THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

JOHN AND WILLIE LEONE FAMILY DEPARTMENT OF ENERGY AND MINERAL ENGINEERING

IMPACTS OF THE CLEAN POWER PLAN ON THE RESOURCE MIX AND RENEWABLE ENERGY DEVELOPMENT

EVELYN BATEMAN
SPRING 2016

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Energy Engineering
with honors in Energy Engineering

Reviewed and approved* by the following:

Susan Stewart
Research Associate and Assistant Professor of Aerospace Engineering
Thesis Supervisor

Sarma Pisupati
Professor of Energy and Mineral Engineering
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

ABSTRACT

Currently under a stay of proceedings from the Supreme Court, the Clean Power Plan is a carbon emission policy proposed by President Obama in response to international climate change discussions. The Plan gives each State the leeway to design individualized strategies for specified carbon reduction targets in the electricity sector by 2030. While the government and other independent agencies have predicted the impacts of the Clean Power Plan, this study aims to assess the effectiveness of the policy at promoting affordable means of achieving carbon reduction goals and incentivizing wind power, and to suggest future policy decisions beyond the 2030 goal. A linear optimization model written in GAMS is used to perform an economic dispatch for Texas and New York case studies under baseline, carbon cap, and carbon cap plus new wind technology scenarios. The carbon cap constraint on the dispatch model shifted the resource mix from coal to natural gas, as predicted by previous studies. However, the implementation of hypothetical wind resources in each State shifted the dispatch back to coal, suggesting that renewable energy development could actually reduce the negative impacts of the Clean Power Plan on the coal industry. Other factors impacting the State's decisions, including regulated/deregulated electricity markets, renewable influx, and economic growth under the Clean Power Plan are discussed. While the Clean Power Plan offers successful alternatives for reducing carbon emissions including fuel switching, demand side reductions, and energy efficiency projects, the Plan lacks financial incentives for wind production that will be crucial for future carbon mitigation. While this may be adequate in the short term, it is suggested that legislation beyond 2030 should include more specific incentives for wind and renewable energy development.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Dr. Susan Stewart, for her willingness to supervise my work and her desire to learn alongside me throughout the research process. She has been a great inspiration to be as an undergraduate and I hope to use what I have learned as her advisee to promote wind energy development. I would also like to thank Dr. Mort Webster for his assistance with GAMS and his commitment to helping all students learn and succeed. Dr. Webster has been pivotal to the success of my honors thesis and I am very grateful for his support. I would finally like to thank Dr. Seth Blumsack for suggesting that I take his course, EBF 483, Introduction to Electricity Markets. It is because of his clear and relevant instruction that I was able to pursue this research.

Chapter 1

Introduction

Climate change has become an issue of public scrutiny and a highly debated political topic within the past decade. Throughout his presidency, Barack Obama has firmly supported a reduction of greenhouse gas emissions through the development of clean, domestic energy. In his 2013 State of the Union Address, the President warned that "if Congress won't act soon to protect future generations, I will" (The White House, 2013). The following year, President Obama and President Xi Jinping of China issued a joint announcement describing their individual commitments to reducing greenhouse gas emissions, with the goal of sparking future international climate agreements. (The White House, 2015) Obama discussed his goal of reducing carbon emissions by 26% below 2005 levels by the year 2020. Finally, in August 2015, President Obama and the Environmental Protection Agency announced The Clean Power Plan to address carbon dioxide emissions from fossil-fuel electric generators. The Plan is considered to be the environmental landmark of the Obama Administration because it provides personalized goals for each State to ultimately reduce national carbon dioxide emissions by 32% in the power sector by 2030 based on 2005 levels (The White House, n.d.). The consequence of the Clean Power Plan, should it be implemented, is a reconsideration of the mixture of fuels and renewable resources used to generate electricity in each State. In addition to promoting energy efficiency measures for demand-side reductions, the Clean Power Plan provides an opportunity for natural gas and renewable energy to fulfill a larger role in meeting electricity demand. Wind power plays a particularly important part in this new dispatch because it is a powerful source of carbon-free energy (Environmental Protection Agency, 2015a). While the carbon reduction targets for each State are specified by the EPA, the method for implementing these goals is to be determined by each State.

In the beginning of February, the Supreme Court issued a stay on the Clean Power Plan after two dozen States and several electric utilities sued the EPA. The cost of implementing the Plan is one of the biggest concerns voiced by the suing States, and in particular, by the coal industry, which is threatened by the new regulation (Stohr & Dlouhy, 2016). Moreover, legal authorities are questioning the power of the EPA to enforce such significant regulations. While some States are already preparing for implementation (Holden, 2016) of the Clean Power Plan, a decision about the future of Obama's Plan will be made later in the year by an appeals court.

With the regulation still largely undecided, the EPA and other third party bodies have been assessing the outcomes of the Clean Power Plan to provide decision-making resources to the States during their planning process. In particular, results from the modeling of future electricity prices, economic dispatch, and carbon emissions have been published to inform both utilities and policy-makers. Similarly, this research utilizes an economic dispatch model to test the optimal outcome of the Clean Power Plan for case studies Texas and New York. The goal of this thesis is to assess the impacts of the Clean Power Plan on energy costs and to ultimately judge the appropriateness of the policy to inform future executive actions on carbon mitigation. In particular, the results will determine the effectiveness of wind energy at achieving the carbon reduction goals set forth by the Clean Power Plan. A literature review summarizes the details of the Clean Power Plan and other relevant research on the impacts of the policy. The Methods chapter describes the economic dispatch model, data sources, model scenarios, and assumptions. The Results include the economic dispatch output for Texas and New York for three demand scenarios of regular, carbon constraint, and carbon constraint plus new technology. An evaluation of the results predicts the economic implications under the constraints of the Clean Power Plan and addresses the State-to-State differences that promote wind energy development in New York and Texas. A broader assessment regarding the efficacy of the Clean Power Plan to incentive renewable energy projects and to promote economical alternatives to all States is provided. Recommendations about the course of action for other States, and future carbon reduction schemes are discussed.

Chapter 2

Review of Literature

Clean Power Plan

The Clean Power Plan targets power plants as the single largest source of carbon pollution (Environmental Protection Agency, n.d.). To mitigate the carbon footprint of utility generators, the Clean Air Act Section 111(d) establishes a partnership between the EPA and the States in which the EPA sets carbon reduction goals and the States choose their approach to meeting the standard ("Clean Power Plan," n.d.). The EPA has published carbon caps for each state based on either rate-based (lbs of CO_2 per MWh) or mass-based (total short tons of CO_2) carbon reduction goals. Four *best system of emission reduction* (BSER) building blocks were identified by the EPA as the most effective techniques for meeting the carbon limits. These include increasing the efficiency of existing coal plants, retrofitting coal plants to natural gas plants, developing renewable energy sources including solar and wind, and demand side reductions. The result of these reductions is the creation of emission reduction credits that can be exchanged between States under a national framework. The States must submit plans for achieving the reductions by June 30, 2016. States that refuse to comply with the Plan will be restricted by a carbon cap while carbon credits can be exchanged to minimize costs.

With the flexibility to develop a plan for meeting the Clean Power Plan standards, States are faced with the decision to implement a mass-based or rate-based approach. Several items are under consideration by States and regions making this decision. A presentation from The Brattle Group consulting firm at the 2016 Renewable Energy Law Conference (Spees, 2016) suggested the possible implications of adherence to each scenario in Texas. For a mass-based approach it was suggested that the cost of switching from coal to natural gas would have a significant impact on the cost of implementing the Clean Power Plan. Under the assumption that natural gas prices remain low however, this cost might not be consequential. Wholesale energy prices are expected to increase under the mass-based choice, though this increase might not be felt by customers if the carbon allowances were returned. Spees continued by assessing the rate-based approach, under which a stricter carbon standard corresponds to a higher price for complying. Thus, even cleaner-burning gas combined cycle facilities are expected to compete with coal plants to purchase emission reduction credits rather than sell, as they would under the mass-based plan. From this analysis, it is expected that States which burn more coal would opt for a mass-based approach because switching to natural gas would be less expensive, assuming natural gas prices stay low. Additionally, a rate-based approach would require undesirable competition for credits with coal plants that would detract from revenue earned from selling credits. A further consideration is that States may only trade credits with States that are under the same plan base. Regional cooperation under this new market is then another aspect of the States' decisions. These issues will be further discussed when outlining the potential choices faced by New York and Texas.

Economic Dispatch

Implementing either mass or rate-based carbon emission constraints will ultimately impact the resource mix available to the States for meeting their electrical demands. The typical tool used by day-ahead and hour-ahead electricity markets is economic dispatch. Economic dispatch refers to the determination of which generating facilities should operate at particular times to meet electricity demand and the lowest total cost to utilities and to customers. In general, this is achieved by operating the least expensive generators followed by the most expensive generators until energy demand is met. In this way, generators can be classified as either base-load, shoulder, or peak generators, corresponding to their typical full time or sporadic use based on fluctuating demand (Figure 1) (Blumsack, 2016). Typically, base-loading plants are nuclear, coal, and hydropower facilities, while peaking generators tend to be gas combustion turbines and hydropower. Natural gas serves shoulder generation, along with hydropower and coal in certain areas (Blumsack, 2016). Factors including ramp rates, start-up and operating time constraints, and operating limits can impact the feasibility of certain technologies for meeting electricity demand. For example, nuclear facilities are typically so expensive to start up and require a longer time to shut down as demand decreases that they are often left on for long periods of time to serve as base load power. The introduction of renewable energy into the resource mix is another issue surrounding economic dispatch. Since the availability of energy sources like solar and wind fluctuate based on natural processes, they add significant power variability into the grid that fuel-powered generators that can be dispatched with relatively high flexibility must respond to in order to meet real-time demand. With the influx of renewable energy that the Clean Power Plan hopes to stimulate, utilities and their regulators could see changes in their dispatch and be forced to employ ancillary services to curb fluctuations that increased renewables could present. This shift in the resource mix and its impact on the utilities will be assessed.

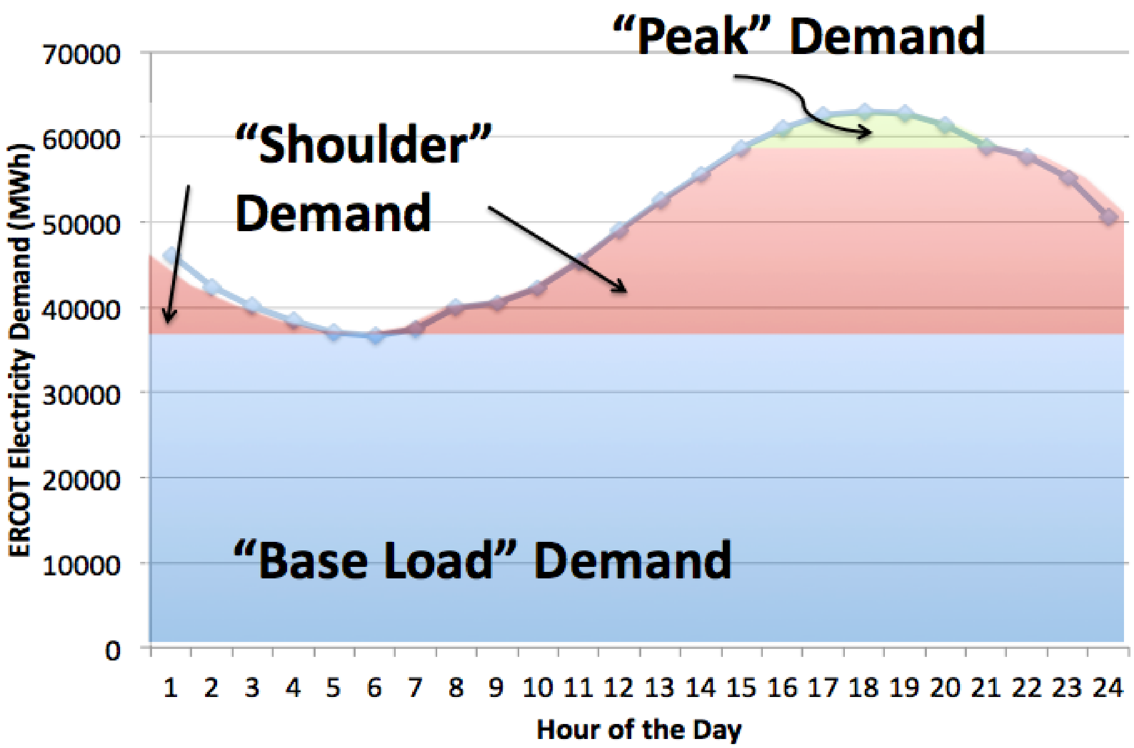


Figure 1. Demand-based generating classification (Blumsack, 2016)

Utility Regulation

Two main types of electricity markets exist in the United States: regulated and deregulated markets. The principle of regulation is that the generation, transmission, and distribution components of electricity flow are all controlled under one, vertically integrated regulatory entity. Deregulated markets, on the other hand, operate under an independent system operator (ISO) or a Regional Transmission Organization (RTO) that manages bids from independent generators throughout its domain. The process by which generators are selected and paid for dispatch, and customers are billed for their electricity, is handled by the ISO under the economic dispatch system described earlier. There are ten ISOs/RTOs in North America as shown in Figure 2 (The Texas Public Utility Counsel, n.d.). Enacting the Clean Power Plan is expected to be a more complex process for deregulated States because of the number of independent stakeholders in a deregulated market. This study will handle two deregulated States for the ease of comparison, although the challenges facing regulated markets will also be mentioned.

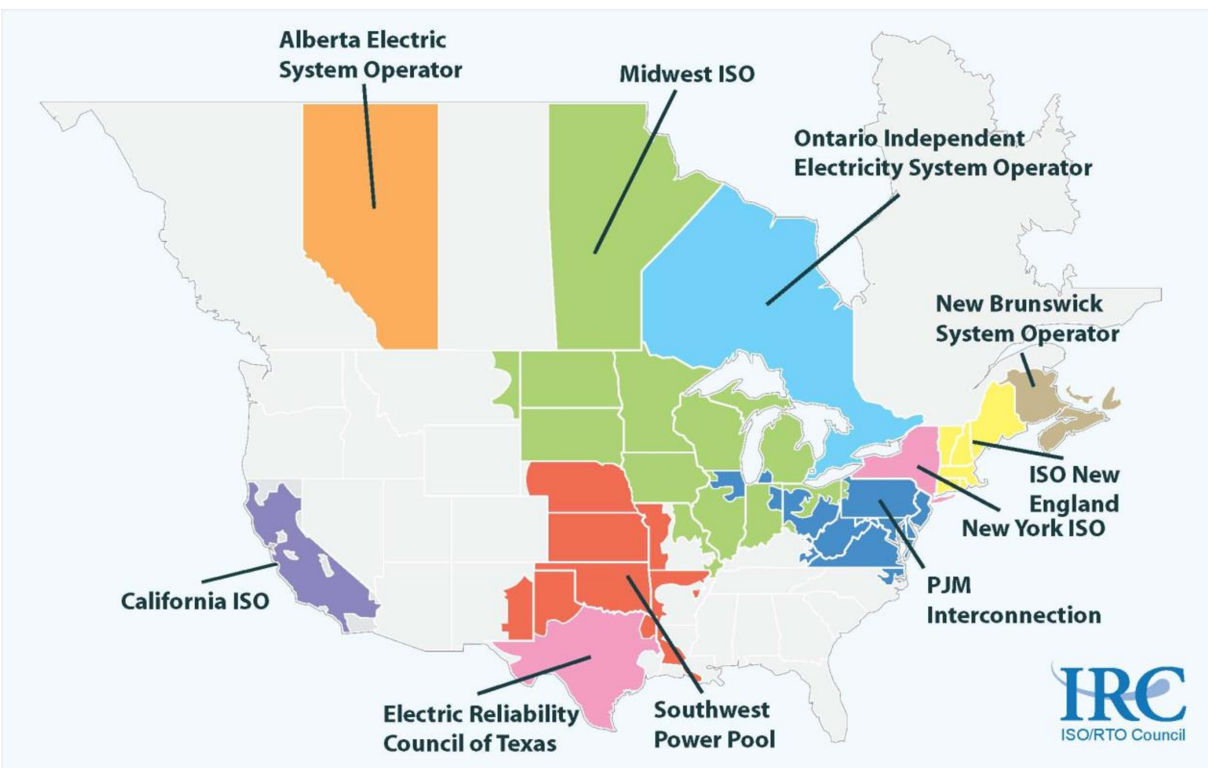


Figure 2. North American ISOs and RTOs (The Texas Public Utility Counsel, n.d.).

Predictions

To fully assess how the previously mentioned factors, including the carbon cap, resource mix, dispatch, and regulation will result in a new electricity scenario, the government and other research institutions have modeled the overall economic and environmental impacts that the proposed legislation might have. The Center for Climate and Energy Solutions published a summary of six economic modeling studies shown in Table 1, gauging the effects of the Clean Power Plan on future energy costs and dispatch (Hopkins, 2015). Each study assessed different components of the policy, including power and/or energy sector regulation, mass or rate based emissions, and energy efficiency or heat rate improvements. The goal of each model was to minimize total costs, which were typically represented by differences between the current prices and prices under the constraints of the Clean Power Plan, and included changes in electricity rates, power sector compliance costs, and market fuel prices. The financial implications of the Clean Power Plan according to the six models were significantly varied. The EPA study predicted the smallest increase in electricity rates for 2020-2030, with a 1.5% average increase. The average electricity rate increase for the studies was 8.35%. The Rhodium study showed the highest increase in electricity rates of 13%. Power sector compliance costs were similarly varied, with NRDC reporting a drop in US power spending from $364 billion (2012) by $4.5 billion (2012). This decrease can be explained by a reduced energy demand through the 2020-2030 period as a result of energy efficiency measures. On the other hand, NERA predicted an increase of $33.5 billion (2012) for the 2020-2030 average. The average power sector compliance across the studies was an increase of $9.68 billion, suggesting that the Clean Power Plan will overall be a costly endeavor for the United States.

The following study will similarly address financial parameters under the Clean Power Plan through power sector compliance costs and the necessary Levelized Cost of Energy (LCOE) required from any new wind installations through 2020-2030. In contrast to the six studies, this study will only model the impacts of the Clean Power Plan for Texas and New York States. Selection of these two States is explained in the Methods chapter. The motivation behind the economic dispatch modeling is to determine the relative success of the Clean Power Plan at minimizing power sector compliance costs while also increasing renewable energy production via wind power. Comparison of the model scope and parameters is shown in Table 1, with this model included as “Bateman.”

Table 1. Clean Power Plan Impact Studies

Study	***Policy Option***	***Full BSER Range***
EPA	State emission rate	Yes
CATF	Mass budget	No energy efficiency
EVA	State emission rate	No heat rate improvements
NERA	State emission rate	Yes
NRDC	State emission rate	Yes
Rhodium-CSIS	Regional emission rate	Yes
Bateman	Mass budget	No energy efficiency, no heat rate improvements

The US government has also provided a multitude of resources for helping States to predict and design Clean Power Plan proposals. In 2015, The Energy Information Administration issued an *Analysis of the Impacts of the Clean Power Plan* upon request by a House committee (U.S. Department of Energy, 2015a). The EIA used the National Energy Modeling System (NEMS) to dispatch generators throughout twenty-two regions covering the contiguous United States. The model was operated under various cases, including scenarios of high economic growth, development of new nuclear power, and an extension of the Clean Power Plan to reduce carbon emissions by 45% in 2040 rather than by 32% in 2030. The results of the study indicate that a switch from coal to natural gas use would be the most effective strategy upon implementation of the plan. Around the mid 2020s, renewables are expected to take on a more substantial role at reducing emissions. Demand side reductions are predicted to be humble compared to fuel switching and renewables. The economics of fuel switching and renewable energy development are determined largely by the supply of natural gas and the prevalence of combined cycle facilities, and the ability of States without preexisting renewable portfolio standards to successfully implement new technology. This study tests these results given the alternative of implementing wind power, and aims to inform general policy considerations for future carbon reduction measures.

Chapter 3

Methods

Economic Dispatch Model

After researching the circumstances and decision variables surrounding the Clean Power Plan, it was determined that an economic dispatch computer program that found the least-cost scenario under different constraints was the best way to model the real-world outcome of the legislation. The model used to acquire dispatch data was written in the General Algebraic Modeling System (GAMS) and modified to make the most economical decisions based on Clean Power Plan emission standards. The objective function of the linear programming model was to minimize total costs of existing, dispatchable plants, namely coal, gas, and nuclear, while obeying a mass based carbon cap established by the EPA under the Clean Power Plan. Since the objective of this study is to assess the potential for wind development under the Plan, wind data was taken from five sites with the best wind resources in each State and adjusted to represent contributions to the overall State demand. The approach for performing the dispatch was largely dependent on the variable nature of the wind resource. Contributions from existing and hypothetical wind sites were subtracted from the demand data in order to quantify the energy required by the coal, gas, and nuclear facilities included in the model. This secondary demand became an input for the optimization program under Clean Power Plan scenarios. The scope of the model is one month, where demand data was taken once a day for the month of July 2015 and wind data was taken every day for July 2012. These procedures are documented below in detail. For the purposes of this study, in the absence of co-current data, the wind data was applied to the demand data time-period as a representative sample for the month of July.

The question of implementing a mass versus rate based carbon reduction scheme, while at the time of writing this thesis it is currently a heavily debated topic for the States, it is considered to be out of the scope of this economic dispatch procedure. The motivation for offering these two options is to prevent stunting economic growth under a mass based cap. Specifically, it is possible that an increase in economic growth and thus in energy demand in the future may not be possible under a fixed mass constraint. In this case, a rate based metric would enable the growth of energy demand while limiting carbon emissions to some number of tons per MWh produced. Since this model is measured over a short period of time and does not account for future economic growth, the differences in dispatch between mass and rate based schemes would be minimal. Therefore, the mass based targets were used to constrain the model.

Data Sources

Hypothetical wind farm sites were first selected using the Wind Integration National Dataset (WIND) Toolkit from the National Renewable Energy Laboratory (U.S. Department of Energy, 2015a). The database includes a wind power dataset at a 100 m hub height for a selected region. For each State, five of the highest wind speed regions were selected to represent potential wind farms. Each region comprised around fifteen sites for which wind power estimations were reported. For each site, an estimation of the energy in the wind was totaled for each day in July 2015. The power data provided by the Toolkit was calculated based on a culmination of four wind turbine power curves for various wind regions. Each turbine was designed to have a 2 MW capacity at a 100 m hub height. Each of the fifteen wind sites contained at most eight wind turbines (King, J., Clifton, A., & Hodge, B., 2014).

Next, energy demand data for Texas and New York were found at the ERCOT (ERCOT, n.d.) and NYISO (NYISO, n.d.) websites. The demand data in MWh was summed for every day in July 2016 and divided by twenty-four hours to arrive at a daily average power demand in MW. Since the economic dispatch model only included dispatchable coal, natural gas, and nuclear facilities, existing wind and hydropower contributions were considered separately. Wind and hydropower energy contributions for both States for the month of July 2015 were obtained from the Energy Information Administration (U.S. Department of Energy, 2015b) and were divided by thirty-one days and twenty-four hours to determine a daily power contribution. The wind and hydro daily power values were subtracted from the total daily demand data. These resultant, unadjusted demand time steps were implemented as a regular dispatch, excluding any new energy developments. A different adjusted set of demand time steps were found by subtracting the new wind contributions calculated from the WIND Toolkit dataset from the unadjusted dispatch demand. This adjusted demand was intended to reflect the installation of new wind farms as a result of addressing Clean Power Plan standards.

The final set of data on existing power plants was acquired from the EPA's eGRID database (Environmental Protection Agency, 2015b), a source that contains detailed operating data on almost every power generator in the United States. For New York and Texas, two lists of operating power plants were extracted, including information on primary fuel type, heat rate, and nameplate capacity. In addition, estimations of the carbon content of the fuels, fuel costs, startup costs, and variable operations and maintenance costs were documented for each plant. The estimations are shown in Table 2.

Table 2. Estimated Plant Properties

Study	*Carbon in fuel [BTU/kWh]*	*Fuel cost [$/MWh]*	*Variable Costs [$/MWh]*	*Startup Cost [$]*
Coal	9500	1.20	4.00	80,000
Gas	6300	8.84	7.00	10,000
Nuclear	0	0	14.60	200,000

State Selection

The decision to select Texas and New York as case studies for the model was carefully considered after researching various State electricity markets. In particular, Texas and New York have several differences in their electricity markets that provide opportunity for comparison under the Clean Power Plan. Texas has a significantly different electricity make-up than New York State, as shown in Figures 3 and 4. Texas produced far more electricity from coal than New York, which produced well under 500 GWh. Texas' renewable energy also constituted a larger percentage of the total generation than New York. On the other hand, New York relied more heavily on nuclear and hydroelectric power than Texas. Texas is also the largest producer of energy-related emissions in the country (U.S. Department of Energy, 2015c). Specifically, Texas had a 2013 energy generation of 433,380 GWh (U.S. Department of Energy, 2015f), about three times as high as New York in 2013 (U.S. Department of Energy, 2015e). These differences offer the opportunity to judge the success of the Clean Power Plan at providing flexibility to different States. On the other hand, both Texas and New York operate under deregulated electricity markets, namely the Electric Reliability Council of Texas (ERCOT, n.d.) and the New York ISO (NYISO, n.d.). This similarity is important because it validates the economic dispatch model approach and limits the number of independent variables for the study.

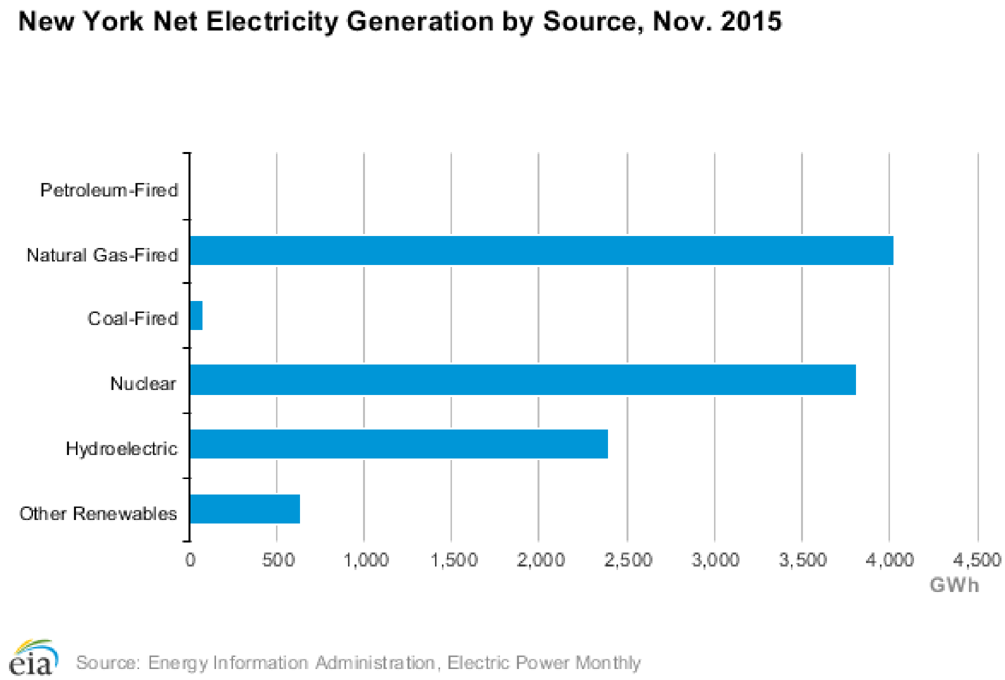


Figure 3. Electricity sources for New York, 2015

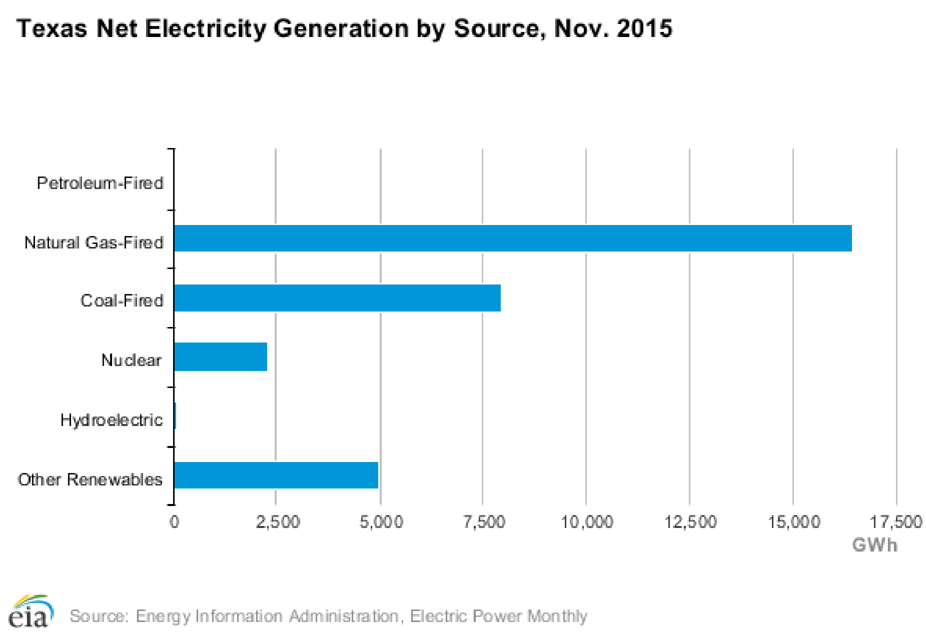


Figure 4. Electricity sources for Texas, 2015

Model Scenarios

Given the variables previously defined, i.e., Texas versus New York, energy demand, wind resource, and existing generators/resource mix, three scenarios were defined and tested under the economic dispatch model to address the questions about dispatched energy sources, costs, and the potential of wind power to help meet the Clean Power Plan. The first dispatch scenario uses the unadjusted demand accounting for reductions only from existing wind and hydropower facilities. The purpose of the first dispatch is to serve as a current standard from which to compare the second and third scenarios. The second dispatch scenario uses the same unadjusted demand but implements a mass based carbon cap. The carbon cap is modeled in GAMS as a percentage of the total carbon emissions from the first scenario, corresponding to the same percentage reduction from historic 2012 emissions to the 2020-2030 goal determined by the EPA (Environmental Protection Agency, n.d.b). This translates to a 10% reduction of carbon emissions for New York (down from 199,744 tons/mo) and 21% reduction for Texas (down from 944,271 tons/mo). The third scenario utilizes the adjusted demand that includes new wind installations and also implements the carbon constraint. The goal of modeling these cases is to determine the overall cost of implementing the Clean Power Plan using only existing facilities and then including new wind development, and also to determine the efficacy of these five potential wind farms at meeting the carbon reduction goals. These three scenarios are summarized in Table 3 below.

Table 3. Economic Dispatch Scenarios

Scenario	***Demand***	***CPP Mass Constraints***
1 – Regular dispatch	Unadjusted	No
2 – CPP Current Technology	Unadjusted	Yes
3 – CPP New Technology	Adjusted	Yes

Calculations and Metrics

The metrics used to assess the model results focused primarily on changes in the resource mix between the three scenarios and economic parameters. Since the Clean Power Plan previously determined the carbon caps, they were not significantly considered in this study. The dispatch results for each scenario were separated by each type of plant and averaged throughout the month to find the resource mix for the month of July. Any significant changes in the distribution of sources were recorded. Total cost data was also acquired from the GAMS model. The total costs for the third scenarios that included new wind installations were adjusted to account for the added cost of wind installations. The installed capacity for each State was multiplied by $1,710/kW (U.S. Department of Energy, 2014). to estimate the total installed cost of all the hypothetical turbines in the State across the five sites. The LCOE was calculated for the turbines in each State. The States were finally judged on the ability to shift from coal to natural gas, the implementation of new wind sites to achieve a larger proportion of energy from wind, and the total costs of meeting the carbon cap with and without the new wind installations.

Assumptions

Several assumptions were made throughout the design process as a result of the complexity and scale of the State-wide electricity markets. First, existing wind and hydropower production values were averaged throughout the month of July to arrive at a constant value for each day. While this does not reflect the reality of the variation of renewable energy sources, the contributions are typically small enough to not greatly affect the overall dispatch. Second, only existing gas, hydropower, wind, coal, and nuclear facilities were considered in the resource mix. Other smaller sources like oil, biomass, and solar were excluded from the dispatch. Third, each power plant in the dispatch was assumed to have reasonable values for fuel carbon content, start-up costs, and operational costs (Table 2). Fourth, the demand data was taken from 2015 and was not inflated to represent possible increases in demand during the 2020-2030 time period by which the Clean Power Plan will be active. The same is true for the wind data and fuel prices, which cannot be accurately predicted so far in advance. Finally, the financial analysis did not account for wind energy incentives like the production tax credit or other state incentives, though it can be expected that these can have a significant impact on lowering the LCOE of wind projects.

Chapter 4

Results and Discussion

New York

Figures 5 and 6 show the average dispatch results using 2012 generator data and demand data from 2015, unadjusted for new wind installations. As predicted from EIA data in Figure 3, nuclear and gas make up the greatest portion of the electricity generation. From the dispatch, an equal amount of electricity comes from hydropower and coal, whereas the actual generation from Figure 3 shows a significantly higher contribution from hydropower than coal. Since hydropower generation data was referenced and fixed over the course of the July, the more relevant difference between the real data and the dispatch results is the higher use of natural gas in the real data. One likely explanation for the greater use of natural gas than the optimal, lowest-cost dispatch scenario is the cap-and-trade program that was created in 2005 involving nine States in the Northeast including New York. The Regional Greenhouse Gas Initiative (Center for Climate and Energy Solutions, n.d.) is the first mandatory cap-and-trade program established in the United States and aims to reduce carbon emissions by 45% in the electricity sector by 2020 based on 2005 levels. The program has led to a shift from petroleum and coal to natural gas reliance, and could explain the deviation of the dispatch data from the real data.

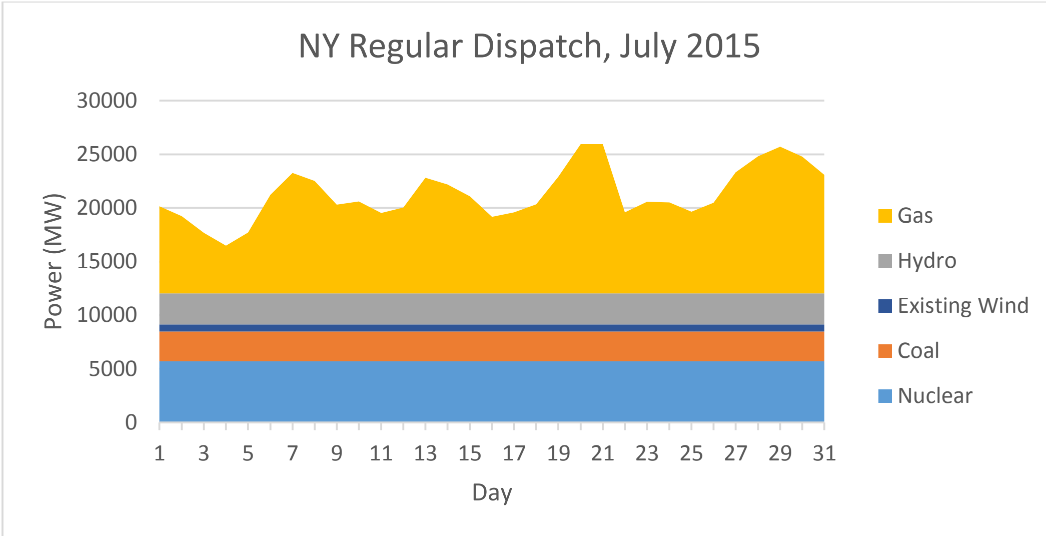


Figure 5. Scenario 1: NY Regular Dispatch

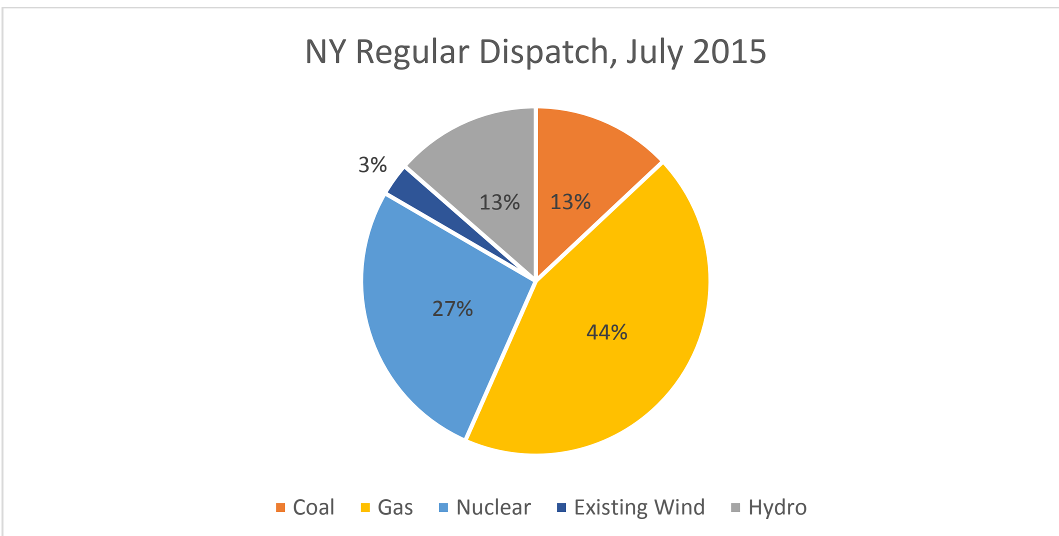


Figure 6. Scenario 1: NY Energy Mix for Regular Dispatch

The differences in the economic dispatch that includes the Clean Power Plan carbon constraint can be seen by comparing the results from Figures 4 and 5 with the results from the 10% emissions reduction for New York shown in Figures 7 and 8. As a base load electricity resource, nuclear facilities saw no changes in output. Coal production dropped by 5% in favor of an increase in gas production.

Interestingly, coal remained relatively constant at 1,500MW until the total demand approached 25,000MW around days 19 and 27, at which point the power from coal increased slightly to shoulder the unusually high demand. Further, the electricity produced from coal likely did not decrease after the periods of high demand because of prohibitive start-up costs.

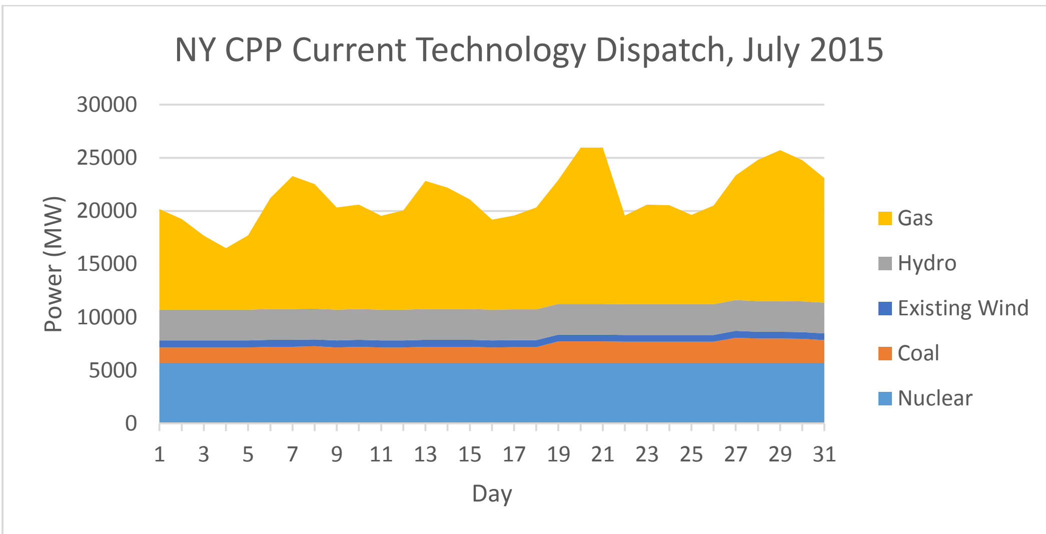


Figure 7. Scenario 2: NY Current Technology Carbon Cap Dispatch

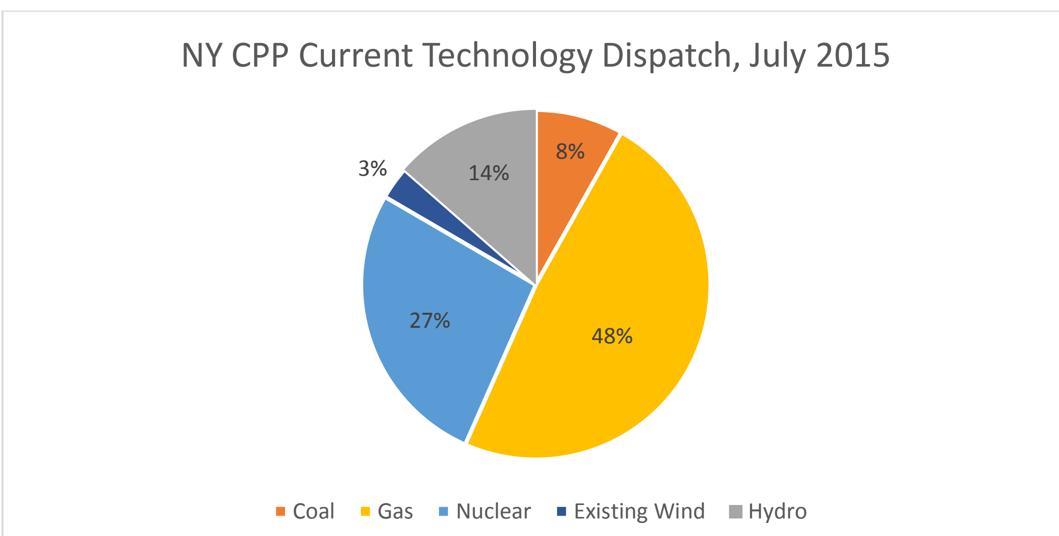


Figure 8. Scenario 2: NY Energy Mix for Current Technology Carbon Cap Dispatch

Figures 9 and 10 show the dispatch results for the new wind installations with the carbon cap. The five sites selected are shown to contribute to 2% of the electricity demand. Interestingly, the coal fraction increases by 5% from the second to the third scenarios, while gas use is reduced by 8%. Nuclear power remains at a constant 28%. The explanation for the increase in coal use and the decrease in gas, despite higher emissions from coal is that the new wind installations awarded carbon emissions to the other generators. Thus, New York can afford to operate less expensive and more polluting coal plants since it is meeting more of its demand from a zero emission source.

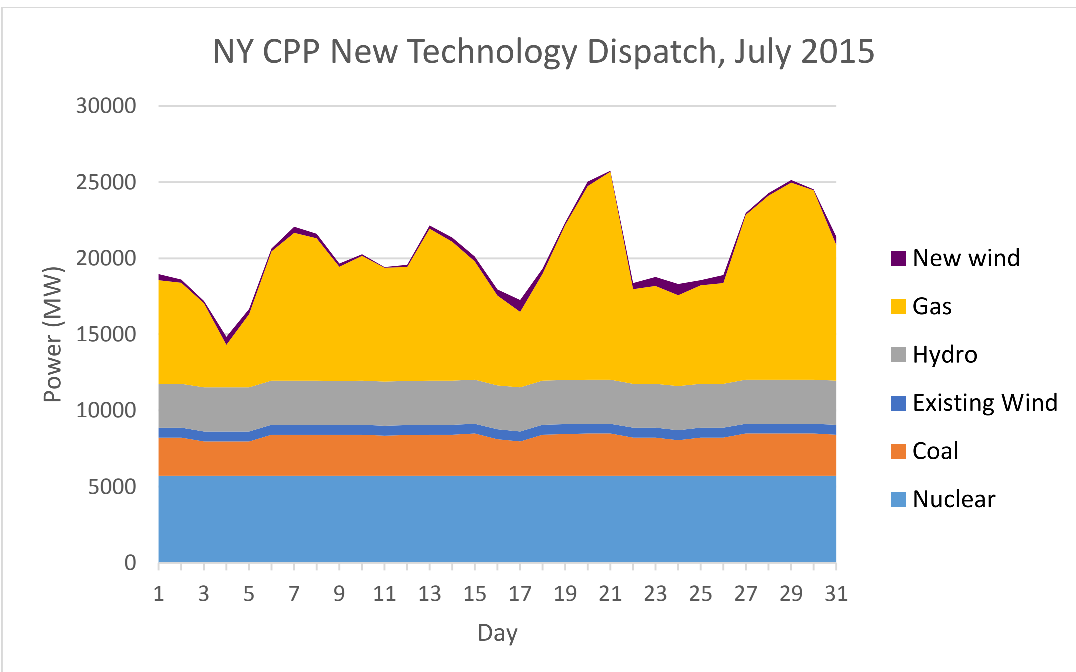


Figure 9. Scenario 3: NY New Technology Carbon Cap Dispatch

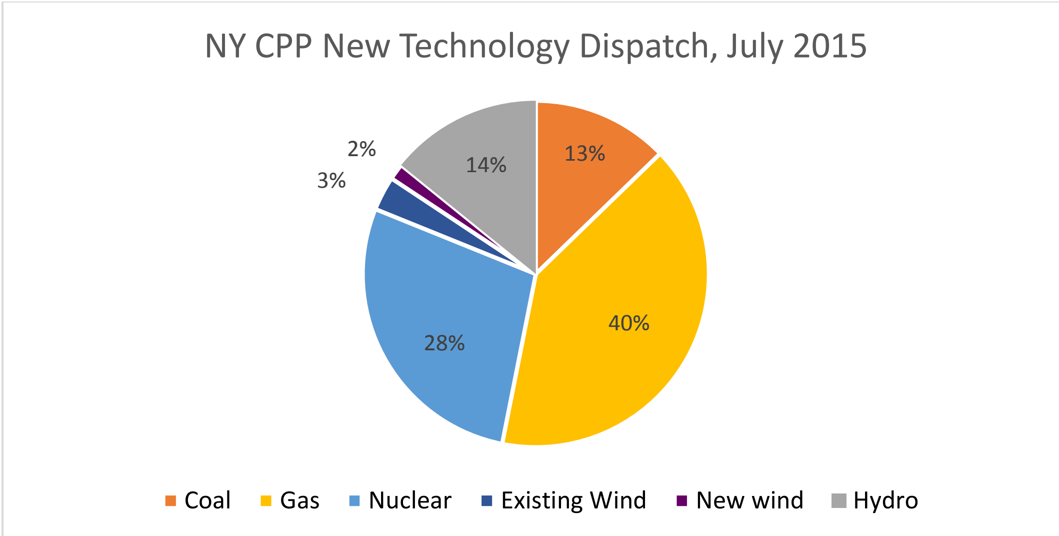


Figure 10. Scenario 3: NY Energy Mix for New Technology Carbon Cap Dispatch

Texas

Figures 11 and 12 show the economic dispatch results for current technology and no carbon constraints. Consistent with the EIA data from Figure 4, hydropower makes up less than a percent of the resource mix and nuclear plays a small role with 10% contribution. Wind power, while only meeting 8% of the State's electricity demand, is still much more prevalent in Texas than in New York, especially when considering that Texas demands around twice as much power for the month of July than New York. Inconsistent with the EIA data are the proportions of coal and gas that satisfy the State's electricity demands. Similar to New York, Texas derives significantly more power from natural gas in actuality than the dispatch results indicate. While similar cap and trade programs like the Regional Greenhouse Gas Initiative in New York could explain part of this difference, the gap is so significant that other factors are likely to contribute. Investigating natural gas prices over 2015 reveals that a drop of around $0.50/mmBTU from July (month of dispatch) to November (month of real data) (InvestmentMine, n.d.). With natural gas prices continuing to cascade beyond November 2015, an increase in the use of cheaper natural gas in November than in July could help to explain the differences between the dispatch data and the real data. According to EIA data, Texas also utilizes about twice the amount of energy from "other renewables" than from nuclear facilities, while the dispatch data indicates that wind and nuclear are about equal. This could be because a more significant portion of demand in Texas is met by other renewable sources like biomass and solar facilities, which were not included in the dispatch.

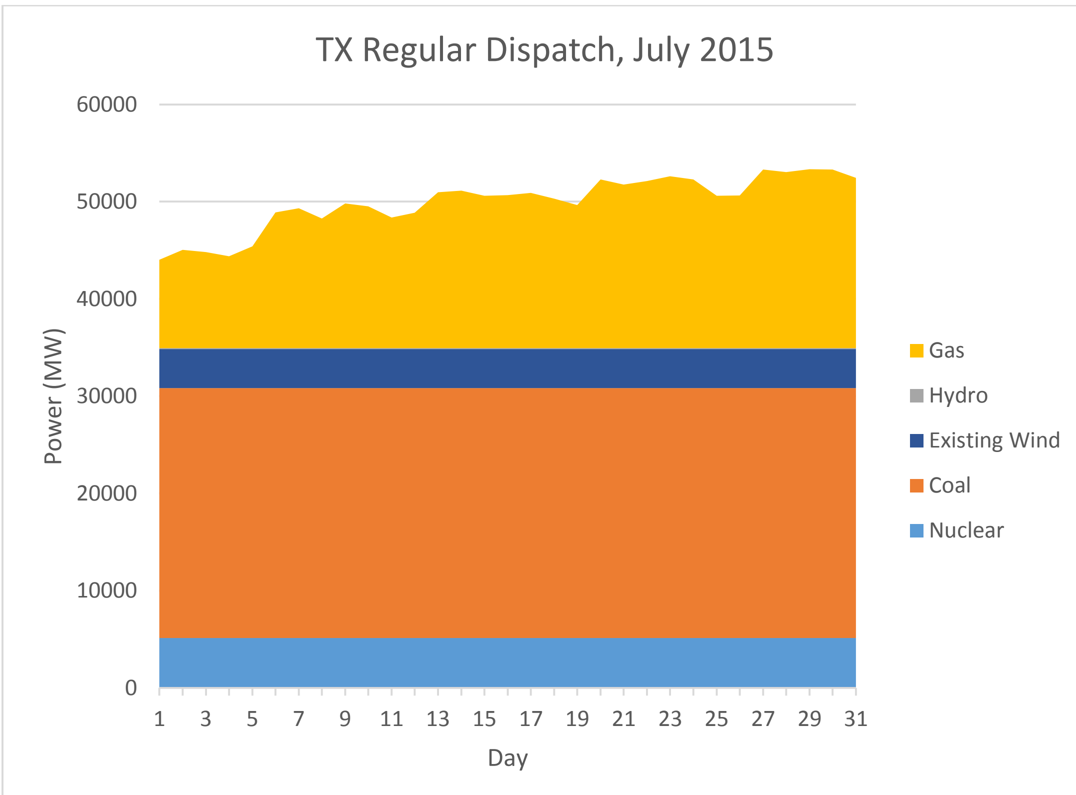


Figure 11. Scenario 1: TX Regular Dispatch

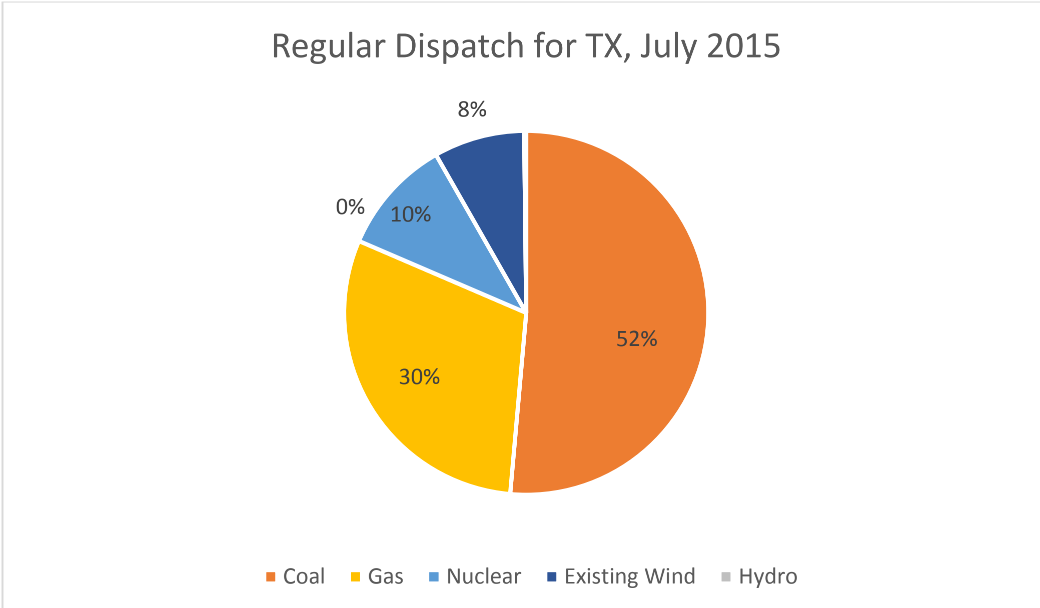


Figure 12. Scenario 1: TX Energy Mix for Regular Dispatch

Figures 13 and 14 depict the consequence of the 20% carbon reduction for Texas under the Clean Power Plan. The power from coal decreases by 19% while the gas contribution increases by 19% to reflect a dispatch that more closely resembles the EIA's data. However, since the real data indicates that Texas already uses less coal and more natural gas than predicted, the changes seen under the Clean Power Plan will likely be less significant than those seen under the model scenarios. Such is the case with New York, which uses more natural gas than coal, and so the shift under the carbon constraint is not as substantial.

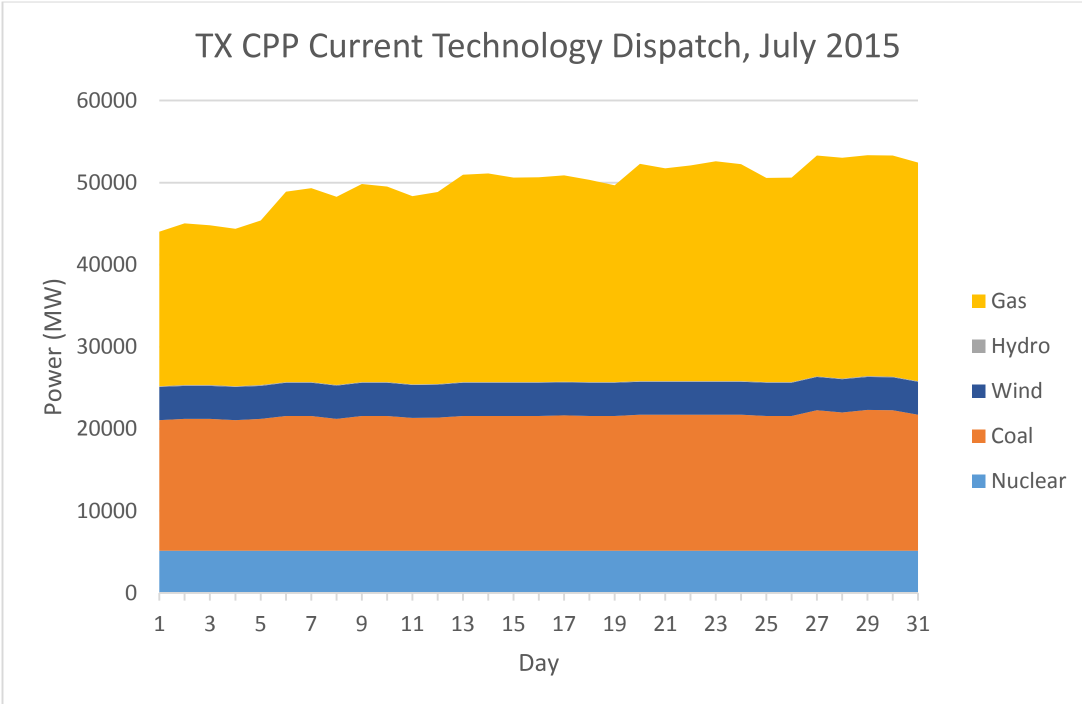


Figure 13. Scenario 2: TX Current Technology Carbon Cap Dispatch

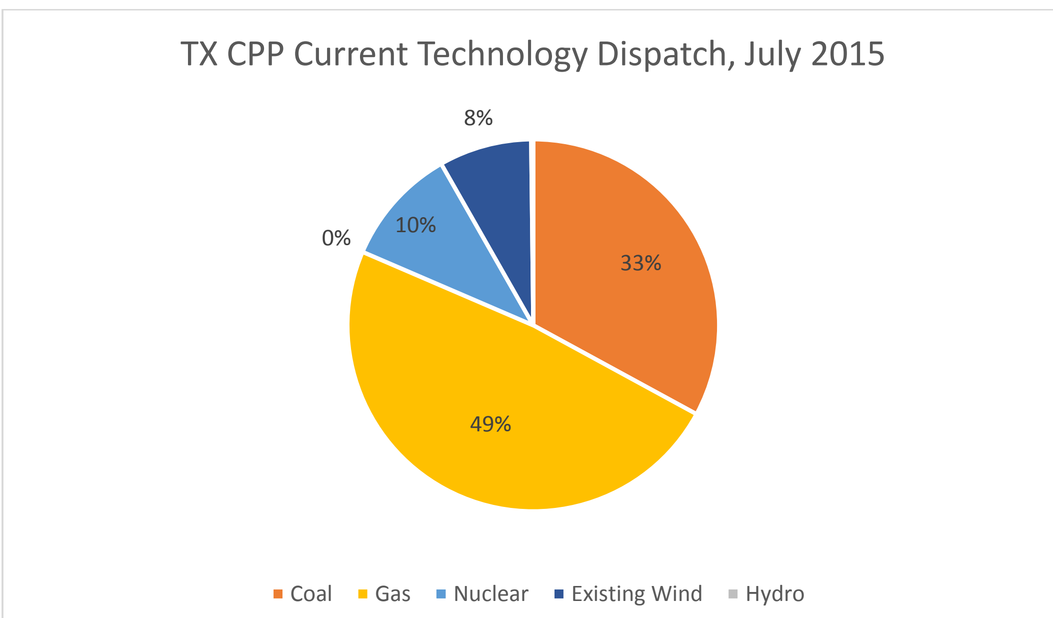


Figure 14. Scenario 2: TX Energy Mix for Current Technology Carbon Cap Dispatch

The third scenario final dispatch for Texas is shown in Figures 15 and 16. The inclusion of new wind only accounts for 1% of the new dispatch, although this is reasonable given that the total power from new wind for Texas is about equal to that for New York yet the demand is twice as great. Coal increases slightly from the second to third scenarios, though gas decreases more significantly, indicating that the new wind contribution is suppressing natural gas use more than it is stimulating coal, as was also seen in New York.

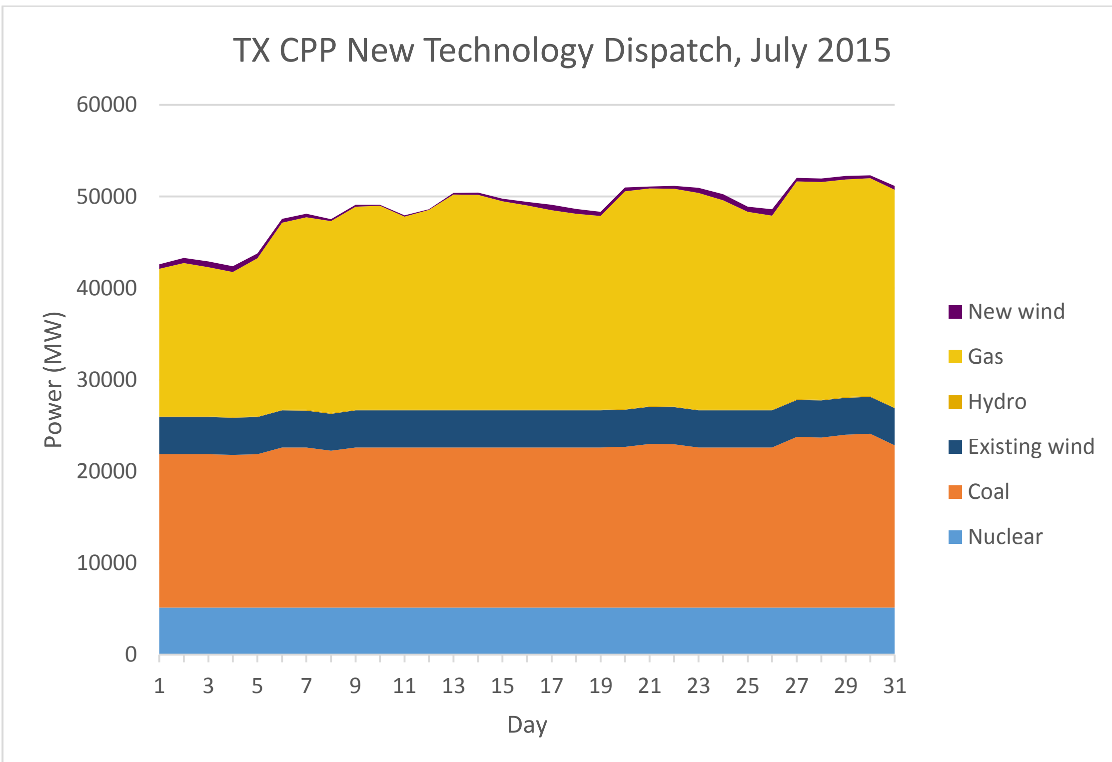


Figure 15. Scenario 3: TX New Technology Carbon Cap Dispatch

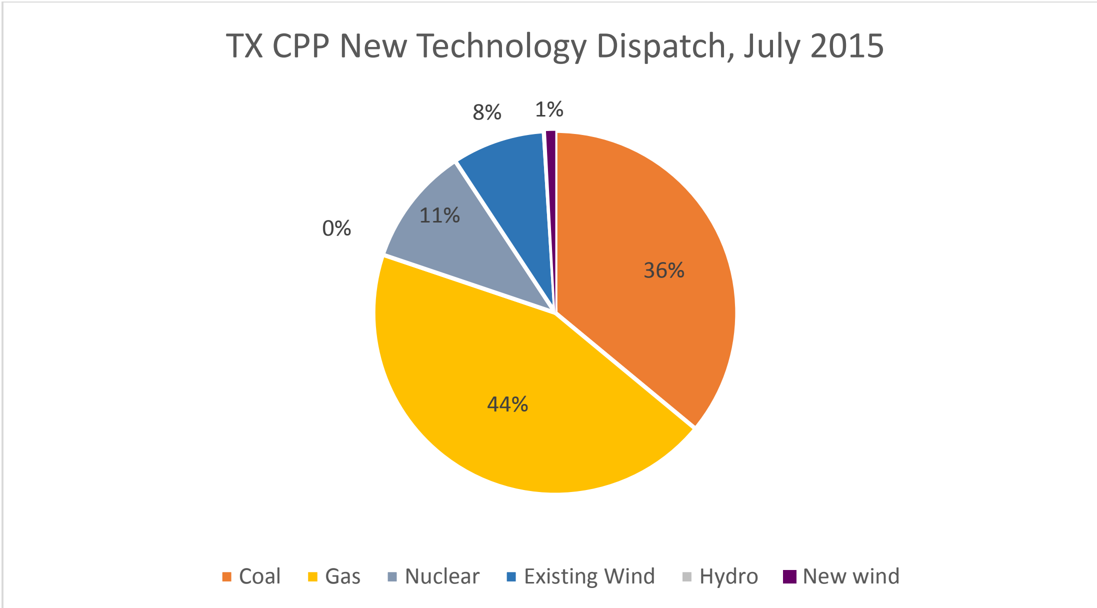


Figure 16. Scenario 3: TX Energy Mix for New Technology Carbon Cap Dispatch

Scenario Assessment

Given the results, the States can be assessed under the three metrics previously established. The first metric established by the Clean Power Plan is the overall switch from natural gas coal, for which Texas was more successful. The 5% coal use reduction for New York under the cap only returned to around the original percentage when implementing wind energy. On the other hand, the 19% reduction for Texas under the cap increased by only 2% when implementing new wind. Texas' success at switching from coal to gas, and retaining this proportion while developing more wind is likely the result of its original higher reliance on coal than New York. The second metric relates to the natural resource capacity in the two States, for which Texas also seems to exceed New York. While New York's new wind farms met 2% of the total demand on top of the original 3% demand met by existing wind facilities, Texas met 1% with new wind production in addition to the existing 8%. Texas' 8% demand met by wind power translates to an even greater total installed capacity because of the State's particularly high demand. The higher prior investment could be explained by Texas' exceptional wind resource and the renewable portfolio standard established in 2008 by the State government. The policy set a goal of producing 10,000 MW of renewable energy by 2025, a feat that has already been achieved largely through wind power (Database of State Incentives for Renewables and Efficiency, 2015). The final metric to consider is the cost of switching to natural gas and to wind power for each State. In terms of the costs to switch from coal to natural gas, New York sees a much lower cost than Texas, with a 27% difference between the States in terms of the change in total costs between scenarios one and two. This is reasonable since Texas has a higher proportion of coal plants than New York, so greater switching is required and the cost to do so will be higher. New York and Texas can expect to spend almost $2.05 billion in capital costs for the 1200 MW wind installations. As such, the levelized cost of energy for the wind turbines provides a more accurate assessment of the economics of these investments. The levelized cost of energy for both Texas and New York was calculated to be around $0.06/kWh, assuming a 20 year lifetime, 8% interest rate, and installed cost of $1710/kW. It is expected that any governmental incentives for wind power would further reduce the LCOE as would accelerated depreciation.

Trends

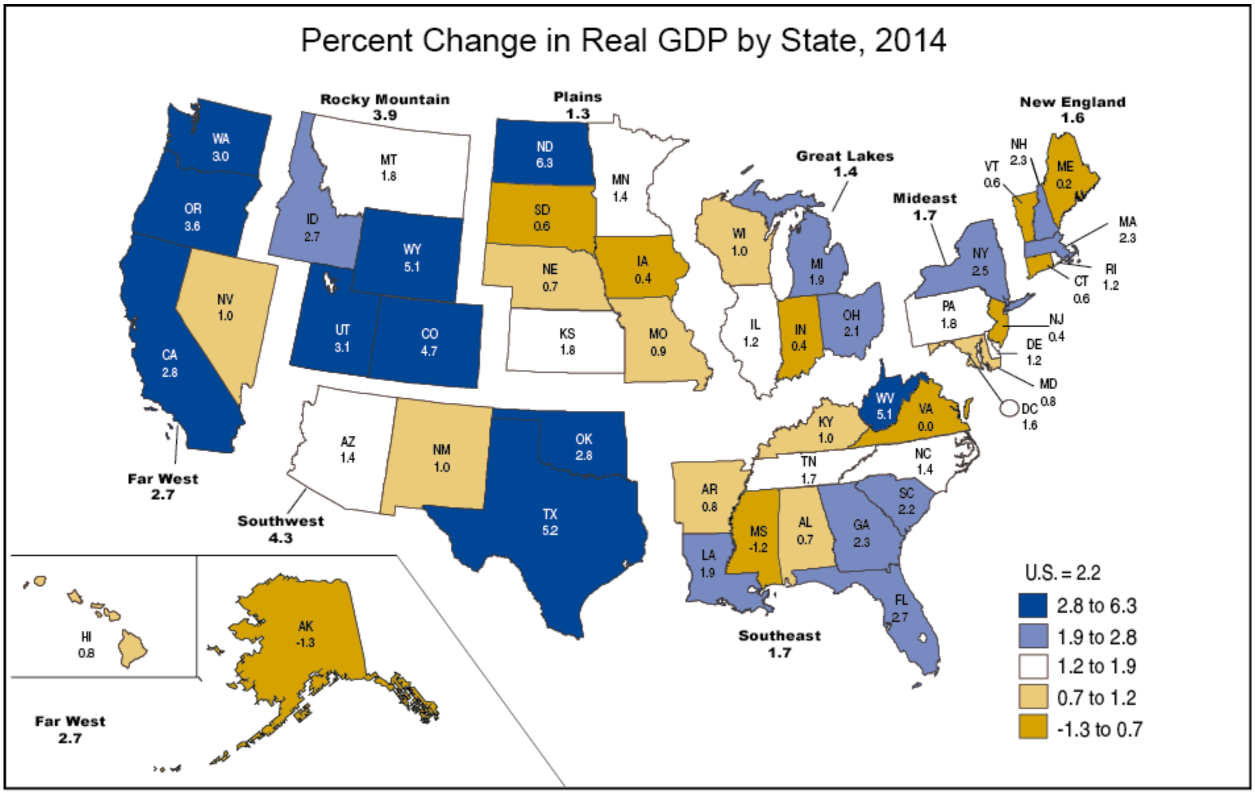
From the analysis of the results, four overarching themes regarding the relationship between carbon restriction measures and economic dispatch can be deduced. First, incentive programs like cap and trade are largely successful at shifting fuels from coal to natural gas, as seen with the Regional Greenhouse Gas Initiative in New York and the results of the Clean Power Plan model under the second scenario. Intuitively, falling prices of natural gas will also support this trend. Second, the change from coal to natural gas is greatest in States that already rely more heavily on coal than natural gas, and in States that do not pursue non-emitting renewables in response to the cap. For States that already use more natural gas than coal, a percentage based carbon reduction will naturally be lower, and so the magnitude of the change from coal to natural gas required to achieve the reduction will be lower. This creates a cycle where a resource mix high in natural gas makes meeting carbon constraints easier as long as there are still improvements to be made, i.e. fuel switching, clean coal technology, renewable investment. Under the carbon constraint, coal dispatch resembles more of a shoulder load than a base load operation, where the facilities are used conservatively except in times of higher demand. However, because the startup costs and time for coal plants are substantial, coal will never become a peaking plant. Third, the development of clean energy sources in conjunction with a carbon cap could actually increase coal production, although this might not stay true if natural gas prices continue to decline. Finally, it is seen that new wind development, while adding capital costs, has a comparatively low break-even price when installed in regions of excellent wind resource. The addition of new natural gas plants or coal plants was not considered in this study.

Chapter 5

Conclusions

In general, studies on the consequences of the Clean Power Plan have all pointed to a few common trends. In particular, fuel switching, renewable investment, and full BSER considerations will be the most economical ways for States to meet the demands of the new legislation. The economic dispatch model used in this study indicated similar findings. More specifically, implementing a carbon cap will result in the transition from natural gas to coal resources, and this shift will be greatest when no other clean sources are developed. Along with this, coal dispatch will be somewhat repressed except during times of peak demand, at which point coal power will behave less like a base load source as it fluctuates to meet higher demand. As coal fades and natural gas assumes a larger contribution under a percent-based carbon restriction, States that already rely heavily on natural gas will have lower standards to meet than States with the same demand but higher coal use, at least until a point when coal, oil, or other more polluting facilities are either eliminated or updated with carbon mitigating technologies. In this way, States like New York that already use a lot of natural gas will have lower carbon constraints that require less changes in order to meet them.

While not specifically tested in this model, there are other factors that can be informed by the results in regard to the future of the Clean Power Plan. Perhaps most pertinent to the Clean Power Plan is the mass versus rate based decision. As discussed, the issue stems from concerns of stunting economic growth. Figure 17 (U.S. Department of Commerce, 2014) shows the change in GDP by state in 2014. Texas shows a growth of almost twice the national average, while New York lies only slightly above the average. With this information, it seems likely that Texas would opt for a rate-based policy, while New York would be more inclined to pursue a mass-based reduction. Because States may only trade credits with States under the same option, it is also likely that the faster growing States like Texas and California will end up trading with each other under a rate-based scenario, while slower growing States like New York and Florida will trade under a mass-based policy.



U.S. Bureau of Economic Analysis

Figure 17. Scenario 3: TX Energy Mix for New Technology Carbon Cap Dispatch

Future energy demand increases are often indicated by economic growth rate, and these State-by-State differences are captured by the mass and rate based options under the Clean Power Plan as discussed. An additional decision faced by the States in regard to increasing demand within the next decade is the choice to build new natural gas plants or new wind farms. While this model did not provide the option for new generation in response to higher demand, predictions from the EIA suggest that natural gas and renewables, in particular wind power, will rise to meet increasing demand (U.S. Department of energy, 2015d). This trend is justified by carbon reduction measures like the Clean Power Plan, and also by persistently low natural gas prices. Since low natural gas prices tend to lower the renewable energy additions, then persistently low natural gas prices would seem to repress renewable energy development. However, because of carbon restrictions, the consequential phasing out of coal, and a long term increase in demand, natural gas and renewables will likely work together to address economic growth.

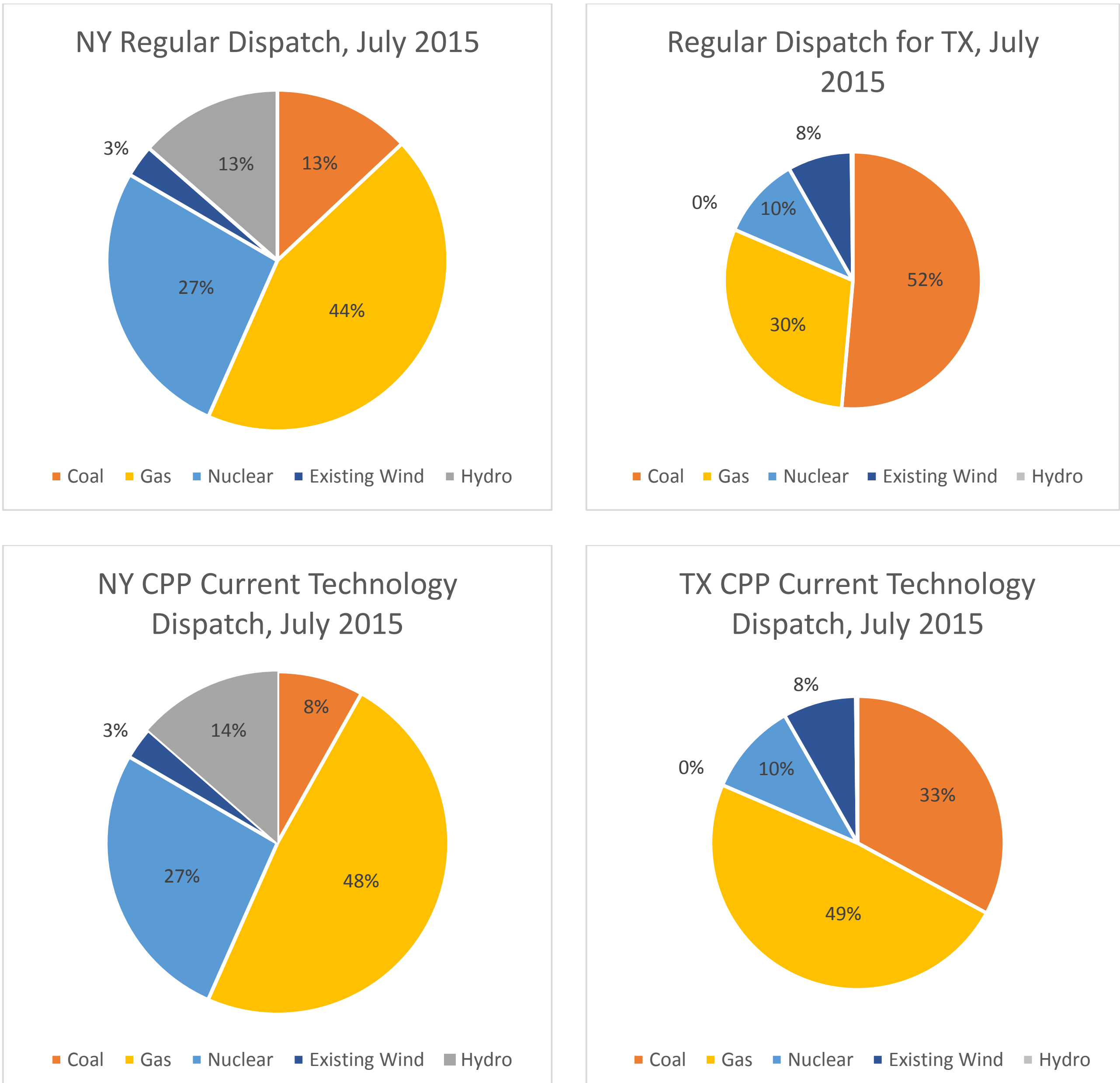
The difference between implementing the Clean Power Plan in regulated and deregulated markets is another consideration for the States that was not covered by the model. While Texas and New York are both involved in competitive electricity markets, other States under vertically integrated markets will likely face simpler planning criteria than states under deregulated markets. In particular, regulated markets might witness higher costs as a result of RTOs and ISOs needing to enforce carbon standards among groups of generating companies. Further, issues arising from transmission limitations could require new infrastructure or higher electricity costs resulting from dispatch of more expensive generators. In general, the Clean Power Plan will incur extra planning and costs from the deregulated markets. Similarly, a new influx of non-dispatchable, renewable energy driven by the carbon caps could introduce fluctuations in the electricity grid that need to be regulated by ancillary services. Building new generators that can quickly respond to changes in power could cost extra money for all States, particularly those that choose to invest heavily in renewable energy.

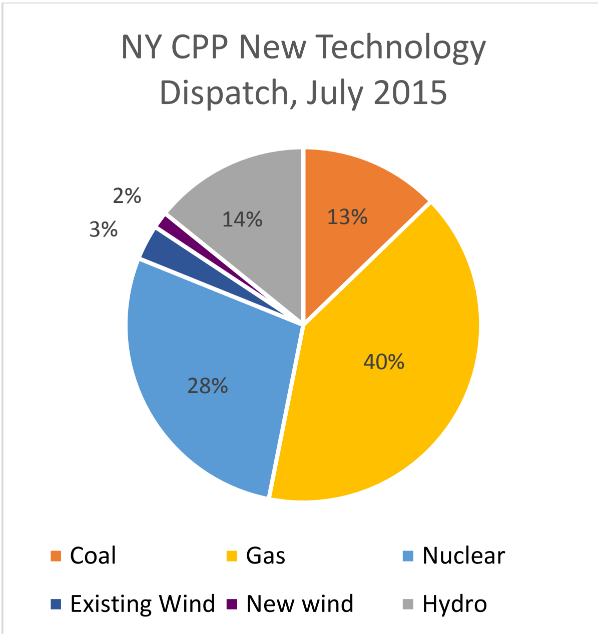
In terms of the incentive to install wind energy in response to the carbon legislation, a variety of factors are involved. The strength of the wind resource is the most obvious factor, although as was also discovered, high capital costs do not translate directly to an expensive resource. While the installation of the hypothetical wind farms in Texas and New York resulted in exceptional increases in total costs immediately following investment, the minimal operational costs and nonexistent fuel costs gave a low LCOE that was aided by the selection of excellent wind sites. The contribution of new wind to the total energy demand for each State was very low, although its effects on the increased dispatch of coal were significant. While it seems counterintuitive, States that have strong coal industries should perhaps consider promoting renewable energy to mitigate the emissions from coal plants and allow these existing plants to continue operating. In favor of this suggestion is evidence that the LCOE for good wind resource development is promising. It should also be noted that the other BSER building blocks outlined by the EPA, including demand side reductions and energy efficiency measures would also help to reduce the strain of the coal industry under the Clean Power Plan. As such, States dominated by coal will likely consider renewables and efficiency measures, while States dominated by natural gas that are not facing such stringent reduction targets, will likely promote fuel switching. All States should consider the costs of upgrading facilities to reduce carbon emissions as a first measure.

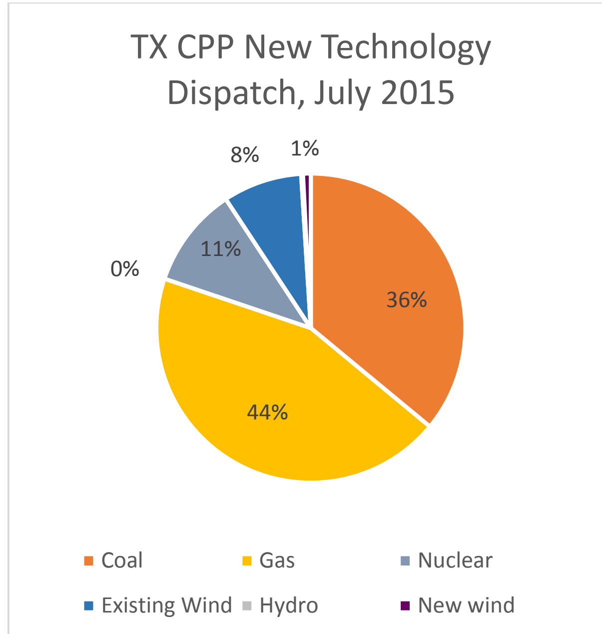
Overall, the Clean Power Plan successfully meets the goals outlined by President Obama to reduce greenhouse gas emissions through reasonable measures . The flexibility for the States to determine their own course of action for meeting the carbon standards is the strongest aspect of the plan. The policy succeeds at achieving carbon reductions, favoring the development of natural gas, and mandating an alternative cap and trade system for States that do not comply. On the other hand, the Clean Power Plan could do more to incentivize wind development. While the natural wind resources and LCOE estimations do favor wind development, it seems that demand side reductions and fuel switching are going to be the first courses of action for most States because of the ease of working with existing infrastructure and the high capital costs of installing wind turbines. However, it is necessary to realize that the Clean Power Plan aims to achieve its carbon reduction goal within fourteen years, which a long-term solution. As such, the Clean Power Plan seems appropriate as the first major piece of carbon legislation in the United States. As carbon reductions are achieved over time, however, opportunities for fuel switching, demand side reductions, and energy efficiency increases will lessen. If carbon emissions are to be curtailed in the future, renewable energy will take on a more substantial role in achieving this. Beyond 2030, legislation to reduce greenhouse gas emissions will need to be paired with long-term incentives for wind power like a production tax credit. While in the present, natural gas development seems to be the most feasible solution to the Clean Power Plan standards, renewable resources will eventually need to take the forefront if carbon reductions are to be a long-term goal in the United States.

Appendix

Figure A.1. Dispatch Results for Both States Under All Scenarios




NY CPP New Technology Dispatch, July 2015
2%
3%
14%
13%
40%
28%
Coal
Gas
Nuclear
Existing Wind
New wind
Hydro


TX CPP New Technology Dispatch, July 2015
8%
1%
0%
11%
36%
44%
Coal
Gas
Nuclear
Existing Wind
Hydro
New wind

REFERENCES

Blumsack, S. (2016). Economics of Electricity Generation [PowerPoint slides].

Center for Climate and Energy Solutions. (n.d.). *Regional Greenhouse Gas Initiative*. Retrieved from http://www.c2es.org/us-states-regions/regional-climate-initiatives/rggi.

Database of State Incentives for Renewables and Efficiency. (2015). *Renewable Generation Requirement*. Retrieved from http://programs.dsireusa.org/system/program/detail/182.

Environmental Protection Agency. (n.d.a). *Clean Power Plan – Technical Summary for States*. Retrieved from http://www3.epa.gov/airquality/cpptoolbox/technical-summary-for-states.pdf.

Environmental Protection Agency. (n.d.b). *Ten Things to Know About EPA's Clean Power Plan*. Retrieved from https://cleanpowerplanmaps.epa.gov/cpp/.

Environmental Protection Agency. (2015a). *Renewable Energy in the Clean Power Plan*. Retrieved from https://www.epa.gov/sites/production/files/2015-11/documents/fs-cpp-renewable-energy.pdf.

Environmental Protection Agency. (2015b). *eGrid*. Retrieved from https://www.epa.gov/energy/egrid.

ERCOT. (n.d.). *Hourly Load Data Archives*. Retrieved from http://www.ercot.com/gridinfo/load/load_hist/index.html.

Holden, G.. (2016). *2016 holds flurry of state planning, legal drama for Clean Power Plan*. E&E Publishing. Retrieved from http://www.eenews.net/stories/1060030047.

Hopkins, J. (2015). *Modeling EPA's Clean Power Plan: Insights for Cost-Effective Implementation* Center for Climate and Energy Solutions. Retrieved from: http://www.c2es.org/publications/modeling-epas-clean-power-plan-insights-cost-effective-implementation.

InvestmentMine. (n.d.) *1 Year Natural Gas Prices and Price Charts*. Retrieved from: http://www.infomine.com/investment/metal-prices/natural-gas/1-year/.

King, J., Clifton, A., & Hodge, B. (2014). *Validation of the Power Output for the WIND Toolkit*. National Renewable Energy Laboratory. Retrieved from http://www.nrel.gov/docs/fy14osti/61714.pdf.

NYISO. (n.d.) *Real Time Actual Load*. Retrieved from http://mis.nyiso.com/public/P-58Blist.htm.

Spees, K. (2016). Clean Power Plan in Texas [PowerPoint slides]. Retrieved from http://www.brattle.com/system/publications/pdfs/000/005/272/original/2016-02-09_-_Spees_Texas_CPP_Renewables.pdf?14567.

Stohr, G., & Dlouhy, J. (2016). *Obama's Clean-Power Plan Put on Hold by U.S. Supreme Court*. Bloomberg. Retrieved from http://www.bloomberg.com/politics/articles/2016-02-09/obama-s-clean-power-plan-put-on-hold-by-u-s-supreme-court.

The Texas Office of Public Utility Counsel. (n.d.). *Electric Reliability Council of Texas*. Retrieved from http://www.opuc.texas.gov/ercot.html.

The White House. (2013). *Remarks by the President in the State of the Union Address*. Washington, DC: Office of the Press Secretary. Retrieved from: https://www.whitehouse.gov/the-press-office/2013/02/12/remarks-president-state-union-address.

The White House. (2015). *U.S.-China Joint Presidential Statement on Climate Change*. Washington, DC: Office of the Press Secretary. Retrieved from: https://www.whitehouse.gov/the-press-office/2015/09/25/us-china-joint-presidential-statement-climate-change.

The White House. (n.d.). *Climate Change and President Obama's Action Plan*. Retrieved from https://www.whitehouse.gov/climate-change.

U.S. Department of Commerce, Bureau of Economic Analysis. (2014). *Broad Growth Across States in 2014.* Retrieved from http://www.bea.gov/newsreleases/regional/gdp_state/gsp_newsrelease.htm.

U.S. Department of Energy. (2014). *2014 Wind Technologies Market Report*. Retrieved from http://energy.gov/sites/prod/files/2015/08/f25/2014-Wind-Technologies-Market-Report-8.7.pdf.

U.S. Department of Energy, Energy Information Administration. (2015a). *Analysis of the Impacts of the Clean Power Plan*. Retrieved from https://www.eia.gov/analysis/requests/powerplants/cleanplan/.

U.S. Department of Energy, Energy Information Administration. (2015b). *Electric Power Monthly with Data for January 2015*. Retrieved from http://www.eia.gov/electricity/monthly/current_year/march2015.pdf.

U.S. Department of Energy, Energy Information Administration. (2015c). *Energy-Related Carbon Dioxide Emissions at the State Level, 2000-2013*. Retrieved from http://www.eia.gov/environment/emissions/state/analysis/.

U.S. Department of Energy, Energy Information Administration. (2015d). *Natural gas, renewables projected to provide larger shares of electricity generation*. Retrieved from https://www.eia.gov/todayinenergy/detail.cfm?id=21072.

U.S. Department of Energy, Energy Information Administration. (2015e). *New York Electricity Profile*. Retrieved from http://www.eia.gov/electricity/state/NewYork/.

U.S. Department of Energy, Energy Information Administration. (2015f). *Texas Electricity Profile*. Retrieved from http://www.eia.gov/electricity/state/Texas/.

U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, National Renewable Energy Laboratory. (2015a). *Wind Integration National Dataset Toolkit*. Retrieved from http://www.nrel.gov/electricity/transmission/wind_toolkit.html.

ACADEMIC VITA

Evelyn Bateman
ewb5207@psu.edu

Education: The Pennsylvania State University
Major: Energy Engineering
Honors: Energy Engineering

Thesis Title: Impacts of the Clean Power Plan on the Resource Mix and Renewable Energy Development

Thesis Supervisor: Dr. Susan Stewart

Work Experience

January 2016 – May 2016
Teaching Assistant for EGEE 438 – Wind and Hydropower Energy Conversion
The Pennsylvania State University
Dr. Susan Stewart

August 2016 – December 2015
Teaching Assistant for EME 303 – Fluid Mechanics
The Pennsylvania State University
Dr. Derek Elsworth

August 2015 – December 2015
DAAD RISE Intern
Friedrich-Alexander Universität Erlangen-Nürnberg
Dipl.-Ing Sebastian Luther

Grants Received: 2016 Tuition Waiver Scholarship for Master's Program at Technical University of Denmark; 2014, 2015 Schreyer Ambassador Travel Grants; Travel Grants from the Department of Energy and Mineral Engineering

Awards: 2014 President Sparks Award; 2013 President's Freshman Award

Community Service Involvement: 2013-2015 Community Service Chairperson for Earth and Mineral Sciences Special Living Option

International Education: 2016-2018 Master's degree in Wind Energy at the Technical University of Denmark; 2014 Summer Semester Rheinische Friedrich-Wilhelms Universität Bonn