STEVEN L. BESHEAR
GOVERNOR

LEONARD K. PETERS
SECRETARY

ENERGY AND ENVIRONMENT CABINET
OFFICE OF THE SECRETARY
500 MERO STREET
12TH FLOOR, CAPITAL PLAZA TOWER
FRANKFORT, KY 40601
TELEPHONE: (502) 564-3350
FACSIMILE: (502) 564-3354
www.eec.ky.gov

December 16, 2013

The Honorable Steven L. Beshear
Governor of Kentucky
700 Capitol Avenue, Suite 100
Frankfort, KY 40601

Dear Governor Beshear:

As you and I have discussed on numerous occasions, the energy challenges facing Kentucky are enormous, and the possible solutions to these challenges are multi-faceted. On an intuitive level, we know that Kentucky's electricity portfolio will certainly change as federal policies limiting greenhouse gas emissions are implemented. The attached paper, completed from extensive analyses conducted within the Energy and Environment Cabinet with support from energy policy experts, takes our intuitive understanding of these challenges to the next level. It demonstrates that our electricity portfolio will undergo dramatic changes—beginning as soon as the year 2016. Recent announcements of coal-fired power plants being closed and replaced with natural gas-fired capacity are already reshaping Kentucky's energy landscape. These changes are occurring, even without the forced changes we can expect when federal greenhouse gas standards are in place.

This paper, *Economic Challenges Facing Kentucky's Electricity Generation Under Greenhouse Gas Constraints*, presents the results of an electricity generation dispatch model that was added to EEC's existing energy forecasting tools. We began the study prior to President Obama's June 2013 announcement of his Climate Action Plan. Much of the analyses also supported the work EEC conducted on the Whitepaper, *Greenhouse Gas Policy Implications for Kentucky Under Section 111(d) of the Clean Air Act*. This study, therefore, can be viewed as a companion to the Whitepaper.

Both documents, the Whitepaper and now this study, reinforce the position that Kentucky's manufacturing economy is particularly vulnerable to energy sector dynamics. The Whitepaper urged EPA to consider for Kentucky and other manufacturing states the substantial impacts of rigid standards to reduce greenhouse gas emissions from existing power plants.

This study shows that Kentucky's generation portfolio will become almost entirely dependent on natural gas if we do not examine state-level policy barriers to maintaining a diversified energy portfolio which includes coal. The shift to natural gas will accelerate and become more extreme depending on the nature of federal climate constraints. One such barrier to maintain a diversified portfolio which includes coal is Kentucky's very narrowly defined least-cost electricity generation principle. Today, the narrowly defined least-cost provision is moving Kentucky away from coal and toward natural gas, as utilities must

weigh the costs of expensive retrofits to an aged coal-fired fleet to comply with rules such as the Mercury and Air Toxics standards against the costs of building new compliant natural gas units.

This restrictive least-cost electricity generation principle that has benefited Kentucky in the past may not serve our longer-term interests in the future. If utilities cannot invest in projects such as more efficient, advanced coal generation, then our coal industry will continue to suffer. Our analyses show even renewable energy resources, given today's capacity limits and cost constraints, cannot compete against low-cost natural gas. These are just two examples of the implications identified in the study of the challenges facing Kentucky today, and the expected larger challenges under federal greenhouse gas constraints.

A primary purpose of this study, therefore, is to encourage in-depth discussions among policymakers and our citizens regarding our energy future and our economy. In a coal-dependent state that has long enjoyed affordable, predictable electricity prices, these discussions are not easy. Conveying the message that our historic competitive economic advantage is at risk carries its own risk, but it is one we must be willing to take. Informed discussion is the first step to ensure wise policy considerations that will help Kentucky move forward. And move forward is what we have to do—we will not be going back to our 20th century energy economy.

In 2008, when I worked with you in developing the state's energy plan, we stressed the importance of diversifying Kentucky's electricity portfolio as the only way to protect Kentucky's economy in a carbon-constrained world. That imperative is clearer to us today, as the study results demonstrate. The steps we take next will require forthright dialogue among all Kentuckians, including policymakers, utilities, and the manufacturing sector.

Sincerely yours,

Leonard K. Peters
Secretary

LKP:wh
Enclosure

cc: Senator Robert Stivers
        Representative Greg Stumbo
        Senator Damon Thayer
        Representative Rocky Adkins
        Senator Jared Carpenter
        Representative Jim Gooch
        w/enclosure

Economic Challenges Facing Kentucky's Electricity Generation Under Greenhouse Gas Constraints

**Commonwealth of Kentucky
Energy and Environment Cabinet**

December 2013

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PREFACE

For the Energy and Environment Cabinet (EEC), which has primacy in administering most federal environmental laws and regulations at the state level, we have to understand the implications of what is arguably one of the most challenging issues to confront us—greenhouse gas (GHG) emissions and their impact on climate change. Efforts to reduce GHG or carbon dioxide (CO_2) emissions have moved beyond the point of discussion at the national level, and the United States Supreme Court has ruled that the U.S. Environmental Protection Agency (EPA) has the authority to regulate GHG emissions. Furthermore, while public opinion on climate change has fluctuated over the years, a majority of Americans accept some linkage between GHG emissions and climate change.[1] Although public opinion should never be a driver for science-based policy decisions, it is clear that people expect the nation to take action on this issue. And it is. Thus, discussion and consideration of contingency plans to meet such possible future regulatory frameworks is well advised.

Shifting from one single fuel resource to another presents untenable risks for Kentucky's citizens and for our manufacturing sector. Such a movement toward an all natural gas infrastructure also further erodes our state's coal mining sector.

For Kentucky, which is already experiencing the impacts of shifts away from coal and toward natural gas, regulatory mechanisms to reduce GHG emissions will have significant repercussions. Greenhouse gas emissions from natural gas electric generating units (EGUs) are about half those from existing coal-fired units. Natural gas is also currently more cost competitive than coal from a levelized cost standpoint. With Kentucky's existing narrowly defined least-cost principle guiding electric generation development, combined with existing and anticipated regulatory constraints, natural gas is becoming the fuel of choice. With this narrowly defined least-cost principle being a primary determining factor for utility business decisions, Kentucky will simply go from relying predominantly on coal for electricity generation to being predominantly dependent on natural gas. Shifting from one single fuel resource to another presents untenable risks for Kentucky's citizens and for our manufacturing sector. Such a movement toward an all natural gas infrastructure also further erodes our state's coal mining sector. And finally, and importantly, such a movement does not allow us to address GHG emissions in a more holistic, effective manner.

In essence, near-term decisions are being made that have long-term consequences. And these decisions are driven by policies and principles that need to be examined more broadly given the growing impact that federal policies will have on our state. A holistic approach is one that will encourage electricity generation diversity to protect our economy, to hedge against risk, and to allow the state to take advantage of technological advancements relating to coal as they emerge. For example, today, technologies for making our coal generation plants more efficient, meaning fewer emissions per input, are for all intents off the table—they cannot compete cost-effectively with natural gas. We can reduce GHG emissions using coal with advanced technologies—they have a monetary cost, but the longer-term economic and energy security benefits also need to be considered.

It is important that coal continue to be a strong component of Kentucky's electricity portfolio. And we must understand specific coal-use strategies to reduce GHG emissions. One important strategy is to improve boiler efficiency for electricity generation. Moving from conventional pulverized coal (PC) boilers

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[1] http://www.gallup.com/poll/161645/americans-concerns-global-warming-rise.aspx

to more efficient, advanced coal technologies—even without carbon capture and sequestration (CCS)—can reduce CO_2 emissions per MWh by as much as 25 percent. Further, these efficiency improvements reduce the quantity of CO_2 to be separated and sequestered from flue gas, making CCS more feasible at the scale necessary for realistic carbon reduction strategies.

With a narrow least-cost decision criteria, the technologies that might present longer-term affordable, reliable coal-fired generating units that can comply with environmental requirements are not able to be considered. The technologies available today and the technologies that will be available to us in the future need to be considered more comprehensively. In this paper, we analyze the opportunities that enhancements to coal-fired boiler efficiency and other technologies can have on maintaining coal as an important part of Kentucky's portfolio. Clearly, in a meaningful "all of the above" strategy to meet current energy demand and future energy growth, coal must be included for Kentucky, the nation, and indeed the world. The analyses included in this paper lead to a number of specific findings and some recommendations on multiple paths forward.

INTRODUCTION

The Energy and Environment Cabinet initiated this study in June 2013, a few weeks prior to President Obama's announcement of his Climate Action Plan. Realizing GHG standards for existing power plants were a matter of when, not if, our intent with the study was multi-purposed. First, we wanted to determine the potential impact of federal GHG policies on Kentucky's electricity generation portfolio. This part of the study supported another ongoing project that resulted in the EEC's whitepaper, *Greenhouse Gas Policy Implications for Kentucky under Section 111(d) of the Clean Air Act.*[2]

Changes to Kentucky's electricity generation portfolio, changes already occurring even in the absence of federal GHG standards, will have an impact on electricity prices, with resulting effects on overall employment[3] and coal consumption. Therefore, this study also sought to determine the extent of the changes under various possible federal climate policies and to evaluate state-level options for minimizing potential impacts.

Kentucky's generation portfolio will shift from reliance on one fuel source—coal—to reliance on another fuel source—natural gas—if certain obstacles leading to a more diverse portfolio are not addressed.

A significant driver for the extensive analyses we have conducted arose from a preliminary examination of likely changes to Kentucky's electricity portfolio given low natural gas prices, existing EPA regulations not related to GHGs, and EPA regulations limiting GHGs for new fossil power plants.[4]   Namely, in the absence of some type of policy response, Kentucky's electricity portfolio would start to shift dramatically from coal-fired generation to natural gas beginning in the 2016 timeframe, as shown in Figure 1. Unless other low-carbon technologies, including technologies to reduce emissions at coal-fired power plants, are given the chance to come on-line, this trend will continue as rules limiting CO_2 from existing plants become a reality.

Kentucky's generation portfolio will shift from reliance on one fuel source—coal—to reliance on another fuel source—natural gas—if certain obstacles leading to a more diverse portfolio are not addressed. This report looks at a range of generation technologies that can lead to reduced GHG emissions, discusses some of the economic risks associated with various technologies, analyzes impacts to electricity generation under different GHG reduction constraints, and makes recommendations for consideration to help ensure Kentucky's economy can continue to grow with affordable, relatively stable electricity prices.

Also evident is the large upward shift in natural gas generation and away from coal beginning in 2016, which is the effective date for new EPA regulations. This represents a forced retirement of existing coal-fired units, many of which will not have been fully depreciated. In other words, utility ratepayers will

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[2] Greenhouse Gas Policy Implications for Kentucky under Section 111(d) of the Clean Air Act, Oct. 22, 2013.

[3] Kentucky Energy and Environment Cabinet. (2012). The Vulnerability of Kentucky's Manufacturing Economy to Increasing Electricity Prices. Department for Energy Development and Independence, Frankfort.
http://energy.ky.gov/Programs/Documents/Vulnerability%20of%20Kentucky's%20Manufacturing%20Economy.pdf

[4] EPA's proposed rules (CAA, Section 111(b)) for new fossil generation require that new large natural gas-fired turbines meet a limit of 1,000 pounds of CO_2 per megawatt-hour, while new small natural gas-fired turbines need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour. New coal-fired units would need to meet a limit of 1,100 pounds of CO_2 per megawatt-hour, and would have the option to meet a somewhat tighter limit if they choose to average emissions over multiple years, giving those units additional operational flexibility.

still be paying for these coal units even though they will have been taken out of service. This "stranded investment" will continue to be a drag on Kentucky's economy for some time. Further, the EPA could exacerbate this problem if new CO_2 emission rules are implemented too aggressively and force additional units out of service prematurely.

Figure 1: Kentucky Electricity Generation, 1990-2050, Reference Case Without Additional Environmental Regulations
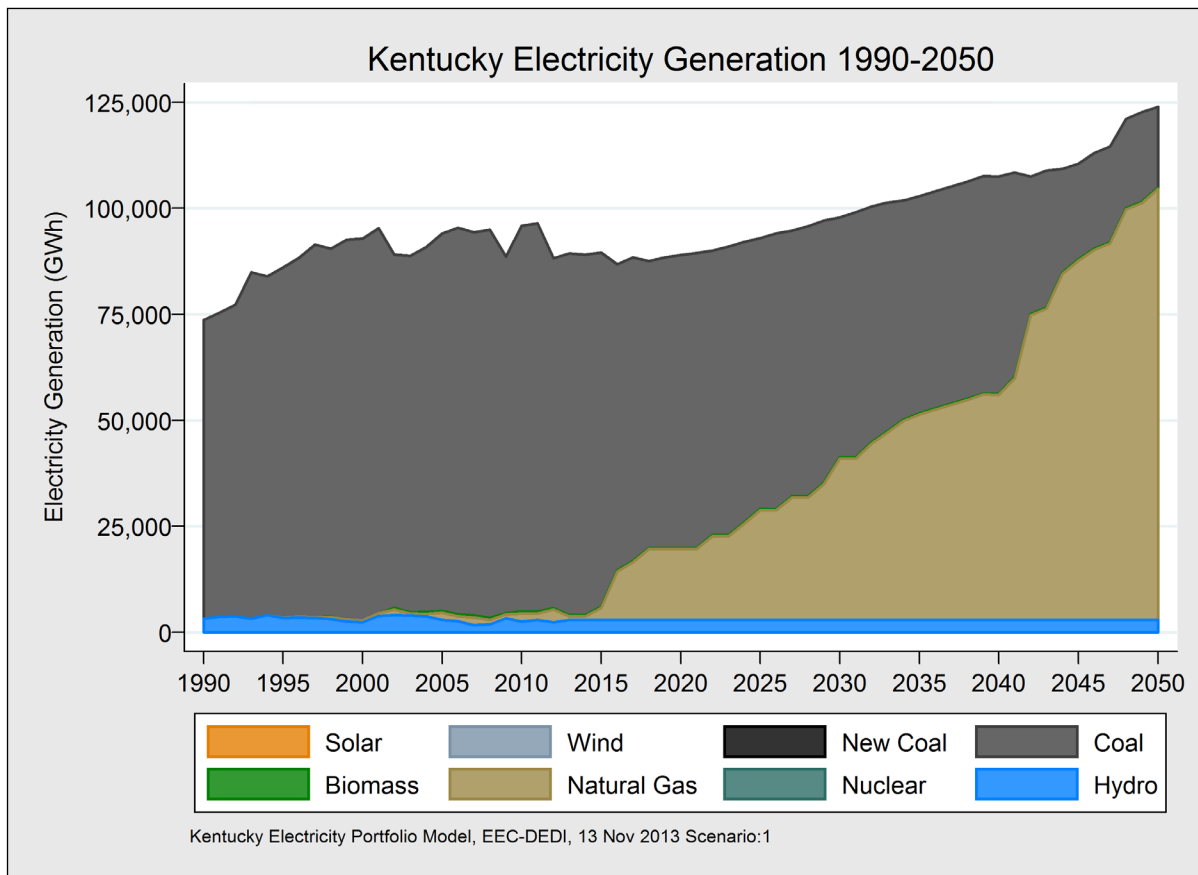
Kentucky must be prepared to comply with future GHG rules while maintaining its strength as a manufacturing state and while minimizing the impact on an already struggling coal mining sector. Price increases pose a threat to all utility customers, especially Kentucky's energy-intensive industries that rely on stable, relatively predictable low-cost electricity. To the extent possible, Kentucky environmental and energy leaders are participating in discussions with the EPA offering suggestions for the development of GHG rules affecting existing power plants that are flexible, account for carbon reductions already underway, and that minimize the impact on Kentucky's ratepayers. The results from this study will help to further inform these discussions. Additionally, these results can help policymakers, utilities, and others within the state understand implications of GHG policies and possible options for least-cost compliance.

Technology Options to Achieve Potential GHG Reductions

Kentucky's least-cost requirement[5] for electricity generation technology has traditionally led to coal as the most affordable option for utilities. This has been the case even when expensive capital costs are required to achieve environmental compliance. Today, the least-cost requirement is driving the shift in Kentucky's generation portfolio to natural gas. With the deadline for achieving federal regulations such as the Mercury and Air Toxics Standards (MATS) approaching, many utilities are faced with a choice: install costly upgrades or retire a coal-fired plant before the end of its useful life. In many if not most cases, the lost generation capacity that occurs when a utility retires a coal unit is being replaced with natural gas, which is abundant and forecast to remain inexpensive compared with its historical trends. Greenhouse gas standards will accelerate this trend because natural gas meets the CO_2 thresholds for new units while coal without carbon capture and storage does not.

The current low costs for natural gas are also precluding consideration of many other lower-carbon resources and technologies. This section looks at some of these technologies from a range of cost standpoints and the degree to which they provide CO_2 emission reductions. Appendix A lists the technologies compiled for the current study, along with corresponding data for efficiency, fuel type, emissions, cost, and fuel resource availability. Figure 2 shows a plot of two of the most common comparison metrics for potential new technologies, the levelized-cost of electricity[6] and the capital cost in dollars per kW.

Figure 2: Levelized Costs and Overnight Capital Costs by Generating Technology

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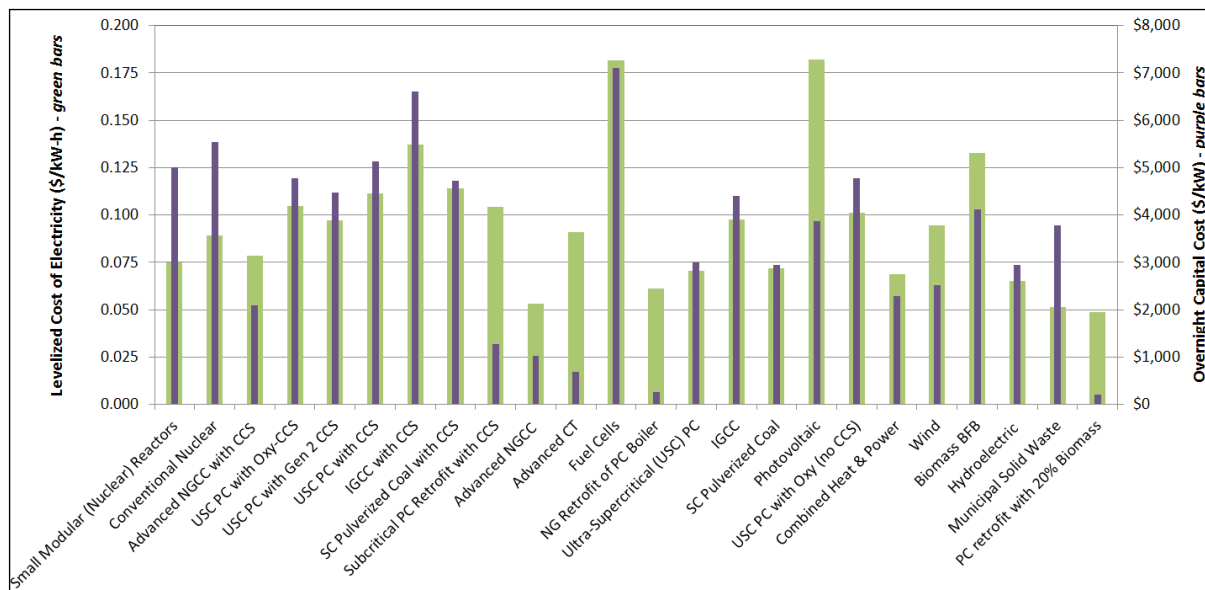
[5] The Kentucky Public Service Commission applies the principle of least-cost as a normal part of its approval processes. See Case No. 2009-00545, Application of Kentucky Power Company for Approval of Renewable Energy Purchase Agreement for Wind Energy Resources Between Kentucky Power Company and FPL Illinois Wind LLC., Order dated June 28, 2010, at Pages 5-10 and Case No. 2011-00375, Joint Application of Louisville Gas and Electric and Kentucky Utilities Company for a Certificate of Public Convenience and Necessity and Site Compatibility Certificate for the Construction of a Combined Cycle Combustion Turbine at the Cane Run Generating Station and the Purchase of Existing Simple Cycle Combustion Turbine Facilities From Bluegrass Generation Company LLC in Lagrange, Kentucky, Order dated May 3, 2012 at Page 15.

[6] The total cost to build and operate a given electricity generating unit per kilowatt-hour of electricity that would be generated over the lifetime of the system.

While the data in Figure 2 show many of the known differences for a technology's levelized cost of electricity and capital costs, they reflect electricity pricing and do not necessarily help understand the costs related to CO_2 reductions. When looking at how a given power generation technology might impact CO_2 emissions, a common approach is to determine how much CO_2 would be "avoided" with that technology's implementation. For example, if one MWh per year of current Kentucky power generation were replaced with solar power, the annual "avoided" CO_2 would be 2,074 lbs,[7] which is simply the difference between the CO_2 generation rate for solar (nearly zero) and the CO_2 generation rate for an existing pulverized coal unit. There are limitations to the energy resources associated with low-carbon-emitting technologies. For this reason the total possible avoided CO_2 was estimated for each technology option based on Kentucky resource limits (see Appendix B). For example, 10,000 GWh per year of solar was deemed a practical maximum in Kentucky, resulting in the maximum possible avoided CO_2 from that technology to be about 10 million tons per year. Figure 3 shows a plot of the estimated possible avoided CO_2 in Kentucky for each of the candidate power generation technologies (blue bars). Also plotted in Figure 3 is the levelized cost of electricity for each technology, normalized to the corresponding tons of CO_2 avoided (red bars). This metric reflects the relative cost required to reduce a unit mass of CO_2 emitted.

For illustrative purposes, consider that Kentucky must avoid 60 percent of current CO_2 emissions (approximately 55 million tons per year). Given the estimated maximum CO_2 avoided for each technology, the only single technologies capable of achieving a 60 percent reduction are nuclear; advanced natural gas combined cycle (NGCC)—with or without CCS; and pulverized coal with CCS. When the CO_2 avoidance costs are factored in, both NGCC and nuclear have the lowest total cost, approximately $70 per ton of CO_2 avoided. Technologies associated with coal power generation using CCS, new or retrofitted, have higher estimated costs compared to natural gas and nuclear, ranging from $100 to $145 per ton of CO_2 avoided.

The individual technologies in Figure 3 capable of 25 percent to 50 percent reductions in current CO_2 emissions include natural gas combustion turbines, retrofits of PC boilers with natural gas, and full conversion of the coal power fleet to ultra-super critical boiler technology. Of these technologies, retrofitting PC boilers with natural gas has the lowest cost, at $125 per ton of CO_2 avoided, but with potential significant increase if natural gas prices were to increase.

The lower-end CO_2 emission reductions (less than 10 percent of current emissions) in Figure 3 are comprised of the renewables, along with combined heat and power (CHP). The most economical of these technologies ($55 to $90 per ton of CO_2 avoided) are CHP, wind, hydroelectric, and municipal solid waste (MSW). If combined these technologies could perhaps achieve a cumulative CO_2 avoidance of approximately 10 million tons per year.

Certain technologies are more capital intensive than others. Figure 4 shows the same data in Figure 3 but with initial capital costs in terms of annual CO_2 avoided ($/ton CO_2 avoided). The data in Figure 4 show the least capital intensive investments to be natural gas retrofits of the (eligible) existing fleet, advanced NGCC, and the retrofit of existing PC boilers with CCS technology. Comparing nuclear and advanced NGCC, the latter is less than half of the initial capital cost on a CO_2 avoided basis, where the two were

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[7] In 2012, based upon 89,819 GWh, the weighted generation emission rate average of coal (92 percent) and oil and gas (4 percent) was 2,074 lbs/MWh.

Figure 3: Carbon Dioxide Avoidance and Levelized Costs by Generating Technology
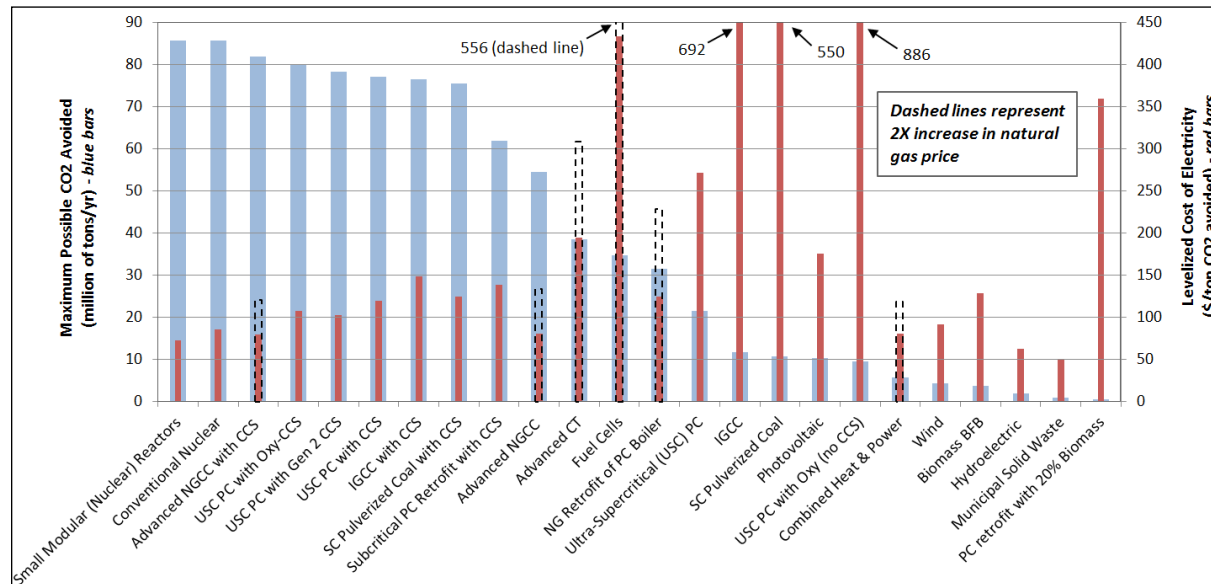
much closer based on the levelized costs in Figure 3. This could point out an important economic consideration in technology decisions, where upfront capital may be as important, if not more important, than levelized costs. Figures 2 through 4 also show that by itself, the new advanced coal-fired generation technology might not remove a sufficient amount of CO_2 depending on the future carbon reduction requirement imposed upon Kentucky, and it is expensive relative to other technology options. However, CCS technology can reduce CO_2 emissions and when paired with lesser expensive, low-CO_2 emitting technologies, coal can be an option.

Figure 4: Carbon Dioxide Avoidance and Capital Costs by Generating Technology
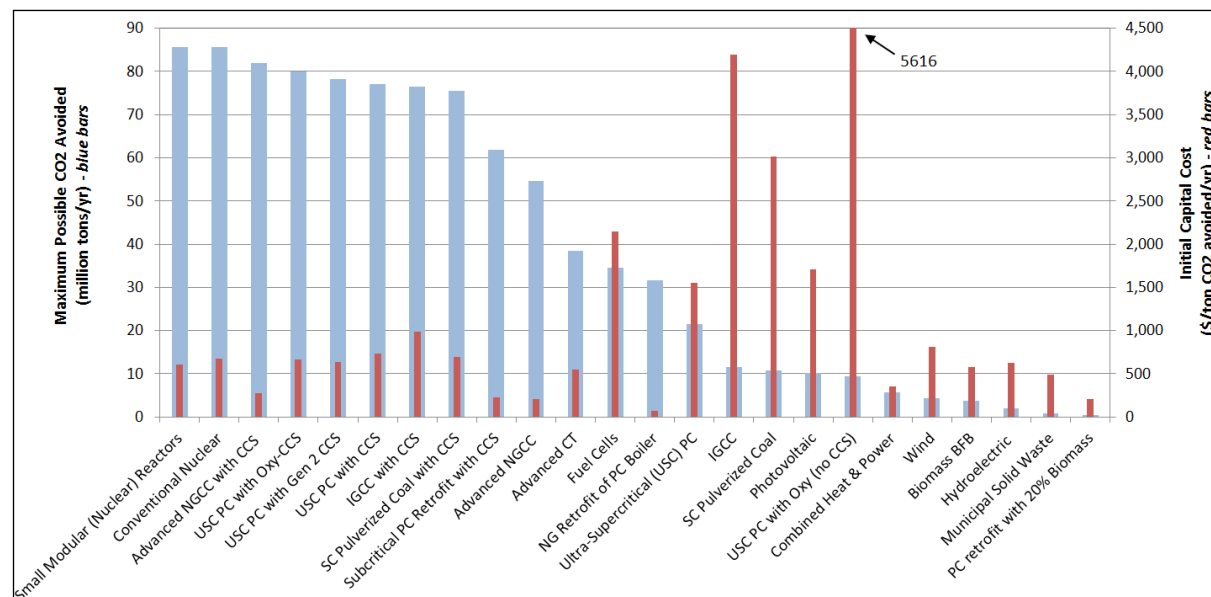
Several insights can be gained on how technologies vary as GHG reduction tools.

- Individual technologies capable of achieving a 60 percent CO_2 reduction compared to Kentucky's existing power generation fleet are limited to nuclear, advanced NGCC (with or without CCS), and pulverized coal with CCS. Of these technologies, at current prices for natural gas, NGCC has the lowest total cost, at $75 per ton of CO_2 avoided, and a relatively lower upfront capital cost, but with potential price sensitivity to increasing natural gas costs. Nuclear technology is estimated to have a total cost similar to that of NGCC, but with higher upfront capital costs and potentially higher risks associated with permitting and adoption. Coal power generation with CCS has a higher estimated cost than the other two technologies, but could represent one of the lowest upfront capital cost options if current coal power capacity were retrofitted.

- Retrofitting PC boilers with natural gas could achieve intermediate reductions of up to 30 million tons of CO_2 per year for Kentucky (one-third of current total emissions), assuming the "eligible" PC units listed in Appendix B. This option has an estimated levelized cost of $125 per ton of CO_2 avoided, but could significantly increase with rising natural gas prices. However, PC boiler retrofits could be achieved for much smaller initial capital investments compared to other technologies, and may allow for conversion back to coal firing if other abatement technologies were brought on line in the future.

- Individual renewable power generation technologies and combined heat and power have more limited ability to reduce Kentucky's CO_2 emissions due to the general limitations of the corresponding resources. However, combinations of the most viable of these technologies (CHP, wind, hydroelectric and MSW) could potentially achieve a cumulative CO_2 avoidance of 10 million tons per year (one-tenth of current total emissions), and an average levelized cost of $50 to $90 per ton of CO_2 avoided.

NSR/PSD Barriers to Technology Adoption

One purpose of this study was to investigate the potential for coal to maintain a substantial role in the production of electricity in Kentucky. This could be accomplished by improving boiler and turbine efficiency, through replacements or new green field construction of coal-fired capacity. The study team met with each of Kentucky's major electric generating utilities to discuss these issues in the context of environmental compliance. A barrier for utilities to engage in any significant efficiency or technology upgrade has been the EPA's enforcement of the New Source Review/Prevention of Significant Deterioration (NSR/PSD) rules.[8] However, general comments from the utilities indicated that in the current economic and regulatory environment, most utility companies would choose to build an entirely new unit rather than invest in upgrades that would substantially improve boiler efficiency. This is made evident by many utilities' current actions to comply with existing environmental rules by retiring current coal-fired generation and building new natural gas capacity to maintain the lowest cost portfolio. Even if the EPA were to ease NSR/PSD requirements, with the looming prospect of CO_2 regulation, it is not clear whether that would be sufficient to encourage boiler efficiency upgrades. However, the NSR/PSD rules are a barrier to this type of upgrade.

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[8] http://www.epa.gov/NSR/psd.html

Risk Exposure

Economic projections for generation technologies are useful, but they do not tell a complete story. Risks—economic, social, and technological—are also factors in whether a given technology is adopted, or the degree to which it is adopted on a large scale. For illustrative purposes, Table 1 shows a risk comparison for three of the technologies discussed above: Nuclear, CCS retrofits, and NGCC. The risk scenarios are ranked through an index that combines both probability and impact to CO_2 emissions reductions. Risk Category I reflects the greatest risk and Category III the least.

The risk comparison is not intended to provide a measure of absolute risk. Rather, it allows a relative ranking of the dominant risk factors associated with a particular technology, normalized across the identified options. While the exact placement of a risk scenario in a given category may be refined with further analyses, the general takeaway from the comparison is that there are significant, different risk elements associated with a given technology. For example, the readiness of small modular (nuclear) reactors (SMRs) as a viable option surfaces as a major risk consideration, along with cost and financing risks for nuclear in general. Liability protection concerns are a major risk consideration for CCS, and potential future price volatility is a major risk factor for natural gas. Some of these risks could be mitigated through policy actions, such as lifting the ban on nuclear power in Kentucky.

High natural gas prices also pose risk, as shown in Figure 3. Current EIA reference case natural gas price projections favor advanced NGCC with or without CCS as having cost advantages over both coal and nuclear technology. Even though nuclear has similar costs in terms of CO_2 avoided, its much higher upfront capital costs and higher permitting risks take it out of consideration in the immediate future. Figure 2 also shows the cost differentials when natural gas prices are doubled. With gas prices doubled, pulverized coal technologies with CCS become cost competitive in terms of CO_2 avoided; however, the upfront capital costs for pulverized coal with CCS still favor natural gas.

... the breadth of risks emphasizes the benefits of a balanced power generation portfolio, as opposed to reliance on a single technology or fuel option.

Figure 5 depicts the Energy Information Administration (EIA) natural gas price forecasts since 1979 and illustrates that a reliance on stable predictable natural gas prices as the basis for a major shift in generation technology is not without risk. The dark dotted line depicts the actual historical prices and the multiple colored lines represent the various annual EIA gas price forecasts. As can be seen, natural gas prices have proved difficult to forecast. The graph also illustrates the extent of recent gas price volatility and the risks to Kentucky of converting a large percentage of its electric generation fleet to natural gas if the U.S. returns to the high gas prices of the recent past.

Although this study did not attempt to quantify the impact of these risks, the breadth of risks emphasizes the benefits of a balanced power generation portfolio, as opposed to reliance on a single technology or fuel option.

Table 1: Preliminary risk scenario comparison for nuclear, CCS (retrofit), and natural gas power generation. Risk categorization based on the likelihood of the scenario and its relative impact.

Risk Category*	Nuclear	CCS (Retrofit)	Natural Gas
I	• Cost advantage of mass manufacturing (SMRs) not realized. • Financing issues encountered with heavy upfront capital costs. • Construction cost/ schedule overruns.	• Inadequate liability protection for CO_2 storage sites. • Cannot deploy CCS to scale.	• Future prices of natural gas could escalate by more than 2 times current rates.
II	• Unable to lift current Kentucky ban on nuclear. • Significant delays in (SMR) technology commercialization beyond 2020. • Adoption of nuclear slower than anticipated due to lack of current Kentucky infrastructure.	• Major CO_2 release or seismic event from CCS site (anywhere) impacts overall industry. • Timeline for commercial viability of CCS delayed. • Financing issues encountered with heavy upfront capital costs.	• Grid security compromised due to dependency on limited pipeline capacity. • Financing issues encountered with heavy upfront capital costs if CCS required.
III	• Major/visible nuclear disaster impacts overall nuclear market. • No progress on national policy for nuclear waste disposal. • Licensing delays. • Future in-state nuclear accident/ incident.	• Inadequate geologic storage capacity for CO_2 in Kentucky. • Adoption of CCS limited due to lack of public acceptance. • Capital costs much higher than currently anticipated. • Overall permitting timeline delays implementation.	• Grid stability issues encountered due to supply issues with natural gas - no buffer. • Regulatory constraints on production.

* Category I – Potentially unacceptable risk that requires mitigation action, such as legislation.
Category II – Significant risks but lower priority than Category I for mitigation measures.
Category III – Lower risks, in terms of priority for mitigation investment.

Figure 5: EIA Natural Gas Price Forecasts vs. Observed Natural Gas Prices

EIA Natural Gas Price Forecasts, 1979-2013
Energy Information Administration Annual Energy Outlook Forecasts vs. Actual

Kentucky Energy Database, EEC-DEDI, 2013

Data Sources: EIA-AEO 1979-2013 - Reference Case Delivered Price - All Sectors & BLS-CPI, 2013
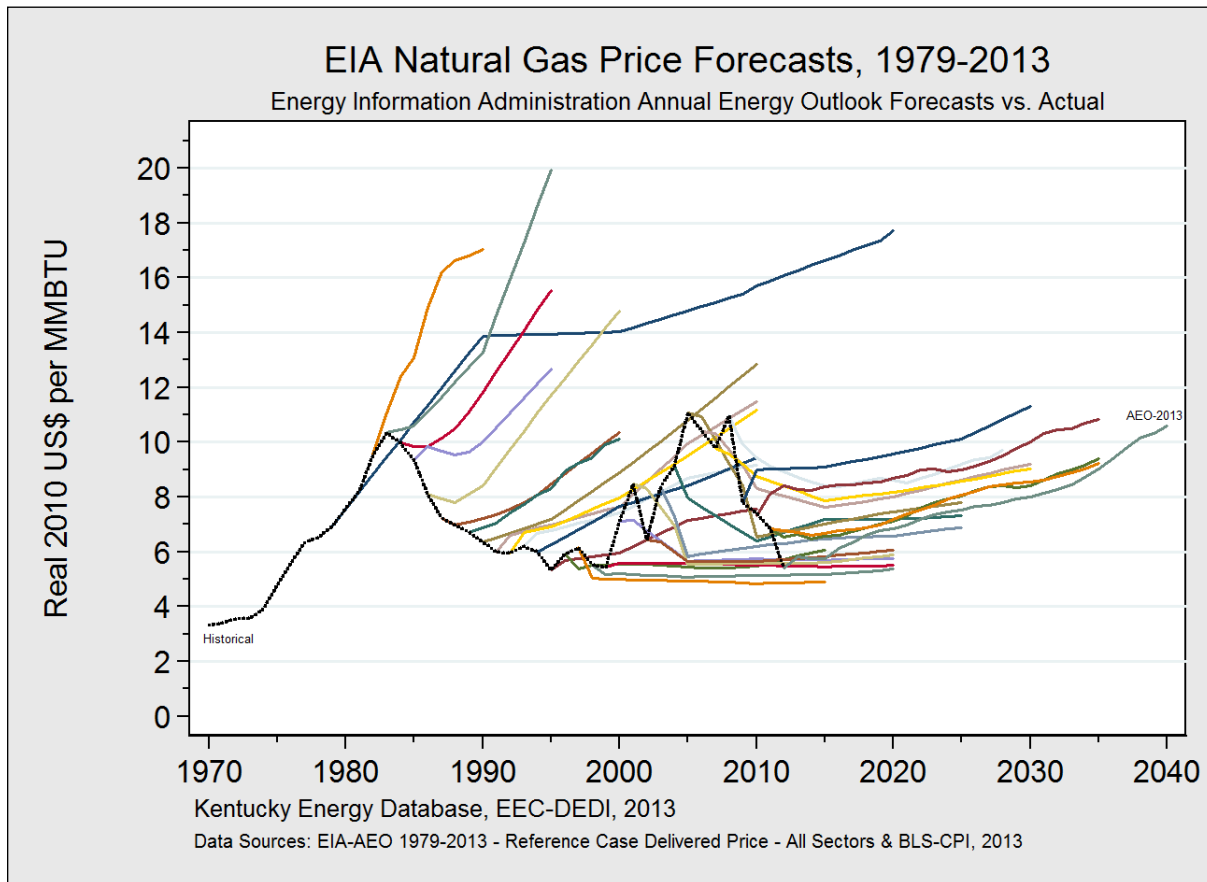
STUDY APPROACH AND RESULTS

The previous section identifies existing and future power technologies that could be employed to reduce CO_2 emissions. A more complex forecasting tool is required to assess specific assumed policy actions and the resulting impacts over time. For this study, an electric generation dispatch model was added to the EEC's existing energy forecasting models to evaluate how potential technology improvements could be made to the generation fleet and how the fleet would evolve over time. The model uses a constrained optimization algorithm to find the least-cost electricity generation portfolio that complies with all environmental regulations, including specified GHG emission constraints. The analysis incorporates all generation capacity across the state as a hypothetical single fleet and considers compliance strategies over time on a unit-by-unit basis considering three different federally imposed CO_2 emission limit regimes or constraints. Four possible responses Kentucky could take to meet the various assumed federal emission constraints were also considered.

The model dispatches all electricity generation units across the state on a constrained least-cost basis while satisfying demand and environmental requirements for electricity in a given year. The ultimate goals are (1) to understand the impact of different federal CO_2 policies, and (2) to explore how various Kentucky-specific compliance strategies affect CO_2 emissions, electricity prices, and employment.

Federal Policy Options

At this time, it can only be surmised how EPA will regulate GHG emissions from modified, reconstructed, and existing power plants. Therefore, the study considered three possible frameworks for regulations: a carbon tax, a rate emissions standard, and a mass emissions standard. For purposes of the study, we used emissions limits that correspond to President Obama's U.S. goals: a reduction in CO_2 of 17 percent by 2020 compared to 2005 levels and a reduction of 80 percent by 2050. The reduction levels in intervening years are simply a linear interpolation between 2020 and 2050.

The carbon tax is a dollar amount levied on every ton of CO_2 emitted. Three different sets of carbon taxes were evaluated: $10 in 2020 to $20 in 2040; $20 in 2020 to $40 in 2040; and $40 in 2020 to $60 in 2040.

The rate emission analysis takes the form of a statewide fleet annual average, where the actual state limit is the weighted average of coal-, gas-, and oil-fired generation emissions from a 2005 (per the President's goals) baseline. The first rate regime takes effect in two periods: 1,472 lbs/MWh by 2020 to 1,189 lbs/MWh by 2025, a lesser standard that does not achieve the assumed targets based on the President's goals. The second rate regime is designed to achieve the President's CO_2 emission goals of 17 percent by 2020 and extending to 80 percent by 2050 and takes effect in two periods: 1,655 lbs/MWh by 2020 to 330 lbs/MWh by 2050.

The mass emission analysis follows the assumed targets by initially requiring a 17 percent reduction in CO_2 levels by 2020 extending to an 80 percent reduction by 2050. The limit is based upon a percentage reduction from the statewide emissions levels during the 2005 baseline period. The premise of this constraint is that once emission limits are set for any given period, the state can employ any generation technology available over time, as long as state emission limits are not breached. The constraint requires a 17 percent reduction from the baseline period by 2020 and a 30 percent reduction by 2030.

Kentucky-Specific Response/Modeled Policy Options

The study simulated four possible policy responses Kentucky could take to meet the various assumed federal emission constraints considered.

First, a business as usual (BAU) response is simulated. Here, the model assumes no changes are made to Kentucky's energy regulatory framework. The model assumes compliance with existing environmental rules as well as compliance with EPA's rule that limits GHG emissions from new fossil fuel power plants. The BAU case sets the benchmark by which the other three portfolios are evaluated using each of the federal GHG constraints described above. EPA regulations already in place have set utility planning and investment compliance actions in motion. As a result, certain older coal-fired generation units in Kentucky have either been retired or are slated to be retired by 2016. New additional natural gas-fired generation capacity is either being constructed or being considered as replacement for many of the retired units. As existing units are retired, all new fossil generation will adhere to the new proposed CO_2 emission limits.

For the second response (Flexible Portfolio), the BAU assumptions are relaxed to simulate elimination of the state's ban on nuclear power. No other federal or state mandate is changed. The model builds the optimal least-cost generation portfolio based on price, with all fuels available with no additional constraints.

In the third response (Balanced Portfolio), the BAU assumptions are relaxed to eliminate the state's ban on nuclear power and to place a limit on any type of generation source within the portfolio to simulate a more diversified energy mix. In the modeled optimal least-cost portfolio, no single resource (coal, gas, wind, solar, etc.) generates more than 60 percent of total electricity (MWh) in a given year.

In the final response (Coal Portfolio), the BAU assumptions are relaxed to eliminate the state's ban on nuclear power and, to understand how coal could remain a part of Kentucky's electricity mix despite carbon regulation, the model is required to meet a certain percentage of demand with coal. The optimal least-cost portfolio must be structured such that at least 40 percent of the electricity (MWh) is generated from coal in a given year. The model first complies with federal environmental rules and then attempts to meet the 40 percent generation requirement. However, in some years, given certain federal carbon policies being modeled, the 40 percent requirement cannot be met.

Simulation Results

The full simulation results are in Appendix C. A Scenario Matrix is provided for quick reference of each Policy/Portfolio simulation. Following the Scenario Matrix, a series of snapshot estimation results matrices are provided for the years 2025, 2035, and 2050 covering employment, Kentucky gross domestic product (GDP), electricity prices, a variety of emissions including CO_2, coal consumption, and percent coal-fired electricity generation. Each of the scenarios is summarized using graphs that depict changes to the metrics listed above over time. Finally, a description of the model itself and assumptions are provided. Twenty-eight scenarios were simulated based on the EIA's reference case natural gas price. An additional 28 scenarios were simulated based on EIA's low oil and gas recovery case that led to high natural gas price forecasts. The following are several key findings derived from the simulations.

Even without new rules limiting GHG emissions, Kentucky is already on a path to reduce its greenhouse gas emissions.

Kentucky's energy mix is changing even without new regulations on greenhouse gases. Environmental regulations unrelated to GHGs coupled with low natural gas price are already forcing retirements of existing coal capacity. Even without new rules limiting GHG emissions, Kentucky is already on a path to reduce its GHG emissions because of these changes. Over time, if gas prices remain low and utilities replace older coal-fired power plants with new natural gas combined cycle plants, the switch to gas will become more apparent. Figure 1 showed the gradual switch to natural gas over time, with resulting reductions in GHGs depicted in Figure 6. The greater reliance on natural gas will become the norm as utilities are forced to comply with existing regulations while meeting Kentucky's least-cost requirement for construction of new electric generating units. Kentucky's least-cost requirements currently favor natural gas due to currently low natural gas prices and the relatively low upfront capital costs for new construction. Based on study computer simulations, the contribution of natural gas to Kentucky's energy mix will range from 40 percent to over 90 percent by 2035, depending on the stringency of the carbon policy that is assumed and Kentucky's response to that policy. Figure 7 shows the projected generation mix for the year 2035 based on reference case computer simulations.

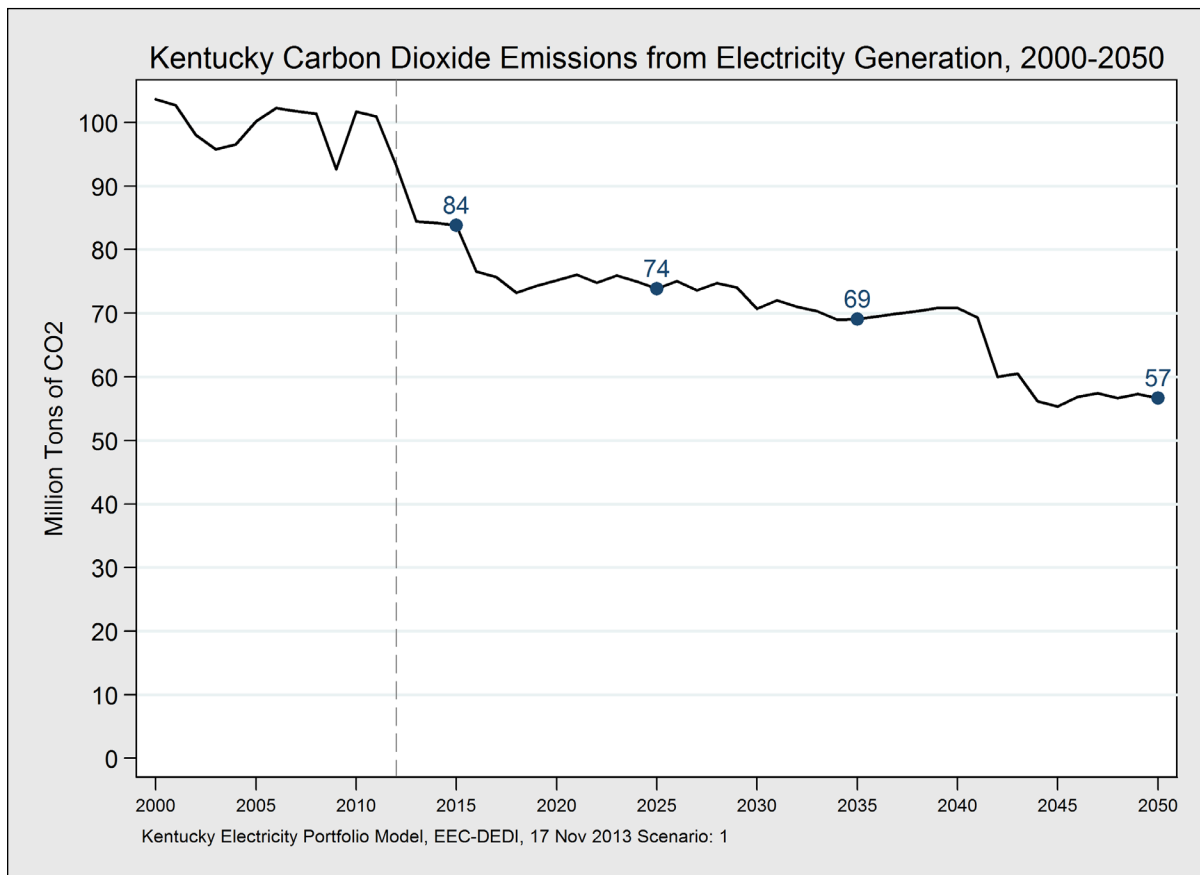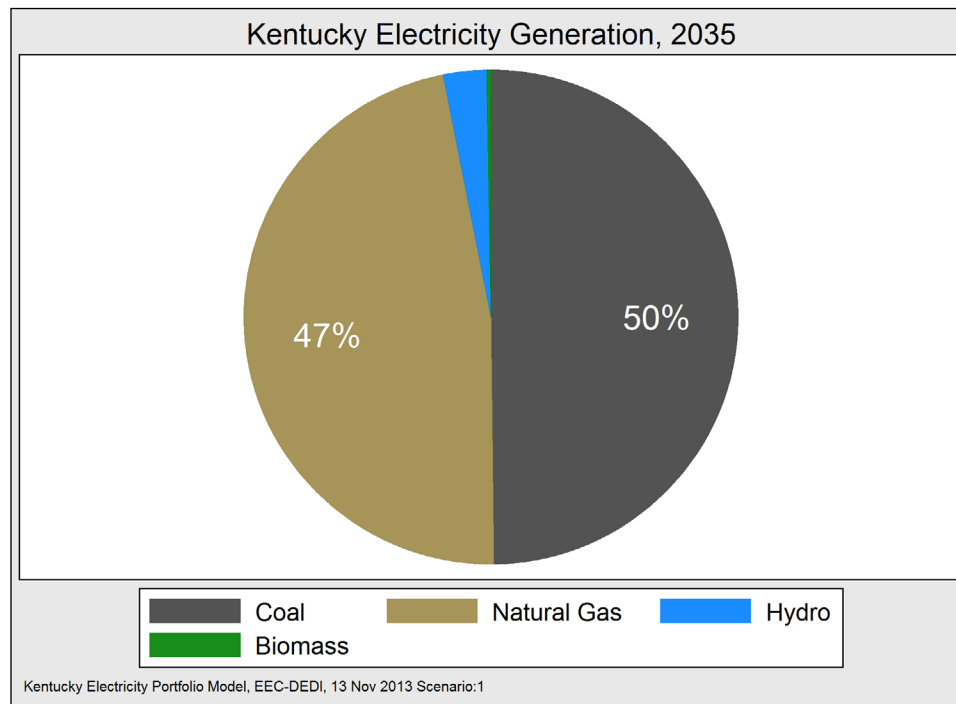**Figure 6: Kentucky CO$_2$ Emissions from Electricity Generation, 2000-2050, Reference Case**

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Figure 7: Kentucky's Electricity Generation, 2035, Reference Case

Kentucky Electricity Generation, 2035

50%

47%

Coal   Natural Gas   Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 13 Nov 2013 Scenario:1

If Kentucky is required to reduce its CO_2 emissions in line with the President's goals, then the primary options for replacing baseload generation capacity from forced retirements are nuclear, natural gas combined cycle, and coal with carbon capture and sequestration. Each option carries risks as described in Table 1. There are advanced technologies being developed for both nuclear and coal requiring time to be market-ready. Nuclear is a zero emitting CO_2 source and advanced coal with CCS, when commercially available, will be a very low emitting source. In certain circumstances, it is possible for the two technologies to work in tandem in a carbon-constrained world. However, the current ban on nuclear power makes it an omitted choice during utility planning processes. Even though relaxing the ban on nuclear generation does not have an immediate effect on the generation technology choices in the short or mid-term, removing the ban is still an important first step. The most advantageous nuclear technology (small modular reactors) is still a few years away from deployment, and the planning and permitting processes are lengthy. As described in Table 1, there are specific risks unique to nuclear, coal with CCS, and natural gas for future baseload electric generating units (EGU). Diversification of future EGUs can mitigate the risk associated with a single fuel type as illustrated by the high natural gas price scenarios described below.

However, the federal policy options simulated by this study do have varying impacts on prices and Kentucky's economic health, and Kentucky can take steps to mitigate those impacts.

Federal carbon policies will likely increase the price of electricity, thereby weakening Kentucky's economy. Kentucky's electricity prices will increase with federal GHG policies relative to the reference case, thereby negatively affecting employment and state GDP. This finding holds regardless of the policy option the federal government might employ to reduce emissions. However, the federal policy options simulated by this study do have varying impacts on prices and Kentucky's economic health

(see Tables 2 and 3), and Kentucky can take steps to mitigate those impacts. The mid- and high-level carbon taxes have the most severe impact on the price of electricity through 2035. By 2050 there is less variation in price among the federal policy options simulated in this study, and it becomes clear that nuclear power is a price stabilizer. The scenarios that simulate maintaining the ban on nuclear power yield the highest priced energy mix for Kentucky under each of the federal carbon policies with the exception of the lowest carbon tax. Scenarios marked NA were unable to meet the assumed federal policy mandate and achieve a 40 percent coal portfolio.

Although not the only driver, low-cost electricity is very important for Kentucky's economy. Kentucky's low-cost electricity has fostered the single most electricity-intensive economy in the U.S., and increases in prices will have a notable impact. A study initiated by the Energy and Environment Cabinet in 2012 predicted a 25 percent increase in electricity prices would be associated with a net loss of 30,000

Table 2: Kentucky Electricity Prices, 2035

Kentucky Total Electricity Price, 2035 (Real Cents per KWh)				
Federal Policy Options	Portfolios			
	1: Nuclear Banned	**2: Nuclear Allowed**	**3: Balanced Portfolio**	**4: Coal Portfolio**
1: Reference Case	10.1	10.1	10.1	9.7
2: Carbon Price: $10 - $20	11.7	11.7	11.7	11.3
3: Carbon Price: $20 - $40	13.0	13.0	13.1	12.9
4: Carbon Price: $40 -$60	13.6	13.6	13.6	14.2
5: CO2 Rate Limit	11.8	10.2	10.2	NA
6: Presidential CO2 Rate Limit	11.9	10.7	11.1	NA
7: Mass Emissions Reduction	11.9	10.9	11.1	NA

Table 3: Kentucky Electricity Prices, 2050

Kentucky Total Electricity Price, 2050 (Real Cents per KWh)				
Federal Policy Options	Portfolios			
	1: Nuclear Banned	**2: Nuclear Allowed**	**3: Balanced Portfolio**	**4: Coal Portfolio**
1: Reference Case	13.5	13.5	13.9	14.3
2: Carbon Price: $10 - $20	14.7	14.7	14.7	15.2
3: Carbon Price: $20 - $40	15.9	15.0	15.1	15.7
4: Carbon Price: $40 -$60	16.1	14.2	14.7	14.9
5: CO2 Rate Limit	14.7	13.5	13.9	14.3
6: Presidential CO2 Rate Limit	17.1	15.1	15.1	NA
7: Mass Emissions Reduction	17.0	15.2	15.1	NA

full-time jobs, primarily in the manufacturing sector. [9] So, it is not surprising that in Kentucky, a policy that increases the price of electricity will have a similar impact on jobs and overall GDP. Tables 4 and 5 show that in the early years through 2035, the mid- and high-level carbon taxes have the most negative impact on employment. By 2050 nuclear power, if allowed, can mitigate the harmful effects on Kentucky's economy of most of the federal policy options simulated. The three portfolios allowing nuclear power create the greatest employment opportunities.

Table 4: Kentucky Change in Employment, 2035

Change in Employment, 2035 (Full Time Jobs)				
	Portfolios			
Federal Policy Options	**1: Nuclear Banned**	**2: Nuclear Allowed**	**3: Balanced Portfolio**	**4: Coal Portfolio**
1: Reference Case	0	0	0	0
2: Carbon Price: $10 - $20	-60,000	-60,000	-60,000	-70,000
3: Carbon Price: $20 - $40	-110,000	-110,000	-110,000	-130,000
4: Carbon Price: $40 -$60	-130,000	-130,000	-130,000	-170,000
5: CO2 Rate Limit	-70,000	0	0	NA
6: Presidential CO2 Rate Limit	-70,000	-20,000	-40,000	NA
7: Mass Emissions Reduction	-70,000	-30,000	-40,000	NA

Scenarios marked NA indicate the scenario was unable to meet the assumed federal policy limits.

Table 5: Change in Employment, 2050

Change in Employment, 2050 (Full Time Jobs)				
	Portfolios			
Federal Policy Options	**1: Nuclear Banned**	**2: Nuclear Allowed**	**3: Balanced Portfolio**	**4: Coal Portfolio**
1: Reference Case	0	0	0	0
2: Carbon Price: $10 - $20	-40,000	-40,000	-30,000	-20,000
3: Carbon Price: $20 - $40	-70,000	-50,000	-40,000	-40,000
4: Carbon Price: $40 -$60	-80,000	-20,000	-30,000	-10,000
5: CO2 Rate Limit	-40,000	0	0	0
6: Presidential CO2 Rate Limit	-110,000	-50,000	-40,000	NA
7: Mass Emissions Reduction	-100,000	-50,000	-40,000	NA

[9] Kentucky Energy and Environment Cabinet. (2012). The Vulnerability of Kentucky's Manufacturing Economy to Increasing Electricity Prices. Department for Energy Development and Independence, Frankfort.
http://energy.ky.gov/Programs/Documents/Vulnerability%20of%20Kentucky's%20Manufacturing%20Economy.pdf

By 2035, the employment loss is similar across all portfolios ranging from approximately 60,000 to 70,000 fewer potential jobs relative to the reference case.

A federal carbon tax would likely have the most extreme impact on Kentucky. The lowest carbon tax slightly reduces carbon emissions by increasing the cost of electricity from carbon-emitting resources. This reduces the overall demand for electricity in each of the sectors—residential, commercial, and industrial—as compared to the reference case, as shown in Figure 8. The lowest carbon tax is not high enough to cause a significant shift in Kentucky's energy mix relative to the reference case; it simply taxes the consumer of carbon-emitting electricity who responds by consuming less electricity. By 2035, the employment loss is similar across all portfolios ranging from approximately 60,000 to 70,000 fewer potential jobs relative to the reference case. Electricity price increases range from about 0.5 to 1.6 cents/kwh greater than in the reference case across the portfolios. By 2025 the low carbon tax can force enough reduction in CO_2 emissions to meet the assumed targets, but by 2050 the low carbon tax falls short of the target and only reduces about 1.6 million tons more CO_2 emissions than the reference case.

Figure 8: Kentucky Electricity Consumption, 1960-2050, Low Carbon Price - Reference Case Comparison

Kentucky Electricity Consumption, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, Scenarios 1 & 2, 13 Nov 2013
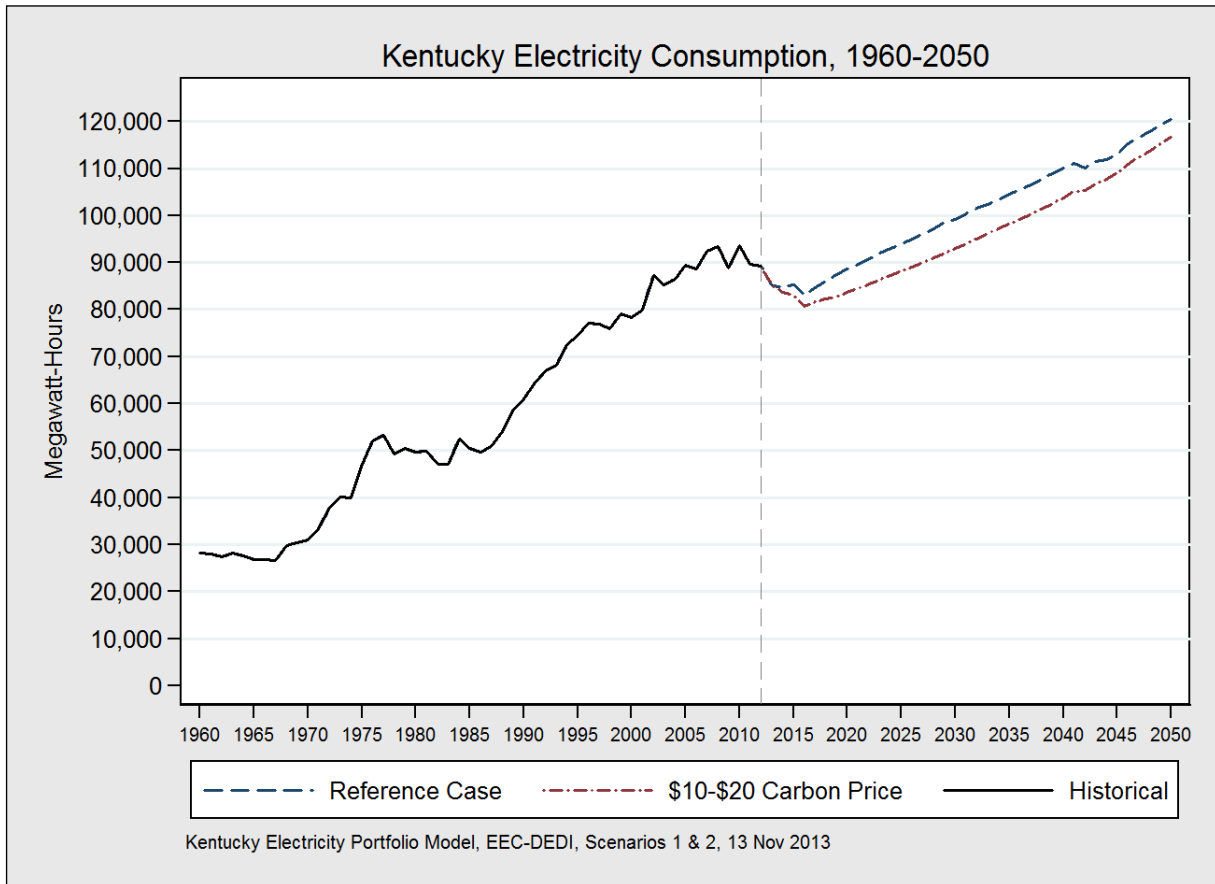
The mid- and high-level carbon tax simulations tell a different story. These tax levels drive Kentucky to natural gas for power generation faster than any other federal carbon policy analyzed. Under the mid-level carbon tax, Kentucky becomes reliant on natural gas for 75 percent of its electricity by 2035 (Appendix C). However, a significant build out of new natural gas power plants occurs before then between 2016 and 2020. The high-level carbon tax creates a powerful economic driver to replace coal-fired power plants with natural gas as well. By 2035 nearly all of Kentucky's electricity generation is natural gas-fired. It costs the ratepayers less money to abandon coal-fired power plants and build new natural-gas-fired power plants, which also emit carbon that is taxed, than to continue utilizing coal and paying the mid- and high-level taxes. The abrupt build out of natural gas forced by the highest level carbon tax actually reduces Kentucky's carbon emissions below the assumed targets as shown in Table 6. Electricity price increases range from about 2.9 to 3.2 cents/kwh compared to the reference case across the portfolios in 2035 for the mid-level carbon price and about 3.5 to 4.5 cents/kwh for the high carbon price. Potential employment levels are similar across all portfolios. In 2035, relative to the reference case, the mid-level carbon price results in approximately 110,000 to 130,000 fewer jobs. In 2035, the high carbon price results in more potential job losses, creating an estimated 130,000 to 170,000 fewer jobs than in the reference case.

By 2050, maintaining the nuclear ban results in up to 70,000 fewer jobs created compared to the more diversified portfolios.

Table 6: Kentucky CO_2 Emissions from Electricity Generation, 2050

Kentucky CO_2 Emissions, 2050 (Million Tons of CO_2)				
Federal Policy Options	**Portfolios**			
	1: Nuclear Banned	**2: Nuclear Allowed**	**3: Balanced Portfolio**	**4: Coal Portfolio**
1: Reference Case	56.6	56.7	46.6	46.2
2: Carbon Price: $10 - $20	55.1	55.1	45.5	45.1
3: Carbon Price: $20 - $40	48.8	20.7	22.3	33.9
4: Carbon Price: $40 -$60	35.9	7.5	15.4	21.8
5: CO2 Rate Limit	55.1	56.7	46.6	46.2
6: Presidential CO2 Rate Limit	18.4	18.7	19.2	NA
7: Mass Emissions Reduction	19.4	19.1	19.2	NA

If Kentucky must face a carbon tax greater than $20/ton, nuclear power will be necessary to moderate the price of electricity beyond 2035. It becomes the preferred option since it can meet electricity demand while avoiding both the tax on carbon and higher natural gas prices in the out years. It is important to remember that natural gas-fired electricity does emit carbon and cannot avoid the tax entirely as nuclear can. As shown in Tables 2 and 3, when the carbon price is above $20/ton, the nuclear-banned scenarios are the most costly for ratepayers in terms of price per kilowatt hour.

All three carbon tax levels simulated increase the price of electricity and reduce employment relative to the reference case, regardless of the response Kentucky takes to mitigate the impact of the taxes. Tables 2 through 5 demonstrate the carbon tax levels' worsening impact on price and employment.

By relying on new generating capacity that emits zero carbon emissions such as nuclear power, Kentucky can meet carbon regulations while still relying on coal for some of its electricity generation mix. However, the most coal could contribute to Kentucky's electricity mix under the assumed targets by 2050 would be no more than 40 percent. The impact of maintaining coal in the generation portfolio, assuming the cost inputs described in Appendix A, varies depending on the federal policy option being simulated. In the near term, the coal portfolio is most expensive under a carbon tax option. In 2035, the coal portfolio does not satisfy the federal CO_2 limit analyzed.

A rigid rate limit as proposed by NRDC removes compliance flexibility and, more importantly, would not achieve emissions reductions in line with assumed federal reduction goals beyond 2025; CO_2 emissions would continue to grow, tracking growth in the state economy.

Rate and mass emission limit regimes produce similar results under flexible statewide compliance portfolios. The EEC's GHG whitepaper demonstrated how a rigid emissions rate limit, as proposed by the Natural Resources Defense Council (NRDC), would be detrimental to Kentucky, especially if credit were not given for emissions reductions already underway. A rigid rate limit as proposed by NRDC removes compliance flexibility and, more import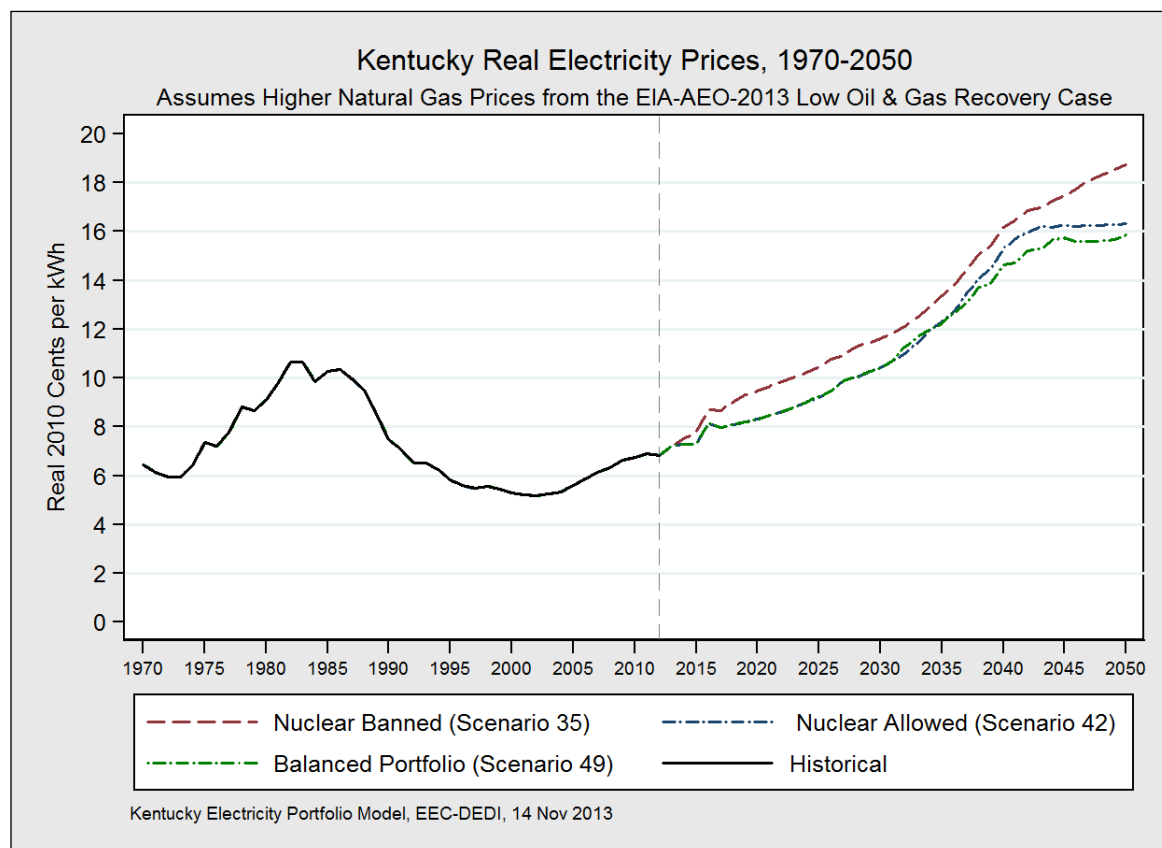antly, would not achieve emissions reductions in line with assumed federal reduction goals beyond 2025; CO_2 emissions would continue to grow, tracking growth in the state economy. Since, Kentucky's generation fleet is currently undergoing a shift away from coal-fired EGUs to gas-fired EGUs, the whitepaper advocated for a mass emissions limit. Under this regulatory regime, the state would have the necessary flexibility to take full credit for the CO_2 emission reductions that were going to result from the ongoing transformation of Kentucky's generation fleet. Furthermore, in this study, we did not consider any avoided GHG reductions via energy efficiency, carbon offsets, etc.

This study attempted to compare specific state responses to different federal CO_2 regulatory regimes. Applying emission rate limits to specific EGUs would mean shutting down the coal units as soon as limits became effective. Advanced coal combustion, CCS and advanced nuclear technologies are not mature, and additional time is needed for these technologies to be proven and implemented. Therefore, the rate limit was modeled two ways: first, a rate limit structure similar to NRDC's and second, a rate limit specifically designed to track the mass emissions corresponding to the assumed targets of the President's goals. The rate limit, as well as the mass emission limit, was applied to the state's entire generation fleet. As expected, the NRDC structured rate limit failed to produce the requisite CO_2 reduction levels beyond 2025, and employment and price levels were similar to the reference case results. The latter rate limit regime and the mass emission regime produced very similar results. By design, CO_2 limits were achieved with very similar results for employment and price level changes. Also, as expected, allowing flexibility in the generation portfolio had a beneficial effect on the economy over time by allowing more jobs to be created with lower electricity prices.

Higher natural gas prices will cost Kentucky jobs; a diversified portfolio moderates those impacts. Assuming that natural gas prices follow the EIA high natural gas price forecast, simulation results indicate that the higher price trajectory does not slow Kentucky's transition to natural gas, although the higher gas price does make this transition more costly for Kentuckians, with resulting impacts on employment. By 2035 the reference case, assuming the high natural gas price trajectory, results in 50,000 fewer jobs than the reference case that assumes EIA's lower reference gas prices. Many of these jobs are in Kentucky's manufacturing sector.

When federal carbon policies are simulated assuming the high gas price forecast, some notable differences occur compared to the lower gas price forecast. Nuclear power becomes a preferred option sooner with higher gas prices, and the cost of Kentucky's nuclear ban is more severe. In 2035 assuming the mass emission standard is in effect, the nuclear banned portfolio produces higher gas prices compared to the other three portfolios examined. Higher gas prices also make diversification more attractive. Assuming Kentucky must meet the mass emission reduction simulated and assuming gas prices follow the EIA high gas price forecast, the difference in price between the portfolio that simulates a diversified or balanced approach and the portfolio that simulates just removing the nuclear ban is minimal. In many years the balanced portfolio is less costly. Figure 9 illustrates the effect of the nuclear ban on electricity prices and shows that through 2030 the cost of the balanced portfolio tracks with the non-diversified portfolio (Scenario 42). In later years the balanced portfolio is less costly for ratepayers. It should be noted a similar finding exists when gas prices are low.

Figure 9: Kentucky Electricity Prices, Nuclear Banned, Nuclear Allowed, Diversified Portfolio

Kentucky Real Electricity Prices, 1970-2050
Assumes Higher Natural Gas Prices from the EIA-AEO-2013 Low Oil & Gas Recovery Case

Kentucky Electricity Portfolio Model, EEC-DEDI, 14 Nov 2013

RECOMMENDATIONS

Given the uncertainty regarding EPA's rules for existing EGUs, states must think about potential economic impacts and consider potential actions to respond. In this paper, we have considered several impacts and diverse mitigation responses for Kentucky. The timing and details that will result from EPA's proposed regulations when they are issued in June 2014 will undoubtedly affect reactions and responses from individual states, which will be very different and suggest that contingency planning is crucial. Certainly, our thinking and planning will evolve. But based on our current understanding, several recommendations relative to Kentucky's EGU fleet follow.

1. Kentucky must continue to advocate for and find ways to maintain low-priced electricity. If low relative rates are not maintained, there will be reduced employment opportunities for Kentuckians, especially in the manufacturing sector.

2. As described in Table 1, there are specific risks unique to nuclear, coal with CCS, and natural gas for future baseload electric generating units, and, for the most part, these risks do not overlap. Because of these unique risks and since it is impossible to determine which risk factors may ultimately dominate, it is imperative that Kentucky policy makers ensure that there is the

... it is imperative that Kentucky policy makers ensure that there is the flexibility necessary to diversify Kentucky's future EGU fleet.

flexibility necessary to diversify Kentucky's future EGU fleet. Kentucky's strict requirement that new electric generating facilities be least cost coupled with the current low price of natural gas strongly favors natural gas as the preferred fuel for future baseload EGU. However, policy makers may want to modify the existing least-cost framework to prevent Kentucky from relying on natural gas for all new generation capacity as Kentucky's existing power plant fleet is modified to comply with GHG regulations. It is important to note that an alternative EGU technology that is not least cost to build and operate today may shelter rate payers from risk and may prove to be a least-cost resource in the future. The avoided risks of alternative EGUs may be well worth the expected added upfront cost to the ratepayers, but strict interpretation of Kentucky's least-cost requirement for construction of new EGUs will stymie Kentucky's efforts to diversify its future EGU fleet.

3. To maintain coal as a viable fuel for electricity generation, policies should be considered to encourage transition to more efficient coal generation technologies in a timely manner. Further, consideration should be given to relaxing the NSR/PSD rule that stymies serious consideration of coal generation efficiency upgrades at existing power plants. Research should continue to address those risks associated with CCS described in Table 1 to bring down the cost of the technology and remove barriers to its implementation.

4. The existing statutory provision in KRS 278.605, which effectively bans the construction of nuclear power plants in Kentucky, should be repealed so that utilities have the option to consider developing nuclear power generation in their planning processes. Nuclear power is a zero carbon emitting resource that can enable Kentucky to meet GHG reduction requirements while still utilizing coal, and it can stabilize electricity prices in the long term. By moderating the increase in electricity price, nuclear power can protect jobs in a carbon-constrained world. Many

of the scenarios show nuclear power edged out by low-cost natural gas in the earlier years. However, development of nuclear power has a lengthy lead time and removing the ban can enable it to be a part of the planning process. Furthermore, the risk of a sudden shift to higher future natural gas prices may warrant the construction of nuclear power plants sooner.

5. Kentucky is already on the path to reduce its carbon emissions as a result of combined market and regulatory forces. Any federal policy that requires further carbon emission reduction should allow Kentucky to use reductions already realized or expected because of power plant retirements and existing programs in its compliance plan. Further, Kentucky should be given flexibility in how it meets the target so that coal can remain in the energy mix. A mass-emission reduction strategy as compared to a rate-based or carbon tax strategy will provide Kentucky greater flexibility in minimizing the impact on ratepayers and its existing coal fleet.

A mass-emission reduction strategy as compared to a rate-based or carbon tax strategy will provide Kentucky greater flexibility in minimizing the impact on ratepayers and its existing coal fleet.

6. If Kentucky is afforded the responsibility to manage the GHG emissions on a statewide basis, ratepayers will benefit if utilities operating in Kentucky engage in enhanced cooperation and sector-wide planning. Therefore, it is important to afford utilities the opportunity to take advantage of regional differences in planning future compliance strategies. This is especially important if Kentucky must comply with a rate-based standard, which could have uneven economic impacts across the state. To a certain extent, the utilities already cooperate with each other in areas of network planning and operations. Furthermore, the shared ownership of assets is not uncommon in the industry. Enhanced coordination and long-range planning and coordination among utilities may result in better balancing of resources and services overall to Kentucky's customers and more affordable prices.

ACRONYMS AND ABBREVIATIONS

B	billion
BFB	biomass fed boiler
btu	British thermal unit
CC	combined cycle
CCS	carbon capture and storage
CHP	combined heat and power
CT	combustion turbine (simple cycle natural gas power plant)
EGU	electricity generating unit
GDP	Gross Domestic Product
GHG	greenhouse gas
GWh	gigawatt hour
IGCC	integrated gasification combined cycle plant
lb	pound
kwh	kilowatt hour
MSW	municipal solid waste
MW	megawatt
MWh	megawatt hour
NGCC	natural gas combined cycle (power plant)
NSR/PSD	New Source Review/Prevention of Significant Deterioration
NRDC	Natural Resources Defense Council
O&M	operating and maintenance (costs)
PC	pulverized coal
SC	supercritical (power plant)
SMR	small modular (nuclear) reactor
USC	ultra-supercritical (power plant)

APPENDIX A - Future Power Generation Options

Defining the future power generation options for Kentucky is a key part of the current regulatory impact assessment. Future technologies could include improvements to current coal power generation units - including CCS, natural gas power generation, and renewables. Table A.1. shows the list of future power generation options assumed for Kentucky. Each of the technologies is accompanied by the necessary data required for modeling predictions. The color coding in the table corresponds to the sources of the various pieces of information (sources listed below the table).

The coal technologies in Table A.1 include both supercritical (SC) and ultra-supercritical (USC) power generation. The respective power generation efficiencies of those technologies are 39 percent and 45 percent (HHV). The impacts of CCS (assumed to be amine technology) to these systems is on both the efficiency and capital cost. Second-generation CCS technologies that are currently in earlier stages of research and development are also included in the projections.

For natural gas, technology options include combined cycle (CC) and combustion turbine (CT). Fuel cells and natural gas retrofits of PC boilers are also included, along with combined heat and power (CHP).

Finally, a variety of renewable (and nuclear) technologies are specified in Table A.1. The listed renewables include photovoltaic, nuclear (including small module reactors), wind, hydroelectric, municipal solid waste (MSW), and biomass. Biomass options include both 100 percent biomass power generation and 20 percent co-feeding options with coal.

For each of the technologies in Table A.1 estimates were made for levelized cost of electricity, maximum possible avoided CO_2, etc. The supporting assumptions that were necessary for those estimates are shown in Appendix B. Outside of those assumptions, the key assumptions used in generating the estimates in Table A.1 are as follows:

1) Nuclear power generation is not prohibited in Kentucky.

2) Fuel prices are constant for the total cost estimates shown, except for the 2X natural gas price representations in several plots.

3) A constant capital charge factor or 0.0965 was used for every technology type, which implies the same depreciation period and interest rates.

4) An average (current) CO_2 generation rate of 2,074 lb/MW-h was assumed for Kentucky.

5) The specified lag time (permitting, construction, etc.) in Table A.1 was not taken into account in the cost and emissions comparison estimates. Also, only the current electricity demand values were used. The higher fidelity model is necessary to incorporate these parameters.

6) Only CO_2 emissions from biomass and MSW were exempted from CO_2 emission totals used in the rollups, as they were not deemed as being from fossil energy sources.

Table A.1: Data for Power Generation Technology Options

	Plant Characteristics				Emissions (lb/MMBtu)				Plant Costs (2012$)									Estimates		
	Nominal Capacity (MW)	Capacity Factor	Heat Rate (Btu/kWh)	Fuel	CO2 (Total)	CO2 (from biomass & MSW)	Total CO2 Emissions (lb/MW-h)	CO2 from Fossil Sources (lb/MW-h)	Fixed O&M Cost ($/kW-yr)	Variable O&M Cost ($/MWh)	Overnight Capital Cost ($/kW)	Time Until Commerc Available (yrs)	Permitting Time (yrs)	Construction Time (yrs)	Total Lead Time (yrs)	Assumed Fuel Price ($/MMBTU)	Total LEC ($/kW-hr)	Max. Offset to KY Coal Power Generation	Max. Possible CO2 Avoided (M tons/yr)	Total Cost ($/ton CO2 avoided)
Subcritical PC Retrofit with CCS	650	85%	13,046	Coal	44.1	0	576	576	$216.4	$21.2	$1,267	2	2	3	7	2.87	0.104	100%	62	139
SC Pulverized Coal	1,300	85%	8,800	Coal	206	0	1813	1813	$31.18	$4.47	$2,934	0	3	5	8	2.87	0.072	100%	11	550
SC Pulverized Coal with CCS	1,300	85%	12,000	Coal	20.6	0	247	247	$66.43	$9.51	$4,724	0	3	6	9	2.87	0.114	100%	75	125
Ultra-Supercritical (USC) PC	550	85%	7,654	Coal	203	0	1554	1554	$34.2	$5.2	$3,000	0	2.5	4	6.5	2.87	0.071	100%	21	271
USC PC with CCS	550	85%	10,270	Coal	20	0	205	205	$47.3	$9.2	$5,130	5	2.5	5	12.5	2.87	0.111	100%	77	119
USC PC with Oxy-CCS	550	85%	10,353	Coal	13	0	135	135	$45.55	$7.10	$4,770	5	2.5	5	12.5	2.87	0.105	100%	80	108
USC PC with Oxy (no CCS)	550	85%	9,093	Coal	203	0	1846	1846	$45.55	$7.10	$4,770	5	2.5	5	12.5	2.87	0.101	100%	9	886
USC PC with Gen 2 CCS	550	85%	8,962	Coal	20	0	179	179	$41.3	$8.0	$4,470	10	2.5	5	17.5	2.87	0.097	100%	78	103
IGCC	600	85%	8,700	Coal	206	0	1792	1792	$62.3	$7.2	$4,400	0	2.5	4	6.5	2.87	0.098	100%	12	692
IGCC with CCS	520	83%	10,700	Coal	20.6	0	220	220	$72.8	$8.5	$6,599	0	2.5	5	7.5	2.87	0.137	100%	77	148
NG Retrofit of PC Boiler	250	87%	9,355	Gas	117	0	1095	1095	$25.0	$3.6	$250	0	1	1	2	5.45	0.061	78%	32	125
Combined Heat & Power	10	87%	6,007	Gas	61	0	364	364	$7.5	$6.1	$2,278	0	1.5	1	2.5	5.45	0.069	8.0%	6	80
Advanced CT	210	30%	9,750	Gas	117	0	1141	1141	$7.0	$10.4	$676	0	2	1	3	5.45	0.091	100%	39	195
Advanced NGCC	400	87%	6,430	Gas	117	0	752	752	$15.4	$3.3	$1,023	0	1.5	2	3.5	5.45	0.053	100%	55	81
Advanced NGCC with CCS	340	87%	7,525	Gas	12	0	90	90	$31.8	$6.8	$2,095	0	2	3	5	5.45	0.078	100%	82	79
Fuel Cells	10	90%	9,500	Gas	130	0	1235	1235	$0.0	$43.0	$7,108	0	1	1	2	5.45	0.182	100%	35	433
PC retrofit with 20% Biomass	650	85%	10,600	Co-feed	206	36	2184	1802	$40.0	$6.4	$213	0	1	1	2	3.24	0.049	4.4%	0	359
Biomass BFB	50	78%	13,500	Biomass	195	195	2633	0	$105.6	$5.3	$4,114	0	1.5	2	3.5	4.00	0.133	4.4%	4	128
Municipal Solid Waste	27	85%	13,500	MSW	115	115	1551	0	$90.5	($10.0)	$3,784	0	2	3	5	0.00	0.051	1.0%	1	49
Photovoltaic	150	25%	N/A	Solar	0	0	0	0	$24.7	$0.0	$3,873	0	1	1	2	0.00	0.182	12.0%	10	175
Small Modular (Nuclear) Reactors	180	90%	N/A	Uranium	0	0	0	0	$93.3	$2.1	$5,000	4	2	3	9	0.72	0.075	100%	86	72
Conventional Nuclear	2,234	90%	10,452	Uranium	0	0	0	0	$93.3	$2.1	$5,530	0	4	7	11	0.72	0.089	100%	86	86
Wind	30	34%	N/A	Wind	0	0	0	0	$39.6	$0.0	$2,513	0	1	1	2	0.00	0.095	5.0%	4	91
Hydroelectric	10	52%	N/A	Hydro	0	0	0	0	$14.1	$0.0	$2,936	0	2	4	6	0.00	0.065	2.3%	2	63

U.S. Energy Information Administration (EIA), Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants, April 2013 [all unhighlighted data in black font]
Higman, Christopher; van der Burgt, Maarten (2008). Gasification (2nd Edition), Table 9.3. Elsevier.
Levelized Cost of New Generation Resources in the Annual Energy Outlook 2013, U.S. Energy Information Administration (EIA), January 2013.
Pulverized Coal Oxycombustion Power Plants – Volume 1: Bituminous Coal to Electricity, DOE/NETL-2007/1291, Revision 2, August 2008
Assumes 1/2 the parasitic energy for amine baseline carbon capture
Craig Welling, US Dept. Energy Office of Nuclear Energy, Dec. 2010.
Technology Characterization: Gas Turbines, Prepared by Energy and Environmental Analysis for EPA Climate Protection Partnership Division, Washington DC, Dec. 2008.
Feasibility and cost of converting coal fired utility boilers to natural gas. MIT EL 86-009, Dec. 1986. 3–5% efficiency drop for NG substitution. B&V paper: +200 btu/kWh increase to subcritical cycle.
Male JL, et.al. "Logistics, Costs, and GHG Impacts of Utility-Scale Co-firing with 20% Biomass." PNNL-SA-94835, U.S. Department of Energy.
Skone TJ, et.al. Role of Alternative Energy Sources: Pulverized Coal and Biomass Co-firing, Technology Assessment, August 30, 2012, DOE/NETL-2012/1537, U.S. Department of Energy.
Estimates from PNNL (various sources).
"Renewable Energy Opportunities at Fort Campbell, Tennessee/Kentucky," JR Hand, et. al., Pacific Northwest National Laboratory, for the U.S. DOE, PNNL-20223.
"Is It Better To Burn or Bury Waste for Clean Electricity Generation?" P. Ozgen Kaplan, et. al., U.S. EPA, Environ. Sci. Technol. 2009, 43, 1711–1717.
"The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies," Mills, et. al. LBNL-1471E, February 2009. $2,213/kW from EIA report plus $300/kW of MISO transmission upgrade.

The following plot shows the CO_2 generation rates for each of the potential power generation technologies in Table A.1. Technologies using coal and natural gas include options with carbon capture and storage (CCS). The renewable technologies, nuclear, and municipal solid waste plants have near zero CO_2 emissions.

Figure A.1: CO_2 Emission Rates for Future Candidate Power Generation Technologies
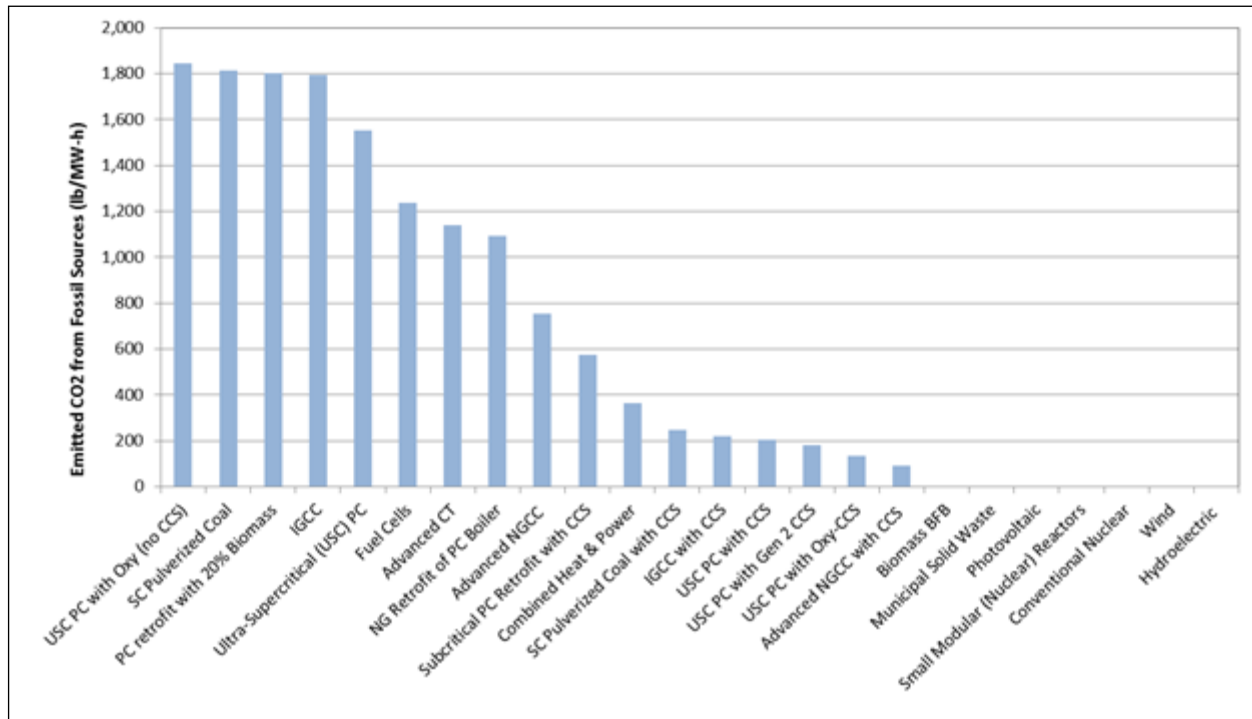
The next plot shows the levelized cost of electricity for the technologies in Table A.1 along with the cost sensitivity of a 2X increase in natural gas price. Here the initial price of natural gas was assumed to be $5.45 per million Btu.

Figure A.2: Levelized Cost of Electricity from Table A.1 - with 2X increase in natural gas price represented.
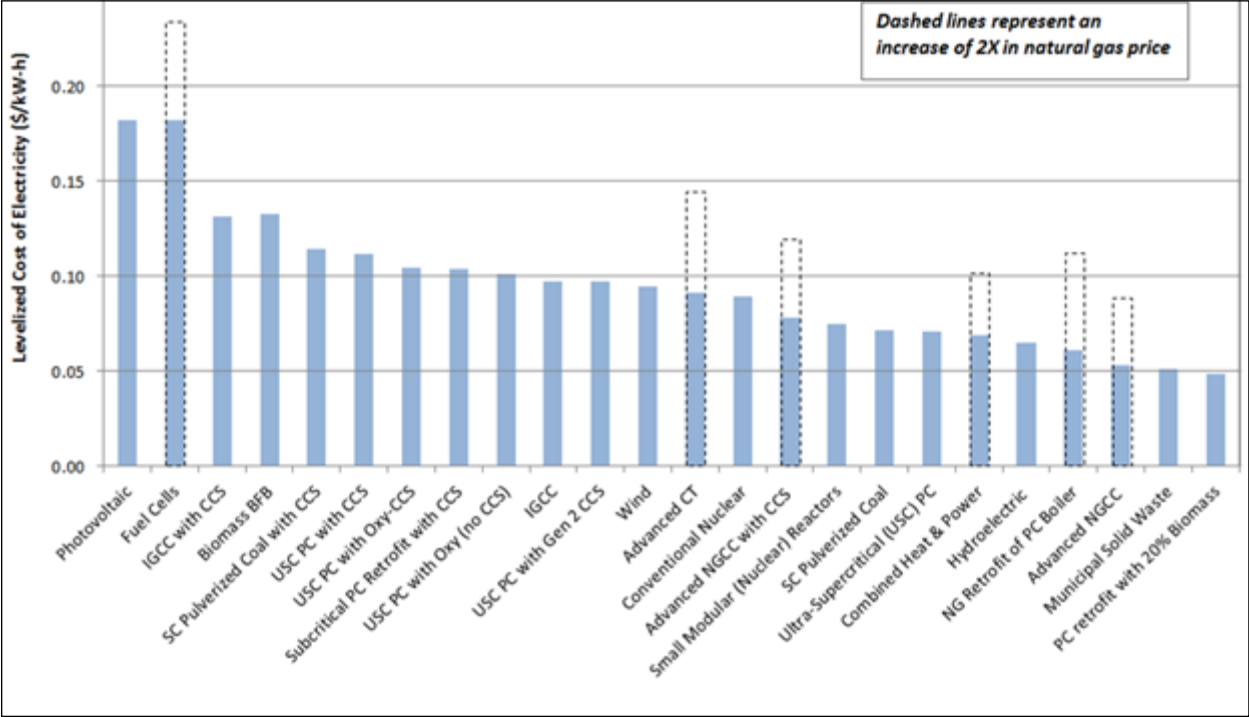
APPENDIX B – Estimated Limits on Power Generation Sources for Kentucky

The following sections outline the key assumptions and statewide potential for a given resource (biomass, MSW, wind, etc.). These assumptions were used to generate the estimates shown in Table A.1.

B.1   Biomass Potential

5.7 to 6.0 million dry tons of annual biomass potential are estimated for the entire state of Kentucky.[10]
The primary sources for the biomass are forest residue, dedicated crops, crop residue, and urban wood.
There are two primary technology options for biomass use in power generation, one as a co-feed component in current (or future) coal power plants, and two as a devoted (100 percent) feedstock for smaller power generation systems. The total state level resource assumptions for each of these two options are as follows:

Co-fed Biomass with Coal

- The form of the biomass fuel is assumed to be char from a torrefaction process, which is a type of mild pyrolysis. The char yield from unprocessed biomass is typically around 55 percent.

- The fuel value of the char is assumed to be 9,100 btu/lb.

- The cost of the torrefied biomass is assumed to be $86 per ton, or $4.72 per million btu.

- The biomass char is assumed to be co-fed with coal at 20 percent of the total feedstock mass.

- The average heat rate of power generation (co-fed blend) is assumed to be 8,800 btu/kwh.

- Using the fuel value, the co-feeding percentage and the heat rate, the total annual energy potential for Kentucky is 6,650,000 MW-h, which equates to 760 MW of total possible power.

- The assumed size of the co-fed power plant is 650 MW. Therefore, the total number 650 MW coal power plants that could be 20 percent co-fired equates to 760 MW / (20 percent * 650 MW per plant * 85 percent assumed capacity factor) = 7 plants.

Devoted (100 percent) Biomass Power Generation

- The form of the biomass fuel may be field dried but is otherwise unprocessed.

- The fuel value of the biomass is conservatively assumed to be 5,000 btu/lb.

- The cost of the biomass is assumed to be $40 per ton = $4 per million btu. [11]

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[10] NREL Dec. 2005. TP-560-39181. Technical Report. A Geographic Perspective on Current Biomass Resource Availability in the United States.

[11] U.S. Billion Ton Update - Biomass Supply for a Bioenergy and Bioproducts Industry, Oak Ridge National Laboratory, for the U.S. DOE under contract DE-AC05-00OR22725, August 2011.

- The average heat rate of power generation is assumed to be 13,500 btu/kwh.

- Using the fuel value, the co-feeding percentage, and the heat rate, the total annual energy potential for Kentucky is 4,300,000 MW-h, which equates to 490 MW of total possible power.

- The assumed size of a devoted biomass power plant is 50 MW. Therefore, the total number 50 MW coal power plants equates to 490 MW / (50 MW per plant * 85 percent assumed capacity factor) = 11 plants.

    Hybrid Examples

- If fractions of the total biomass are to be used for co-fed and devoted scenarios, simply multiply the corresponding energy potential by that fraction. For example, 75 percent co-fed and 25 percent devoted and would result in 75 percent * 6,650,000 MW-h/yr = 5,000,000 MW-h/yr for co-fed applications and 25 percent * 4,300,000 MW-h/yr = 1,075,000 MW-h/yr for devoted applications.

B.2   Municipal Solid Waste Potential

Municipal Solid Waste (MSW) enters Kentucky landfills at a rate of 4.2 million tons per year and approximately one-third is estimated to be recoverable.[12]   The energy content of recoverable MSW is approximately 11 million Btu per ton (5,500 Btu/lb), heavily weighted towards biogenic resources such as paper, paperboard, and yard debris.[13]   Power production from MSW can be achieved by either combustion or gasification-based systems, with typical heat rates of 18,000 and 13,600 Btu/kwh, respectively.[14]   The assumptions for potential future MSW power production are as follows:

- Using the above parameters, and the lower of the two heat rates, the total annual energy potential for Kentucky is 1,100,000 MW-h, which equates to approximately 130 MW of total possible power.

- The assumed sizes of the combustion and gasification-based MSW power production units are 20 and 27 MW, respectively. Therefore, the total number 20 MW MSW power plants possible in Kentucky equates to 130 MW / (20 MW per plant * 85 percent assumed capacity factor) = 8 plants.

- MSW fuel costs are rolled into the Variable O&M. Therefore, tipping fees received by the power producer result in an overall negative Variable O&M.

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[12] "Is It Better To Burn or Bury Waste for Clean Electricity Generation?" P. Ozgen Kaplan, et. al., U.S. EPA, Environ. Sci. Technol. 2009, 43, 1711–1717.
[13] "Renewable Energy Opportunities at Fort Campbell, Tennessee/Kentucky," JR Hand, PNNL-20223.
[14] U.S. EIA, Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants, April 2013

B.3   Hydroelectric Capacity

Total developable hydroelectric capacity in Kentucky is estimated at 439 MW, with the Meldahl project already under construction at 110 MW.[15]   This results in approximately 300 MW of remaining hydroelectric capacity for the state. Hydroelectric opportunities in the 0 to 10 MW size range sum up to a total of 107 MW, with an average size of 2.6 MW. Opportunities in the 0 to 50 MW range sum to a total of 297 MW, with an average size of 6 MW. Therefore, an average size of no more than 10 MW was assumed in the analysis for an individual future unit.

B.4   Wind Power

A national wind power assessment showed 1,900 GWh of possible in-state wind generation potential for Kentucky at 100-meters.[16]   This total is reduced to 173 GWh for wind generation potential at 80 meters. The corresponding power production of these two options (at 30 percent capacity factor) is 700 MW and 61 MW, respectively. A Synapse study identified up to 2,000 GWh of out-of-state wind that may be available for Kentucky use.[17]   Based on these two assessments an in-state maximum of 1,900 GWh (700 MW at a 30 percent capacity factor) and 2,000 GWh of maximum out-of-state wind capacity were assumed. These values equate to a corresponding (current) coal power displacement potential of 5 percent.

Future wind power imported to Kentucky is assumed to come from Indiana, with transmission into western Kentucky via existing MISO lines. The overnight capital cost of imported wind is assumed to be $2,213 per kW. This includes costs for a substation to increase voltage from the collection system at 34.5 kV to interconnected transmission system high voltage at 115 kV.[18] The capital cost estimate does not include MISO upgrades necessary for transmission to Kentucky. Upgrades are not likely necessary for small amounts of wind transmission (<100 MW). For significant wind transmission a capital adder should be applied. A transmission cost adder estimate of approximately $300/kW is given in one study and is the assumed value for the current assessment.[19]

B.5   Potential for Solar Power Generation via Photovoltaic Technology

Several sources were studied to determine the extent of potential Kentucky solar resources using photovoltaic power generation.[20,21,22] The referenced studies spanned from large scale (>10 MW) installations to small (0.1 MW) distributed generation systems, with projections out to 2025. The estimates of possible electric energy from solar ranged from 1,200 to 17,000 GWh per year, or 1.4 to 13 GW of potentially displaced power for the state. Based on this range a value of 10,000 GWh per year, or 8.0 GW at an assumed capacity factor, was assumed to be the state solar resource maximum for the current study. This value has a corresponding (current) coal power displacement potential of 12 percent.

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[15] http://hydropower.inel.gov/resourceassessment/app_a/index_states.shtml?ky

[16] http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=ky. Accessed 10/29/2013.

[17] Synapse. KY REPS/EE Potential Impacts. January 2012.

[18] Appendix B, page 21-1 of EIA April 2013 report

[19] "The Cost of Transmission for Wind Energy: A Review of Transmission Planning Studies," Andrew Mills, Ryan Wiser, and Kevin Porter. LBNL-1471E, February 2009.

[20] Potential Impacts of a Renewable and Energy Efficiency Portfolio Standard in Kentucky. Synapse Jan. 12, 2012.

[21] The Opportunities for Distributed Renewable Energy in Kentucky. Downstream Strategies, LLC. June 18, 2012.

[22] Intelligent Energy Choices for Kentucky's Future. Governor Steven L. Beshear. Nov. 2008.

B.6   Combined Heat and Power Potential

Combined Heat and Power (CHP) implies the use of waste heat from a power production plant for industrial heating. Natural gas is the most common fuel for CHP applications and is assumed for any of the modeling forecasts.

The current CHP potential in Kentucky is estimated between 4 percent and 12 percent of current power generation.[23]   Therefore, 8 percent is assumed as the current CHP potential for modeling purposes. This value equates to approximately 2,000 MW of current power generation for Kentucky. Future estimates for CHP potential are even larger.[24,25]   Therefore, it is assumed that the CHP "resource" could increase (linearly) to 30 percent of Kentucky's power generation (approximately 7,000 MW in today's power usage) over the next 20 years, where it should stay at the 30 percent maximum from there on out. The average size for an assumed CHP system is 10 MW.

The assumed reduction in CO_2 emission from CHP should be as high as 1,040 lb of CO_2/MW-h.[26]   This value is close to the stated CO_2 emissions from an average natural gas power generation source. The reason for the large potential offset is that total recoverable heat recovery from fuel in CHP is similar to the electricity yield. However, a key assumption in reducing projected CO_2 emissions is that the CO_2 that would otherwise be used in an industrial heating operation is not part of the power base rollup.

A net power generation heat rate of 6,000 Btu/kwh was also assumed for CHP, versus a starting point of around 12,000 Btu/kwh (for a 10 MW system). This adjustment is due to the fact that CHP thermal energy is nearly equivalent to the electricity energy itself and, therefore, could result in a 50 percent reduction in the effective heat rates for those systems.

B.7   Potential for Retrofits of PC Boilers with Carbon Capture and Storage (CCS)

The existing Kentucky coal fleet was assessed for the potential of retrofitting to CCS. Kentucky currently has 63 coal-fired power generation units for a total pulverized coal (PC) capacity of 16,283 MW.[27]   The criteria used for CCS retrofit-ability were (1) units must have a capacity of at least 500 MW, either singly or combined at a single site (consolidate flue gas into a single CCS system); (2) units must have FGD, or analog, for high efficiency sulfur removal; and (3) units must not be slated for retirement and must be newer than 1970 vintage so as to preclude or reduce their retirement over the short term. Using these criteria 22 units were deemed "eligible" for retrofit, or a total current name plate capacity of 9,400 MW. The following table shows the subset of "eligible" plants along with CCS cost projections.

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[23] "Combined Heat and Power, Effective Energy Solutions for a Sustainable Future," Shipley, et. al., Oak Ridge National Laboratory for the U.S. DOE, ORNL/TM-2008/224, December 1, 2008.

[24] "The Market and Technical Potential for Combined Heat and Power in the Commercial/Institutional Sector," ONSITE SYCOM Energy, for U.S. DOE – Energy Information Administration, January 2000.

[25] "The Opportunities for Distributed Renewable Energy in Kentucky," McIlmoil, et. al. Downstream Strategies, LLC, June 18, 2012

[26] "Technology Characterization: Gas Turbines," Prepared by Energy and Environmental Analysis for EPA Climate Protection Partnership Division, Washington DC, December 2008.

[27] EIA dataset for Kentucky power generation.

For any carbon capture technology a significant drain of power from the plant, or "parasitic load," is required for the separation and compression of the CO_2. The estimates in Table B.1 assume that commercial amine-based CO_2 scrubbing (90 percent removal) is used for CCS, with a conservative parasitic load of 29 percent of the net electric power production. Therefore, the 9,400 MW of retrofitted power would only produce a net amount of 6,667 MW after retrofit. The capital cost estimates in Table B.1 total $5,377 million. This equates to $849 per kW of net power production with CCS.

Fixed and variable costs will also increase with a CCS retrofit. The same baseline assessment for CCS on subcritical PC used for the capital projection was also used for the fixed and variable cost predictions.[28] These costs were normalized to total CO_2 production to aide in the subsequent estimates for a given plant retrofit. Here, the fixed costs with and without CCS were $9.8 and $8.3 per ton of total CO_2 production, respectively. Similarly, the respective variable costs with and without CCS were $6.9 and $5.5.

Note that all of the above costs for CCS retrofit were adjusted for the parasitic power associated for the technology. This was done by assuming that all parasitic power would be replaced by new NGCC technology. Therefore, the individual costs were increased by the associated fraction of NGCC costs that would be required. For example, the capital costs was increased by the capital cost of NGCC ($1,023 per kW in Table A.1) multiplied by the parasitic load fraction (29 percent/71 percent).

Table B.1: Estimates of Existing Kentucky Coal Power Production "Eligible" for CCS Retrofit

Commercial amine-based CO_2 scrubbing (90 percent) estimates used with a parasitic load of 33 percent of the net electric power produced. Capital costs extrapolated using CO_2 production rate.[29]

Unit Code	Site Name	Name Plate Capacity (MW)	Heat Rate (Btu/kW-h)	Online Year	Age Out Year	Total CO2 Generation (lb/hr)	Revised Capacity w/ CCS (MW)	Number of CCS Systems per Group	CO2 Generation in Group (lb/hr)	Capital Cost for CCS Retrofits (2012$ M)
6823_W1	D B Wilson	566	9,956	1984	2044	1,154,963	401	1	1,154,963	373
1355_3	E W Brown	412	10,487	1971	2048	886,505	292	1	1,480,753	433
1355_2	E W Brown	166	10,553	1963	2036	359,478	118			
1355_1	E W Brown	106	10,794	1957	2034	234,771	75			
6018_2	East Bend	600	9,218	1981	2042	1,136,268	426	1	1,136,268	369
1356_2	Ghent	495	8,904	1977	2057	903,405	351	2	1,804,945	488
1356_3	Ghent	489	8,982	1981	2042	901,540	347			
1356_1	Ghent	479	9,694	1974	2041	952,190	340		1,772,832	483
1356_4	Ghent	469	8,512	1984	2044	820,642	333			
6041_2	H L Spurlock	510	9,752	1981	2057	1,021,754	362	2	1,259,974	393
6041_1	H L Spurlock	300	8,861	1977	2050	545,748	213			
6041_3	H L Spurlock	268	8,826	2005	2075	485,407	190		1,259,974	393
6041_4	H L Spurlock	268	8,501	2005	2067	467,038	190			
1364_4	Mill Creek	477	9,557	1982	2042	936,160	338	2	1,398,396	418
1364_3	Mill Creek	391	9,483	1978	2042	761,168	277			
1364_1	Mill Creek	303	8,507	1972	2042	528,844	215		1,398,396	418
1364_2	Mill Creek	301	9,246	1974	2042	570,621	213			
1378_3	Paradise	971	10,236	1970	2030	2,038,760	689	1	2,038,760	525
6639_G2	R D Green	293	10,434	1981	2045	628,391	208	1	1,231,423	331
6639_G1	R D Green	293	10,004	1979	2033	603,032	208			
6071_2	Trimble County	732	8,892	2010	2070	1,366,527	519	1	1,366,527	413
6071_1	Trimble County	511	9,420	1990	2066	987,870	362	1	987,870	340
Totals		**9,400**					**6,667**			**5,377**

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[28] Pulverized Coal Oxy-combustion Power Plants - Volume 1: Bituminous Coal to Electricity, DOE/NETL-2007/1291, Revision 2, August 2008. Data for subcritical PC: Cases 9 and 10.

[29] Quality Guidelines for Energy System Studies: Capital Cost Scaling Methodology, DOE/NETL-341/013113, January 2013

B.8   Potential for Natural Gas Power Generation

Conversion of existing capacity to natural gas-fired technologies could proceed under several different mechanisms including retrofit of pulverized coal (PC) fired furnaces to support natural gas combustion (fuel switching); replacement of existing capacity with natural gas combined cycle (NGCC) units; and/or replacement of existing PC produced energy to higher percentages of combined heat and power (CHP). All are considered technically viable and relevant. The intent of this section is to describe the potential impacts under each of these scenarios when considered discretely; it does not however attempt to optimize a portfolio of generating options based on natural gas. The following is predicated on the natural gas fuel price as provided in EIA fuel price projections through 2040.

Retrofit of Existing Pulverized Coal Furnaces to Natural Gas Combustion

The retrofit of PC furnaces to natural gas combustion can be a relatively simple process if the existing furnace and balance of plant can support the fuel switch. It can also be complex, and is inherently site specific. Traditionally, retrofit of PC furnaces to natural gas combustion has not been executed due to the lower efficiency steam cycle (when compared to a NGCC) and wide variation in natural gas fuel pricing compared to coal.

Of the existing PC capacity in Kentucky, approximately 80 percent of the fleet could fire natural gas. Removed from consideration were furnaces that would be difficult to repower without a technology switch such as stoker boilers and fluidized bed boilers. Plants that were declared as retired, or to be retired within the next three years, were also eliminated.

EIA (2012) indicated that of the 89,820 GWh produced in Kentucky, approximately 92 percent (82,566 GWh) was generated by coal-fired facilities. On an energy basis, replacing that electricity with retrofit PC furnaces operating at an average heat rate of 10,186 [30] btu/kwh, would require the conversion of approximately 9,200 MWs[31] ; an approximate capital outlay of $2.3 billion; and annual non-fuel operating expenses (fixed and variable) of approximately $500 million per year. From an infrastructure standpoint, natural gas consumption for converted PC plants alone could consume almost 17 percent of the entire natural gas pipeline capacity entering the state of Kentucky[32]; the capital required for expansion of distribution is not captured in the analysis, nor is the estimated cost for actual transmission of gas.

Transition to Natural Gas Combined Cycle

The transition away from coal-fired capacity to natural gas combined cycle is already happening throughout the United States. For similar reasons as discussed earlier, such as higher efficiency power production when compared to coal-fired capacity and historically low fuel prices, existing NGCC units are experiencing much higher utilization rates (capacity factors), and new build capacity is quickly expanding as well.

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[30] Fleet average of the PC furnaces considered eligible for NG retrofit.

[31] Assumes conversion can happen within two years. Costs are representative of 2016 which is the first year that furnaces could be transitioned.

[32] Accessed at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/usage.html

Analysis of NGCC started with the same baseline energy production data from EIA for 2012. In addition to considering full replacement of coal-fired capacity, power production from existing natural gas-fired capacity was also included to understand the total demand for fuel, and the potential impact to natural gas pipeline infrastructure.

On an energy basis, replacing the currently produced electricity from pulverized coal would require the greenfield development of approximately 11,400 MW[33]; a capital outlay of $11.7 billion, and annual non-fuel operating expenses (fixed and variable) of $450 million per year.   Natural gas consumption for new NGCC plants constructed to replace PC capacity would consume approximately 13 percent of the entire natural gas pipeline capacity entering the state of Kentucky.

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[33] Assumes conversion can happen within four years. Costs are representative of 2017 which is the first year that NGCC could be commissioned based on scheduled permitting and construction lead times.

APPENDIX C— Simulation Results

Appendix C summarizes preliminary simulations for 28 different scenarios. 7 different sets of possible federal environmental policies were modeled, referred here to as federal policy options. Each federal policy option is modeled with four separate generating portfolio strategies. The combination of each of the 7 federal policy options and 4 portfolios forms the 28 scenarios summarized in the matrix on page C.2. The specifics of each possible Federal Policy and Portfolios are discussed in greater detail on pages 12 and 13 of the main report.

Federal Policy Options

1. Reference Case – No new environmental regulations are implemented.

2. Carbon Tax: $10 -$20 – Carbon dioxide emissions from electricity generation are taxed at $10 per ton by 2020 and $20 per ton by 2040.

3. Carbon Tax: $20 -$40 – Carbon dioxide emissions from electricity generation are taxed at $20 per ton by 2020 and $40 per ton by 2040.

4. Carbon Tax: $40 -$60 – Carbon dioxide emissions from electricity generation are taxed at $40 per ton by 2020 and $60 per ton by 2040.

5. CO2 Rate Limit – Statewide electricity generating unit carbon dioxide emissions rates are limited to 1,472 lb. per MWh by 2020 and 1,189 by 2025.

6. Presidential CO2 Rate Limit – Statewide electricity generating unit carbon dioxide emissions rates are limited by the equivalent of the emissions reduction results in scenario 7.

7. Presidential Mass Emissions Reduction – Carbon dioxide emissions must be reduced by 17% by 2020 and 80% by 2050.

Portfolios

1. Nuclear Banned – Nuclear power in Kentucky is prohibited.

2. Nuclear Allowed – Nuclear power in Kentucky is no longer prohibited.

3. Balanced – No single fuel source may exceed 60% of total generation.

4. Coal – Coal-fired electricity generation must be at least 40% of generation.

This appendix is organized as follows: pages C.3 through C.10 contain results matrices comparing the 28 scenarios, pages C.12 through C.67 contain profiles of individual scenario results, pages C.68 through C.75 contain comparisons of generating portfolios, pages C.76 through C.87 contain comparisons of portfolio options and federal policy options across various outcomes, pages C.88 through C.90 contain input assumptions, pages C.91 through C.100 contain more detailed descriptions of the model, and a list of contributors is provided on pages C.101 and C.102.

Kentucky Electricity Portfolio Model Simulation Matrix

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	1	8	15	22
2: Carbon Tax: $10 - $20	2	9	16	23
3: Carbon Tax: $20 - $40	3	10	17	24
4: Carbon Tax: $40 -$60	4	11	18	25
5: CO_2 Rate Limit	5	12	19	26
6: Presidential CO_2 Rate Limit	6	13	20	27
7: Presidential Mass Emissions Reduction	7	14	21	28

Employment Results Matrices

2025 Full-Time Jobs

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	2,690,000	2,690,000	2,690,000	2,710,000
2: Carbon Price: $10 - $20	2,620,000	2,620,000	2,620,000	2,640,000
3: Carbon Price: $20 - $40	2,590,000	2,580,000	2,580,000	2,580,000
4: Carbon Price: $40 -$60	2,550,000	2,560,000	2,540,000	2,510,000
5: CO2 Rate Limit	2,620,000	2,670,000	2,670,000	NA
6: Presidential CO2 Rate Limit	2,620,000	2,690,000	2,690,000	NA
7: Mass Emissions Reduction	2,620,000	2,690,000	2,690,000	NA

2035 Full-Time Jobs

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	2,840,000	2,840,000	2,840,000	2,860,000
2: Carbon Price: $10 - $20	2,780,000	2,780,000	2,780,000	2,790,000
3: Carbon Price: $20 - $40	2,730,000	2,730,000	2,730,000	2,730,000
4: Carbon Price: $40 -$60	2,710,000	2,710,000	2,710,000	2,690,000
5: CO2 Rate Limit	2,770,000	2,840,000	2,840,000	NA
6: Presidential CO2 Rate Limit	2,770,000	2,820,000	2,800,000	NA
7: Mass Emissions Reduction	2,770,000	2,810,000	2,800,000	NA

2050 Full-Time Jobs

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	3,100,000	3,100,000	3,090,000	3,070,000
2: Carbon Price: $10 - $20	3,060,000	3,060,000	3,060,000	3,050,000
3: Carbon Price: $20 - $40	3,030,000	3,050,000	3,050,000	3,030,000
4: Carbon Price: $40 -$60	3,020,000	3,080,000	3,060,000	3,060,000
5: CO2 Rate Limit	3,060,000	3,100,000	3,090,000	NA
6: Presidential CO2 Rate Limit	2,990,000	3,050,000	3,050,000	NA
7: Mass Emissions Reduction	3,000,000	3,050,000	3,050,000	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

GDP Results Matrices

2025 (Billion 2010 US$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	194,000	194,000	194,000	195,000
2: Carbon Price: $10 - $20	191,000	191,000	191,000	192,000
3: Carbon Price: $20 - $40	189,000	189,000	189,000	189,000
4: Carbon Price: $40 -$60	188,000	188,000	187,000	185,000
5: CO2 Rate Limit	191,000	193,000	194,000	NA
6: Presidential CO2 Rate Limit	191,000	194,000	194,000	NA
7: Mass Emissions Reduction	191,000	195,000	194,000	NA

2035 (Billion 2010 US$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	219,000	219,000	219,000	220,000
2: Carbon Price: $10 - $20	216,000	216,000	216,000	216,000
3: Carbon Price: $20 - $40	213,000	213,000	213,000	213,000
4: Carbon Price: $40 -$60	212,000	212,000	212,000	211,000
5: CO2 Rate Limit	215,000	219,000	219,000	NA
6: Presidential CO2 Rate Limit	215,000	218,000	217,000	NA
7: Mass Emissions Reduction	215,000	217,000	217,000	NA

2050 (Billion 2010 US$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	260,000	260,000	259,000	258,000
2: Carbon Price: $10 - $20	257,000	257,000	257,000	256,000
3: Carbon Price: $20 - $40	255,000	257,000	256,000	255,000
4: Carbon Price: $40 -$60	255,000	258,000	257,000	257,000
5: CO2 Rate Limit	257,000	260,000	259,000	NA
6: Presidential CO2 Rate Limit	253,000	256,000	256,000	NA
7: Mass Emissions Reduction	253,000	256,000	256,000	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

Electricity Price Results Matrices

2025 (2010 Cents per kWh)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	8.6	8.6	8.6	8.2
2: Carbon Price: $10 - $20	9.9	9.9	9.9	9.6
3: Carbon Price: $20 - $40	10.8	10.8	10.9	11.0
4: Carbon Price: $40 -$60	11.6	11.5	12.1	13.0
5: CO2 Rate Limit	9.9	8.9	8.9	NA
6: Presidential CO2 Rate Limit	9.9	8.6	8.6	NA
7: Mass Emissions Reduction	9.9	8.5	8.6	NA

2035 (2010 Cents per kWh)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	10.1	10.1	10.1	9.7
2: Carbon Price: $10 - $20	11.7	11.7	11.7	11.3
3: Carbon Price: $20 - $40	13.0	13.0	13.1	12.9
4: Carbon Price: $40 -$60	13.6	13.6	13.6	14.2
5: CO2 Rate Limit	11.8	10.2	10.2	NA
6: Presidential CO2 Rate Limit	11.9	10.7	11.1	NA
7: Mass Emissions Reduction	11.9	10.9	11.1	NA

2050 (2010 Cents per kWh)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	13.5	13.5	13.9	14.3
2: Carbon Price: $10 - $20	14.7	14.7	14.7	15.2
3: Carbon Price: $20 - $40	15.9	15.0	15.1	15.7
4: Carbon Price: $40 -$60	16.1	14.2	14.7	14.9
5: CO2 Rate Limit	14.7	13.5	13.9	NA
6: Presidential CO2 Rate Limit	17.1	15.1	15.1	NA
7: Mass Emissions Reduction	17.0	15.2	15.1	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

CO$_2$ Results Matrices

2025 (Million Tons CO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	73.8	73.8	69.4	75.3
2: Carbon Price: $10 - $20	71.3	71.3	65.2	73.3
3: Carbon Price: $20 - $40	44.3	45.3	49.8	71.5
4: Carbon Price: $40 -$60	25.2	32.5	46.8	68.8
5: CO2 Rate Limit	53.5	56.2	57.5	NA
6: Presidential CO2 Rate Limit	71.2	73.8	69.4	NA
7: Mass Emissions Reduction	71.2	70.9	69.2	NA

2035 (Million Tons CO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	69.1	69.1	69.1	69.5
2: Carbon Price: $10 - $20	63.7	63.7	63.7	67.5
3: Carbon Price: $20 - $40	44.8	45.9	54.2	65.3
4: Carbon Price: $40 -$60	29.1	36.2	20.1	63.8
5: CO2 Rate Limit	61.1	63.8	63.2	NA
6: Presidential CO2 Rate Limit	48.4	52.8	50.1	NA
7: Mass Emissions Reduction	50.3	51.2	50.0	NA

2050 (Million Tons CO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	56.6	56.7	46.6	46.2
2: Carbon Price: $10 - $20	55.1	55.1	45.5	45.1
3: Carbon Price: $20 - $40	48.8	20.7	22.3	33.9
4: Carbon Price: $40 -$60	35.9	7.5	15.4	21.8
5: CO2 Rate Limit	55.1	56.7	46.6	NA
6: Presidential CO2 Rate Limit	18.4	18.7	19.2	NA
7: Mass Emissions Reduction	19.4	19.1	19.2	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

NO$_X$ Results Matrices

2025 (Thousand Tons NO$_X$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	46.2	46.1	38.0	49.4
2: Carbon Price: $10 - $20	45.4	45.3	35.3	50.1
3: Carbon Price: $20 - $40	17.9	19.2	23.3	51.2
4: Carbon Price: $40 -$60	7.6	5.7	21.9	50.9
5: CO2 Rate Limit	24.2	24.0	27.2	NA
6: Presidential CO2 Rate Limit	45.3	46.1	38.0	NA
7: Mass Emissions Reduction	45.3	37.1	37.6	NA

2035 (Thousand Tons NO$_X$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	35.9	35.9	35.9	36.0
2: Carbon Price: $10 - $20	30.6	30.7	30.7	35.7
3: Carbon Price: $20 - $40	14.1	14.6	25.4	35.4
4: Carbon Price: $40 -$60	7.8	5.9	5.1	35.2
5: CO2 Rate Limit	28.9	28.5	30.0	NA
6: Presidential CO2 Rate Limit	17.5	21.5	23.9	NA
7: Mass Emissions Reduction	20.9	18.0	23.9	NA

2050 (Thousand Tons CO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	13.6	13.6	13.1	23.0
2: Carbon Price: $10 - $20	13.5	13.5	13.0	22.9
3: Carbon Price: $20 - $40	9.9	8.0	8.5	22.4
4: Carbon Price: $40 -$60	6.2	4.4	6.8	21.7
5: CO2 Rate Limit	13.5	13.6	13.1	NA
6: Presidential CO2 Rate Limit	9.4	5.0	5.0	NA
7: Mass Emissions Reduction	9.4	4.7	5.0	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

SO$_2$ Results Matrices

2025 (Thousand Tons SO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	89.9	89.9	81.5	90.8
2: Carbon Price: $10 - $20	88.8	88.8	74.8	90.9
3: Carbon Price: $20 - $40	28.9	31.1	44.4	91.2
4: Carbon Price: $40 -$60	3.3	3.4	42.2	91.0
5: CO2 Rate Limit	53.2	53.7	57.1	NA
6: Presidential CO2 Rate Limit	88.8	89.9	81.5	NA
7: Mass Emissions Reduction	88.8	78.3	80.6	NA

2035 (Thousand Tons SO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	70.8	70.8	70.8	70.8
2: Carbon Price: $10 - $20	67.1	67.1	67.2	70.8
3: Carbon Price: $20 - $40	16.5	17.9	47.1	70.7
4: Carbon Price: $40 -$60	3.3	3.3	3.1	70.7
5: CO2 Rate Limit	61.7	58.5	58.8	NA
6: Presidential CO2 Rate Limit	26.9	29.6	34.9	NA
7: Mass Emissions Reduction	30.0	26.8	34.9	NA

2050 (Thousand Tons CO$_2$)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	14.6	14.6	14.5	14.5
2: Carbon Price: $10 - $20	14.6	14.6	14.5	14.4
3: Carbon Price: $20 - $40	8.6	7.5	8.2	14.4
4: Carbon Price: $40 -$60	2.5	2.3	5.5	14.1
5: CO2 Rate Limit	14.6	14.6	14.5	NA
6: Presidential CO2 Rate Limit	2.5	2.4	2.4	NA
7: Mass Emissions Reduction	2.5	1.4	2.4	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

Coal Consumption Results Matrices

2025 Coal Consumption (Thousand Tons)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	25,100	25,100	22,500	25,800
2: Carbon Price: $10 - $20	24,700	24,700	21,000	25,800
3: Carbon Price: $20 - $40	8,300	8,900	12,000	25,800
4: Carbon Price: $40 -$60	600	600	10,900	25,800
5: CO2 Rate Limit	13,600	14,500	15,500	NA
6: Presidential CO2 Rate Limit	24,700	25,100	22,500	NA
7: Mass Emissions Reduction	24,700	22,900	22,400	NA

2035 Coal Consumption (Thousand Tons)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	19,300	19,300	19,300	19,300
2: Carbon Price: $10 - $20	17,500	17,500	17,600	19,300
3: Carbon Price: $20 - $40	6,200	6,800	12,300	19,300
4: Carbon Price: $40 -$60	0	0	0	19,300
5: CO2 Rate Limit	15,600	16,000	16,000	NA
6: Presidential CO2 Rate Limit	7,900	9,500	10,200	NA
7: Mass Emissions Reduction	9,100	8,300	10,200	NA

2050 Coal Consumption (Thousand Tons)

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	7,100	7,100	7,100	19,000
2: Carbon Price: $10 - $20	7,100	7,100	7,100	19,000
3: Carbon Price: $20 - $40	4,000	3,700	3,900	19,000
4: Carbon Price: $40 -$60	0	0	3,100	19,000
5: CO2 Rate Limit	7,100	7,100	7,100	NA
6: Presidential CO2 Rate Limit	0	0	0	NA
7: Mass Emissions Reduction	0	0	0	NA

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

Coal-Fired Electricity Generation

2025 — Percent Coal Generation

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	65%	65%	58%	65%
2: Carbon Price: $10 - $20	68%	68%	58%	70%
3: Carbon Price: $20 - $40	24%	26%	35%	74%
4: Carbon Price: $40 -$60	0%	0%	33%	79%
5: CO2 Rate Limit	38%	39%	42%	41%
6: Presidential CO2 Rate Limit	68%	65%	58%	65%
7: Mass Emissions Reduction	68%	59%	58%	60%

2035 — Percent Coal Generation

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	47%	47%	47%	46%
2: Carbon Price: $10 - $20	46%	46%	46%	49%
3: Carbon Price: $20 - $40	18%	19%	34%	52%
4: Carbon Price: $40 -$60	0%	0%	0%	54%
5: CO2 Rate Limit	41%	40%	40%	39%
6: Presidential CO2 Rate Limit	21%	25%	27%	24%
7: Mass Emissions Reduction	25%	22%	27%	21%

2050 — Percent Coal Generation

Federal Policy Options	Portfolios			
	1: Nuclear Banned	2: Nuclear Allowed	3: Balanced Portfolio	4: Coal Portfolio
1: Reference Case	15%	15%	15%	42%
2: Carbon Price: $10 - $20	16%	16%	16%	43%
3: Carbon Price: $20 - $40	9%	9%	9%	43%
4: Carbon Price: $40 -$60	0%	0%	7%	43%
5: CO2 Rate Limit	16%	15%	15%	42%
6: Presidential CO2 Rate Limit	0%	0%	0%	27%
7: Mass Emissions Reduction	0%	0%	0%	27%

Scenarios marked NA when the state portfolio standard was unable to meet federal policy constraints.

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Scenario 1

**Federal Policy Option 1: Reference
Portfolio 1: Nuclear Banned**

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:1

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Scenario 1

Federal Policy Option 1: Reference
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation, 2035

Coal 50%
Natural Gas 47%

Coal | Natural Gas | Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

BBTU

Coal | Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons

35
25
19
7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF)

669
366
220
37

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$

259639
219278
194365
171638

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:1

Kentucky Total Employment, 1970-2050

Full-Time Jobs

3102096
2844347
2689733
2557279

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Scenario 2

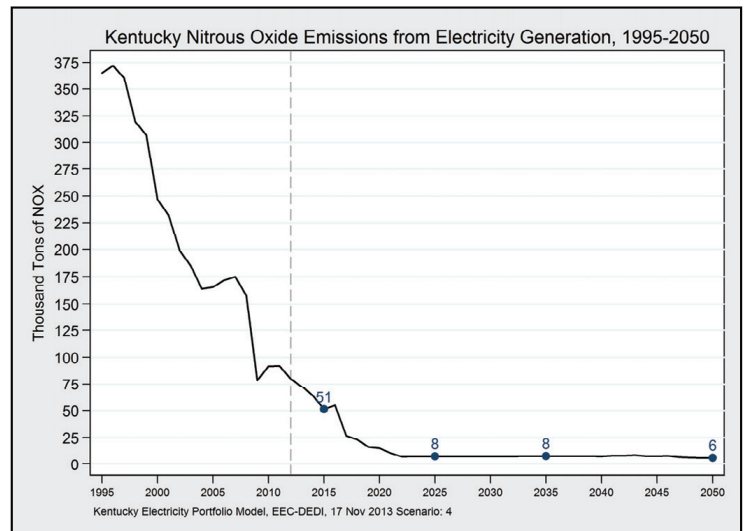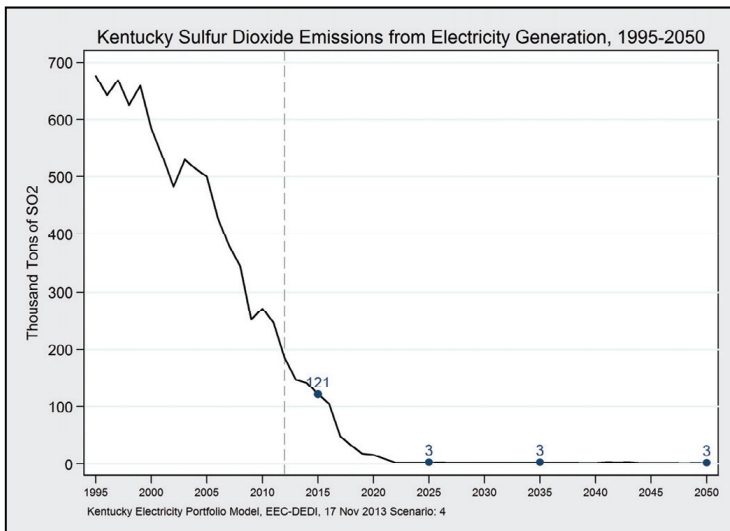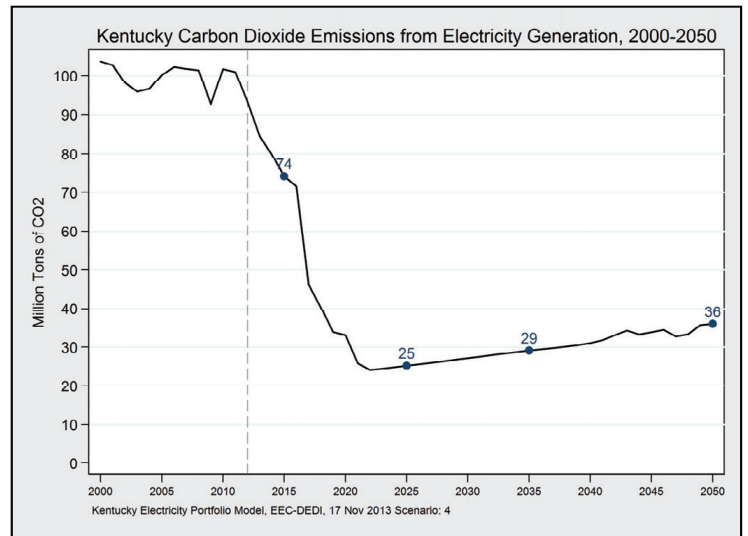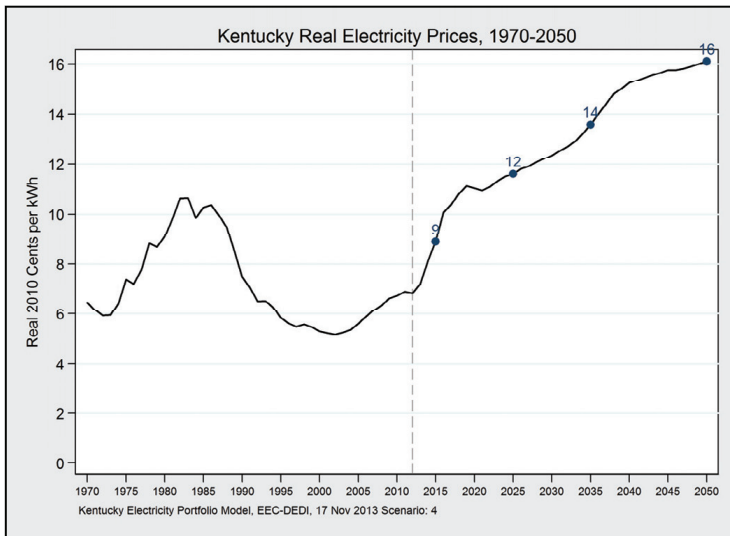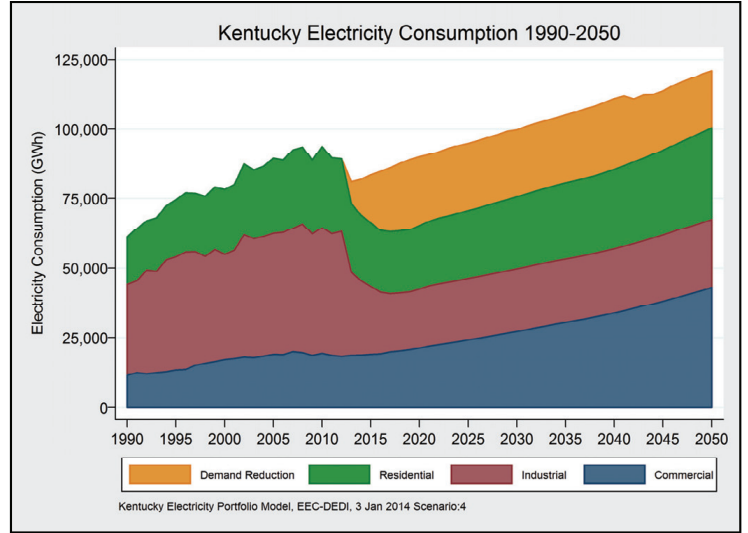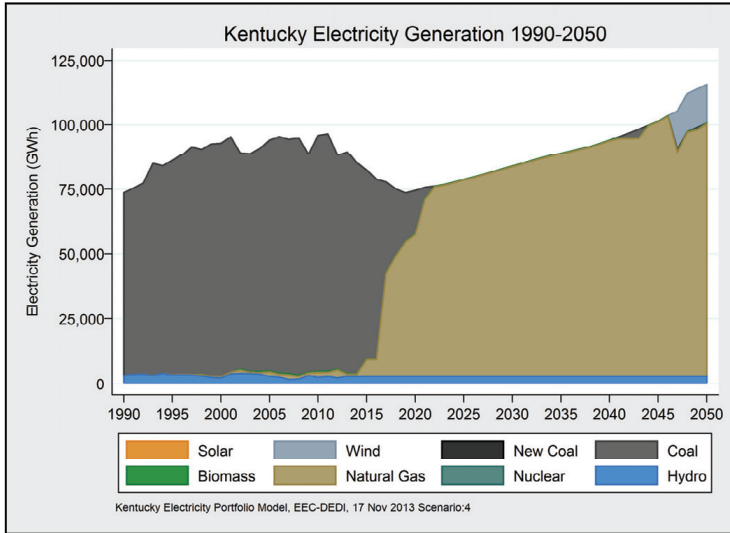## Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:2

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:2

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

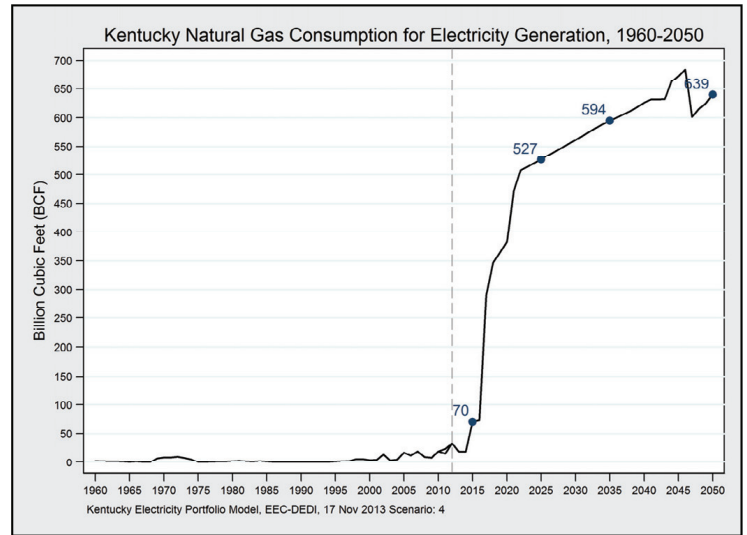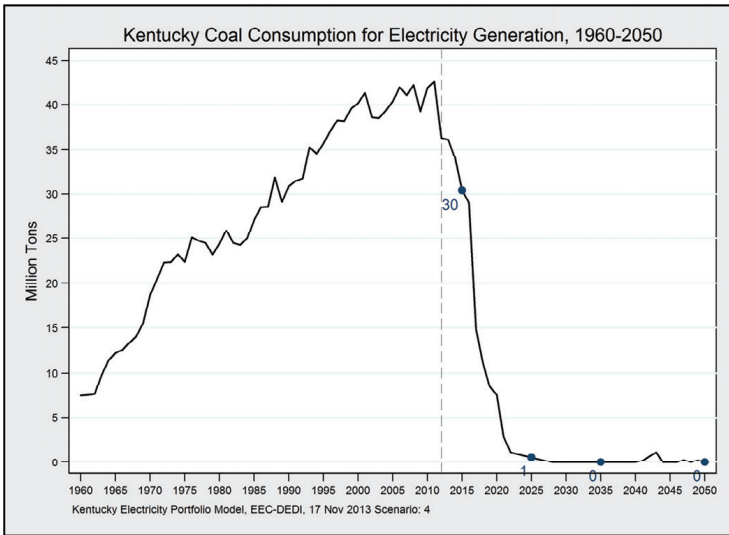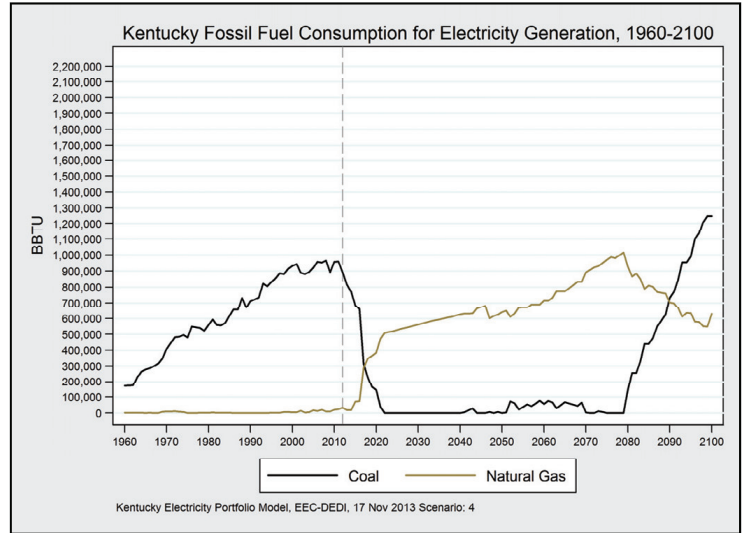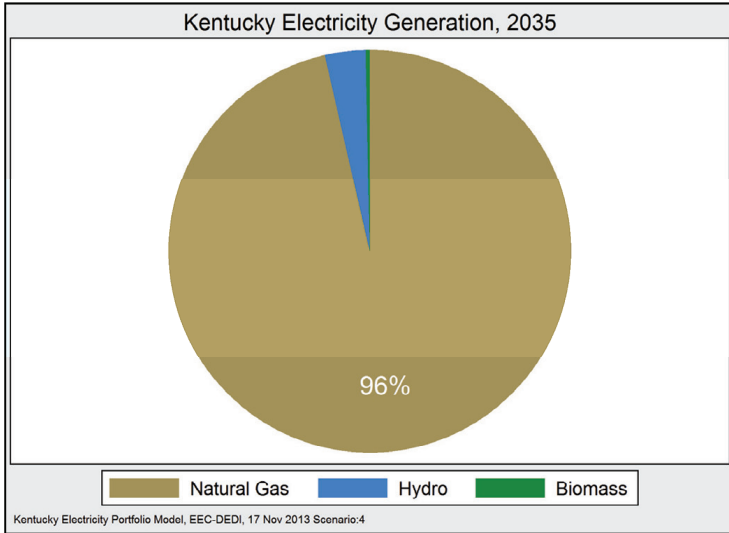Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Scenario 2

Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation, 2035

- Coal 50%
- Natural Gas 47%
- Hydro
- Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:2

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

- Coal
- Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35, 25, 18, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

19, 184, 343, 642

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 2

Kentucky Gross Domestic Product, 1970-2050

170383, 191074, 215556, 257213

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:2

Kentucky Total Employment, 1970-2050

2528427, 2622673, 2775929, 3063171

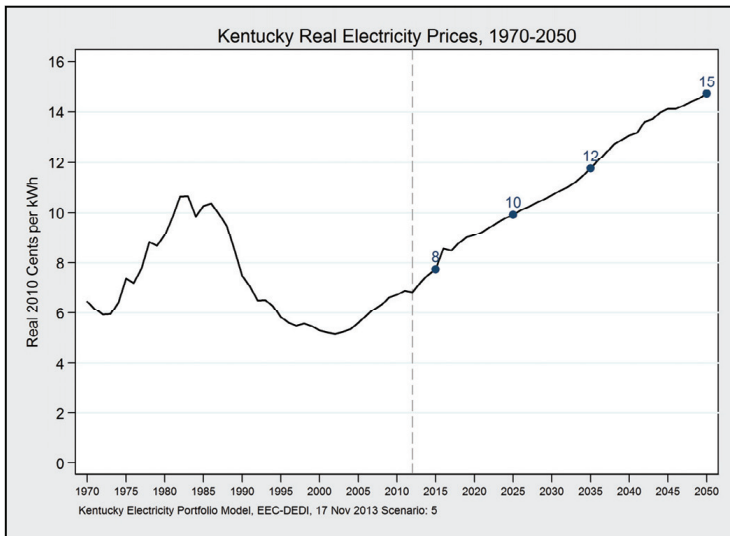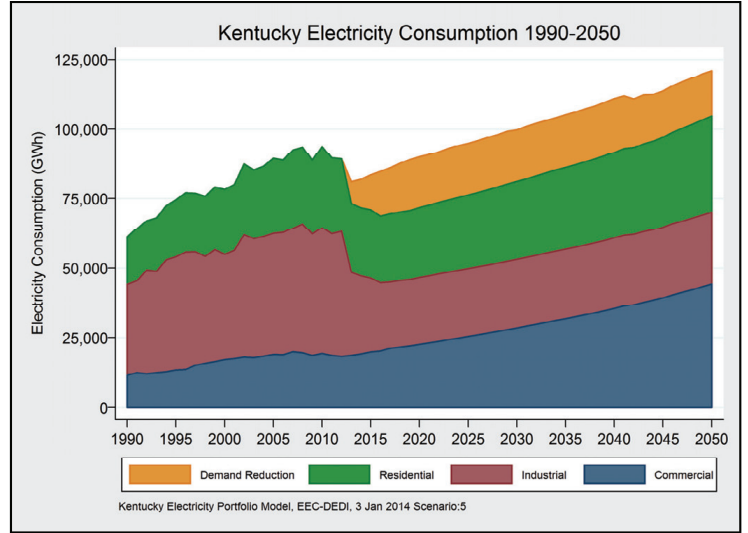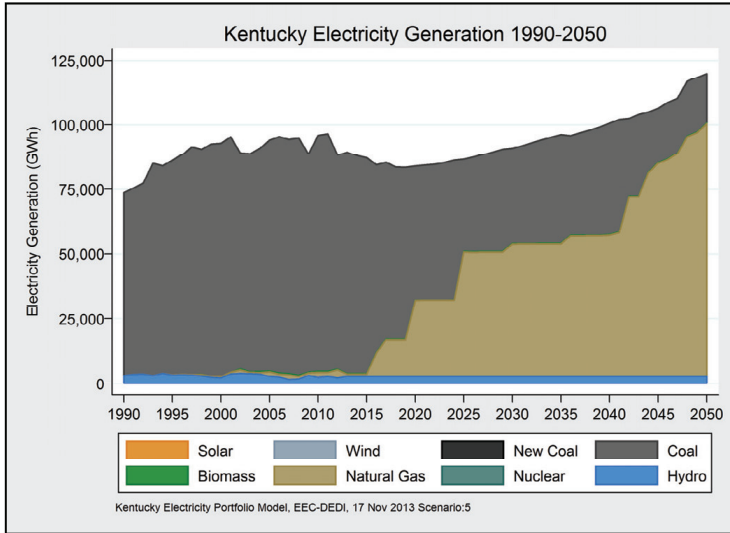Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:2

Scenario 3

Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation 1990-2050

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:3

Kentucky Electricity Consumption 1990-2050

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:3

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Scenario 3

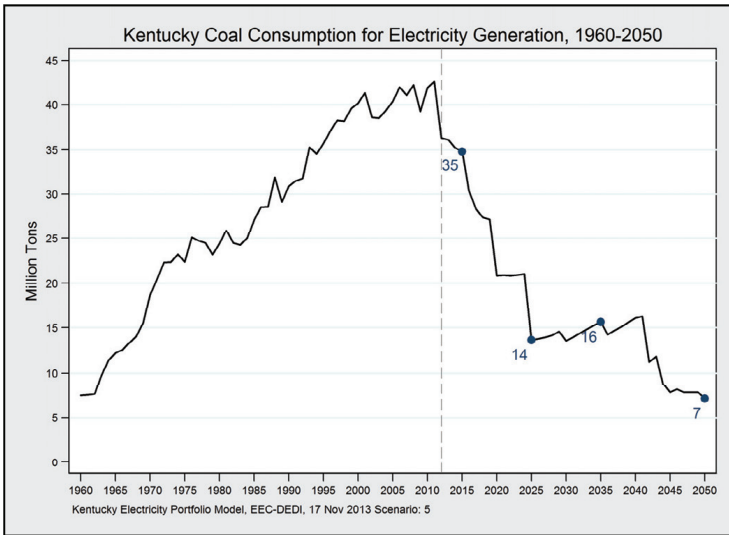## Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation, 2035

19%

77%

Coal   Natural Gas   Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:3

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal   Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Kentucky Coal Consumption for Electricity Generation, 1960-2050

34

8
6
4

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

670
510
430
19

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 3

Kentucky Gross Domestic Product, 1970-2050

254993
213029
189357
169296

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:3

Kentucky Total Employment, 1970-2050

3027718
2729937
2588028
2503583

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:3

Scenario 4

Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:4

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:4

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 4

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 4

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:4

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:4

Scenario 4

Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation, 2035

96%

Natural Gas   Hydro   Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:4

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal   Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 4

Kentucky Coal Consumption for Electricity Generation, 1960-2050

30
1   01   01

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 4

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

639
594
527
70

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 4

Kentucky Gross Domestic Product, 1970-2050

254584
211976
187705
167685

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:4

Kentucky Total Employment, 1970-2050

3021215
2710864
2554915
2467002

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:4

Scenario 5

Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation 1990-2050

Electricity Generation (GWh)

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:5

Kentucky Electricity Consumption 1990-2050

Electricity Consumption (GWh)

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:5

Kentucky Real Electricity Prices, 1970-2050

Real 2010 Cents per kWh

Data points: 8, 10, 13, 15

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Million Tons of CO2

Data points: 82, 53, 61, 55

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Thousand Tons of SO2

Data points: 137, 53, 62, 15

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Thousand Tons of NOX

Data points: 67, 24, 29, 13

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Scenario 5

Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation, 2035

44% Coal
53% Natural Gas

Coal   Natural Gas   Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:5

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal   Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35
14   16
7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

642
361   382
19

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 5

Kentucky Gross Domestic Product, 1970-2050

257213
215465
191108
170383

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:5

Kentucky Total Employment, 1970-2050

3063171
2774266
2623363
2528427

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:5

Scenario 6

Federal Policy Option 6: Presidential CO$_2$ Rate Limit
Portfolio 1: Nuclear Banned

Kentucky Electricity Generation 1990-2050

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:6

Kentucky Electricity Consumption 1990-2050

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:6

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Scenario 6

**Federal Policy Option 6: Presidential CO$_2$ Rate Limit
Portfolio 1: Nuclear Banned**

Kentucky Electricity Generation, 2035

- Coal 23%
- Natural Gas 73%
- Hydro
- Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:6

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons

35, 25, 8, 0

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF)

19, 184, 499, 625

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 6

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$

170383, 191071, 215187, 252878

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:6

Kentucky Total Employment, 1970-2050

Full-Time Jobs

2528415, 2622604, 2769184, 2994124

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:6

Scenario 7

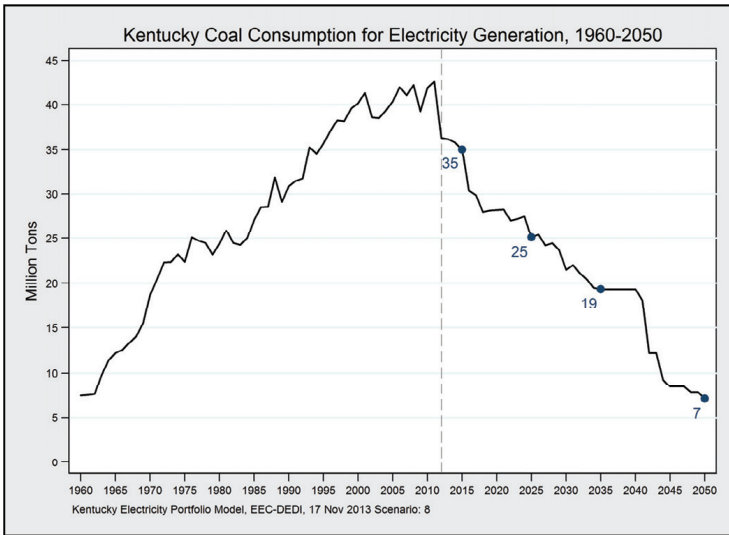**Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 1: Nuclear Banned**

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:7

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:7

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Scenario 7

**Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 1: Nuclear Banned**

Kentucky Electricity Generation, 2035

27% Coal
70% Natural Gas

Coal Natural Gas Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:7

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35
25
9
0

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

623
480
184
19

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 7

Kentucky Gross Domestic Product, 1970-2050

253044
215260
191074
170383

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:7

Kentucky Total Employment, 1970-2050

2996748
2770510
2622665
2528414

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:7

Scenario 8

Federal Policy Option 1: Reference
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:8

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:8

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Scenario 8

Federal Policy Option 1: Reference
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation, 2035

Coal 50%
Natural Gas 47%
Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:8

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35, 25, 19, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

670, 367, 221, 38

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 8

Kentucky Gross Domestic Product, 1970-2050

171638, 194355, 219270, 259643

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:8

Kentucky Total Employment, 1970-2050

2557274, 2689509, 2844197, 3102177

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:8

Scenario 9

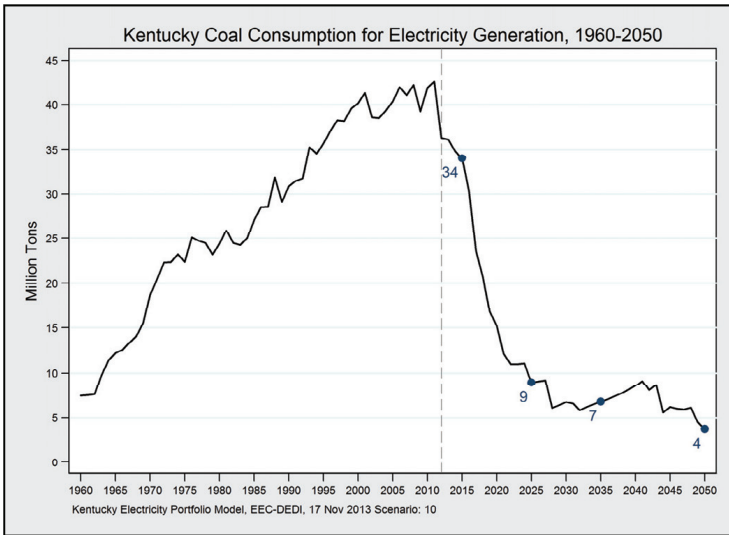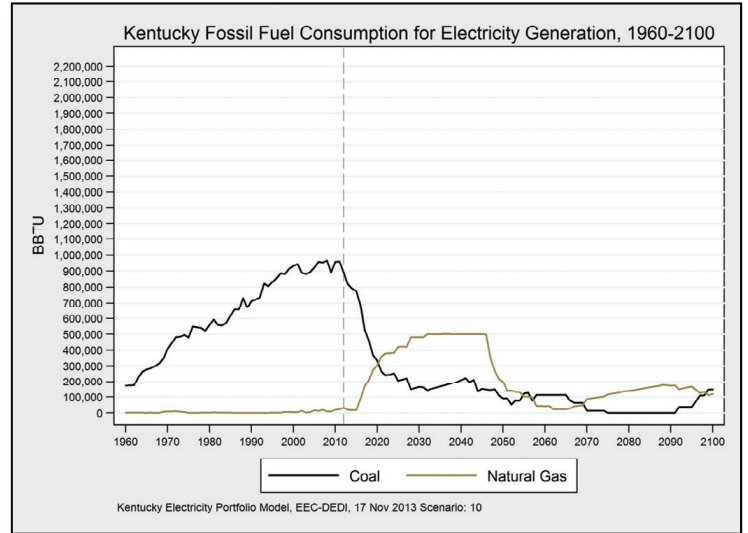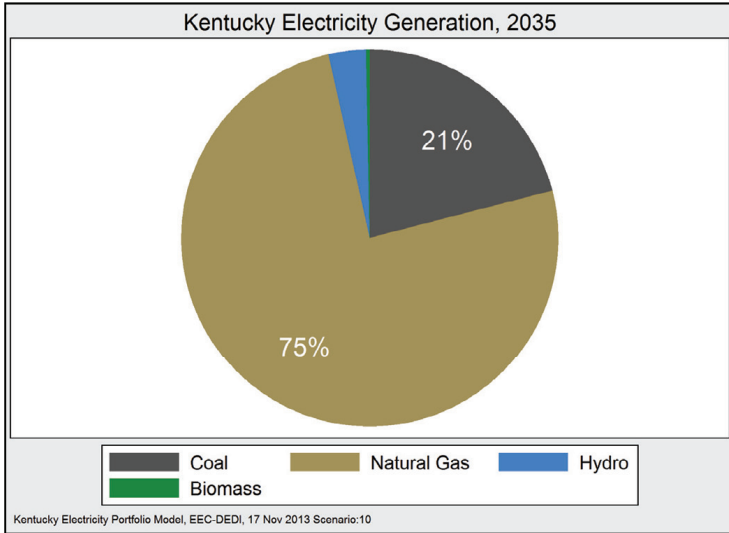## Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation 1990-2050

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:9

Kentucky Electricity Consumption 1990-2050

Legend: Demand Reduction, Residential, Industrial, Commercial
Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:9

Kentucky Real Electricity Prices, 1970-2050
8, 10, 12, 15
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050
82, 71, 64, 55
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
137, 89, 67, 15
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
68, 45, 31, 13
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Scenario 9

**Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 2: Nuclear Allowed**

Kentucky Electricity Generation, 2035

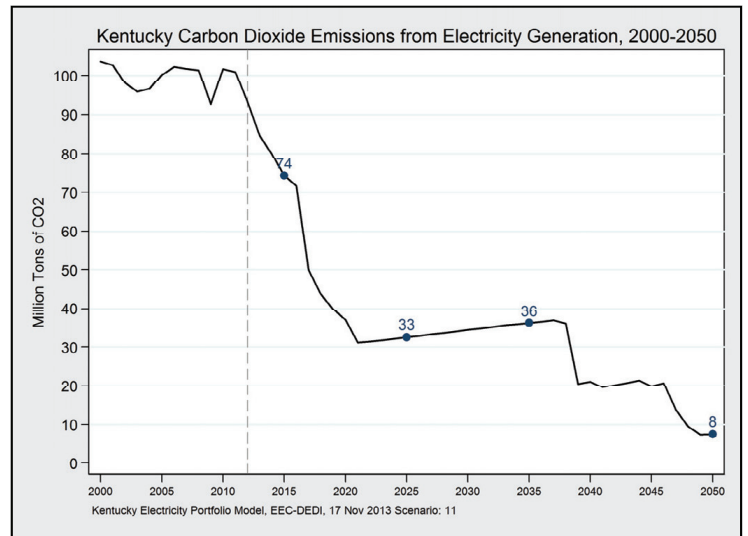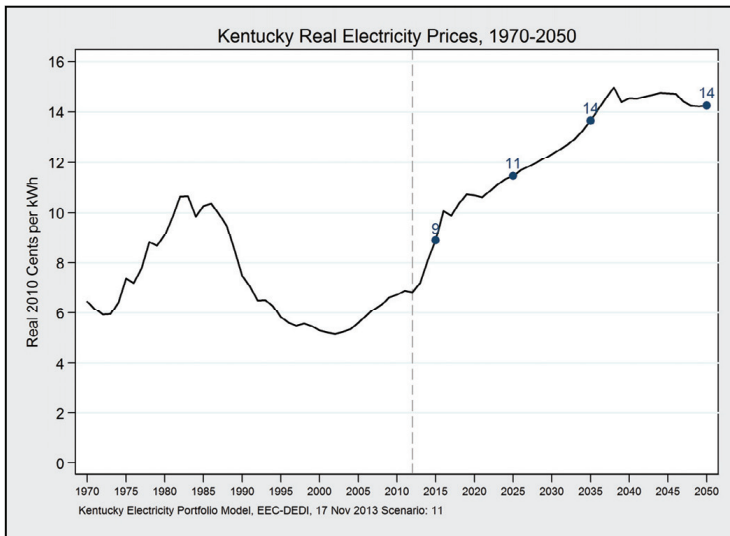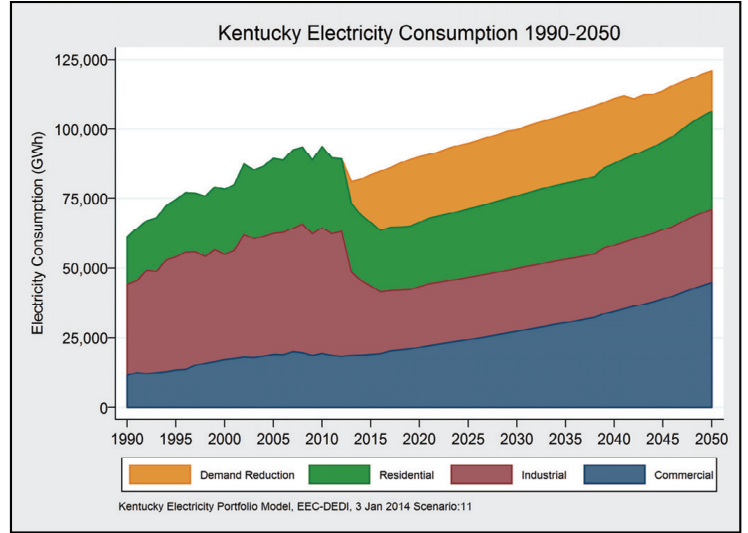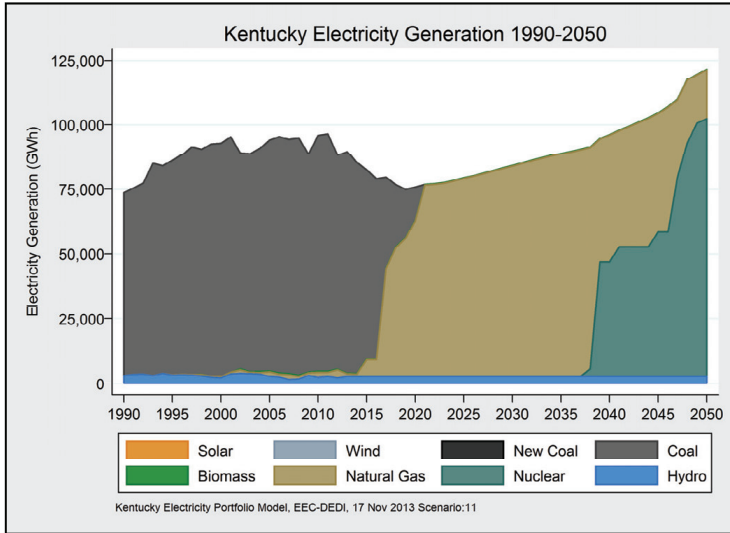- Coal 49%
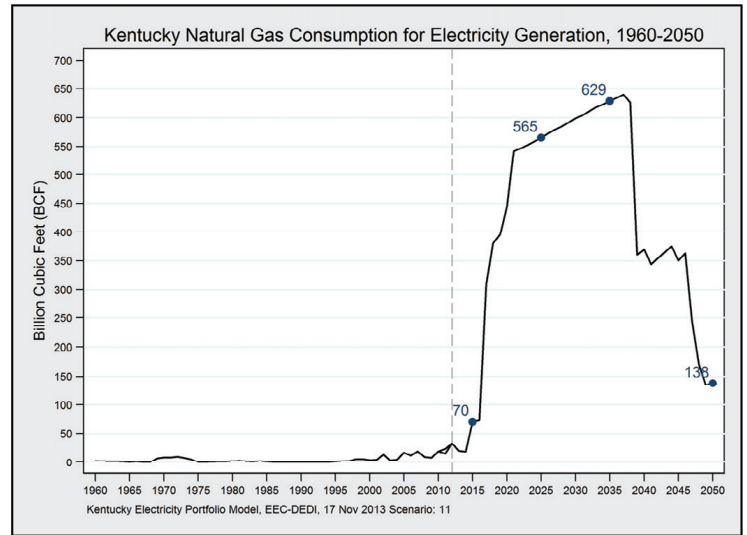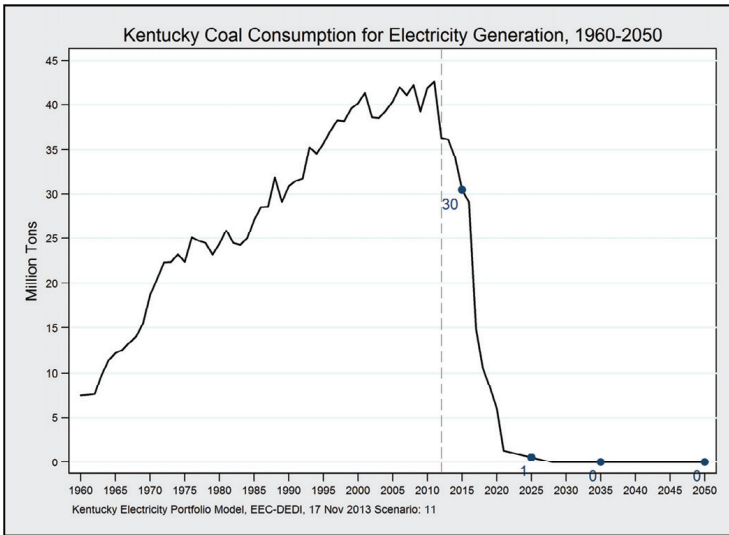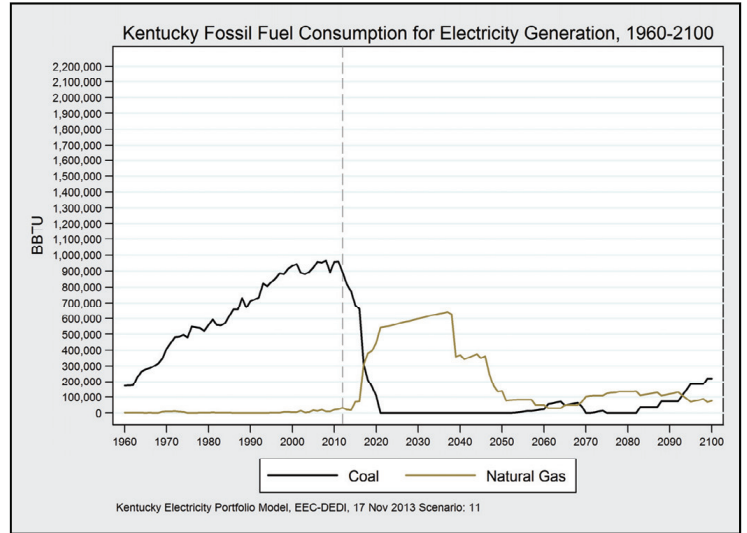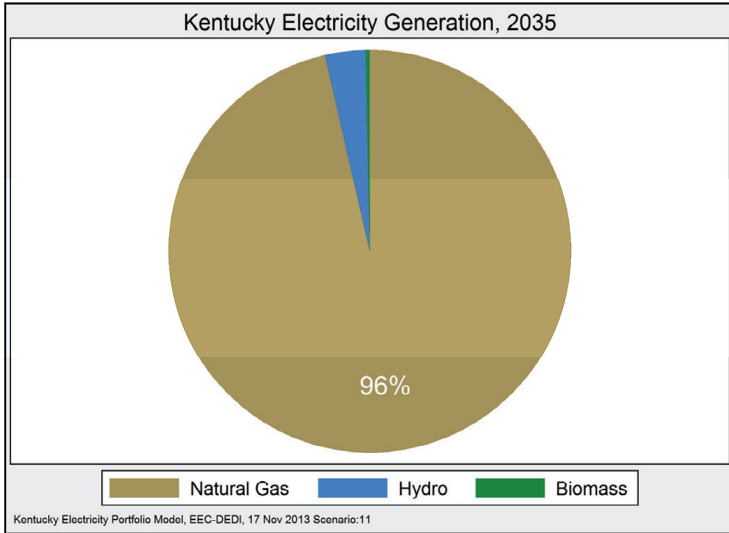- Natural Gas 47%
- Hydro
- Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:9

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35, 25, 18, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

644, 344, 185, 19

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 9

Kentucky Gross Domestic Product, 1970-2050

170389, 191076, 215561, 257227

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:9

Kentucky Total Employment, 1970-2050

2528556, 2622713, 2776010, 3063390

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:9

Scenario 10

Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:10

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:10

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

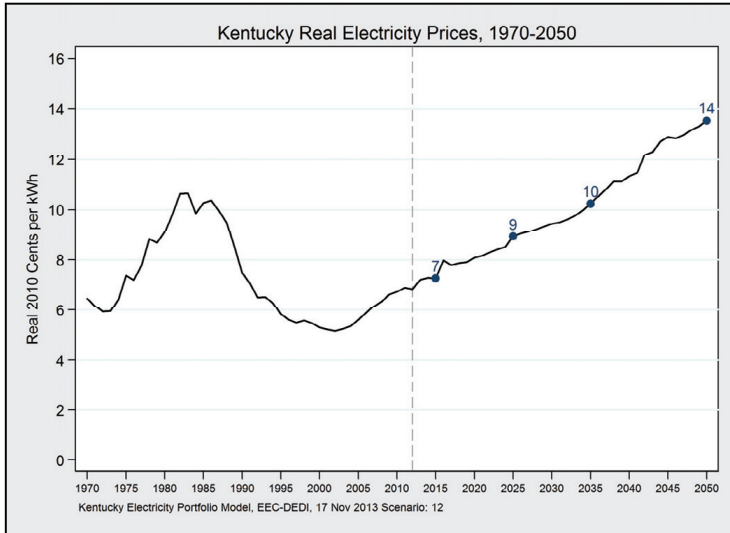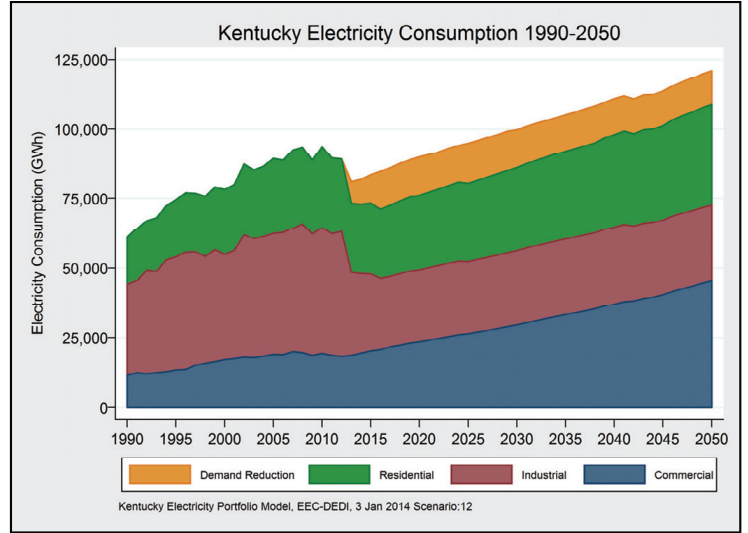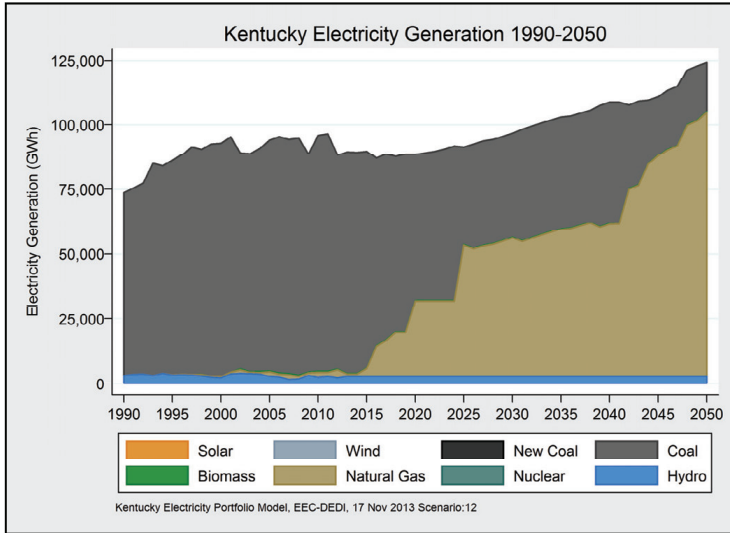Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Scenario 10

Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation, 2035

- 21% Coal
- 75% Natural Gas

Legend: Coal, Natural Gas, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:10

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 10

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:10

Kentucky Total Employment, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:10

Scenario 11

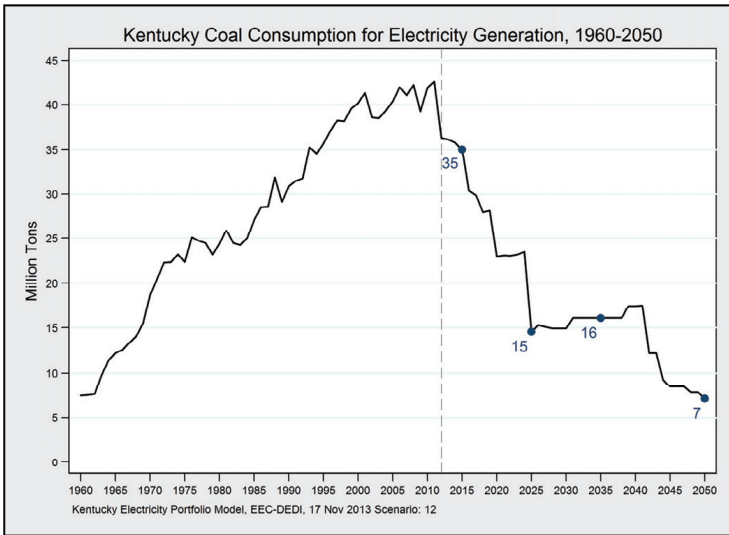## Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation 1990-2050

Solar | Wind | New Coal | Coal
Biomass | Natural Gas | Nuclear | Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:11

Kentucky Electricity Consumption 1990-2050

Demand Reduction | Residential | Industrial | Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:11

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Scenario 11

Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation, 2035

96%

Natural Gas   Hydro   Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:11

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal   Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Kentucky Coal Consumption for Electricity Generation, 1960-2050

30
1   01   01

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

629
565
70   138

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 11

Kentucky Gross Domestic Product, 1970-2050

258139
211840
187980
167691

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:11

Kentucky Total Employment, 1970-2050

3078007
2708416
2560413
2467153

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:11

Scenario 12

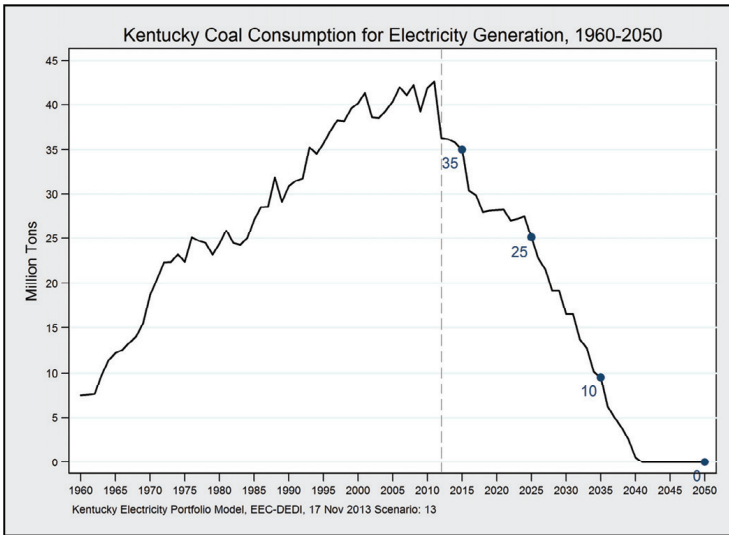## Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Consumption 1990-2050

Kentucky Real Electricity Prices, 1970-2050

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Scenario 12

Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation, 2035

Coal 42%
Natural Gas 55%

Legend: Coal, Natural Gas, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:12

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

BB'U

Legend: Coal, Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 12

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons

35, 15, 16, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 12

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF)

670, 418, 377, 38

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 12

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$

171638, 193447, 218900, 259643

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:12

Kentucky Total Employment, 1970-2050

Full-Time Jobs

2557274, 2670933, 2837364, 3102177

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:12

Scenario 13

**Federal Policy Option 6: Presidential CO₂ Rate Limit
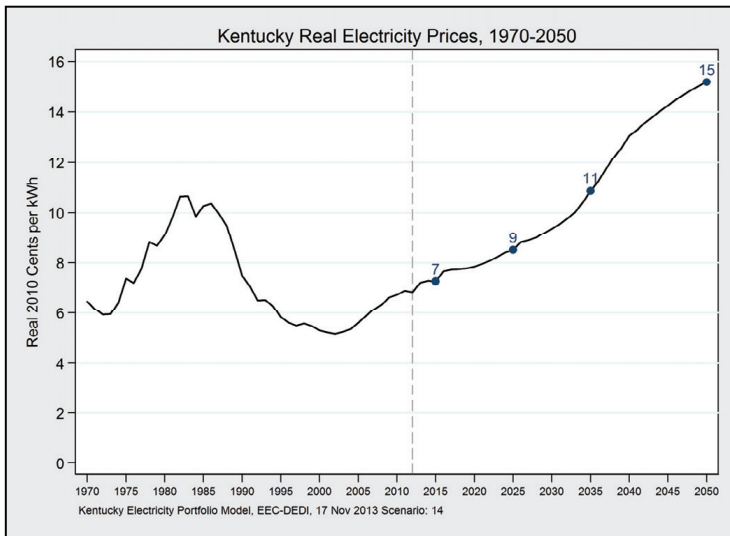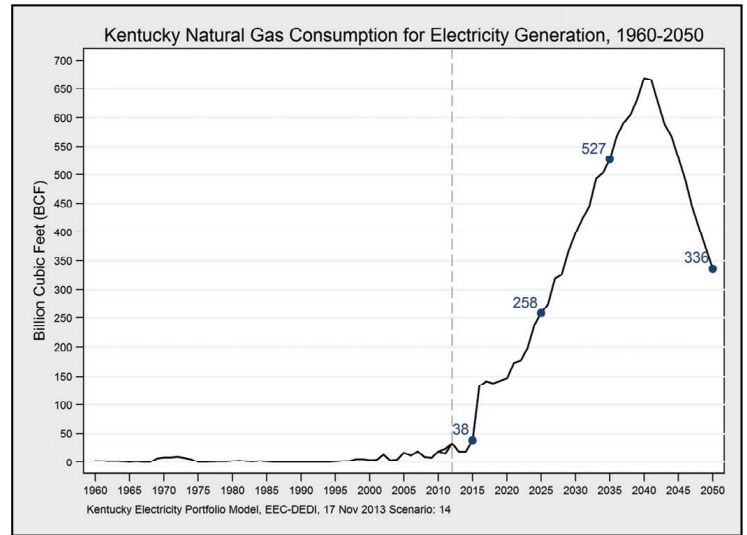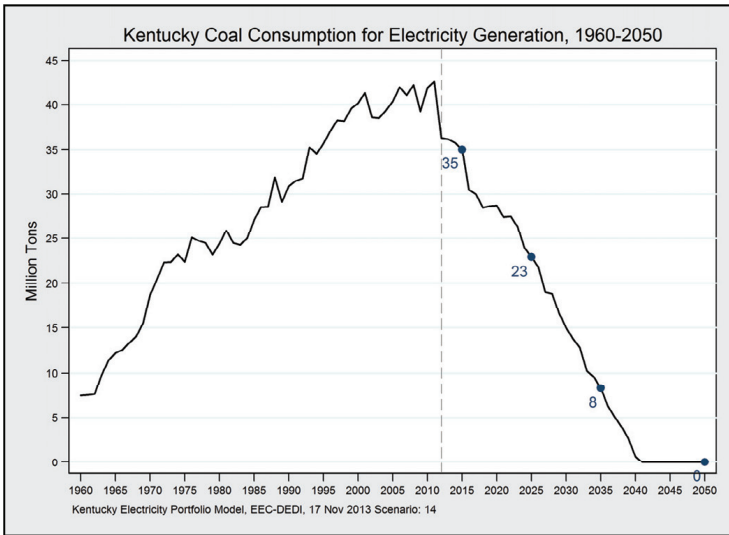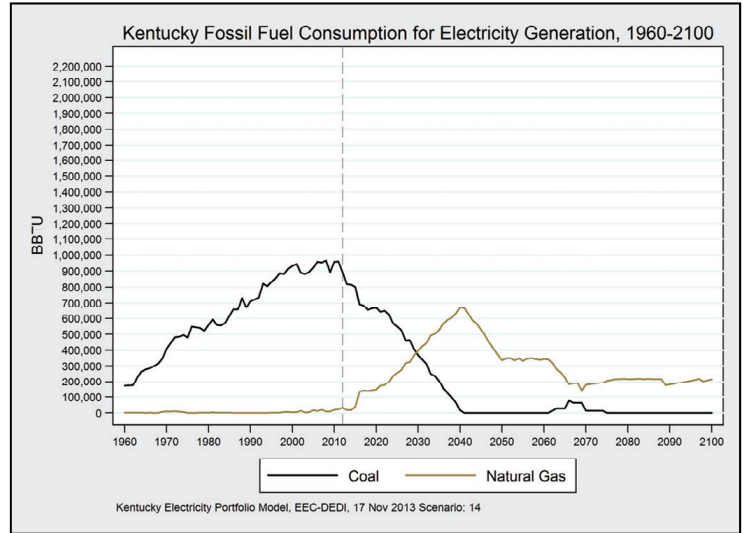Portfolio 2: Nuclear Allowed**

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:13

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:13

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Scenario 13

**Federal Policy Option 6: Presidential CO$_2$ Rate Limit
Portfolio 2: Nuclear Allowed**

Kentucky Electricity Generation, 2035

26% Coal
70% Natural Gas
Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:13

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35
25
10
0

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

510
328
221
38

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 13

Kentucky Gross Domestic Product, 1970-2050

256426
217879
194355
171638

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:13

Kentucky Total Employment, 1970-2050

3050574
2818530
2689509
2557274

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:13

Scenario 14

Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 2: Nuclear Allowed

Kentucky Electricity Generation 1990-2050
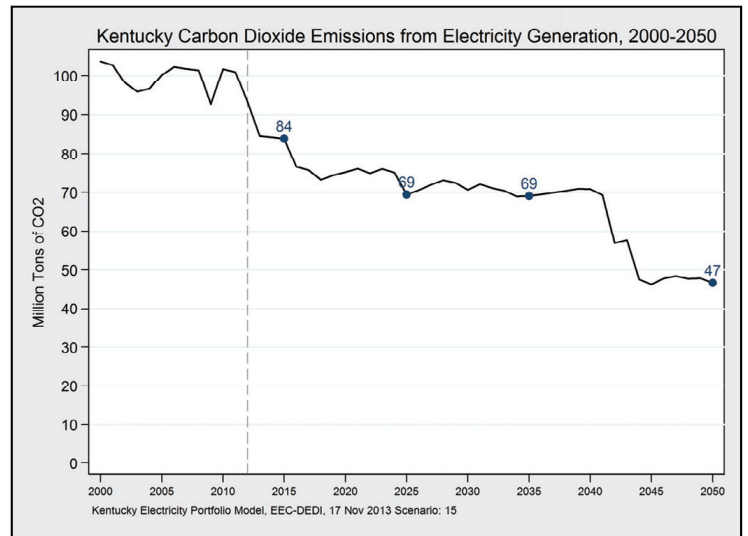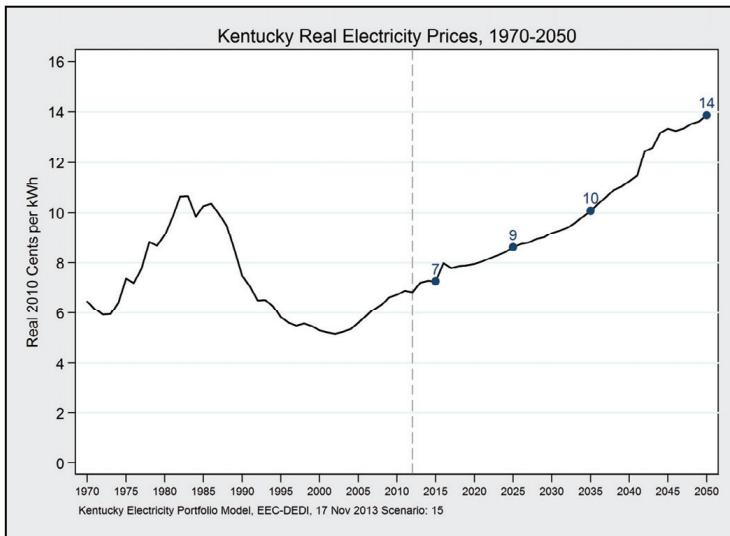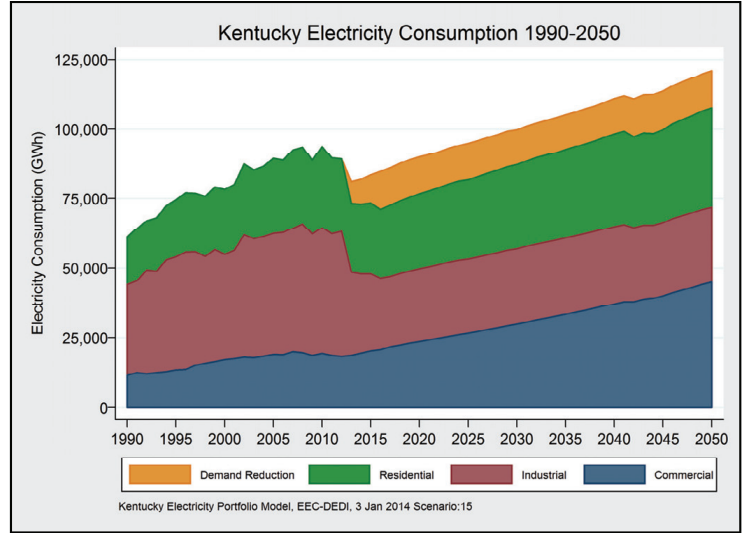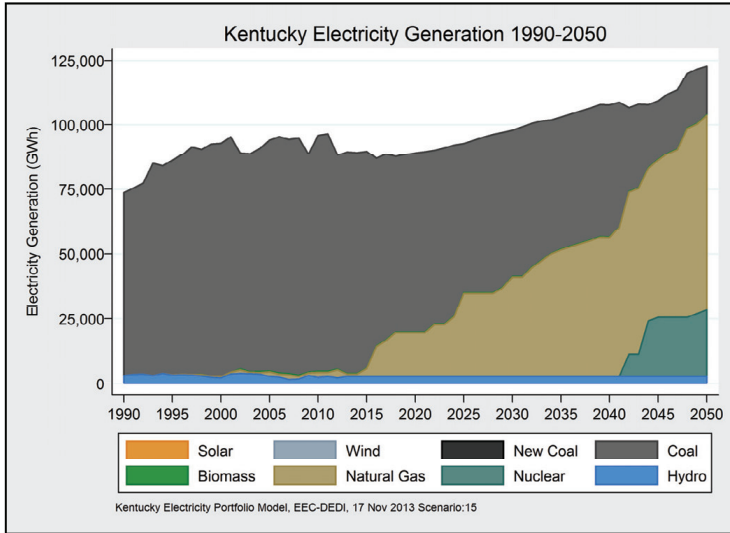
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:14

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:14

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Real Electricity Prices, 1970-2050

7, 9, 11, 15

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

84, 71, 51, 19

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

136, 78, 27, 1

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

68, 37, 18, 5

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Scenario 14

**Federal Policy Option 7: Presidential Mass Emissions Goal
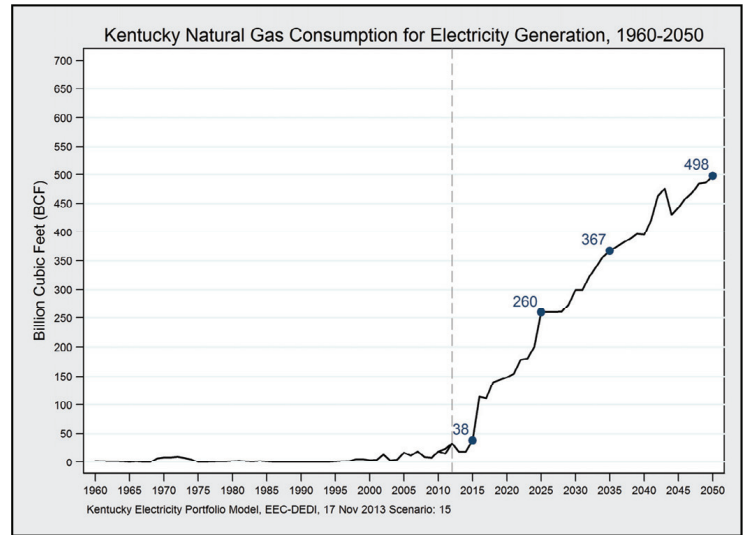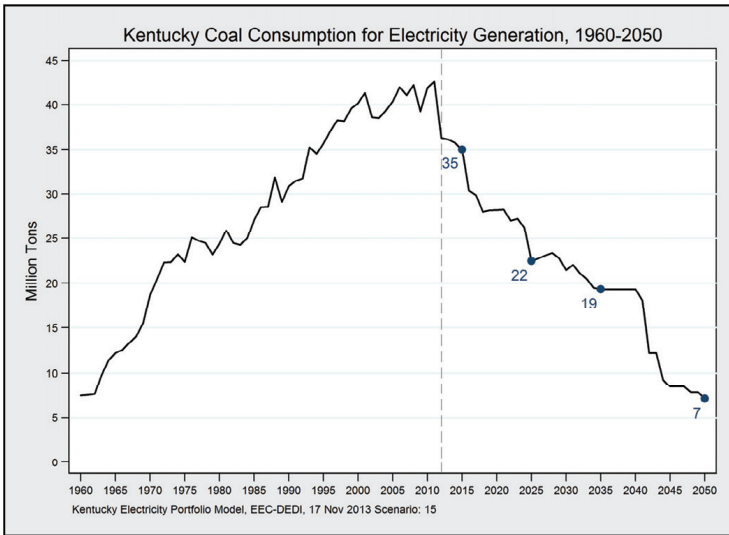Portfolio 2: Nuclear Allowed**

Kentucky Electricity Generation, 2035

- Coal 23%
- Natural Gas 74%
- Hydro
- Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:14

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons: 35, 23, 8, 0

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF): 38, 258, 527, 336

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 14

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$: 171639, 194506, 217404, 256289

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:14

Kentucky Total Employment, 1970-2050

Full-Time Jobs: 2557291, 2692621, 2809794, 3048396

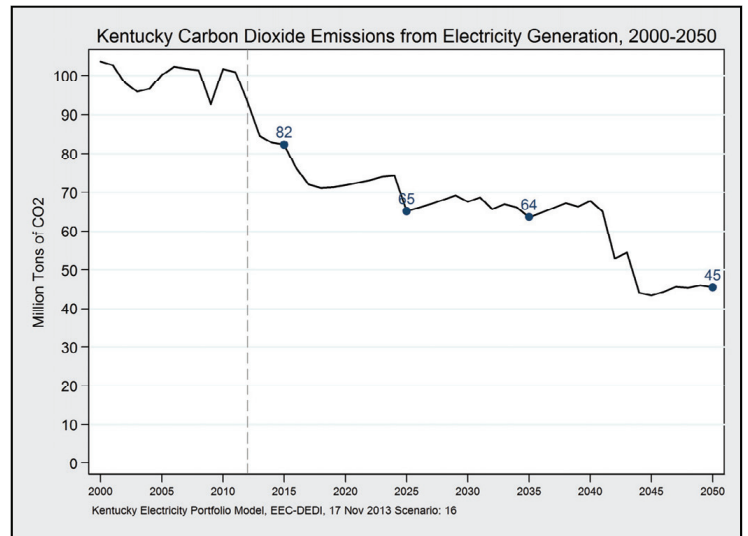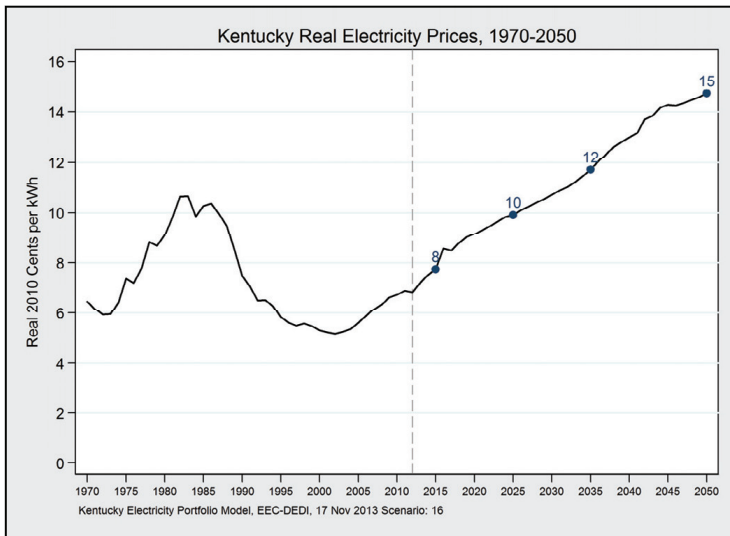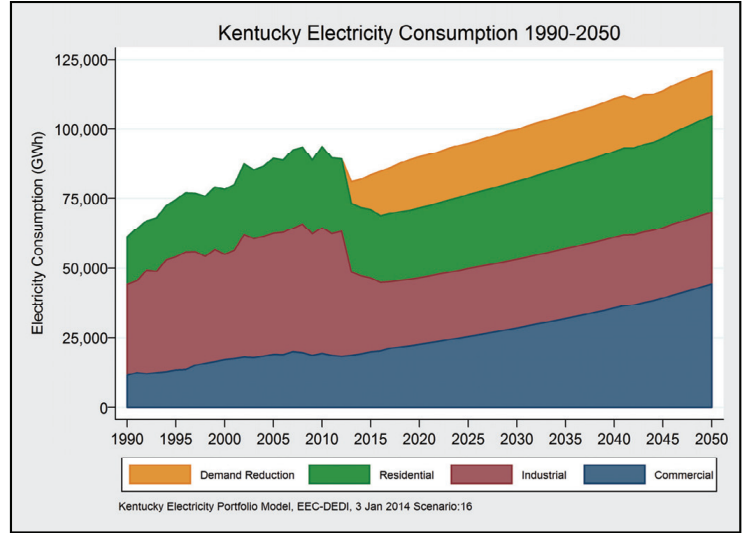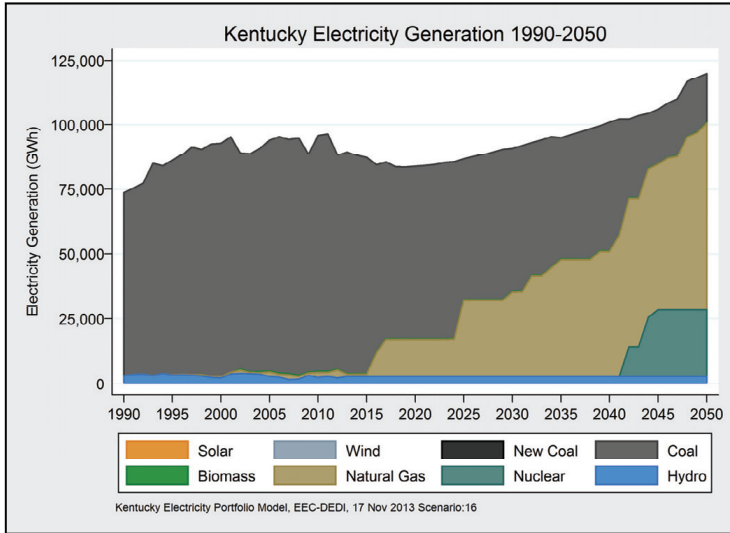Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:14

Scenario 15

Federal Policy Option 1: Reference
Portfolio 3: Balanced Portfolio Standard

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:15

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:15

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Scenario 15

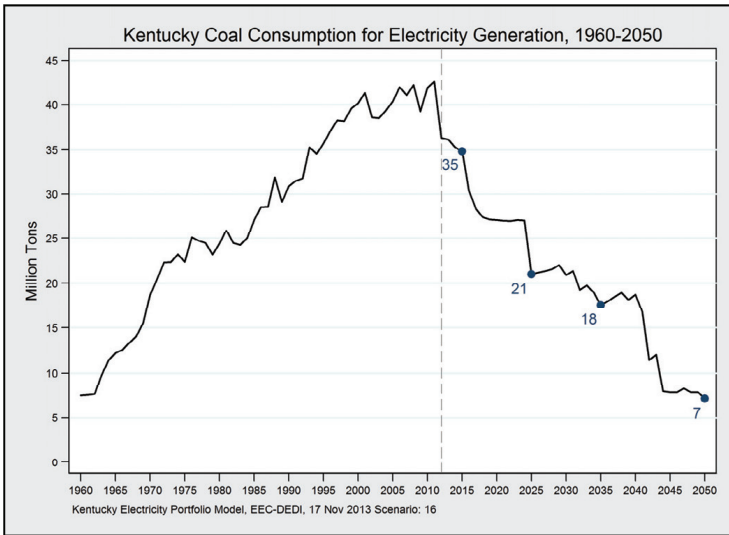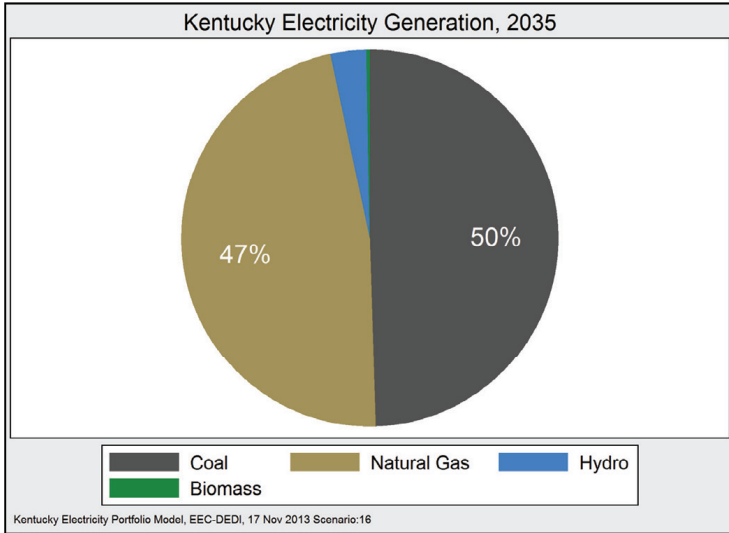**Federal Policy Option 1: Reference
Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation, 2035

Coal 50% Natural Gas 47%

Legend: Coal, Natural Gas, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:15

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

BB'U

Legend: Coal, Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons

35, 22, 19, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF)

38, 260, 367, 498

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 15

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$

171638, 194224, 219275, 258948

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:15

Kentucky Total Employment, 1970-2050

Full-Time Jobs

2557276, 2686829, 2844280, 3090994

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:15

Scenario 16

**Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation 1990-2050
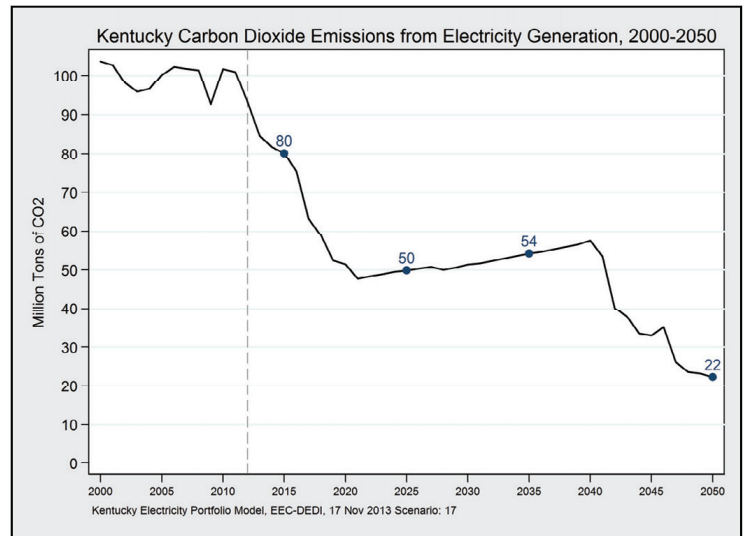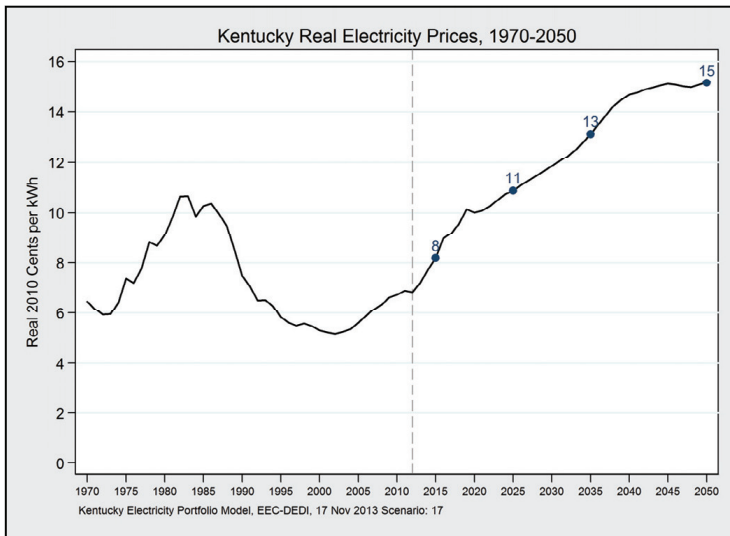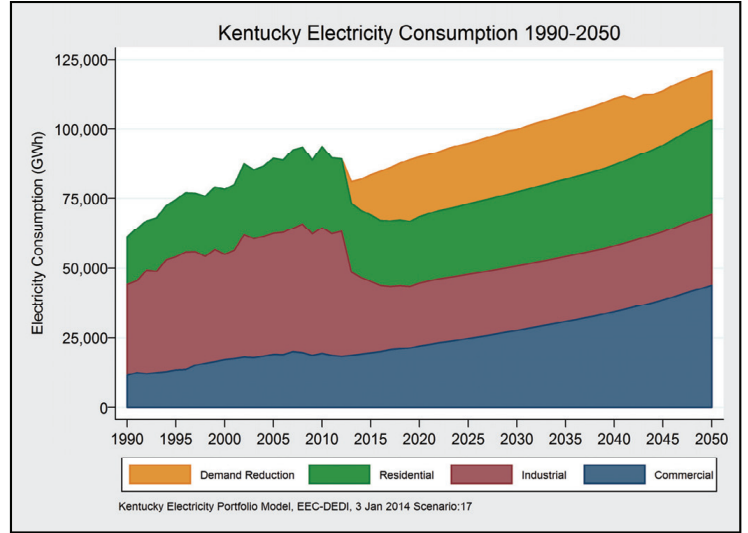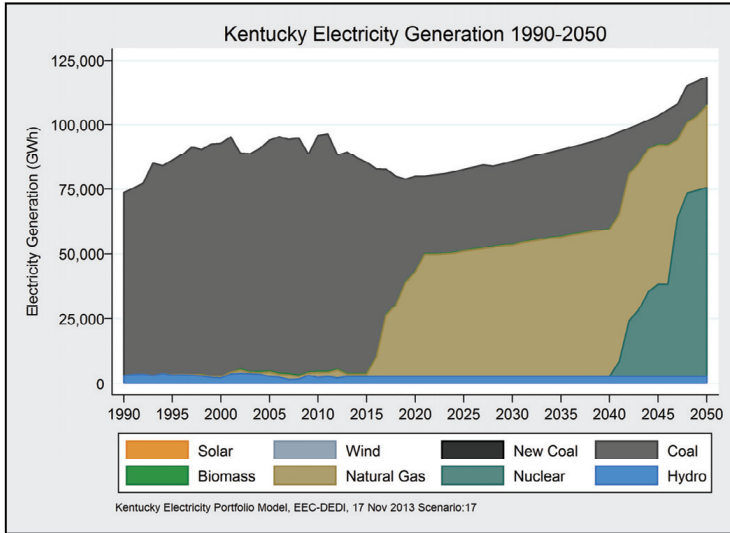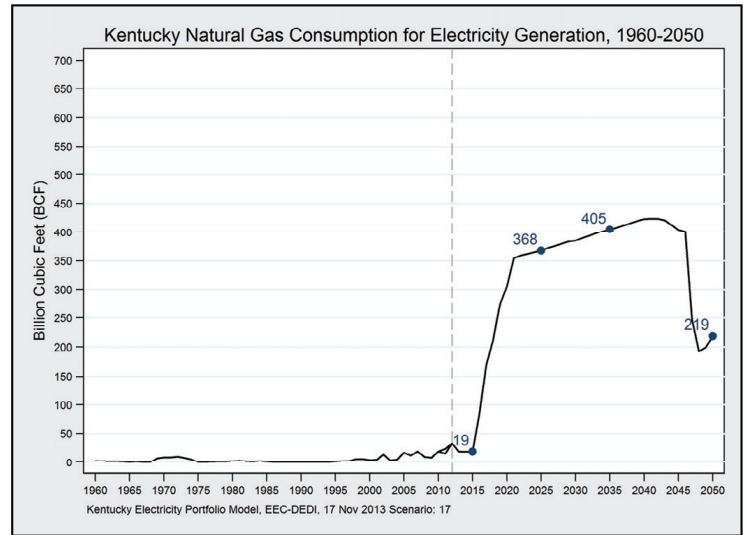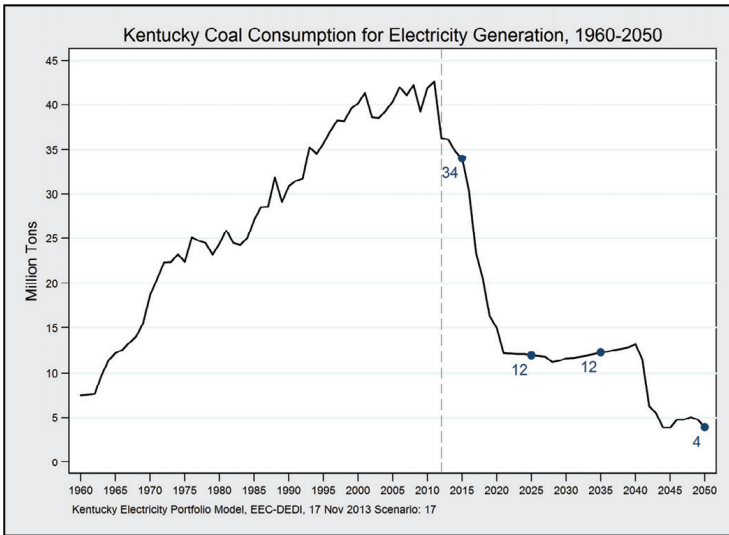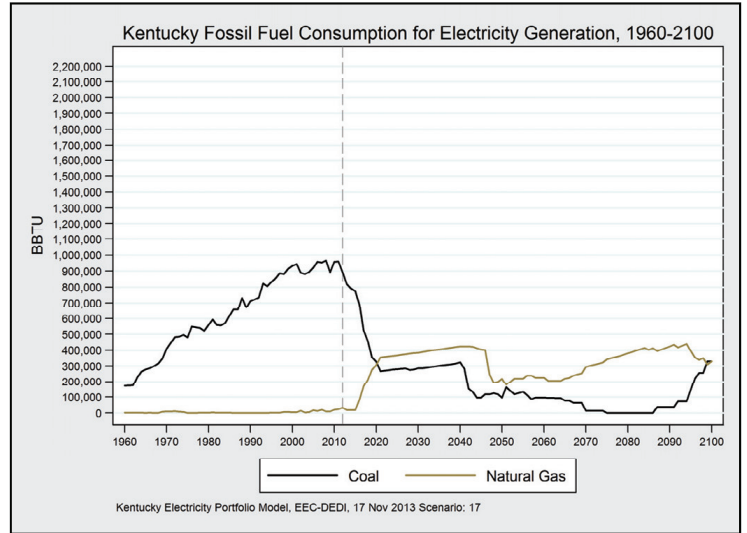
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:16

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:16

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

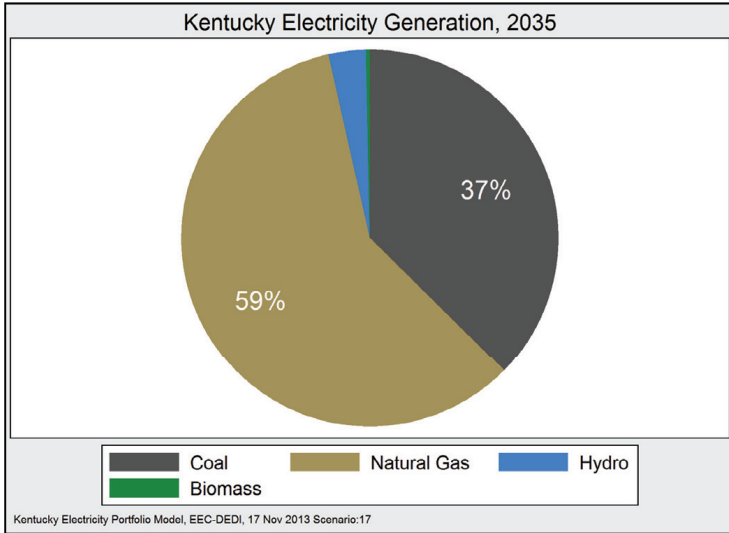Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Scenario 16

**Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation, 2035

Coal 50% — Natural Gas 47% — Hydro — Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:16

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35, 21, 18, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

19, 243, 344, 479

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 16

Kentucky Gross Domestic Product, 1970-2050

170384, 191118, 215556, 257182

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:16

Kentucky Total Employment, 1970-2050

2528437, 2623549, 2775930, 3062671

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:16

Scenario 17

**Federal Policy Option 3: $20-$40 Carbon Tax
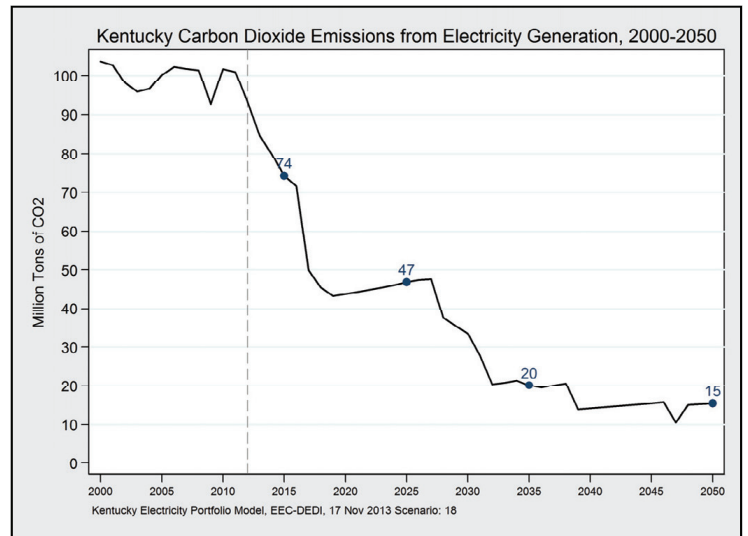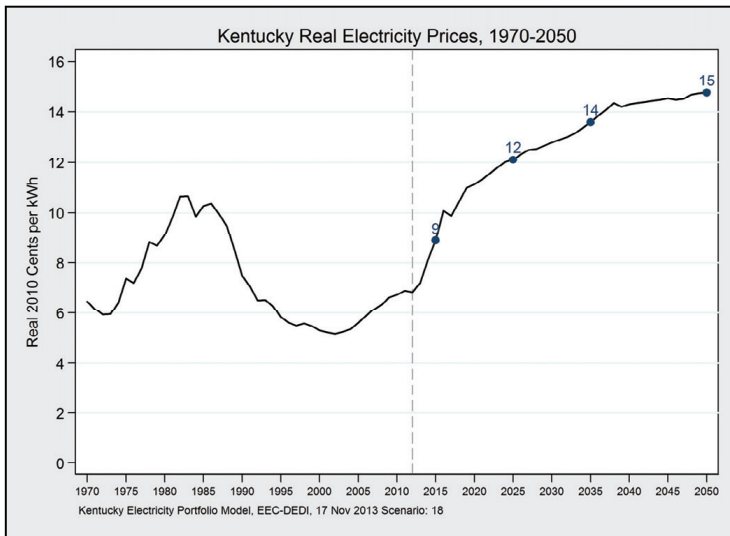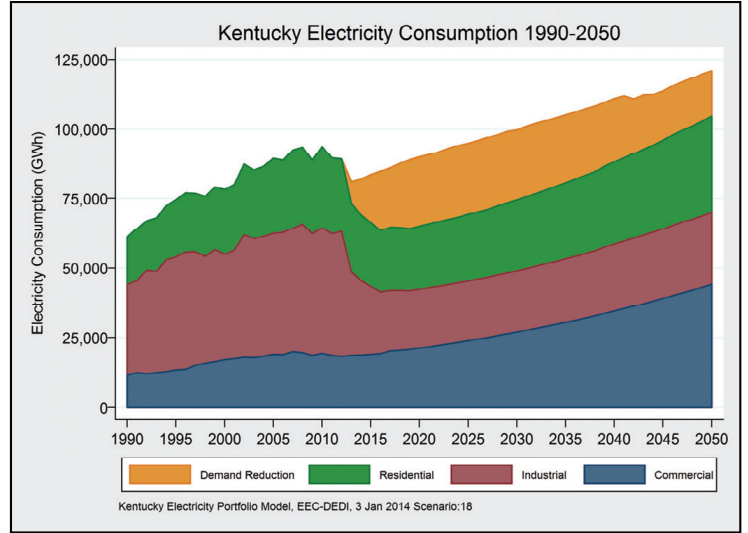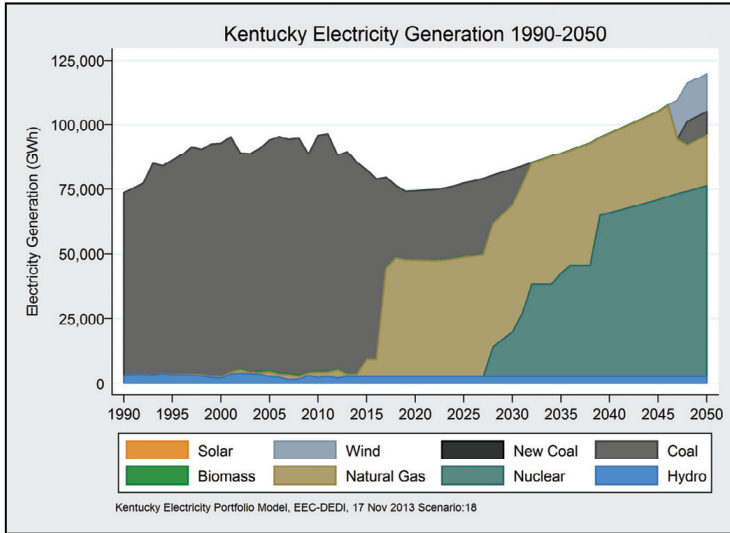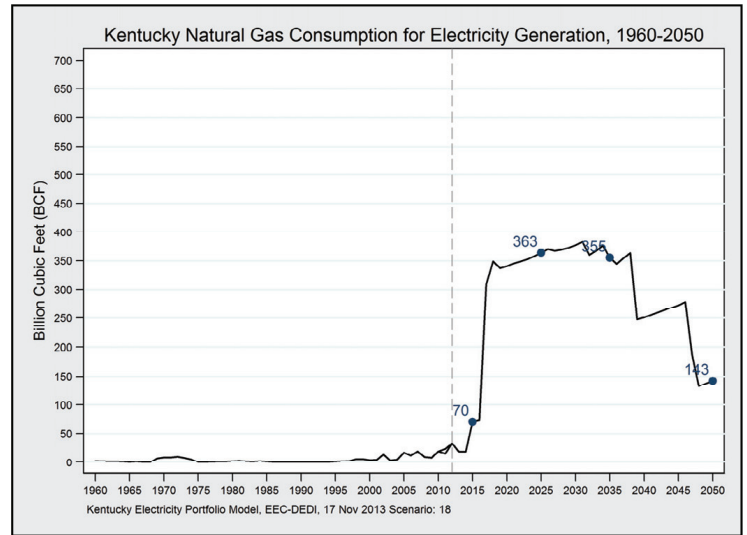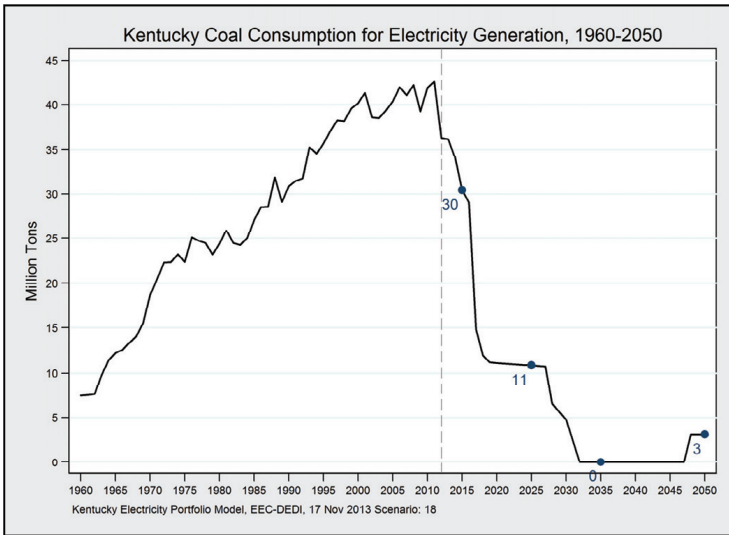Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:17

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:17

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

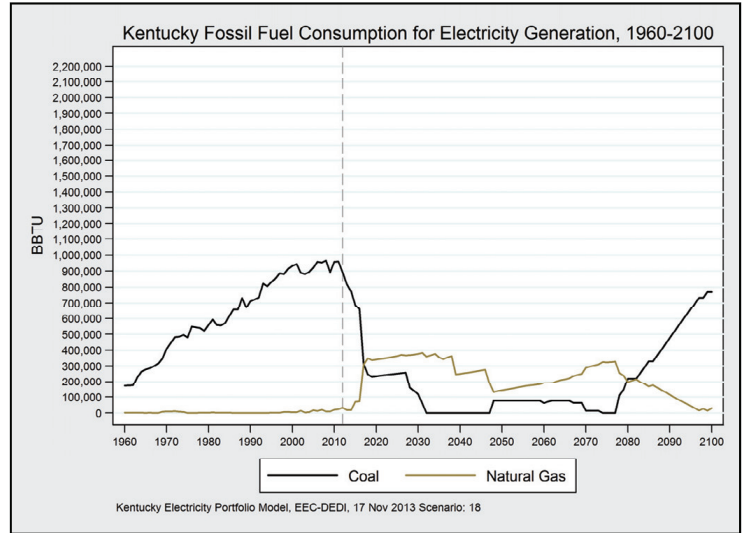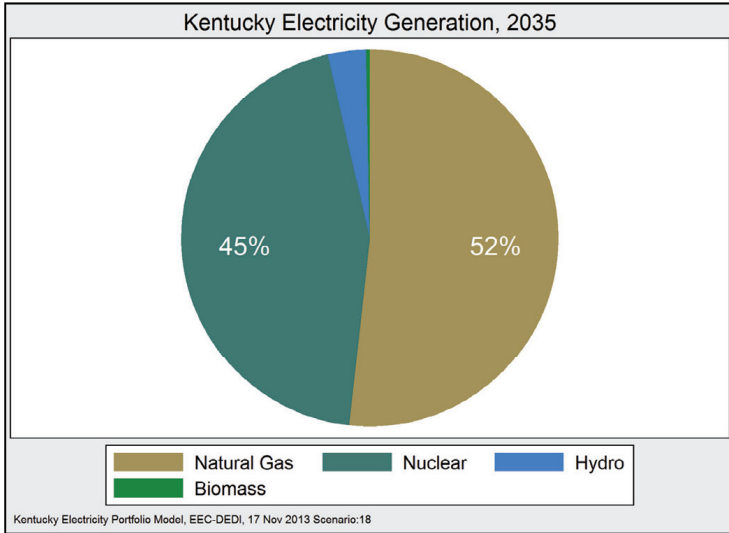Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Scenario 17

**Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation, 2035

Coal 37%, Natural Gas 59%, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:17

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 17

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:17

Kentucky Total Employment, 1970-2050

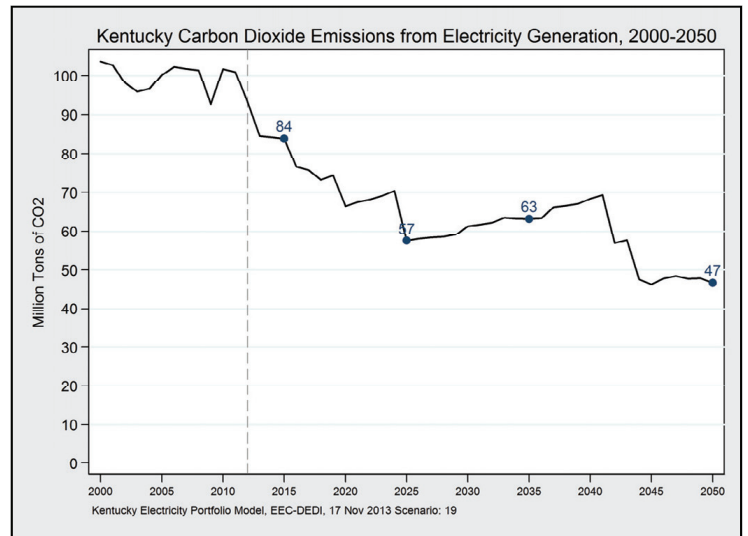Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:17

Scenario 18

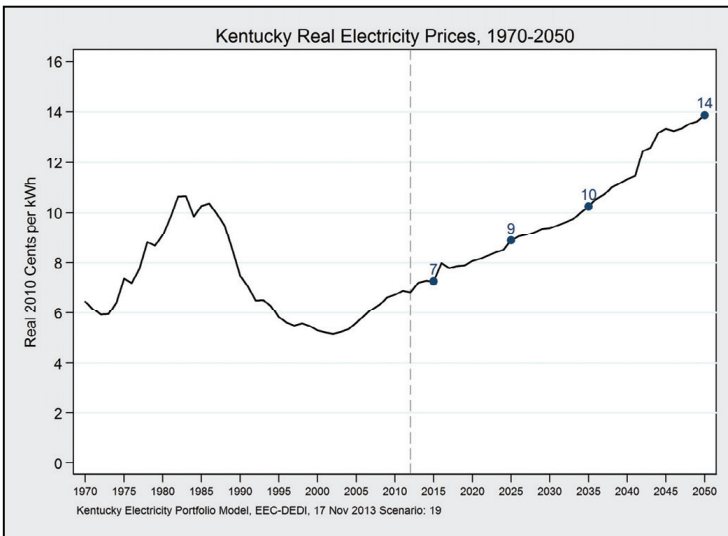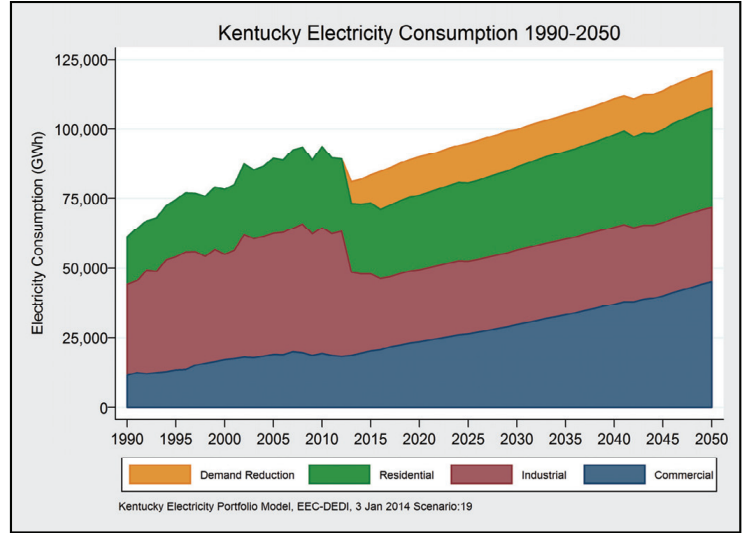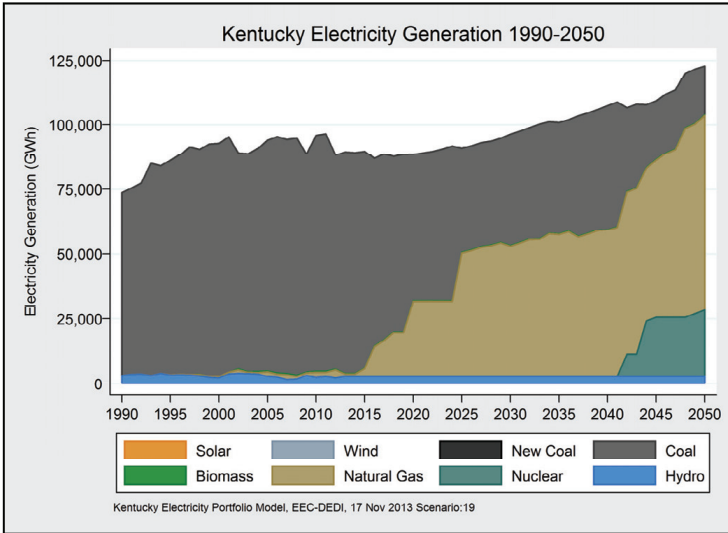## Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

Kentucky Electricity Generation 1990-2050

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:18

Kentucky Electricity Consumption 1990-2050

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:18

Kentucky Real Electricity Prices, 1970-2050

Data points: 9, 12, 14, 15

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Data points: 74, 47, 20, 15

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Data points: 122, 42, 3, 6

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Data points: 51, 22, 5, 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Scenario 18

**Federal Policy Option 4: $40-$60 Carbon Tax
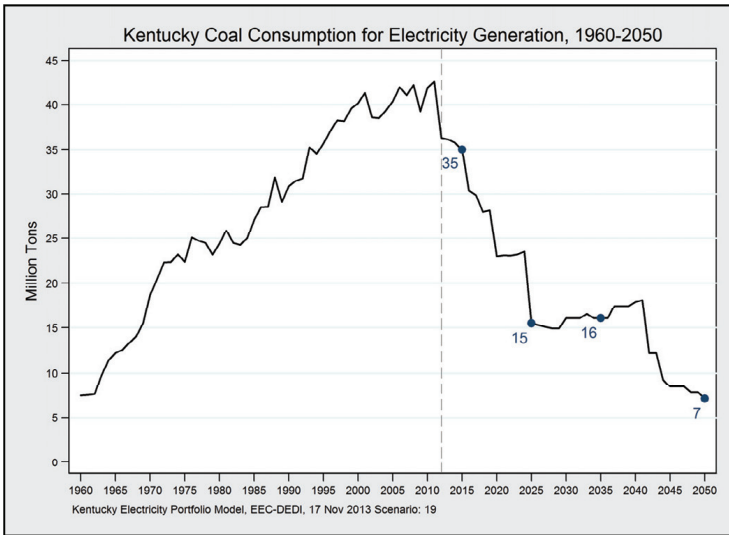Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation, 2035

Natural Gas 52%
Nuclear 45%
Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:18

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal — Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Kentucky Coal Consumption for Electricity Generation, 1960-2050

30
11
01
3

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

363 355
70
143

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 18

Kentucky Gross Domestic Product, 1970-2050

167691
186799
211949
257131

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:18

Kentucky Total Employment, 1970-2050

2467137
2536851
2710385
3061855

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:18

Scenario 19

**Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation 1990-2050

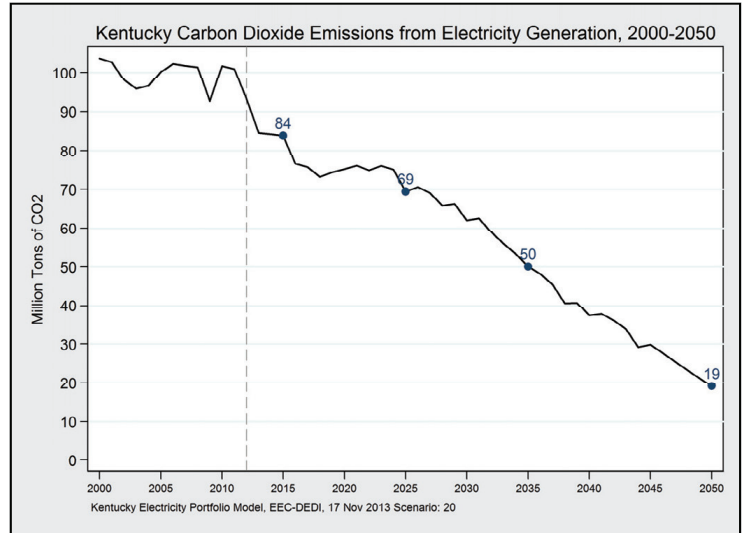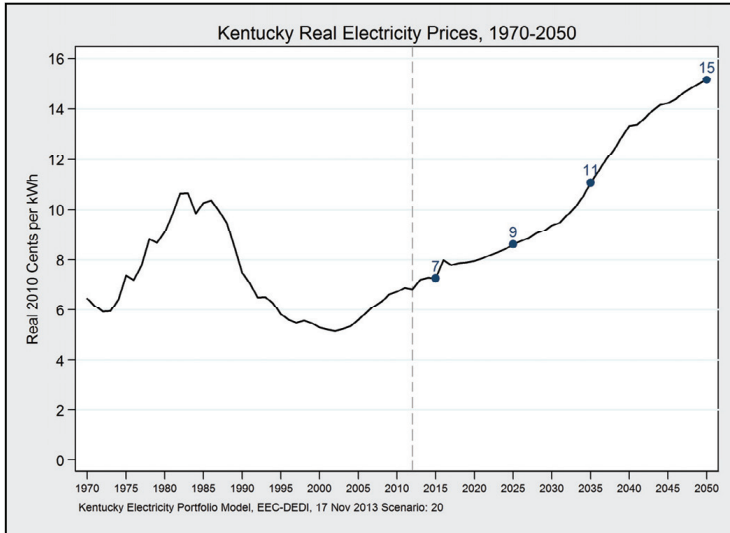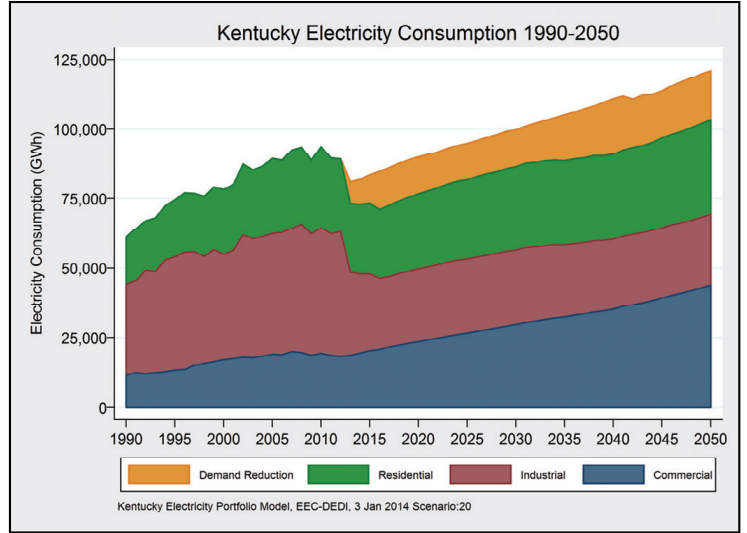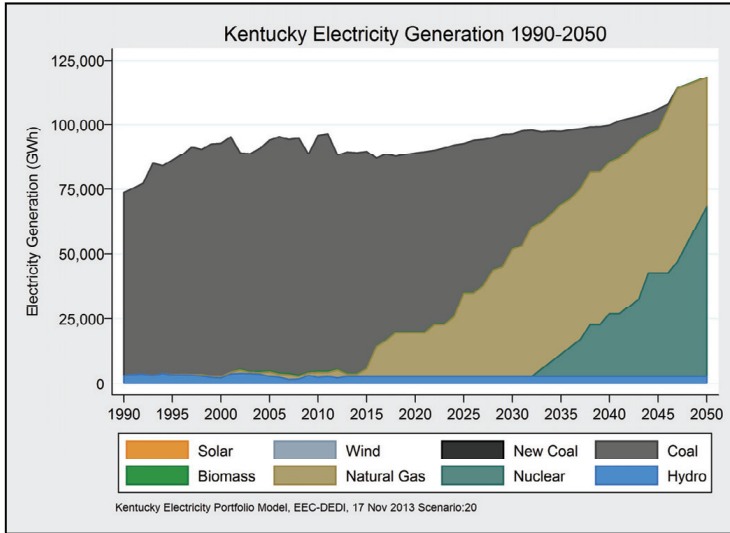Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:19

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:19

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Scenario 19

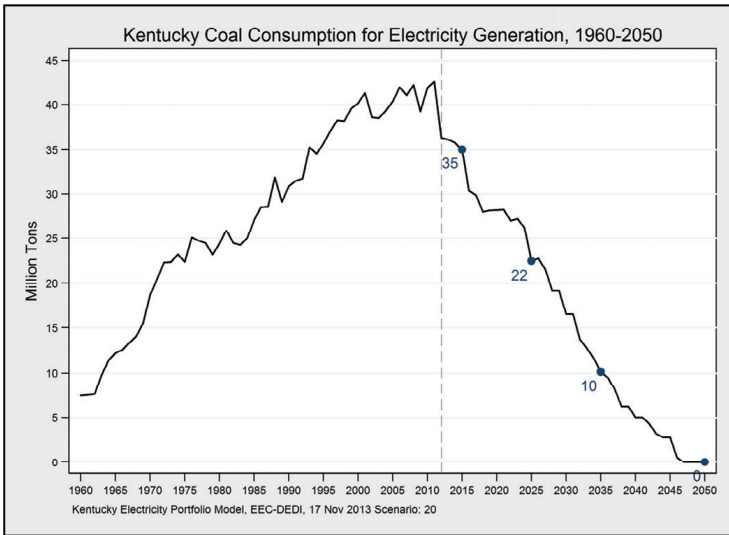**Federal Policy Option 5: CO$_2$ Rate Limit**
Portfolio 3: Balanced Portfolio Standard

Kentucky Electricity Generation, 2035

43%
54%

Coal   Natural Gas   Hydro
Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:19

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

BB'U

Coal   Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons

35
15   16
7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF)

498
407
358

38

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 19

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$

258948
218886
193542
171638

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:19

Kentucky Total Employment, 1970-2050

Full-Time Jobs

3090994
2837097
2672874
2557276

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:19

Scenario 20

Federal Policy Option 6: Presidential CO$_2$ Rate Limit
Portfolio 3: Balanced Portfolio Standard

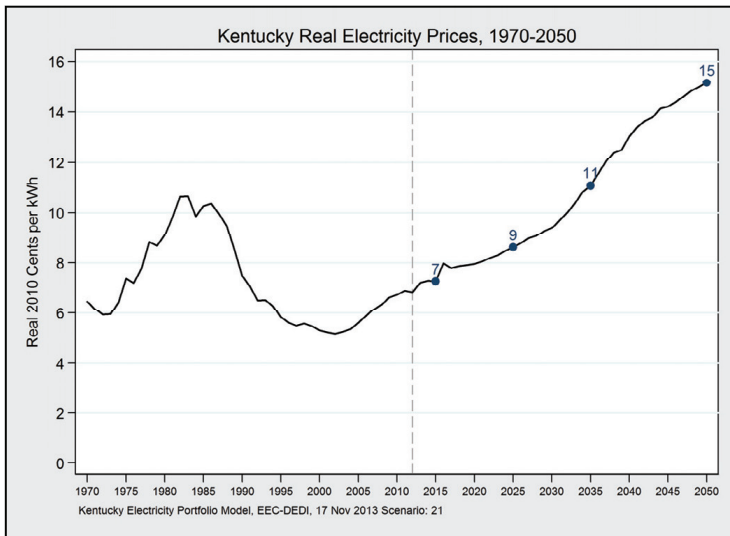### Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:20

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:20

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
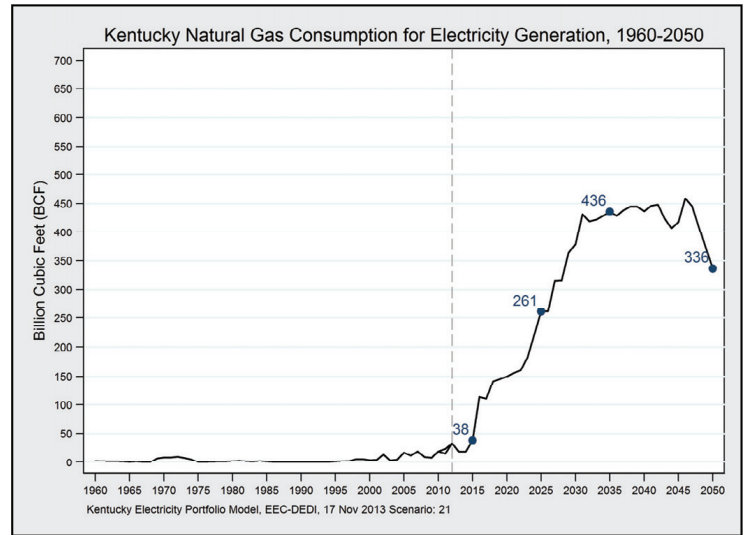

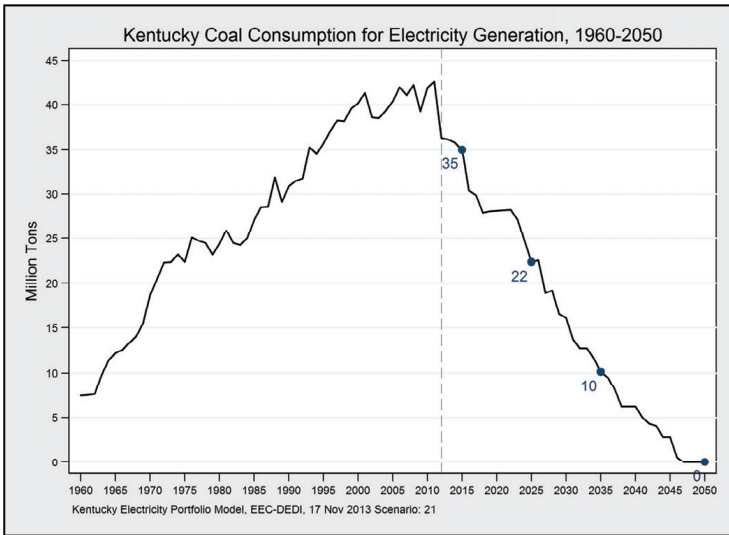Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Scenario 20

Federal Policy Option 6: Presidential CO₂ Rate Limit
Portfolio 3: Balanced Portfolio Standard

Kentucky Electricity Generation, 2035

Coal 29%
Natural Gas 59%
Nuclear 9%

Legend: Coal, Natural Gas, Nuclear, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:20

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Legend: Coal, Natural Gas

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35, 22, 10, 0

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

38, 260, 437, 336

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 20

Kentucky Gross Domestic Product, 1970-2050

171638, 194224, 216951, 256353

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:20

Kentucky Total Employment, 1970-2050

2557276, 2686827, 2801484, 3049419

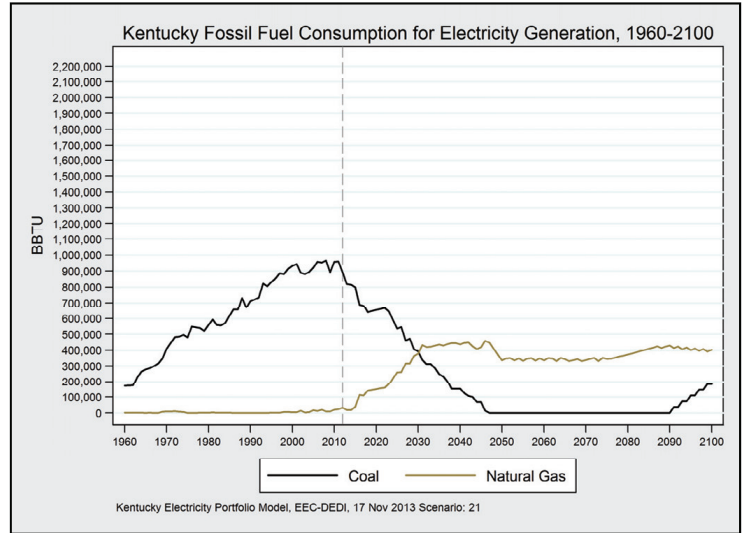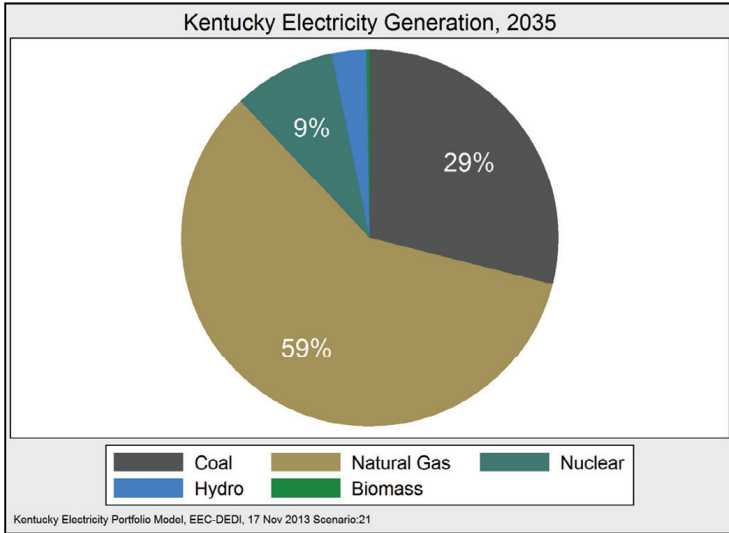Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:20

Scenario 21

Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 3: Balanced Portfolio Standard

Kentucky Electricity Generation 1990-2050
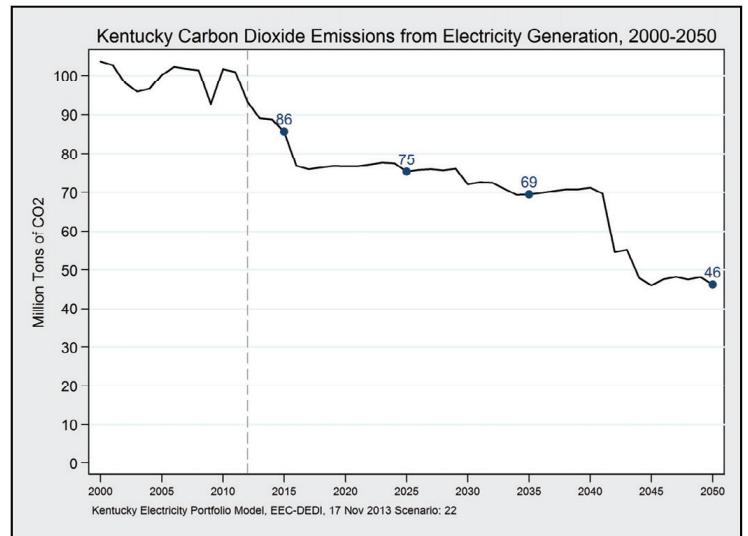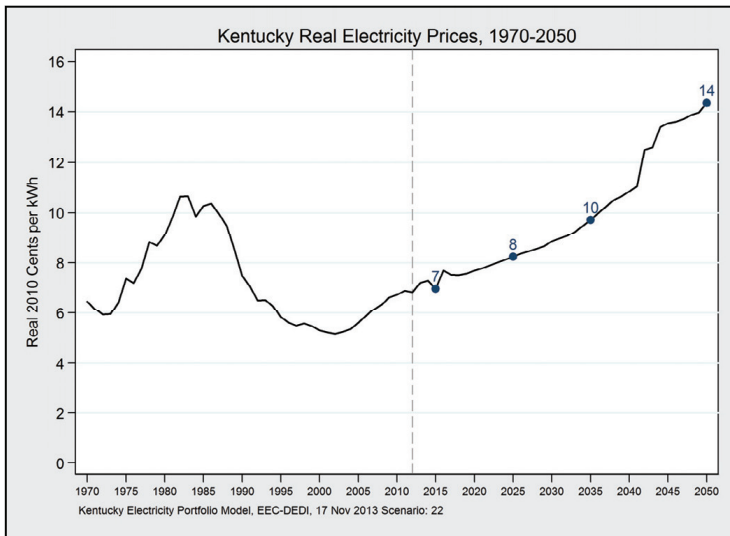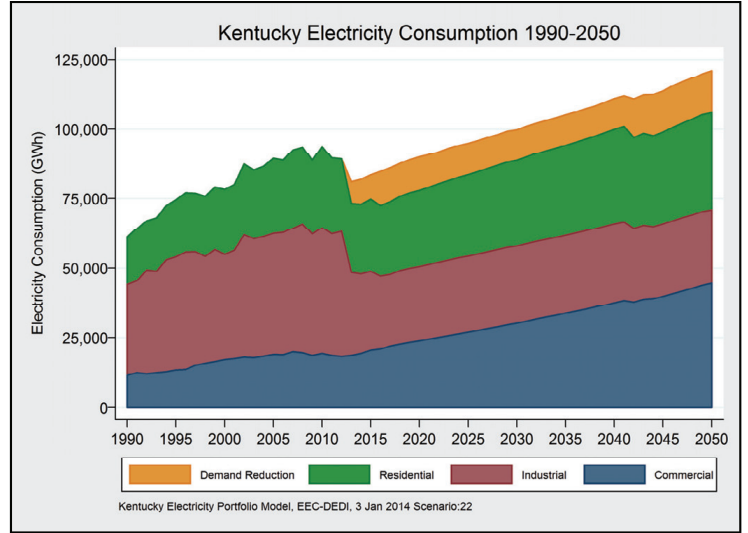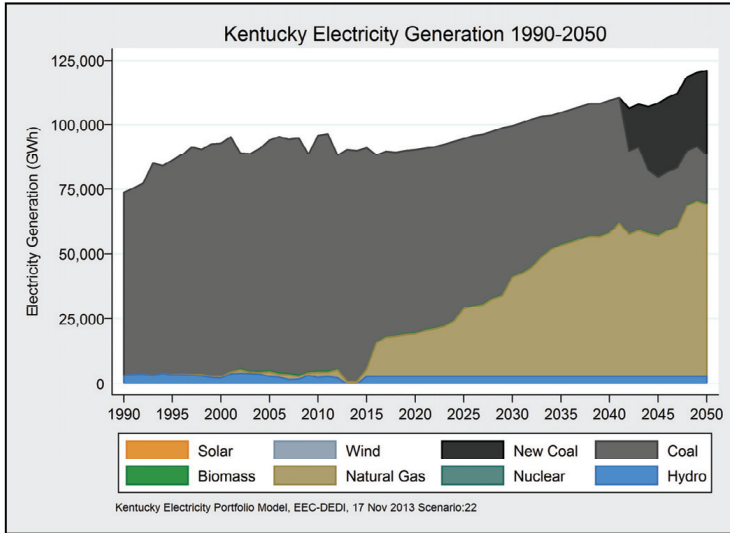
Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:21

Kentucky Electricity Consumption 1990-2050

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:21

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Scenario 21

Federal Policy Option 7: Presidential Mass Emissions Goal
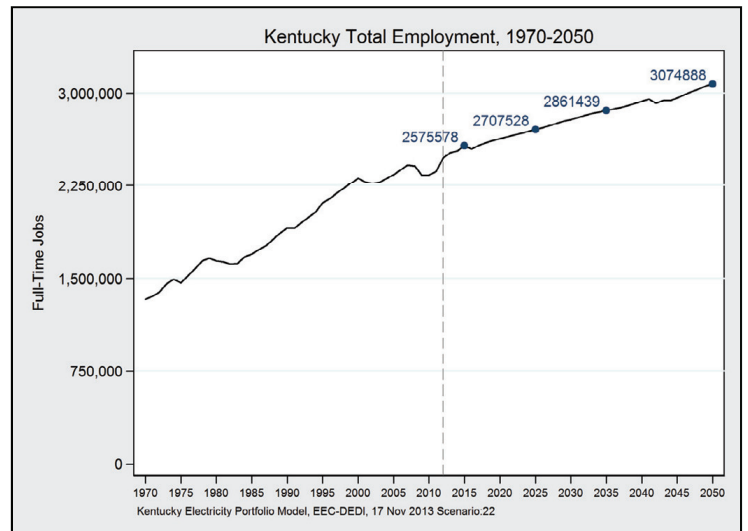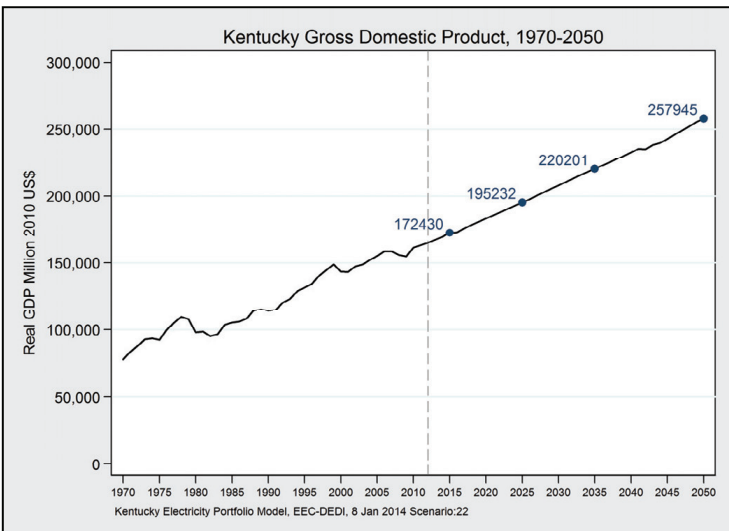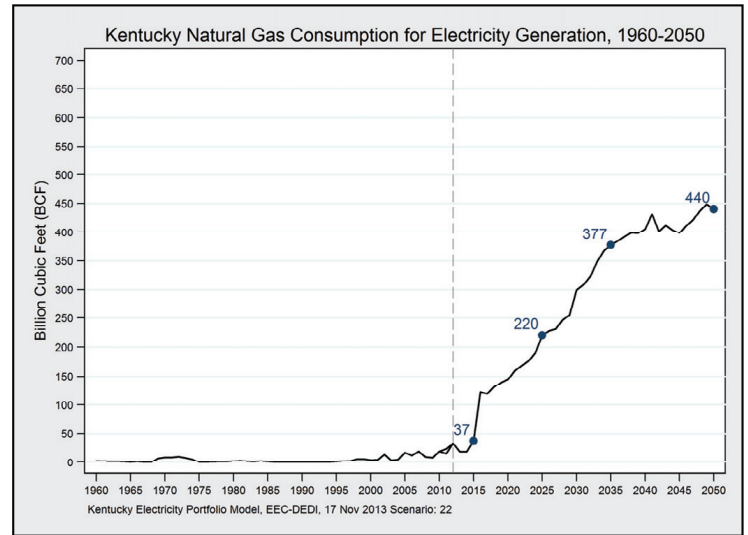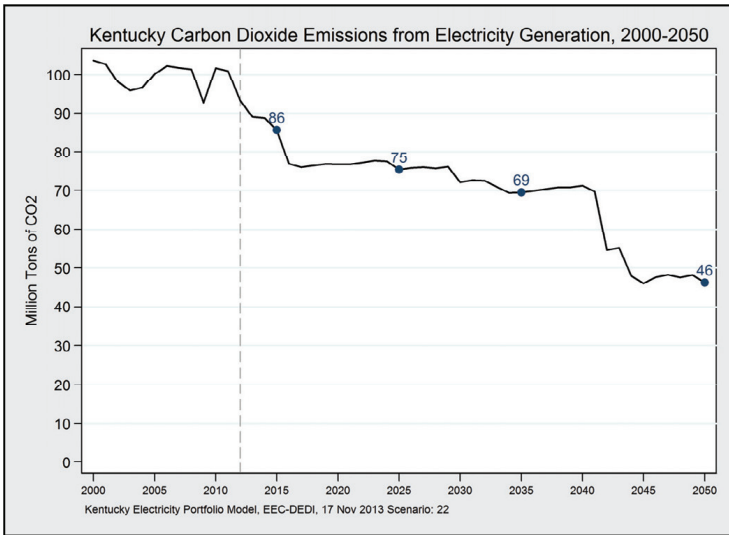**Portfolio 3: Balanced Portfolio Standard**

Kentucky Electricity Generation, 2035

Coal 29%
Natural Gas 59%
Nuclear 9%

Coal   Natural Gas   Nuclear
Hydro   Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:21

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal   Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Kentucky Coal Consumption for Electricity Generation, 1960-2050

35
22
10
0

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

436
261
38
336

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 21

Kentucky Gross Domestic Product, 1970-2050

171638
194215
216950
256355

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:21

Kentucky Total Employment, 1970-2050

2557276
2686645
2801457
3049440

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:21
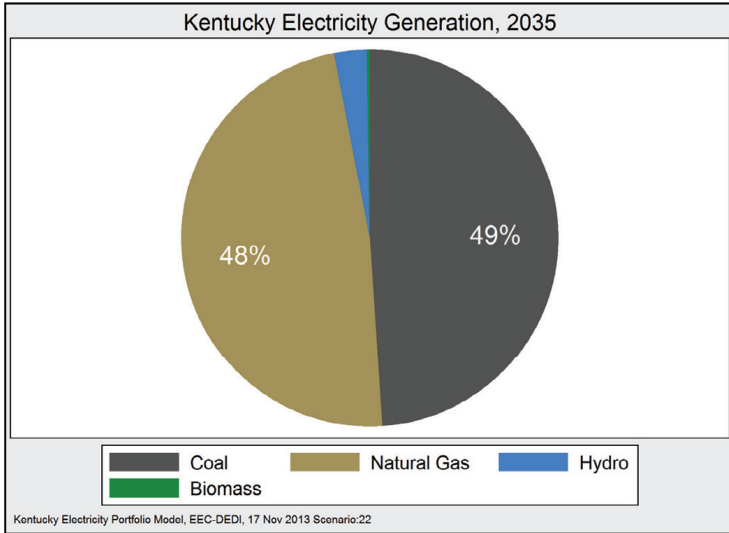
Scenario 22

**Federal Policy Option 1: Reference
Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation 1990-2050

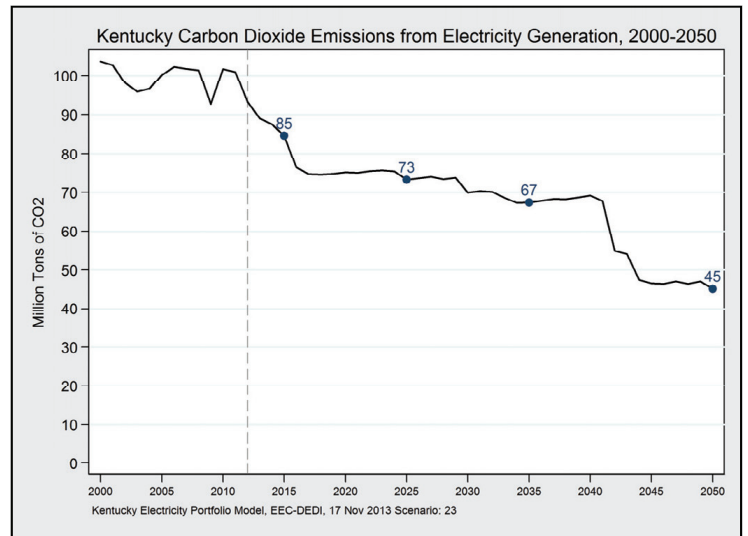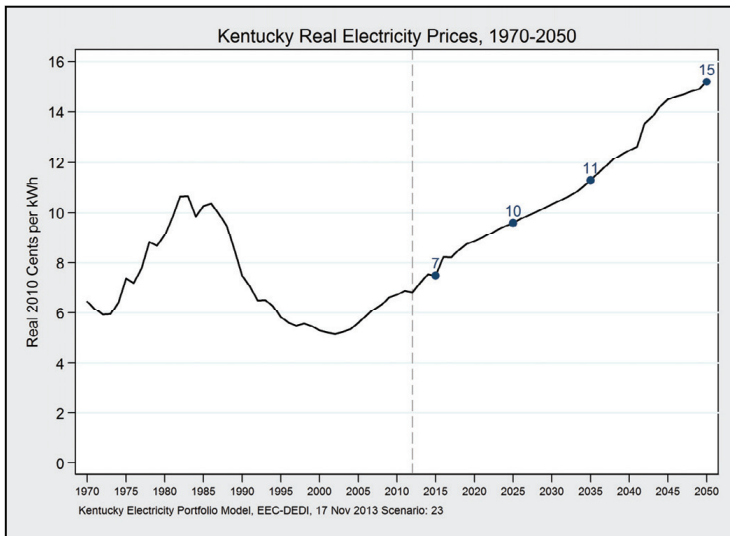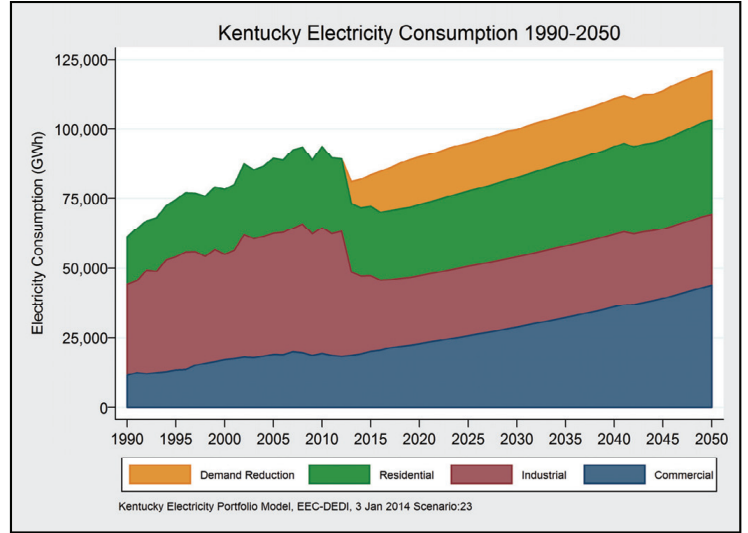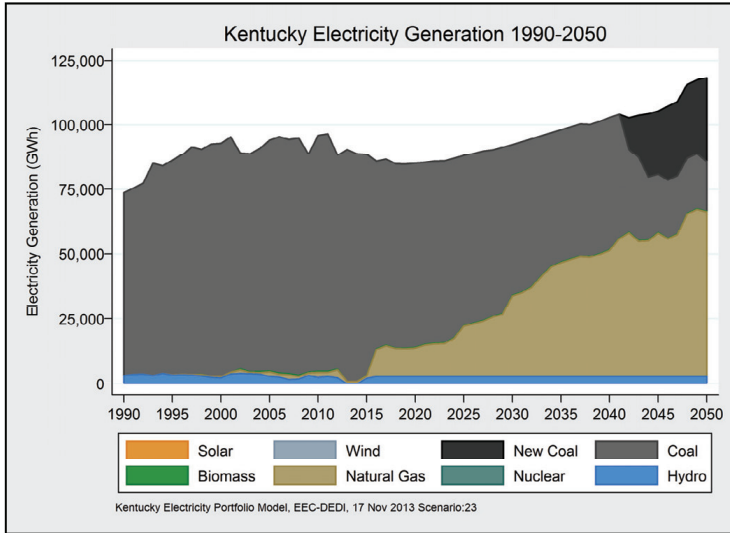Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:22

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:22

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Scenario 22

Federal Policy Option 1: Reference
Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation, 2035

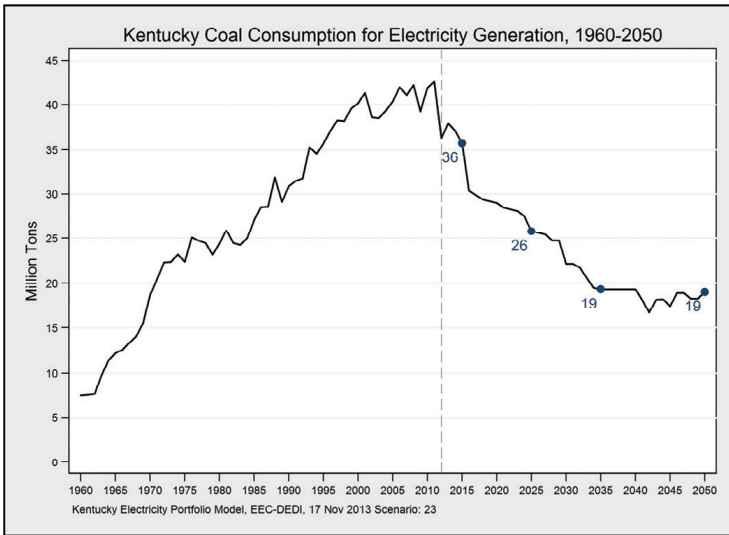Coal 49%, Natural Gas 48%

Legend: Coal, Natural Gas, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:22

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Legend: Coal, Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Values: 86, 75, 69, 46

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Values: 37, 220, 377, 440

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 22

Kentucky Gross Domestic Product, 1970-2050

Values: 172430, 195232, 220201, 257945

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:22

Kentucky Total Employment, 1970-2050

Values: 2575578, 2707528, 2861439, 3074888

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:22

Scenario 23

Federal Policy Option 2: $10-$20 Carbon Tax
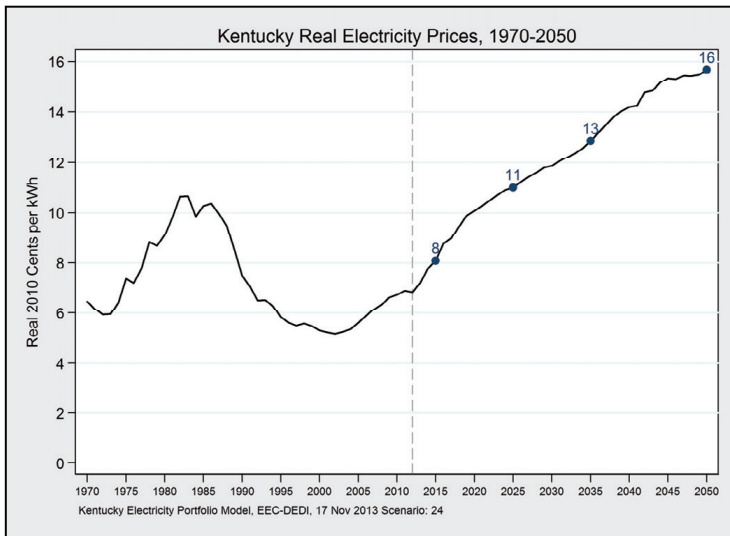## Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation 1990-2050

Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:23

Kentucky Electricity Consumption 1990-2050

Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:23

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Scenario 23

Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation, 2035

- Coal — 52%
- Natural Gas — 44%
- Hydro
- Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:23

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 23

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:23

Kentucky Total Employment, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:23

Scenario 24

Federal Policy Option 3: $20-$40 Carbon Tax
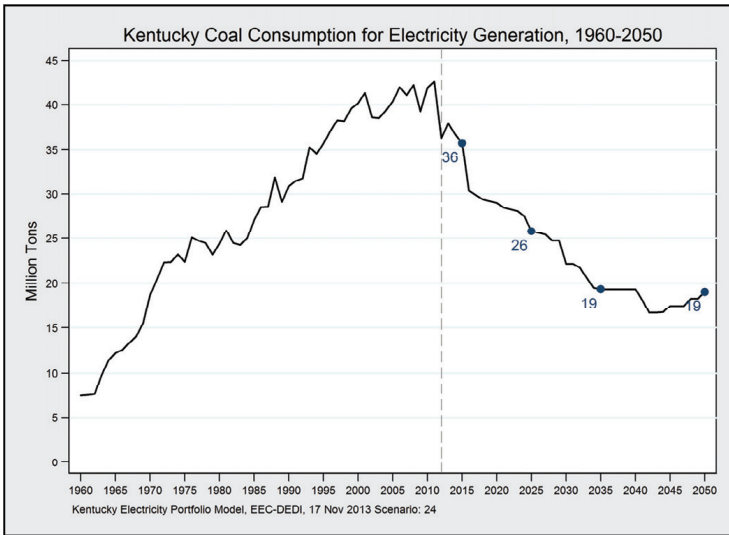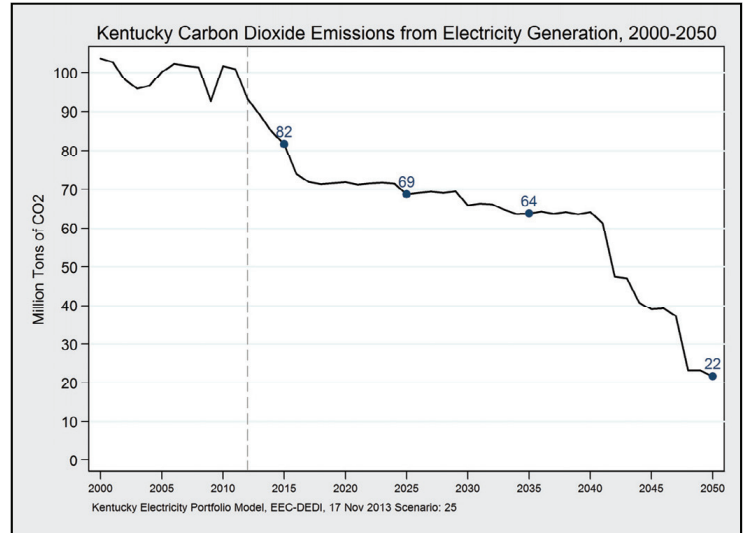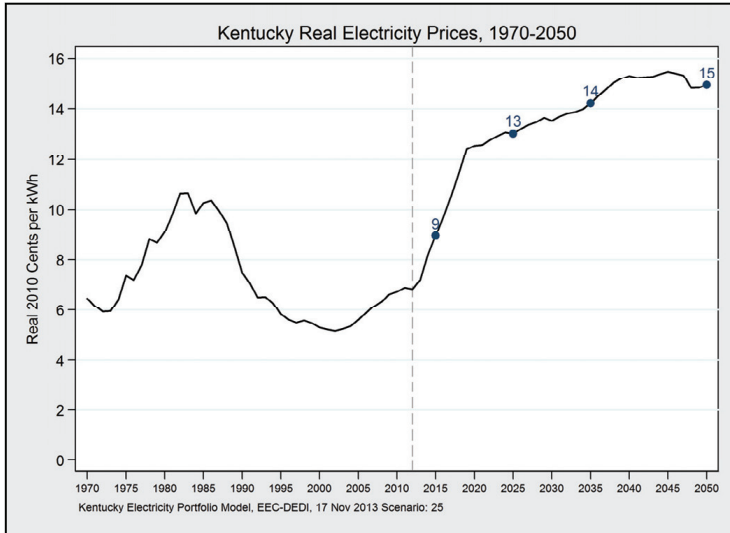**Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation 1990-2050

Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:24

Kentucky Electricity Consumption 1990-2050

Legend: Demand Reduction, Residential, Industrial, Commercial

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:24

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

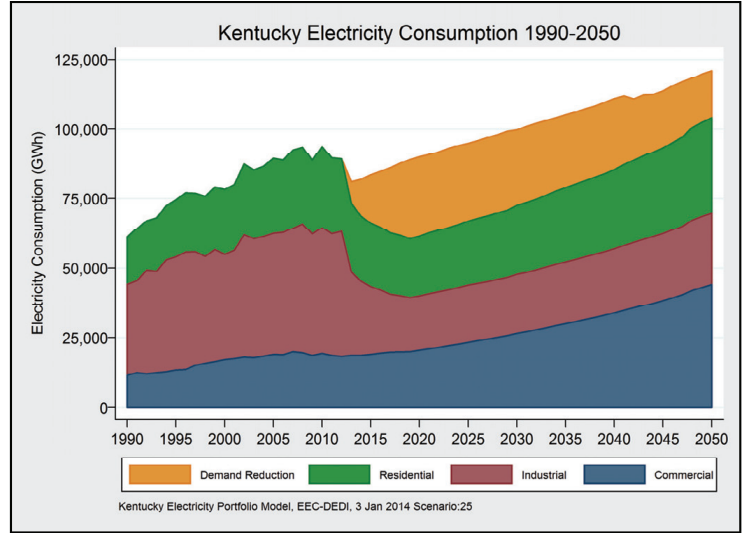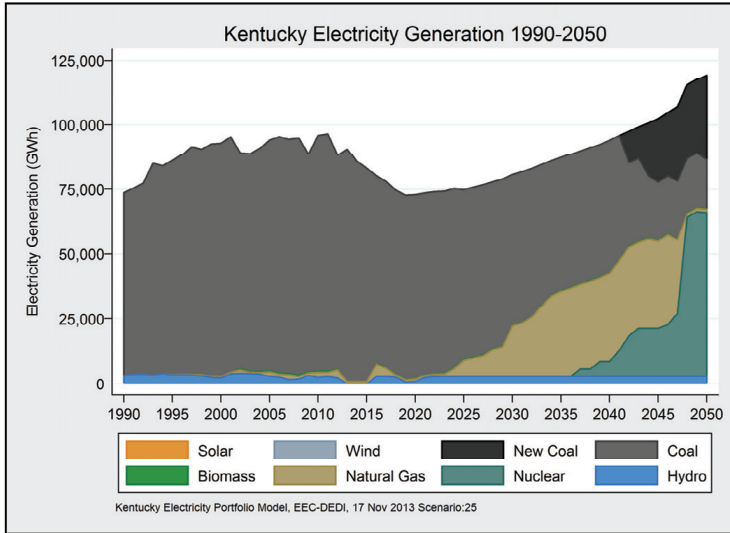Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Scenario 24

**Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation, 2035
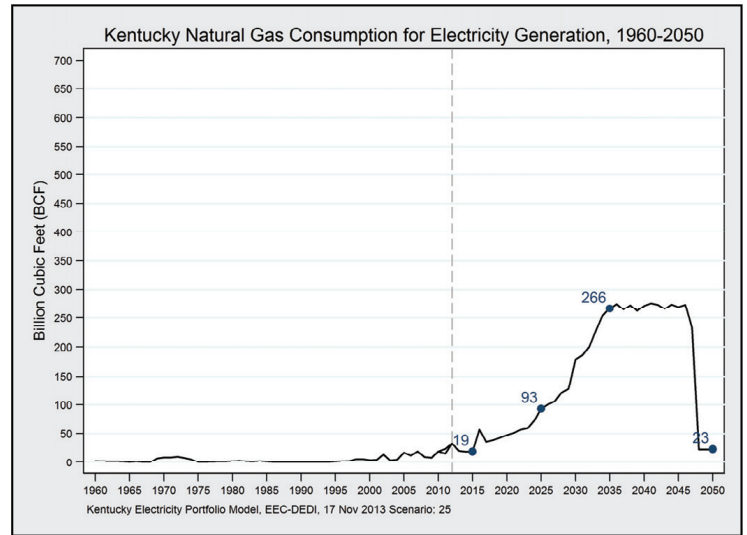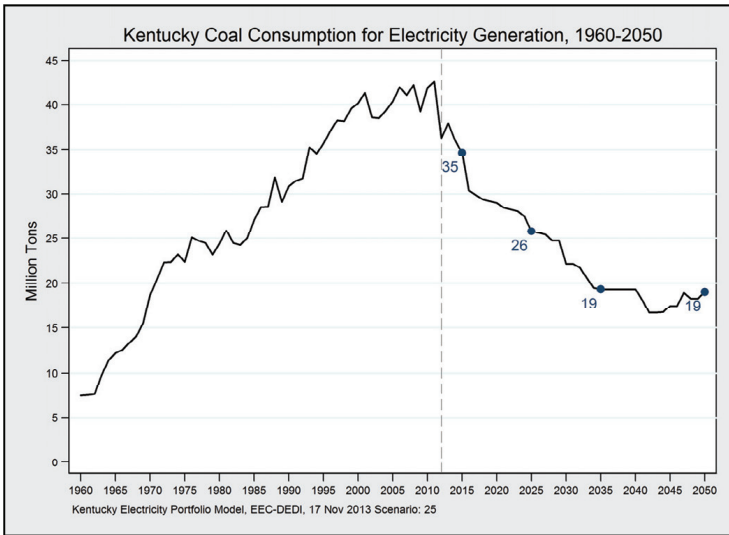
Coal 56%, Natural Gas 40%, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:24

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Coal, Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 24

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:24

Kentucky Total Employment, 1970-2050

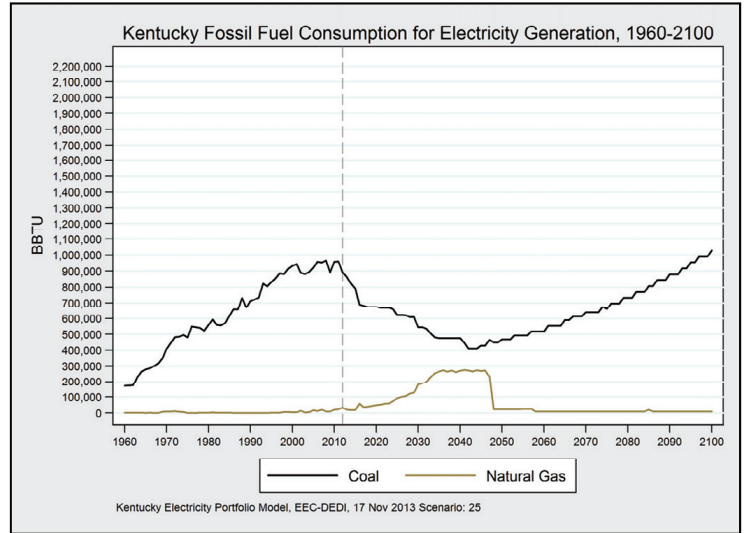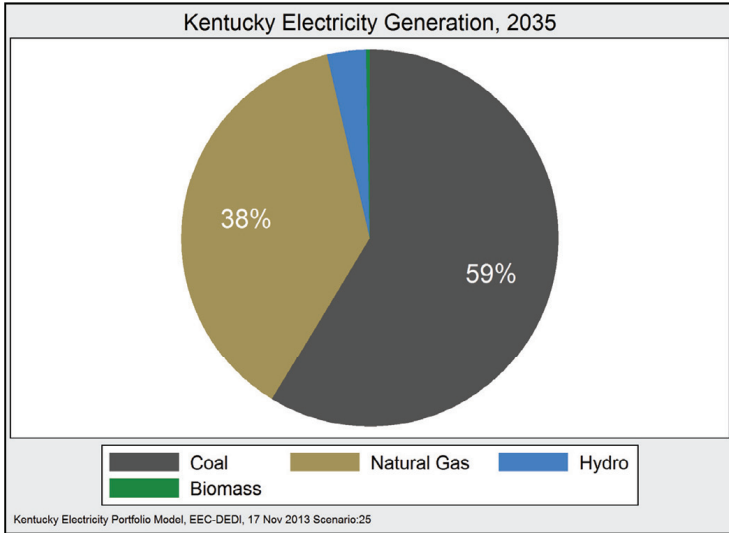Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:24

Scenario 25

Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Consumption 1990-2050

Kentucky Real Electricity Prices, 1970-2050

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Scenario 25

Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation, 2035
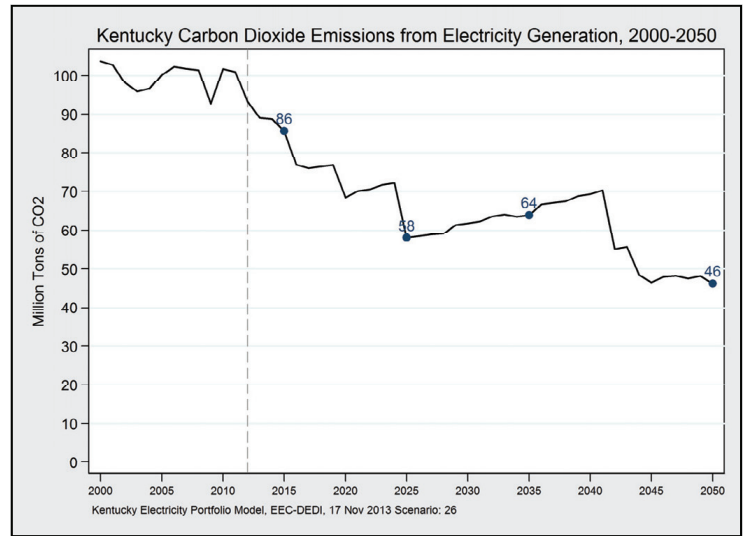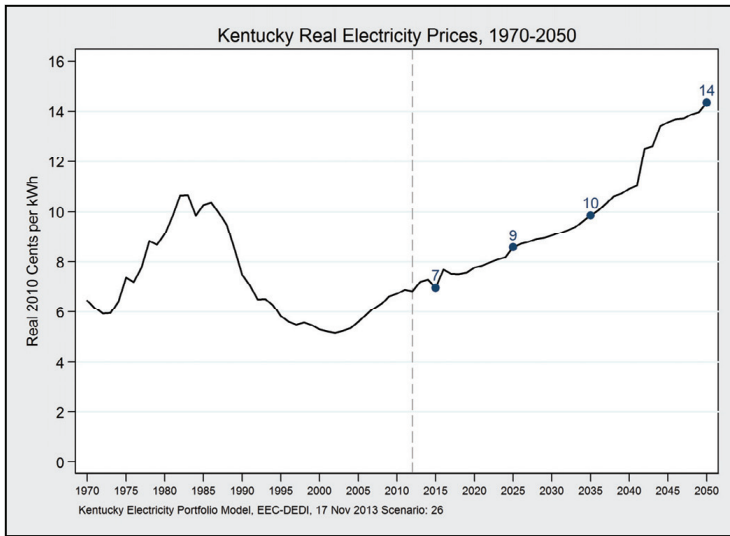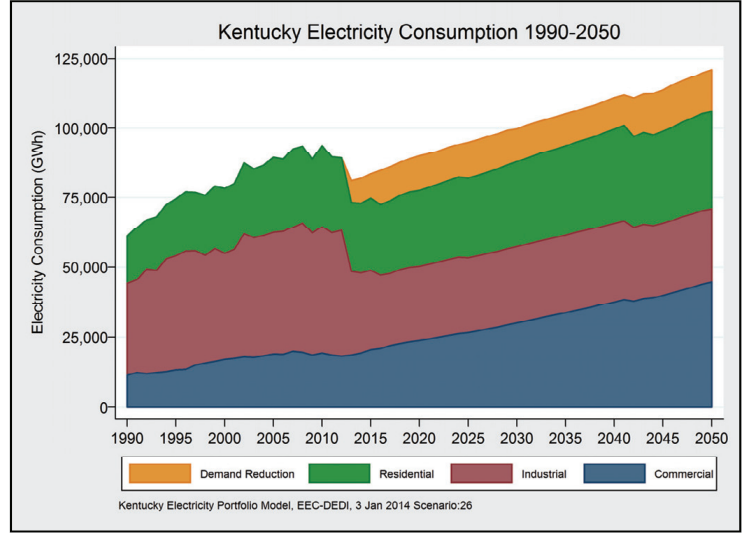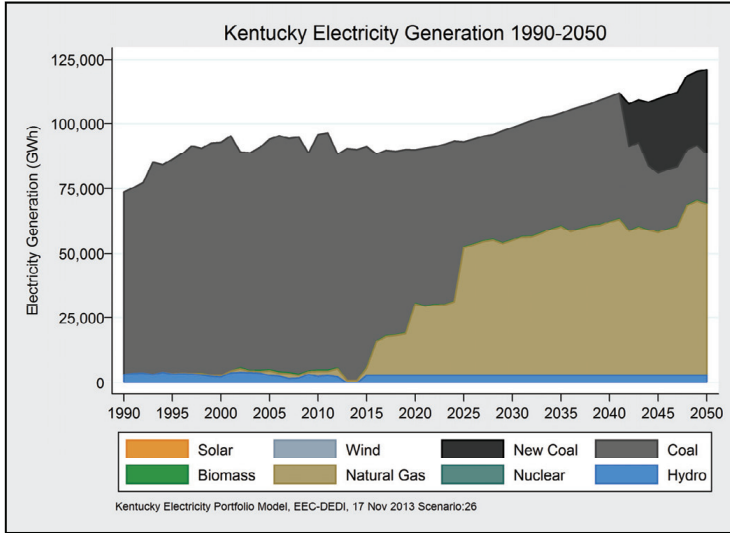
Coal 59%, Natural Gas 38%, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:25

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 25

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 25

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 25

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:25

Kentucky Total Employment, 1970-2050

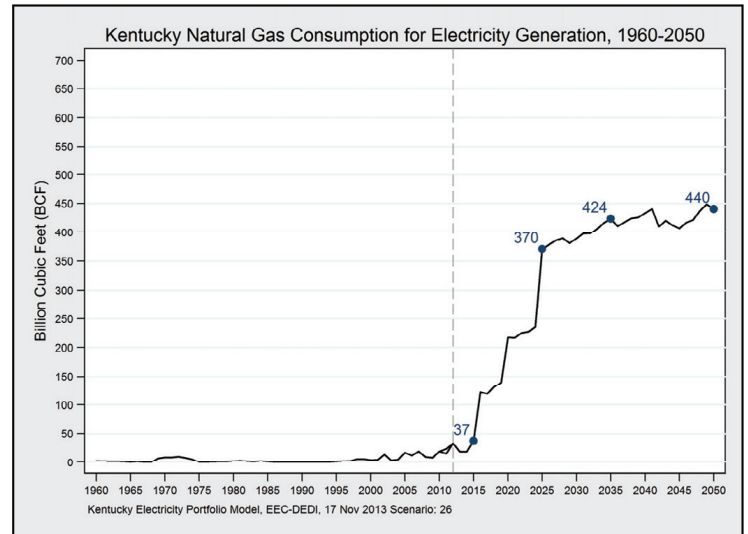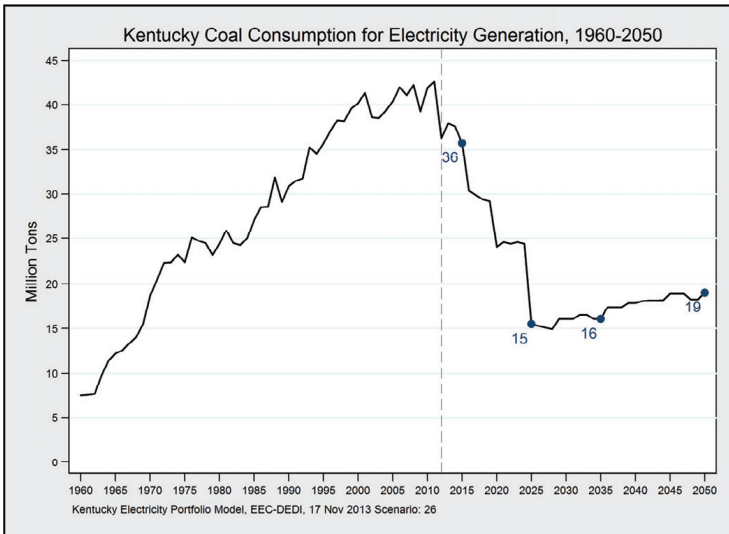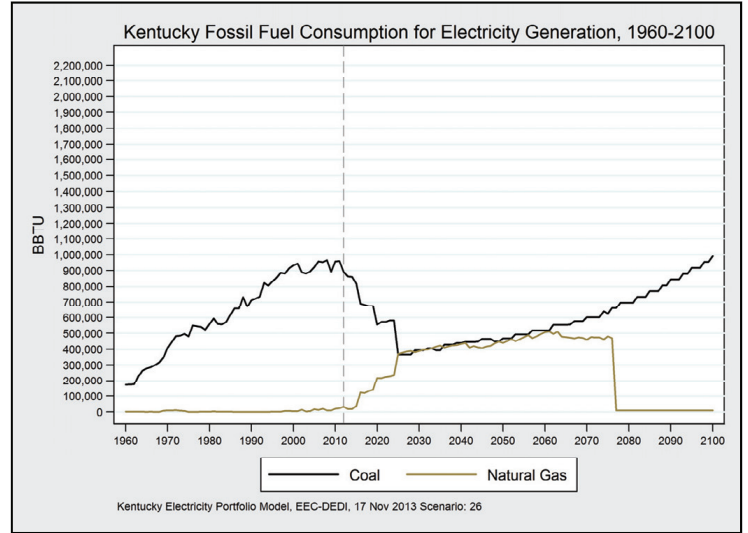Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:25

Scenario 26

**Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:26

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:26

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

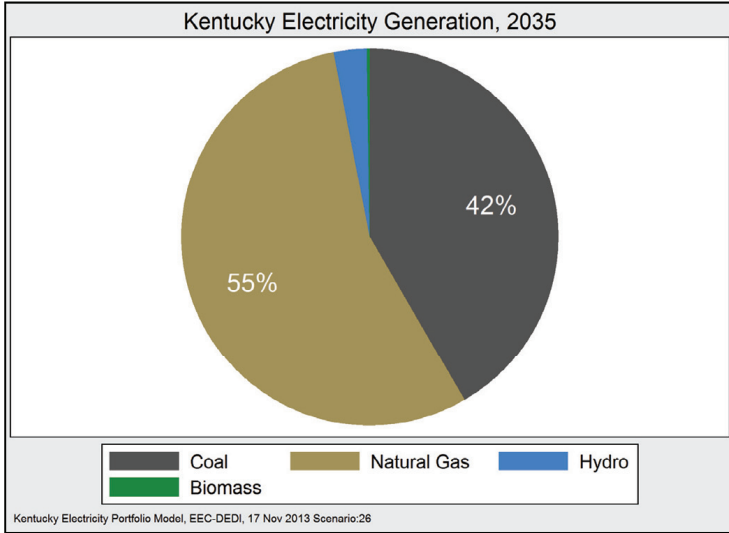Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Scenario 26

**Federal Policy Option 5: CO$_2$ Rate Limit
Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation, 2035
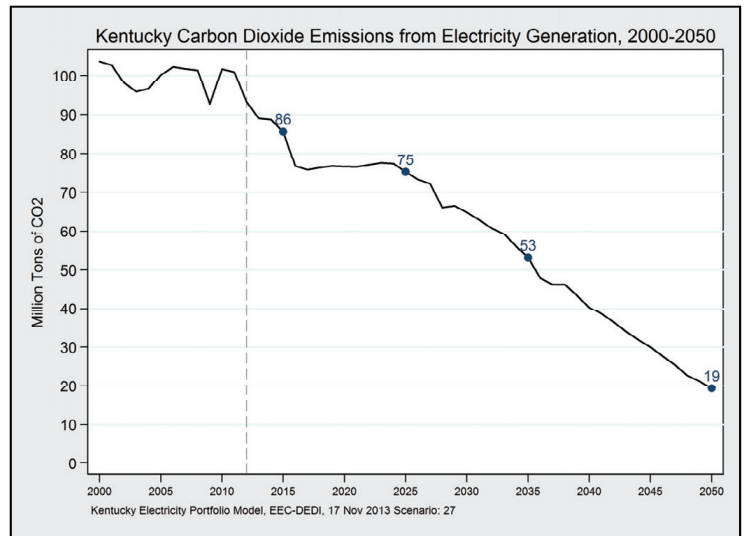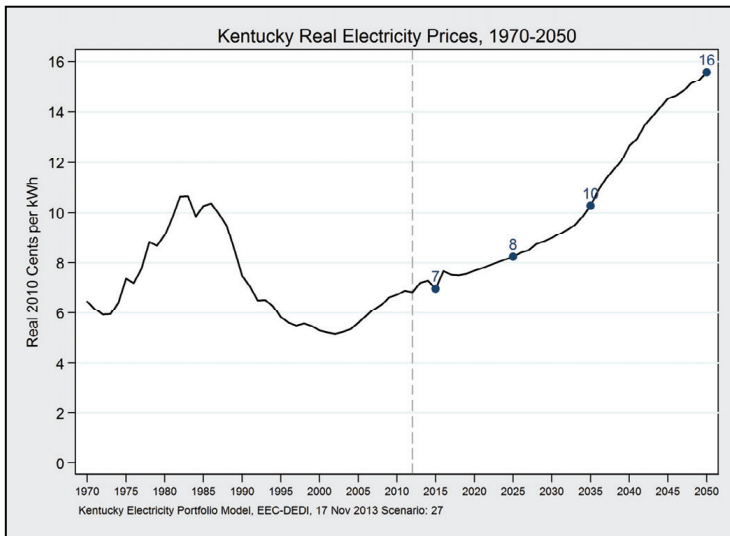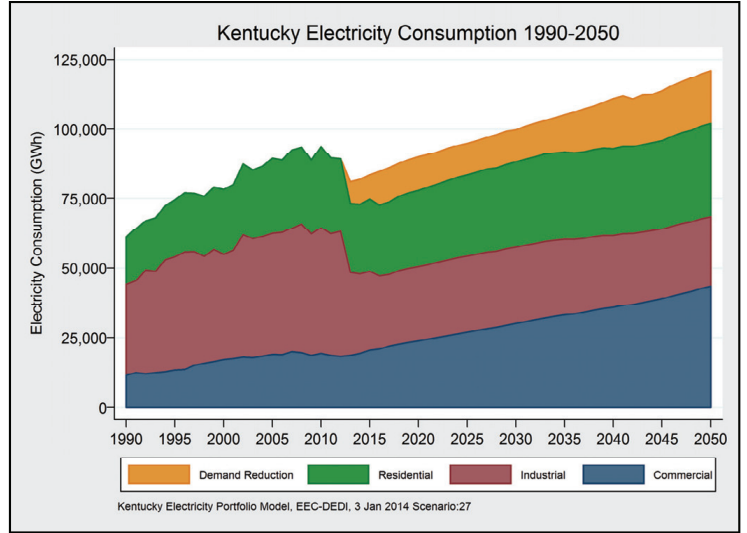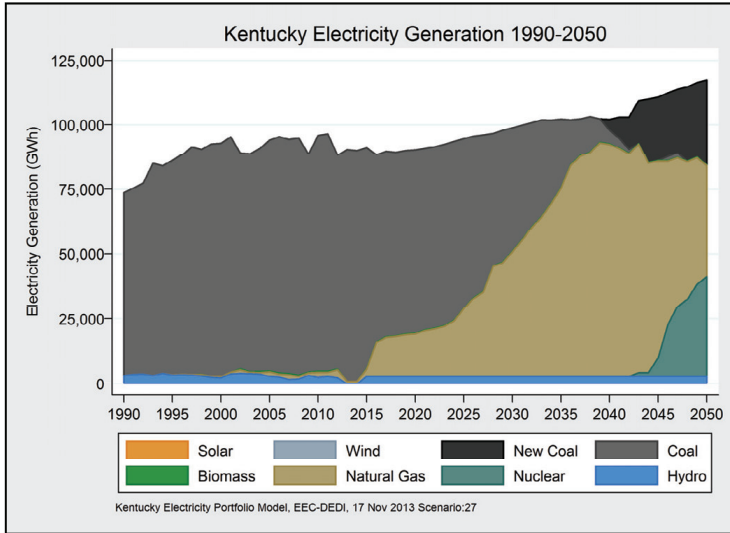- Coal — 42%
- Natural Gas — 55%
- Hydro
- Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:26

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 26

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:26

Kentucky Total Employment, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:26

Scenario 27

**Federal Policy Option 6: Presidential CO$_2$ Rate Limit
Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation 1990-2050
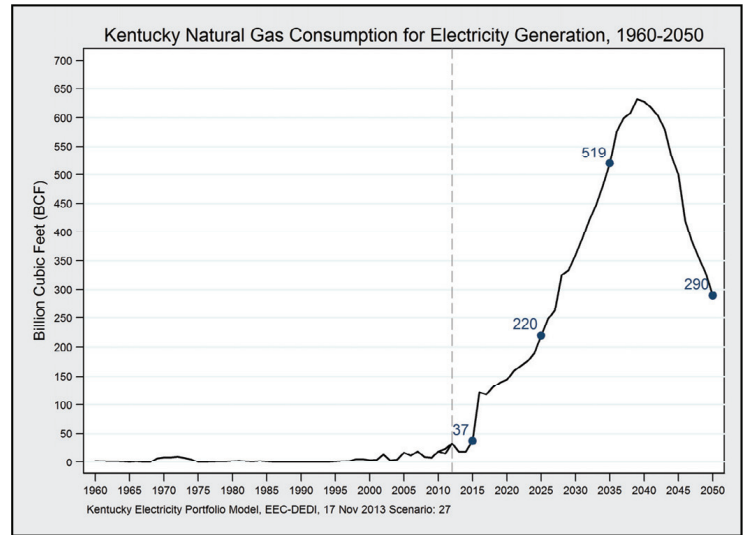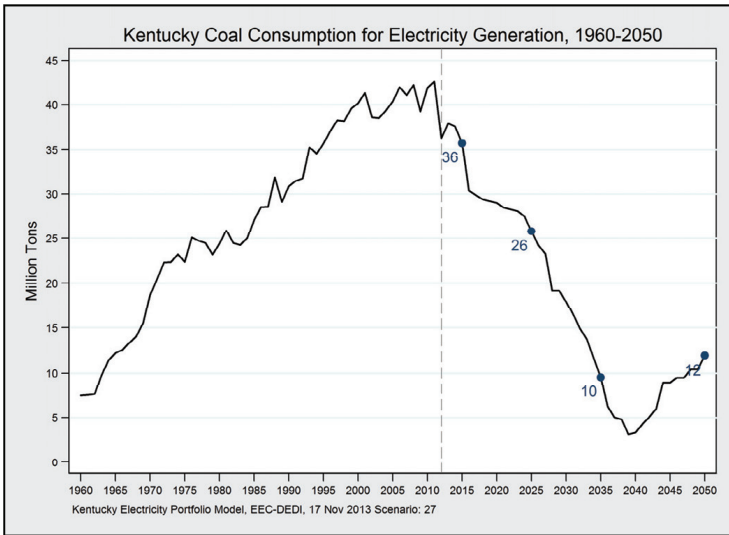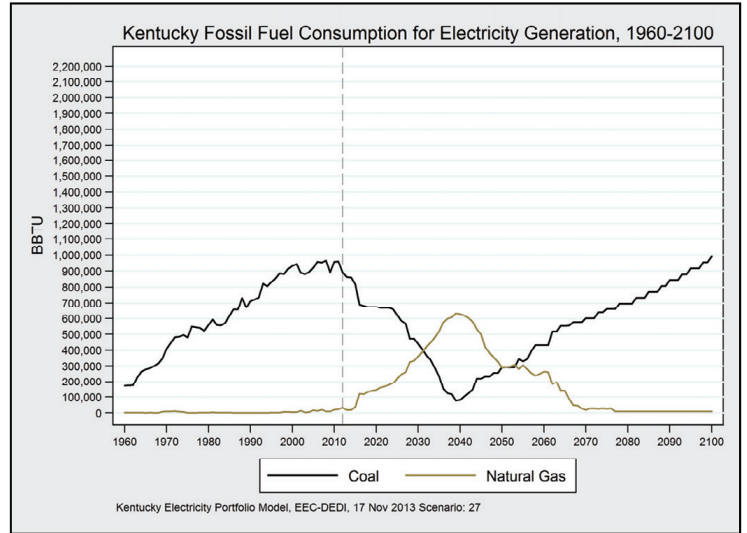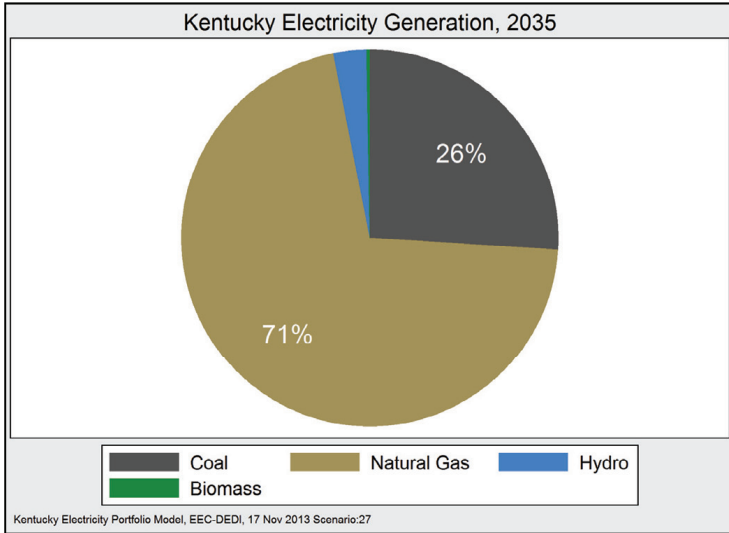
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:27

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:27

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Scenario 27

Federal Policy Option 6: Presidential CO$_2$ Rate Limit
Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation, 2035
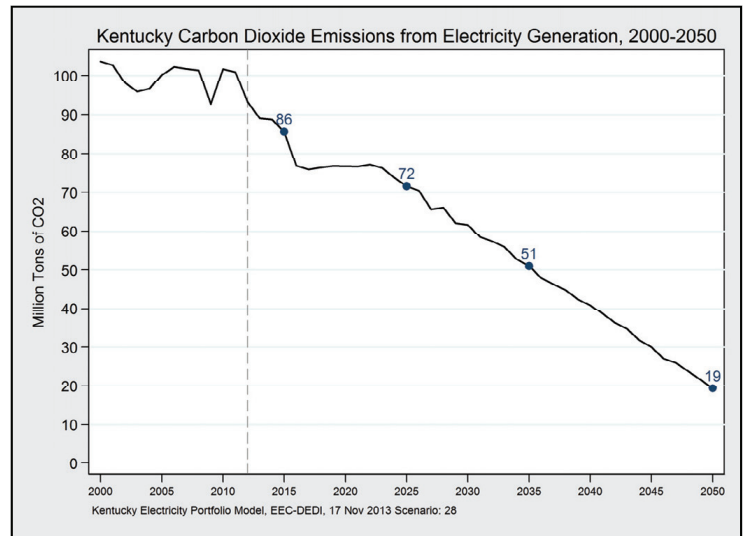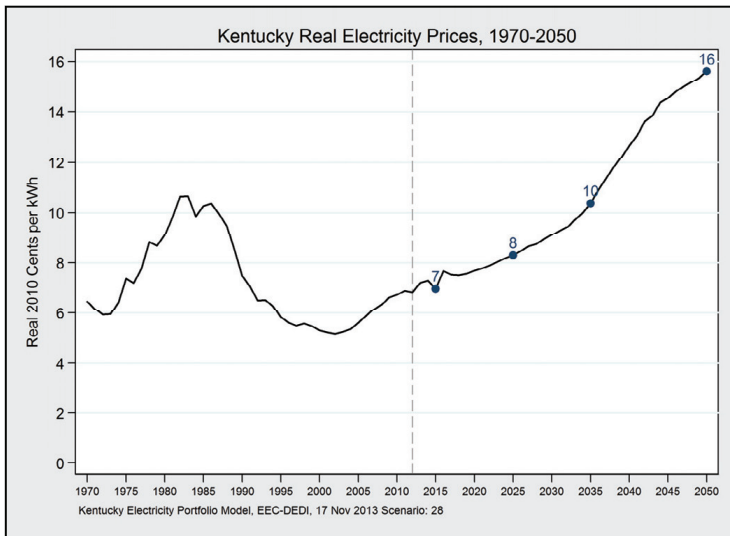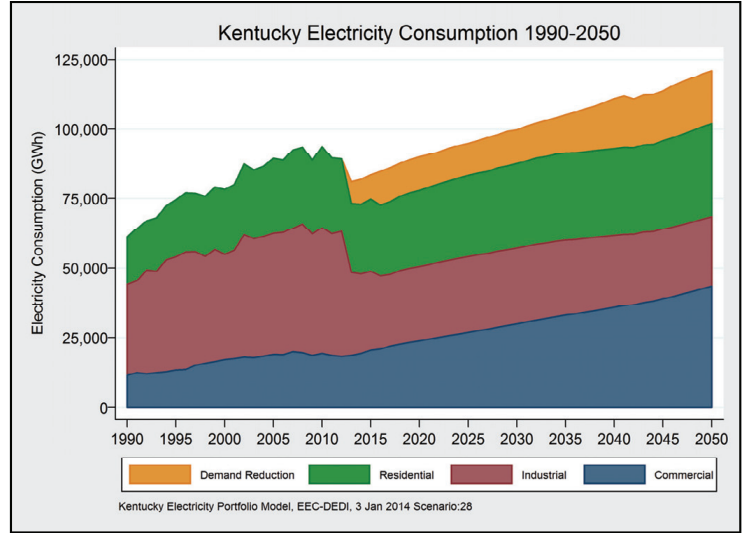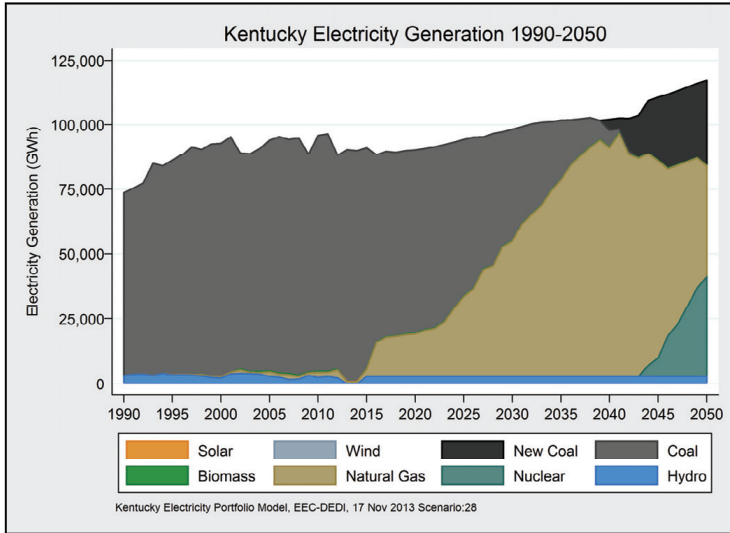

- 26% Coal
- 71% Natural Gas

Legend: Coal, Natural Gas, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:27

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

BB"U

Legend: Coal, Natural Gas

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Million Tons

36, 26, 10, 12

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Billion Cubic Feet (BCF)

519, 220, 37, 290

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 27

Kentucky Gross Domestic Product, 1970-2050

Real GDP Million 2010 US$

172429, 195219, 218804, 255535

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:27

Kentucky Total Employment, 1970-2050

Full-Time Jobs

2575576, 2707267, 2835586, 3036360

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:27

Scenario 28

Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 4: Coal Portfolio Standard

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:28

Kentucky Electricity Consumption 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Jan 2014 Scenario:28

Kentucky Real Electricity Prices, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050

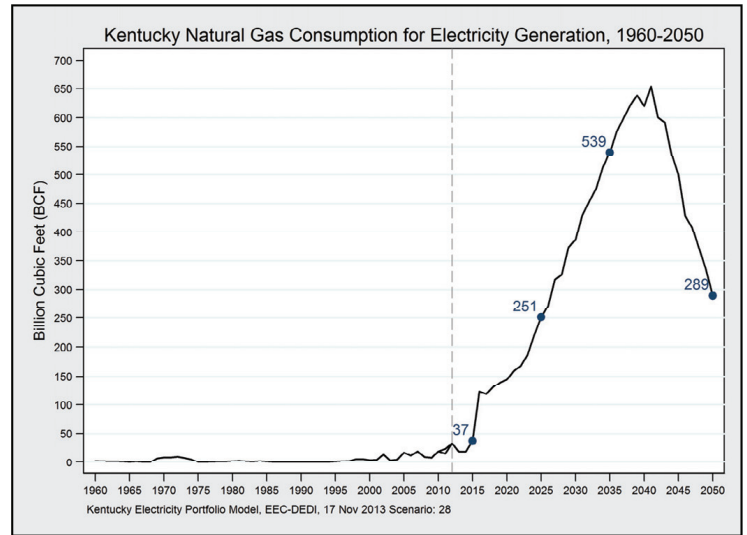Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28
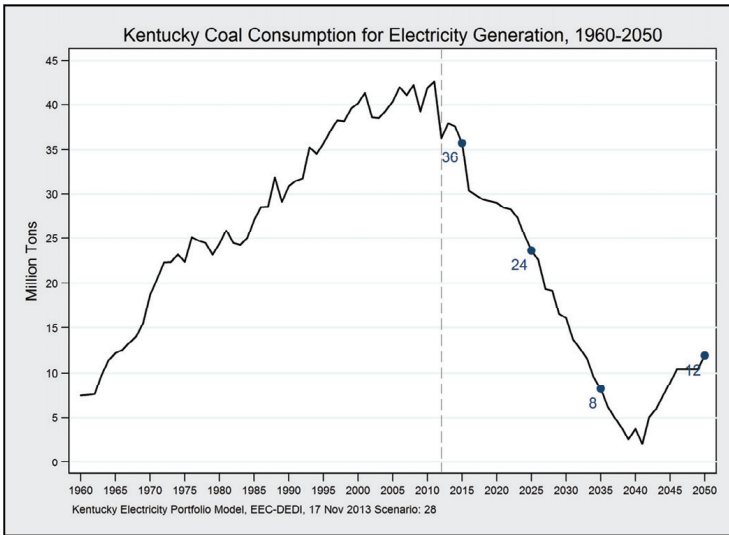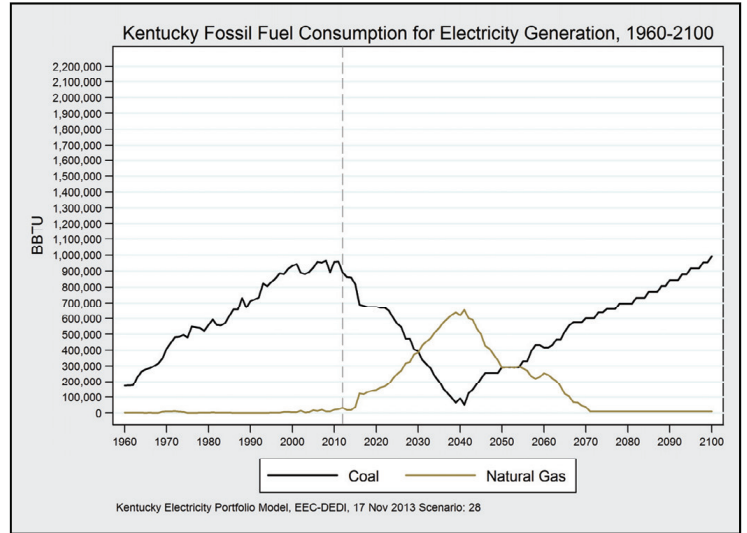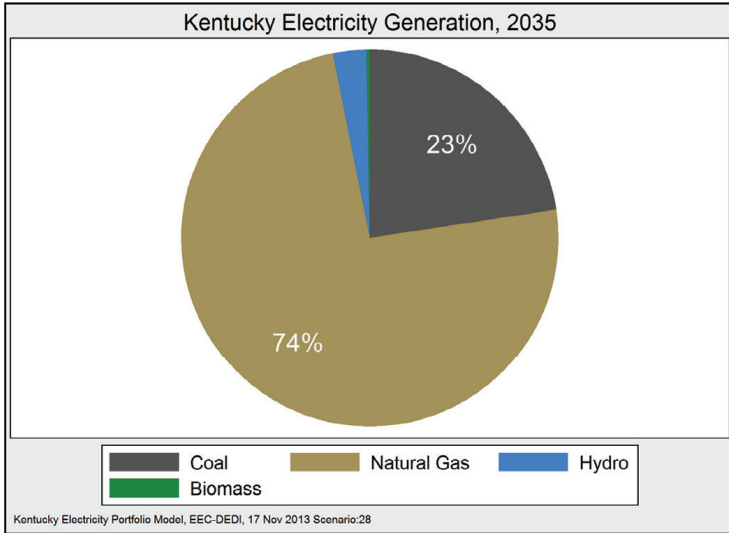
Scenario 28

**Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 4: Coal Portfolio Standard**

Kentucky Electricity Generation, 2035
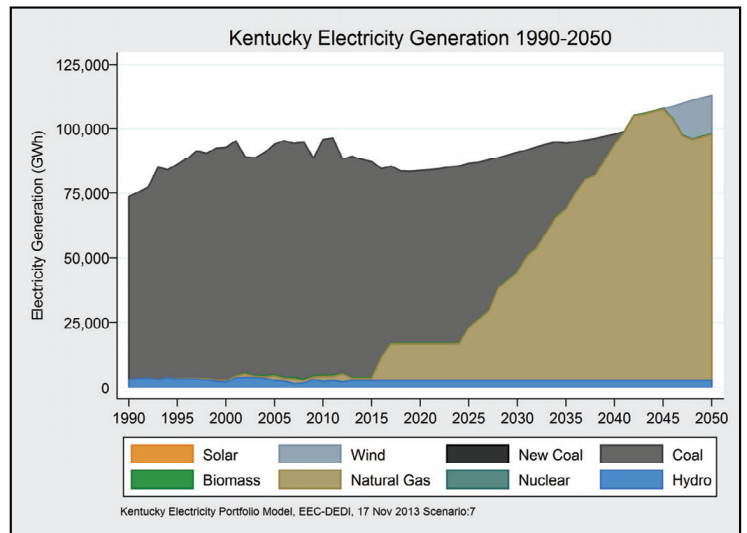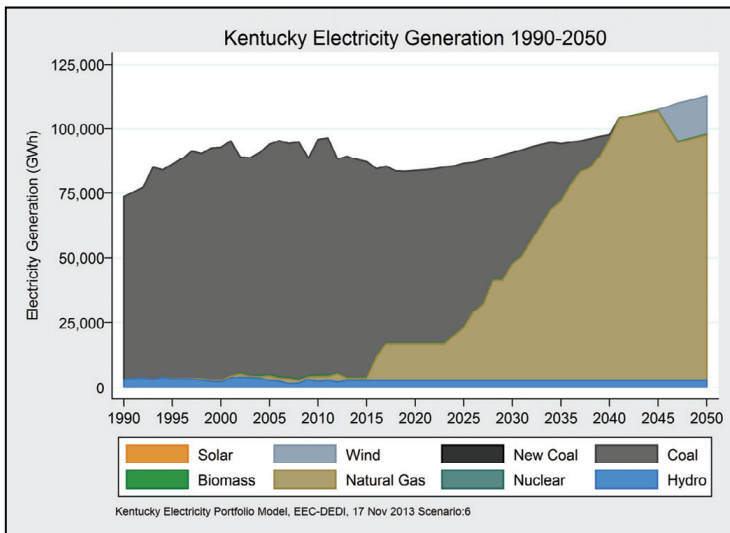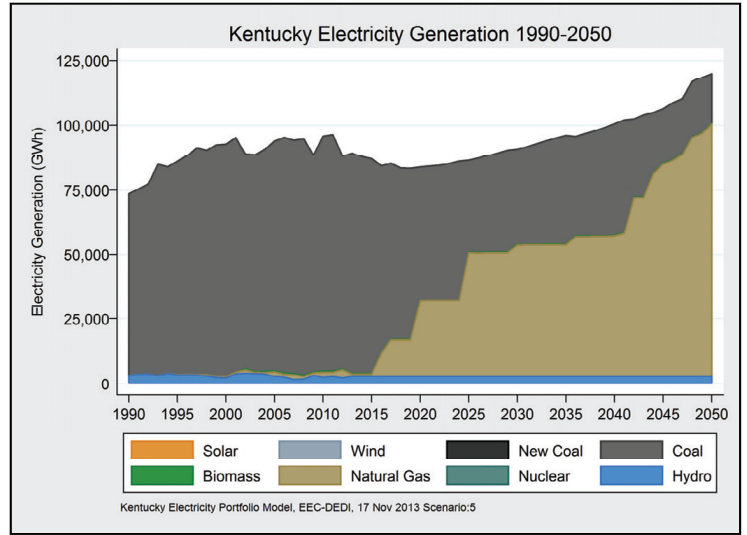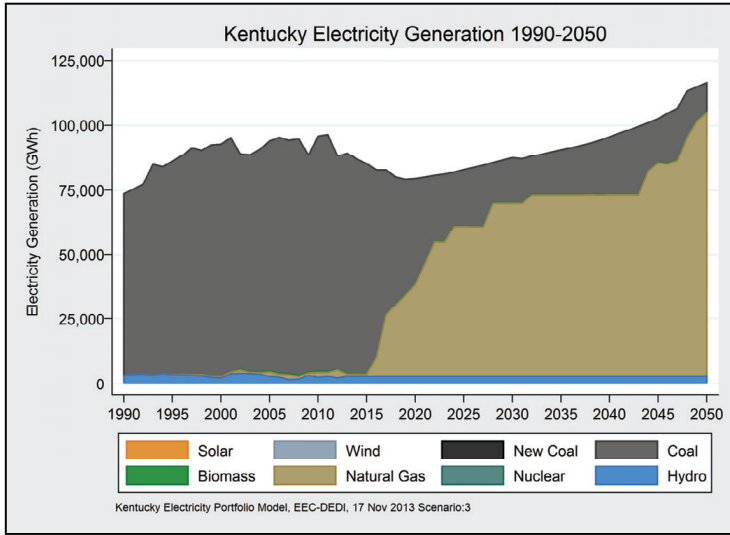
Coal 23%, Natural Gas 74%, Hydro, Biomass

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:28

Kentucky Fossil Fuel Consumption for Electricity Generation, 1960-2100

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28

Kentucky Coal Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28

Kentucky Natural Gas Consumption for Electricity Generation, 1960-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 28

Kentucky Gross Domestic Product, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014 Scenario:28

Kentucky Total Employment, 1970-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:28

Generation Portfolio 1, 1990-2050

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:2

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:3

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:5

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:6

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:7

Generation Portfolio 2, 1990-2050

Kentucky Electricity Generation 1990-2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:8

Kentucky Electricity Generation 1990-2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:9

Kentucky Electricity Generation 1990-2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:10

Kentucky Electricity Generation 1990-2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:12

Kentucky Electricity Generation 1990-2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:13

Kentucky Electricity Generation 1990-2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:14

Generation Portfolio 3, 1990-2050

Kentucky Electricity Generation 1990-2050

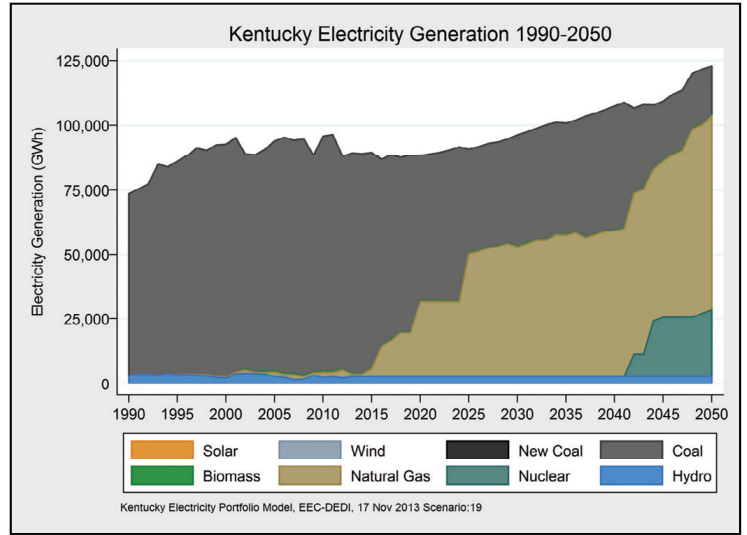Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:15

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:16

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:17

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:19

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:20

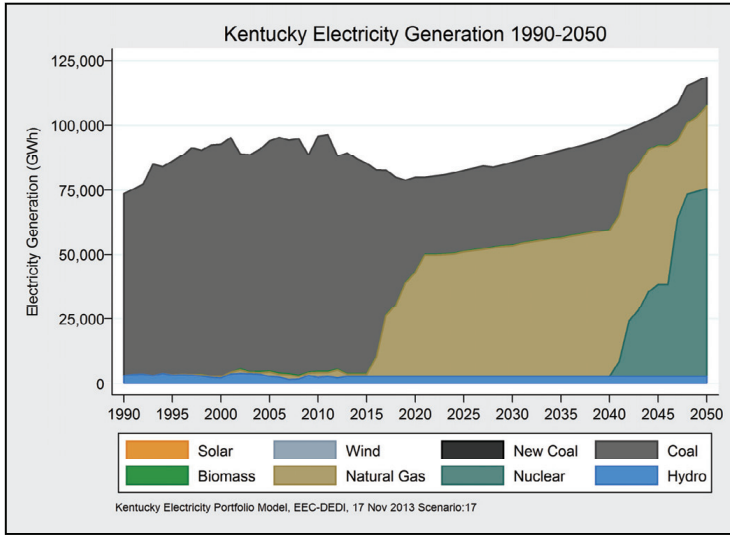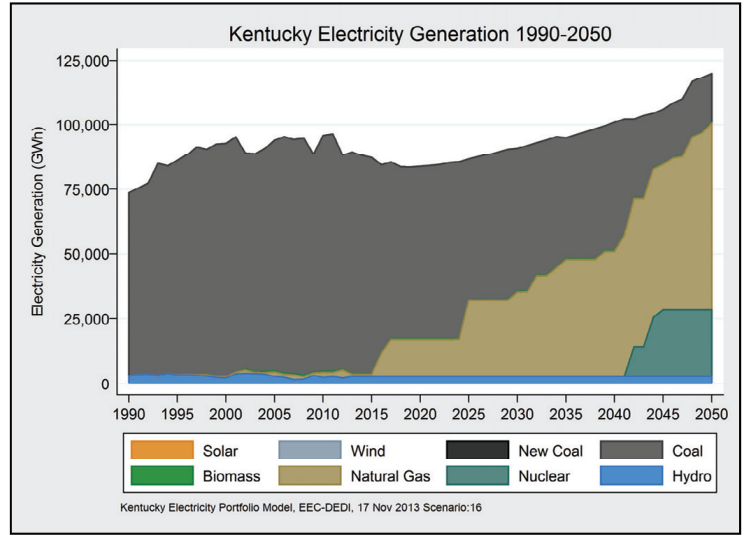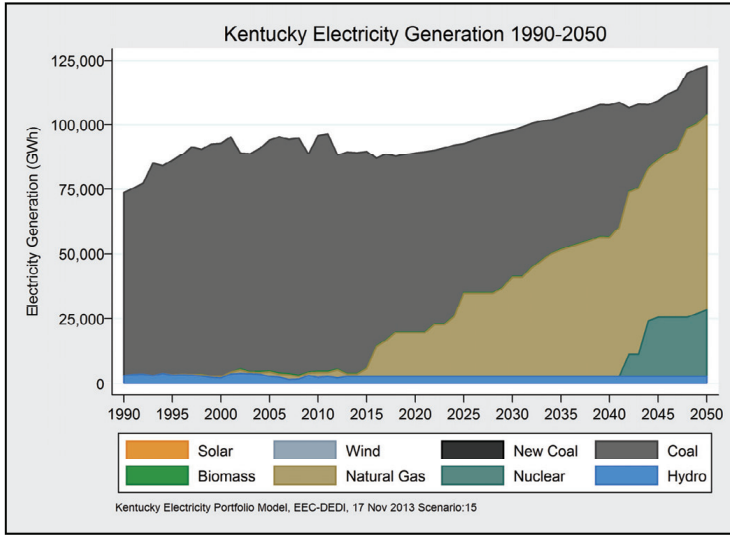Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:21

Generation Portfolio 4, 1990-2050

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:22

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:23

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:24

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:26

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:27

Kentucky Electricity Generation 1990-2050

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:28

Generation Portfolio 1, 1990-2100

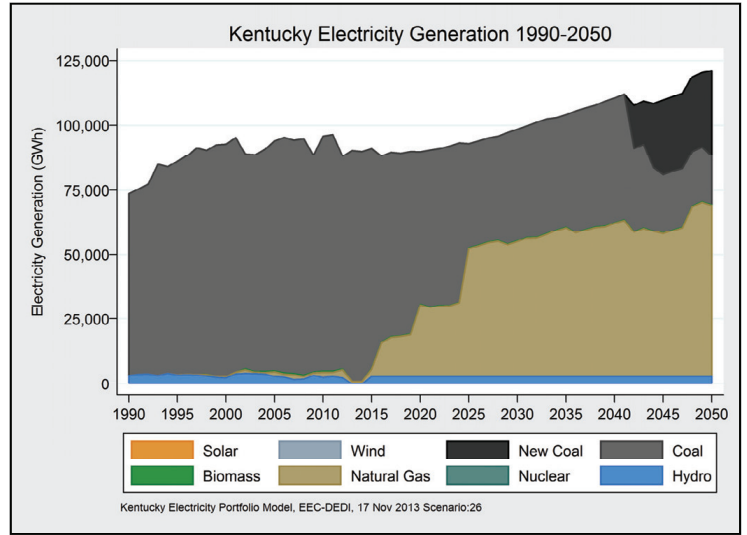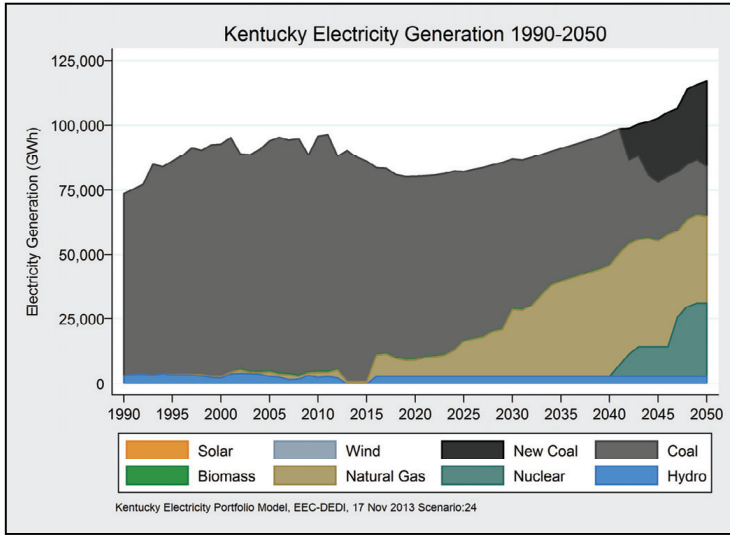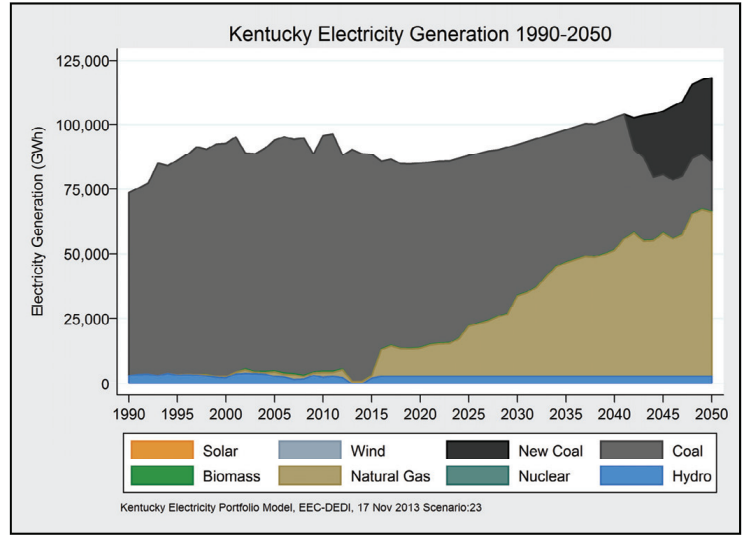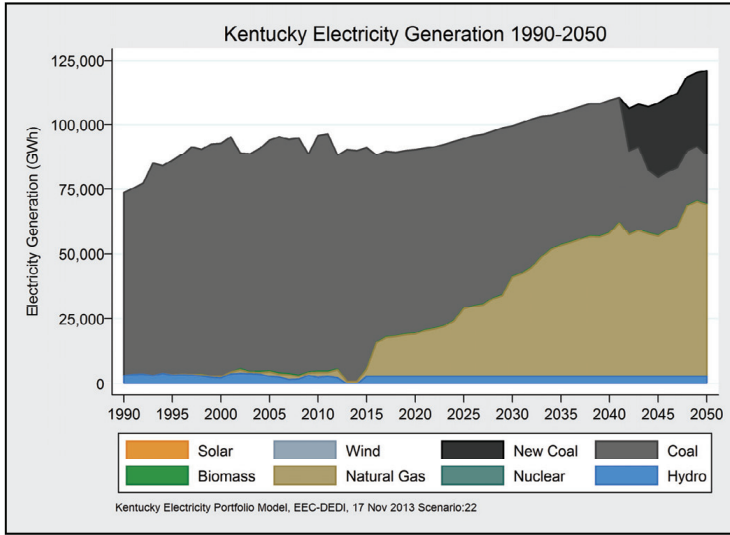Kentucky Electricity Generation 1990-2100

Scenario: 1

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation 1990-2100

Scenario: 2

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:2

Kentucky Electricity Generation 1990-2100

Scenario: 3

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:3

Kentucky Electricity Generation 1990-2100

Scenario: 5

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:5

Kentucky Electricity Generation 1990-2100

Scenario: 6

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:6

Kentucky Electricity Generation 1990-2100

Scenario: 7

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:7

Generation Portfolio 2, 1990-2100

Kentucky Electricity Generation 1990-2100 — Scenario: 8
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:8

Kentucky Electricity Generation 1990-2100 — Scenario: 9
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:9

Kentucky Electricity Generation 1990-2100 — Scenario: 10
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:10

Kentucky Electricity Generation 1990-2100 — Scenario: 12
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:12

Kentucky Electricity Generation 1990-2100 — Scenario: 13
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:13

Kentucky Electricity Generation 1990-2100 — Scenario: 14
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:14

Generation Portfolio 3, 1990-2100
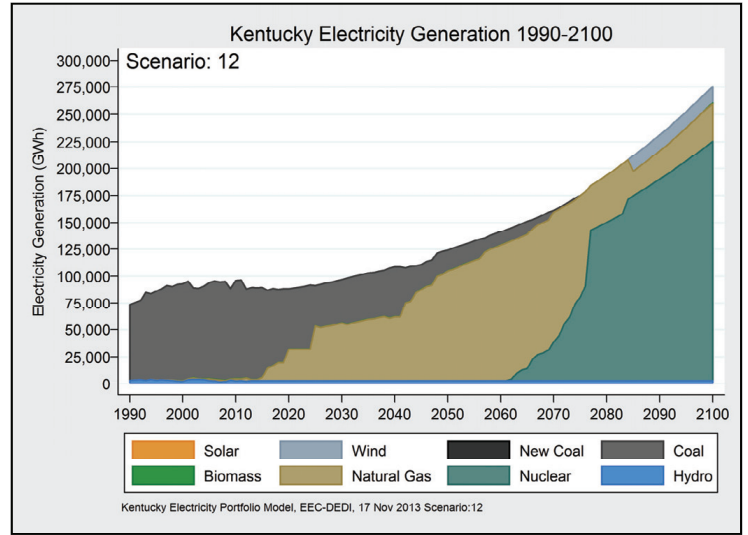

Kentucky Electricity Generation 1990-2100 — Scenario: 15
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:15

Kentucky Electricity Generation 1990-2100 — Scenario: 16
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:16

Kentucky Electricity Generation 1990-2100 — Scenario: 17
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:17

Kentucky Electricity Generation 1990-2100 — Scenario: 19
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:19

Kentucky Electricity Generation 1990-2100 — Scenario: 20
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:20

Kentucky Electricity Generation 1990-2100 — Scenario: 21
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:21
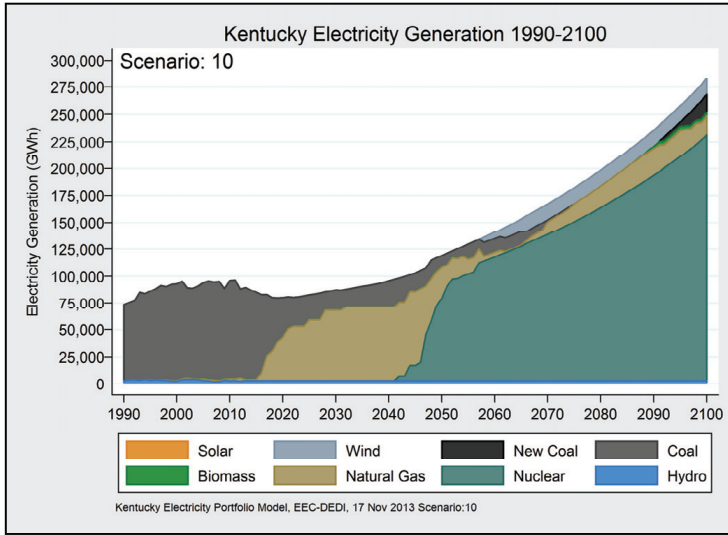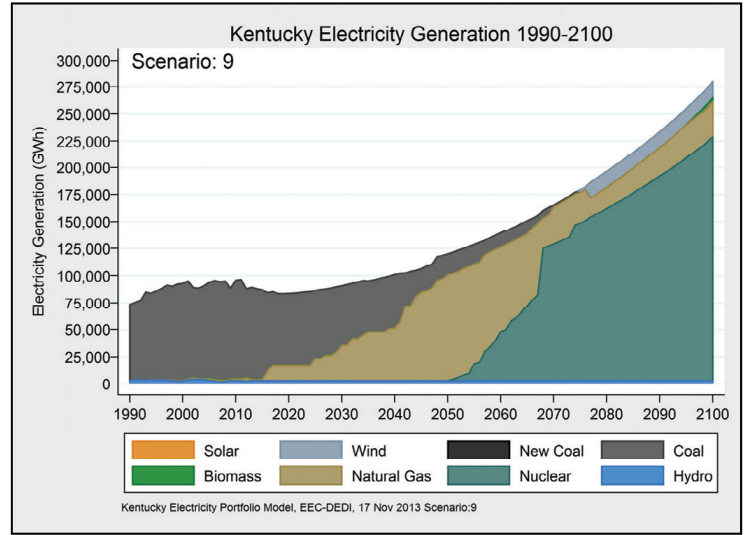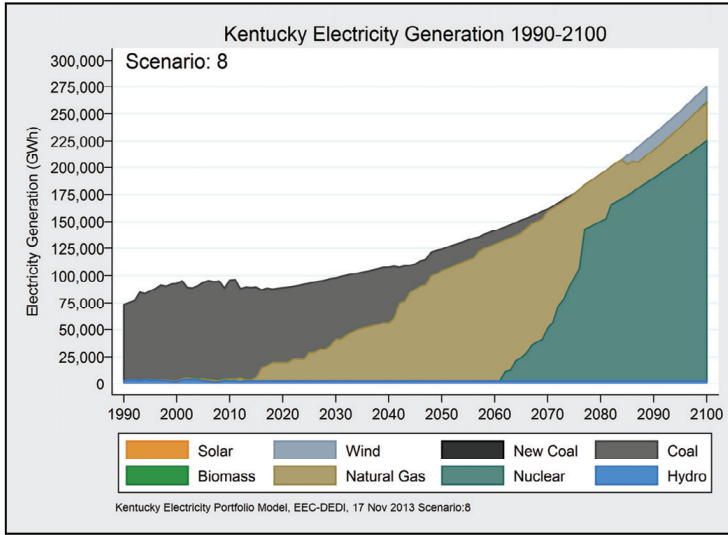
Legend: Solar, Wind, New Coal, Coal, Biomass, Natural Gas, Nuclear, Hydro

Generation Portfolio 4, 1990-2100

Kentucky Electricity Generation 1990-2100 — Scenario: 22

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:22

Kentucky Electricity Generation 1990-2100 — Scenario: 23

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:23

Kentucky Electricity Generation 1990-2100 — Scenario: 24

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:24

Kentucky Electricity Generation 1990-2100 — Scenario: 26

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:26

Kentucky Electricity Generation 1990-2100 — Scenario: 27

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:27

Kentucky Electricity Generation 1990-2100 — Scenario: 28

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:28

Portfolios & Prices, 1995-2050

Kentucky Real Electricity Prices, 1995-2050
Nuclear Banned Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Real Electricity Prices, 1995-2050
Nuclear Allowed Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Real Electricity Prices, 1995-2050
Balanced Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Real Electricity Prices, 1995-2050
Coal Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Portfolios & CO$_2$ Emissions, 1995-2050

Kentucky Carbon Dioxide Emissions from Electricity Generation, 1995-2050
Nuclear Banned Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Carbon Dioxide Emissions from Electricity Generation, 1995-2050
Nuclear Allowed Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Carbon Dioxide Emissions from Electricity Generation, 1995-2050
Balanced Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Carbon Dioxide Emissions from Electricity Generation, 1995-2050
Coal Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Portfolios & SO₂ Emissions, 1995-2050

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050 — Nuclear Banned Portfolio

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2100 — Nuclear Allowed Portfolio

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050 — Balanced Portfolio

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050 — Coal Portfolio

Portfolios & NO$_X$ Emissions, 1995-2050

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Nuclear Banned Portfolio

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Nuclear Allowed Portfolio

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Balanced Portfolio

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Coal Portfolio

Portfolios & Kentucky GDP, 1970-2050

Portfolios & Employment, 1970-2050

Kentucky Employment Forecast, 1970-2050
Nuclear Banned Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 11 Nov 2013

Kentucky Employment Forecast, 1970-2050
Nuclear Allowed Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 11 Nov 2013

Kentucky Employment Forecast, 1970-2050
Balanced Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 11 Nov 2013

Kentucky Employment Forecast, 1970-2050
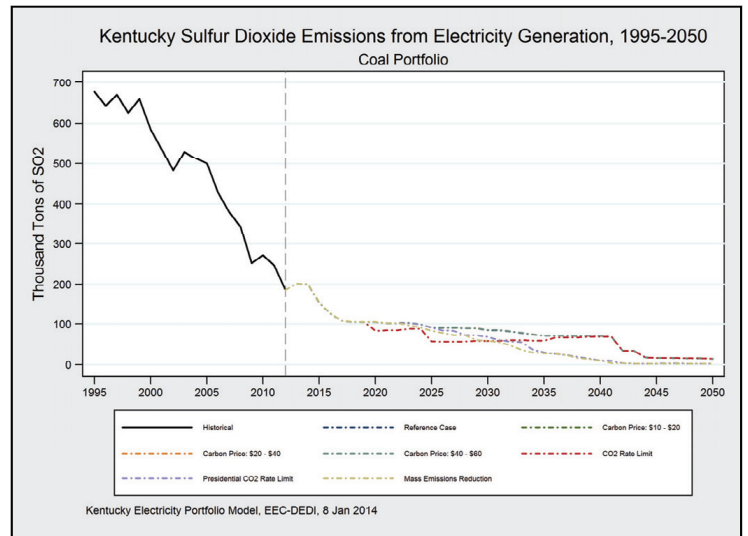Coal Portfolio

Kentucky Electricity Portfolio Model, EEC-DEDI, 11 Nov 2013

Federal Policy Options & Prices, 1995-2050

Kentucky Real Electricity Prices, 1995-2050
Reference Case

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Real Electricity Prices, 1995-2050
Carbon Price: $10 - $20

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Real Electricity Prices, 1995-2050
Carbon Price: $20 - $40

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Real Electricity Prices, 1995-2050
CO2 Rate Limit

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Real Electricity Prices, 1995-2050
CO2 Rate Limit 5-Year Stay

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Real Electricity Prices, 1995-2050
Mass Emissions Reduction

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Federal Policy Options & CO_2 Emissions, 1995-2050

Federal Policy Options & SO₂ Emissions, 1995-2050

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
Reference Case

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
Carbon Price: $10 - $20

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
Carbon Price: $20 - $40

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
CO2 Rate Limit

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
CO2 Rate Limit 5-Year Stay

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
Mass Emissions Reduction

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Federal Policy Options & NO$_X$ Emissions, 1995-2050

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Reference Case

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Carbon Price: $10 - $20

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Carbon Price: $20 - $40

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
CO2 Rate Limit

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Sulfur Dioxide Emissions from Electricity Generation, 1995-2050
CO2 Rate Limit 5-Year Stay

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Nitrous Oxide Emissions from Electricity Generation, 1995-2050
Mass Emissions Reduction

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Federal Policy Options & GDP, 1970-2050

Kentucky Gross Domestic Product, 1970-2050
Reference Case

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Gross Domestic Product, 1970-2050
Carbon Price: $10 - $20

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Gross Domestic Product, 1970-2050
Carbon Price: $20 - $40

Kentucky Electricity Portfolio Model, EEC-DEDI, 8 Jan 2014

Kentucky Gross Domestic Product, 1970-2050
CO2 Rate Limit

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Gross Domestic Product, 1970-2050
CO2 Rate Limit 5-Year Stay

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Kentucky Gross Domestic Product, 1970-2050
Mass Emissions Reduction

Kentucky Electricity Portfolio Model, EEC-DEDI, 18 Nov 2013

Federal Policy Options & Employment, 1970-2050

Kentucky Employment Forecast, 1970-2050
Reference Case

Kentucky Employment Forecast, 1970-2050
Carbon Price: $10 - $20

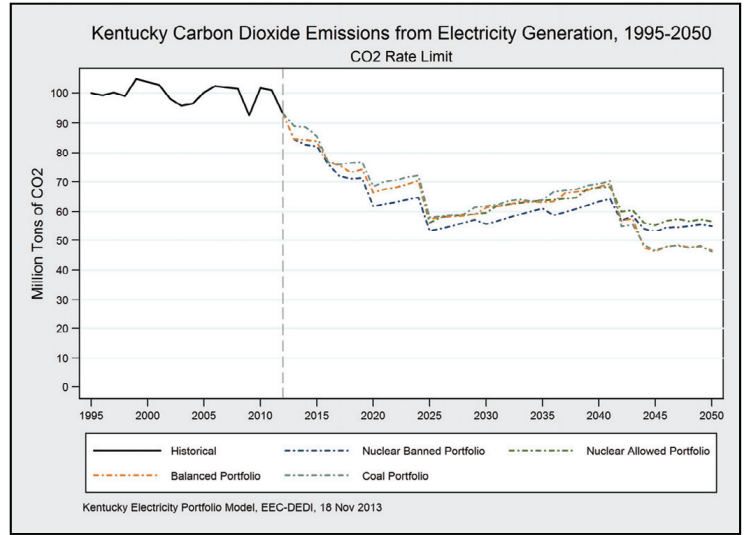Kentucky Employment Forecast, 1970-2050
Carbon Price: $20 - $40

Kentucky Employment Forecast, 1970-2050
CO2 Rate Limit

Kentucky Employment Forecast, 1970-2050
CO2 Rate Limit 5-Year Stay

Kentucky Employment Forecast, 1970-2050
Mass Emissions Reduction

Basic Input Assumptions

Kentucky Population Forecast: 1960-2100

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Kentucky Personal Income Forecast: 1960-2100

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Kentucky Temperature Forecast, 1895-2100

Reference Case = Historical Means

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model v.2.0

Kentucky Population with a Bachelor's Degree or Higher, 1940-2100

Kentucky Electricity Portfolio Model, EEC-DEDI,

Kentucky Fossil Fuel Price Forecast, 1970-2100
Based on the EIA-AEO-2013 Reference Case

Scenarios 1 to 28 Only—Other Cases May Vary

Natural Gas   Coal

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Electricity demand, generation, costs, and emissions are estimated as a function of basic socioeconomic, weather, and fuel price factors. Although these input factors are subject to change, in this specific reference simulation, Kentucky's future population, per capita personal income, educational attainment, and weather are assumed to be consistent with how they have been historically. For fossil fuel prices, the United States Department of Energy, Energy Information Administration, Annual Energy Outlook 2013 Reference Case price forecasts were assumed. Changes to any of these factors could significantly change the model results. Accordingly, EEC staff have performed various sensitivity analysis using broader ranges of plausible values for these factors, which due to space limitations have not been discussed here. The exact coefficients for each model are provided on subsequent pages.

Technology Cost Assumptions

Kentucky Costs of Electricity Generation by Technology, 2030
Low Carbon Technologies Only (<=1.1lbs per kWh)

Technology	$ per kWh
Biomass Combined Cycle	.211
20 MW Photovoltaic	.197
150 MW Photovoltaic	.182
Single Unit IGCC with CCS	.137
Single Unit Advanced SCPC with CCS	.122
Biomass Bubbling Fluidized Bed	.118
Dual Unit Advanced PC with CCS	.114
USCPC with CCS	.111
USC with Oxy Combustion CCS	.105
Kentucky Wind	.098
Imported Wind	.095
Dual Unit Nuclear Reactor	.089
Small Modular Nuclear Reactors	.083
Advanced NGCC with CCS	.078
Combined Heat & Power	.069
Conventional Hydroelectric	.065
Natural Gas Retrofit of SC PC Boiler	.061
Municipal Solid Waste Combustion	.056
Natural Gas Combined Cycle	.055
Advanced NGCC	.053
Municipal Solid Waste Gasification	.051

Detailed Generating Technology & Cost Parameters on Page C.90

$ per kWh

Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

Annual Costs of Electricity Generation by Fuel and Technology, 2015-2100

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Annual Costs of Electricity Generation by Fuel and Technology, 2015-2100
Low Carbon Technologies Only (<=1.1lbs per kWh)

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model
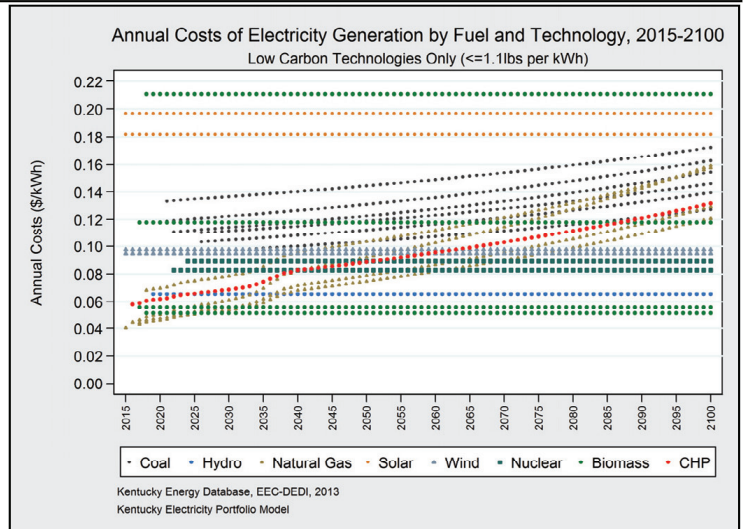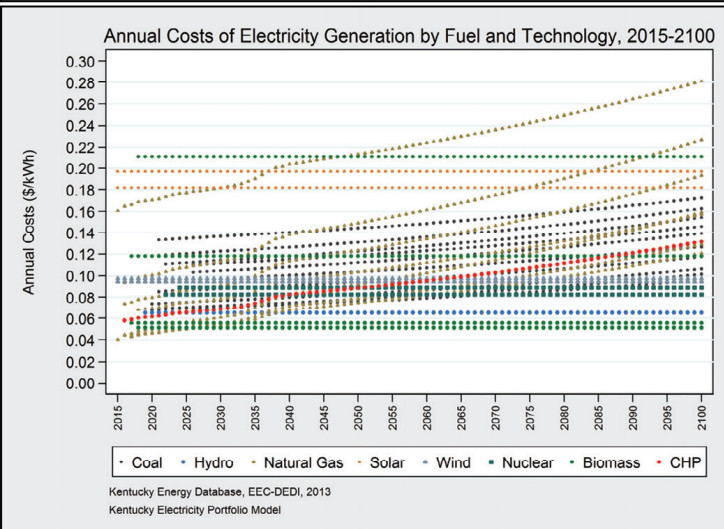
Plots illustrate how electricity generation costs change over time in this simulation.

Detailed Generating Technology & Cost Parameters

Technology	2030 Cost ($ per kWh)	Primary Fuel	Name-plate (MW)	Capacity Factor	$ / kW	$ / kW-yr	$ / MWh	System Life	Heat Rate	Lead Time (Years)	CO$_2$ (lb./MWh)	NO$_x$ (lb./MWh)	SO$_2$ (lb./MWh)
Biomass Combined Cycle	$0.21079	Biomass	20	0.83	8180	356.07	17.49	30	12350	5	0	0.09	0
20 MW Photovoltaic	$0.19691	Solar	20	0.25	4183	27.75	0	30	0	2	0	0.01	0
150 MW Photovoltaic	$0.18186	Solar	150	0.25	3873	24.69	0	30	0	2	0	0.01	0
Fuel Cells	$0.18170	Natural Gas	10	0.9	7108	0	43	30	9500	2	1235	0.1235	0.00124
Single Unit IGCC with CCS	$0.13668	Coal	520	0.83	6599	72.83	8.45	30	10700	7.5	220	0.08025	0.1605
Single Unit Advanced SCPC with CCS	$0.12244	Coal	650	0.85	5227	80.53	9.51	30	12000	7.5	247	0.72	0.24
Biomass Bubbling Fluidized Bed	$0.11795	Biomass	50	0.78	4114	105.63	5.26	30	13500	3.5	0	1.08	0
Dual Unit Advanced PC with CCS	$0.11403	Coal	1300	0.85	4724	66.43	9.51	30	12000	9	247	0.72	0.24
Combustion Turbine	$0.11308	Natural Gas	85	0.3	973	7.34	15.45	30	10850	3	1269	0.3255	0.01085
USCPC with CCS	$0.11145	Coal	550	0.85	5130	47.3	9.2	30	10270	12.5	205	0.7189	0.00001
USC with Oxy Combustion CCS	$0.10469	Coal	550	0.85	4770	45.55	7.1	30	10353	12.5	135	0.72471	0.21741
Single Unit IGCC	$0.09752	Coal	600	0.85	4400	62.25	7.22	30	8700	6.5	1792	0.065	0.2175
Imported Wind	$0.09468	Wind	30	0.34	2513	39.55	0	30	0	2	0	0.01	0
Advanced Combustion Turbine	$0.09100	Natural Gas	210	0.3	676	7.04	10.37	30	9750	3	1141	0.2925	0.00975
Dual Unit Nuclear Reactor	$0.08915	Uranium	2234	0.9	5530	93.28	2.14	30	10452	11	0	0.01	0
Dual Unit IGCC	$0.08809	Coal	1200	0.85	3784	51.39	7.22	30	8700	8	1792	0.065	0.2175
Small Modular Nuclear Reactors	$0.08267	Uranium	180	0.9	5000	93.28	2.14	30	10452	9	0	0.01	0
Advanced NGCC with CCS	$0.07846	Natural Gas	340	0.87	2095	31.79	6.78	30	7525	5	90	0.05644	0.00753
Single Unit Advanced SCPC	$0.07683	Coal	650	0.85	3246	37.8	4.47	30	8800	6.5	1813	0.528	0.88
USCPC with 20% Biomass	$0.07345	Cofire	650	0.85	3147	31.18	4.47	30	8800	6.5	1496	0.53	0.88
Dual Unit Advanced SCPC	$0.07190	Coal	1300	0.85	2934	31.18	4.47	30	8800	8	1813	0.528	0.88
Ultra-Supercritical PC	$0.07060	Coal	550	0.85	3000	34.16	5.2	30	7654	6.5	1554	0.53578	0.65824
Combined Heat & Power	$0.06864	Natural Gas	10	0.87	2278	7.5	6.1	30	6007	2.5	364	0.1802	0.006
Conventional Hydroelectric	$0.06528	Hydro	10	0.52	2936	14.13	0	30	0	6	0	0	0
Natural Gas Retrofit of SC PC Boiler	$0.06101	Natural Gas	250	0.87	250	25	3.6	30	9355	2	1095	0.28065	0
Municipal Solid Waste Combustion	$0.05587	LFG	20	0.85	4001	97.1	-9	30	18000	3.5	0	4.86	1.26
Natural Gas Combined Cycle	$0.05534	Natural Gas	620	0.87	917	13.17	3.6	30	7050	3.5	825	0.05288	0.00705
Advanced NGCC	$0.05327	Natural Gas	400	0.87	1023	15.37	3.27	30	6430	3.5	752	0.04823	0.0064
Municipal Solid Waste Gasification	$0.05118	LFG	27	0.85	3784	90.5	-10	30	13600	5	0	3.67	0.952
USCPC with 20% Biomass - Retrofit	$0.03230	Cofire	650	0.85	213	1.06	0.45	30	10600	2	1802	0.64	1.06

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Design Plan

Kentucky Electricity Portfolio Model v.2.0 Design Plan

Historical Data Inputs, 1895-2013

Socioeconomic Factors
Gross Domestic Product (GDP)
Educational Achievement
Population
Employment
Public Health

Fuel Prices
Natural Gas Prices
Coal Prices
Petroleum Prices

Weather Data
Temperature
Rainfall
Cooling Degree Days
Heating Degree Days

Policy Options
Portfolio Standards (Min / Max)
Portfolio CO2e Limits
Portfolio CO2, SO2, NOX, Pricing
Unit-Level Emission Standards
    CO2, SO2, HG, NOX, PM
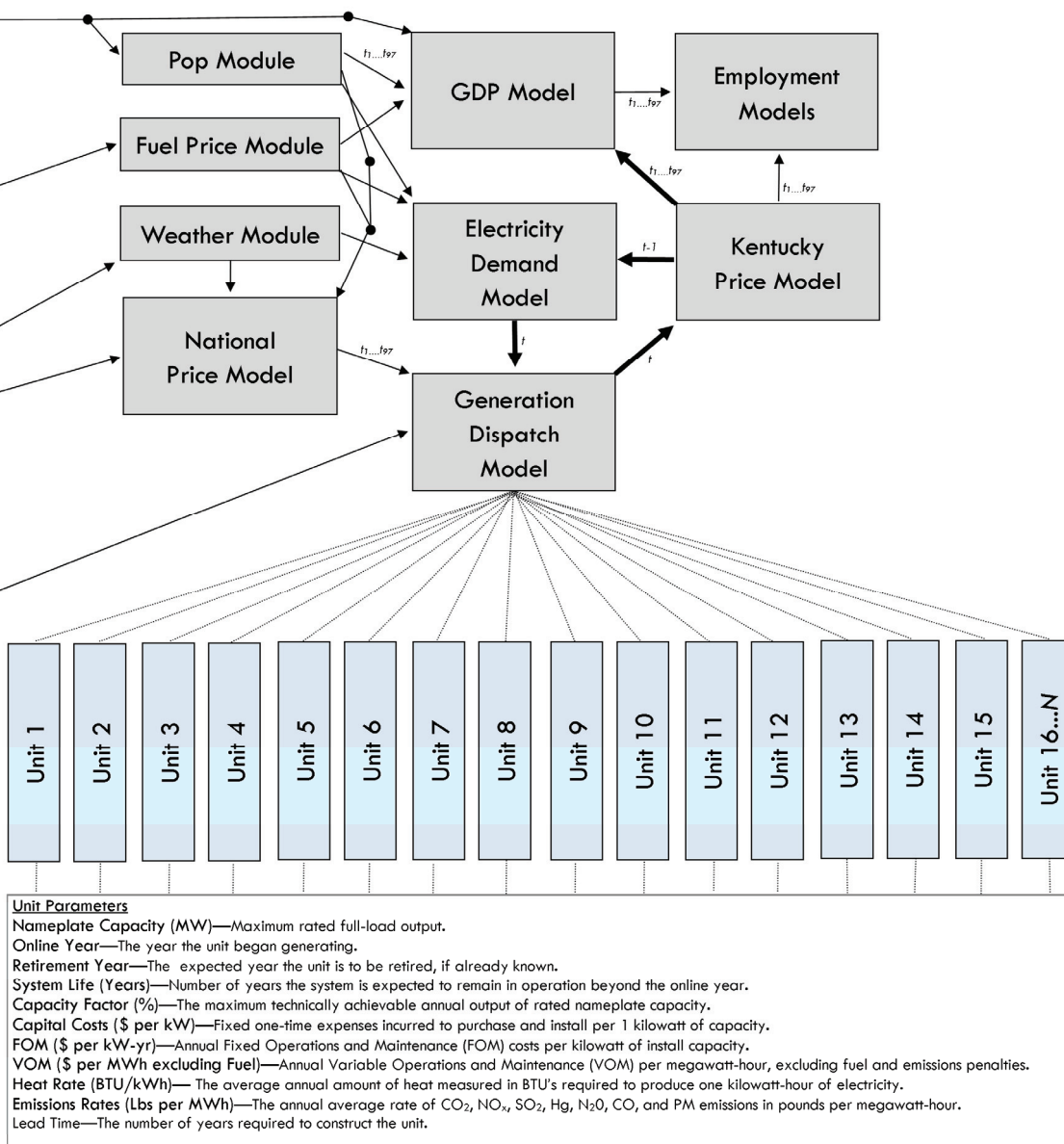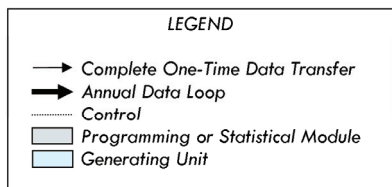
Forecast Outputs, 2013-2100

Endogenous Electric Power Factors
Electricity Consumption by Sector
Electricity Prices by Sector
Electricity Expenditures
Electricity Generation by Unit
Electric Power Emissions
Natural Gas Consumption
Coal Consumption

Endogenous Socioeconomic Factors
Gross Domestic Product (GDP)
Per Capita Personal Income
Manufacturing Employment
Retail Employment
Hospitality Employment
Electric Power Employment
Coal Mining Employment
Other Employment

Exogenous Independent Factors
Temperature
Cooling Degree Days
Heating Degree Days
Rainfall
Population
Educational Attainment
Natural Gas Prices
Coal Prices

Modules: Pop Module, Fuel Price Module, Weather Module, National Price Model, GDP Model, Electricity Demand Model, Employment Models, Kentucky Price Model, Generation Dispatch Model

Generating Units: Unit 1, Unit 2, Unit 3, Unit 4, Unit 5, Unit 6, Unit 7, Unit 8, Unit 9, Unit 10, Unit 11, Unit 12, Unit 13, Unit 14, Unit 15, Unit 16...N

LEGEND
→ Complete One-Time Data Transfer
➔ Annual Data Loop
⋯⋯ Control
▦ Programming or Statistical Module
▨ Generating Unit

Unit Parameters
Nameplate Capacity (MW)—Maximum rated full-load output.
Online Year—The year the unit began generating.
Retirement Year—The expected year the unit is to be retired, if already known.
System Life (Years)—Number of years the system is expected to remain in operation beyond the online year.
Capacity Factor (%)—The maximum technically achievable annual output of rated nameplate capacity.
Capital Costs ($ per kW)—Fixed one-time expenses incurred to purchase and install per 1 kilowatt of capacity.
FOM ($ per kW-yr)—Annual Fixed Operations and Maintenance (FOM) costs per kilowatt of install capacity.
VOM ($ per MWh excluding Fuel)—Annual Variable Operations and Maintenance (VOM) per megawatt-hour, excluding fuel and emissions penalties.
Heat Rate (BTU/kWh)— The average annual amount of heat measured in BTU's required to produce one kilowatt-hour of electricity.
Emissions Rates (Lbs per MWh)—The annual average rate of CO_2, NO_x, SO_2, Hg, N_2O, CO, and PM emissions in pounds per megawatt-hour.
Lead Time—The number of years required to construct the unit.

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Electricity Demand Model

Future electricity consumption is forecasted dynamically as a function of electricity prices, temperature, population, per capita personal income, substitute fuel prices, and time. Separate forecasts are developed for each economic sector: commercial, industrial, and residential. In addition to estimating the electricity that would be required based on weather and socioeconomic factors, this model also estimates electricity Price Elasticity of Demand (PED) coefficients, which are the percentage change in the quantity of electricity demanded given a percentage change in the price of electricity, ceteris paribus. Informally, elasticity coefficients can be understood as estimates of consumer sensitivity and responsiveness to changes in electricity prices, holding all other factors constant. Elasticities are also bidirectional, such that a decrease in electricity prices would increase demand. Logically, electricity price elasticity of demand coefficients are understood to be negative as demand should have an inverse relationship with price, as implied by the Law of Demand. These PED coefficients are the primary reason for differing levels of demand and generation requirements between scenarios.

Unlike other historical metrics that can be extrapolated to forecast electricity demand, such as population, income, or climate conditions, consumer sensitivity is unique in that it cannot be directly measured. Electricity price elasticity coefficients must, therefore, be estimated using statistical analysis techniques. Furthermore, consumer behavior in response to Kentucky's low and stable electricity prices offer an insufficient sample for modeling future responsiveness to significant price increases. More simply stated, that Kentucky consumers have never experienced the substantially higher electricity prices observed in other states, or price volatility caused by exogenous shocks to fuel prices, is certainly not to say that Kentucky consumers would not respond in a similar fashion were they to experience the same price stimuli. Given that the anticipated trend for electricity prices is upward, towards the national average; this model leveraged a national database of electricity consumption and prices across the United States to estimate electricity price elasticity of demand coefficients. Specifically, the price elasticity coefficients in this model imply that a 10% increase in the real price of electricity in Kentucky, and holding all other included factors constant, commercial consumers would reduce electricity consumption by between 3.1%, industrial consumers by 4.1%, and residential consumers by 5.3%

Consumer responsiveness to increases in electricity prices can take many forms. Businesses and residents may implement energy efficiency measures that are designed to reduce the amount of energy that is wasted in production or climate control; thus, lowering their electricity consumption and expenditures. As technology continues to develop, consumer responsiveness will also materialize as increased adoption of distributed electricity generation systems, namely small-scale renewable resources such as geothermal, biomass, wind, and solar power. As the cost of these systems approach parity with retail electricity prices, consumers can be expected to increasingly seek to generate their own electricity. Large electricity consumers, such as manufacturers, could also substitute electricity with alternative energy sources, for example natural gas, provided that pipeline access is economically viable. Electricity-intensive manufacturing operations may also choose to relocate to areas where electricity costs will be lower or go out of business entirely, which will negatively affect employment and economic growth. The responsiveness of employment and Gross Domestic Product (GDP) have both been modeled separately.

Regardless of the form it takes, from the perspective of electricity generation requirements, energy efficiency measures, energy substitutes, distributed electricity generation from renewable resources, and consumers leaving the service territory are types of electricity price elasticity of demand abating future electricity demand growth rates. Consumer responsiveness has been estimated here in order to model sufficient electricity generation capacity to service future electricity demand while also avoiding the risk of modeling more capacity than will be required.

The mixed fixed and random coefficient model to forecast electricity consumption by sector and state can be given by,

$$Y_{it} = \beta_0 + \sum_{j=1}^{k-1} \beta_j X_{jit} + \beta_{1i} X_{1it} + \alpha_i + \varepsilon_{it}$$

Where i and t index states and years, such that y_{it} is the dependent variable of interest, electricity consumption by economic sector, in state i in year t, β_0 is the constant y intercept across all states, X is a k x 1 vector of explanatory variables, $\beta_j X_{jit}$ is the product of the observation for each independent variable j through k for state i in year t and the coefficient of X, $\beta_{1i} X_{1it}$ is the product of time invariant PED and electricity price for different states, k is the total number of included independent variables, α_i is the time-invariant fixed effect for state i, and ε_{it} are the residuals, and where $\varepsilon_{it} \sim N(0, \sigma^2)$, or are approximately normally distributed with a mean of zero. (Hsiao, Cheng et al. 1989)

The Mixed Fixed and Random Coefficient Model, referred to here as an RCM, in addition to estimating a time-invariant fixed effect (α_i) for electricity demand for each state, also estimates the degree of homogeneity and heterogeneity of coefficients between cross sectional units. Such that, there is a certain portion of price sensitivity common to all states (β_1) and another that is allowed to vary from state to state (β_{1i}), while the remainder of the coefficients for the control variable in the model ($\beta_2... \beta_k$) remain homogeneous. This model is, thus, a mixed model with both fixed and random coefficients as well as fixed effects. By allowing both β_{1i} and α_i to vary between units, the resulting historical electricity demand forecasts are significantly improved versus the inclusion of α_i alone.

The complete demand model for each sector is provided below. All variables were transformed into their natural logarithms such that their coefficients below may be simply interpreted as elasticities.

Logged Variables	Commercial	Industrial	Residential
Real Electricity Price	-0.211***	-0.321***	-0.297***
	-0.05	-0.06	-0.03
Cooling Degree Days	-0.003	-0.052*	0.036***
	-0.02	-0.03	-0.01
Heating Degree Days	-0.090*	-0.077	0.084***
	-0.04	-0.06	-0.02
Population	0.522***	0.886***	0.821***
	-0.03	-0.04	-0.02
Year	38.911***	-1.932	20.903***
	-2.16	-3.22	-1.33
Real Natural Gas Price	0.111***	0.169***	0.183***
	-0.01	-0.02	-0.01
Real Per Capita Personal Income	0.372***	0.11	0.160***
	-0.06	-0.09	-0.04
National Constant	-296.951***	10.906	-163.982***
	-15.67	-23.42	-9.69
Kentucky Fixed Effect	2.00E-01	2.40E-13	1.08E+00

Standard Errors in Parentheses
Asterisk Denotes Statistical Significance at the Following Levels: * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Demand Model Validation

Observed Commercial Demand Against Predicted Commercial Demand, 1970-2010
Varying Coefficients Model
Kentucky Energy Database, EEC-DEDI, 2012

Q-Q Plot of Residuals in Commercial Electricity Demand, 1970-2010
Varying Coefficients Model
Kentucky Energy Database, EEC-DEDI, 2012

Observed Industrial Demand Against Predicted Industrial Demand, 1970-2010
Varying Coefficients Model
Kentucky Energy Database, EEC-DEDI, 2012

Q-Q Plot of Residuals in Industrial Electricity Demand, 1970-2010
Varying Coefficients Model
Kentucky Energy Database, EEC-DEDI, 2012

Observed Residential Demand Against Predicted Residential Demand, 1970-2010
Varying Coefficients Model
Kentucky Energy Database, EEC-DEDI, 2012

Q-Q Plot of Residuals in Residential Electricity Demand, 1970-2010
Varying Coefficients Model
Kentucky Energy Database, EEC-DEDI, 2012

Dispatch Model

The purpose of the dispatch model is to simulate building and operating the least-cost electricity generating portfolio that complies with all environmental regulations and portfolio standards. Users can specify carbon dioxide emissions standards for the entire generating portfolio by either setting a mass CO_2 emissions target or a maximum CO_2 emissions rate per megawatt-hour of electricity generated for each year 2013 to 2100. Unit-level emission rate standards can also be specified for CO_2, SO_2, NO_X, Hg, and particulate matter. Users may additionally set prices for emissions of CO_2, SO_2, NO_X, which are then factored into the variable costs of running each unit. Users can create categories of generating units, renewable for example, and designate which units or types of units are considered part of this category. A portfolio standard may then be specified in each year as a minimum generation requirement from a unit or category of units, as either a percentage of total generation or minimum megawatt-hours or both. Conversely, a portfolio standard can also be specified as a maximum allowable generation from a unit or category of units, as either a percentage of total generation or minimum megawatt-hours or both.
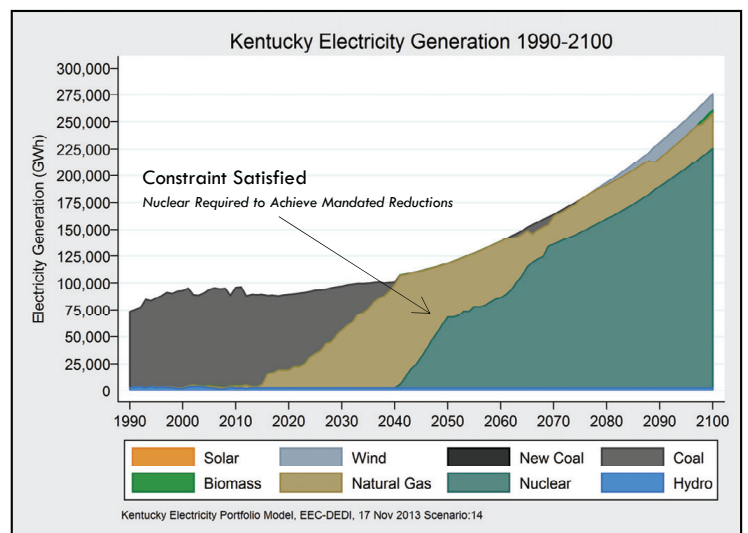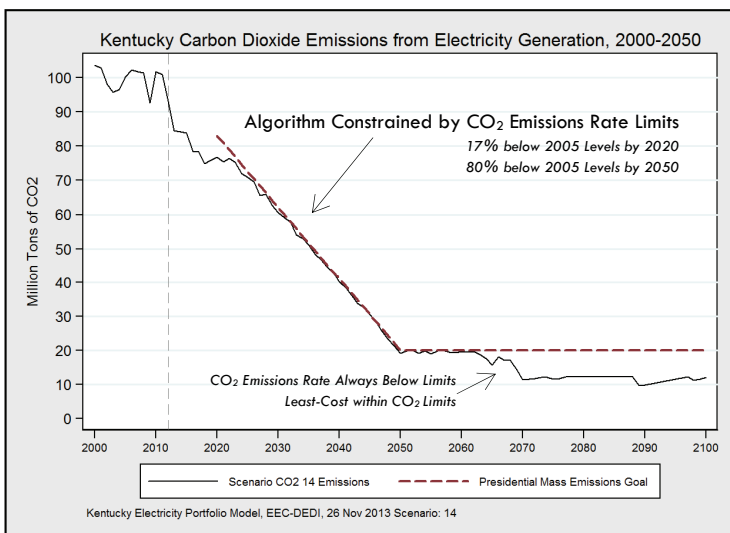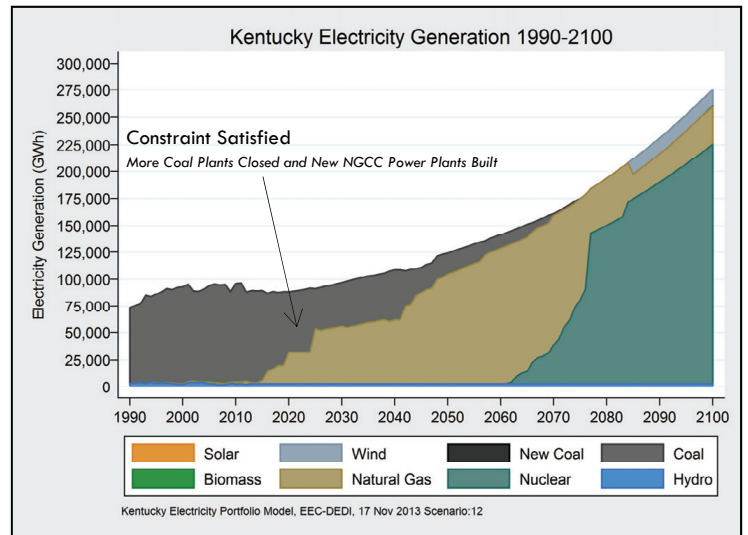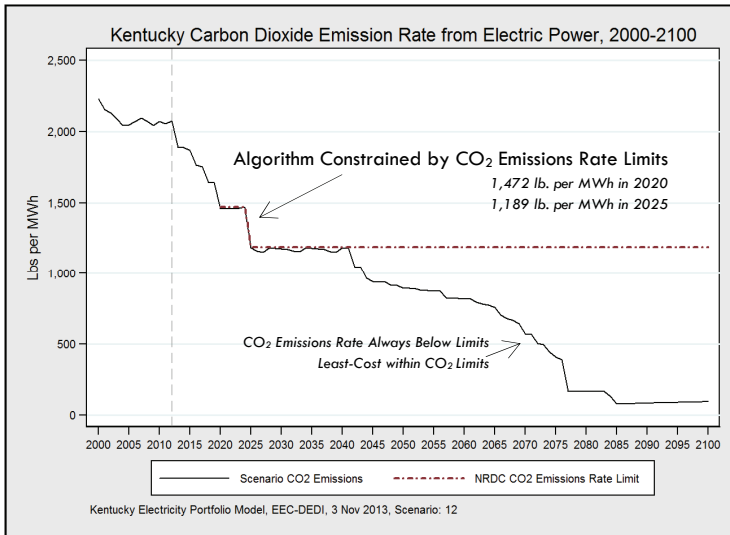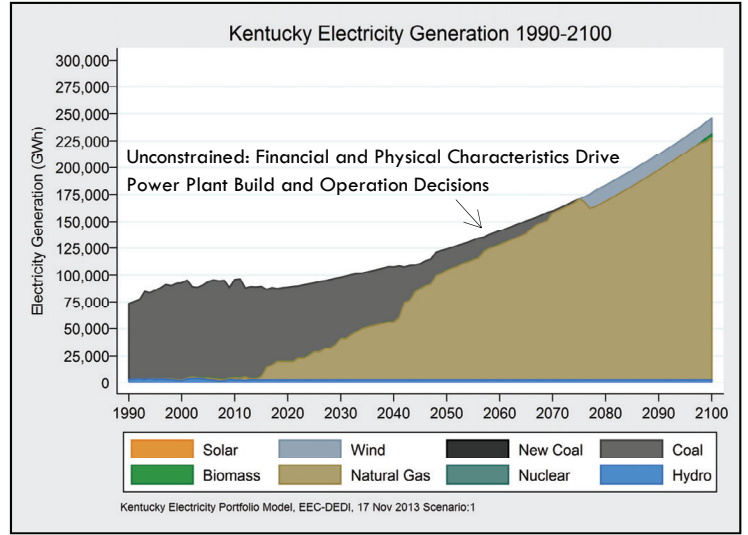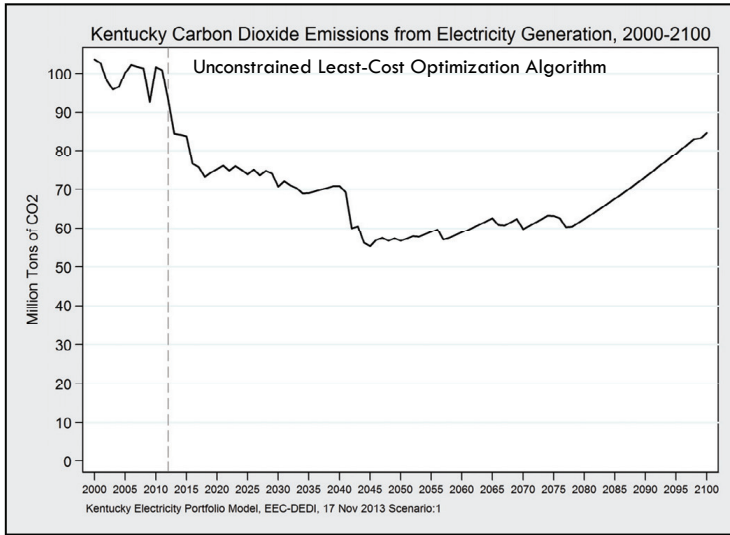
The dispatch model optimization algorithm will then identify the least-cost generating portfolio that complies with the user-specified criteria. In order to prevent a contradiction between constraints, for example an emissions target to reduce greenhouse gas emissions by 80% but with a portfolio standard dictating 95% of the generation portfolio must be coal-fired; constraints have been coded as hierarchical. Emissions targets and constraints are treated as paramount—the dispatch model will never violate environmental regulation regardless of the cost of compliance or potential socioeconomic implications. Portfolio standards are complied with, regardless of the cost of compliance, so long as they do not violate environmental regulation. To some extent, this hierarchical distinction is intended to mirror the dichotomy between federal environmental regulations and state portfolio standards, which cannot violate federal law.

The dispatch model utilizes two separate databases of generating units to determine how best to meet electricity demand. First, the existing unit database contains confidential financial and emissions data of power plants and generating units that are already operating or that will operate in the future. These confidential operations data were in most-cases provided voluntarily by the electric utilities that own the facility, or from state and federal agencies that regulate them. These commercial proprietary data cannot be shared and are not subject to Freedom of Information Act requests. Second, the potential unit database contains financial, operational, and emissions data for any number of types of generating units that could be built and operated in the future. The physical and cost characteristics of these units have been developed by the Pacific Northwest National Laboratory (PNNL) for the Kentucky Energy and Environment Cabinet and a table of these potential technologies is provided on page C.90.

Using an initial electricity demand forecast provided by the demand module, the dispatch model develops a plan for how best to meet electricity demand long-term given the variable parameters of the active scenario. This initial plan includes the timing and type of generation assets that should be built or retired and when, a process similar to an Integrated Resource Plan (IRP) developed by electric utilities. The dispatch model is impartial—it chooses between generating units and technologies based solely upon their distinguishing cost and emissions characteristics. Simply stated, the algorithm is only capable of preferring one technology over another if using that technology helps to reduce costs or emissions or because its use is required by law.

The model then simulates running and dispatching the individual electricity generating units forwards in time. Individual units, if selected by the dispatch optimization algorithm for their cost and emissions profiles, then produce electricity according to their generating potential, which is defined here as the product of the nameplate capacity, capacity factor, and time. Each unit consumes fuel according to its individual heat rate, and emits CO_2, SO_2, NO_X, Hg, and particulate matter according to the specified emissions coefficient for each in terms of lb. per megawatt-hour generated. The individual unit emissions are then aggregated to produce total portfolio mass and rate emissions. The capital costs of construction, as well as the fixed and variable operations and maintenance costs, including emissions fines if emissions prices were specified, are then incorporated into the total portfolio price of electricity delivered.

Constrained Optimization Algorithm

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2100

Unconstrained Least-Cost Optimization Algorithm

Million Tons of CO2

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation 1990-2100

Electricity Generation (GWh)

Unconstrained: Financial and Physical Characteristics Drive Power Plant Build and Operation Decisions

| Solar | Wind | New Coal | Coal |
| Biomass | Natural Gas | Nuclear | Hydro |

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Carbon Dioxide Emission Rate from Electric Power, 2000-2100

Lbs per MWh

Algorithm Constrained by CO₂ Emissions Rate Limits
1,472 lb. per MWh in 2020
1,189 lb. per MWh in 2025

CO₂ Emissions Rate Always Below Limits
Least-Cost within CO₂ Limits

Scenario CO2 Emissions   NRDC CO2 Emissions Rate Limit

Kentucky Electricity Portfolio Model, EEC-DEDI, 3 Nov 2013, Scenario: 12

Kentucky Electricity Generation 1990-2100

Electricity Generation (GWh)

Constraint Satisfied
More Coal Plants Closed and New NGCC Power Plants Built

| Solar | Wind | New Coal | Coal |
| Biomass | Natural Gas | Nuclear | Hydro |

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:12

Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050

Million Tons of CO2

Algorithm Constrained by CO₂ Emissions Rate Limits
17% below 2005 Levels by 2020
80% below 2005 Levels by 2050

CO₂ Emissions Rate Always Below Limits
Least-Cost within CO₂ Limits

Scenario CO2 14 Emissions   Presidential Mass Emissions Goal

Kentucky Electricity Portfolio Model, EEC-DEDI, 26 Nov 2013 Scenario: 14

Kentucky Electricity Generation 1990-2100

Electricity Generation (GWh)

Constraint Satisfied
Nuclear Required to Achieve Mandated Reductions

| Solar | Wind | New Coal | Coal |
| Biomass | Natural Gas | Nuclear | Hydro |

Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:14

The dispatch algorithm can autonomously choose to retire existing and future electricity generation units for one or more of the four following reasons. First, environmental retirements occur when a unit's individual emissions of a criteria pollutant violate the maximum allowable emissions rates or when shutting off the unit is the least-cost means of complying with a portfolio-wide CO_2 emissions standard. Second, economic retirements occur when the total costs of continuing to operate a generating asset are higher than the costs of abandoning the asset, including the capital invested into it, and building and operating a suitable replacement. An economic retirement can also occur if the unit is no longer needed to generate electricity. Third, age out retirements occur when the unit has exhausted its usable system life as specified in its physical characteristics. Fourth, staff-specified retirements occur when the planned date that a particular unit will go offline has already been made known to staff, either publically or confidentially, by the owner or government regulator of the asset.

Although this option is not recommended, to allow for maximum flexibility the dispatch model also enables staff analysts to take complete manual control of all individual build, retirement, and dispatch decisions by specifying each within the existing units database. Staff can override least-cost and environmental optimization by manually designating an existing or potential unit as required, i.e. "must run." Staff analysts could, given sufficient time, manually specify exactly which generating units should be retired or built and when; however, the model's dispatch optimization algorithm is able to make these decisions without prejudice incomparably faster and more efficiently than any human analyst. The accuracy of the dispatch model depends upon the accuracy of the data on existing and potential generating units as well as the physical resource limitations that have been specified by staff.

Employment Model

Total employment is forecasted dynamically as a function of electricity prices, population, educational attainment, and time. Six unique employment models were developed, one for total employment and one for each of the top five employment sectors in Kentucky: manufacturing (NAICS 31, 32, & 33), retail services (NAICS 44), hospitality (NAICS 72), healthcare (NAICS 62), and government (NAICS 92). Using a statistical analysis technique called multiple regression of panel data model with fixed effects, elasticities were developed for each of these economic sectors to calculate changes in employment given a specific change in the price of electricity, which can be generally applied to any state and year. Simply stated, these electricity price elasticity coefficients mean that an increase of 10% in forecasted real electricity prices will induce a forecasted reduction of 3.37% in manufacturing employment, 1.58% in retail employment, 1.42% in hospitality employment, a 0% reduction in healthcare and government, and a 1.23% reduction in employment in all other sectors.

To develop these models, historical data from the United States as whole from 1990 to 2010 were organized into a multidimensional panel, i.e. both time series and cross sectional, enabling simultaneous modeling of the relationships of multiple statistics across both space and time (N x t). Since each observation is non-random, and not independent, for example electricity prices in state i and year t are not independent of prices in state i in year t-1, a fixed effects model was used, which builds upon Ordinary Least Squares (OLS) regression by isolating the time-independent constant difference between states that is correlated with the explanatory variables. Multiple regression of panel data using fixed effects facilitated controlling for the numerous factors inherently affecting sector-specific employment as well as electricity prices from state to state that may not have been accounted for in the independent variables included in this study to isolate the primary national effect of the variable of interest, real electricity prices, on each of the dependent variables, employment by industry.

This multiple regression of panel data model with fixed effects can be given by,

$$Y_{it} = \beta_0 + \sum_{j=1}^{k-1} \beta_j X_{jit} + \alpha_i + \varepsilon_{it}$$

Where i and t index states and years, such that y_{it} is the dependent variable of interest, employment by economic sector, in state i in year t, β_0 is the constant y intercept across all states, $\beta_j X_{jit}$ is the product of the observation for each independent variable 1 through k for state i in year t and the coefficient of X, k is the total number of included independent variables, α_i is the time-invariant fixed effect for state i, and ε_{it} are the residuals, and where $\varepsilon_{it} \sim N(0, \sigma^2)$, or are approximately normally distributed with a mean of zero.

Table 3 below provides the complete multiple regression models with fixed effects estimated for each sector. These five models were subsequently rerun using robust standard errors, which had no impact on the coefficients of interest. Prior to analysis, all variables were converted to their natural logarithms such that the estimated coefficients for each may be simply interpreted as elasticities, which measure the percentage change in the dependent variable given a percentage change in one of the independent variables, ceteris paribus.

Table 3: Model of Electricity Prices & Employment by Economic Sector

Logged Variables	Manufacturing Employment	Retail Employment	Food and Accommodation Employment	Healthcare Employment	Government Employment	All Other Employment
Real Electricity Price	-0.337***	-0.158***	-0.142***	-0.0426***	0.00084	-0.122804***
	-0.0307	-0.0136	-0.0152	-0.0158	-0.0101	-0.0278
Educational Attainment	0.0249	-0.108	-0.679	-0.536***	-0.14**	0.420868***
	-0.146	-0.065	-0.0728	-0.0758	-0.0482	-0.111
State GDP (Real US$)	0.744***	0.509***	0.318***	.017***	.253***	0.4659***
	-0.0514	-0.0228	-0.0255	-0.0265	-0.0169	-0.07953
Population	0.166**	0.26***	0.129***	0.37***	0.258***	0.539355***
	-0.0532	-0.0236	-0.0264	-0.0275	-0.0175	-0.08166
Year	-76.05***	-11.31***	21.11***	55.21***	3.801*	2.83759*
	-5.536	-2.457	-2.752	-2.861	-1.819	-0.05505
National Constant	579.4**	88.85***	-153.9***	-413.5***	-22.72	-21.34278
	-41.38	-18.36	-20.57	-21.39	-13.6	-25.45
Kentucky FE α_i	0.3551	-0.0096	-0.0528	-0.1213	0.0298	0.3258
N	51	51	51	51	51	51

Coefficients with robust standard errors in parentheses at the following significance levels: * p<0.05, ** p<0.01, *** p<0.001

Gross Domestic Product Model

This model forecasts state Gross Domestic Product (GDP) as a function of real electricity prices, population, educational attainment, employment, and time. The primary interaction of GDP model with the electricity generation portfolio is in response to changes in electricity prices. Higher electricity prices, holding all other factors constant, are associated with lower levels of economic output. Similar to electricity demand discussed on page C.92, and employment responsiveness discussed on page C.97, this model uses a statistical analysis of historical data from across the United States from 1970 to 2011 to estimate a multiple regression of panel data model with fixed effects that includes an electricity price elasticity of GDP coefficient. Specifically, a 10% increase in the real price of electricity would be associated with a 1.1% reduction in state GDP, and with robust 95% confidence, between 0.6 and 1.6%. The preliminary version of this model, given accurate input assumptions, has an absolute mean error of ±0.43% and was able to predict historical GDP within ±1% over 94% of the time, within ±2% of GDP 99.99% of the time, and always within ±3.34%.

To be sure, electricity prices are considerably influenced by public policy, namely environmental regulations and the makeup of the generating portfolio in addition to variable costs such as fuel. Electricity prices, in turn, are significant drivers of economic growth in a community. Electricity consumers opting to use energy more efficiently in response to increasing electricity prices will reduce waste and lower their own electricity costs, which is obviously good for both the individual consumer and the community as a whole. However, whenever electricity price elasticity of demand emerges in the form of a business closing or relocating to another region, there will be significant negative implications for the community, namely lost economic growth, employment opportunities, and diminished tax revenue.

This multiple regression of panel data model with fixed effects can be generally given by,

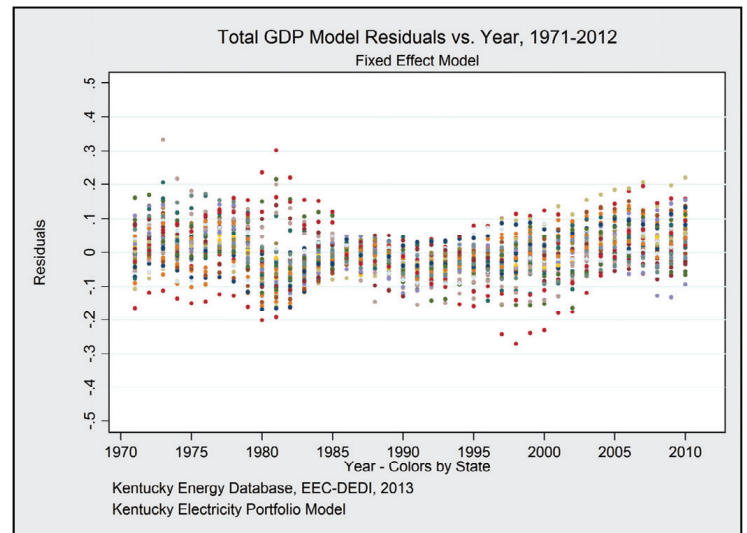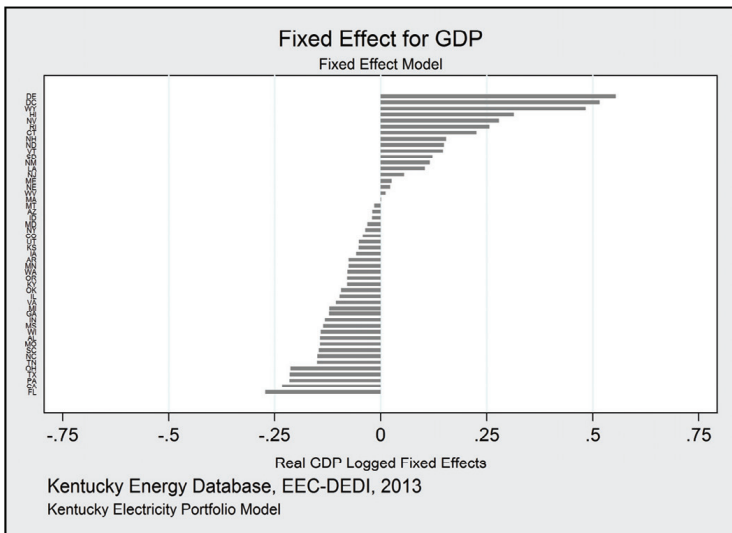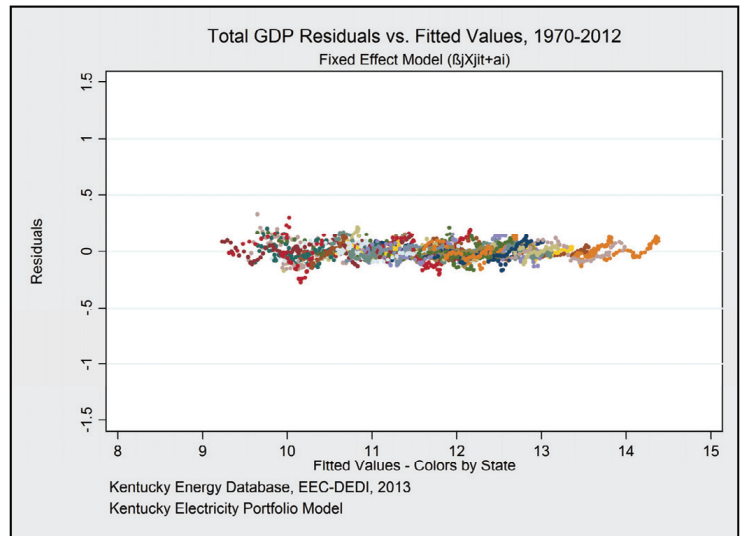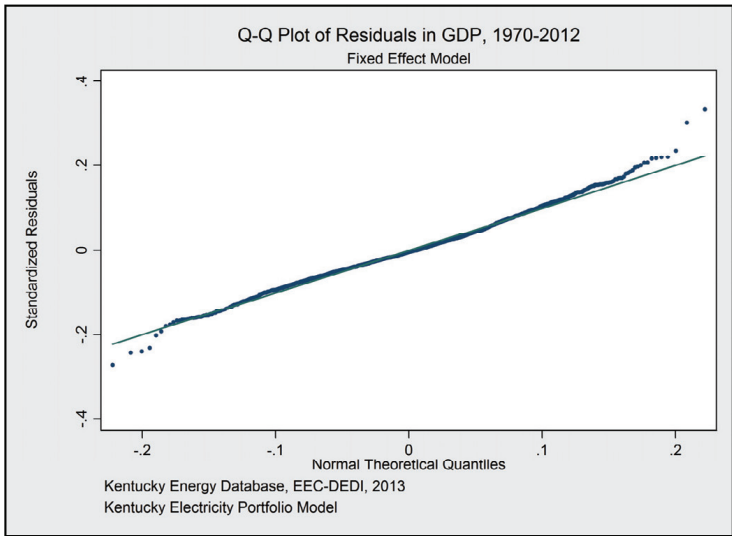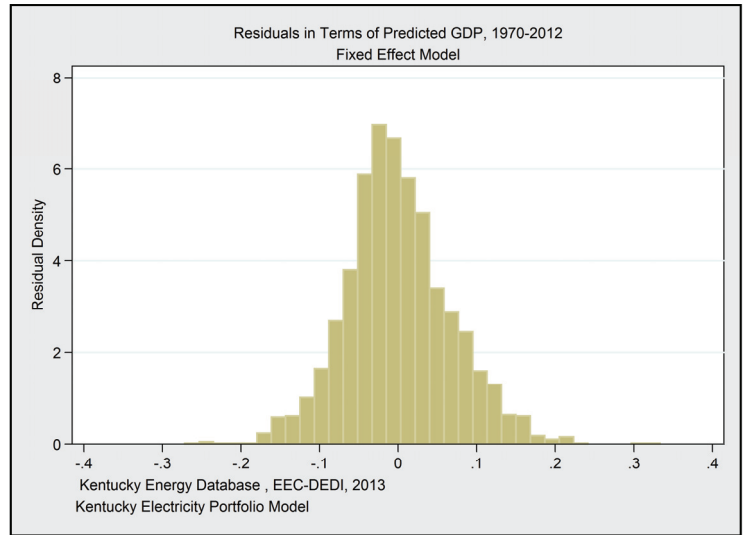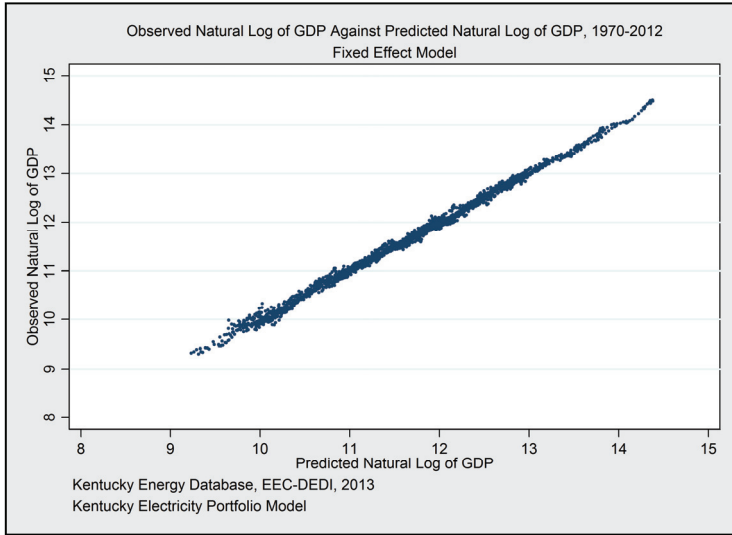$$Y_{it} = \beta_0 + \sum_{j=1}^{k-1} \beta_j X_{jit} + \alpha_i + \varepsilon_{it}$$

Where i and t index states and years, such that y_{it} is the dependent variable of interest, Gross Domestic Product, in state i in year t, β_0 is the constant y intercept across all states, X is a k x 1 vector of explanatory variables, $\beta_j X_{jit}$ is the product of the observation for each independent variable j through k for state i in year t and the coefficient of X, k is the total number of included independent variables, α_i is the time-invariant fixed effect for state i, and ε_{it} are the residuals, and where $\varepsilon_{it} \sim N(0, \sigma^2)$, or are approximately normally distributed with a mean of zero. The mechanics of the fixed effects model are discussed in further detail on pages C.98.

The GDP model is intended to estimate the relationship between electricity prices and economic output and has no way to predict major economic events including recessions or recoveries, since these may be determined by other exogenous factors. While the model is able to explain past variations in economic output, some of its inputs are difficult to extrapolate into the future and therefore decrease the predictive ability of the model forwards in time.

The table below provides the complete multiple regression model coefficients and robust standard errors in parentheses. The natural log of all variables was taken such that the coefficients may be interpreted as elasticities. All coefficients were significant at the 0.001 level both with and without robust standard errors.

Real Electricity Price	-0.111*** (-0.0255)		
Population	1.185*** (-0.0514)	**R-Squared (Overall)**	0.9801
Education Index	0.370*** (-0.0604)	**R-Squared (Within)**	0.9536
Employment	1.312*** (-0.129)	**R-Squared (Between)**	0.9839
Constant	-7.963*** (-0.659)	**AIC** **N**	-5237.2 2050

GDP Model Validation

Observed Natural Log of GDP Against Predicted Natural Log of GDP, 1970-2012
Fixed Effect Model

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Residuals in Terms of Predicted GDP, 1970-2012
Fixed Effect Model

Kentucky Energy Database , EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Q-Q Plot of Residuals in GDP, 1970-2012
Fixed Effect Model

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Total GDP Residuals vs. Fitted Values, 1970-2012
Fixed Effect Model (ßjXjit+ai)

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Fixed Effect for GDP
Fixed Effect Model

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Total GDP Model Residuals vs. Year, 1971-2012
Fixed Effect Model

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

Project Leadership and Policy Analysis Team

Dr. Len Peters
Secretary, Kentucky Energy and Environment Cabinet
Commissioner, Kentucky Department of Energy Development and Independence
len.peters@ky.gov

John Lyons
Assistant Secretary, Kentucky Energy and Environment Cabinet
john.lyons@ky.gov

Karen Wilson
Chief of Staff, Kentucky Energy and Environment Cabinet
karenL.wilson@ky.gov

Kate Shanks
Executive Director, Kentucky Energy and Environment Cabinet
kate.shanks@ky.gov

John Davies
Deputy Commissioner, Kentucky Department of Energy Development and Independence
john.davies@ky.gov

Dr. John Rogness,
Director, Kentucky Department of Energy Development and Independence
john.rogness@ky.gov

Shiela Medina
Associate Director, University of Kentucky Center for Applied Energy Research
shiela.medina@uky.edu or shiela.medina@ky.gov

Physical Engineering Team

Michael Elliot, Principal Investigator and Project Manager
Technical Group Manager, Pacific Northwest National Laboratory
michael.elliot@pnnl.gov

Mark Bearden, Physical Engineering Analyst
Process Engineering Modeling & Economics, Pacific Northwest National Laboratory
mark.bearden@pnnl.gov

Charles Freeman, Physical Engineering Analyst
Hydrocarbon Processing, Pacific Northwest National Laboratory
charles.freeman@pnnl.gov

James Cabe, Physical Engineering Analyst
Energy Tech & Market Adoption, Pacific Northwest National Laboratory
james.cabe@pnnl.gov

Kentucky Electricity Portfolio Model Design Team

Aron Patrick, Concept, Project Manager, and Programming Statistician
Assistant Director, Kentucky Department of Energy Development and Independence
aron.patrick@ky.gov or aron.patrick@uky.edu

Adam Blandford, Analyst and Programming Statistician
Analyst, Kentucky Department of Energy Development and Independence
adam.blandford@ky.gov

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Kentucky Electricity Portfolio Model Design Team (Continued)

Edward Roualdes, Graduate Research Assistant and Programming Statistician, Dispatch and Elasticity Modeling
Doctoral Candidate, University of Kentucky Department of Statistics
edward.roualdes@uky.edu

Woody Burchett, Graduate Research Assistant and Programming Statistician, Dispatch Modeling
Doctoral Candidate, University of Kentucky Department of Statistics
woodrow.burchett@uky.edu

Matt Rutledge, Graduate Research Assistant and Programming Statistician, Dispatch Modeling
Doctoral Candidate, University of Kentucky Department of Statistics
mhru222@uky.edu

Shaoceng Wei, Graduate Research Assistant and Programming Statistician, Cost Modeling
Doctoral Candidate, University of Kentucky Department of Statistics
shaoceng.wei@uky.edu

Zhiheng Xie, Graduate Research Assistant and Programming Statistician, Demand and Elasticity Modeling
Doctoral Candidate, University of Kentucky Department of Statistics
zhiheng.xie@uky.edu

Joel Perry, Graduate Research Assistant and Programming Statistician, Demand and Elasticity Modeling
Masters Candidate, University of Kentucky Department of Statistics
joel.perry@uku.edu

Yang Luo, Graduate Research Assistant and Programming Statistician, Cost Modeling and Graphics
Masters Candidate, University of Kentucky Department of Statistics
yang.luo@uky.edu

Michael Skapes, Graduate Student Intern, Employment and Elasticity Modeling
Masters Candidate, University of Kentucky Patterson School of Diplomacy and International Commerce
skapesmm@miamioh.edu

Dr. Arne Bathke, Technical Advisor
Professor, Director of Graduate Studies, University of Kentucky Department of Statistics
arne@uky.edu

Dr. Arny Stromberg, Technical Advisor
Professor, Department Chair, University of Kentucky Department of Statistics
astro11@email.uky.edu

Dominique Zépher, Technical Advisor
Statistician, University of Kentucky Department of Statistics
dominique.zephyr@uky.edu

Technical Advisors

Dr. Talina Mathews, Technical Advisor
Special Assistant for Policy, Kentucky Public Service Commission
talina.mathews@ky.gov

Bob Amato, Technical Advisor
Director (Retired), Kentucky Department for Energy Development and Independence

Alan Waddell, Technical Advisor
Analyst (Former), Kentucky Department for Energy Development and Independence