IMPACT ANALYSIS OF THE CLEAN POWER PLAN RULE ON THE STATE OF OKLAHOMA

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"To strive, to seek, to find, and not to yield".

- Lord Alfred Tennyson (Ulysses)

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Abstract: This research analyzes the potential economic, environmental, and social impacts of the Obama Administration's Clean Power Plan (CPP) rule on the state of Oklahoma. Climate change is a global concern, and the CPP was the Obama Administration's flagship climate policy intended to address the U.S. contribution to carbon mitigation. The goal of the CPP is to cut U.S. carbon pollution generated by the electric power sector by 870 million tons, or 32% below 2005 levels, by 2030. Oklahoma is responsible for reducing its CO_2 emissions by 23.41% below the 2005 level under the proposed CPP. This research creates and evaluates the efficacy and costs of multiple generation scenarios to meet the state obligation. The methodologies used are: Linear Programming, Mixed Integer Linear Programming, and Cost-Benefit Analysis. Scientific data from the Environmental Protection Agency (EPA), Energy Information Administration (EIA), Southwest Power Pool (SPP), and Oklahoma's utilities provided the fundamental information needed to create and analyze the energy generation scenarios. The scenarios evaluated are: the Regional Haze Rule and Mercury Air Toxics Standards (RM) scenario, Beyond Coal (BC) scenario, Carbon Tax (CT) scenario and Generic Industry (GI) Scenario. The results of the research show that Oklahoma will meet its CPP emissions reduction target under the RM scenario with no additional cost incurred by the state. The research further demonstrates that phasing out coal generation by 2030 and replacing that capacity with wind and natural gas generation, as modeled in the BC scenario, is possible with no increase in electricity cost. This scenario would accrue approximately $4 billion more in net benefits when compared to the RM scenario. The BC and the CT scenarios are more resilient to water shortages and climate change that negatively affect the operation of thermal EGU. This scenario is less sensitive to environmental regulations and to possible future carbon taxes than the RM scenario. Based on the findings of this research, utilities and state regulators should consider supporting the federal CPP rule and the adoption of an energy generation portfolio similar to the BC scenario.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION ... 1
 1.1 Purpose ... 3
 1.2 Significance of the Study ... 5

II. BACKGROUND AND LITERATURE REVIEW ... 7
 2.1 Fossil Fuel and Climate Change ... 7
 2.2 State of Knowledge ... 10
 2.3 Climate Change Policy Response ... 11
  2.3.1 Clean Power Plan ... 16
 2.4 Fossil Fuel, Public Health, and the Environment ... 21
 2.5 Oklahoma Coal Power Plants ... 24
 2.6 Coal Pollution Regulatory Response ... 26
  2.6.1 Regional Haze Rule ... 28
  2.6.2 Mercury and Air Toxics Standards ... 29
  2.6.3 MATS and RHR Compliance Cost ... 29
  2.6.4 MATS and RHR Impacts on Coal Fleet ... 31
 2.7 The National Electric Grid ... 32
  2.7.1 Southwest Power Pool ... 35
  2.7.2 Oklahoma Electric Suppliers ... 37
 2.8 Literature Review ... 39
  2.8.1 Policy Alignments ... 40
  2.8.2 Energy and the Environment ... 42
  2.8.3 CPP Case Studies ... 46
  2.8.4 Wind Energy and the CPP ... 48
  2.8.5 Cost Benefit Evaluation ... 52
  2.8.6 Emissions Record Keeping and Reporting ... 54
  2.8.7 Tracking of Emissions Trade Program ... 57

III. RESEARCH METHODOLOGY ... 60
 3.1 Methods ... 60
  3.1.1 Generations Emission Data ... 62
 3.2 Best Systems for Emission Reduction Strategy and Technology ... 64
 3.3 Linear Programming ... 66
 3.4 Mixed Integer Linear Programming ... 70
 3.5 Modeling Scenarios ... 72
  3.5.1 RHR and MATS Scenario ... 73
  3.5.2 Generic Industry (GI) Scenario ... 74
  3.5.3 Beyond Coal Scenario ... 75
  3.5.4 Carbon Tax Scenario ... 75
 3.6 Cost-Benefit Analysis ... 77

IV. RESULTS ... 81
 4.1 RHR & MATS Scenario ... 83
 4.2 Beyond Coal Scenario ... 87
 4.3 Carbon Tax Scenario ... 92
 4.4 GI Scenario ... 96
 4.5 Costs and Benefits ... 100
 4.6 Sensitivity ... 105

V. CONCLUSION AND RECOMMENDATIONS 107
5.1 Research Conclusion 107
5.2 Recommendations 111
5.3 Final Thoughts 115

REFERENCES 117

APPENDICES 127
APPENDIX A: ENERGY STORAGE SYSTEMS 127

LIST OF TABLES

Table Page

Table 2.1 Clean Power Plan compliance options. Rate-based and Mass-based CO_2 limits for the state of Oklahoma (EPA, 2015a) 18

Table 2.2 Compliance Costs and benefits for simulated Rate-Based and Mass-Based Plan Approaches (EPA, 2015a) 18

Table 2.3 Clean Power Plan goal for the state of Oklahoma (EPA, 2015a) 19

Table 2.4 Monetized Benefits, Compliance Costs, and Net Benefits under the Mass-based approach (EPA, 2015b) 21

Table 2.5 Coal-Fired power plants. Water use Gallons per Megawatt-hour 23

Table 2.6 Oklahoma's coal power plants (OCC, 2015) 25

Table 2.7 Environmental rules impacting electric utilities (EPA, 2015a) 27

Table 2.8 Air Pollution Control Technologies Cost (OG&E, 2015; ERCOT, 2015) 30

Table 3.0 EPA's Technology Estimates of 2030 Building Block Potential Identified for Each Region (EPA, 2015b) 65

Table 3.1 List of variables for the LP model. 67

Table 3.2 Air Pollution Numerical Standard (EPA, 2012) 74

Table 3.3 Summary of the four SCC estimates (IWG, 2015) 80

Table 4.1 Oklahoma actual 2012 total electric generation (EPA, 2015a) 81

Table 4.2 Actual 2012 Oklahoma total CO_2 emission (EPA, 2015a) 82

Table 4.3 Oklahoma cost-benefit of the three generation scenarios in dollars 103

LIST OF FIGURES

Figure Page

Figure 2.1 The Keeling Curve**.** Source: scripps.ucsd.edu/programs/keeling curve. 9

Figure 2.2 Total Anthropogenic GHG by economic sector (EPA, 2014).......................................11

Figure 2.3 Global scale climate change (IPCC, 2013) 15

Figure 2.4 Coal plants locations in Oklahoma (Google Maps, 2016) 25

Figure 2.6 Southwest Power Pool electric region. Source: (FERC, 2017) 36

Figure 2.7 Example of PI Clients Emissions Monitoring application 57

Figure 2.8 Example of PI Clients Emission Trade application...58

Figure 3.1 LP Model Structure 69

Figure 4.1 Oklahoma power system capacity in MW (RHR & MATS Scenario)..........................84

Figure 4.2 Oklahoma Power Generation in MWh (RHR & MATS Scenario) 85

Figure 4.3 Oklahoma power sector CO_2 emission in millions short Tons (RHR & MATS Scenario) 86

Figure 4.4 Oklahoma power system investment in million dollars (RHR & MATS Scenario) 86

Figure 4.5 Oklahoma power system annualized cost of electricity (RHR & MATS Scenario) 87

Figure 4.6 Oklahoma power system capacity in MW (BC Scenario)...88

Figure 4.7 Oklahoma Power Generation in MWh (BC Scenario) 89

Figure 4.8 Oklahoma power sector CO_2 emission in millions short Tons (BC Scenario)...............90

Figure 4.9 Oklahoma power system investment in Million Dollars (BC Scenario) 91

Figure 4.10 Oklahoma power system annualized cost of electricity (BC Scenario) 91

Figure 4.11 Oklahoma power system capacity in MW (CT Scenario)...93

Figure 4.12 Oklahoma Power Generation in MWh (CT Scenario) 94

Figure 4.13 Oklahoma power sector CO_2 emission in millions short Tons (CT Scenario) 94

Figure 4.14 Oklahoma power system investment in Million Dollars (CT Scenario) 95

Figure 4.15 Oklahoma power system annualized cost of electricity (CT Scenario).......................96

Figure 4.16 Oklahoma power system capacity in MW (GI Scenario)..96

Figure 4.17 Oklahoma Power Generation in MWh (GI Scenario) 97

Figure 4.18 Oklahoma Mercury, Particulate Matter, and Sulfur Dioxide emission (GI Scenario) 98

Figure 4.19 Oklahoma power system CO_2 emissions (GI Scenario) 98

Figure 4.20 Oklahoma power system annualized cost of electricity (GI Scenario) 99

Figure 4.21 Total CO_2 reduction for each of the three scenarios compared to the CPP target 101

Figure 4.22 Electricity cost $/kWh for all three scenarios 102

Figure 4.23 CO_2 reduction and associated monetary benefit for the three scenarios 103

Figure 4.24 Electricity cost $/kWh for all scenarios with $15/ton carbon tax added for sensitivity analysis 105

Figure 4.25 Electricity cost $/kWh for all scenarios with increased NG fuel cost added for sensitivity analysis 106

Figure A-1 Compressed Air Energy System cost comparison with other storage technologies (Source, National Renewable Energy Laboratory) 127

Figure A-2 Compressed Air Energy System (CAES) with underground storage (Crotogino et al., 2001) 128

Figure A-3 Potential underground storage location, depleted oil and gas wells (Source: Oklahoma Corporation Commission) 129

ACRONYMS

Abbreviations	Explanation
AEO	Annual Energy Outlook
AQ	Air quality
BACT	Best Available Control Technology
BSER	Best System of Emissions Reduction
Btu	British Thermal Units
C	Celsius
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CCR	Coal Combustion Residuals
CCS	Carbon Capture and Sequestration or Carbon Capture and Storage
CCSP	Climate Change Science Program
CFR	Code of Federal Regulations
CH4	Methane
CHP	Combined Heat and Power
CO	Carbon Monoxide
CO2	Carbon Dioxide
CRF	Capital Recovery Factor
CSAPR	Cross State Air Pollution Rule
CT	Combustion Turbines
CUA	Climate Uncertainty Adder
DICE	Dynamic Integrated Climate and Economy Model
DOE	U.S. Department of Energy
EAB	Environmental Appeals Board
EC	Elemental carbon
ECS	Energy Cost Share
EE	Demand-Side Energy Efficiency
EG	Emissions guidelines
EGR	Enhanced Gas Recovery
EGU	Electric Generating Unit
EIA	U.S. Energy Information Administration
EMM	Electricity Market Module
EM&V	Evaluation, Measurement & Verification
EO	Executive Order
EPA	U.S. Environmental Protection Agency

ERC	Emission Rate Credit
FERC	Federal Energy Regulatory Commission
FGD	Flue Gas Desulfurization
FOM	Fixed Operating and Maintenance
FR	Federal Register
FRCC	Florida Reliability Coordinating Council
FUND	Framework for Uncertainty, Negotiation, and Distribution Model v
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GS	Geologic Sequestration
Gt	Gigaton
H2S	Hydrogen Sulfide
HAP	Hazardous air pollutant
HCl	Hydrogen chloride
HFC	Hydrofluorocarbons
HIA	Health impact assessment
HR	Heat Rate
IAM	Integrated Assessment Model
IGCC	Integrated Gasification Combined Cycle
IOU	Investor Owned Utility
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Planning Model
IRP	Integrated Resource Plan
ISA	Integrated Science Assessment
kWh	Kilowatt-hour
lbs	Pounds
LCOE	Levelized Cost of Electricity
LML	Lowest measured level
LNB	Low NOX Burners
MATS	Mercury and Air Toxics Standards
MeHg	Methylmercury
MGD	Millions of Gallons per Day
mg/L	Milligrams per Liter
MMBtu	Million British Thermal Units
MW	Megawatt
MWh	Megawatt-hour
N2O	Nitrous Oxide
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NATCARB	National Carbon Sequestration Database and Geographic Information System
NEEDS	National Electric Energy Data System
NEMS	National Energy Modeling System
NERC	North American Electric Reliability Corporation
NETL	National Energy Technology Laboratory

NGCC	Natural Gas Combined Cycle
NMMAPS	National Morbidity, Mortality Air Pollution Study
NOX	Nitrogen Oxide
NRC	National Research Council
NSPS	New Source Performance Standard
NSR	New Source Review
OC	Organic carbon
OFA	Overfire Air
OMB	Office of Management and Budget
PAGE	Policy Analysis of the Greenhouse Gas Effect Model
PFC	Perfluorocarbons
PVC	Photovoltaic Cell
PM2.5	Fine Particulate Matter
ppm	Parts per Million
PSD	Prevention of Significant Deterioration
RES	Renewable Electricity Standards
RGGI	Regional Greenhouse Gas Initiative
RIA	Regulatory Impact Analysis
RPS	Renewable Portfolio Standards
SBA	Small Business Administration
SCC	Social Cost of Carbon
SCPC	Super Critical Pulverized Coal
SCR	Selective Catalytic Reduction
SF6	Sulfur Hexafluoride
SIP	State Implementation Plan
SO2	Sulfur Dioxide
Tcf	Trillion Cubic Feet
TDS	Total Dissolved Solids
TSD	Technical Support Document
UMRA	Unfunded Mandates Reform Act
U.S.C.	U.S. Code
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USG SCC	U.S. Government’s Social Cost of Carbon
VOC	Volatile Organic Compounds
VOM	Variable Operating and Maintenance
VSL	Value of a statistical life
WTP	Willingness to pay

CHAPTER I

INTRODUCTION

The purpose of this study is to answer state officials' concerns regarding the economic impact of implementing the Clean Power Plan (CPP) rule in the State of Oklahoma. The study creates alternative generation scenarios to meet Oklahoma's carbon dioxide (CO_2) mitigation targets under the rule, analyzes the cost and efficacy of these scenarios and evaluates their environmental and social impacts. The study also proposes strategies to ease the burden of monitoring and reporting various requirements per the CPP rule.

The Clean Power Plan rule was the Obama Administration's flagship climate policy. It was the manifestation of the Obama Administration's efforts to address the threat of global warming and climate change. The intent behind the CPP rule was to reduce the emission of the greenhouse gas CO_2 and to slow down climate change overall. The Obama Administration and the Environmental Protection Agency (EPA) considered anthropogenic CO_2 to be a contributor to climate change and an imminent threat to Americans' health and welfare that will lead to long-lasting detrimental changes to the Earth's climate if left unchecked (Environmental Protection Agency [EPA], 2015a).

As part of the Obama Administration's Climate Action Plan, the CPP rule and the Carbon Pollution Standards (CPS) rule (EPA, 2015b) were promulgated by President Obama on August 3, 2015 in an attempt to regulate and limit the emission of carbon pollution from Electric Power Utilities. The goal of the CPP and CPS was to cut U.S. carbon pollution from the sector by 870 million tons or 32% below the levels recorded in 2005 levels by 2030. Oklahoma's portion of CO_2 emission reduction is 12.4 million tons or 23.41% below the level recorded in 2005 by 2030. The final CPP was promulgated pursuant to Section 111(d) of the Clean Air Act (Standards of performance for new stationary sources, 1990) and applies to CO_2 emissions from existing Electric Generating Units (EGUs). The final CPS rule was issued pursuant to Section 111(b) of the Clean Air Act and applies to the emissions of new, modified, and reconstructed EGUs. The two rules are historic because they are the first rules ever adopted by the United States Federal Government to comprehensively control and reduce CO_2 emissions from the power sector. In a simultaneous rulemaking decision, the EPA also issued a proposed Federal Implementation Plan (proposed FIP) for the final CPP (EPA, 2015c).

Although the data related to the deleterious effects of anthropogenic CO_2 is scientifically undisputable, political divisiveness continues to plague the issue and the implementation of the Clean Power Plan. States are divided into two ideological groups. One group sides against the rule. Conservative states claim that the EPA has outstepped its boundary as authorized by Congress to regulate air emissions under the Clean Air Act and have instituted legal proceedings against the EPA. The other states are in support of the rule. Liberal states believe it is essential in order to protect the health and well-being of people and the planet. The state of Oklahoma has joined the former group without any detailed study or analysis as to the positive or negative impacts of the rule on the state (Christian, 2015; Overton, 2015).

Implementation of the CPP has been on hold since the Supreme Court granted a stay on the rule in February 2016, pending the outcome of the D.C. Circuit Court. In 2017, the Trump Administration asked the D.C. Circuit to forego or postpone consideration of the Clean Power Plan while the EPA started the process to repeal the rule. In October 2017, the new head of the EPA signed a measure to repeal the Clean Power Plan rule. This move clouded the intentions of the U.S. to address climate change and to reduce CO_2 emissions and set the stage for new legal challenges.

On October 16, 2017, the EPA issued a notice of proposed rulemaking (NPRM) announcing the repeal. The EPA stated it would accept public comments until April 26, 2018. A review was conducted of the CPP as directed by the Energy Independence Executive Order. The review resulted in a proposed change in the legal interpretation as applied to Section 111(d) of the Clean Air Act, the section the CPP is based on. The proposed change in interpretation would limit the measures that could be applied to a particular power plant to measures that would take place "inside the fenceline" of the existing power plants.

Regardless of the legal wrangling and the repeal efforts, Oklahoma still has to reckon with the fact that climate change will not cease (Wuebbles et al., 2017). Regulations on carbon emission are forthcoming, and the longer it takes to comply, the costlier it will be. It would be prudent for the state of Oklahoma to develop options to deal with the issue while it is still manageable.

1.1 Purpose

The primary purpose of this research is to answer state officials' concerns regarding the economic cost of implementing the CPP rule. The study identifies the optimal energy generation scenario to comply with the rule, while minimizing economic costs and maximizing health and environmental benefits. The study provides background information on the science behind global warming to enable informed political judgments to be made and identify trade-offs in achieving competing objectives. The generation scenarios explored in this study include:

1. Mercury and Air Toxics Standards (MATS) and the Regional Haze (RHR) scenario
2. Beyond Coal Scenario
3. Carbon Tax Scenario
4. Generic Industry Scenario.

The secondary purpose of this study is to evaluate the environmental and social impacts of implementing the CPP rule in the state of Oklahoma. The research focuses on observing the avoided costs and gained benefits associated with the reduction of CO_2 and the associated hazardous emissions and their impact on health and natural ecosystems as valued by the Social Cost of Carbon (SCC). By analyzing the costs and benefits in this way, the recommendations provided intend to ease compliance with the rule and reduce the cost of monitoring and reporting CPP requirements.

The hypothesis is that compliance with the CPP will have minimal economic cost and great environmental and social benefits for the state of Oklahoma because utilities are obligated to comply with existing environmental regulations. The MATS rule that came into effect on April 16, 2015, and the RHR that was finalized on July 6, 2005, are both included in the category of existing regulations. The state’s energy policy (Oklahoma Energy Security Act, 2010) set a voluntary target that required 15% of all installed electric generation capacity within the state to be generated from renewable energy sources by 2015, which the state has already met (Oklahoma Corporation Commission [OCC], 2014). A concomitant effect of the utilities compliance with these federal and state regulations will be a reduction in the state's mass-based CO_2 emissions and associated hazardous emissions. This will bring the state closer to compliance with the CPP rule.

1.2 Significance of the Study

There are several studies on the costs and benefits of the Clean Power Plan. Many of them were conducted or financed by special interest groups on both sides of the issue, and were intended to support their previously held positions. None are specific to the state of Oklahoma. As a result, the goal of the research is to provide policy makers with an objective, scientific assessment of the effects of the CPP rule on the state of Oklahoma in terms of economic, environmental, and social impacts. The research also serves as a platform to inform policy discussions and to highlight the detrimental consequences of rising anthropogenic CO_2 in the atmosphere.

Oklahoma's policy-making modus operandi of reactivity to events, crisis management, and brinksmanship will not work when dealing with issues related to global environmental changes. Tackling a global problem like climate change starts with local solutions. Energy generation systems based on fossil fuels are used at a local level worldwide. Their adverse impacts on the local environment, as well as the health and well-being of local populations, are enormous. According to researchers Sarah Rizk and Ben Machol (Clean Energy and Climate Change Office, U.S. EPA), if externalities associated with fossil fuel energy systems are taken into consideration, they would add an average of 14 to 35¢ per kilowatt-hour to the retail cost of electricity. The economic health impact of associated externalities add up to $361.7 - $886.5 billion annually in the U.S. alone (Machol & Rizk, 2012).

Fossil fuel generation systems are unique in the sense that they will both respond to and influence global warming. Forward-looking or preventive energy policies are needed now to protect public health and the environment. The Earth's natural systems are slow to respond, so proactive thinking may benefit future generations by protecting the world from the effects of global warming. The study supplies additional framework to assist in the implementation of the rule and reduce the costs of measuring and reporting. Even though this study focuses on the state of Oklahoma, some of the proposed solutions and benefits delineated in this study could be used and implemented nationwide.

CHAPTER II

BACKGROUND AND LITERATURE REVIEW

"C*limate change looks as if it was designed to be ignored. It is a global problem, with no obvious villains and no one-step solutions, whose worst effects seem as if they'll befall somebody else at some other time. In short, if someone set out to draw up a problem that people would not care about, it would look exactly like climate change*."

-- David Fahrenthold

2.1 Fossil Fuel and Climate Change

Climate change is the principal cause and driving force behind the Clean Power Plan rule. Without an understanding of global warming, it is impossible to fully understand and analyze the impact of the CPP. It is thought that if individuals do not have an adequate understanding of the problem, any proposed solution or mitigation policy risks being ineffective or even rejected. It is imperative that people be informed about the impact of climate change, and the health and environmental impacts associated with the use of coal-based power generation. Without this understanding, environmental regulations appear to be burdensome and unnecessary. Solutions needed in order to comply with these regulations are perceived as irrelevant. This section will review the recent history of climate change, the mechanism behind it, and the possible future outcome if present trends of fossil fuel consumption continue unabated. The environmental and public health impacts of coal generation will be examined.

The present trend of increased CO_2 concentration in the atmosphere can be traced back to the start of the Industrial Revolution in the mid-18th century. This was the era that ushered in the mechanization of the agriculture, industry, and transportation sectors (IPCC, 2013). With industrialization, there was a shift from horse power to steam power and from wood fuel to coal fuel, heralding the start of the Anthropocene age. This continuous rise in fossil fuel consumption precipitated the rise of anthropogenic CO_2. Its concentration in the atmosphere has risen from ~285 ppm in the 1850s to above 400 ppm in 2017. This level of concentration is unprecedented in the last 800,000 years (Intergovernmental Panel on Climate Change [IPCC], 2013).

The science behind global warming is not new. It was first examined by Joseph Fourier in 1824. Fourier conducted a study to show that naturally occurring atmospheric gases enable the atmosphere to trap heat that would otherwise be lost to space (as cited in Fleming, 2008). The atmospheric gases behave like glass in a greenhouse, which lets in light and traps the resulting heat. Without the naturally occurring greenhouse effect, the Earth's average temperature would be near 0°F and life on Earth would cease to exist (Ma, 1998).

Fourier’s work was followed up by British mathematician John Tyndall. Tyndall began studying the radiative properties of various gases in 1959. Part of his experimentation included the construction of the first ratio spectrophotometer. The device was used to measure the absorptive powers of gases such as water vapor, carbonic acid (CO_2), ozone, and hydrocarbons. Among his most important discoveries were the vast differences in the abilities of colorless and invisible gases and vapors to absorb and transmit radiant heat. He noted that oxygen, nitrogen, and hydrogen are almost transparent to radiant heat, while other gases such as carbonic acid, water vapor, and hydrocarbons are quite opaque (Fleming, 1998).

In 1896, Swedish chemist Svante Arrhenius attempted the first numerical correlation between greenhouse gases in the atmosphere and increased global temperature (Arrhenius, 1896). Arrhenius' calculations show that if one were to double the CO_2 content of the atmosphere, there would be an increase of 4 to 6 °C. He expected this to occur over thousands of years but did not foresee the technological advances that gave way to humans altering the climate through the uncontrolled consumption of fossil fuel. Instead, this change occurred within a couple of centuries (IPCC, 2013).

Research in atmospheric chemistry continued in 1957. In the same year the International Geophysical Year (IGY) was formed as an 18-month international scientific effort to measure basic geological and geophysical data at particular points around the Earth. Many of these findings were instrumental in tracking atmospheric and Earth-based changes resulting from rising greenhouse gas (GHG) emissions. As part of the IGY, scientist Roger Revelle commissioned physicist Charles Keeling to monitor atmospheric CO_2 levels in Mauna Loa, Hawaii beginning in 1958. Keeling's work produced the most concrete evidence to date that anthropogenic GHG emissions were building up in the atmosphere (Keeling, 1961). Keeling died in 2005, but his work

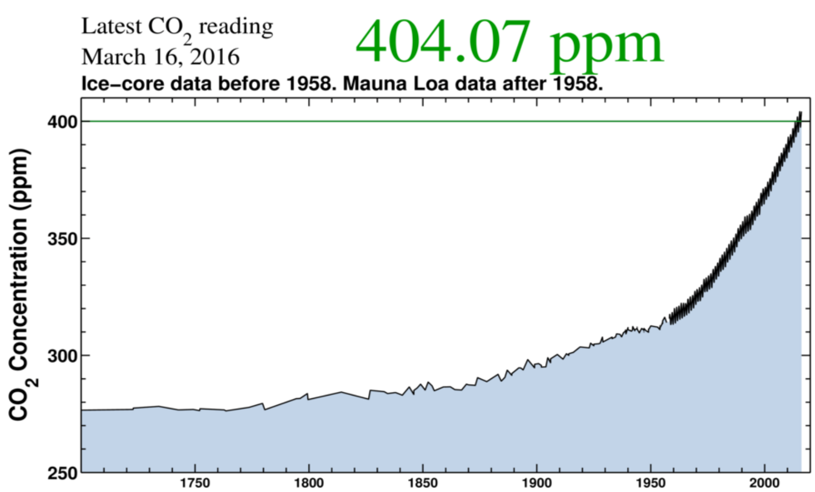

Figure 2.1 The Keeling Curve**.** Source: scripps.ucsd.edu/programs/keeling curve.

continues today under the auspices of the Scripps CO_2 Program. The Keeling Curve (Figure 2.1) shows the cyclical pattern of CO_2 levels rising and falling each year, and more importantly, the steady increase in total atmospheric CO_2 concentration from year to year.

2.2 State of Knowledge

Naturally occurring greenhouse gases play a key role in regulating the Earth's temperature and in keeping the temperature in the Goldilocks zone viable for evolved flora and fauna. The problem started at the turn of the 19th century with the Industrial Revolution. This era ushered in the increase in fossil fuel usage to power industries and transportation. Anthropogenic CO_2 emissions in the atmosphere reached record highs as a result. These record increases have continued to present day, with an overall increase of 115 ppm from the 1850s to today ("The Keeling Curve," 2017).

According to the EPA's annual Inventory of the U.S. Greenhouse Gas Emissions and Sinks 2014 report (Figure 2.2), the largest source of CO_2 emissions in the United States is the electric generation sector. This accounts for 30% of total GHG emissions. Most of these emissions are a direct result of burning coal and natural gas. The transportation sector is a close second, accounting for 26% of CO_2 emissions. This is followed by the industrial sector at 21%, the commercial and residential sector at 12%, and the agriculture sector coming in at 9%. Total emissions from all the above sectors comes to 6,870 million metric tons of CO_2 equivalent in 2014, which adds to an ever-increasing level of GHG that drives global warming (EPA, 2016). This increase in anthropogenic CO_2 emissions, along with other greenhouse gases such as methane, nitrous oxide, and fluorinated, are perturbing the Earth's energy balance by trapping in extra heat that warms the atmosphere and drives climate change (IPCC, 2014).

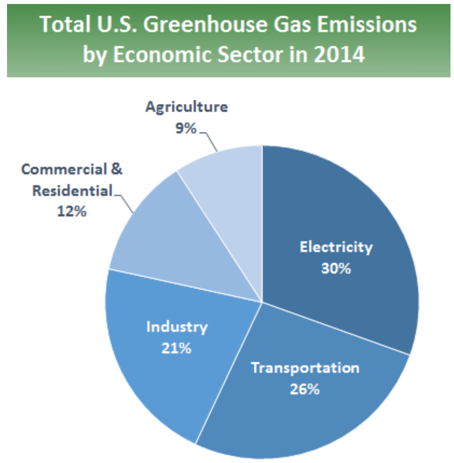

Figure 2.2 Total Anthropogenic GHG emissions by economic sector (EPA, 2014)

One of the most important metrics in defining the status of global climate change is the Earth's energy imbalance (EEI) metric. EEI is more useful than global surface temperature measures in determining the Earth's stored energy level. It measures the difference between solar radiation absorbed by the Earth and the thermal infra-red radiation emitted into space. The value of EEI is approximately 0.6 W/m^2 (Hansen et al., 2011). This positive energy imbalance is the engine that propels global warming.

Global oceans absorb approximately 93% of the EEI, thereby transforming it into a major heat reservoir. The remainder of the EEI goes into warming the land and the atmosphere as well as melting both terrestrial and oceanic ice. This energy buildup is changing the climate. It results in a rise in the Earth's surface temperature, ocean heat content, ocean mass, global mean sea level, atmospheric temperature and moisture, evaporation, precipitation, flooding, erosion, drought, and increased extreme weather anomalies (Schuckmann et al., 2016).

2.3 Climate Change Policy Response

The steady rise of CO_2 in the1970s coincided with severe weather anomalies throughout the decade. One such anomaly was the collapse of the anchovy fisheries of northern and central Peru during the warming of the 1972 El Niño (Hulme, 2001). There was also a devastating drought from 1972 to 1974 in the African Sahel that resulted in famine, death, and suffering for humans and livestock. This ultimately negatively impacted most of the Sahel's 50 million people (Hulme, 2001). In 1972, the Soviet Union faced a drought that reduced grain production by 12%, forcing the country to purchase grain abroad. This resulted in a reduction in world grain reserves and drove up food prices across the globe (Justus & Morrison, 1988). The Midwest of the United States was also negatively impacted. There were floods, a drought, and an early frost in 1974. The summer of 1977 was one of the three hottest recorded in a century (Justus & Morrison, 1988).

These events, combined with new data and modeling techniques, demonstrated that the world's climate might change far sooner and more drastically than was thought possible only a decade earlier. This spurred Congress to introduce legislation calling for a National Climate Program (Justus & Morrison, 1988). The Climate Program finally passed and became a reality in 1978 and was then established by Public Law 95-367. The goal of the Climate Program is to "assist the Nation and the world to understand and respond to natural and human-induced climate processes and their implications" (National Climate Program Act, 1978). Responsibilities for basic climate research, remote sensing, and coordination of the United States' participation in international programs were delegated to various governmental agencies including DOE, DOS, EPA, NASA, NOAA, NSF, USDA, and USGS (Justus & Morrison, 1988).

In 1989, the National Climate Program morphed under President Reagan into the U.S. Global Change Research Program (USGCRP) and was later mandated by Congress in the Global Change Research Act (GCRA) of 1990. The USGCRP was tasked with developing and coordinating the climate research activities of the various federal agencies and departments with the goal of creating, “a comprehensive and integrated United States research program which would assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change” (Global Change Research Act, 1990). They were asked to provide usable information on an annual basis to policy makers in order to help them make informed political judgments in matters relating to global climate change.

The USGCRP looked at the global climate change phenomenon and analyzed its present and future impacts on major U.S. regions with the intention to assist states and provide them with actionable recommendations to help them understand and respond to climate change. The following findings form the 2014 USGCRP’s *National Climate Assessment* (NSA) report apply specifically to the Great Plains region of the United States.

The southwest sector of the Great Plains is facing the harshest impact. Rising temperatures are leading to increased demand for water and energy. This is constraining development, stressing natural resources and increasing competition for water among communities, agriculture, energy production, and ecological needs. These changes are increasing the potential risk of crop failures and altering crop growth cycles due to warmer winters. They also .3

the timing and magnitude of rainfall events. The magnitude of these expected changes will exceed those of the last century. Existing adaptation and planning efforts are inadequate to respond to these projected impacts. The observed warming along with other climatic changes are triggering wide-ranging impacts in every region of the U.S. and throughout the economy as well. Most of these changes will be detrimental to society and infrastructures largely because they were adapted for the climate present at the time, not the rapidly changing one of today's world (Shafer, et al., 2014).

The NSA report cited empirical impact data from summer 2011 on cities including Houston, Dallas, Austin, Oklahoma City, and Wichita, among others. All of these cities set records for the highest number of days with recorded temperatures of 100ºF or higher in history. Impacts on Oklahoma and Texas were severe as both states set new records for the hottest summer since record keeping began in 1895. Rates of water loss, due in part to evaporation, were double the long-term average. The heat and drought depleted water resources and contributed to more than $10 billion in direct losses to agriculture alone. Many locations in Texas and Oklahoma experienced more than 100 days over 100ºF (Shafer et al., 2014). The 2011 heat record was toppled in 2104, 2015 and again in 2016 (National Aeronautics and Space Administration [NASA], 2017a).

Other risks to Oklahoma and Texas are the climate change variability and extreme weather impacts on the electric power sector. Decreased coolant water availability for thermoelectric power plants, combined with increased ambient temperature and increased demand for electricity, causes the supply system to be unreliable and vulnerable to power outages. This has far-reaching consequences for the electric power sector and the economy. The severe water constraints experienced in Oklahoma and Texas during summer 2011 strained the ability to meet electricity demands. These conditions were exacerbated for Texas in 2011 and 2012 because the state's electric grid is not tied to the national grid (Shafer et al., 2014).

The 2014 National Climate Assessment (NCA) report to Congress stated that "numerous independent evidence confirmed that human activities were the primary cause of the global warming over the past 50 years" (Melillo et al., 2014). The report is the result of a three-year analytical effort by a team of over 300 experts. The report goes on to state that the observed warming and other climatic changes triggered a wide-range of impacts in every region of the

United States and throughout the economy. In the NCA Fifth-Order Draft (5OD) report released in June 2017, the USGRCP stated with 99% to 100% probabilistic certainty “that human influence has been the dominant cause of the observed warming since the mid-20th century” (Wuebbles et al., 2017). The report projected an increase in temperature and number of hot days from 2041-2070 for Oklahoma’s region. Without measures controlling GHGs growth, weather anomalies, like summer 2011, will be the norm, not the exception.

The USGCRP is not alone in its critical assessment of climate change causes and impacts. The Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report confirmed that the observed changes since the 1950s are unparalleled over decades to millennia. Both the ocean and the atmosphere have increased in temperature. This causes a decrease in the amount of

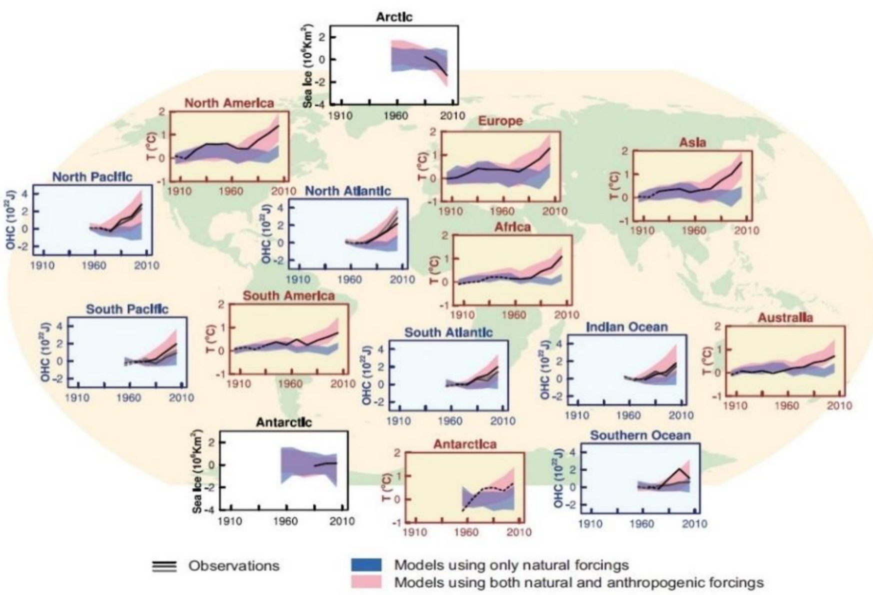

Figure 2.3 Global scale climate change (IPCC, 2013)

snow and ice and an increase in the sea level (IPCC, 2013). The report goes on further to state that the atmosphere has been successively warmer over the last three decades than any preceding decade since the 1850s (Figure 2.3).

In addition to the atmosphere, the ocean is warming as well and is absorbing about 30% of the emitted anthropogenic CO_2. This outcome is causing ocean acidification and is impacting ocean life. The cryosphere is also impacted as Greenland, Antarctica, and glaciers worldwide are shrinking and losing mass. At the same time, the sea level has risen by ~0.19 meters from 1901 to 2010. The rise is larger than the mean rate during the previous two millennia (IPCC, 2013).

These dire warnings pushed the Obama Administration to act to protect public health and to safeguard the planet for posterity. The Obama Administration tried to work with Congress to resolve the climate change issue in the form of the Waxman-Markey bill, but ultimately, this work proved futile (American Clean Energy and Security Act, 2009). The bill proposed the establishment of emissions caps through 2050 for several greenhouse gases, the institution of a system for trading emissions allowances, and the setting of a Renewable Electricity Standard to encourage the development and use of renewable energy. The failure of the Waxman-Markey bill in the Senate spurred the Obama Administration to aggressively use the executive branch to issue new regulations intended to reduce GHG emissions. The Waxman-Markey bill failed to become law, but it became the genesis for the Environmental Protection Agency's work on the Clean Power Plan. It set the path to reduce CO_2 emissions from power plants and for helping negotiate the international climate change deal in Paris December 2015.

2.3.1 Clean Power Plan

The Clean Power Plant (CPP) rule was established by the Environmental Protection Agency (EPA) to set guidelines for CO_2 emissions for existing fossil fuel-fired electric generation units (EGUs). This regulation guaranteed the reduction of CO_2 emissions on a national level within the power sector by recommending Best Systems of Emission Reduction (BSER) be implemented by each state. The EPA took into consideration current efforts within the power sector to eliminate carbon emissions as well as assessing technologies and measures already in use by power plants. They collected 4.3 million comments from policy makers, energy industry representatives, investors, regulators, and ratepayers. These comments, along with the Clean Air Act, played a big role in establishing the BSER.

The BSER provides the states multiple options for compliance that include heat rate improvements at existing plants, switching from coal to natural gas; expanding zero-emission generation sources such as wind, solar, or nuclear; and even demand-side energy efficiency. The last mitigation option is no longer a mandatory part of the BSER because it is considered a beyond-the-fenceline measure. The EPA still highly recommends that it be used by the states (EPA, 2015a).

The CPP is based on the concept of federalism, as is the Clean Air Act. EPA sets the performance standards for affected electric generators and then states implement them. The EPA projects that implementation of the CPP will result in CO_2 reductions from the power sector by 870 million tons, 32% below the levels of 2005, by 2030. The EPA set a firm target for every state. The net benefit of emission reductions on a national level is estimated to be $25 billion to $45 billion in 2030 (EPA, 2015a). Oklahoma's 2030 CO_2 reduction target is set at 22.4% of its 2005 emission level.

The CPP provides states with two options to account for their CO_2 emissions and comply with the rule. The first option is rate-based and the second option is mass-based. The rate-based option involves an EGU-based emission standards plan type to be generated, and the amount of CO_2 emissions per unit of electricity generated is specifically set for each type of affected EGU. An affected EGU is defined as any fossil fuel-fired electric utility steam-generating unit or stationary combustion turbine that was in operation or had commenced construction as of January 8, 2014. It must also be capable of selling greater than 25 MW of its output to a utility power distribution system (EPA, 2015a). In the mass-based approach, a limit or cap on CO_2 emissions is set for the whole state regardless of the amount of energy produced (Table 2.1).

Table 2.1 Clean Power Plan compliance options. Rate-based and Mass-based CO_2 limits for the state of Oklahoma (EPA, 2015a)

	Rate-based Goal CO_2 Rate (lbs/Net MWh)	Mass-based Goal (annual average CO_2 emissions in short tons)	Mass Goal (Existing & New Source Complement short tons)
2012 EPA Adjusted Base Line	1,565	52,862,077	52,862,077
2020 Projections (without CPP)	1,598	43,872,962	
Final Goal 2030 and Beyond	1,068	40,488,199	41,000,852
Reduction Target	497	12,373,878	11,861,225
% Reduction Target	31.76%	23.41%	22.44%

The mass-based approach is recommended by the EPA due to the ease of implementation, lower cost of monitoring and reporting, and higher benefits than the rate-based approach (Table 2.2).

Table 2.2 Compliance Costs and benefits for simulated Rate-Based and Mass-Based Plan Approaches (EPA, 2015a)

Incremental Cost from Base Case (billions of 2011$)			
	Rate-based Approach	Mass-based Approach	Total Benefits @ 3%
2020	$2.5	$1.4	$4.6
2025	$1.0	$3.0	$28
2030	$8.4	$5.1	$54

Under mass-based standards, there may be an incentive for more natural gas combined cycle (NGCC) generation capacity to replace coal generation in the state as there is no requirement for crediting renewable energy. This approach favors Oklahoma’s natural gas sector. Under the rate-based approach, a larger renewable generation may be encouraged because renewable sources can sell emissions reduction credits to CO_2 emitters such as coal-fired power plants. This may displace investment in new NGCC plants and allow for more coal-fired plants to stay operational. Emission allowances and credits are allowable under both options and may be freely traded as defined by the CPP rule (EPA, 2015a). The CPP rule calls on each state to reduce CO_2 emissions gradually, until it reaches its set goal in 2030. Oklahoma's interim and final goals for CO_2 emissions reduction are shown in Table 2.3.

Table 2.3 Clean Power Plan goal for the state of Oklahoma (EPA, 2015a)

	Interim Period			**Final Period**
Oklahoma	Step 1 2022-2024	Step 2 2025-2027	Step 3 2028-2029	2030-2031 and thereafter
Short Tons	47,577,611	43,665,021	41,577,379	40,488,199

In setting the emissions targets, the EPA used the BSER. This approach is already in widespread use by states and utilities and has resulted in reductions of carbon pollution. The CPP gives states the option to formulate their own plans that will achieve these rates by choosing from the following three building blocks (though they are not limited to them):

- Building block 1: Improved efficiency at power plants. This building block delivers 2.1% to 4.3% improvement, depending upon the region.
- Building block 2: Shifting generation from higher-emitting coal to lower-emitting natural gas power plants. In the final CPP rule, this building block assumes natural gas can be used at 75% of net summer capacity.
- Building block 3: Shifting generation to zero-emitting renewables.
- Building block 4: Demand Side - energy efficiency program and demand reduction (no longer mandatory in the final rule, but highly recommended).

The increased penetration of intermittent wind and solar energy into the power grid directly affects the reliability of the grid. The large fluctuations in wind speed and solar insolation cause large power variations. To remedy the variations, utilities use spinning reserves and fast-response natural gas generators, which tend to be an expensive solution. One interesting technology that could afford large energy storage economically is compressed air energy storage (CAES). Combined with underground storage, CAES could help store electric energy on large scale and would facilitate the expansion of renewable energy. Integrating a grid scale CAES system into the energy mix can smooth out energy fluctuations and provide additional services such as energy arbitrages, spinning reserves, and capacity values. CAES was not considered in this research due to a need for additional study to confirm the suitability of use with existing depleted gas wells in Oklahoma, but this would make a great topic for future research (for additional information on CAES see Appendix A).

The CPP does not impose specific technology solutions or federally enforceable requirements on states or non-emitting entities. Only affected EGUs have federally enforceable obligations in the final rule. Once a state formulates and submits its plan, it becomes federally enforceable upon approval. This means that the implementing state and the EPA may initiate an enforcement action when an affected EGU violates a specific requirement or prohibition (42 U.S.C. §7413(a)(1), (b)).

Implementing the CPP rule nationwide is expected to reduce CO_2 emissions by 870 million tons no later than 2030 (EPA, 2015). The associated emission reductions co-benefits of SO_2, NO_2, and directly emitted $PM_{2.5}$, would lead to lower ambient concentrations of $PM_{2.5}$ and ozone. The climate benefit estimates have been calculated using the estimated values of marginal climate impacts as presented in the Technical Support Document (Interagency Working Group [IWG], 2015).

The estimated net benefits associated with implementing the CPP are shown in Table 2.4. It includes estimates of climate benefits and health co-benefits, minus compliance cost. The benefits are calculated based on the mass-based approach. There are additional important benefits that are not included in this estimate due to the EPA's inability to monetize them such as the impacts on ocean acidification or potential tipping points in natural or managed ecosystems. Upon considering these limitations, the estimated benefits are incomplete and may be under-appraised.

Table 2.4 Monetized Benefits, Compliance Costs, and Net Benefits under the Mass-based approach (EPA, 2015b)

Monetized Benefits, Compliance Costs, and Net Benefits under the Mass-based (billions of 2011$)			
	2020	2025	2030
Climate Benefits*			
5% discount rate	$0.94	$3.6	$6.4
3% discount rate	$3.3	$12	$20
2.5% discount rate	$4.9	$17	$29
95th percentile at 3% discount rate	$9.7	$35	$60

*The climate benefit estimate in this summary table reflects global impacts from CO_2 emission changes and does not account for changes in non-CO_2 GHG emissions.

2.4 Fossil Fuel, Public Health, and the Environment

Fossil fuels in general and coal fuel in particular are used worldwide to generate energy. They play a big role in powering the world, driving economies, and making modern life possible. If the life-cycle (cradle-to-grave) of coal from extraction to disposal is evaluated comprehensively, it would appear to be a Faustian bargain.

There are externalities associated with fossil fuels that are not included in the market price. Externalities are the consequences of an activity. They can be either a cost or a benefit, and they affect a party who did not choose to incur said cost or benefit. In this case, fossil fuels are affecting other parties, and the weight of these consequences is not accounted for in the price of electricity. Not only are fossil fuels impacting the climate long-term, but they are also having local and current impacts on public health and the environment anywhere they are used. The negative externalities associated with fossil fuel extraction and use are exacting a heavy toll on public health and the environment (Epstein et al., 2011).

In the extraction, or mining phase, the cost is incurred on the local environment, wildlife, and local communities. Landscapes are being destroyed when trees, plants, and topsoil are removed to access the coal. This leads to soil degradation, soil erosion, and water pollution as runoff water laden with sediments, metals, and chemicals pour into waterways from mountaintops. This negatively impacts entire watersheds. In Appalachia, 2000 miles of biologically diverse headwater streams were buried due to mountaintop coal extraction operations (EPA, 2010). Miners are also at risk for black lung disease, which was responsible for the deaths of approximately 78,000 former miners between 1968 and 2000. A new study published in February 2018 identified 416 coal miners with the deadly disease from January 2013 to February 2017. The study covered only 3 clinics in Appalachia, so the actual numbers could be much higher (Blackley et al., 2018).

The transportation phase of fossil fuel extraction adds more air pollution, wear and tear on aging railroads, and an increased risk of death or injury from accidents. In the production phase, coal is burned to extract its heat energy and more pollutants are released into the air, water, and soil. According to the U.S. Energy Information Administration’s Electric Power Annual report in 2016, the United States has around 1,400 coal- and oil-fired electric generating units (EGUs), and they emit many of the 187 hazardous air pollutants listed in the Clean Air Act (EPA, 2011a). Some of these airborne toxic pollutants include mercury, arsenic, chromium, lead, nickel, sulfur dioxide, nitrogen oxides, particulates, acid gases, and organic air toxics such as dioxin. Acidic gases can burn lung tissue and exasperate asthma, bronchitis, and other chronic respiratory diseases (EPA, 2016). In 2013, the Oklahoma State Department of Health released a fact sheet about asthma statistics in Oklahoma showing more than 123,000 children younger than age 18 had asthma. It also showed that, in 2011, there were 1,434 hospital visits for asthma attacks with the total medical costs around $12.7 million. Not all of these cases can be attributed directly to the pollution associated with coal, but research has shown a direct link between air quality indices and emergency room visits (Kesten et al., 1995).

Nationwide, the demand for water for electricity generation is colliding with the need for agriculture and healthy freshwater for recreation. A typical 500 MW coal EGU using a once-through cooling uses approximately 300 million gallons of water each day (Table 2.5). That amount of water is the equivalent of water used by 3 million people according to the U.S. Department of Interior (Department of Interior [DOI], 2015). The returned water is normally 20 to 25ºF warmer than when it was withdrawn. Thermal pollution from these plants is stressing aquatic life. The cooling water is used to dilute process water from desulfurization units and other apparatuses used to control pollution in the flue gas stream. This represents another source of hazardous contaminants released into the water. According to the EPA, steam electric power plants contribute to approximately 50 to 60% of all toxic pollutants discharged to surface waters by all industrial categories regulated in the U.S. under the Clean Water Act (EPA, 2011).

Table 2.5 Coal-Fired power plants. Water use Gallons per Megawatt-hour (DOI, 2015)

	Once-Through		**Recirculating**		**Dry-Cooling**	
	Withdrawal	Consumption	Withdrawal	Consumption	Withdrawal	Consumption
Coal (conventional)	20,000 - 50,000	100 - 317	500 - 1,200	480 - 1,100	N/A	N/A

In the waste disposal, or grave phase, coal combustion residues (fly ash, bottom ash, and coal slurry) are still dangerous to public health and the environment. It is laden with arsenic, mercury, chromium, cadmium, and other heavy metals (EPA, 2011). The presence of all these hazardous pollutants in the air and drinking water has been found to make people more susceptible to asthma, bronchitis, and other chronic respiratory diseases. It also causes cancer, birth defects, reproductive disorders, neurological damage, learning disabilities, and kidney disease (Epstein et al., 2011).

These systematic damages to the environment and public health that are associated with the exploitation of cheap coal fuel for energy generation is the Faustian payment coming due. The cost of these externalities was assessed by a Harvard University study, which evaluated the full life-cycle externalities cost of coal fuel on public health and the environment and estimated it to be at $345.3 billion with a range from $175.2 billion to $523.3 billion. On a per-kWh basis that translates to 17.84 ¢/kWh, with an estimated range from 9.42 ¢/kWh to 26.89 ¢/kWh (Epstein et al., 2011).

2.5 Oklahoma Coal Power Plants

Oklahoma has six coal plants (Figure 2.4), and their CO_2 emissions are listed in Table 2.6. All units are subject to the EPA's Regional Haze Rule and MATS rules, and all utilities are working to comply with these rules. The Public Service Company of Oklahoma (PSO) is phasing coal generation completely out of their portfolio. The Oklahoma Gas & Electric (OG&E) Company is converting two of their EGUs to natural gas and retrofitting the other three coal EGUs for emission compliance. The Grand River Dam Authority (GRDA) is replacing one coal unit with a new high-efficiency NGCC unit and keeping the second unit until 2030.

Table 2.6 Oklahoma's coal power plants (OCC, 2015)

Plant Name	County	Owner	Year(s) Built	Capacity	2007 CO_2 Emissions
1- Muskogee	Muskogee	OGE	1977, 1978, 1984	1716 MW	10,600,000 tons
2- Sooner	Noble	OGE	1979, 1980	1138 MW	7,308,000 tons
3- Chouteau	Mayes	GRD	1981, 1985	1010 MW	7,926,000 tons
4- Northeastern	Rogers	PSO	1979, 1980	946 MW	7,511,000 tons
5- Hugo	Choctaw	WFEC	1982	446 MW	3,547,000 tons
6- Panama	Le Flore	AES Shady Point LLC	1991	350 MW	2,171,521 tons

Figure 2.4 Coal plants locations in Oklahoma (Google Maps, 2016)

No specific studies have been conducted to determine the impacts of Oklahoma's coal plants and ash disposal sites, including their impacts on health and the environment. Some impacted communities are on the frontlines of this issue. The Town of Bokoshe is an example of a community that is forced to deal with ash disposal sites that are polluting the environment and negatively impacting their health (Lombardi & Wertz, 2016).

Another significant problem with coal plants is mercury in the air emissions. According to the EPA's MATS home page, 50% of mercury emissions, 75% of acid gases, and 20-60% of toxic metals emitted in the US are from coal power plants. Airborne mercury can be deposited in streams and lakes through condensation in the atmosphere and microorganisms change it into methylmercury, a highly toxic form that bioaccumulates in fish (EPA, 2011). Humans are primarily exposed to mercury by eating contaminated fish. Fetuses can be negatively impacted in utero through maternal consumption of fish. This exposure to mercury is of particular concern for women of childbearing age, unborn babies, and young children because high levels of methylmercury have been linked to damage of the developing nervous system in children which can impair a child's mental faculties (Davidson et al., 2006). Mercury is a neurotoxin that is especially dangerous to developing fetuses and children. It can interfere with thinking, memory, attention span, language, fine motor function, and visual spatial skills (Epstein et al., 2011).

Oklahoma has many lakes with predatory fish species that are popular with fishermen such as bass, catfish, walleye, and saugeye. Some of these lakes are contaminated with mercury, prompting the Oklahoma Department of Environmental Quality (ODEQ) to issue *Mercury in Fish* consumption advisories for 54 of these lakes (Oklahoma Department of Environmental Quality [ODEQ], 2017).

2.6 Coal Pollution Regulatory Response

Fossil fuel power plants are subject to numerous environmental regulations under the Clean Air Act (CAA) to curb their emissions and limit the damage they cause (Table 2.7). This is due to their hazardous emissions and negative impacts on public health and the environment. Not all power plants in the United States are in compliance with these environmental rules. The EPA estimates that about 40% of current EGUs are still not equipped with advanced pollution control equipment and are emitting mercury and other contaminants into the environment (EPA, 2011a). The majority of Oklahoma's coal plants fall into the EPA's non-compliance category (American Electric Power [AEP], 2015; Oklahoma Gas & Electric [OG&E], 2015).

Table 2.7 Environmental rules impacting electric utilities (EPA, 2015a)

	SO_2	NOx	CO_2	O_3	Acid Gases	PM-10 PM-2.5	CCR	Sluice Water & Leachate	Water-Aquatic Life	Mercury & Other Toxics Metals
Regional Haze Rule (RHR)	X	X				X				
Mercury Air Toxics Standard (MATS)					X					X
Clean Power Plan (CPP)			X							
Cross-State Air Pollution Rule (CSAPR)	X	X								
National Ambient Air Quality Standards (NAAQS)	X	X		X						
Coal Combustion Residuals (CCR) Rule							X			
Effluent Limitations Guidelines (ELG)								X		
Clean Water Act 316 (b) Rule – NPDES									X	
Clean Power Plan (CPP)			X							

Two existing laws significantly impact utilities' compliance with the CPP even though they do not directly address GHGs: the RHR rule and the MATS rule. The RHR rule aims to cut down on visible pollution, while the MATS rule regulates mercury emissions and other hazardous air pollutants from electric power plants. The Public Service Company of Oklahoma (PSO) reached an agreement back in 2012 with the EPA over compliance with the rules and set plans into action starting in 2015. They installed emissions control equipment and retired one coal unit in 2017, and a second unit is scheduled to be retired by 2026 (AEP, 2015). The OG&E chose to continue to litigate the rules all the way to the Supreme Court and lost. The outcome of the litigation resulted in the OG&E complying with the MATS requirements by April 16, 2016, and the RHR requirements by January 2019 (OG&E, 2015). The other utilities that own and operate coal plants in Oklahoma (e.g. GRDA, WFEC, and AES) did not challenge the rules and are in various stages of compliance.

2.6.1 Regional Haze Rule

The RHR calls for state and federal agencies to work together to improve visibility impairment in Class I national parks and wilderness areas. It also protects public health from the damaging effects of manmade air pollution by cutting haze-causing emissions from coal power plants. In Oklahoma, this rule is intended to clean up the haze problem at Wichita Mountains Wildlife Refuge. Although the rule appears to only serve the interests of local parks and areas, in reality, the rule will help in cleaning air nationwide by removing precursor haze pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter (PM) 10 and 2.5 (EPA, 1999). The rule was released under the CAA Section 169A. Congress announced a national goal of preventing the impairment of visibility and resolving any existing impairment in national parks and wilderness areas that results from anthropogenic emissions (EPA, 1999). To accomplish this goal, Congress directed the EPA to create and release regulations directing states to submit plans that define emissions limits for local polluters and set a timeline with measurable goals to ensure that progress is made toward meeting the goals. The EPA issued the final Regional Haze rule in 1999 (EPA, 1999).

The rule requires states to develop their own State Implementation Plan (SIP) to restrict the emission of NO_X, SO_2, elemental and organic carbon, and fine particulates matter emissions to the projected lowest levels by retrofitting plants that contribute to regional haze with the best available retrofit technology (BART). In the event that the state's SIP fails to comply with the rule, the EPA creates a Federal Implementation Plan (FIP) for the state to follow (EPA, 1999). Each state's impacts on other states' parks will also be taken into consideration. The rule applies to EGUs that were built between 1962 and 1977. Utilities can comply with the rule by choosing to retrofit their old coal plants with the BART, convert them to natural gas, or retire them.

2.6.2 Mercury and Air Toxics Standards

The EPA promulgated the Mercury and Air Toxics Standards (MATS) in February 2012 pursuant to CAA Section 112. The MATS established national emission standards for hazardous air pollutants (NESHAP), which required new and existing coal- and oil-fired EGUs to meet hazardous air pollutant (HAP) standards. The main objective of the MATS rule is to improve air quality and public health nationwide. The rule is expected to improve public health by preventing 4,200 to 11,000 premature deaths, 4,700 nonfatal heart attacks, 2,600 hospitalizations for respiratory and cardiovascular diseases, 540,000 lost work days, and 3.2 million days of restricted activities due to respiratory symptoms (EPA, 2011).

The new standards set a quantitative limit on pollutants to reduce harmful toxic emissions of heavy metals (mercury, arsenic, chromium, and nickel), acid gases (hydrochloric acid and hydrofluoric acid), and particulate matter. These standards reflect the application of the maximum achievable control technology (MACT) to protect air quality and promote public health (EPA, 2012). Coal plants without the sufficient controls to meet the MATS rule have to install new control technology, including the use of scrubbers, baghouses, activated carbon injections (ACI), and dry sorbent injections (DSI). Utilities had until April 2015 to comply, with an option to apply for a one-year compliance extension through the ODEQ (EPA, 2011a).

2.6.3 MATS and RHR Compliance Cost

The cost for compliance with the MATS and RHR rule varies depending on the age and the condition of the EGUs and the technology solutions selected by the utilities. The most common retrofit option is the installation of a DSI and/or an ACI system(s). Based on the utilities' reports, the average capital cost for MATS compliance is approximately $10/kW, with an average operation and maintenance (O&M) cost of $0.75/MWh (OG&E, 2014; Electrical Reliability Council of Texas [ERCOT], 2015). It is notable that these report costs are averages and do not correspond to a specific retrofit technology. The MATS impact on natural gas EGUs is negligible.

Retrofitting old plants incurs a one-time capital cost and on-going O&M costs as shown in Table 2.8. The retrofit can result in capacity degradation and changes in operating parameters such as variable costs, heat rates, and emission rates. These changes should be considered when choosing an emissions control technology.

Table 2.8 Air Pollution Control Technologies Cost (OG&E, 2015; ERCOT, 2015)

Technology	**Overnight Capital Cost ($/kW)**	**Fixed O&M Cost ($/kW*-yr)**	**Variable O&M Cost ($/MWh)**
Dry Scrubber	$455.00	$14.33	$2.72
Low NOx Burners	$20.00	$0.44	-
Activated Carbon Injection	$45.00	$1.45	$2.50
Conversion to Gas	$73.00	$11.00	$3.50

The costs in Table 2.8 represent the average cost of BART as they pertain to the utilities in Oklahoma and Texas (OG&E, 2015; ERCOT, 2015). Even though this research only evaluates the cost of complying with the MATS, the RHR, and the CPP, utilities will need to also consider the cost of complying with other environmental regulations such as:

- 316(b) Cooling Water Intake Structures Rule. Compliance cost $5-$25/kW (ERCOT, 2015).

- Steam Electric Effluent Limitation Guidelines. Compliance cost \$10-\$60/kW; \$0.40-\$1.40/MWh (ERCOT, 2015).
- Coal Combustion Residuals Disposal Rule. Compliance cost \$50/kW; \$15-\$37.50/ton ash (ERCOT, 2015).

The compliance cost with the MATS and RHR rules, which include capital, fixed, and variable costs of control emission technologies (i.e. dry scrubbers to reduce sulfur dioxide, activated carbon injection for mercury removal, and low NOx burners for removal of NOx), are added to the cost of generating electricity at each plant accordingly. There are also extra costs associated with retrofits and conversions to control emissions that are not included in the cost calculations showing in Table 2.8. These extra costs materialize in the form of capacity penalties and heat rate penalties that could be as high as 1.5 or even 2% (ERCOT, 2015). Retrofits and conversions do not change the age profile of the underlying capacity, which translates to a higher O&M cost.

2.6.4 MATS and RHR Impacts on Coal Fleet

According to the American Coalition for Clean Coal Electricity (ACCCE), approximately 40% of the U.S. coal fleet that operated less than 10 years ago is retiring due to one or more of the factors discussed previously. The combined impact of the MATS and the RHR rule on older coal plants creates a near-term comply/retire decision for utilities. They must either make the required capital investments, or retire the units (2016 for the MATS and 2019 for the RHR).

Coal plant casualties from the RHR and MATS are abundant. In 2013, Georgia Power Company announced that it would seek approval from the Georgia Public Service Commission for the retirement of 15 coal- and oil-fired generating units. The reasons given to retire those units were MATS compliance and lower natural gas prices (Teichler & Hough, 2013).

First Energy Generation announced the retirement of 21 coal-fired units, totaling 3,300 MW, at an investor presentation. The President of the company stated that, “MATS put these units out of business” (American Coalition for Clean Electricity [ACCCE], 2017). The Tennessee Valley Authority (TVA) reached a settlement in April 2011 with the EPA regarding New Source Review (NSR) violations at 11 of its coal-fired power plants in Alabama, Kentucky, and Tennessee. The settlement called for TVA to retrofit, repower, or retire 51 units at these plants. TVA has retired or announced the retirement of 32 units, totaling 6,690 MW (ACCCE, 2017).

Another environmental rule that the utilities are taking into consideration when making decisions on MATS and RHR compliance is the Clean Power Plan or a future derivative of it that would limit GHG emissions. Interest in the CPP stems from the fact that investing in new, efficient natural gas and renewable energy generations will pay dividends when it comes to CPP compliance. Investing in retrofit technologies would not contribute to a reduction in CO_2 emissions and would leave utilities and ratepayers exposed to additional costs for compliance with additional environmental rules.

2.7 The National Electric Grid

The United States National Electric Grid (Grid) is the largest man-made machine on earth. It is a highly integrated network of generation, transmission, distribution, and control facilities, interconnecting 3,269 utilities with generating capacity over 1,164,384 MW to 148 million customers in all regions of the United States (Energy Information Administration [EIA], 2015a).

The Grid is divided into three regions. The Eastern Interconnection is the largest, which includes Oklahoma, the Western Interconnection, and the Texas Interconnection. The regions are not directly connected or synchronized to each other, but there are some high-voltage, direct current

(HVDC) interconnections (Figure 2.5) with limited abilities to transfer energy between the regions (EIA, 2017a). Unlike telecom networks, pipelines, or railways, the flow of electricity in

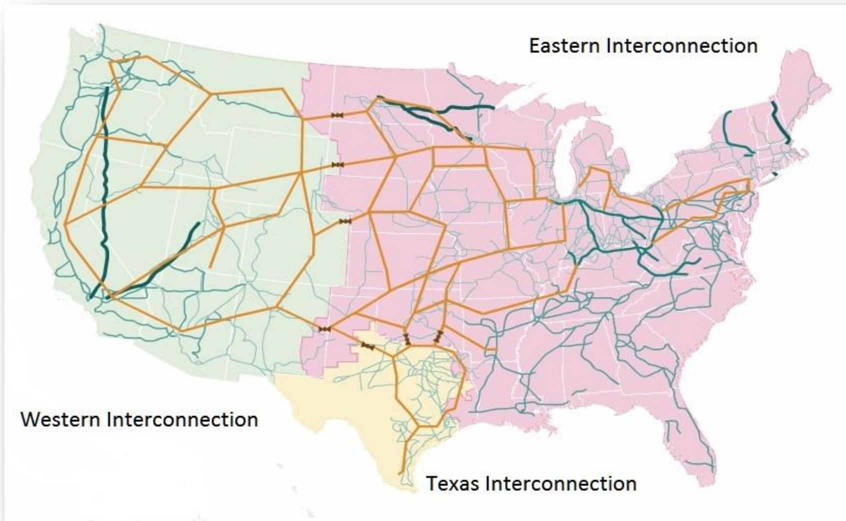

Figure 2.5 The National Electric Grid (EIA, 2015a)

the present grid cannot be routed or controlled. Power flows via the path of least resistance and is consumed simultaneously as it is produced with no large storage in the grid. Balancing supply and demand and ensuring that transmission flows and voltage levels are within reliability ranges is critical to the security and reliability of the electric supply systems across the Grid (EIA, 2017a). Overflow or overvoltage conditions can create high current flow, overheating wires, transformers, and equipment. If these conditions were to persist, they would cause equipment failure and blow-out. Underflow, or undervoltage, weakens electricity supply. It causes a decrease in EGU rotational speed below the mandated 60 Hz (NERC standard), leads to brownout, and could cause system collapse and blackout (EIA, 2017b).

There are multiple government and private organizations that have oversight and duty to ensure the proper operation and reliability of the Grid. They include:

- Federal Energy Regulatory Commission (FERC)
- North America Electric Reliability Corporation (NERC)
- Regional Transmission Organization (RTO)
- Independent system Operator (ISO)

FERC is a governmental agency that was created in 1977 to govern the natural gas industry, hydroelectric projects, electric companies, and oil pipelines. It also regulates the transmission in interstate commerce and approves rates for wholesale interstate electric power. FERC is responsible for protecting the reliability of the high voltage interstate transmission system through mandatory reliability standards (Federal Energy Regulatory Commission, 1977).

NERC is a non-profit organization that was created in 1968 by electric companies in response to the 1965 New York blackout. Founders of NERC organized themselves to self-police their operations by setting up an organization with the mission of developing and enforcing reliability standards, sharing best practices, and improving the quality and reliability of the Grid. NERC is the electric reliability organization for North America and is subject to oversight by FERC and governmental authorities in Canada. Section 215 of the Federal Power Act of 2007 gives legal authority to electric reliability organizations such as NERC and its regional reliability organizations, to develop mandatory and enforceable reliability standards (16 U.S. Code § 824o - Electric reliability).

Regional Transmission Organizations (RTOs) were created by the FERC to break the monopoly of electric utilities that owned generation and transmission assets. It removed control of the transmission lines from the utilities and instead shared them among all generators. The goal was to encourage efficiency in wholesale markets and guarantee that consumers have reliable service while paying the lowest price possible (89 FERC ¶ 61,285, 1999). RTOs coordinate, control, and monitor the operation of the electrical transmission systems encompassing multiple states and act as the air traffic controllers for the Grid. They do not own the Grid, but they independently operate it in real time, minute by minute, to ensure that demands, generations, and power interchange are continuously flowing and in balance to meet customers demand safely and reliably (89 FERC ¶ 61,285, 1999). There are currently four RTOs in North America: PJM Interconnection, Midcontinent Independent System Operator (MISO), ISO New England (ISONE), and Southwest Power Pool (SPP); Oklahoma is a member of the SPP.

Independent System Operators (ISO) are independent, federally regulated entities established to coordinate existing tight power pools access to regional transmission in a non-discriminatory manner and ensure the efficient management, safety, and reliability of the bulk power system. ISO was created out of Order Nos. 888/889 where the Commission suggested the concept as part of its initiatives to deregulate the electric industry (Federal Energy Regulatory [FERC], 2017). ISOs and RTOs perform the same basic functions, but the ITOs are restricted to within a single State border (89 FERC ¶ 61,285, 1999).

2.7.1 Southwest Power Pool

The Southwest Power Pool (SPP) was founded in 1941 as an 11-member power pool in Little Rock, Arkansas. It was designed to supply Arkansas aluminum factories with power around the clock in order to meet critical air defense needs during WWII (Southwest Power Pool [SPP], 2016). After the war, the SPP's board decided to keep the organization together. This made sense as it would be beneficial in maintaining electric reliability, coordination, and power sharing. In 1968, the SPP joined with other electric utilities to form NERC. In 1994, it was incorporated in Arkansas as a non-profit organization. In 2004, the SPP was approved as an RTO by the Federal Energy Regulatory Commission. In 2014, the SPP established and launched the Integrated

Marketplace (IM). The following year, the SPP expanded its operations to serve all or parts of 14 states (Figure 2.6) covering 575,000-square-mile region, including more than 56,000 miles of high-voltage transmission lines and 90 member organizations (FERC, 2017).

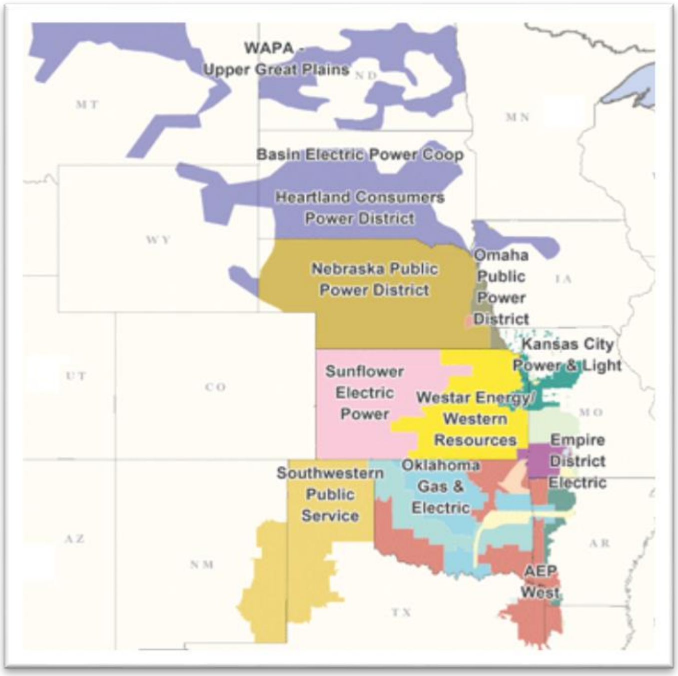

Figure 2.6 Southwest Power Pool electric region. Source: (FERC, 2017)

As an RTO for 14 states pool, the SPP is responsible for ensuring a reliable supply of power, an adequate transmission infrastructure, and competitive wholesale electricity prices. With the addition of the Integrated Marketplace, the SPP is able to optimize the deployment of energy and operating reserves to dispatch resources on a least-cost basis. The IM provides additional functionality to the market including a day-ahead energy market, a real-time energy market, an operating reserve market, and a Transmission Congestion Rights market. The latter helps improve the regional balance of electricity supply and demand and facilitates the integration of renewable resources (SPP, 2016).

2.7.2 Oklahoma Electric Suppliers

Oklahoma's electric power needs are met by seven major suppliers that operate within the state. The impact analysis presented in this research is restricted to the top three suppliers as they are also the top CO_2 emitters. Both Oklahoma Gas & Electric Company (OG&E) and Public Service Company of Oklahoma (PSO) are publicly owned utilities which are regulated by the Oklahoma Corporation Commission (OCC) by virtue of Article IX, Section 18 et seq., of the Oklahoma Constitution. This gives the OCC the authority and responsibility to supervise, regulate, and control electric utilities in Oklahoma. The Grand River Dam Authority (GRDA) is a state agency that is not regulated by the OCC. State law prevents the OCC from regulating any electric utility company that is operated by a governmental entity or cities that are members of the Oklahoma Municipal Power Authority (OMPA). The legislature passed a statute allowing electric cooperatives to opt out of OCC price regulations. Western Farmers Electric Cooperative (WFEC) has utilized this option and opted out. Listed below are the top seven utility companies in order of largest to smallest (OCC, 2015).

1. Oklahoma Gas & Electric Company (OG&E)
2. AEP - Public Service Company of Oklahoma (PSO)
3. Grand River Dam Authority (GRDA)
4. Western Farmers Electric Cooperative (WFEC)
5. KAMO Electric Cooperative (KAMO)
6. Oklahoma Municipal Power Authority (OMPA)
7. Empire District Electric Company (Empire)

OG&E is the largest provider of electricity in Oklahoma. It serves clients in Oklahoma and western Arkansas. In Oklahoma, OG&E provides electricity to about 750,000 people. Their overall generation capacity is 6,845 MW. As of 2014, 61% of their total capacity came from coal-fired units, 32% from natural gas-fired units, and only 7% from wind generation (OG&E, 2015).

PSO is the second largest provider of electricity in the state. It delivers energy to 527,000 people throughout eastern and southwestern Oklahoma. Total generation capacity for PSO is 4,274 MW, of which 35% is from coal-fired EGUs, 15% is from natural gas EGUs, and 12% is from wind (Public Service Company of Oklahoma [PSO], 2015).

The GRDA is a state agency and has a 24-county service area in northeastern Oklahoma. They sell energy to municipalities, electric cooperatives, and industries. Their generation capacity is about 2,260 MW, and this includes coal-fired, hydroelectric, and natural gas-fueled generation. GRDA has 300 MWs of wind capacity due to a renewable purchase power agreement (PPA) with a number of independent power producers. GRDA supplies electricity to approximately 500,000 metered customers (Grand River Dam Authority [GRDA], 2016).

WFEC serves customers in Oklahoma and New Mexico and distributes energy to 18 Oklahoma member cooperatives. Their current generation capacity is 1,320 MW: 34% of the total comes from coal, 19% from wind, 15% from natural gas, and 7% from hydroelectricity (OCC, 2015).

KAMO provides energy to northeastern Oklahoma and southwestern Missouri, with nine-member distribution cooperatives located in Oklahoma. KAMO owns part of GDRA's coal-fired Unit 2 equal to 198 MW, and an additional 478 MW of hydroelectricity is obtained from the Tulsa-based Southwestern Power Administration (SPA). SPA sells electricity from 24 U.S. Army Corps of Engineers dams (OCC, 2015).

OMPA delivers energy to 39 cities in which the municipality owns the electric system. Their overall generation capacity is 600 MW. In Oklahoma, 435 MW of the total is generated by coal, natural gas, hydropower, and wind power through a PPA (OCC, 2015).

Empire provides electricity to customers in four states: Oklahoma, Missouri, Arkansas, and Kansas. In northeastern Oklahoma, 4,700 people are serviced by Empire. Their total generation capacity is 1,280 MW (OCC, 2015).

The Oklahoma Corporation Commission (OCC) requires each public utility to submit an Integrated Resource Plan (IRP), which covers its strategy to ensure that it has a sufficient supply to meet its obligation to serve its clients. The plan covers a planning period of 10 years, and subsequent plans are due every three years thereafter (OCC, 2015a). The data from these IRPs are used in this research in the RHR and MATS scenarios in order to model the impacts of these plans on Oklahoma's CO_2 emissions.

2.8 Literature Review

As Oklahoma reviews its options to act on carbon mitigation driven by the CPP or a future mutation of it, it is important for state policymakers to understand the costs and efficacy of alternative strategies. Although there is no lack of literature on the impact of carbon policies, no research has been conducted to address this issue specifically for Oklahoma. The state energy portfolio could be viewed as representative of states with sizable coal and natural gas generations, but also with a great potential for wind and solar energy generations.

Climate change and variability poses a serious challenge for electricity production and use. Understanding climate change and its impacts on electric power systems is crucial for planning and implementing economy-wide mitigation and adaptation policies in the future. This review highlights the research areas showing the impact of climate change on the power sector, the impacts of coal plants on the environment, and the approaches taken by others to resolve the energy-versus-environment quandary.

The intended outcome of this research review is to inform the design of a future electrical energy portfolio/policy that would economically transition the state to clean energy and minimize the impacts of the electricity sector on the environment.

2.8.1 Policy Alignments

In setting an energy portfolio or a policy to comply with the CPP rule, it is important to ensure that the new policy would take into consideration not just energy needs and cost, but also the environmental impacts and rules. The two fields must be aligned to ensure that they work together in synergy to accomplish their intended benefits without constraining one another. Todd Aagaard of Villanova University School of Law, in his paper on *Energy-Environment Policy Alignments* (Aagaard, 2016), analyzes energy and environmental laws, which are often in conflict, and how they work to constrain each other. Historically, energy laws focus on making energy widely available at minimal cost without the consideration of environmental impacts, and environmental laws focused mainly on preventing pollution. It posits that policy alignments to address the energy-environmental law gap is a step forward from the traditional strain between energy and environmental laws. Instead of using negative constraints as a means to control policy, energy-environmental synergy is the model that is most beneficial for society (Aagaard, 2016).

Protecting the environment and to keeping energy costs reasonable can be a difficult balance to maintain, especially since the power sector is rapidly changing. In recent years, both FERC and the EPA have written policies that prove cooperation between the two agencies is better than tension. Aagaard’s exploration of energy and environmental law rightly states that a landmark rule like the CPP that affects both the energy sector and the environment will induce combined efforts between FERC and the EPA to create a policy alignment around the rule that would achieve the objectives of both agencies. This shift from constraint to cooperation is crucial because the CPP will not be effective if energy and environmental laws are in conflict. This policy alignment could be used in Oklahoma to amend the Energy Security Act SB 3028 in support of the Clean Power Plan and to leverage renewable energy resources and the natural gas industry to benefit Oklahoma's energy security as well as the state's environment.

Joseph Tomain, dean emeritus and professor of law at Cincinnati University, in his research on the Clean Power Plan titled *A Perspective on Clean Power and the Future of US Energy Politics and Policy* (Tomain, 2016), points out the challenges facing the industry and provides possible solutions to these challenges. The CPP aims to reduce carbon emissions as the United States attempts to transition to clean energy. This is the first policy of its kind to come from the federal government that brings together energy and environmental regulation (Tomain, 2016).

Energy and environmental regulation are traditionally talked about as two separate issues, creating two separate narratives that downplay the other in order to increase their narrative's appeal. The CPP is instrumental in bringing together these two narratives in the United States in a way that has never been done before (Tomain, 2016).

The two main challenges discussed are the need for a multi-trillion-dollar investment and the increased regulation due to climate change. A partial solution to these challenges is to decentralize the industry and increase competition by increasing citizen engagement.

Decentralization can increase grid reliability, lead to decongestion, reduce long-distance transmission, increase efficiency, and diversify the energy resources used. Smaller grids stand to avoid the grid failures that occur at the distribution level. Smart grids will allow individuals to take a more active role in the industry as it becomes more feasible for them to sell and store electricity (Tomin, 2016). Over time, it is expected that regulation would transfer to local governments where citizen demands can be addressed more efficiently. The CPP provides much-needed regulations that, for the first time, combine energy and environmental goals and aim to help the United States transition into a clean-energy future (Tomain, 2016). This shows a path wherein Oklahoma could benefit greatly from the CPP. It would create a greater demand for its natural gas and renewable energy, locally and nationwide. Creating an energy policy that is in compliance with the CPP would benefit Oklahoma's economy and environment.

2.8.2 Energy and the Environment

In addition to considering the impacts of fossil fuel power plants on the environment and their contribution to climate change, it is also important to consider climate change impacts on the electricity system. Shankdar Chandramowli, a researcher at the State University of New Jersey, Graduate School-New Brunswick Rutgers, conducted a study on the *Impact of Climate Change on Electricity Systems and Markets for New Jersey* (Chandramowli, 2015). In his study, he uses Linear Programming based Capacity Expansion Models (LP-CEM) to look at the various impacts of climate change and mandatory emissions reduction in relation to the economy, public policy, and extreme weather.

By running simulations with the LP-CEM, an analysis of the long-term climate change effects and macroeconomic trends on a state and regional level can be explored. Scenarios with climate variability continuously show that climate change and high economic growth rates result in higher capacity additions, supply costs, prices, and ratepayers' costs. Additional capacity is found through the use of combined cycle units, nuclear power, and on-shore wind electricity generation (Chandramowli, 2015).

When the LP-CEM is run under different assumptions of renewable portfolio standards (RPS) and carbon cap policies, several important results are found. The CPP is likely to moderately raise the cost to ratepayers over the next 40 years and, as RPS mandates are added, there is going to be an increase in the supply-side costs. The model shows the faster emissions goals are implemented, societal costs will stay relatively low, and quick implementation will result in higher levels of CO_2 emissions reductions (Chandramowli, 2015).

When looking at climate change, extreme weather events, and electricity markets, infrastructural vulnerabilities and institutional shortcomings were located within the current situation. With rising temperatures, there will be an increase in energy demands from cooling systems and a decrease in supplies and transmission capacity due to thermal EGUs sensitivity to changes in air temperature and water shortages. Transmission lines and transformers will reach their current-capacity limit, thereby decreasing the reliability of the grid and increasing generation demands and prices. To combat these deficiencies and create a resilient power sector, it is essential that utilities, regulators, state and the federal governments, and ratepayers work coherently to adjust the electrical system to new changes and reduce the contribution of the sector to climate change (Chandramowli, 2015).

These findings show that significant reductions in emissions are possible with minimal economic costs and without hurting economic growth. The public health and environment benefits far outweigh any costs associated with the reductions. Climate change has far-reaching effects, including freshwater availability and extreme weather impacts; the weight of these effects will only increase over time if policies are not introduced to counteract climate change. Long-term policy solutions are needed to meet current climate change stabilization goals, and the CPP is the first step in such policy implementation (Chandramowli, 2015).

The results of his research indicate that RPS policies and carbon caps can positively influence public health and the environment with minimal monetary costs. Other renewable sources of energy generation are needed in order to reduce emissions and limit the effects of climate change. Long-term policies are needed in Oklahoma to address electrical energy needs in a holistic way that not only takes into consideration the economic impacts but also the impacts of climate change on the electricity system and on public health and environment.

In complying with environmental rules like the RHR, MATS and the CPP, it is crucial to examine other environmental impacts of coal plants that are not addressed by these rules but could have negative impacts on the environment and public health. Research conducted by Ruhl, Vengosh, Dwyer, Gary, Hsu-Kim, Schwartz, Romanski, and Smith on the *Impact of Coal Combustion Residue Effluent on Water Resources in North Carolina* (Ruhl et al., 2012) analyzed the impact of coal combustion residue (CCR) effluent from coal power plants on water resources in North Carolina. The research answers questions about the effects of CCR disposal on the aquatic systems surrounding coal-fired power plants. This problem is not unique to North Carolina, as the United States' electric industry generates over 130 million tons of CCR a year (Ruhl et al., 2012).

The Clean Water Act set standards for the National Pollution Discharge Elimination System (NPDES) program, which regulates disposal of CCR wastewater. The federal standard set limits for total suspended solids and oil and grease only. It is up to each state to enhance this regulation to include other contaminants that might be applicable to CCR effluents. Nevertheless, North Carolina, Oklahoma, and many other states do not add any additional limits (Ruhl et al., 2012).

In the North Carolina (NC) study, samples from 10 CCR emission and cooling water discharge sites were collected to analyze the quality of various contaminants. Samples were obtained as well from associated lakes and rivers in order to gain information on the impact of CCR waste. To analyze the impact of CCR, the study looks at the concentrations of major and trace elements in 76 CCR samples, 129 samples from surface water sources, and 98 extracted samples from sediments. Samples involving lakes and rivers were taken from both upstream and downstream sites in order to account for the effect of CCR emissions on water (Ruhl et al., 2012).

The NC study revealed that cooling water plays an important part in moderating the contaminant levels of NPDES outfall. The CCR discharge was significantly diluted when cooling water was utilized. However, these contaminants accumulated in pore water and bottom sediments in levels exceeding the EPA limits. The impact on aquatic systems was observed by analyzing upstream and downstream water from the same river or lake and comparing it to samples collected from the control lake. There was concentration elevation of Arsenic, Born, Bromine, Calcium, Chlorine, Chromium, Fluorine, Lithium, Magnesium, Molybdenum, Selenium, Strontium, Sulfate, Thallium, and Vanadium in downstream water compared to that found upstream. This implies that coal plant waste is polluting downstream water. The study also found that coal plants equipped with wet Flue-gas desulfurization (FGD) units have a larger concentration of contaminants in their wastewater compared to plants without FGD units (Ruhl et al., 2012).

The NC study shows that contamination from CCR facilities also has an ecological impact as contaminants are taken up by benthic organisms, thus impacting the whole food chain. Organisms living in the affected water exhibit abnormalities due to the elevated level of contaminants. Fish with elevated levels of arsenic and selenium in their tissues show deformities such as an extended lower jaw and a spinal curvature (Ruhl et al., 2012).

When making the decision to retrofit old coal-fired power plants or to replace them with a clean energy source, CCR waste from these plants should be considered, as a retrofit decision will continue to contaminate surface and ground water and possibly lead to very serious health consequences for humans. The results of this study are applicable to Oklahoma's coal plants, and the study highlights the risk to Oklahoma's water resources and to the surrounding communities because of diffusion of containments outside designated areas and bioaccumulation in aquatic ecosystems (Oklahoma Department of Environmental Quality [ODEQ], 2017).

2.8.3 CPP Case Studies

A case study of compliance with the CPP rule was conducted by Lu, Preckel, Gotham, and Liu, at Purdue University. The study, *An Assessment of Alternative Carbon Mitigation Policies for Achieving the Emissions Reduction of the Clean Power Plan: Case study for the State of Indiana* (Lu et al., 2016) shows the importance of why each state needs to consider the CPP's implications. Indiana will be greatly impacted by the CPP because it is heavily dependent on coal for electricity generation. In fact, 90% of the electricity generation in 2010 came from coal, which puts Indiana in the top 10 states with the highest carbon emissions. At the time of the study, no research had been conducted in regard to CPP compliance. The model used in the study was based on the MARKAL model, which employs a linear programming engine. IN-MARKAL is an energy-economy model representing major sectors of Indiana's energy system (Lu et al., 2016). The model includes the following elements:

a. Planning horizon from 2007-2045
b. 13 3-year periods
c. 4 major components: resource supply, conversion sectors, end-use technologies, and end-use energy service demands
d. 4 scenarios: base, carbon cap, carbon tax, and renewable portfolio standard

The study identifies the carbon cap and carbon tax scenarios as the best options for Indiana to achieve its CPP goals while also diversifying the state's generation portfolio with the smallest cost to the state and strain on the power system. The study shows that even for a state that is heavily dependent on coal for electric generation, complying with the CPP can be achieved at a cost that varies with an increase between 21.01% – 38.59% over the base scenario (Lu et al., 2016). The scope of the study was limited to finding the least costly scenario that would meet the CCP carbon emission target strictly on an economic basis and did not take into consideration environmental and social impacts associated with each of these scenarios.

Another study, "State Cooperation Under the EPA's Proposed Clean Power Plan," conducted by professors Oates and Jaramillo from Carnegie Mellon University, evaluated the EPA's proposed 111(d) portion of the CPP rule. They examined how state choices affect the cost of compliance and total CO_2 emissions, how cooperation affects the economic surplus shared among the states, how the impacts of the rules will affect producers and consumers, how decisions affect shadow prices, and how decisions affect revenues for various EGUs (Oates & Jaramillo, 2015).

Under the CPP, states are allowed to comply individually or in cooperation with other states. States can also choose to comply with a rate-based standard or mass-based standard. When the proposed rule was modeled, it was shown that compliance will likely increase electricity costs, notably increase the net revenue of natural gas combined-cycle units, and decrease the net revenue of coal units. It is important to note that the cost of compliance went down when increasing cooperation and choosing the mass-based standard for compliance. The cost of compliance was lowest with national cooperation and mass-based compliance (Oates & Jaramillo, 2015).

The study also found that overall compliance led to an increase in new revenue associated with NGCC units. Regardless of these nuances and the decisions that states must make, the 111(d) rule stands to be one of the most significant rules produced by the EPA due to its meaningful standards in reducing GHG emissions (Oates & Jaramillo, 2015). This study shows that Oklahoma would benefit more from the mass-based approach than the rate-based approach and from complying in cooperation with other states compared to complying individually. It also shows that the natural gas sector would stand to benefit greatly from the implementation of the CPP rule.

2.8.4 Wind Energy and the CPP

There are two solid arguments that coal supporters cite in opposing the CPP. The first argument is that electricity prices will skyrocket; the second argument is that electric grid reliability will be reduced as the electric generating sector is significantly transformed by the introduction of renewable technologies. While both of these concerns must be taken seriously, a study by Cardell and Anderson from the National Science Foundation *Targeting Existing Power Plants: EPA Emission Reduction with Wind and Demand Response* (Cardell & Anderson, 2015) shows that integration of renewable technologies, when managed effectively, can reduce pollution and minimize price increase without a negative impact on grid reliability.

This study modeled wind energy generation with 10% and 20% wind penetration using the CPP's proposed BSER as its guidelines. A Monte Carlo simulation with a two-stage power flow optimization framework was applied to the New England region. The New England region, along with California, is currently structured using a cap and trade program. CPP implementation will be easier for these two regions because a solid framework geared toward CO_2 emission reduction is already in place (Cardell & Anderson, 2015).

The results of the study prove that BSER will reduce CO_2 emissions, but using BSER alone without supplemental strategies could threaten system reliability. However, this is remedied by the addition of recourse to real-time demand response. The modeling shows that, using the BSER with extra measures, the researchers were able to achieve 20% CO_2 emission reduction across all load levels with 10% wind, and 33% reduction with 20% wind. In the process, they were also able to decrease price volatility and eliminate concerns of system reliability (Cardell & Anderson, 2015). This shows that pursuing an energy policy in Oklahoma that supports renewable technologies is fundamentally sound, would be effective in reducing pollution, and would act as a hedge against fuel price fluctuation.

In Oklahoma, the integration of wind energy into the grid can go as high as 45% without any impacts on the reliability of the electric system according to a study conducted by the Southwest Power Pool (SPP). The *2016 Wind Integration Study,* assessed the results of added wind generation in their operating area. Three levels of wind penetration are looked at in the study: a 30% Case, a 45% Case, and a 60% Case. The aim is to further understand the overall impacts and reliability associated with an increased use of wind energy (SPP, 2016).

At the end of 2015, wind generation made up 14% of the SPP's total generation capacity. To analyze the effects of additional wind generation, the study utilizes the Inflexion tool from the Electric Power Research Institute. The tool allows for an assessment of ramping, variability, and generator flexibility. The study found that the 30% and 45% wind penetration power flow cases are able to utilize existing facilities to achieve the target penetration levels. The 60% Case was able to achieve the target, but it required additional installed capacity and utilized the SPP generation interconnection queue. The study also confirms the need for planned integrated transmission plan (ITP) projects. It recommends the acceleration of some of these projects and identifies additional transmission needs to handle the 60% wind penetration case reliably (SPP, 2016).

For Oklahoma, this means that increasing the renewable energy share up to 45% of the total production capacity is presently feasible without impacting the reliability of the network. While some changes need to be made in order for 60% wind penetration to work, it is well within the realm of reason to believe that these changes can be made within the next five to 10 years as more ITP projects are completed in wind regions. Added transmission capacity would allow for increased wind energy generation and utilization (SPP, 2016).

A year after this study, in February 2017, SPP set a new record of being the first Regional Transmission Organization (RTO) in the United States to serve 52.1% of its load using wind energy in a given time (SPP, 2017). This demonstrates that the same tools the SPP uses every day to deal with variations in electricity supply and demand are well-suited to accommodate the variability of wind energy and that 60% wind penetration is within reach.

Oklahoma is fortuitous by way of its geographic location with access to a variety of natural energy resources. In addition to oil and gas, wind energy has emerged as an economically viable, pollution-free complement to traditional energy sources. A 2015 report by Ferrell and Conaway, *Wind Energy Industry Impacts in Oklahoma* (Ferrell et al., 2015) showed that the policy the state created and implemented in order to grow the wind sector is very successful. The wind energy sector is growing rapidly and is ushering in an economic boom for rural Oklahoma.

Oklahoma went from having no utility-scale wind energy capacity and a very limited number of wind turbines in 2002 to having over 5,377 MW of capacity and 2884 wind turbines in 2015. Wind energy generated more than 17% of Oklahoma's electricity in 2015, making it the fourth largest wind energy state (Ferrell et al., 2015). This is a percentage that will continue to grow as the industry expands. In fact, the SPP is currently planning additional transmission line projects to connect these wind farms to its electrical network and channel that power to areas with high demand for electrical power (SPP, 2016). The success of Oklahoma's wind energy industry has led to the creation of 1,600 full-time jobs, $22 million a year in land-lease payments to rural landowners, and approximately $1 billion in ad valorem taxes from wind farm enterprises. The majority of the ad valorem contributions will go to rural counties where there is slow growth and downward pressure on other sources of ad valorem revenue. PSO and OG&E are estimating $2 billion in savings to ratepayers over the span of 40 years (2003-2043) by incorporating wind energy into their generation portfolio (Ferrell et al., 2015).

The report debunks many of the common negative outlooks about wind energy. It shows that investing in wind energy is a winning strategy on more than one front. The mapping project shows that the wind energy industry not only has a small footprint in Oklahoma, but it also has the ability to coexist on the same property with livestock, crops, and oil and gas operations.

Wind energy projects are able to generate additional revenue without any disturbance or interference with those operations (Ferrell et al., 2015).

The report shows the state has been very successful so far in incentivizing companies to harness wind energy to create clean power, jobs, and revenue. This investment in the wind energy sector is already contributing to reducing CO_2 emission in the state and will make complying with the CPP rule much easier if and when it becomes law. The report makes a strong case for a continuing support of wind energy projects and increasing wind energy generations regardless of the outcome of the CPP litigation (Ferrell et al., 2015).

2.8.5 Cost Benefit Evaluation

With any complex environmental problem, there are many factors to analyze and consider in order to determine the best solution for the problem. In environmental regulation, the main evaluation method is cost-benefits analysis (CBA). CBA is not a new method; it has been in use for over 150 years. It was first used in France, in the context of public investments in railroads. It came into widespread use in the United States during the 1940s and 1950s to evaluate water quality projects, such as dams and reservoirs (Pearce et al., 2006).

Since 1981, the executive branch of the federal government by (Executive Order 12291) has required regulatory agencies in promulgating new regulations or reviewing existing regulations to assess the costs and benefits of such regulations and to attempt to ensure that the potential benefits to society for the regulation outweigh its potential costs. In a formal sense, CBA is the official measuring stick used by all U.S. agencies for measuring regulations economic qualification.

The general structure of CBA is: benefits are defined as increases in human wellbeing, and costs are defined as reductions in human wellbeing. For environmental problems, CBA involves two main elements: (a) Importance of the issue to society and the serious environmental problem and (b) Monetary Valuation, in which the measurement of benefits is essentially the measurement of avoided damages. For a project or policy to qualify on cost-benefit grounds, its social benefits must exceed its social costs (Pearce et al., 2006).

Even though CBA is widely used in the environmental field, its use for the evaluation of climate policy has drawn some criticisms, as many think it is not suited for this this type of problem. Geographically, the effects of climate change transcend national boundaries, and they transcend generational time scales (Dennig, 2017). The problem with the distributional consequences on different income groups, ethnic groups, sensitive populations, and future generations is magnified as CBA calculations have to deal with the spread of these variances on global scale.

In *Pricing the Priceless* (Heinzerling, 2002), the report highlights the fact that monetizing benefits where there are no natural prices for items such as a healthy environment or a long life leads to the creation of artificial prices. Economists create artificial prices for public health and environmental benefits by studying what people would be willing to pay (WTP), which is essentially an opinion poll. Researchers ask a cross section of the affected population how much they would be willing to pay to preserve or protect something that cannot be bought in a store (Heinzerling, 2002).

This type of WTP valuation tends to reinforce existing patterns of economic and social inequality in poor countries and communities. Individuals are more likely to express less WTP to avoid environmental harms simply because they have fewer resources. Therefore, cost-benefit analysis would justify imposing greater environmental burdens on them than on their wealthier counterparts (Heinzerling, 2002).

Another flaw raised is the practice of discounting the future. This practice might be sound in an economic setting where you need to evaluate investments that produce future income, but when it comes to environmental policy, discounting a long life and good health, discounting becomes ethically troubling. Heinzerling highlights the fact that a 5% discount rate means that the death of one billion people, 500 years from now, is less important than the death of one person today.

CBA continues to be widely used for computing the cost benefit of regulations. Efforts by leading economists are ongoing to improve it. They are exploring and re-evaluating the role of risk, time consistency, market prices, hyperbolic discounting, and the prejudice against the future (Zuber & Asheim, 2012).

2.8.6 Emissions Record Keeping and Reporting

The CPP rule requires states and utilities to monitor and report their CO_2 emissions for affected EGUs, in order to ensure that they are meeting their emissions goals. Each state plan must include a set requirement that outlines the emissions budget and related compliance mechanisms. These requirements include CO_2 emissions monitoring, reporting, and recordkeeping for the affected EGUs. States can assign each utility company a cap on their CO_2 emissions and allocate an allowance, thereby allowing each utility company to come up with their own plan to meet their assigned CO_2 emissions reduction target (EPA, 2015a).

To ease the monitoring and reporting requirement of the CPP rule, the EPA allows states to use existing monitoring, data collection, and reporting pathways. Under the Acid Rain Program's continuous emissions monitoring (CEM), 40 CFR Part 75 establishes requirements for the majority of the affected EGUs to monitor CO_2 emissions on an hourly basis and to report the collected data using the Emissions Collection and Monitoring Plan System (ECMPS). The EPA will allow states to utilize ECMPS to facilitate data reporting of additional net energy output as required by the CPP. Because the Acid Rain Program does not require net energy output reporting, additional modifications would be needed to update the affected EGUs' monitoring systems (EPA, 2015a).

In a meeting with representatives from Oklahoma's utilities regarding CPP compliance, concerns were voiced about the interstate nature of the electric grid and the seamless flow of energy between various generators and load centers over state lines, which is in constant flux. This makes the process of monitoring and recording CO_2 emissions for intrastate energy consumption a very complex and arduous task for utilities. This is especially difficult when a third-party entity, like the SPP, is doing the actual dispatch. To ease the burden of tracking CO_2 emissions and other pollutants associated with electricity generation, one possible solution is to make the RTO (in Oklahoma's case, the SPP) a central piece of tracking the emissions of affected EGUs.

The SPP provides broad services to its utilities members, such as reliability coordination, transmission service and tariff administration, market operation, and balancing authority. To facilitate this functionality, the SPP has an extensive communication network with its utilities members that help it monitor and control 627 generating plants, 4,103 substations, and 48,930 miles of transmission (SPP, 2014). Having the emission monitoring centralized at SPP makes it easier to collect such data as they already run the Integrated Market and the dispatch process. This will also save the utilities time and money because they will not have to set up their own individual monitoring and reporting system.

One of the software packages that the SPP uses to monitor its complex network is OSIsoft's PI System. The PI System provides an open infrastructure to connect sensor-based data, operations, and people to enable real-time intelligence. The PI System gives the SPP the ability to capture and leverage sensor-based data across its entire network to improve efficiency, reliability, and safety. It also makes a great platform upon which to fulfill the CPP's monitoring and reporting requirements (SPP, 2014a).

The PI System has an existing database of all power generation assets that are under their dispatch system. The SPP network has connections to 2,700 generators. The PI System makes it feasible to interface and collect data from various incompatible systems through its Tags or Points interface feature (SPP, 2014a). Most of Oklahoma's generating plants are already in their PI assets framework database with a unique resource identifier. New PI Tags and Attributes can be created to collect data from continuous emissions monitoring sensors (CEMS). That data is then stored in the PI Server. Real-time data and historical data can then be viewed by the user employing a proposed PI Clients application in a similar format to Figure 2.7. The system would keep track of the following data for each power plant: number of hours it ran, energy output, and CO_2 emissions as required to comply with the CPP rule. The system can also be programed to keep track of any other emissions that the utility wishes to track.

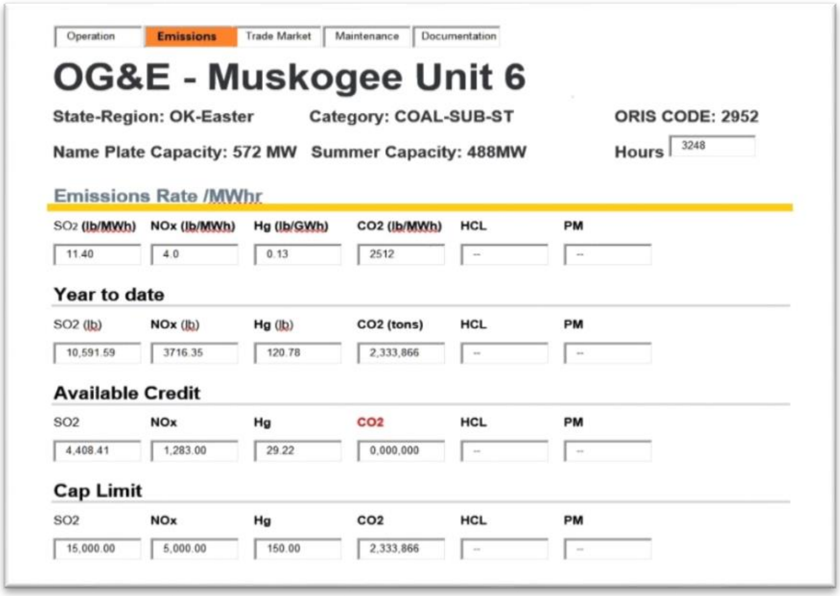

Figure 2.7 Example of PI Clients Emissions Monitoring application

The application behind Figure 2.7 would keep track, in real-time, of emissions data and enable users to set cap limits for the various air pollutants including sulfur dioxide, nitrogen oxides, mercury, hydrogen chloride, and particulate matter to comply with the appropriate rules. Once limits are set, the application can automatically monitor the emission levels and act to prevent violations of any environmental laws. The application would inform utilities of approaching limits on their EGUs and keep the SPP from dispatching any EGUs if it exceeds its cap limit.

2.8.7 Tracking of Emissions Trade Program

Emissions trade, or the cap and trade program, is an approach that has been successfully used in the past by the EPA (e.g. the Acid Rain Program) to reduce pollution and protect public health and the environment (EPA, 2007). The program uses market-based incentives to reduce pollution, allowing utilities to select the most economical solution to reduce emissions. Similar programs to control CO_2 emissions are also active in the European Union, the US east coast RGGI (Northeast Regional Greenhouse Gas Initiative), and the west coast (Western Climate Initiative). The CPP equally gives the states the option to create a regional cap and trade program that would allow utilities to trade emissions allowance and renewable energy credits (EPA, 2015a). Such a market will be beneficial to Oklahoma as the state has the potential of having surplus credits due to the high availability of wind energy and NG generations that can be used to supplant coal generations.

A possible scenario for the market operation is that a state's regulating authority, like the ODEQ, sets a yearly cap on total mass emissions for the utilities based on their yearly CO_2 emissions. ODEQ splits the cap proportionally among utilities and distributes it in the form of CO_2 emission allowances, each representing their quota to emit a specific quantity of CO_2 and other pollutants. At the end of the compliance period, utilities will obtain emission data from SPP for each source and submit their emissions report with allowances to cover the quantity of pollutants they emitted. If a source does not hold sufficient allowances to cover its emissions, they can either buy allowances on the market or be subjected to fines by the regulating authority. Figure 2.8 shows an example of a user interface application to trade allowances. Utilities can buy and sell EAs and RECs in real-time to keep their operations running and in compliance.

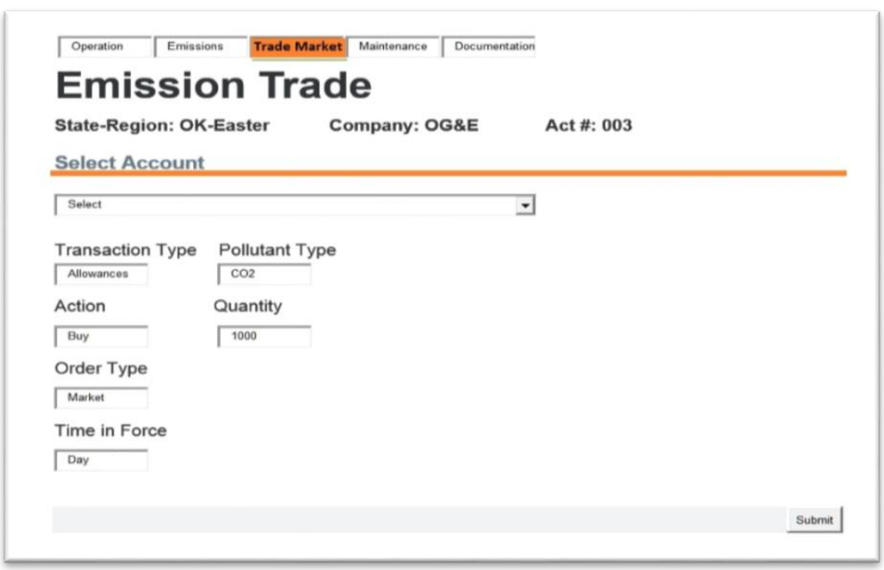

Figure 2.8 Example of PI Clients Emission Trade application

Again, SPP will be the entity that is most capable to take on such a responsibility. They already track energy sales transactions for the integrated market, dispatch generators, track emission data as described previously, and create the platform to track allowances from issuance through submission for compliance (SPP, 2017b). Having all the energy transactions, emission data, and the integrated and cap and trade market in a centralized location makes the operation less complex, more robust, and seamless.

There are various approaches to compliance with the clean power plan, and in doing so it is important to take into consideration the major aspects and impacts of each proposed solution. This becomes very important if the decision is to keep and retrofit old coal power plants. The body of research shows a path to compliance is best achieved with policy alignment that combines the objectives of energy statutes with environmental statutes (Tomain, 2016). Doing so will serve both constituencies and will yield tangible benefits for all concerned parties. The literature also shows the inclusion of renewable energy into the state electricity generation portfolio up to the reliability threshold of the ISO or RTO is a valid policy approach (SPP, 2016). This will meet environmental regulations, reduce harmful pollutants, improve public health, and stimulate economic developments (Cardell & Anderson, 2015).

CHAPTER III

RESEARCH METHODOLOGY

The value of any scientific approach must be evaluated in light of the importance of the research question it is trying to answer. The research question evaluated herein is the determination of the economic, environmental, and social impact of the Clean Power Plan on the state of Oklahoma.

This question is inherently an interdisciplinary question; solving it requires a diverse approach to methodology. I will be using the best attributes of three different methodologies to guide this research in setting up the appropriate framework to formulate the problem and to collect and synthesize disparate raw data into knowledge that is actionable. The desired result is sound information for those in the position to make decisions, enabling informed judgments to be made about complying with the CPP rule, and identifying trade-offs in achieving competing objectives.

3.1 Methods

The methodologies used in this research are: Linear Programming (LP), Mixed Integer Linear Programming (MILP), and Cost-Benefit Analysis (CBA). LP modeling is used to determine Oklahoma's CO_2 emissions level from all affected fossil fuel EGUs on a temporal scale from

2012 to 2030. The goal is to find a scenario that would enable Oklahoma to meet the CO_2 emissions reduction targets as mandated by the CPP. The hope is that this can be achieved while minimizing costs and harmful emissions and maximizing social and environmental benefits.

The LP Modeling approach will be used in all the scenarios to model the impacts of the CPP, except for the Industry Generic scenario. The MILP modelling approach is used in the Industry Generic scenario to model the CPP impacts; however, it does so in the context of first finding the optimized solution to comply with the RHR and MATS rule. The MILP model adds rigor to the research by providing another method to compare and to validate the LP approach, as well as to compare the utilities' plans for compliance with the RHR and MATS rule.

Cost-Benefit Analysis will be used to compare the cost of compliance to the projected benefit associated with the proposed scenarios. The projected benefits monetary valuation is based on the benefits accrued from the reduction of CO_2 emissions and the avoided damages associated with that reduction. This will identify trade-offs in providing affordable power and protecting public health and the environment.

In order to establish boundaries for the study, two major assumptions are made. The first assumption is that commitments made by the utilities to comply with existing environmental rules are presumed to be irreversible. The next assumption is that only affected EGUs within Oklahoma will count towards the CO_2 emissions.

Oklahoma utilities are members of the Southwest Power Pool (SPP) and participate in the SPP Integrated Marketplace (IM). The IM co-optimizes the deployment of energy and operating reserves to dispatch resources on a least-cost basis throughout Oklahoma and the surrounding states. For the purpose of this study, Oklahoma will be considered as an island when it comes to carbon emission, and only CO_2 emissions from affected EGUs that are physically located within the state geographic border will be considered. This assumption will not alter the overall CO_2 emissions for the state as Oklahoma utilities are responsible for providing adequate generation resources to meet their customers' forecasted loads in addition to 12% reserve capacity (SPP, 2017a). This assumption is needed to minimize the complexity of tracking CO_2 emissions from multiple generation sources within the SPP territory.

The SPP dispatches electricity on a regional basis, and it also operates a Real-Time Balancing Market (RTBM). This means that resources receive updated dispatch commands for energy and operating reserve every five minutes (SPP, 2017b). The resource can be self-dispatched or it can come from any resource within the SPP territory. Tracking carbon emissions from hundreds of sources in the SPP region that are dispatched in five-minute intervals is a very complex endeavor and near impossible for a local utility to keep track of. A solution for tracking CO_2 emissions in this dynamic environment is proposed in Section 4.6.

3.1.1 Generations Emission Data

The main sources for the generations and emissions data are:

- AEP-PSO Integrated Resource Plan 2015
- EIA Annual Energy Outlook 2015
- EPA Clean Power Plan Rule
- GRDA Comprehensive Annual Financial Report 2015
- ODEQ Air Quality Division
- OG&E Integrated Resource Plan 2015
- The AES Corporation Form 10K 2015
- The state of Oklahoma's 13th Electric System Planning Report
- WFEC 2015 Annual Report

The base CO_2 emission rate for all the EGUs located in the state was obtained from the EPA Clean Power Plan Toolbox for States (EPA, 2015d). The generation and emission information the EPA is using is aggregations of different sources from survey forms EIA-860, EIA-923, and EPA Part 75 data. The survey Form EIA-860 collects generator-level specific information about existing and planned generators and associated environmental equipment at electric power plants with one megawatt or greater of combined nameplate capacity. Survey Form EIA-923 requires the collection of detailed electric power data on electricity generation, fuel consumption, fossil fuel stocks, and receipts at the power plant and at the generator level. The data is to be collected on a monthly and yearly basis. 40 CFR Part 75 establishes the requirement for the Acid Rain Program's continuous emission monitoring (CEM) and reporting under Title IV of the Clean Air Act. Part 75 requires the utilities to continuously monitor and report sulfur dioxide mass emissions, CO_2 mass emissions, nitrogen oxides emission rate, and heat input (EPA, 2015e).

To verify the EPA's emissions data, the following formula is used to determine the theoretical CO_2 emissions (lb/MWh) of EGUs to ensure the reported emission rates are within the theoretical limit. Burning one million British Thermal Units hour (MMBTUH) of natural gas fuel will create 117 lbs. of CO_2 according to 40 CFR Part 98, Subpart C. The efficiency of a simple combustion turbine (CT) generator is approximately 35%, meaning for each MMBTU input, 0.35 MMBTU output of electrical energy will be generated (DOE, 2018). The conversion factor for heat to electrical energy is 1 MMBTUH = 0.293 MW. So the formula is:

$$CO_2 = (EF*CFKP) / (GE * CFHE) \qquad (1)$$

Where:

CO_2 = CO_2 emissions from natural gas or coal EGU (lb/MWh).

EF = Fuel-specific default CO_2 Emission Factor from Table C–1 of 40 CFR Part 98, Subpart C (kg CO_2/mmBtu).

GE = Generator Efficiency, means if a generator has a 35% efficiency, it will generate 0.35 MMBTU electrical energy for each MMBTU input.

CFHE = The Conversion Factor from heat to electrical energy is 1 MMBTUH = 0.293 MW

CFKP = 2.2 Conversion factor from kilograms to pounds

Using Eq. 1 above, the CO_2 emission rate for any generator with a known fuel type and efficiency can be determined. The following example shows the CO_2 emission rate for a natural gas fueled Simple-Cycle Combustion Turbine CT generator:

$$CO_2 = (53.07 \text{ kg } CO_2 * 2.2) / (1 \text{ MMBTUH} * 35\% * 0.293 \text{ MW per MMBTU}) = 1{,}140 \text{ lb/ MWh}$$

3.2 Best Systems for Emission Reduction Strategy and Technology

The EPA conducted extensive research and evaluation of various strategies and technologies that are used in the industry to reduce CO_2 emissions from power plants to create the Best Systems for Emission Reduction (BSER). The EPA engaged in an analytical approach that identified systems of emission reduction that have been adequately demonstrated for a particular source category. They determined the best of these systems after evaluating the amount of reductions, costs, non-air health and environmental impacts, and energy requirements. Then they selected an achievable emission limit (EPA, 2015b).

The EPA encapsulated the BSER into the following three Building Blocks (BB):

- BB 1: Region-specific heat rate improvement applied to the coal steam fleet to make these units more efficient (a range from 2.1 to 4.3%).
- BB 2: Phased-in shift of generation from coal to natural gas, and an increase of the duty cycle for existing natural gas combined-cycles (NGCC) to 75% net summer capacity.
- BB 3: Greater use of new renewable energy (RE) based on regional RE potential.

While demand-side energy efficiency (EE) is not a BSER building block in the final rule, the CPP’s flexible compliance options provide a wide margin for states to fully deploy EE to meet their goals.

The EPA also recognized the interconnected generation and distribution of power within the electricity grid and based their analysis on the three established regional electricity interconnects: the Western Interconnection, Eastern Interconnection and Electricity Reliability Council of Texas interconnection. The EPA applied the Building Blocks to all coal plants and all natural gas power plants in each region to produce regional emission performance rates for each category as shown in Table 3.0. Oklahoma is part of the Eastern Interconnection region, with great potential for increased utilization of natural gas and renewable energy.

Table 3.0 EPA's Technology Estimates of 2030 Building Block Potential Identified for Each Region (EPA, 2015b)

2030 Building Block Potential Identified for Each Region			
	BB1 – Heat Rate Improvement (HRI) for Coal Fleet	**BB2** - TWh of Total NGCC Generation at 75 % Utilization, (Amount of NGCC Generation Potential Incremental to Baseline)	**BB3** - Incremental RE Potential (TWh)
Eastern Interconnection	4.3%	988, (253)	438
Western Interconnection	2.1%	306, (108)	161
Texas Interconnection	2.3%	204, (66)	107

In this paper, the BSER Building Blocks are incorporated into the scenarios and modeled to provide a forecast for CO_2 emissions reduction, cost of investment and electricity, and risk. Cost-benefit analysis is conducted on all the scenarios to determine the best path for the state to comply with the CPP rule. Costs for the various generation technologies and fuel are based on the Energy Information Administration's (EIA) Annual Energy Outlook reports. Demand-side EE is not part of the BSER, but it is an important, proven strategy that states are already widely using due to its low costs and high potential. It can substantially and cost-effectively lower CO_2 emissions from the power sector. Oklahoma utilities are investing in demand-side energy efficiency and conservation voltage reduction (CVR) measures to reduce energy consumption outside the fence line. These projects are already in progress; some measures are in place, and others will be implemented at a future date (AEP, 2015; OG&E, 2015). These measures affect power consumption the same way in all three scenarios. These changes are reflected within the total load estimation by the utilities, so it is not included in the models.

3.3 Linear Programming

Linear Programming (LP) is a mathematical technique that finds the optimal solution in allocating limited resources and optimizing them to achieve the best outcome. The classical LP problem, starting with Dantzig's basic formulation (Dantzig, 1951), consists of the determination of the decision variable vector (*x*) minimizing or maximizing a linear objective function F(x). This is subject to linear equality or inequality constraints that represent the boundary of the feasible region. Several different versions of the LP method have been proposed. In this research, the solution is obtained by means of the Simplex method, as implemented in the Microsoft Excel "Solver" function (Microsoft, 2016).

The following LP model's objective function is optimized to determine the minimum Total Cost of Electricity (TCOE) per MWh for the various scenarios.

The objective function: $$TCOE = \frac{\sum_{t=2012}^{2030} \sum_{i=0}^{n} (f_i * x_i) + Fc_i}{\sum_{t=2012}^{2030} \sum_{i=0}^{n} GEN} \quad (2)$$

The objective function is expressed as a linear combination of the product of the decision variables (f_i) and terms (x_i), where (f_i) is the decision variable controlled by the LP and represents the amount of a generation type (i.e. coal, natural gas, wind, etc.) in megawatt-hour (MWh) as listed below:

*(f_i) = (Decision Variable * Generation Resource (MW) * 8760 (Hours) * Capf)* (3)

Table 3.1 List of variables for the LP model.

Variables	Description	Units
CAP	Total generation capacity all sources	MWh/h
iCAP	Total instantaneous generation capacity all sources	MW
Capf	Capacity Factor	%
CO_2emi	Aggregate CO_2 emission all sources	Short Tons
CO_2lm	CO_2 emission limit as set by the CPP	Short Tons
cP	Aggregate generation capacity of coal steam power plants	MWh/h
cR	Coal steam capacity retirement/replacement	MW
eE	Aggregate Energy Efficiency	MWh/h
hP	Hydroelectric generation capacity	MWh/h
ngP	Aggregate generation capacity of NGCC plants	MWh/h
mI	EGU module type (i.e. coal, NG, wind)	MW
ogP	Aggregate generation capacity of oil and gas steam plants	MWh/h
sP	Aggregate generation of photovoltaic plants	MWh/h
Xi	Decision variable associated with generator capacity	
wtP	Aggregate generation capacity of wind turbine farms	MWh/h

The decision variable (f_i) is iterated according to the specific action considered. The goal is to optimize the objective function for minimal total cost of electricity, meeting electric generation demands, and CO_2 emissions reduction targets.

The Levelized Cost of Electricity (LCOE) is represented by (x_i) for new generation capacity and production cost for existing plants and is equal to:

$$x_i = (VC_i + fc_i) \qquad (4)$$

The variable O&M cost is VC_i, and fc_i is the fuel cost per MWh. Fixed cost (FC_i) is the yearly fixed operation and maintenance (O&M) cost of the plant and is separated from LCOE to account properly for the fixed cost in the case of plants are used below their capacity factor.

The following constraints are applied to the program in order to formulate the best scenario.

- Total CO_2 emissions must be at or below the CPP target.

$$\sum_{t=2022}^{2030} \sum_{i=0}^{n} CO_2emi < CO_2lm \qquad (5)$$

- Total generation capacity (MWh) from all sources cannot be less than the base-case output generation capacity plus forecasted growth.

$$\sum_{t=2012}^{2030} \sum_{i=0}^{n} CAP => Load \qquad (6)$$

- Total instantaneous output (MW) of all plants available to meet instantaneous demand, cannot be less than the base-case output generation capacity plus forecasted growth.

$$\sum_{t=2012}^{2030} \sum_{i=0}^{n} iCAP => Load \qquad (7)$$

- The wind and solar upper limit is set at 40% of the total planning capacity to ensure reliability of present grid structure and to reduce transmission congestion and wind curtailments.

$$\sum_{t=2012}^{2030} \sum_{i=0}^{n} sP + wtP =< 0.40\, CAP \qquad (8)$$

  The 40% upper limit constraint of total electric generation capacity was chosen because it is in-line with the SPP's 2016 Wind Integration Study, which shows that wind energy penetration up to 45% level into the SPP region, including Oklahoma, is feasible and will not require extensive infrastructure if changes are made to operational practices. Increasing wind and solar power integration beyond this level will require a detailed study of the distribution network capacity in potential wind areas to handle the additional power without congestion and curtailment, and the addition of backup power. This is beyond the scope of this research.

LCOE represents the real cost of electricity per kilowatt-hour in discounted real dollars over the lifetime of a generating asset. It provides a consistent method to compare different types of electricity generation technologies. It is determined by a complex set of factors that include economic conditions, energy use and efficiency, capital costs in present and new generations, discount rate, the competitiveness of the electricity supply market, fuel costs, O&M costs, transmission upgrades, state and federal incentives and regulations, location, weather conditions, and the capacity factor of each plant type. The estimated LCOE values are obtained from the EIA's Annual Energy Outlook 2015 report (EIA, 2015).

This LP model is not meant to be a full energy systems modeling program. It is specifically designed to solve the problem of finding the optimum combination of resource generation types (i.e. coal, natural gas, wind, solar, hydropower, EE) that will achieve the quantitative criteria of the objective function. It is optimized to find the lowest cost of electricity by selecting the proper combination of generation resources within the defined constraints, while meeting the CO_2 reduction targets of the CPP starting from 2022 until 2030 (Figure 3.1).

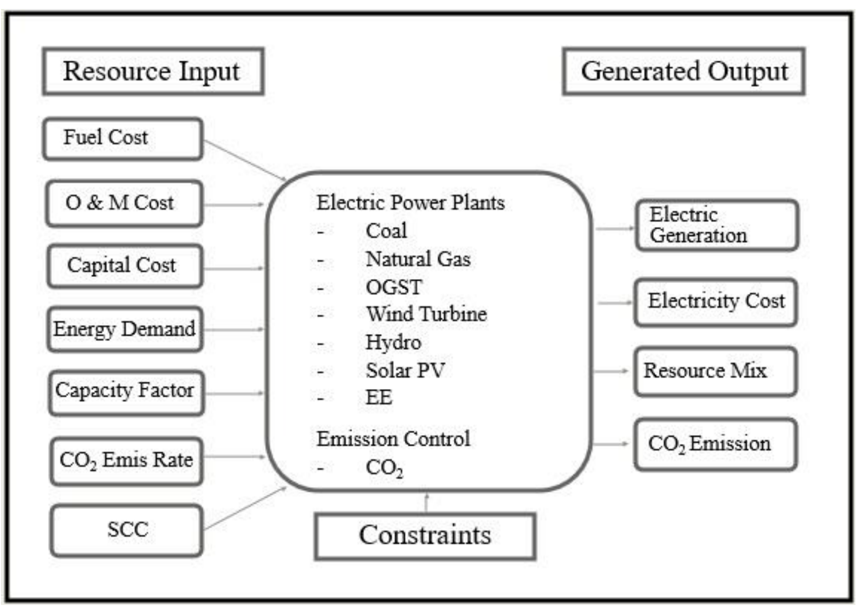

Figure 3.1 LP Model Structure

Projections made by the LP model are highly sensitive to fuel costs and carbon taxes. All three scenarios are tested to determine their sensitivity level to the aforementioned elements. The complex modeling and computation of economic, physical, and ecological systems that are needed for the forecasting of future fuel prices, and LCOE values for various energy generation resources, are created by the EIA's National Energy Modeling System (NEMS). These values are found in the Annual Energy Outlook Report (EIA, 2015). The social cost of carbon (SCC) values were produced by the Interagency Working Group (IWG)'s Integrated Assessment Models.

3.4 Mixed Integer Linear Programming

Mixed Integer Linear Programming (MILP) is similar to the LP methodology, where the solution is obtained by means of the Simplex method, as implemented in the Microsoft Excel "Solver" function (Microsoft, 2016). The main differences are in setting Solver for handling mixed integers and the addition of constraints to handle mercury, particulate matter, and sulfur dioxide emissions. The mixed integer approach controls all of the decisions to retain or retire generation plants under the cost minimization model. Using only linear programming with continuous decision variables would not represent discrete phenomena encountered in facility siting and power expansion problems as precisely as MILP. A high-resolution model would require that structural discrete entities with their capital and fixed costs are represented by integer decision variables, while the operational characteristics are represented by continuous decision variables (Antues et al., 2001).

The model's objective function is optimized to determine the minimum Total Cost of Electricity (TCOE) per MWh for the various options.

The objective function: $$TCOE = \frac{\sum_{t=2012}^{2030} \sum_{i=0}^{n} FC_i * S_{i,t} + (f_i * x_i)}{\sum_{t=2012}^{2030} \sum_{i=0}^{n} GEN} \quad (9)$$

Where, (FC_i) is the yearly fixed capital cost and O&M cost of the plant. It is separated from the LCOE to account properly for the fixed cost in case of plants are deployed below their full capacity factor.

The binary variable ($S_{i,t}$) indicating unit selection (i) for the planning period (t). Set to “1” if the decision variable for selecting the power is at any value above “0”, else it is set to zero, $S_{i,t} \in \{0,1)$.

$$(f_i) = (Decision\ Variable) * mI\ (MW) * 8760\ (Hours) * Capf) \quad (10)$$

The continuous variable (f_i) is iterated by a decision variable with a range from (0 to 1) according to the specific action considered. The goal is to optimize the objective function for minimal total cost of electricity, while meeting electric generation demands, and achieving environmental emissions reduction targets. The electric generation unit module (*mI*) represent the EGU group type (*I*) (i.e. coal (retrofit), coal (convert), NGCC, wind, solar).

The LCOE is represented by (x_i) for new generation capacity and the production cost for existing plants, and is equal to:

$$(x_i) = (VC_i + fc_i) \quad (11)$$

The variable O&M cost is (VC_i), and (fc_i) is the fuel cost per MWh.

The following additional constraints are applied to this scenario in order to control mercury and sulfur dioxide emissions:

- Mercury emissions must be at or below the MATS target.

$$\sum_{t=2016}^{2030} \sum_{i=0}^{n} Hgemi < Hglm \quad (12)$$

- Sulfur dioxide emissions must be at or below the RHR target.

$$\sum_{t=2019}^{2030} \sum_{i=0}^{n} SO_2emi < SO_2lm \quad (13)$$

- Particulate Matter emissions must be at or below the MATS target.

$$\sum_{t=2016}^{2030} \sum_{i=0}^{n} SO_2emi < SO_2lm \quad (14)$$

Unlike the CPP, where CO_2 constraint can be set on a rate basis or mass basis for the whole state. The MATS and the RHR pollutants constraints are set on a rate basis of (lb/MMBtu) or (lb/GWh) and are applied to the emitting source.

3.5 Modeling Scenarios

In order to determine the cost of the proposed changes to the generation resources mix required to meet the CPP target, three scenarios with plausible outcomes are created. The selected scenarios focus on the factors expected to shape the state energy markets through 2030. This takes into consideration environmental regulations including the MATS, the RHR, the CPP, and the growth of wind and solar energy. Together with lower natural gas prices, these changes significantly affect the projected electricity generation fuel mix and represent highly plausible outcomes.

The modeling scenarios are the:

- RHR and MATS (RM): this scenario models the changes that the utilities are planning or in the process of making to their generation fleets to meet the RHR and MATS regulations, and their impacts on CO_2 emissions and electricity cost. This case is also considered the base-case as there is no constraint on carbon emissions and some of the changes are already implemented and the rest are in progress regardless of the outcome of the CPP rule.
- Generic Industry (GI): this scenario is similar to the RM scenario. The main difference is instead of modeling the impact of the CPP based on Oklahoma's utilities

plans for compliance with the RHR and MATS rule, this scenario models the most cost-effective option for the industry to comply with MATS and RHR requirements. It then determines if any additional changes are needed to comply with the CPP, making it more applicable to other regions.

- Beyond Coal (BC): in this scenario it is assumed that all coal plants will be supplanted by natural gas plants in response to stricter government regulations and the high availability of natural gas.
- Carbon Tax (CT): this scenario adds a carbon tax with ascending trajectory over time in order to find at what price level renewables will become more competitive.

3.5.1 RHR and MATS Scenario

The baseline year used for cost and CO_2 emissions levels is 2012. Future fuel prices used in this modeling (e.g. natural gas, coal, oil) are based on forecasts generated by the EIA’s Annual Energy Outlook report (EIA, 2015). In this scenario, it is assumed that the laws and regulations in place in 2012, and natural market growth and forces for energy supply and demand are continuous. The projections provide regulation-neutral baselines that can be used to analyze the impacts of the CPP rule.

Compliance with MATS and RHR has forced power producers to take a hard look at the older, less efficient coal plants in their fleets to determine whether adding emissions control equipment is an economical way to bring those plants into compliance. The alternative is that some other option would be more practical. Such options include converting coal plants to natural gas, or shutting them down and replacing that capacity with highly efficient plants like natural gas combined cycle or renewables. Different strategies were pursued by Oklahoma’s utilities to comply with the above rules. This scenario will model the aggregate effects of their strategies and will project the impact of these laws on CO_2 emissions in the state.

The MATS' regulations compliance cut-in date was in the first quarter of 2016, and the RHR's date starts by 2019. As part of Oklahoma’s utilities compliance plans with the MATS and the RHR regulations, 3.2 GW of coal-fired units are planned for retirement. Some units will be converted to natural gas-fired steam, while others will be replaced by NGCC, simple cycle GT units, and wind power between 2016 and 2030 (AEP, 2015; OG&E, 2015; GRDA, 2016).

3.5.2 Generic Industry (GI) Scenario

This scenario assesses the impacts of compliance with the MATS, RHR, and CPP rules, and is based on the existing generation capacity and forecasted electricity demand in Oklahoma. Unlike the previous scenario that analyzed the impact of the CPP in the context of planned retirements of coal plants, this scenario makes no assumptions about changes or retirement of coal plants. Instead, it models the most cost-effective option for enabling the industry to comply with the MATS and RHR requirements and then determines if any additional changes are needed in order to comply with the CPP. The results of this scenario are relevant to other regions because all changes in generation activity are based on the optimal response to environmental regulation constraints instead of announced or planned changes. The methodology of this section could be easily adapted to other regions in cases where information on planned changes is not available.

The emissions that are tracked in this scenario in addition to CO_2 are: mercury, particulate matter (it is used as a surrogate for the rest of the toxic metals), sulfur dioxide (it is used as a surrogate for the rest of the acid gases), and nitrogen oxide. Their numerical standards and emissions limits are listed in Table 3.2.

Table 3.2 Air Pollution Numerical Standard (EPA, 2012)

Pollutant	Limit lb/GWh Existing Coal EGU
Mercury (Hg)	0.013
Sulfur Dioxide ($SO_{2)}$ (RHR)	60
Nitrogen Oxides (NO_x)	530
Filterable PM	300

3.5.3 Beyond Coal Scenario

The Beyond Coal scenario is a what-if scenario that assumes all the coal power plants in the state will be phased out either due to strict environmental regulations or market conditions. These units will be supplanted by high efficiency natural gas combined cycle power plants, wind and solar energy, and simple-cycle gas turbines. This scenario reflects stricter environmental regulations that would result from the U.S. government's commitment to the Conference of the Parties (COP) in Paris in 2015 (United Nations Framework Convention on Climate Change [UNFCC], 2015). This is currently on hold, but the intent is to keep temperature increase below 2º C by the end of the century. Ratification of the treaty by the U.S government would mandate deeper CO_2 emissions cuts in the next 10 to 15 years. Achieving that goal would require cutting CO_2 emissions from the proposed 30% below the 2005 level to 50% below the 2005 level (Kharas et al., 2015). For Oklahoma, that would require a further decrease in the CO_2 emission target level from 41 million short tons to 26 million short tons.

This scenario models the impact of such regulations. It reflects a trend that started about ten years ago with new gas power plants replacing the aging coal fleet nationwide as natural gas availability increased and prices decrease. Wind energy was also becoming more affordable and efficient at this time. This trend is expected to continue in the future (EIA, 2015), and will accelerate as gas turbine efficiency and reliability continue to improve. Their flexibility to quickly cycle-up and down make them an excellent resource to balance wind and solar energy intermittencies, and to regulate their output capacity.

3.5.4 Carbon Tax Scenario

In this scenario, a carbon tax with ascending trajectory over time is developed to discern at what price level the tax will stimulates the use of clean technology. Stimulating the increase of renewable technology with the carbon tax would drive market innovation and fuel new, low-carbon drivers of economic growth (Morris, 2013). The added carbon tax to the CO_2 emissions surcharge is levied on a per megawatt-hour basis on all fossil fuel powered EGUs. This could account for some of the externalities of using fossil fuels in power plants and helps in shifting the burden for the damage back to those who are responsible for it and who can reduce it. There are several paths for governments to take to set a price on carbon. It could set a price equal to the externalities that cause serious harm to our health and environment at $187 billion annually or 9.3 cents per kWh (Epstein et al., 2011). Another option is to set a cap and trade system and allows those utilities with low emissions to sell their extra allowances to larger emitters, creating supply and demand for emissions allowances and establishing a market price for GHG emissions (EPA, 2003).

In this scenario, the model gradually increased the carbon tax and showed where the shift to renewable energy would naturally occur. The revenue from the tax could be invested in energy efficiency programs to further reduce energy consumption and pollution emissions. It could also be used to help the state balance its budget, and part of it could be used to fund programs to help impoverished families with their utility bills.

This scenario highlights the risk of stricter environmental regulations on investing in and upgrading existing coal plants, and to existing less efficient natural gas plants to a smaller extent. The introduction of carbon tax into the electricity market would weaken the economic competitiveness of fossil fuels relative to renewable forms of energy through extra costs incurred. The effects of such regulations could cause these power plants to underperform as they become too expensive to dispatch and subsequently turn into stranded assets to utilities, investors, and ratepayers.

There currently is no nationwide carbon tax that has been imposed in the United States, but carbon tax is instituted in other countries. Worldwide there are about 40 national jurisdictions and over 20 cities, states, and regions —representing almost a quarter of global GHG emissions —putting a price on carbon. In North America, California and Québec's cap and trade programs expanded their GHG emissions coverage from about 35 to 85% by including transport fuel (World Bank Group [WBG], 2015).

3.6 Cost-Benefit Analysis

Cost-benefit analysis will be used to compare the cost of the various scenarios of generation resources, as created by the LP model, to their associated environmental and social benefits. The social and environmental cost-benefits are calculated based on the reduction of CO_2 emissions achieved, multiplied by the SCC value to estimate the cost-benefits of that particular scenario. The general structure of the benefit assessment for the different environmental problems involve two main elements: (a) Importance of the issue, which encompasses a brief discussion stating how public and expert opinion rank the issue as a serious environmental problem, and (b) Monetary Valuation, in which the measurement of benefits is essentially the measurement of avoided damages. In this context, the cost-benefit information allows for the computation of the net gains from an investment (benefits minus costs). This can be used as a means of comparing the desirability of alternative investments. Those with positive net benefits increase the welfare of society while those with net costs decrease welfare (Pearce et al., 2006).

The SCC on the other hand is a new method and is the product of the combined efforts of 12 government agencies. It is defined as the marginal global damage costs of carbon emissions and is usually estimated as the present economic value of damages associated with the release of one additional metric ton of CO_2 in a given year (IWG, 2015). The SCC is used to incorporate the social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that impact cumulative global emissions.

To calculate the value of the SCC, the IWG uses the Integrated Assessment Models (IAMs). The IAM is a complex scientific modeling tool that starts with GHG increases and their impact on temperature. It then moves into the temperature increase's impact on ecosystems, farms, food production, forests, coastal destruction, human health, and the economy on a global scale. The model then computes the complex task of figuring out what the future damage costs in today's dollars (IWG, 2015). In constructing the tool, the IWG linked together three global climate and economic models. The models are William Nordhaus' Dynamic Integrated Climate-Economy (DICE) model (Yale University), Richard Tol's Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model (Sussex University), and Chris Hope's Policy Analysis of the Greenhouse Effect (PAGE) model (Cambridge University). This integration of models helps in taking a unit of carbon emissions from burning fossil fuel and translates it into an estimate of the cost of the long-term damage that GHG emissions will have on the environment, public health, well-being, and quality of life in terms of dollars. The models also allow a weighing of the costs and benefits of policies aimed to slow greenhouse warming. These models are based on the best available science and economics from peer-reviewed publications (EPA, 2015f).

The IWG reports the estimates for the social cost of carbon pollution in dollars per metric ton of CO_2. Even though the SCC is based on the best available science and economic information, it is not without weakness and detractors. In terms of weakness, the core logic software behind IAMs (DICE, PAGE, and FUND) currently do not include all of the up to date physical, ecological, and economic impacts of climate change (i.e. ocean acidification, rapid sea level rise, wildfires, changes in heat, and precipitation extremes). It does not include the possibilities of catastrophes or tipping points. This exclusion is mainly due to the lack and lag of precise information on the nature of damages that need to be incorporated into these models (IWG, 2015). In terms of detractors, there is plenty of opposition to its use mainly by oil companies, coal companies, electric utilities, and their political allies. They are currently lobbying the Trump administration to rescind it, as it plays a central role in evaluating and quantifying the costs and benefits of environmental regulations. A low or zero SCC value would make it harder for the EPA to justify a strong carbon pollution limit (Morgan et al., 2017).

In 2015, the group selected four SCC values to use in regulatory CBA analyses. These values are based on the average SCC estimates from the DICE, PAGE, and FUND models at a discount rate of 2.5, 3, and 5 percent. This equates to $56, $36, and $11, respectively. The fourth estimate of $105 uses a 3% discount rate and describes the 95th-percentile value of the normal distribution curve. It attempts to capture the damages associated with extreme climatic outcomes further out in the tails of the distribution curve (Table 3.3). The discount rate is how economists measure the value of money over time. Using a higher discount rate to estimate the SCC values will minimize the value of future damages from CO_2 pollution and show a bias to favor present generation over posterity, when used in cost-benefit analyses.

The cost-benefit analysis for the environmental and social impacts of the CPP rule on Oklahoma would be mainly based on compliance cost and the projected cost of global warming damages associated with increasing anthropogenic CO_2 emissions. These damages are linked to the quantitative increase of GHG emissions and the concomitant hazardous emissions as monetized by the SCC. Policies that reduce GHG emissions can also reduce outdoor levels of air pollutants that harm human health by targeting the same emissions sources (EPA, 2015a).

Table 3.3 Summary of the four SCC estimates (IWG, 2015)

SCC Discount Rate Statistic				
Year	5% Average	3% Average	2.5% Average	3% 95th percentile
2015	$11	$36	$56	$105
2020	$12	$42	$62	$123
2025	$14	$46	$68	$138
2030	$16	$50	$73	$152
2035	$18	$55	$78	$168
2040	$21	$60	$84	$183
2045	$23	$64	$89	$197
2050	$26	$69	$95	$212

The SCC values that are used in this research are based on the 2.5% discount rate values. This rate was chosen because the SCC is not an exact science, but rather a best effort at estimating the impacts of climate change. According to the IWG, the SCC is limited in coverage, and since it does not include up-to-date information (IWG, 2015) it underestimates the impacts of global warming.

To assess the net social benefit of the CPP rule compared to the costs of compliance, the study will take the reduction of CO_2 emissions that is attributed to the implementation of the CPP rule and multiply those tons of CO_2 by the value of SCC. That number is then counted as a social benefit. The projected benefit would be based on the avoided damages associated with the decrease of CO_2 emissions and associated pollutants resulting from the implementation of the CPP rule. Other benefits associated with the wind industry construction and operation activities (e.g. job creation, ad valorem tax revenues, and payments to land owners) will also be added.

CHAPTER IV

RESULTS

This chapter provides some of the important results from the methodologies used to analyze Oklahoma's present power system and forecast its future path to a low carbon emission power system. In 2012, the bulk of Oklahoma's electric generation came from EGUs that are affected by the CPP rule. Natural gas combined cycles and coal-fired steam tied for the top generator of electricity, with 38.39% and 37.43% production respectively. Oil and gas steam generation placed third at 10.92%, followed by wind at 10.31% (Table 4.1).

Table 4.1 Oklahoma actual 2012 total electric generation (EPA, 2015a)

2012 Total Electric Generation	Summer Generation Capacity (MW)	Electricity Production (MWh)	Percentage of Total Generation	Calculated Capacity Factor
COALST	5,231	29,102,160	37.43%	63.52%
NGCC	7,156	29,852,813	38.39%	47.62%
OGST	5,064	8,488,758	10.92%	19.14%
Wind	3,297	8,020,367	10.31%	27.77%
Hydro	1,058	1,097,705	1.41%	11.84%
Misc.	3,633	1,194,232	1.54%	3.75%
Total	25,903	77,756,035	100.00%	

A quick review of Table 4.1 shows that Oklahoma has more natural gas (NGCC) generation capacity than coal (COALST) generation capacity, but coal units were dispatched at higher rates than natural gas units. The criteria for dispatching these units are based on the Federal Energy Regulatory Commission's (FERC) Security Constrained Economic Dispatch (SCED). Section 1234 of EP Act 2005 defines SCED as: the operation of power plants to produce energy reliably and at the lowest cost to consumers. The security aspect of the SCED directive is to ensure the supplier's optimal dispatch can meet the customer's load demand reliably. As a consequence of the SCED guideline, a majority (63.8%) of CO_2 emissions, as reported by Oklahoma's power system portfolio in 2012, were generated by coal plants (Table 4.2). Externalities, such as environmental and public health impacts of concomitant pollutants, are not part of the economic dispatch equation.

Table 4.2 Actual 2012 Oklahoma total CO_2 emission (EPA, 2015a)

2012 Total Carbon Dioxide Emissions All Sources	Emission Rate (Lb/MWh)	CO_2 Emission (Short tons)	CO_2 Emission (Percentage)
COALST	2,309	33,592,415	63.79%
NGCC	884	13,201,556	25.07%
OGST	1,382	5,865,837	11.14%
Wind	0	NA	0.00%
Hydro	0	NA	0.00%
Misc.	0	NA	0.00%
Total		52,695,809	100.00%

According to the CPP rule, 2005 is considered the base year for the comparison purposes of CO_2 emission reduction. The EPA uses the year 2012 as the reference year for comparison. This is because 2012 was the last year the EPA had complete data at the time of the proposal, and using the most recent data more acutely reflects the current status of the industry (EPA, 2015d). The 2012 CO_2 emission data and future CO_2 emission projections, based on the utilities future generation plans, will be providing reference points needed for understanding how each model formulation will impact generation, cost, and emission reduction in comparison to the CPP's target.

The following modeling sections show the outputs of four scenarios that would solve the generation capacity resource mix. The models are optimized for the lowest electricity cost resource within a set boundary delimited by defined constraints. The output of the LP models is illustrated in a temporal graphical representation over the CPP's time horizon (2022-2030). It includes: capacity, production cost, CO_2 emission, and environmental cost/benefits. The data is generated to foster quantitative assessments of the plausibility of each scenario's ability to meet the CPP target. Identifying cost in terms of generation and impact across the models will aid in understanding which combination of energy resources will be the most beneficial solution for Oklahoma.

4.1 RHR & MATS Scenario

The Regional Haze Rule and Mercury and Air Toxics Standards (RM) Scenario (Figure 4.1) shows the generation capacity from 2012 to 2030 in the state. The decrease in coal generation started in 2016 with the Public Service Company of Oklahoma (PSO) retiring Northeastern (NE) Unit 4. In 2017, the Grand River Dam Authority (GRDA) retired Unit 1. Oklahoma Gas & Electric (OG&E) will convert Muskogee Units 4 and 5 from coal to natural gas starting in 2019. Following these conversions, PSO will gradually retire Unit 3 starting in 2023, and GRDA will retire Unit 2 in 2030 (AEP, 2015; GRDA, 2016; OG&E, 2015).

As coal units are retiring, utilities are adding new capacity. This process is starting with GRDA adding a total of 234 megawatt (MW) in wind capacity in 2017 and a new J-Class NGCC 495 MW unit with over 60% efficiency. This will be the first unit of its type in North America (GRDA, 2016). OG&E will repower Muskogee Units 4 and 5 with natural gas and add 20 MW of solar power in 2020 (OG&E, 2015). PSO is projected to add 600 MW of wind energy in 2020, 80 MW of solar power between 2021 and 2024, repower NE Unit 4 with natural gas in 2022, add

435 MW with an NGCC unit in 2023 (AEP, 2015), and repower NE Unit 3 with natural gas in 2026. The GRDA will replace Unit 2 with a natural gas unit in 2030. In this scenario, with no additional restriction on CO_2 emissions, the model illustrates that it is economically competitive to upgrade and install environmental retrofits on the remaining coal plants in order to comply with the RHR & MATS rules. This will keep over 2 GW of coal capacity in the state's fleet beyond the year 2030.

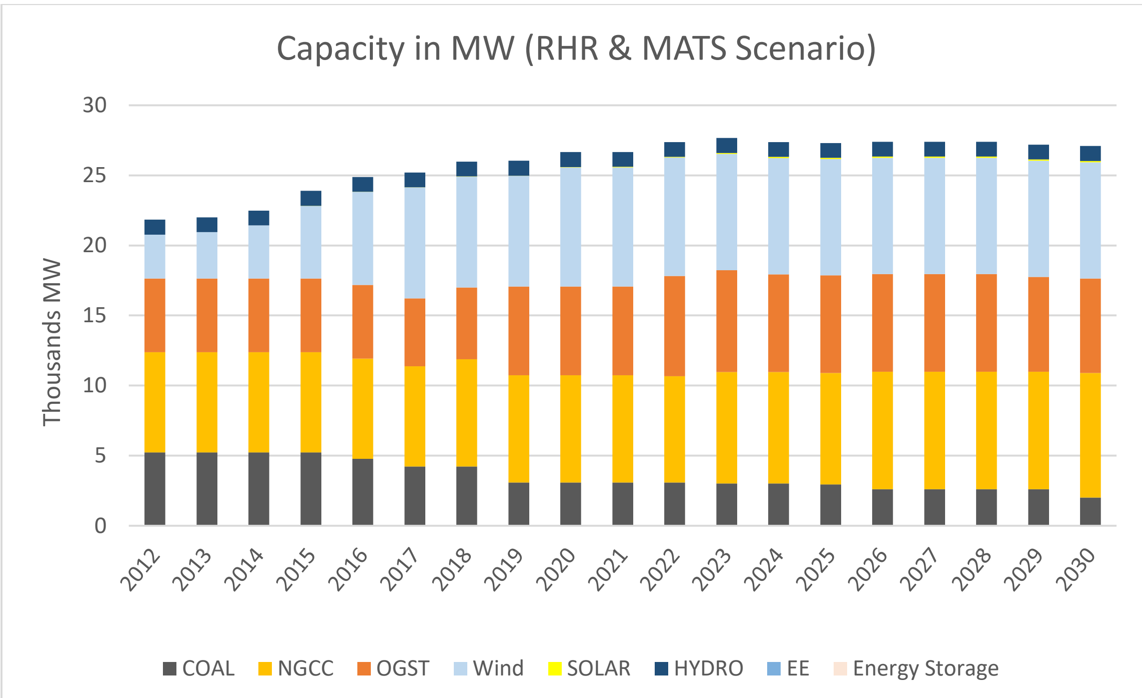

Figure 4.1 Oklahoma power system capacity in MW (RHR & MATS Scenario)

The power capacity in Figure 4.1 is used to calculate the power generation output in megawatt hours (MWh) illustrated in Figure 4.2. This is based on the projected capacity and the power factors from the EPA database as reported by the utility companies (EPA, 2015d). Capacity factors for the new units are based on projections from the Energy Information Administration's (EIA) Annual Energy Outlook report (EIA, 2015). The total output is plotted against the state's projected power requirements from 2012 to 2030 as forecasted by the utilities IRPs.

The power generation graph of (Figure 4.2) shows that 2016 marked a milestone for wind energy generation in Oklahoma. Wind generation supplied 25.3% of the state's electricity generation, edging out coal generation for the first time at 24%. NGCC units were the top producers at 34.9%, followed by OGST units at 11.2% (EIA, 2016b). This gradual shift in generation from coal to wind and natural gas will continue forward based on commitments utilities made to comply with the RHR and MATS rules.

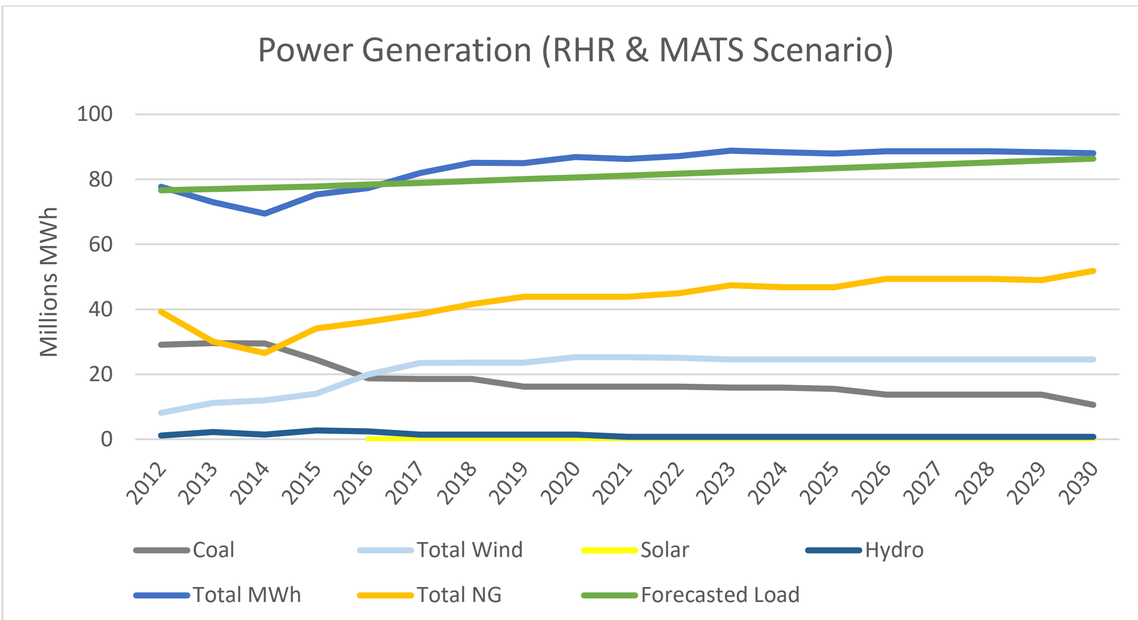

Figure 4.2 Oklahoma Power Generation in MWh (RHR & MATS Scenario)

Figure 4.3 presents the mass CO_2 emission output for the RM scenario simulation. It is plotted against the mass CO_2 emission goal set by the CPP rule over a timeline from 2012 to 2030. The graphical representation of the emission projection data provides a clear visual measure of compliance of the aggregate energy generation resources' emission in the time domain, where duration and magnitude are plotted against the CPP target. The resulting analysis reveals that Oklahoma will be in compliance with the CPP rule with no additional expenses beyond what the utilities have already committed to in order to comply with the RHR & MATS rules.

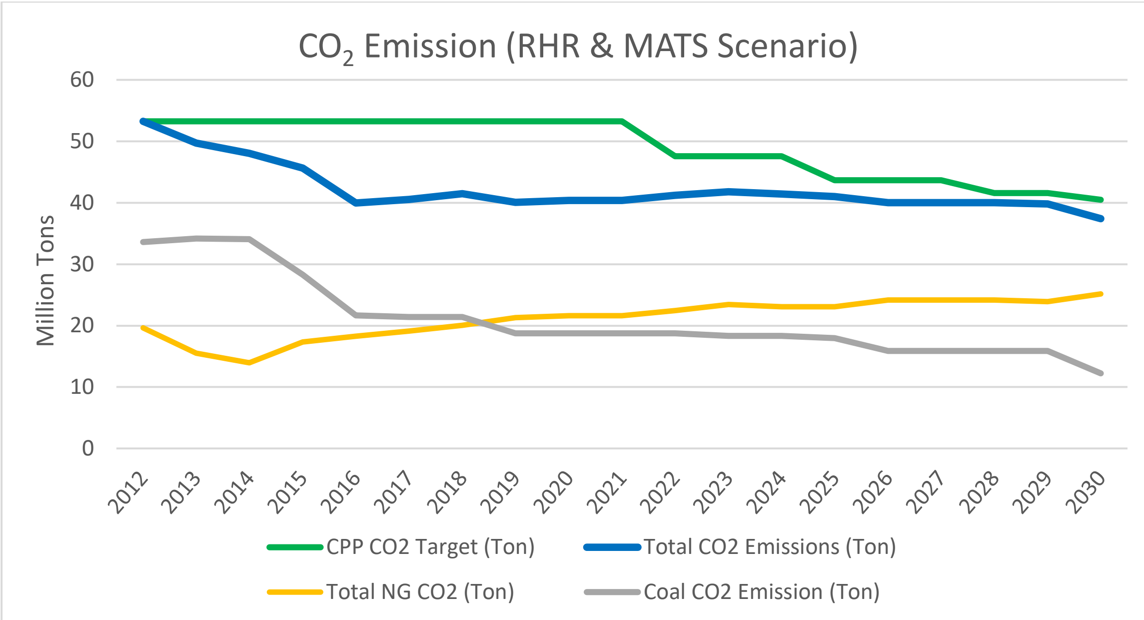

Figure 4.3 Oklahoma power sector CO2 emission in millions short Tons (RHR & MATS Scenario)

Figure 4.4 shows the cost for implementing the proposed changes to comply with the RHR & MATS rules.

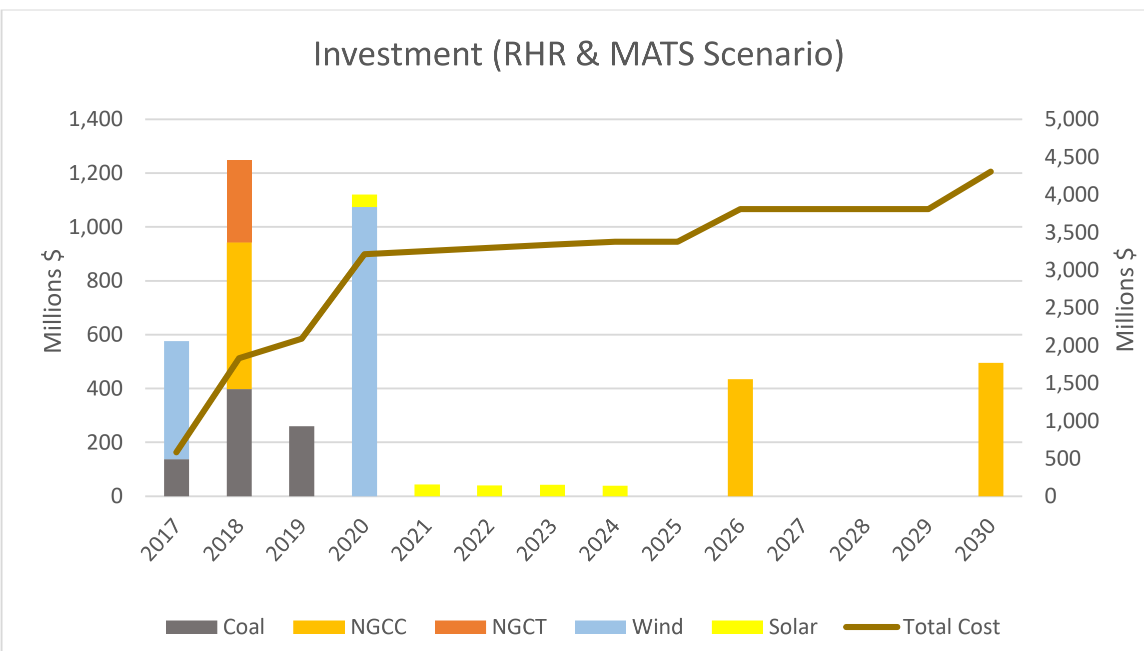

Figure 4.4 Oklahoma power system investment in million dollars (RHR & MATS Scenario)

The investment cost for this model and the timing for the build came from the utilities' IRPs (OG&E, 2015; AEP, 2015). The total investment cost is approximately 4.3 billion dollars in terms of 2015 dollars. Figure 4.5 shows the annual projected cost of electricity production, and the average cost in dollar per kilowatt hour ($/kWh). The analysis shows an increase of 21.89%, or 0.8 cent/kWh, by the year 2030 compared to 2012.

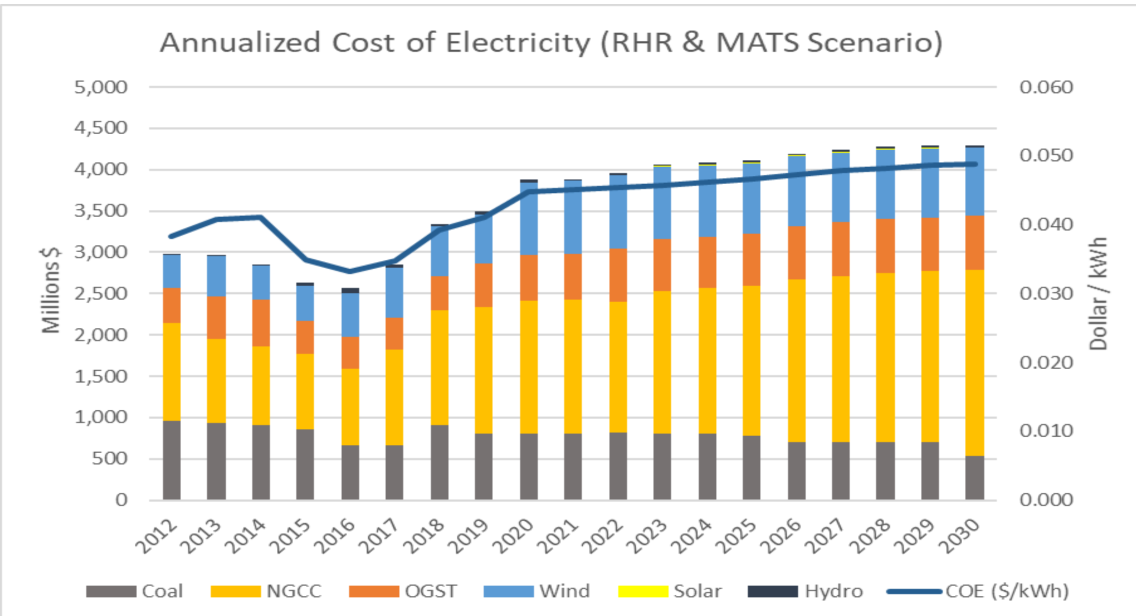

Figure 4.5 Oklahoma power system annualized cost of electricity (RHR & MATS Scenario)

4.2 Beyond Coal Scenario

In the BC scenario, the coal-fired steam generation is gradually reduced starting in 2020 from 3 GW down to zero by 2030 (Figure 4.6). In order to replace the remaining 3 GW of coal generation capacity, the model determines that wind energy is the most suitable replacement for coal units before selecting natural gas generation due to its lower cost and absence of emissions. The program settles upon wind energy up to its maximum set constraint of 40% (SPP, 2017) of total energy production. This insures the reliability of the electric system before it starts selecting NGCC units. No solar generation was selected by the model mainly due to its high cost and low power factor when compared to wind generation (EIA, 2017). The BC modeling result is similar to the strategy pursued by PSO to meet the RHR and MATS rules (PSO, 2015), wherein PSO completely phased out coal plants in Oklahoma and replaced them with natural gas and wind generation units.

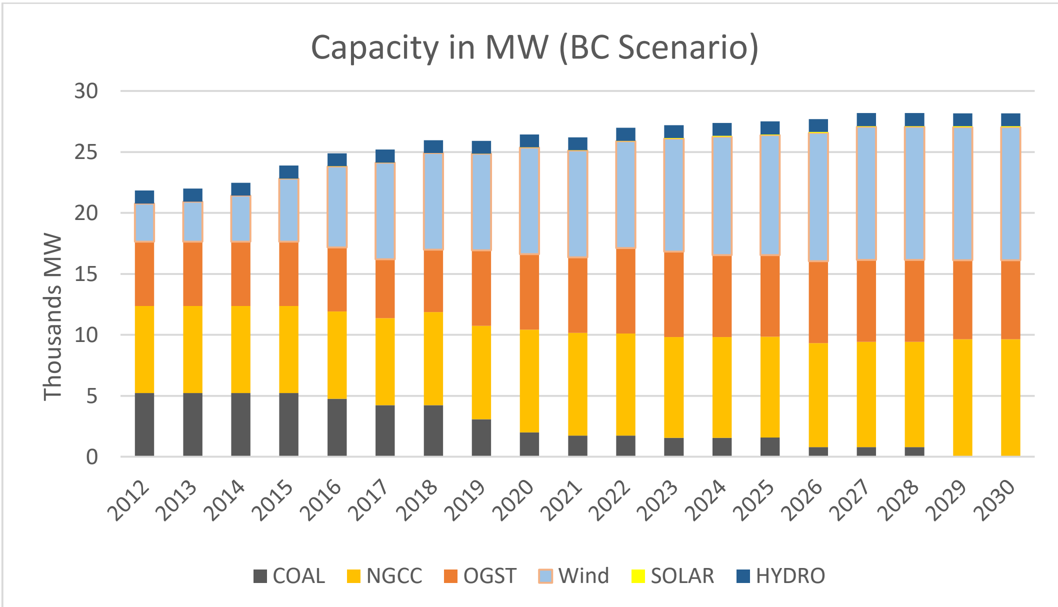

Figure 4.6 Oklahoma power system capacity in MW (BC Scenario)

Under this scenario, the reduction of coal generation stimulates the growth of natural gas and wind capacity. The resulting energy mix in 2030 is drastically different from the RHR and MATS (RM) scenario (Figure 4.7). Coal energy decreases from 12% to 0% as would be expected, natural gas electric energy increases from 58.8% to 61.4%, wind energy increases from 27.9% to 36.8%, and there is no change for solar energy.

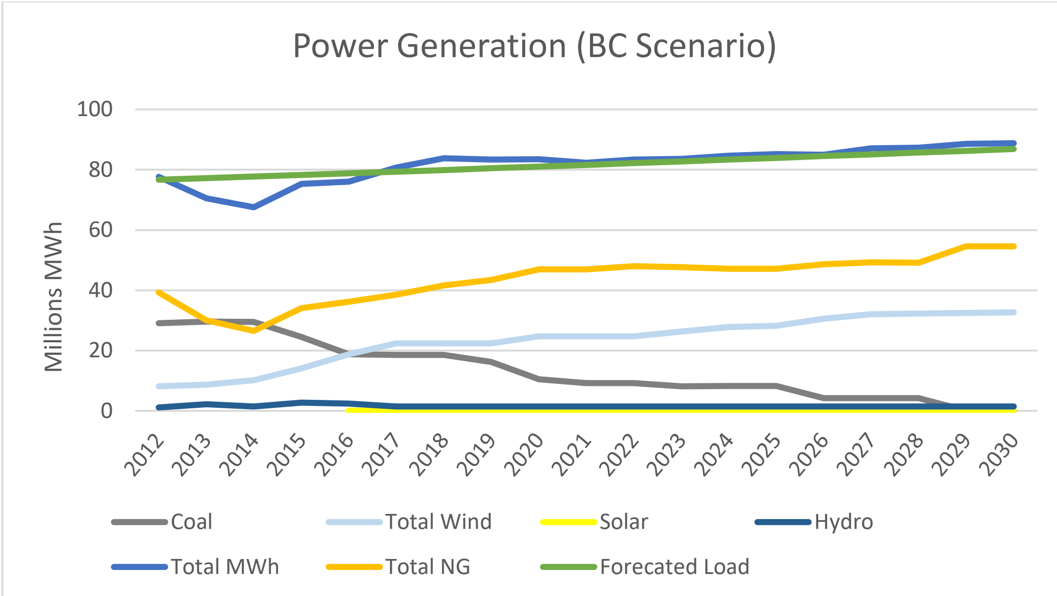

Figure 4.7 Oklahoma Power Generation in MWh (BC Scenario)

The requirement for cleaner energy resources is reflected in its CO_2 emission profile (Figure 4.8). CO_2 emissions are aggressively reduced over the CPP horizon to 50% when compared to the 2012 CO_2 level in compliance with the COP21 requirement. It is also 42% below the CPP 2030 target. This is mainly achieved by the retirement of coal EGUs, which emit the highest levels of hazardous emissions and replacing that capacity with natural gas and wind generation. The phasing out of coal plants will remove 51,252 tons of sulfur dioxide and 16,716 tons of nitrogen oxides (EPA, 2015e). Crucial information from this scenario shows that (Figure 4.8) if additional CO_2 emission reduction is required beyond 2030, natural gas generation will have to be reduced and more renewable energy will have to be deployed.

In one of the simulation runs, the CO_2 emissions cap was set to zero to see what the result would be. The LP model added wind and solar to their maximum limit and then added natural gas combustion turbine (NGCT) power to meet the rest of the load demand. The total CO_2 emission under this scenario was not increasing. It appeared as an error in the model; however, it was later found that the CO_2 emission from the NGCT unit was not being added to the total CO_2 emission.

This occurred because they are exempt under the CPP rule (EPA, 2015b). The EPA considers NGCT units as peaking units, since they run infrequently for short durations to help electric systems meet short-term increases in electricity demand related to ramping or when loads are peaking. Overall, their capacity factor and share of total CO_2 emissions is very small. Based on their small share of total generation, the EPA exempted NGCT units from the CPP rule (EPA, 2015a). The model had no limit set on using NGCTs. When the model needed to add capacity without adding emissions to meet load demands, the NGCT met the criteria. This highlights the fact that as NGCT technology advances by improving their power factor and efficiency, deploying NGCTs in large numbers could become a loophole to circumvent the CO_2 emission cap level.

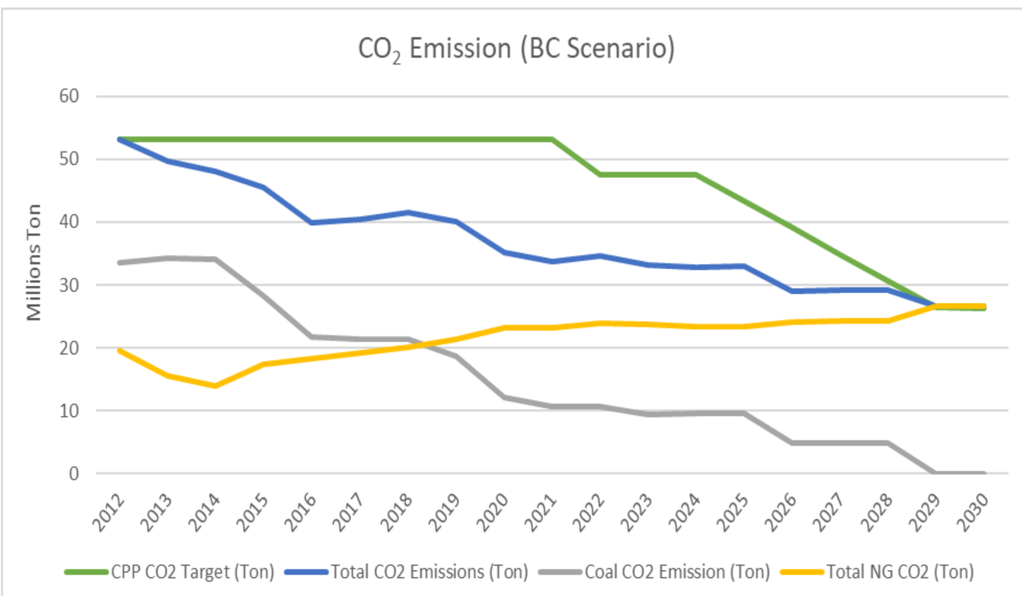

Figure 4.8 Oklahoma power sector CO_2 emission in millions short Tons (BC Scenario)

The investment cost for capital equipment is spread over time and totals up to approximately $9 billion (Figure 4.9). This is an increase of $3.5 billion over the RM scenario, reflecting the intensive upfront investment cost needed for wind generation. The cost of energy (Figure 4.10) is almost the same for both scenarios at 0.05 $/kWh. This is because fossil fuel generation costs account for the majority share of the operating cost. The majority of the cost for wind and solar energy generation is attributed to capital cost, with zero fuel costs. This shows that adding wind energy in Oklahoma is a competitive option even with existing coal generation. Wind energy also has low environmental impacts and less volatile cost over time.

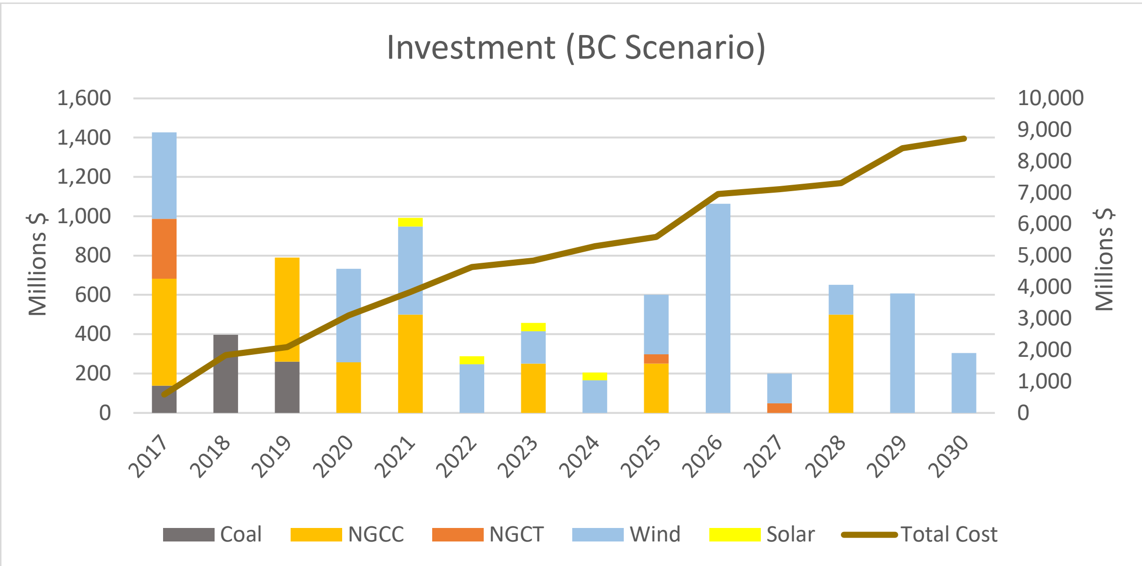

Figure 4.9 Oklahoma power system investment in Million Dollars (BC Scenario)

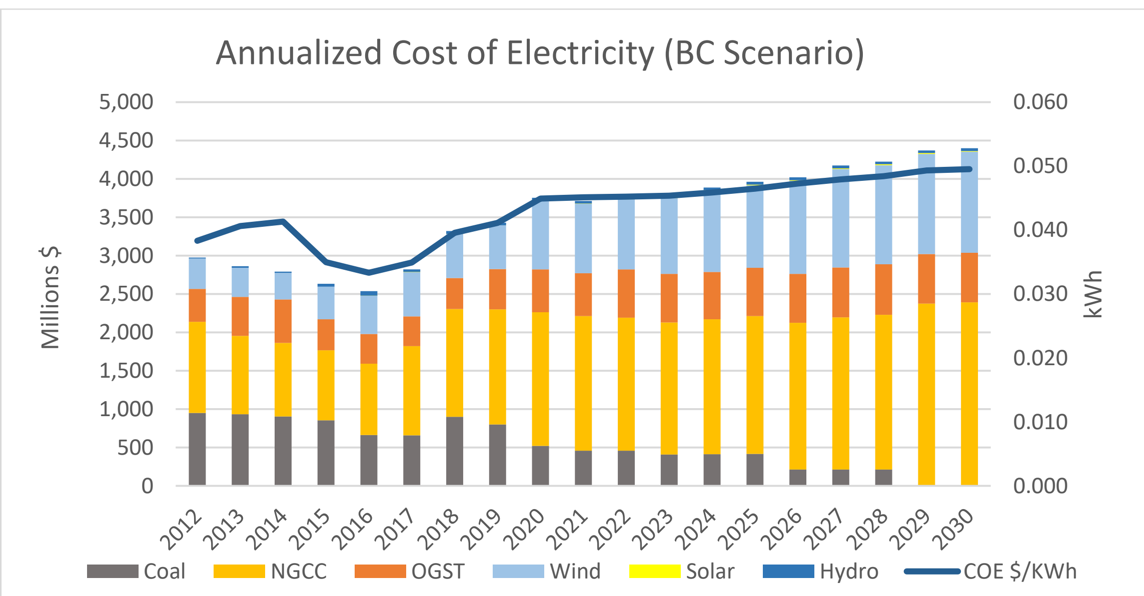

Figure 4.10 Oklahoma power system annualized cost of electricity (BC Scenario)

4.3 Carbon Tax Scenario

The outcome achieved in the RM scenario demonstrates that CPP compliance will be achieved with no additional measures or costs beyond the measures needed to comply with the RHR & MATS rules. The carbon tax level needed to meet the CPP emission reduction is essentially zero. This scenario shows at what level of carbon tax coal generation would be phased out and replaced with cleaner technologies. The LP model starts adding carbon tax with the commencement of the CPP interim period starting with the year 2022. The model selects the existing coal generation with no renewable generation added (Figure 4.11). This result is expected as the LP model is optimized for choosing the energy resource with the smallest cost. As the carbon tax is gradually increased, starting in 2022, the program chooses wind energy consistently at $14/ton carbon tax. The model continues to reduce coal energy and add wind energy until it reaches its constrained level of 40%. At this point, the program starts to add more natural gas, but solar energy remained unselected. Upon reaching a carbon tax value of $24/ton (starting in 2028), the model adds solar capacity.

The CT model adds solar capacity only after the carbon tax is $24/ton in 2028. This is based on the LCOE values provided by the EIA's Energy Outlook Report for 2015. Other LCOE forecasts show much lower costs for wind and solar photovoltaic (PV) capacity. Researchers found systematic under-prediction of renewables in a dozen of EIA's outlooks (Gilbert et al., 2016). Some of the discrepancies in underestimating wind and solar capacity range between 55% to 93% over a 4- to 10-year period (Gilbert et al., 2016). The EIA's Outlook Energy Report 2015 forecasted solar PV costs at $2,480 per kW for the year 2017.

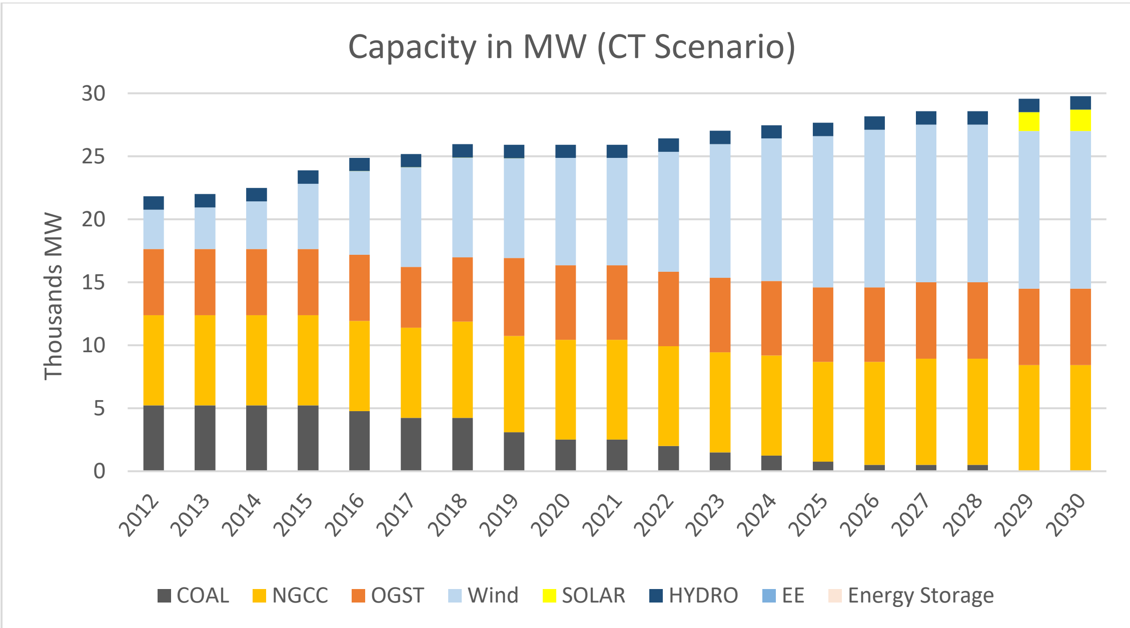

Figure 4.11 Oklahoma power system capacity in MW (CT Scenario)

The Solar Energy Industries Association (SEIA) reports utility solar costs have already fallen to around $1,200/kW in 2016. This cost is confirmed by Berkeley Lab's Utility-Scale Report (Bolinger et al., 2017). Based on the $1,200/kW installed price, solar PV would be viable in this model starting in 2023 and at a CT level of $14/ton. The generation graph in Figure 4.12 shows that natural gas generation is less competitive in this scenario than in the BC scenario. Natural gas generation drops from 63.8% in the BC scenario to 56.8%. Wind generation increases from 34.4% to 39.4%, and solar PV increases from less than 0.21% to 2.8%.

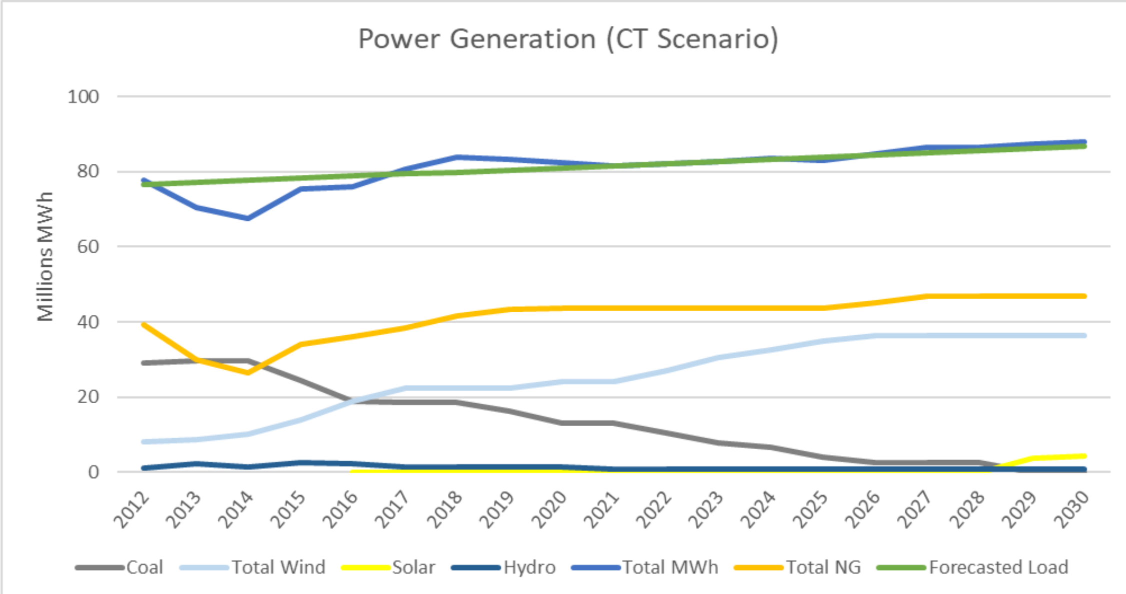

Figure 4.12 Oklahoma Power Generation in MWh (CT Scenario)

The CO_2 emission profile for the CT scenario is shown in Figure 4.13. It illustrates a steeper decline in CO_2 emission than the BC scenario. This starts in 2023 and ends in 2030 with CO_2 emission reduction at 54.6% below the 2012 emission level. This mainly due to the increase in wind energy generation.

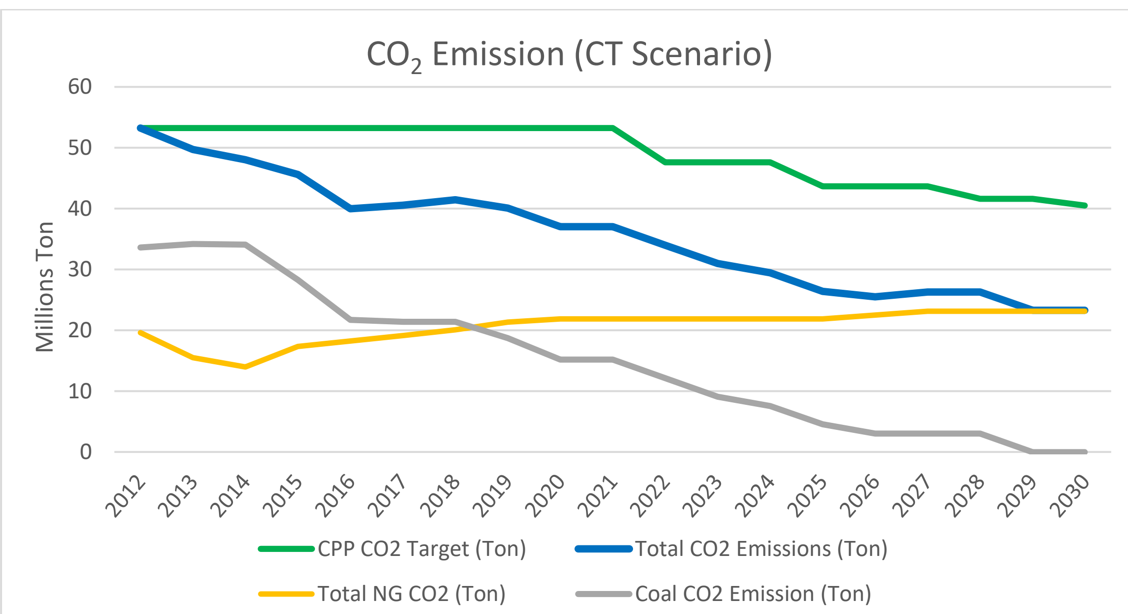

Figure 4.13 Oklahoma power sector CO_2 emission in millions short Tons (CT Scenario)

The investment cost in Figure 4.14 shows a larger capacity investment of $10.5 billion over time in renewable energy than the other two scenarios. This cost is based on data from the EIA's outlook (EIA, 2015), which can be overestimated by as much as 50%. Even with the high estimation, the cost of electricity $/kWh is only $0.057 or 0.07¢ more than the RM base scenario as depicted in Figure 4.15.

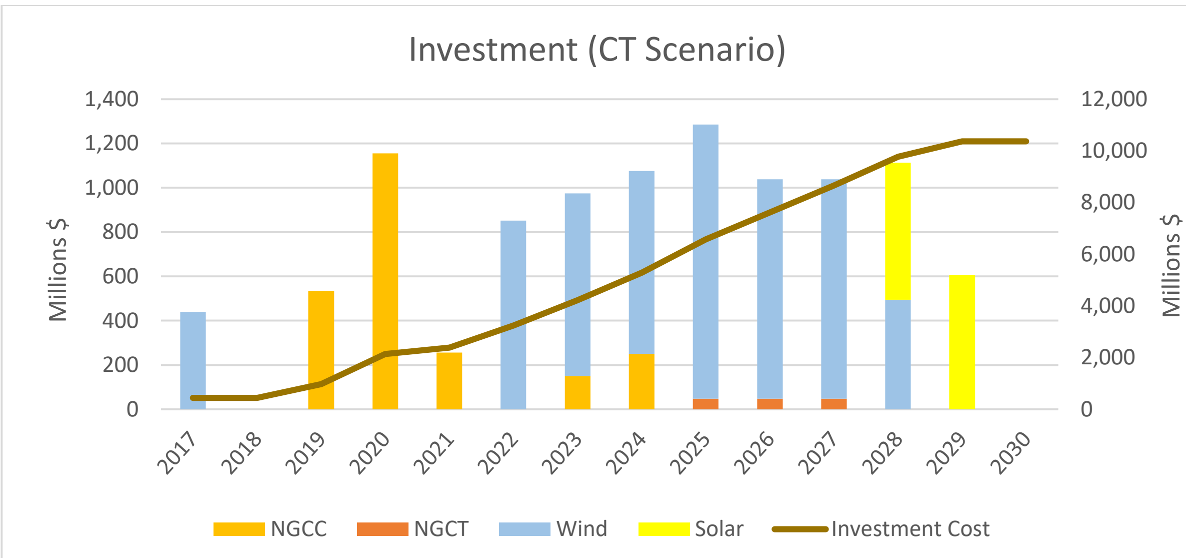

Figure 4.14 Oklahoma power system investment in Million Dollars (CT Scenario)

Analyzing the generation capacity investment of the CT model (Figure 4.14) shows that a larger total amount of generation capacity is observed compared to the RM scenario. A substantial increase in the total amount of generation capacity is observed in all three modeling scenarios compared to the generation capacity of the base year 2012. This phenomenon is largely due to the intermittent nature of wind and solar generation resulting in a much lower availability factor (20 to 40%) versus conventional generation technologies (50 to 95%) (EIA, 2015). This would imply that intermittent generations such as wind and solar energy sources require notably more capacity to achieve the same level of generation provided by a smaller amount of fossil fuel capacity.

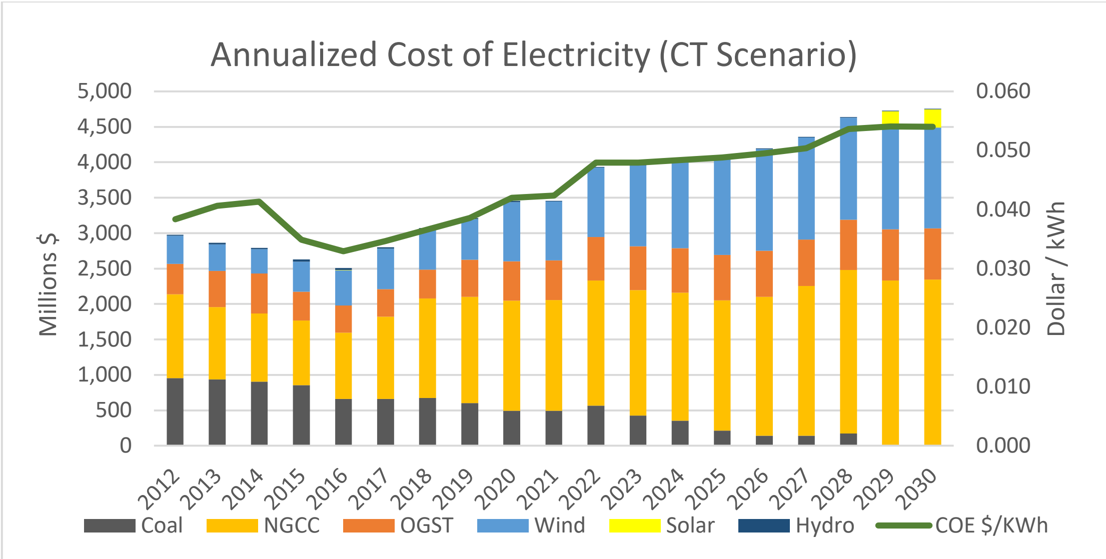

Figure 4.15 Oklahoma power system annualized cost of electricity (CT Scenario)

4.4 GI Scenario

The major variance in the findings of this scenario compared to the base case MATS and RHR scenario is the retirement of an additional 1 GW of coal and the replacement of that capacity with natural gas and wind energy (Figure 4.16). The departure is mainly due to the additional retrofit costs to coal plants under the MATS and the RHR rule, which make NGCC and wind generation more competitive.

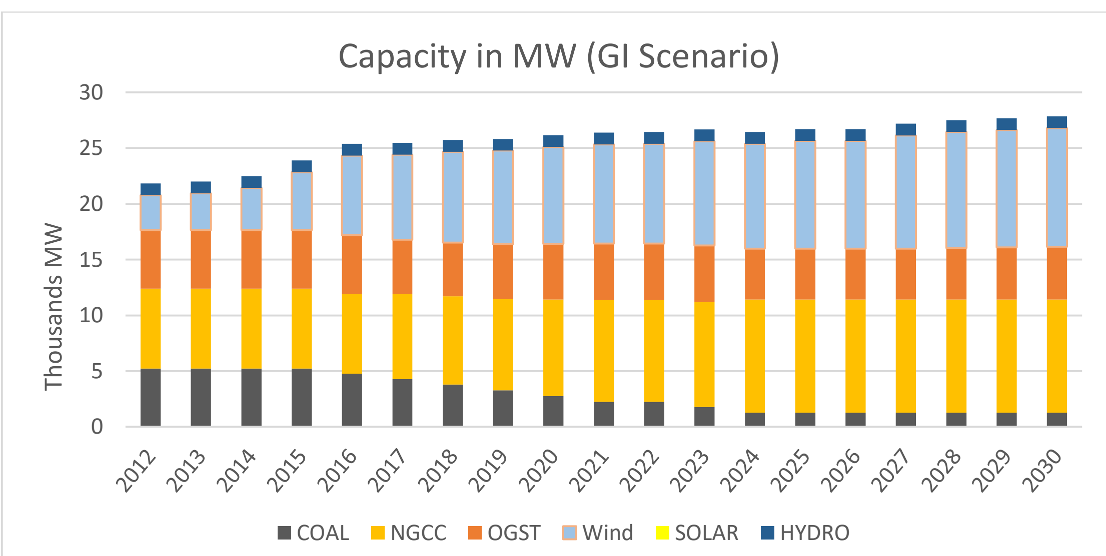

Figure 4.16 Oklahoma power system capacity in MW (GI Scenario)

Based on the age of Oklahoma's coal fleet, approximately 76% or 4,362 MW of coal-fired capacity in Oklahoma face cumulative retrofit requirements of $500/kW or more (AEP, 2015; OG&E, 2015). The majority of the cost for these units is associated with the cost of scrubbing SO_2 in order to comply with the Regional Haze Rule requirements. Given the magnitude of these costs, it is not surprising that some of the impacted units will be retired. In the base case scenario, 2.4 GW or 46% of coal generation will be retired. The GI scenario model projected a total of 3.4 GW of coal generations or 65% for retirement.

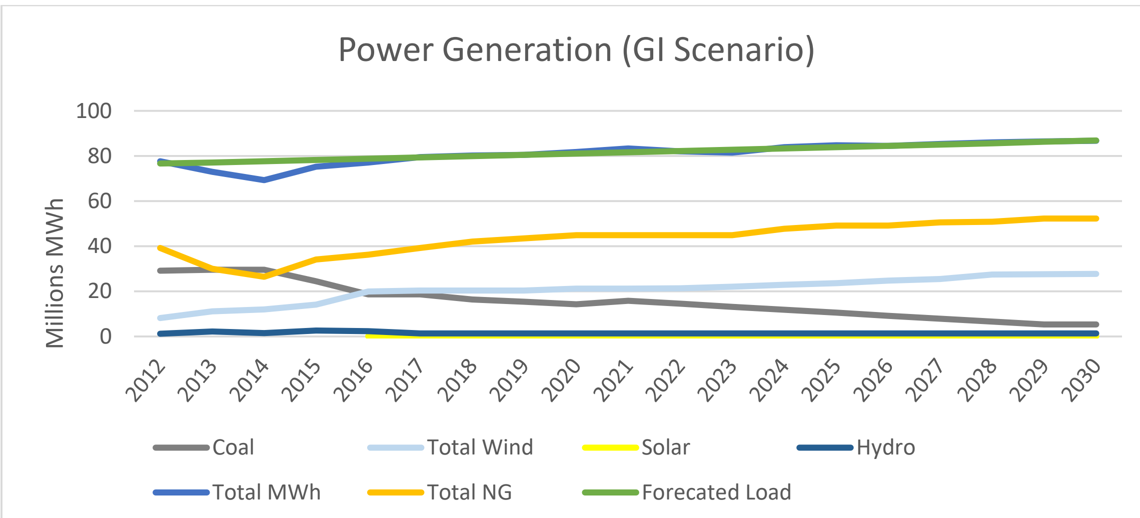

Figure 4.17 Oklahoma Power Generation in MWh (GI Scenario)

Figure 4.17 shows that natural gas generation is the dominant source of generation for the foreseeable future, supplying approximately 58 TWh or 54% of generation. That is down from the projected 62% in the base case scenario. Wind energy is second at 33 TWh or 31%, which is an increase from 25% in the base case. Coal generation is last at 7 TWh or 7%, which is down from 11 TWh or 11% in the base case. Solar did not appear in this scenario, but this could change in the future as it continues to decrease in price and as grid scale storage technologies become more affordable.

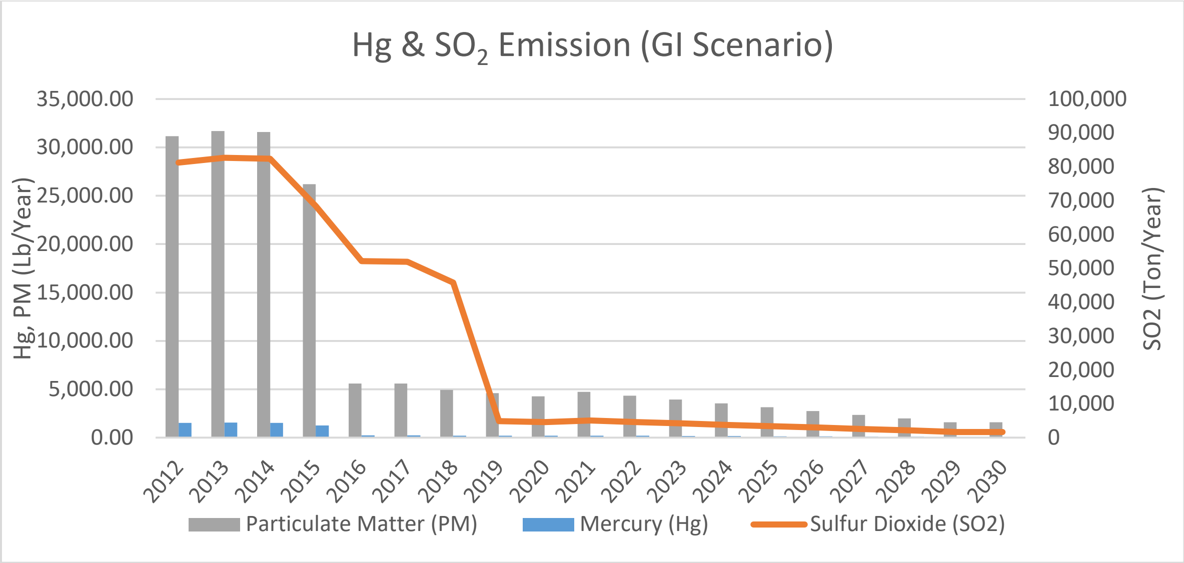

Figure 4.18 Oklahoma Mercury, Particulate Matter, and Sulfur Dioxide emission (GI Scenario)

The HAP emissions as indicated by their surrogates in Figure 4.18 shows the steep reduction in emission limits for mercury, particulates matter, and sulfur dioxide. These are the binding constraints for the MATS and the RHR rules. Complying with these rules places significant pressure on the economic viability of old coal EGUs to the point that retirement and replacement is the most cost-effective approach.

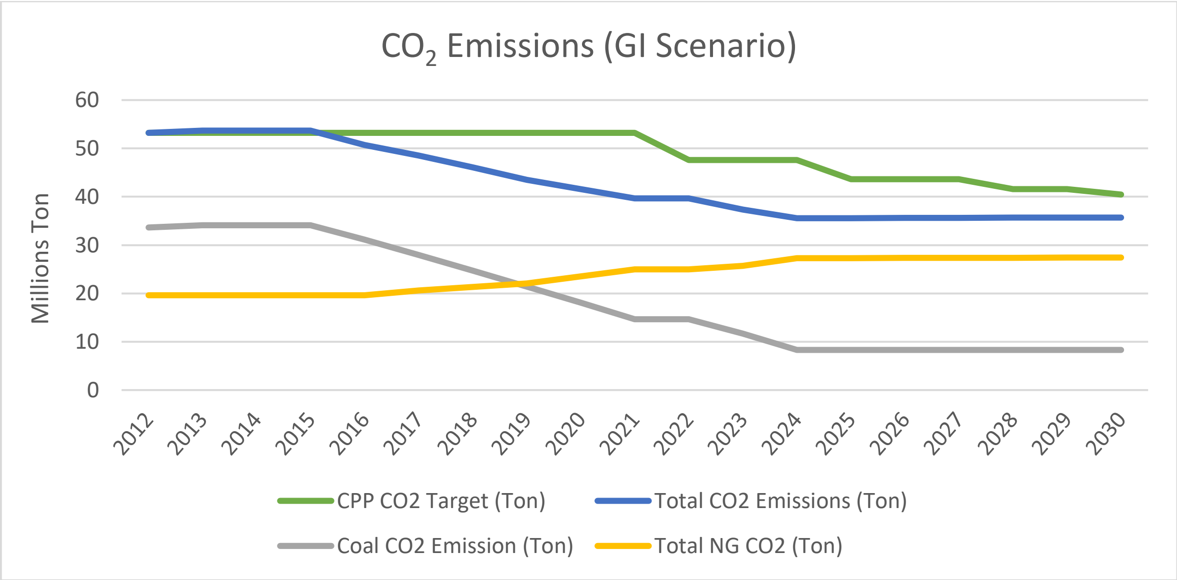

Figure 4.19 Oklahoma power system CO_2 emissions (GI Scenario)

In Oklahoma, natural gas is readily available, and there is an abundance of wind energy that has immense potential. Based on their availability, it is reasonable to conclude that these resources would be utilized at a higher rate than in other states that do not have them available. Examining Figure 4.19 beginning with the year 2022, which is the starting phase of compliance with the CPP rule, shows the CO_2 level to be already below the CPP target level set for Oklahoma. It also shows that the state CO_2 emission level will stay below the target level of the CPP all the way to the final phase in 2030. This achieves full compliance with the CPP. It highlights the benefit of investing in natural gas and wind energy to comply with the MATS and the RHR rules. The changes made to comply with these rules also contributed greatly to compliance with the CPP.

The cost of electricity in this scenario (Figure 4.20) shows the annual projected cost, and the average cost in dollars per kilowatt hour ($/kWh). The analysis shows a reduction of 3.85%, or 0.1 cent/kWh, when compared to the base case scenario. This reduction is attributed to the higher rate of utilization of wind energy in this scenario compared to the base case.

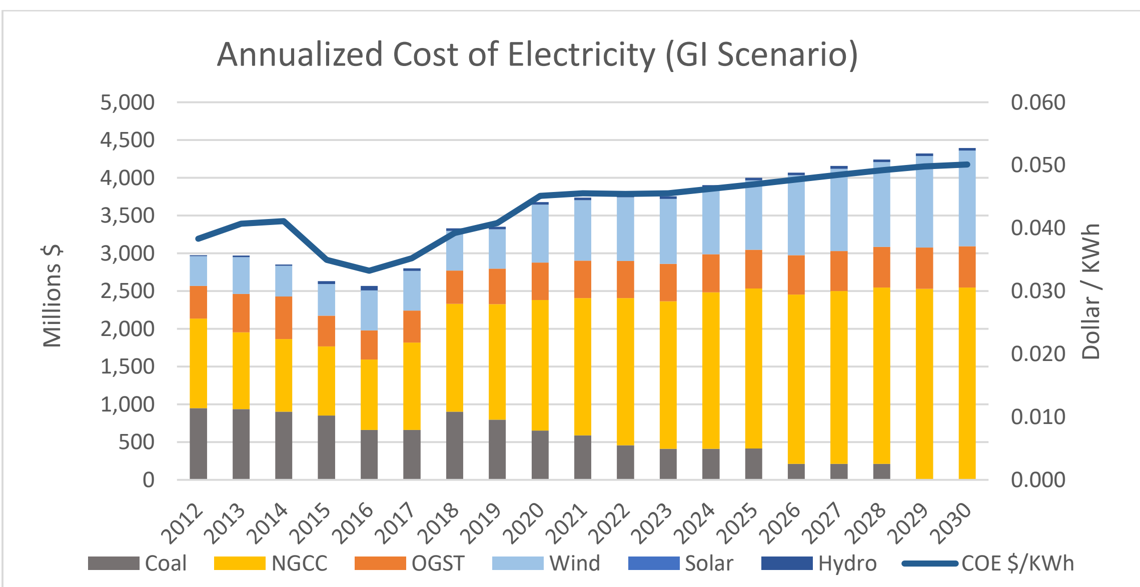

Figure 4.20 Oklahoma power system annualized cost of electricity (GI Scenario)

There is no single solution to comply with the rules. In Oklahoma, the two investor-owned utilities with the largest coal generation portfolios chose two completely different solutions for compliance. OG&E chose to convert two of their coal plants to natural gas and retrofit the other three coal plants (O&GE, 2015). PSO chose to get out of the coal generation business by retiring one unit in 2016 and retiring the second unit in 2026. PSO is planning to replace their coal plants with natural gas combined cycle EGUs and invest in wind energy (AEP, 2015).

The exact emission levels and the cost of compliance technologies are somewhat plant specific. For that reason, it is not surprising that the planned generation changes in Oklahoma vary slightly from those determined by the mixed integer model. The close similarity of the results suggests that the Oklahoma industry made economically rational choices in planning changes in their generation infrastructure to comply with the MATS and RHR rule and that those changes will prepare them for compliance with the CPP. The degree to which that conclusion is applicable to coal generation utilities in other regions would be a fruitful topic for additional research.

4.5 Costs and Benefits

The cost-benefit analysis for the three scenarios is based on the reduction of CO_2 emissions associated with each scenario relative to the reference year of 2012. The monetary valuation of the benefits of removing such emission and concomitant pollutants is monetized by multiplying each ton of CO_2 by the SCC amount as evaluated by the Interagency Working Group report (IWG, 2015). Figure 4.21 illustrates that CO_2 emission reduction levels of all four scenarios met the CPP's interim and final targets. In the RM scenario, CO_2 emission reduction is achieved through the efforts of PSO, OG&E, and the GRDA to meet the RHR and MATS regulations.

The GI scenario shows that investing in replacing additional 1 GW of coal plants with natural gas and wind is more economically and environmentally beneficial than the RM scenario and would contribute directly to reducing CO_2 emissions. The BC scenario shows that additional and deeper reduction can be achieved by replacing the remaining coal plants with wind and natural gas generation. The CT scenario achieves the deepest cut in CO_2 emissions. It removes approximately 30 million tons compared 2012. This is a direct result of making wind and solar energy more economically competitive by adding some of the externalities associated with the use of fossil fuel into the pricing equation.

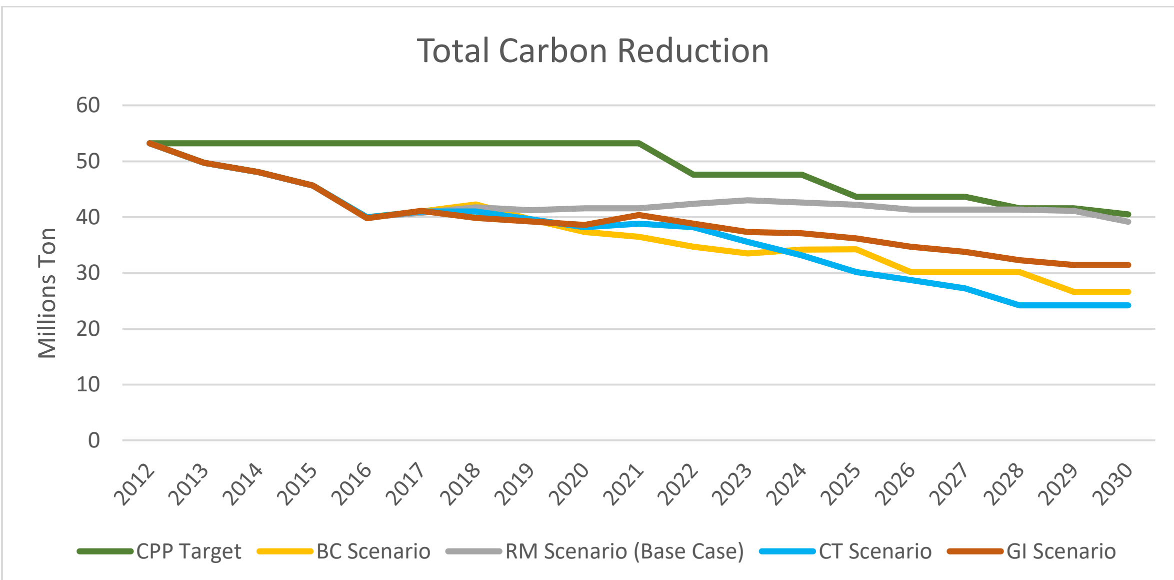

Figure 4.21 Total CO_2 reduction for each of the three scenarios compared to the CPP target

The modeling of electricity cost for the four scenarios in Figure 4.22 shows that the cost of energy for the RM, GI, and BC scenarios is very close. On the emission reduction side, the GI scenario attains a better environmental mark for preventing the emission of an additional 7.8 million tons of CO_2 into Oklahoma's environment compared to the RM case. The BC case reduce CO_2 emissions by an additional 4.8 million tons compared to the GI case.

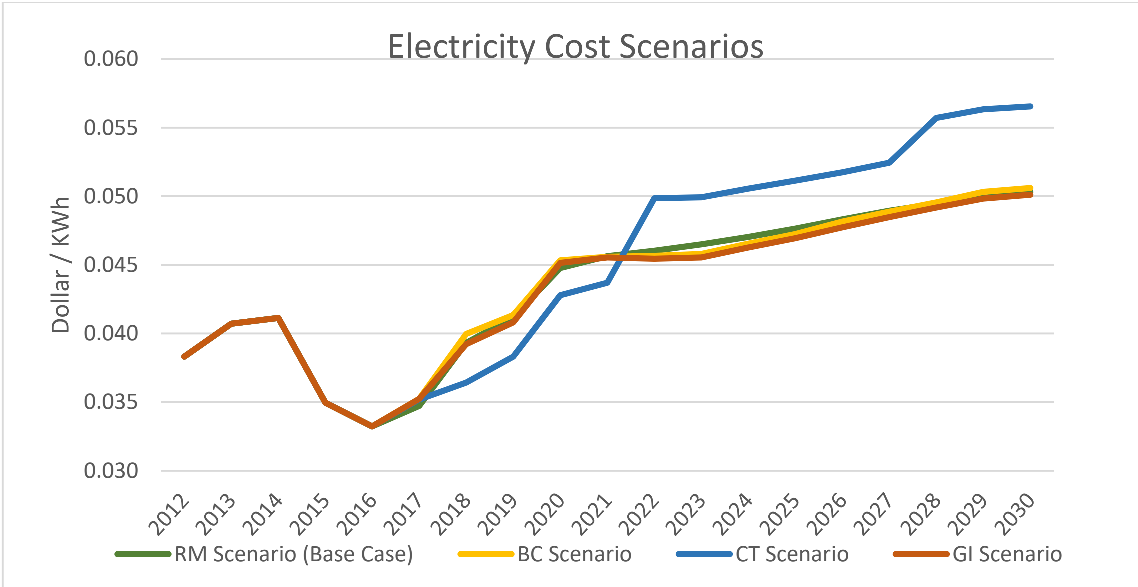

Figure 4.22 Electricity cost $/kWh for all three scenarios

The cost of the CT scenario is about 9% higher than the other three scenarios, which is mainly due to the actual carbon tax that is added into the pricing equation. The CO_2 emission reduction associated with each of the scenarios and the monetary valuation of that reduction is illustrated in Figure 4.23. The valuation of CO_2 is based on the 2.5% SCC values as listed in the IWG's Technical Support Document (IWG, 2015). The RM scenario shows that the cumulative monetary benefits from 2012 to 2030 equal $13.2 billion in environmental and public health benefits. The benefits in the BC scenario are $19.9 billion, and the CT scenario attains the highest benefit at $21.5 billion.

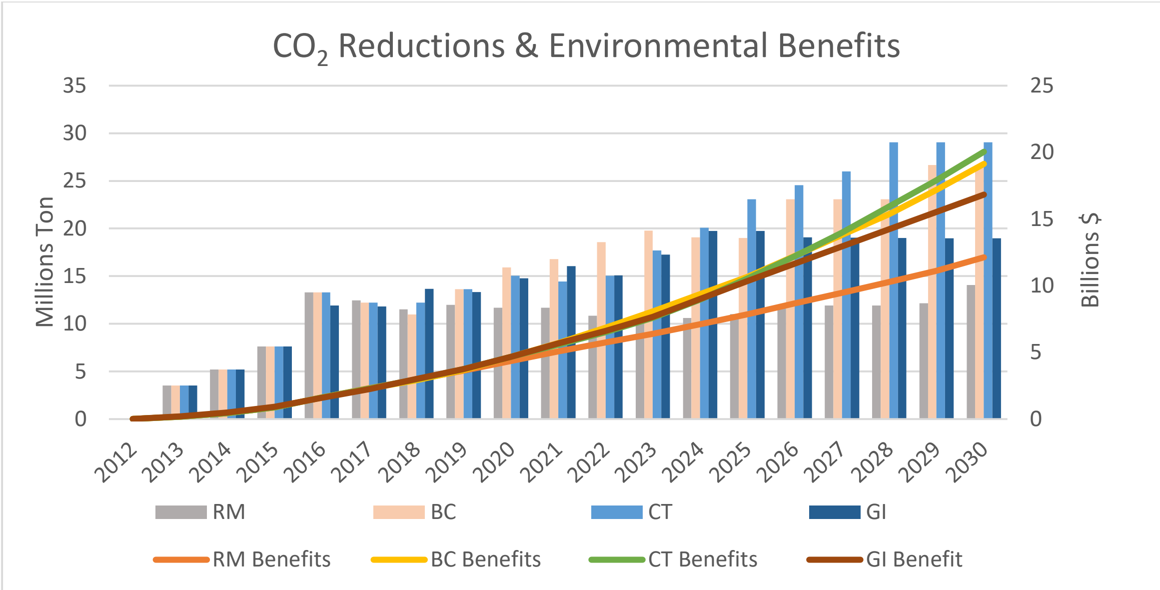

Figure 4.23 CO_2 reduction and associated monetary benefit for the three scenarios

Table 4.3 exhibits the greatest benefits in the CT scenario, followed by the BC scenario, GI scenario, and RM scenario. This ranking changes when taking investment cost into the equation. The BC scenario advances to first place with $10.4 billion in net benefits, followed by the GI scenario ($10.2 million), CT scenario ($10.9 billion), and RM scenario ($7.8 billion).

Table 4.3 Oklahoma cost-benefit of the three generation scenarios in dollars

Scenario	Investment Cost	Cost of Electricity	Benefit	Net
RM	4,304,004,232	70,648,511,401	12,132,786,563	7,828,782,330
GI	6,558,509,279	67,090,786,819	16,766,486,996	10,207,977,717
BC	8,717,203,512	67,626,032,140	19,125,628,027	10,408,424,515
CT	10,371,864,096	69,887,595,798	20,035,841,934	9,663,977,838

Setting aside the monetary benefits as ascribed by the social cost of carbon, using more natural gas and wind energy and less coal energy generation creates numerous economic and health benefits for Oklahoma, which include:

- The replacement of coal units with natural gas and wind units will redirect over approximately $500 million per year of coal purchases (EIA, 2015) to in-state purchases of natural gas and wind energy.
- Oklahoma’s wind energy industry is responsible for the creation of 1,600 full-time jobs and $22 million a year in land-lease payments to rural landowners, with over $1.8 billion in economic activity during the first 20 years (Dean et al., 2014).
- Wind farms will generate approximately $1 billion in ad valorem taxes, mostly in disadvantaged rural counties, and $2 billion in savings to ratepayers over the span of 40 years, from 2003 to 2043 (Ferrell et al., 2015).
- Renewable energy generation operates at an extremely low cost, having zero fuel costs and no emissions. This provides low cost energy and price stability over time, saving ratepayers millions of dollars in energy costs and fuel surcharges (Cardell & Anderson, 2015).
- The CPP will accelerate the displacement of coal-fired power plants nationwide. This in turn will generate higher demand for Oklahoma's natural gas.
- Oklahoma has 319 GW of developable wind energy resources and 5,304 GW of utility-scale photovoltaic (Brown et el., 2015). Developing a portion of that energy will make Oklahoma a lead producer and exporter of clean electric energy in the 21st century.
- Investment in renewable energy has the potential to create additional revenue from the sale of Emission Rate Credit (ERC) and Renewable Energy Credits (REC) to other states under the CPP rule.
- Protection of water resources from the harmful emissions from coal plants would also preserve the economic lifeline to a lot of communities. The National Recreation Lakes Study Commission estimates that 32,100 people in Oklahoma are employed in support of lakes activities that contributes approximately $2.2 billion each year to Oklahoma’s economy.
- The EPA estimates health benefits of $2.5 billion from implementing the MATS pollution control measures on coal plants, from reducing premature deaths, hospitalization for asthma attacks and heart attacks. For example, in Oklahoma 300 premature deaths are expected to be avoided with adoption of this rule (EPA, 2011).
- The above EPA benefits are achieved by retiring or replacing half of Oklahoma’s coal fleet with natural gas and wind energy, as in the RM scenario. Applying benefits transfer method to the BC and CT scenarios will double those benefits as both scenarios replace the remaining half of the coal fleet with natural gas and wind energy.

4.6 Sensitivity

In order to test the sensitivity of all four scenarios to a possible carbon tax in the future, a plausible tax rate of $25 was added (Figure 4.24). Upon running the simulation, all four scenarios exhibit a sensitivity response to the tax. The CT scenario shows the least sensitivity to a carbon tax, mainly due to using less fossil fuel generation than the other three scenarios. The BC scenario came close, followed by the GI scenario. The RM scenario became the highest cost scenario due to having a large share of fossil fuel generation in its portfolio. This highlights the economic risk that energy portfolios with sizable amounts of coal generation will face if and when such a carbon tax is imposed.

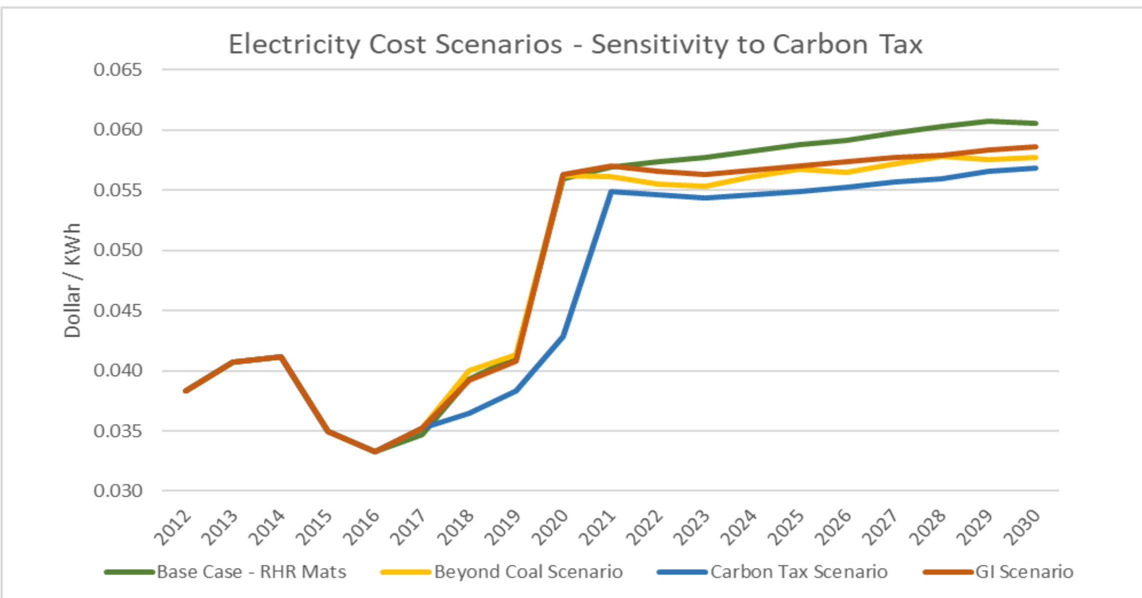

Figure 4.24 Electricity cost $/kWh for all scenarios with $15/ton carbon tax added for sensitivity analysis

Testing all four scenarios for sensitivity to increasing natural gas prices (Figure 4.25) reveals that even with a 50% increase in natural gas prices, all four scenarios exhibit a moderate sensitivity. The CT scenario faces a minimal impact at an increase of 1.1 cents or 20.9%, followed by the RM scenario at 1.12-cent increase or 23.8%, then the GI scenario at 1.13-cent increase or 25.8%, and lastly the BC scenario at 1.13 cents or 26.3%. The model demonstrates the difference in cost increase between the GI and RM scenario is 0.66%. It is 2.5% between the BC and the RM scenario. This low cost increase is negligible and does not justify investing in and maintaining old coal plants as a hedge against rising prices of natural gas.

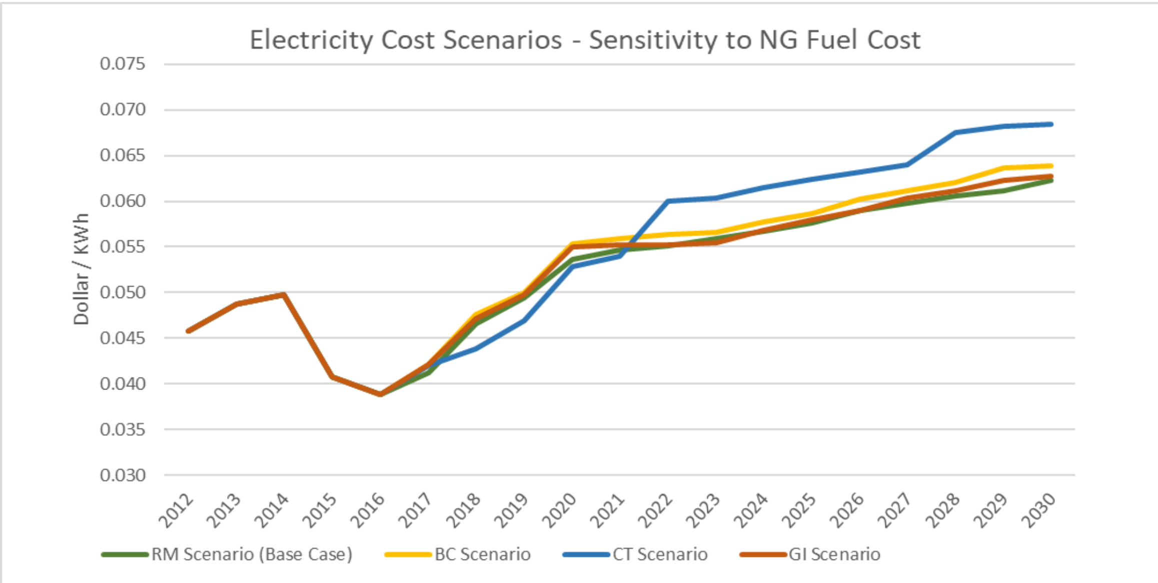

Figure 4.25 Electricity cost $/kWh for all scenarios with increased NG fuel cost added for sensitivity analysis

The LP modeling identifies the carbon reduction trajectory and the cost to achieve compliance with the CPP rule. It suggests that the RM scenario will meet the CPP target with no additional cost for CPP compliance. It also shows that the RM and BC scenarios have similar energy costs. The BC scenario is as effective in reducing CO_2 emissions as the CT scenario at a lower cost. The BC scenario outperforms the other two scenarios in term of net benefits and effectiveness in reducing CO_2 emissions.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1 Research Conclusion

This research study intended to ascertain the impacts of the Clean Power Plan (CPP) rule on the State of Oklahoma. It specifically intended to determine the cost of compliance with the potential new rule compared to the benefits. This study evaluated the environmental and social impacts of implementation. The CPP rule stems from the research and data collected by governmental agencies and academic institutions. These studies strongly indicate that both the atmosphere and ocean are rapidly becoming warmer due to anthropogenic CO_2 (EPA, 2015a). The Obama Administration responded to this information by issuing the CPP rule to counteract the effects of CO_2 emissions. In the United States, the electricity sector is the major emitter of CO_2, SO_x, NO_x, Hg, and other particulate matter that impacts public health and the environment (EPA, 2014). Any effective mitigation efforts should start with the largest source.

Scientific data from the EPA, EIA, SPP, Oklahoma's utilities, and scholarly sources provide the information needed to create and analyze four energy generation scenarios. An analysis of all four scenarios help determine the most effective energy mix to reduce the energy system's CO_2 emissions and meet the CPP targets. The models are optimized to minimize electricity cost and are constrained to meet environmental regulations. The scenarios are the RHR and MATS (RM) scenario – is also the base-case scenario, the Beyond Coal (BC) scenario, the Carbon Tax (CT) scenario, and the Generic Industry (GI) scenario. Some of the data used in the scenarios are robust and are based on governmental agencies' and utilities' quantitative data. Other data are less robust and are based on governmental agencies' forecasts and utilities' future commitments.

The results of the research show that Oklahoma will meet its CPP emissions reduction target under the RM scenario with no additional cost incurred by the state. The research demonstrates that phasing out coal generation completely by 2030 and replacing that capacity with wind and natural gas generation, as modeled in the BC scenario, is completely feasible with no increase in electricity cost. The BC scenario would accrue approximately $2.6 billion more in net benefits when compared to the RM scenario. The BC, GI, and CT scenarios are more resilient to water shortages and climate change that negatively impact the operation of thermal EGUs (Franco & Sanstad, 2006). The BC, GI, and CT scenarios are less sensitive to environmental regulations and possible future carbon taxes than the RM scenario.

The CT scenario shows that with a carbon tax of only $14 per ton of CO_2, wind energy becomes the top choice in the selection process of new energy generation sources. At $24 per ton of CO_2, solar energy becomes a viable generation choice. Selecting higher percentages of wind and solar energy in the CT scenario would reduce CO_2 and concomitant emissions by 50% of the 2012 base level. It would also generate net economic benefits of approximately $9.7 billion for the period between 2012 to 2030. The addition of carbon tax evens out the playing field for wind and solar generation. It increases the renewable energy generations to the constrained level of 45%.

The limit is set at 45% because the SPP wind study shows that 45% renewable energy, as a percent of total energy supply in the SPP region, is feasible presently with minimum change to the transmission network (SPP, 2016). The SPP wind study indicates that the transmission network should be ready to handle up to 60% of its energy from renewable sources in five to 10 years from now (SPP, 2016). Oklahoma's residents in the wind region and ratepayers statewide would greatly benefit from these transmission upgrades. The upgrades would enable the state and the region to use additional renewables at a lower cost and have increased environmental and social benefits (Ferrell et al., 2015; Cardell & Anderson, 2015; EIA, 2015).

The findings of the GI scenario conclude that the MATS and the RHR rule play a big role in the decision to retire old coal plants and push the industry to invest in newer, more efficient generation technology. Compliance with the two rules by investing in new technologies such as high efficiency advanced natural gas combined cycle, wind energy, and solar energy, will set states on a path for compliance with the Clean Power Plan. This will save utilities and ratepayers from incurring additional compliance costs for a slew of environmental regulations (Table 2.8) designed to reduce pollution emissions from existing fossil fuel powered plants.

The results of the GI scenario are very similar to the base case, but with a small increase in coal retirement and a slight shift away from natural gas and toward wind energy. This shift occurs because the SO_2 limit for the RHR rule is the binding constraint for this scenario. The SO_2 limit is more difficult and costlier for the utilities to meet than controlling mercury, oxides of nitrogen, and particulate matter. Sulfur dioxide emissions are much higher from coal units, so meeting the SO_2 limit will have more of an impact on coal capacity compared to natural gas. Meeting the RHR and MATS requirements using renewable generation will facilitate compliance with the CPP.

The RM scenario is the least costly capital expenditure option to achieve the CO_2 emissions reduction target as outlined in the CPP rule. This economic ranking will change when the impacts on the environment and public health are taken into account. Including the environmental and public health impacts cost in the equation shows that the RM scenario will move to the last place behind all other scenarios evaluated. All three scenarios outperform the RM scenario in terms of total net benefit. They lead to a cleaner, more diversified energy portfolio for Oklahoma.

The BC scenario is just as effective at reducing CO_2 emissions as the CT scenario and costs the same as the RM scenario per kWh. The BC scenario attains $10.5 billion in net benefit, outperforming the other three scenarios in net benefit and effectiveness in reducing CO_2 emissions. The GI scenario is similar to the RM scenario in terms of cost of electricity and in showing that the MATS and the RHR rules were the leading factors in the reduction of coal generation in the state.

There are three main points that can be drawn from this research. The first point is the investment the state made in wind energy is paying off in terms of reducing Oklahoma's CO_2 emissions and other pollutants. This helps the state meet its CPP target and create economic opportunities benefiting rural Oklahomans where wind farms are located (Dean et al., 2014). Next, the research reveals that the policy goals of reducing CO_2 emissions and concomitant pollutants are best achieved with the BC scenario, which phases out coal plants and replaces them with natural gas and wind generation. Lastly, retrofitting old coal plants is a venture of high economic risk to both utilities' investors and to Oklahoma ratepayers. There is a high chance that these older, subcritical coal plants will not operate long enough for the utility to recover the upgrade costs. These plants will become less competitive with renewable resources and dispatch less due to the higher cost and stricter future environmental regulations, eventually becoming stranded assets (IDDRI, 2017).

The conclusion drawn implies that planning and implementing an energy policy that phases out coal plants in the state and replaces them with natural gas and wind energy is the proper policy. The CPP rule will not negatively impact Oklahoma's economy or grid reliability (SPP, 2016). It will reduce CO_2 and concomitant pollutions, improve public health, and enhance quality of life (EPA, 2015a). It will stimulate much needed economic activity in the western counties of Oklahoma (Ferrell et al. 2015), and will benefit the gas industry (Stevens et al., 2017).

Pursuing a compliance policy that narrowly focuses on retrofitting old coal plants to extend their operation life beyond their useful life would have multiple impacts throughout the state. Vulnerable communities living near or downwind from these plants and their ash-waste disposal sites will continue to experience negative health impacts and be subject to undue health risks (Epstein et al., 2011). In addition to health risks, environmental degradation will continue due to these plants' hazardous emissions into the air, water, and soil. Ratepayers and shareholders will be financially at risk due to increased electricity rates and lower return from underperforming assets that are prone to environmental regulations and litigations.

5.2 Recommendations

The recommendations included in this research have clean, reliable, and affordable energy as the main objective. Oklahoma should embrace and facilitate compliance with the CPP rule. The state is already heading in the direction of compliance with the rule in the base-case RM scenario incurring no additional costs. Compliance with the CPP rule nationwide would greatly benefit Oklahoma because of the increased demand for natural gas in the interim period (Stevens et al.,

2017) and renewable energy in the long-run (Ferrell et al., 2015). It would also produce a significant reduction in emissions of conventional pollutants associated with coal plants, particularly in low-income communities that are overburdened by pollution. These reductions will have beneficial effects on air quality and public health, both locally and regionally (EPA, 2015a).

The voluntary goal set by HB 3028 in 2010 required 15% of all generation capacity within the state to be renewable. That target was reached in 2014. It is time for the state to review and amend HB 3028 in order to set a new goal. Based on the BC and CT scenarios' model results, a 45% renewable target, set to be achieved by 2030, is feasible; this would provide great economic and environmental benefits to Oklahoma and would protect the gains the state has made thus far. This would also act as a catalyst for the state and utilities to build a clean, affordable, and resilient energy portfolio. This kind of portfolio would make capital of Oklahoma's 319 GW of developable wind energy resources (Brown et el., 2015). The state so far has developed 6.6 GW, or only 2%, which is supplying 26% of total power used in the state as of 2016 (EIA, 2016b). This research shows that the new target is feasible within the present SPP transmission infrastructure (SPP, 2016), and would be of great benefit to the state economically, socially, and environmentally.

It is necessary to evaluate the cost of compliance for all emissions regulation rules, as listed in Table 2.4, that impact fossil fuel generation. That evaluation should include the total life-cycle cost of these plants and their long-term societal impacts. This should occur before making a decision on investments needed to extend their service life. Negative impacts on public health and the environment from fossil fuel plants are well-known and documented problems (Davidson et al., 2006) (EPA, 2011). These plants may also pose financial risk to investors and ratepayers, as these plants fail to operate efficiently in a carbon-constrained and a water-constrained environment, and they then become stranded assets.

Compressed Air Energy Storage (CAES) has proven to be technologically reliable (Crotogino et al., 2001). This combined with underground storage reservoirs makes it a very competitive option for energy storage and generation (National Renewable Energy Laboratory [NREL], 2010). A detailed study to assess the potential use of depleted gas reservoirs located near wind farms in western Oklahoma as underground storage containers for CAES plants is needed. This would provide vital information on the suitability and the potential storage capacity of these sites. Investing in CAES would facilitate renewable energy growth in Oklahoma with great economic and environmental benefits. It could also make Oklahoma the top supplier of clean energy generation and storage in the SPP region.

The SPP should be consulted and made into a partner in any state plan that is enacted to comply with the CPP rule. The SPP has an extensive communication network with its utilities members that helps it monitor and control 627 energy generation plants (SPP, 2014). SPP utilizes a computing platform and software applications (i.e. OSIsoft PI System) in order to connect sensor-based data, operations, and people, which enables real-time intelligence. These technical capabilities and services can be used to help the state and utilities monitor and report on their CO_2 emissions and concomitant pollutants as required by environmental regulations easily and accurately, as described in Section 4.6 of this research.

Cap and trade programs have proven to be successful in the past in reducing emissions. They allow utilities to select the most economical solution to achieve their emissions reduction goal (EPA, 2007). The CPP rule encourages the use of a cap and trade market on either an interstate or a regional basis. This research encourages the creation of a regional cap and trade program that would include all SPP utility members. The state has the potential to accumulate surplus credits due to the high availability of wind energy and natural gas generation that could be used to supplant coal generation. The SPP is the entity that is most capable of creating and administering such an operation. SPP already controls and tracks energy dispatch, it operates the integrated market, and it administers the sales transactions. Creating the trading platform and tracking emissions allowances from issuance through submission for compliance falls within their technical and administrative capabilities.

Utilities should accelerate transmission projects that are listed in the SPP’s Integrated Transmission Planning (ITP) 10 report and add additional transmission projects in western Oklahoma. This would remedy overload potential with 60% wind generation as recommend by the SPP Wind Integration Report 2016. The projects would reduce wind energy curtailments and enable higher wind capacity utilization in powering the grid. This would create economic value for Oklahoma's wind energy producers and reduce hazardous emissions from the fossil fuel-powered EGUs.

In creating a state plan to comply with the CPP, a well-designed state plan needs to meaningfully engage all stakeholders including workers, communities, and indigenous populations living near power plants. Inclusion would ensure that the new policy maintains the affordability of electricity for all and preserves and expands jobs (EPA, 2015a). The state also needs to move forward to set a new energy policy that will continue to attract investment in renewable generation, energy efficiency, and energy storage systems. This would enhance the reliability and the resilience of the power system and reduce harmful emissions. It is also important to ensure that all communities benefit from such a policy.

5.3 Final Thoughts

The best scientific evidence currently available shows that the climate is being altered by increasing anthropogenic GHG concentrations in the atmosphere. This traps extra heat which is perturbing the earth energy balance and driving global warming (IPCC, 2014). Global warming and environmental issues have been politicized and are points of contention between the two major political parties. This political discord has all but halted any progressive governmental action that is needed in order to combat or adapt to climate change. As progress is halted on finding a policy solution to climate change, CO_2 emissions and climate warming continue to exhibit detrimental impacts that must be addressed immediately.

This national division and discord is also paralyzing any activity at the state level as well. In Oklahoma, the Attorney General's office sued the federal government over the CPP rule without a study to determine the impact of the rule on the state. The decision to sue appeared to be rash and solely based on party politics instead of sound scientific data. In this case, the CPP rule is of great economic, social, and environmental benefit to Oklahoma. Technological advances mean that coal generation, which carries with it a vast array of negative consequences, is no longer needed in order to have a reliable source of energy. Phasing out this outdated technology is easily accomplished with NGCC technology combined with wind and solar technologies. All of these renewable technologies have the added benefit of producing zero emissions and zero fuel costs. The decision to upgrade energy generation technology will benefit public health and the environment.

Disregarding the negative impacts associated with the use of coal for the power grid overlooks much of the real cost of these practices. Externality costs need to be assessed and added to the profit and loss calculation to provide the actual total life-cycle costs of electricity. Complying with the CPP requirement to mitigate the environmental and health impacts of coal fuel, and thereby investing in more efficient NGCC generation and renewable energy, is a minimal investment when compared to the expenses of the negative impacts caused by coal generation.

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APPENDICES

APPENDIX A: ENERGY STORAGE SYSTEMS

Searching published literature for energy storage systems revealed a variety of options; some of the more mature storage systems are listed in Figure A-1.

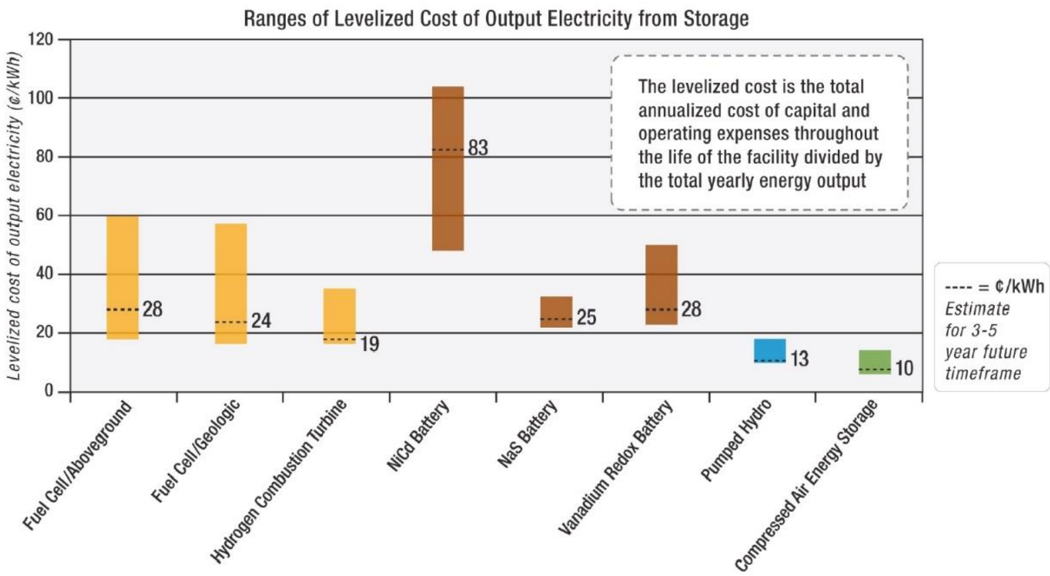

Figure A-1 Compressed Air Energy System cost comparison with other storage technologies (Source, National Renewable Energy Laboratory)

These include pumped hydro, underground pumped hydro, various types of batteries, hydrogen combustion turbines, fuel cells, and compressed air energy storage (CAES). Pumped hydro and CAES methods appear to be the only two options that are technically feasible at the grid scale level (NREL, 2010) that is needed to address the significant wind generation level present in western Oklahoma. Pumped hydro is a less favorable option due to the limited water supply in the western part of the state. This leaves CAES as the best option that also happens to be the least-cost energy storage option.

A.1 Compressed Air Energy Storage

A CAES plant basically operates in a similar manner as a pumped hydro storage facility; however, in the CAES plant, air is used as the storage medium instead of water. Presently, there are only two CAES plants in operation–one in Huntorf, Germany, and one in Alabama. Figure A-2 shows a high level diagram of the Huntorf 290-MW CAES system. The plant has been reliably in operation for the last 40 years (Crotogino et al., 2001).

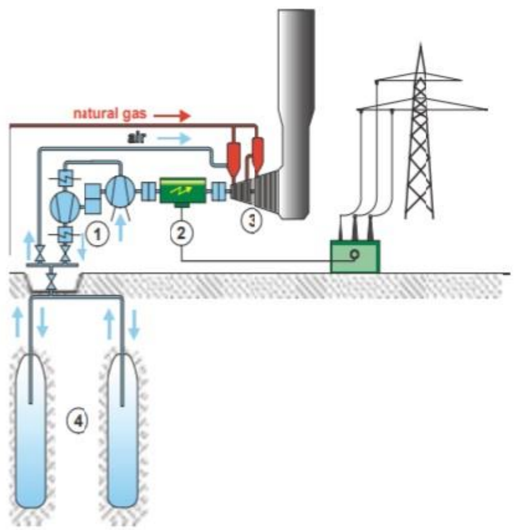

Figure A-2 Compressed Air Energy System (CAES) with underground storage (Crotogino et al., 2001)

The basic idea behind a CAES plant is to shift energy across time by storing excess energy during low demand periods and releasing it for use during high demand periods. It works by using the excess electricity to compress air and store it in an underground reservoir during off-peak, low-cost periods, and the process is reversed during peak load periods by releasing the compressed air into the plants where it is heated by natural gas and fed into a gas turbine to spin the generator and produce electricity. The pre-compressed air reduces the turbine workload to compress the air by approximately two-thirds, enabling it to produce triple the output energy using the same amount of natural gas when compared to a conventional natural gas combustion turbine (Crotogino et al., 2001).

A.2 Potential Underground Air Storage Locations

The economics of a compressed air storage plant are contingent on an appropriately characterized reservoir that enables it to meet its intended storage function (i.e. short-term energy shifting days and weeks vs. long-term months and seasons). Crucial criteria for identifying an acceptable site includes taking into account various aspects: reservoir thickness, permeability and porosity, low-permeability caprock, meeting the storage capacity requirement, and handling repeated cycling between injection and extraction without physical impairment or capacity reduction of the reservoir (DOE, 1983).

Western Oklahoma has an abundance of energetic wind and also hosts many oil and gas drilling operations in the Anadarko basin. The oil production operations have left behind numerous depleted oil and gas wells. Figure A-3 from the Oklahoma Corporation Commission shows the location of over 350,000 depleted wells.

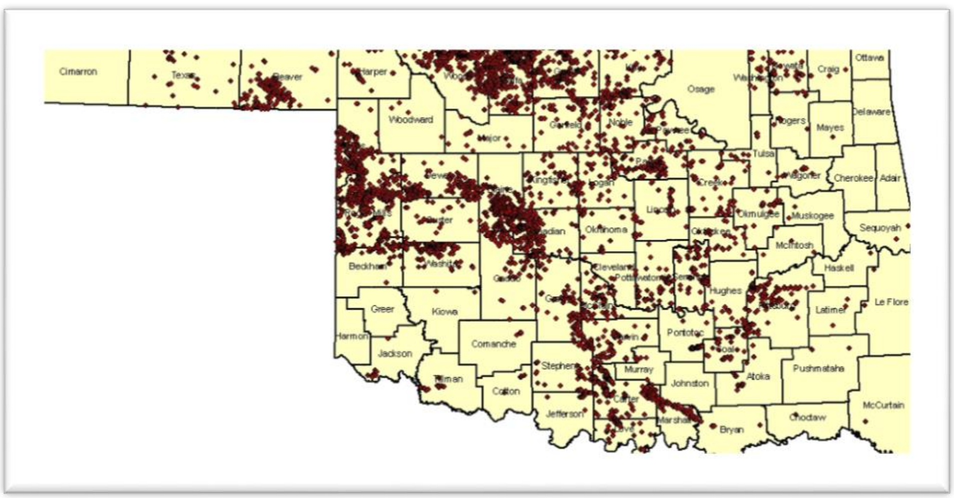

Figure A-3 Potential underground storage location, depleted oil and gas wells (Source: Oklahoma Corporation Commission)

Employing a depleted natural gas reservoir for CAES is technically and economically feasible according to a study conducted by Sandia National Laboratory (Gardner, 2013). In reviewing Oklahoma’s utilities' IRPs and the Oklahoma Corporation Commission’s Electric System

Planning Report, it was surprising to find that there has been a significant lack of research on the topic of energy storage, at the utility, academic, and policy level.

Energy storage is a keystone technology that has a vital contribution towards making renewable energy the main generation resource to power the grid. This contribution can best be made through an effective partnership between utilities, national laboratories, and universities. A study identifying and utilizing some of the depleted gas reservoirs that are located near wind farms in western Oklahoma as underground containers for CAES plants is critically needed. The development and deployment of such a technology would extend the energy available from solar and wind farms and would remove the bottleneck to renewable energy growth. This could potentially make Oklahoma the energy storage center for the whole SPP region.

VITA

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