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	Portfolios			
Federal Policy Options	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	Portfolios			
Federal Policy Options	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	Portfolios			
Federal Policy Options	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$)	Portfolios			
Federal Policy Options	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$)	Portfolios			
Federal Policy Options	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$)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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)	Portfolios			
Federal Policy Options	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	Portfolios			
Federal Policy Options	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	Portfolios			
Federal Policy Options	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	Portfolios			
Federal Policy Options	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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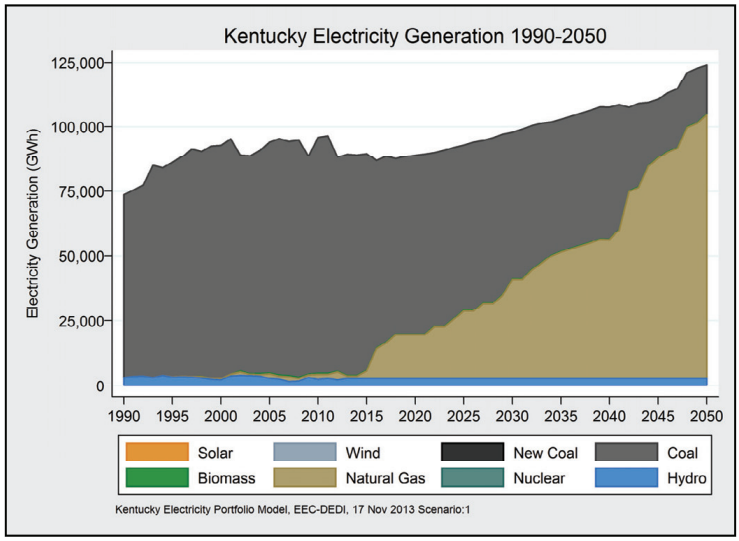
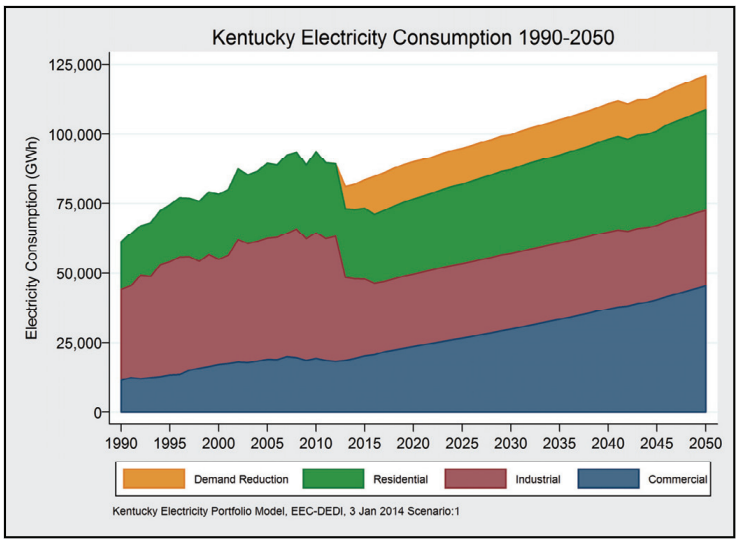
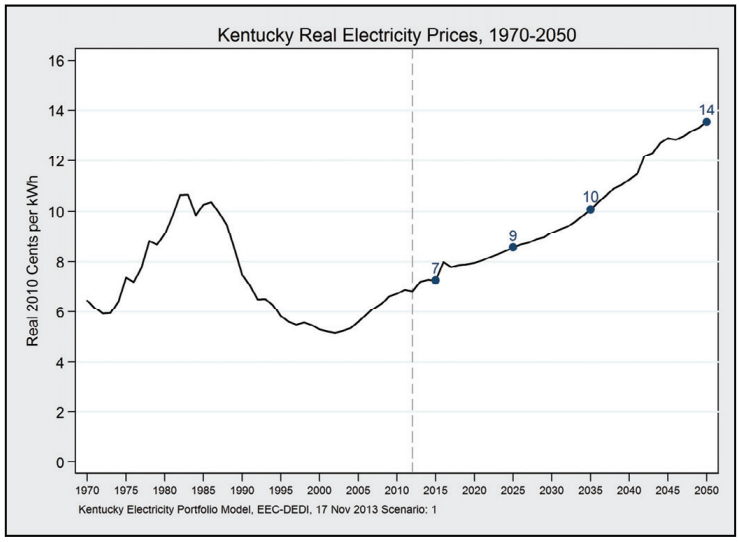
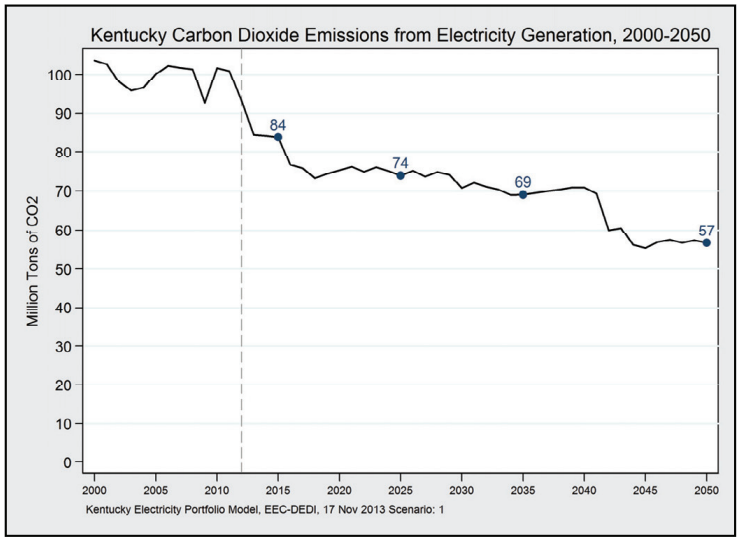
Scenario 1

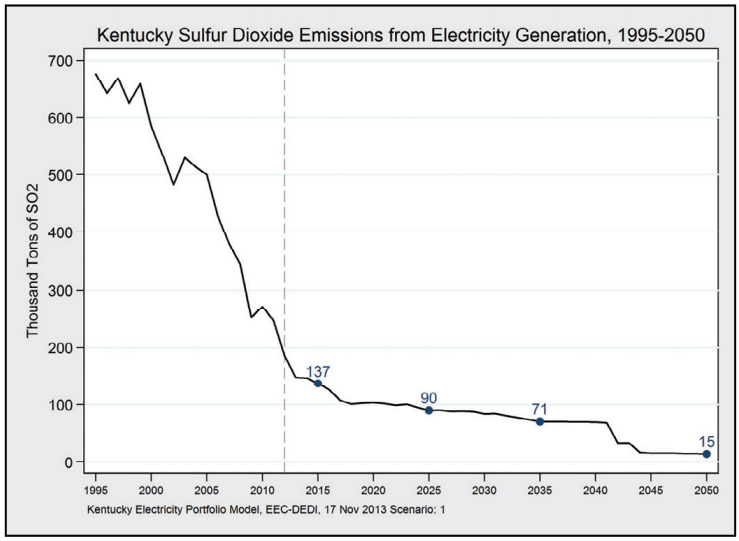
Federal Policy Option 1: Reference Portfolio 1: Nuclear Banned

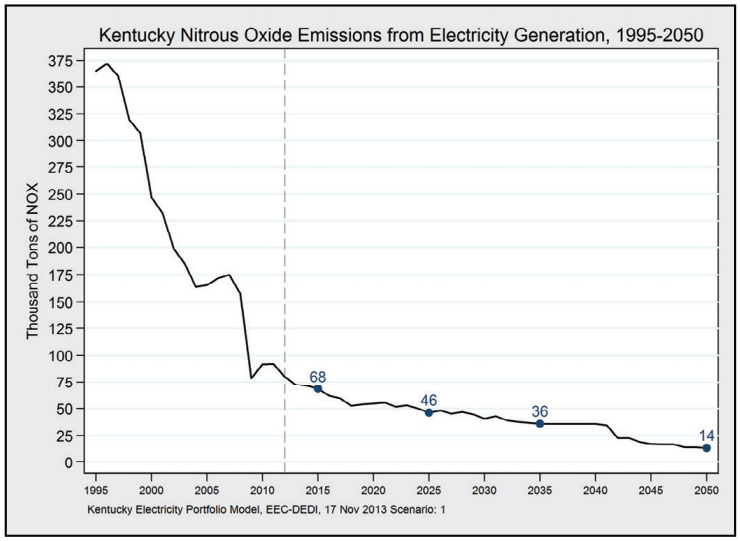






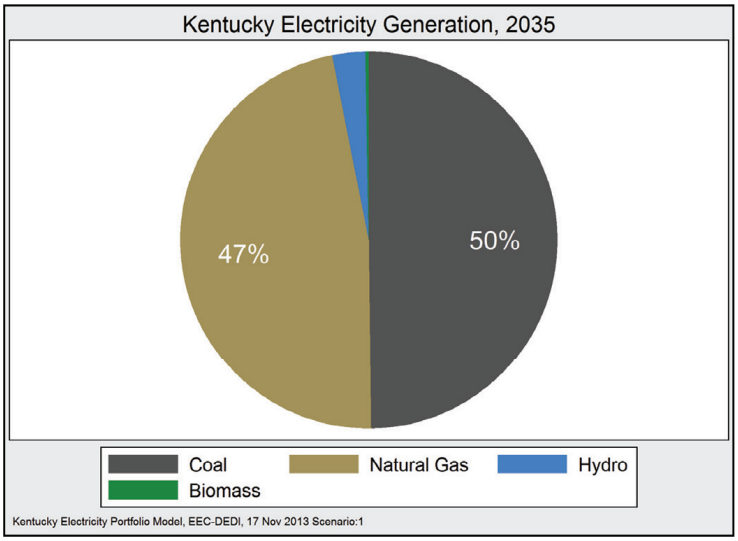


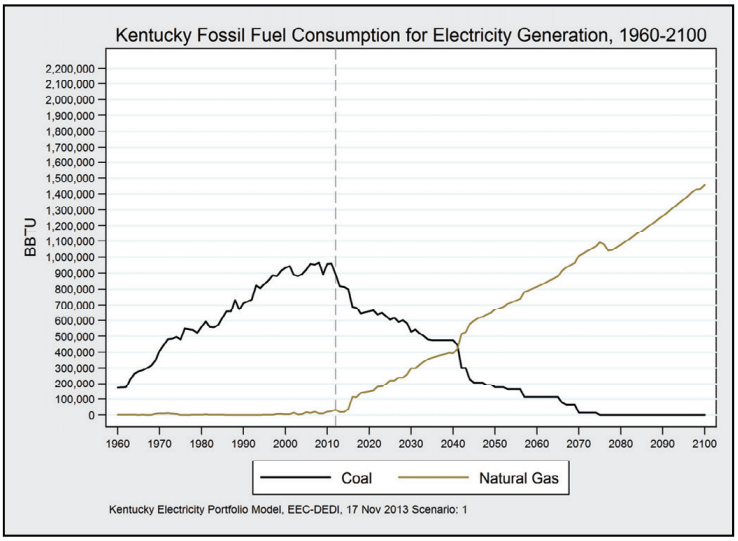


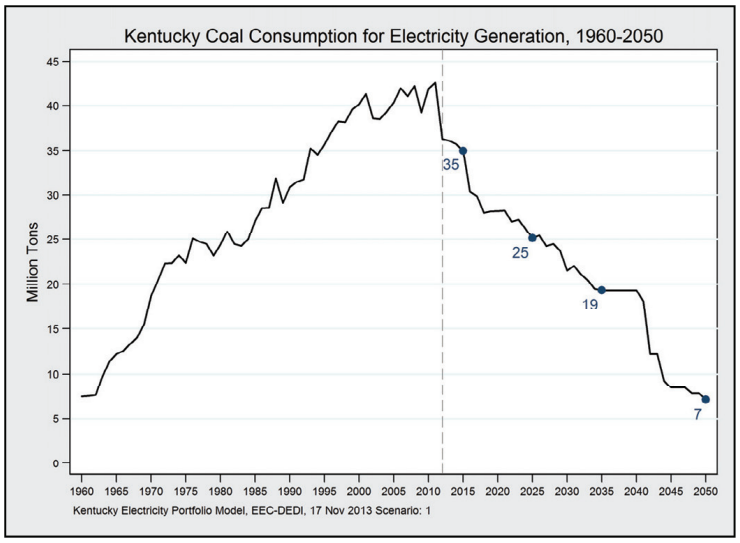


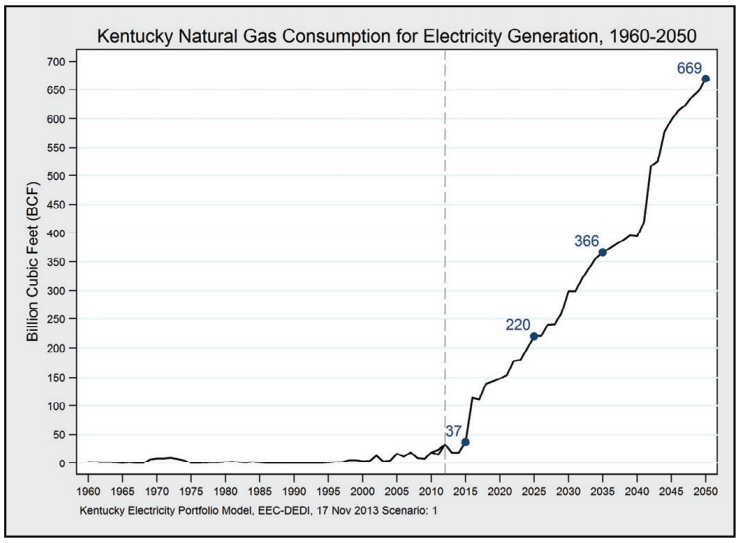
Scenario 1

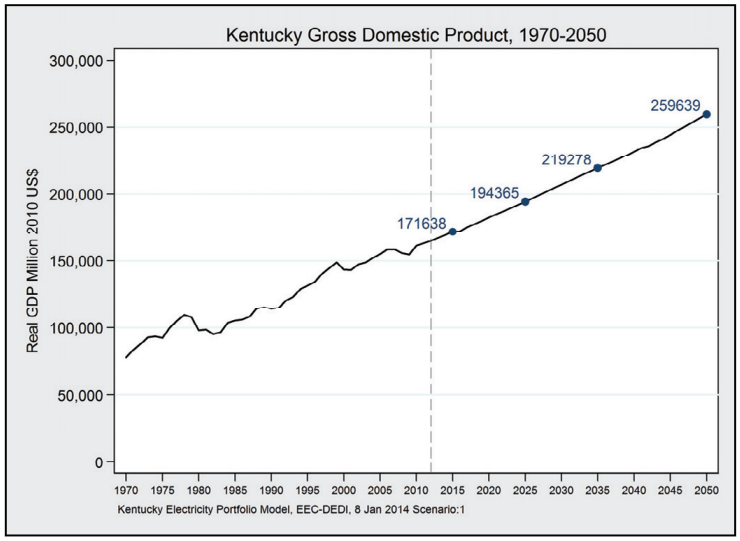
Federal Policy Option 1: Reference Portfolio 1: Nuclear Banned

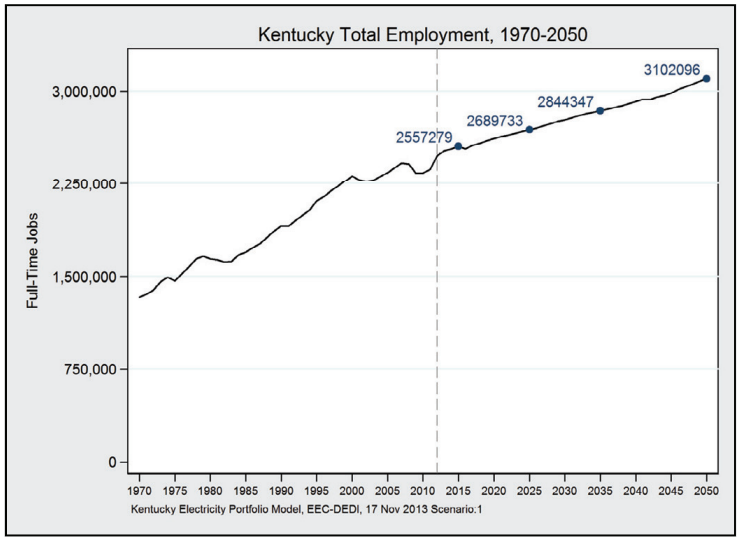






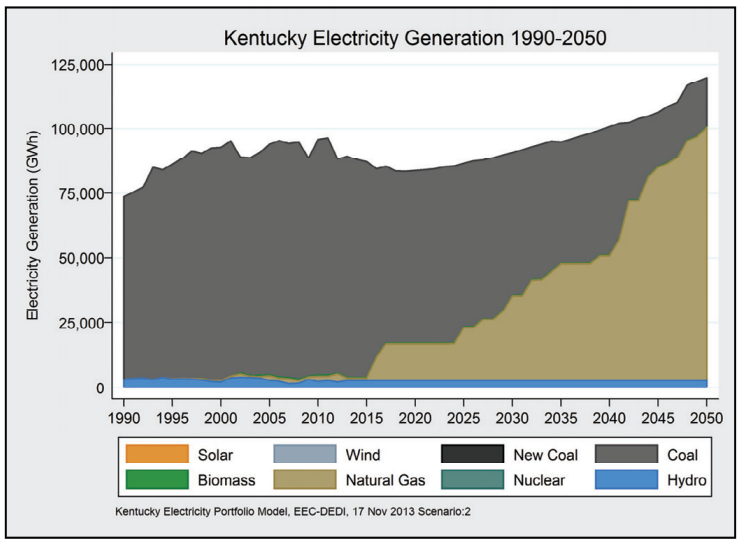


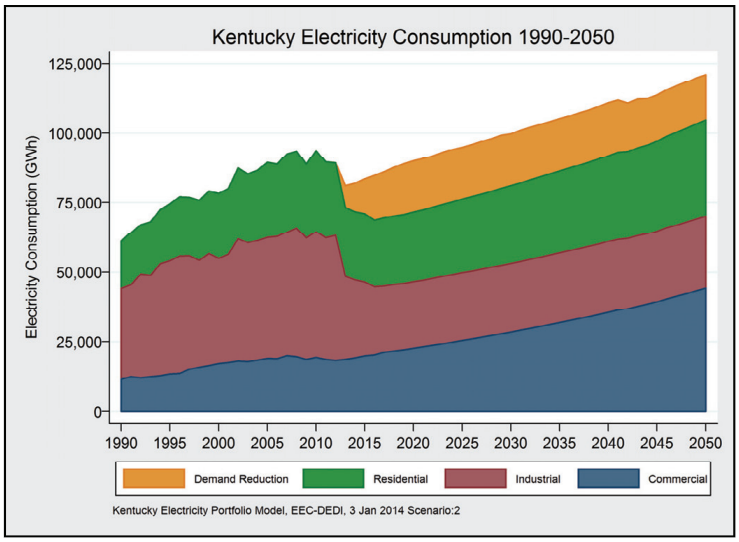


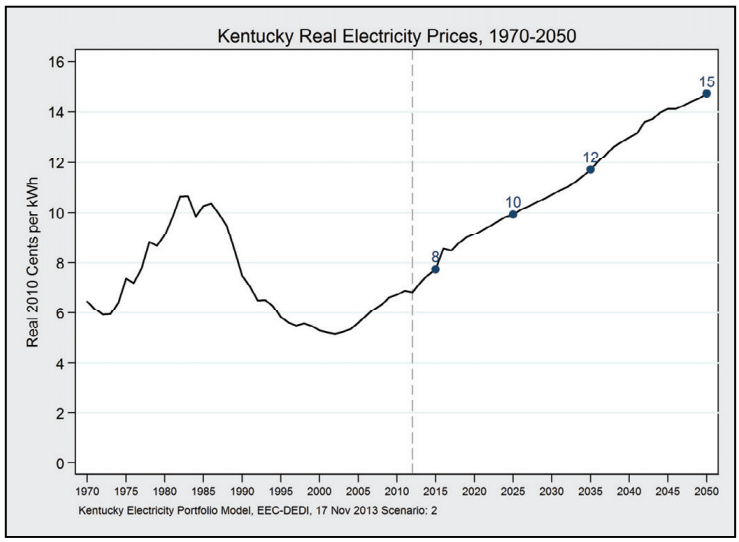


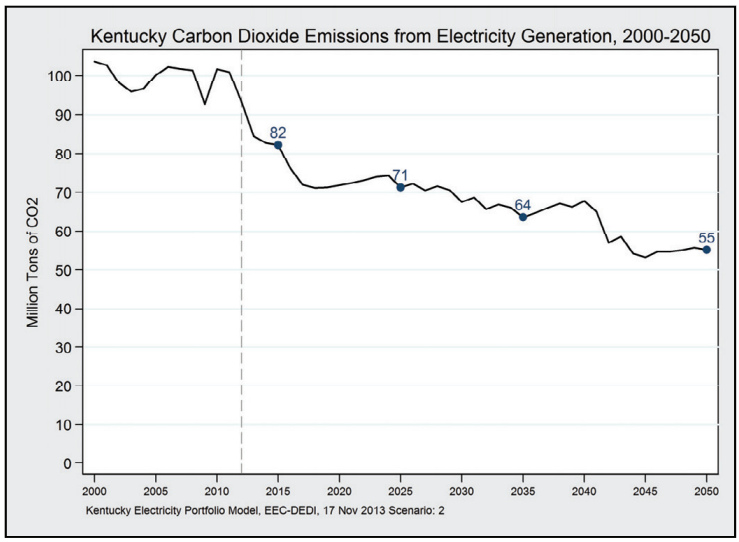
Scenario 2

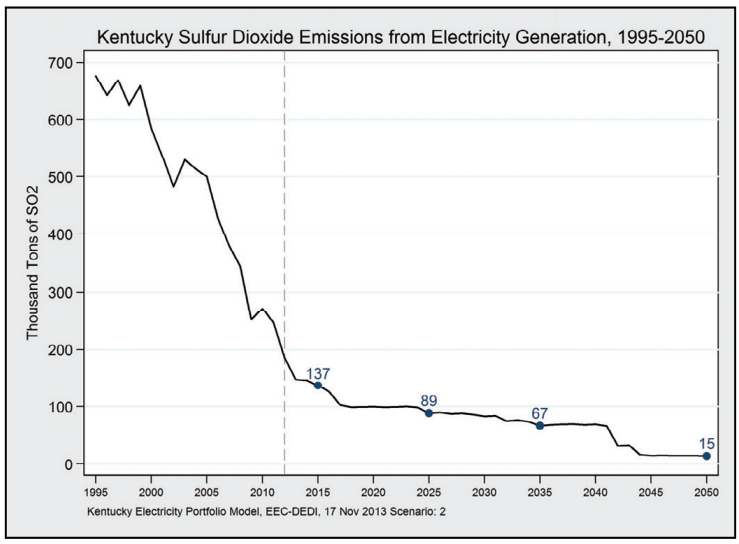
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 1: Nuclear Banned

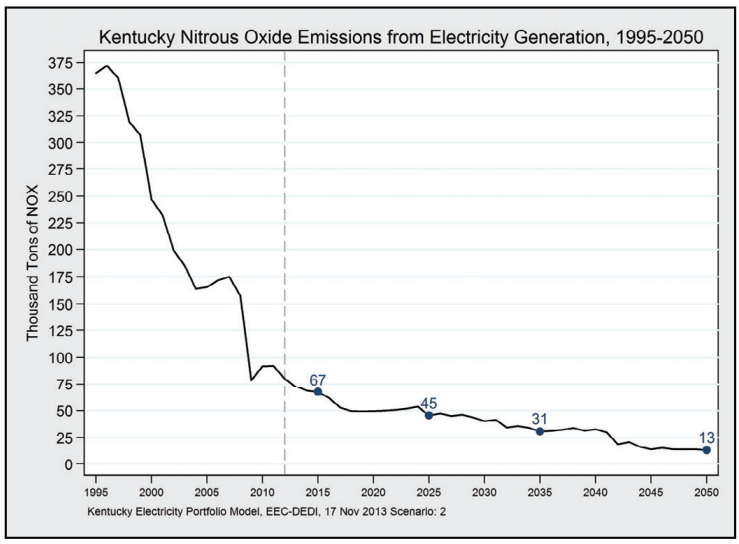






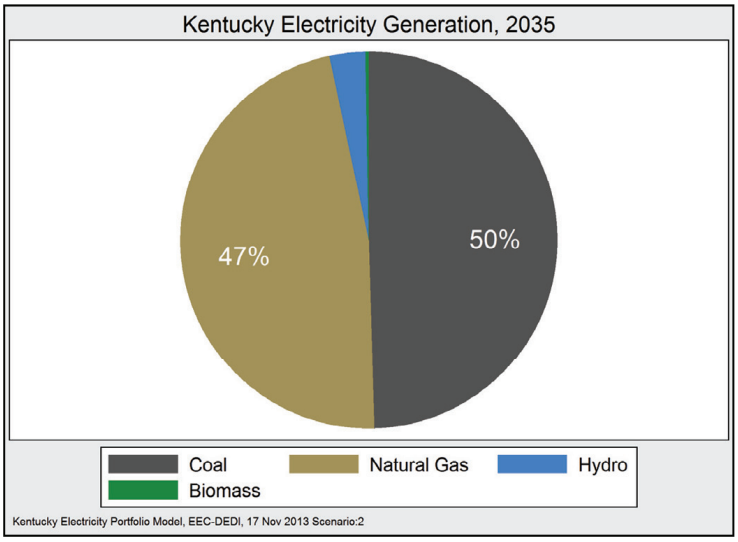


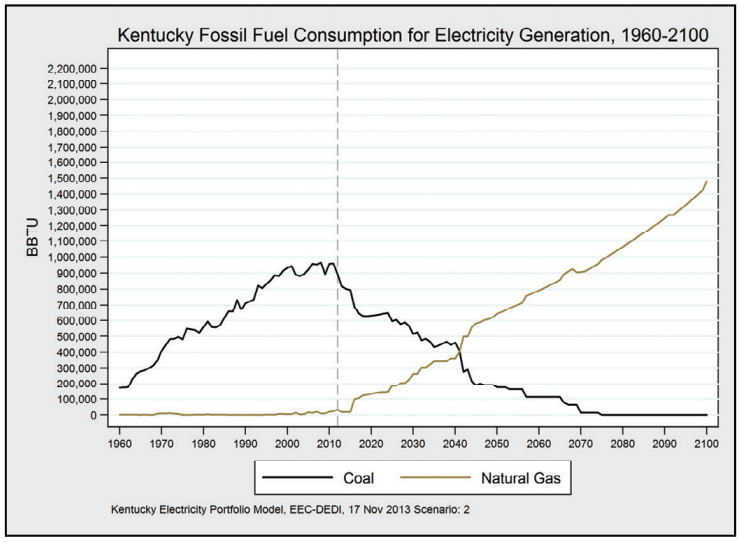


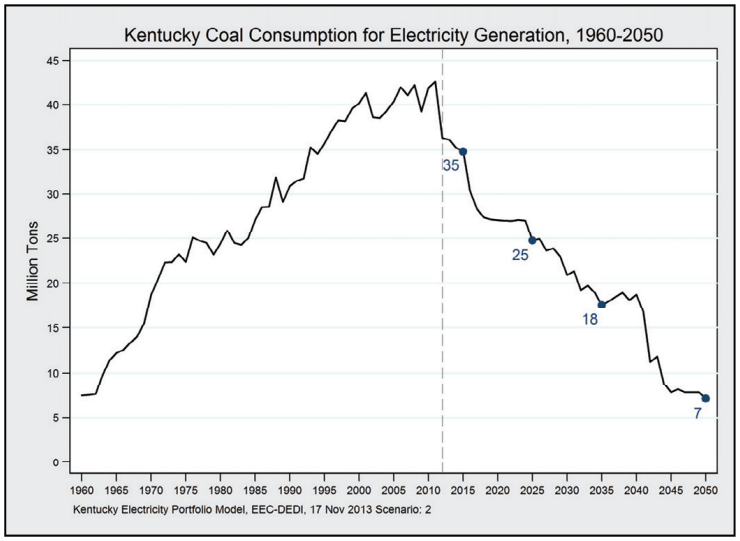


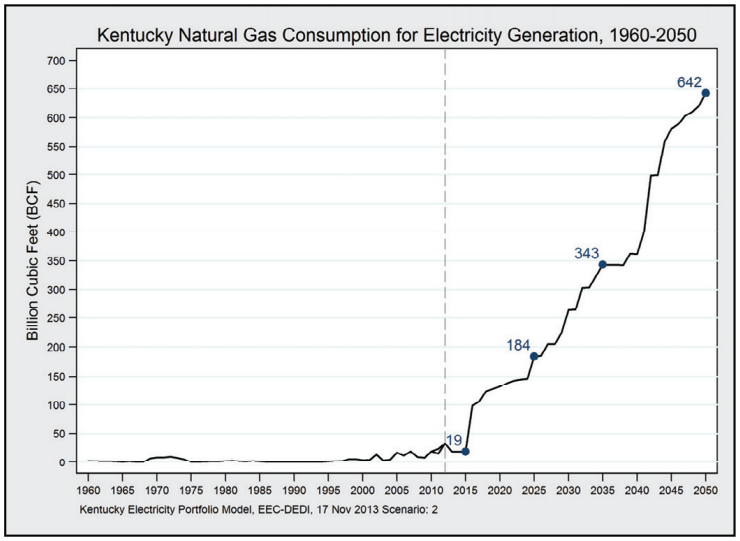
Scenario 2

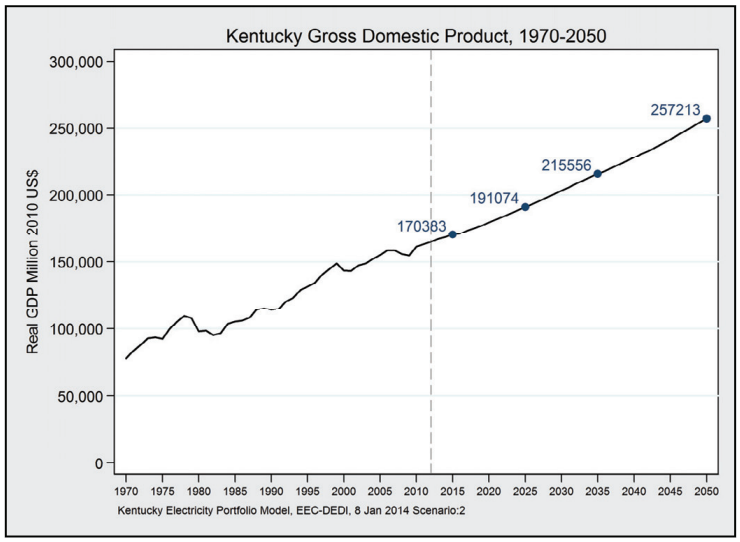
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 1: Nuclear Banned

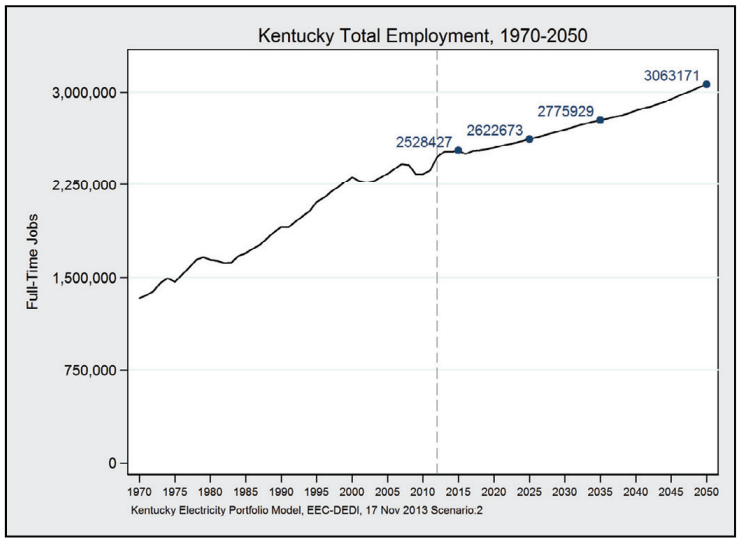






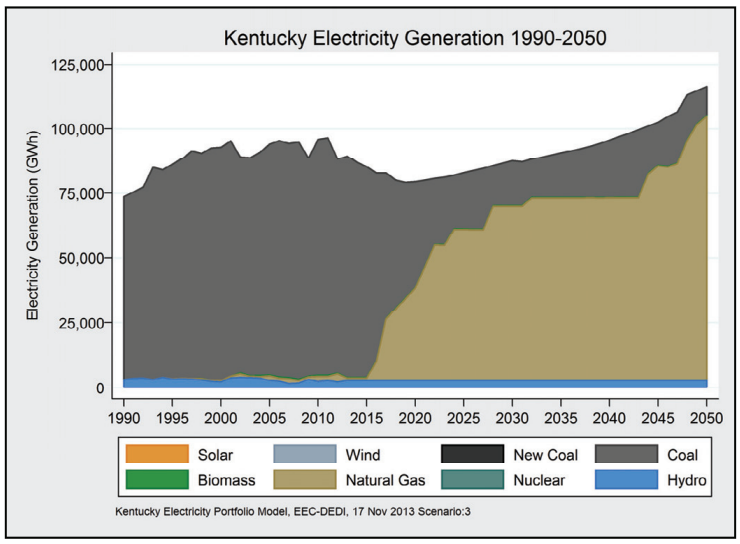


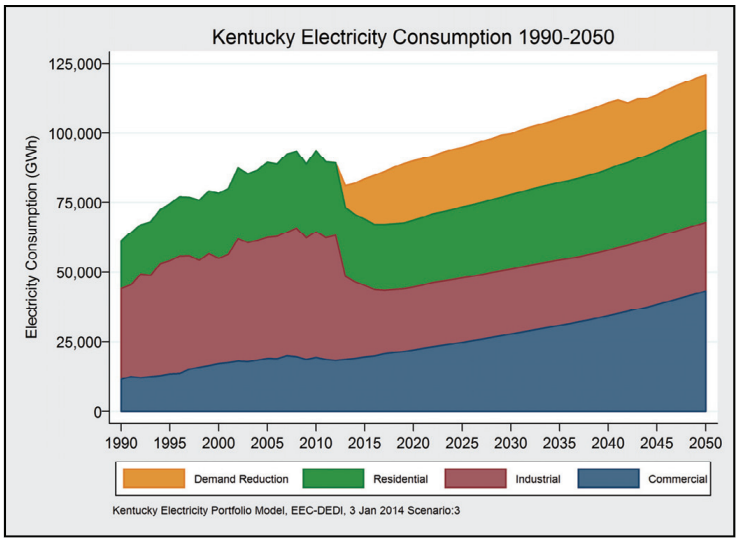


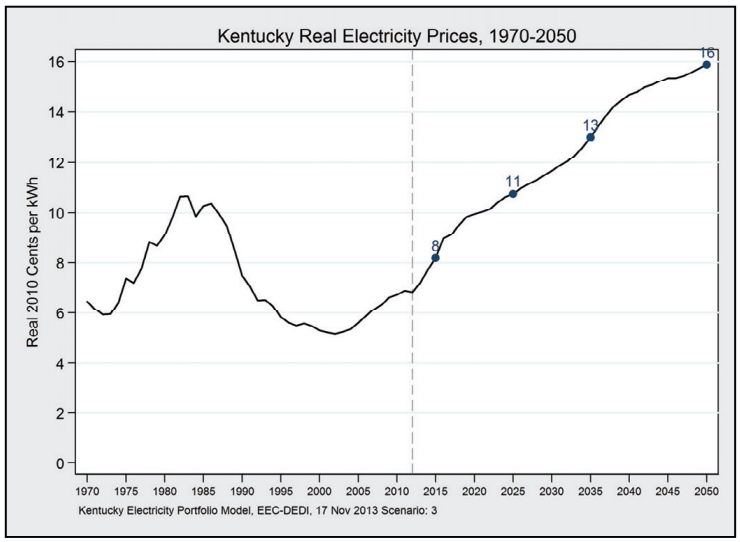


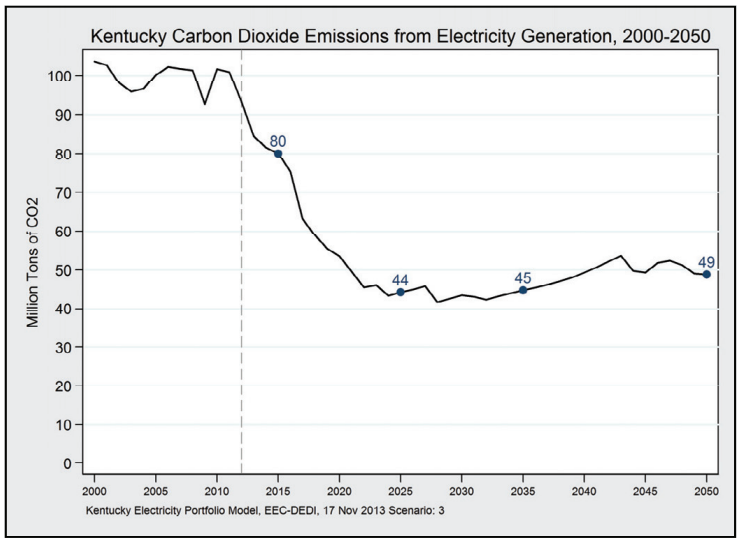
Scenario 3

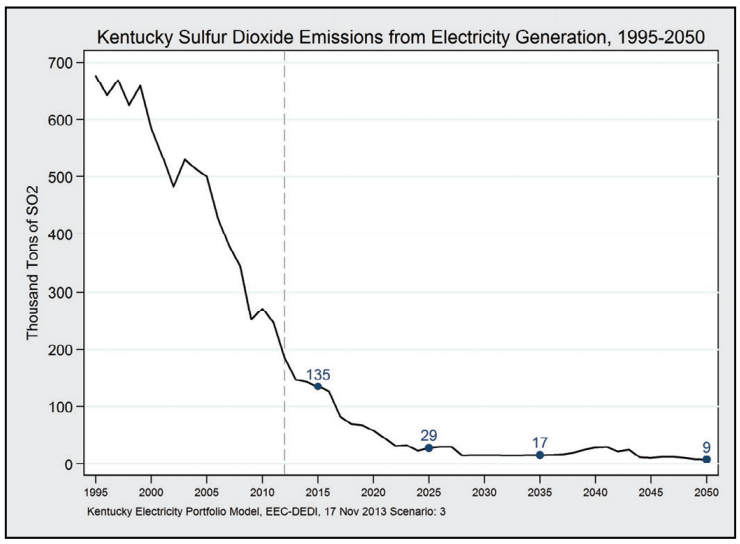
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 1: Nuclear Banned

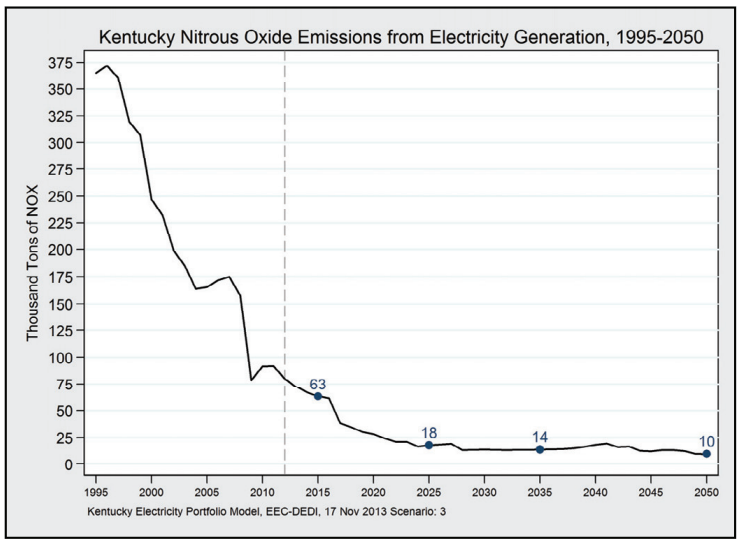






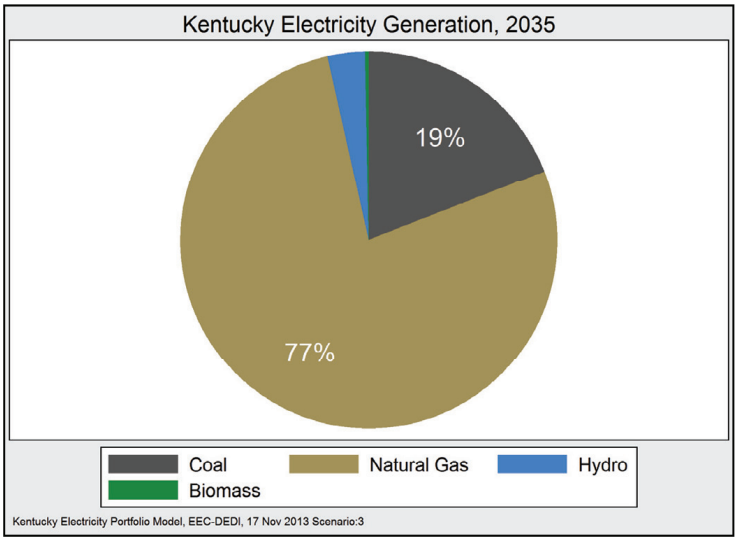


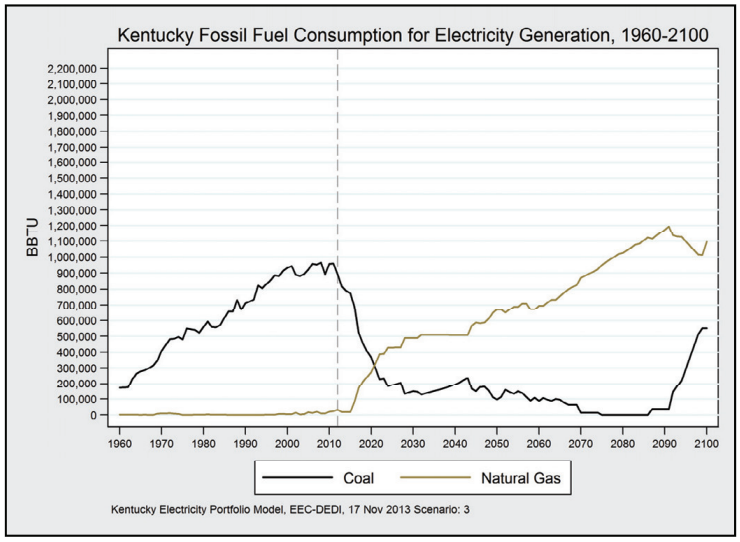


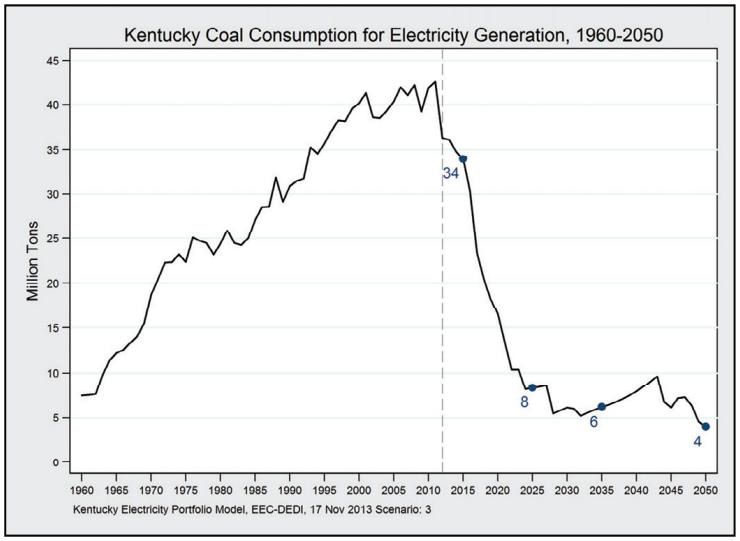


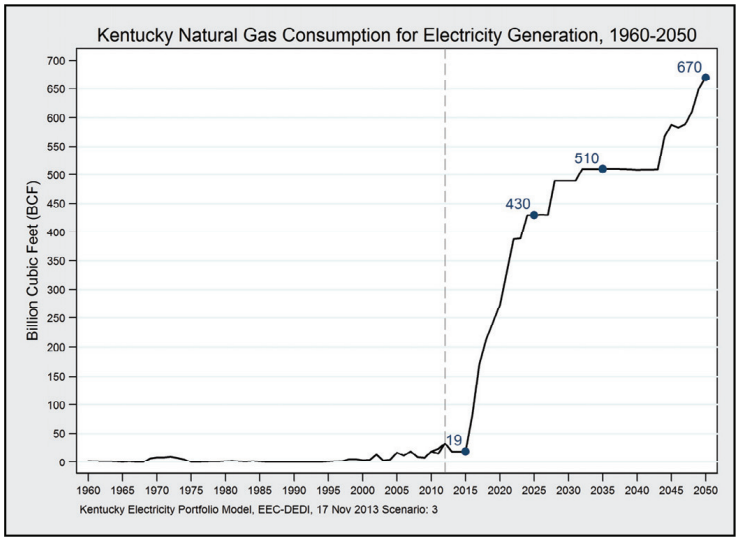
Scenario 3

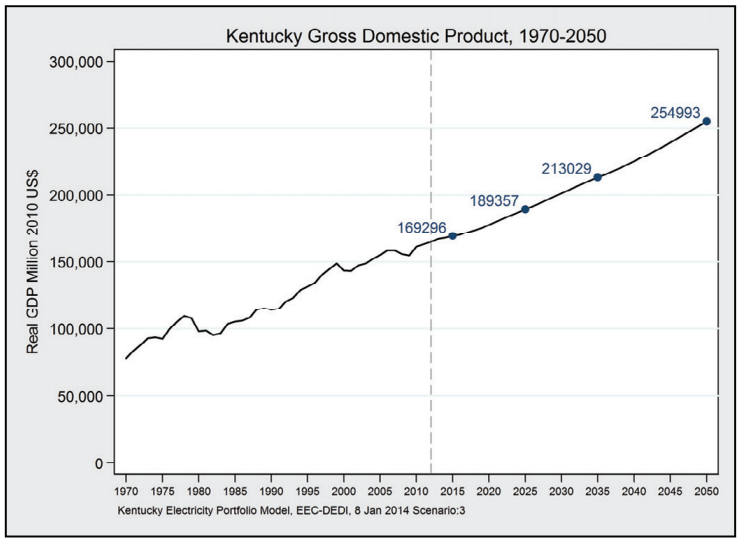
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 1: Nuclear Banned

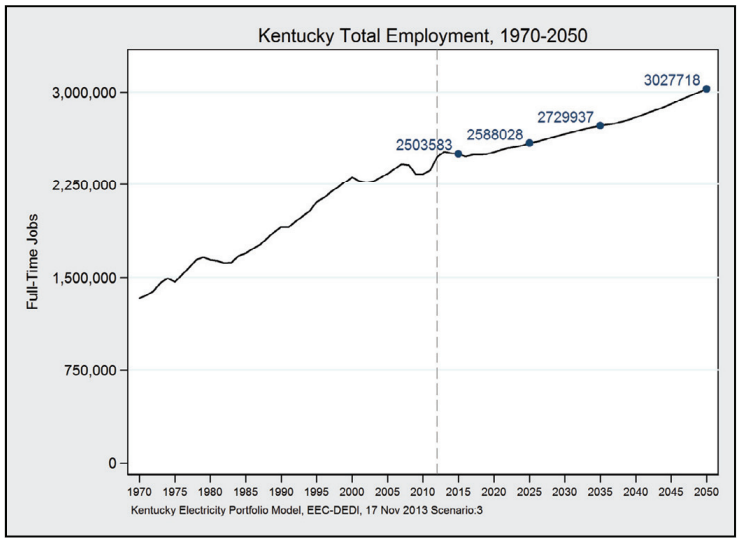






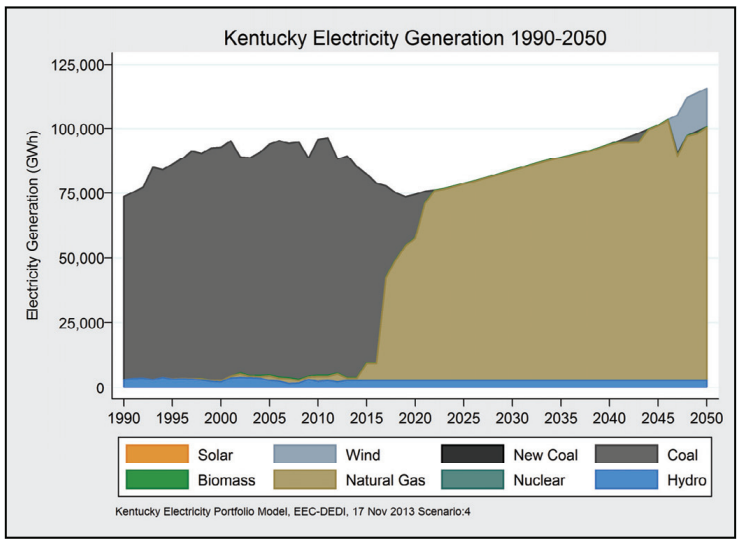


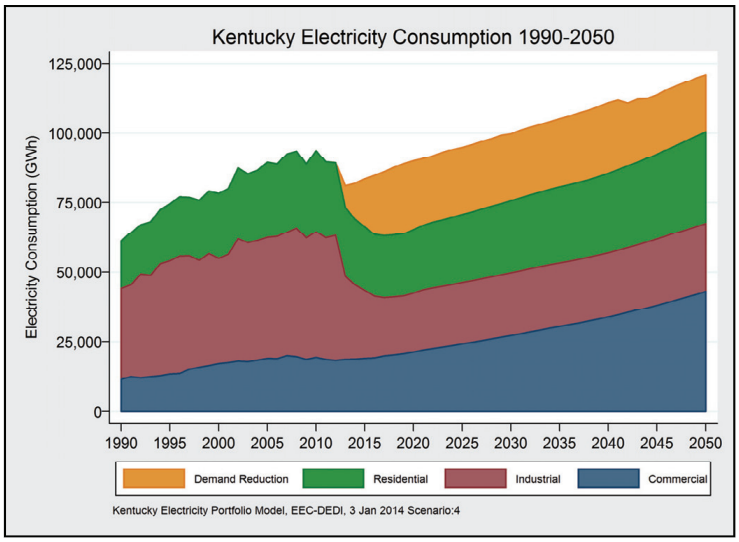


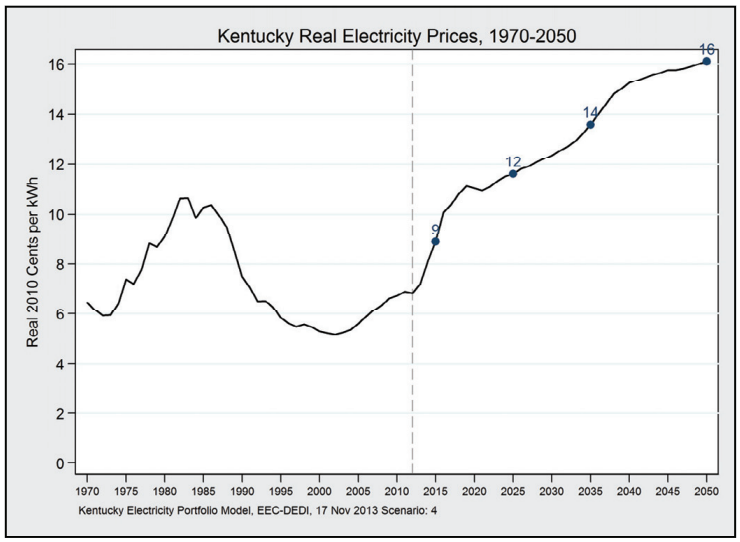


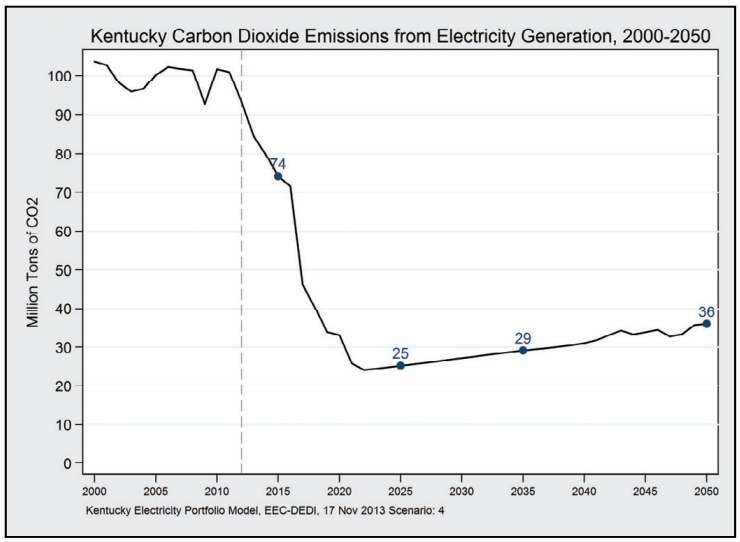
Scenario 4

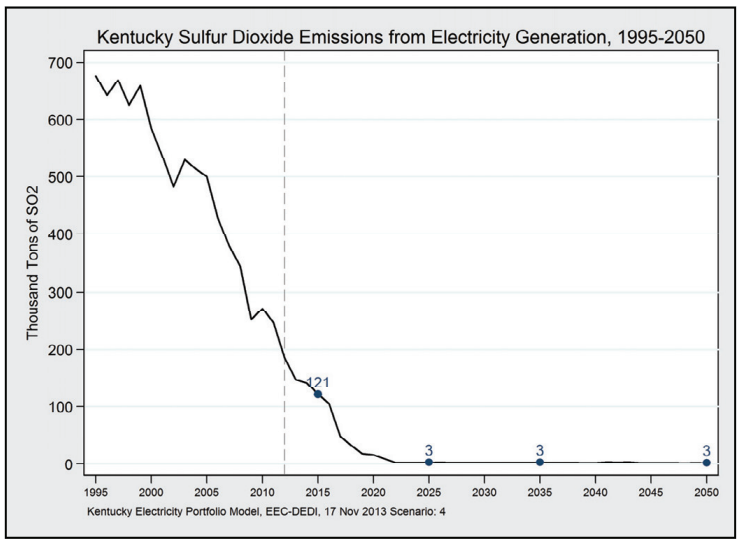
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 1: Nuclear Banned

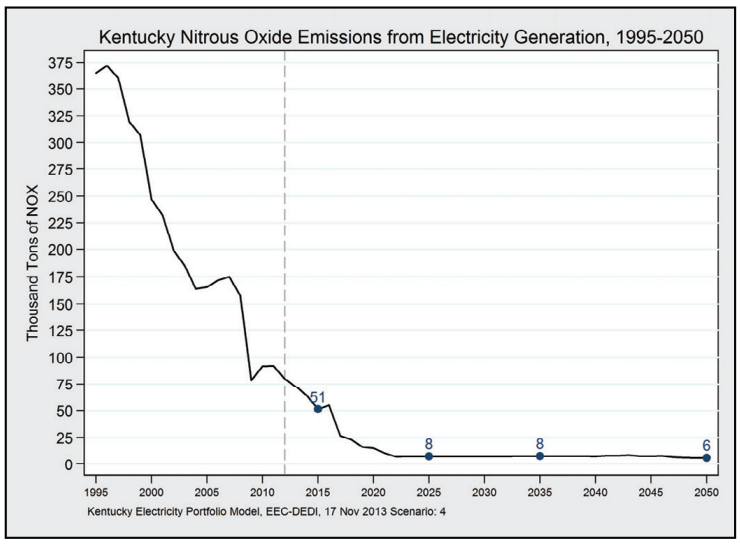






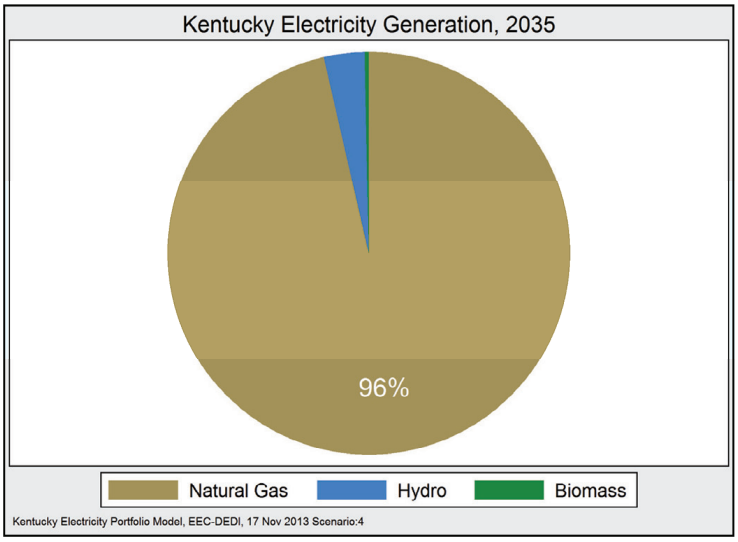


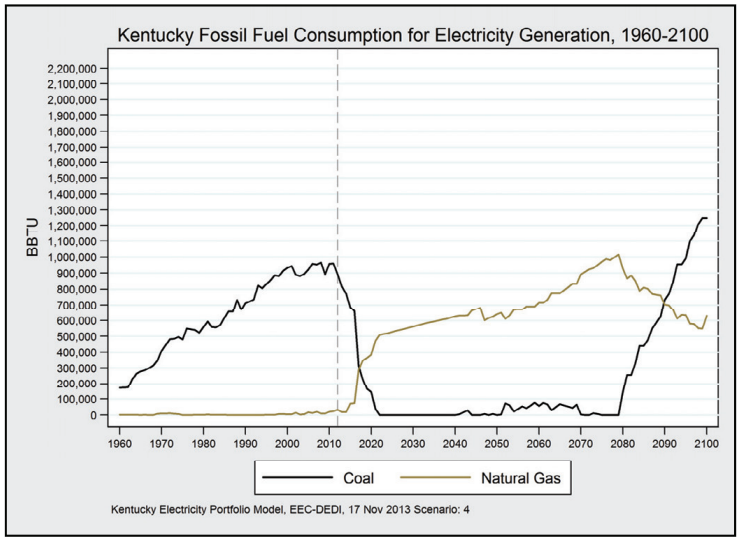


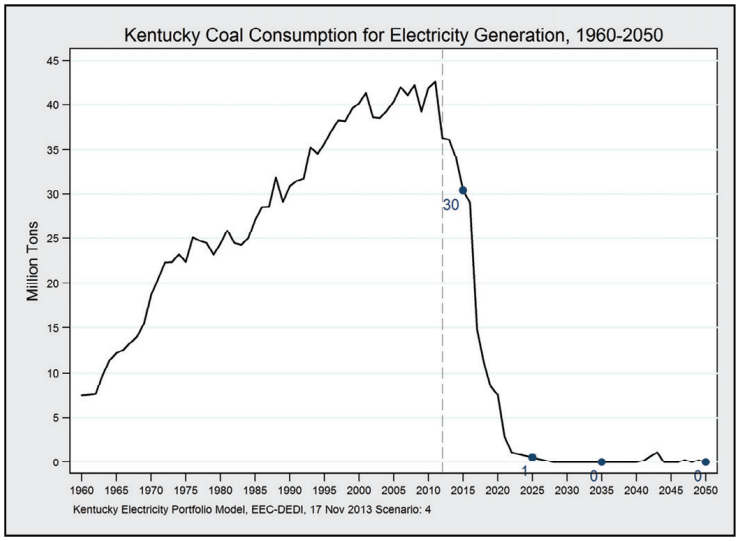


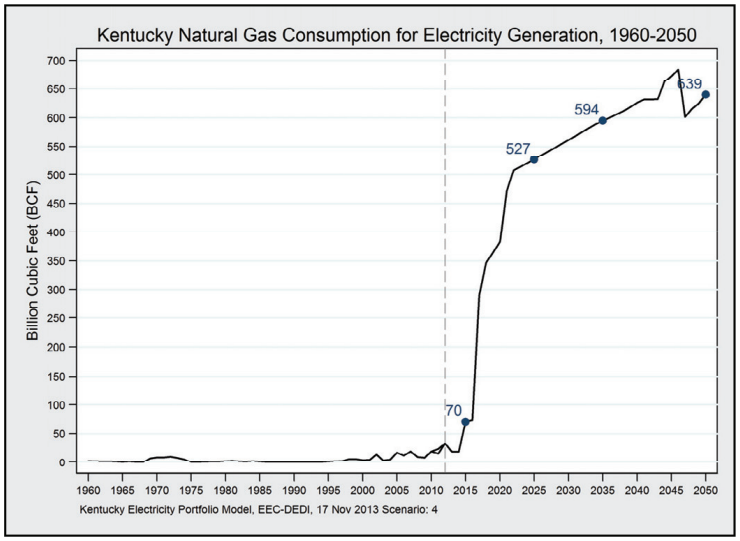
Scenario 4

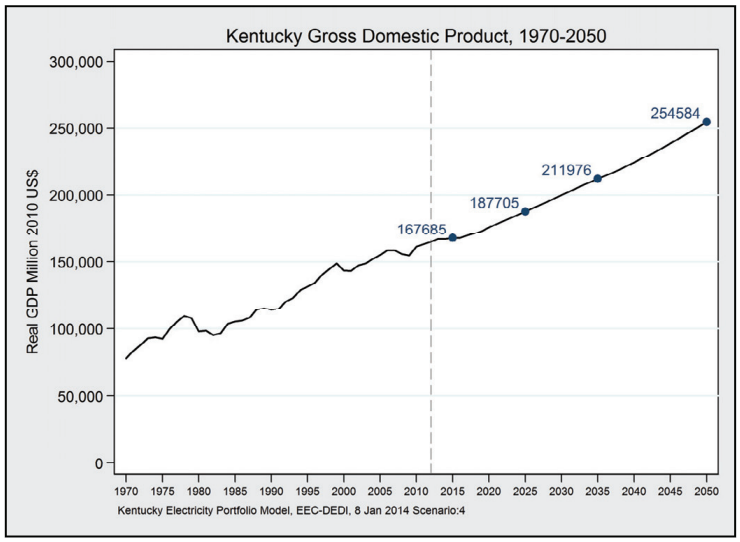
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 1: Nuclear Banned

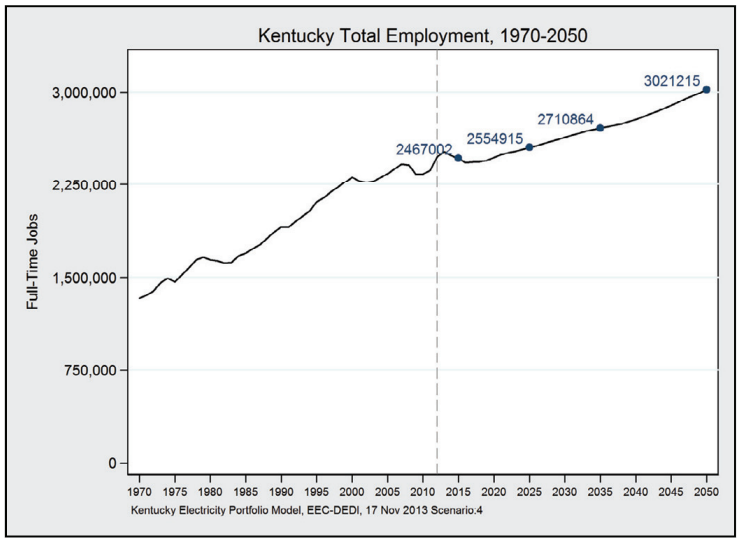






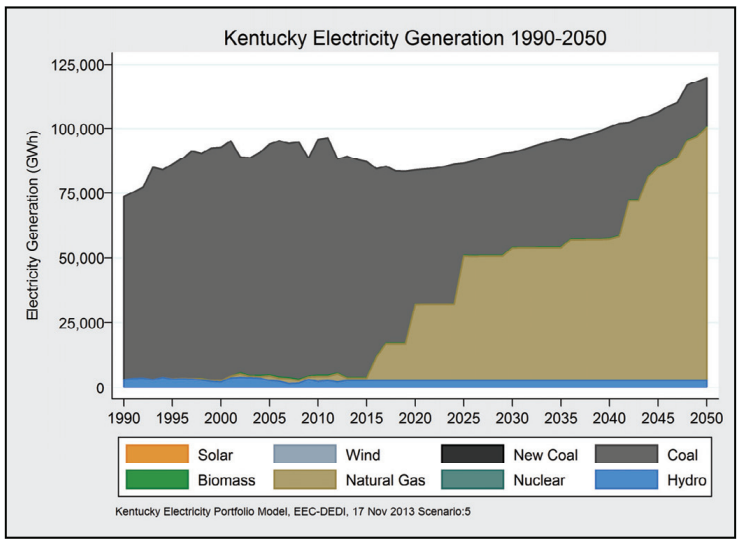


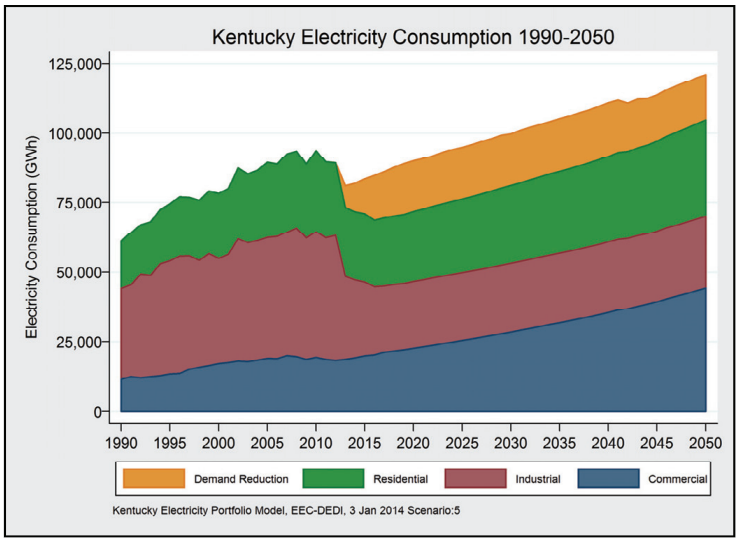


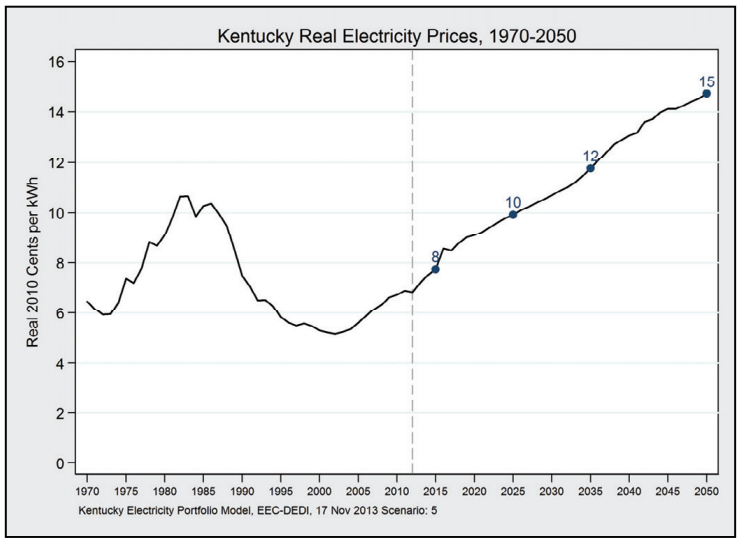


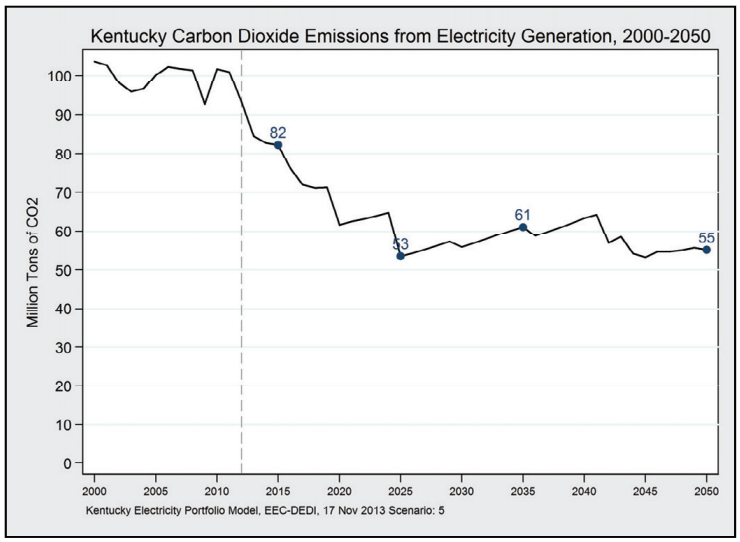
Scenario 5

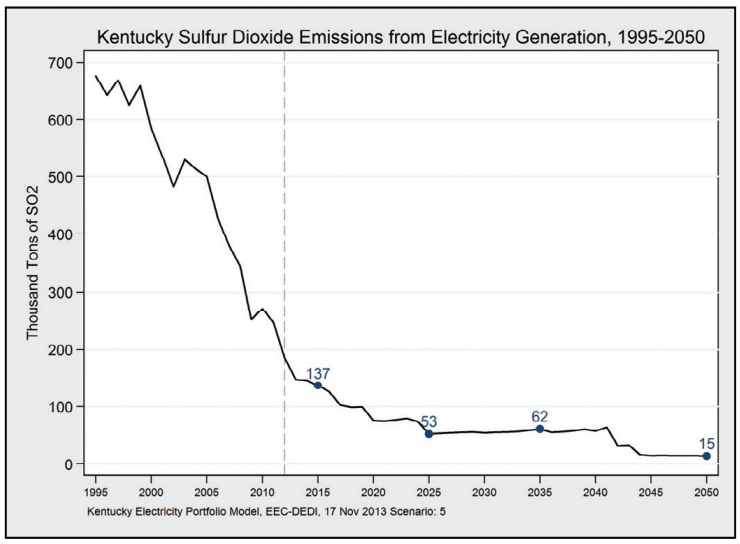
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 1: Nuclear Banned

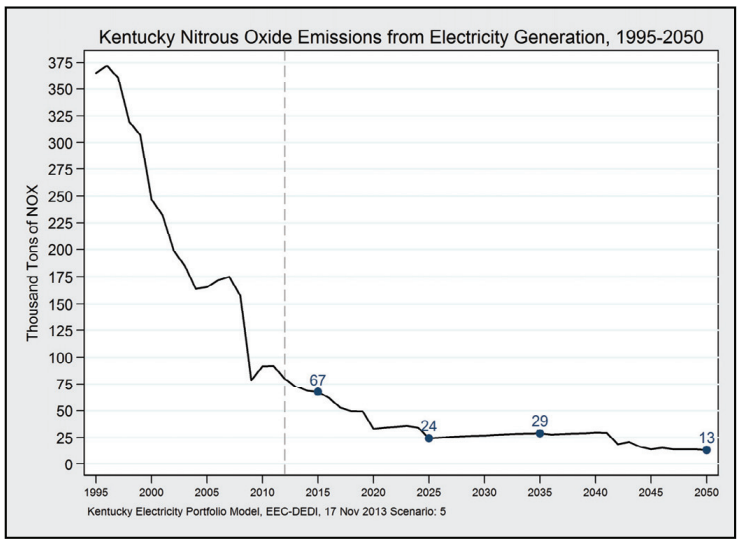






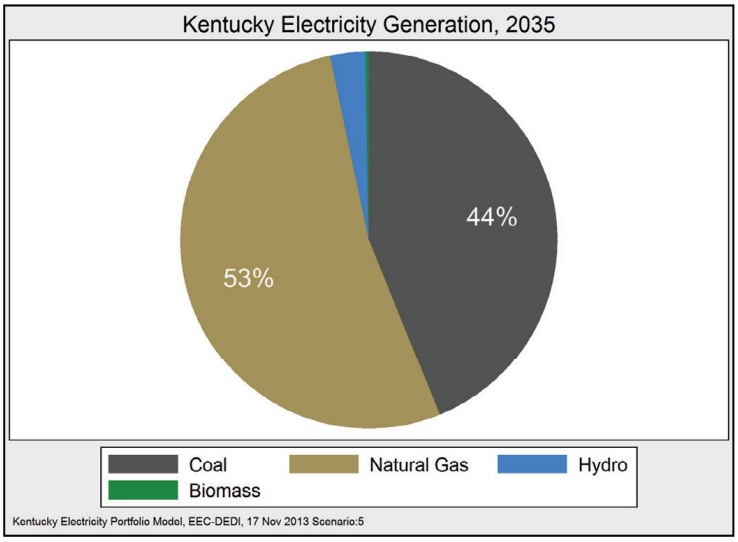


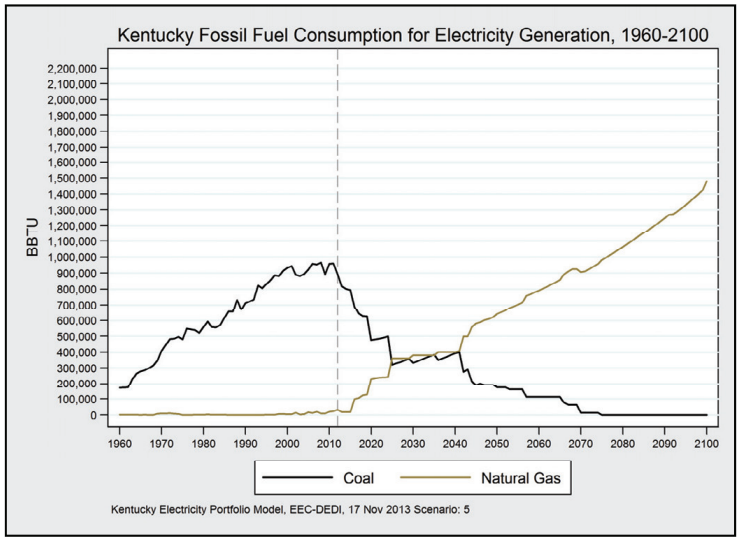


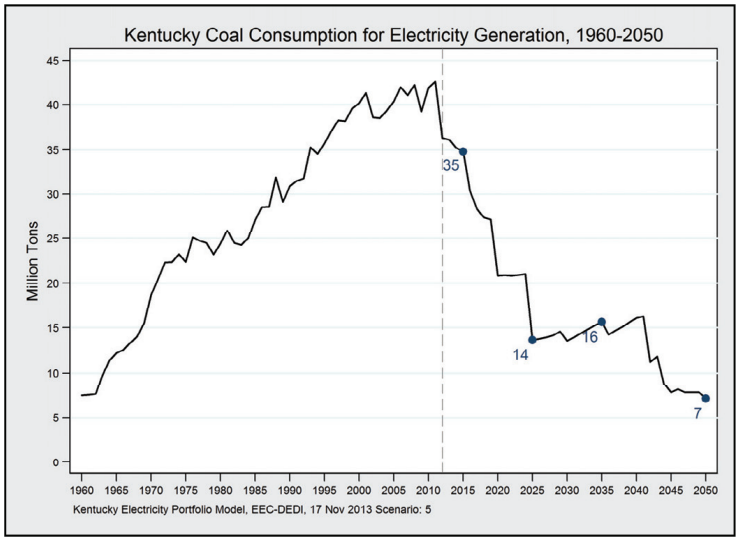


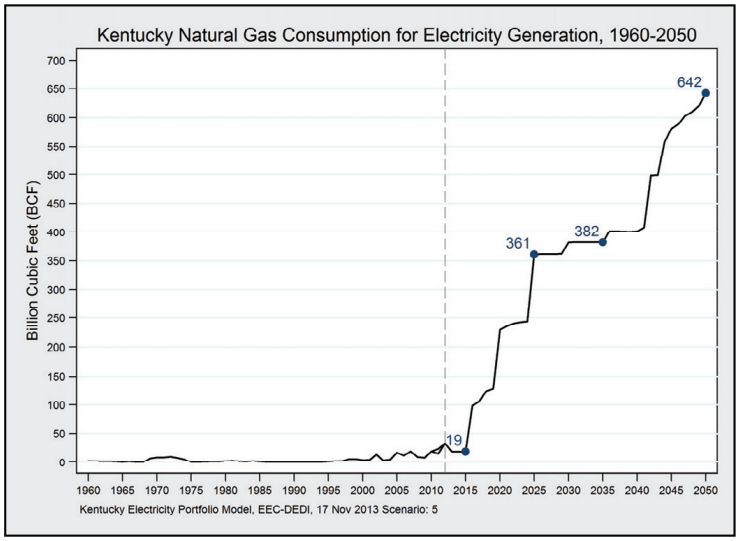
Scenario 5

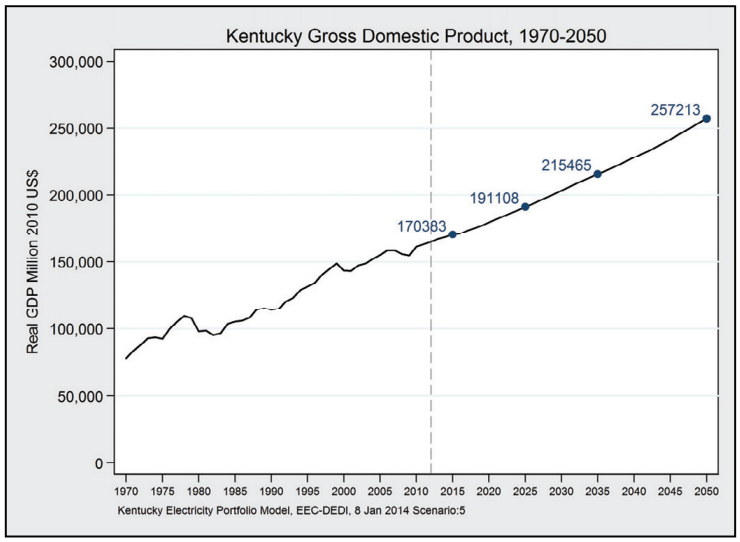
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 1: Nuclear Banned

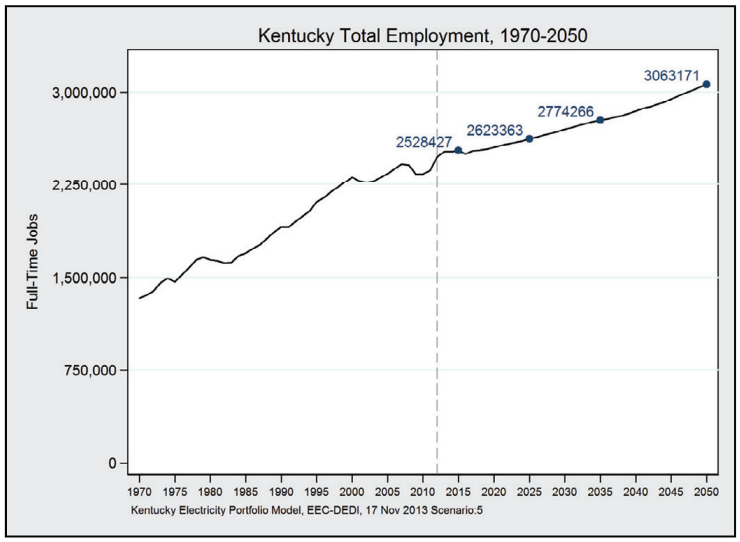






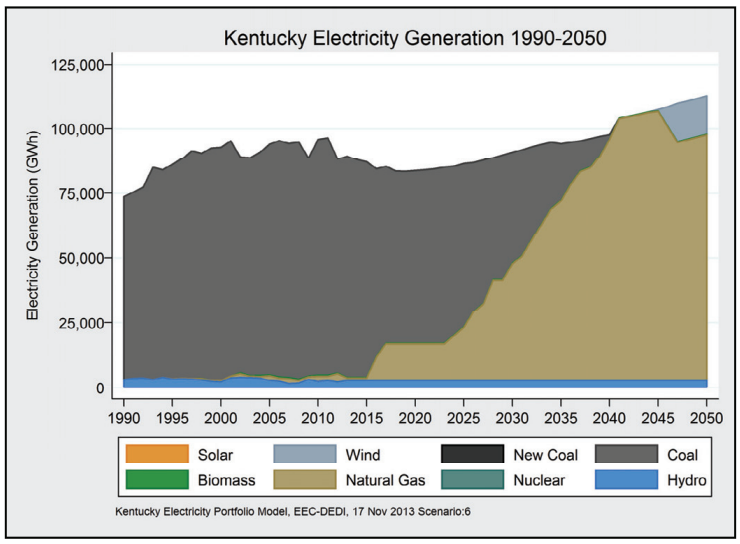


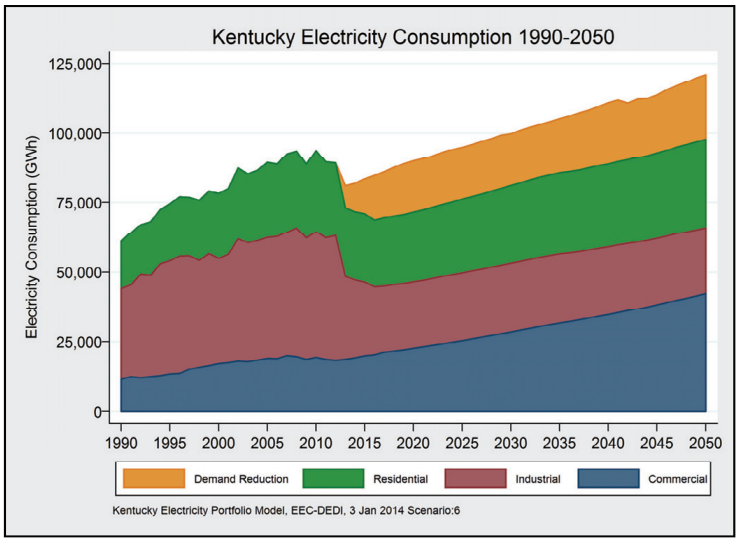


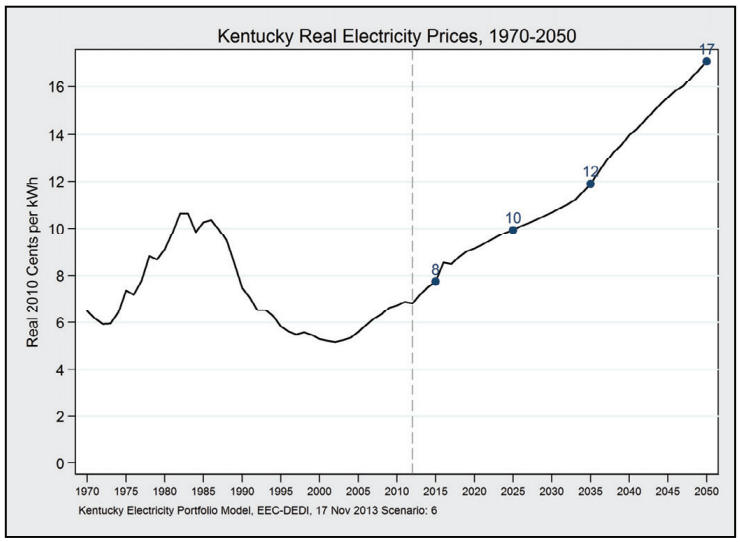


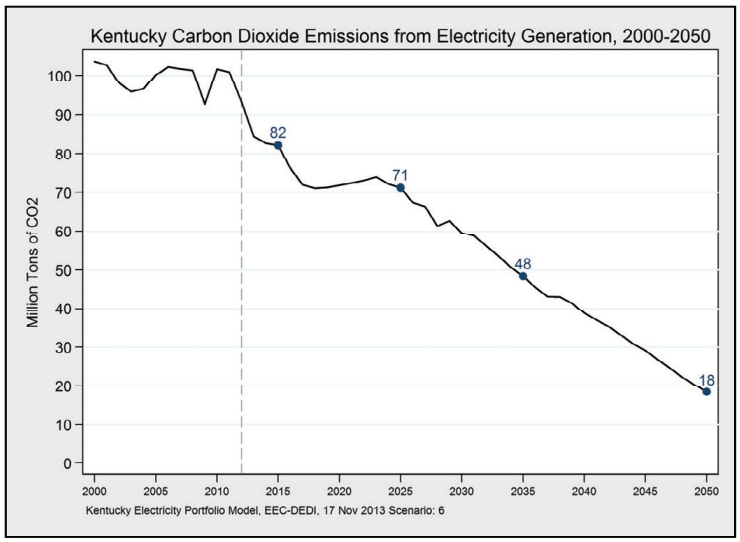
Scenario 6

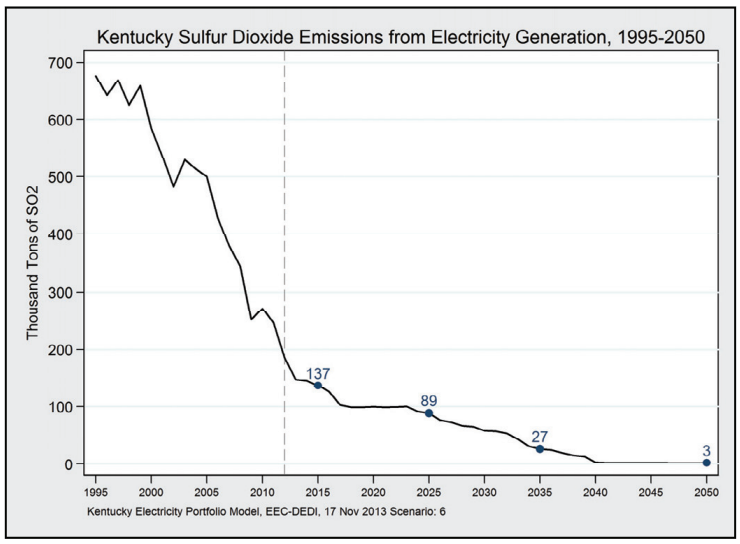
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 1: Nuclear Banned

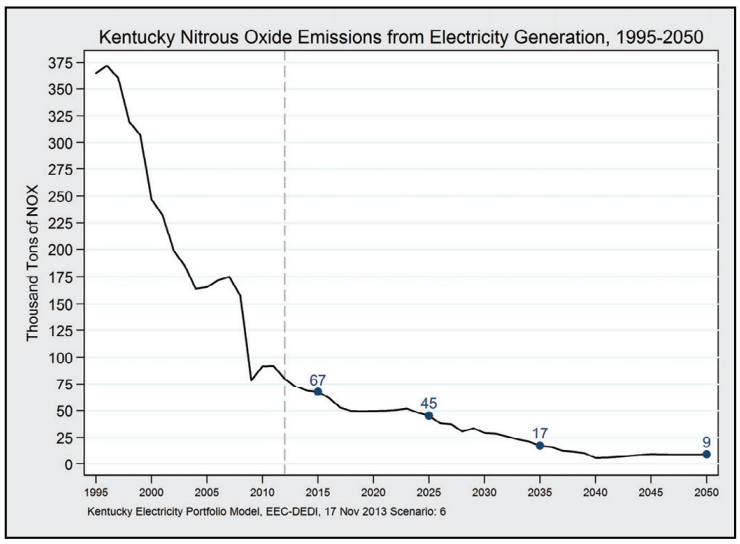






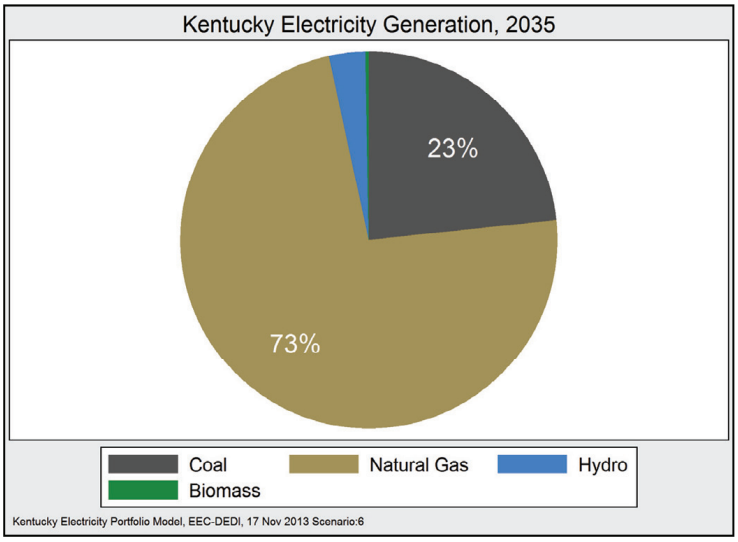


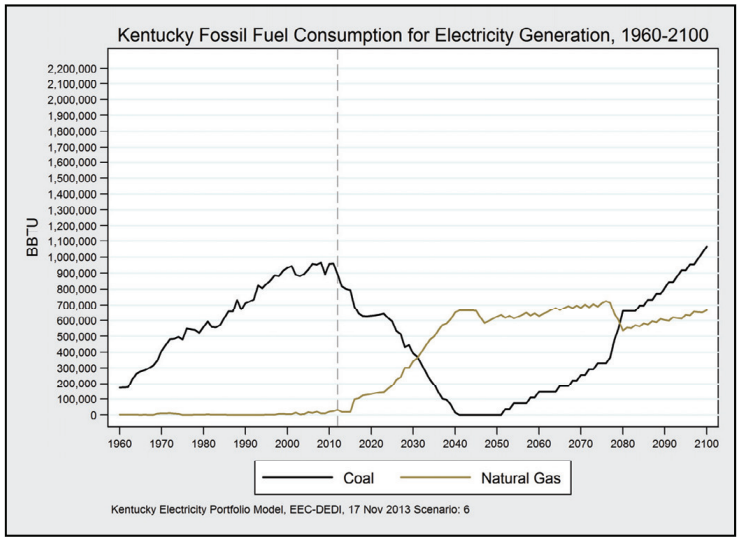


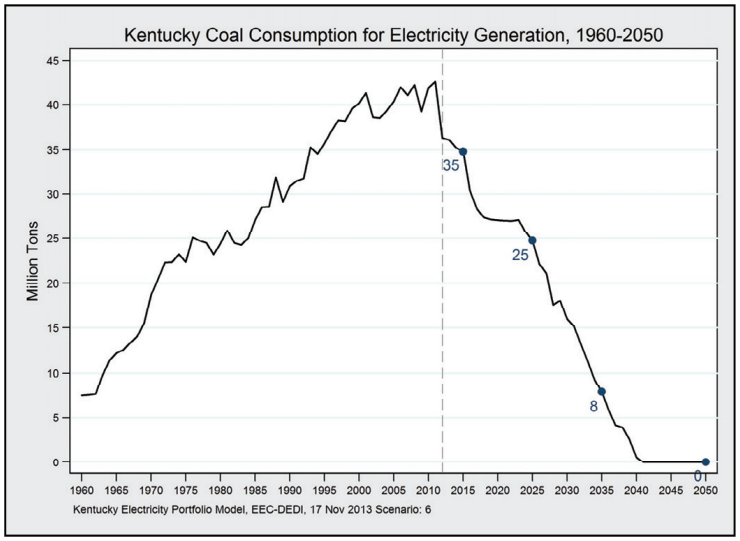


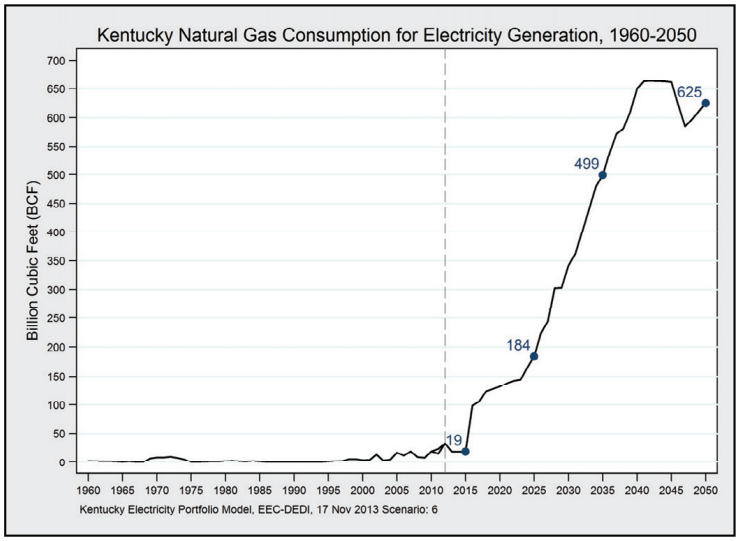
Scenario 6

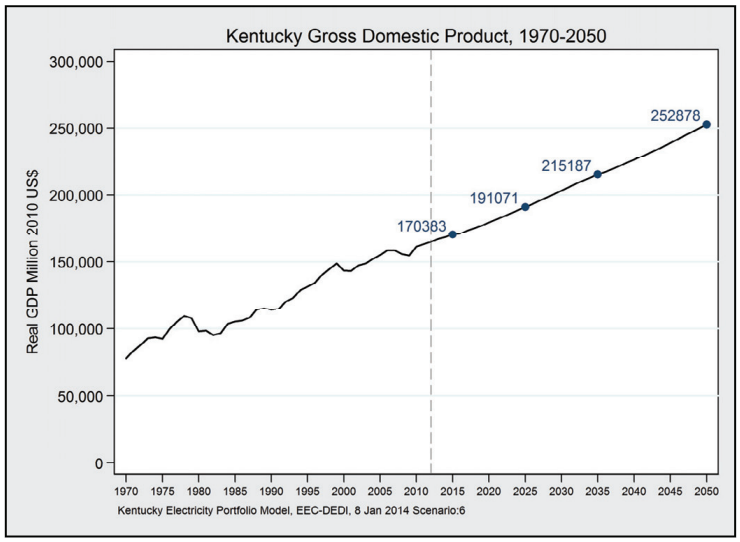
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 1: Nuclear Banned

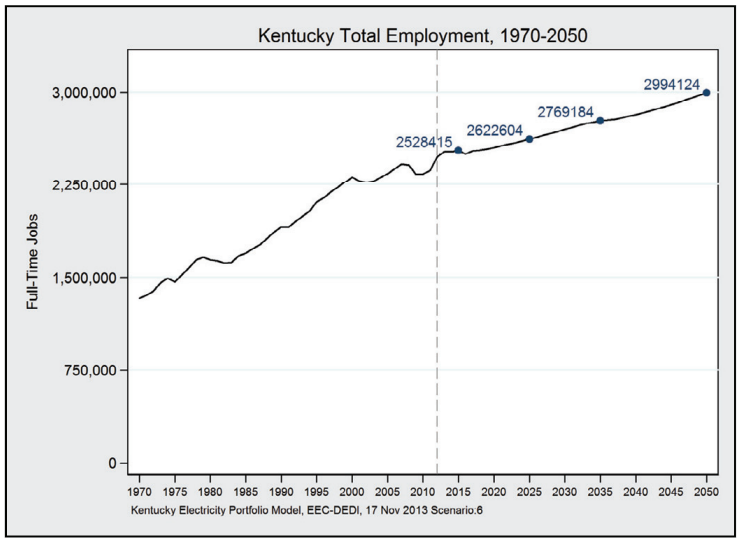






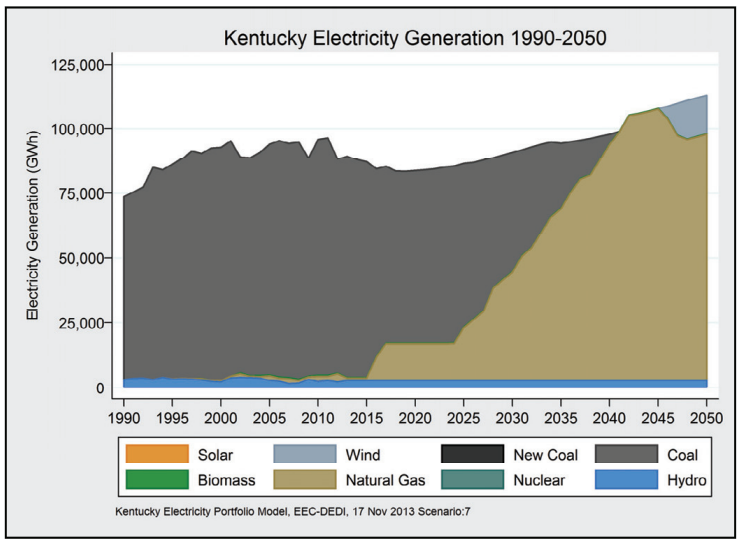


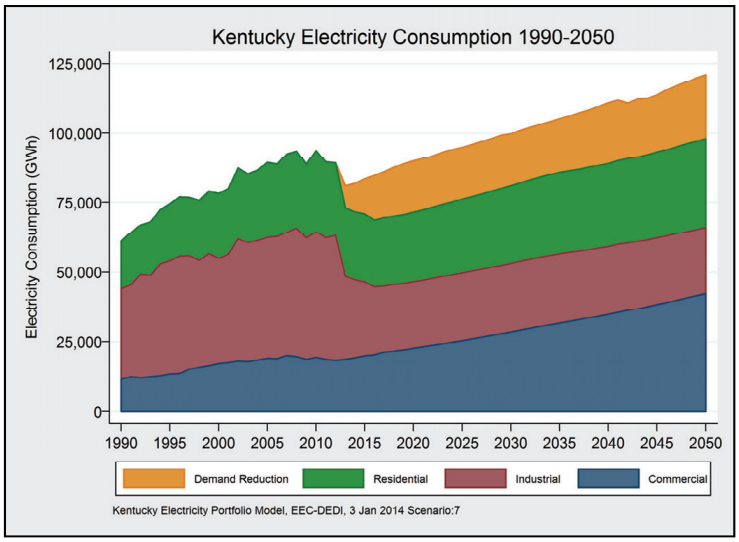


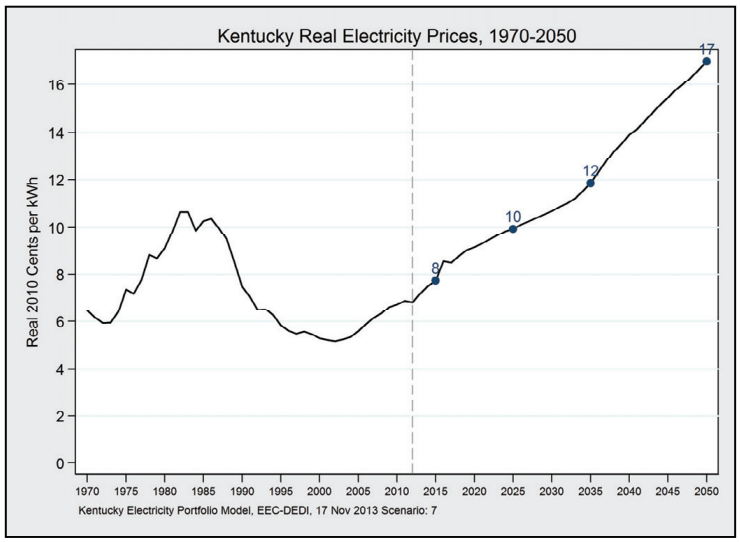


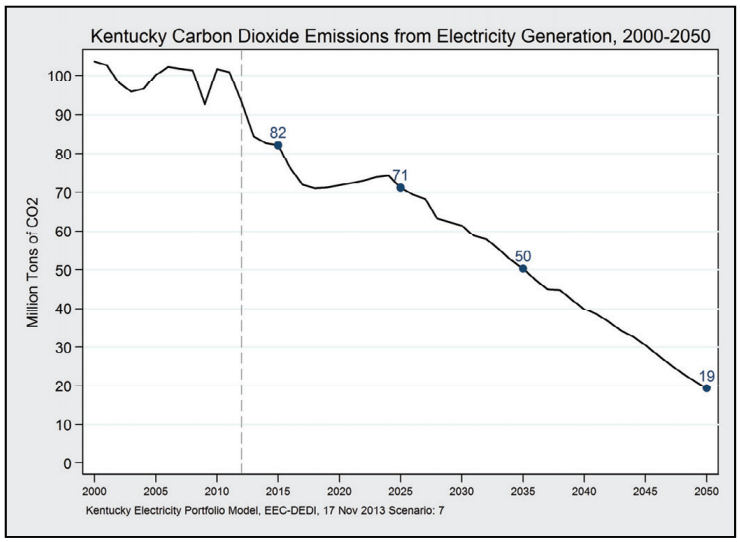
Scenario 7

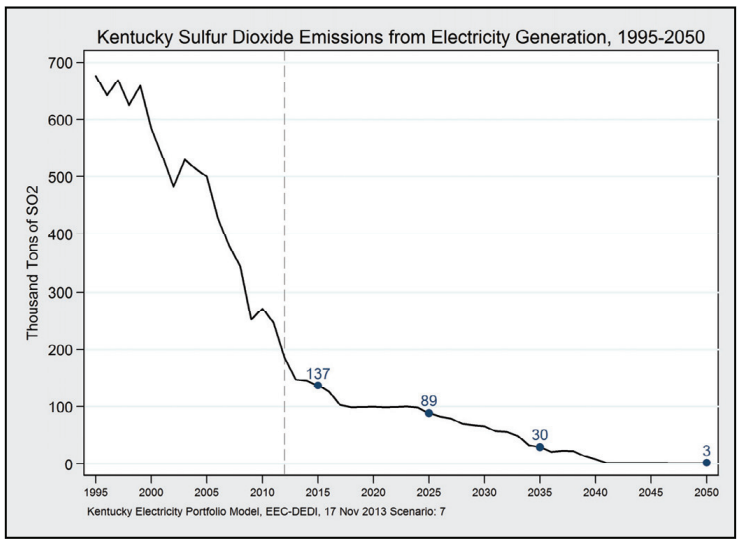
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 1: Nuclear Banned

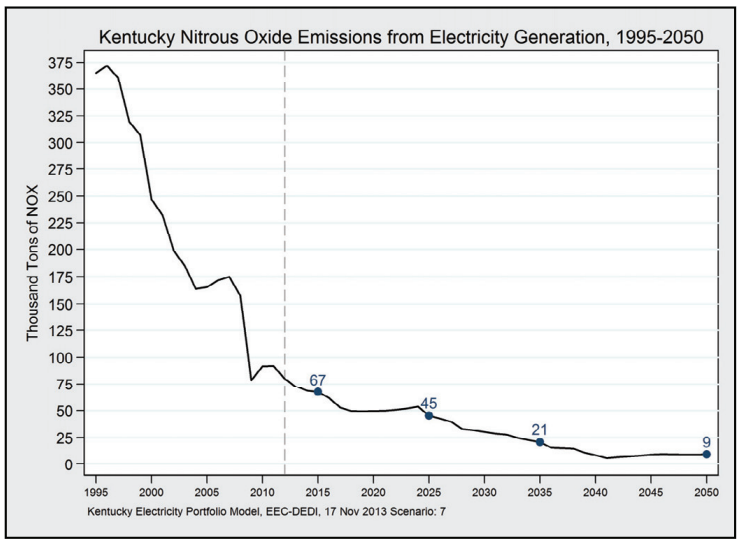






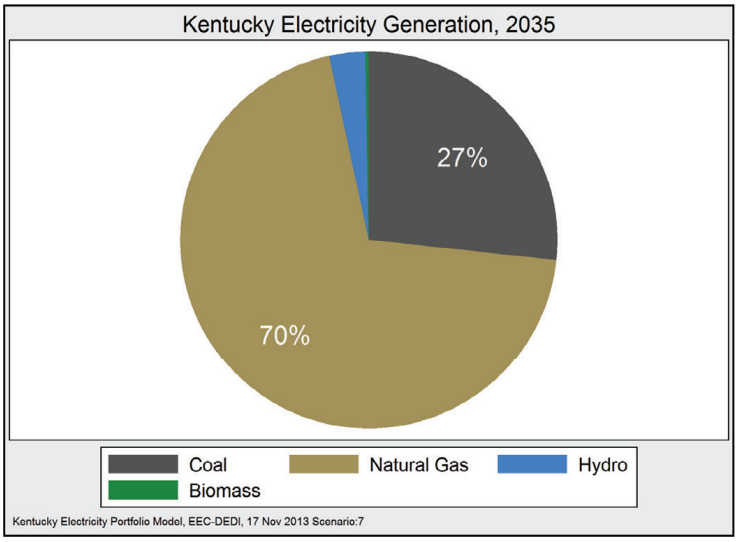


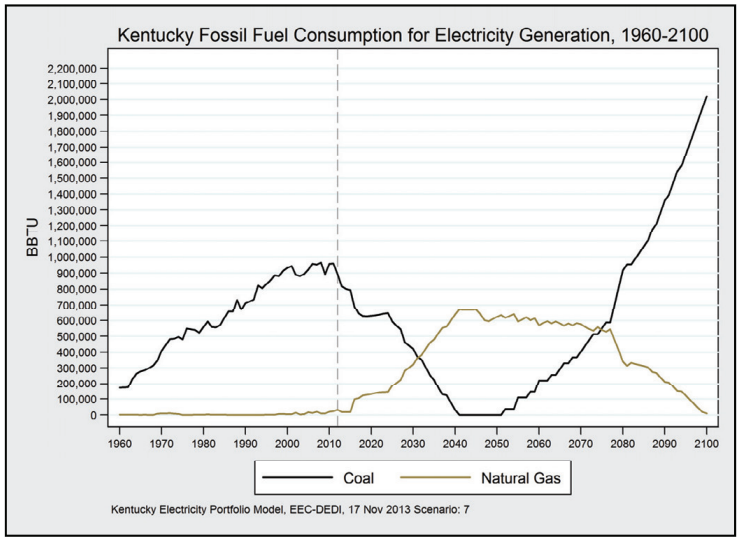


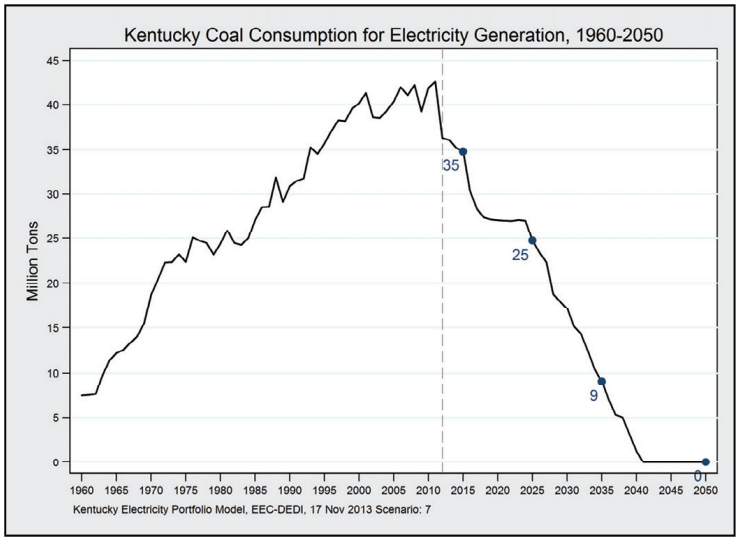


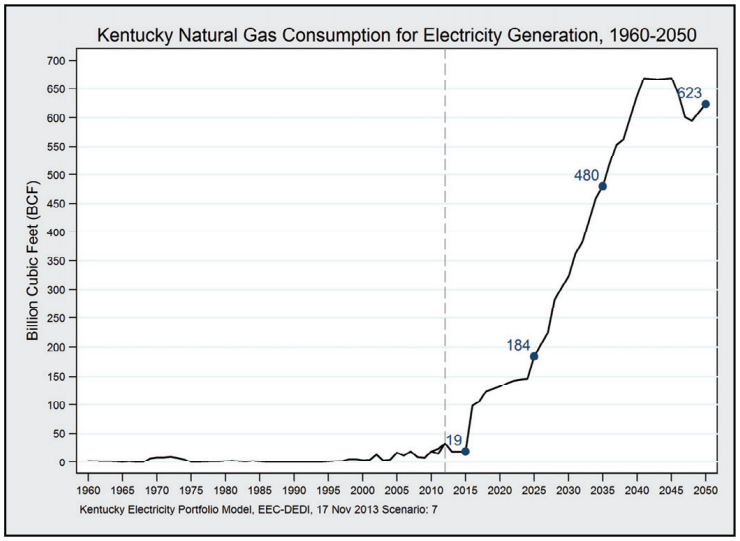
Scenario 7

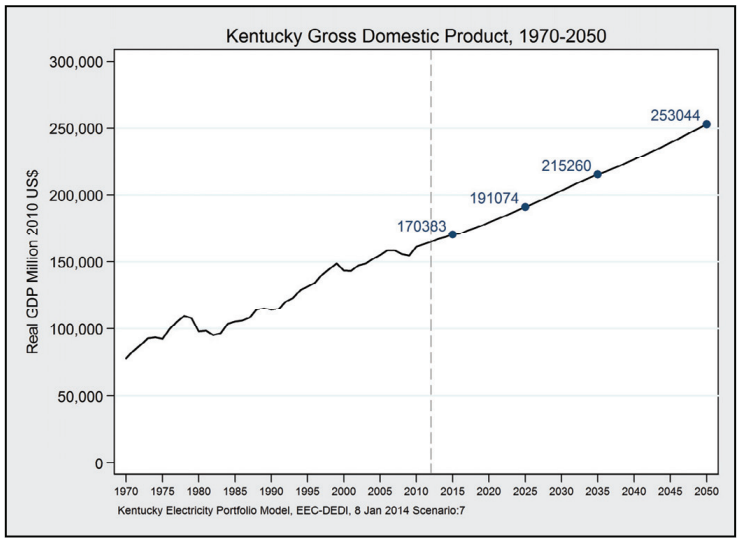
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 1: Nuclear Banned

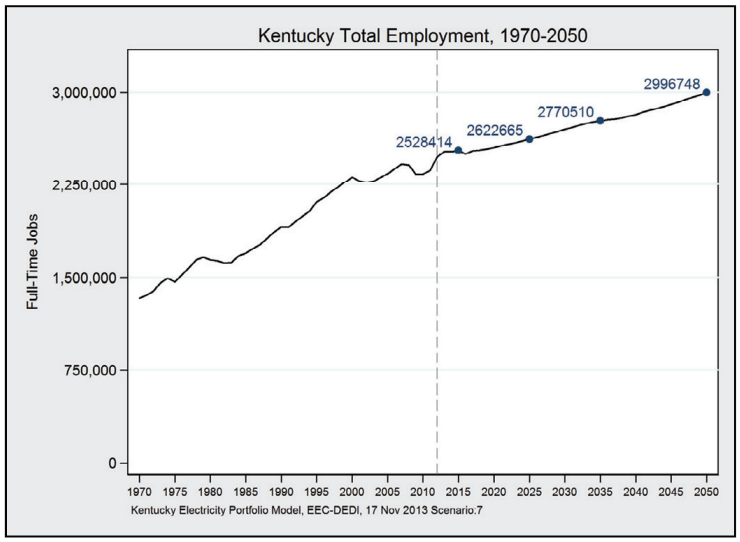






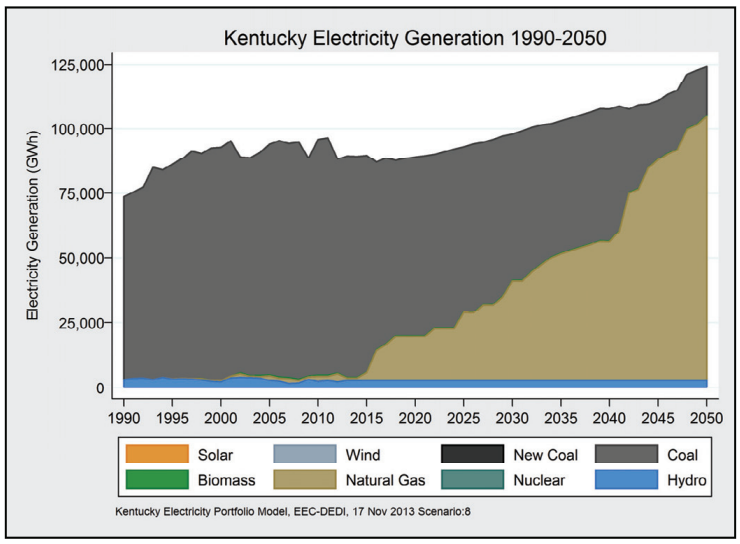


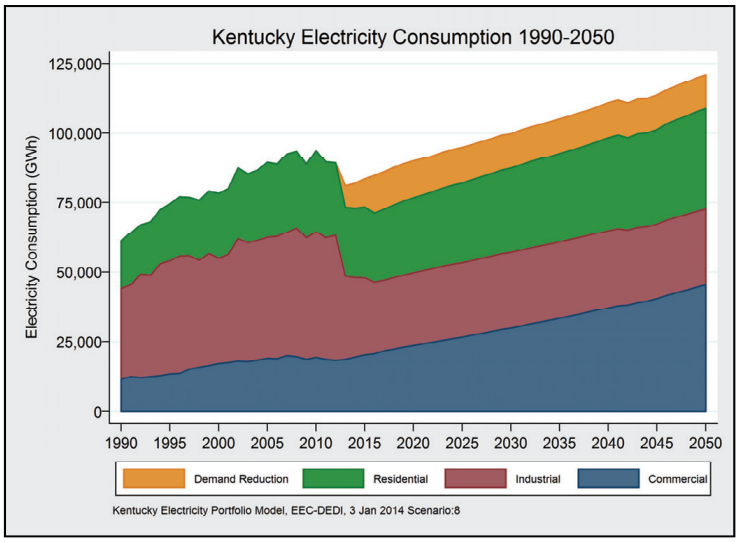


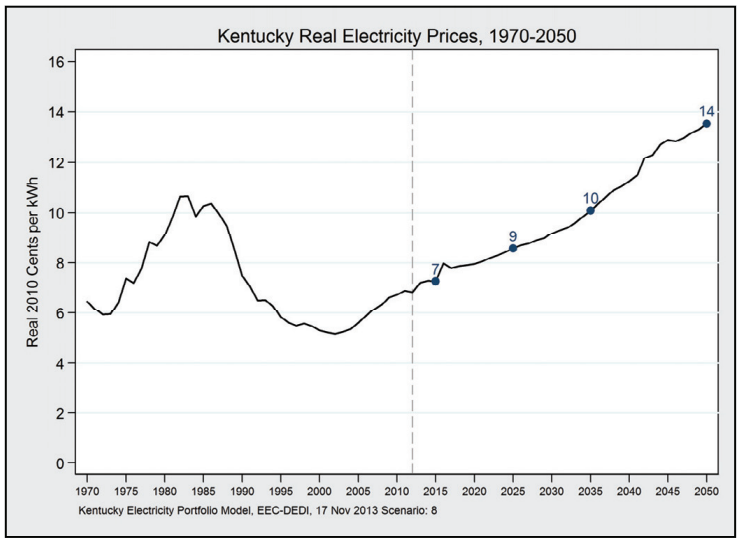


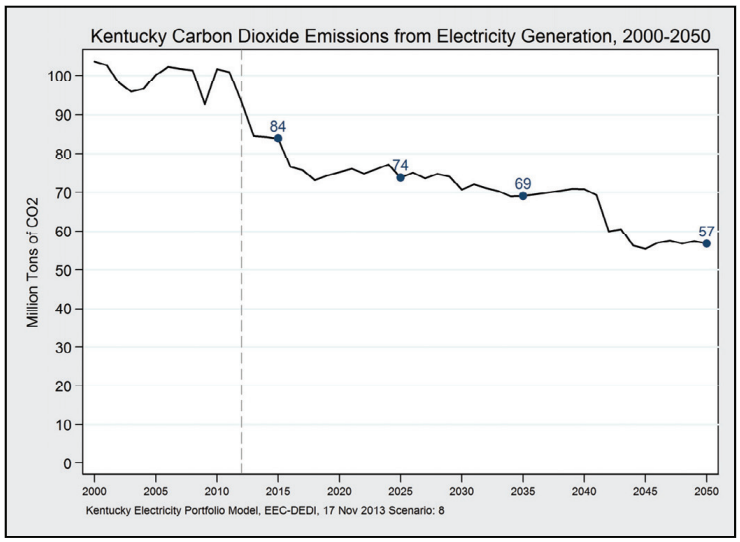
Scenario 8

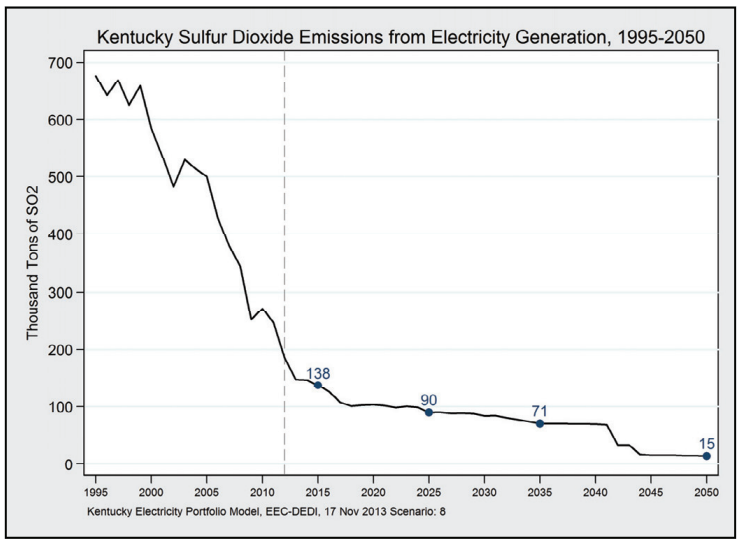
Federal Policy Option 1: Reference Portfolio 2: Nuclear Allowed

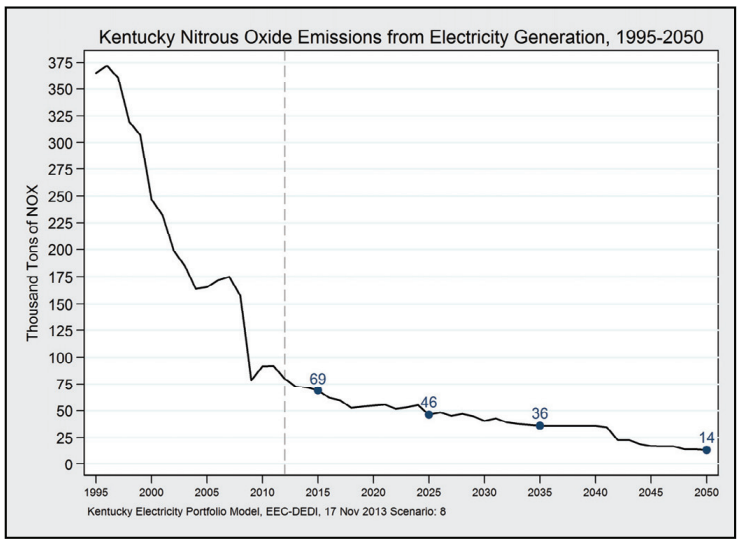






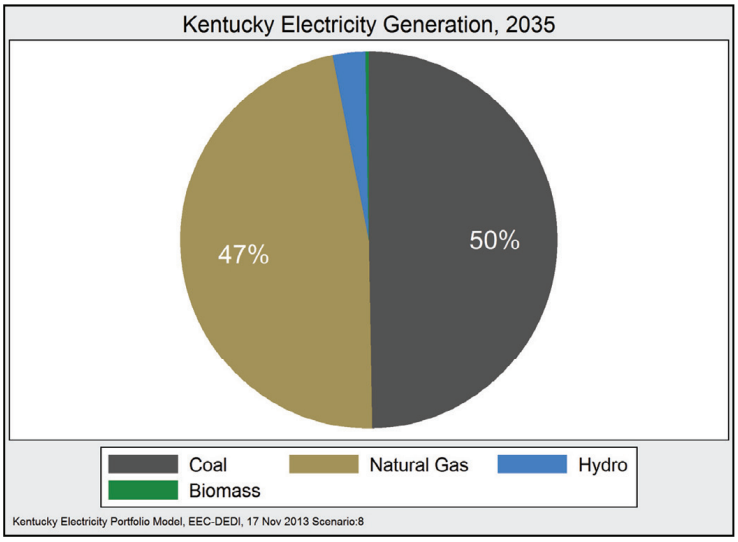


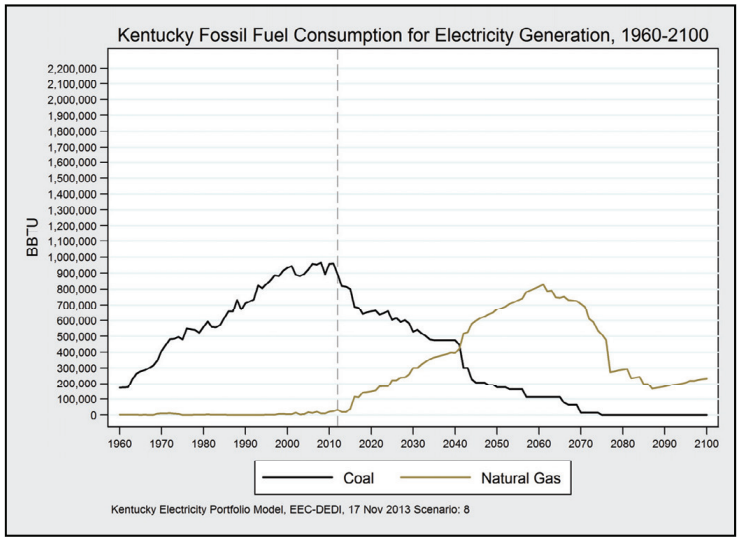


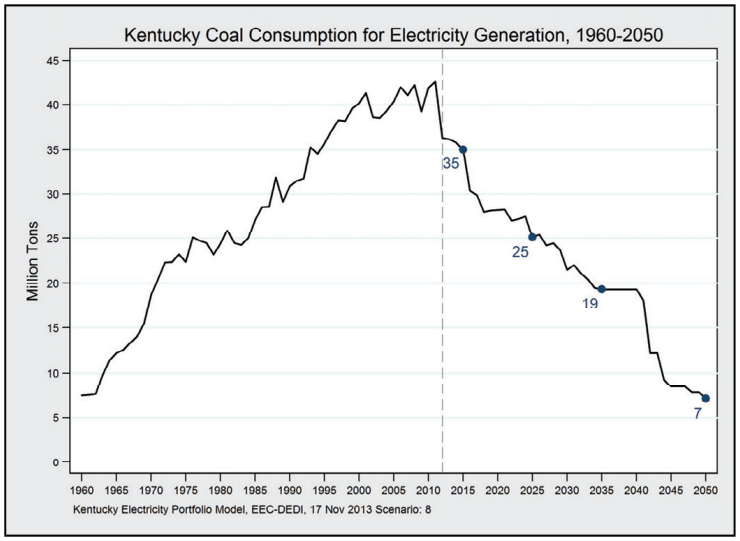


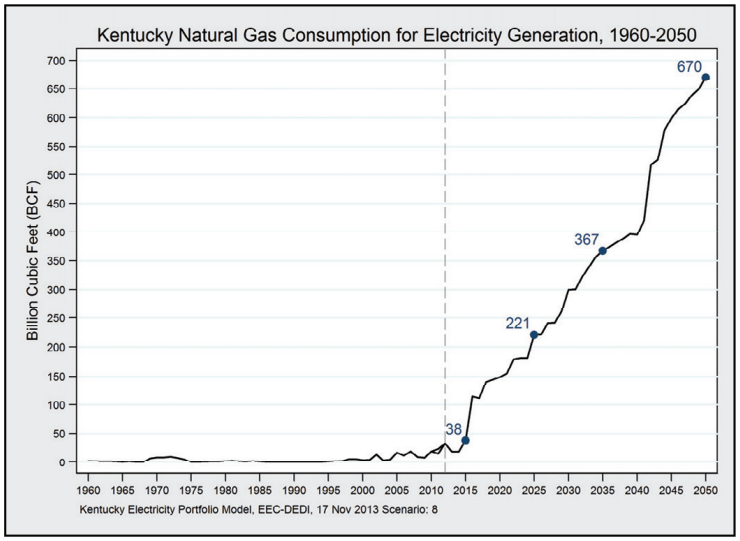
Scenario 8

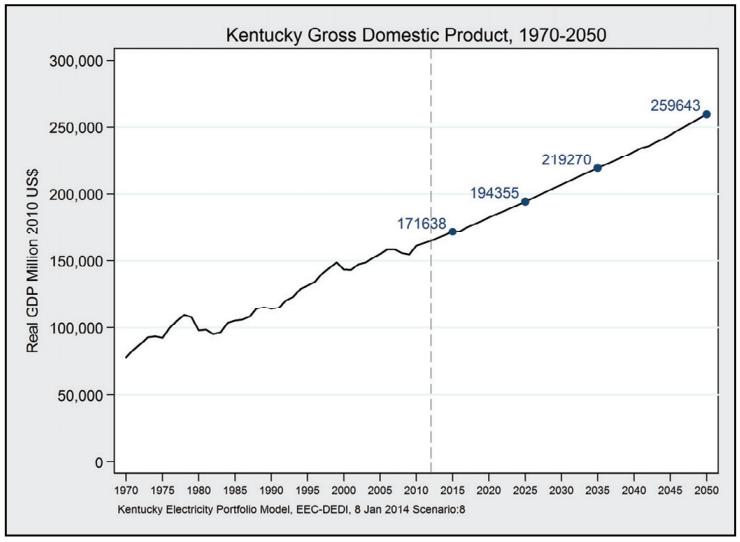
Federal Policy Option 1: Reference Portfolio 2: Nuclear Allowed

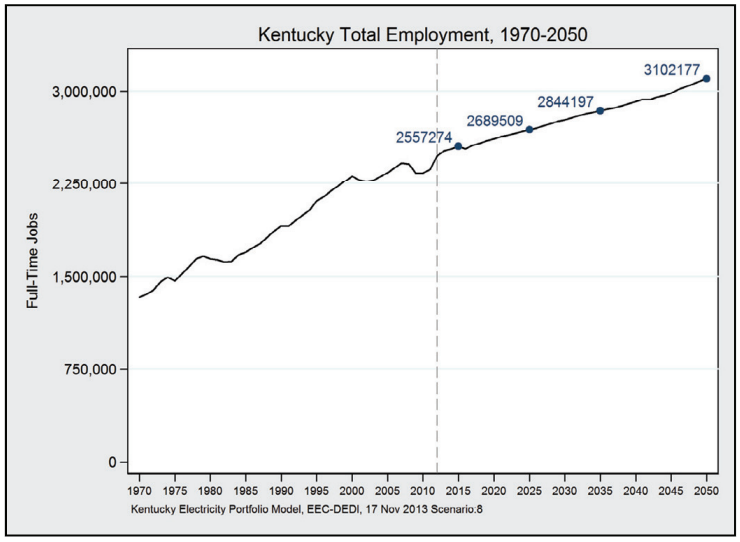






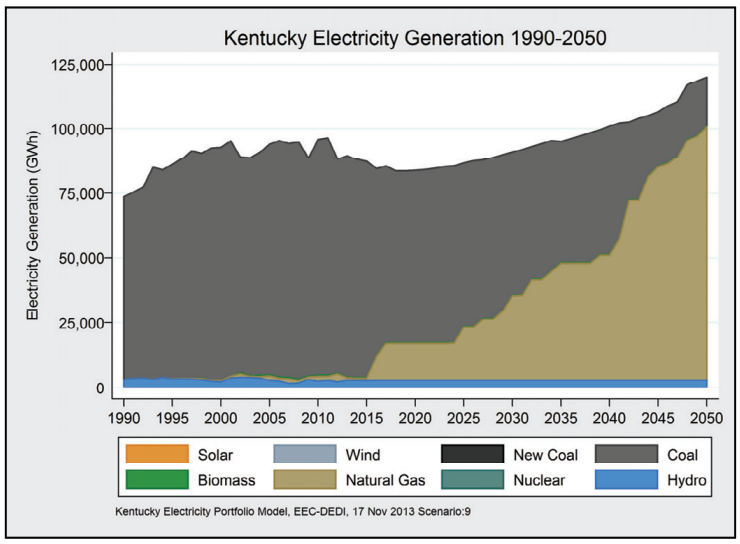


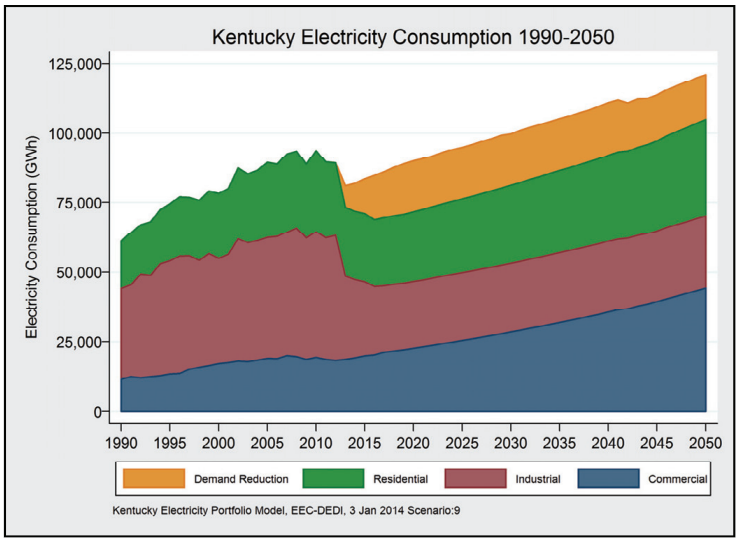


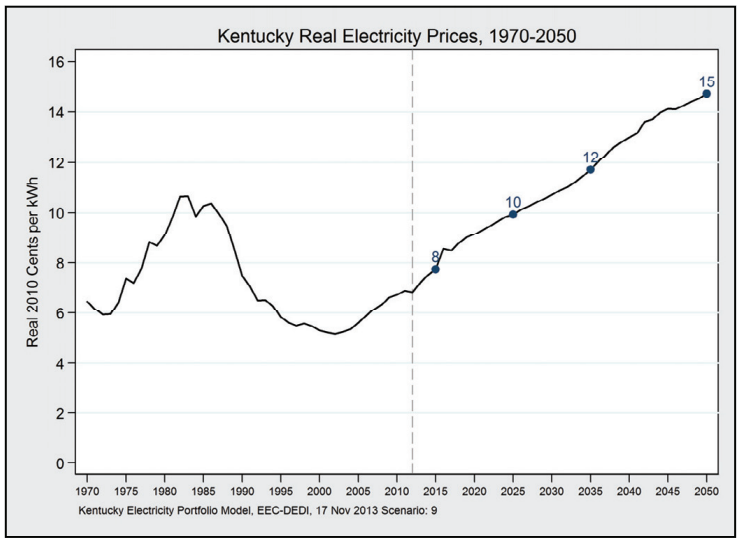


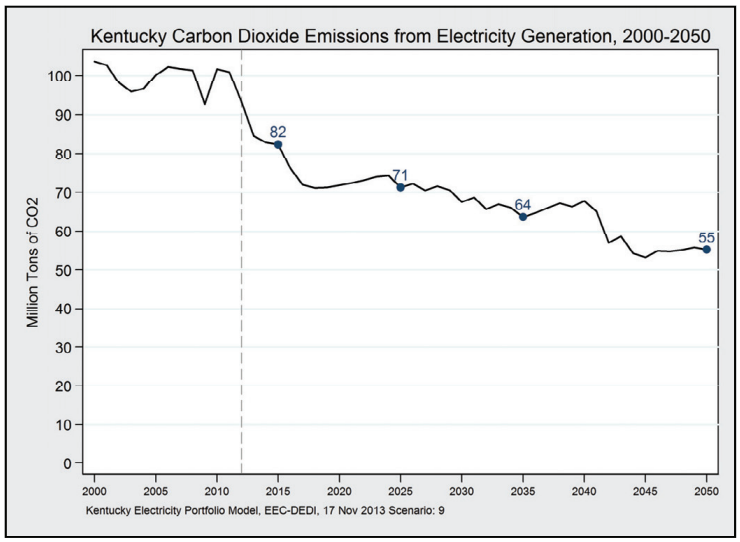
Scenario 9

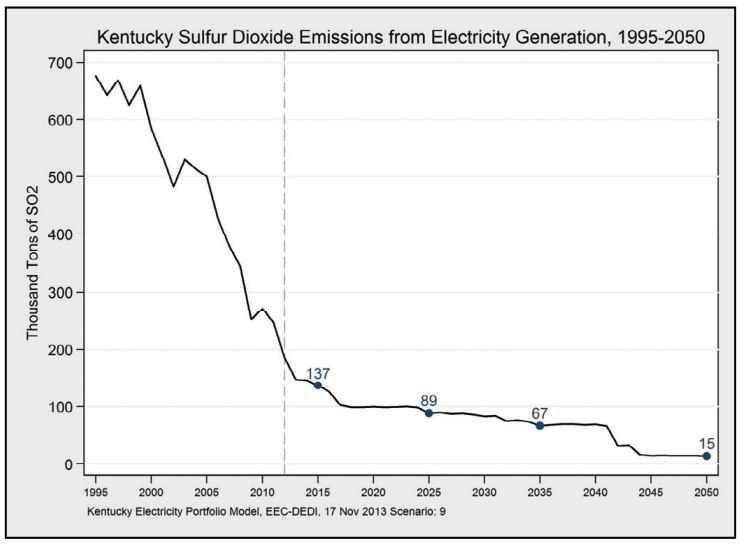
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 2: Nuclear Allowed

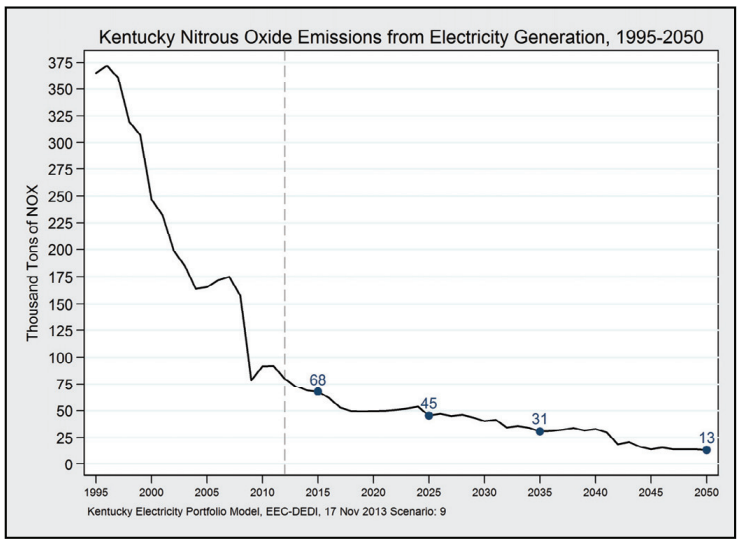






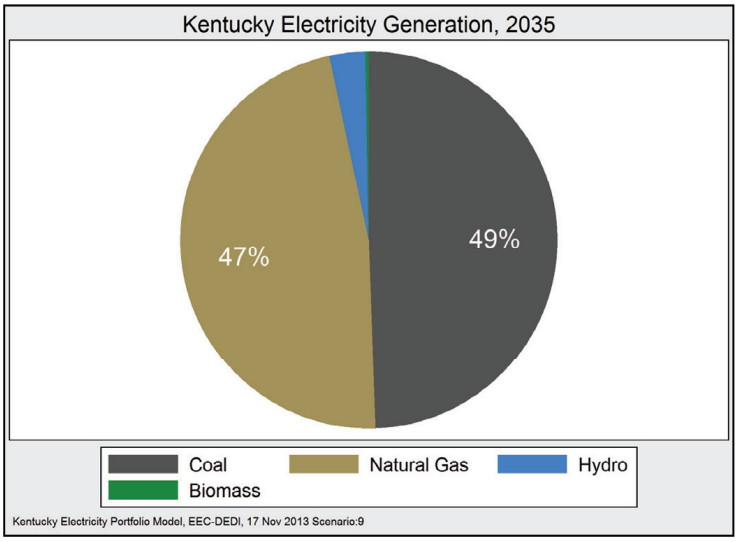


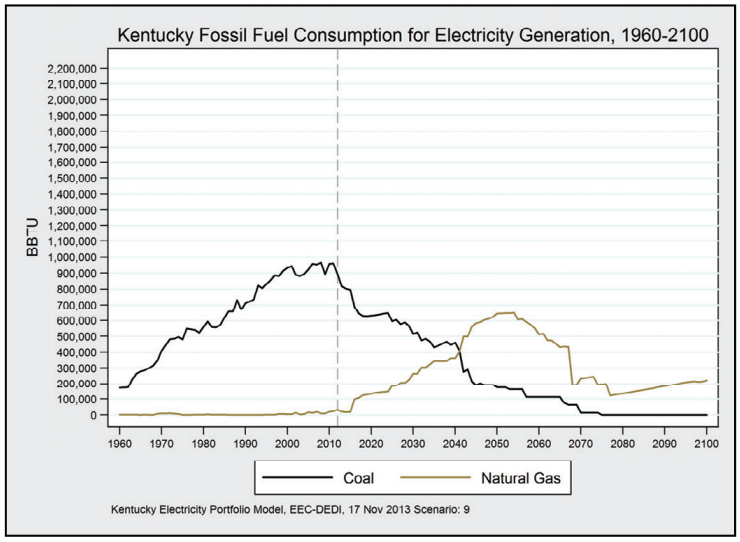


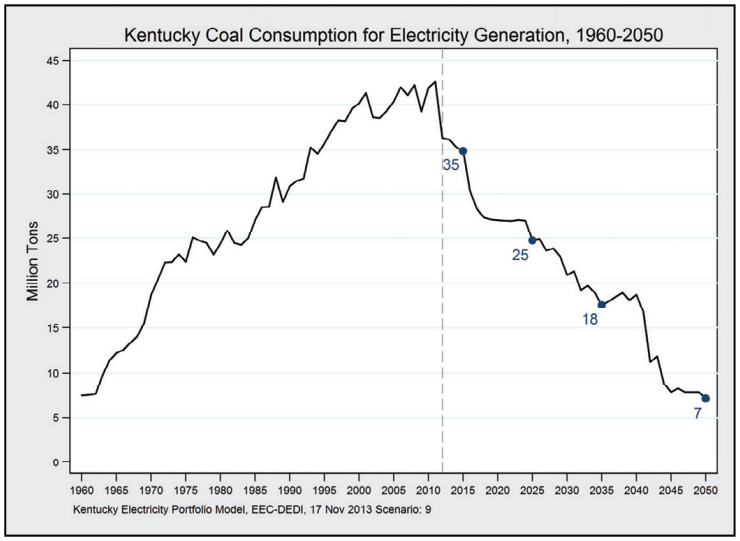


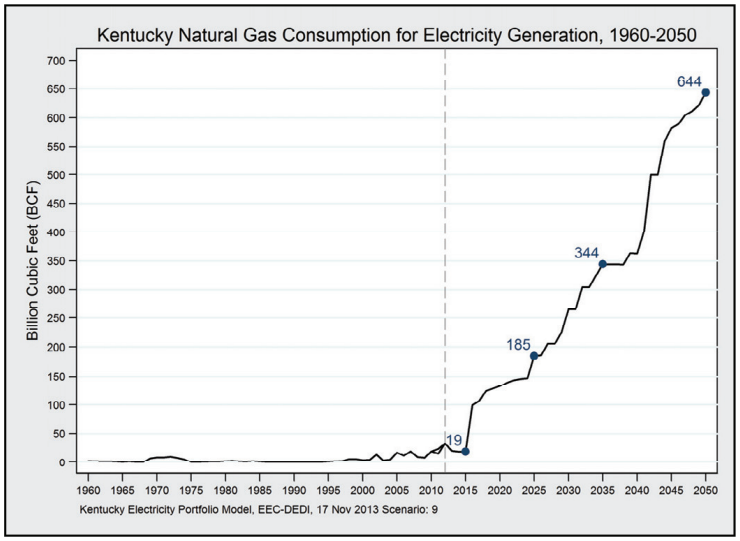
Scenario 9

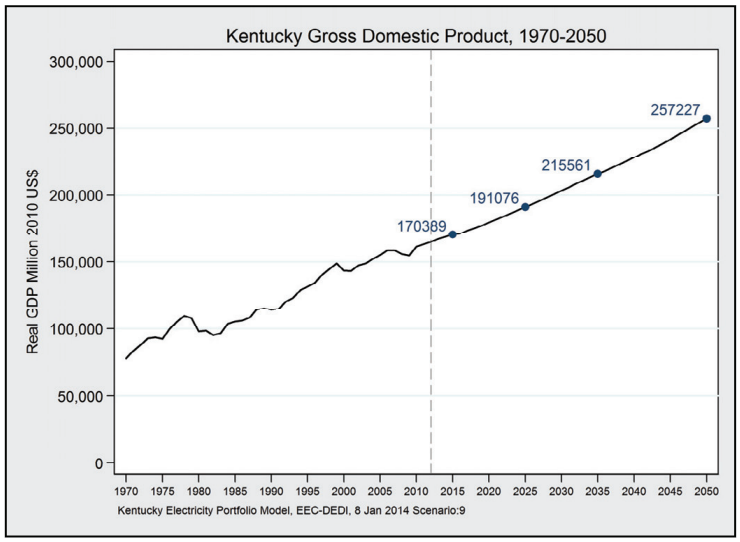
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 2: Nuclear Allowed

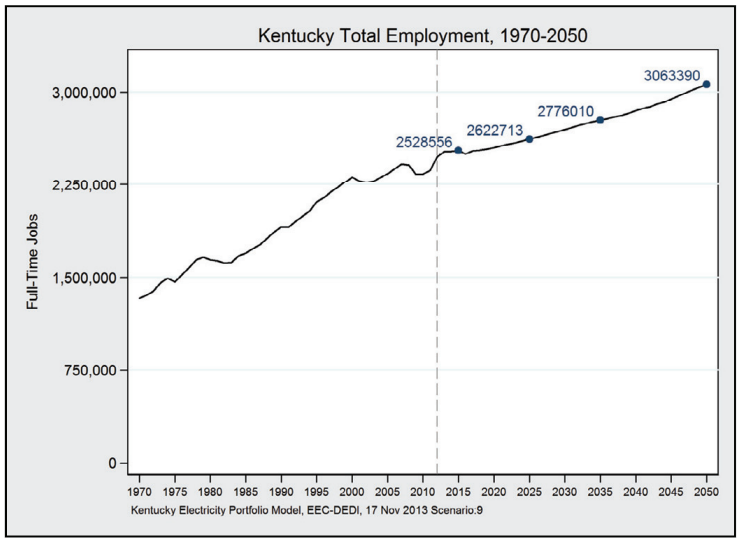






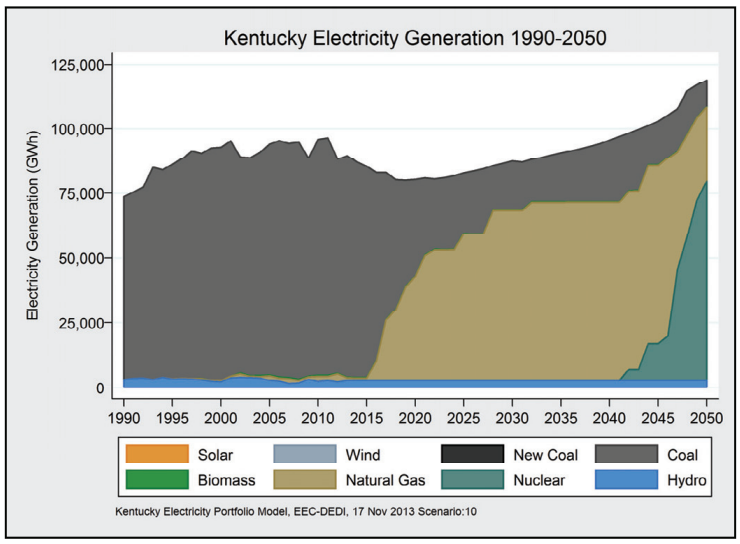


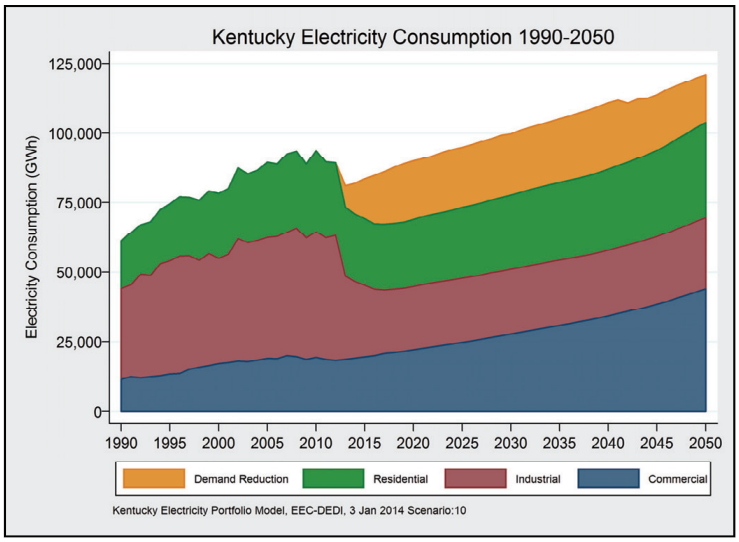


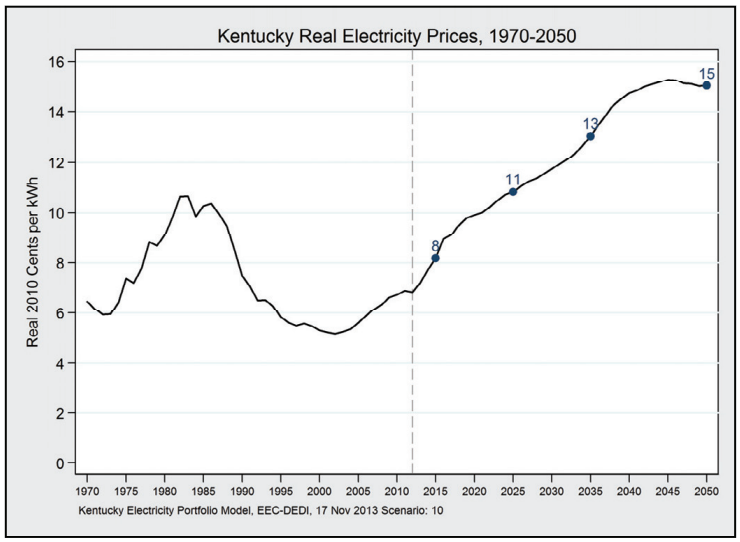


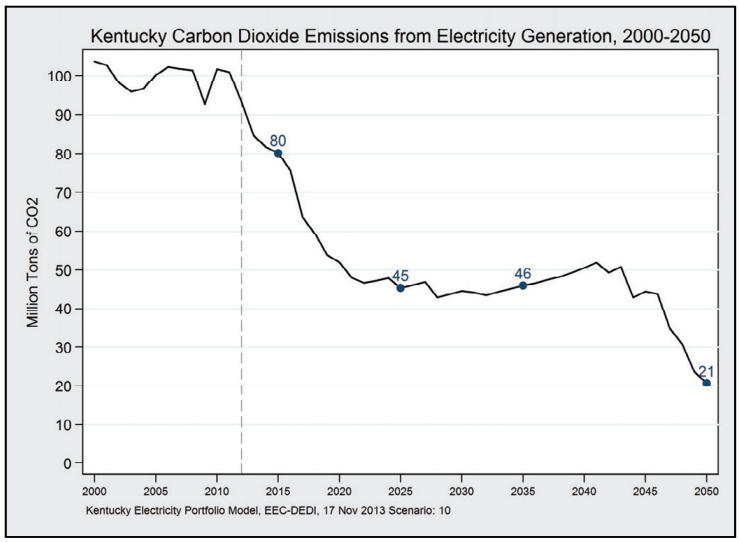
Scenario 10

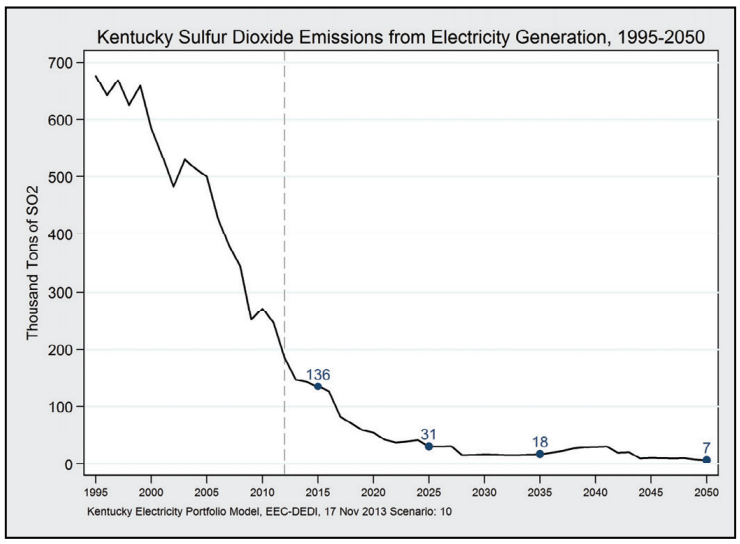
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 2: Nuclear Allowed

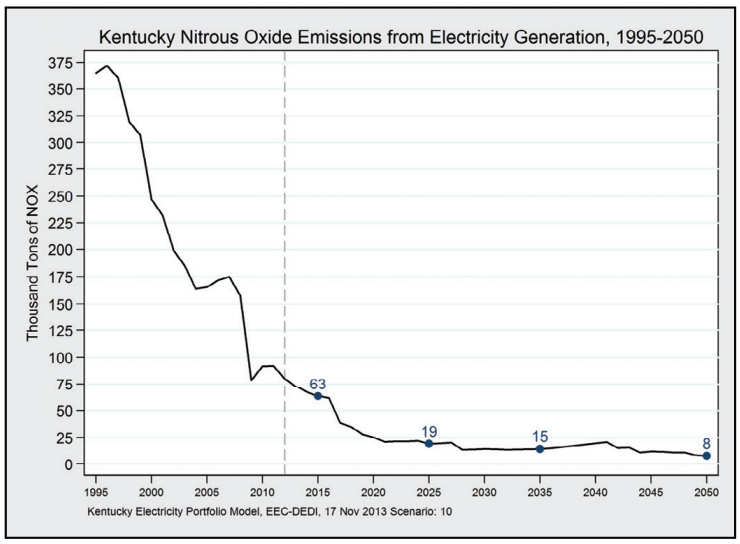






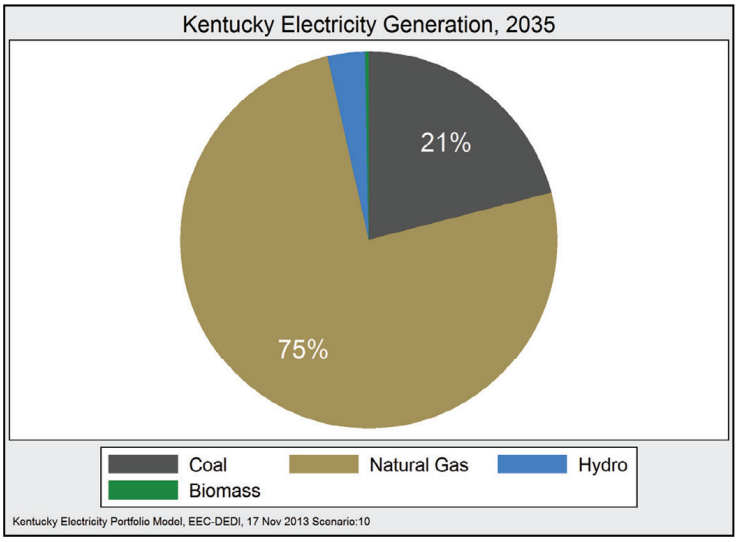


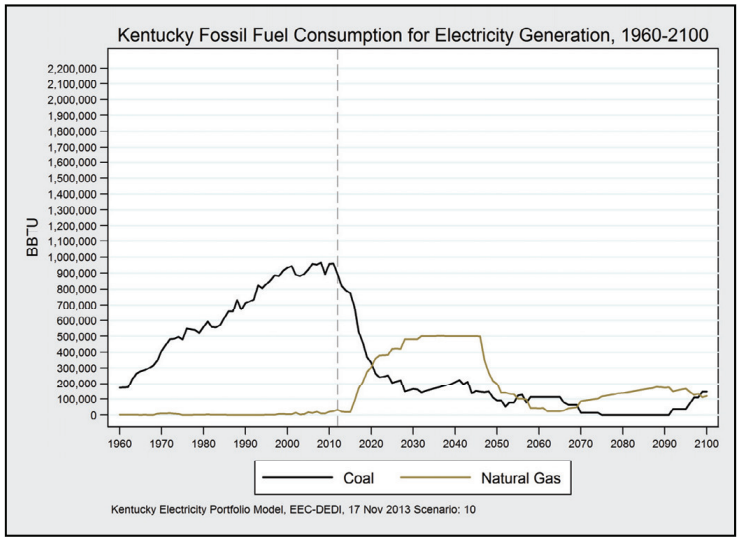


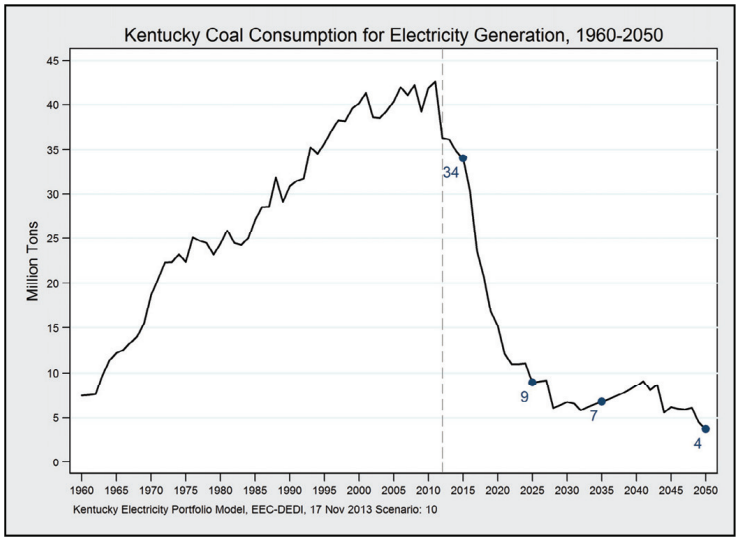


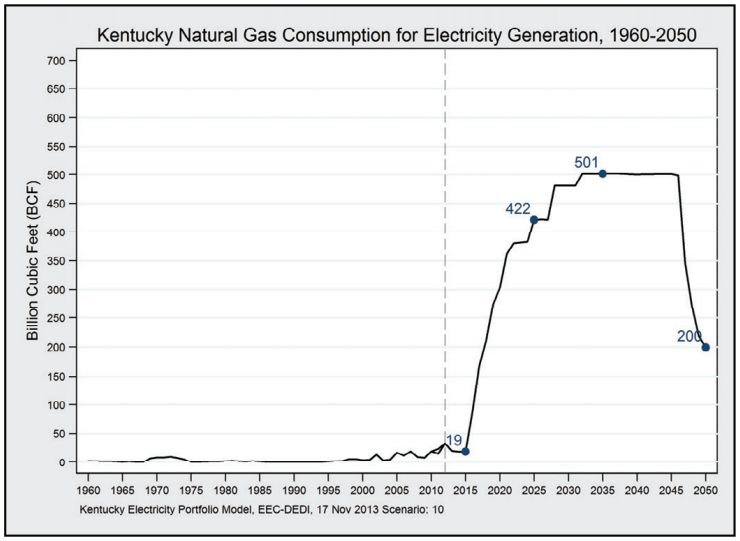
Scenario 10

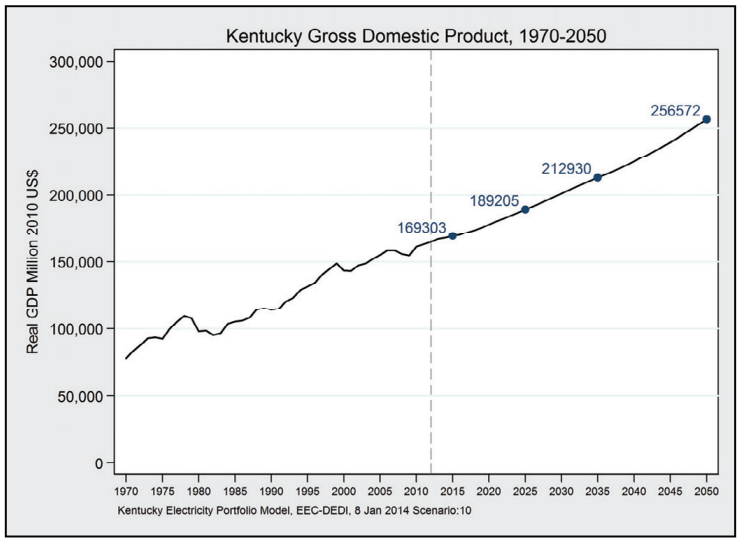
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 2: Nuclear Allowed

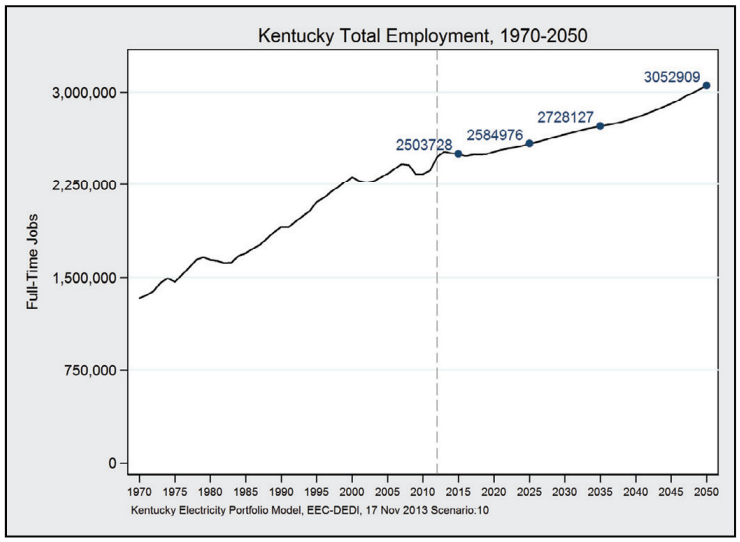






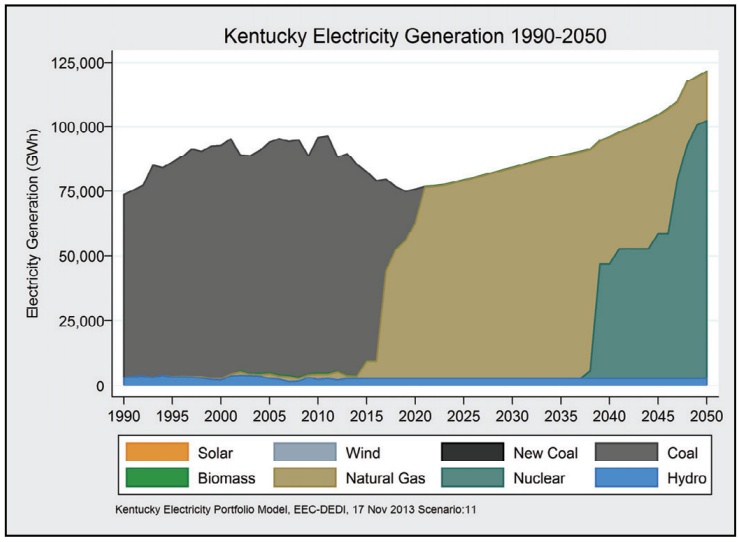


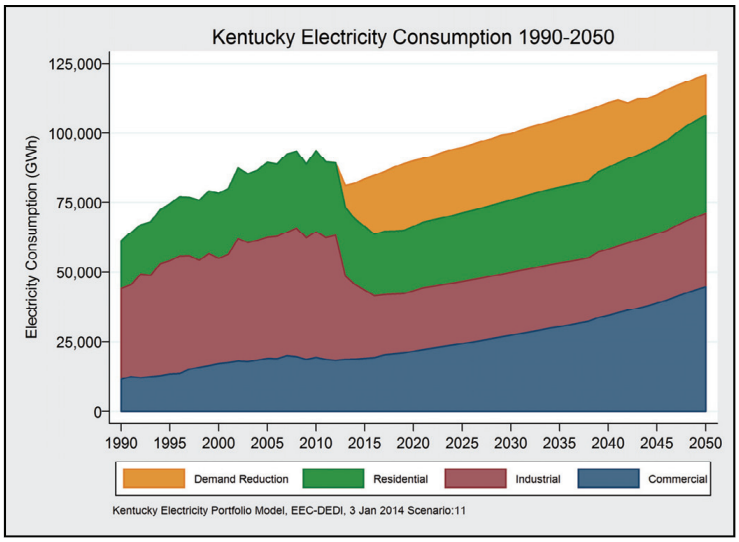


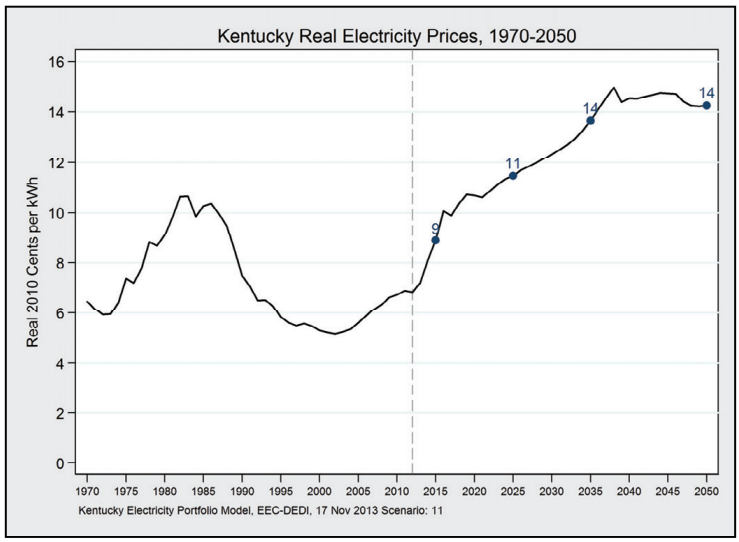


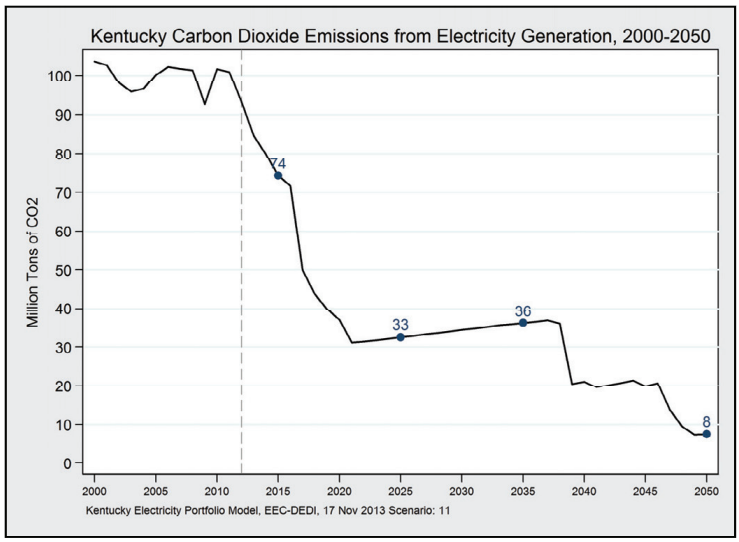
Scenario 11

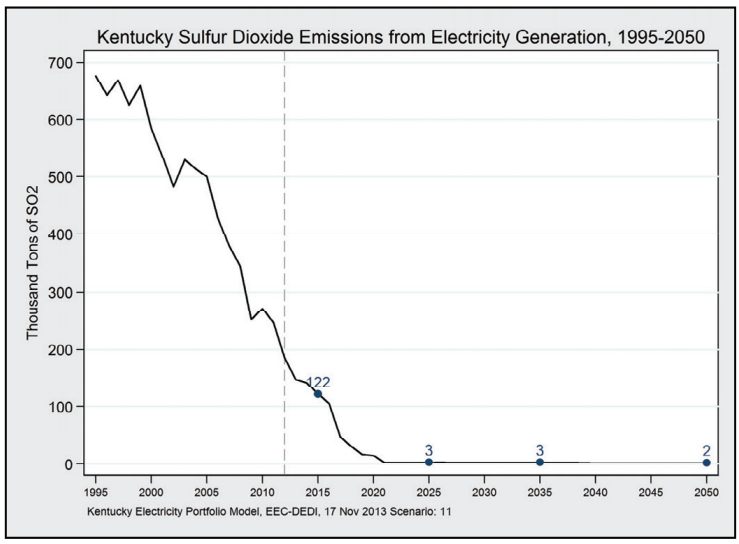
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 2: Nuclear Allowed

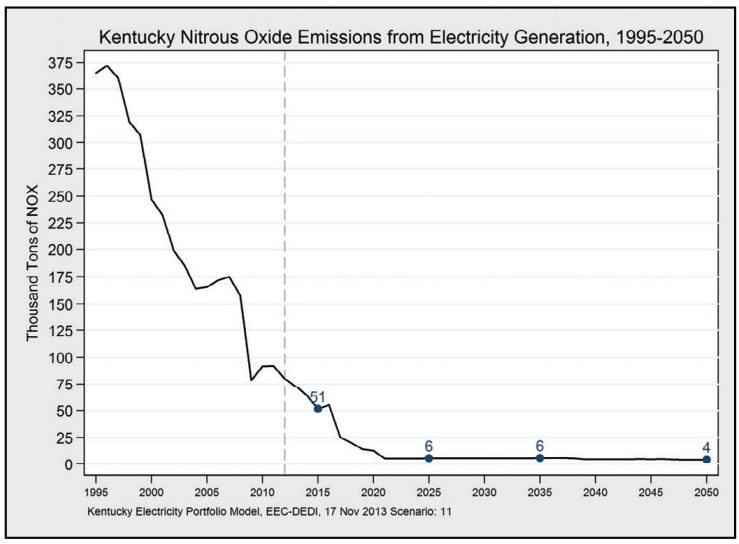






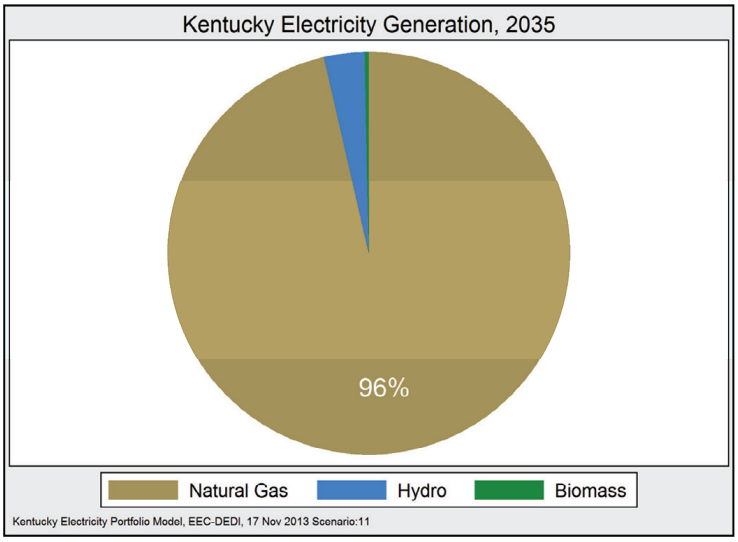


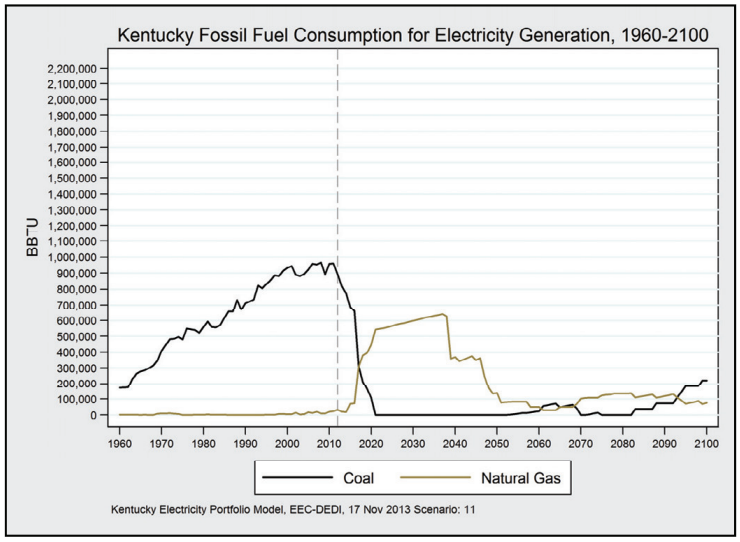


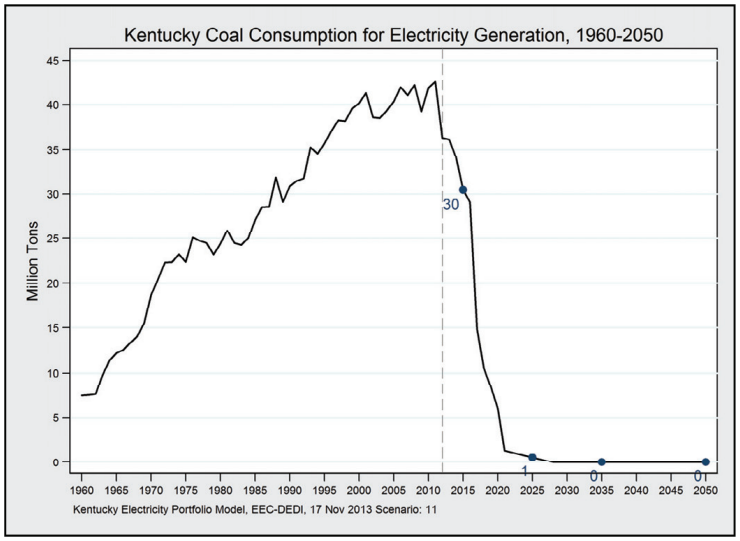


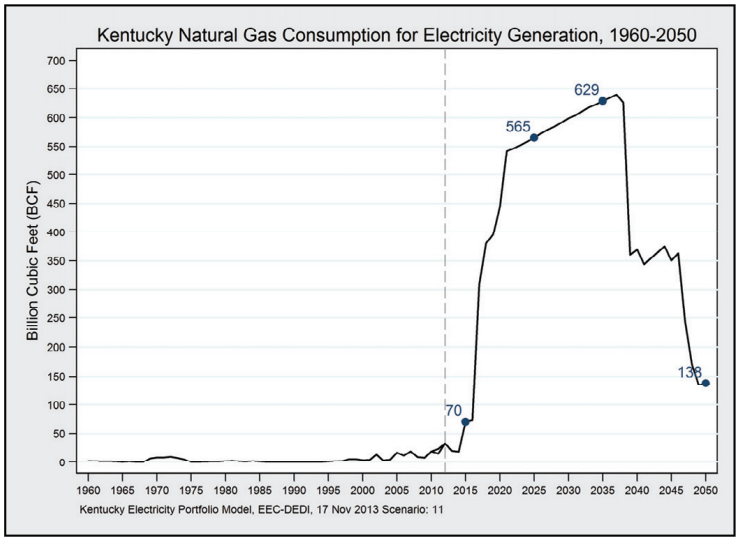
Scenario 11

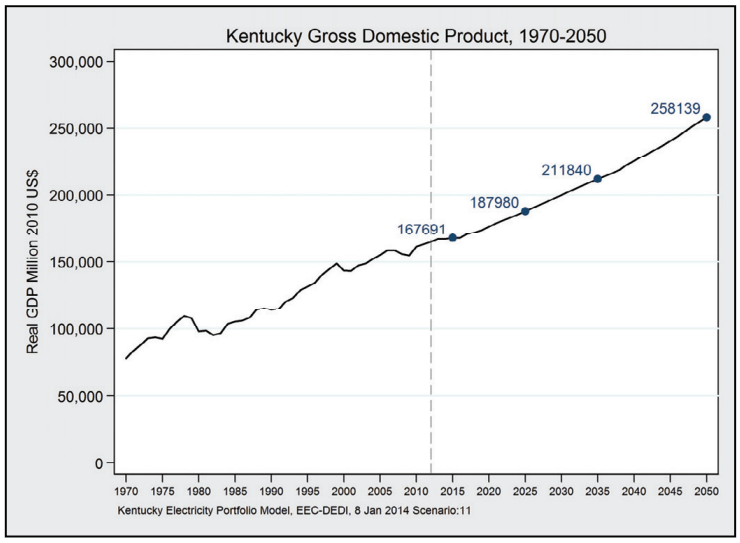
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 2: Nuclear Allowed

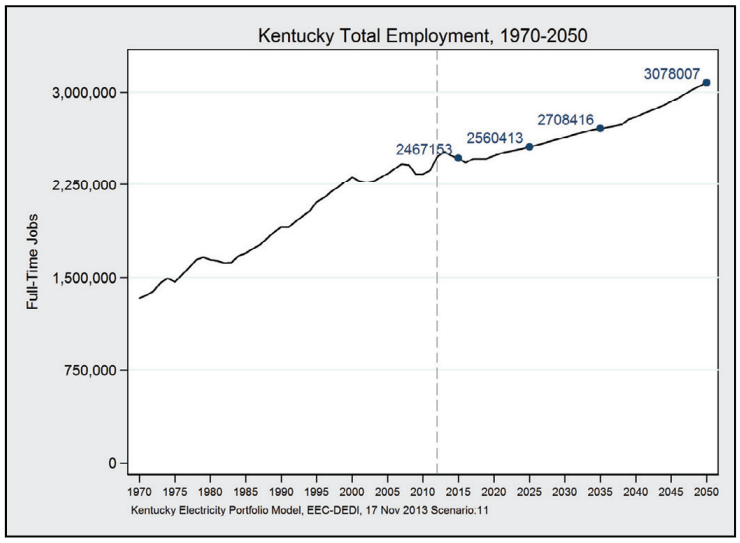






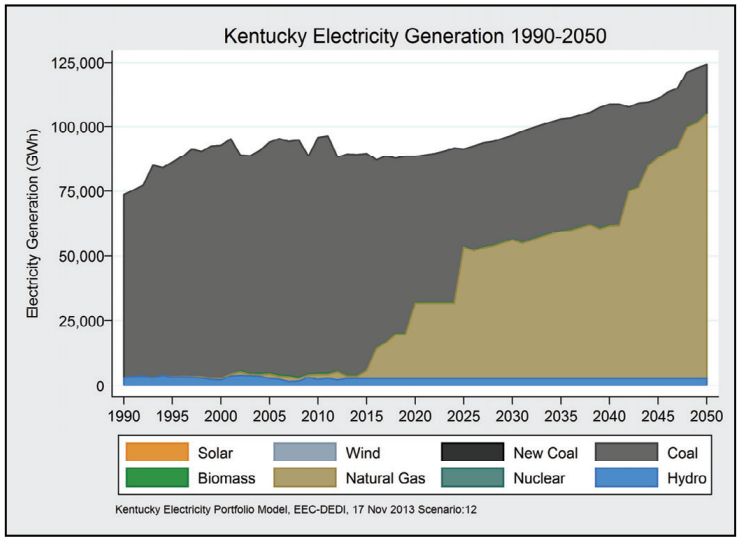


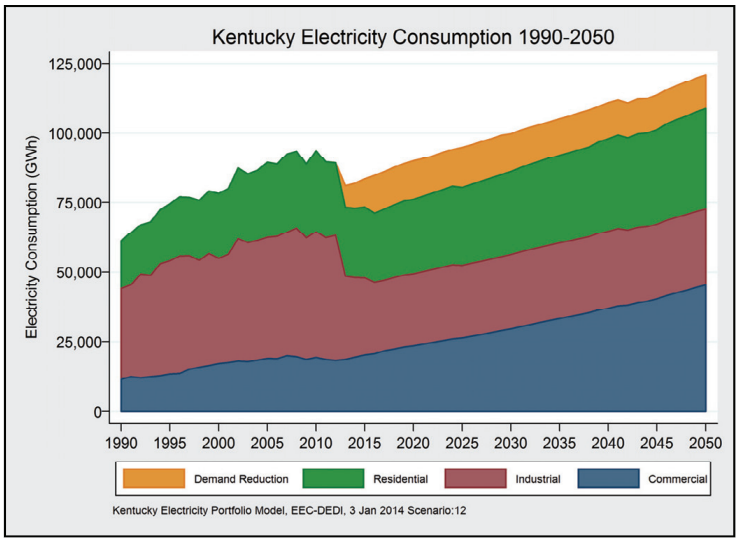


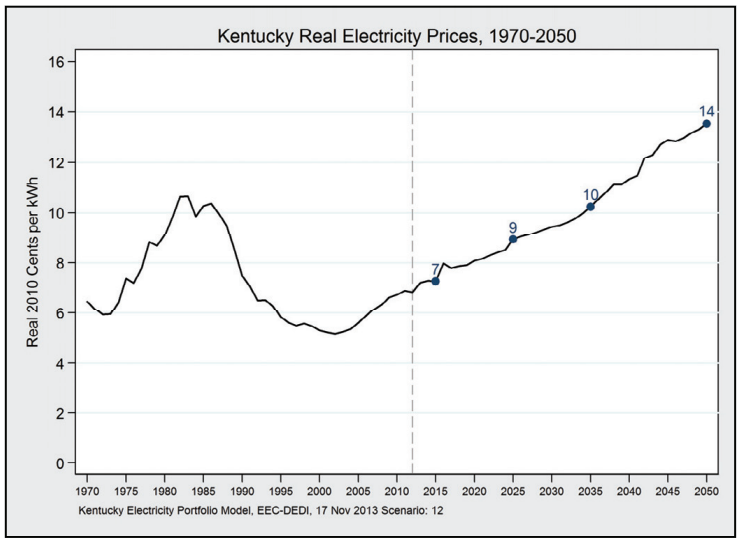


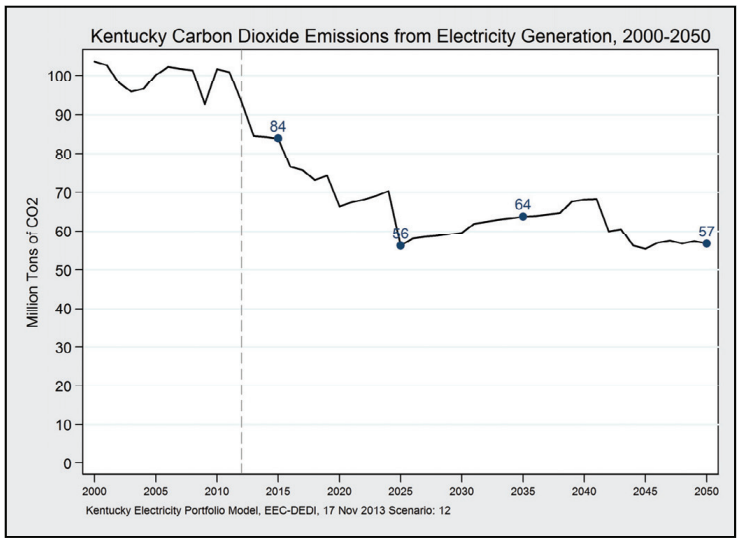
Scenario 12

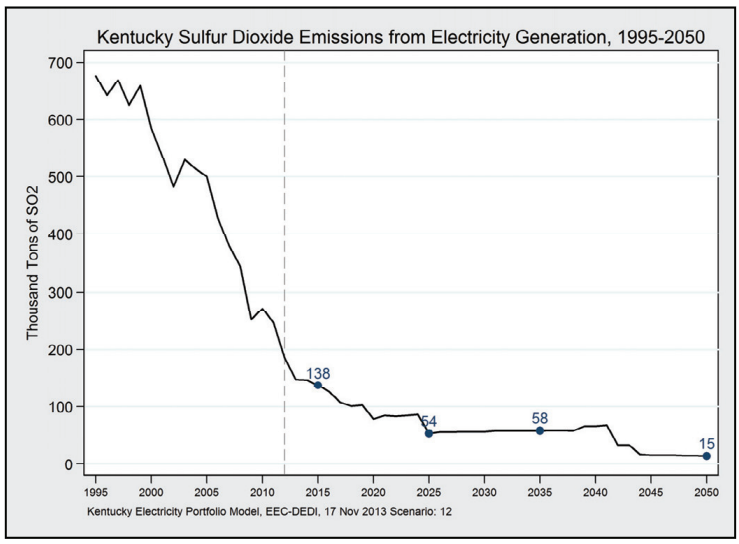
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 2: Nuclear Allowed

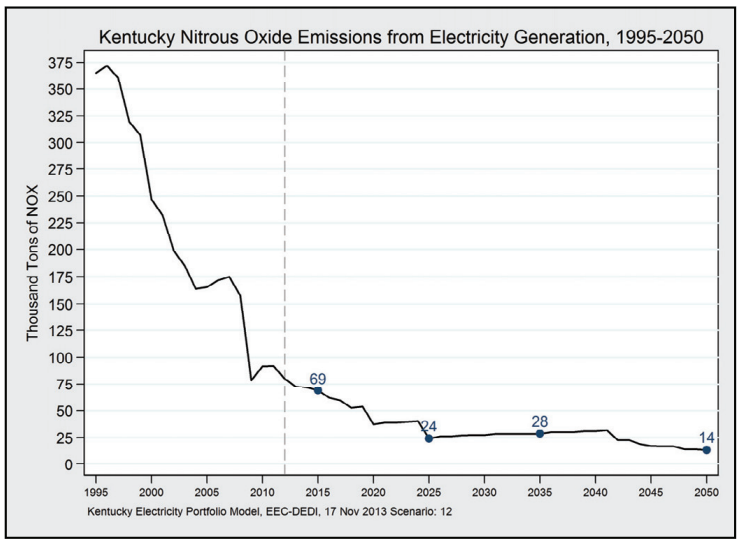






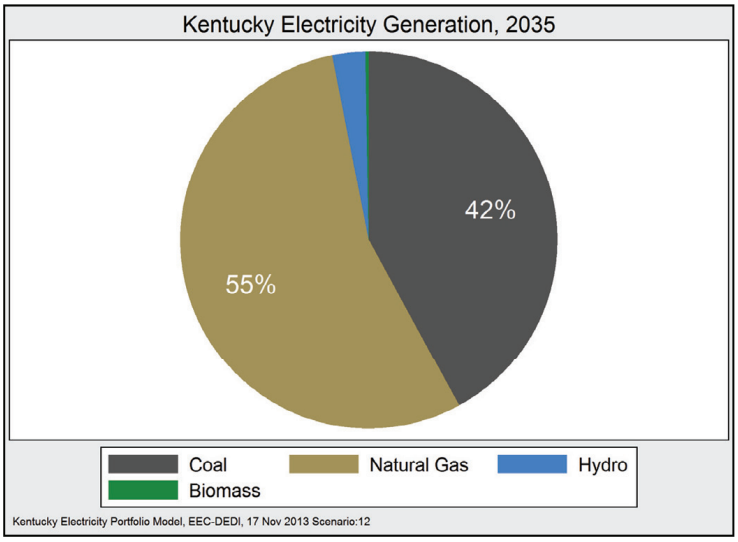


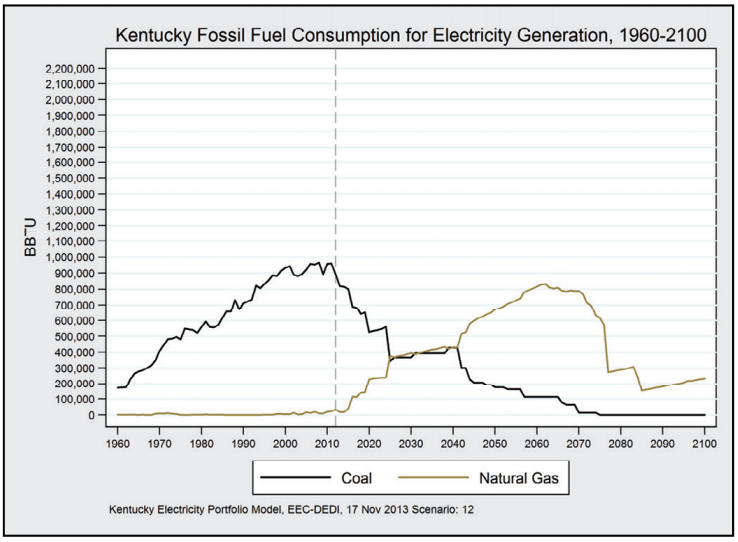


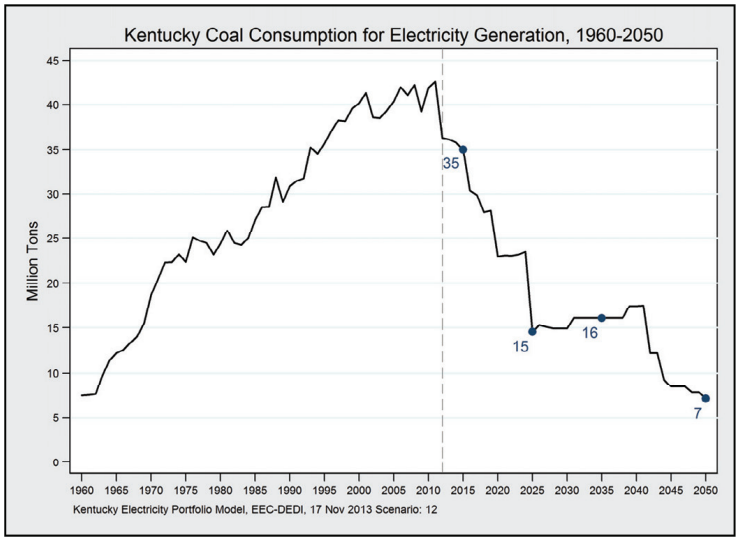


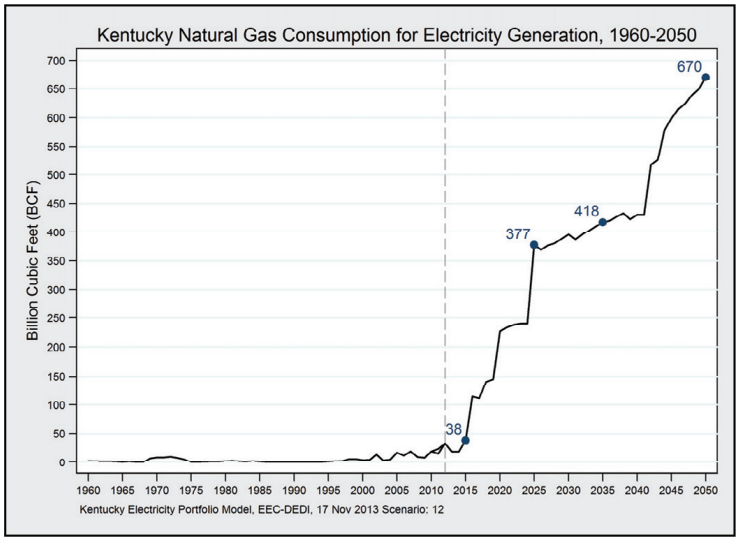
Scenario 12

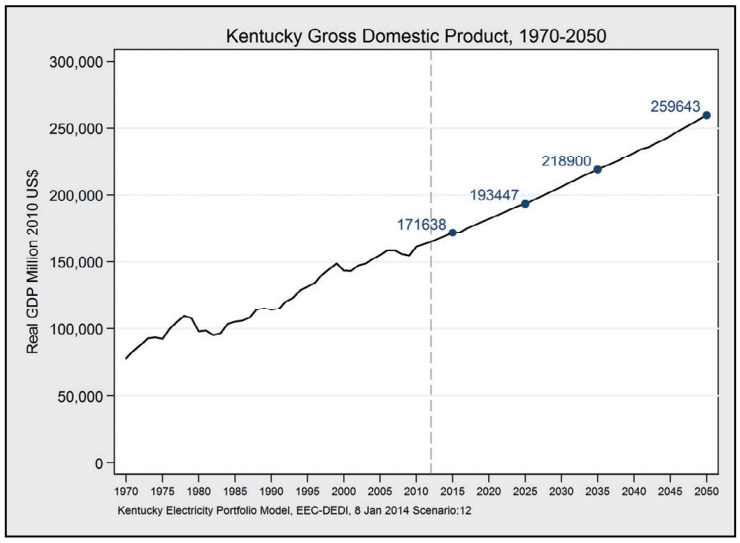
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 2: Nuclear Allowed

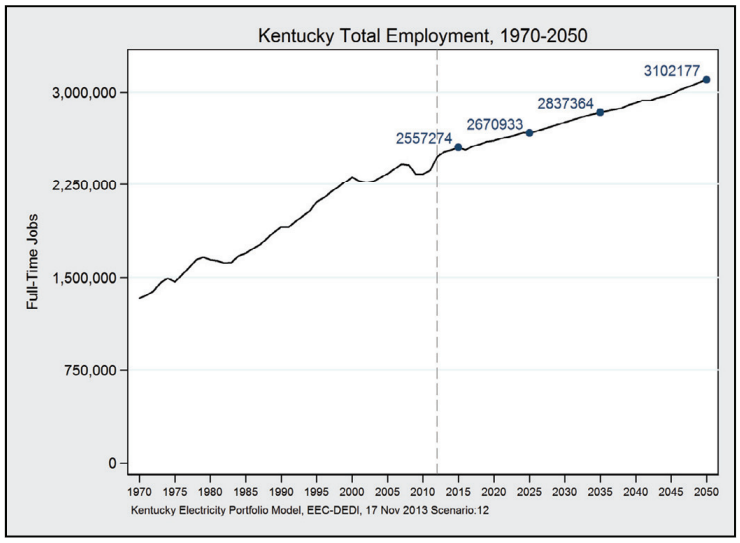






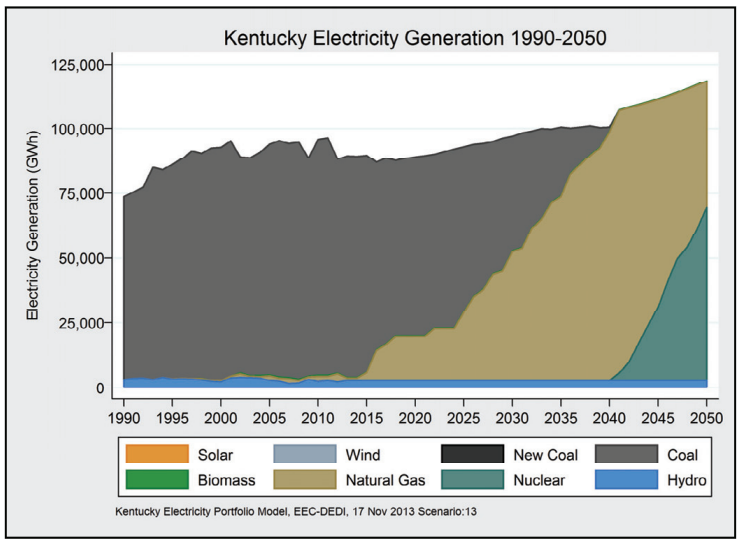


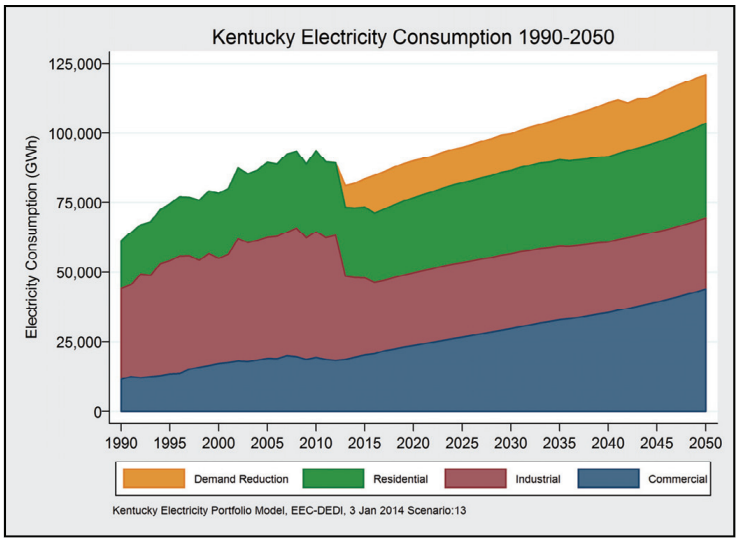


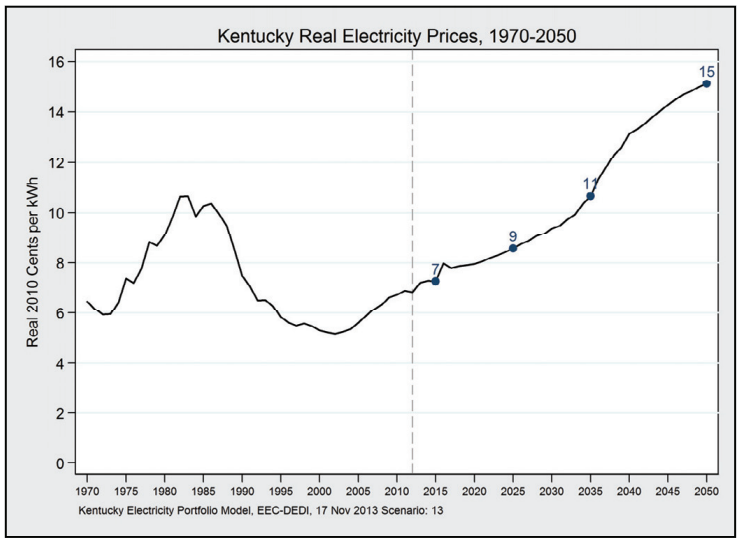


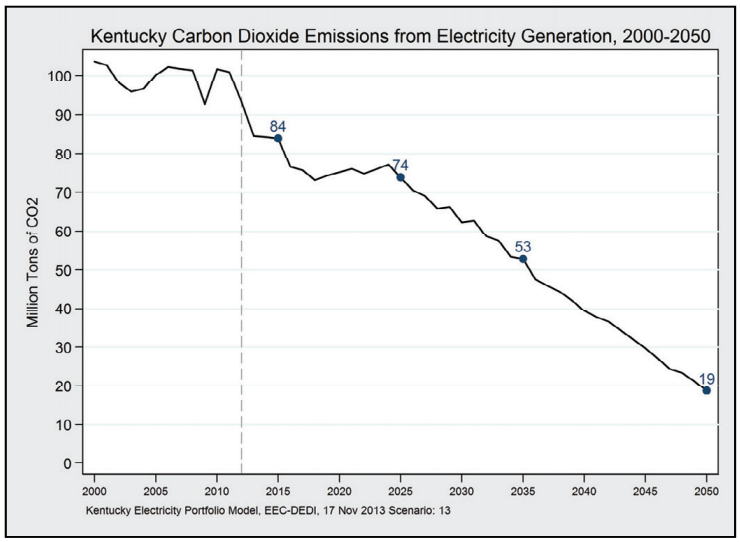
Scenario 13

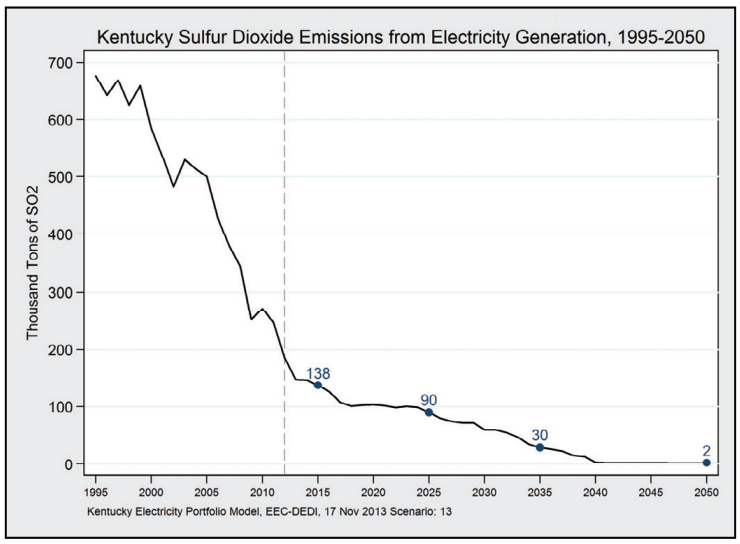
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 2: Nuclear Allowed

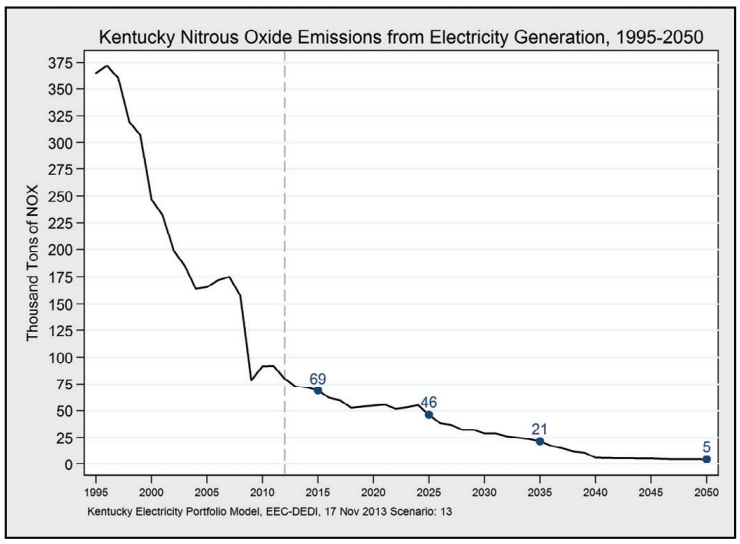






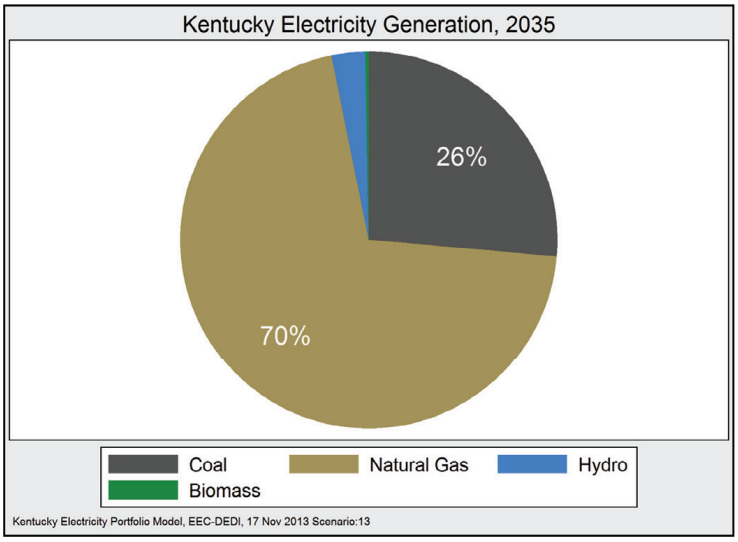


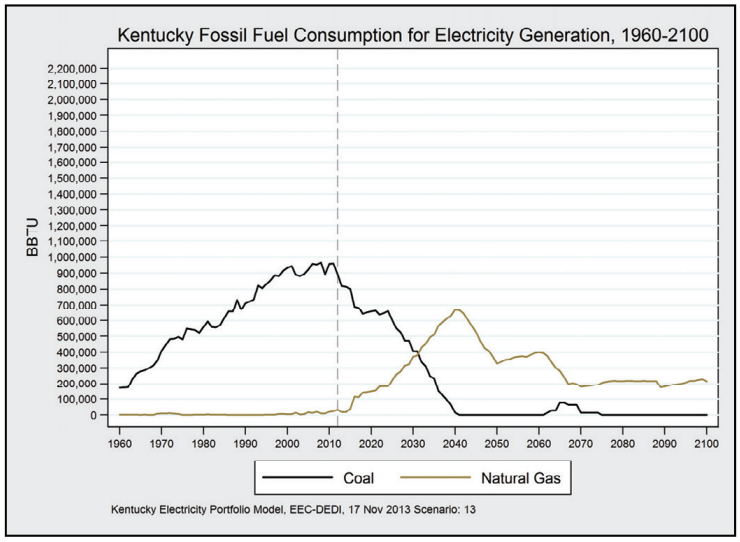


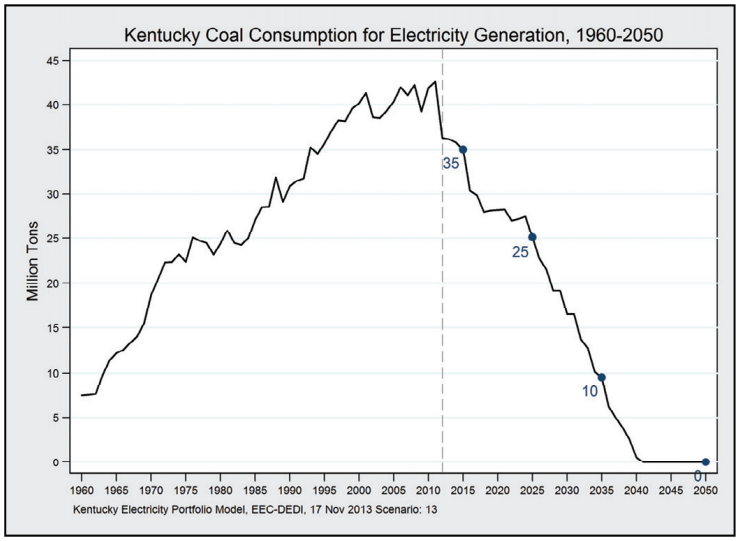


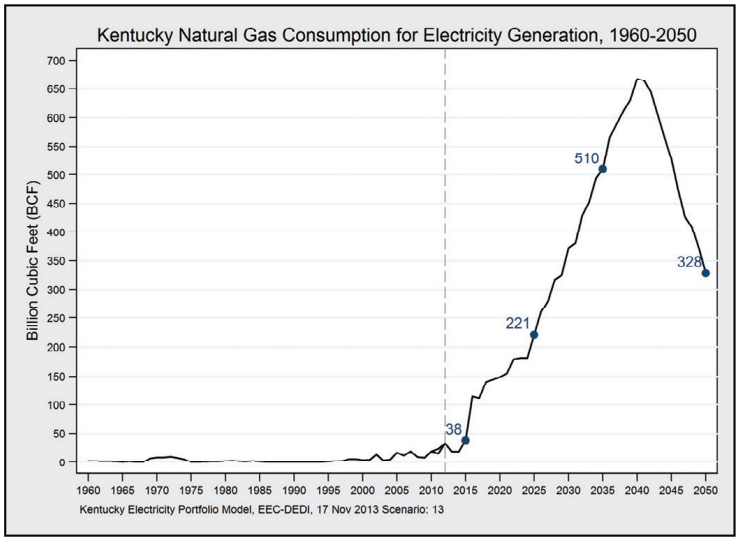
Scenario 13

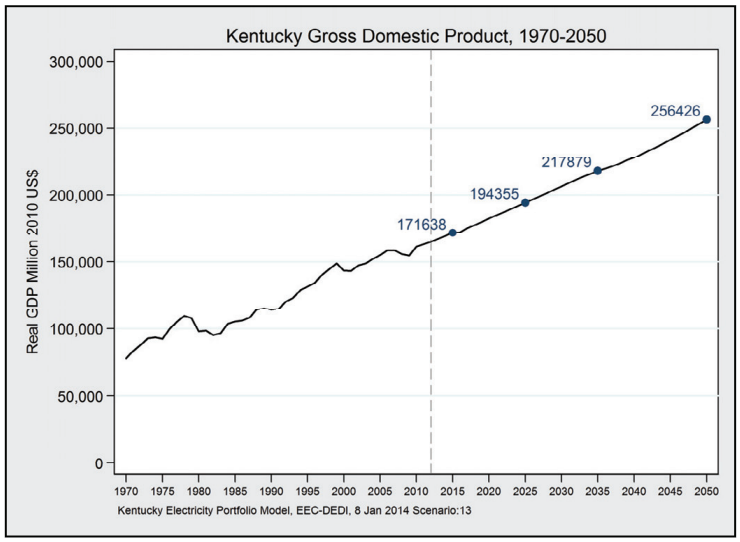
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 2: Nuclear Allowed

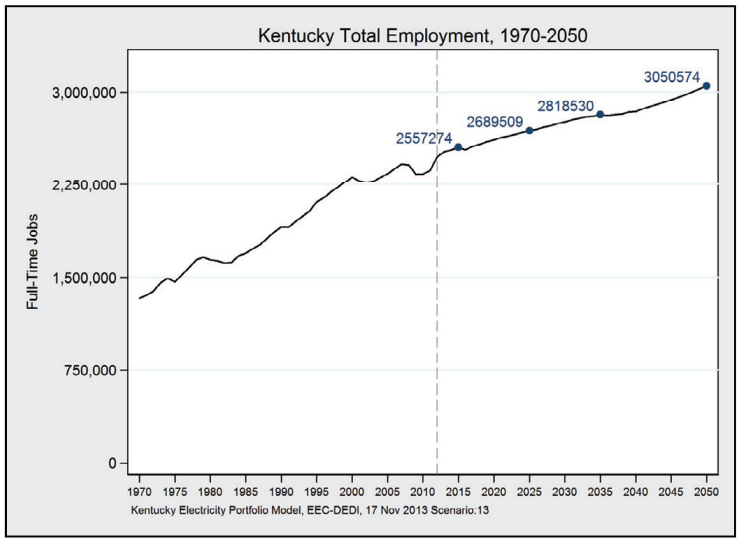






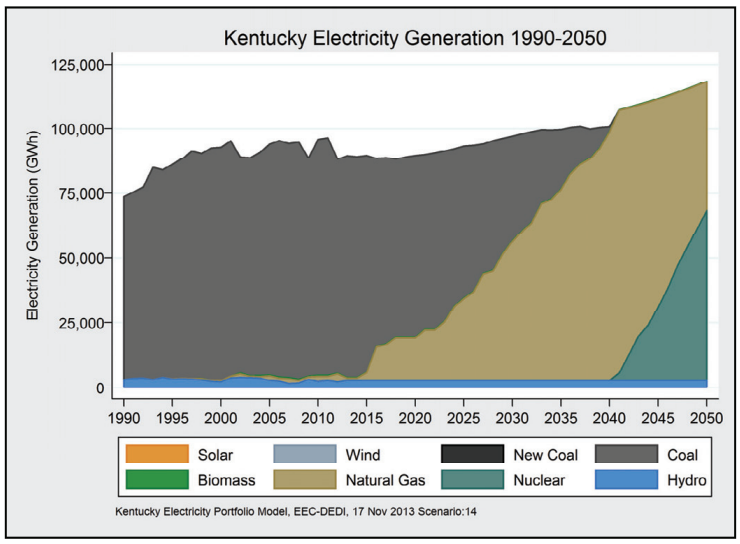


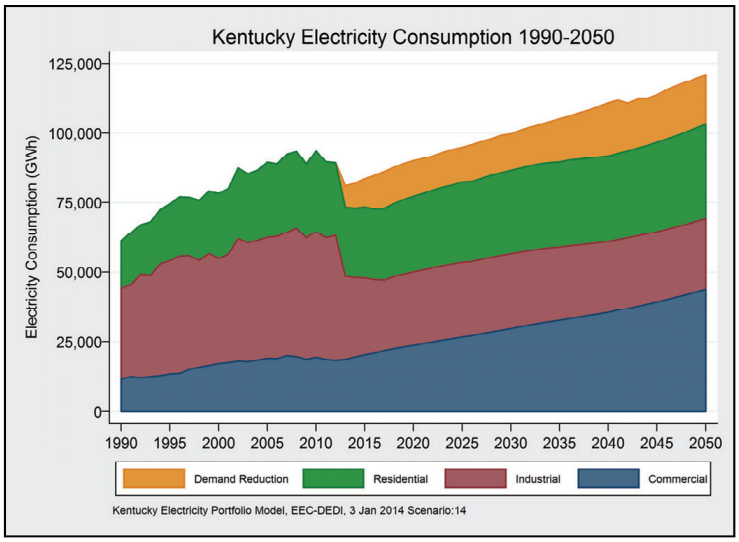


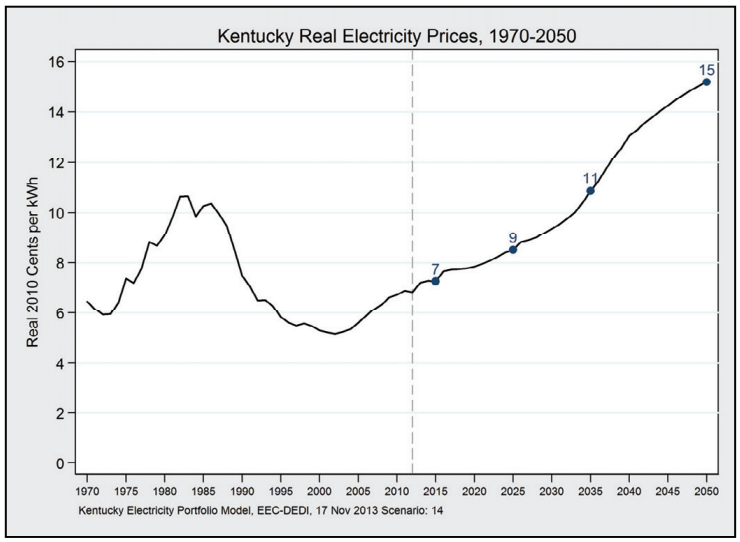


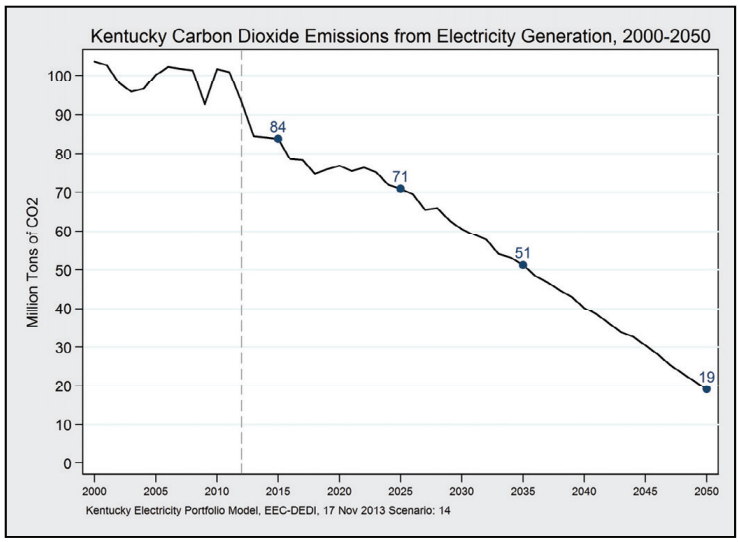
Scenario 14

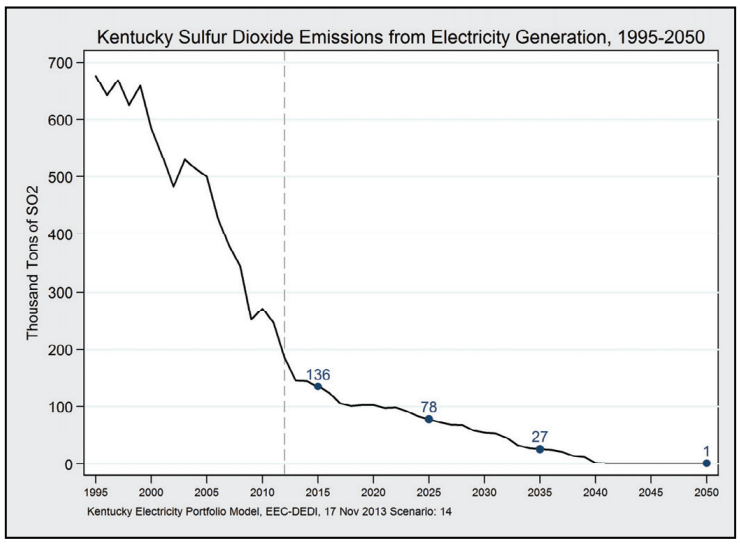
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 2: Nuclear Allowed

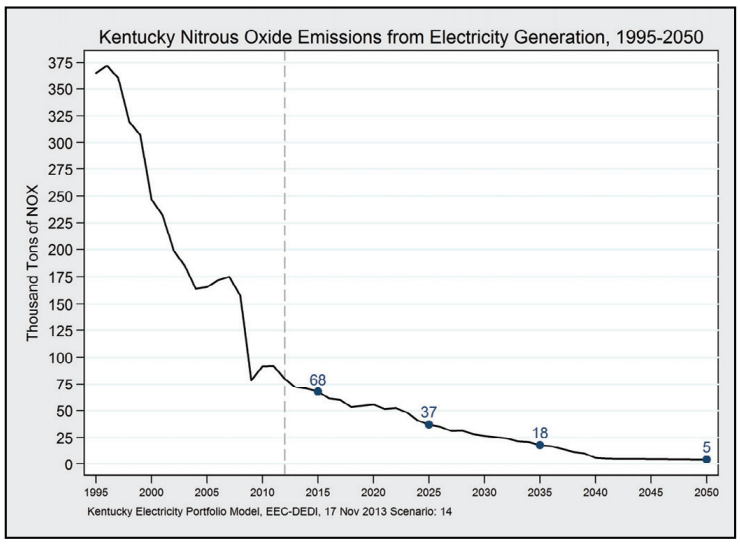






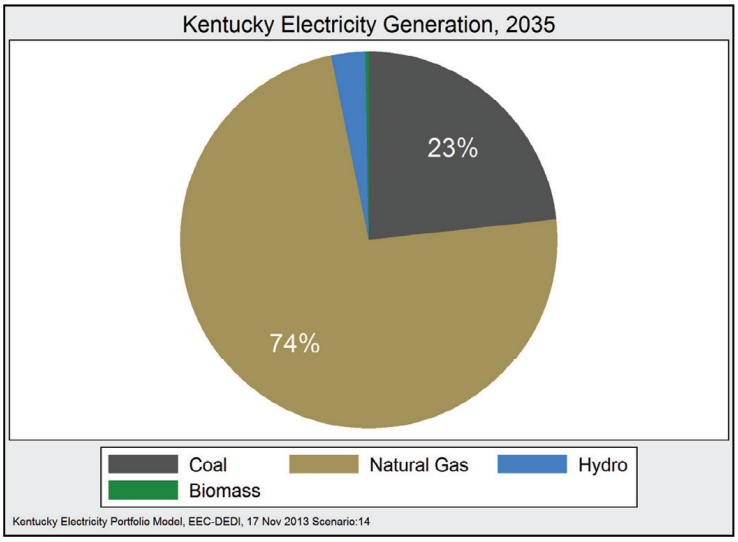


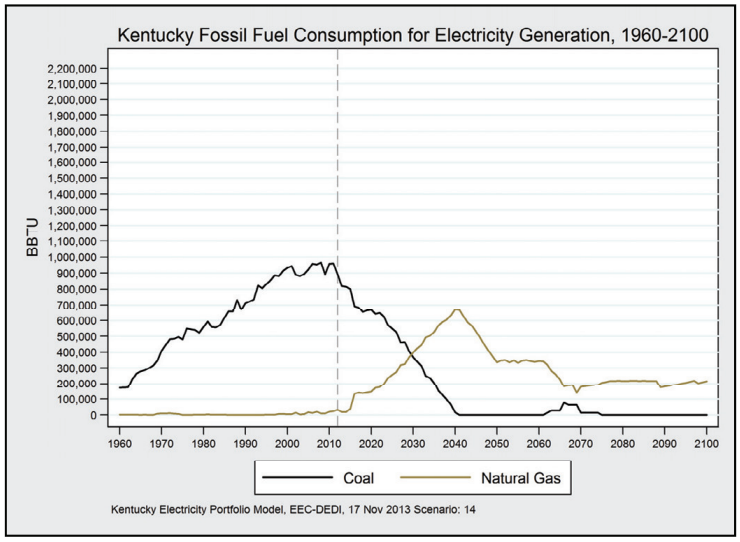


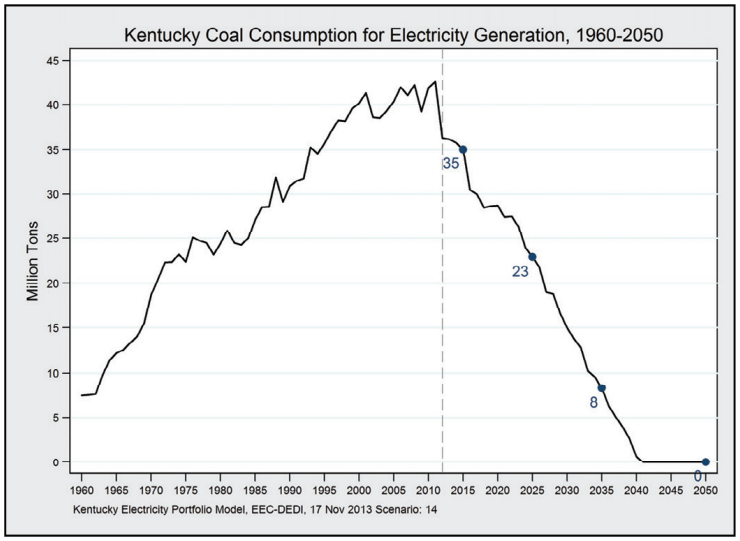


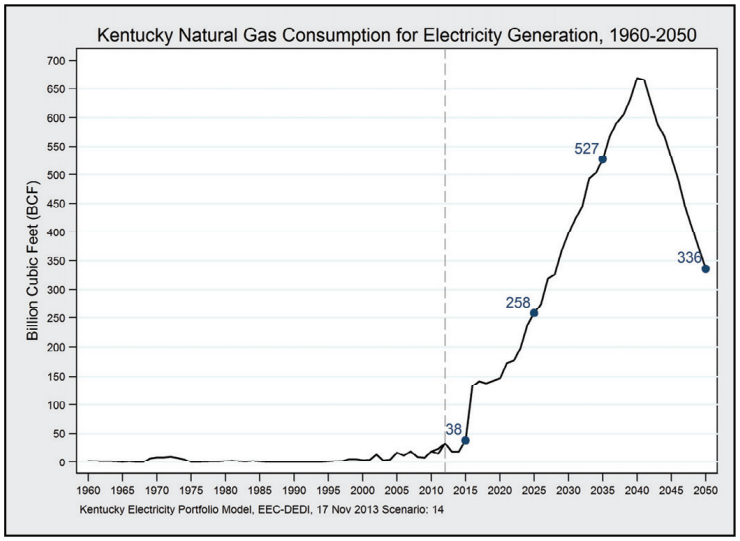
Scenario 14

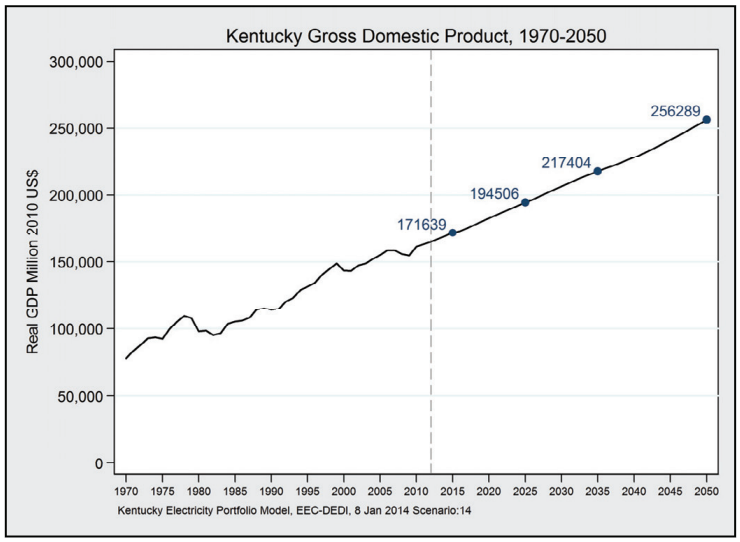
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 2: Nuclear Allowed

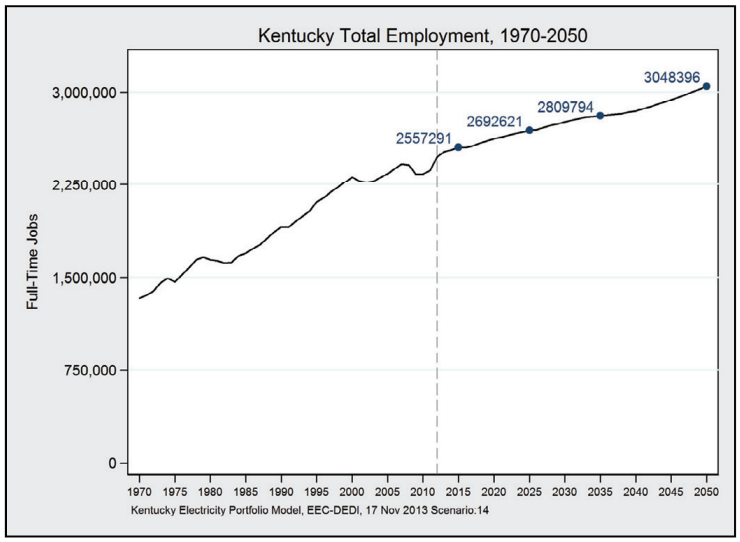






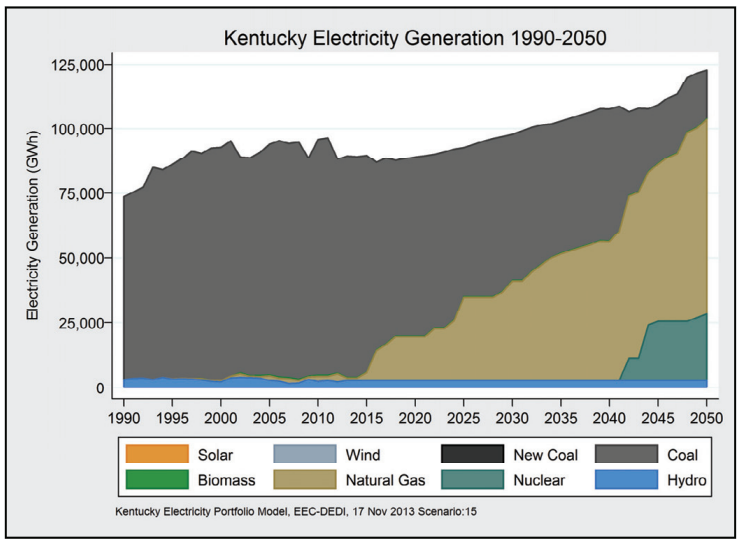


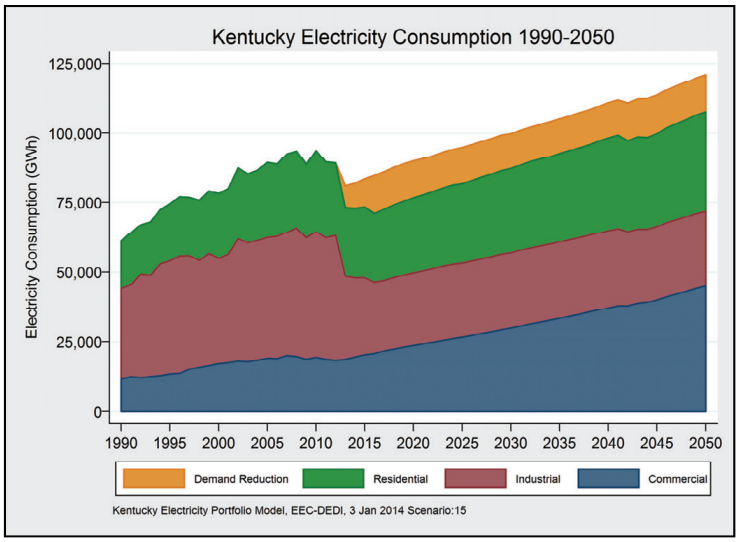


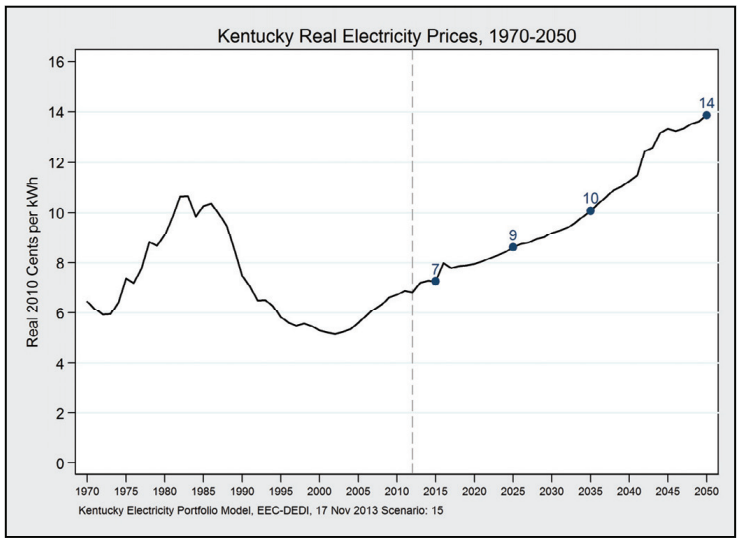


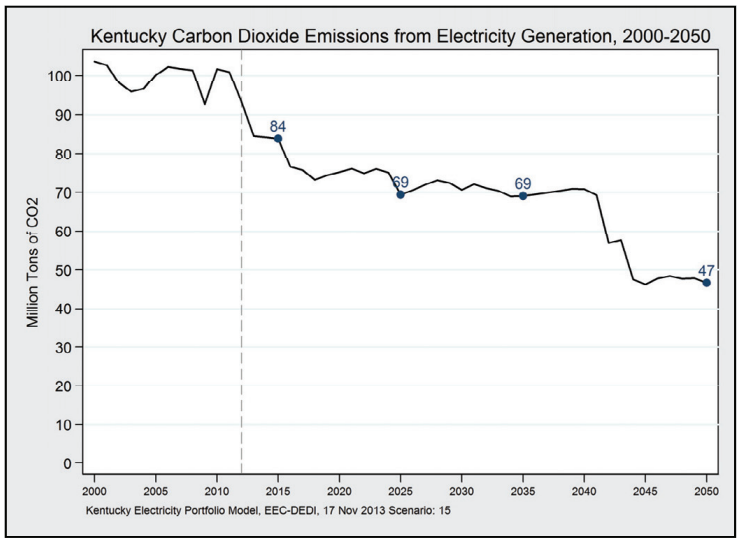
Scenario 15

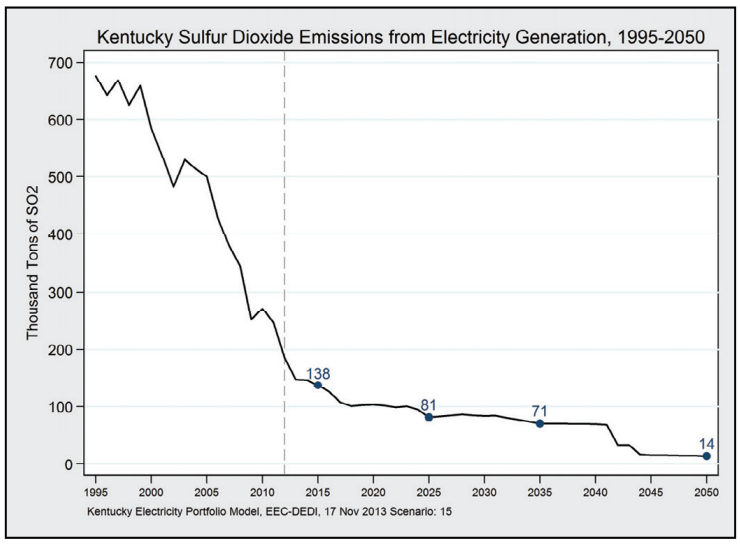
Federal Policy Option 1: Reference Portfolio 3: Balanced Portfolio Standard

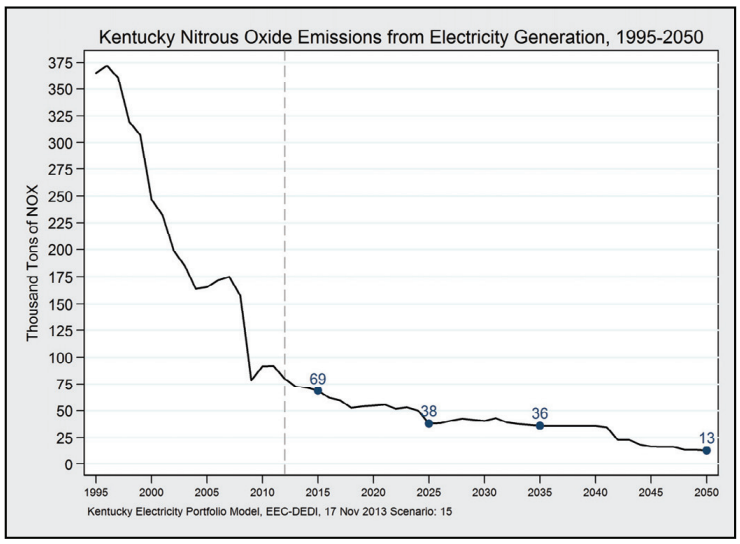






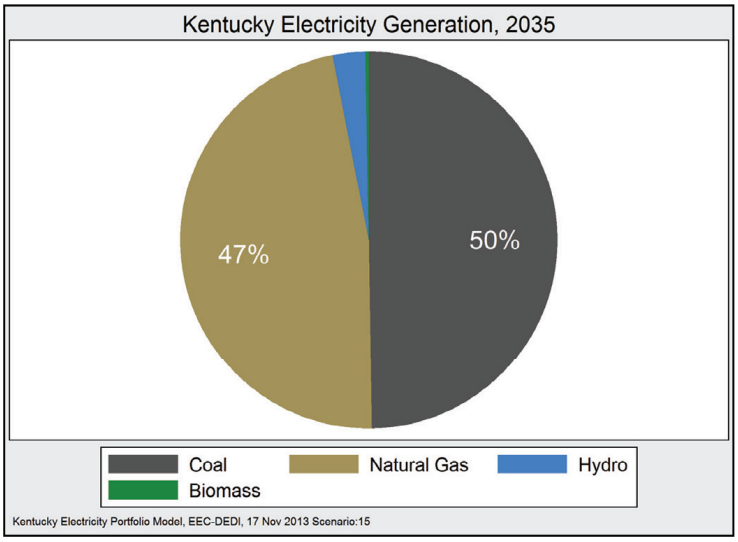


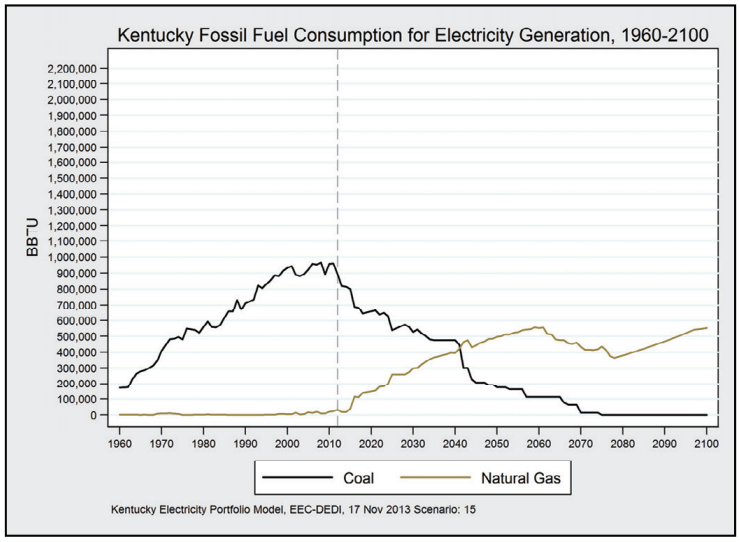


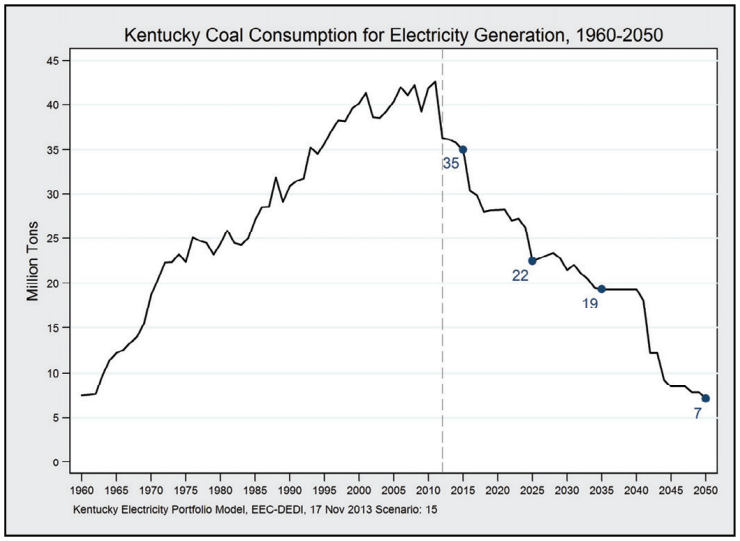


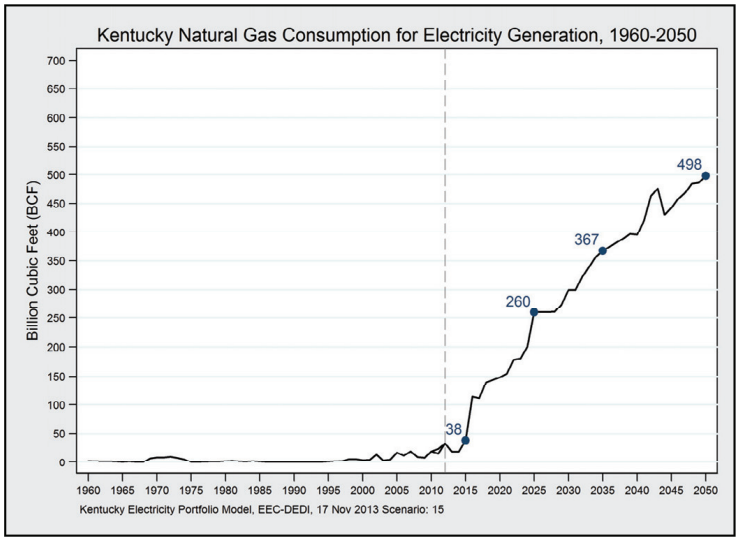
Scenario 15

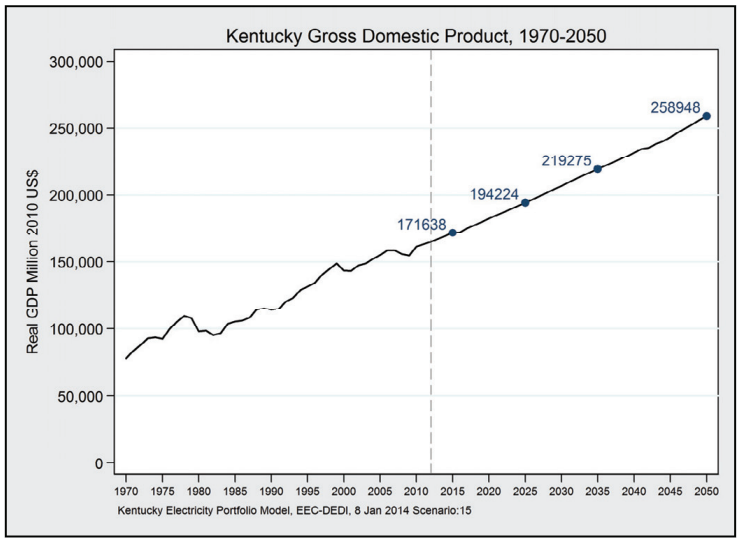
Federal Policy Option 1: Reference Portfolio 3: Balanced Portfolio Standard

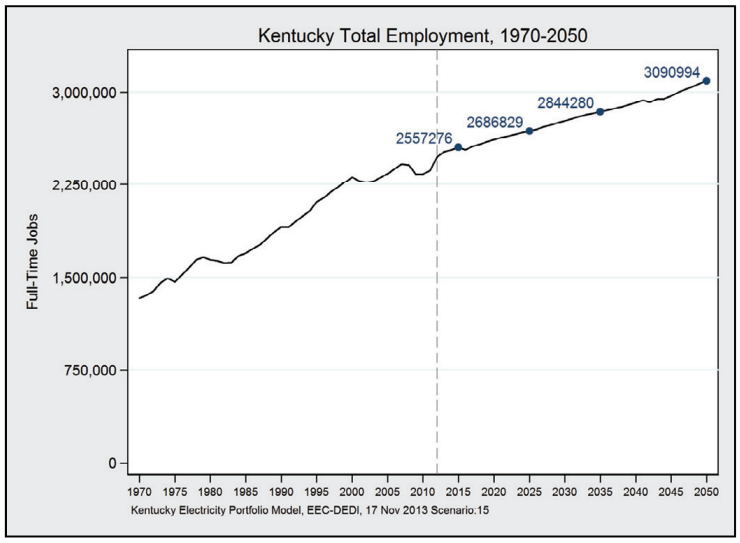






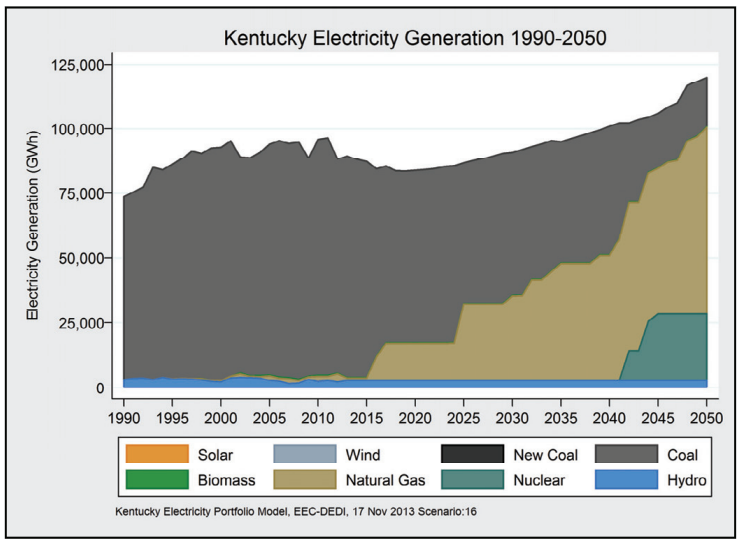


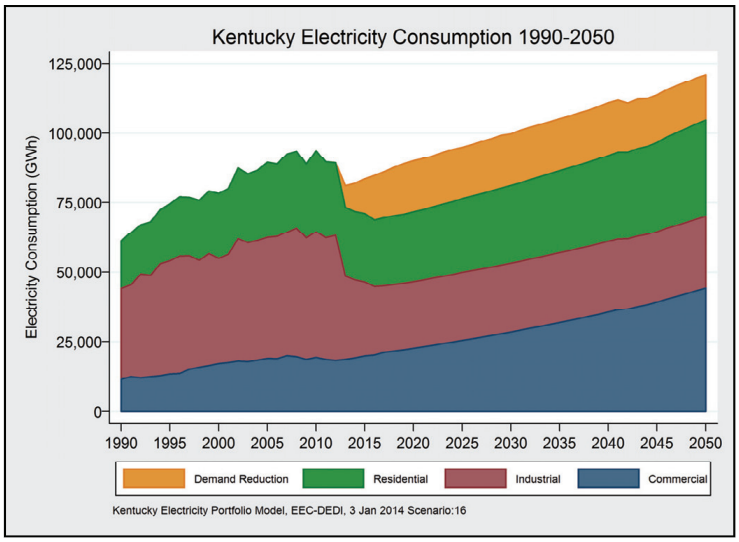


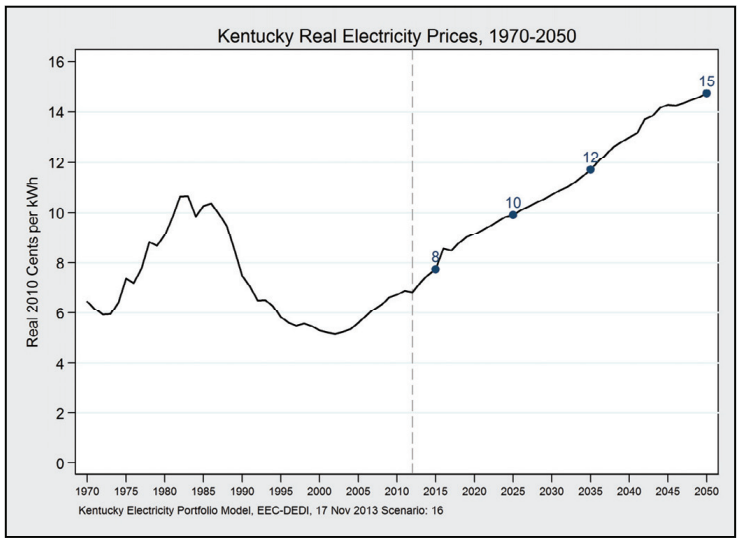


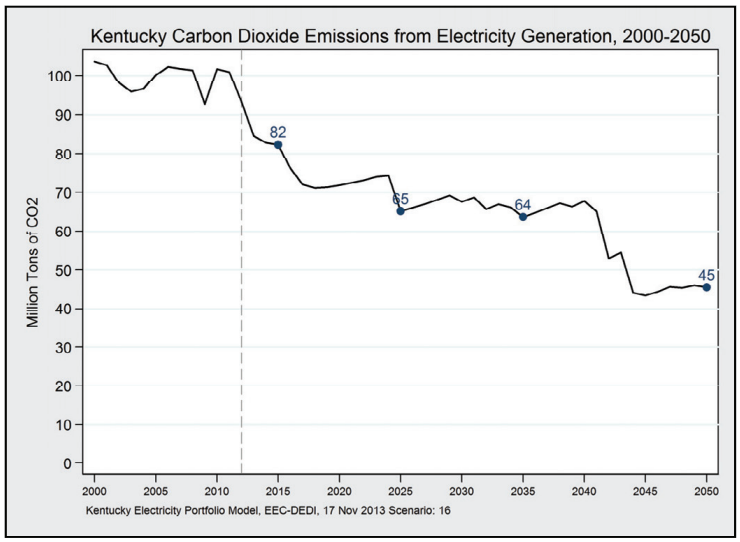
Scenario 16

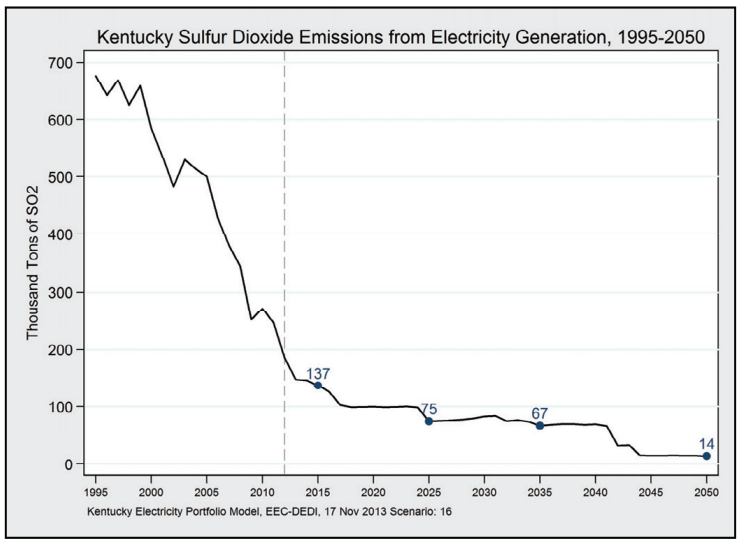
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

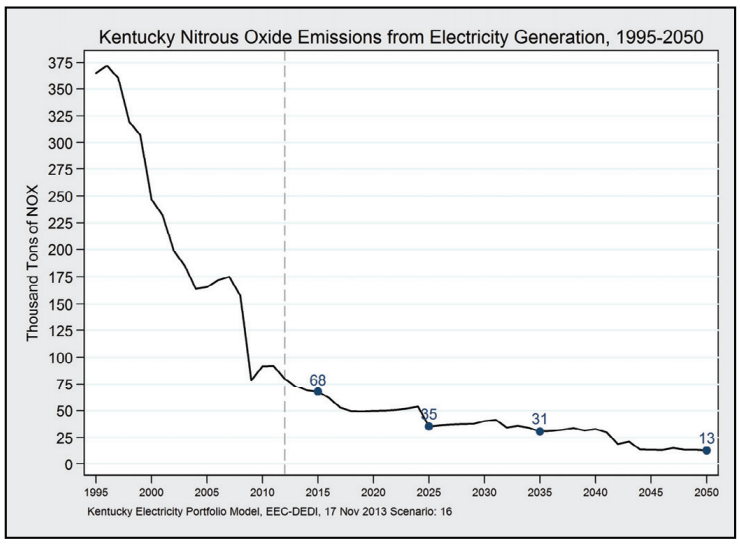






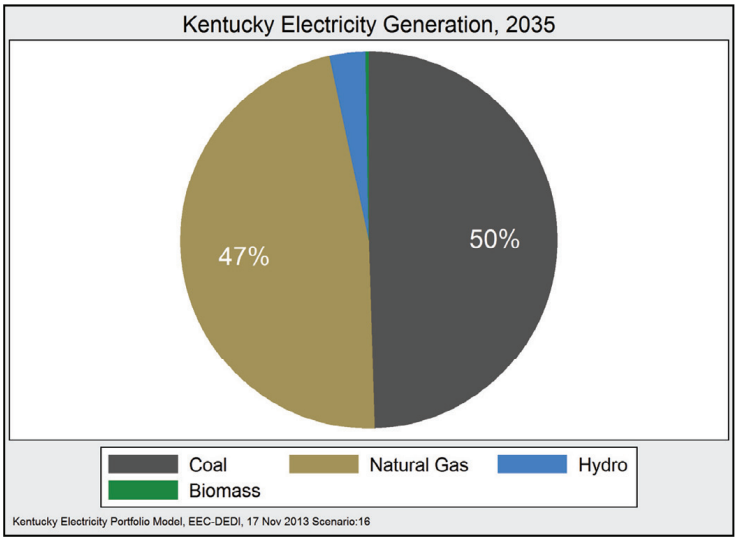


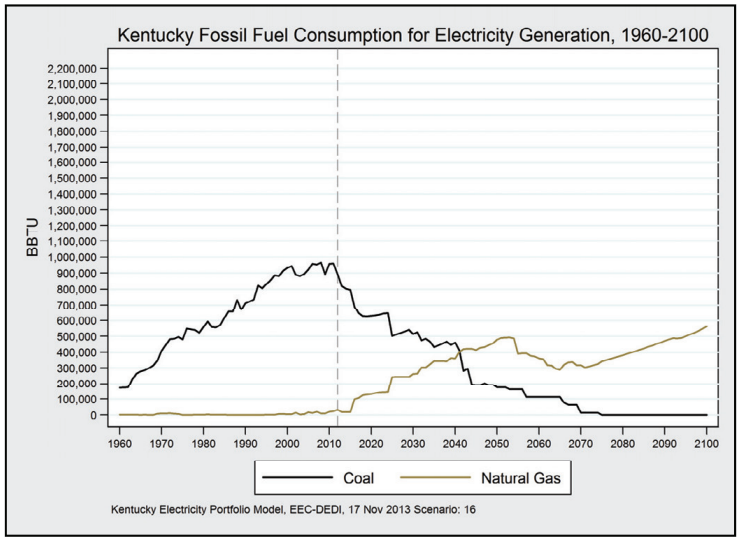


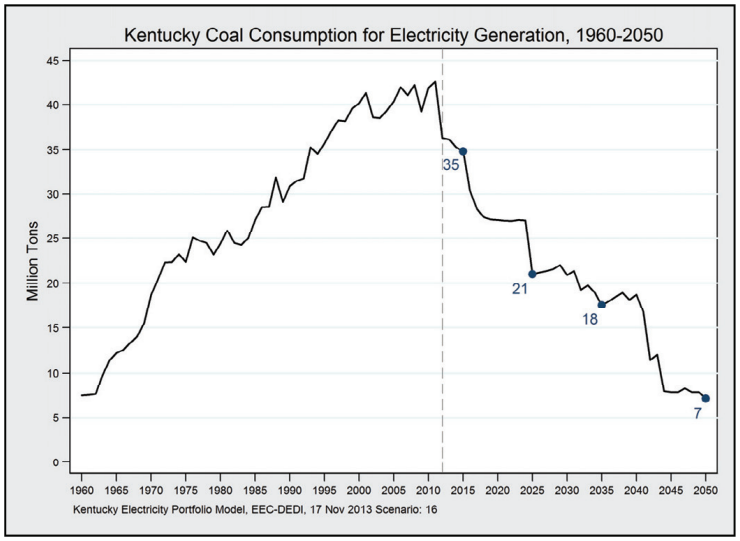


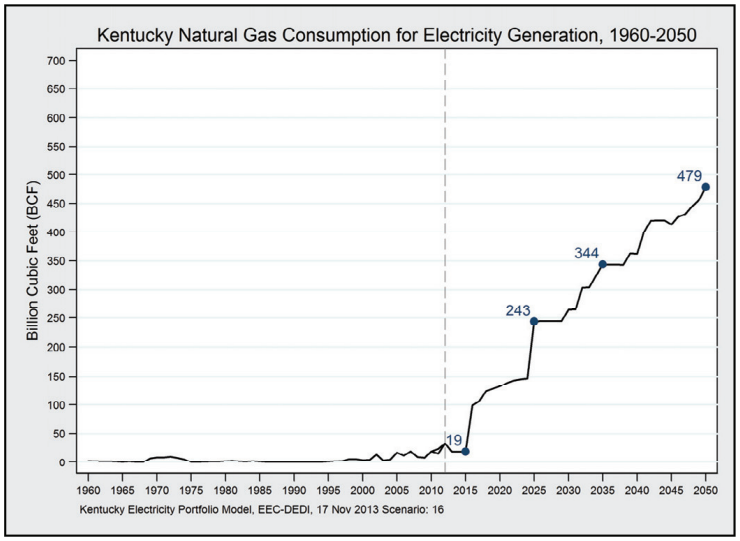
Scenario 16

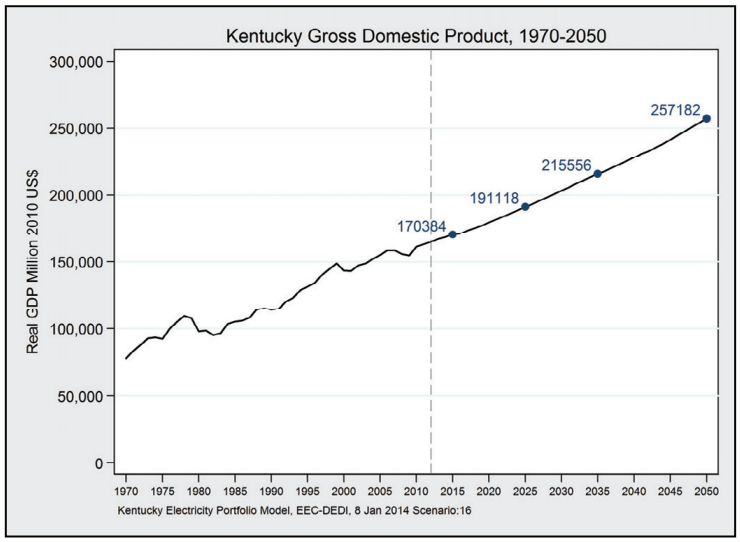
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

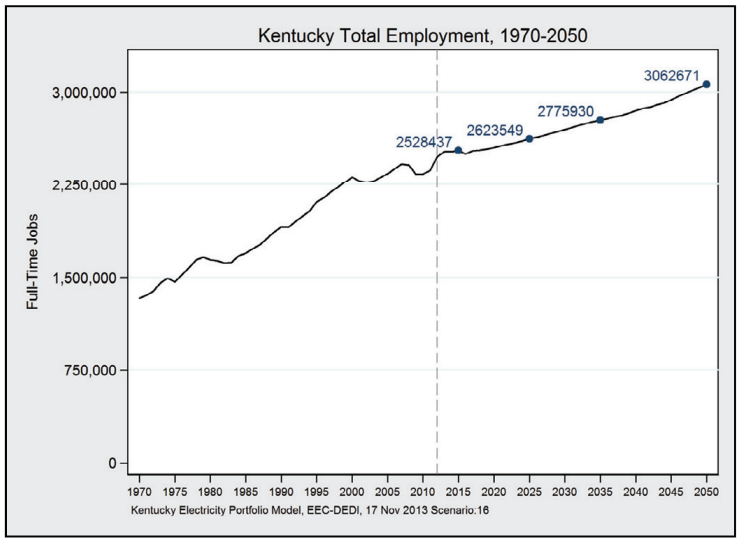






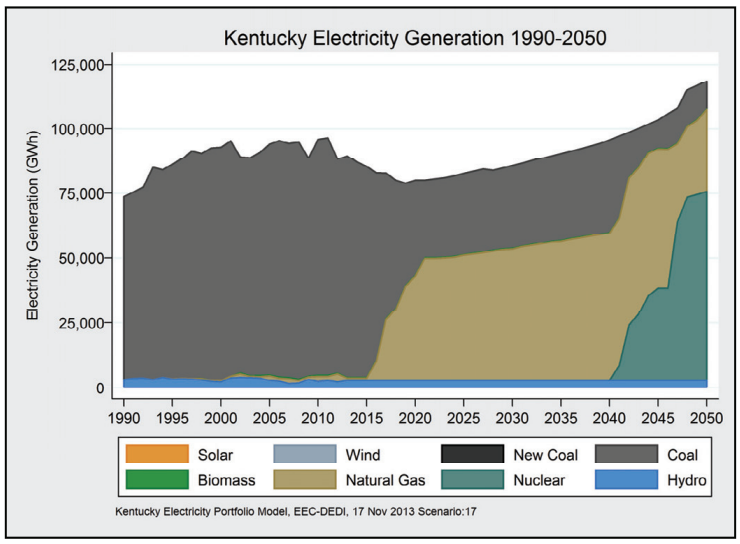


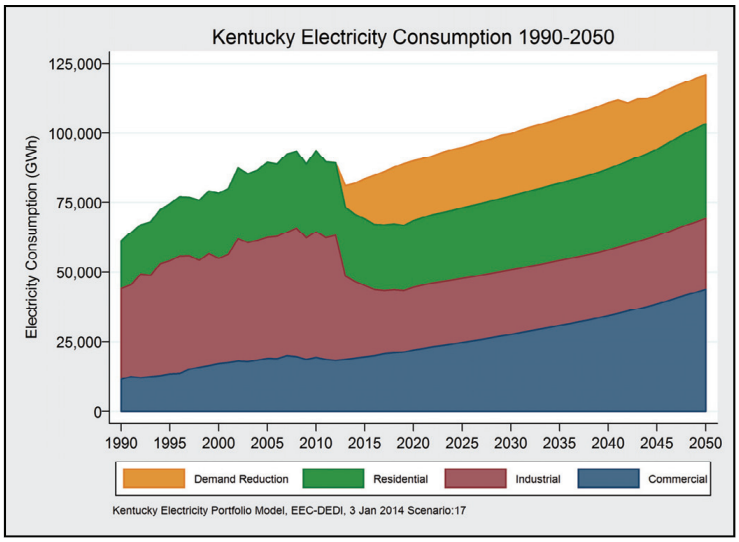


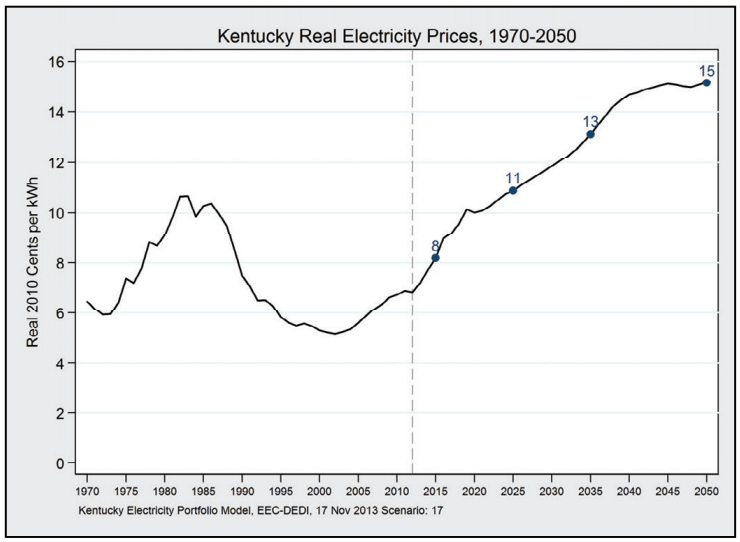


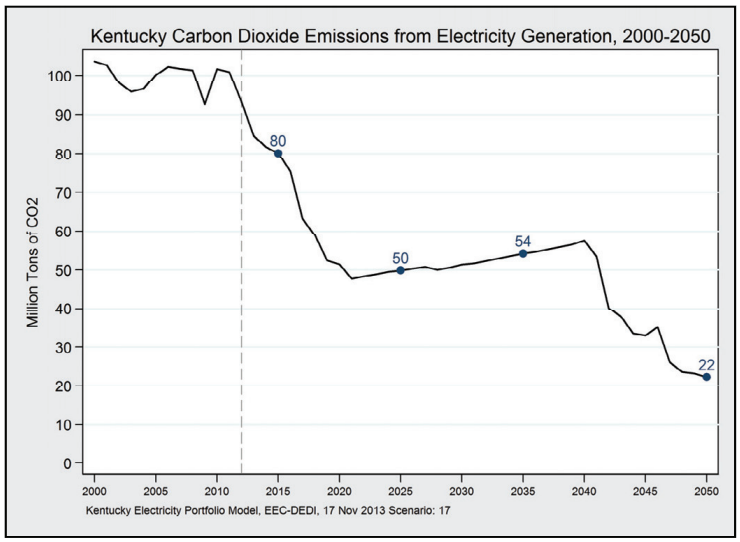
Scenario 17

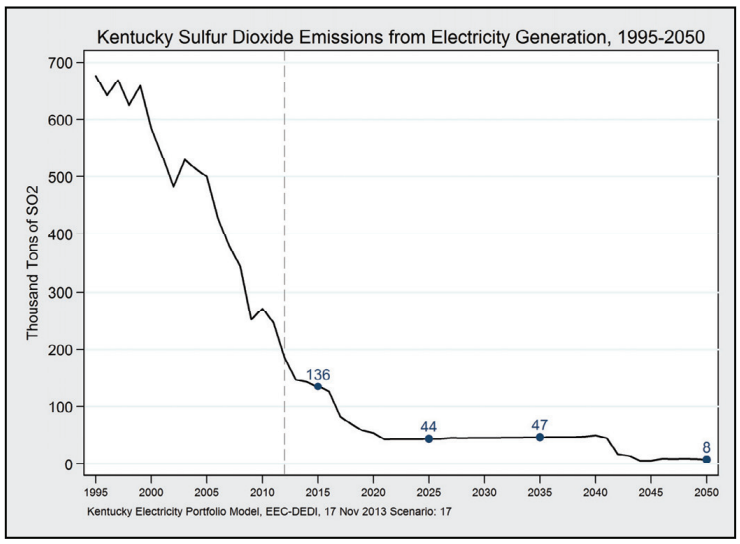
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

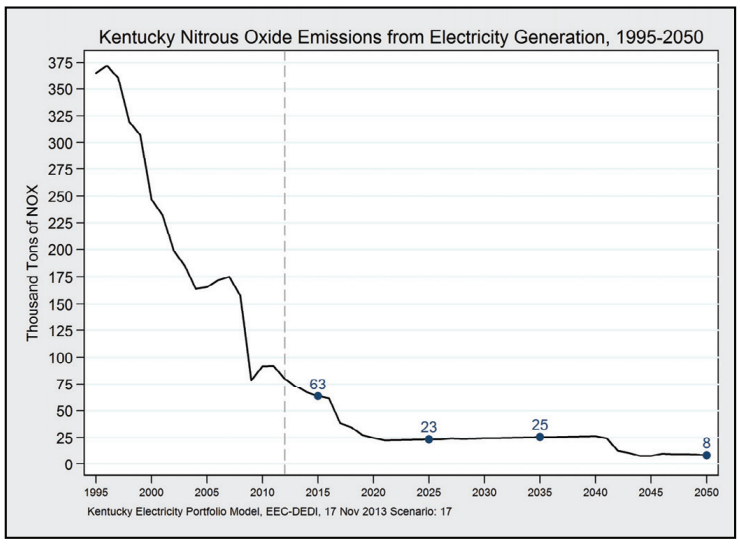






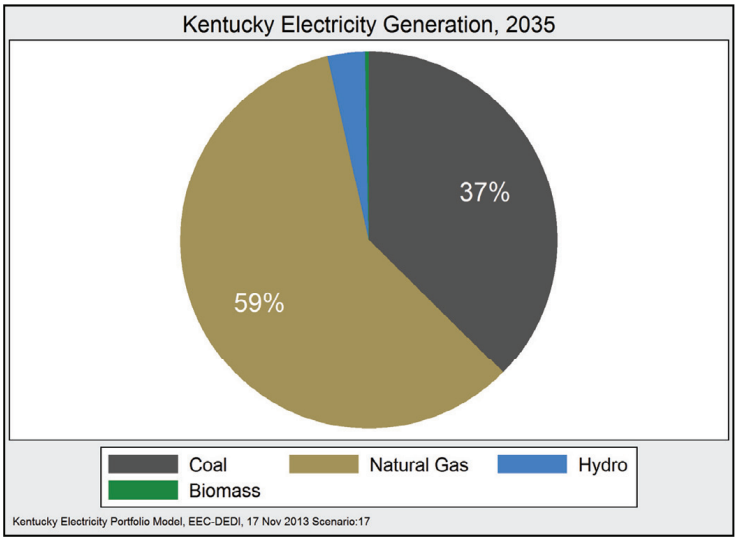


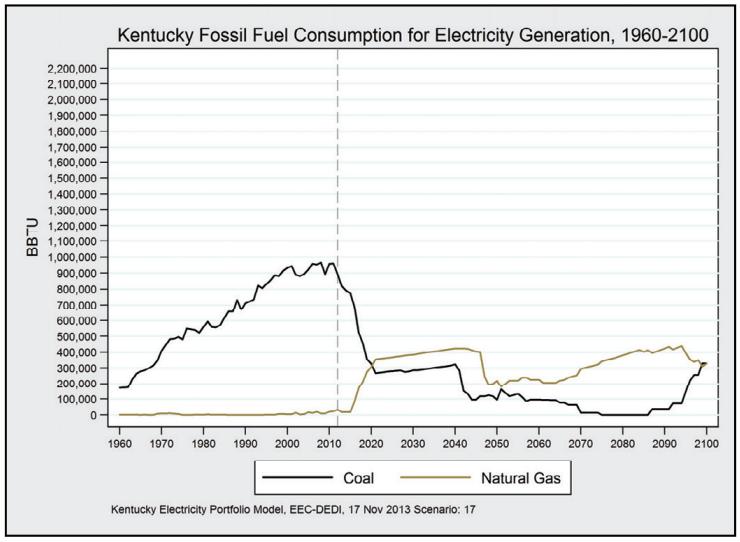


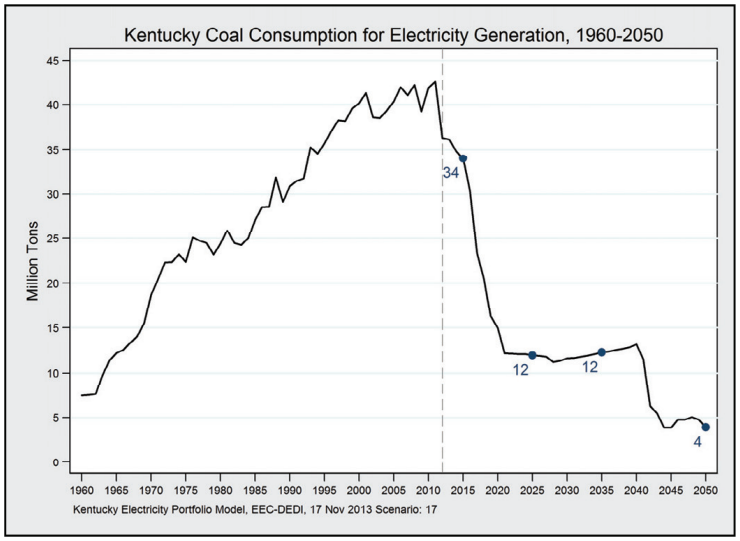


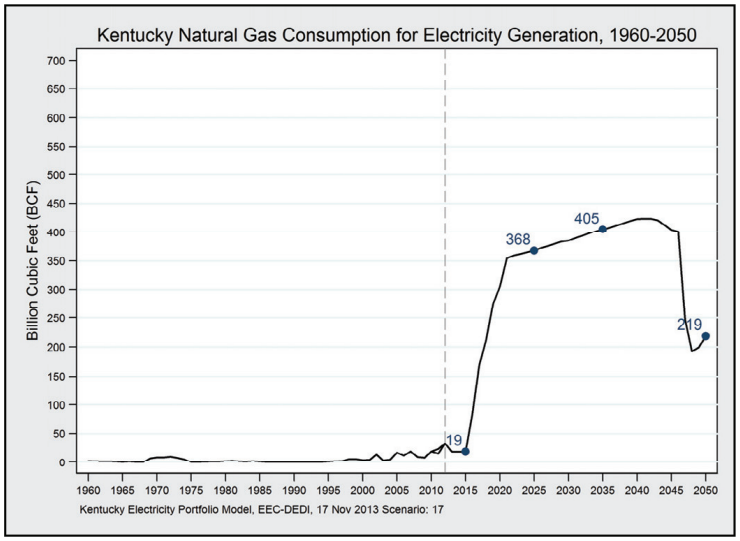
Scenario 17

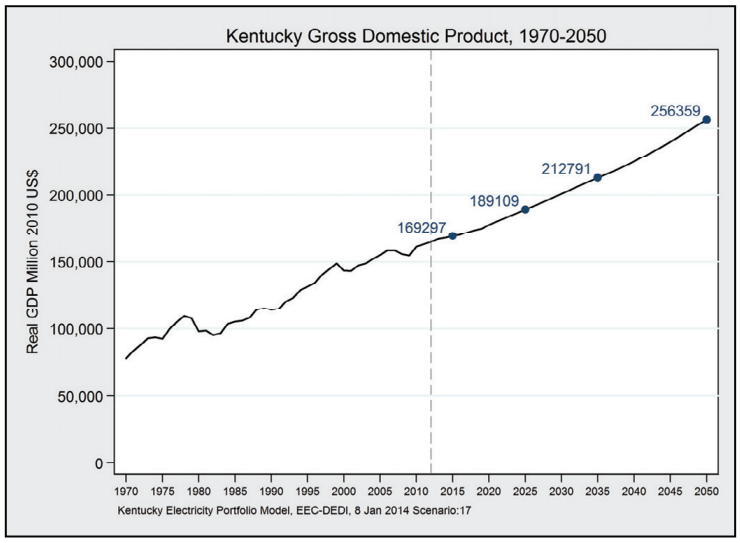
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

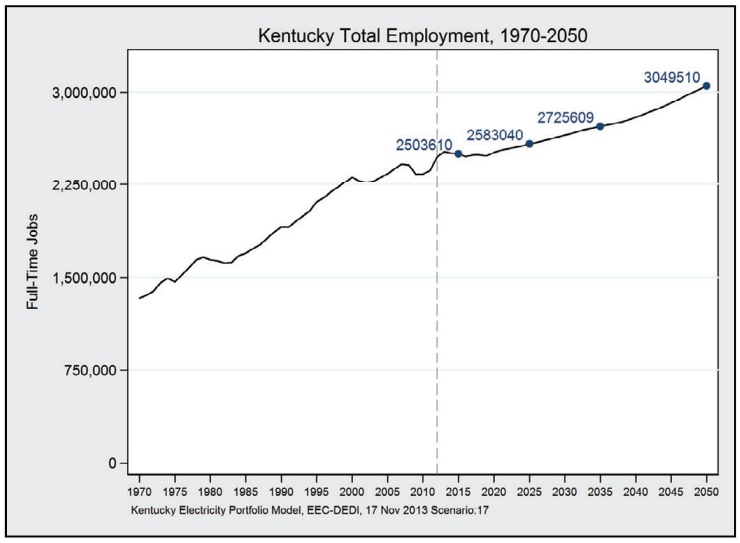






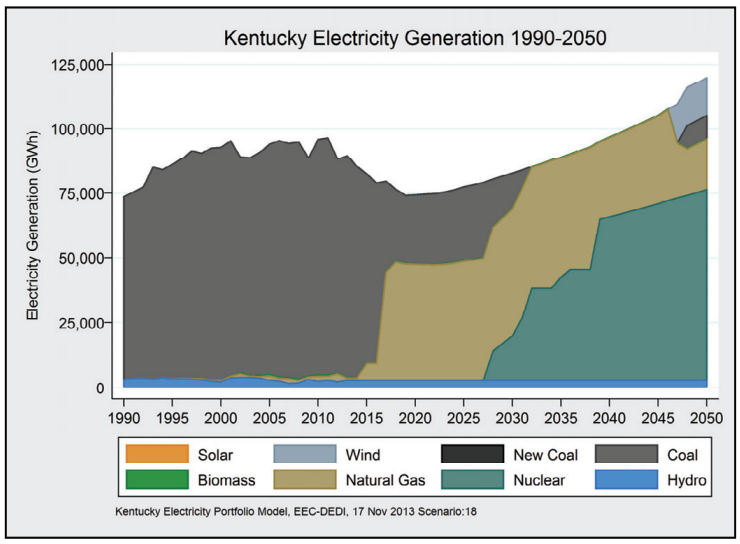


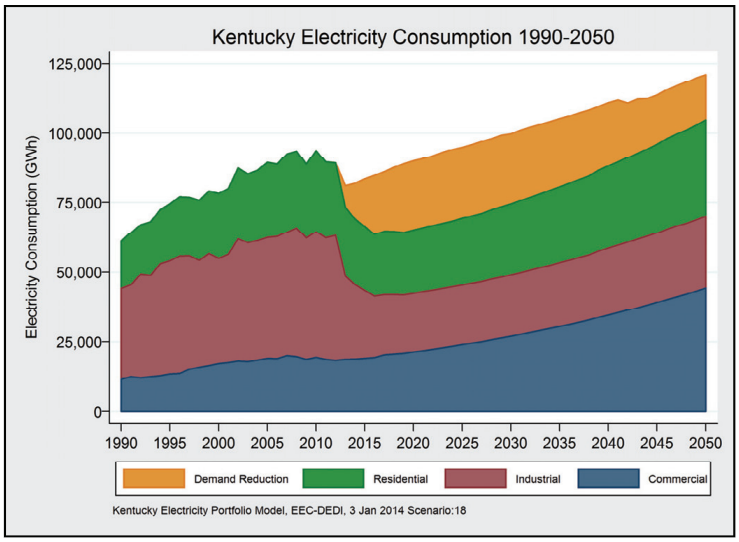


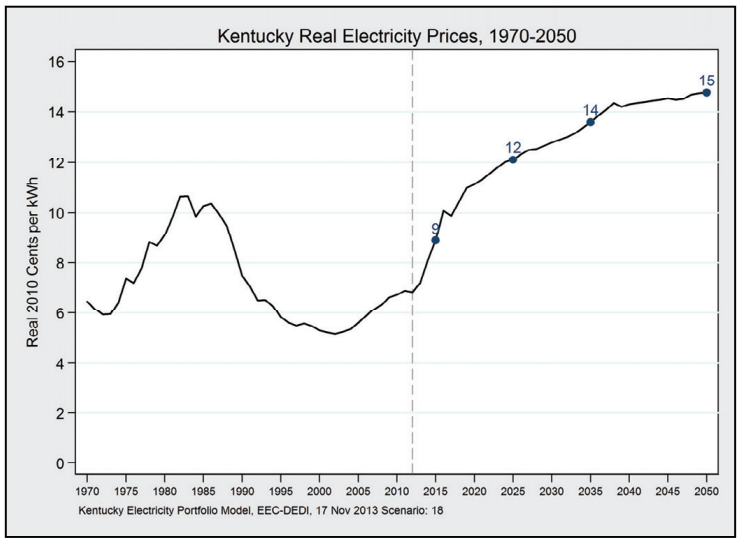


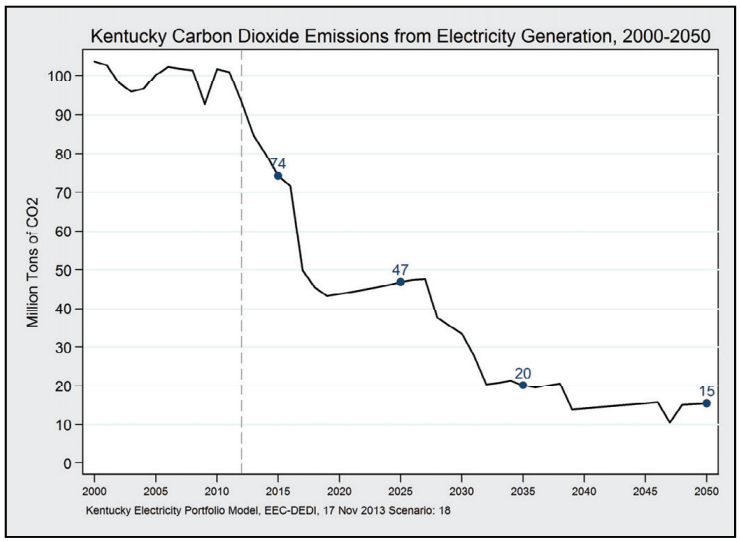
Scenario 18

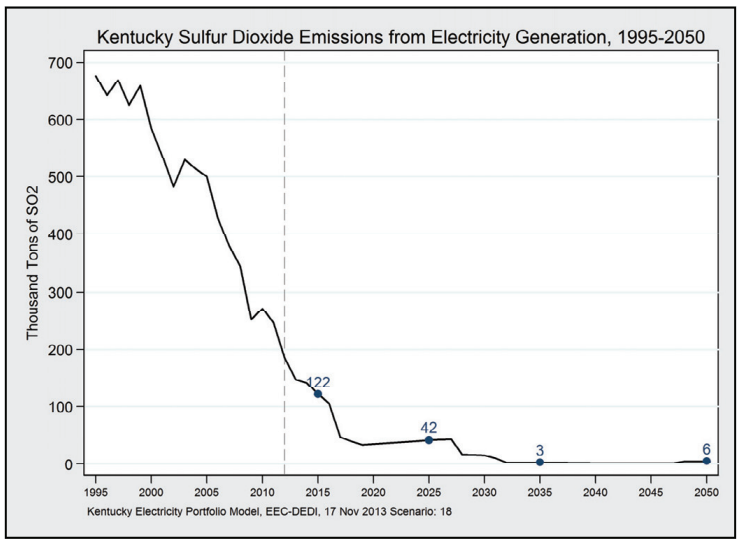
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

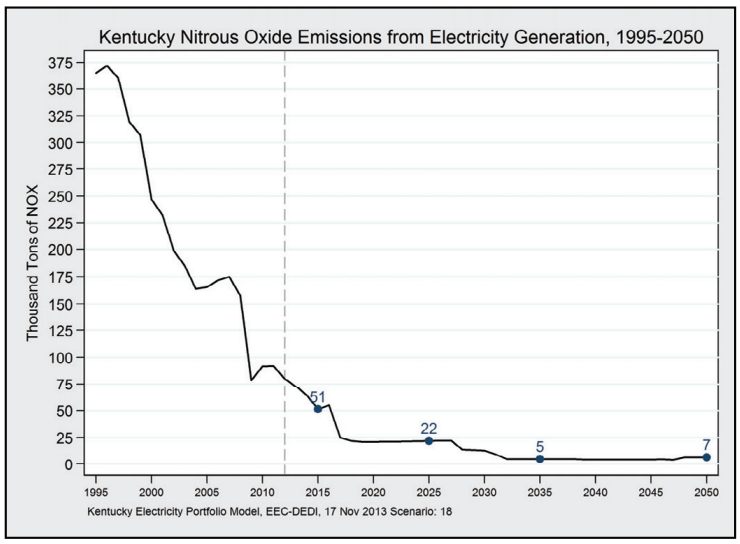






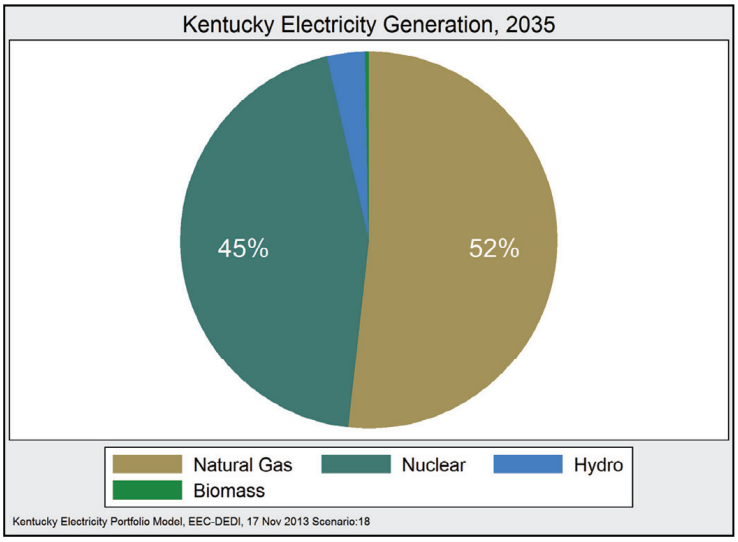


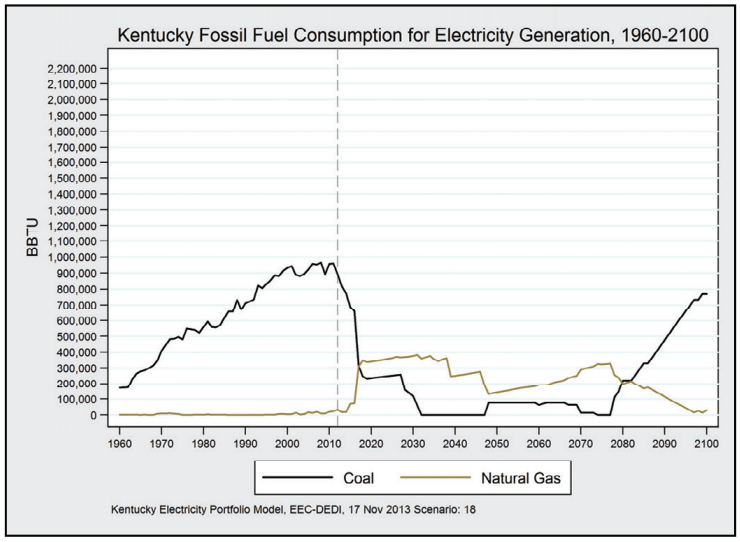


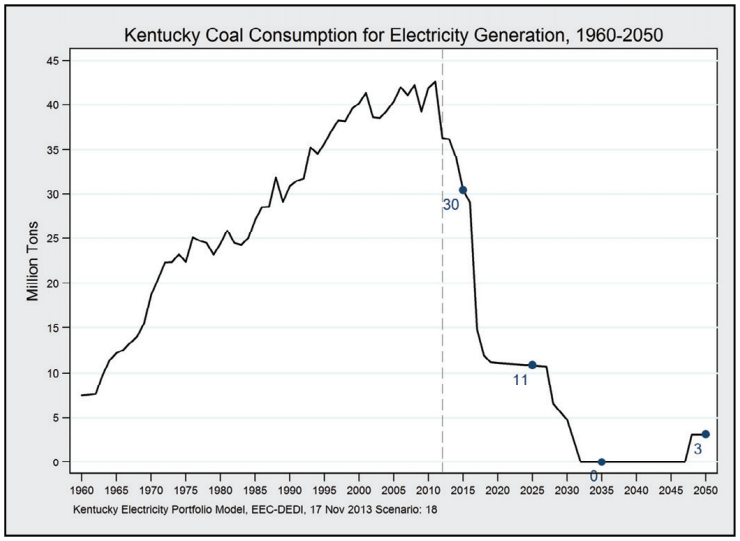


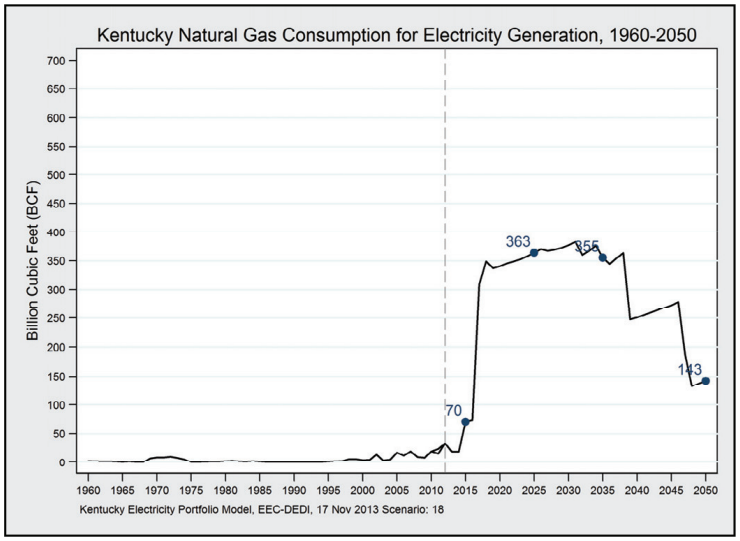
Scenario 18

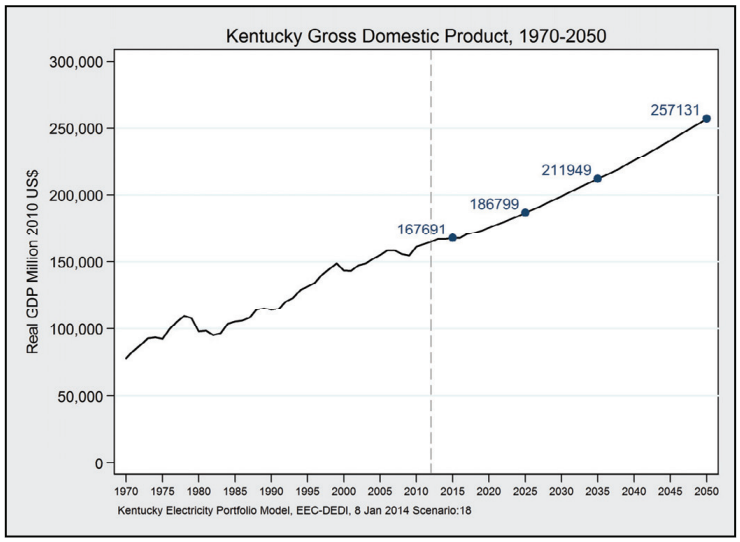
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 3: Balanced Portfolio Standard

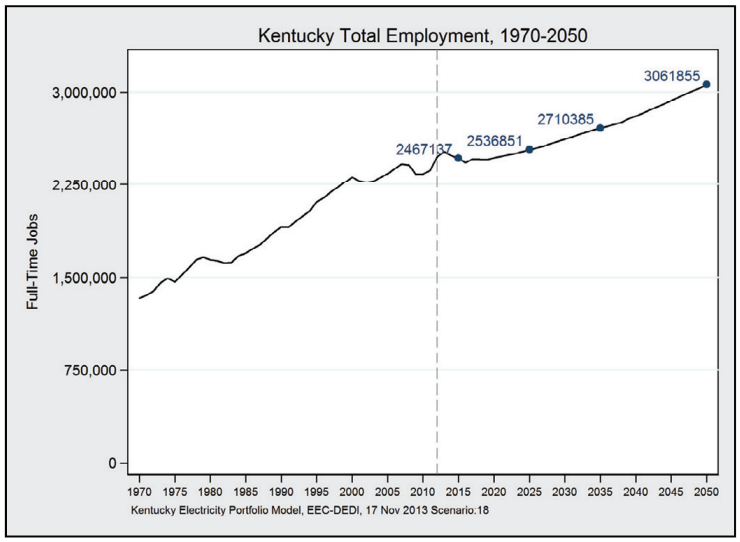






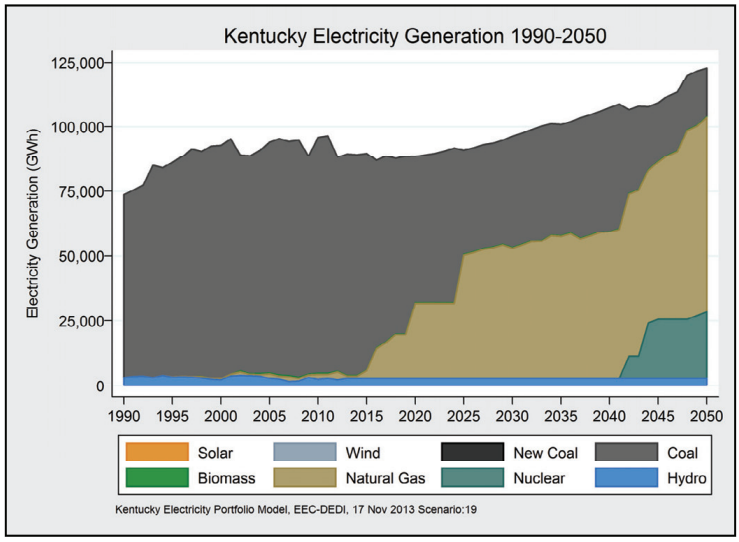


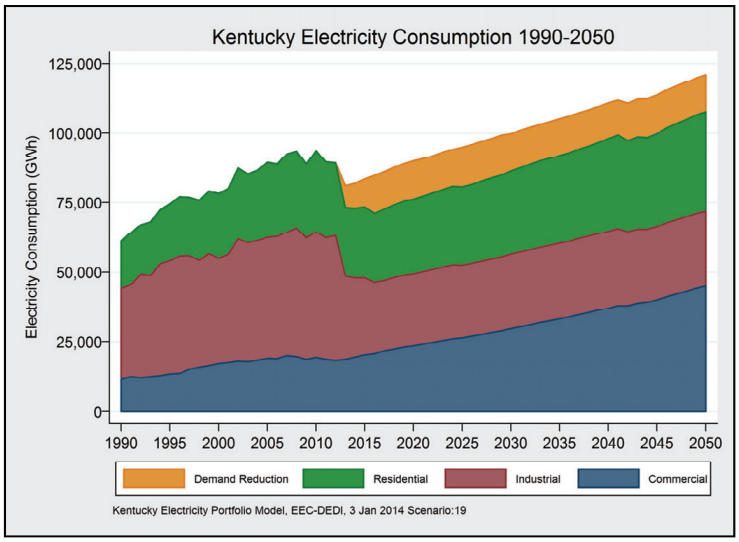


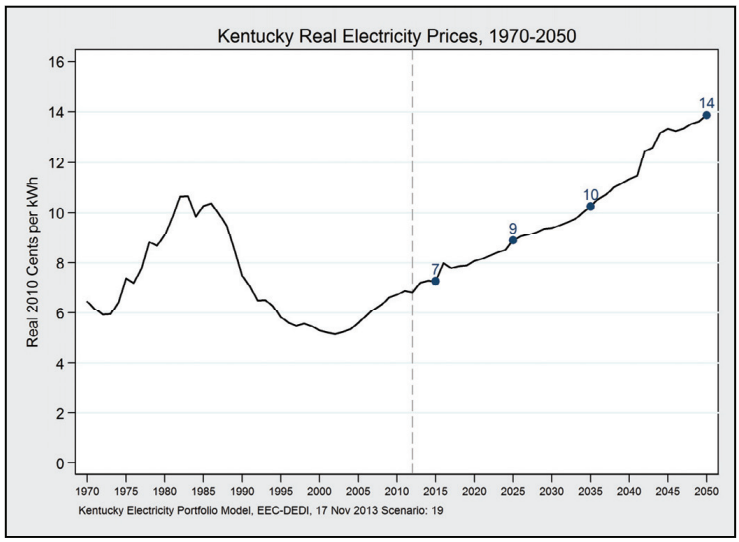


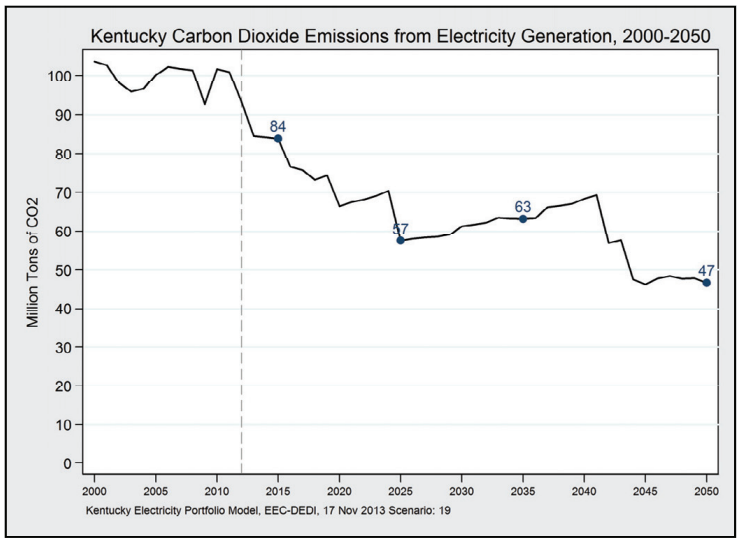
Scenario 19

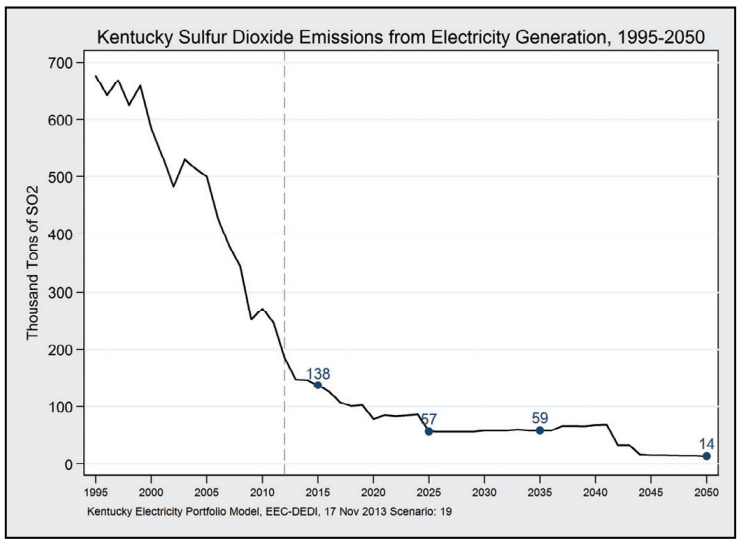
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 3: Balanced Portfolio Standard

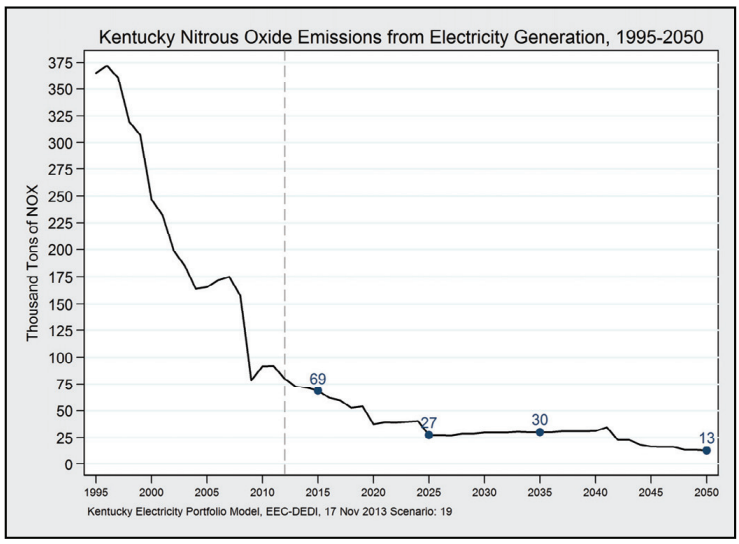






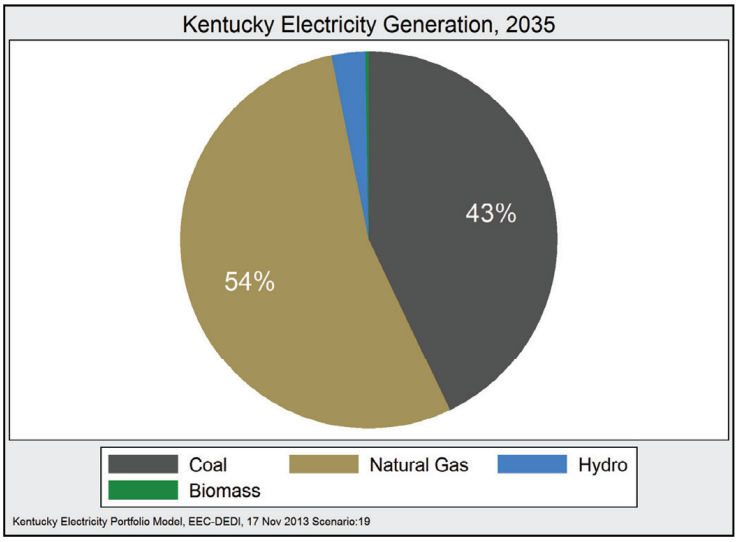


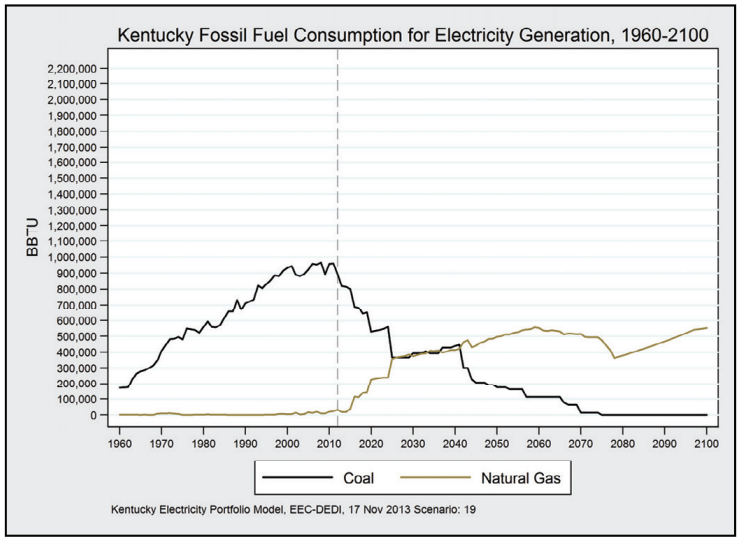


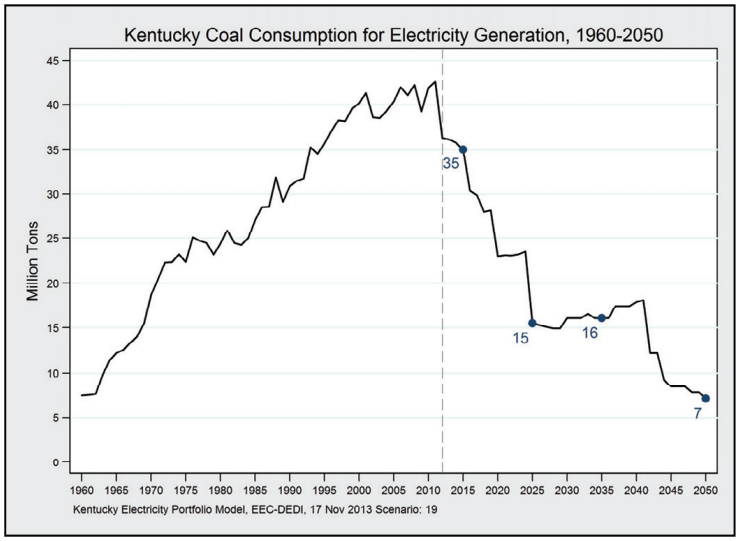


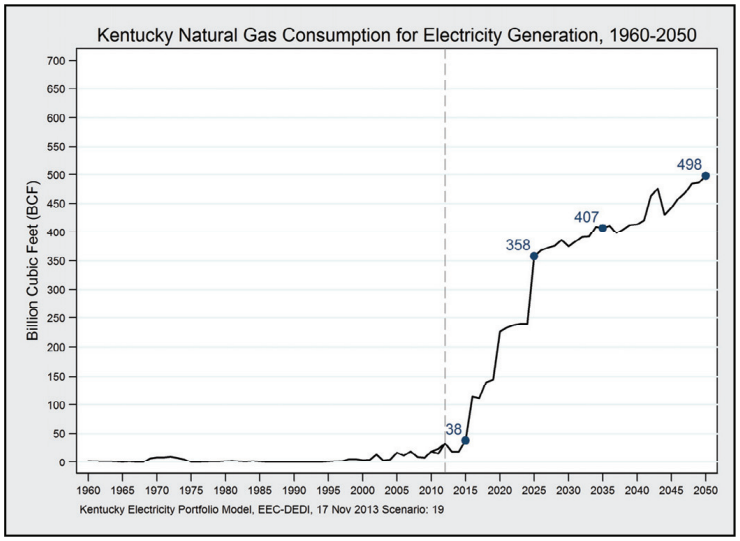
Scenario 19

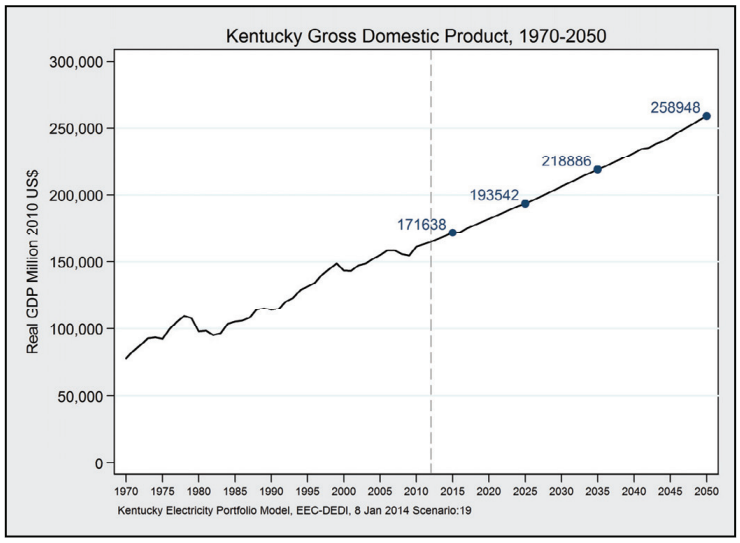
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 3: Balanced Portfolio Standard

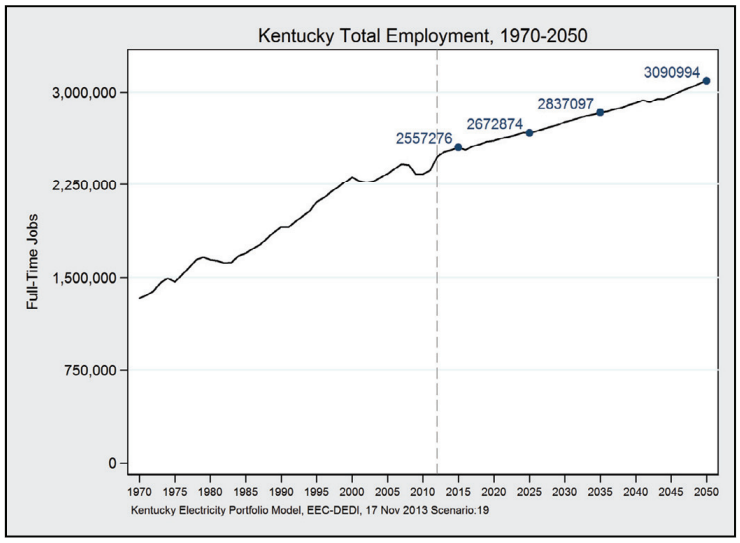






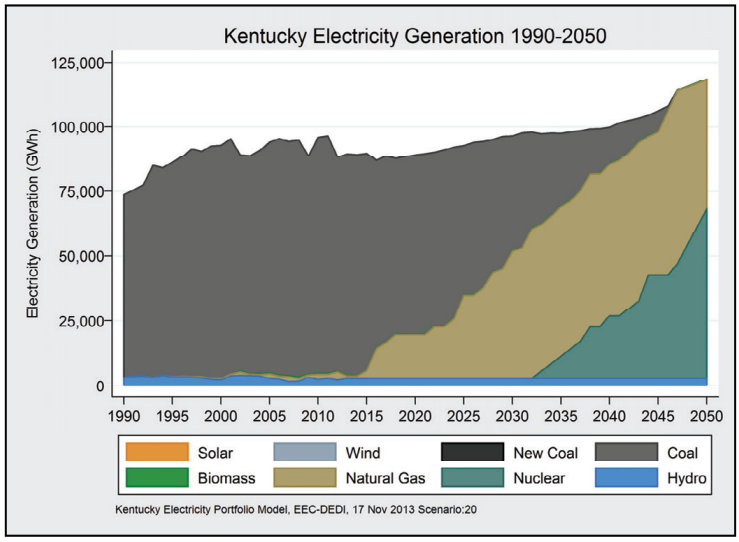


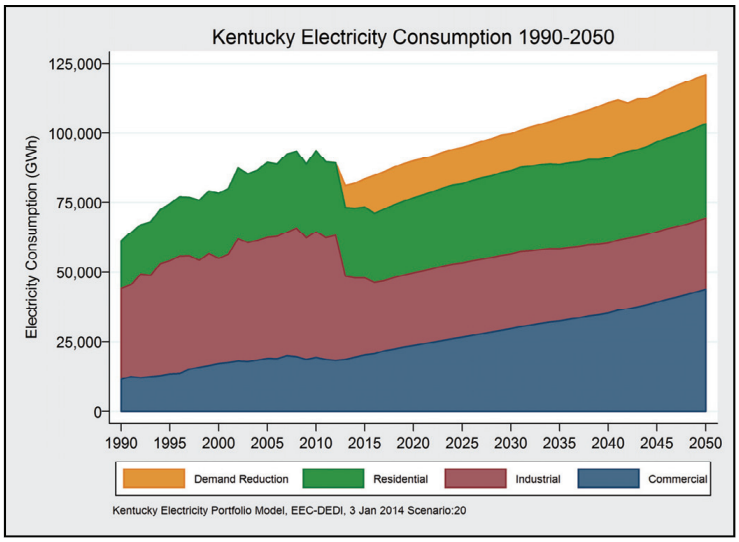


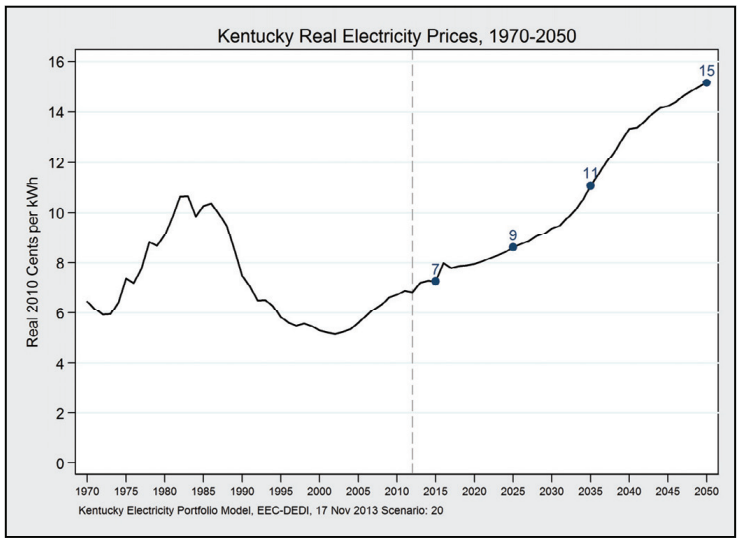


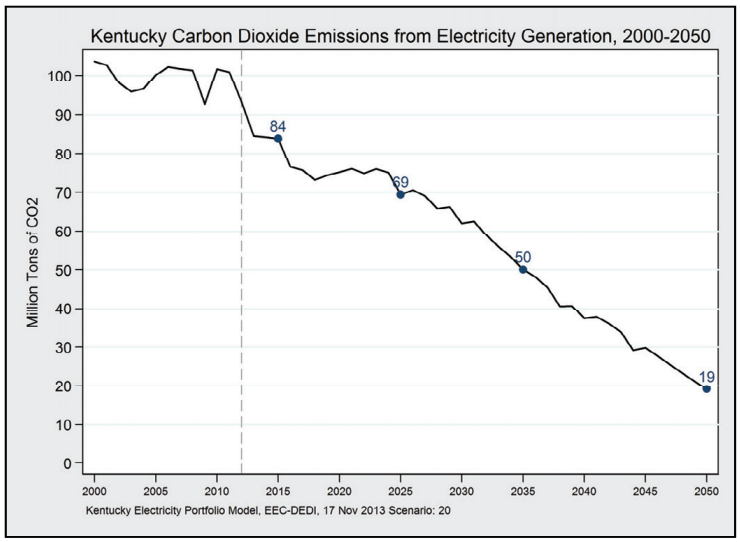
Scenario 20

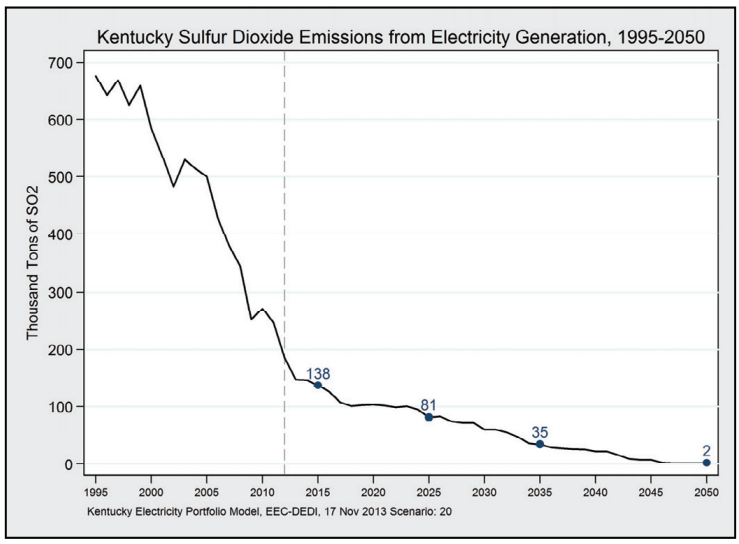
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 3: Balanced Portfolio Standard

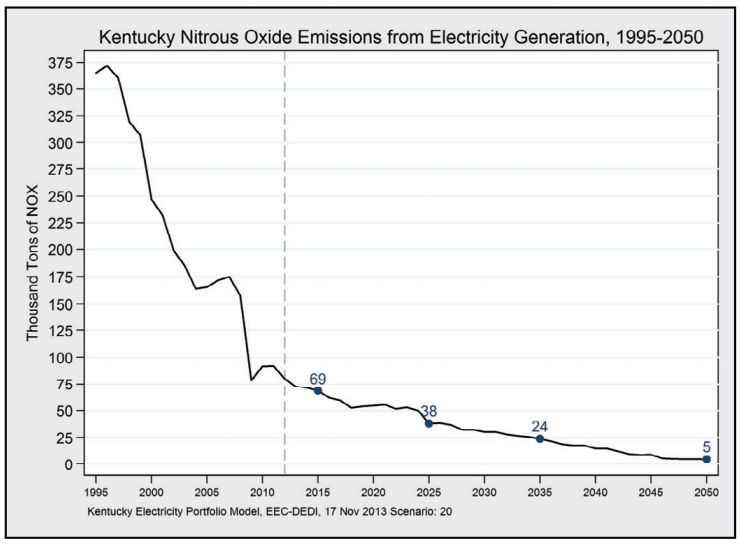






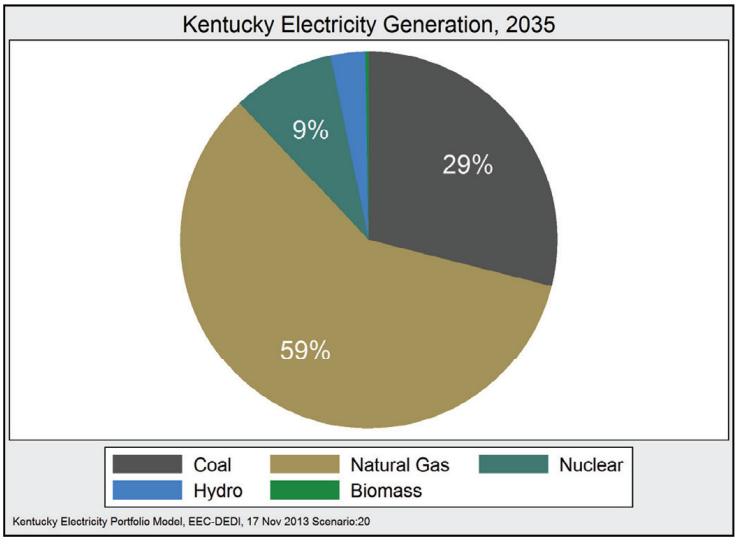


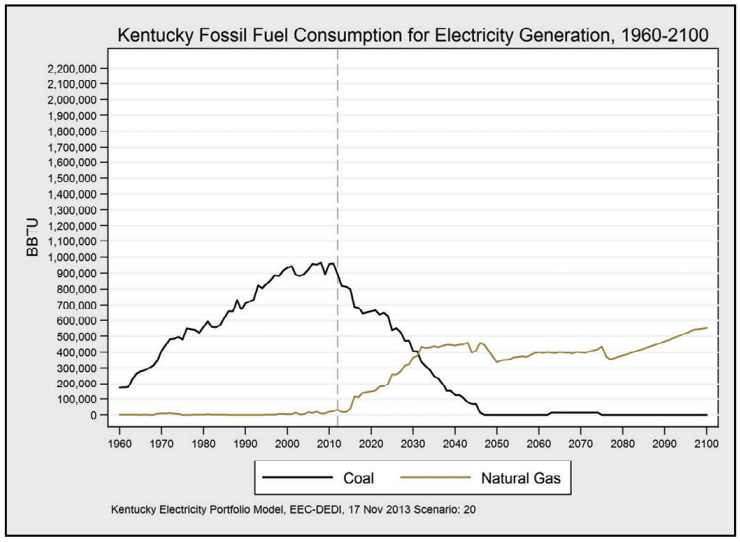


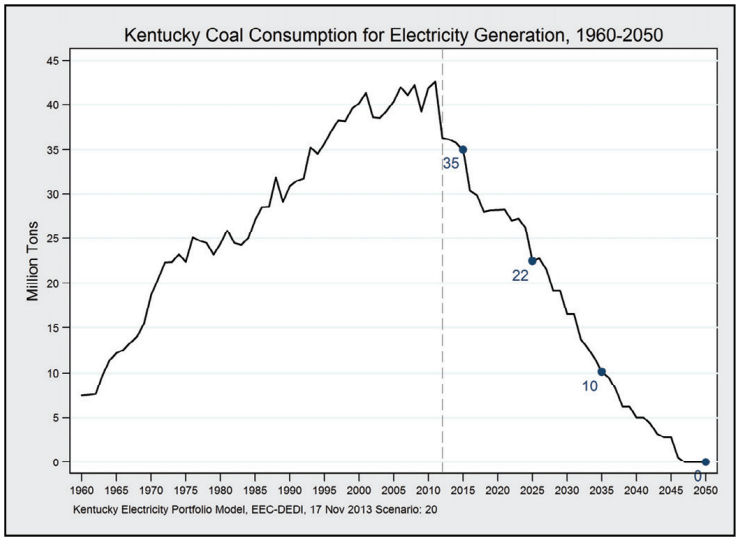


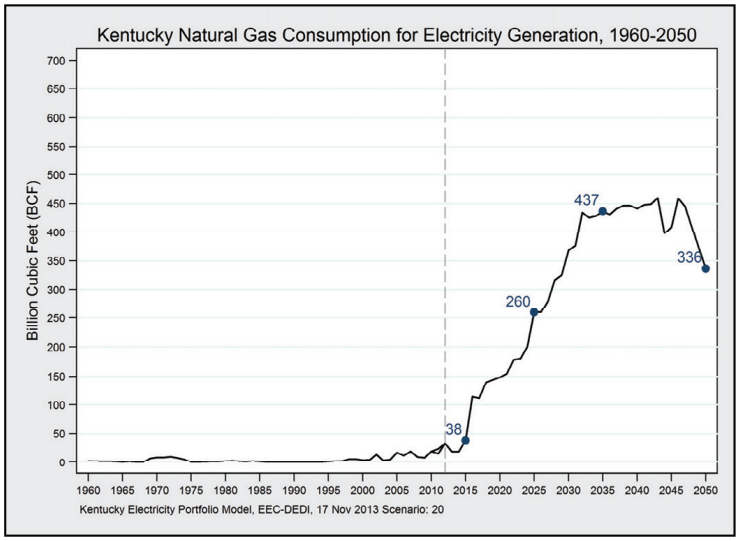
Scenario 20

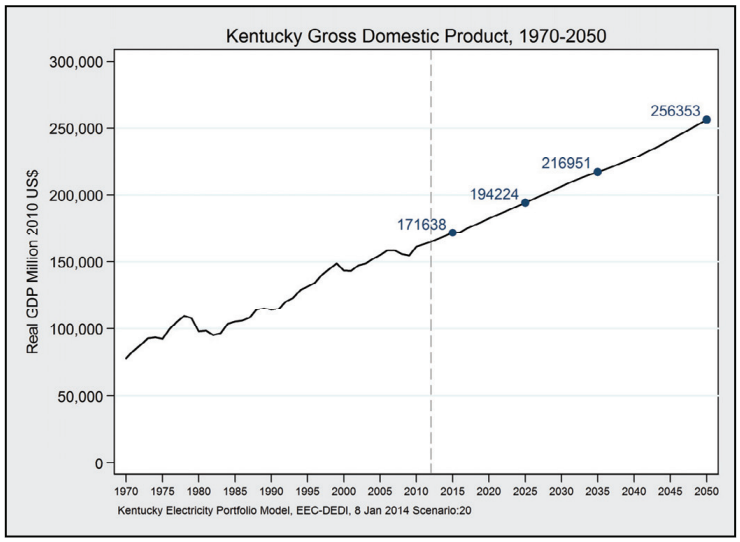
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 3: Balanced Portfolio Standard

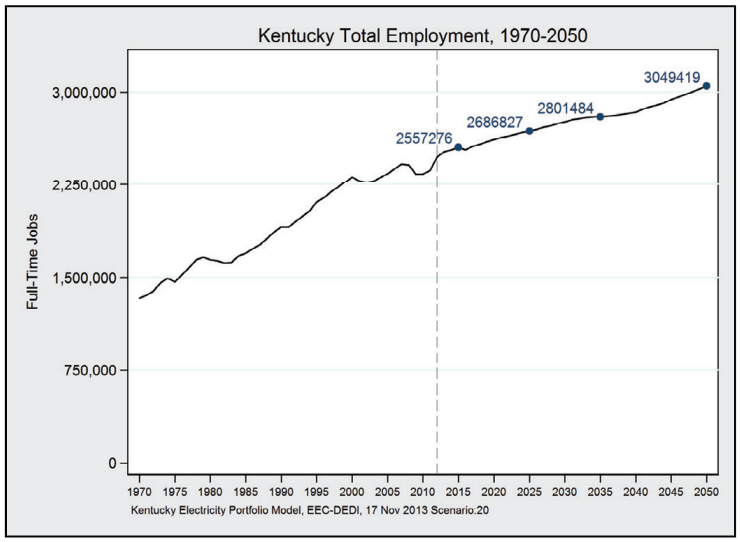






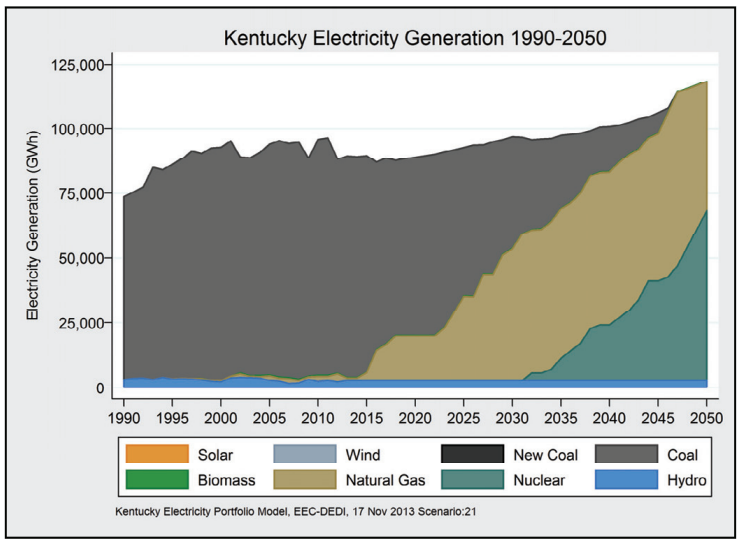


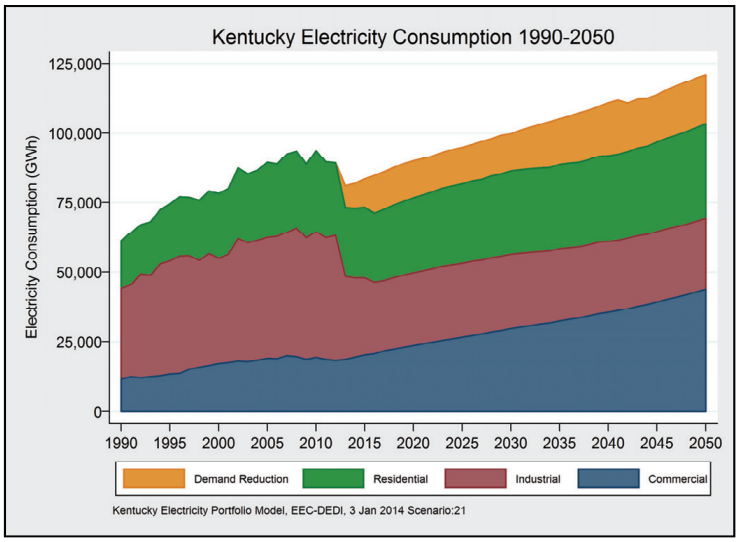


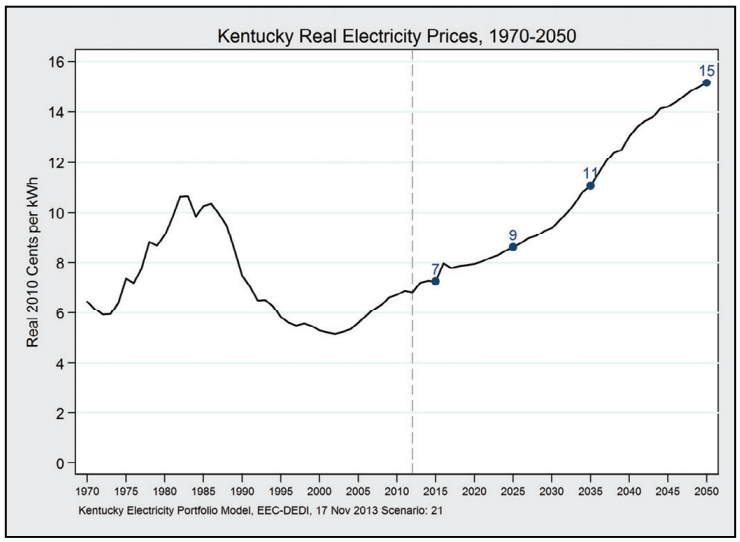


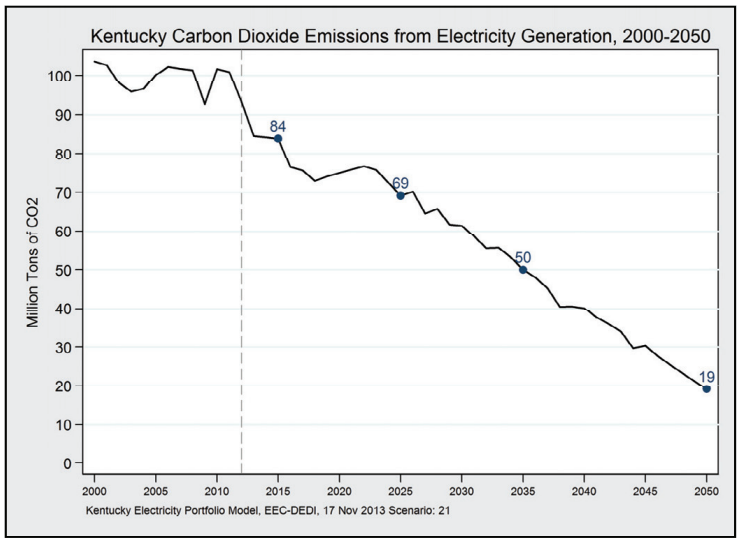
Scenario 21

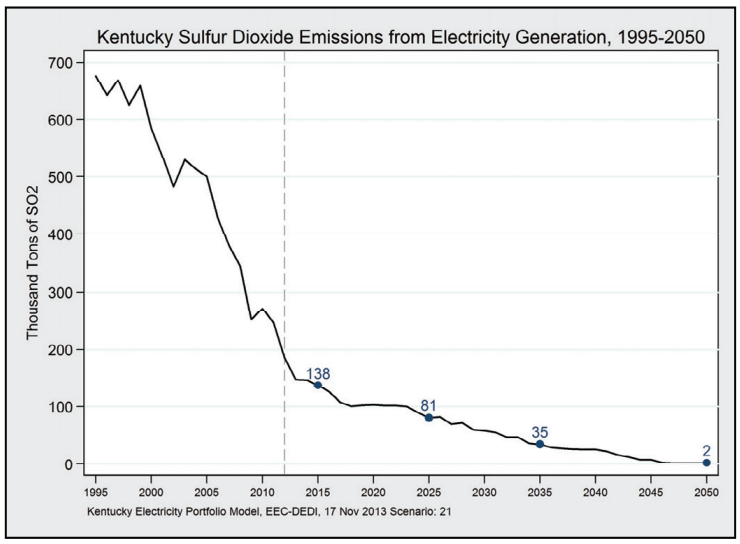
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 3: Balanced Portfolio Standard

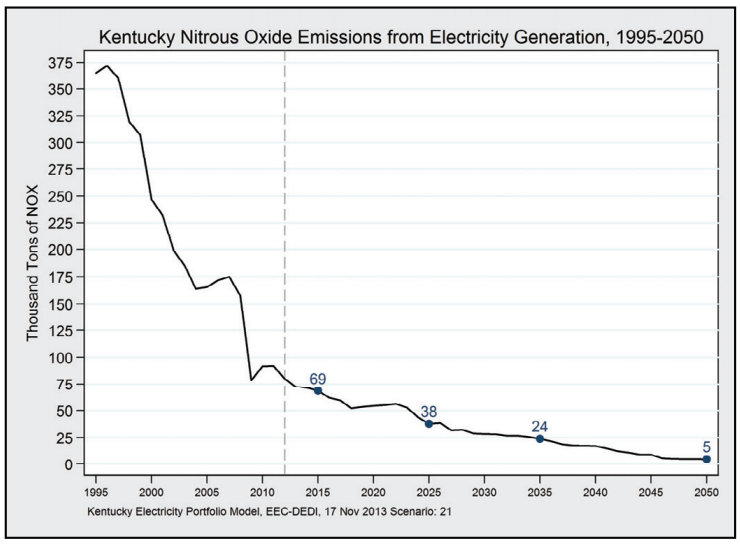






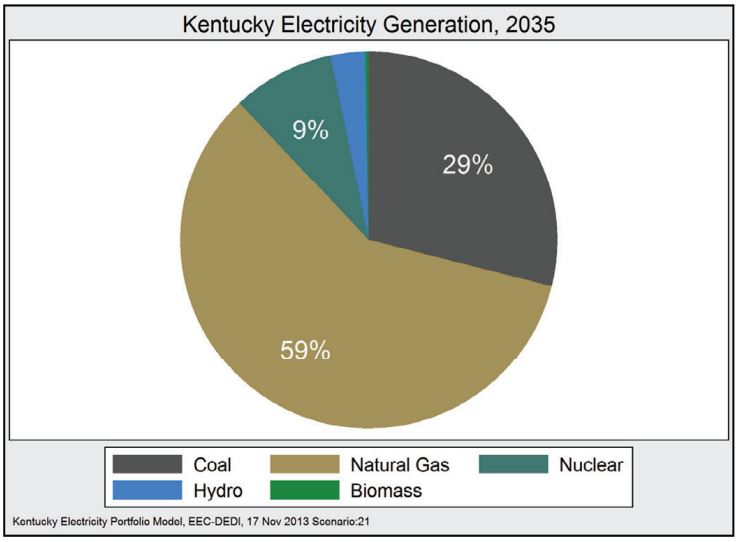


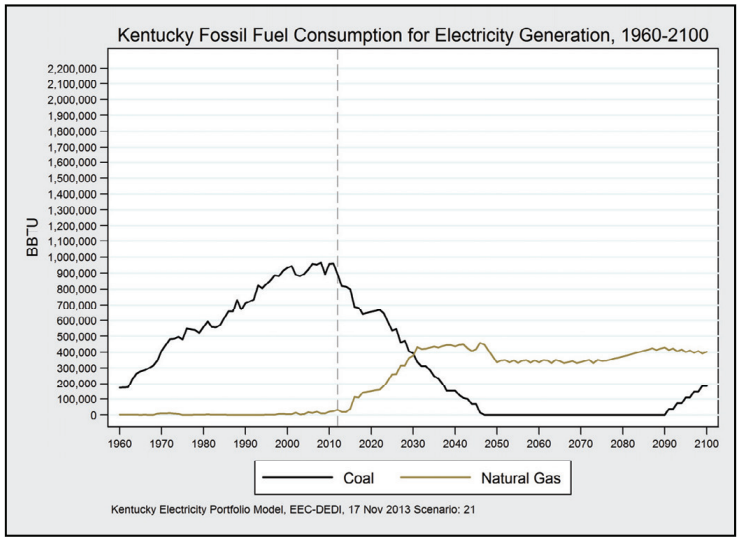


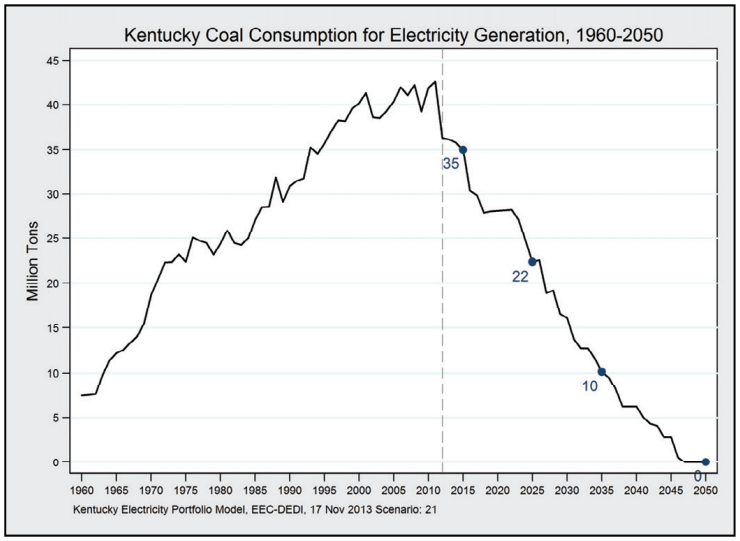


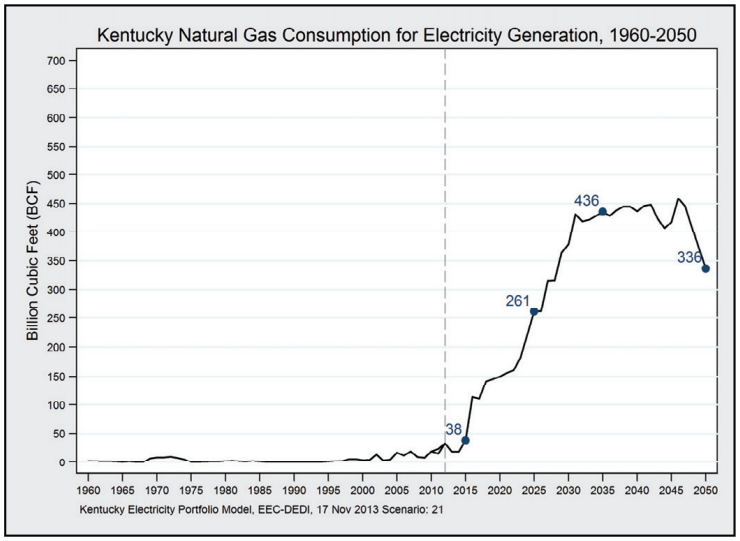
Scenario 21

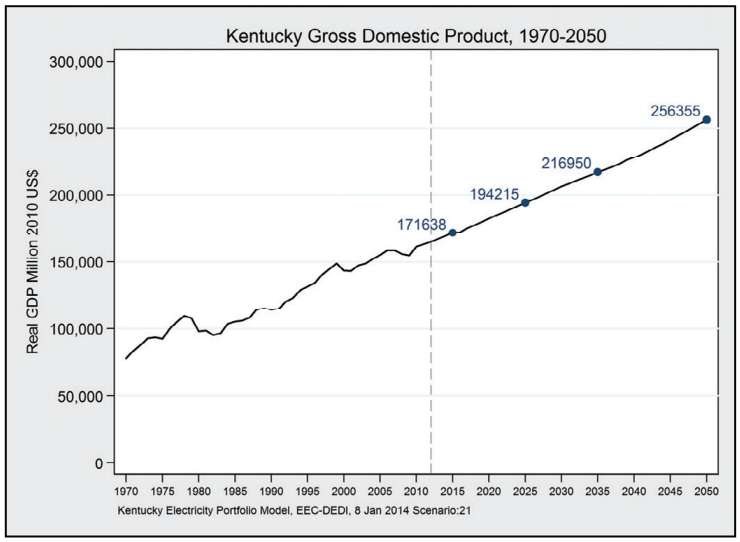
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 3: Balanced Portfolio Standard

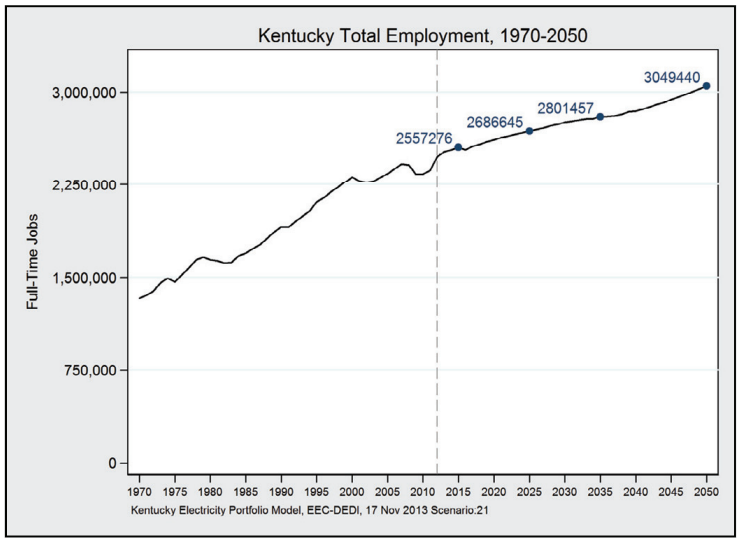






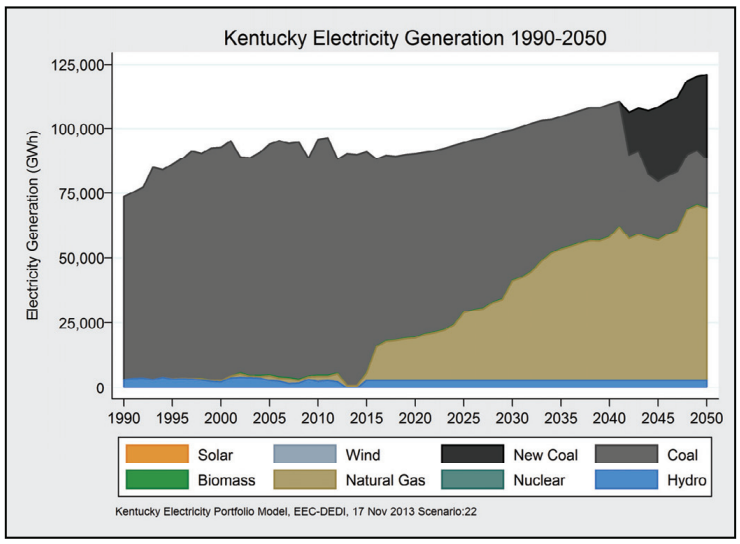


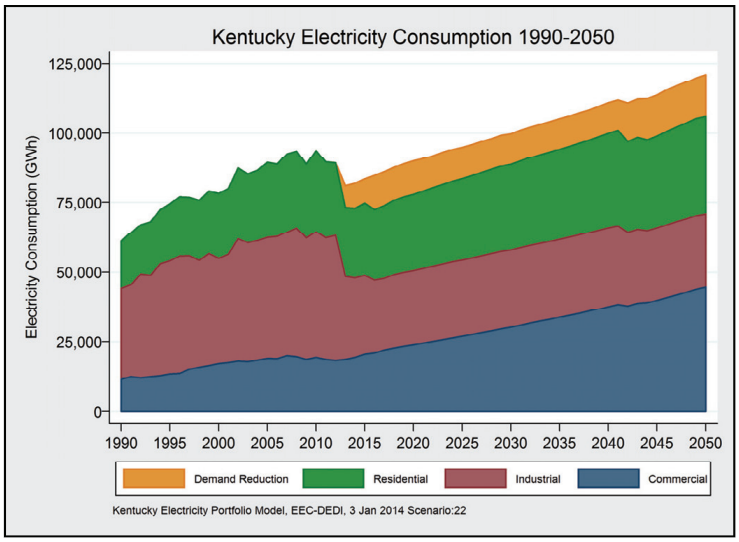


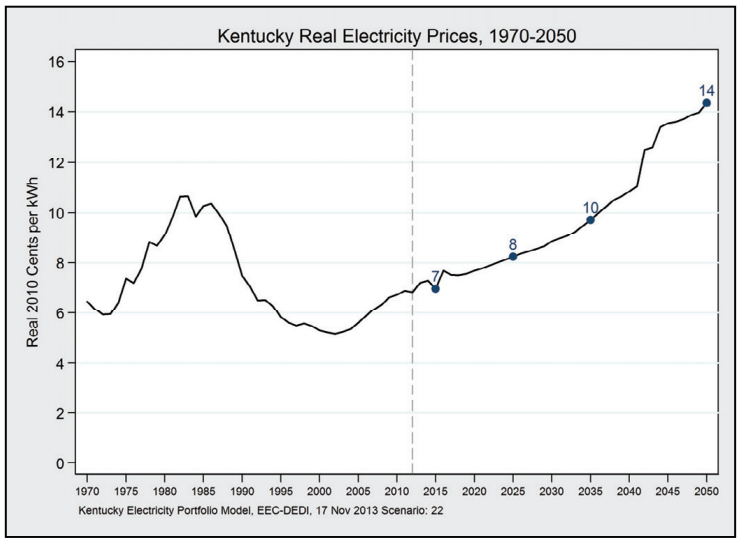


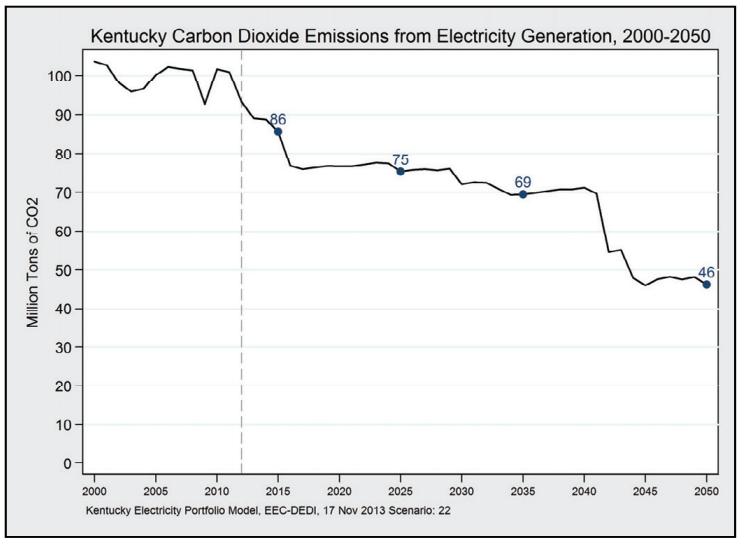
Scenario 22

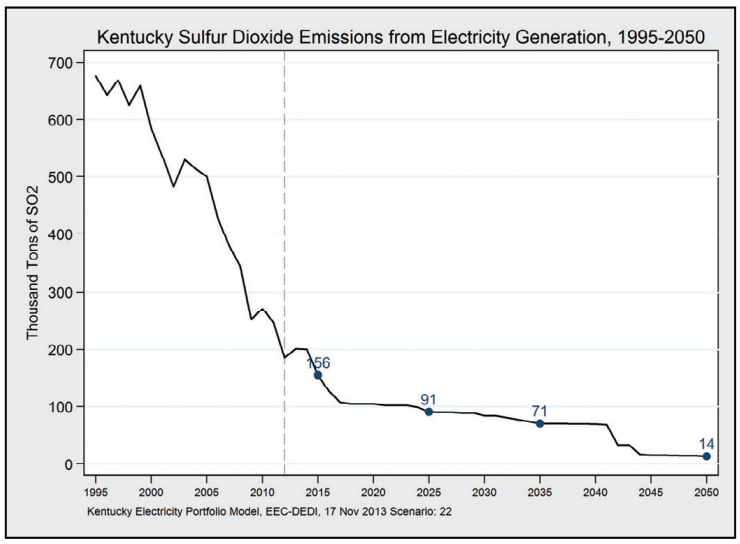
Federal Policy Option 1: Reference Portfolio 4: Coal Portfolio Standard

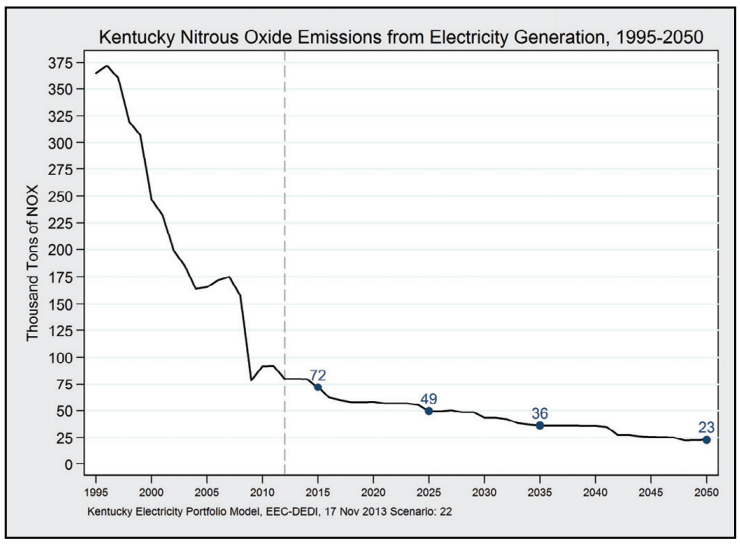






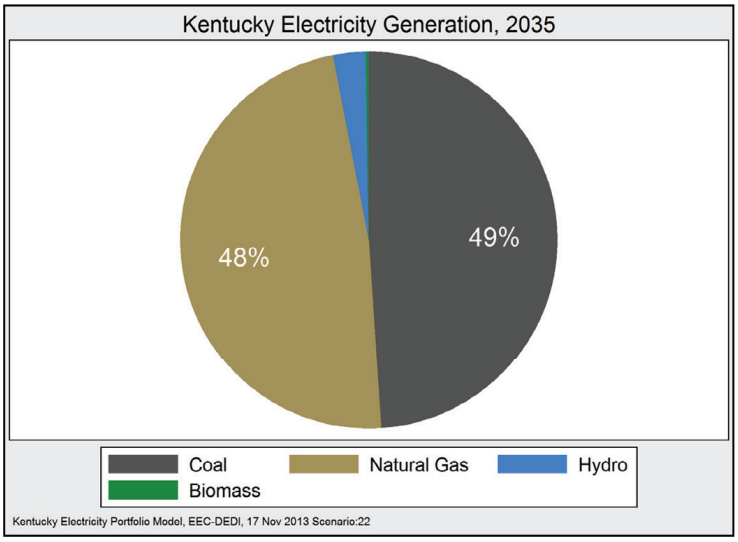


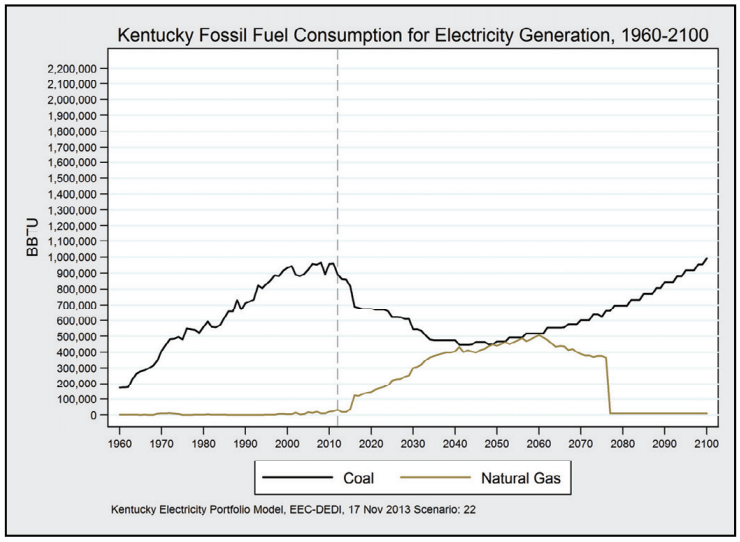


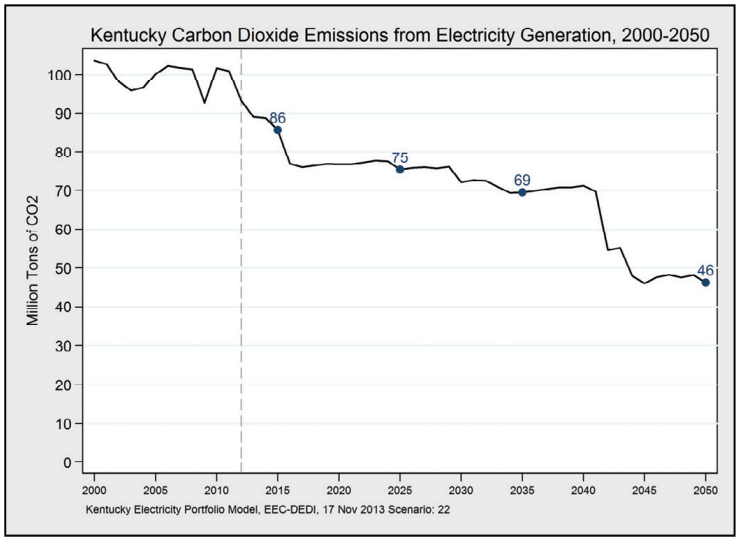


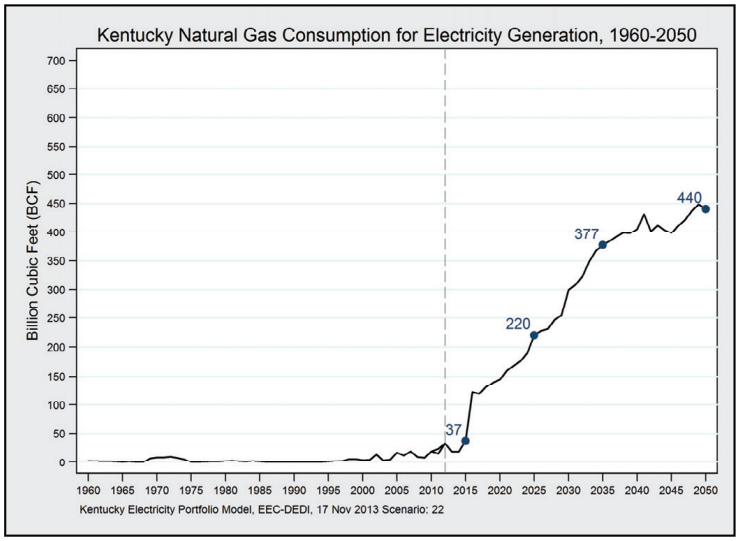
Scenario 22

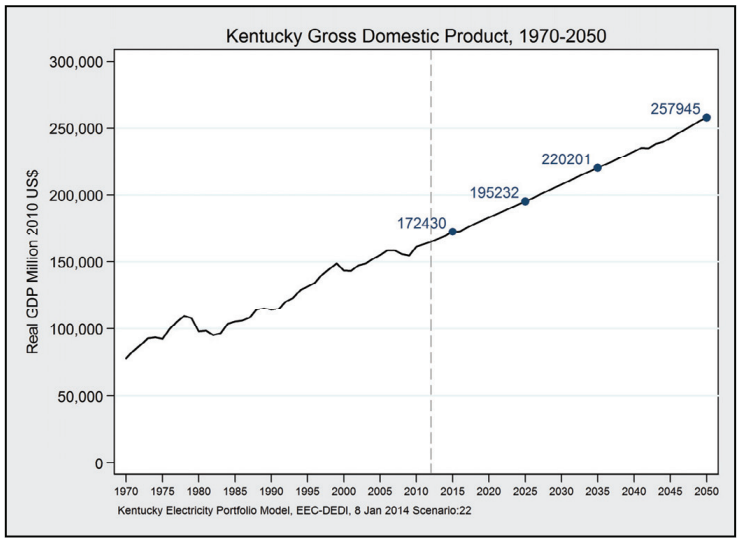
Federal Policy Option 1: Reference Portfolio 4: Coal Portfolio Standard

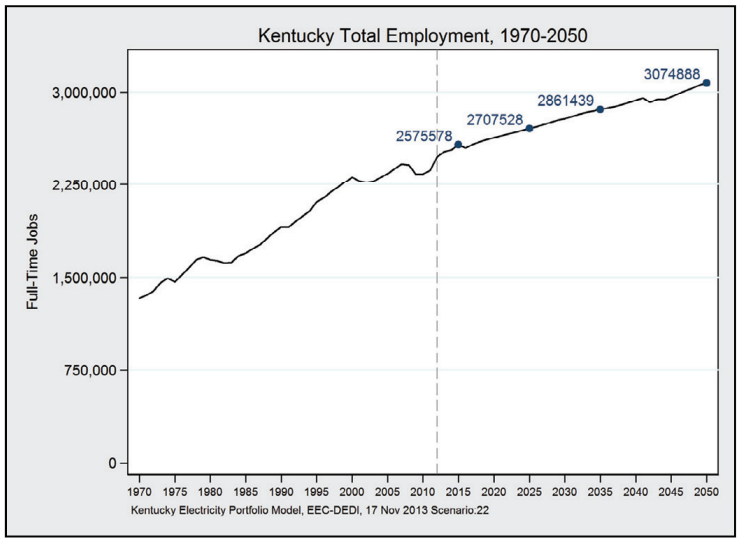






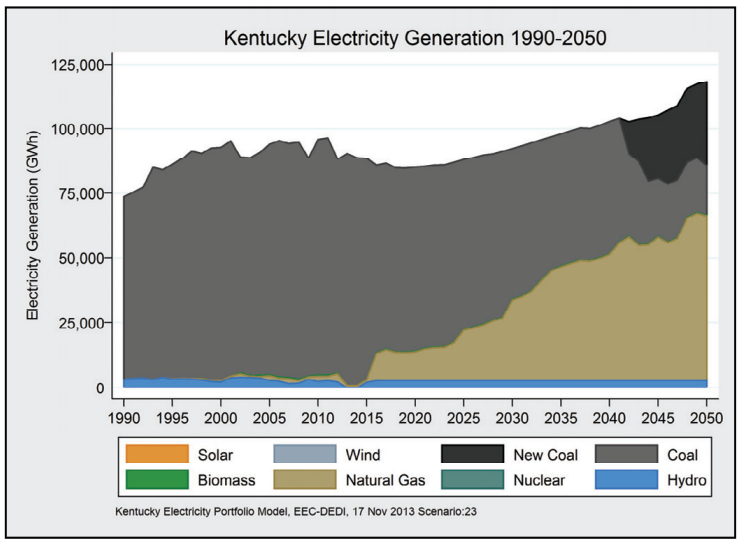


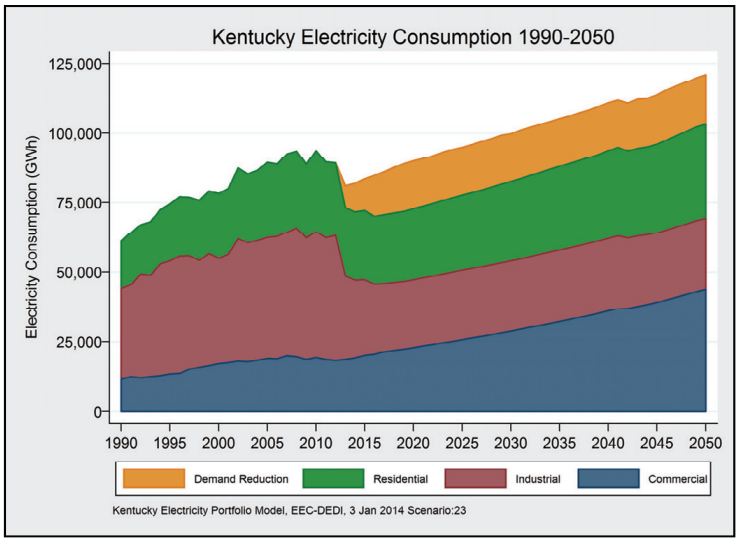


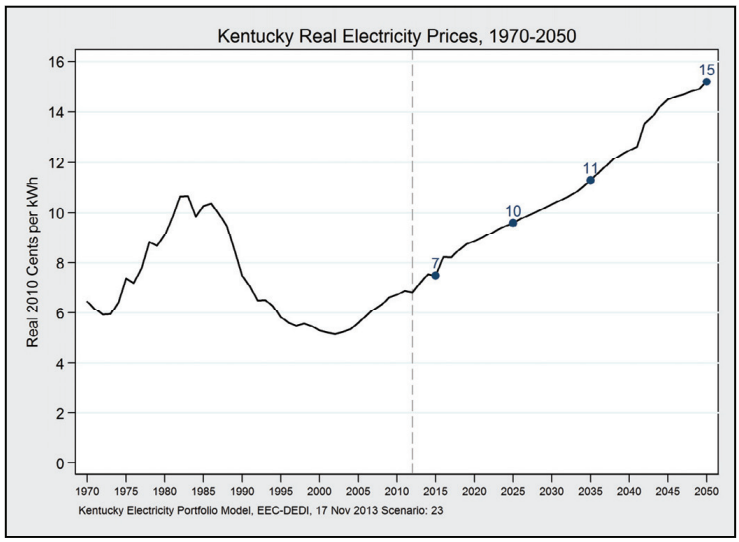


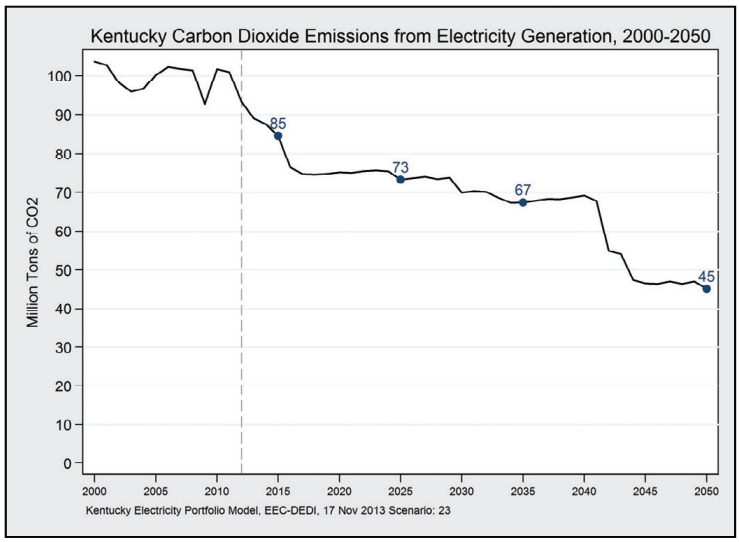
Scenario 23

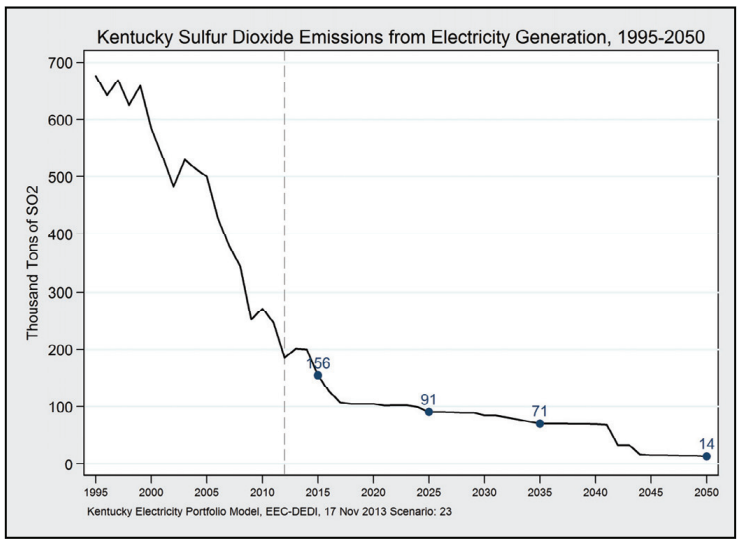
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 4: Coal Portfolio Standard

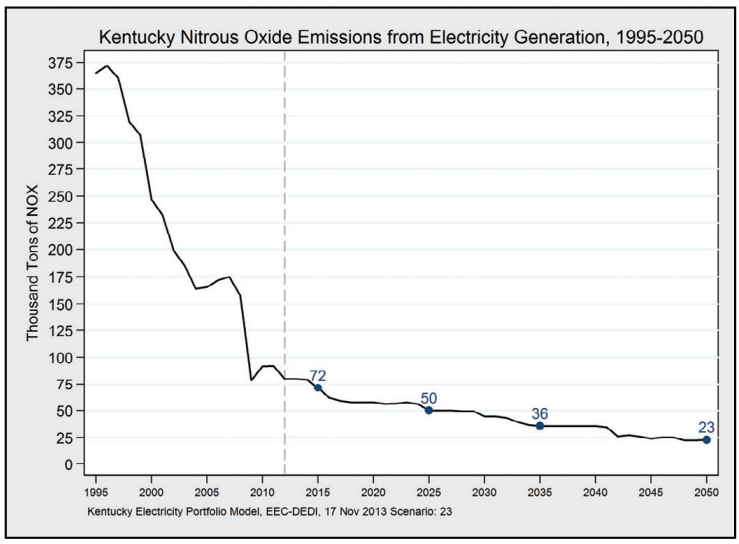






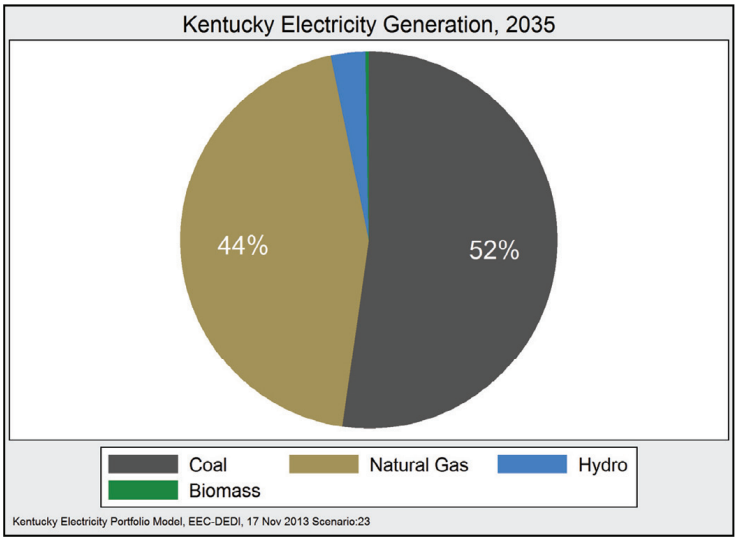


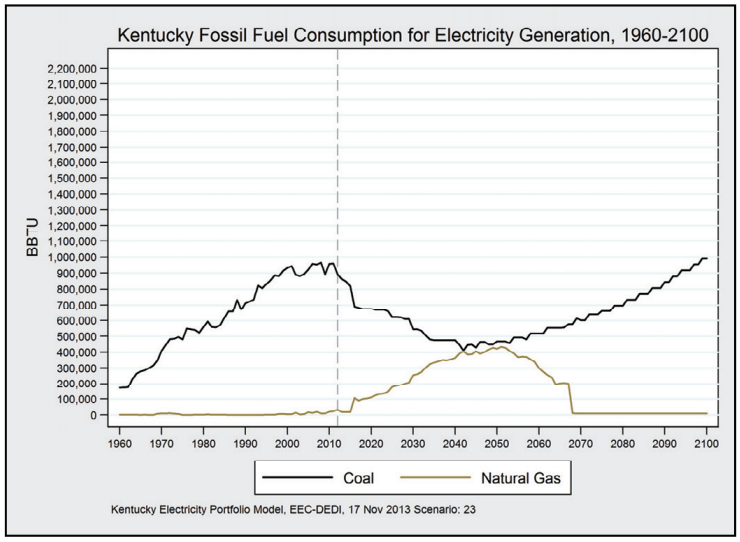


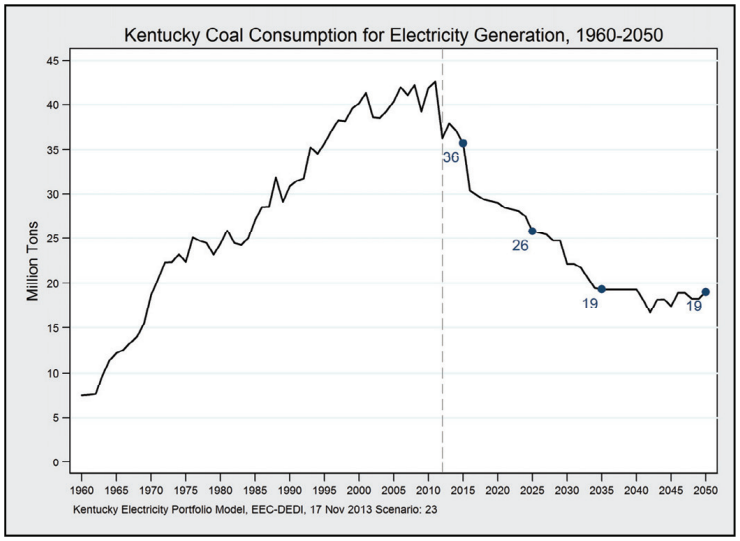


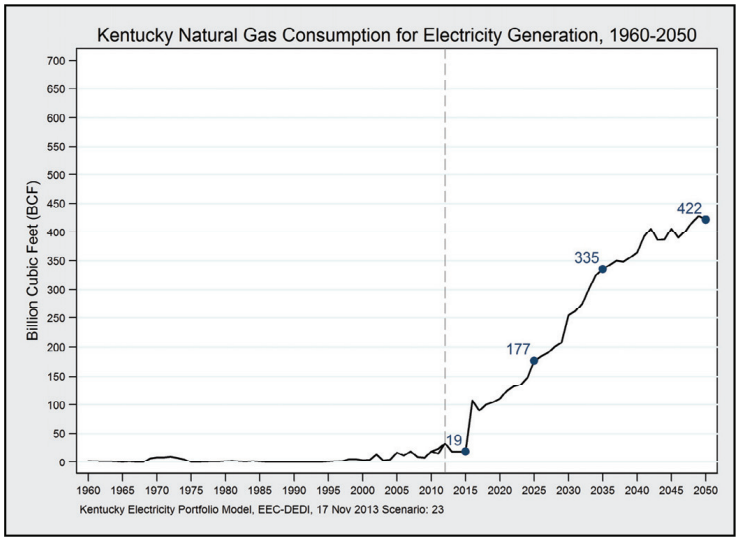
Scenario 23

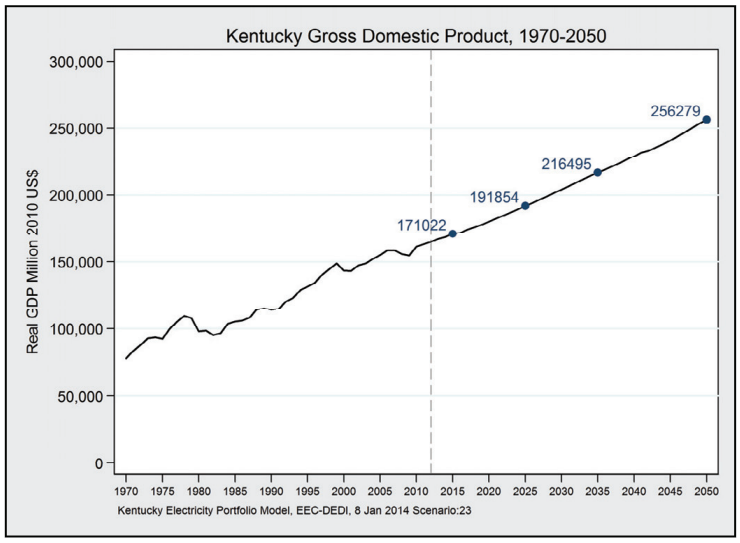
Federal Policy Option 2: $10-$20 Carbon Tax
Portfolio 4: Coal Portfolio Standard

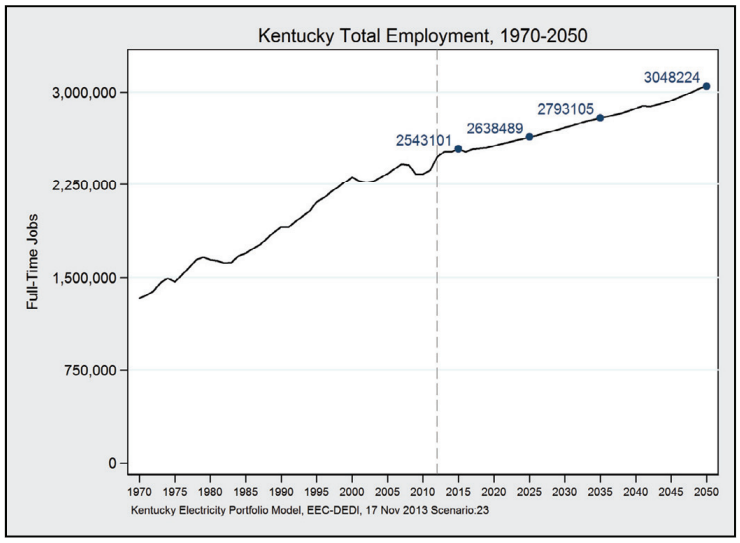






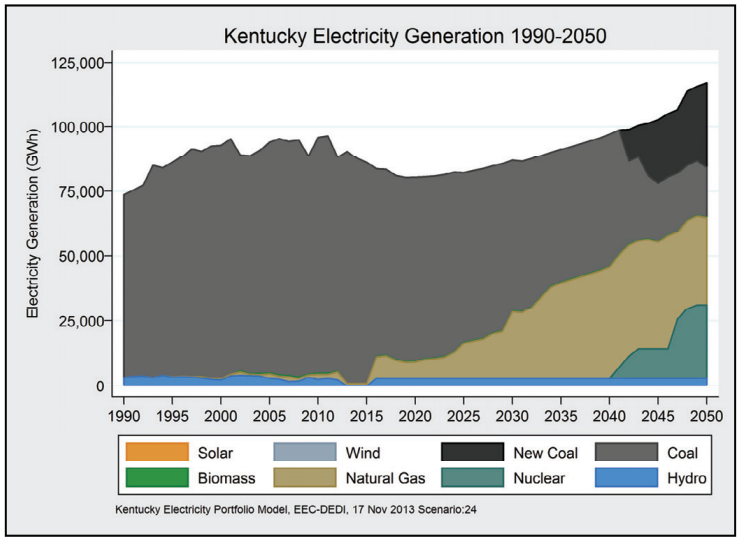


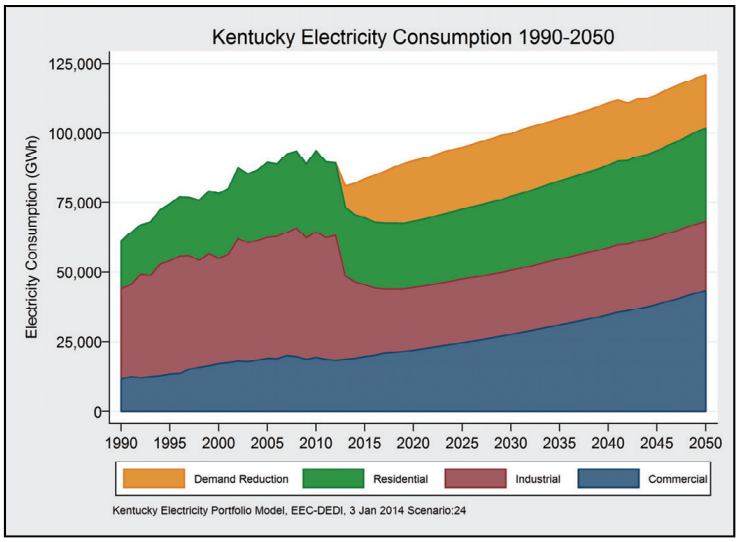


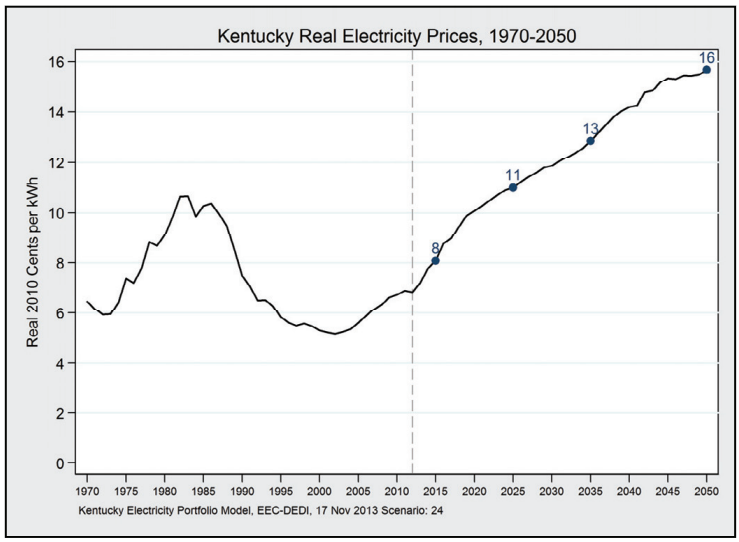


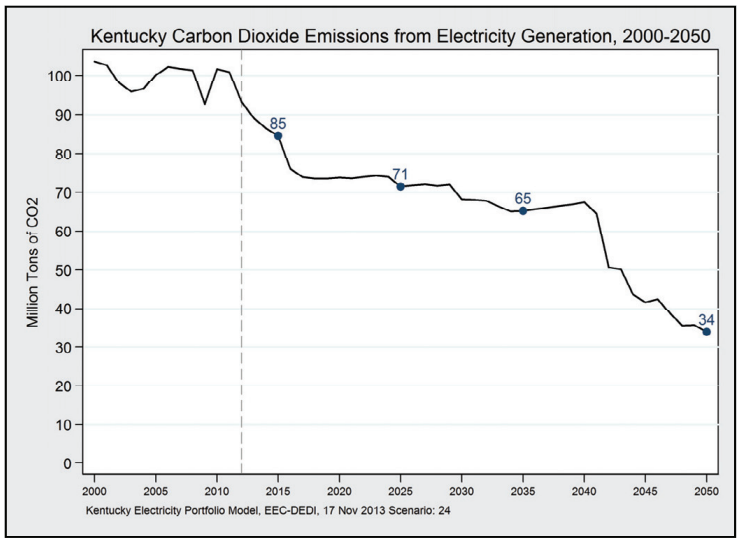
Scenario 24

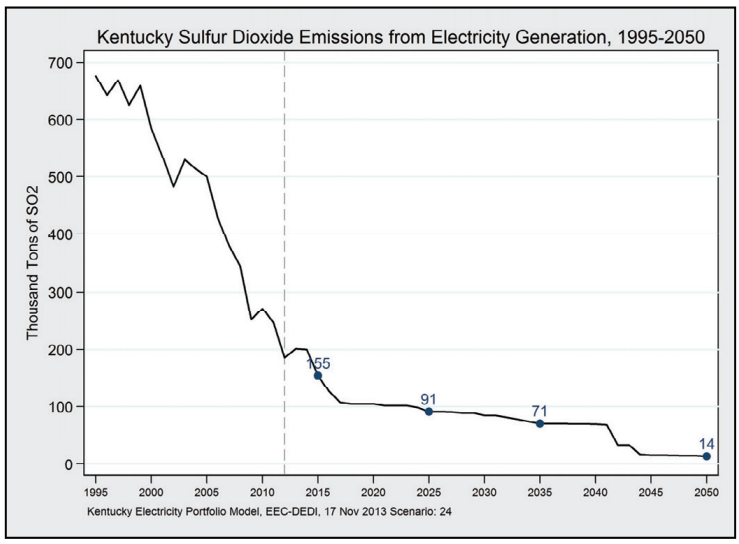
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 4: Coal Portfolio Standard

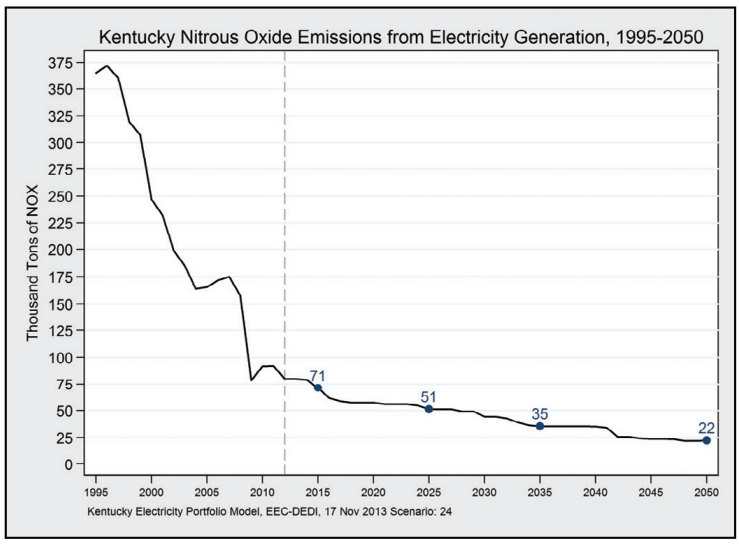






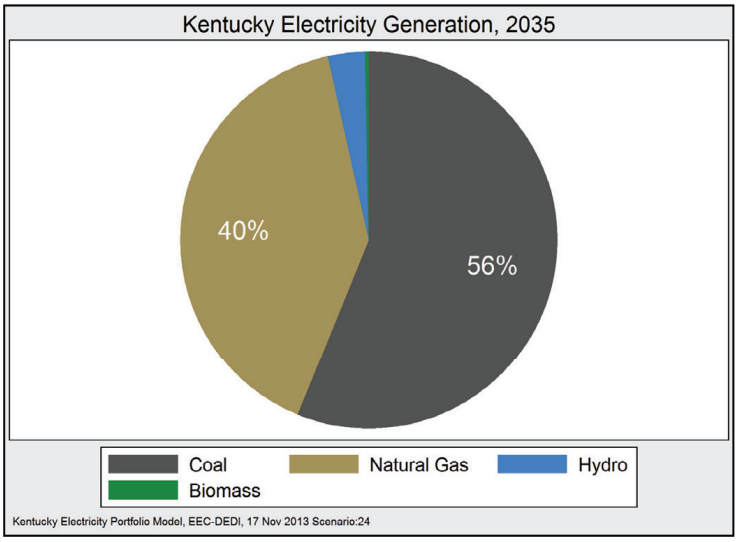


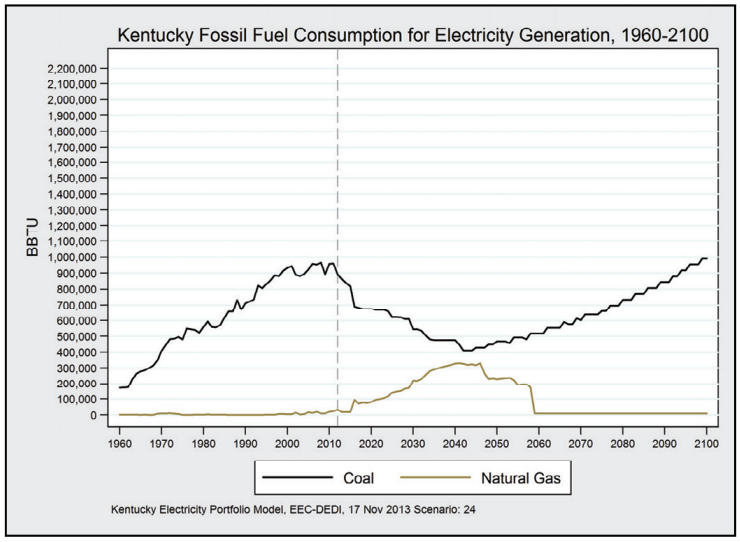


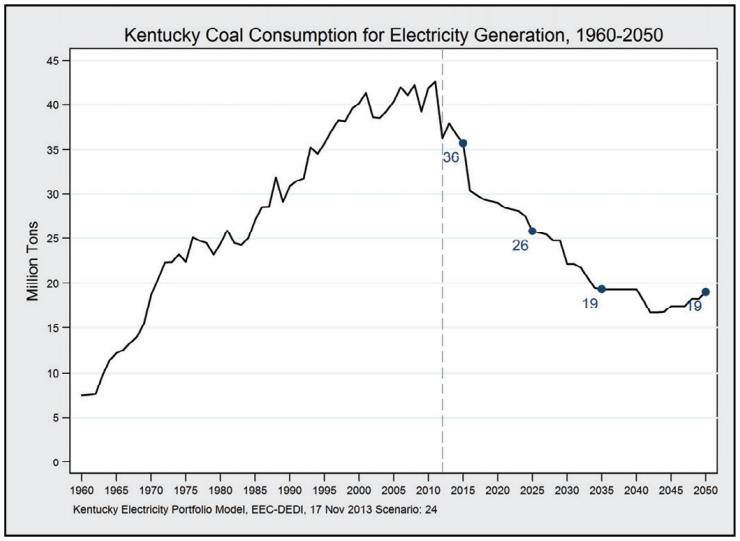


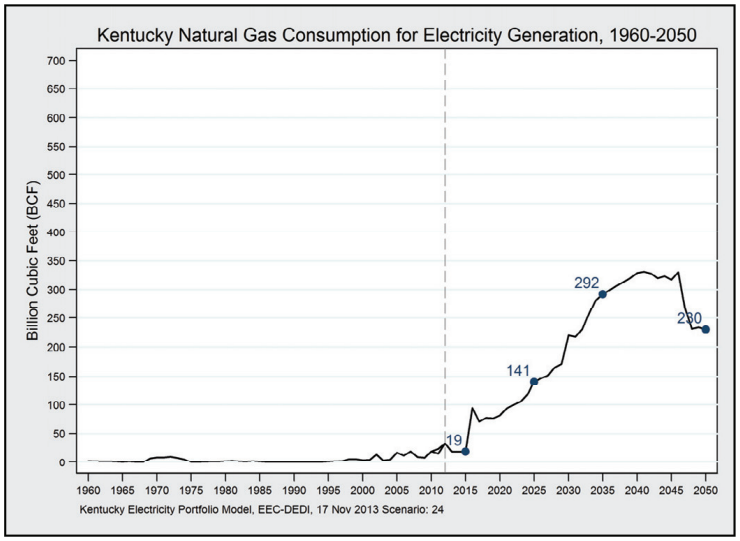
Scenario 24

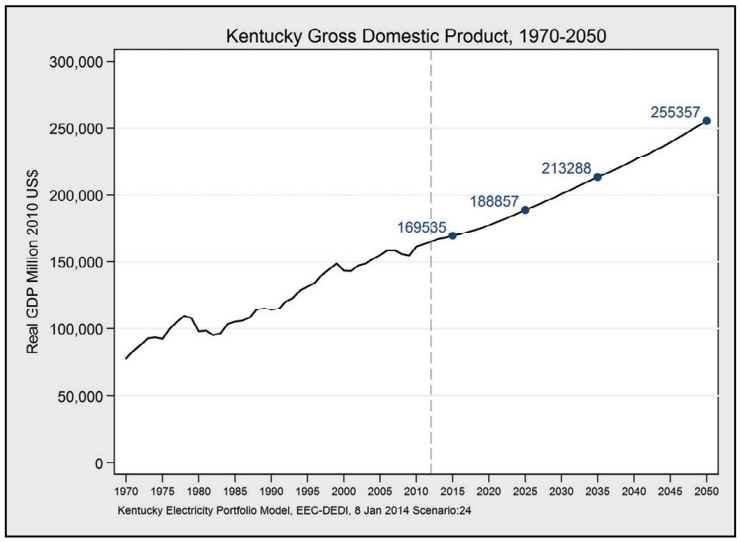
Federal Policy Option 3: $20-$40 Carbon Tax
Portfolio 4: Coal Portfolio Standard

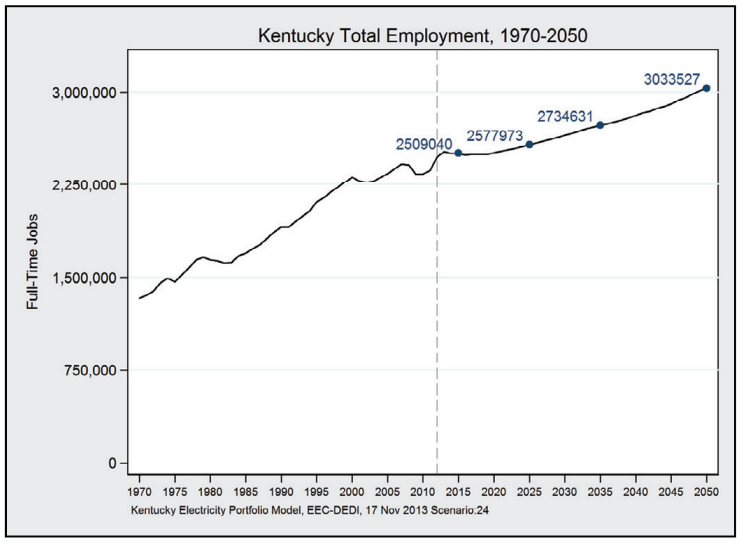






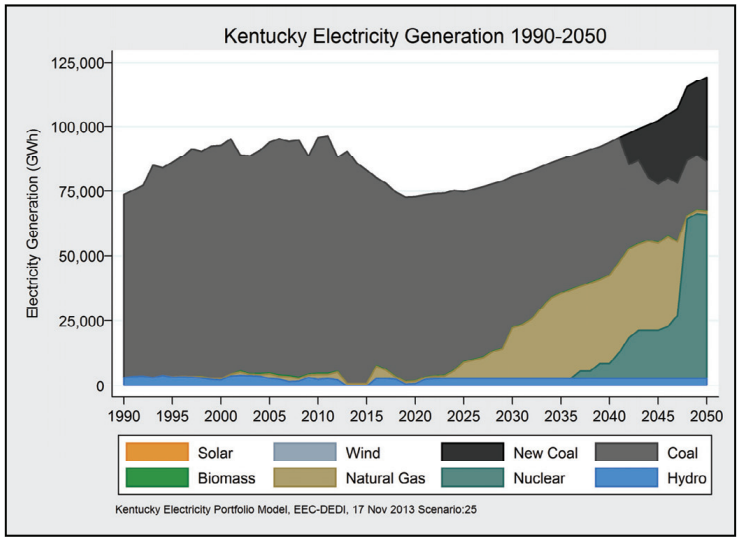


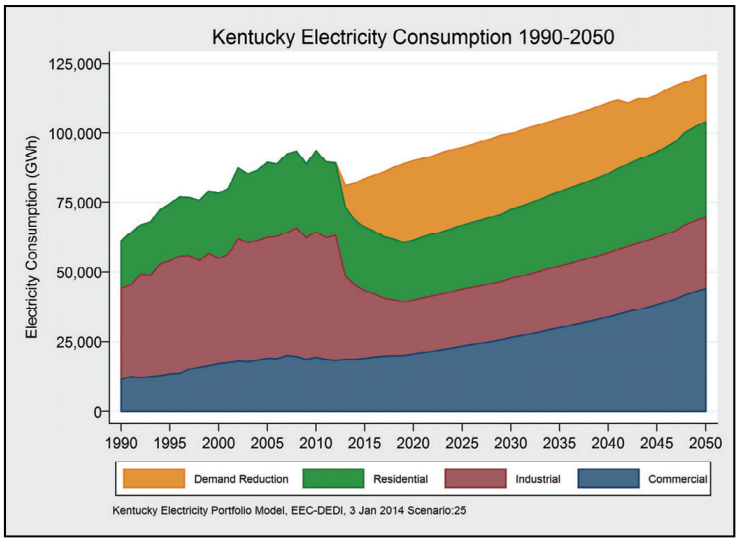


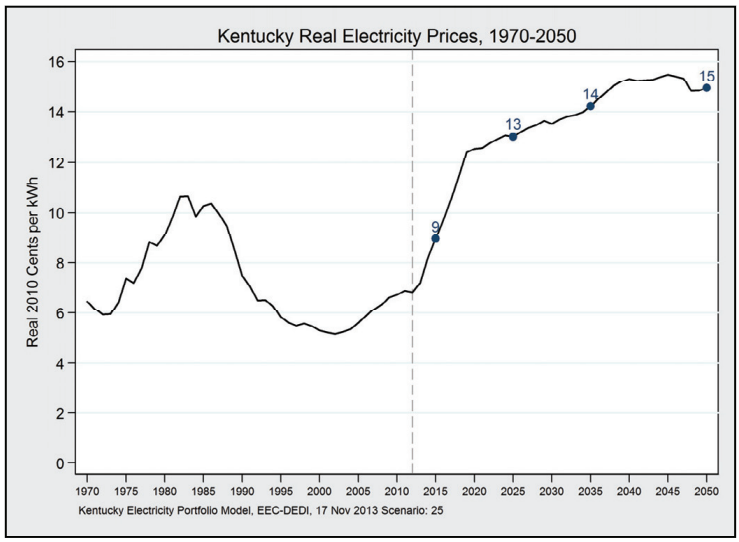


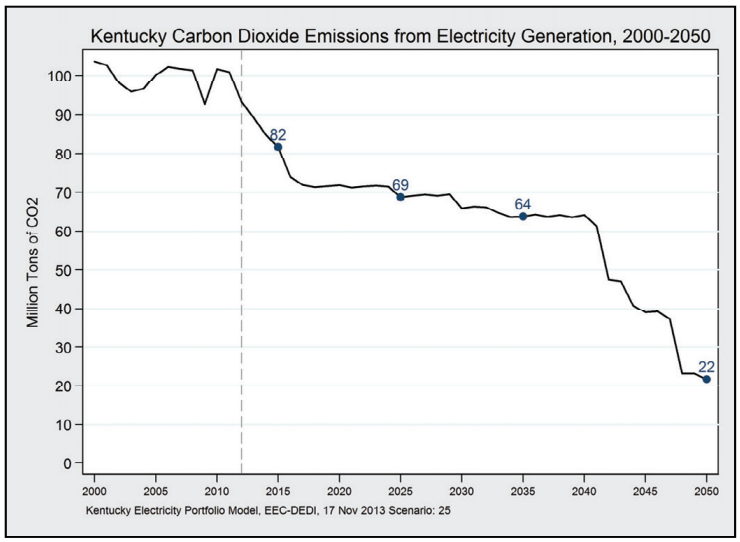
Scenario 25

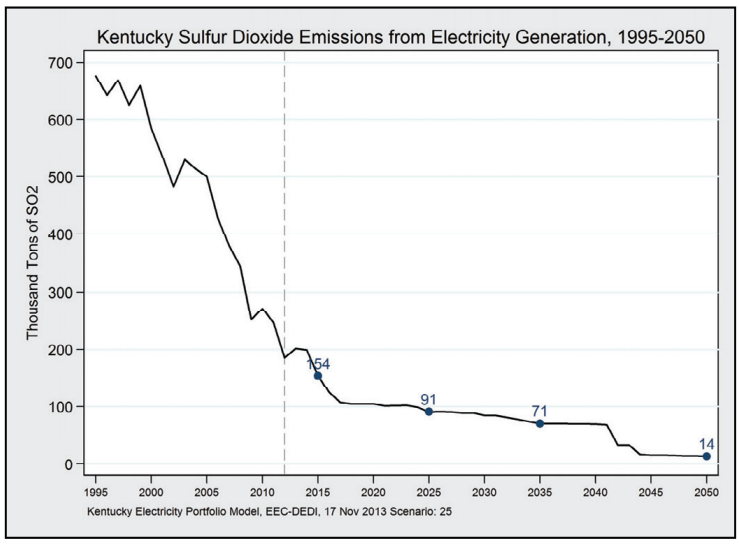
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 4: Coal Portfolio Standard

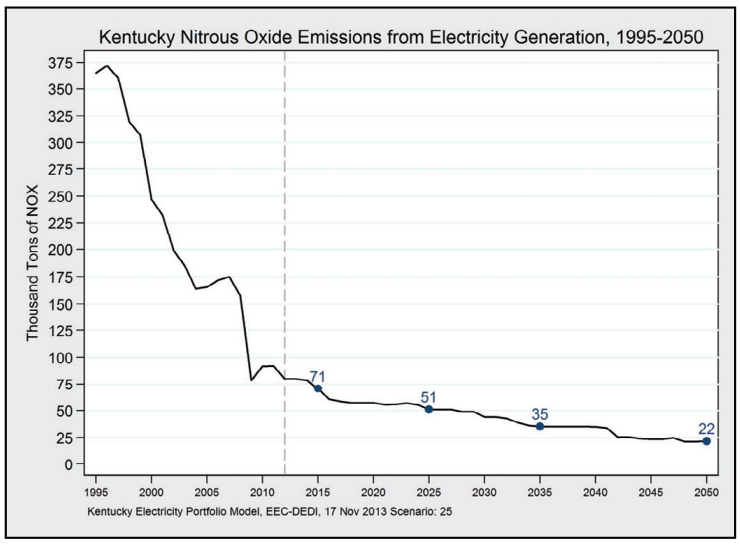






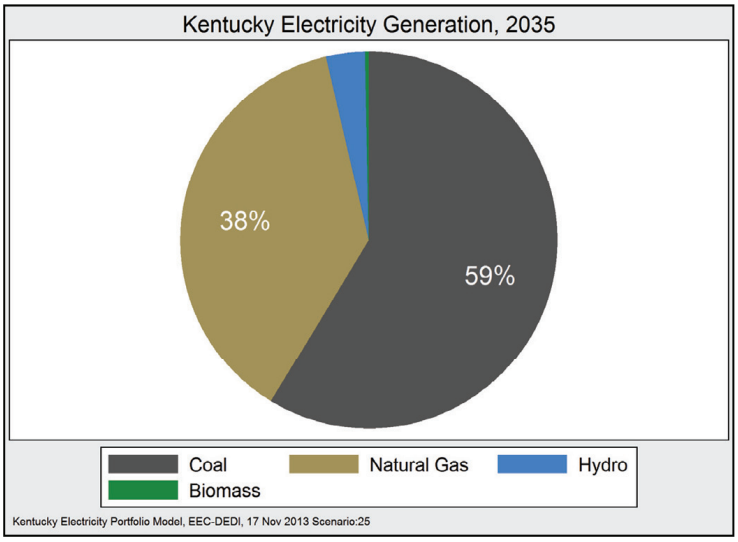


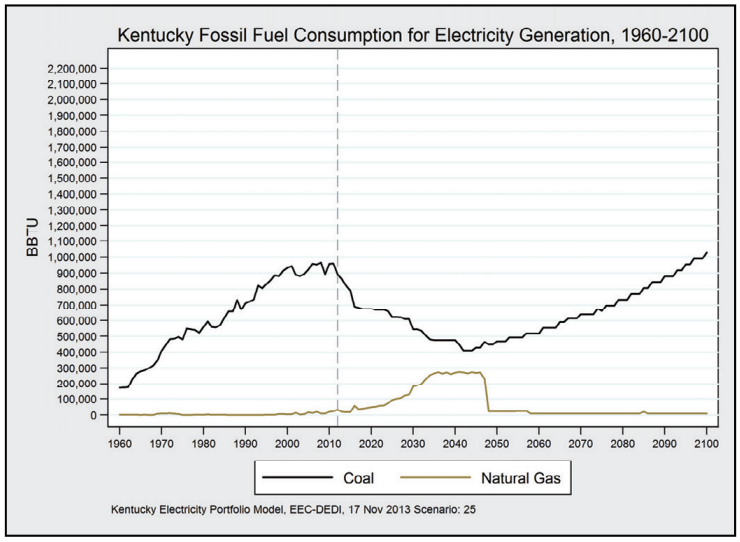


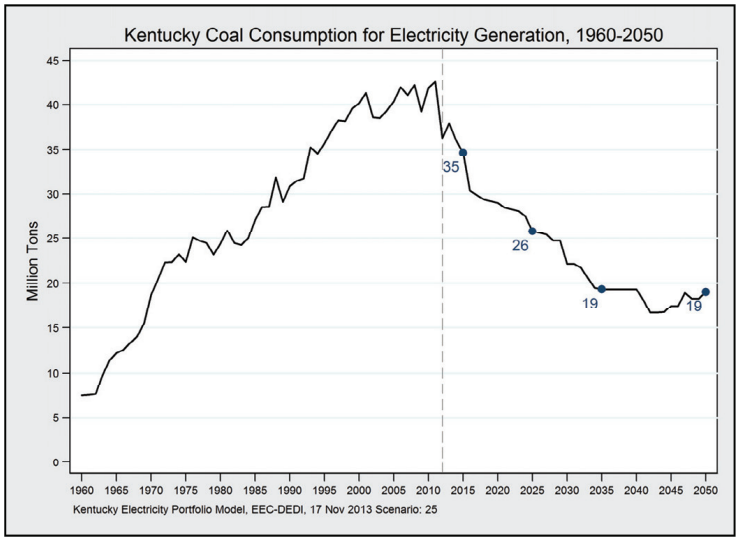


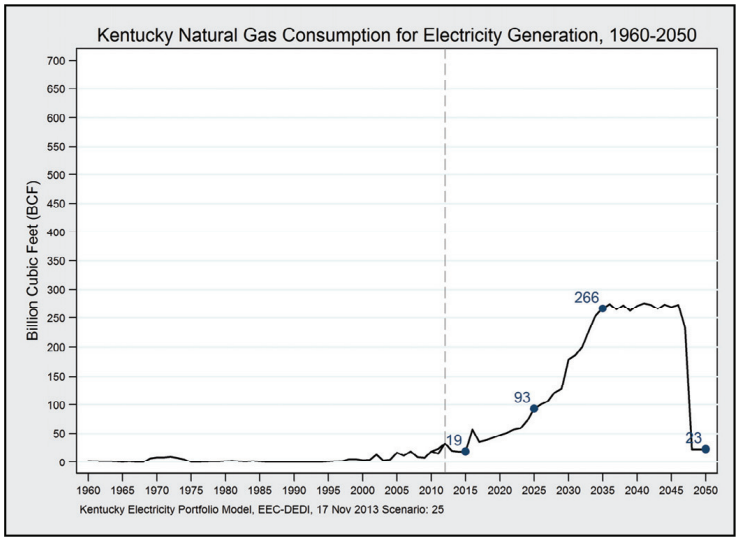
Scenario 25

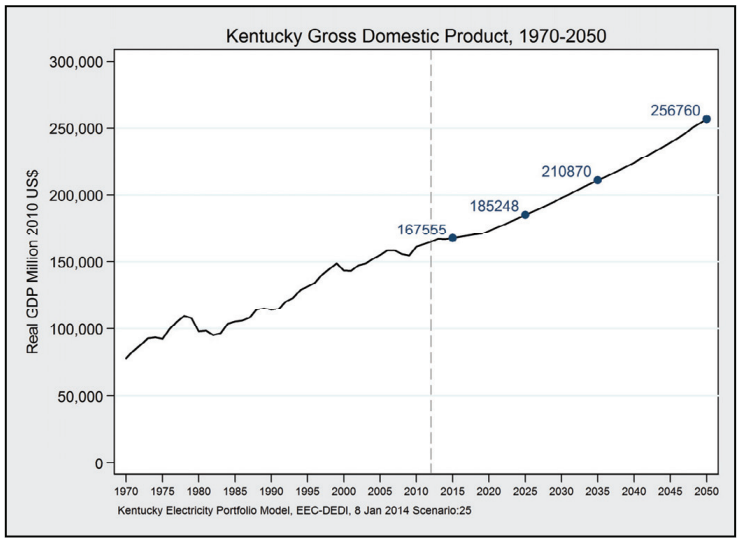
Federal Policy Option 4: $40-$60 Carbon Tax
Portfolio 4: Coal Portfolio Standard

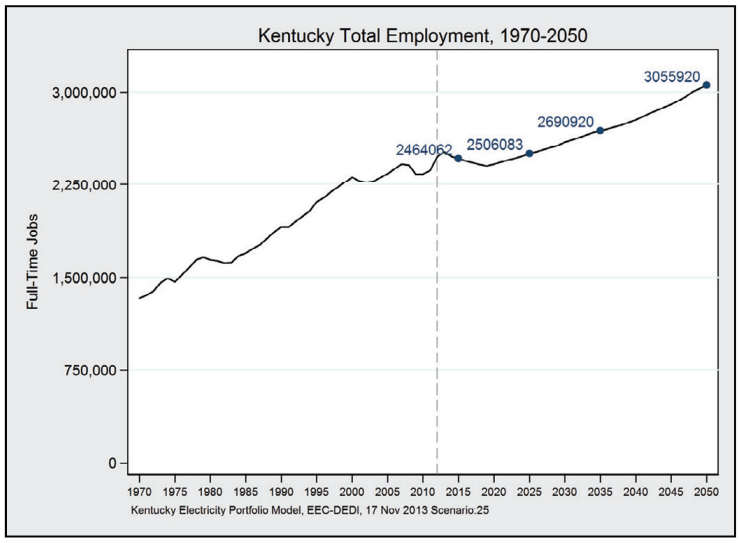






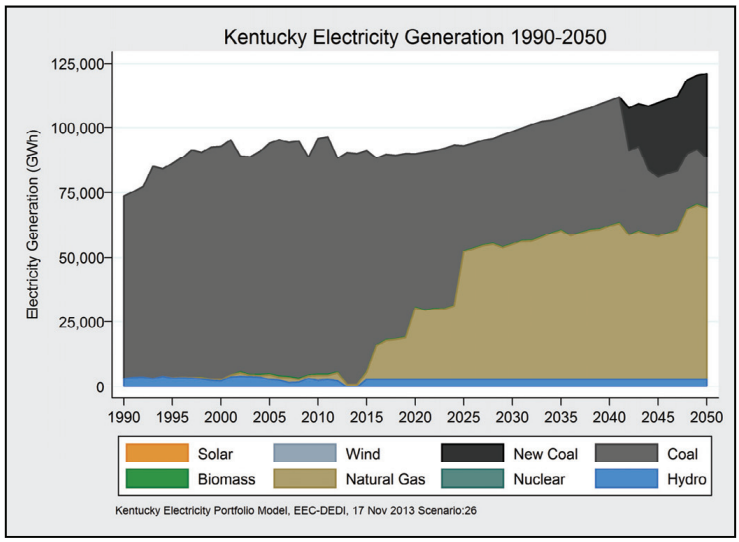


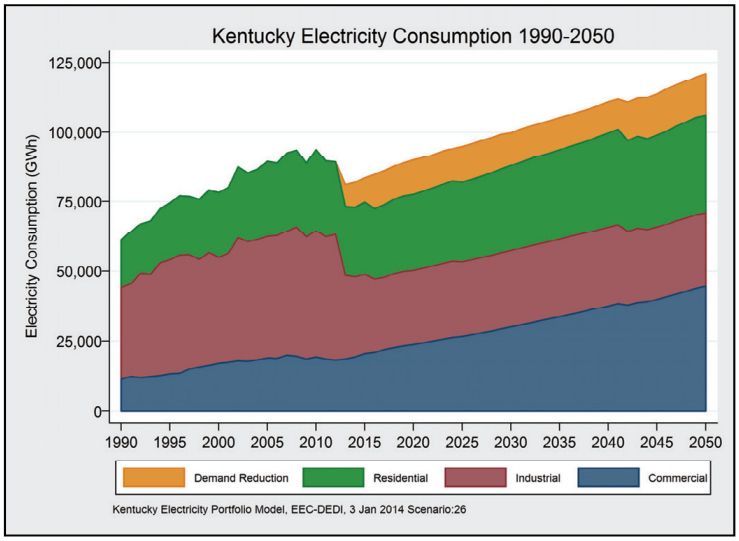


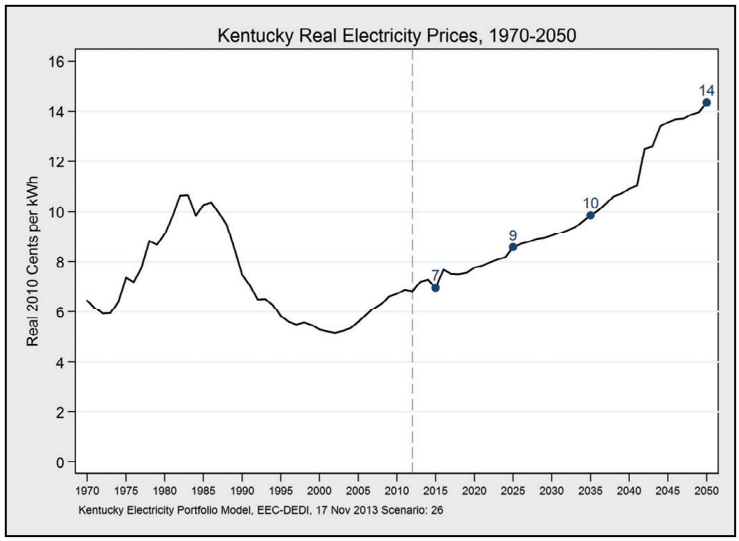


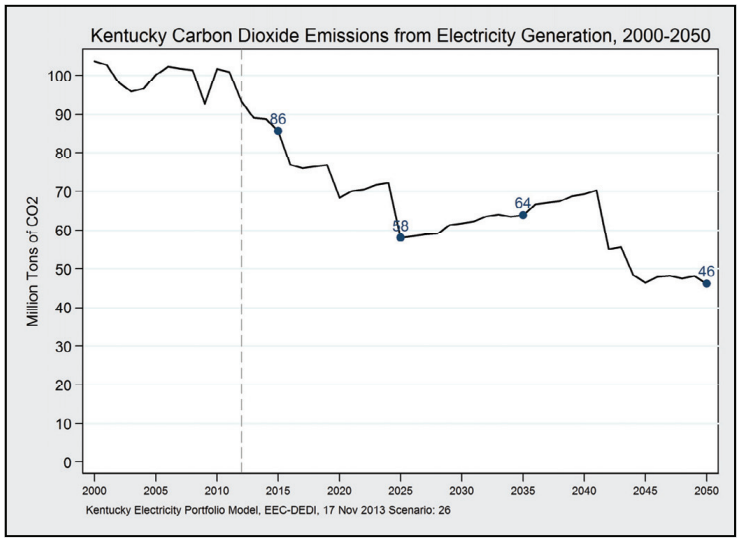
Scenario 26

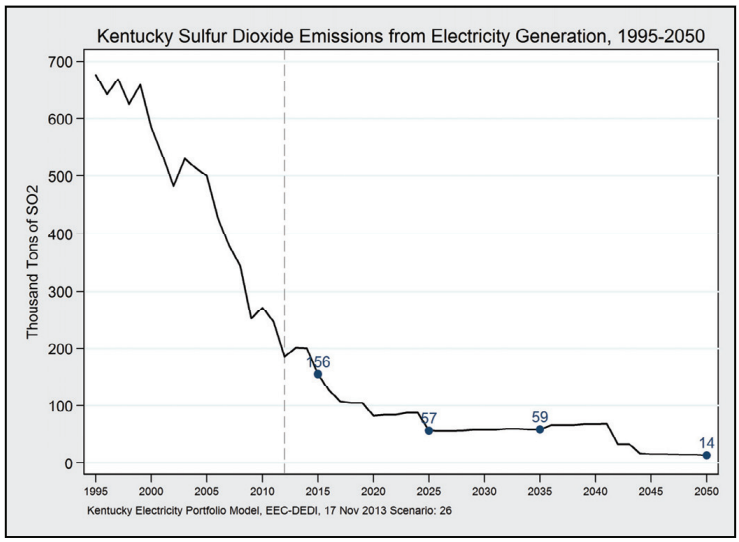
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 4: Coal Portfolio Standard

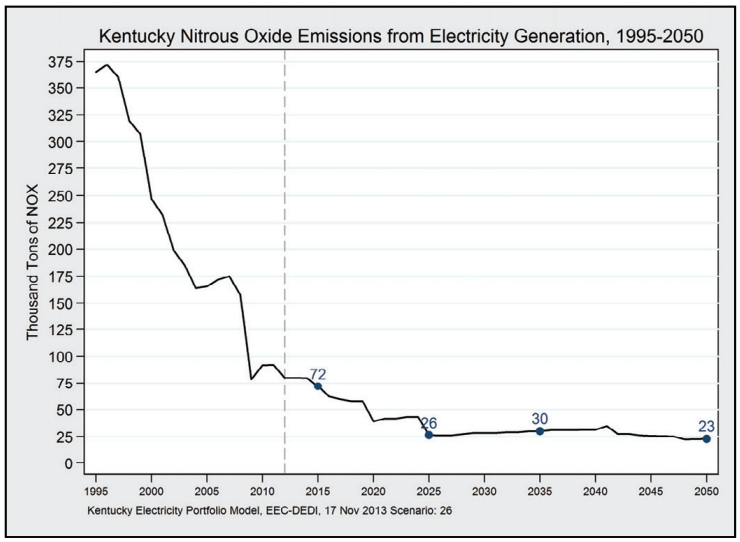






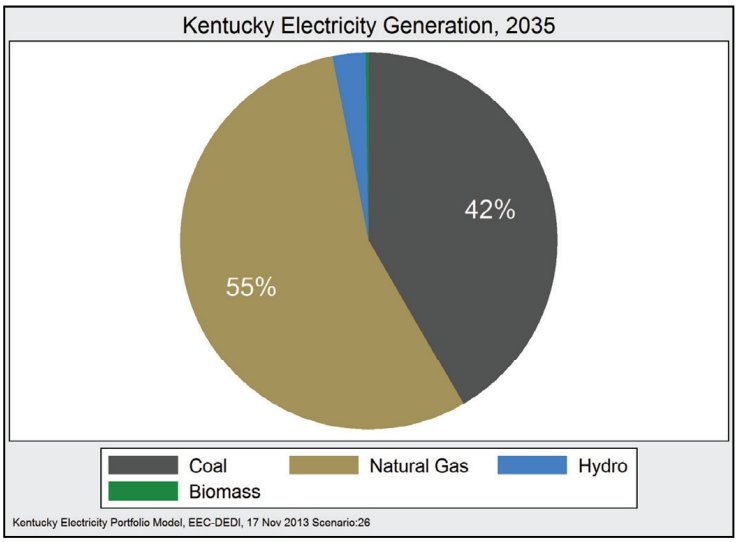


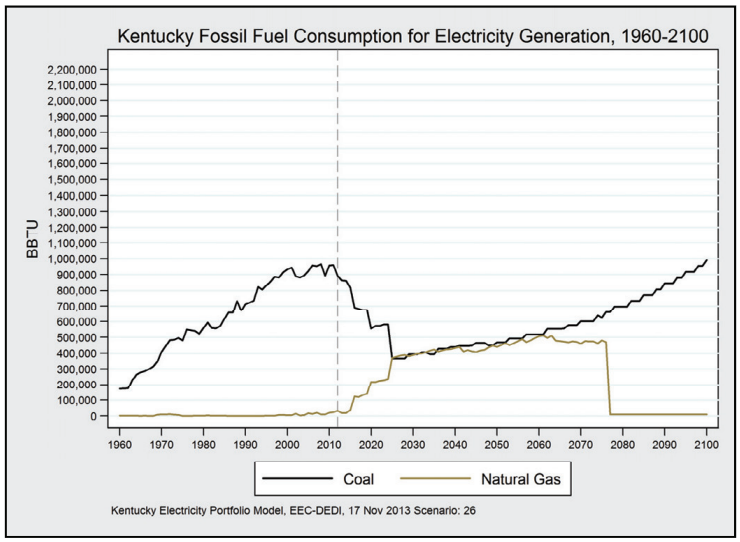


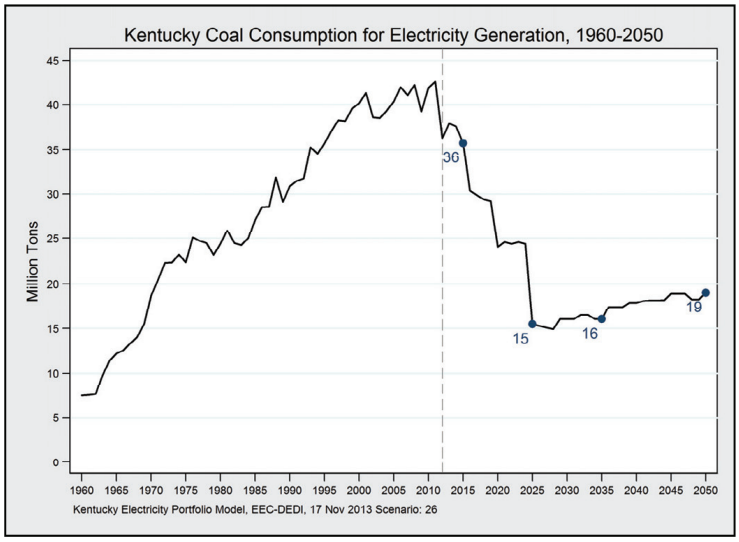


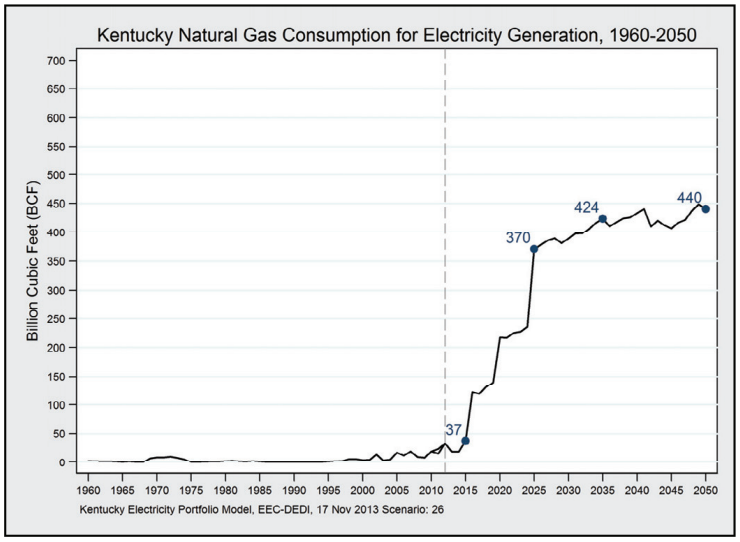
Scenario 26

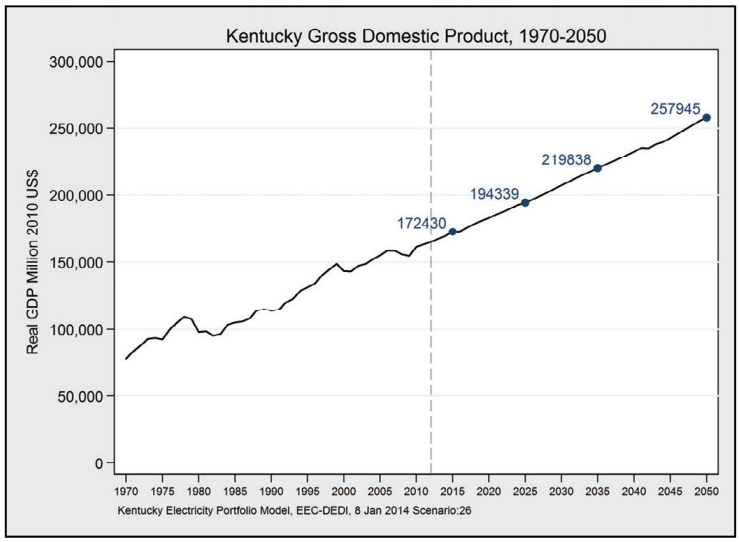
Federal Policy Option 5: CO_2 Rate Limit
Portfolio 4: Coal Portfolio Standard

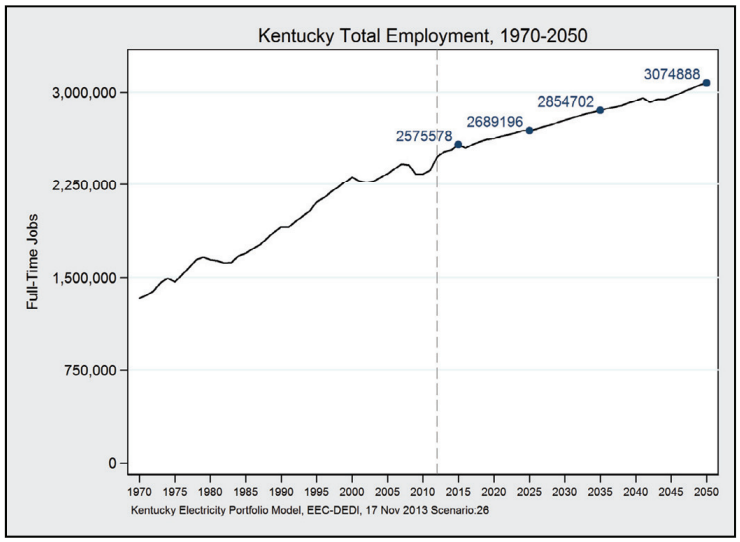






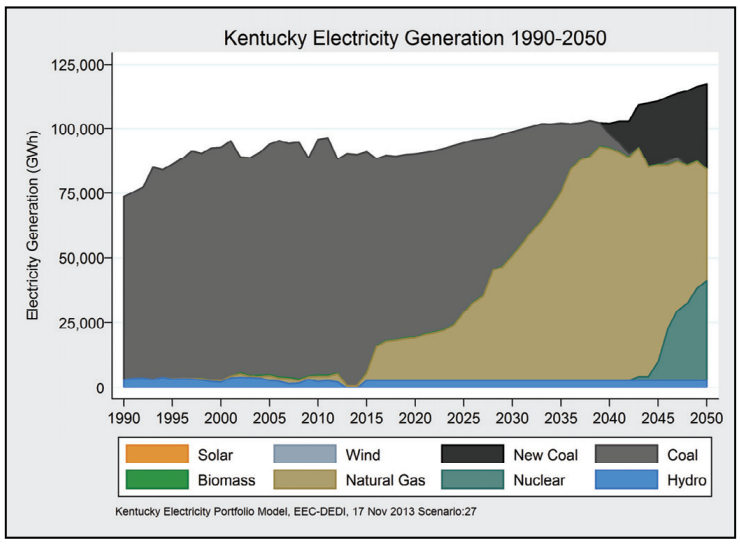


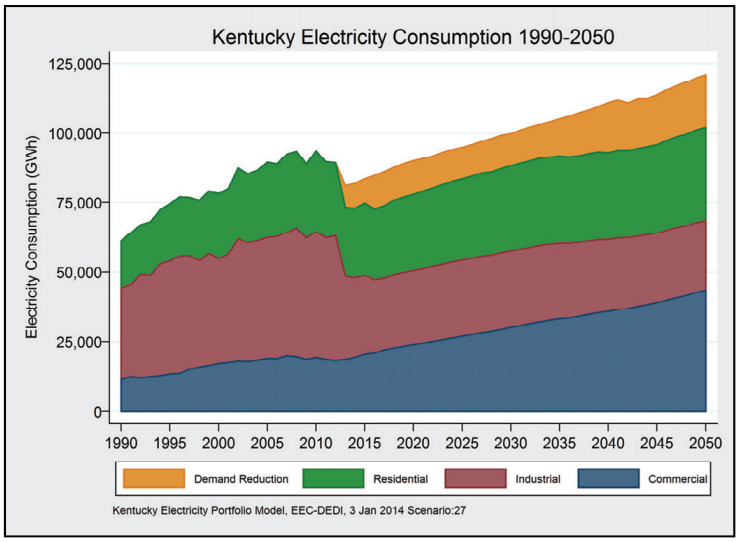


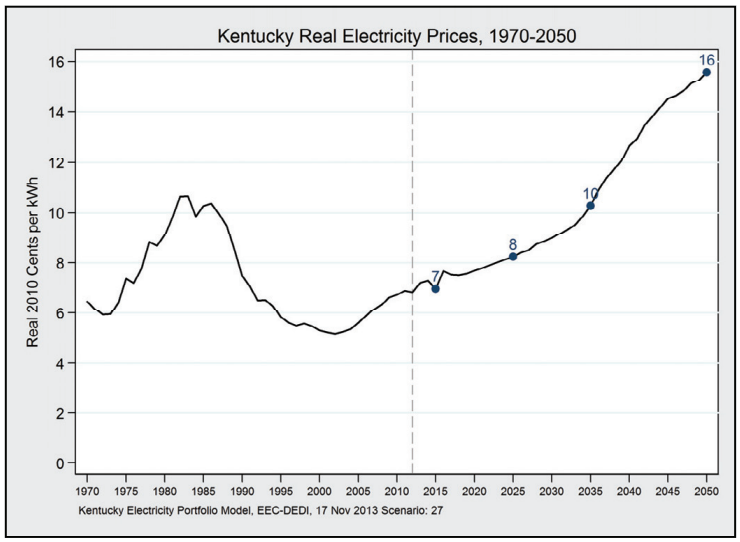


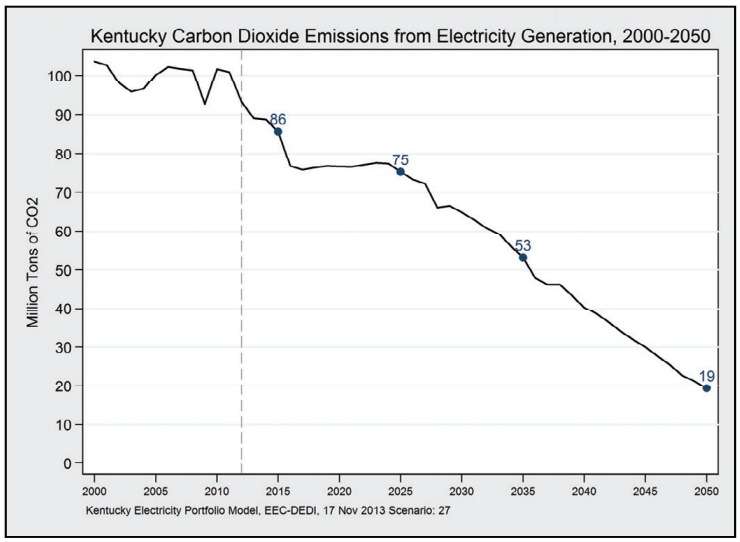
Scenario 27

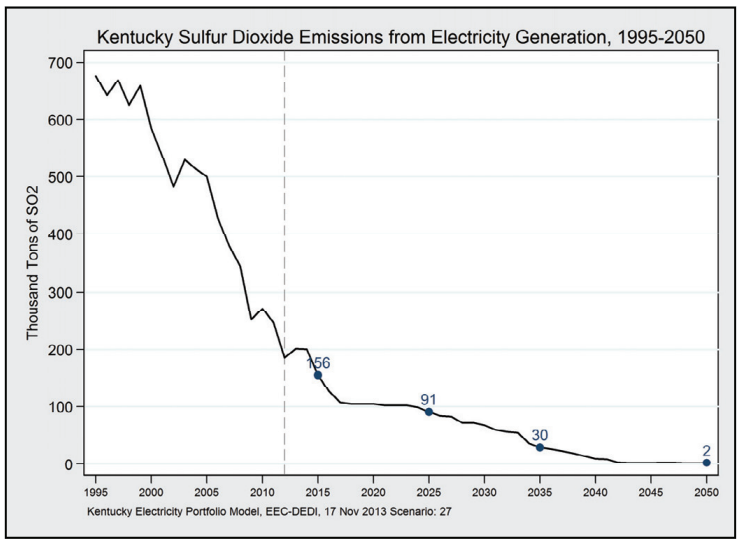
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 4: Coal Portfolio Standard

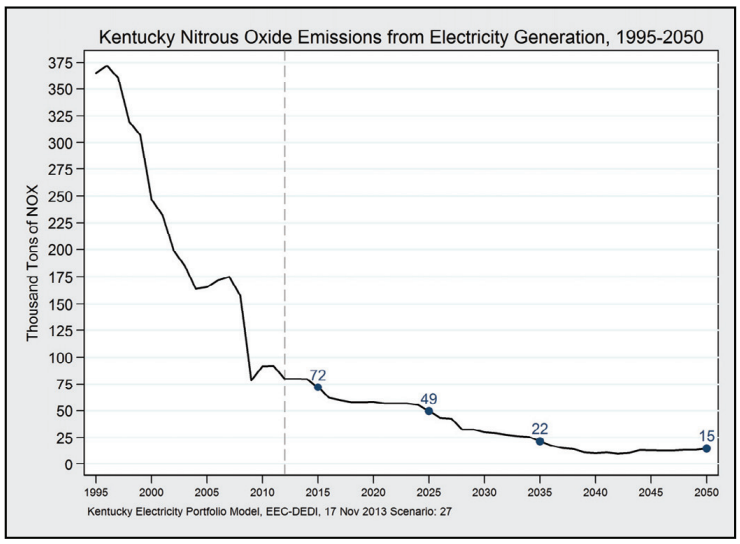






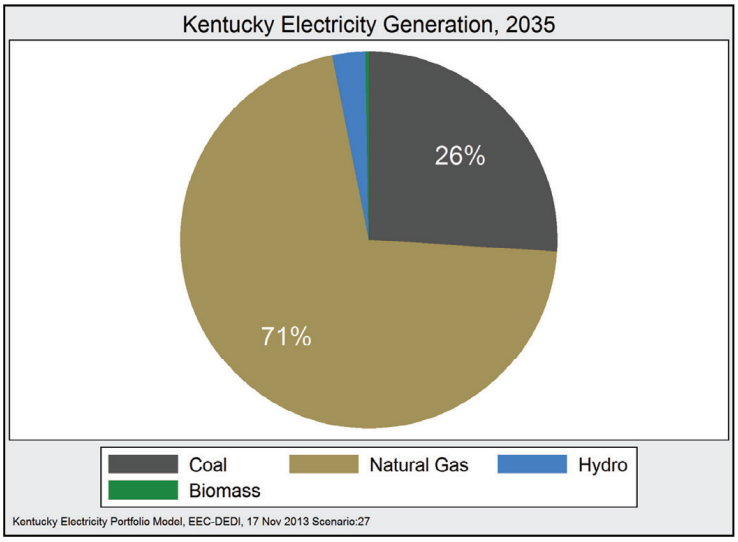


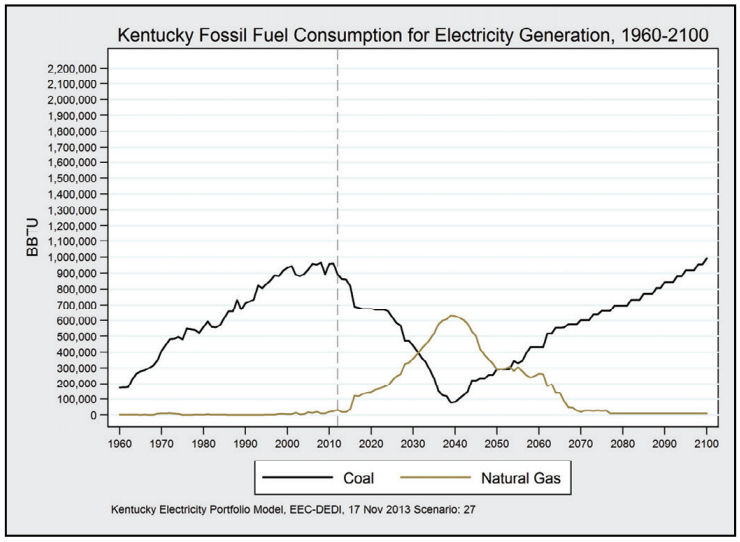


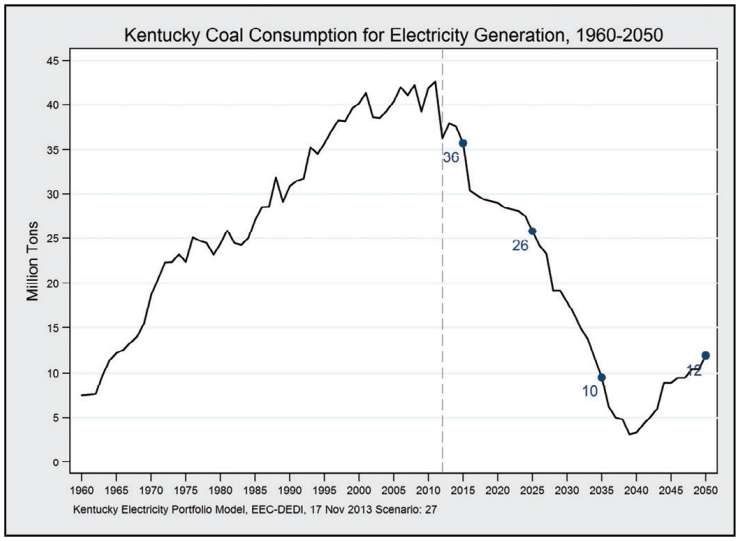


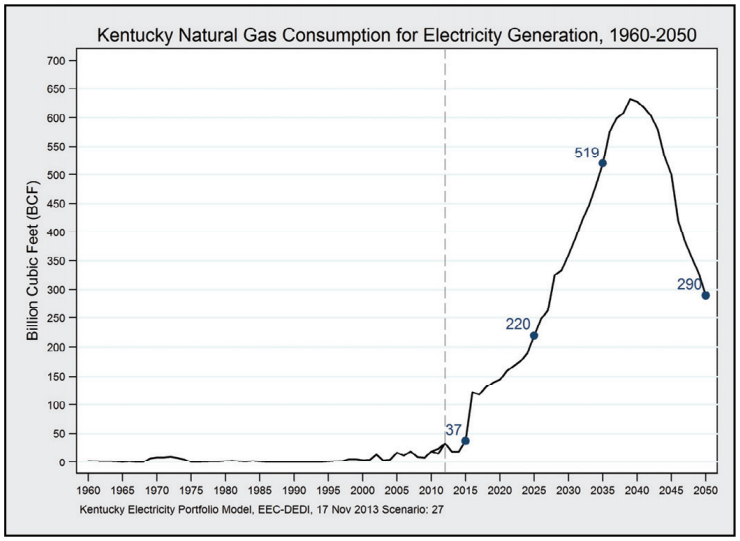
Scenario 27

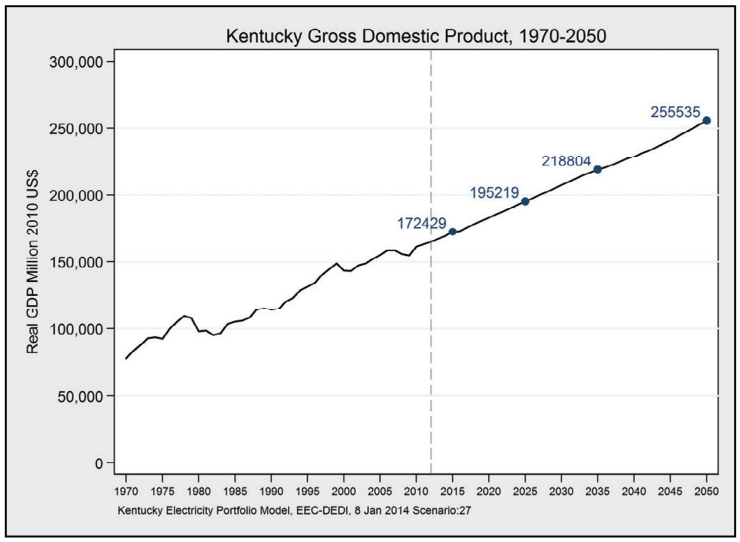
Federal Policy Option 6: Presidential CO_2 Rate Limit
Portfolio 4: Coal Portfolio Standard

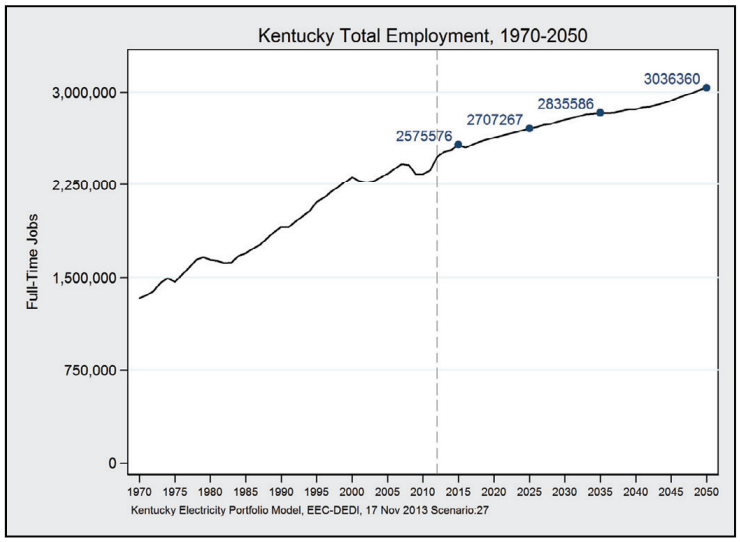






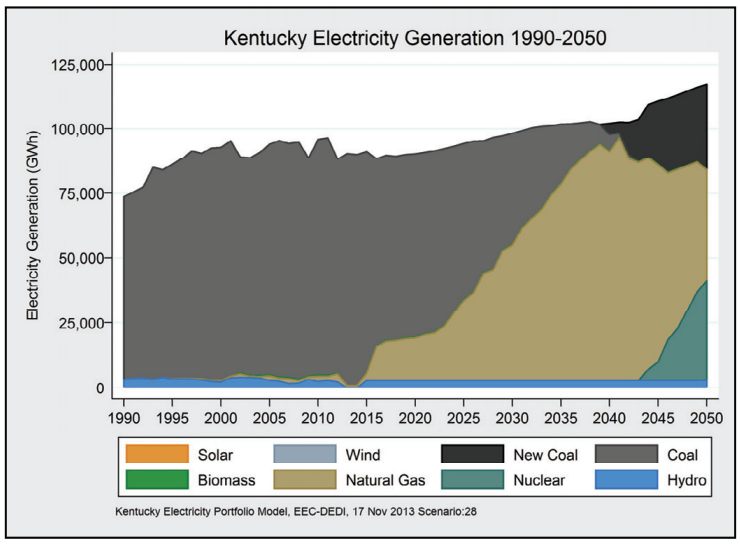


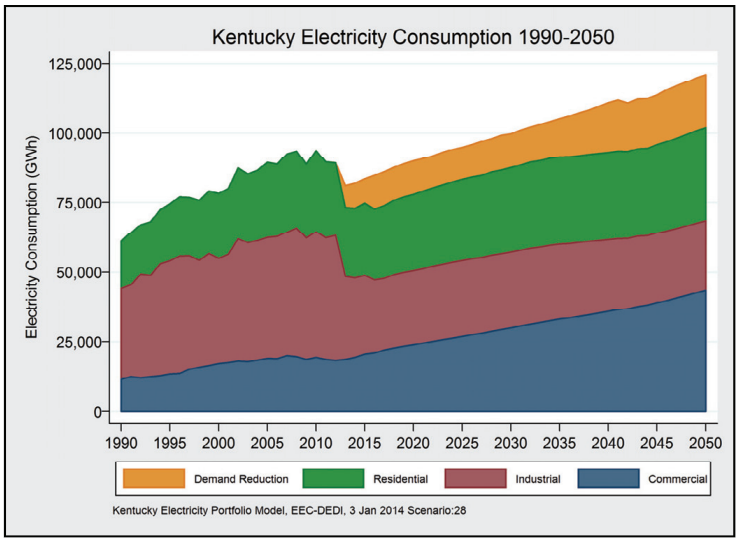


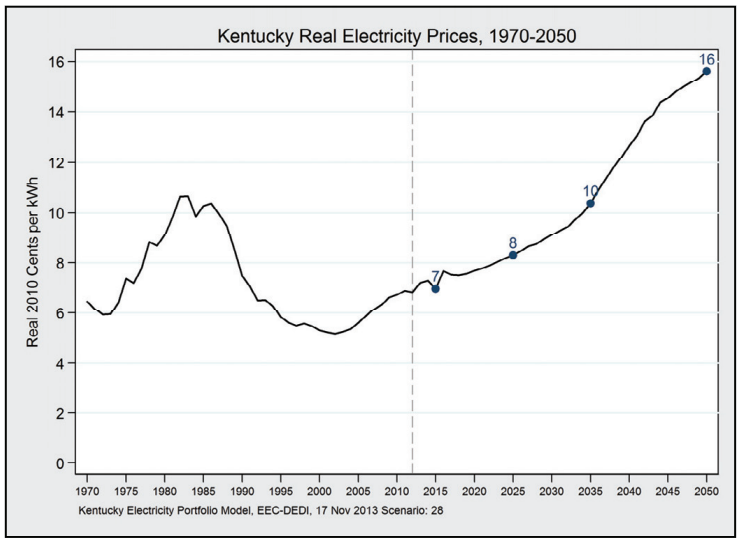


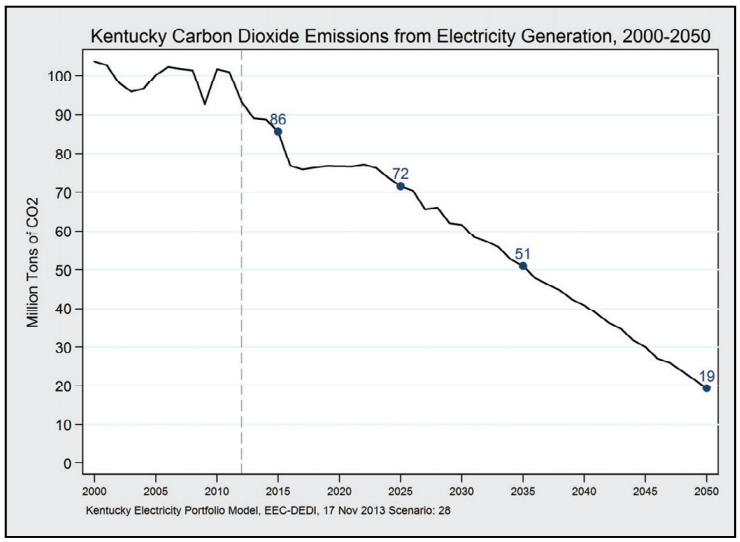
Scenario 28

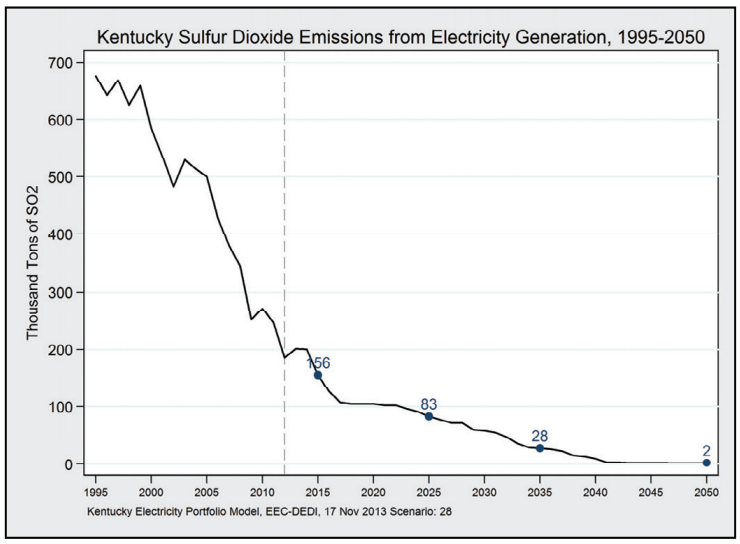
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 4: Coal Portfolio Standard

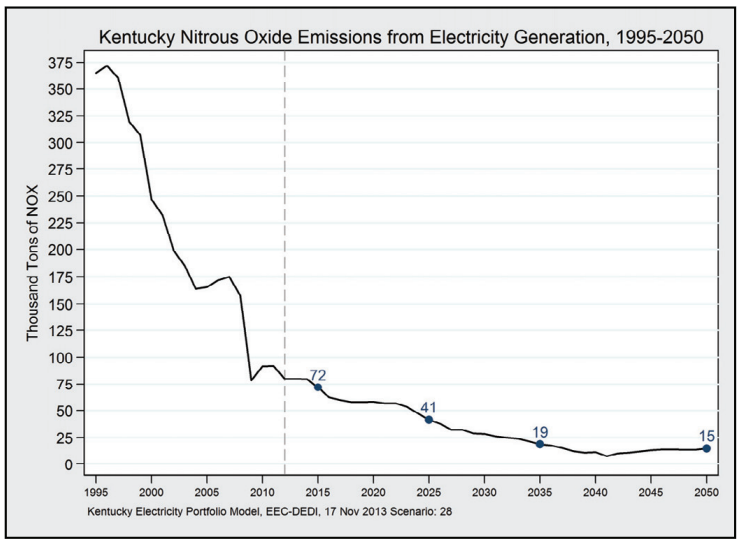






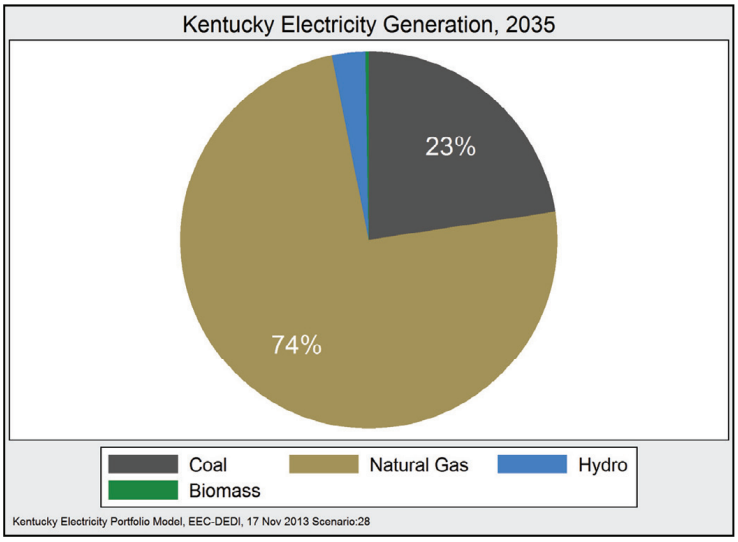


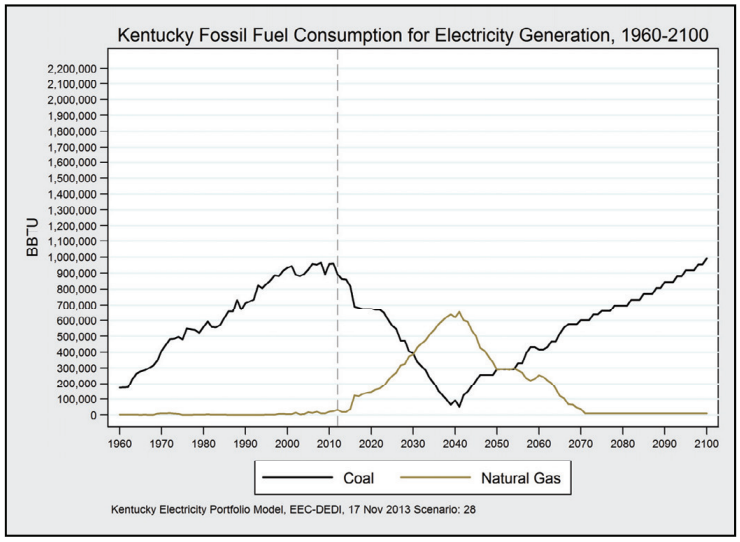


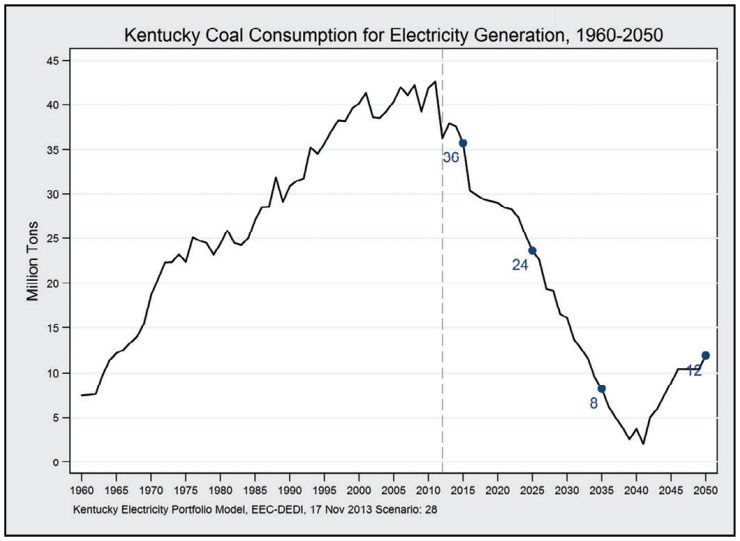


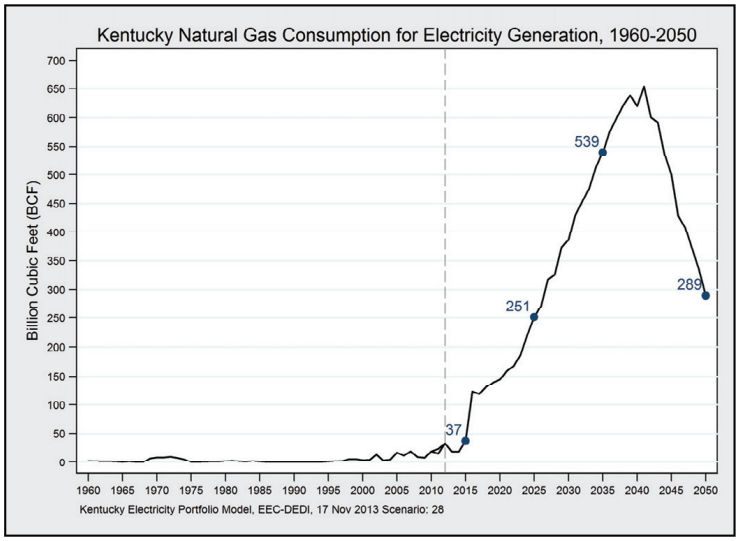
Scenario 28

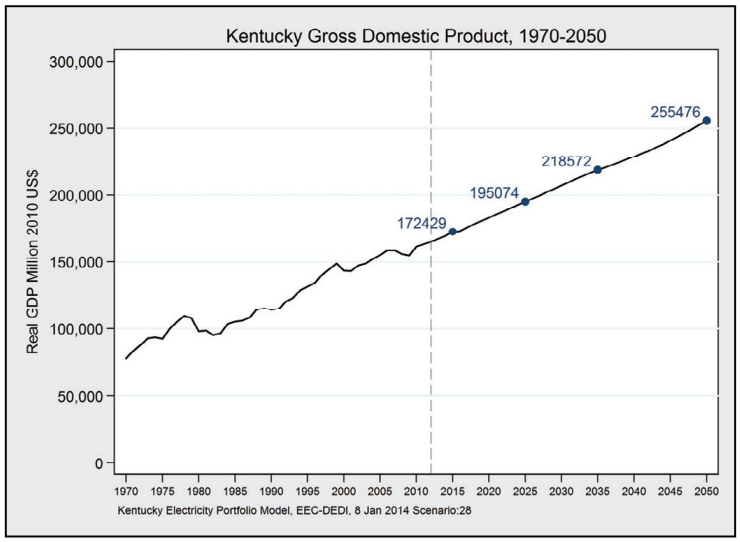
Federal Policy Option 7: Presidential Mass Emissions Goal
Portfolio 4: Coal Portfolio Standard

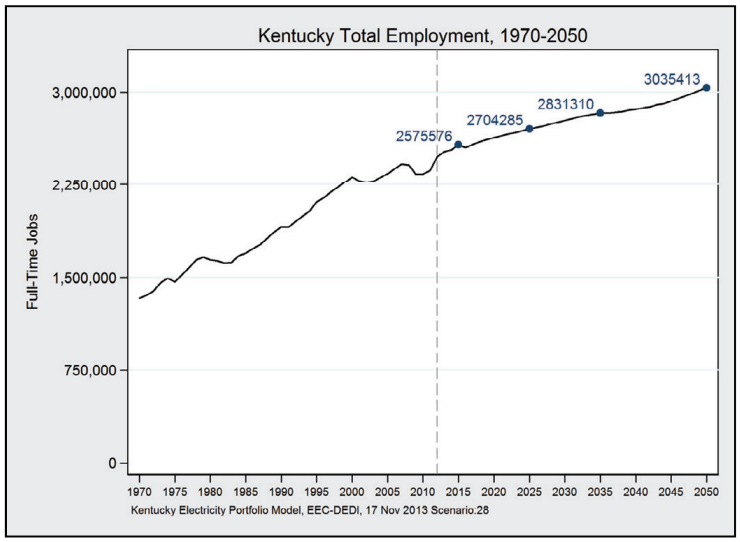




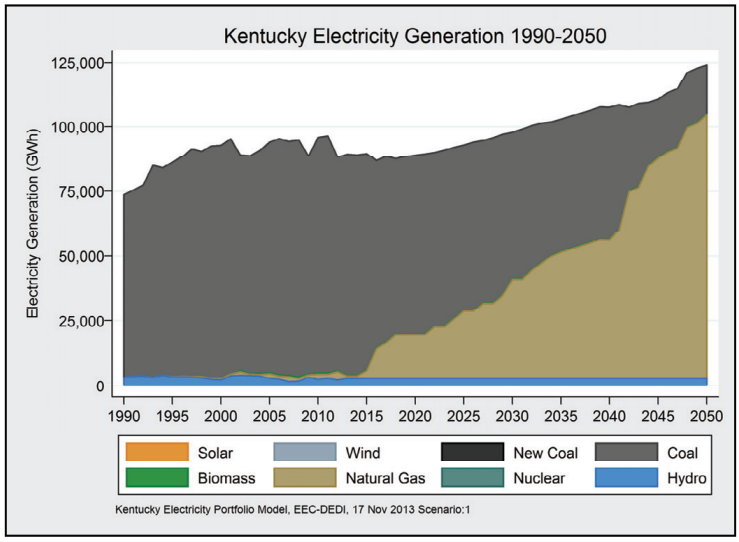


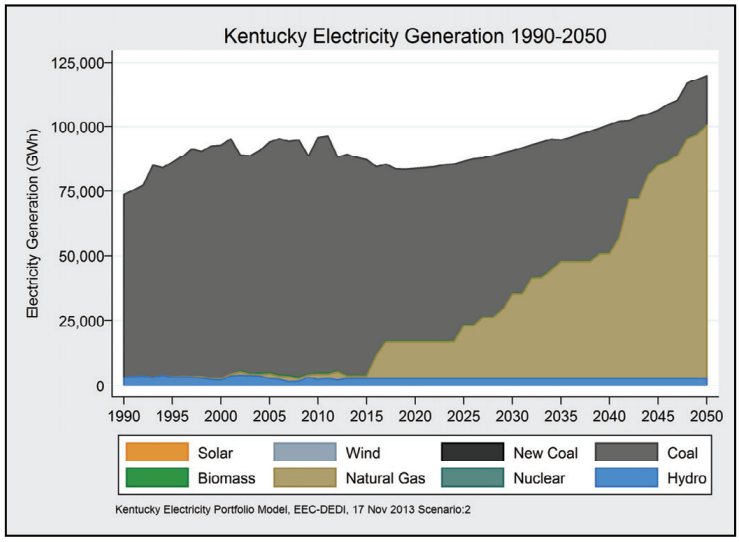


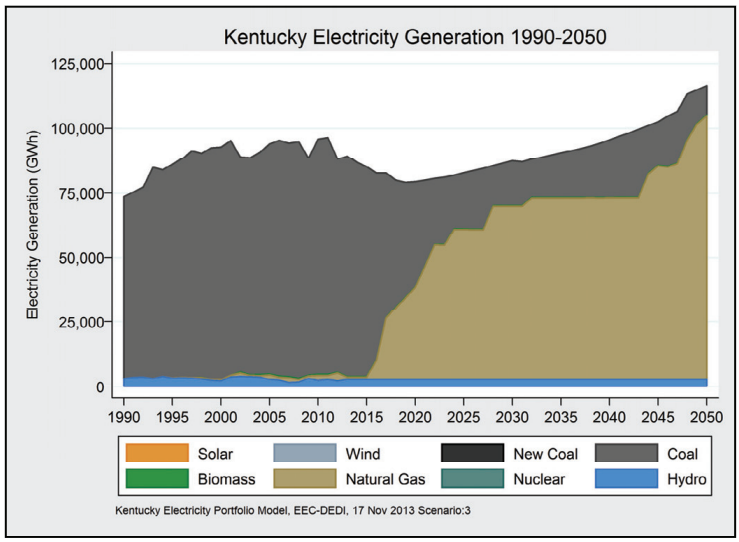


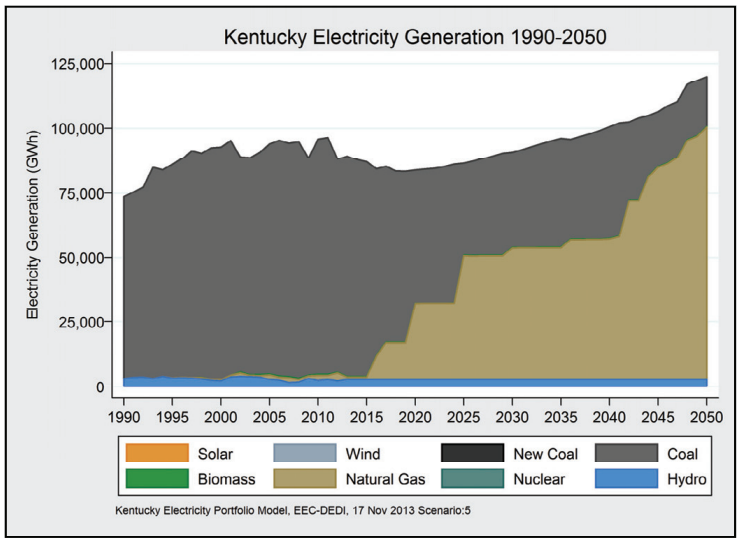


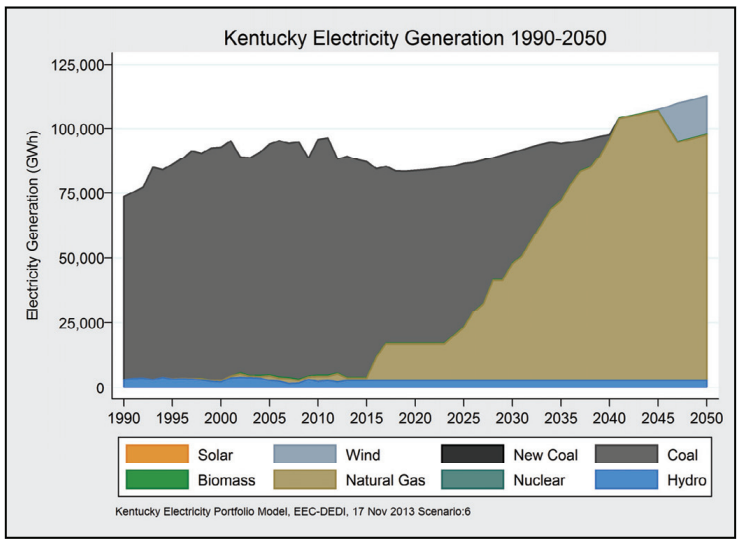
Generation Portfolio 1, 1990-2050

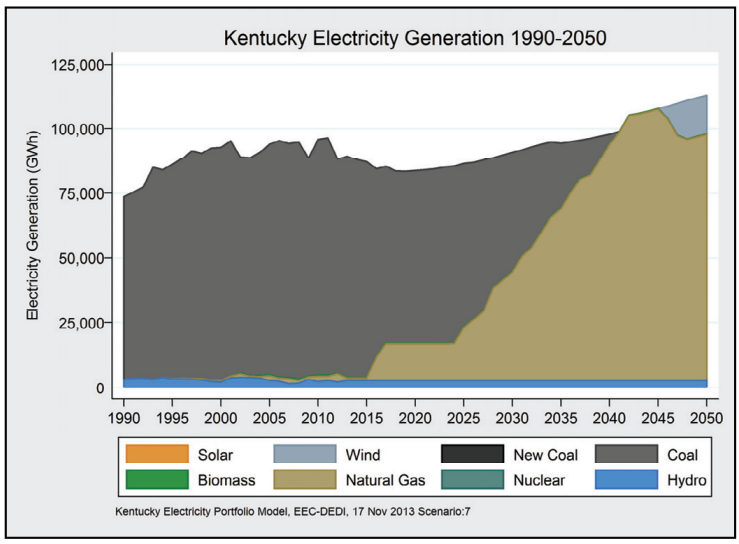




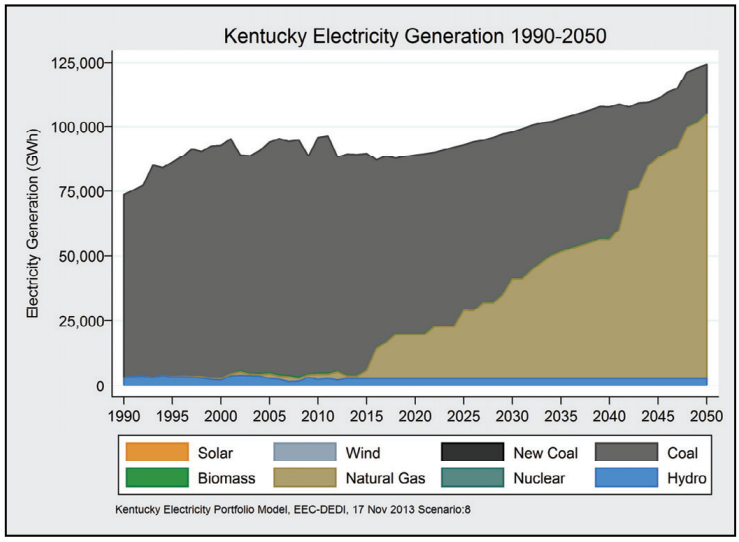


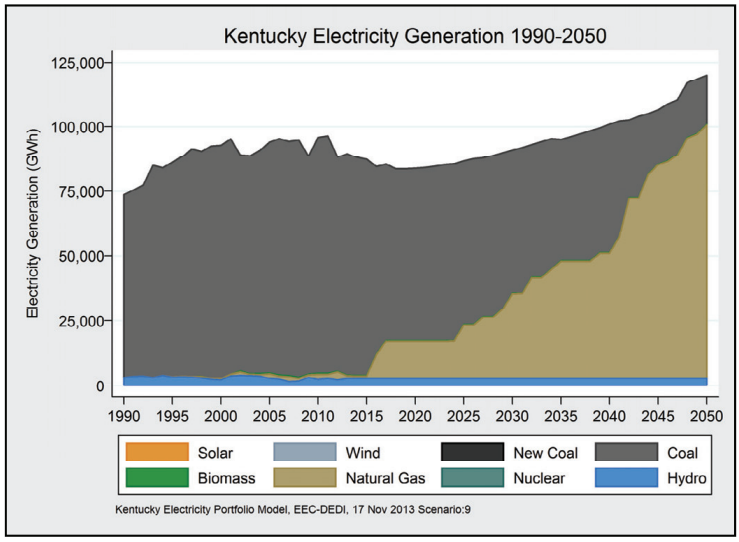


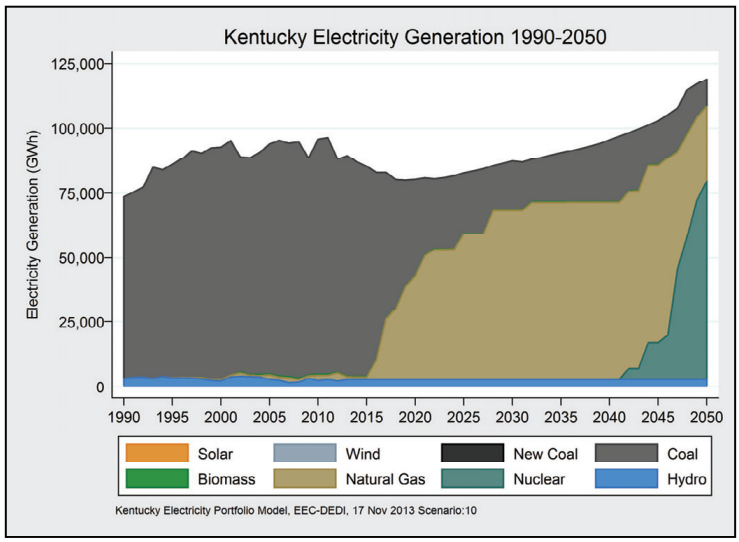


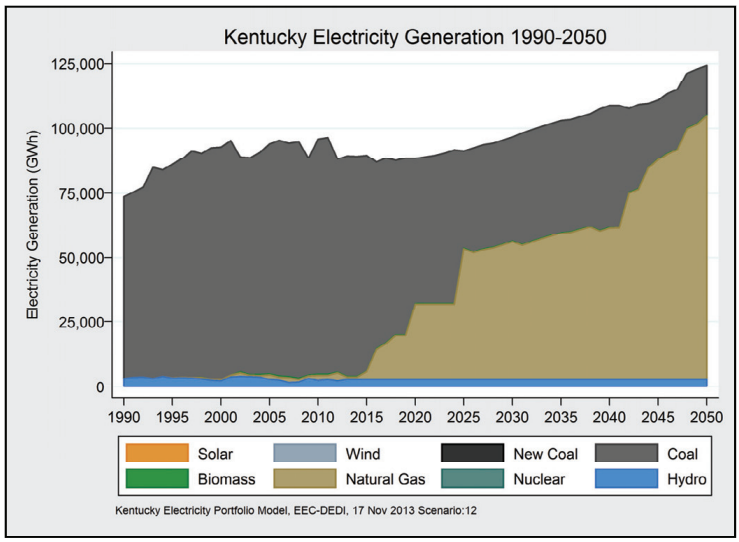


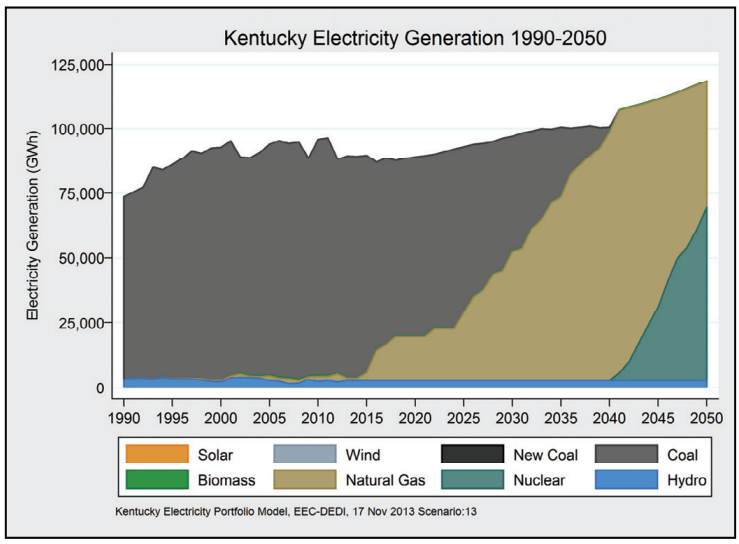
Generation Portfolio 2, 1990-2050

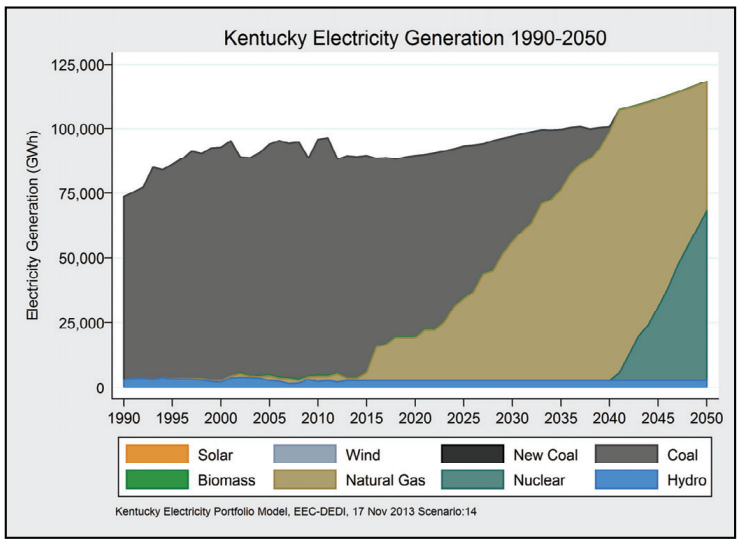




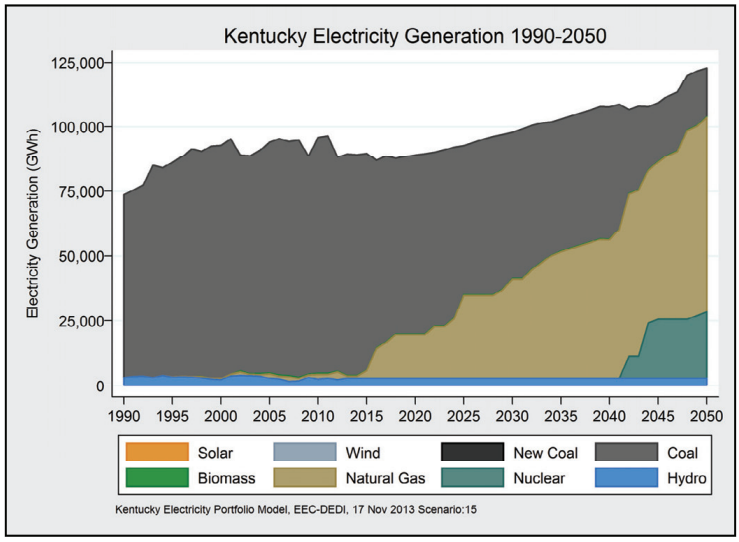


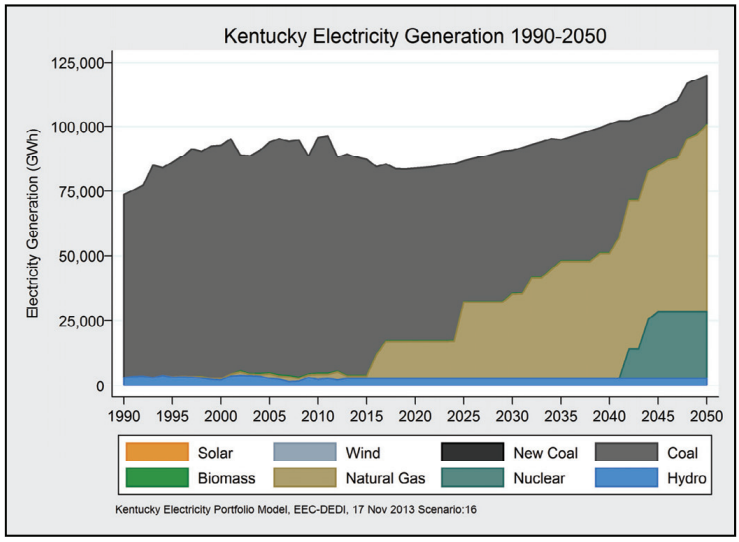


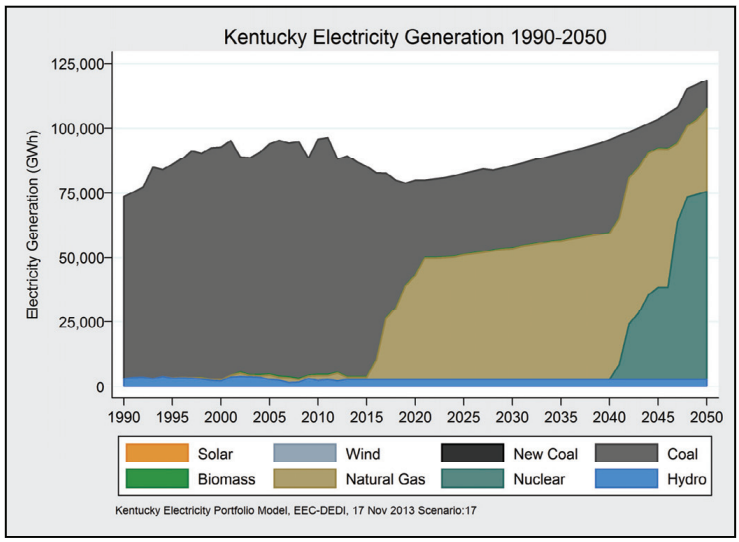


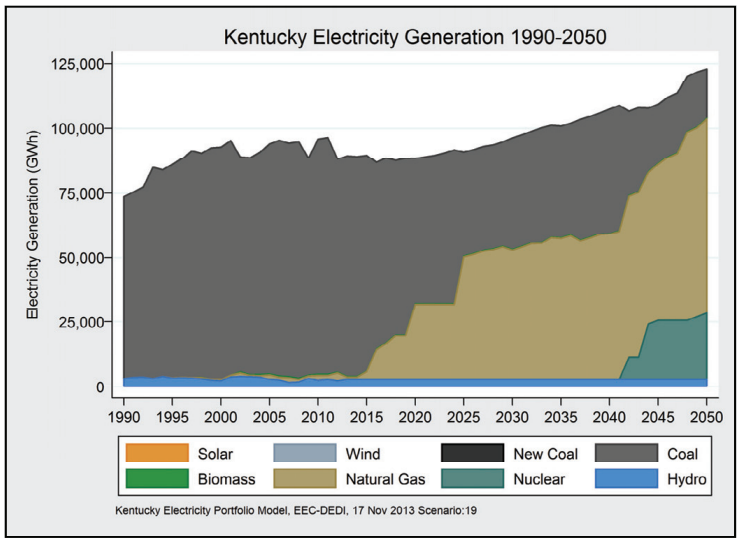


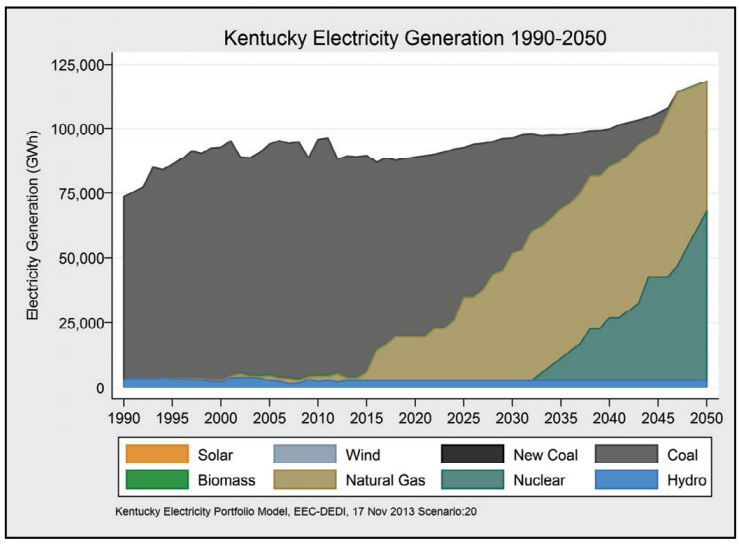
Generation Portfolio 3, 1990-2050

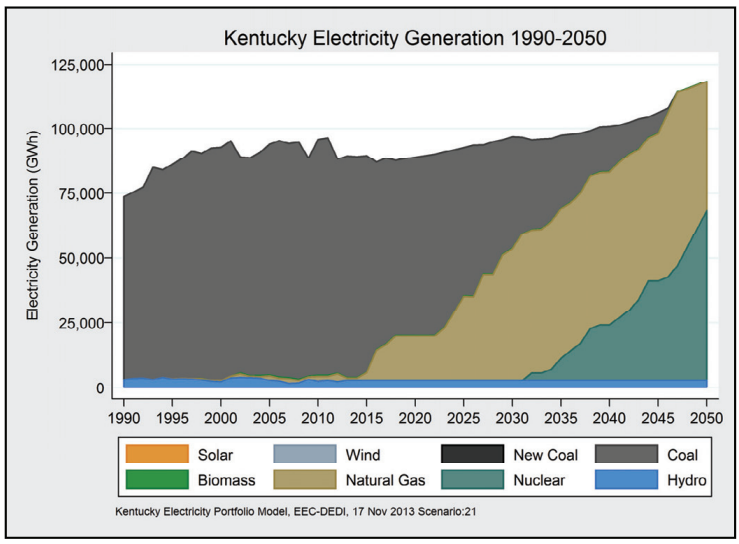




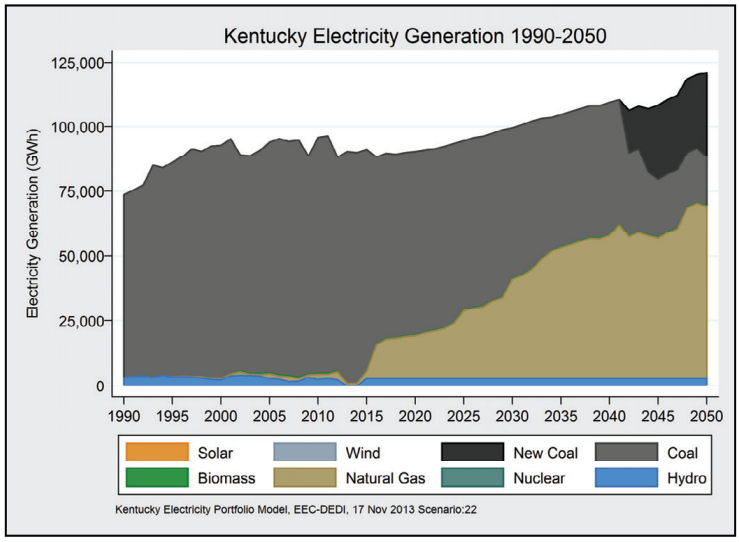


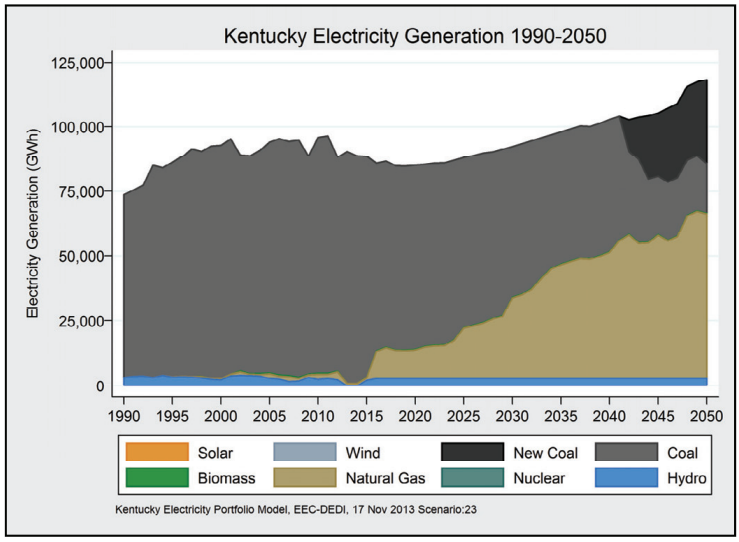


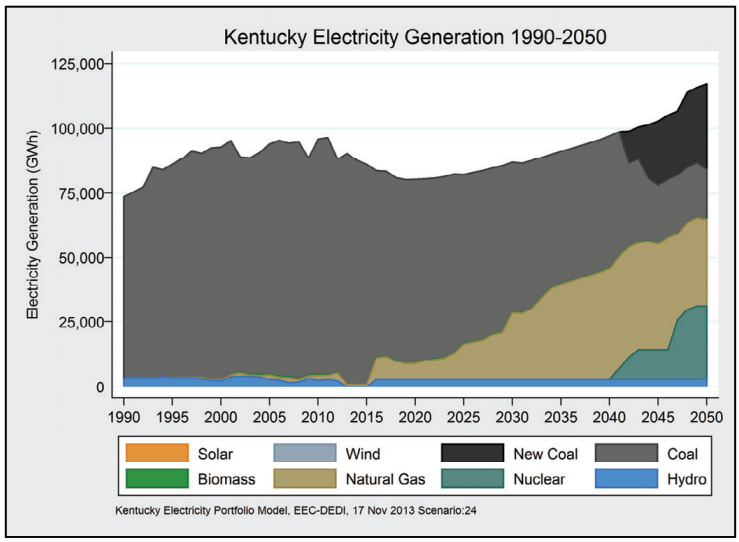


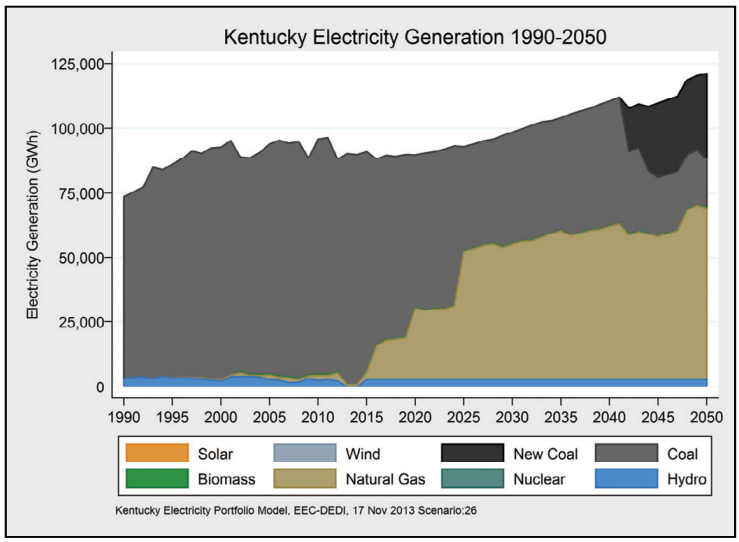


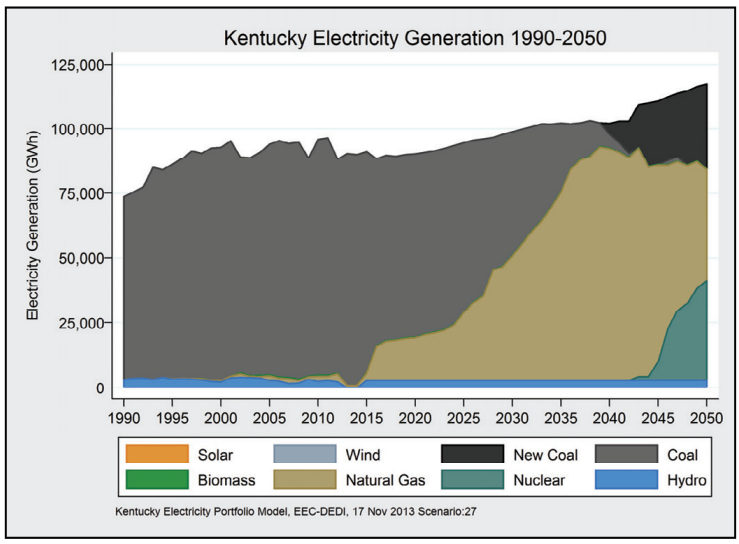
Generation Portfolio 4, 1990-2050

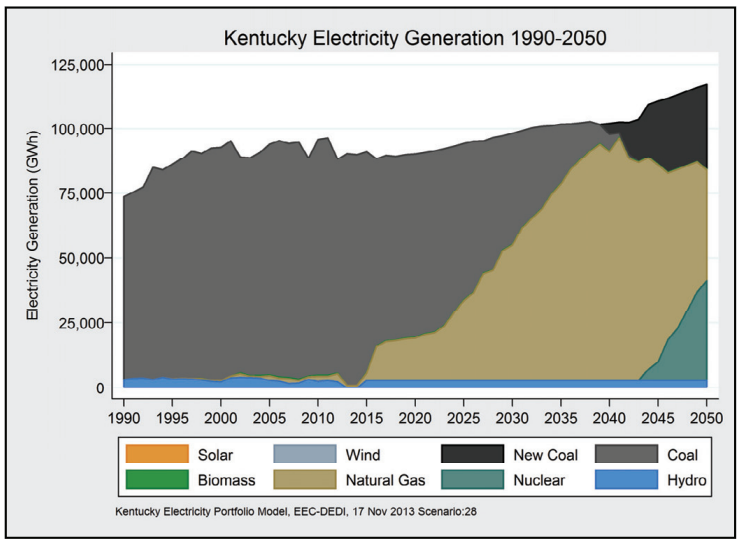




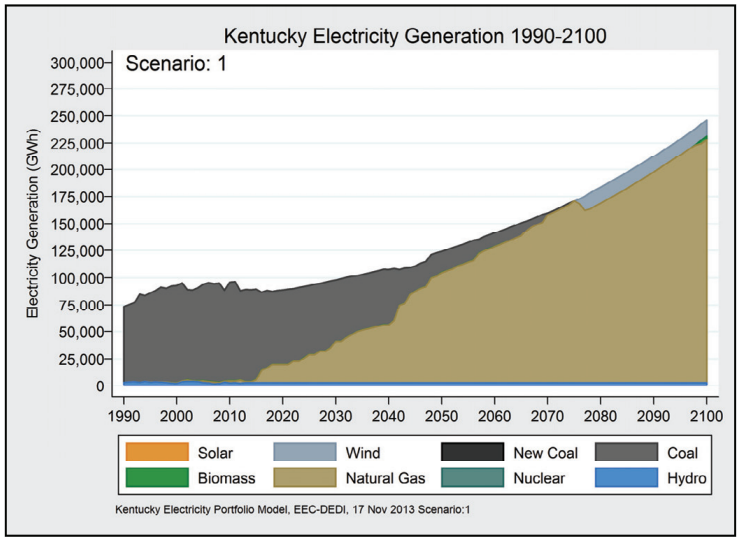


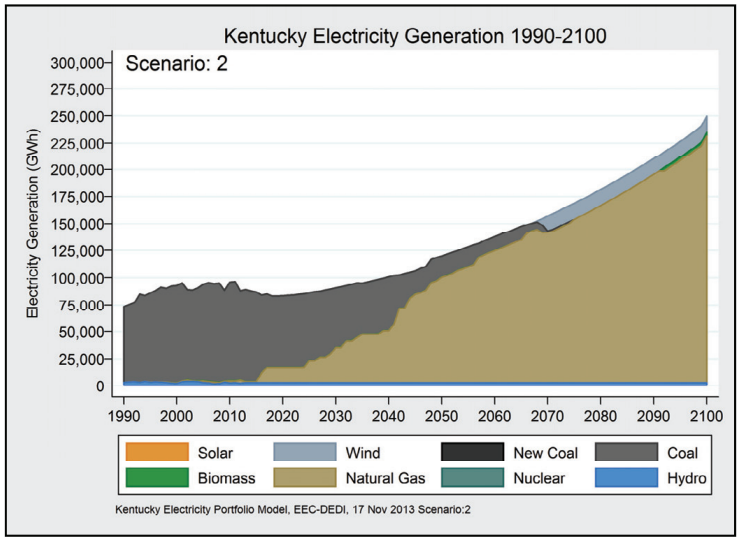


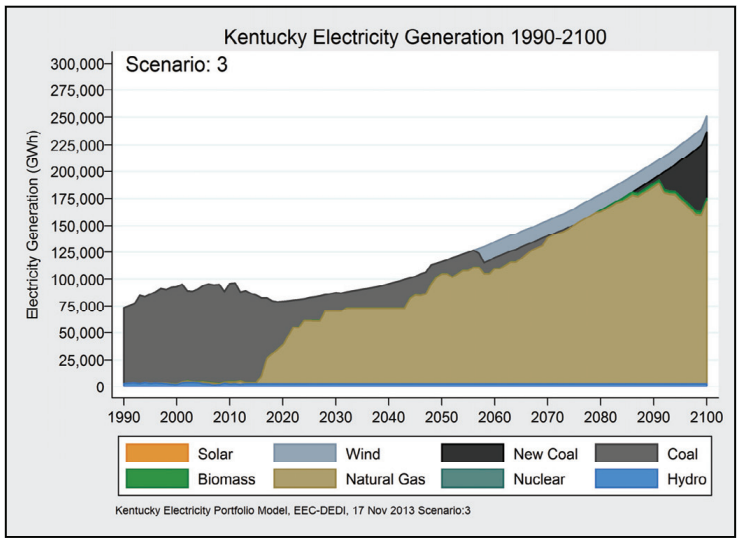


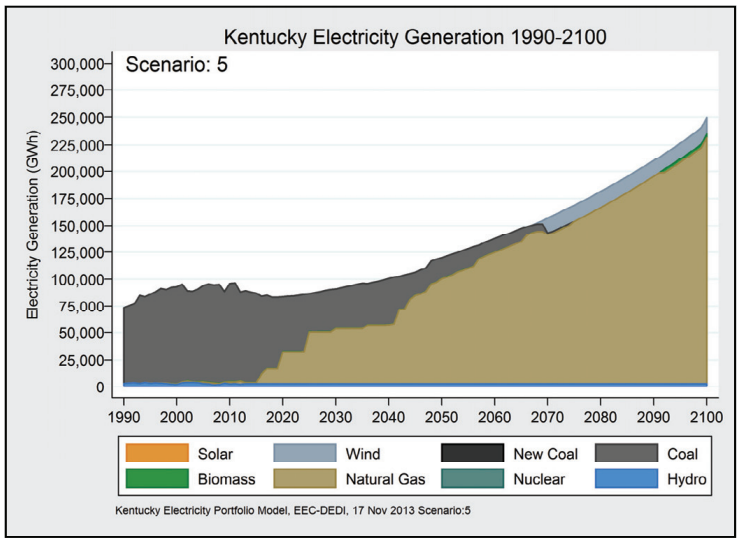


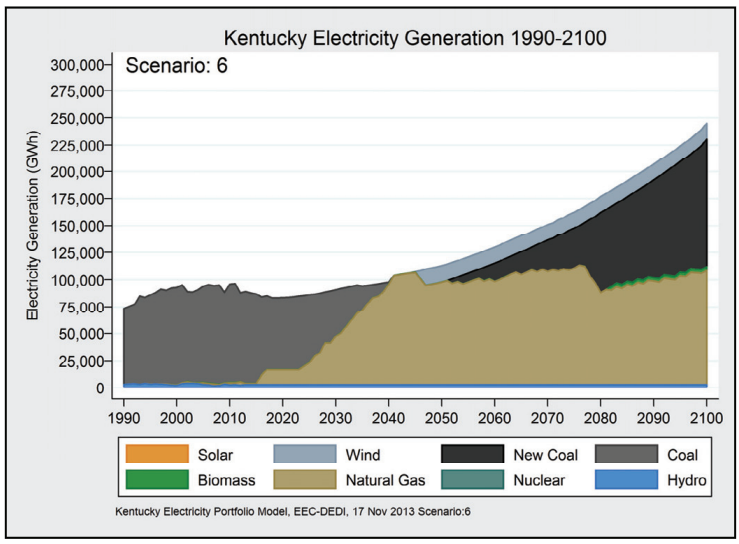
Generation Portfolio 1, 1990-2100

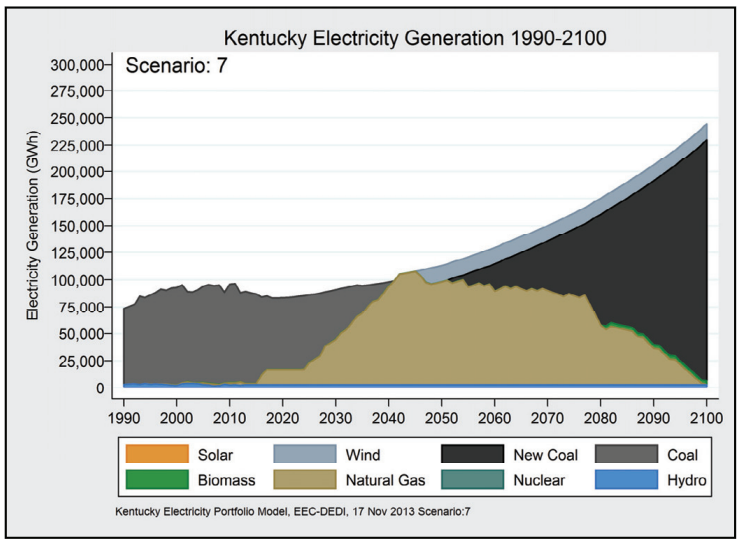




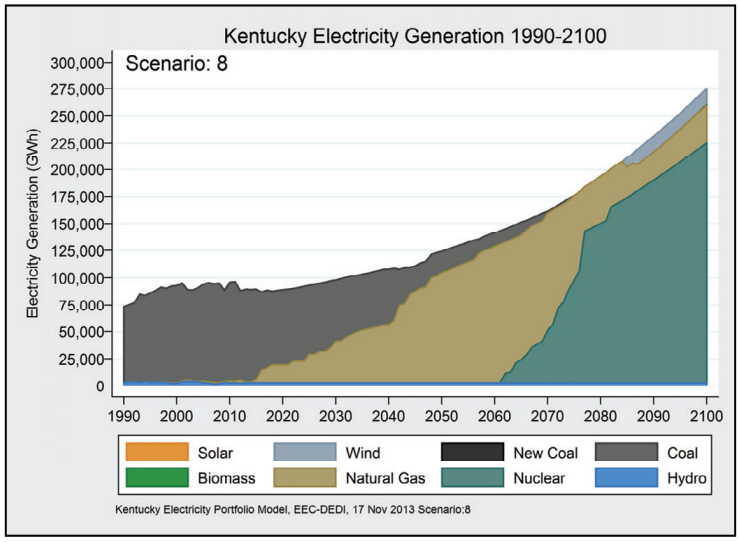


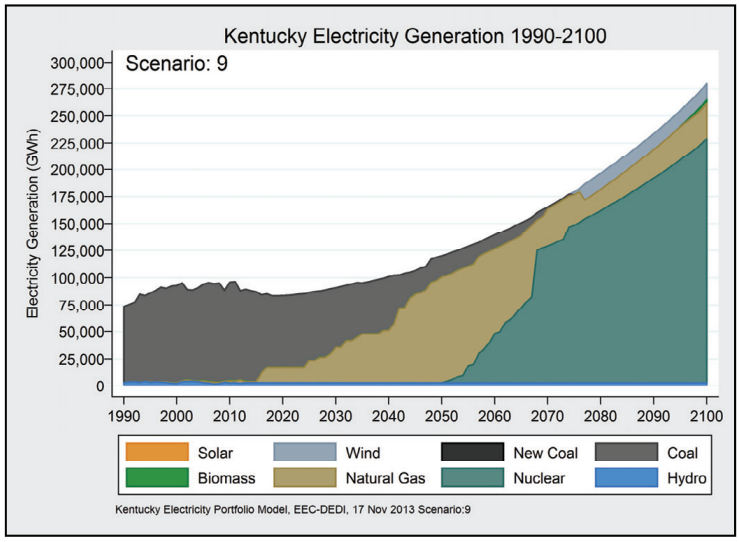


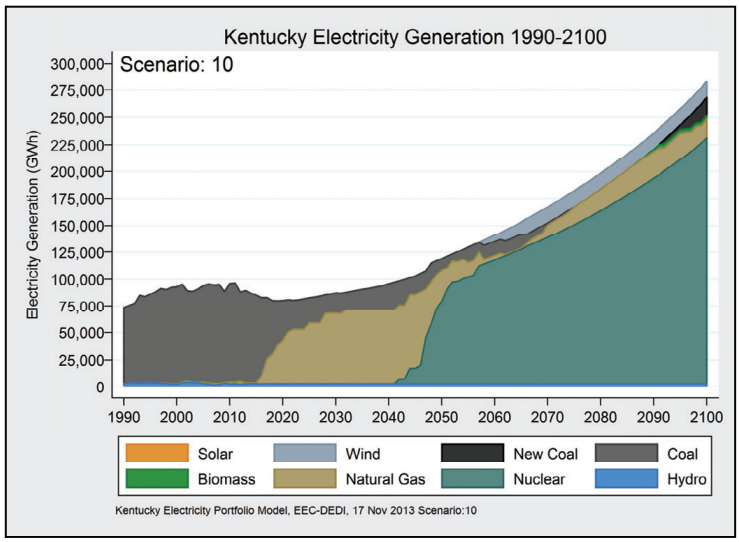


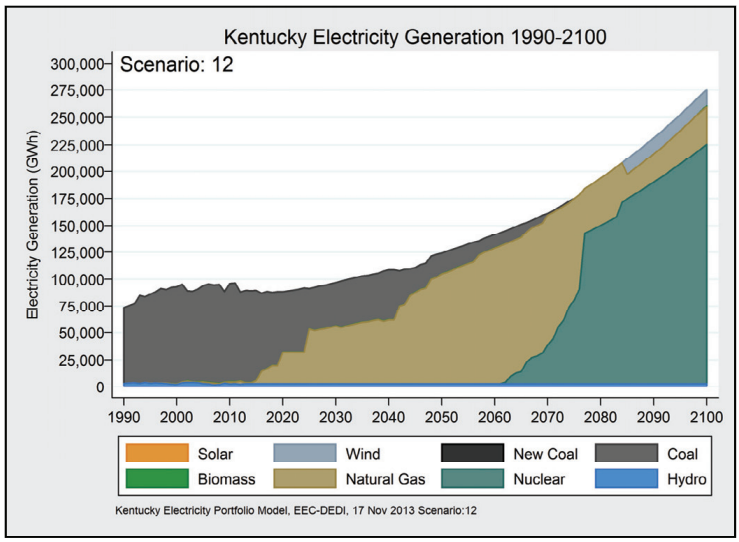


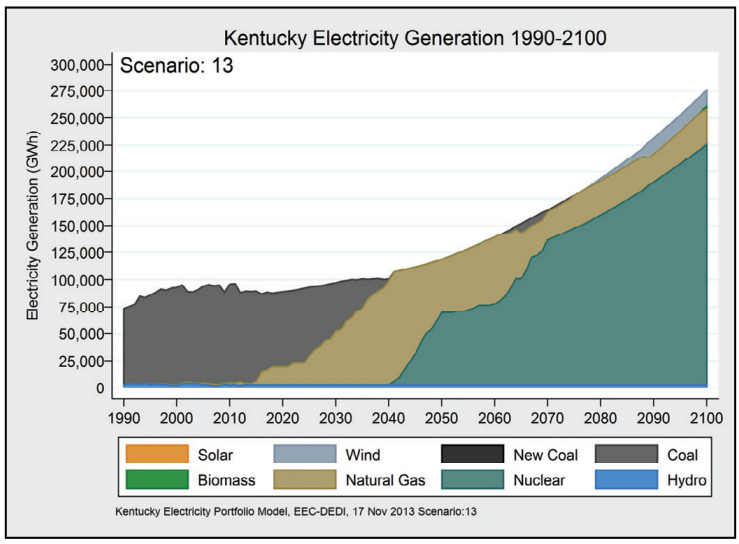
Generation Portfolio 2, 1990-2100

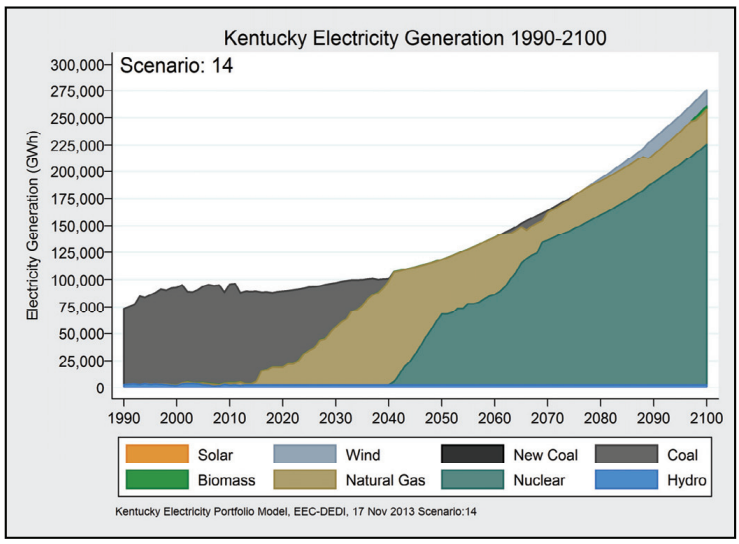




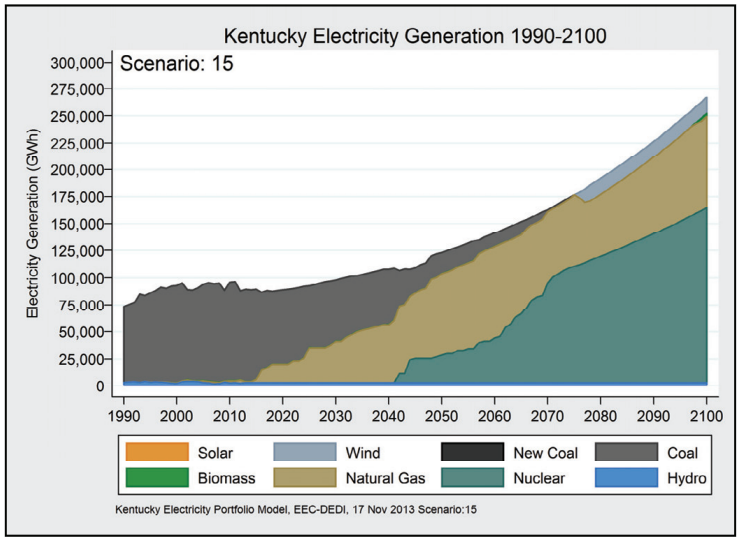


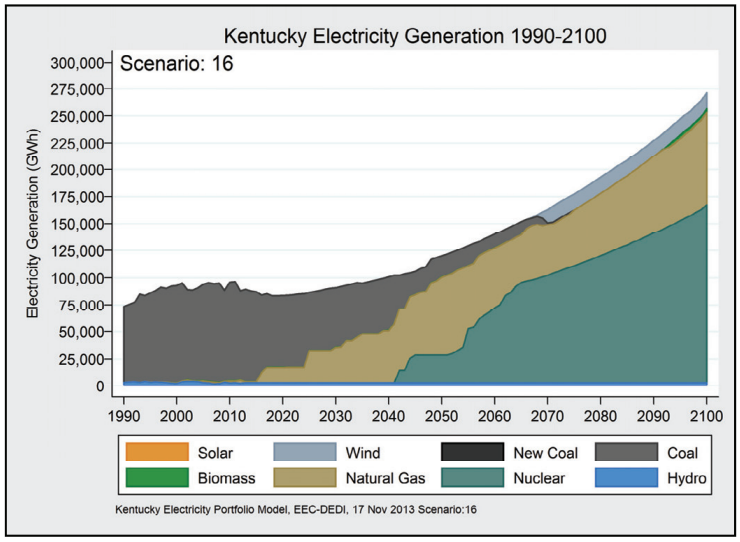


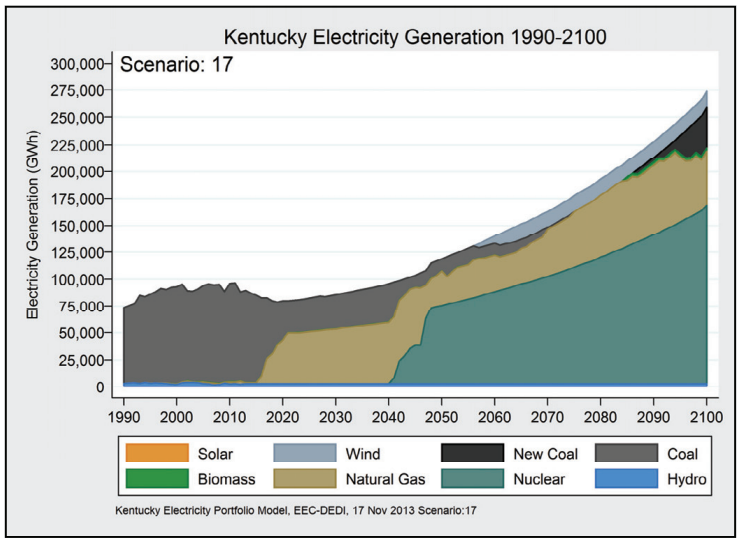


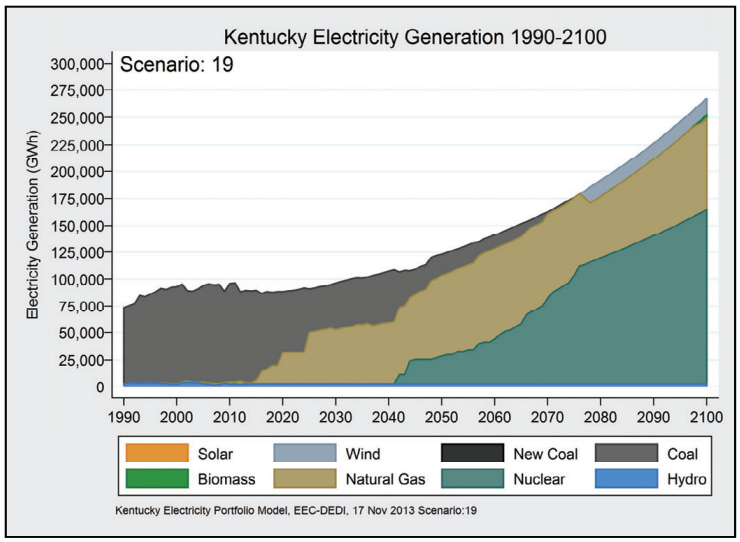


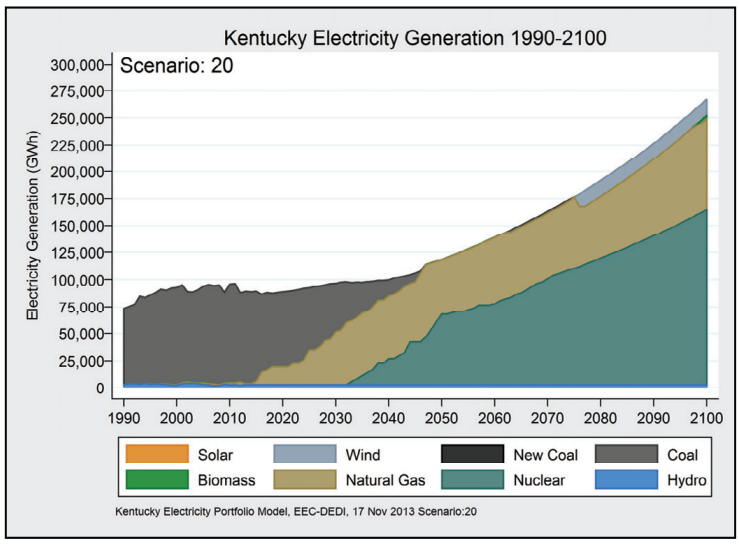
Generation Portfolio 3, 1990-2100

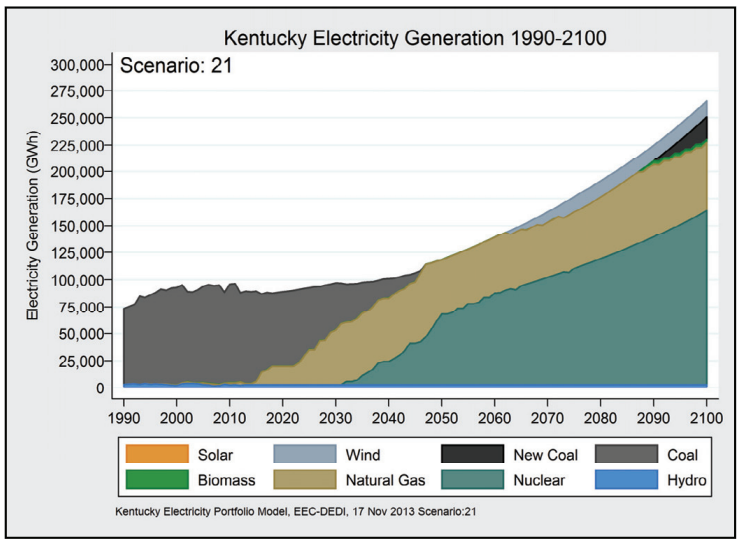




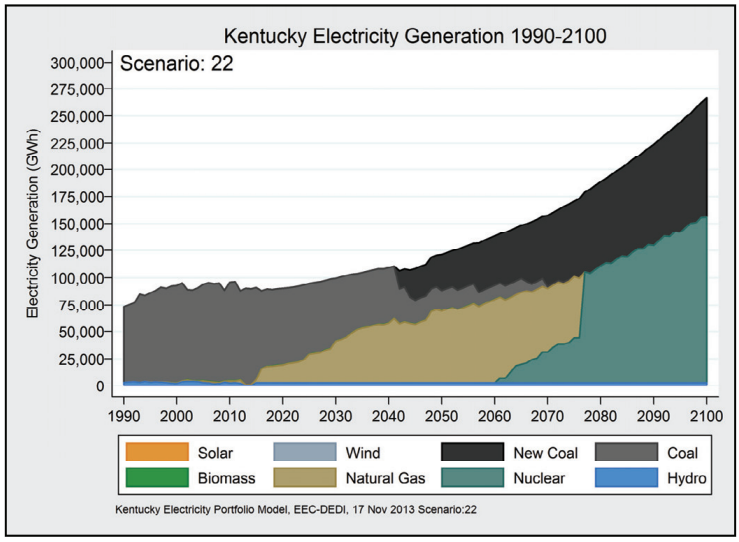


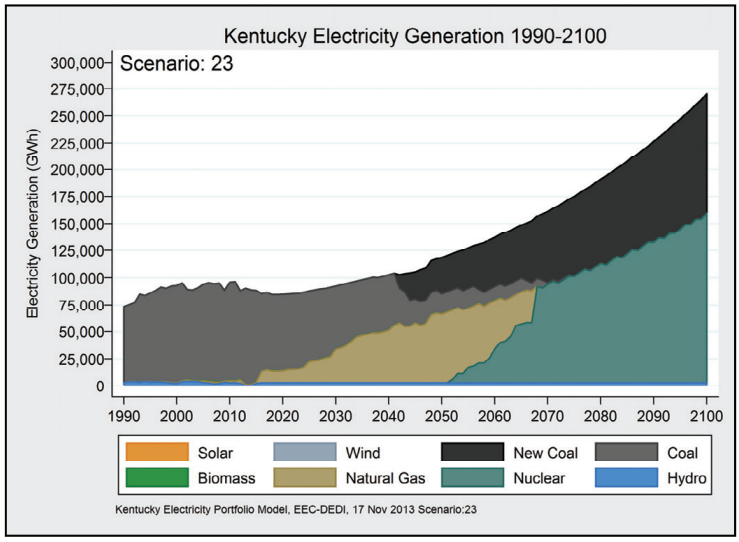


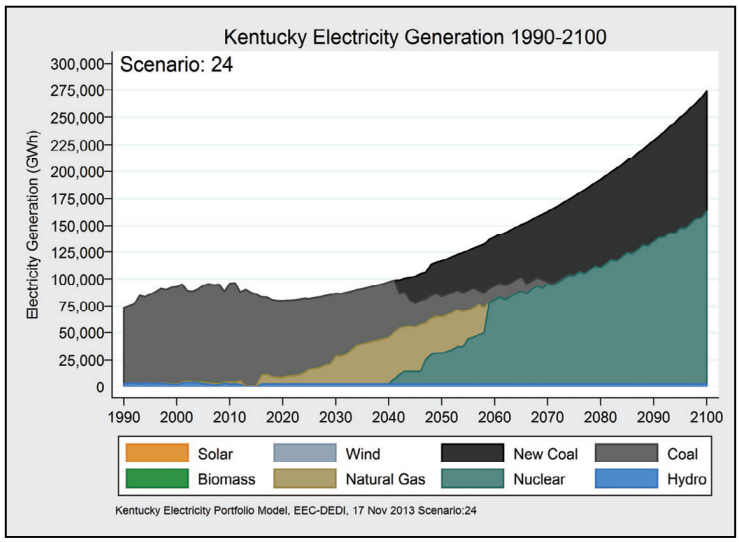


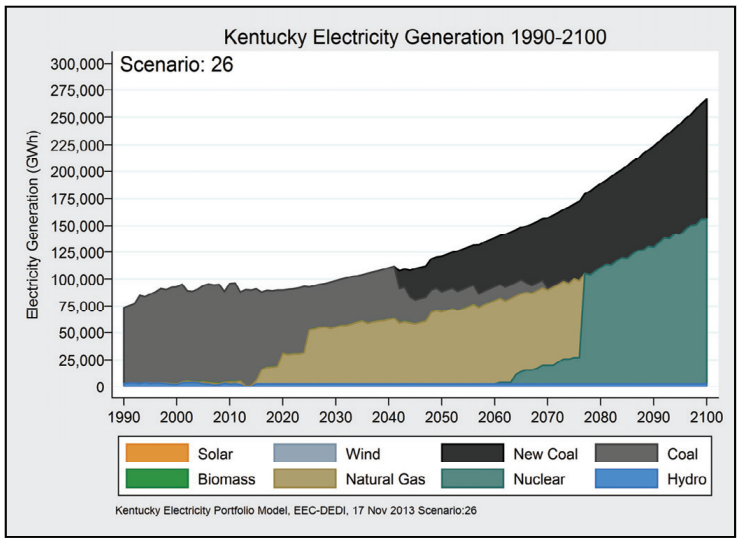


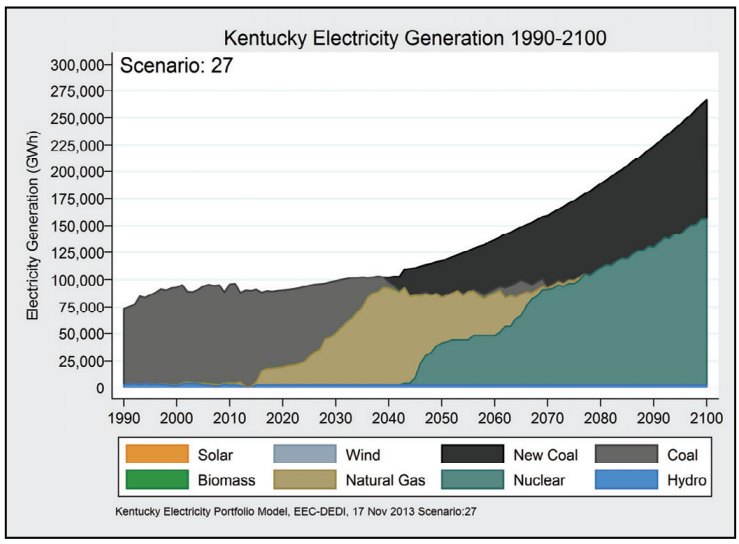
Generation Portfolio 4, 1990-2100

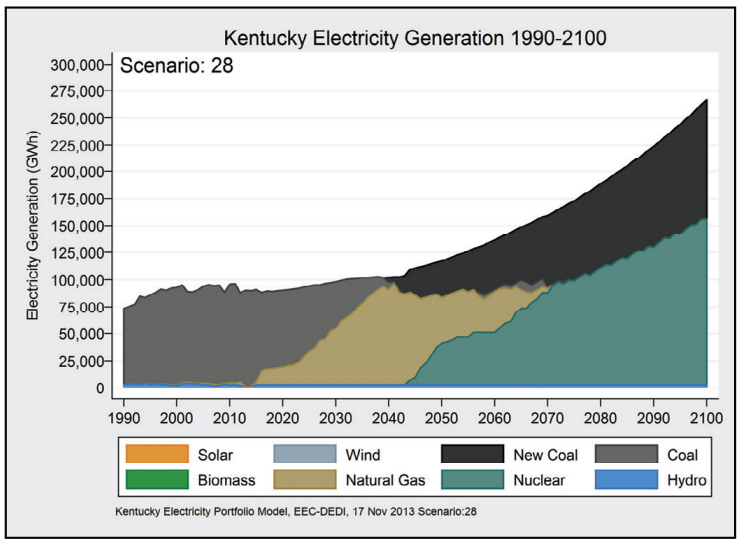




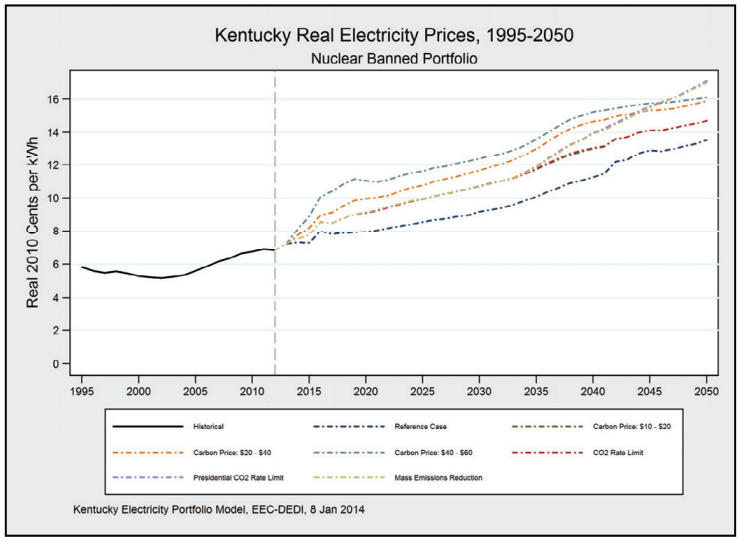


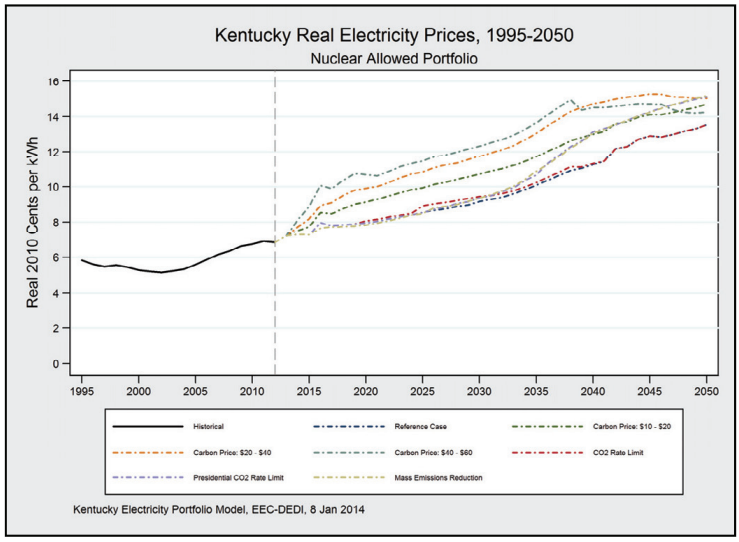


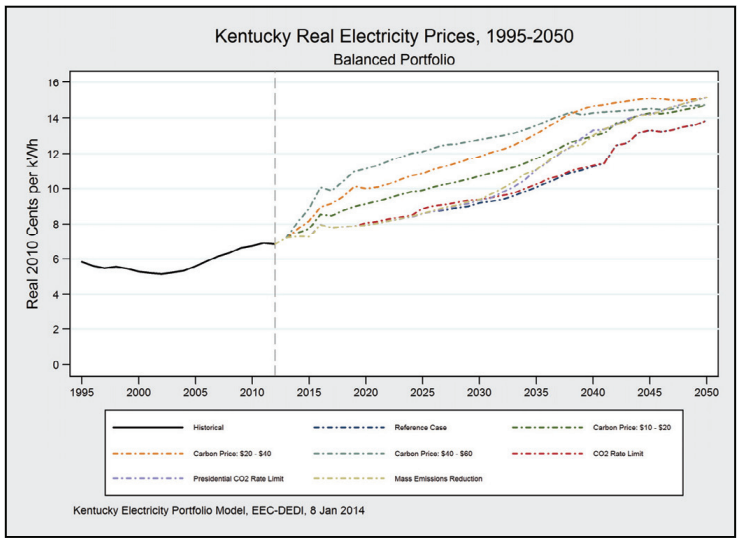


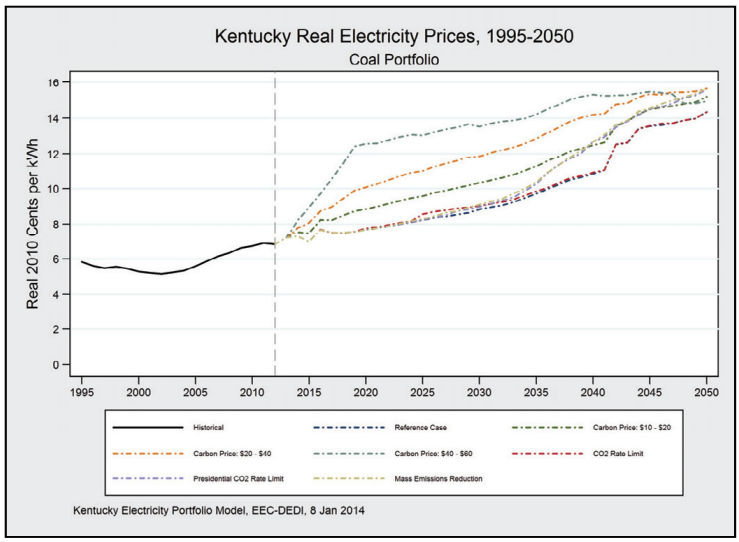


Portfolios & Prices, 1995-2050

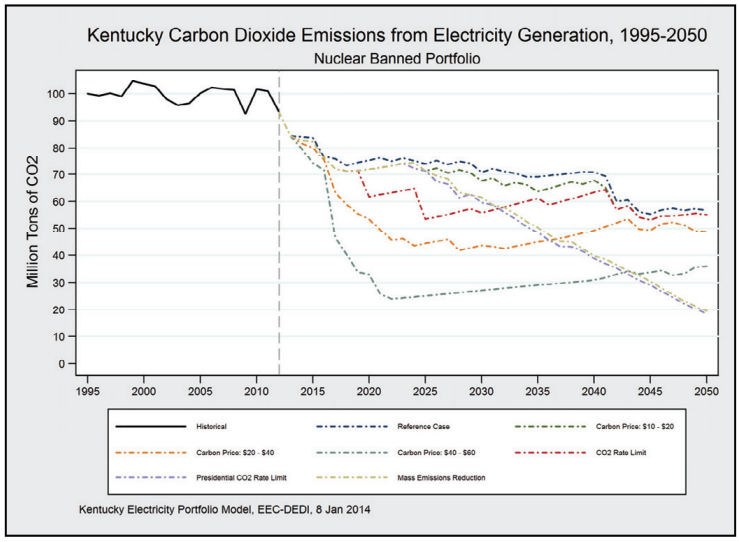


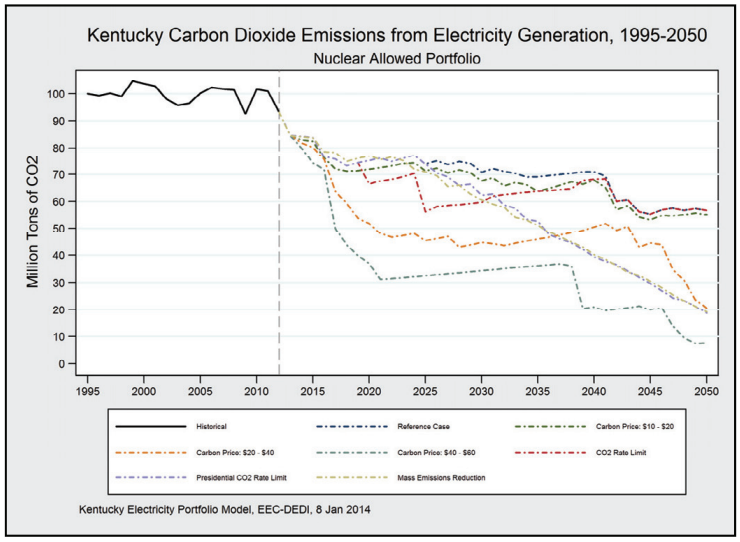


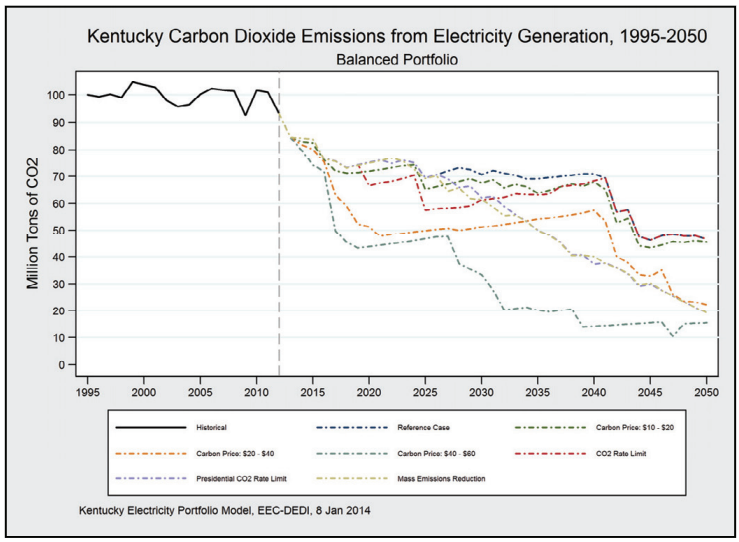


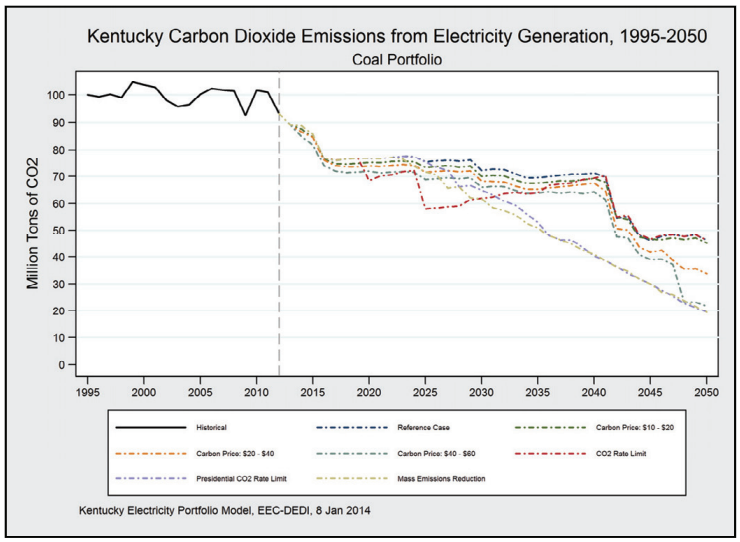


Portfolios & CO_2 Emissions, 1995-2050

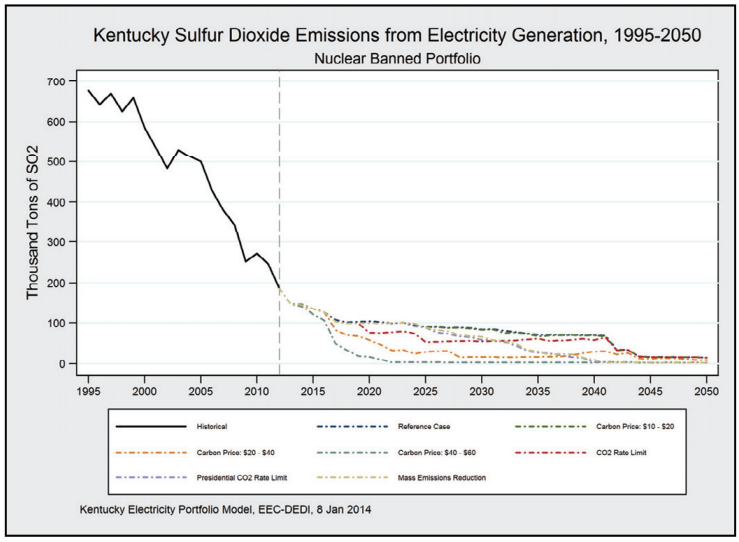


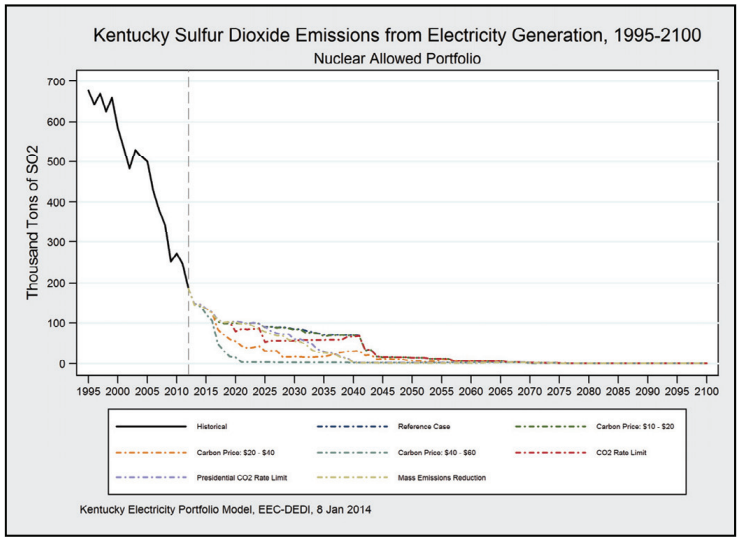


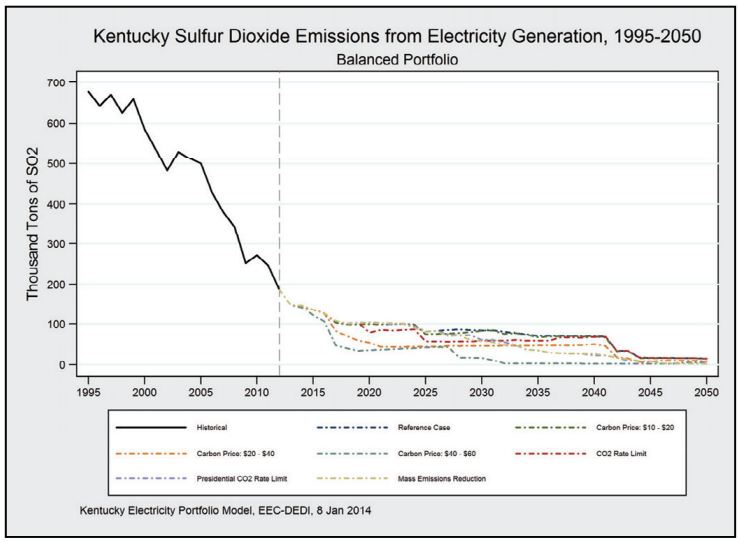


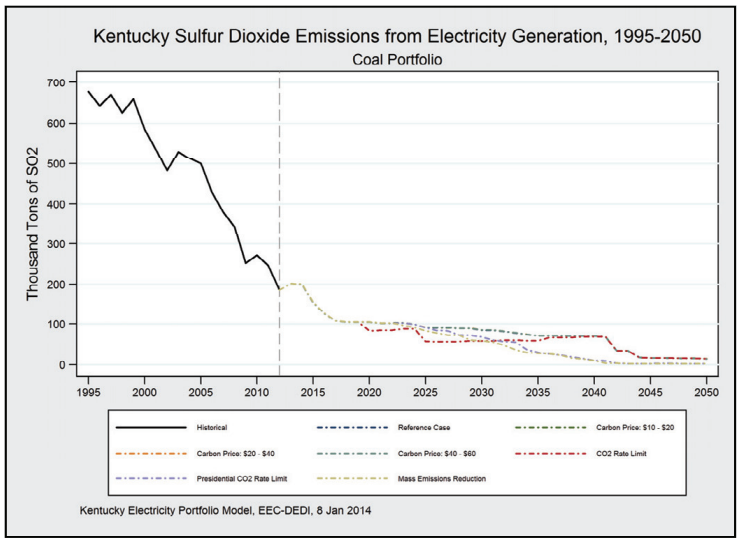


Portfolios & SO_2 Emissions, 1995-2050

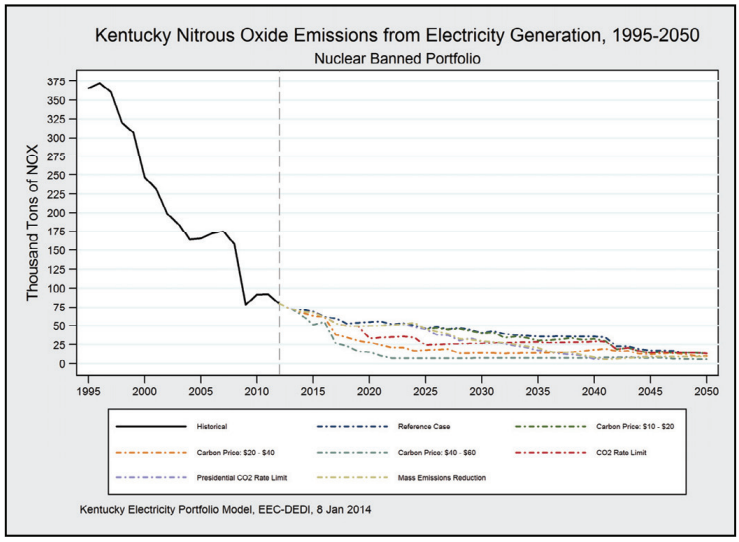


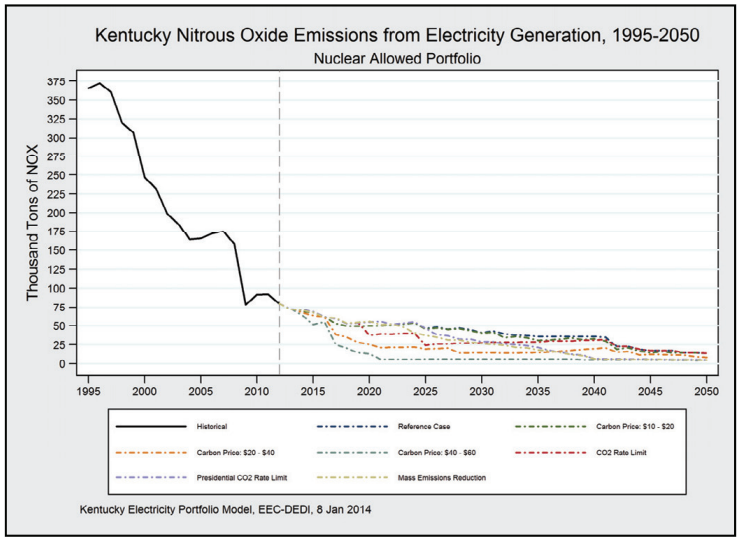


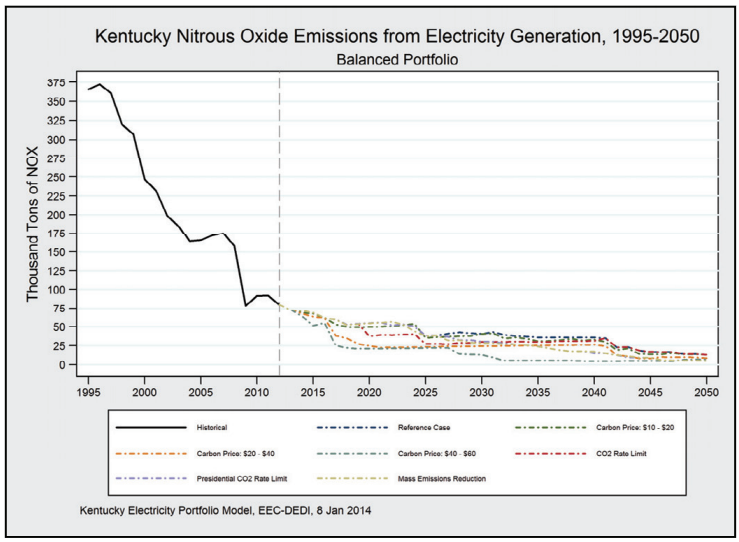


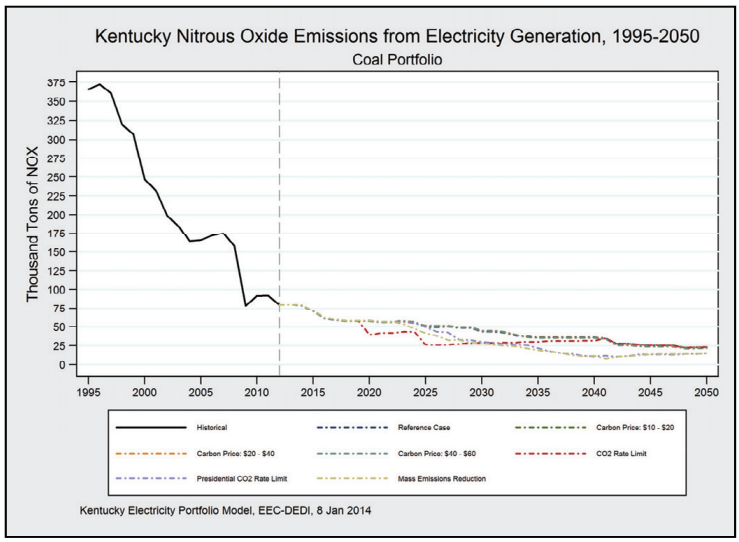


Portfolios & NO_X Emissions, 1995-2050

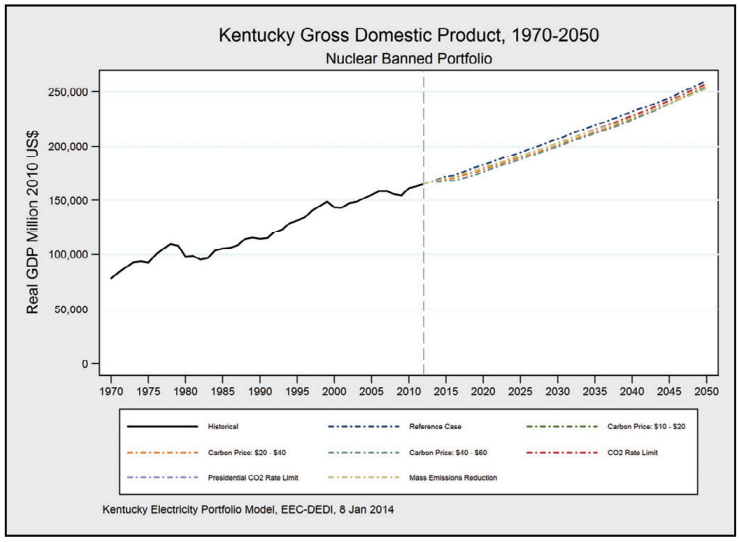


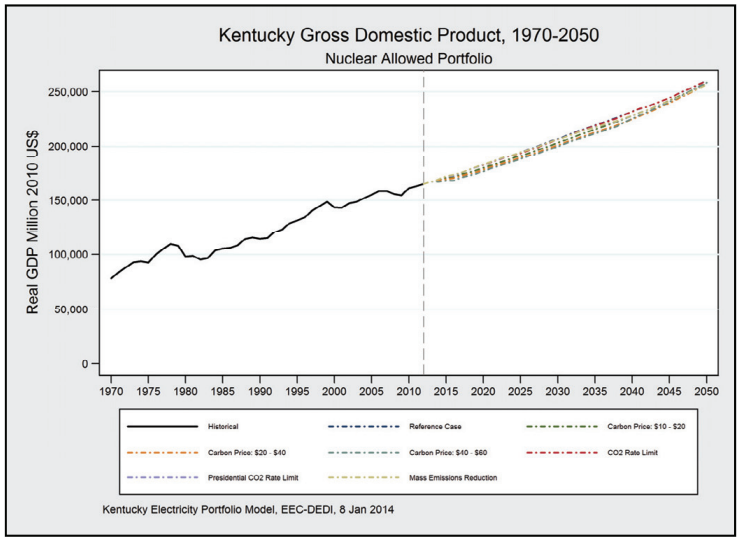


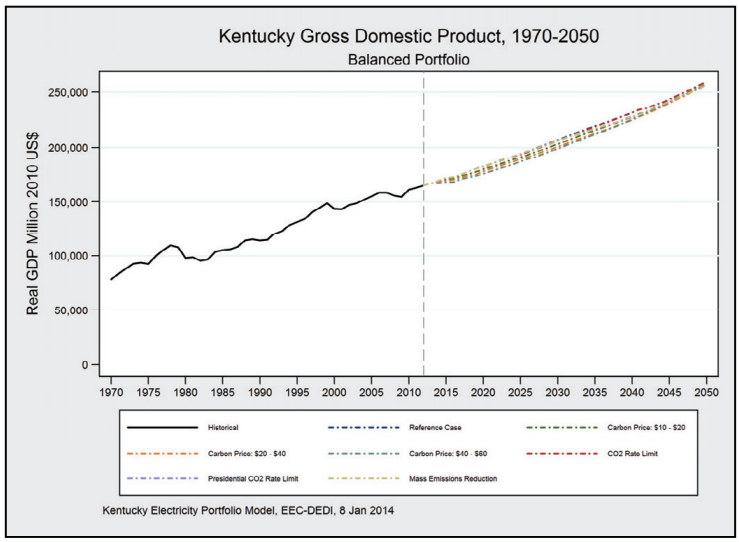


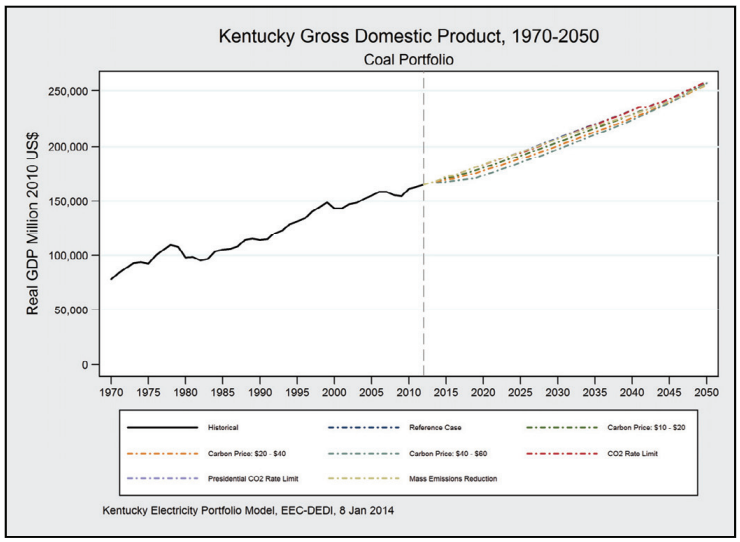


Portfolios & Kentucky GDP, 1970-2050

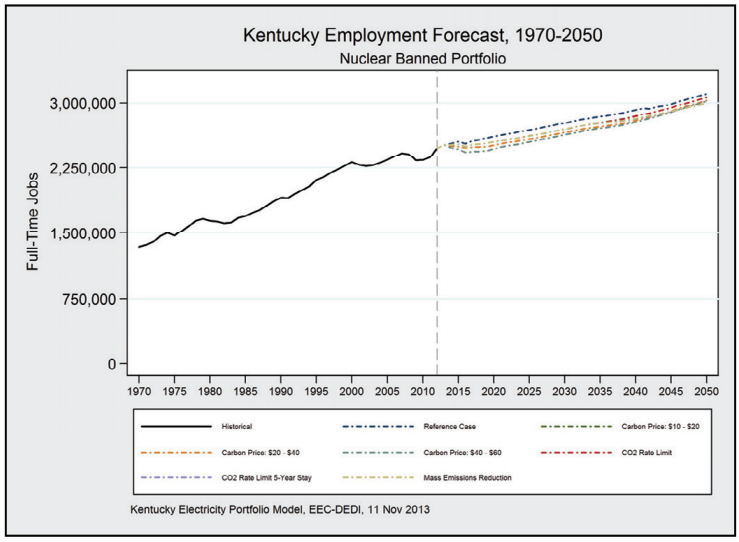


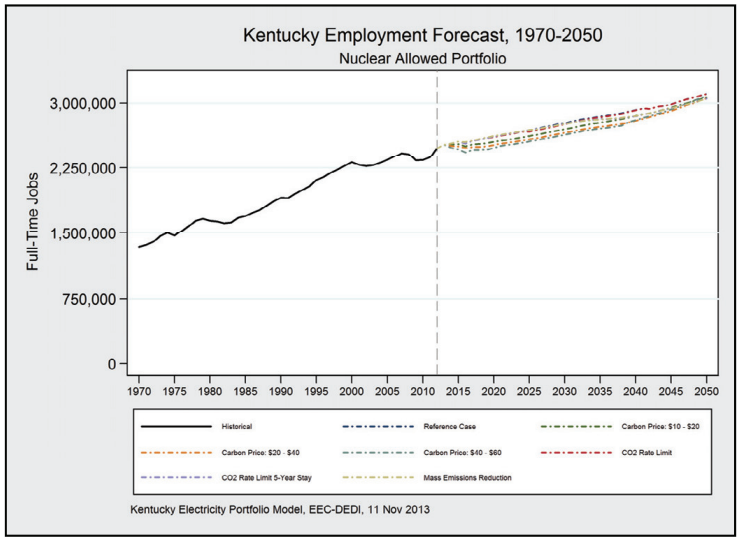


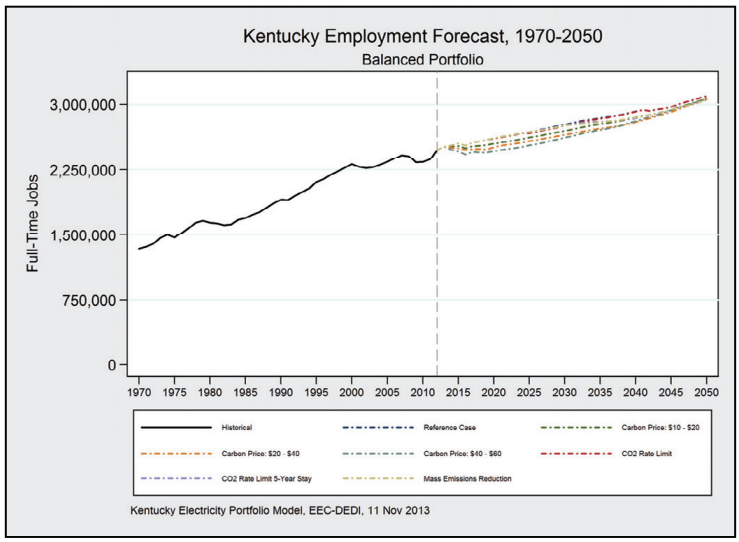


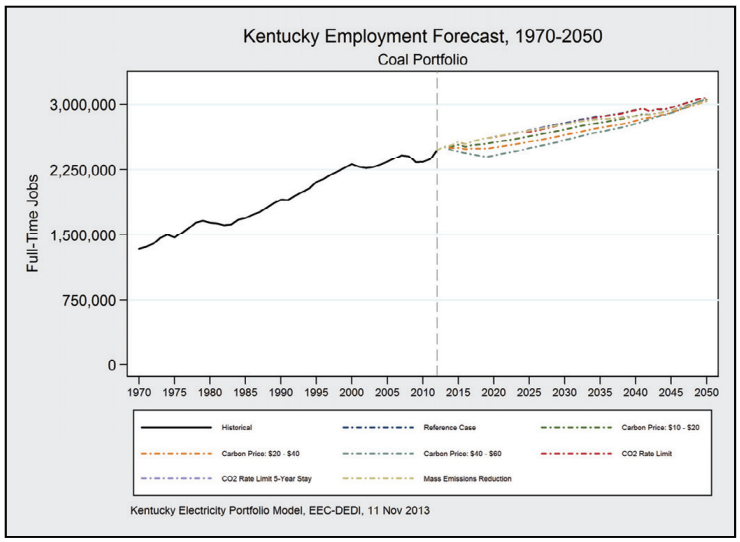


Portfolios & Employment, 1970-2050

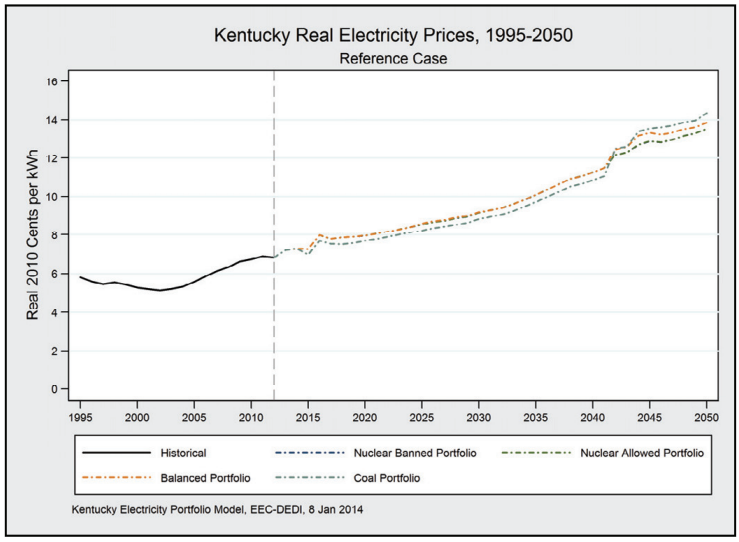


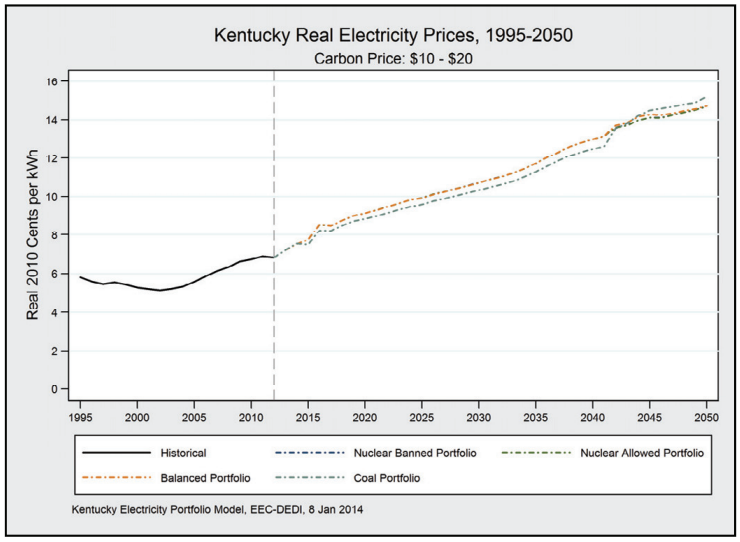


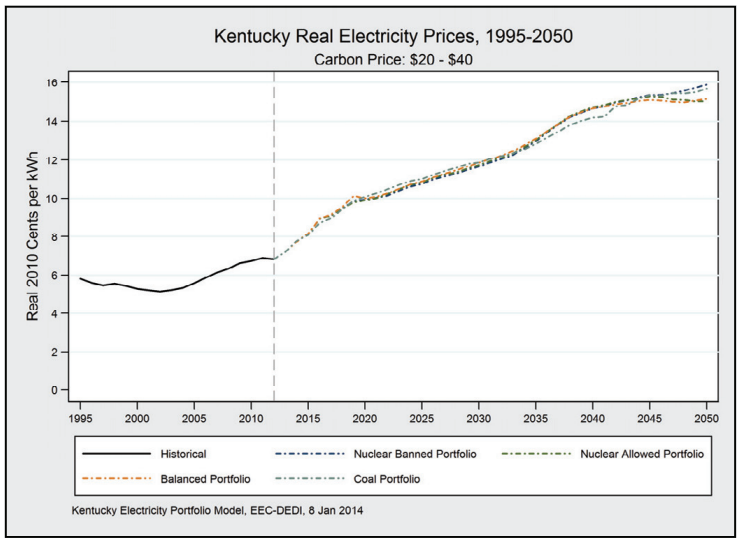


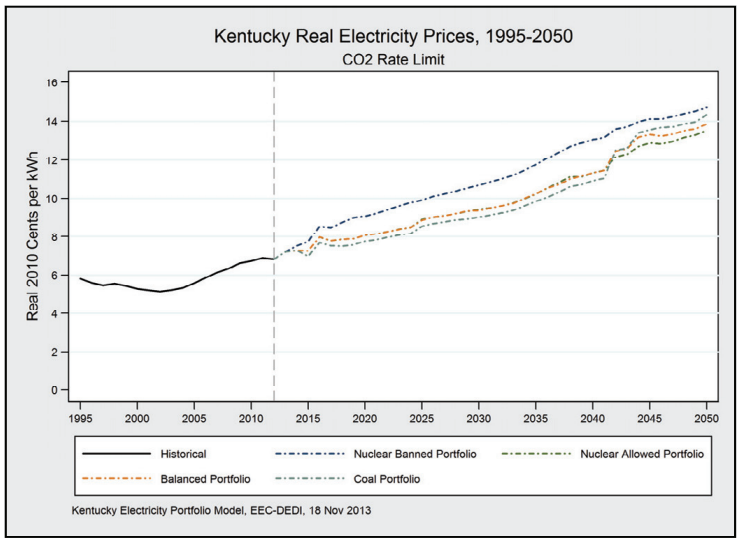


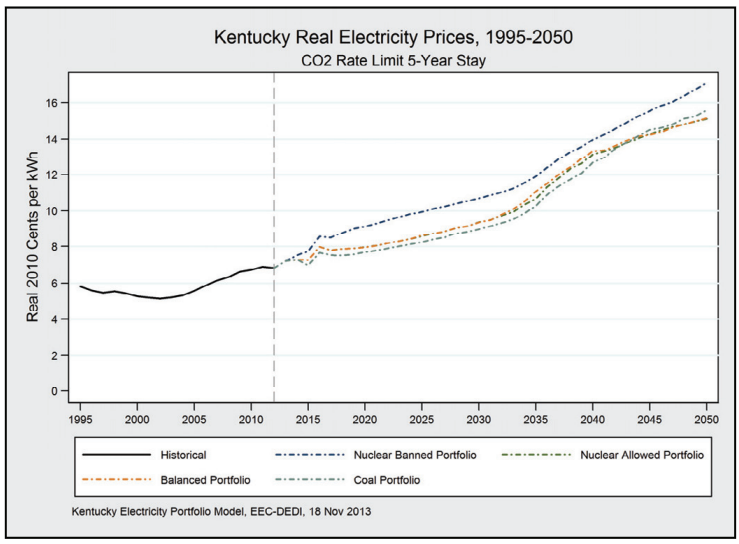
Federal Policy Options & Prices, 1995-2050

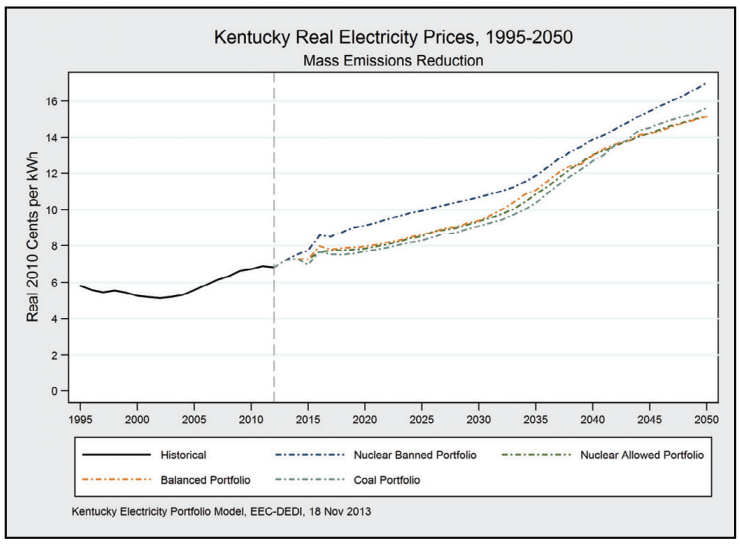




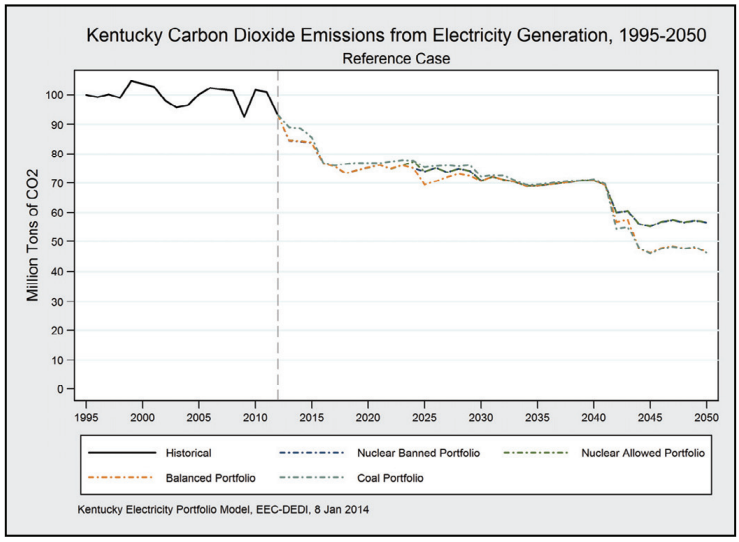


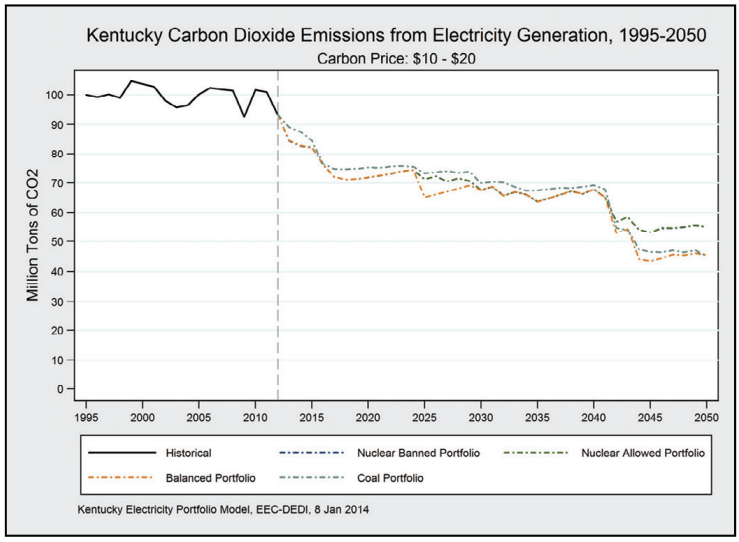


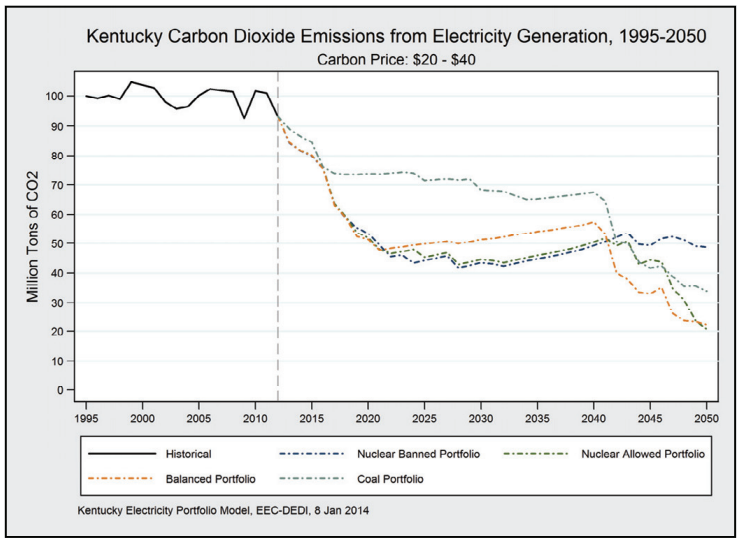


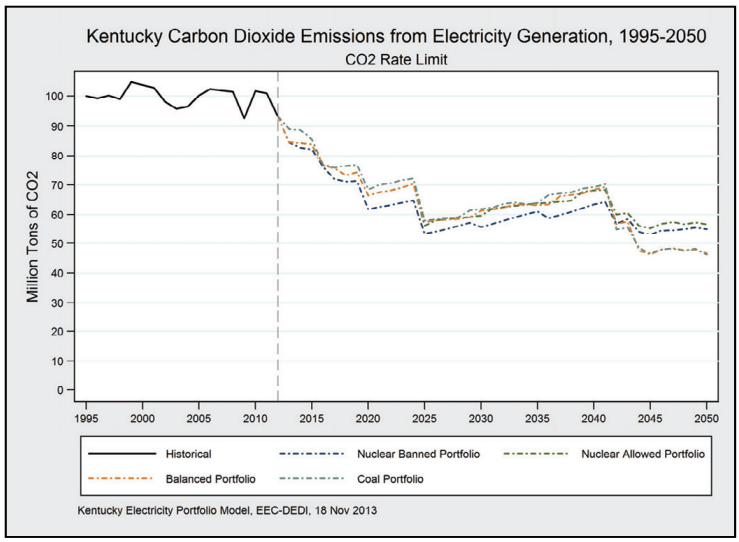


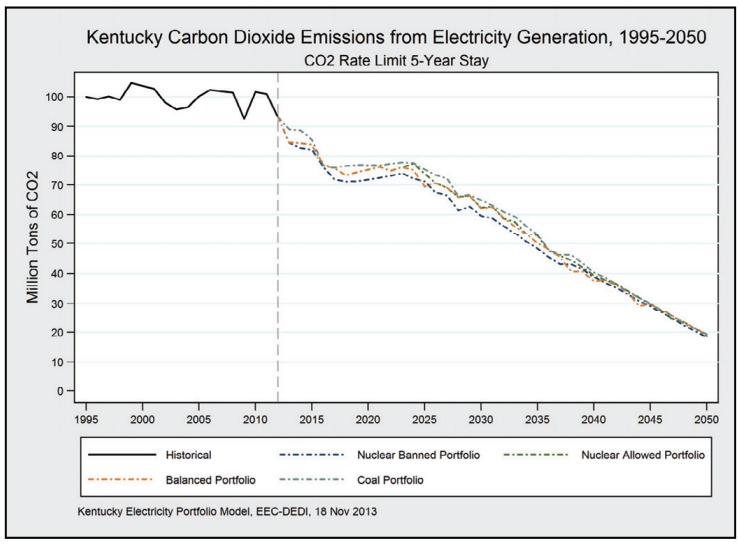
Federal Policy Options & CO_2 Emissions, 1995-2050

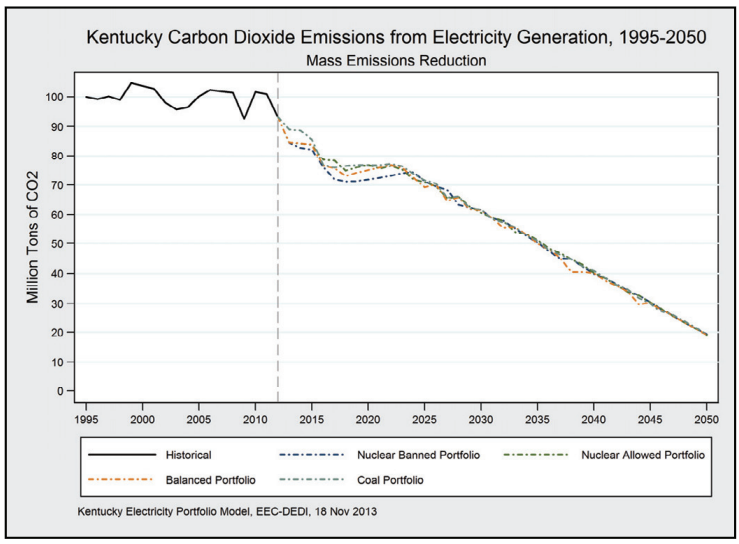




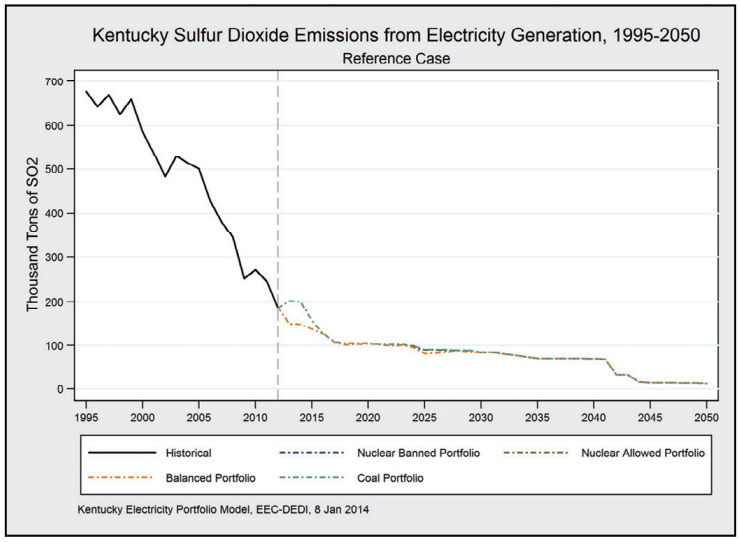


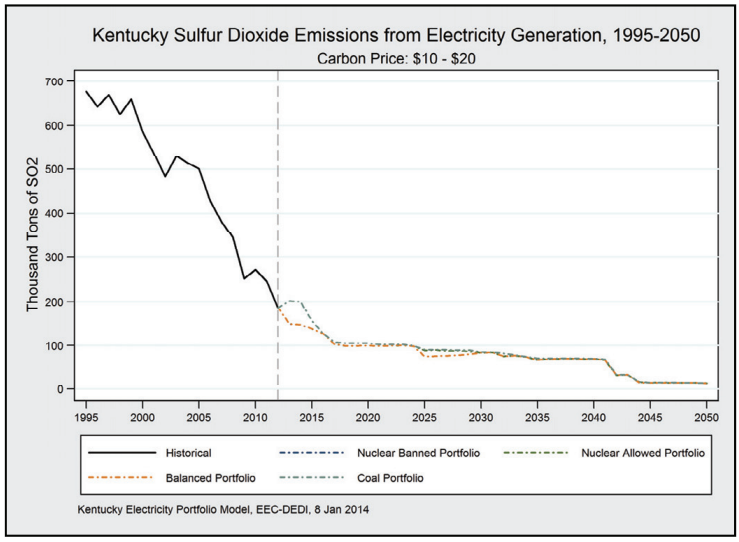


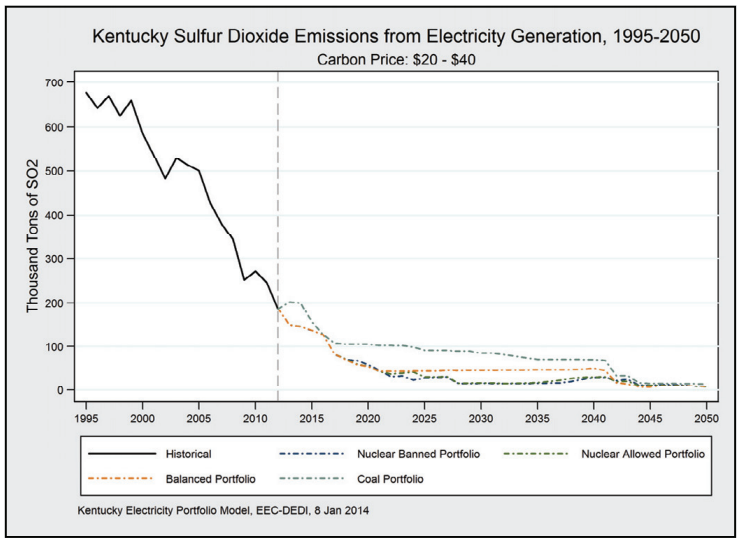


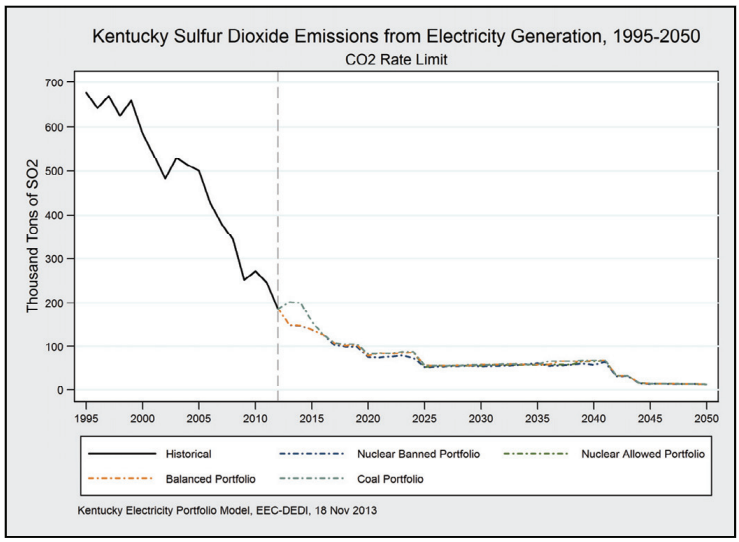


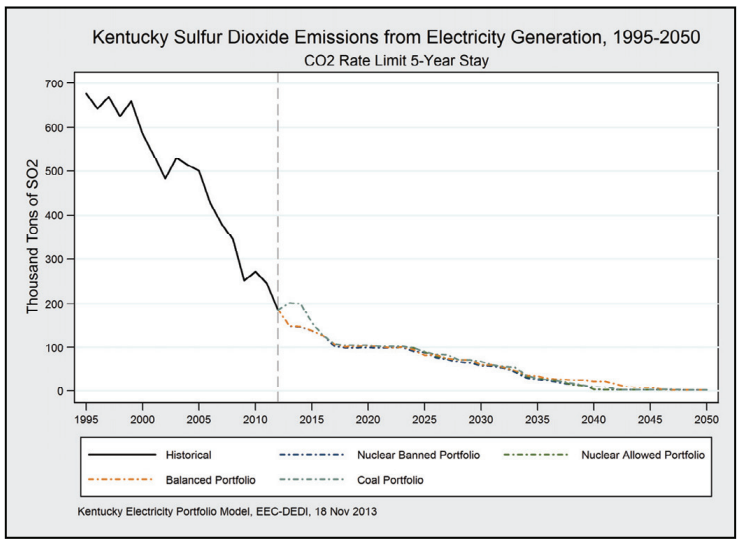
Federal Policy Options & SO_2 Emissions, 1995-2050

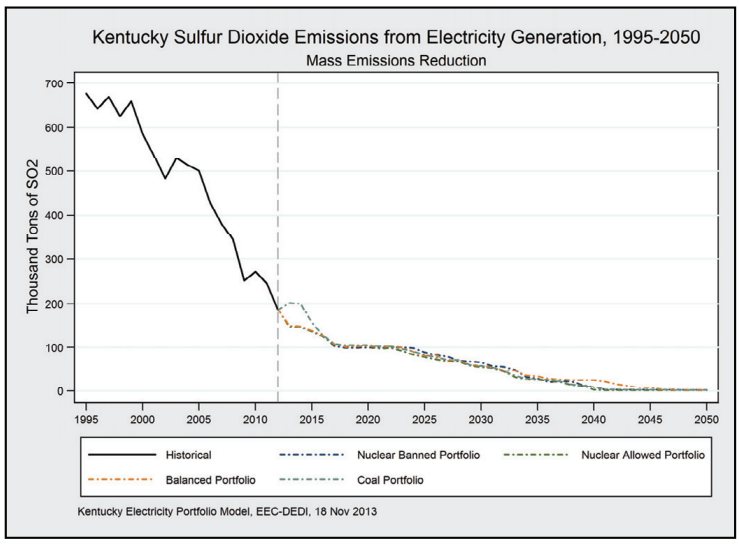




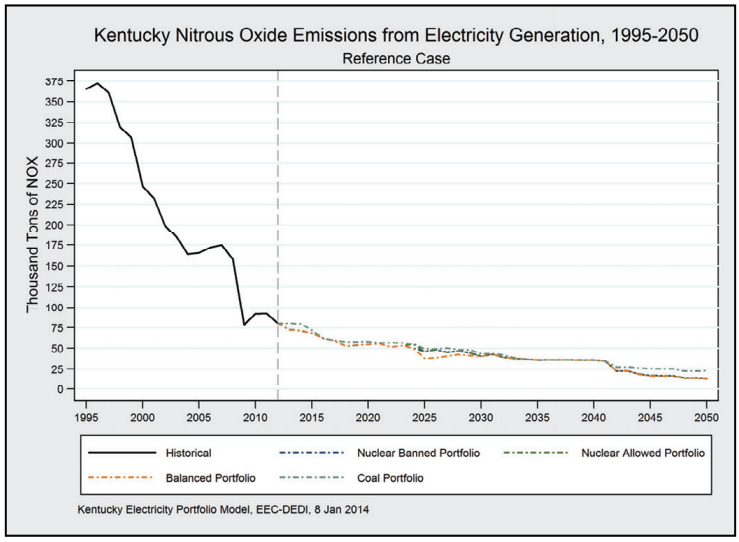


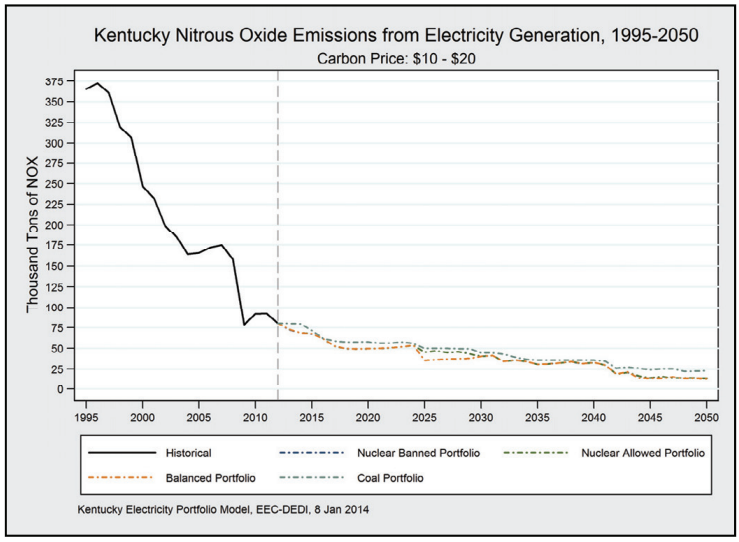


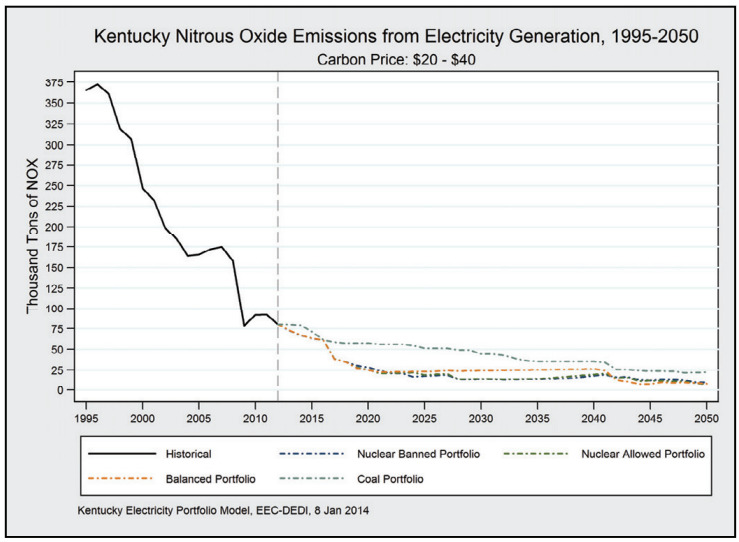


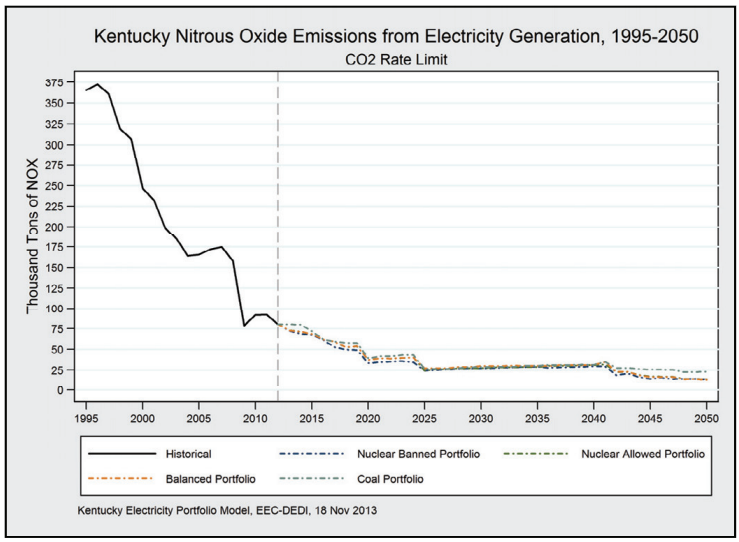


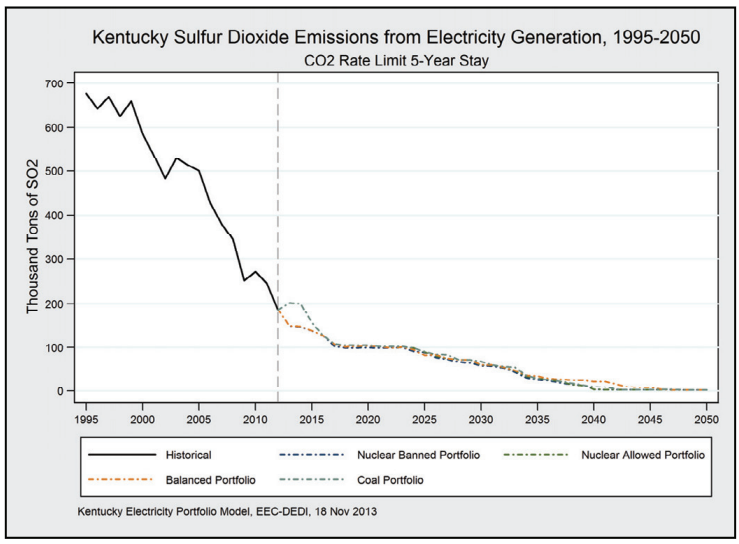
Federal Policy Options & NO_X Emissions, 1995-2050

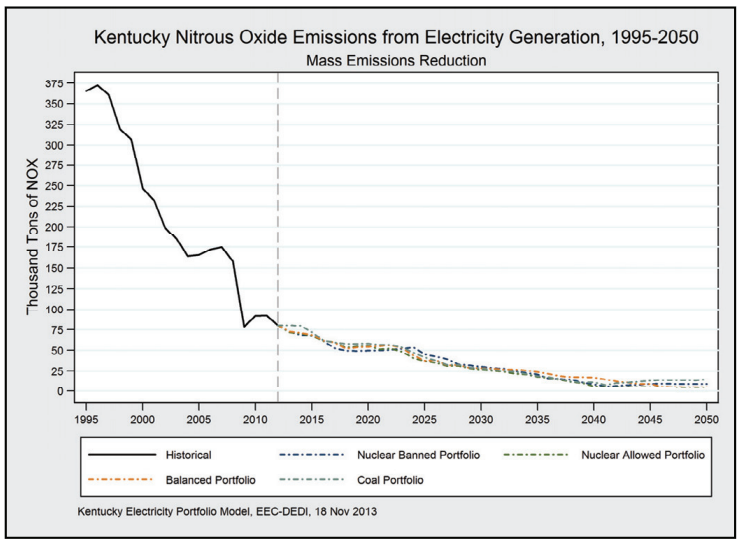




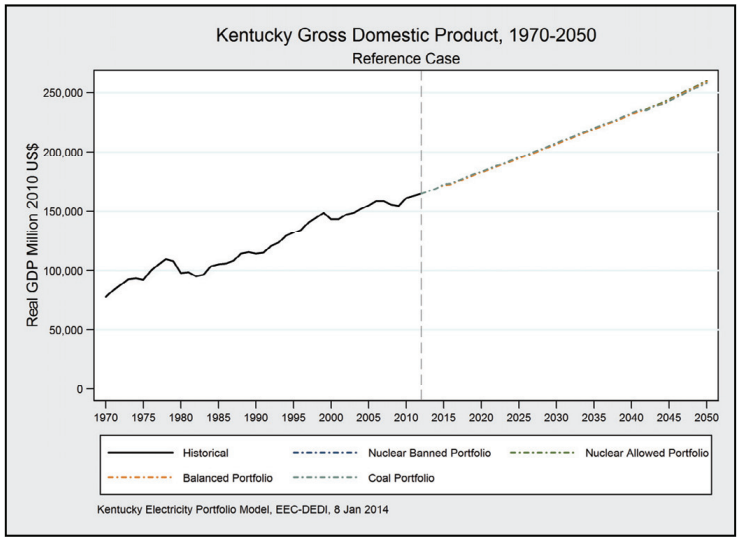


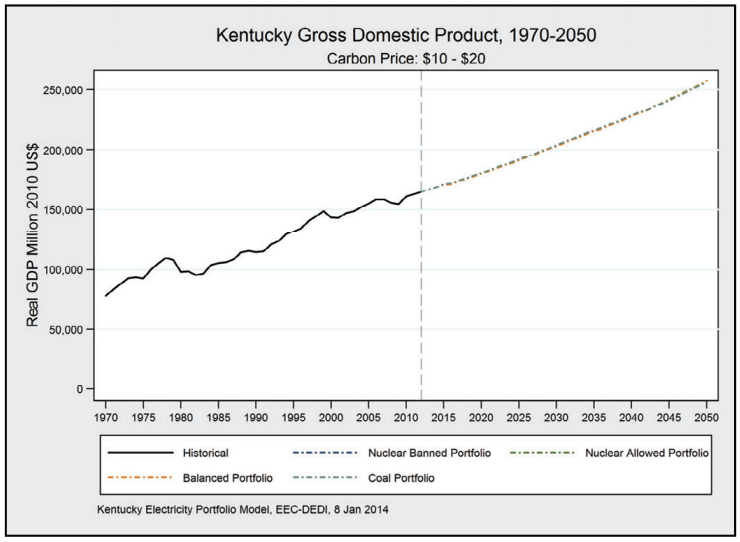


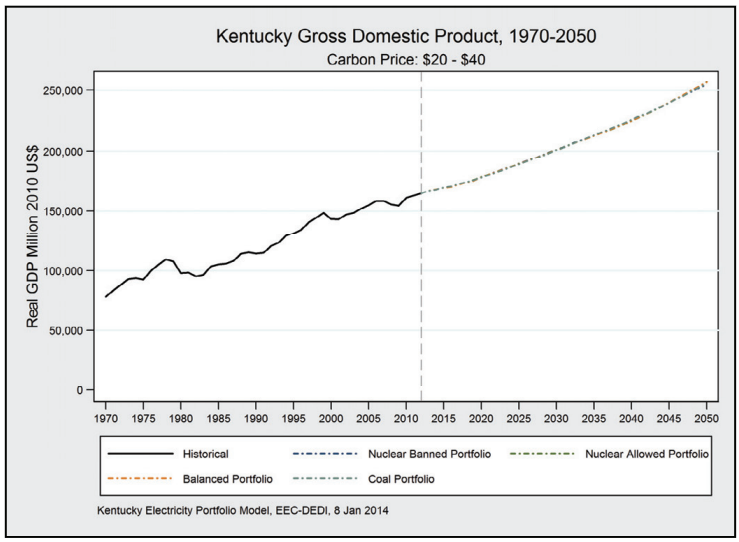


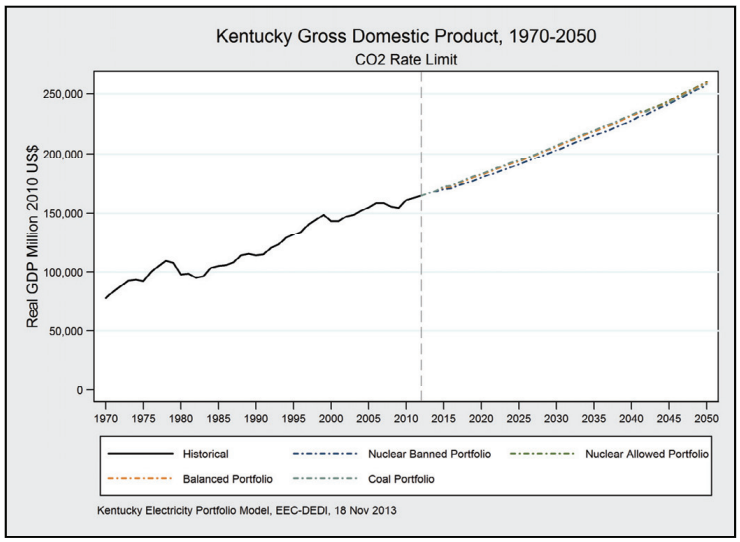


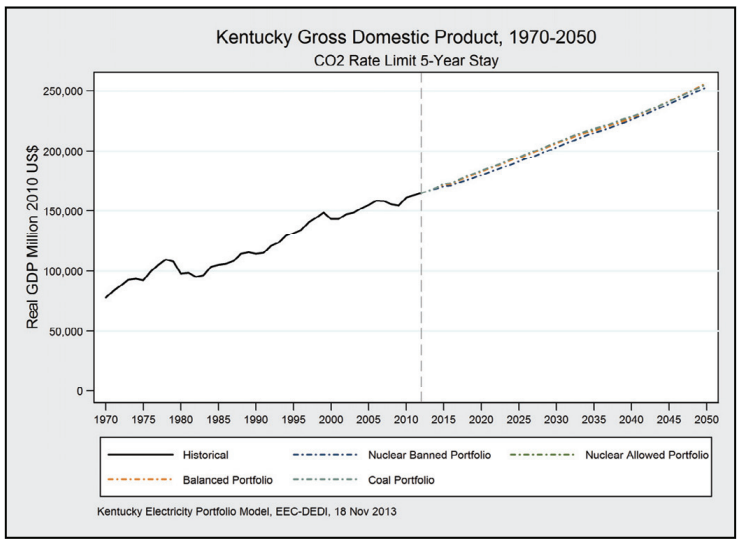
Federal Policy Options & GDP, 1970-2050

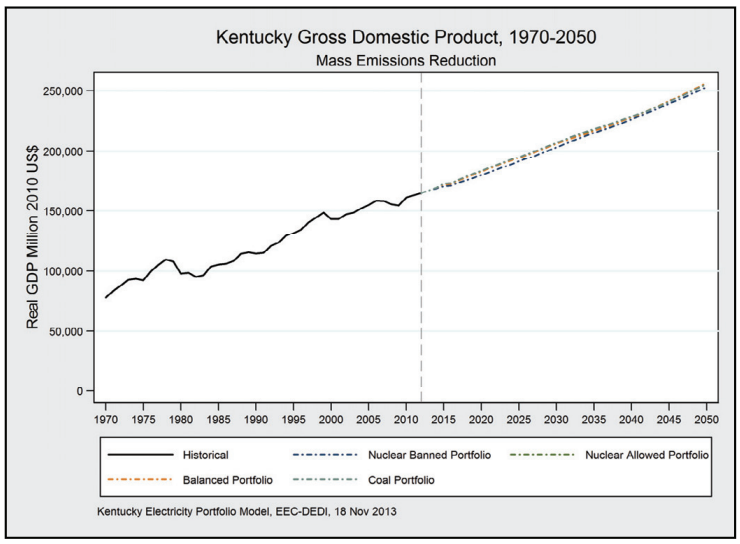




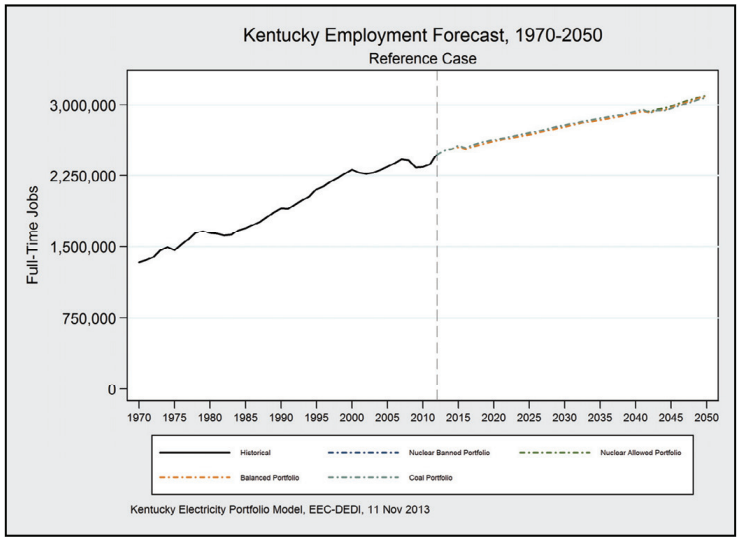


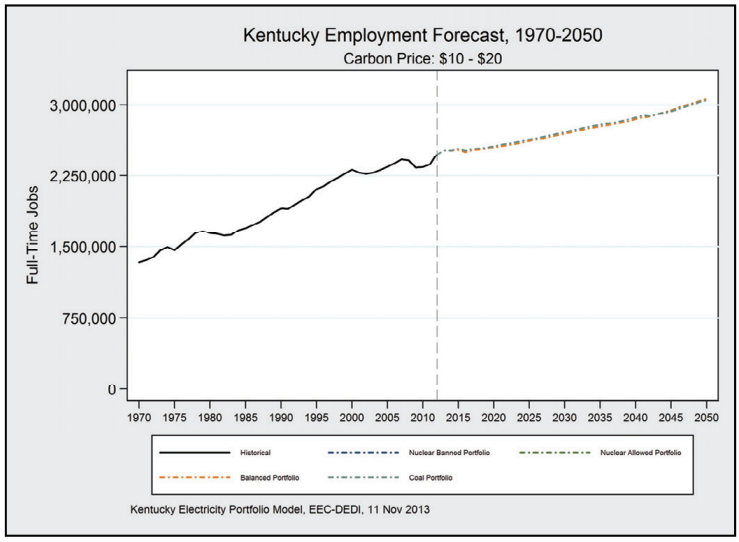


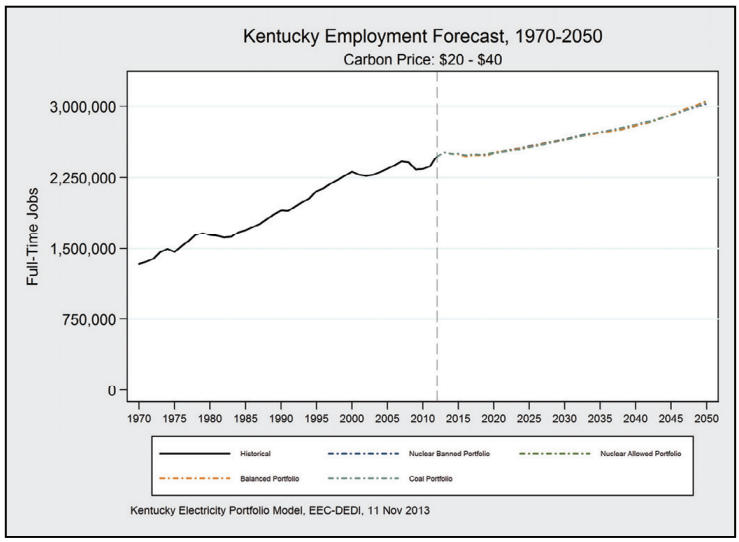


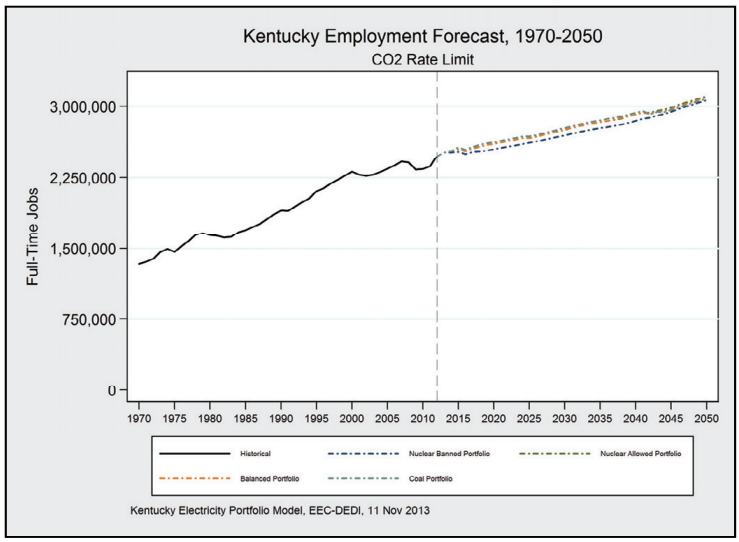


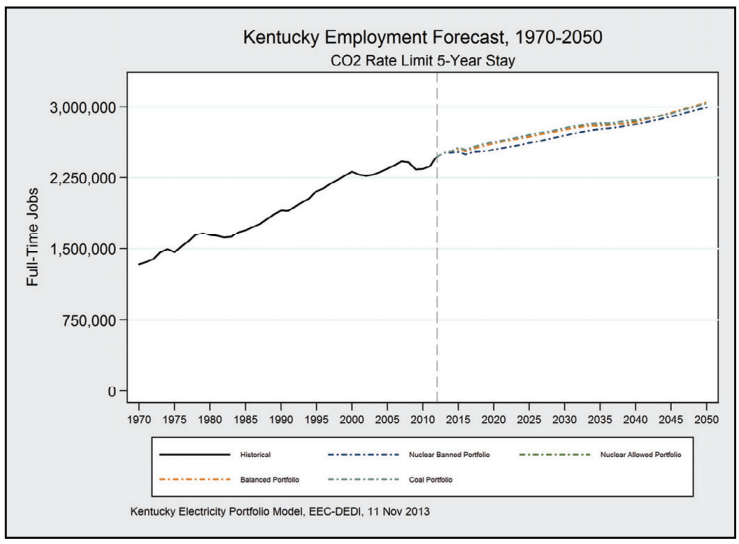
Federal Policy Options & Employment, 1970-2050

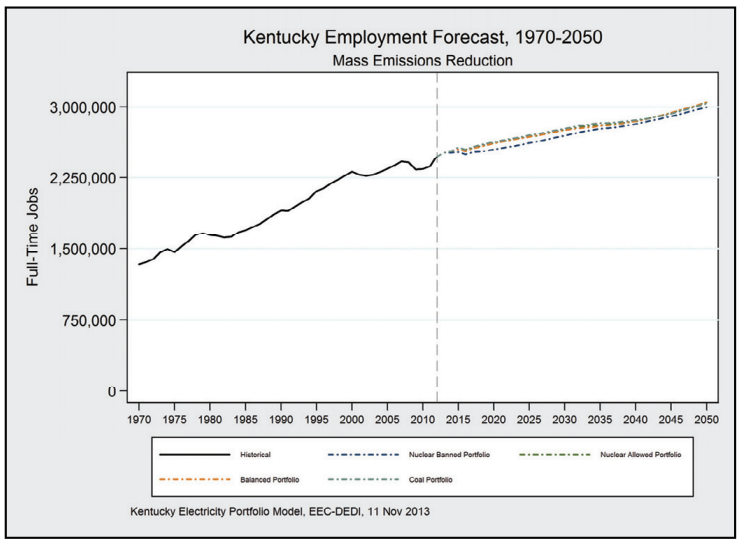




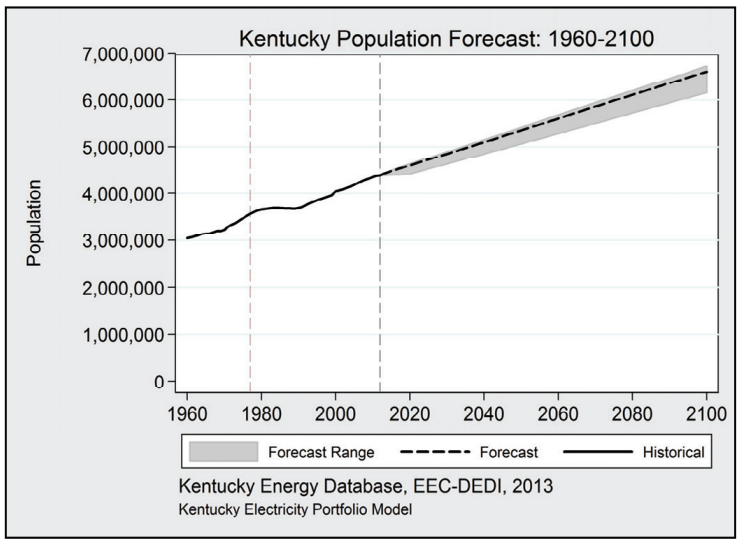


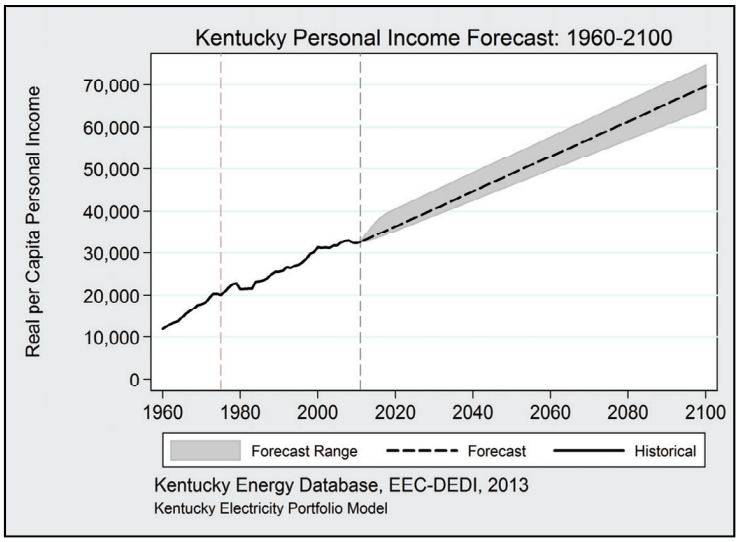


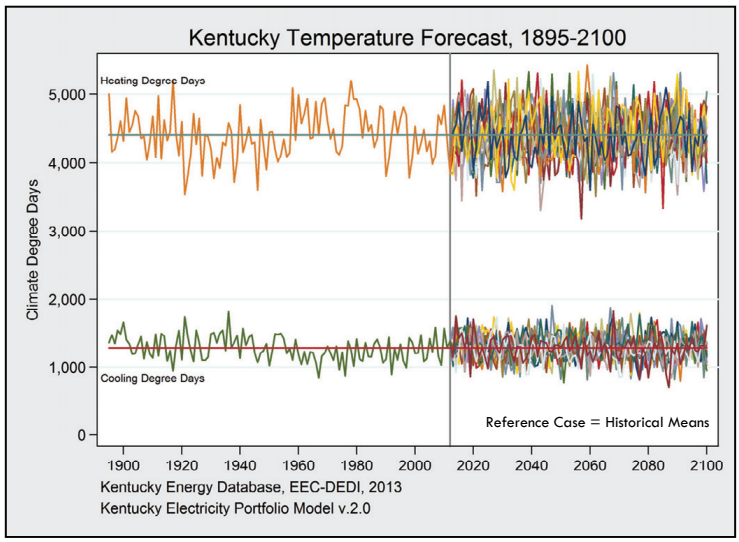


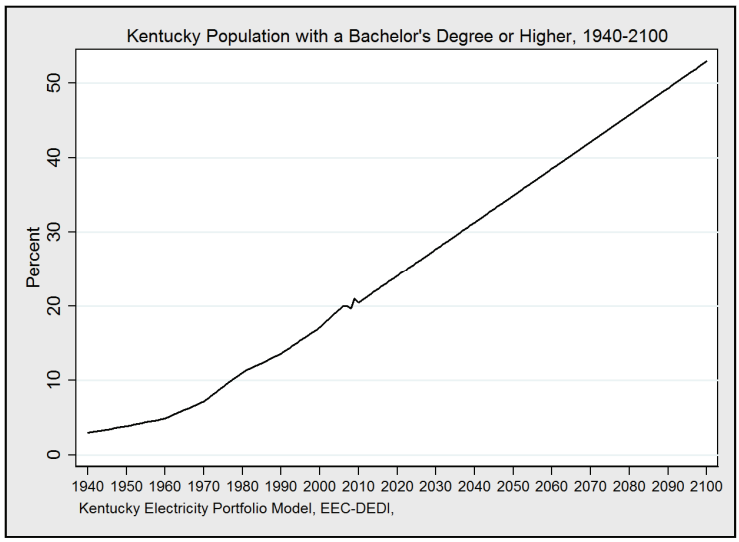


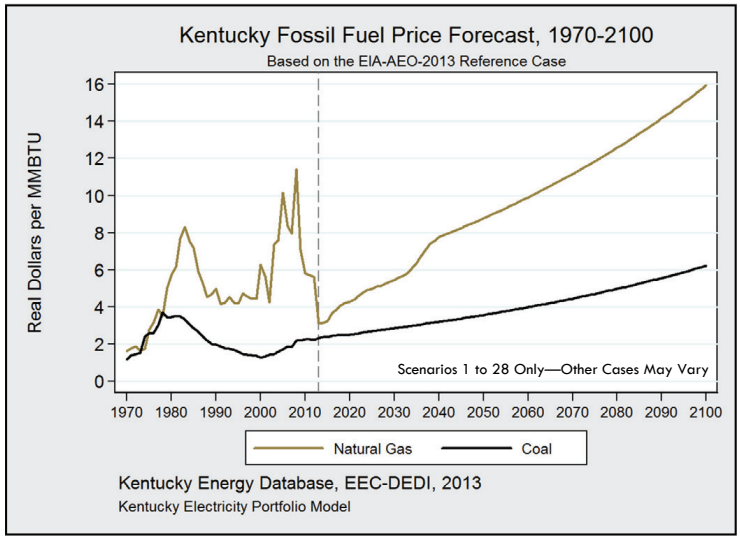
Basic Input Assumptions





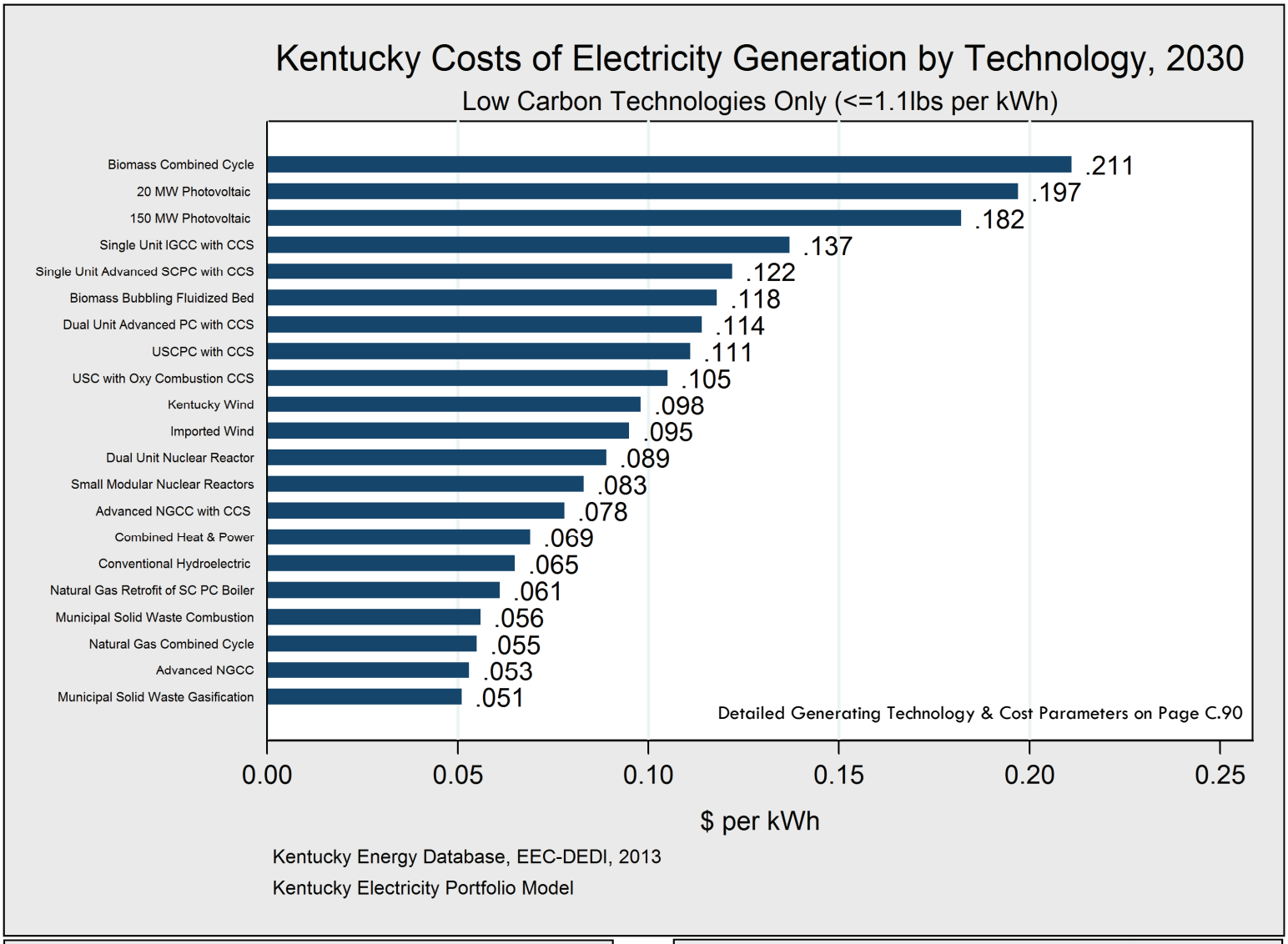


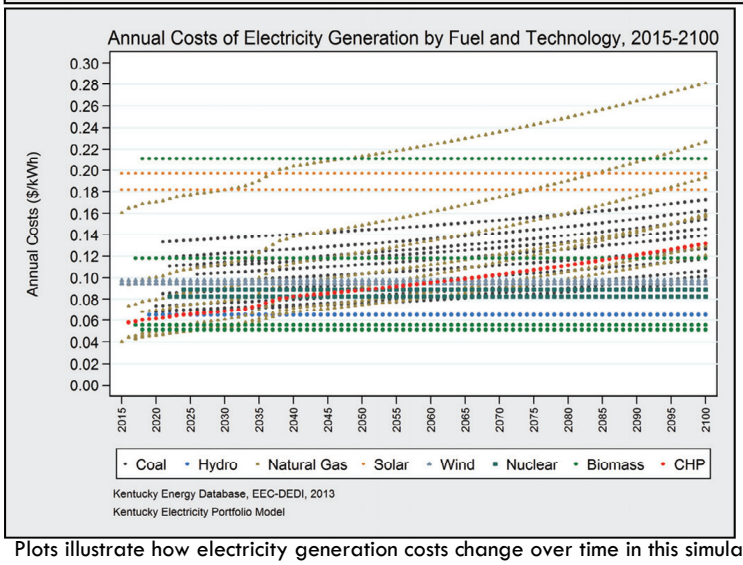


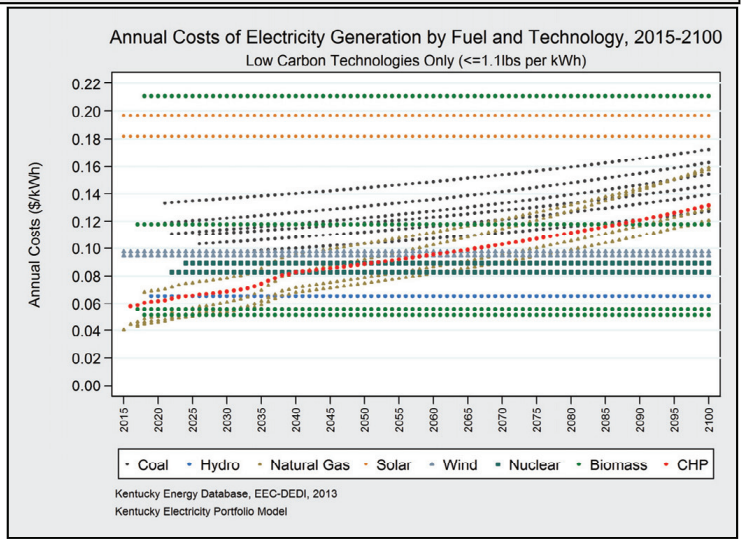


Electricity demand, generation, costs, and emissions are estimated as a function of basic socioeconomic, weather, and fuel price factors. Although these input factors are subject to change, in this specific reference simulation, Kentucky's future population, per capita personal income, educational attainment, 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







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

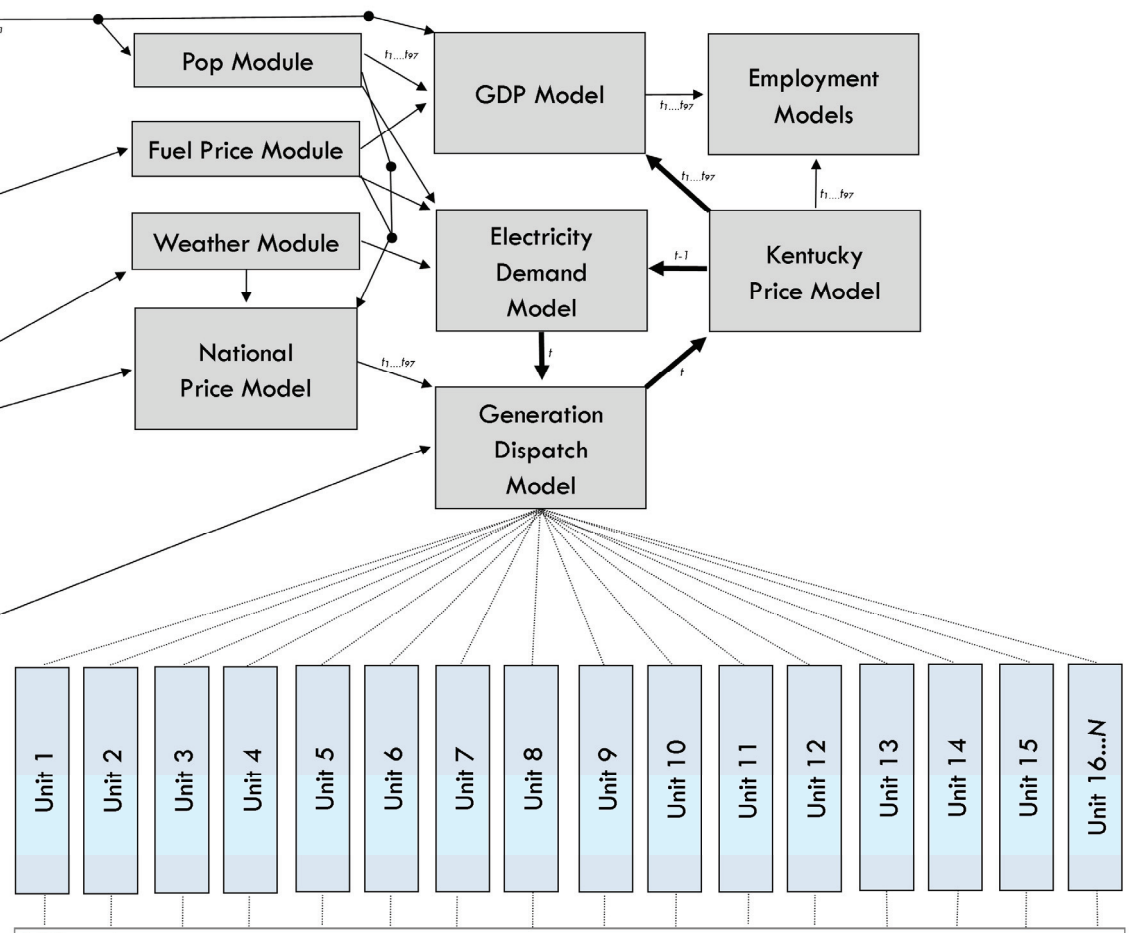
Historical Data Inputs, 1895-2013

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 $CO2_e$ 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

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_20, CO, and PM emissions in pounds per megawatt-hour.
Lead Time—The number of years required to construct the unit.

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)

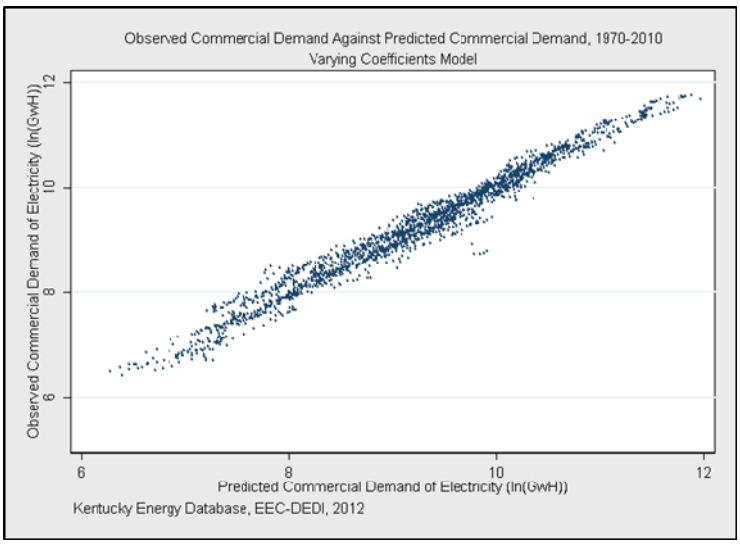
The Mixed Fixed and Random Coefficient Model, referred to here as an RCM, in addition to estimating a time-invariant fixed effect (α_i) for electricity demand for each state, also estimates the degree of homogeneity and heterogeneity of coefficients between cross sectional units. Such that, there is 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 ($\beta_2 \ldots \beta_k$) 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.

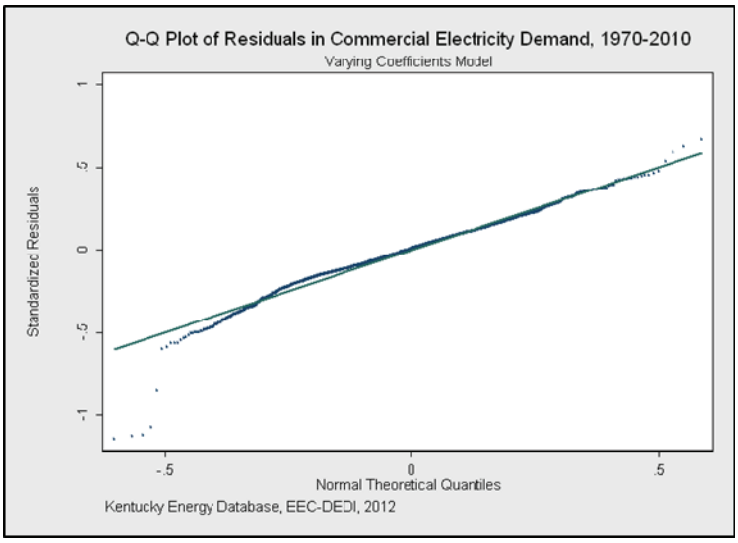
The complete demand model for each sector is provided below. All variables were transformed into their natural logarithms such that their coefficients below may be simply interpreted as elasticities.

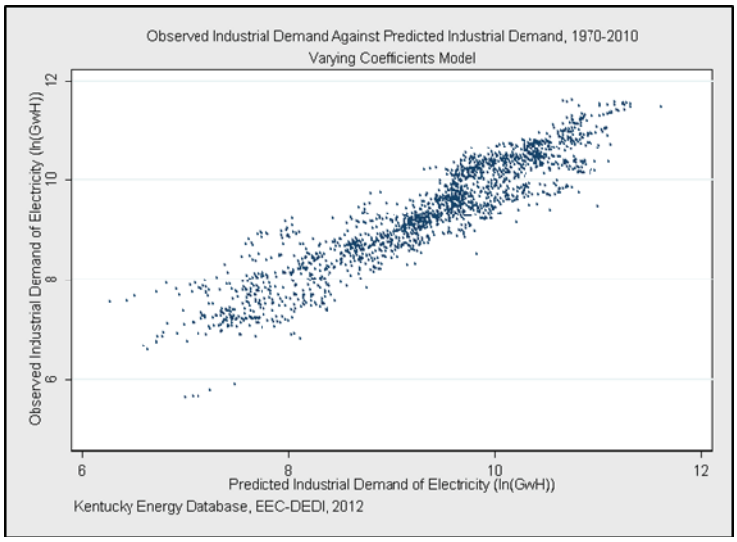
Logged Variables	Commercial	Industrial	Residential
Real Electricity Price	-0.211***	-0.321***	-0.297***
	-0.05	-0.06	-0.03
Cooling Degree Days	-0.003	-0.052*	0.036***
	-0.02	-0.03	-0.01
Heating Degree Days	-0.090*	-0.077	0.084***
	-0.04	-0.06	-0.02
Population	0.522***	0.886***	0.821***
	-0.03	-0.04	-0.02
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

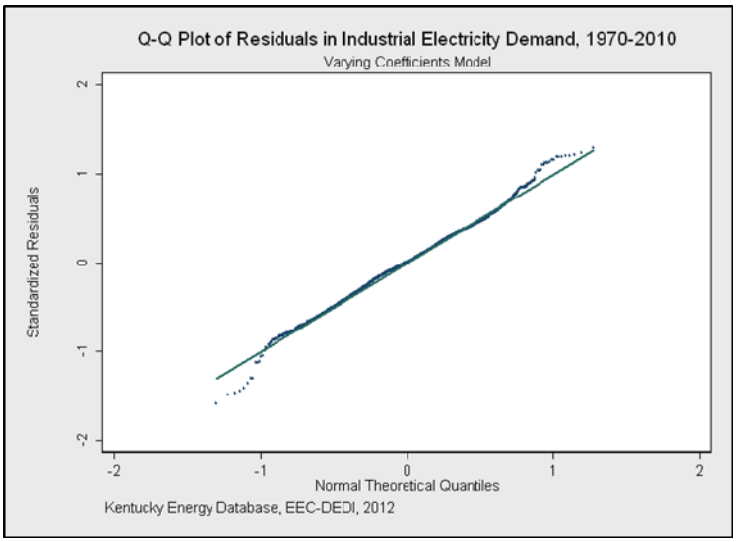
Standard Errors in Parentheses
Asterisk Denotes Statistical Significance at the Following Levels: * p<0.05, ** p<0.01, *** p<0.001

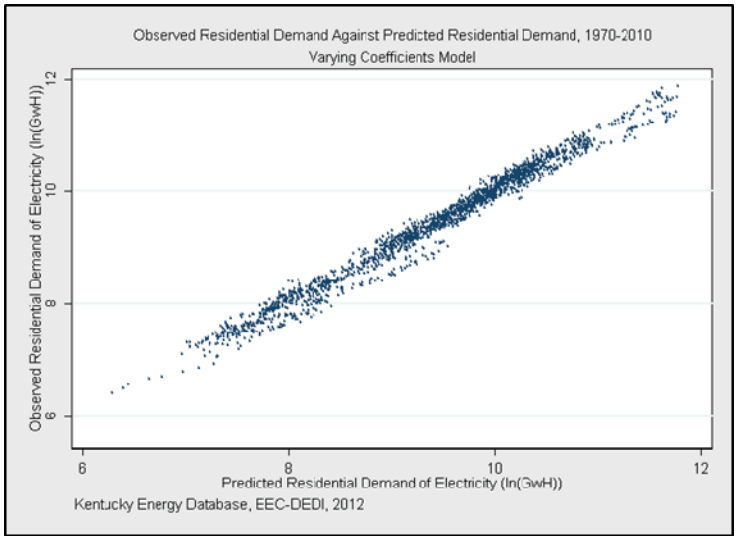
Demand Model Validation

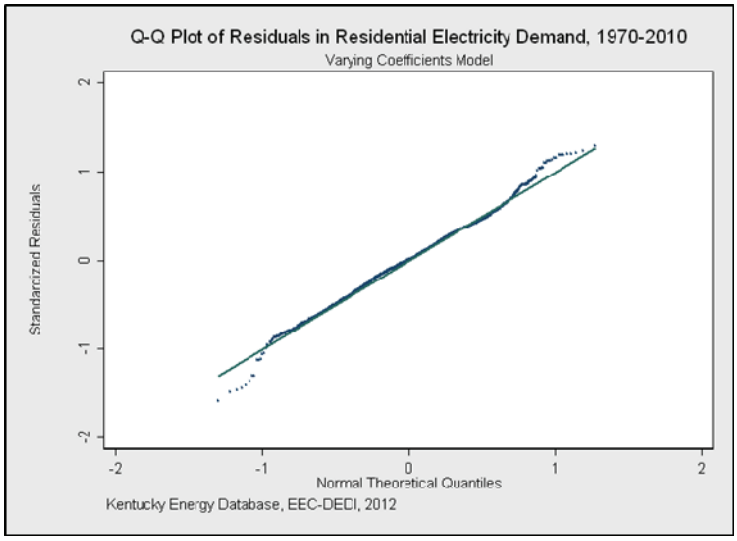












Dispatch Model

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.

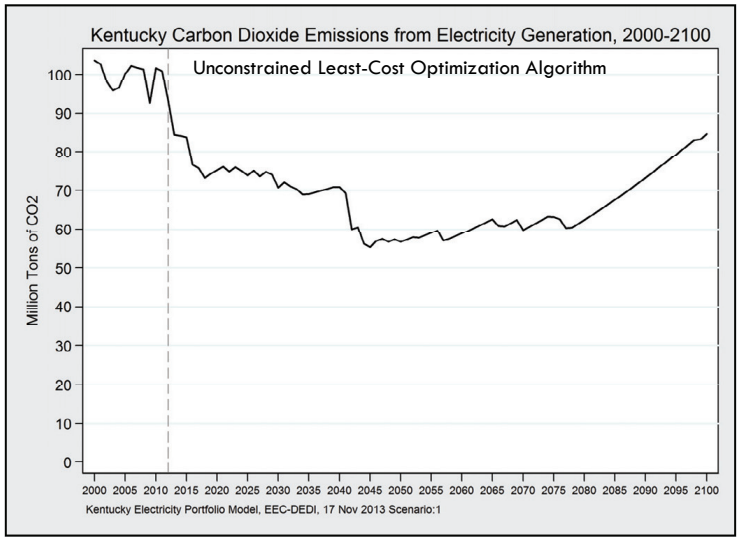
The dispatch model optimization algorithm will then identify the least-cost generating portfolio that complies with the user-specified criteria. In order to prevent a contradiction between constraints, for example an emissions target to reduce greenhouse gas emissions by 80% but with a portfolio standard 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.

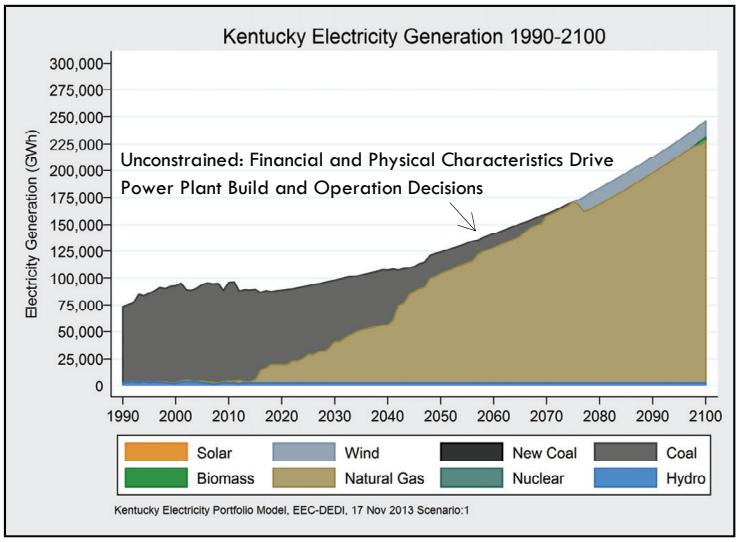
The dispatch model utilizes two separate databases of generating units to determine how best to meet electricity demand. First, the existing unit database contains confidential financial and emissions data of power plants and generating units that are already operating or that will operate in the future. 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.

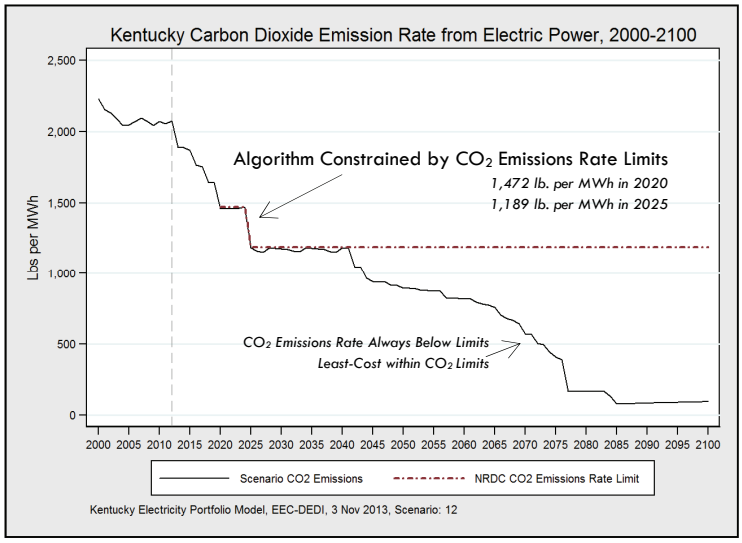
Using an initial electricity demand forecast provided by the demand module, the dispatch model develops a plan for how best to meet electricity demand long-term given the variable parameters of the active scenario. This initial plan includes the timing and type of generation assets that should be built 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.

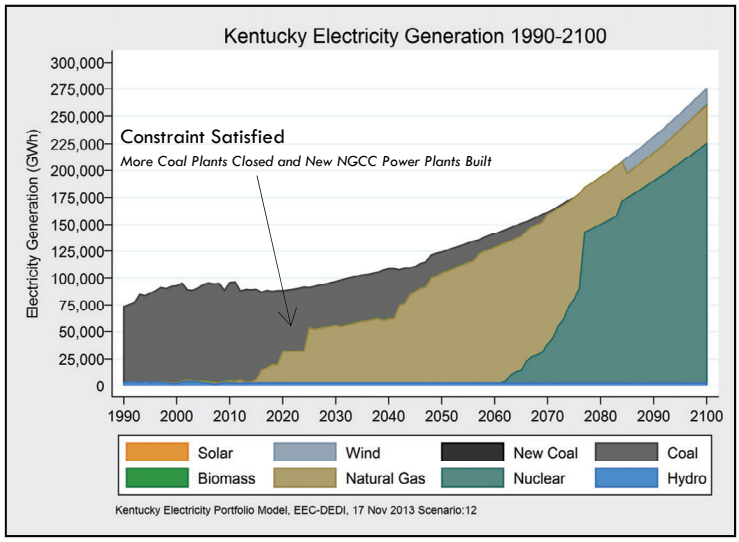
The model then simulates running and dispatching the individual electricity generating units forwards in time. Individual units, if selected by the dispatch optimization algorithm for their cost and emissions profiles, then produce electricity according to their generating potential, which is defined 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.

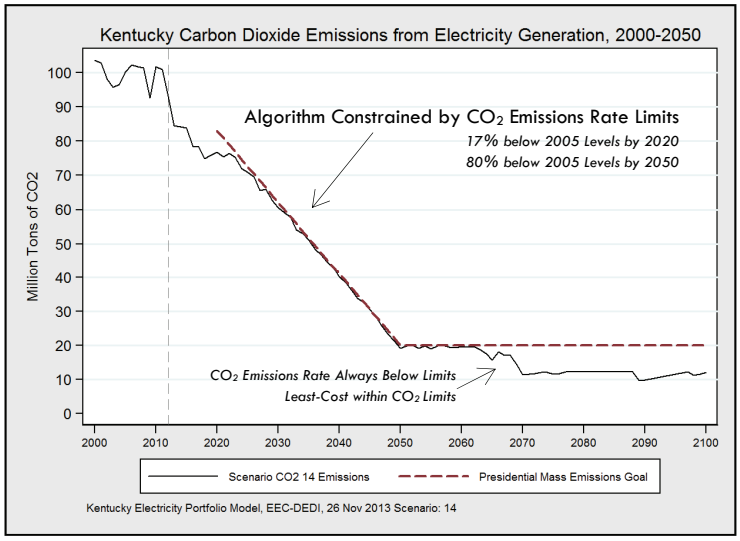
Constrained Optimization Algorithm

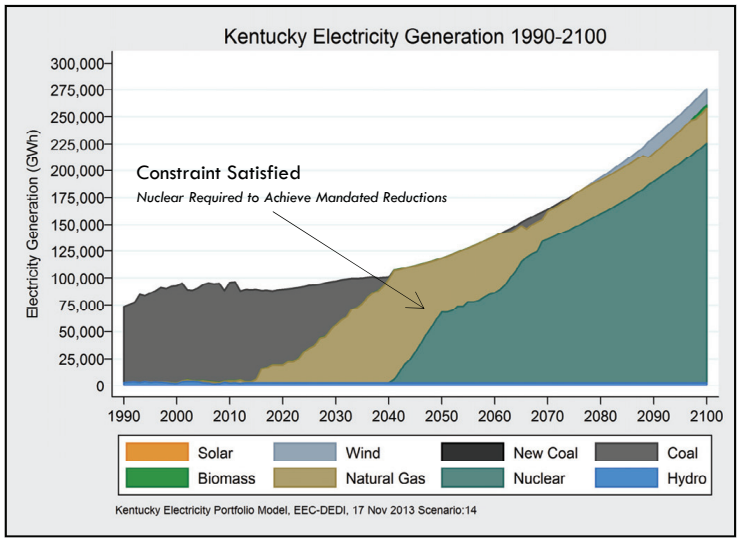












The dispatch algorithm can autonomously choose to retire existing and future electricity generation units for one or more of the four following reasons. First, environmental retirements occur when a unit's individual emissions of a criteria pollutant violate the maximum allowable emissions rates or when 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,

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

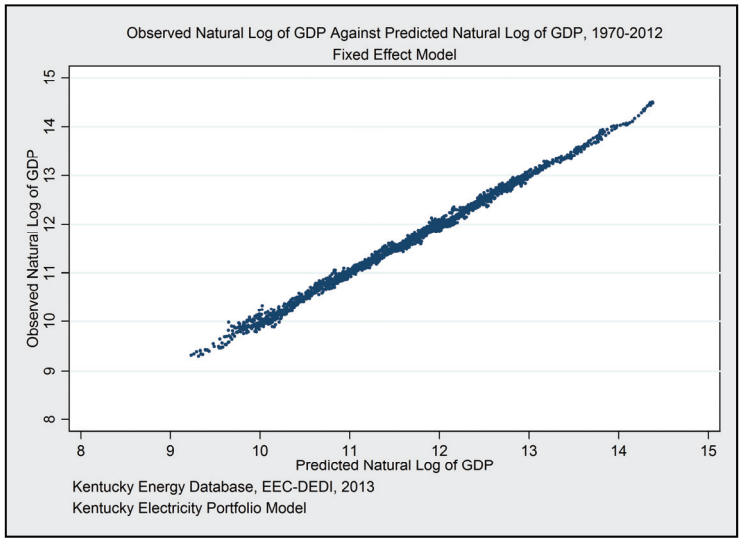
Where i and t index states and years, such that y_{it} is the dependent variable of interest, Gross Domestic Product, in state i in year t, β_0 is the constant y intercept across all states, X is a k x 1 vector of explanatory variables, $\beta_j X_{jit}$ is the product of the observation for each independent 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.

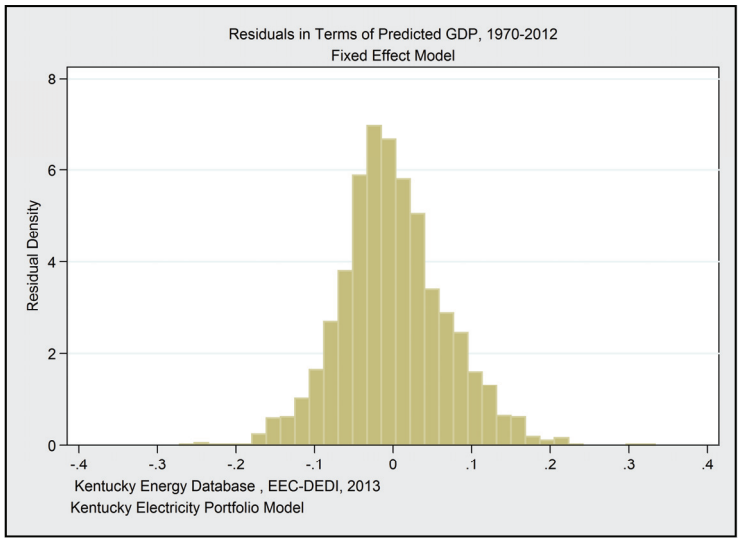
The GDP model is intended to estimate the relationship between electricity prices and economic output and has no way to predict major economic events including recessions or recoveries, since these may be determined by other exogenous factors. While the model is able to explain past variations in economic output, some of its inputs are difficult to extrapolate into the future and therefore decrease the predictive ability of the model forwards in time.

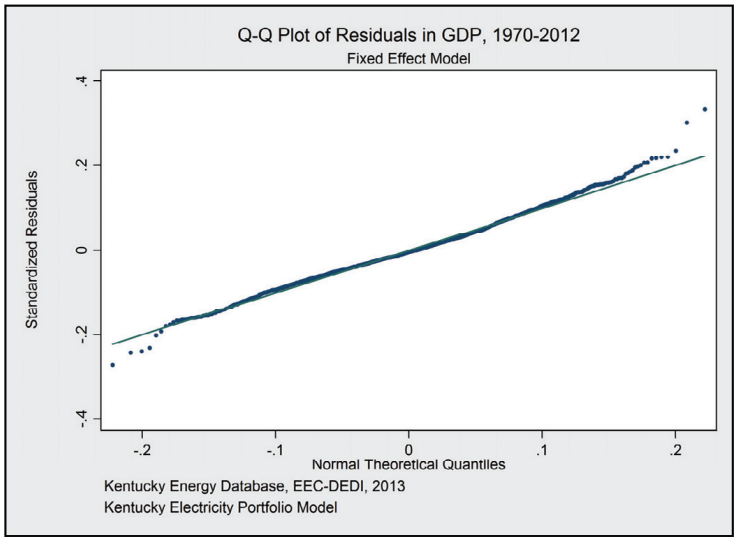
The table below provides the complete multiple regression model coefficients and robust standard errors in parentheses. The natural log of all variables was taken such that the coefficients may be interpreted as elasticities. All coefficients were significant at the 0.001 level both with and without robust standard errors.

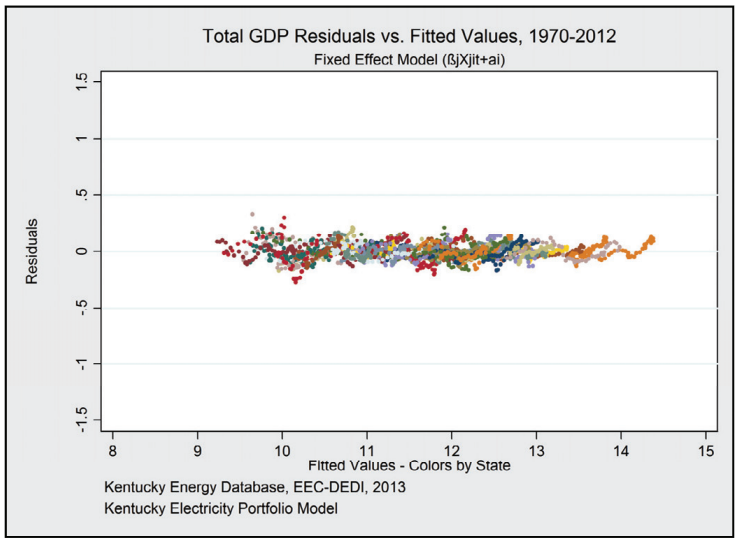
Real Electricity Price	-0.111***		
	(-0.0255)		
Population	1.185***	**R-Squared (Overall)**	0.9801
	(-0.0514)		
Education Index	0.370***	**R-Squared (Within)**	0.9536
	(-0.0604)		
Employment	1.312***	**R-Squared (Between)**	0.9839
	(-0.129)		
Constant	-7.963***	**AIC**	-5237.2
	(-0.659)	***N***	2050

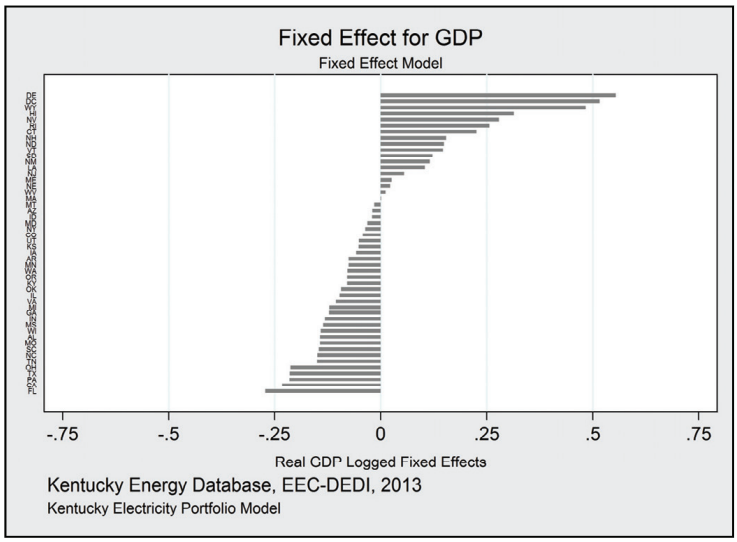
GDP Model Validation

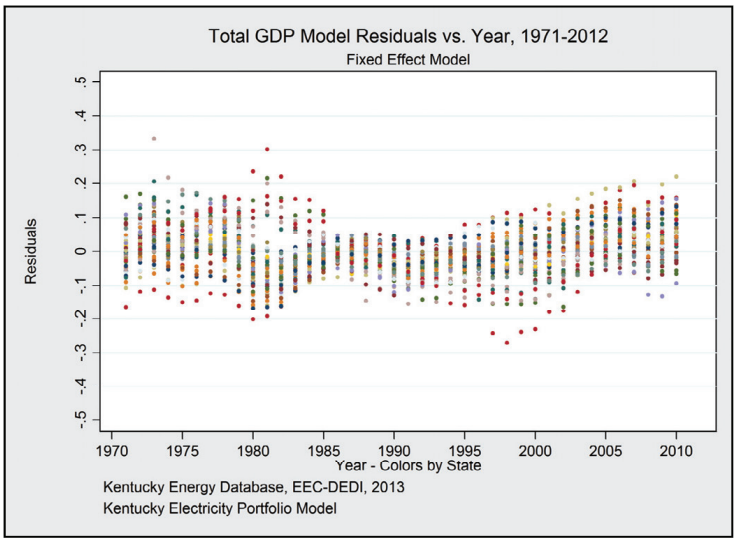












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