Analysis for the First Hypothesis

	Renewables	*Natural Gas*
Mean	53.54189443	60.77636364
Variance	144.991439	67.68446545
Observations	11	11

Hypothesized Mean Difference	0
df	18
t Stat	-1.645295351
P(T<=t) one-tail	0.05862921
t Critical one-tail	1.734063607
P(T<=t) two-tail	0.11725842
t Critical two-tail	2.10092204

Table 11 presents the steps in calculating Type II error, where the estimated beta(β) is 98.3%, meaning there is a high probability of not rejecting the null hypothesis when it is false.

Table 11

Error II Analysis for the First Hypothesis

Renewables	**Value**
Mean	55
Standard deviation	10
Sample size	11
Alpha	0.05
Sample mean	53.54
Standard error of the mean	3.015113
Critical value	59.95942
Beta	98.3%
Power	1.7%

Hypothesis 2- Error I and II analysis

This study uses the same methodology as the first hypothesis to test whether adding renewable energy on a one MW basis significantly decreases average electricity prices. To estimate Type I error, this study used a one-tailed test for the p-value conducted in Excel using a t-test: Two-Sample Assuming Unequal Variances. This study conducted this analysis for all three scenarios. First, the base case and the optimal scenarios are paired, and then the optimal and carbon-free scenarios are paired. The goal was to estimate how the increase in renewable energy affects the t-stat analysis. The analysis in Table 12 indicates that the alfa (Error I) for the first pair (base case scenario and optimal scenario) is 0.018, or 1.8%, meaning there is a 1.8% chance of rejecting the null hypothesis when it is true. Moreover, when the optimal and carbon-free scenarios are compared, there is an even smaller chance, a 0.001%, chance, to reject the null hypothesis when it is true.

Table 12

Error I Analysis for the Second Hypothesis

	Base case	*Optimal case*	Optimal case	Carbon neutral case
Mean	13203150.34	16938910.53	16938910.53	42104377.39
Variance	2.95539E+13	5.77837E+13	5.77837E+13	6.95515E+14
Observations	29	29	29	29
Hypothesized Mean Difference	0		0	
df	51		33	
t Stat	-2.152669721		-4.937650284	
P(T<=t) one-tail	0.018049229		0.0000111	
t Critical one-tail	1.67528495		1.692360309	

For the type II error analysis in Table 13, this study applied the same methodology as the first hypothesis and concluded that there is no chance of accepting the null hypothesis under optimal and carbon-free scenarios when it is false, with a power of 100%. This means that one can be certain that under the assumptions used in this study, adding renewable energy will increase, not decrease, the average electricity price in Wisconsin from 2023 through 2050.

Table 13

Type II Error Analysis for the Second Hypothesis

Mean	12,000,000
Standard deviation	1,000,000
Sample size	18
Alpha	0.05

Sample mean	15,149,508
Standard error of the mean	235,702
Critical value	12,387,696
Beta	0.000%
Power	100.00%

Hypothesis 3 - Error I and II analysis

Under the third hypothesis, the null hypothesis states that there is no significant negative relationship between renewable energy increase and average electricity prices decrease. Similar to the analysis for the second hypothesis, this study conducted two analyses comparing three scenarios. First, this study compared how the increase from the base case scenario impacts the null hypothesis. The t-tests for the one-tailed analysis show that there is a 2.25% chance of committing error I, meaning there is a statistically significant chance of not rejecting the null hypothesis when it is false. When the optimal case scenario is compared to the carbon-free case scenario, the probability of making a type I error is even smaller, only 0.10%. Since the null hypothesis failed to be rejected, as electricity prices increase, the p-test confirms that making type I errors is not statistically significant.

Table 14

Error I Analysis for the Third Hypothesis

	Base case scenario	*Optimal scenario*	*Optimal scenario*	*Carbon-free scenario*
Mean	0.123618294	0.131362996	0.131362996	0.159975388
Variance	0.000149873	0.000394831	0.000394831	0.002156927
Observations	38	38	38	38
Hypothesized Mean Difference	0		0	

df	62	50
t Stat	-2.045578163	-3.491613663
P(T<=t) one-tail	0.022523343	0.000506653
t Critical one-tail	1.669804163	1.675905025
P(T<=t) two-tail	0.045046687	0.001013305
t Critical two-tail	1.998971517	2.008559112

The analysis for committing error II, depicted in Table 15, shows that when renewable energy increases, the electricity price increases as well. Therefore, the chances of rejecting the null hypothesis when false increases as renewable energy is added to different scenarios. This is because adding less expensive renewable energy adds benefits compared to the costs of upgrading the grid and spending backup costs. However, the trend of slower average price increases after 2040 will be less likely, instead electricity prices will decrease when new renewable energy is added to the grid. It is beyond the scope of this study to investigate how average electricity prices will behave when more electricity is added to the grid after 2050.

Table 15

Error II Analysis for the Third Hypothesis

	Base case	Optimal	Carbon-free
Mean	0.100	0.125	0.150
Standard deviation	0.02	0.03	0.03
Sample size	38	38	38
Alpha	0.05	0.05	0.05
Sample mean	0.123	0.130	0.153
Standard error of the mean	0.003	0.005	0.005
Critical value	0.105	0.133	0.158
Beta	0.000%	73.571%	82.974%
Power	100.00%	26.43%	17.03%

Relationship of Findings

This study addresses the first research question by investigating whether hedging natural gas prices through futures contracts is more expensive and volatile than adding renewable energy. This is based on the fact that the SDEV (Table 3) for LCOE of renewable energy sources is less volatile and the LCOE values are declining compared to natural gas prices, which are volatile and increasing. The hedging premium, calculated as the difference between the spot and futures price, exhibits higher volatility than the natural gas prices. Table 6 demonstrates that the volatility of the hedging costs is 883.33, meaning the hedging premium used for protection against volatile natural gas prices is very significant. Recent volatility in the natural gas market was increasing the hedging premium to 30% of the spot market price, meaning that electric utilities must pay $1.30 per MMBtu to hedge against natural gas risk. Using an aggressive heat rate of 7000 Btu for each KWh, this study concluded that utilities need to pay a one-cent premium per KWh to hedge natural gas.

The second research question focuses on the issue of how to quantify the value of each MWh of added renewable energy. The methodology this study uses is to determine such value by creating three scenarios based on the amount of renewable energy added to the grid to meet certain goals. Also, the value of additional renewable energy depends on the grid's ability to absorb large quantities of renewable energy without significant interruptions and investments. Moreover, utilities' ability to choose between different renewable energy sources dictates the value of additional renewable energy. For the three scenarios examined in this study, the value of renewable energy increases with higher levels of grid capability of integrating variable renewable energy. However, the grid`s integration ability depends on the project locations, therefore it is difficult to estimate. Based on the assumption that Wisconsin's grid has a medium capability of absorbing large quantities of renewable energy, this study estimates (Figure 13) that under the base case scenario, adding one KW of renewable energy decreases the price of electricity by 1.4 cents per KWh (Appendix 1). Adding renewable energy to the grid under the optimal scenario keeps electricity prices almost the same, with a decrease of 0.03 cents per KWh when compared to the no additional renewable energy scenario. The most aggressive scenario in terms of adding additional energy to the grid causes the electricity prices to rise an average of three cents per KWh.

The third research question investigates whether the two independent variables, renewable energy and natural gas prices, have a positive or negative relationship with the dependent variable, the average Wisconsin electricity prices. This study shows that there is a relationship between the independent and dependent variables, but it is not statistically significant. The p-value from the multilinear regression of 2.47 for renewable energy under the optimal scenario and 0.09 for natural gas prices shows that natural gas prices have a greater impact on the average electricity price. Under the carbon-free scenario, the values of 1.44 for renewable energy and 0.43 for natural gas reflect the scenario's goal of adding more renewables and decreasing power generation from natural gas (Appendix 1).

As this study addresses the main research questions, the following conclusions can be drawn from the results:

- Natural gas prices are more volatile and unpredictable than renewable energy sources. The volatility index of 833 makes the electric utilities pay up to $1.30 per MMBtu simply to manage this volatility.
- Based on the LCOE metric, adding renewable energy decreases the cost of electricity between 0.03 and 1.3 cents per KWh, assuming no significant grid updates are required.

The rapid expansion of renewable energy could potentially increase the cost of electricity by up to 3.5 cents per KWh.

- On the LCOE basis, renewable energy decreases the price of electricity, while the electricity rate basis likely increases the price of electricity. However, there are many variables associated with demand charges and this needs to be further investigated.

This study utilizes three theoretical frameworks to analyze and interpret the findings. The renewable energy merit-order theory states that because wind energy and solar energy have very low marginal costs compared to coal and gas-fired generating facilities, dispatching more renewables should decrease the overall costs of electricity. This study finds that theory correct if the analysis is based on the LCOE. However, the merit-order theory does not correspond with this study's result in scenarios where the grid cannot easily absorb large amounts of variable renewable energy.

The MVP theory applies the concept of resource diversification to help utilities find the most profitable electricity generation mix. For this study, MVP theory can be applied in two situations. First, the MVP analysis allows electric utilities to analyze their investment decision between traditional hedging mechanisms and renewable energy. Second, the same theory would allow utilities to make feasibility decisions about their electricity generation portfolio. In both cases, this study found MVP theory applicable and correct given that utilities can utilize it in making decisions that would decrease their risk and costs and lower carbon emissions.

The LCOE concept allows electric utilities to properly determine the costs of renewable energy, including capital, operating, and disposition costs. Based on this analysis, the utilities and other entities can compare different electricity mixes and choose the option that would produce the most desirable price with the most significant impact on the environment. This study utilizes the LCOE concept throughout as it is very applicable in assessing different renewable energy scenarios.

Summary of the Findings

This study investigates three pathways for Wisconsin to achieve different energy goals. The base case scenario represents a realistic pathway for Wisconsin to achieve 20% renewables by 2050. The optimal scenario targets to achieve 25% renewable energy by 2050, abandoning coal generation by 2030. The carbon-free scenario eliminates coal generation by 2030 and targets to achieve 100 % power generation from renewables by 2050. Under each scenario, the electricity price increases, and the extent of the increase is based on the grid`s readiness to accept significant amounts of electricity. Although natural gas prices are high and exhibit high volatility currently, achieving a 100% renewable energy goal largely depends on the investments into transmission and distribution networks required, which is difficult to estimate given that potential locations of future renewable energy projects are unknown.

Application to Professional Practice

The main purpose of this study was to incorporate study findings into practical applications to assist utilities in discovering better ways to leverage risks associated with natural gas volatility. This study also attempts to provide utilities with better decision-making tools regarding whether renewable energy installations are a good hedge against volatile natural gas prices. Therefore, this study creates an Excel-based toolkit that allows potential users, across different states, to discover if renewable energy is as an effective hedge against natural gas price volatility.

Improving General Business Practice

This study was specifically designed to have practical applications in the energy sector, especially to assist electricity producers in Wisconsin. This study aims to benefit all affected parties in the energy sector, more specifically electric utilities, government agencies, and other entities interested in comparing the costs of hedging natural gas to investing in renewable energy in Wisconsin. As such, the study results in an Excel toolkit model, a practical tool that allows users to customize the inputs and create their own analysis of how renewable energy impacts electricity prices.

The primary beneficiary of this study is Wisconsin electric utilities. They benefit from finding appropriate information and tools about hedging options against natural gas price volatility risks. The study results, together with the toolkit, will help many electric utilities adopt a long-term strategy for renewable energy to mitigate the fuel price risk within a resource portfolio. The main goal of this study is to come up with a better and more practical hedging methodology for electric utilities to quickly identify hedging strategies.

This study helps utilities to quantify the risk component of hedging that usually creates difficulty in determining the optimal size of the position, under both price and production risk. As the electricity demand changes on the utility side, the quantities of electricity being hedged create significant swings in the costs of hedging mechanisms.

The PSC of Wisconsin, as a governing body in the electric utility arena, benefit from this study by allowing them to understand how adding renewable energy to the grid impacts overall prices. This is very important from the agency`s point of view because in regulated electric markets, such as in Wisconsin, the agency must approve any changes in electricity prices. The PSC could utilize the tool to assess the short- and long-term impact of adding certain quantities of renewable energy on electricity prices. The state and local governing agencies could also be encouraged to utilize the toolkit model to support investments in renewable energy if it shows that the deployment of renewable energy provides lower electricity prices long-term. These types of analyses are extremely important when government entities decide to introduce incentives for renewable energy sources. This is especially true if the design of the subsidies is based on the natural gas spot or futures prices and governments must decide whether those subsidies need to be diverted from market prices as renewable energy sources become more competitive.

Investors in natural gas and electric utilities will find this study beneficial as well. Traditionally, investors used futures to manage their risk exposure and to estimate an optimal hedge ratio (OHR) for their portfolio, allowing investors to minimize the risk associated with the portfolio. Finally, local communities benefit from a cleaner environment and job creation if additional deployment of renewable energy is the more desirable option to hedge against the volatility of fuel prices.

This study is a step toward a more standardized approach to hedging against volatile natural gas prices in the electricity market. This study created a bridge between the existing fragmented theory and a more practical standardized model that could be replicated among different electric utilities.

This study also reduced the gap between theory and practice in the energy sector. First, this study identifies and quantifies critical factors that influence electricity hedging related to particular markets. The existing literature offers general knowledge about individual factors but fails to recognize the practical implications of local factors at the utility level. Second, offering a practical and user-friendly Excel model allows utilities to customize the analysis based on their knowledge of the inputs. In many instances, utilities have firsthand knowledge about many inputs used in this study, therefore the research would stay current.

Potential Application Strategies

The sole purpose of this study was to help utilities, and other affected entities, develop practical strategies that help them decide whether, and in what quantities, to install renewable energy sources to either decrease or stabilize electricity prices in Wisconsin. To investigate practical and feasible strategies, this study developed three scenarios simply understood as low, medium, and high in terms of renewable energy installations. The practicality of the toolkit model can be addressed from three directions.

First, the toolkit with this study allows the user to create as many hedging strategies as necessary to successfully manage risk exposure to volatile natural gas prices. The model is designed in a way that does not limit the user in terms of how many times the model can be run, therefore the user can create as many iterations as desired or until a certain hedging goal is achieved. To help a user navigate the many inputs, the toolkit designates which cells can be changed and which cells cannot be changed because they include calculations.

Second, to create its unique hedging position, the toolkit allows the users to change the inputs, as stated above. The five most significant inputs include renewable energy installations, the potential increase in the efficiency of renewable energy technologies, demand increase, the LCOE estimates, and natural gas price projections. This level of model customization allows a user to adjust the model outputs based on the most accurate data for each output. Given that many of the mentioned variables contain a significant sensibility or volatility, it becomes very important for the user to use the most current and accurate estimates for the input variables. To assess the sensitivity of the variable, the user could potentially use the COV to address the worst and base case scenario. Moreover, the sensitivity of the model outputs can be assessed by running a sensitivity analysis using the what-if function in Excel.

Third, the model allows users to build different strategies by applying different inputs for three different periods, as each decade in the model has its own inputs to help avoid the linearity and the law of averages. Reviewing the historic electricity rates in Wisconsin, the trend does not exhibit linearity, therefore the toolkit user can adjust inputs based on the most recent information. In this regard, the toolkit is capable of incorporating short-term and long-term strategies. The input assumptions for the first planning period, 2023 through 2030, exhibit more certainty compared to the other forecasting periods. Therefore, the estimate for this period should be more accurate and considered a short-term strategy. The inputs for the other two planning periods, 2030 through 2040 and 2041 through 2050 contain more sensitive and uncertain assumptions. Therefore, these planning periods are considered more as long-term strategies. Regardless of which strategy the user chooses, the toolkit model can only be as accurate as the assumptions.

Fourth, the toolkit model allows the user to build different strategies based on different portfolio assumptions. Allowing the user to create an electricity mix based on different renewable energy sources creates an optimized electricity mix based on the most accessible source of energy and the lowest LCOE. Since different states have different renewable energy potentials and different potential LCOEs for different sources, the toolkit allows the user to build the most feasible portfolio unique to its position on the market. In some instances, given the robust nature of the model, the user can create different strategies that achieve the same goal of building the electricity mix or portfolio at the lowest electricity price.

Last, independent electricity producers who sell electricity to utilities could potentially use the model to estimate electricity prices for their portfolio. Because electricity producers do not own transmission and distribution assets, they are able to turn off the part of the model dedicated to demand changes and only estimate the LCOE that can be sold to the grid. The toolkit`s capability to separate the LCOE from demand charges allow these entities to build their strategies based on the most feasible electricity sources, including renewables.

Summary of Application to Professional Practice

This study had a double impact on professional practices in the energy sector. First, this study developed a new theoretical approach, which is based on simplifying the merit-to-order theory by identifying all critical variables impacting hedging strategies of natural gas prices by installing renewable energy sources. Second, to test this theoretical framework, this study built its toolkit to be capable of assessing different scenarios by allowing users to customize inputs at any point in time to build the most optimized strategy leading to the most affordable electricity prices for end users. Finally, the model can be utilized in any territory or state, making it applicable to any country in the world.

Recommendations for Further Study

While that the researcher believes the analysis contains the most accurate data available to the public, the quality of the analysis and results could be greatly improved with more extensive data. Although much of the required data does not have a proprietary component, the experience gained through this research study showed the difficulty of obtaining access to historic records. Some of the public institutions showed no interest in providing additional data or explanations, while others use private databases on a subscription basis, which prevents them from disclosing any information publicly. Considering the fragmentation of the electricity market, government entities must invest effort into making this type of information available to the public for research and verification purposes.

One of the main assumptions made in this study was that the electric grid in Wisconsin would require upgrades to accept larger amounts of renewable energy. Additionally, the costs of upgrading the grid are estimated to be between 2 and 3 cents per KWh. Further research is needed to investigate the readiness of Wisconsin's grid to accept larger amounts of renewable energy and determine the potential costs of such upgrades.

Also, the toolkit model built for this study could be extended to include hourly electricity pricing to capture the correspondence between renewable energy generation and demand in Wisconsin. One of the objectives of such a study is to draw a close parallel between the variability of renewable energy resources and inelastic electricity demand. Given the lack of publicly available information about the hourly and daily pricing for electricity prices, further progress in this area can only be made if such information is tracked and made available to the research community. Currently, some of this information is available through the MISO region, however, it does not separate the information by the states included in this region. Given that each state has its own set of governing rules for the electricity sector, it would be beneficial to track data at the state level.

Further research is also recommended to test the merit-order effect and better understand how renewables alter pricing through the hedging of their variability in the forward market. With low to moderate renewable capacity in Wisconsin, the merit-order effect reduces electricity prices. However, at higher capacity levels of renewable energy, even though the LCOE decreases, the average electricity price may increase. Additional research is required to investigate this apparent paradox in electricity pricing to understand the relationship between two procompetitive variables through adding more renewable energy and lower LCOE for renewable energy sources.

Furthermore, future work should be focused on the hedge value of energy efficiency measures and distributed generation. These mechanisms should be incorporated into decision-making processes regarding the price stability benefits that could potentially be offered to the energy market.

To manage the variability of weather for solar and wind projects, a deeper evaluation of weather and derivative types would be beneficial to mitigate the weather risk. An empirical investigation would provide more information about selective hedging during different times of day for renewable energy generators that could potentially use different hedging strategies to minimize risk exposures associated with weather.

Last, examining the role of storage technologies in the integration of renewable energy to the electricity mix and electricity pricing is essential. The research would need to focus on addressing key concerns about the variation and intermittency challenges associated with renewable power generation and grid integration. This type of research could potentially spur further investment in storage technologies, which could lead to a breakthrough for large-scale applications.

Reflections

Personal & Professional Growth

Modeling a high penetration of renewable energy is a complex task. A system that utilizes 100% renewable energy does not yet exist in reality. Consequently, researchers are forced to rely on theoretical models that are often too abstract to have any practical implications. Additionally, some of the developed models are too incomplete, focusing only on one component of renewable energy development. This toolkit model was designed to provide utilities and other entities with a general estimate regarding electricity price movements when renewables are added to the grid, not an in-depth and precise projection.

Although the researcher has extensive experience in the industry and has been involved in dozens of practical studies, this particular study was a challenge because it required the researcher to understand all the relevant literature as applied to the research conducted in this study. Since this study was the researcher`s first full-scale research project in an academic setting, it differed significantly from other professional research projects completed previously. A significant amount of time and effort was invested to understand the potential applicability of the existing theoretical frameworks developed by other researchers.

One of the biggest challenges of this study was collecting relevant data to verify the existing data. Although this country has the Information Freedom of Information Act which allows individuals to obtain public records with no sensitive data, many public institutions avoided releasing the data or claimed that the data does not exist. Additionally, for areas with missing information, the researcher had to investigate the issues in minute detail to make reasonable assumptions. Estimating the grid`s capability to accept large amounts of energy proved to be the most difficult assignment in this study. This caused the scope of work to be expanded to gaining information regarding how transmission and distribution costs are designed at the utility level, which was not the researcher's initial intention.

Renewable energy modeling in Excel offered plenty of opportunities and challenges for the researcher to grow professionally because the complexity of the modeling task needed to be simplified for the results to be practically meaningful. Also, managing and manipulating large databases to conduct statistical analysis required additional skills to be built. Previous knowledge of Excel helped the researcher to finish the modeling tasks relatively fast, although expected issues and glitches in Excel were ever-present. The complexity of modeling was multi-faceted. First, finding historic data and future forecasting of variable renewable energy sources, especially solar and wind, proved to be a huge challenge as local information was not available to the public. Additionally, modeling the balancing and transferring of unpredictable renewable energy from generation locations to the grid represented another challenge because only NREL has insight into this issue. This type of information was included in its REDS model but could not be easily separated from the rest of the database.

Overall, the research required reading and comprehending at a much faster pace than other academic research in the past, which required developing new strategies for task prioritization, keeping good notes, and time management to the greatest possible extent.

Biblical Perspective

The section below presents the researcher`s views on how Christians should understand the purpose of their work and business in general in today`s economy. According to Keller and Alsdorf (2012), the purpose of our work is not to fulfill ourselves or to gain power and material resources, but rather to serve others, including God and our neighbors. If we understand and accept the Bible as an ultimate source of wisdom, humans should conduct their business activities as a service or calling to build and manage material resources in God`s name and for His glory (Keller & Alsdorf, 2012).

The Bible often utilizes words such as knowing, understanding, studying, and searching in a way that fully supports the idea that research work is not only common for mankind, but is endorsed and supported by God. Because God wants men and women to develop and utilize their intellectual and mental abilities, it is clear that God encourages us to conduct research whenever it is appropriate and useful (Fambro, 2016). Accepting and applying Biblical principles of research allow a Christian researcher to be led to the ultimate truth for the research topic.

Scholars that apply biblical principles establish great work standards and improve their research results (Nabil & Angelidis, 2005). According to the scriptures, God wants us to steward His resources in His name (1 Peter 4:10). As His stewards, God wants us to be accountable and responsible for the actions that we take in His name (Matthew 25:14–30). The entire finance sector is built around the notion that managers, executives, lawyers, and brokers act as agents or stewards on behalf of other individuals and serve their interests (Edgell, 2012). God himself created promises and covenants that He kept. As humans are created in his image, humans also can make promises to each other (Davis, 2007).

The biblical impact on conducting a meaningful and accurate quantitative analysis can be seen from the following perspectives:

First, the researcher should be guided by the moral, ethical, and spiritual principles of the Bible. Some studies have shown that scholars that implement biblical beliefs in their everyday work achieve greater long-term goals compared to their counterparts. Therefore, they should operate with integrity and their analysis should be unbiased and based on truth and the best estimates. The financial metrics cannot be over emphasized for whether to pursue certain financial actions without considering moral, ethical, and spiritual principles first (Vitell, 2010). According to Williams (2019), the main characteristics of an expert should be contentment, hard work, stewardship, and generosity.

Second, we have witnessed that even when researchers do all they possibly can to "crunch the numbers", they often fail to interpret those numbers correctly. According to Beed and Beed (2015), our sinful nature separates us from God`s wisdom and His wealth and causes us to make decisions based on overly optimistic ambitions to own as many material resources as we can. God proclaims, “Seek the Kingdom of God above all else and live righteously, and He will give you everything you need” (New International Version Bible, Mathew 6:33).

Last, if scholars and professionals desire to follow God`s steps, they need to accept their job as a calling given by God to work with other people to create goods and services that benefit our neighbors, communities, and mankind. If someone is conducting research work just to make a living, they will not honor God because they work solely for their own gain. According to Hardy (1990), “[because of our laziness and disobedience, we must approach God through the labor of our obedience”.

The problem-solving issues from the Biblical perspective can be seen from three aspects. First, a person needs to know the facts before engaging in solving an issue. According to the Bible, "What a shame - yes, how stupid! to decide before knowing the facts!" (Proverbs 18:13, TLB). Second, a problem solver should be open to new ideas and different opinions and approaches. The Bible says: "The intelligent man is always open to new ideas. In fact, he looks for them" (The Living Bible, Proverbs 18:15). The third principle supports the idea that a problem-solver needs to hear both sides of the story. Therefore, "any story sounds true until someone tells the other side and sets the record straight” (The Living Bible, Proverbs 18:17).

The Bible teaches us that problems are inevitable and are confirmation that we are being prepared for heaven. God always offers us His help to free us from burdens and problems. The Bible says: "The Lord upholds all those who fall and lifts all who are bowed down." (New International Version Bible, Psalm 145:14).

The foundational principle of the Bible is that God is the source of everything. The Bible says that God owns it all, and humans just manage material resources for Him. “Seek the

Kingdom of God above all else, and live righteously, and He will give you everything you need" (New International Version Bible, Mathew 6:33).

Work is a calling or vocation, which is a part of God's work in the world, and God provides resources to all of us for serving the community (Hardy, 1990). Education and life experiences, including the painful ones, are part of God`s plan to equip people to do some work that no one else can do. "For we are God's handiwork, created in Christ Jesus to do good works, which God prepared in advance for us to do" (New International Version Bible, Ephesians 2:10).

We all must possess stewardship skills based on God's mandate to fill the earth, govern it, work it, and care for it (Genesis 1:28–30; Genesis 2:15). Our role as producers come from mankind's nature, created by God, by which humans are created to be social, live in community, and possess the desire to work with other people. According to the scriptures: "It is not good that the man should be alone" (Genesis 2:18).

The biblical concept of flourishing or producing can be understood as those who walk in the Spirit and build their relationship with God; according to Galatians, their lives will produce fruit within the Spirit. Employees need to express their God-given creativities and passions through work by producing items beneficial to all.

Summary of Reflections

Involving a biblical perspective in research requires implementing honesty, integrity, stewardship, and trustworthiness (Wesley, 2019). The honesty principle is well described in the Bible, as the following verse proclaims: "You shall not commit an unrighteousness in justice, in measures of length, weight, or volume. Just scales, just weights, just dry measures, and just liquid measures you shall have" (New International Version Bible, Leviticus 19:35–36). The same principle can be found in Psalms, which confirms that those who have "clean hands and a pure heart" will be able to climb the "mountain of the Lord and stand in His holy place" (New International Version Bible, Psalm 24:3–4).

The stewardship principle is widely addressed in the Bible and also applies to thinking and learning. The Bible teaches that God is the source of all material things on Earth and that God entrusted humans with being responsible for the preservation of material things for the benefit of all. "Whatever you do, do it enthusiastically, as something done for the Lord and not for men, knowing that you will receive the reward of an inheritance from the Lord (New International Version Bible, Colossians 3:23).

The principle of trustworthiness can be applied to the learning process and is found in the book of Luke in the opening verses where the Bible provides us with a clear understanding of the meaning of being trustworthy. "And if you are untrustworthy about worldly wealth, who will trust you with the true riches of heaven?" (New Living Translation Bible, Luke 16:11). According to Fambro (2016), Paul asked humans to examine everything carefully, thus data gathering, careful analysis, and the formulation of sound conclusions should be utilized to distinguish truth from error.

Summary of Section 3

This study simulates different pathways for achieving Wisconsin's renewable energy goals by 2050. This study created three scenarios with different levels of renewable energy implementation. The base case scenario uses the existing trend of adding renewable energy, the optimal scenario explores a more aggressive pursuit of renewable energy and the carbon-free scenario models 100% renewable energy by 2050. All the scenario analyses are conducted with an Excel-based toolkit built for this research, capable of managing different data inputs.

The base case scenario would achieve 25% renewable energy by 2050 with a projected electricity price of 14.5 cents per kWh, the optimal model would create 33%renewable energy with an electricity price of 16.9 cents per kWh, and the carbon-free scenario would create 100% renewable energy by 2050 with a projected electricity price of 21 cents per kWh.

Using SDEV and COV statistical tools and applying them to LCOE values for each energy source, this study concludes that renewable energy sources are less volatile than natural gas prices. The hedging premium, the difference between the spot and futures price, exhibits higher volatility than natural gas prices. The COV measure shows the volatility of hedging costs is 883.33. Using an aggressive heat rate of 7000 Btu/kWh, for each KWh generated by natural gas plants, the end users need to pay a 1 cent premium per KWh.

For the three scenarios examined in this study, the value of renewable energy increases with greater grid capability to integrate the variable renewable energy. However, the grid`s integration ability depends on the project locations, therefore it is hard to estimate how much renewable energy can be accepted at the current level of grid readiness. Assuming that Wisconsin’s grid has a medium capability to absorb large quantities of renewable energy, this study estimates that under the base case scenario, adding one KW of renewable energy decreases the price of electricity by 1.4 cents per KWh. Under the optimal scenario, electricity prices remain almost the same, 0.03 cents per KWh, compared to the no additional renewable energy scenario. Under the carbon-free scenario, which is the most aggressive in terms of adding renewable energy, electricity prices are estimated to rise on average by 3 cents per KWh.

This study investigates whether and to what degree two independent variables, renewable energy and natural gas prices, have a positive or negative relationship with the dependent variable, average electricity prices in Wisconsin. The third null hypothesis states that there is no significant negative relationship between increases in renewable energy installations and average electricity prices. The multi-regression analysis suggests that there is not a negative relationship between the independent and dependent variables, as the average electricity prices increase with adding renewable energy to the grid.

Summary and Study Conclusions

The main objective of this study is to investigate how Wisconsin could potentially increase its renewable energy generation and achieve the goal of producing all electricity from renewable energy by 2050. This study utilized a fixed design with quantitative research methods involving descriptive statistics and multilinear regression analysis. To explore different pathways, this study created three scenarios with different renewable energy targets. To conduct the analysis, this study created an Excel-based model that allows users to customize inputs based on the most recent data sets.

This study found the following:

1. Natural gas prices exhibit much higher volatility than the levelized costs of renewable energy. Based on Table 8, natural gas prices are more volatile and exhibit an upward trend, while renewable energy resource prices exhibit a downward trend and are less volatile.
2. Adding renewable energy to the grid only lowers electricity prices if the grid does not require significant investments. This is true under all scenarios since renewables have a lower LCOE than traditional energy sources.
3. The multi-regression analysis showed that under a moderate grid capability assumption, adding renewable energy will not decrease or stabilize electricity prices long-term. However, this analysis does not consider the potential of battery storage

technologies and distributed energy generation that avoid the grid`s inability to accept larger amounts of renewable energy.

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Appendix A: Tables

Table 16

Base Case Scenario - Projected Electricity Rates From 2023 Through 2050

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Electricity price ($/kWh)	0.123	0.123	0.122	0.121	0.121	0.120	0.119	0.119	0.121	0.121
Year	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**
Electricity price ($/kWh)	0.122	0.123	0.124	0.125	0.127	0.128	0.130	0.132	0.135	0.136
Year	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**		
Electricity price ($/kWh)	0.137	0.138	0.139	0.140	0.141	0.142	0.144	0.145		

Table 17

Optimal Case Scenario - Projected Electricity Rates From 2023 Through 2050

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Electricity price ($/kWh)	0.124	0.124	0.124	0.123	0.123	0.123	0.123	0.122	0.126	0.128
Year	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**
Electricity price ($/kWh)	0.130	0.133	0.135	0.138	0.141	0.145	0.148	0.152	0.158	0.159
Year	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**		
Electricity price ($/kWh)	0.160	0.161	0.162	0.163	0.164	0.166	0.167	0.169		

Table 18

Carbon-Free Case Scenario - Projected Electricity Rates From 2023 Through 2050

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**

Electricity price ($/kWh)	0.119	0.122	0.123	0.124	0.124	0.125	0.127	0.128	0.136	0.144
Year	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**
Electricity price ($/kWh)	0.154	0.170	0.177	0.183	0.189	0.193	0.197	0.201	0.207	0.210
Year	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**		
Electricity price ($/kWh)	0.211	0.211	0.211	0.211	0.211	0.211	0.210	0.210		

Table 19

Multilinear Regression Analysis for Optimal Scenario

SUMMARY OUTPUT-Optimal Scenario

Regression Statistics	
Multiple R	0.982954131
R Square	0.966198823
Adjusted R Square	0.964267328
Standard Error	0.004060596
Observations	38

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.016496138	0.008248069	500.2334579	1.80429E-26
Residual	35	0.000577095	1.64884E-05		
Total	37	0.017073233			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.088400717	0.002411457	36.65862799	1.62816E-29	0.083505199
Renewable energy	3.26661E-09	2.43987E-10	13.3884639	2.47351E-15	2.77129E-09
Natural Gas Spot Prices	0.001581302	0.000913044	1.731900592	0.09209763	-0.000272276

Table 20

Multilinear Regression Analysis for Carbon-Free Scenario

SUMMARY OUTPUT-CARBON NEUTRAL SCENARIO

Regression Statistics	
Multiple R	0.953337411
R Square	0.908852218
Adjusted R Square	0.903643774
Standard Error	0.014416426
Observations	38

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	0.072532133	0.036266066	174.4958958	6.24535E-19
Residual	35	0.007274167	0.000207833		
Total	37	0.0798063			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.067194291	0.008561452	7.848468989	3.17887E-09	0.049813619
Renewable energy	7.03644E-09	8.66234E-10	8.123027192	1.44539E-09	5.27789E-09
Natural Gas Spot Prices	0.002543099	0.003241601	0.784519399	0.438013296	-0.004037701

Table 21

Electricity Prices in Wisconsin under Different Scenarios

Year	No additional RE	Carbon-free	Optimal	Base case

`23	0.119	0.119	0.124	0.123
`24	0.127	0.122	0.124	0.123
`25	0.128	0.123	0.124	0.122
`26	0.129	0.124	0.123	0.121
`27	0.130	0.124	0.123	0.121
`28	0.130	0.125	0.123	0.120
`29	0.132	0.127	0.123	0.119
`30	0.133	0.128	0.122	0.119
`31	0.135	0.136	0.126	0.121
`32	0.136	0.144	0.128	0.121
`33	0.138	0.154	0.130	0.122
`34	0.139	0.170	0.133	0.123
`35	0.140	0.177	0.135	0.124
`36	0.141	0.183	0.138	0.125
`37	0.142	0.189	0.141	0.127
`38	0.144	0.193	0.145	0.128
`39	0.145	0.197	0.148	0.130
`40	0.146	0.201	0.152	0.132
`41	0.150	0.207	0.158	0.135
`42	0.151	0.210	0.159	0.136
`43	0.153	0.211	0.160	0.137
`44	0.154	0.211	0.161	0.138
`45	0.156	0.211	0.162	0.139
`46	0.157	0.211	0.163	0.140
`47	0.159	0.211	0.164	0.141
`48	0.161	0.211	0.166	0.142
`49	0.162	0.210	0.167	0.144
`50	0.164	0.210	0.169	0.145
Average	0.1428	0.173	0.1425	0.129

Appendix B: Scenario Assumptions

Table 22

Base Case Scenario - Model Assumptions

		2023-2030			2031-2040			2041-2050		
Demand Change (%/year)			1.00%			1.00%			1.00%	
Energy Efficiency (%/year)			1.50%			1.50%			1.50%	
Back-up Costs ($/kWh)			0.11			0.12			0.13	
ransmission and Infrastructure ($/kWh)			0.020			0.025			0.030	
Renewables Variability Factor (%)	7%									
Inflation (%)	3%									
Electricty Mix		**Electricty Mix**	**Capacity Factors Improvement**	**LCOE ($/MWh)**	**Electricty Mix**	**Capacity Factors Improvement**	**LCOE**	**Electricty Mix**	**Capacity Factors Improvement**	**LCOE**
Coal		-6.00%	0.00%	82.61	-22.00%	0.00%	81.04	-55.00%	0.00%	79.46
Hydroelectric		1.00%	0.00%	64.27	1.00%	0.00%	69.86	1.00%	0.00%	75.44
Natural gas		6.00%	0.00%	39.94	2.00%	0.00%	42.00	0.00%	0.00%	44.05
Nuclear		1.00%	0.00%	81.71	1.00%	0.00%	80.96	0.00%	0.00%	80.20
Other		0.00%	0.00%	77.00	0.00%	0.00%	76.00	0.00%	0.00%	75.00
Biomass		1.00%	0.00%	90.17	2.00%	0.00%	88.35	1.00%	0.00%	86.53
Petroleum		-3.00%	0.00%	117.00	-3.00%	0.00%	119.44	-50.00%	0.00%	121.87
Solar		6.00%	2.00%	33.46	10.00%	2.00%	32.27	7.00%	2.00%	31.07
Wind		4.00%	1.00%	40.23	10.00%	1.00%	40.16	3.00%	1.00%	40.08
Wood		1.00%	0.00%	90.00	1.00%	0.00%	88.50	0.00%	0.00%	87.00

Table 23

Optimal Scenario - Model Assumptions

		2023-2030			2031-2040			2041-2050		
and Change (%/year)			1.00%			1.00%			1.00%	
y Efficiency (%/year)			1.50%			1.50%			1.50%	
ack-up Costs ($/kWh)			0.11			0.12			0.13	
frastructure ($/kWh)			0.020			0.025			0.030	
Variability Factor (%)	7%									
Inflation (%)	3%									
Electricty Mix		**Electricty Mix**	**Capacity Factors Improvement**	**LCOE ($/MWh)**	**Electricty Mix**	**Capacity Factors Improvement**	**LCOE**	**Electricty Mix**	**Capacity Factors Improvement**	**LCOE**
Coal		-10.00%	0.00%	82.61	-85.00%	0.00%	81.04	0.00%	0.00%	79.46
Hydroelectric		0.00%	0.00%	64.27	0.00%	0.00%	69.86	0.00%	0.00%	75.44
Natural gas		8.00%	0.00%	39.94	0.00%	0.00%	42.00	0.00%	0.00%	44.05
Nuclear		0.00%	0.00%	81.71	0.00%	0.00%	80.96	0.00%	0.00%	80.20
Other		0.00%	0.00%	77.00	0.00%	0.00%	76.00	0.00%	0.00%	75.00
Biomass		3.00%	0.00%	90.17	2.00%	0.00%	88.35	1.00%	0.00%	86.53
Petroleum		-20.00%	0.00%	117.00	-85.00%	0.00%	119.44	0.00%	0.00%	121.87
Solar		10.00%	2.00%	33.46	10.00%	2.00%	32.27	5.00%	2.00%	31.07
Wind		10.00%	1.00%	40.23	10.00%	1.00%	40.16	3.00%	1.00%	40.08
Wood		4.00%	0.00%	90.00	0.00%	0.00%	88.50	0.00%	0.00%	87.00

Table 24

Carbon-free Scenario - Model Assumptions

		2023-2030			2031-2040			2041-2050		
and Change (%/year)			1.00%			1.00%			1.00%	
y Efficiency (%/year)			1.50%			1.50%			1.50%	
ack-up Costs ($/kWh)			0.11			0.12			0.13	
frastructure ($/kWh)			0.020			0.025			0.030	
Variability Factor (%)	7%									
Inflation (%)	3%									
Electricty Mix		**Electricty Mix**	**Capacity Factors Improvement**	**LCOE ($/MWh)**	**Electricty Mix**	**Capacity Factors Improvement**	**LCOE**	**Electricty Mix**	**Capacity Factors Improvement**	**LCOE**
Coal		-75.00%	0.00%	82.61	-85.00%	0.00%	81.04	0.00%	0.00%	79.46
Hydroelectric		0.00%	0.00%	64.27	0.00%	0.00%	69.86	-5.00%	0.00%	75.44
Natural gas		12.00%	0.00%	39.94	-15.00%	0.00%	42.00	-65.00%	0.00%	44.05
Nuclear		0.00%	0.00%	81.71	-15.00%	0.00%	80.96	-65.00%	0.00%	80.20
Other		0.00%	0.00%	77.00	5.00%	0.00%	76.00	0.00%	0.00%	75.00
Biomass		10.00%	0.00%	90.17	10.00%	0.00%	88.35	10.00%	0.00%	86.53
Petroleum		-100.00%	0.00%	117.00	0.00%	0.00%	119.44	0.00%	0.00%	121.87
Solar		30.00%	2.00%	33.46	10.00%	2.00%	32.27	7.00%	2.00%	31.07
Wind		20.00%	1.00%	40.23	10.00%	1.00%	40.16	5.00%	1.00%	40.08
Wood		12.00%	0.00%	90.00	10.00%	0.00%	88.50	5.00%	0.00%	87.00

Appendix C: Renewable Energy Resource Maps

Figure 19

Biomass Renewable Energy Generation Potential

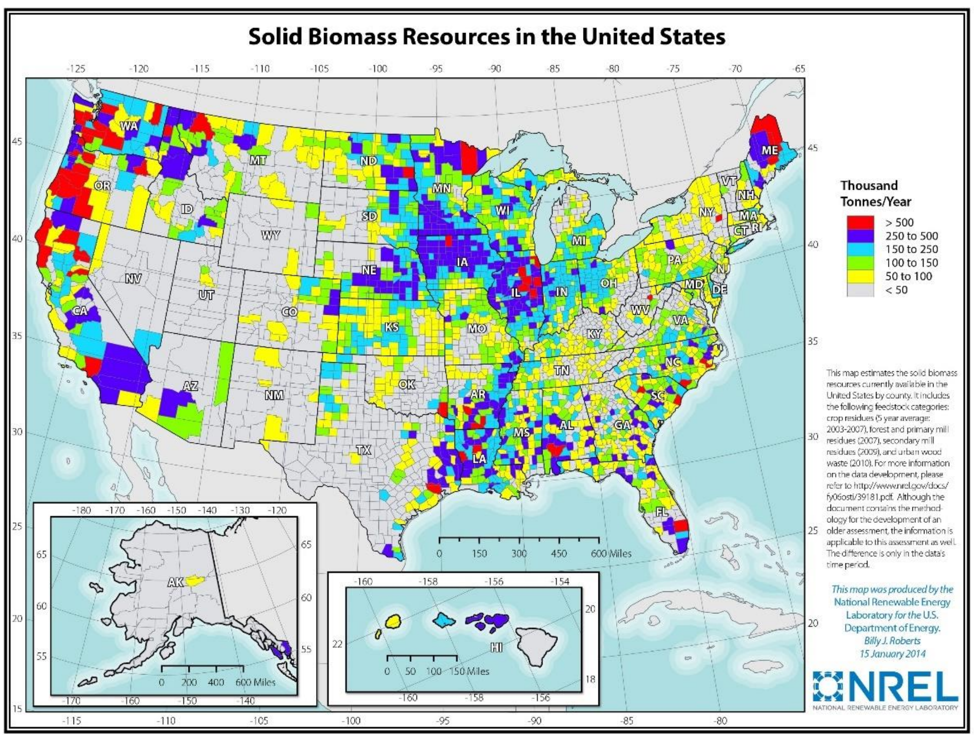

Figure 20

Geothermal Renewable Energy Generation Potential

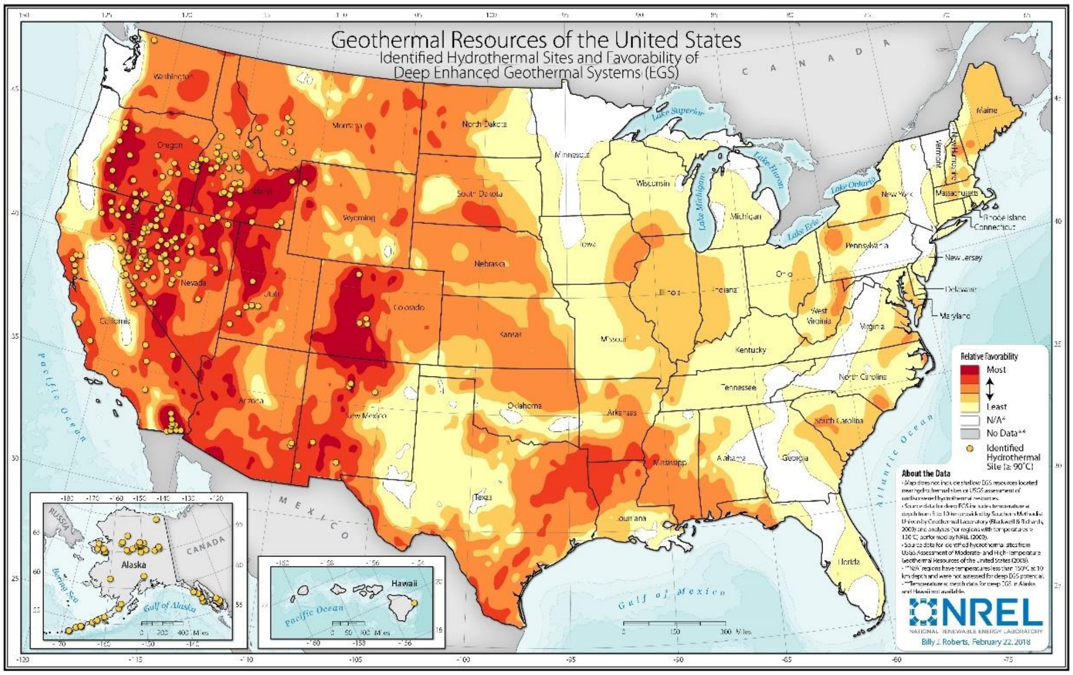

Figure 21

Hydro Renewable Energy Generation Potential

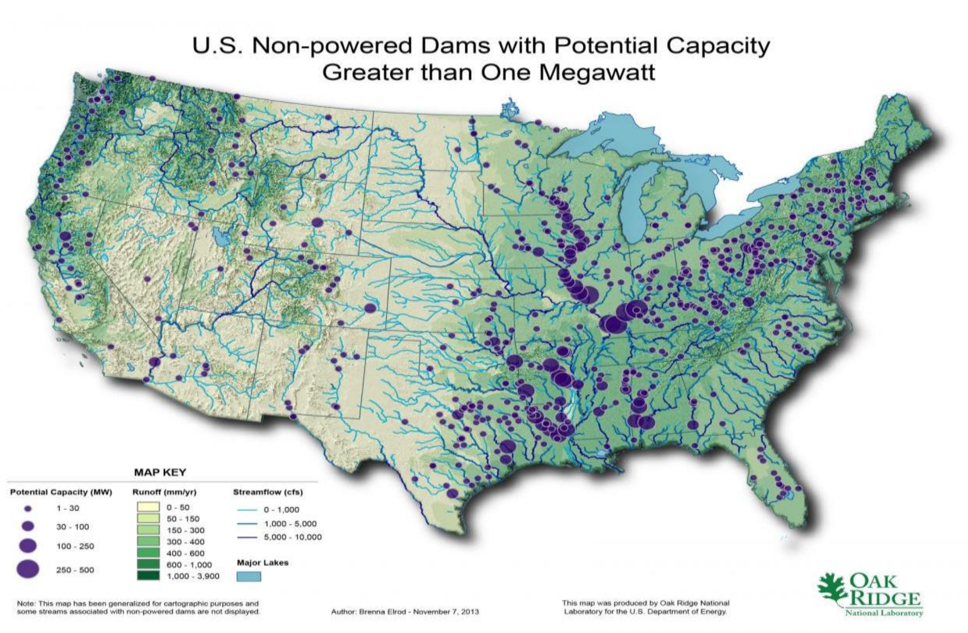

Figure 22

Solar Renewable Energy Generation Potential

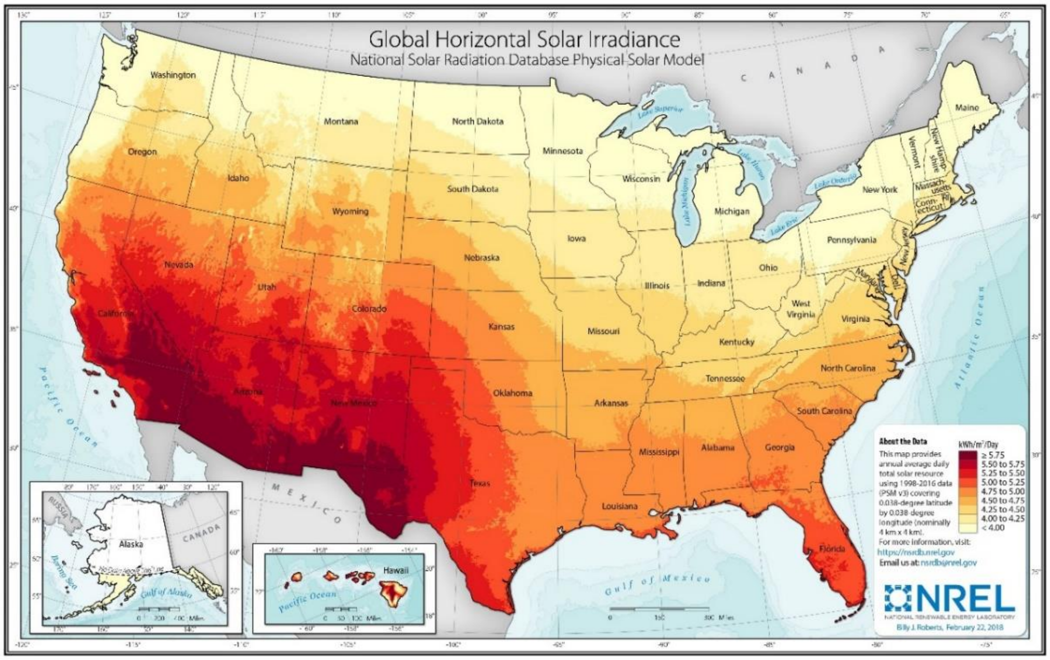

Figure 23

Wind Renewable Energy Generation Potential