Kentucky Energy Data & Modeling

Presentation to the
University of Kentucky
Patterson School of Diplomacy
DIP 735- Energy Security
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Department for Energy Development and Independence
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Facebook: **facebook.com/KentuckyDEDI**
Website: **energy.ky.gov**

Overview

- **Kentucky Renewable Energy Potential:** *Limited*
- **Kentucky Coal Production & Employment:** *Declining*
- **Kentucky's Electricity Portfolio Today:** *Coal*
- **Kentucky's Future Electricity Portfolio:** *Natural Gas*
- **The Significance of Electricity to Kentucky:** *Manufacturing*
- **The Mathematics behind the Models**: $Y_{it} = \beta_0 + \sum_{j=1}^{k-1} \beta_j X_{jit} + \beta_{1i} X_{1it} + \alpha_i + \varepsilon_{it}$ **!**

Kentucky Renewable Energy Potential

Wind Resources

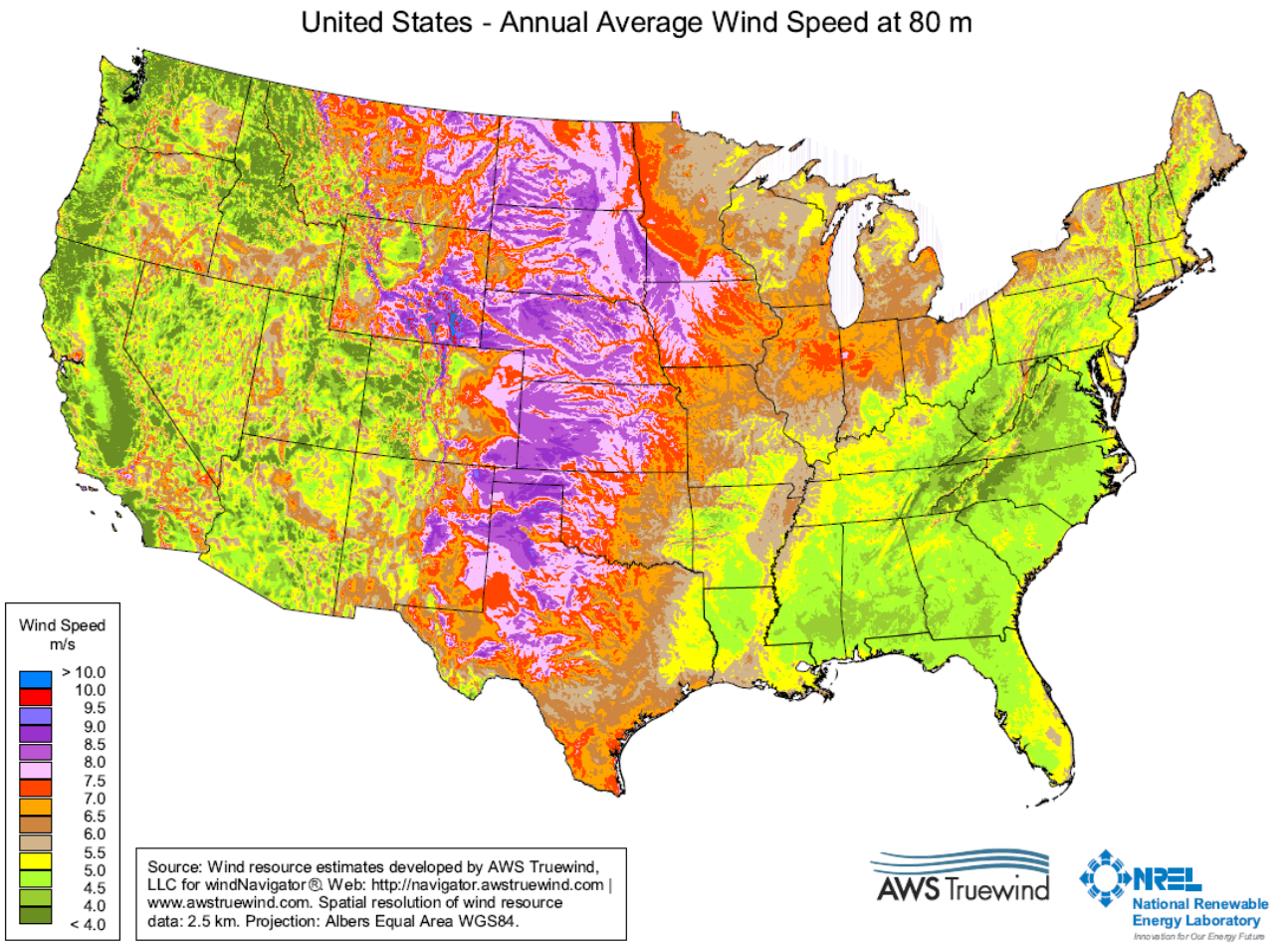
Photo: Kentucky Energy and Environment Cabinet Staff, Buffalo Mountain Wind Farm, Tennessee, 2010.

Wind Resources

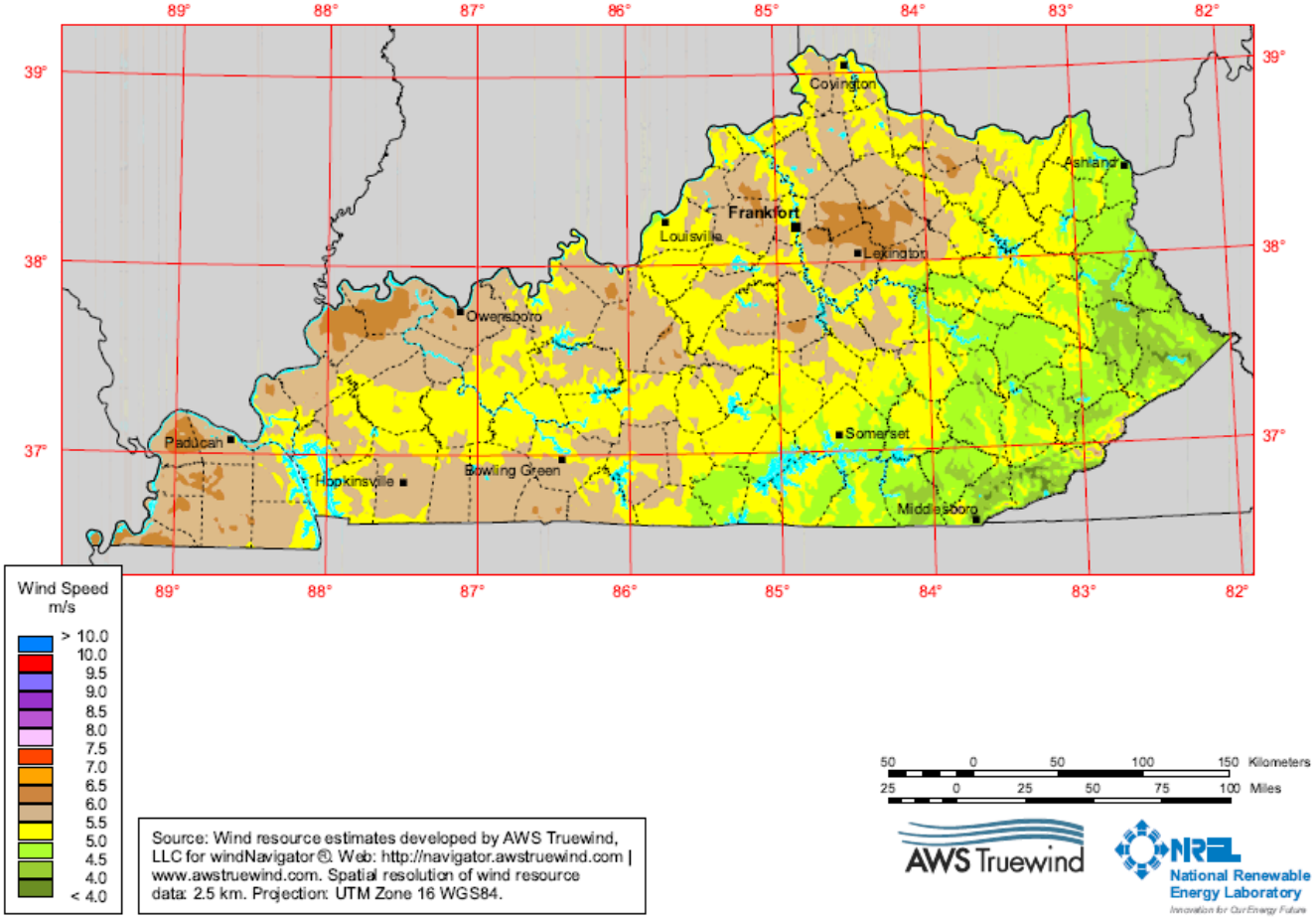
EEC Staff Video of Buffalo Mountain Wind farm in Tennessee

Photo: Kentucky Energy and Environment Cabinet Staff, Buffalo Mountain Wind Farm, Tennessee, 2010.

Wind Resources



Wind Resources

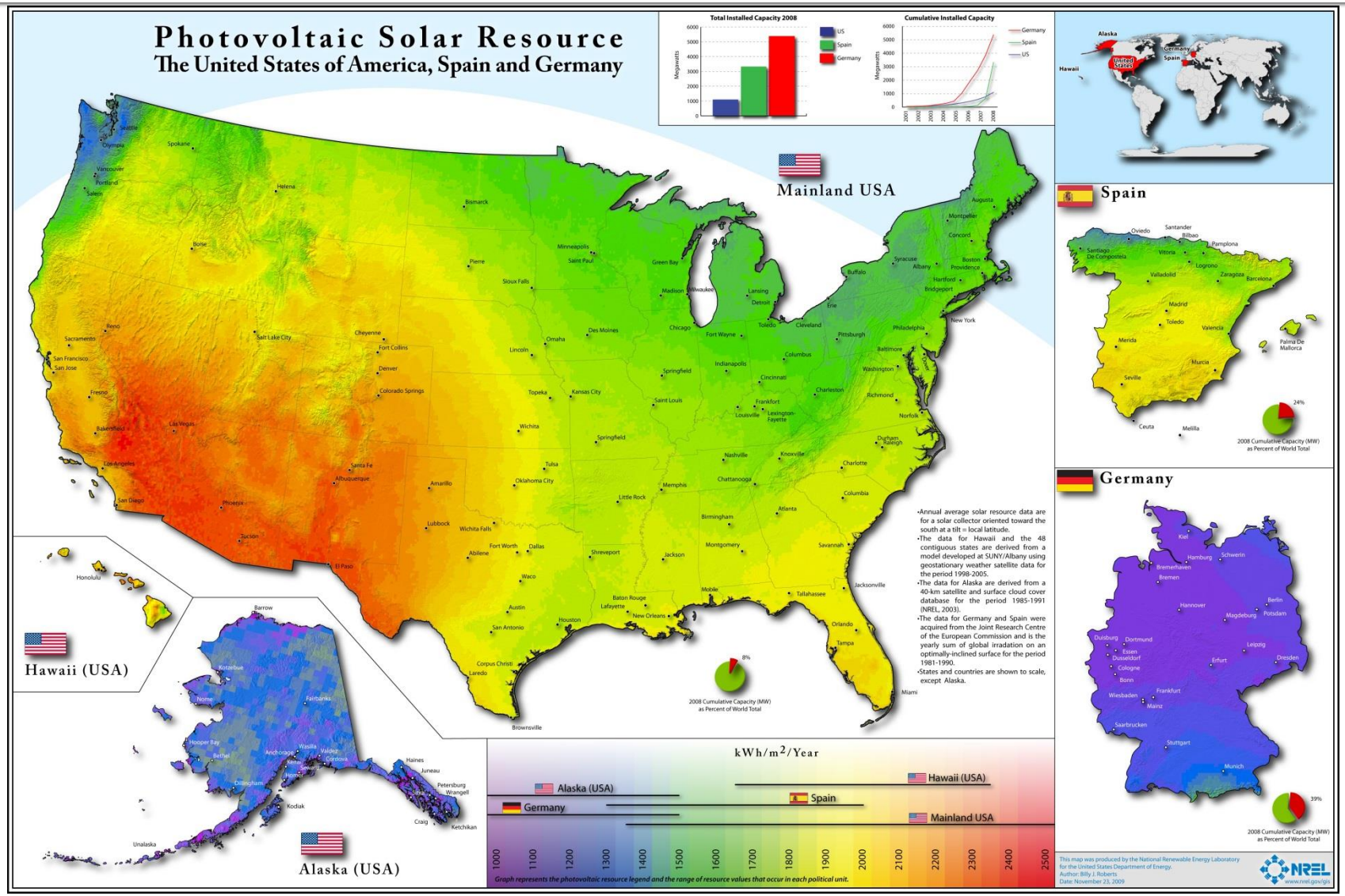


EEC Staff Video of Buffalo Mountain Wind farm in Tennessee

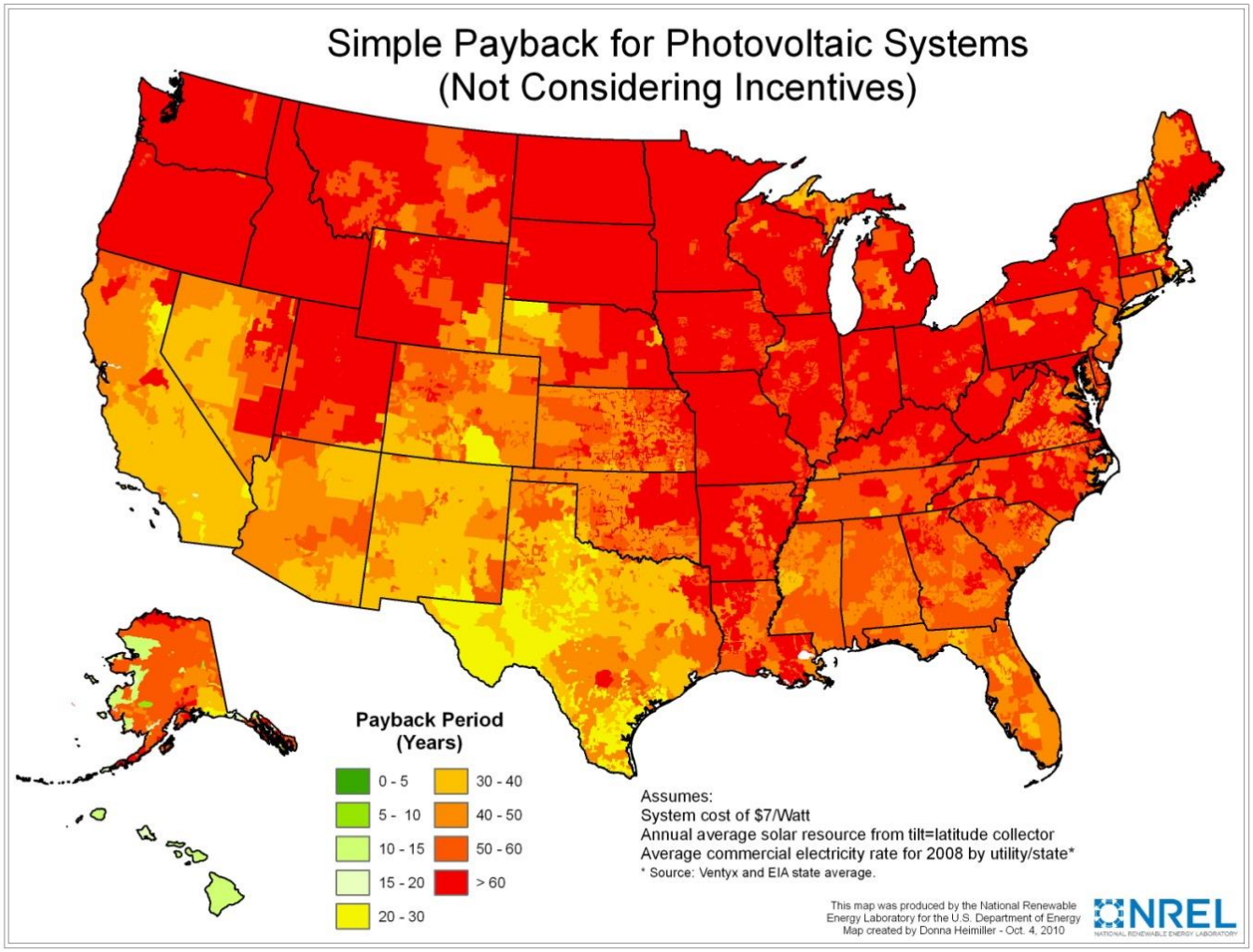
Solar Resources

Photo: University of Kentucky S·KY Blue Solar House at the Solar Decathlon in Washington D.C., 2009

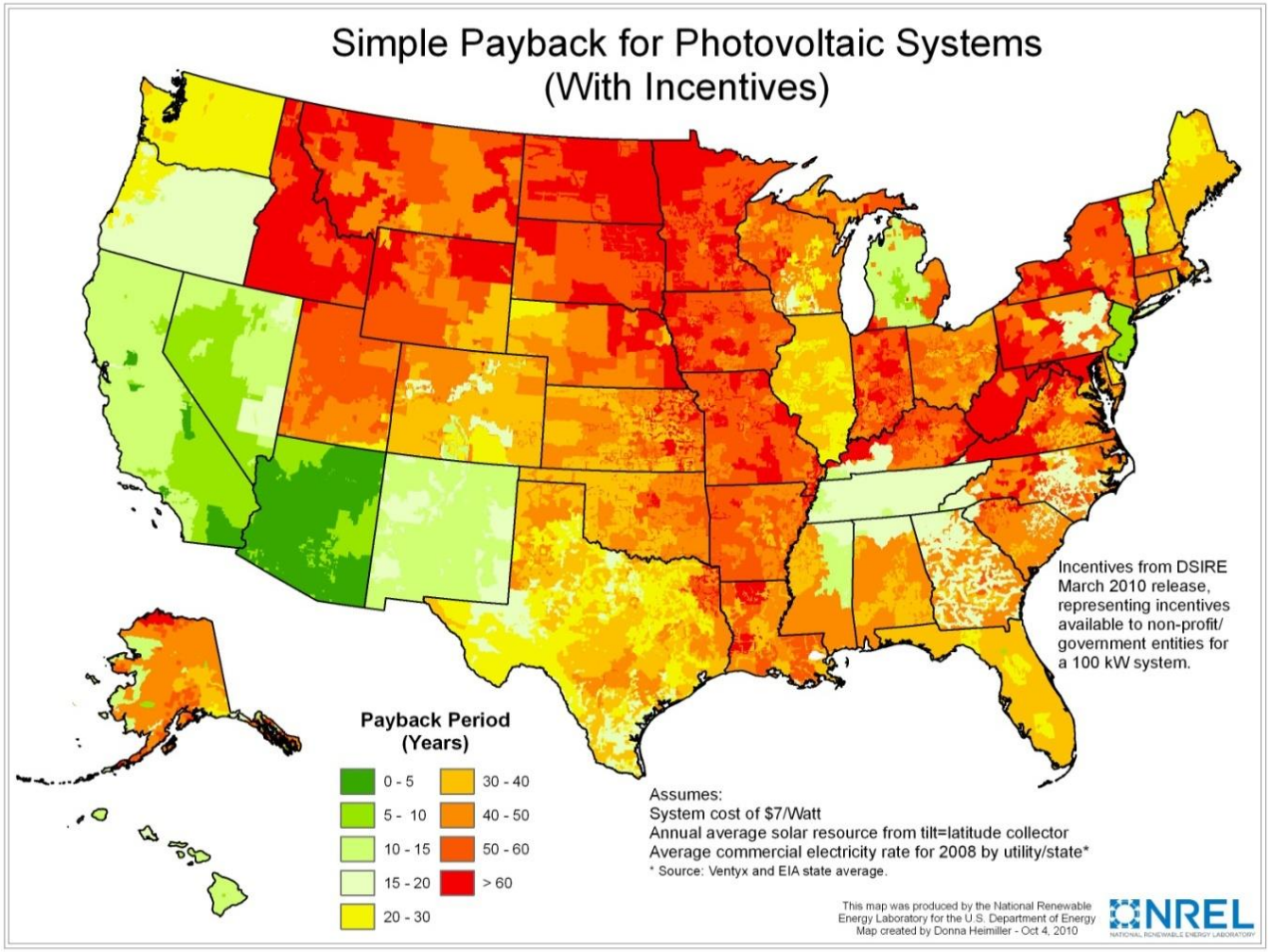
Solar Resources



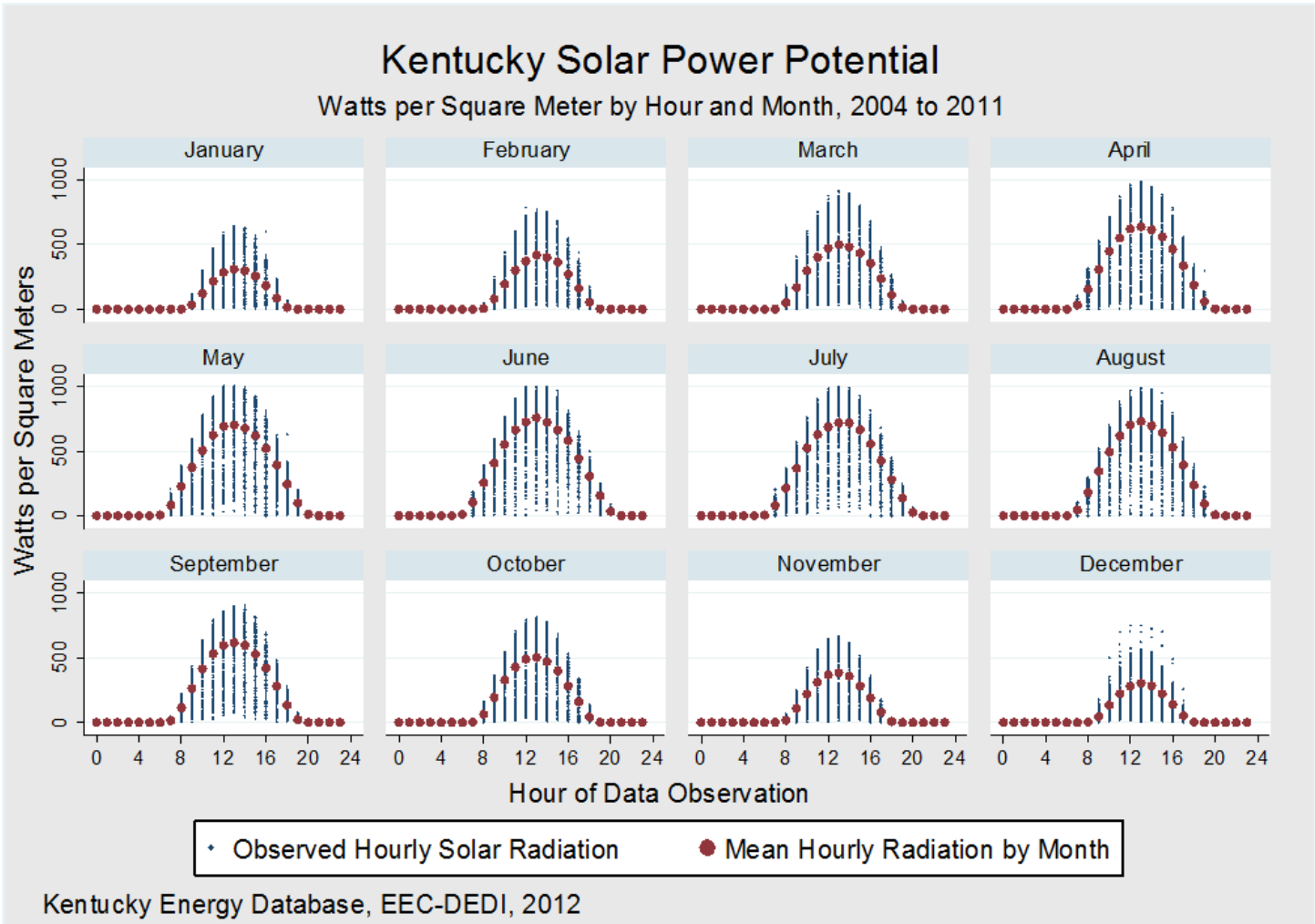
Solar Resources



Solar Resources



Solar Resources



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Solar Resources

Kentucky Average Maximum Achievable Solar Capacity Factors, 2004-2011													
Hour	Annual		January	February	March	April	May	June	July	August	September	October	November	December
24/7	14.85%		6.60%	9.60%	12.87%	18.20%	21.10%	23.34%	22.09%	20.91%	16.56%	12.27%	8.47%	6.14%
5:00	0.000%		0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
6:00	0.196%		0.000%	0.000%	0.000%	0.012%	0.673%	1.192%	0.525%	0.024%	0.000%	0.000%	0.000%	0.000%
7:00	2.997%		0.000%	0.000%	0.115%	3.261%	8.242%	10.378%	7.927%	4.402%	1.355%	0.259%	0.000%	0.000%
8:00	10.651%		0.210%	0.656%	4.967%	15.233%	22.615%	25.471%	21.379%	17.934%	11.319%	6.276%	1.541%	0.080%
9:00	22.358%		3.412%	7.930%	16.790%	30.558%	37.324%	40.458%	36.529%	34.413%	26.143%	19.309%	10.667%	4.435%
10:00	35.151%		12.071%	19.269%	29.657%	44.536%	50.266%	54.952%	52.302%	49.250%	41.347%	32.614%	21.920%	13.331%
11:00	45.633%		21.521%	30.015%	40.180%	54.893%	62.083%	66.078%	62.548%	61.545%	52.872%	42.529%	30.914%	22.198%
12:00	52.219%		28.232%	37.108%	46.994%	62.072%	68.977%	72.146%	68.565%	69.879%	59.308%	48.674%	36.653%	27.839%
13:00	54.647%		30.928%	41.754%	49.742%	63.652%	69.912%	75.576%	71.583%	72.809%	61.501%	50.065%	38.182%	29.999%
14:00	52.430%		29.661%	40.038%	48.129%	61.288%	67.462%	71.968%	71.549%	69.383%	59.444%	46.759%	35.593%	28.040%
15:00	46.760%		25.494%	36.249%	43.110%	55.708%	61.769%	66.218%	66.383%	63.844%	52.556%	39.604%	28.153%	21.972%
16:00	37.260%		18.213%	26.923%	36.366%	46.214%	51.793%	57.906%	55.296%	52.742%	41.795%	28.159%	18.733%	13.908%
17:00	25.275%		8.653%	16.055%	23.433%	33.288%	39.210%	44.043%	42.394%	39.128%	28.148%	15.850%	7.701%	5.212%
18:00	13.378%		1.339%	5.230%	10.832%	18.635%	24.233%	33.032%	27.881%	23.669%	13.263%	4.091%	0.588%	0.209%
19:00	4.833%		0.000%	0.150%	1.492%	5.810%	9.846%	15.339%	13.753%	9.173%	2.097%	0.055%	0.000%	0.000%
20:00	0.669%		0.000%	0.000%	0.000%	0.095%	1.144%	3.249%	2.722%	0.765%	0.002%	0.000%	0.000%	0.000%
21:00	0.001%		0.000%	0.000%	0.000%	0.000%	0.000%	0.005%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%
22:00	0.000%		0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

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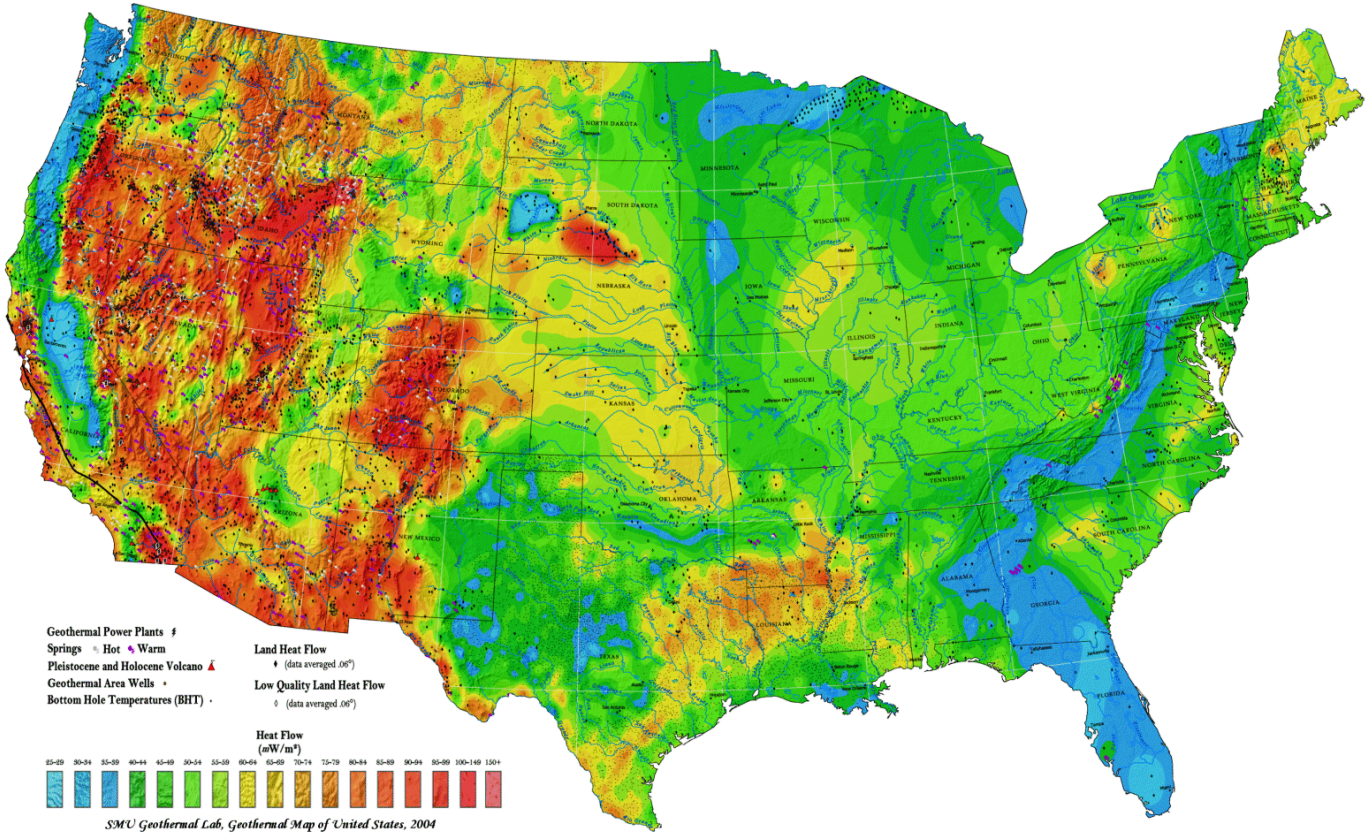
Geothermal Resources

Photo: Nesjavellir Geothermal Power Station in Iceland. Wikimedia Commons.

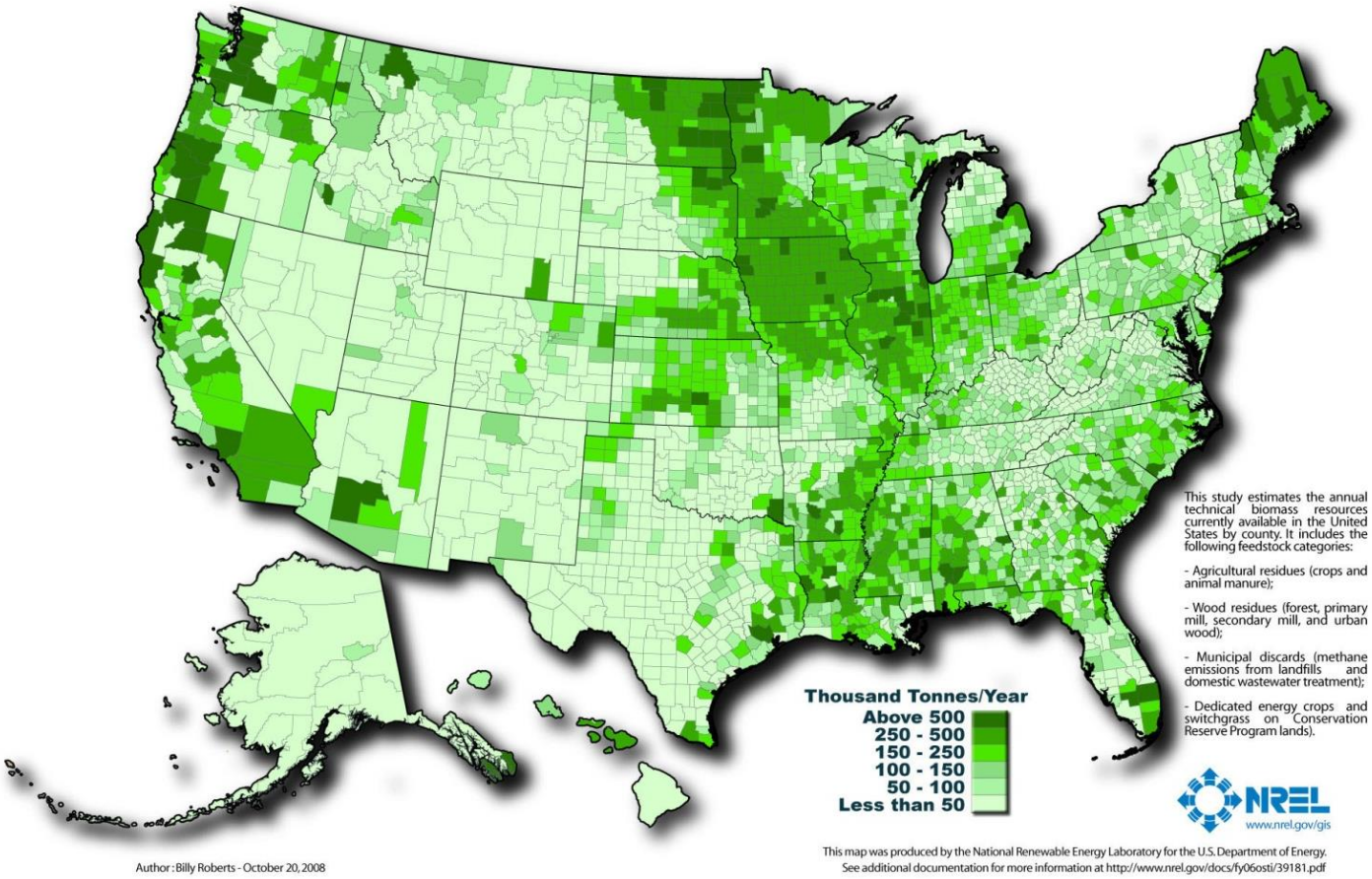
Geothermal Resources



Biomass Resources

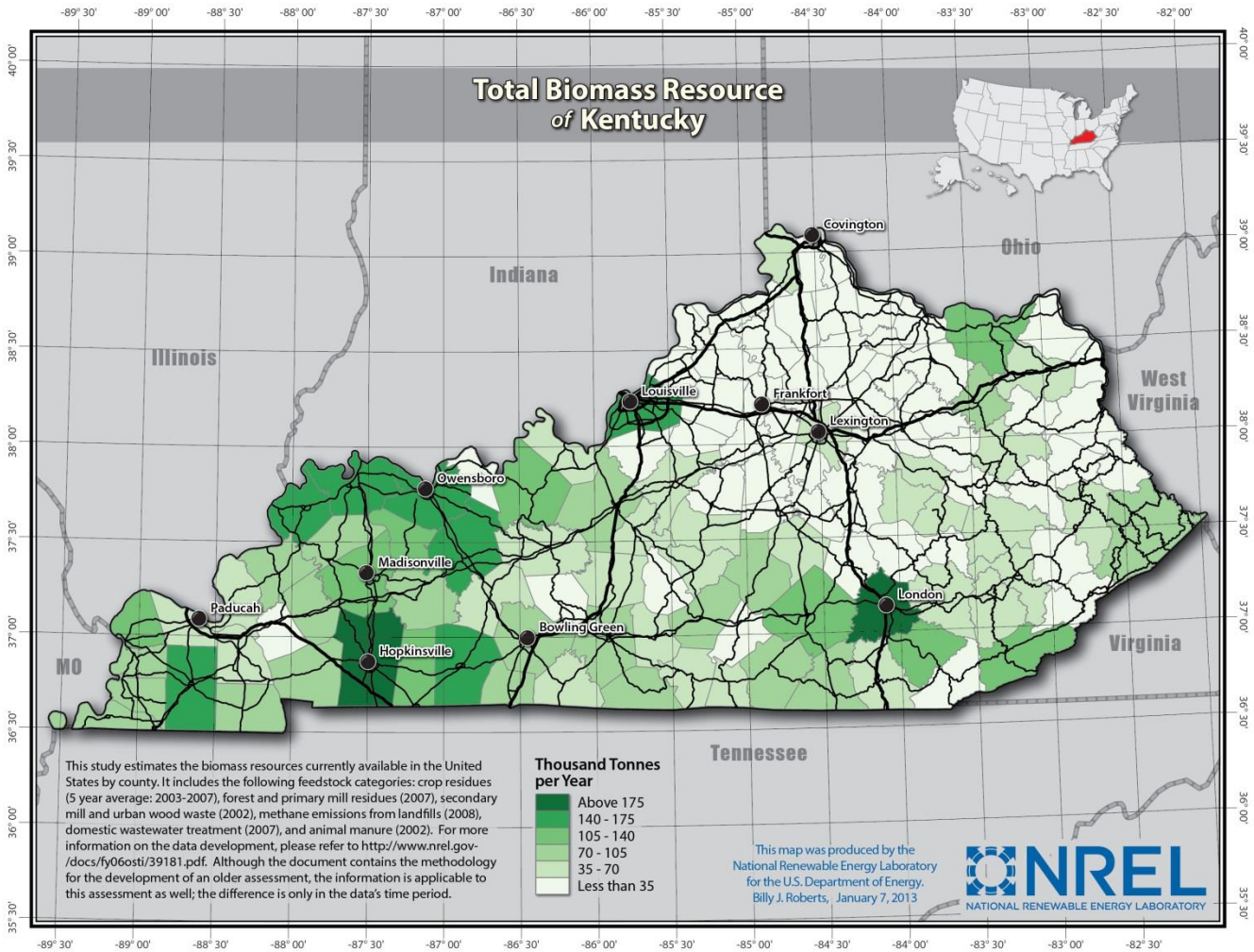
Photo: Kentucky Energy and Environment Cabinet Staff, Recast Energy, Louisville, Kentucky, 2012.

Biomass Resources



Full Report: http://www.nrel.gov/docs/fy06osti/39181.pdf

Biomass Resources



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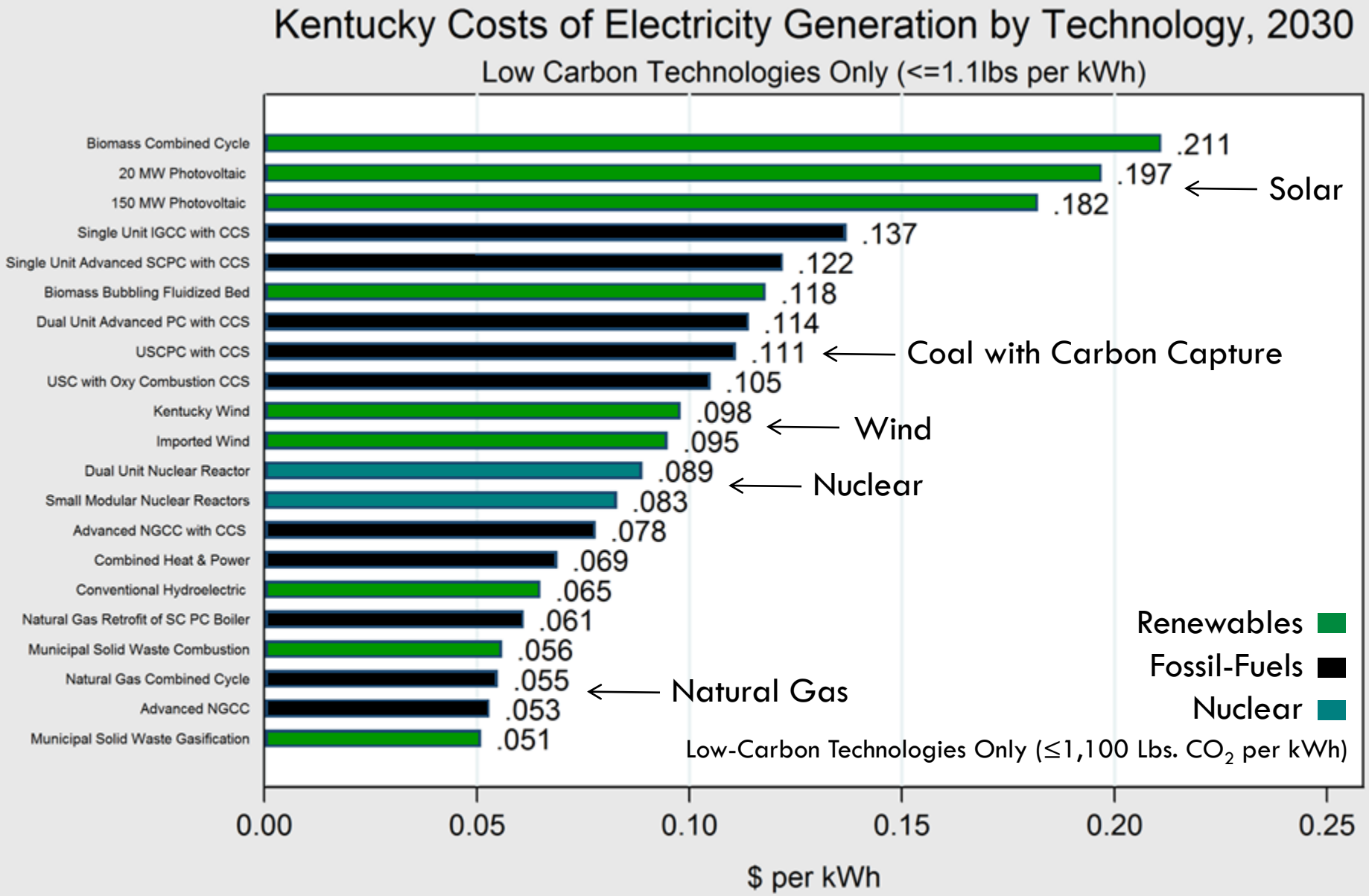
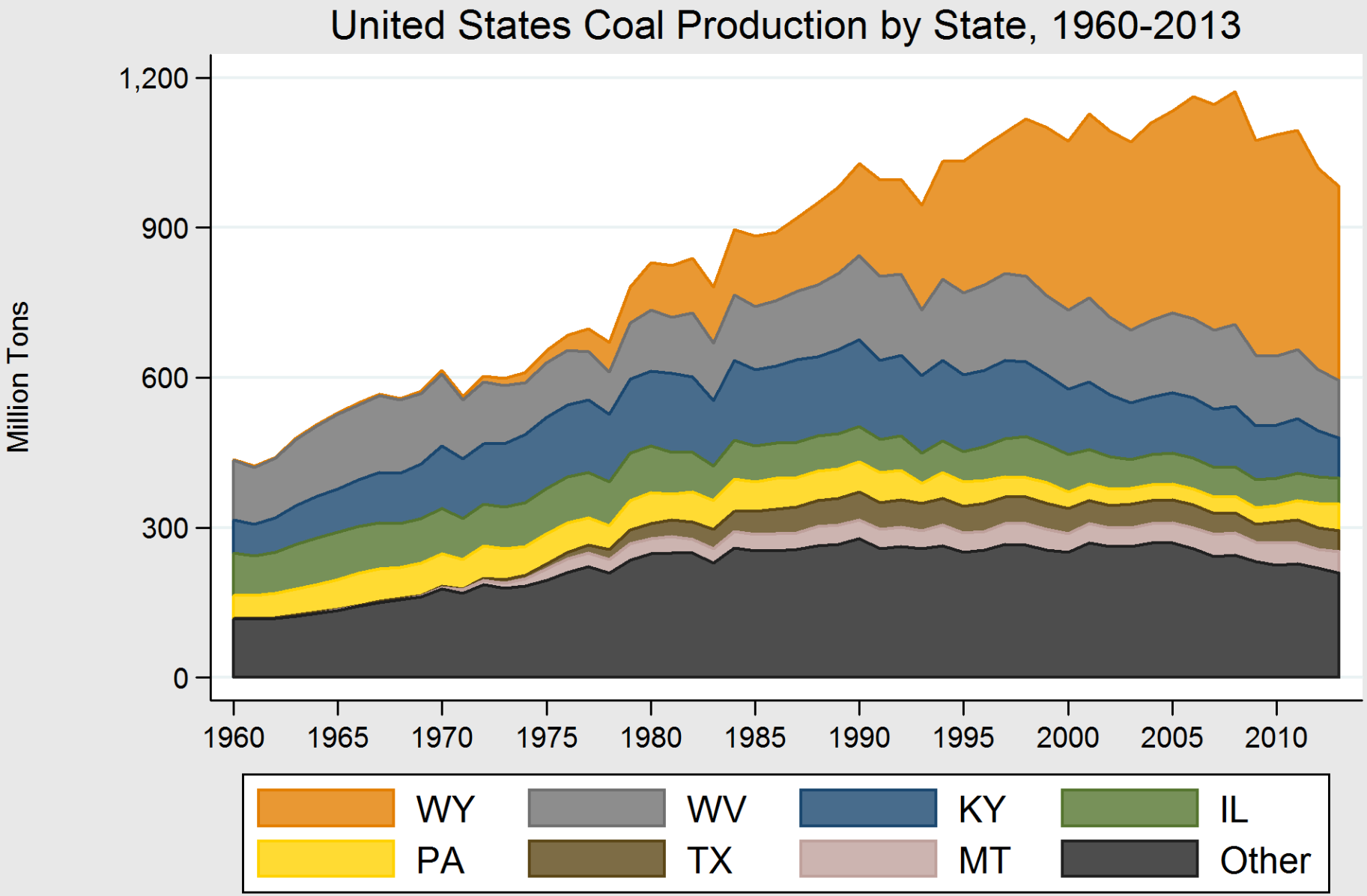


Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

Detailed Cost Data Available on Pages C.89 and C.90 of Complete Report

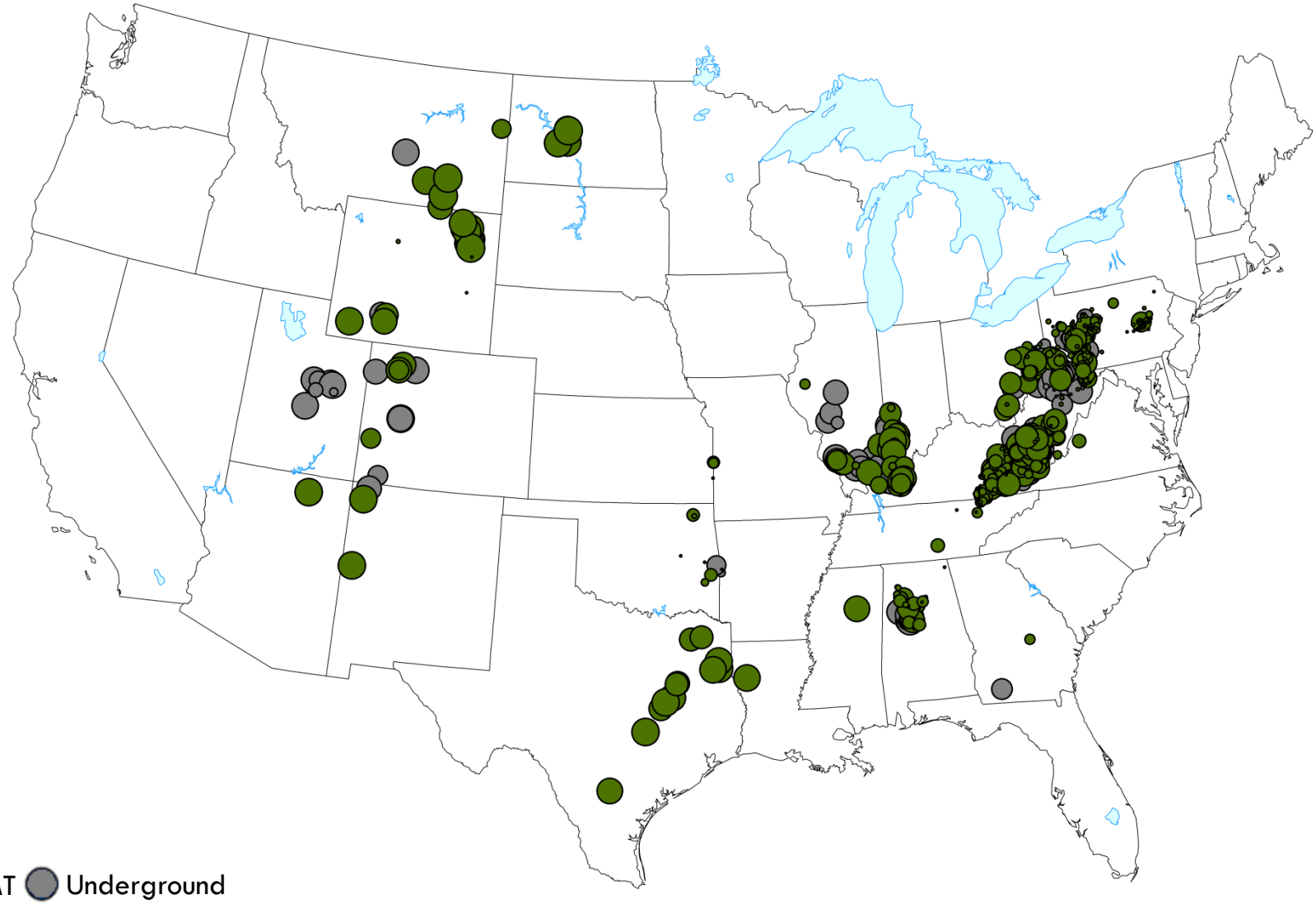
Kentucky Coal Production & Employment



Kentucky Energy Database, EEC-DEDI, 2014

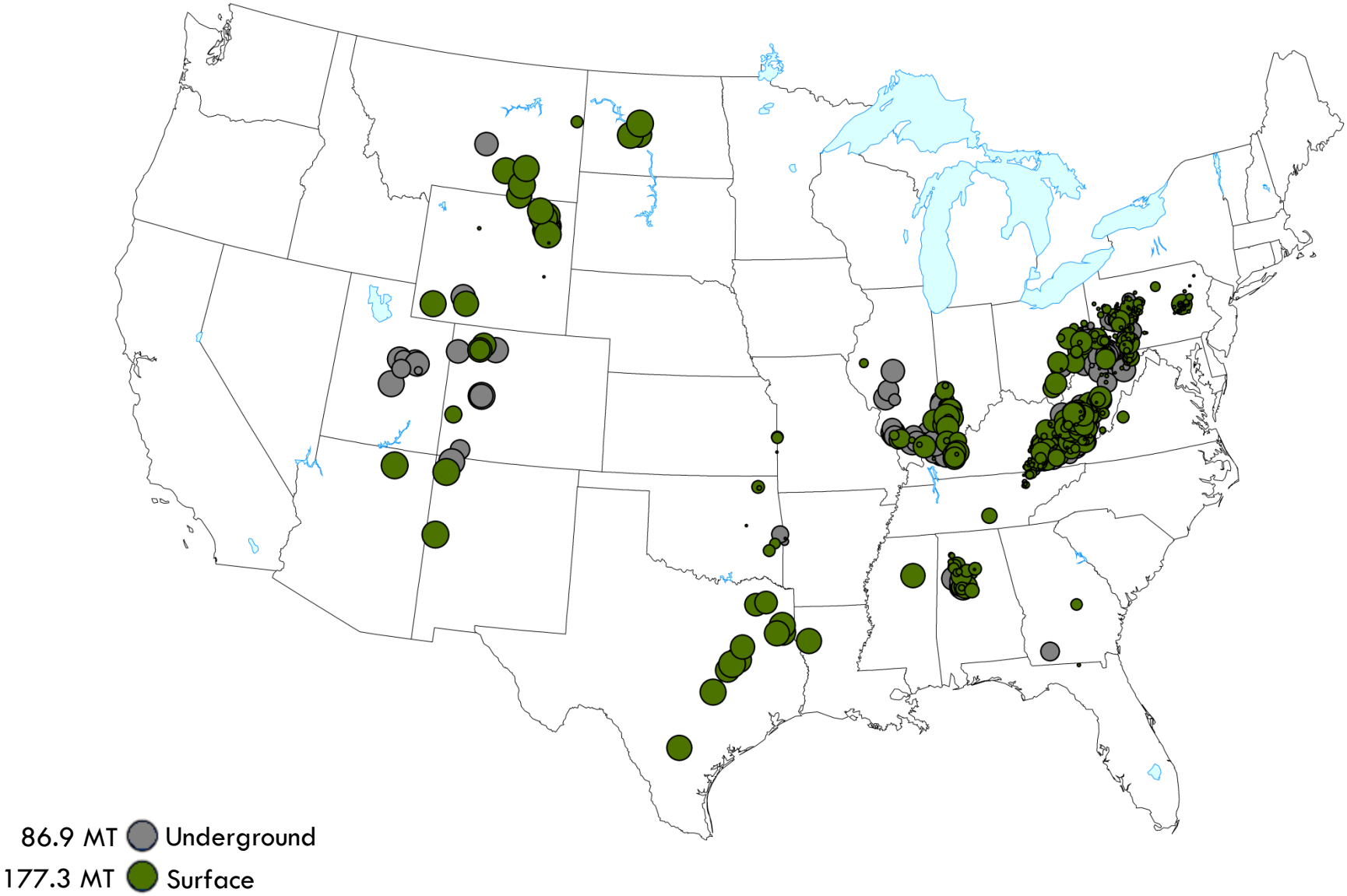
Data Source: United States Mine Safety and Health Administration (MSHA) & EIA State Energy Data System

United States Coal Production, Q1-2011

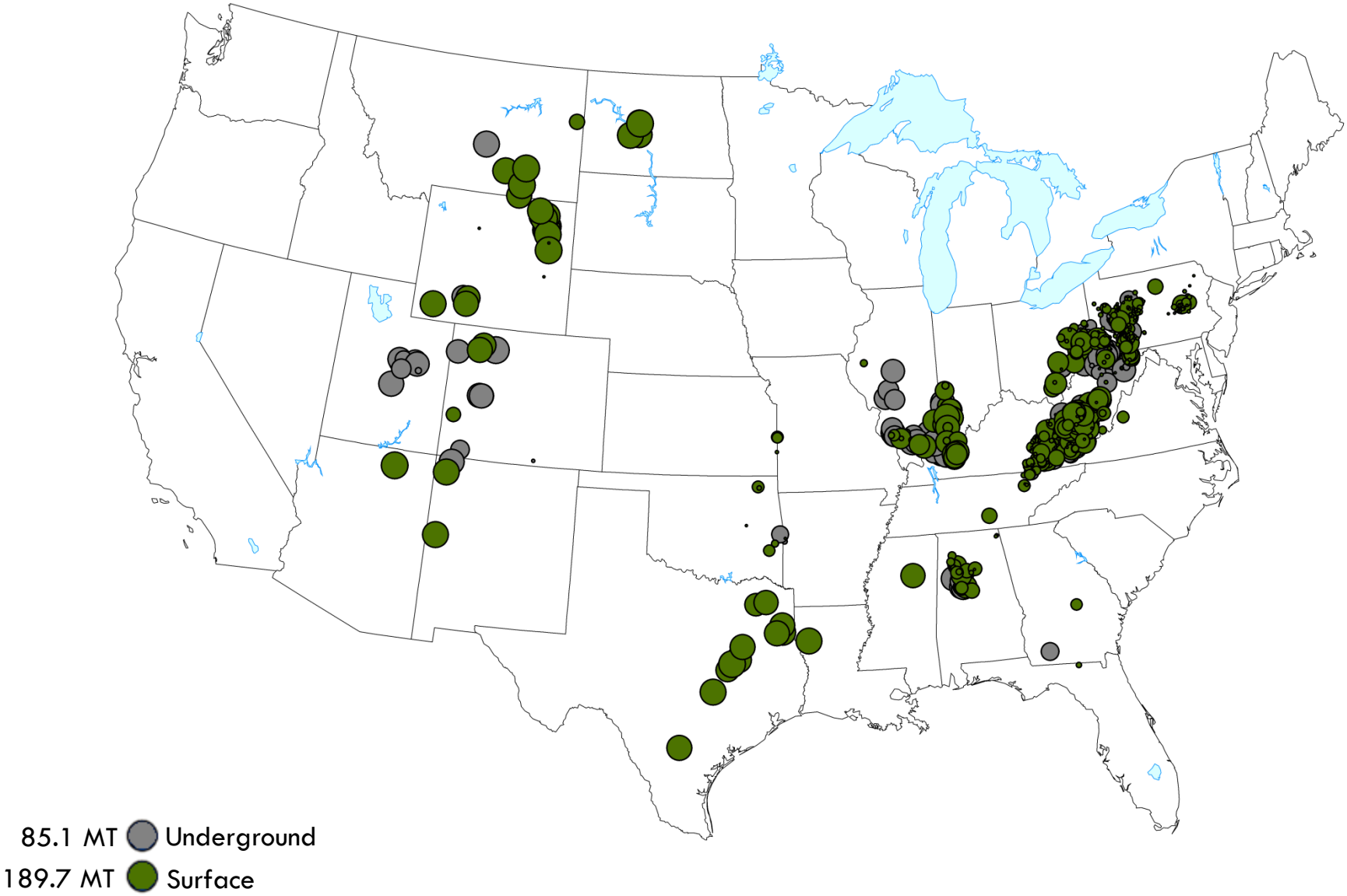


87.2 MT Underground
186.2 MT Surface

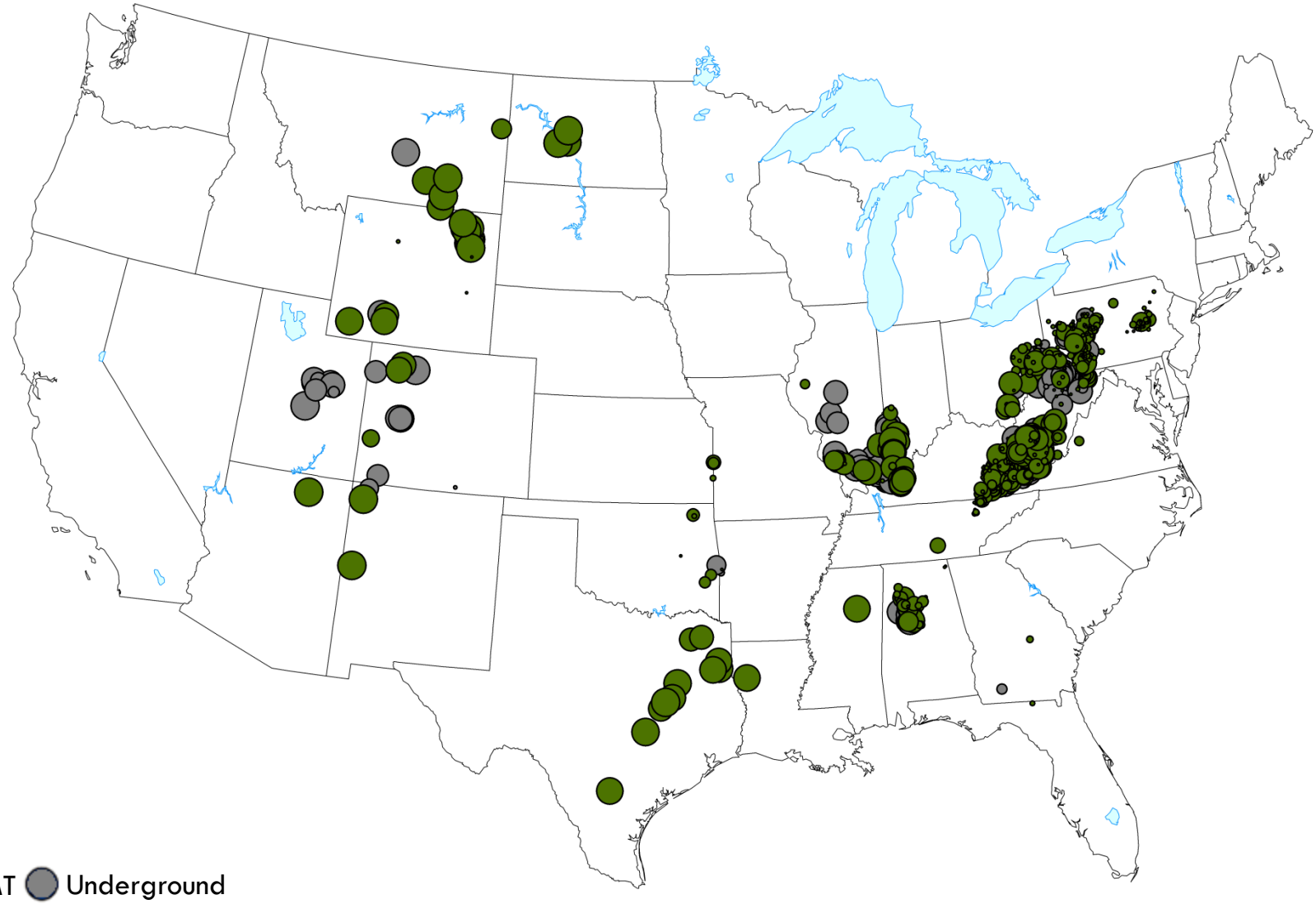
United States Coal Production, Q2-2011



United States Coal Production, Q3-2011

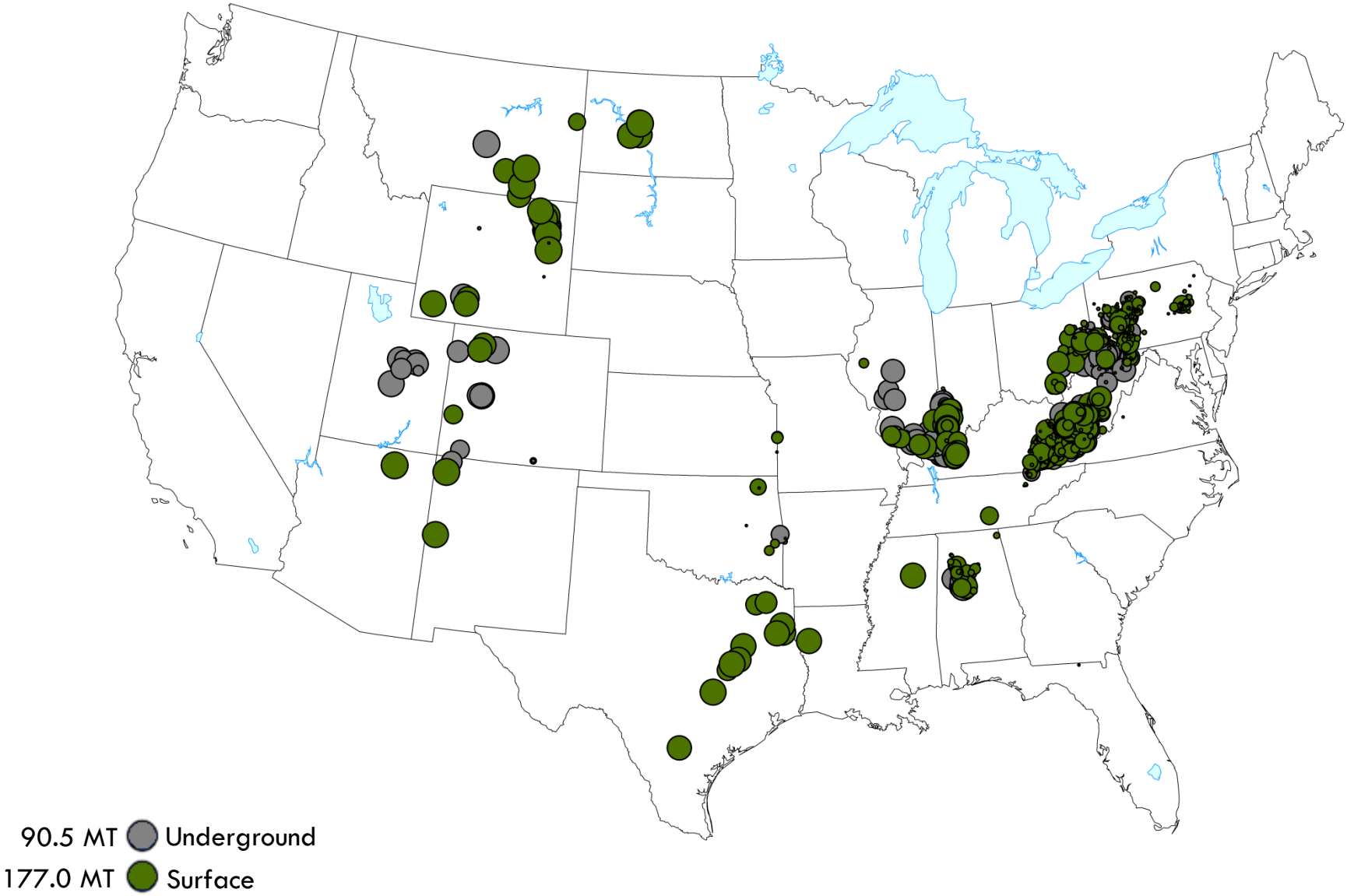


United States Coal Production, Q4-2011

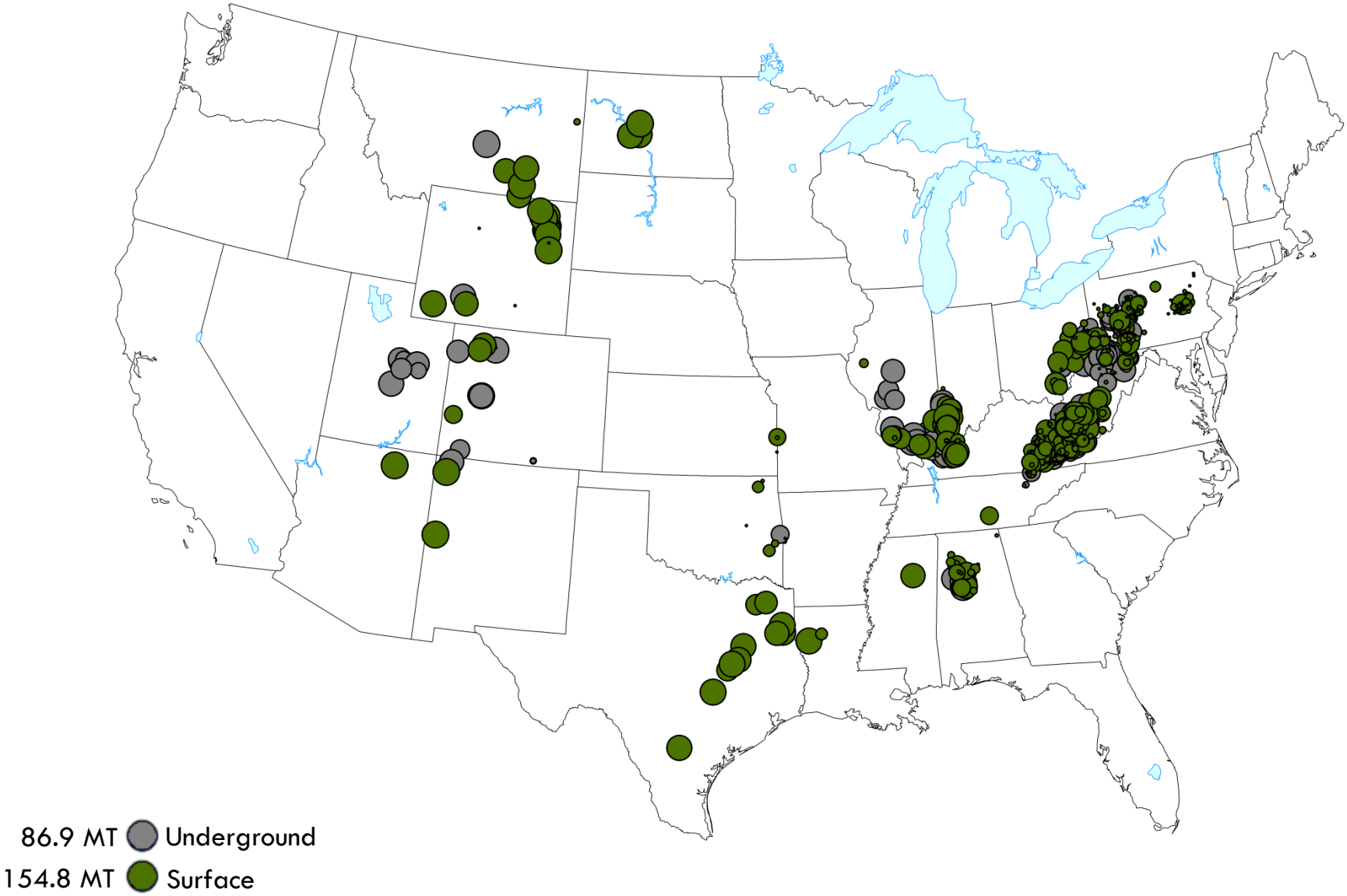


86.2 MT Underground
196.3 MT Surface

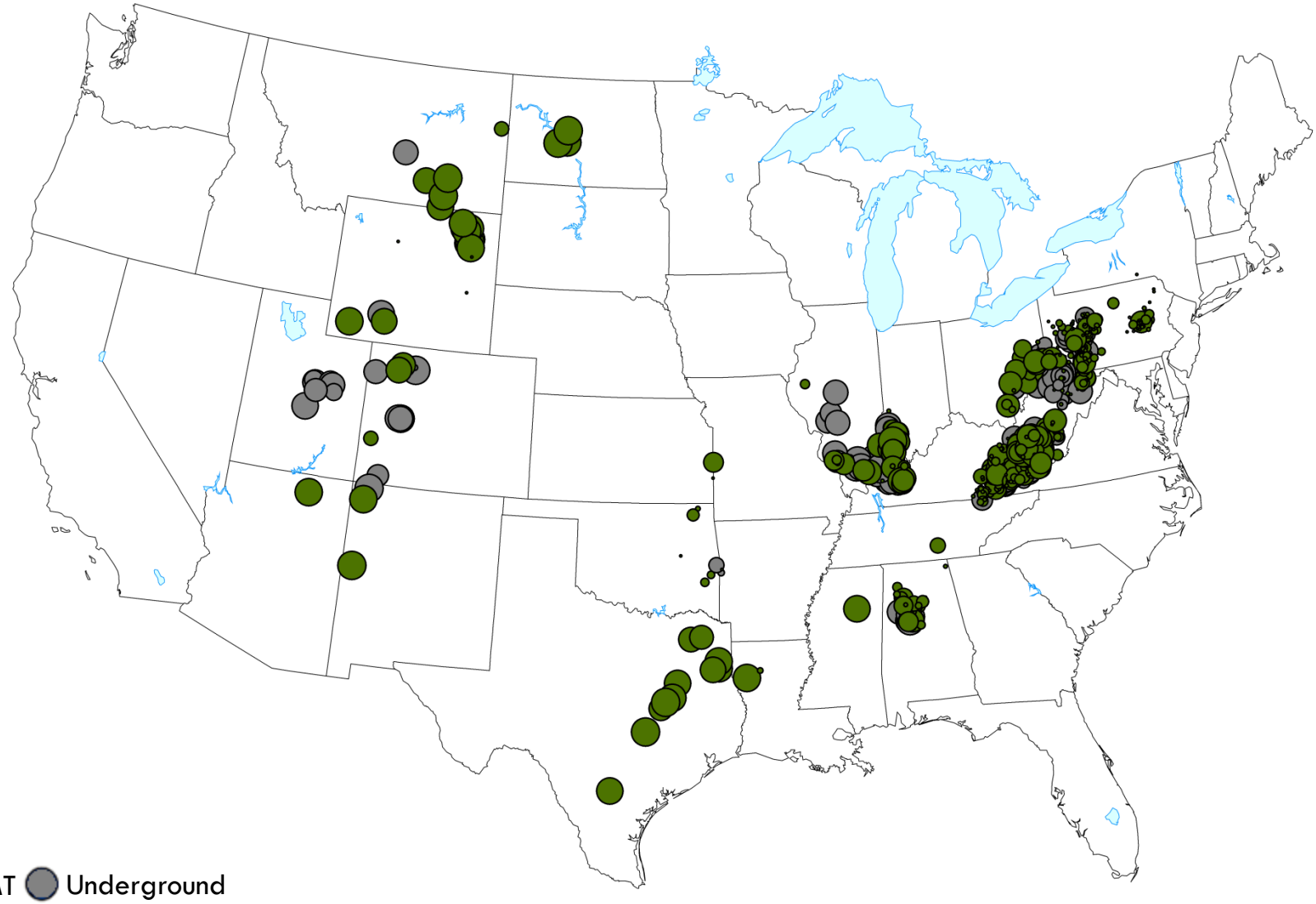
United States Coal Production, Q1-2012



United States Coal Production, Q2-2012

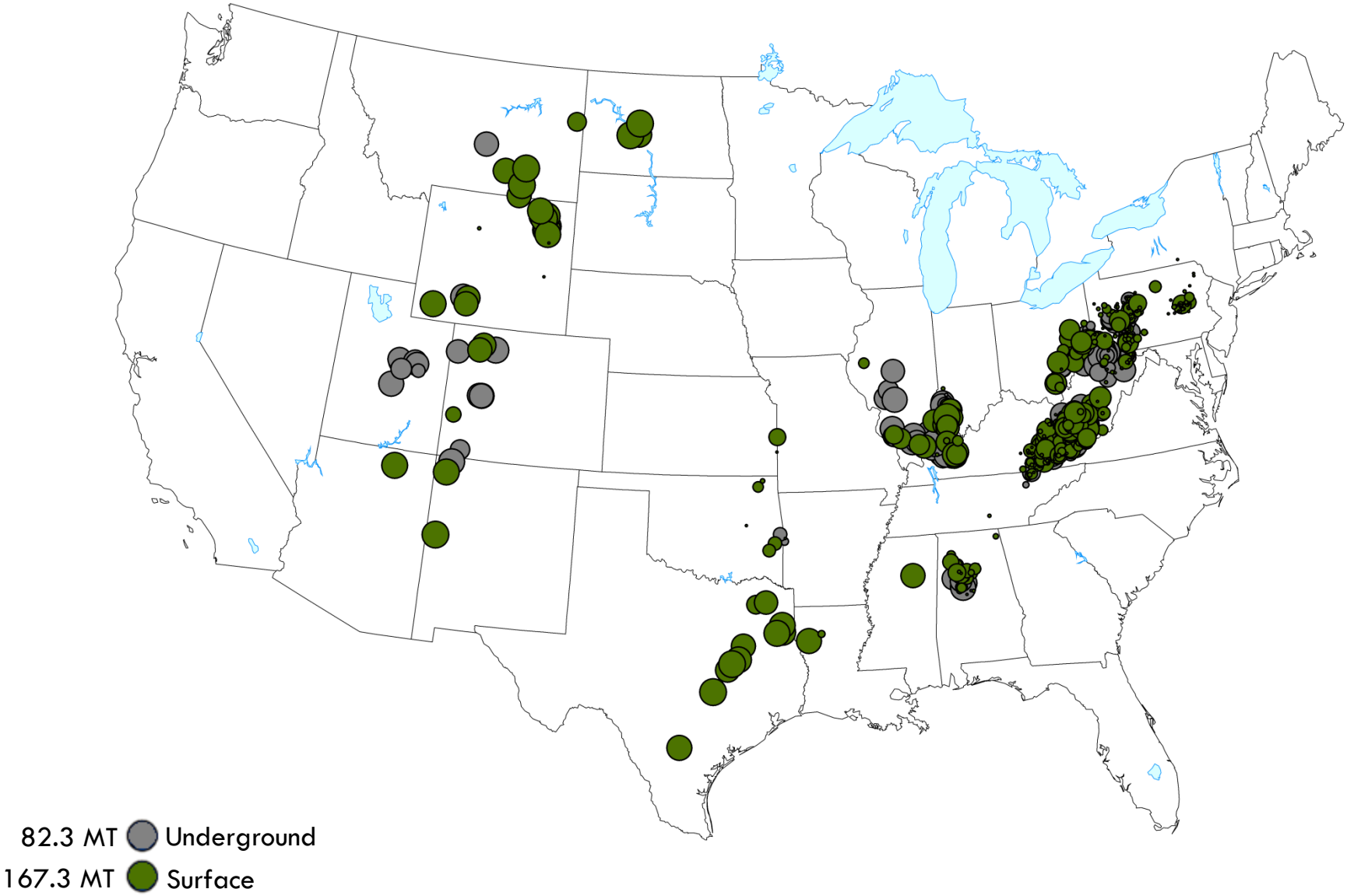


United States Coal Production, Q3-2012

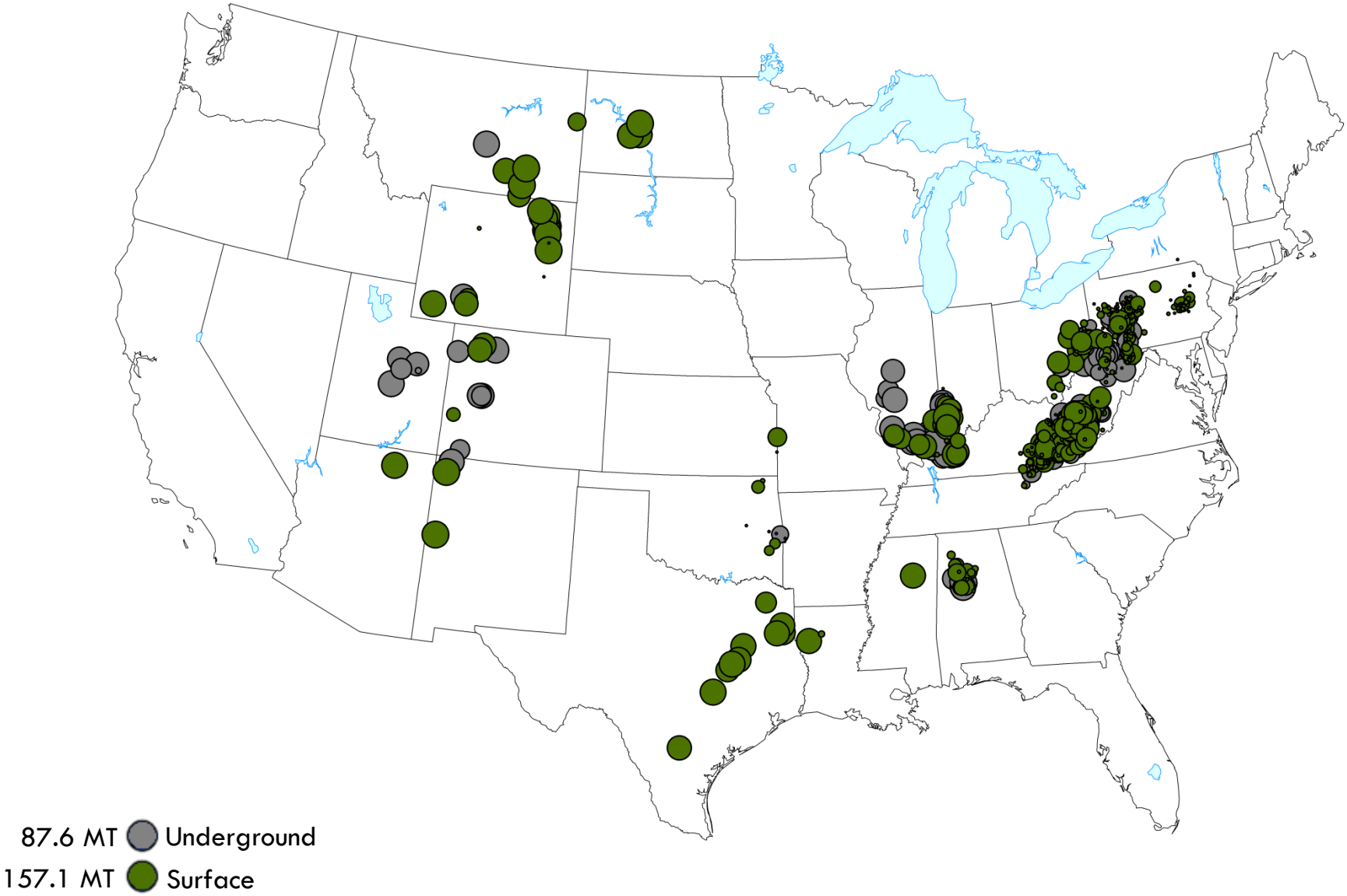


83.7 MT Underground
175.5 MT Surface

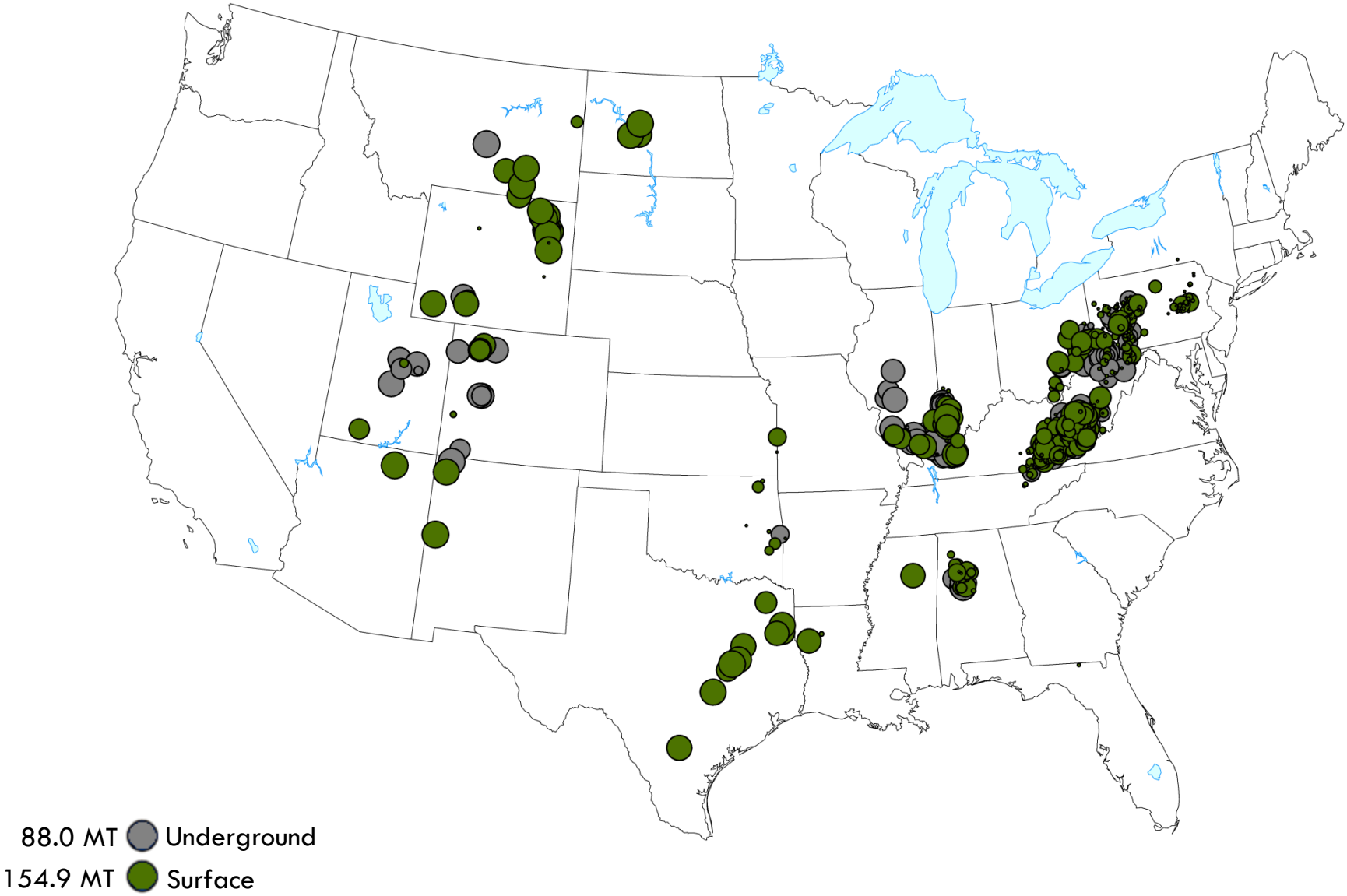
United States Coal Production, Q4-2012



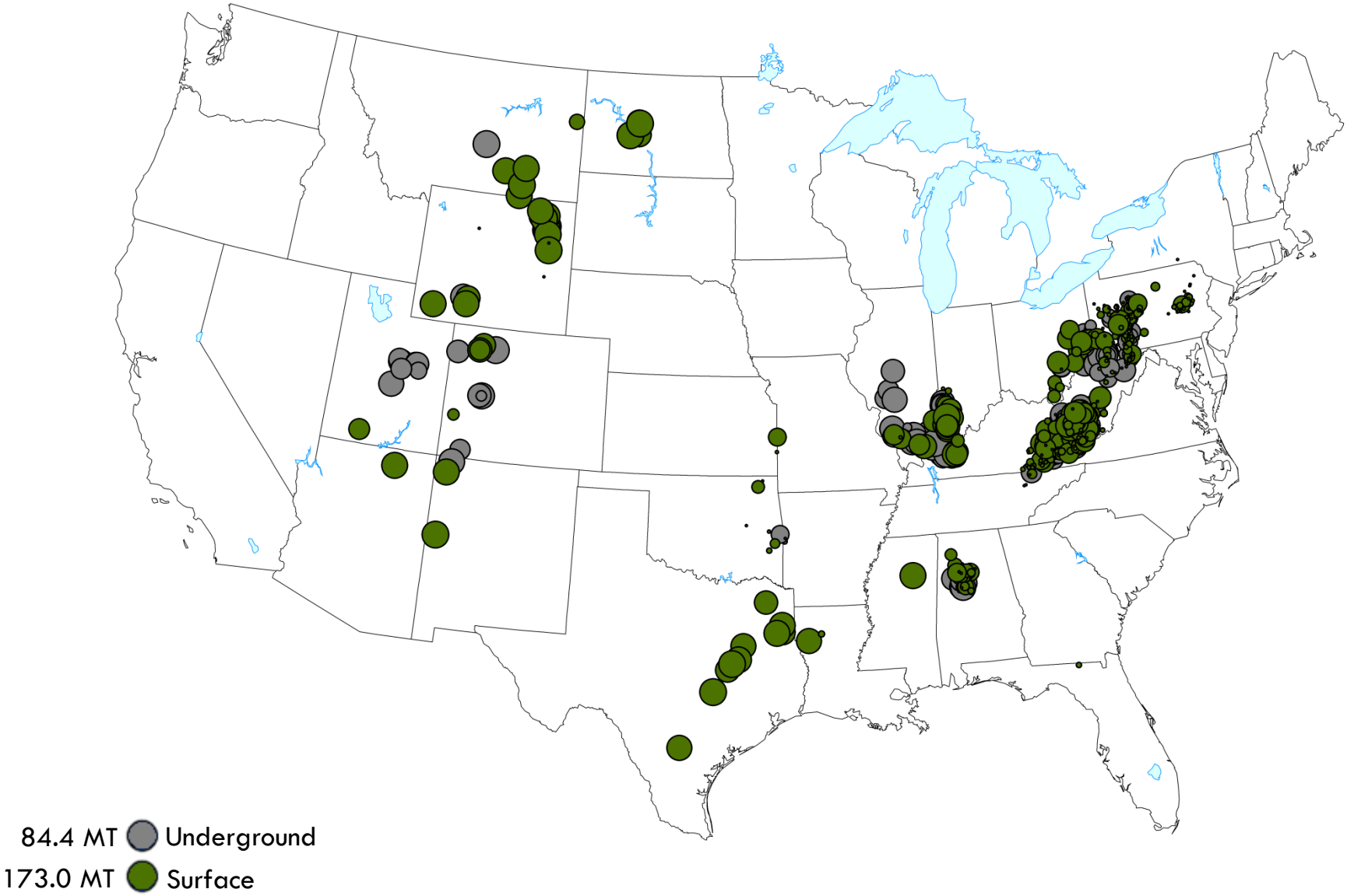
United States Coal Production, Q1-2013



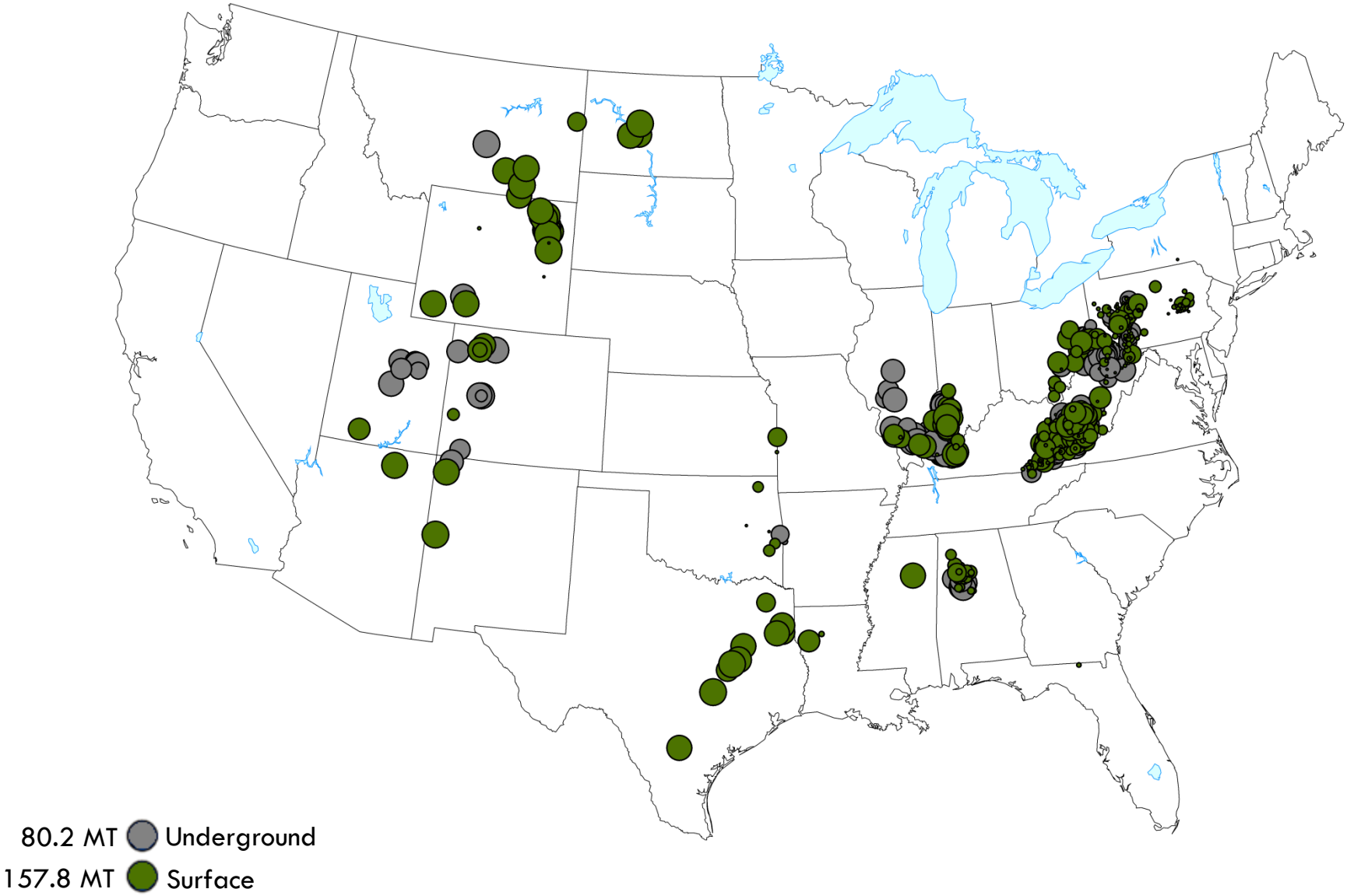
United States Coal Production, Q2-2013



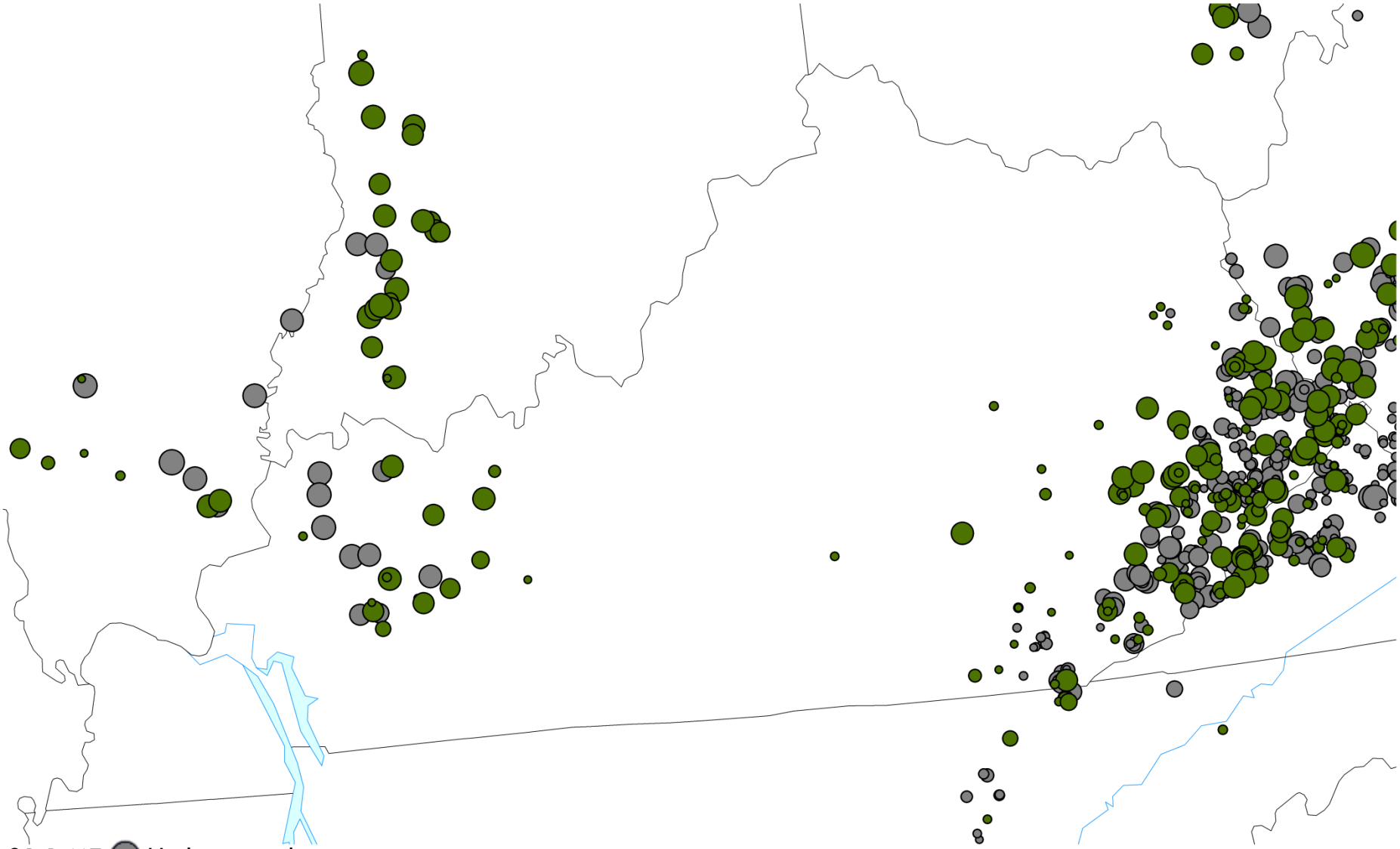
United States Coal Production, Q3-2013



United States Coal Production, Q4-2013



Kentucky Coal Production, Q1-2000



21.1 MT Underground

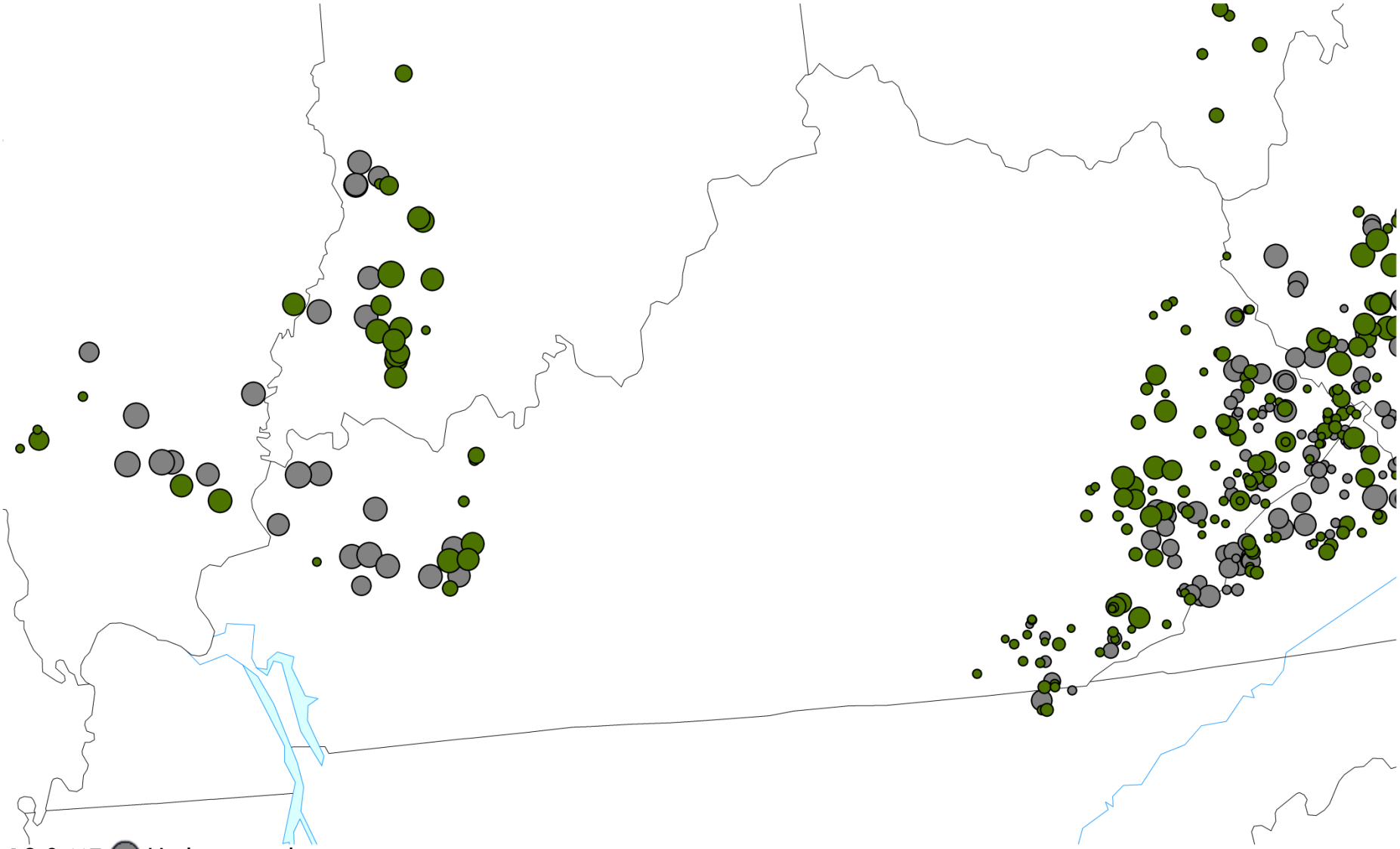
14.2 MT Surface

Animated Version of this Map at:
http://youtu.be/1JckcUUTSsA

Kentucky Energy Database, EEC-DEDI, 2014

energy.ky.gov

Kentucky Coal Production, Q4-2013



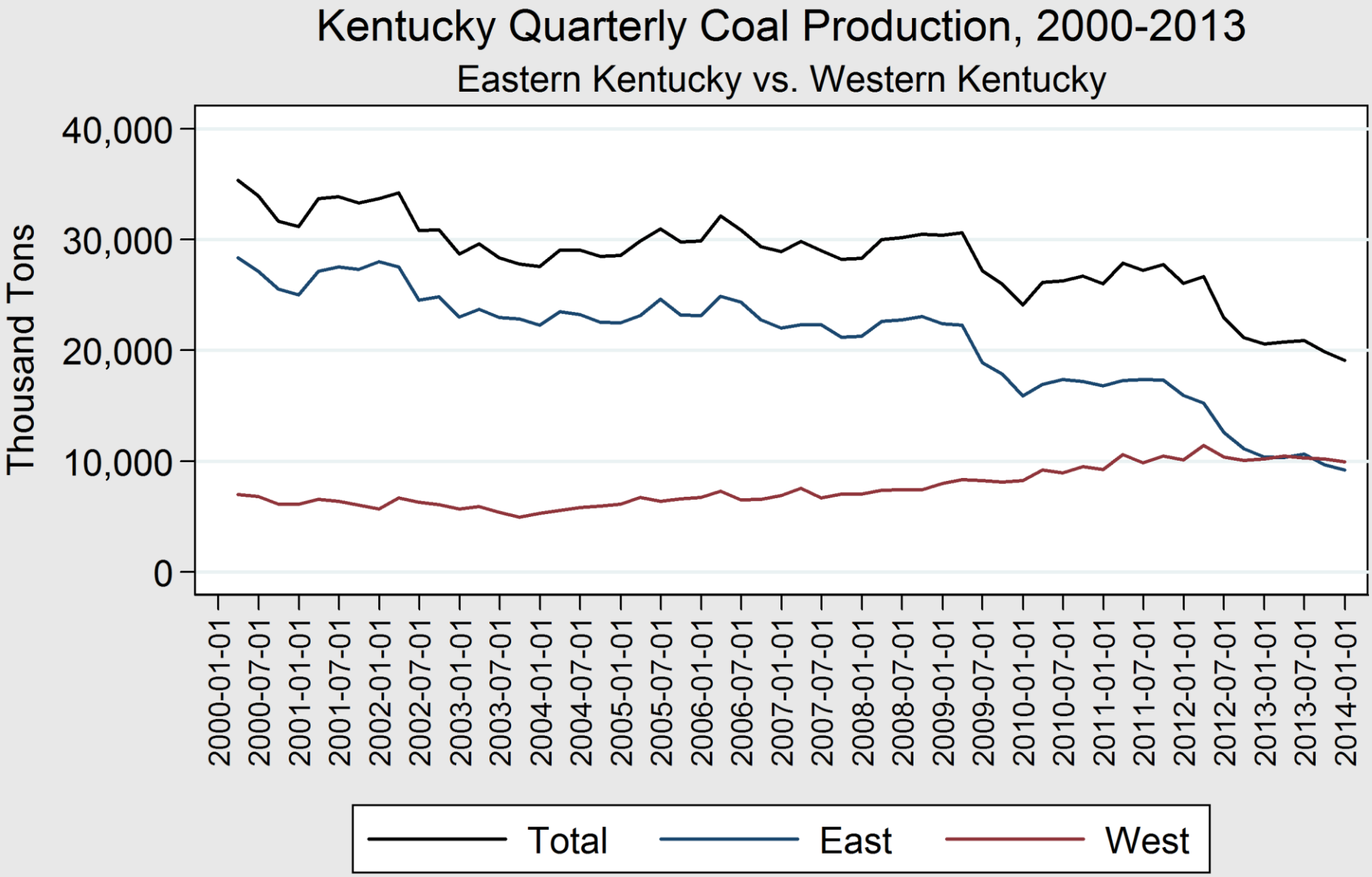
13.0 MT Underground

6.1 MT Surface

Animated Version of this Map at:
http://youtu.be/1JckcUUTSsA

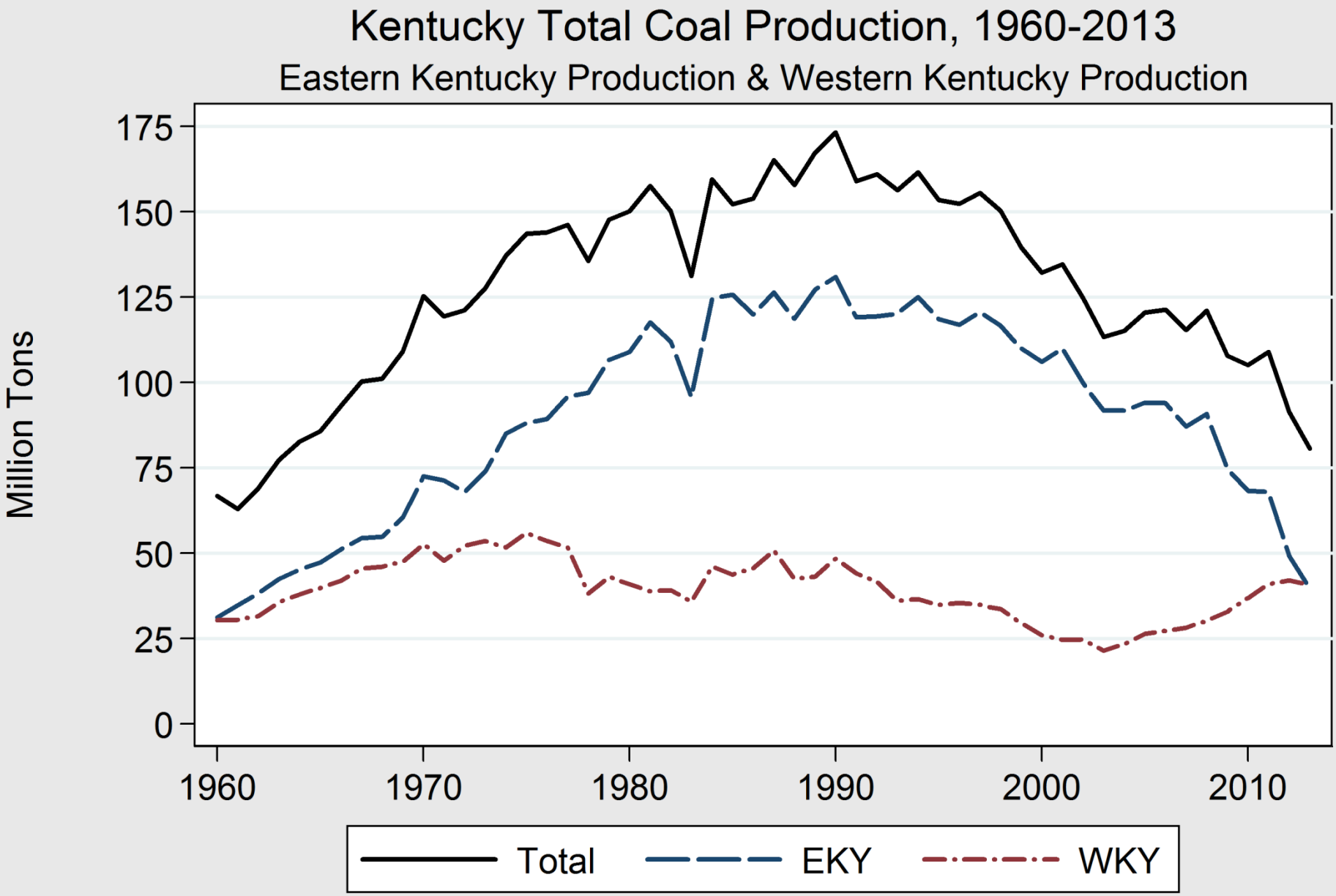
Kentucky Energy Database, EEC-DEDI, 2014

energy.ky.gov

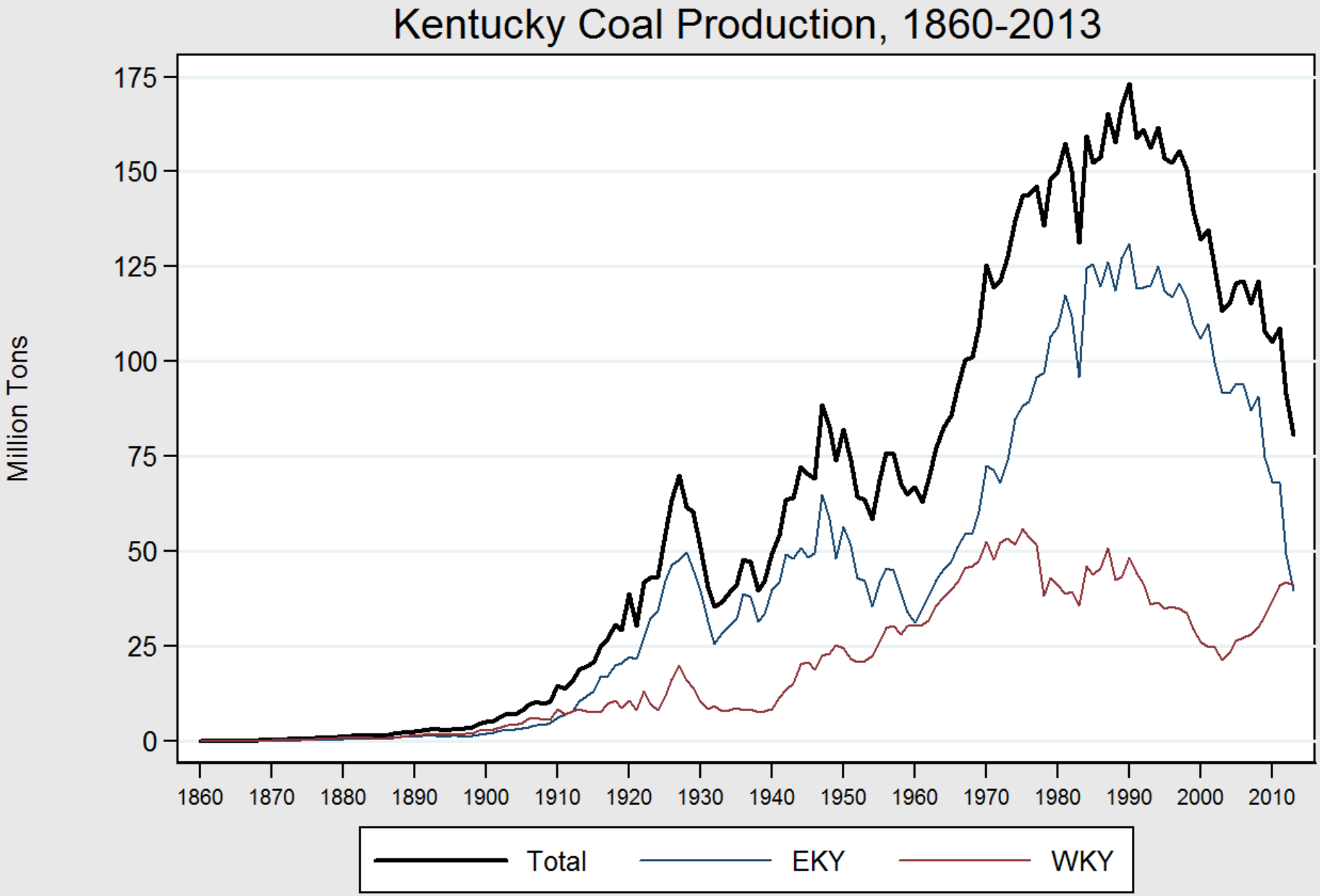


Kentucky Energy Database, EEC-DEDI, 2014

Microdata Source: MSHA-MDRS Queried on: 5 Feb 2014



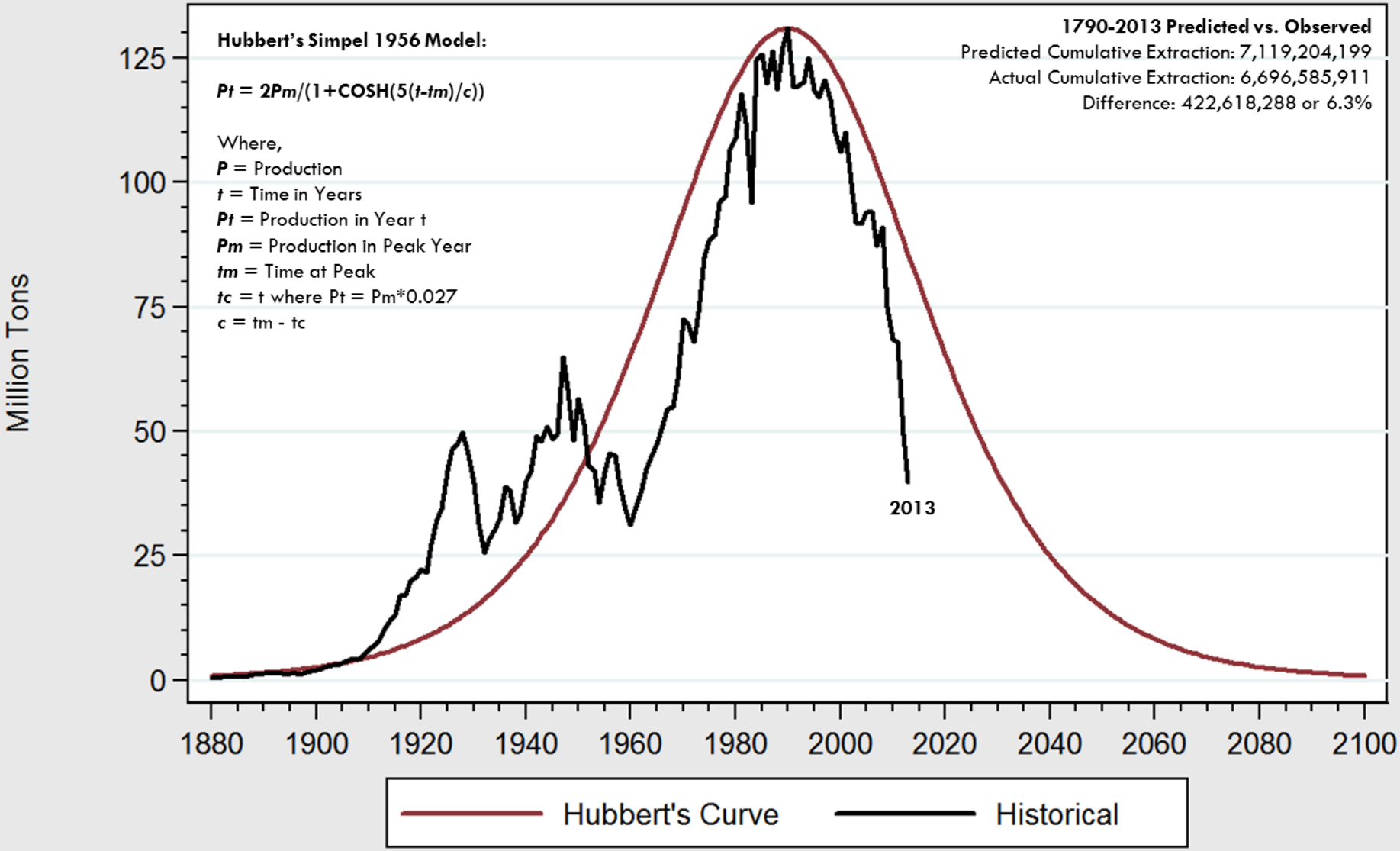
Kentucky Energy Database, EEC-DEDI, 2014



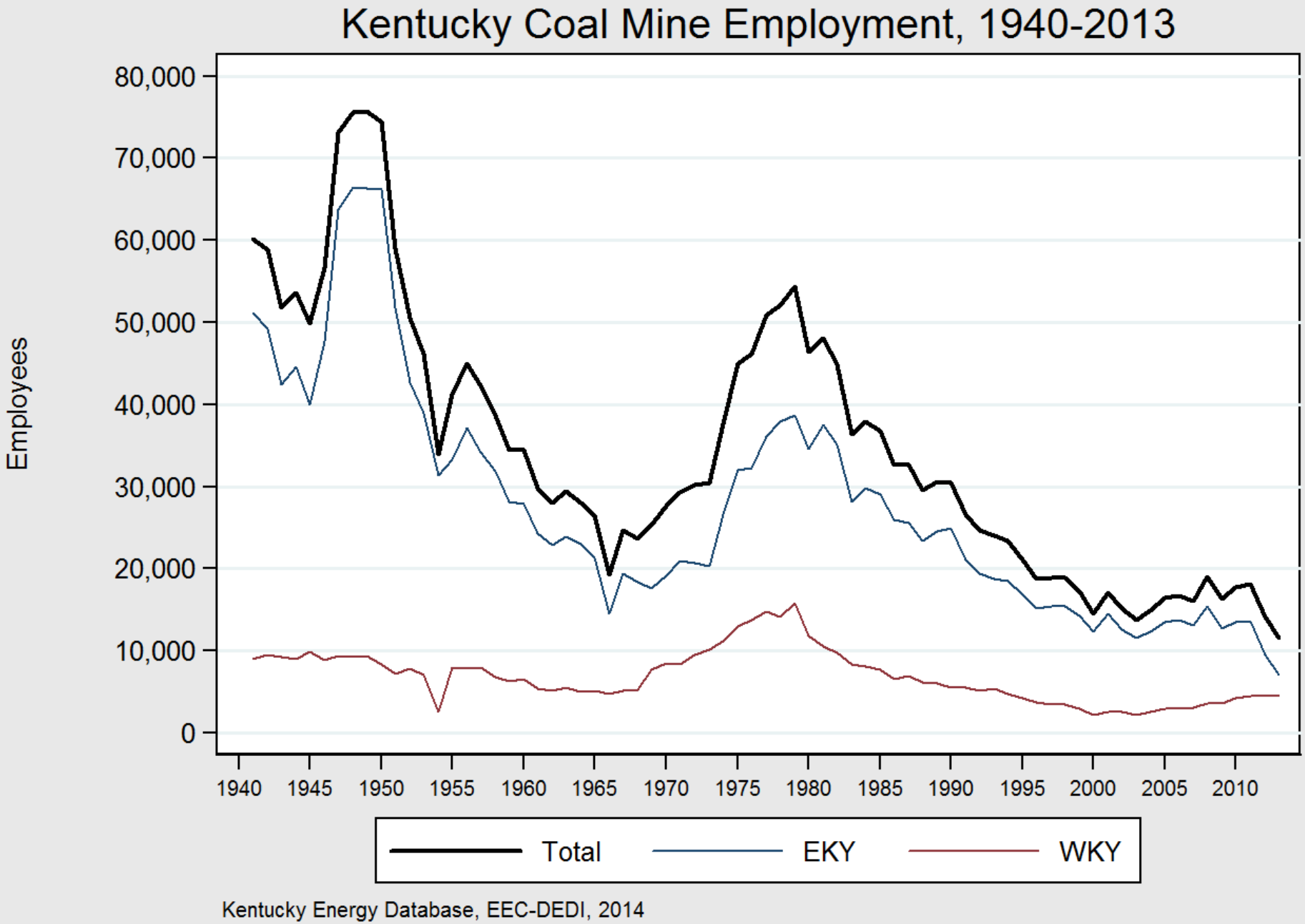
Kentucky Energy Database, EEC-DEDI, 2014

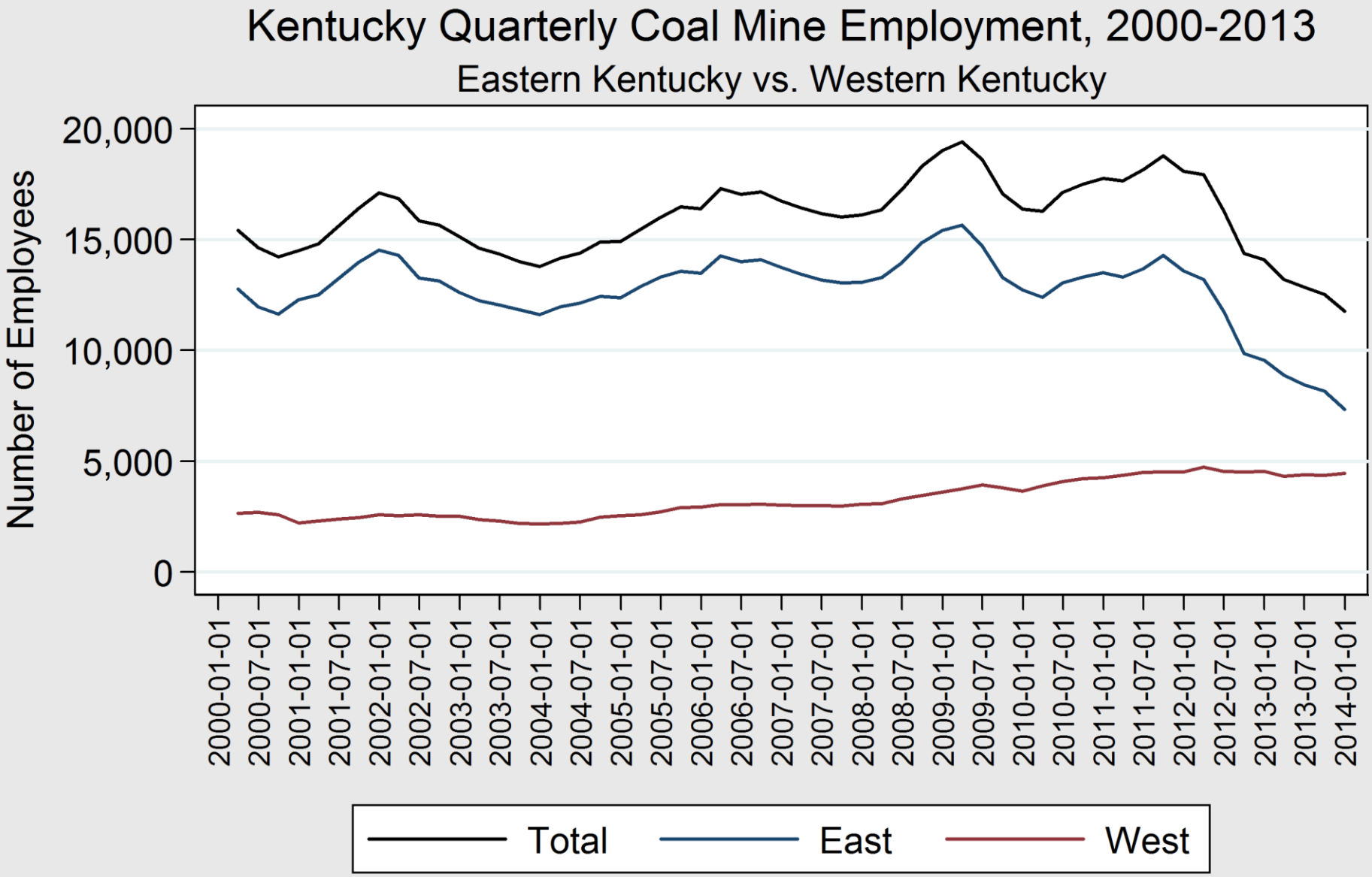
Eastern Kentucky Coal Production, 1880-2100

Hubbert's Curve Applied to Eastern Kentucky Coal Production



Kentucky Energy Database, EEC-DEDI, 2014


Kentucky Coal Mine Employment, 1940-2013
Employees
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
Total
EKY
WKY
Kentucky Energy Database, EEC-DEDI, 2014

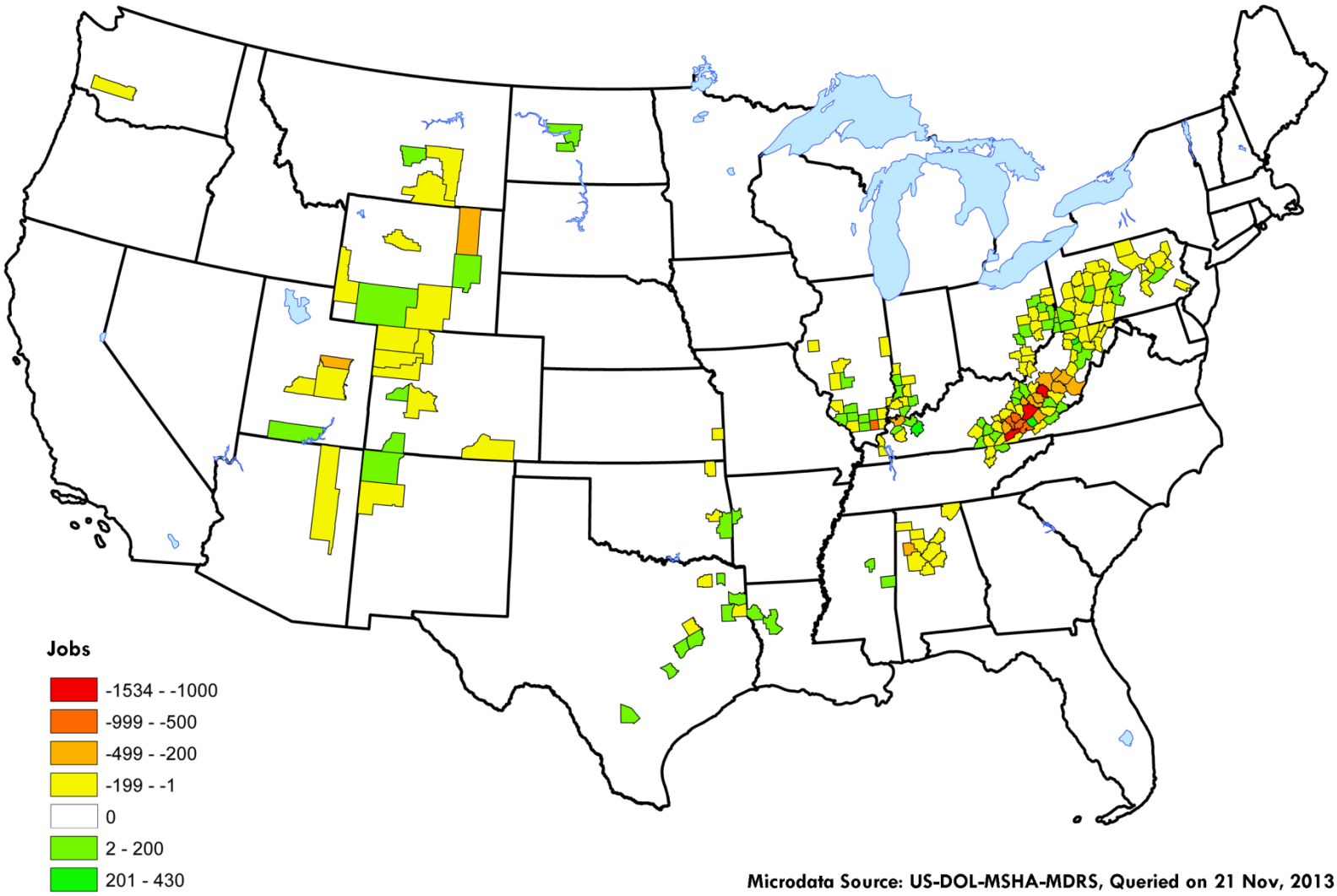


Kentucky Energy Database, EEC-DEDI, 2014

Microdata Source: MSHA-MDRS Queried on: 28 Feb 2014

Change in Coal Mine Employment

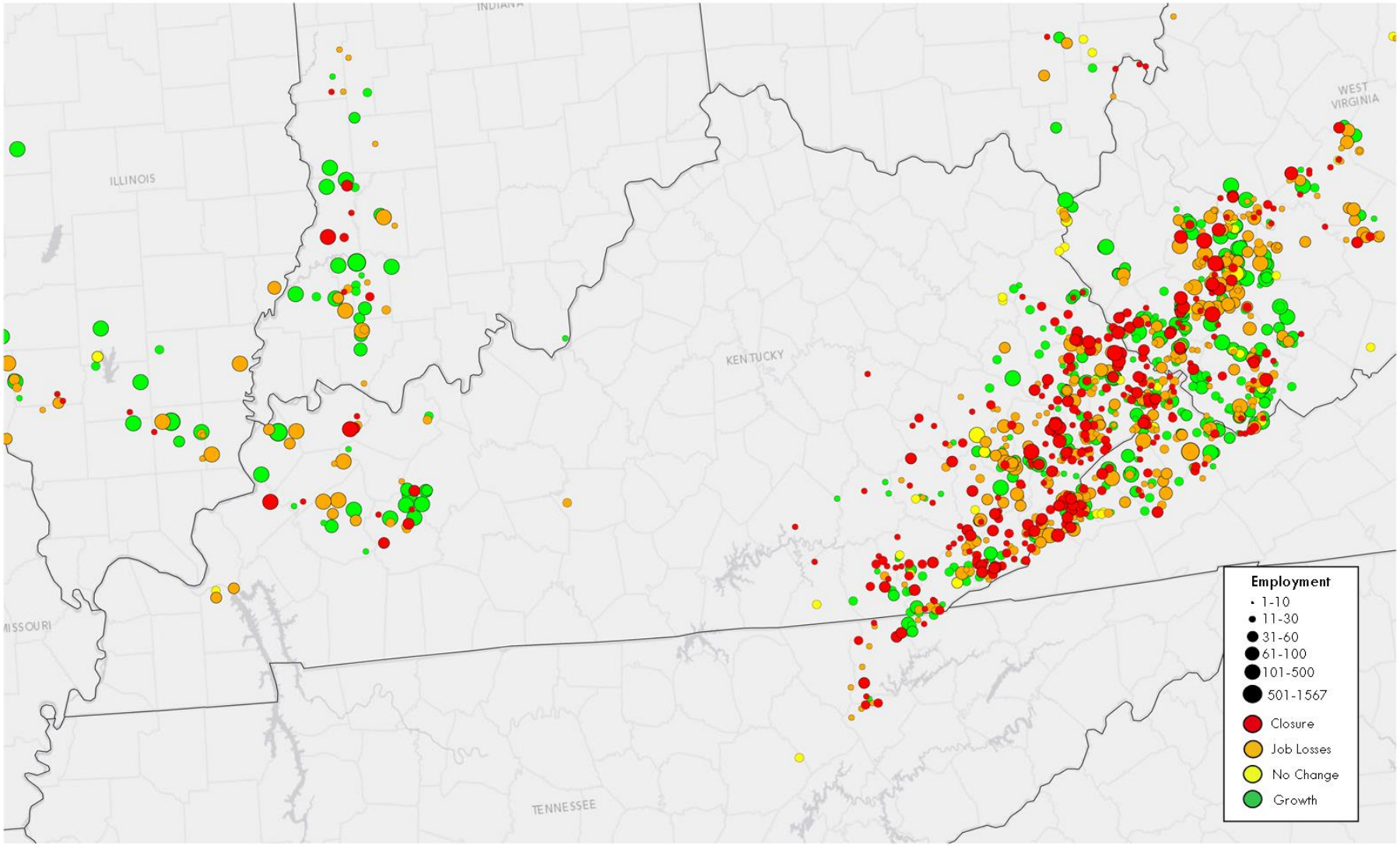
Q3-2011 — Q3-2013



Microdata Source: US-DOL-MSHA-MDRS, Queried on 21 Nov, 2013

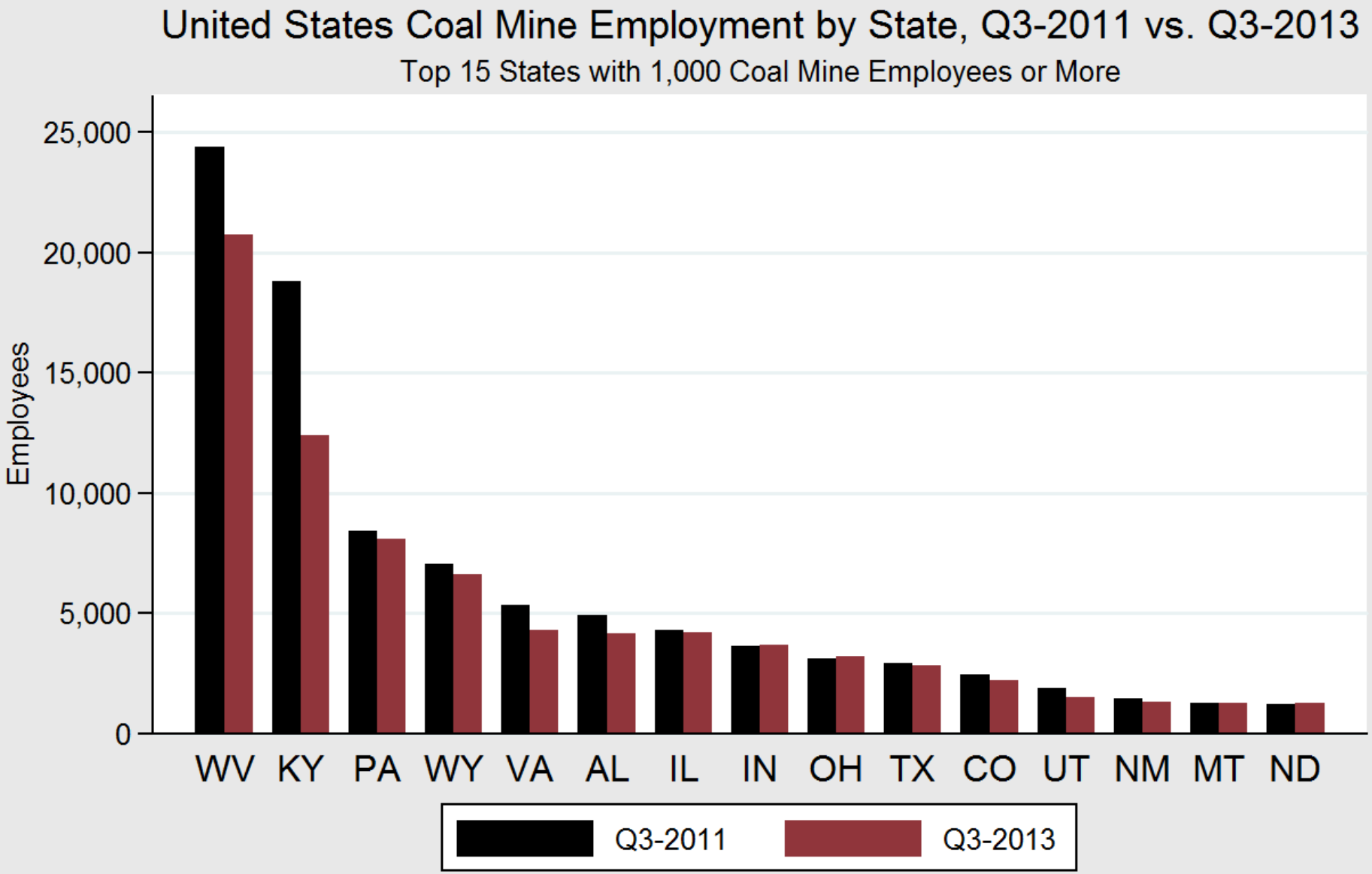
Map by the Kentucky Energy and Environment Cabinet, 2013

Change in Coal Production Employment by Mine, Q3-2011 to Q3-2013



Note: Some coal mines are not visible because of their physical proximity to one-another.

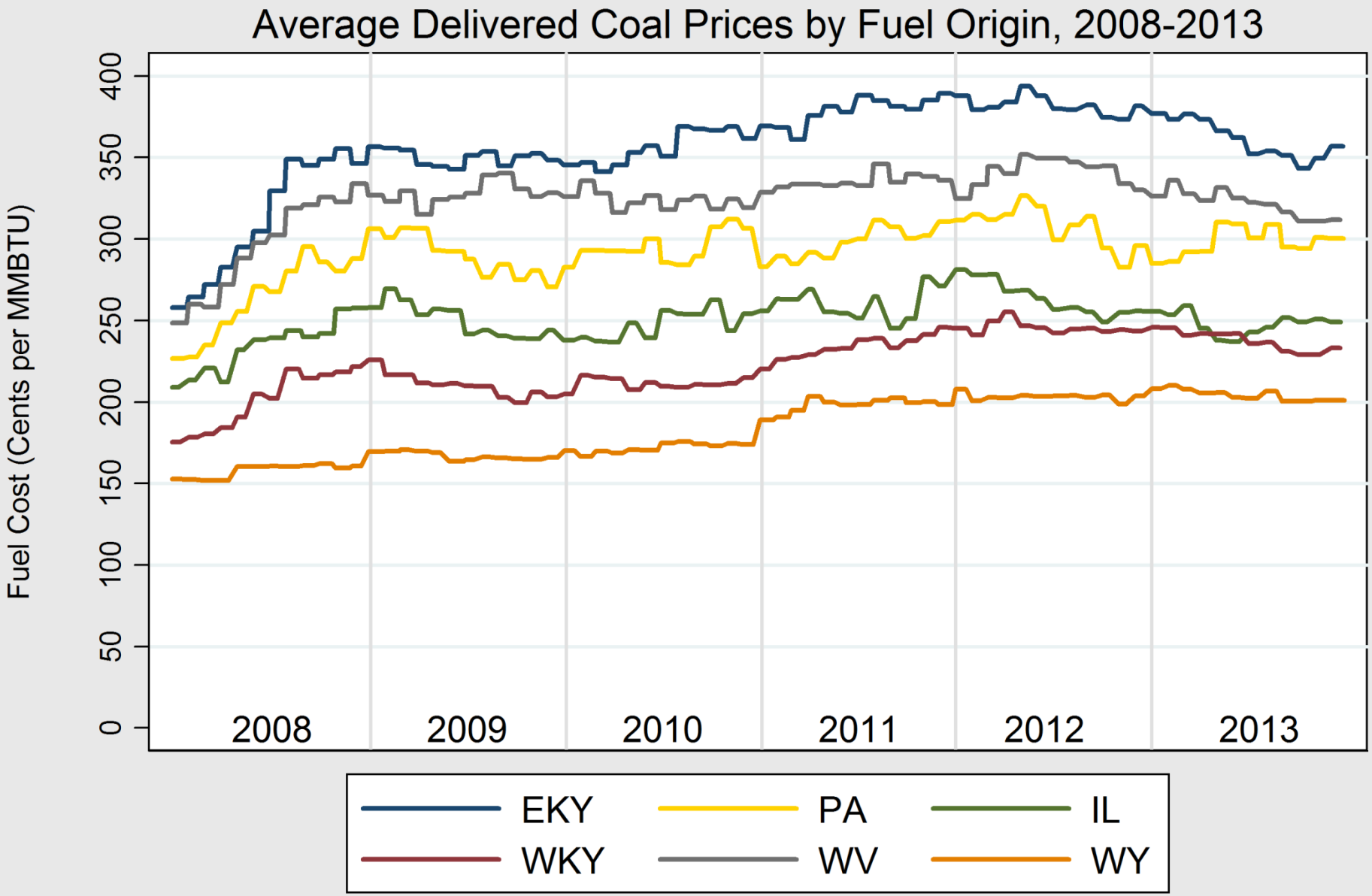
Kentucky Energy Database, EEC-DEDI, 2013
Microdata Source: MSHA-MDRS, Queried 11/15/2013



Kentucky Energy Database, EEC-DEDI, 2013

Microdata Source: MSHA-MDRS, Queried on: 21 Nov 2013

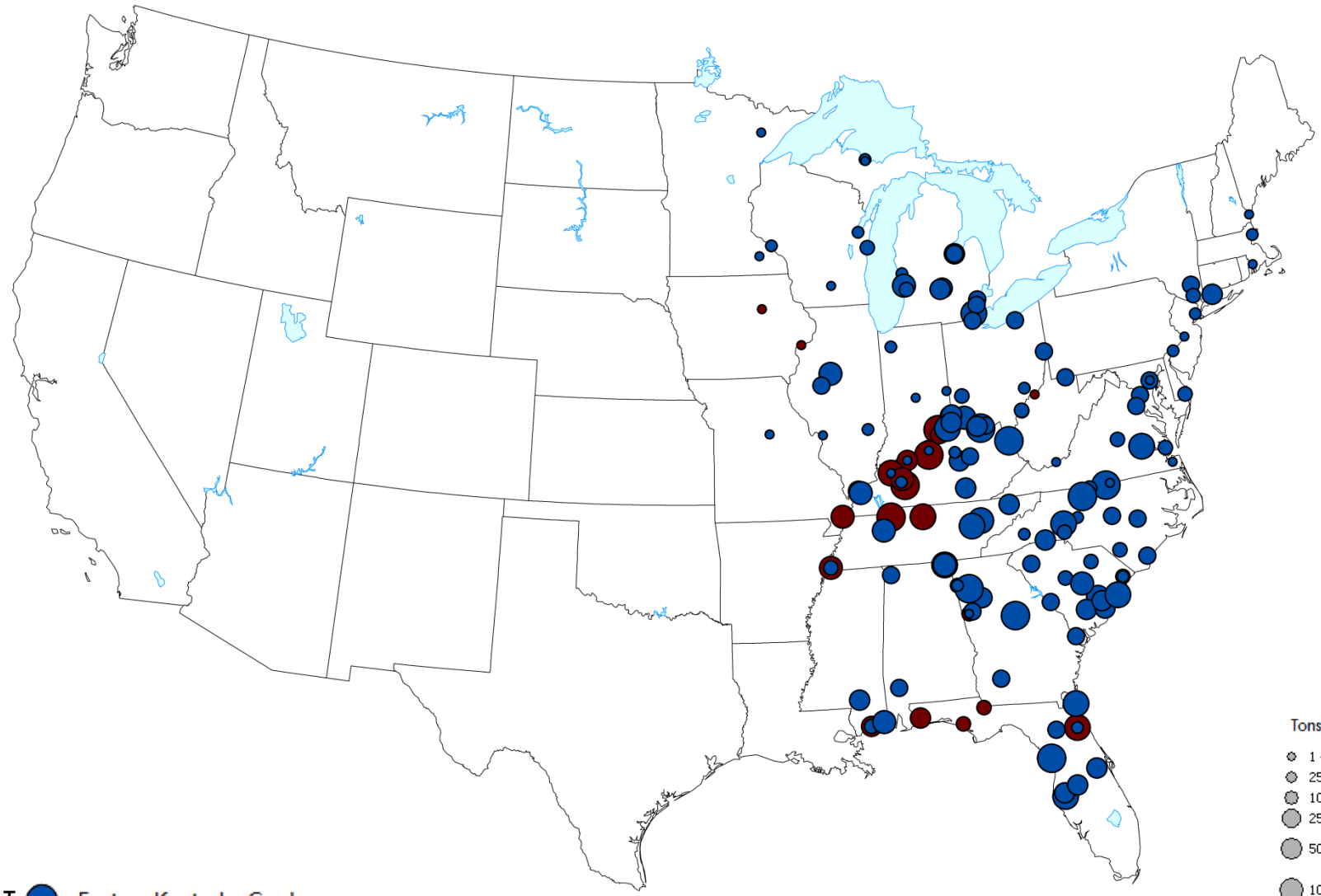
Kentucky Coal Markets



Kentucky Energy Database, EEC-DEDI, 2014

Top Five Coal Producing States in 2013. Microdata Source: Form EIA-923. EKY=Eastern Kentucky. WKY=Western Kentucky

Kentucky Coal Deliveries, 1990



85.2 MT Eastern Kentucky Coal

43.6 MT Western Kentucky Coal

Tons of Coal

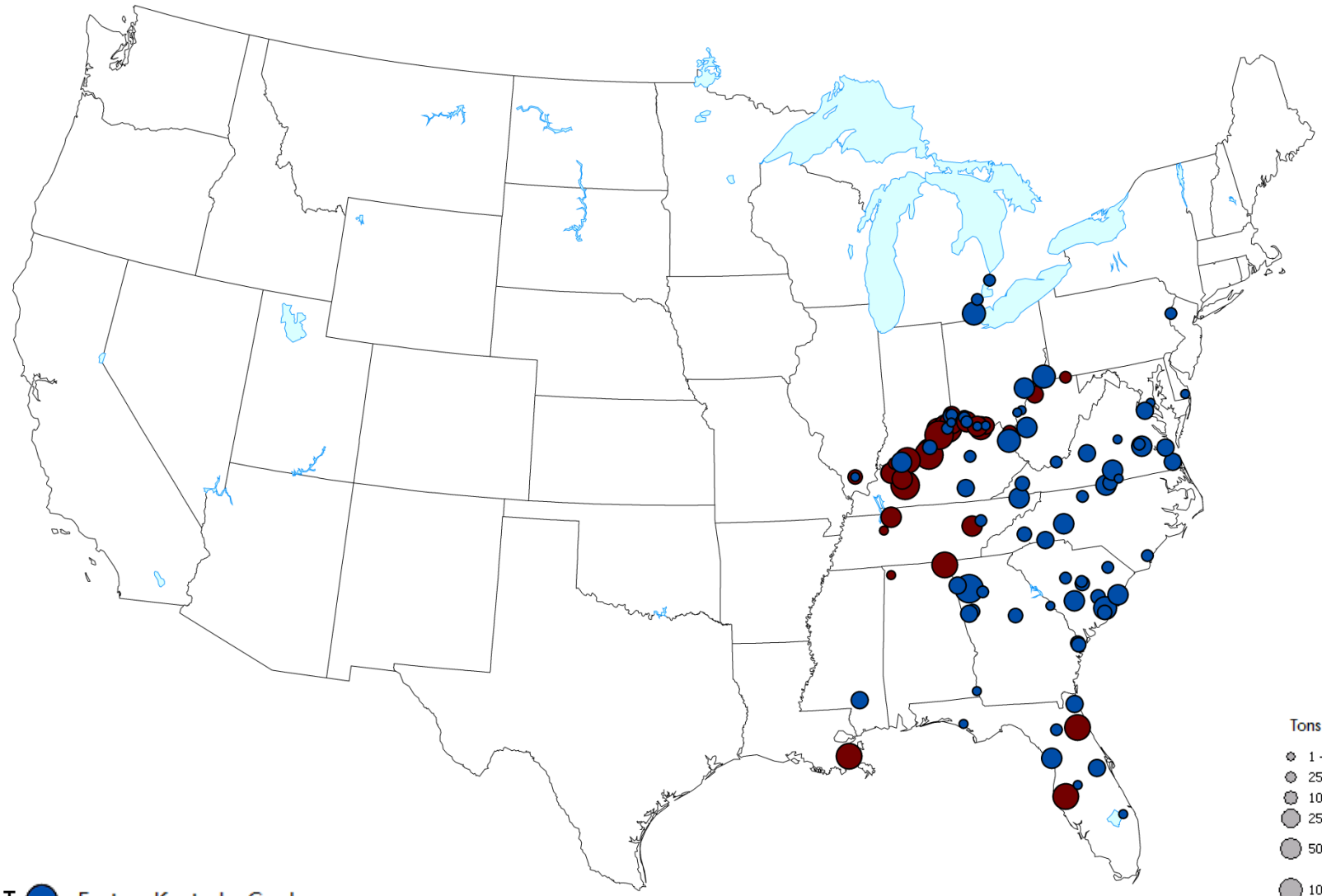
- 1 - 25000
- 25001 - 100000
- 100001 - 250000
- 250001 - 500000
- 500001 - 1000000
- 1000001 - 1500000
- 1500001 - 2500000
- 2500001 +

Kentucky Energy Database, EEC-DEDI, 2014

Animated Version of this Map at:
http://youtu.be/ofNBO8g9xuo

energy.ky.gov

Kentucky Coal Deliveries, 2013



23.7 MT Eastern Kentucky Coal

38.3 MT Western Kentucky Coal

Tons of Coal

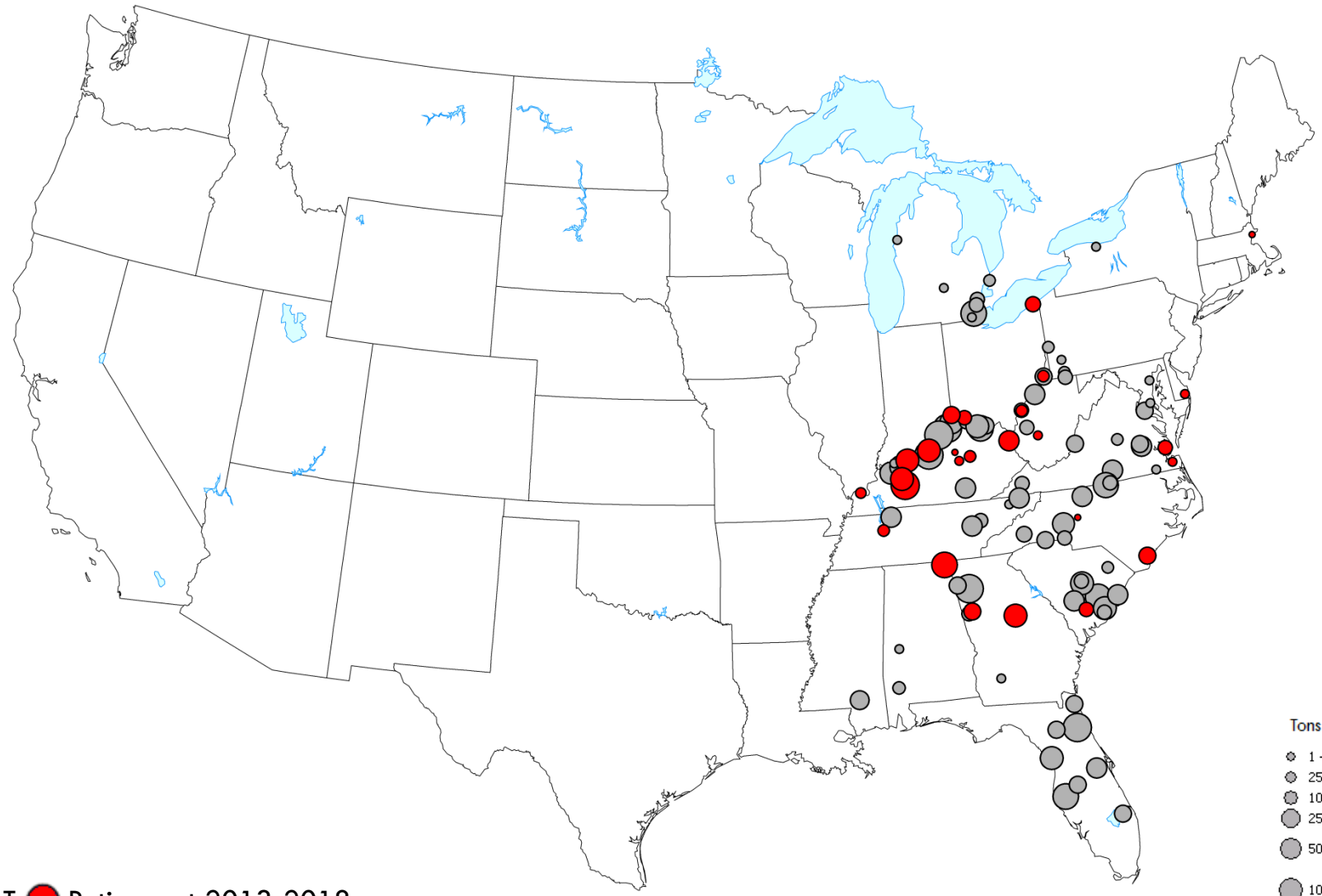
- 1 - 25000
- 25001 - 100000
- 100001 - 250000
- 250001 - 500000
- 500001 - 1000000
- 1000001 - 1500000
- 1500001 - 2500000
- 2500001 +

Kentucky Energy Database, EEC-DEDI, 2014

Animated Version of this Map at:
http://youtu.be/ofNBO8g9xuo

energy.ky.gov

Kentucky Coal Deliveries & Future Retirements, 2012



Tons of Coal

- 1 - 25000
- 25001 - 100000
- 100001 - 250000
- 250001 - 500000
- 500001 - 1000000
- 1000001 - 1500000
- 1500001 - 2500000
- 2500001 +

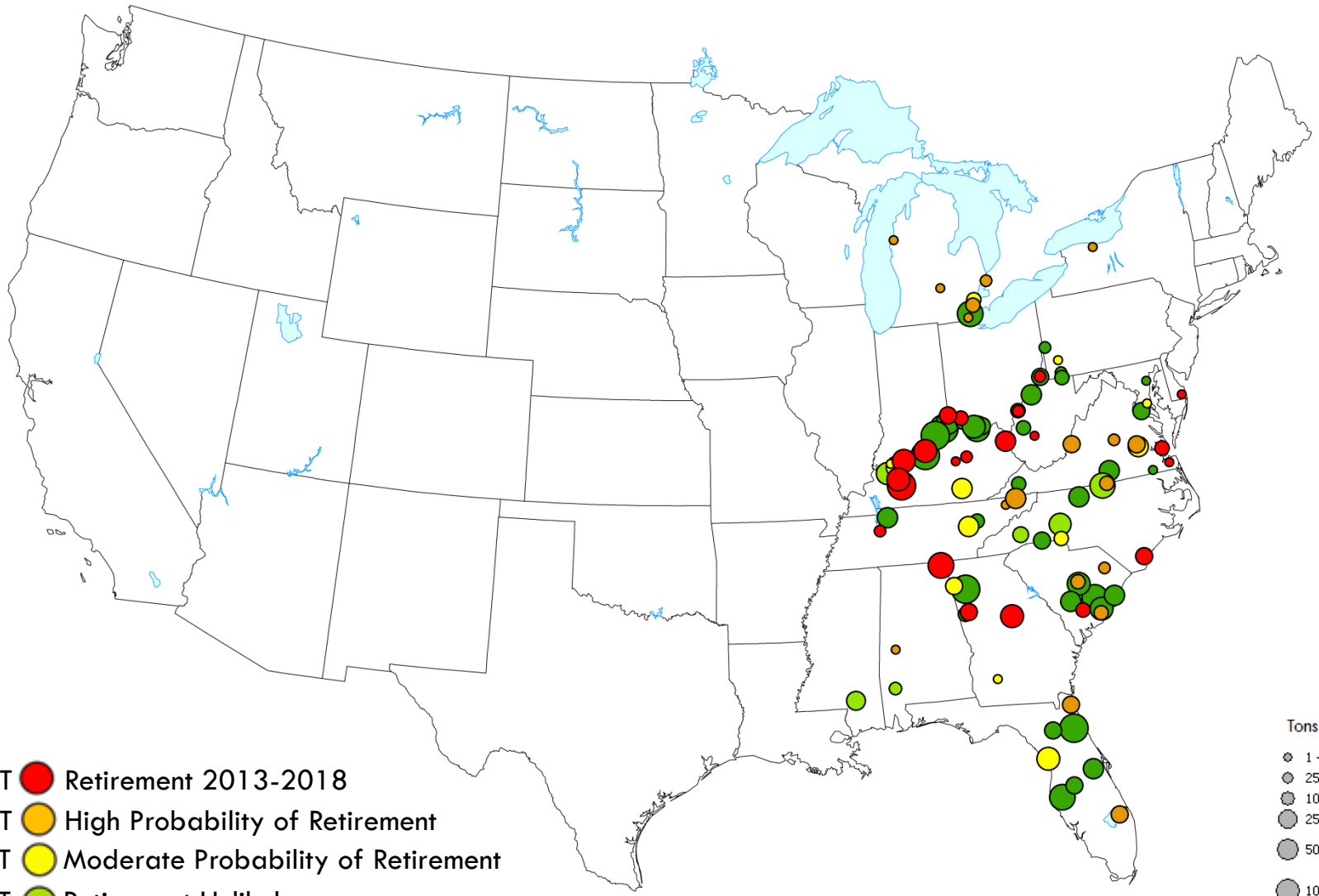
15.4 MT Retirement 2013-2018

53+ MT Unknown Future Retirement

Kentucky Energy Database, EEC-DEDI, 2014

energy.ky.gov

Kentucky Coal Deliveries & Future Retirements, 2012



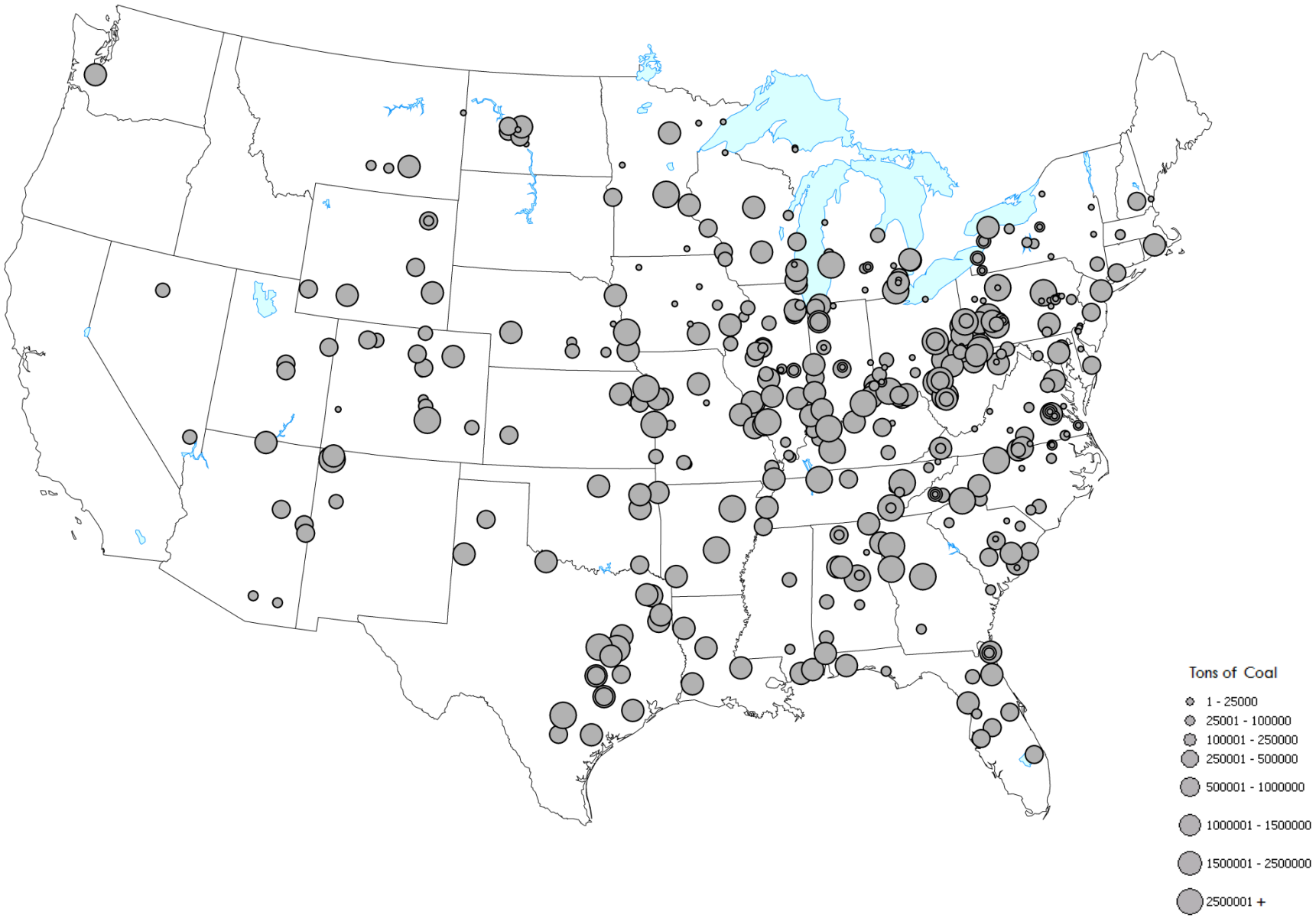
15.4 MT Retirement 2013-2018
3.3 MT High Probability of Retirement
5.2 MT Moderate Probability of Retirement
3.5 MT Retirement Unlikely
40+ MT Retirement Highly Unlikely

Tons of Coal
1 - 25000
25001 - 100000
100001 - 250000
250001 - 500000
500001 - 1000000
1000001 - 1500000
1500001 - 2500000
2500001 +

Kentucky Energy Database, EEC-DEDI, 2014

energy.ky.gov

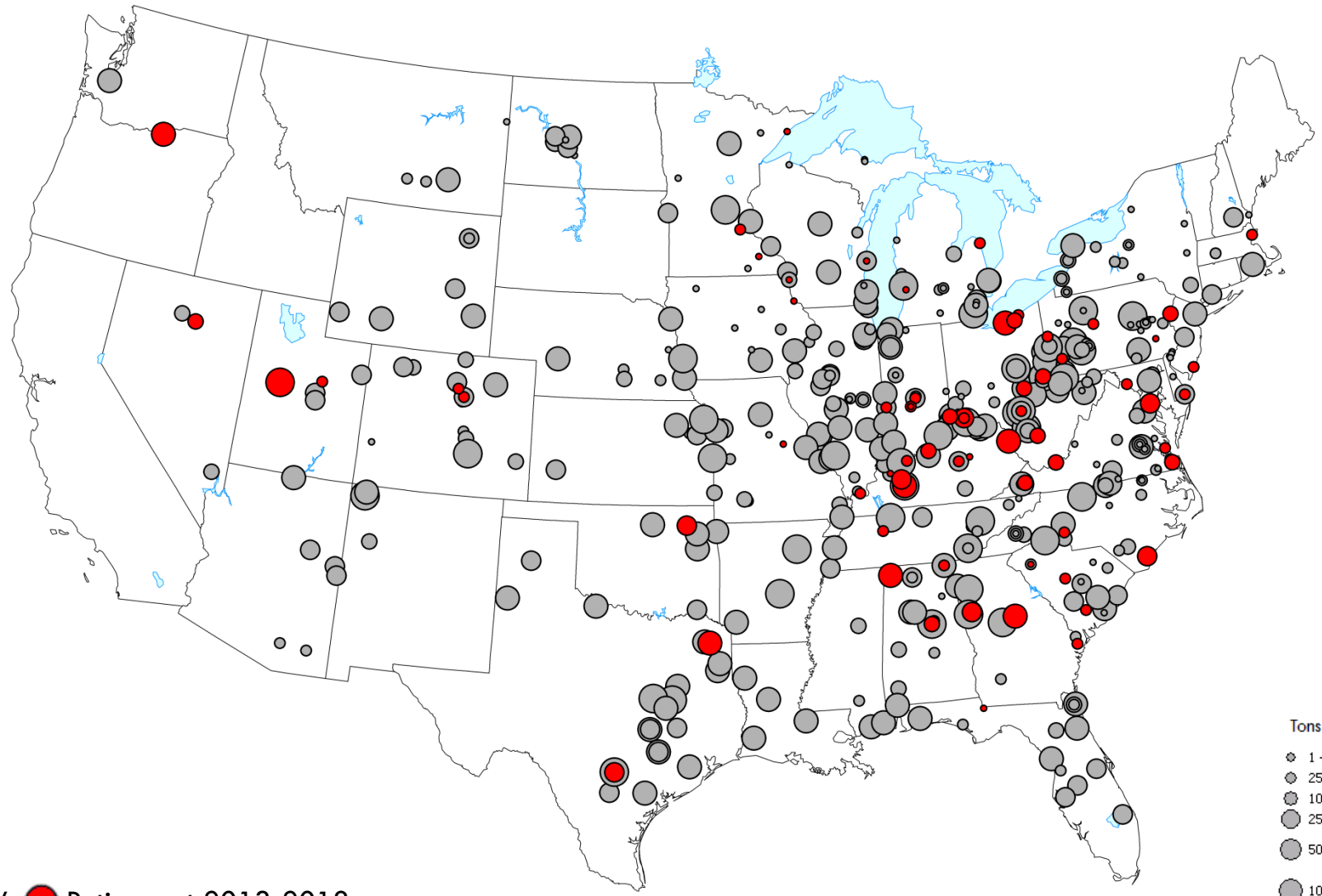
United States Coal-Fired Power Plants, 2012



Kentucky Energy Database, EEC-DEDI, 2014

energy.ky.gov

United States Coal-Fired Power Plants, 2012



Tons of Coal

- 1 - 25000
- 25001 - 100000
- 100001 - 250000
- 250001 - 500000
- 500001 - 1000000
- 1000001 - 1500000
- 1500001 - 2500000
- 2500001 +

33 GW Retirement 2013-2018

312 GW Unknown Future Retirement

Kentucky Energy Database, EEC-DEDI, 2014

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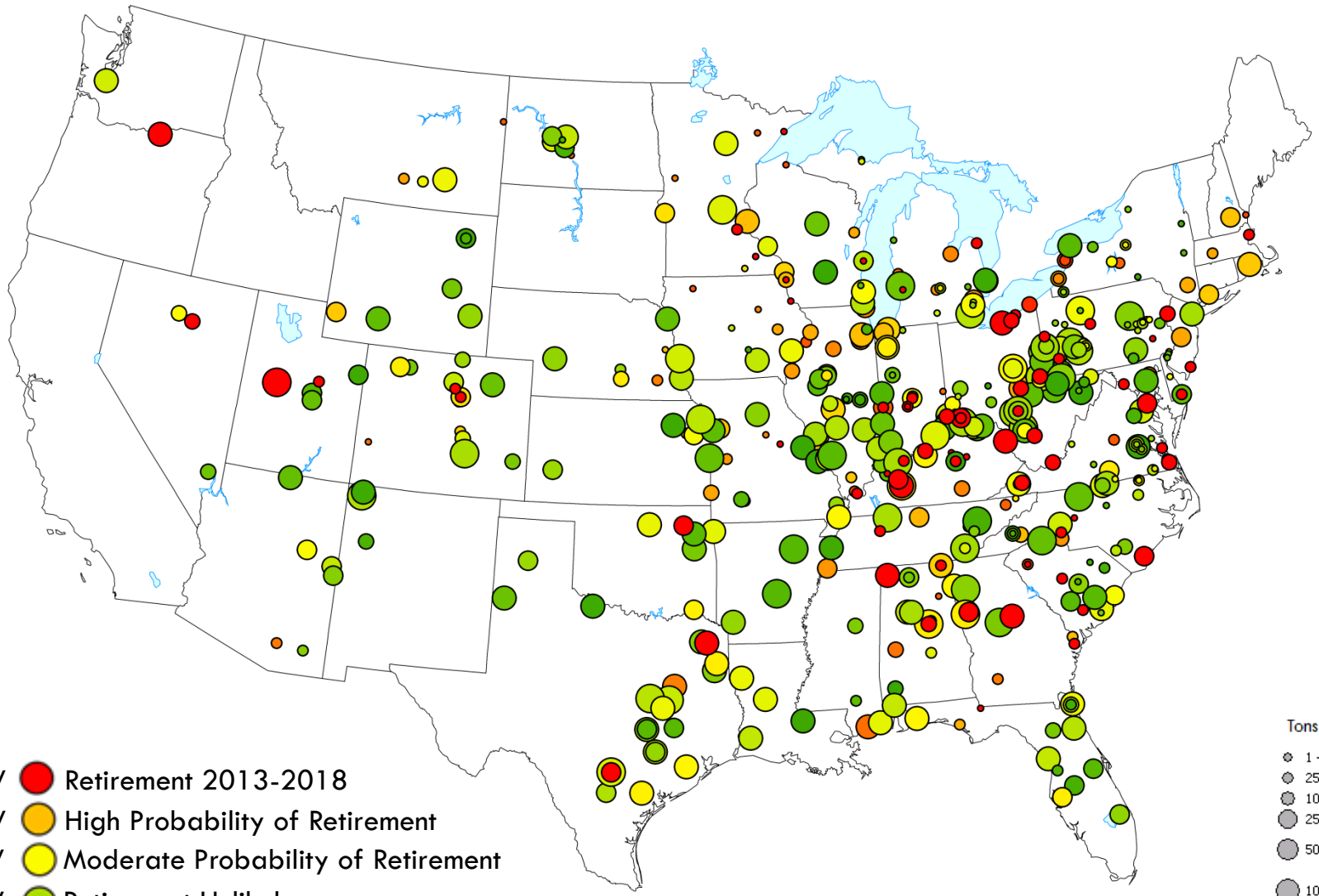
United States Coal-Fired Power Plants, 2012



33 GW Retirement 2013-2018
18 GW High Probability of Retirement
30 GW Moderate Probability of Retirement
25 GW Retirement Unlikely
237 GW Retirement Highly Unlikely

Tons of Coal
1 - 25000
25001 - 100000
100001 - 250000
250001 - 500000
500001 - 1000000
1000001 - 1500000
1500001 - 2500000
2500001 +

Kentucky Energy Database, EEC-DEDI, 2014

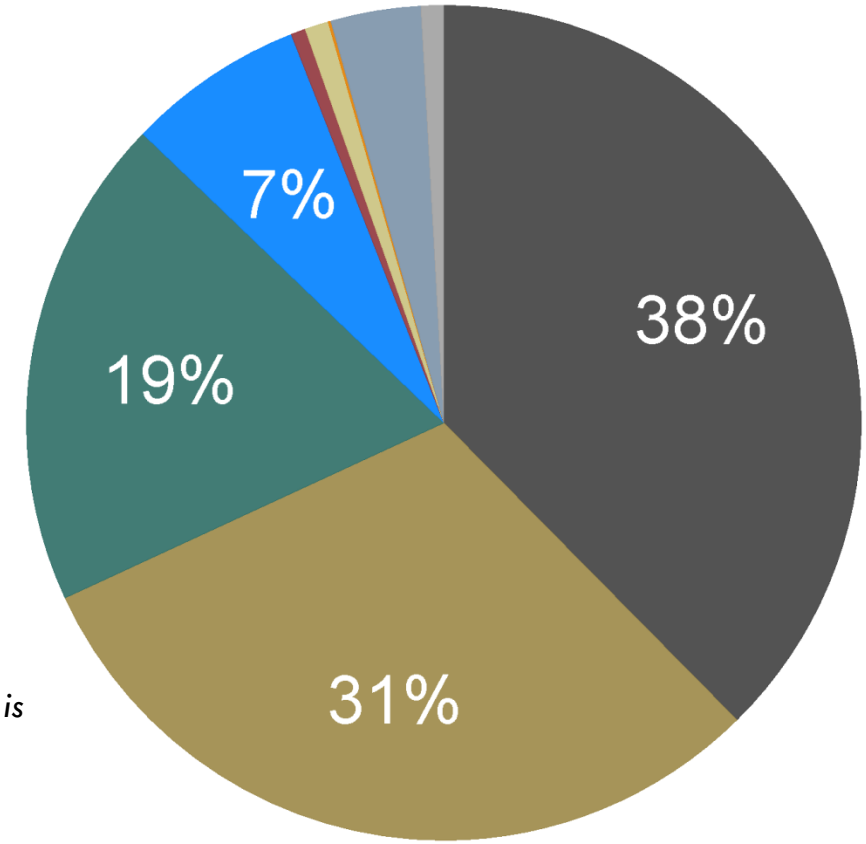
energy.ky.gov

A Quick Introduction to

Kentucky's Electricity Portfolio

United States Electricity Generation, 2012

Electricity Generation by Fuel Type (%)



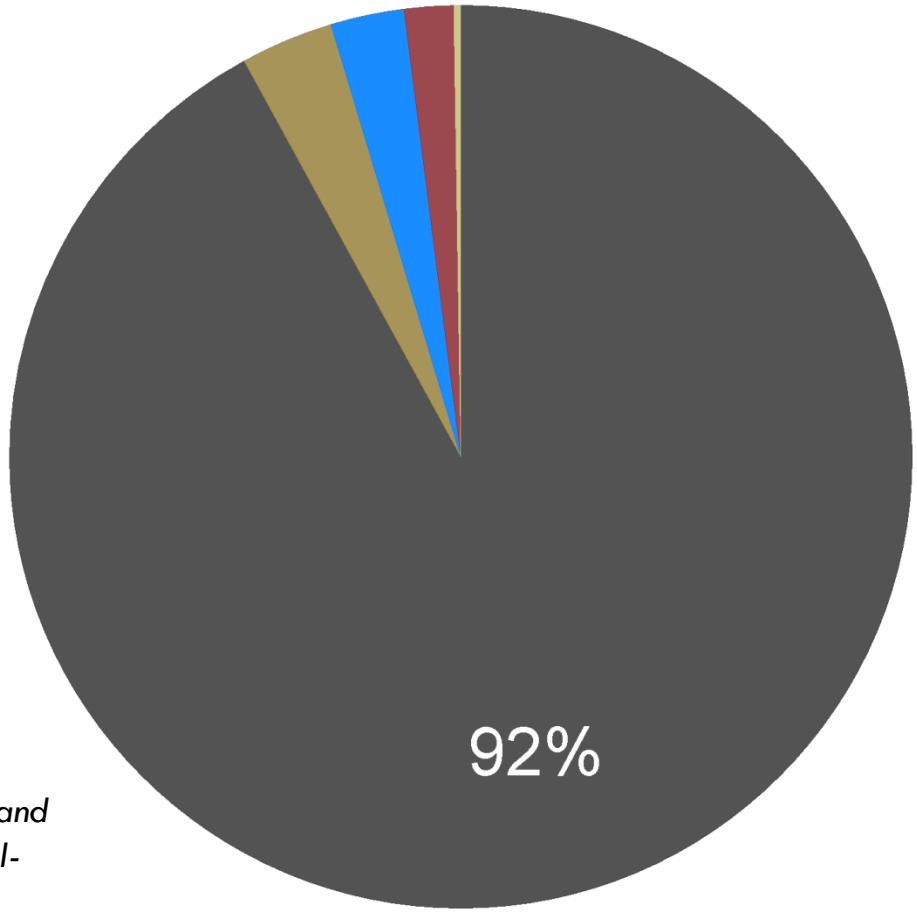
Electricity consumption nationally is relatively balanced between coal, natural gas, nuclear power, hydroelectric, and wind.

Coal	Natural Gas	Nuclear
Hydro	Petroleum	Wood
Solar	Wind	All Other

Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Generation, 2012

Electricity Generation by Fuel Type (%)



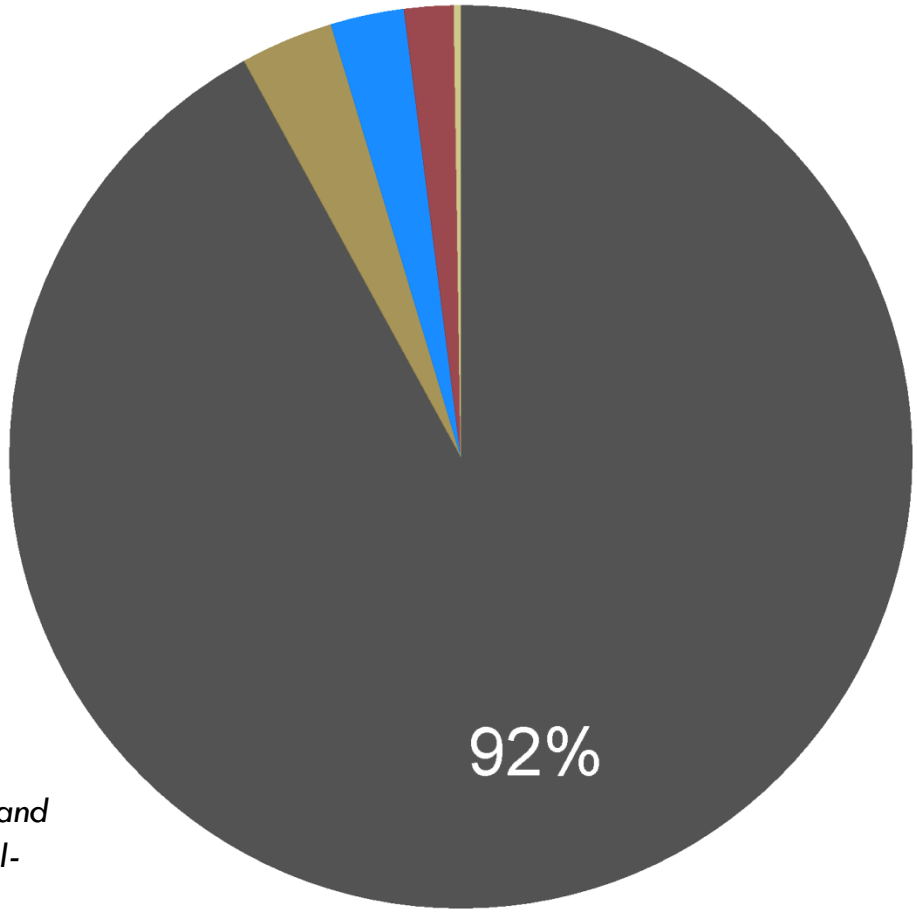
Over 92% of the electricity generated in Kentucky in 2012 and 2013 came from Kentucky's coal-fired power plants.

Coal | Natural Gas | Hydro
Petroleum | Wood

Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Generation, 2012

Electricity Generation by Fuel Type (%)



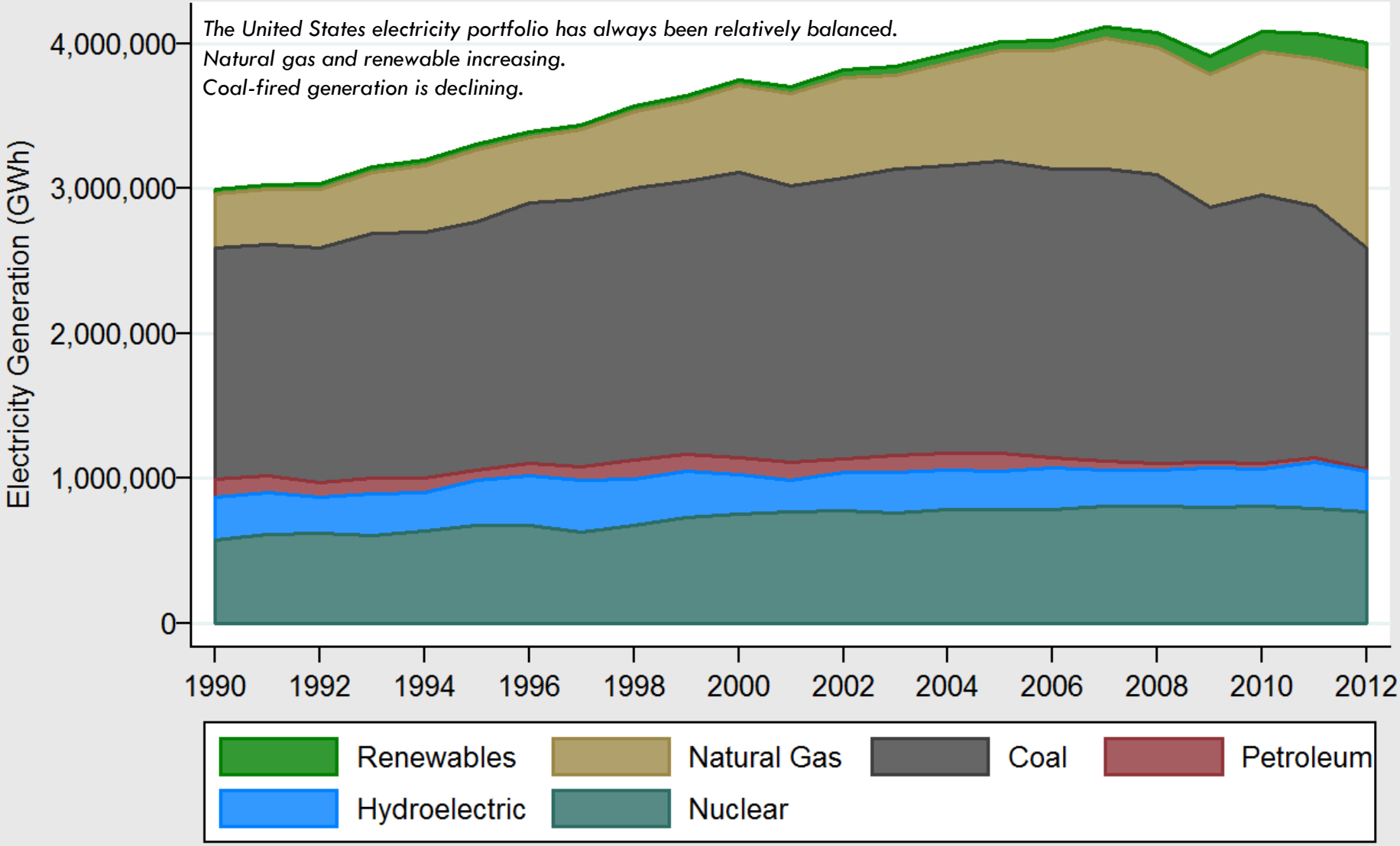
Over 92% of the electricity generated in Kentucky in 2012 and 2013 came from Kentucky's coal-fired power plants.

Coal | Natural Gas | Hydro
Petroleum | Wood

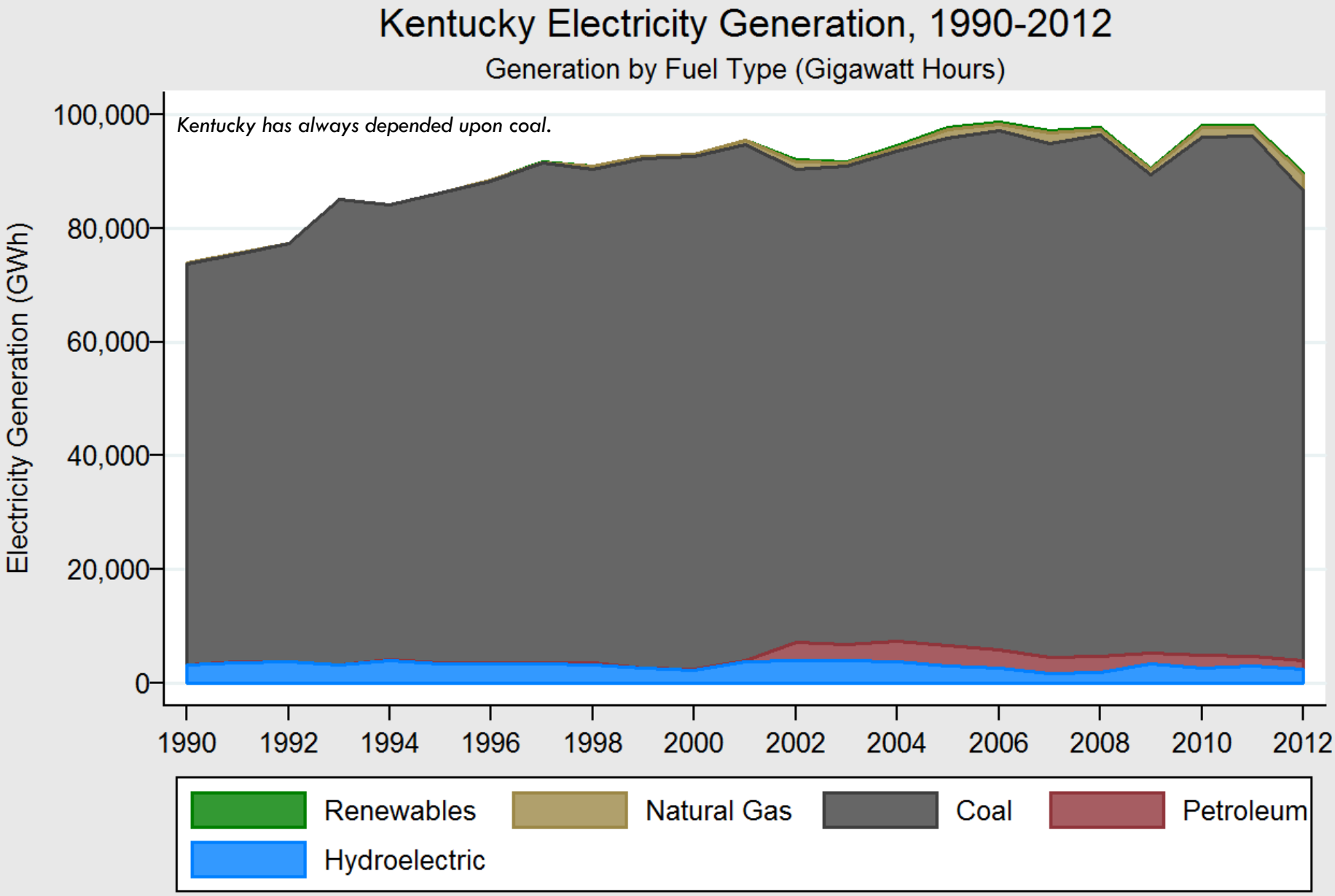
Kentucky Energy Database, EEC-DEDI, 2013

United States Electricity Generation, 1990-2012

Generation by Fuel Type (Gigawatt Hours)

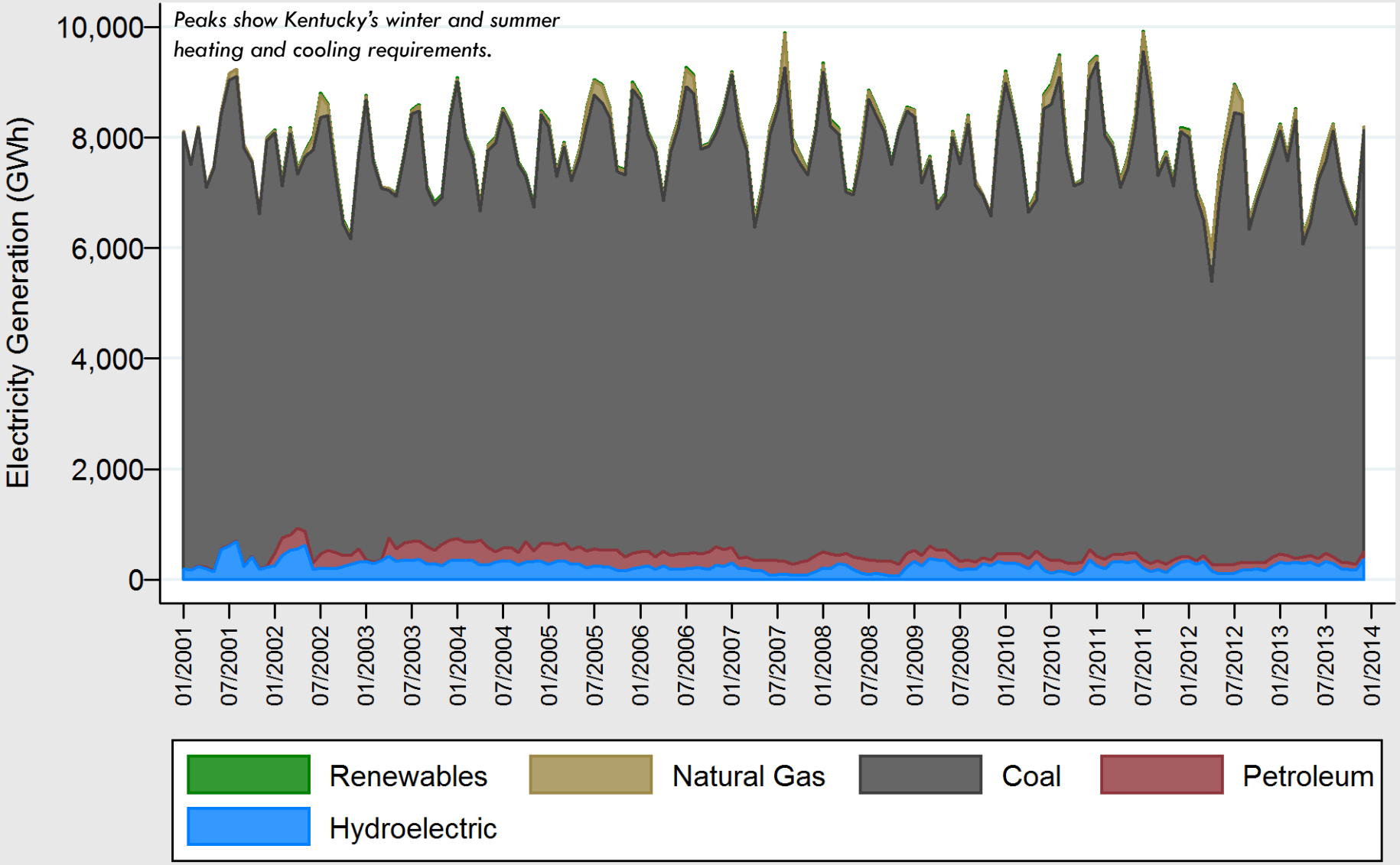


Kentucky Energy Database, EEC-DEDI, 2013



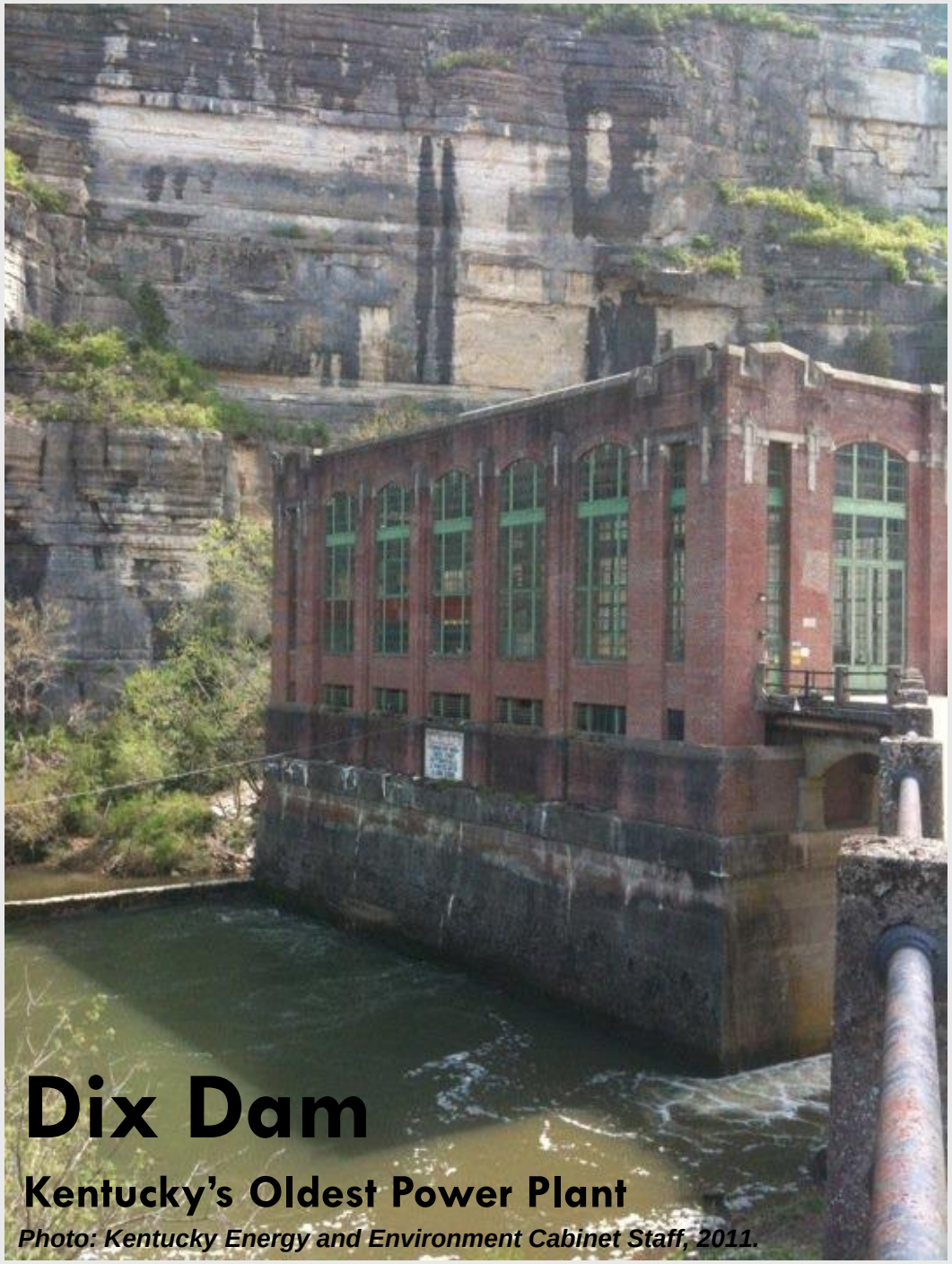
Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Generation by Fuel Type, 2001-2013



Kentucky Energy Database, EEC-DEDI, February 2014

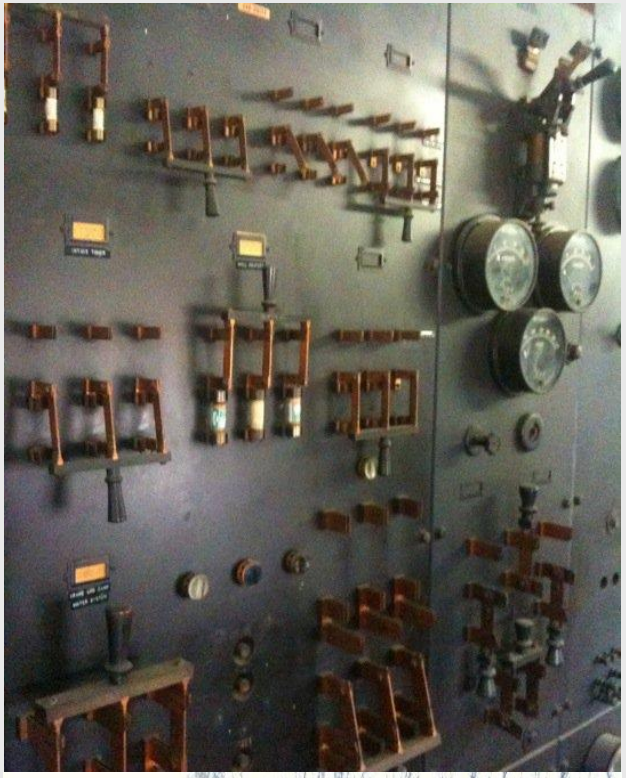
Data Source: EIA Electric Power Monthly, February 2014

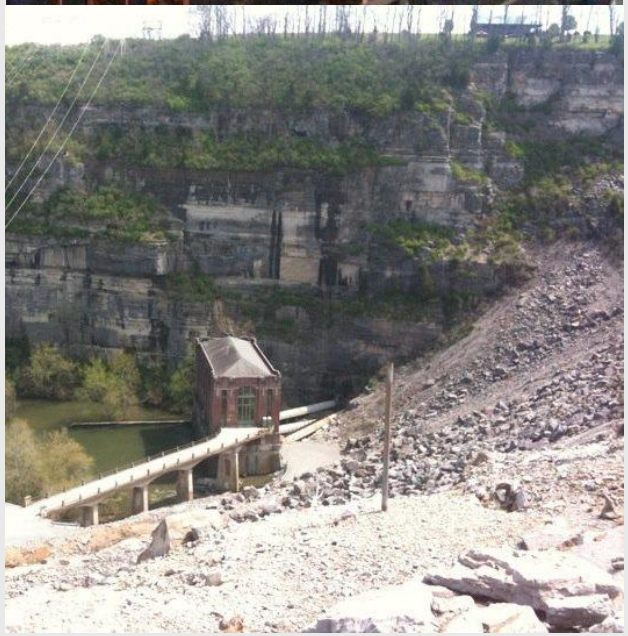


Dix Dam

Kentucky's Oldest Power Plant

Photo: Kentucky Energy and Environment Cabinet Staff, 2011.





Trimble County

Kentucky's Newest Coal Plant

Photo: LG&E-KU, 2014

A Quick Introduction to

Kentucky's Future Electricity Portfolio

Download the Full Report

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

Changes in Federal Regulation

More numerous and more stringent federal environmental regulations affecting coal-fired generation in ways that differ from the past.

Mercury Air Toxics Standards (MATS)

MATS has accounted for a large portion of recent coal plant retirements.

National Ambient Air Quality Standard (NAAQS)

Much more stringent Ozone (O3) standards likely to be proposed.

Cross State Air Pollution Rule (CSAPR)

Supreme Court decision expected in June 2014.

Water Intake & and Effluent Limitations

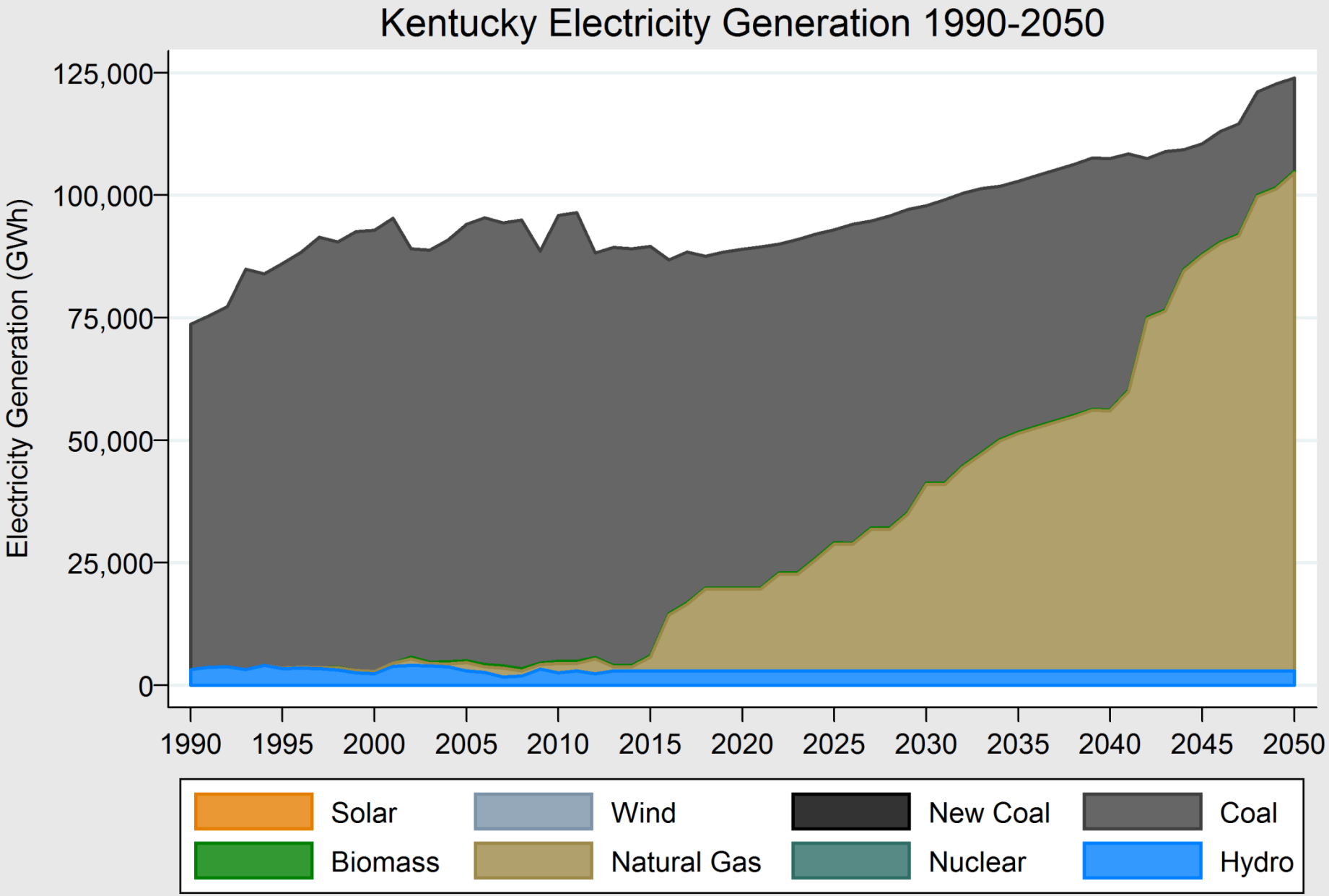
EPA is past deadline to propose rules for water intake structures.

Coal Combustion Residuals (coal ash)

EPA under pressure to act, especially in light of recent spills; depending on approach EPA takes, could require costly compliance for utilities.

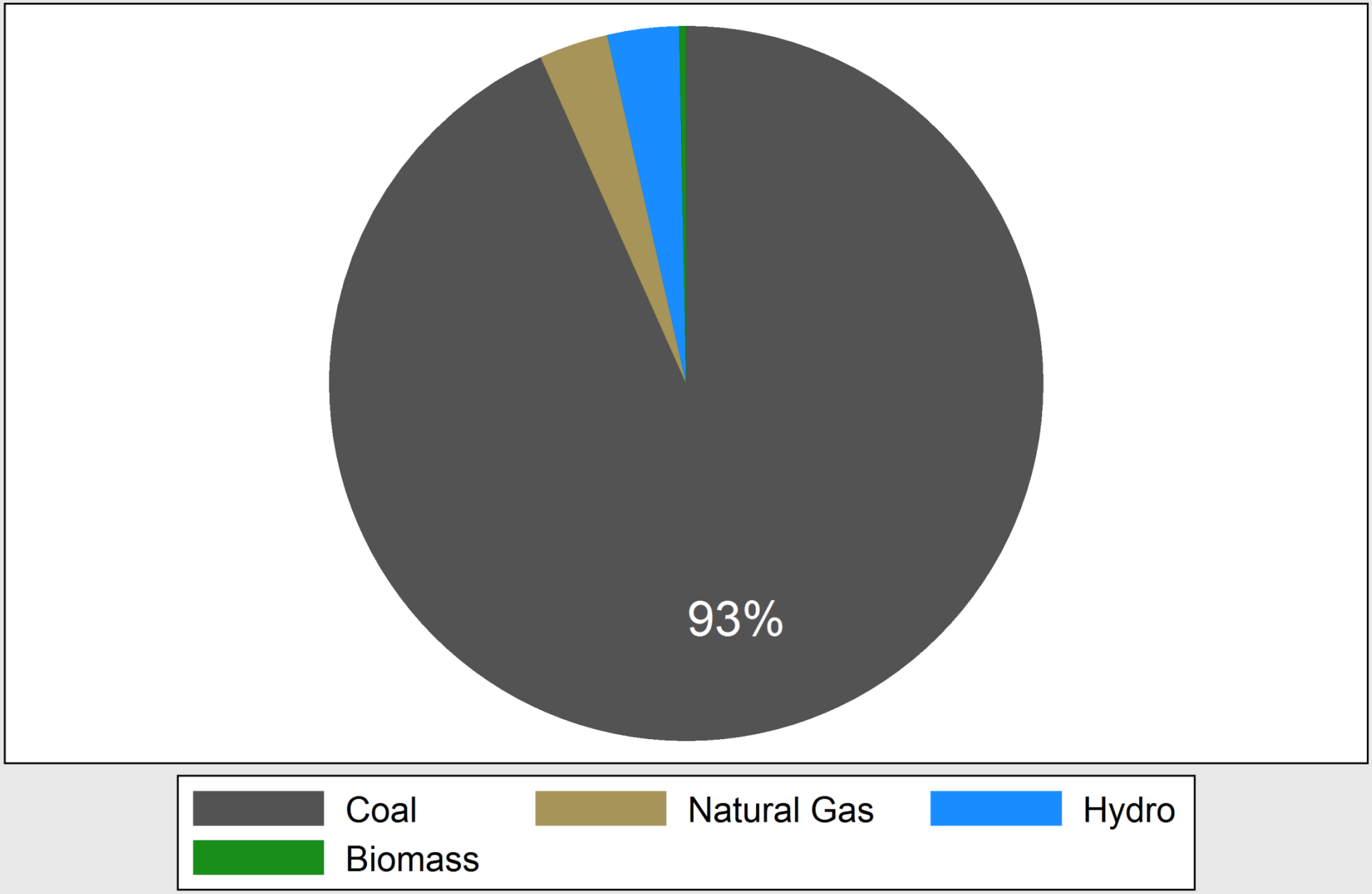
President's Climate Agenda

EPA using Clean Air Act 111(b) to set an unachievable 1,100 lbs. o f CO_2 per MWh limit for new coal power plants.
EPA is considering using Clean Air Act 111(d) to establish CO_2 emission standards for existing coal power plants.



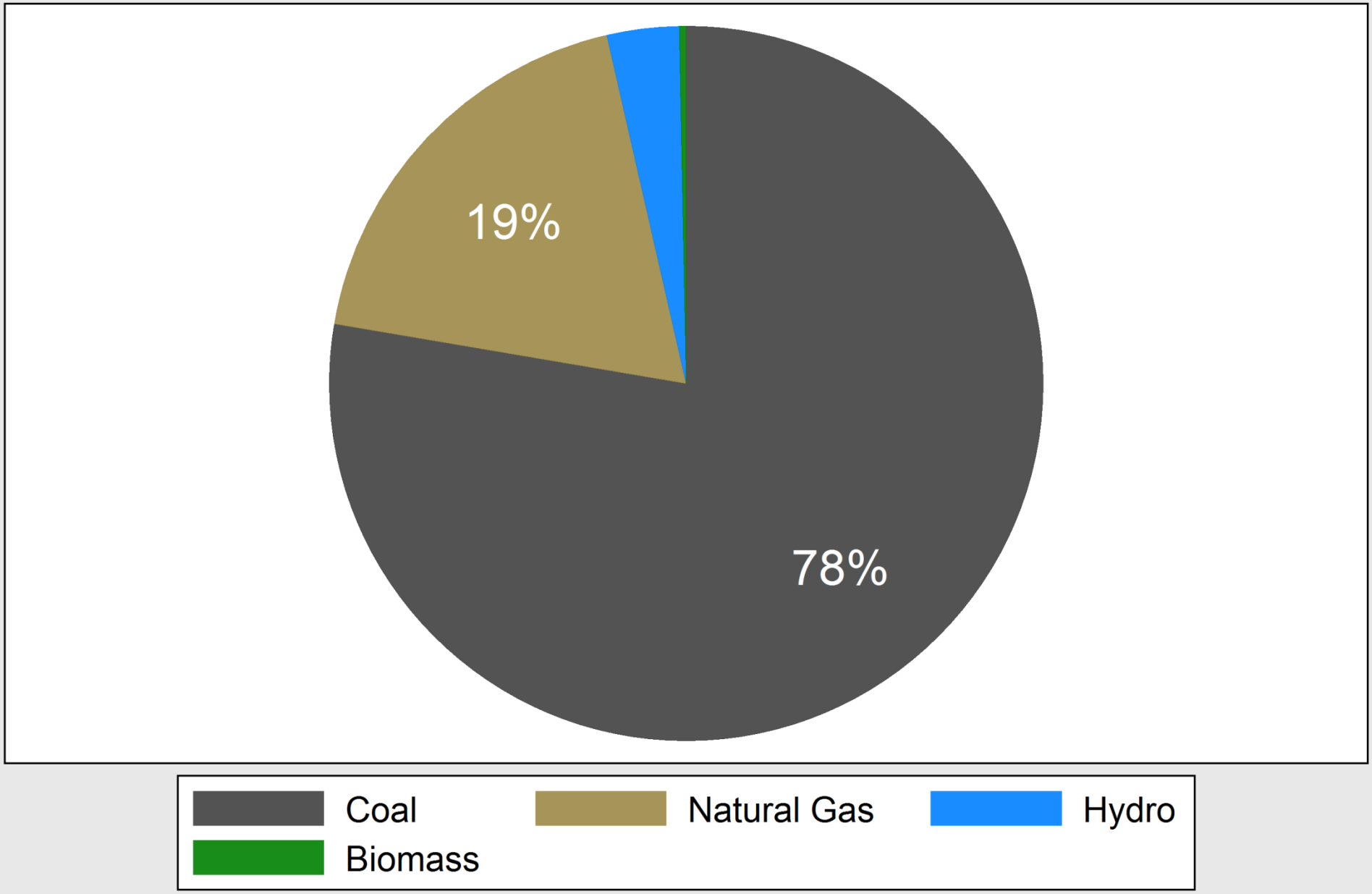
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation, 2015



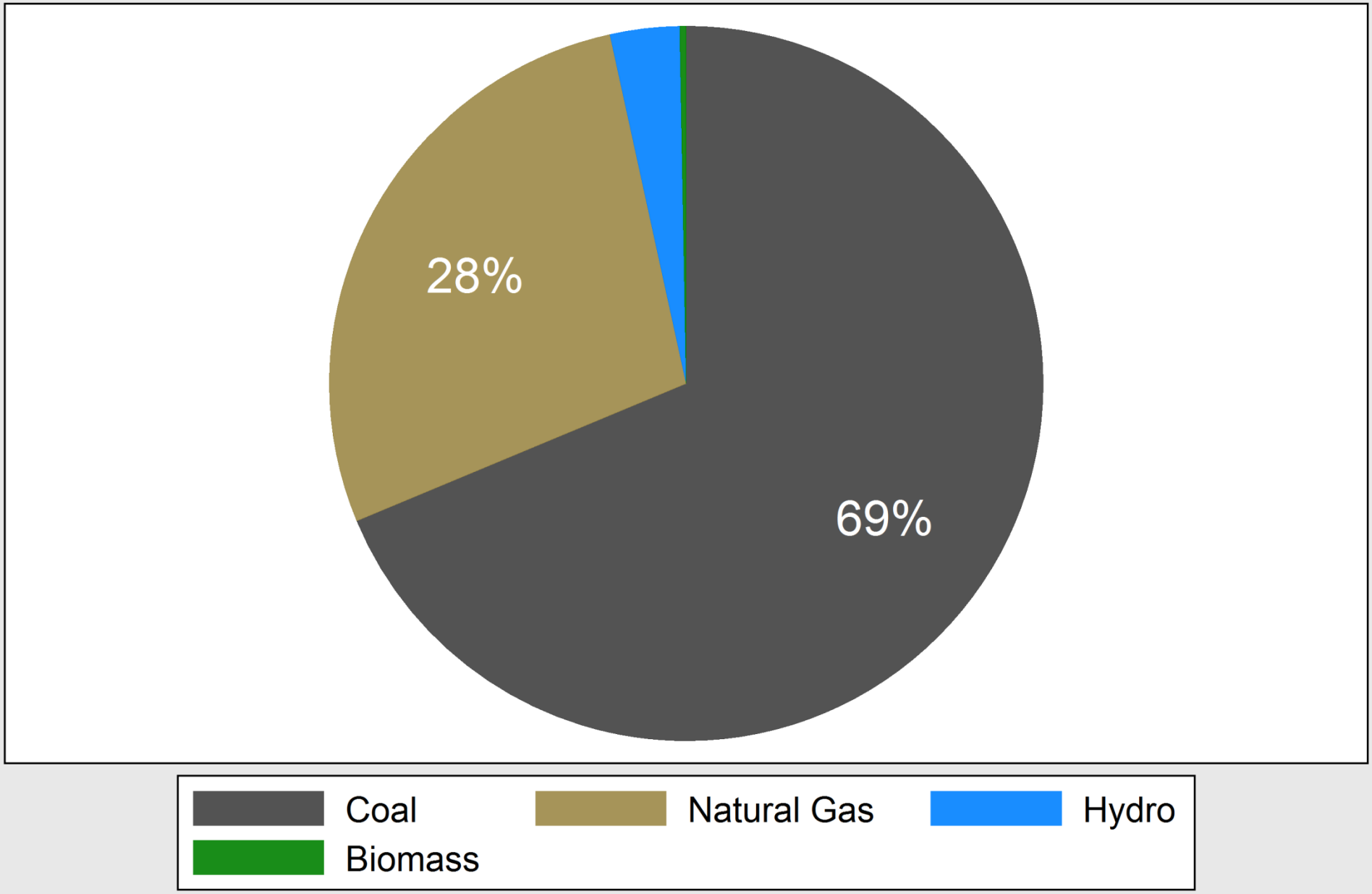
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation, 2020



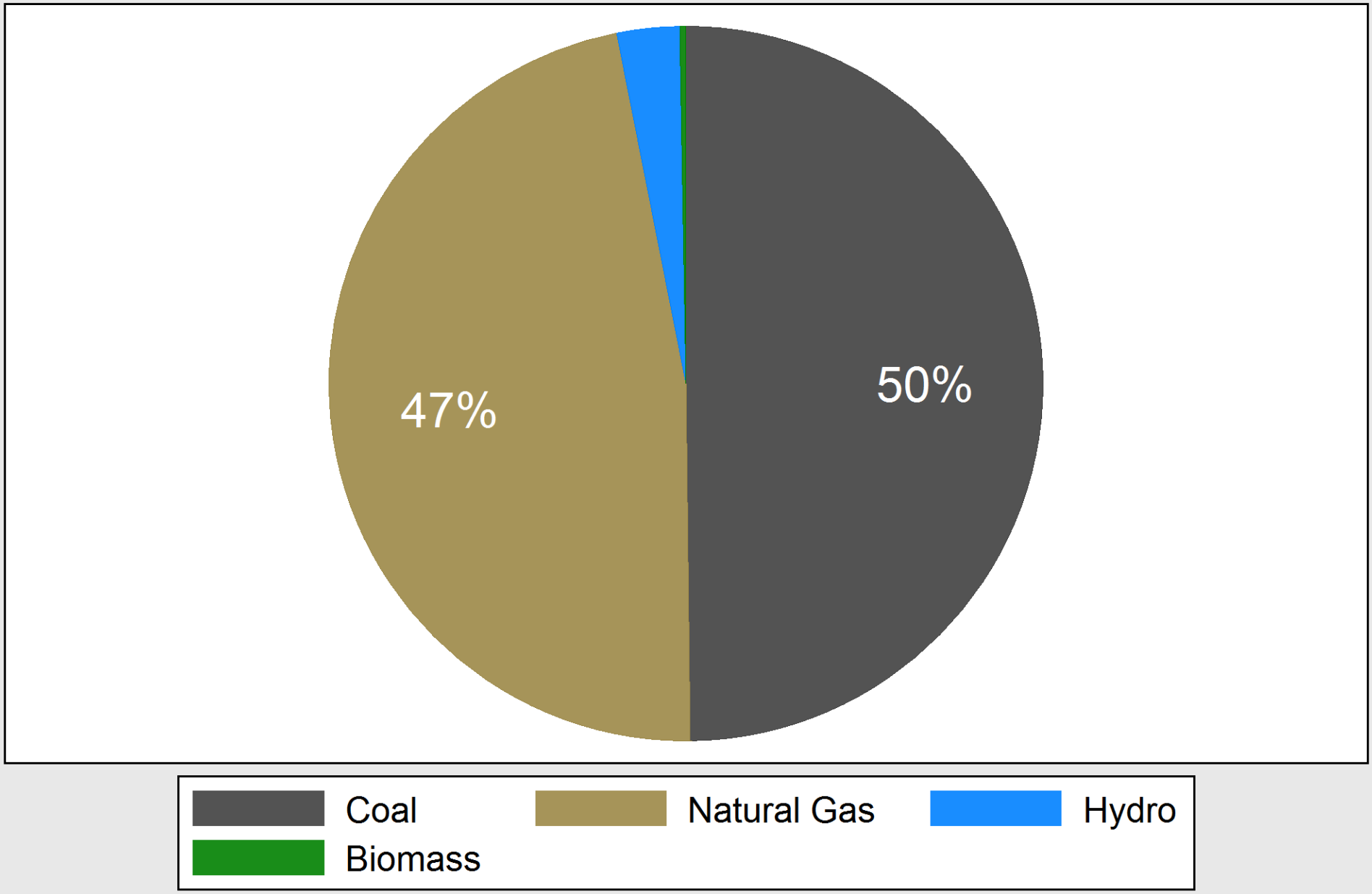
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation, 2025



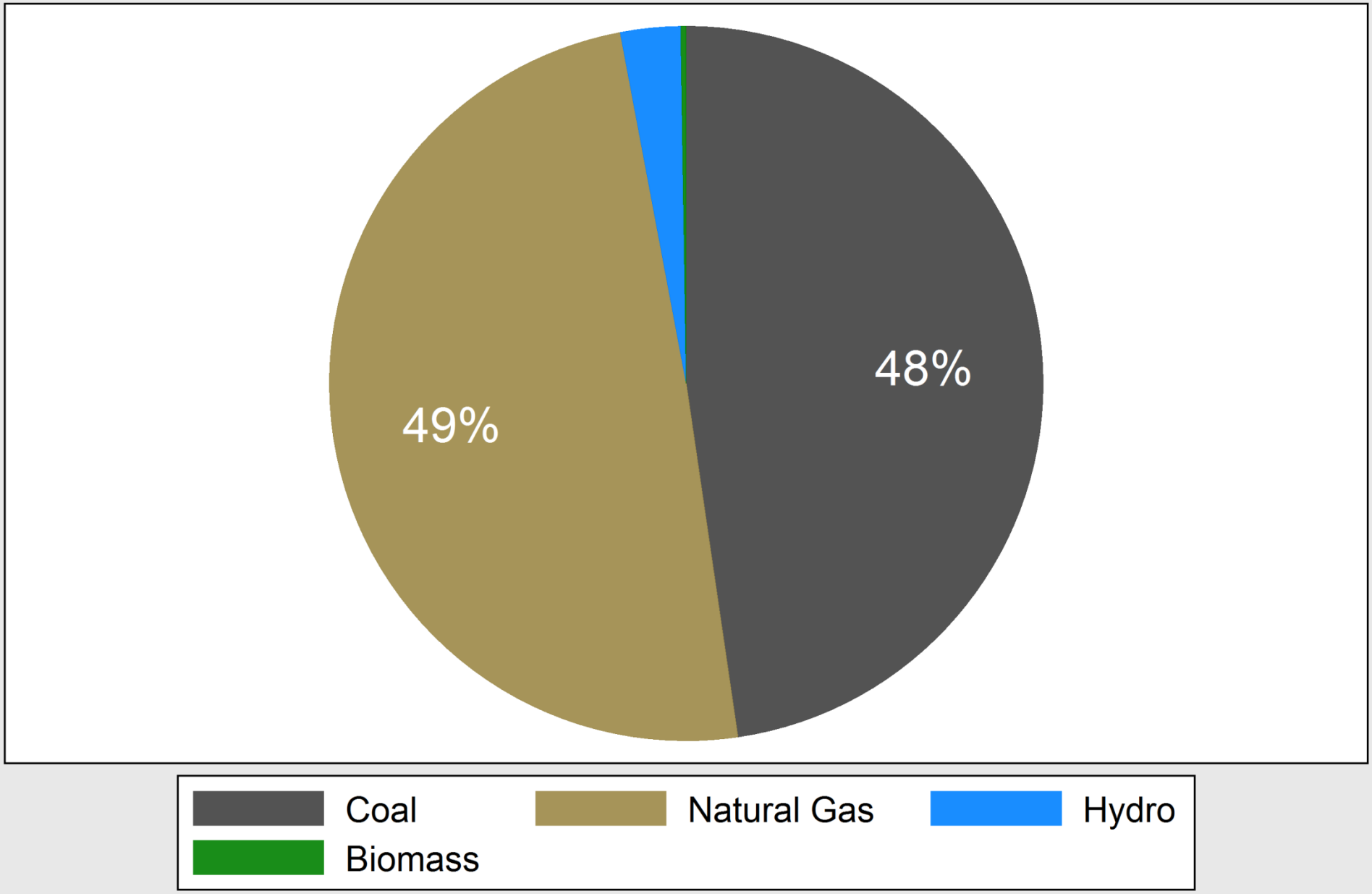
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation, 2035



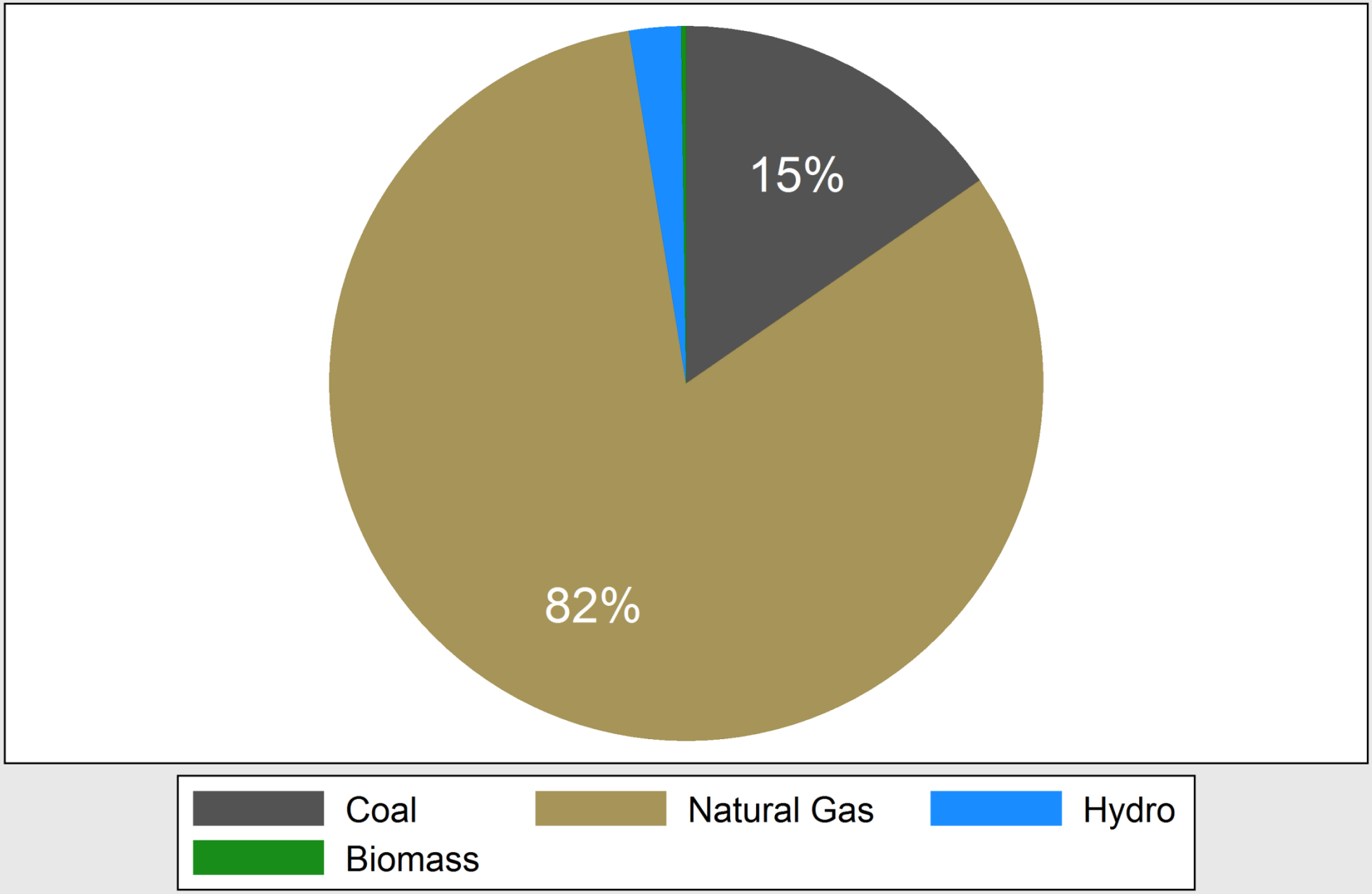
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation, 2040

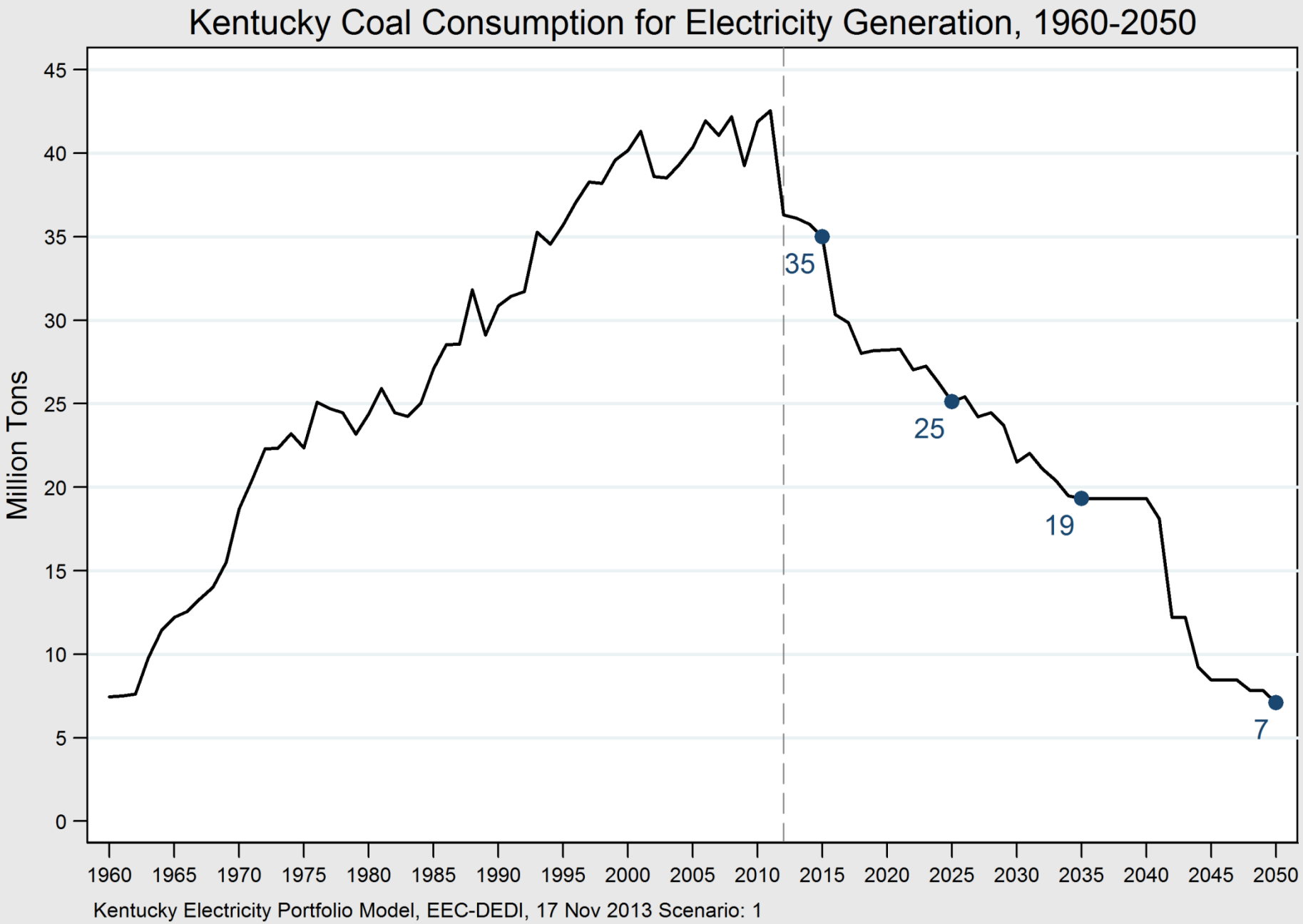


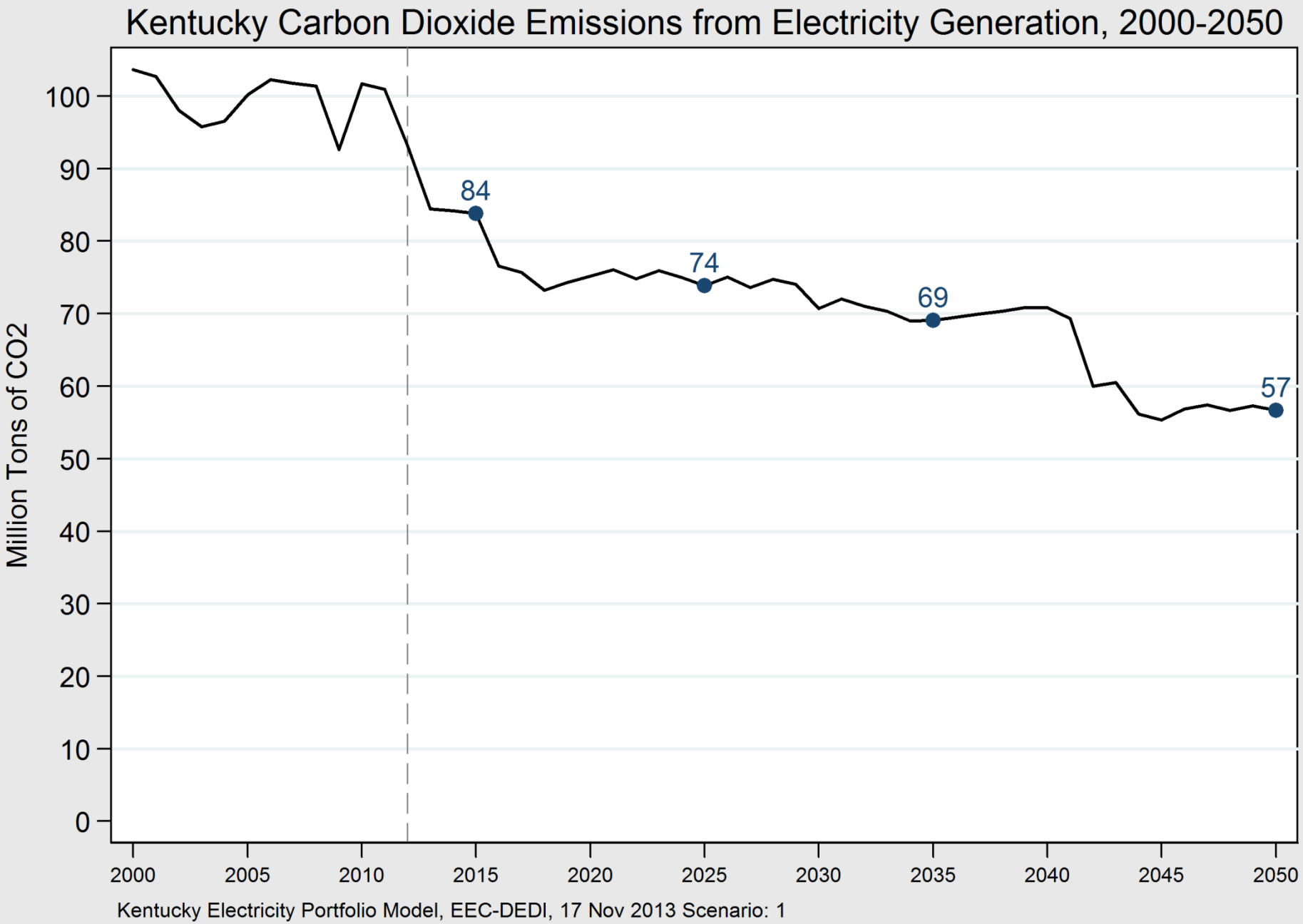
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario:1

Kentucky Electricity Generation, 2050



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


Kentucky Coal Consumption for Electricity Generation, 1960-2050
Million Tons
45
40
35
30
25
20
15
10
5
0
35
25
19
7
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1


Kentucky Carbon Dioxide Emissions from Electricity Generation, 2000-2050
Million Tons of CO2
100
90
80
70
60
50
40
30
20
10
0
84
74
69
57
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
Kentucky Electricity Portfolio Model, EEC-DEDI, 17 Nov 2013 Scenario: 1

Significance of Electricity to Kentucky

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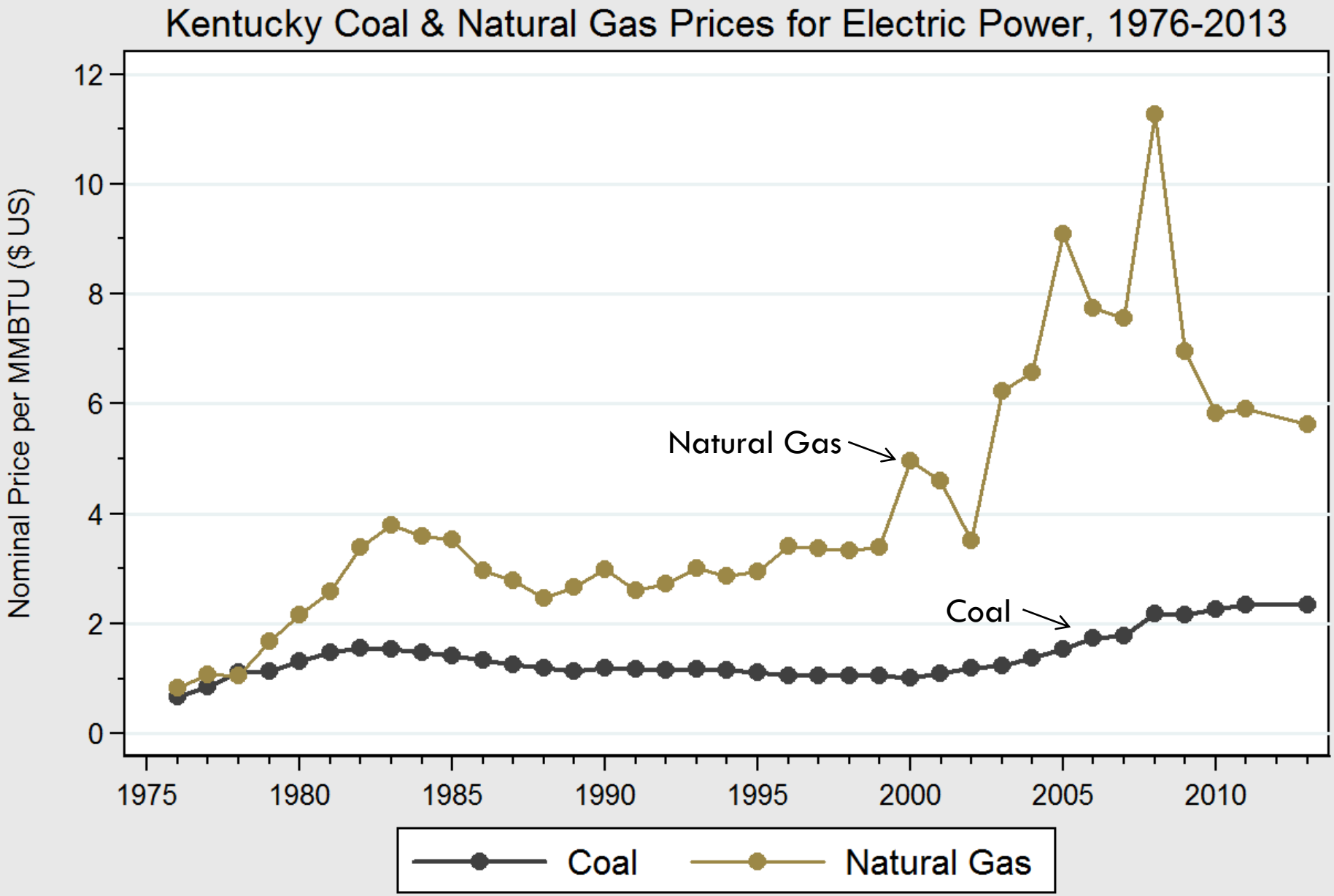
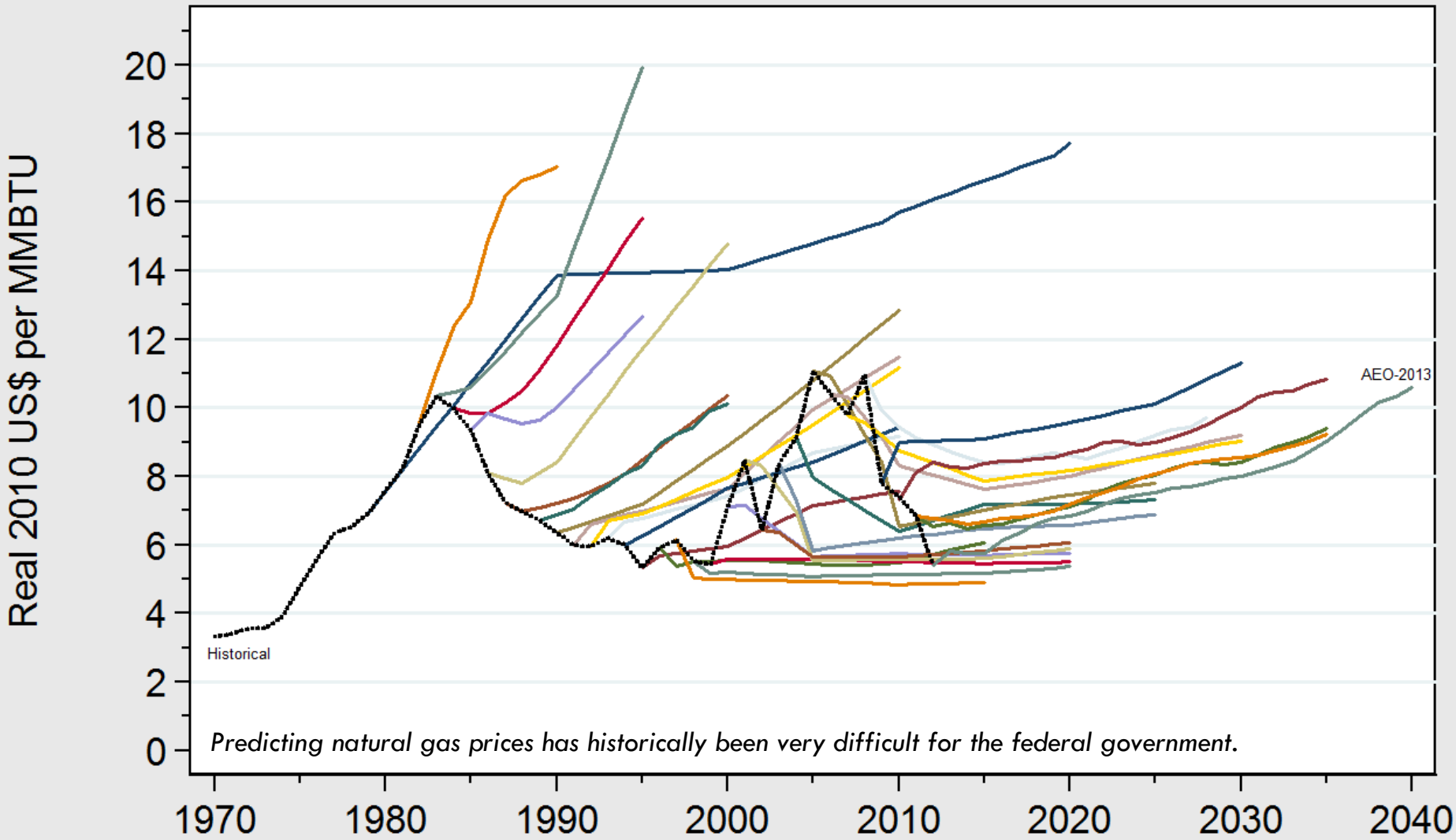


Kentucky Energy Database, EEC-DEDI, 2014

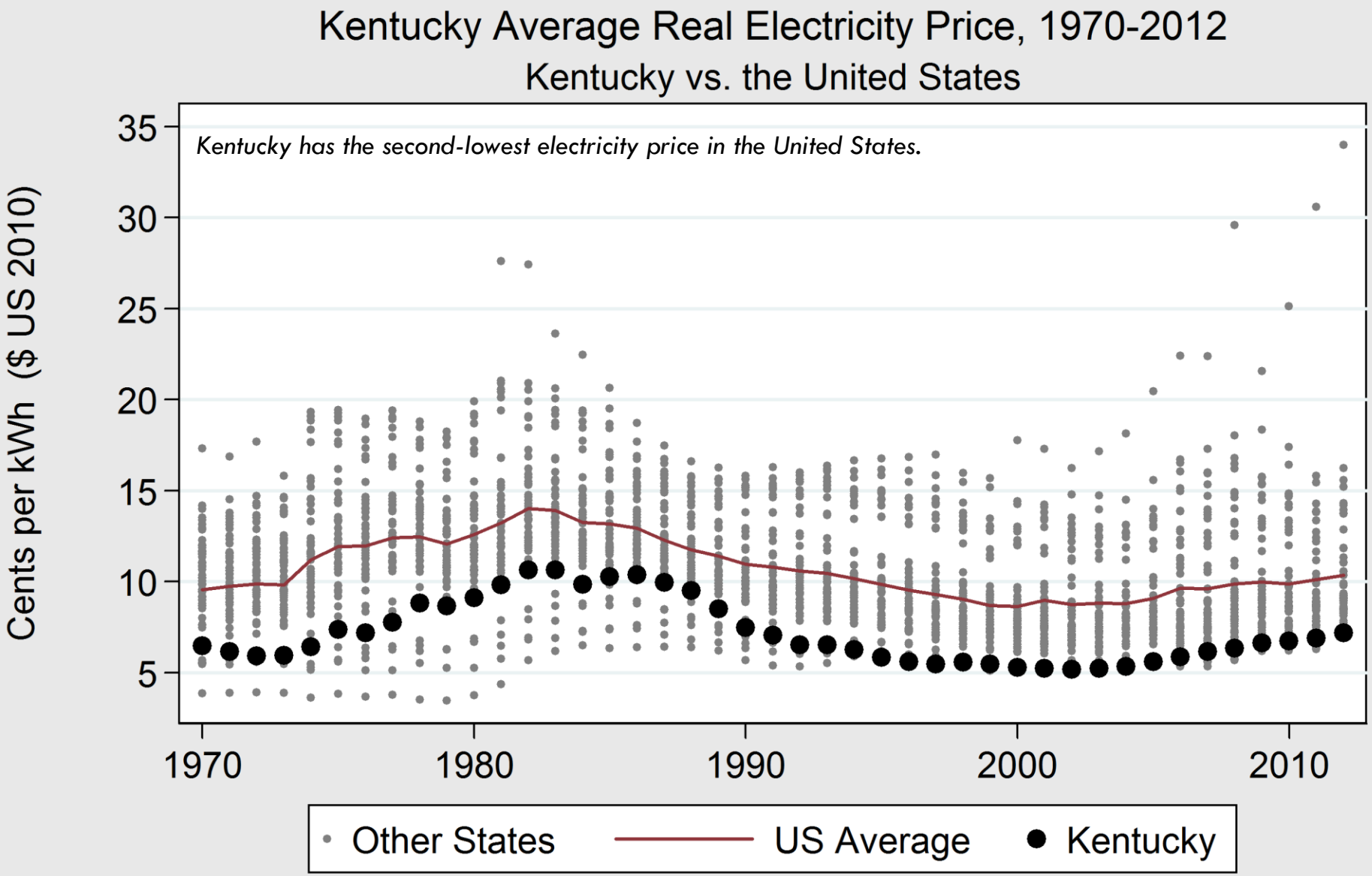
EIA Natural Gas Price Forecasts, 1979-2013

Energy Information Administration Annual Energy Outlook Forecasts vs. Actual



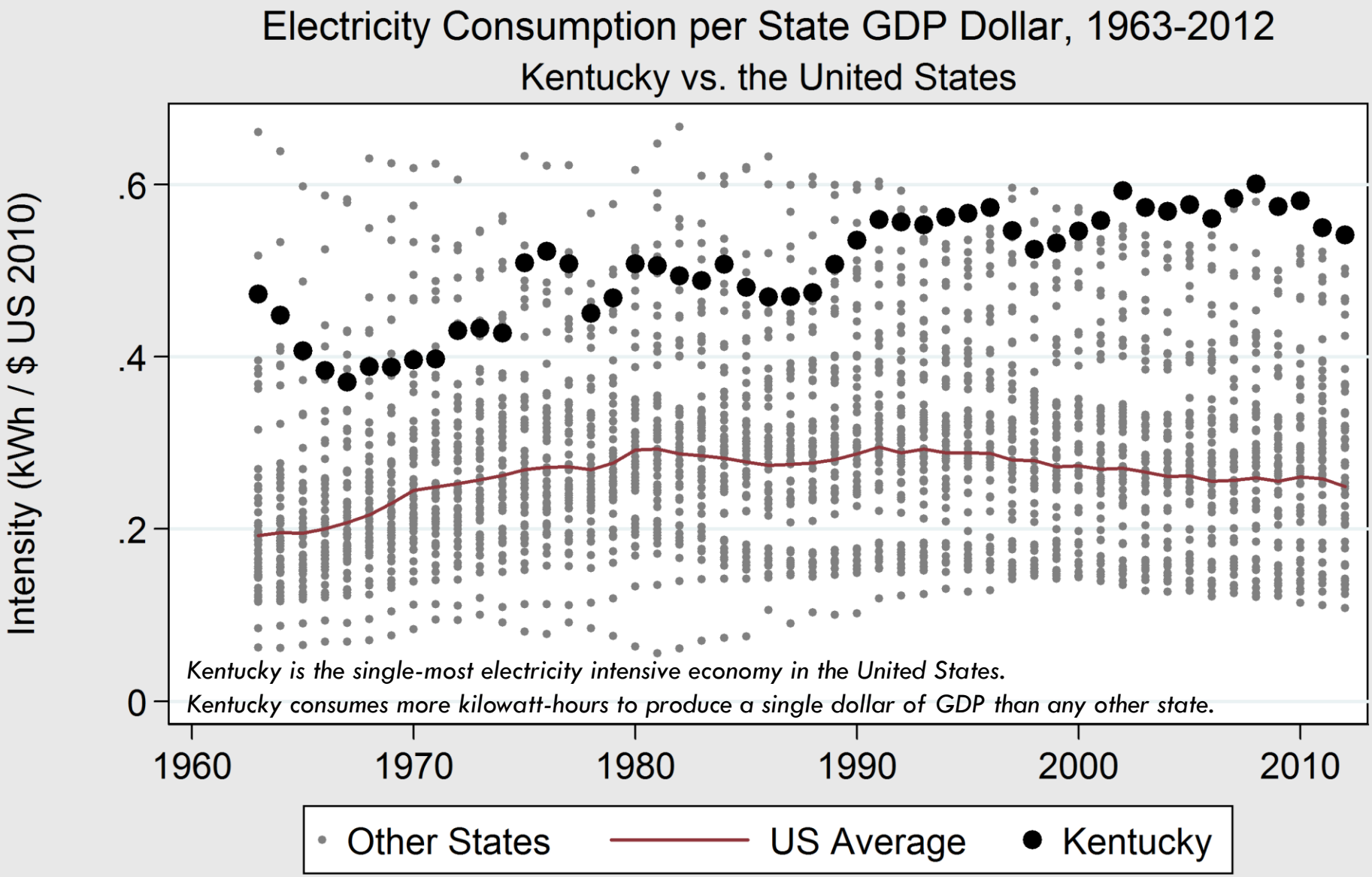
Kentucky Energy Database, EEC-DEDI, 2013

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



Kentucky Energy Database, EEC-DEDI, 2013

Data Source: EIA Form 861 & 826 & BLS-CPI

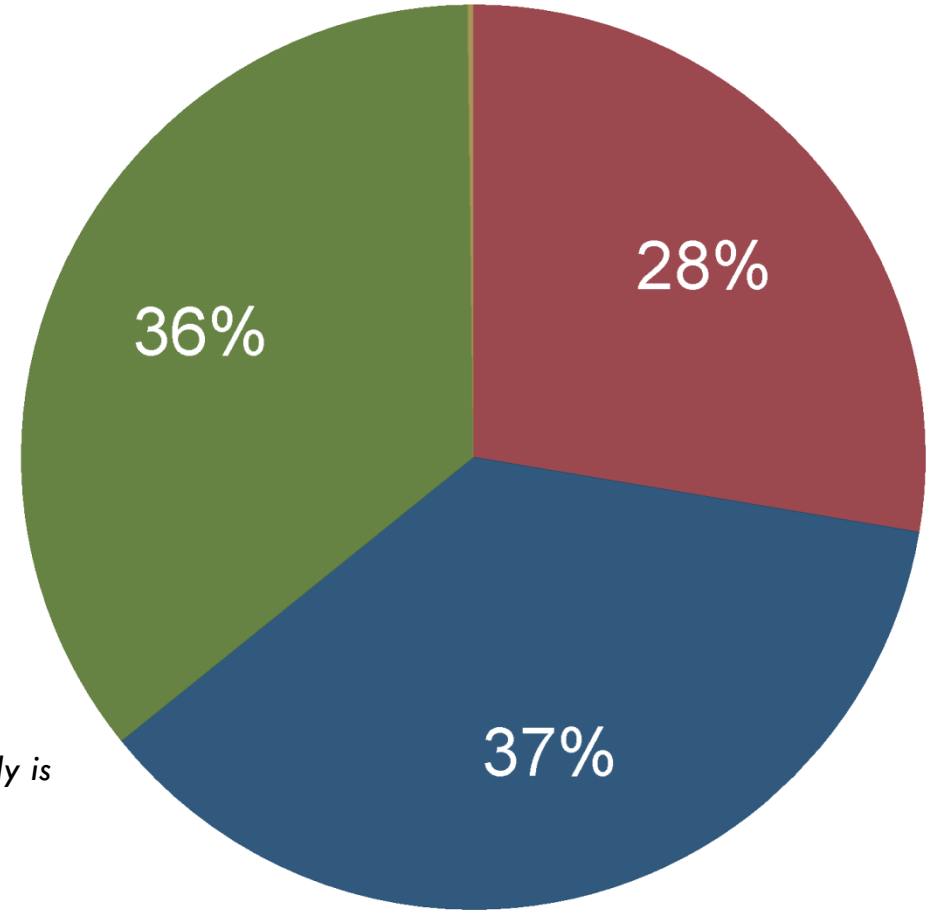


Kentucky Energy Database, EEC-DEDI, 2013

Data Source: EIA Forms 861 & 826 & BEA GDP by State

United States Electricity Consumption, 2012

Consumption by Sector (%)



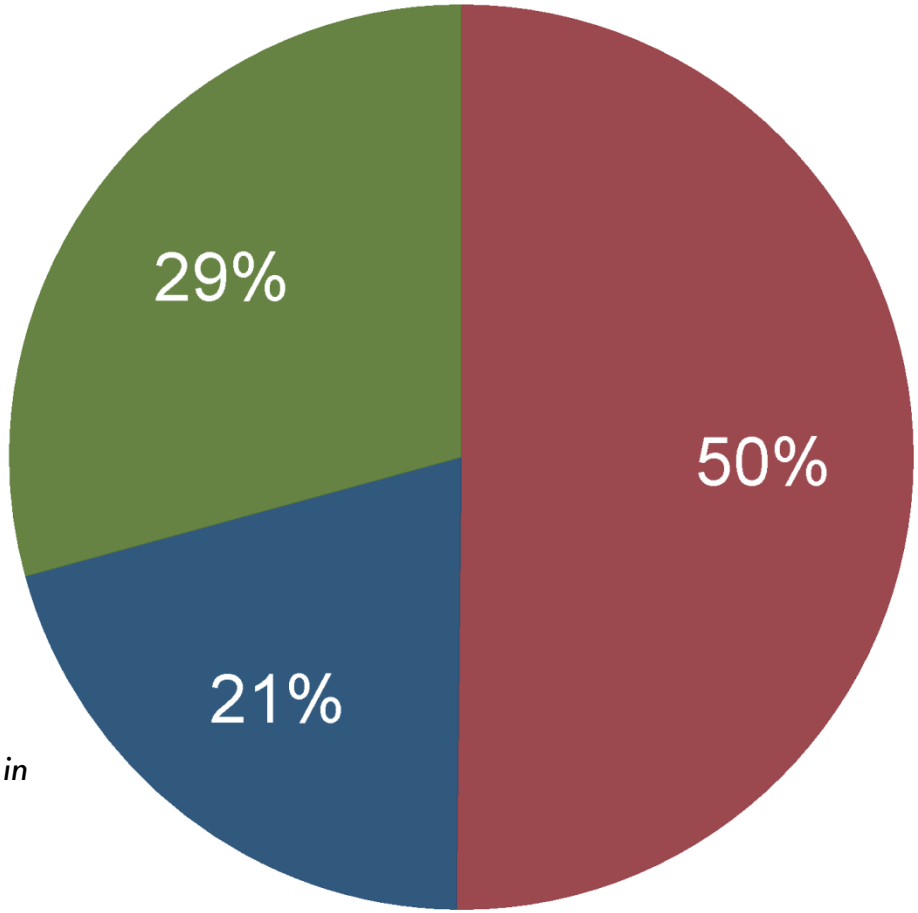
Electricity consumption nationally is split fairly equally between commercial, industrial, and residential consumers.

Industrial
Commercial
Residential
Transportation

Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Consumption, 2012

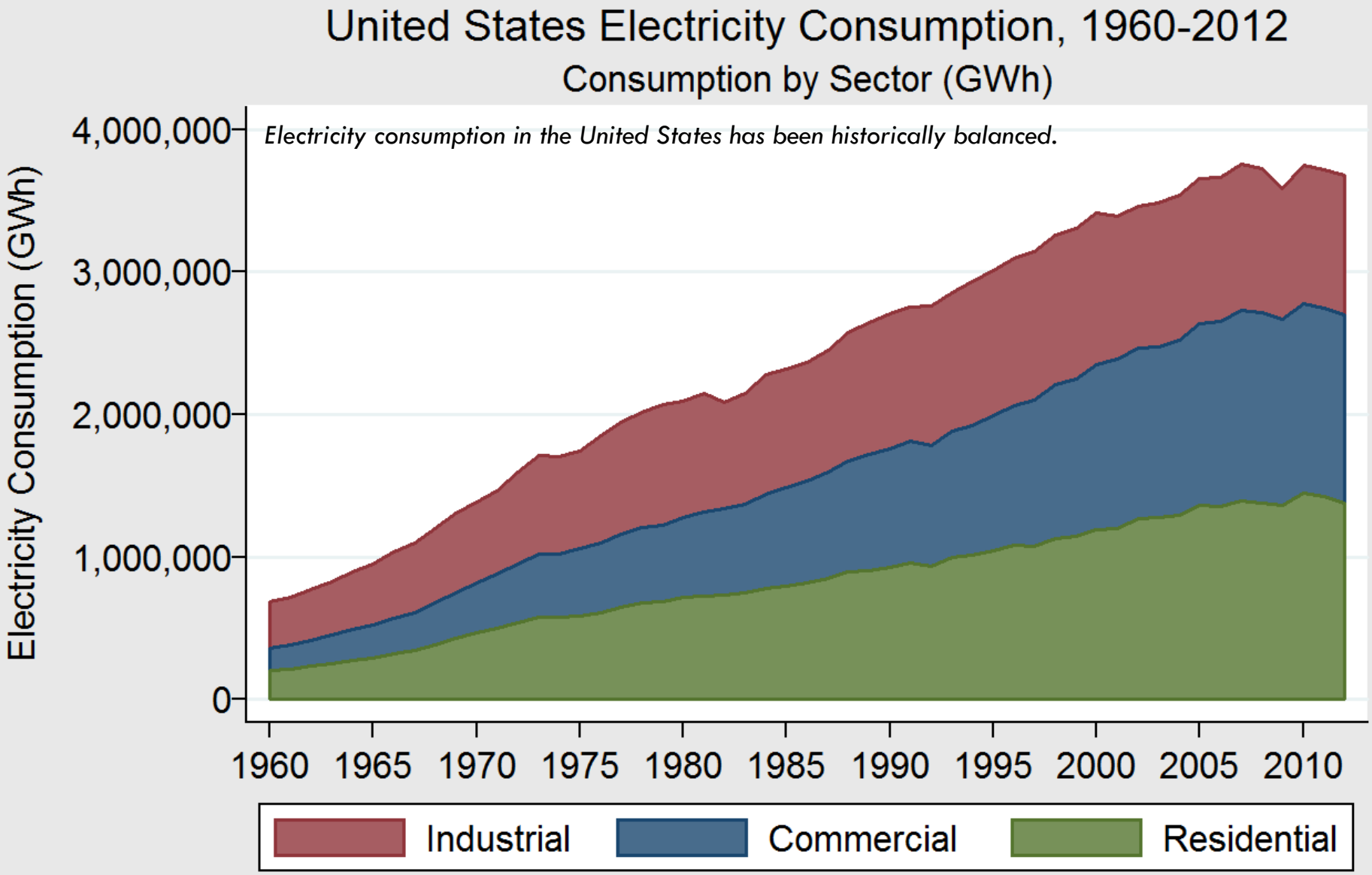
Consumption by Sector (%)



Half of the electricity consumed in Kentucky every year goes to industrial and manufacturing processes.

Industrial
Commercial
Residential

Kentucky Energy Database, EEC-DEDI, 2013

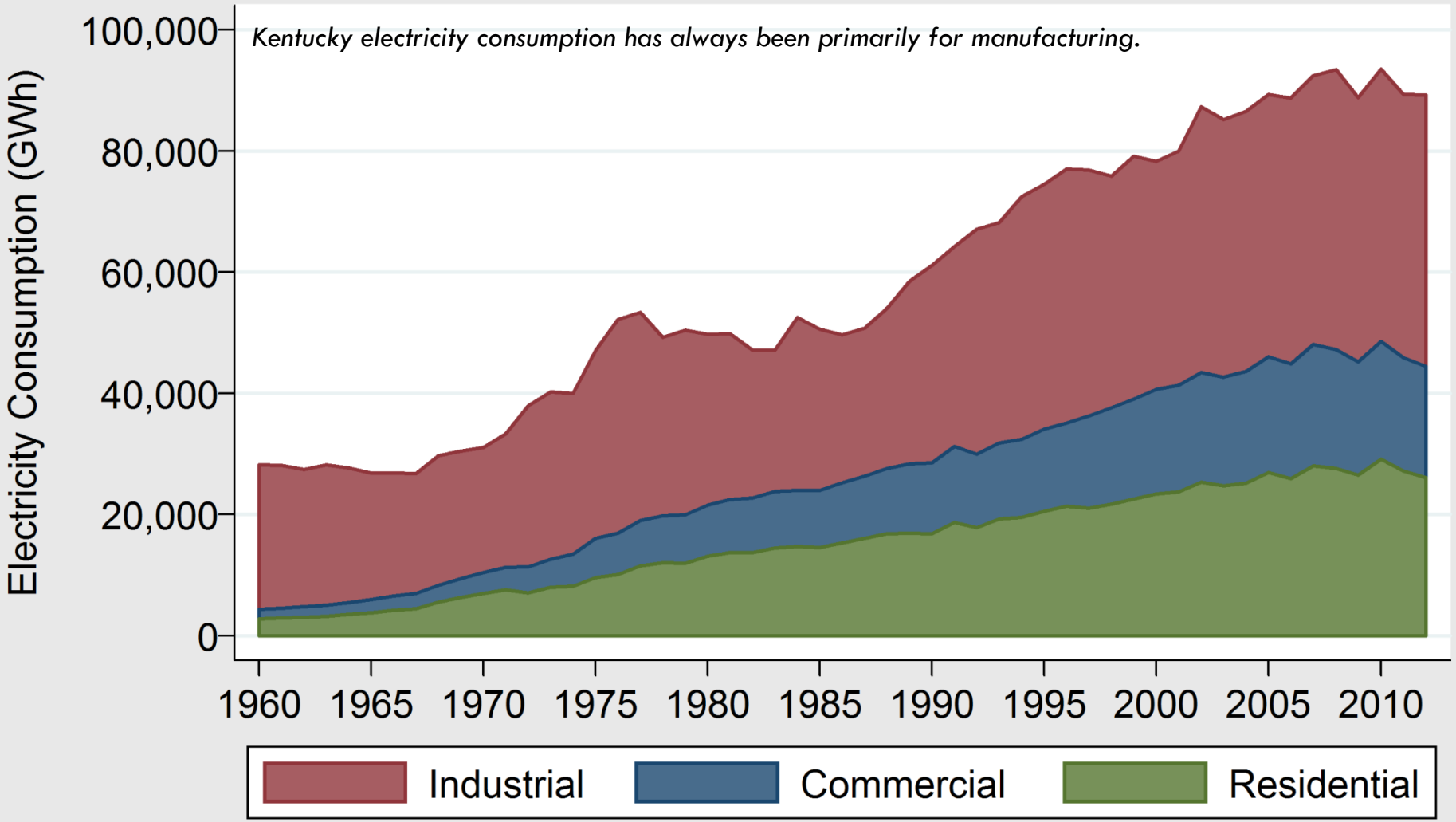


Kentucky Energy Database, EEC-DEDI, 2013

Data Source: EIA Form 861 & 826

Kentucky Electricity Consumption, 1960-2012

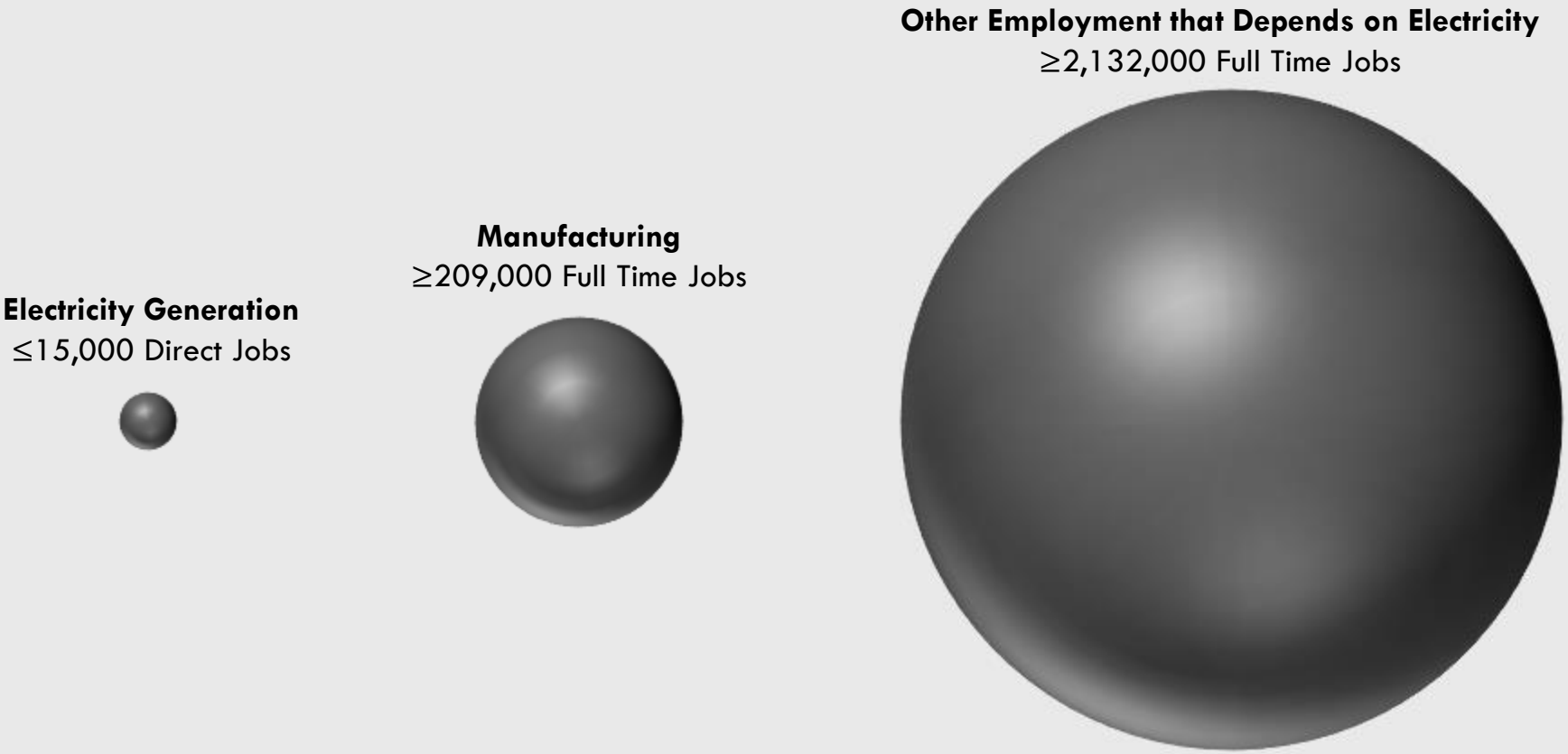
Consumption by Sector (GWh)



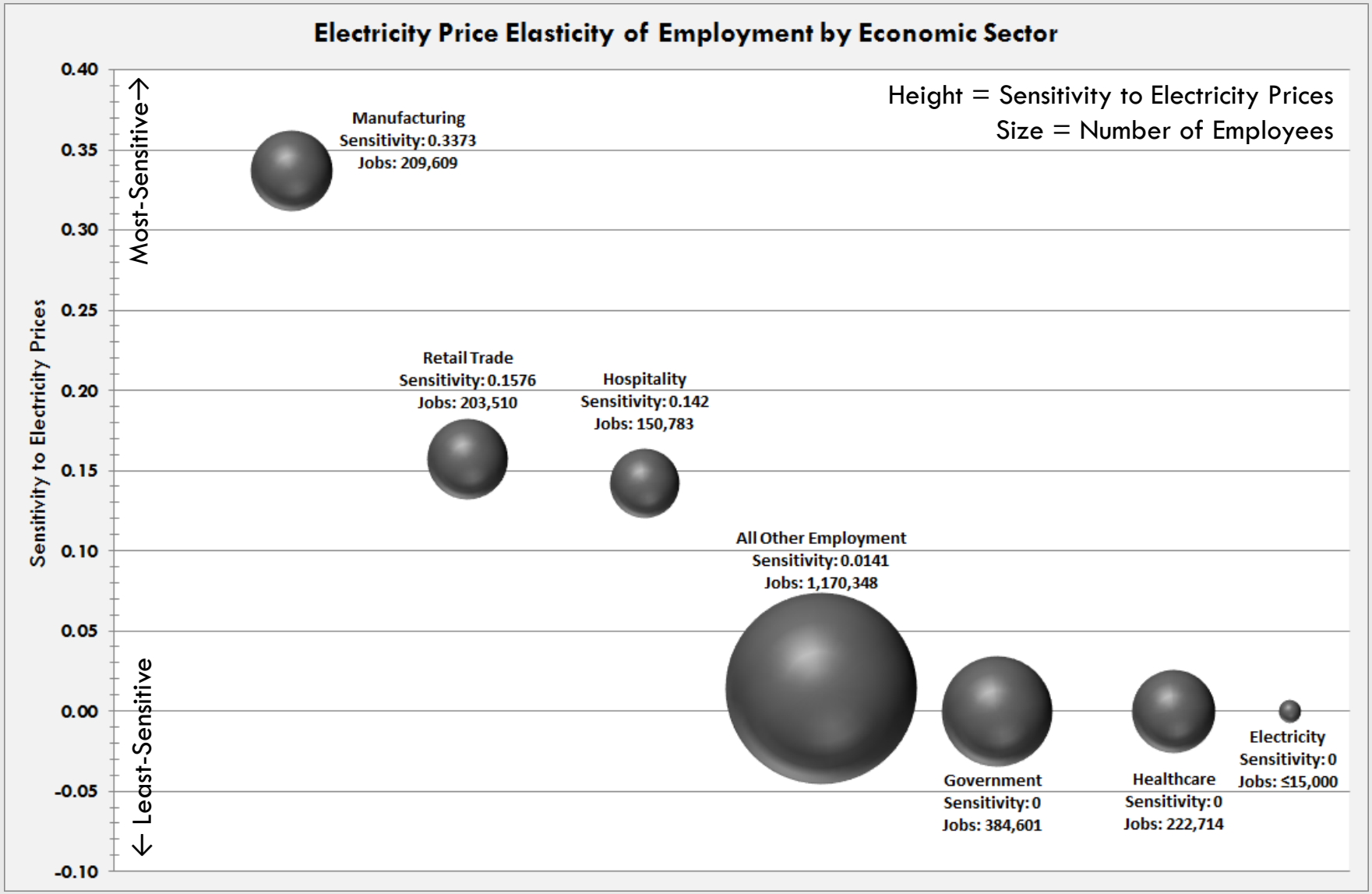
Kentucky Energy Database, EEC-DEDI, 2013

Data Source: EIA Form 861 & 826

Kentucky Electricity Portfolio & Employment



Employment Depends Upon Electricity – Direct employment for electricity generation, such as power plant operators and coal miners, is a relatively smaller portion of total employment in Kentucky compared to the millions of jobs that depend upon the reliable and inexpensive electricity they produce. Electricity-dependent jobs can be modeled with electricity price elasticity of employment coefficients.



Sensitivity to Electricity Prices Differs by Industry – This study developed price elasticity of employment coefficients for the top five employment sectors in Kentucky by modeling the historical responsiveness of employment nationally. Manufacturers were the most-responsive. Retail stores, restaurants, and hotels were less than half as responsive. Government and healthcare showed no responsiveness whatsoever.

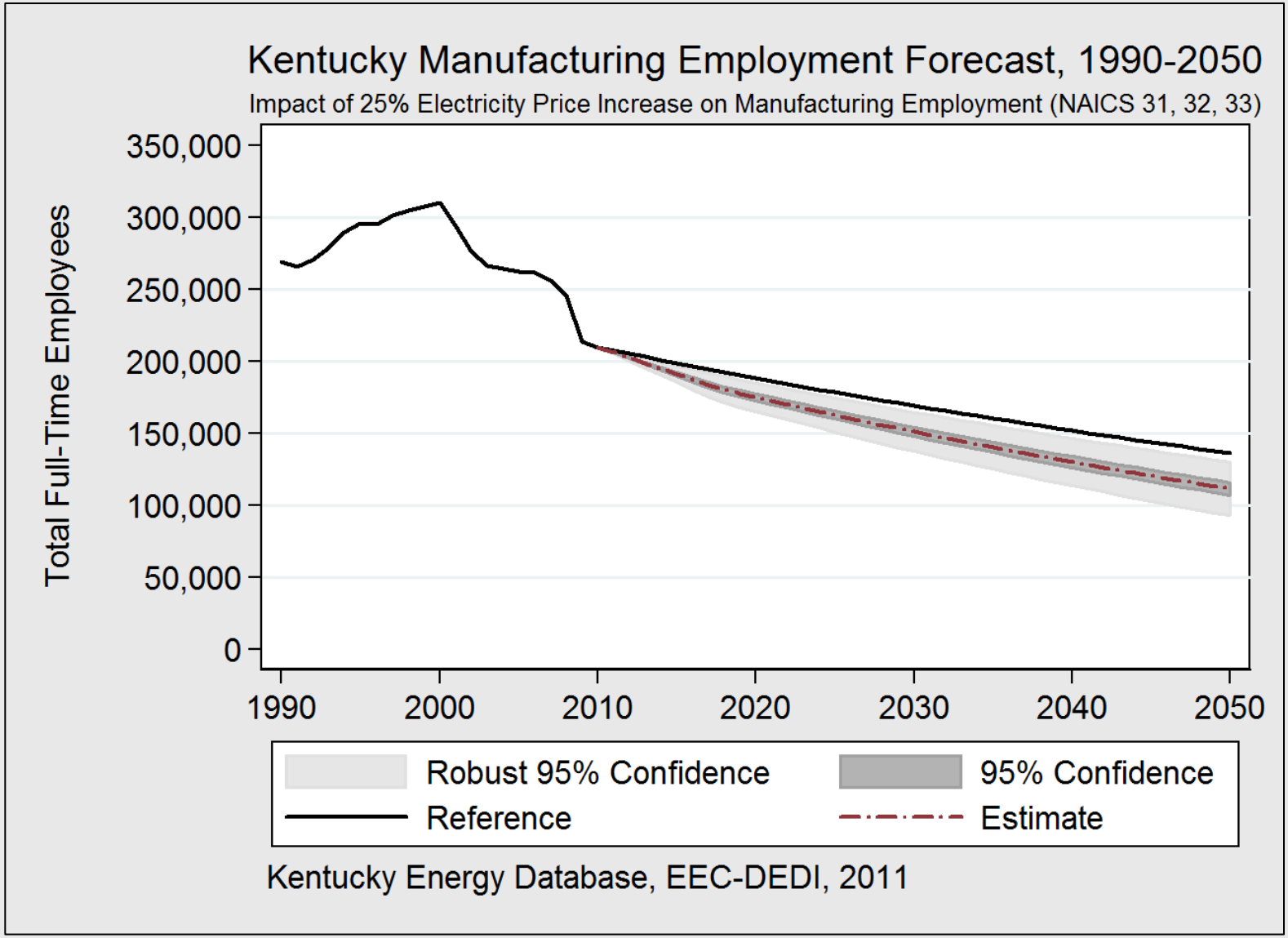
Kentucky Electricity Portfolio & Employment

Intensity Rank	Manufacturing Sector	Kilowatt-hours per $ of Product	Kentucky Electricity Cost per $ of Product	Percentage of Production Costs	Kentucky Workers
1	**Aluminum Smelting**	4.37313	$0.236	23.6%	3,482
2	**Iron & Steel Mills**	1.5764	$0.085	8.5%	2,954
4	**Basic Chemical**	0.71269	$0.039	3.9%	3,043
5	**Glass Manufacturing**	0.60508	$0.033	3.3%	2,015
24	**Motor Vehicle Parts**	0.14747	$0.008	0.8%	16,660
52	**Motor Vehicle Assembly**	0.03654	$0.002	0.2%	11,384

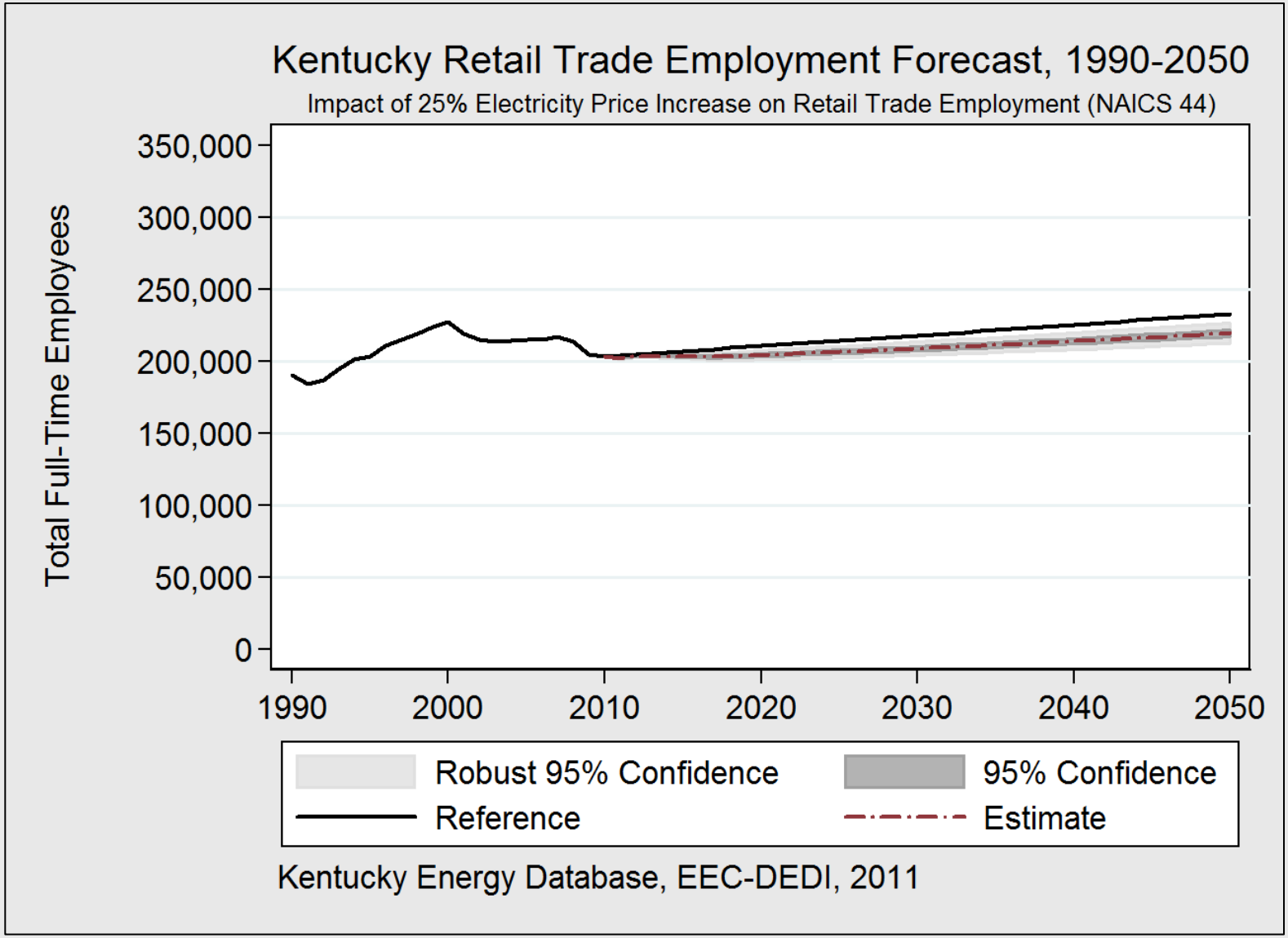
The production of aluminum, iron, steel, chemicals, and glass are some of the most-electricity intensive manufacturing processes, where up to a quarter of total production costs go to electricity expenses.

Other large manufacturing sectors, like motor vehicle assembly, which may be less electricity-intensive, depend upon primary material inputs from more electricity-intensive sectors.

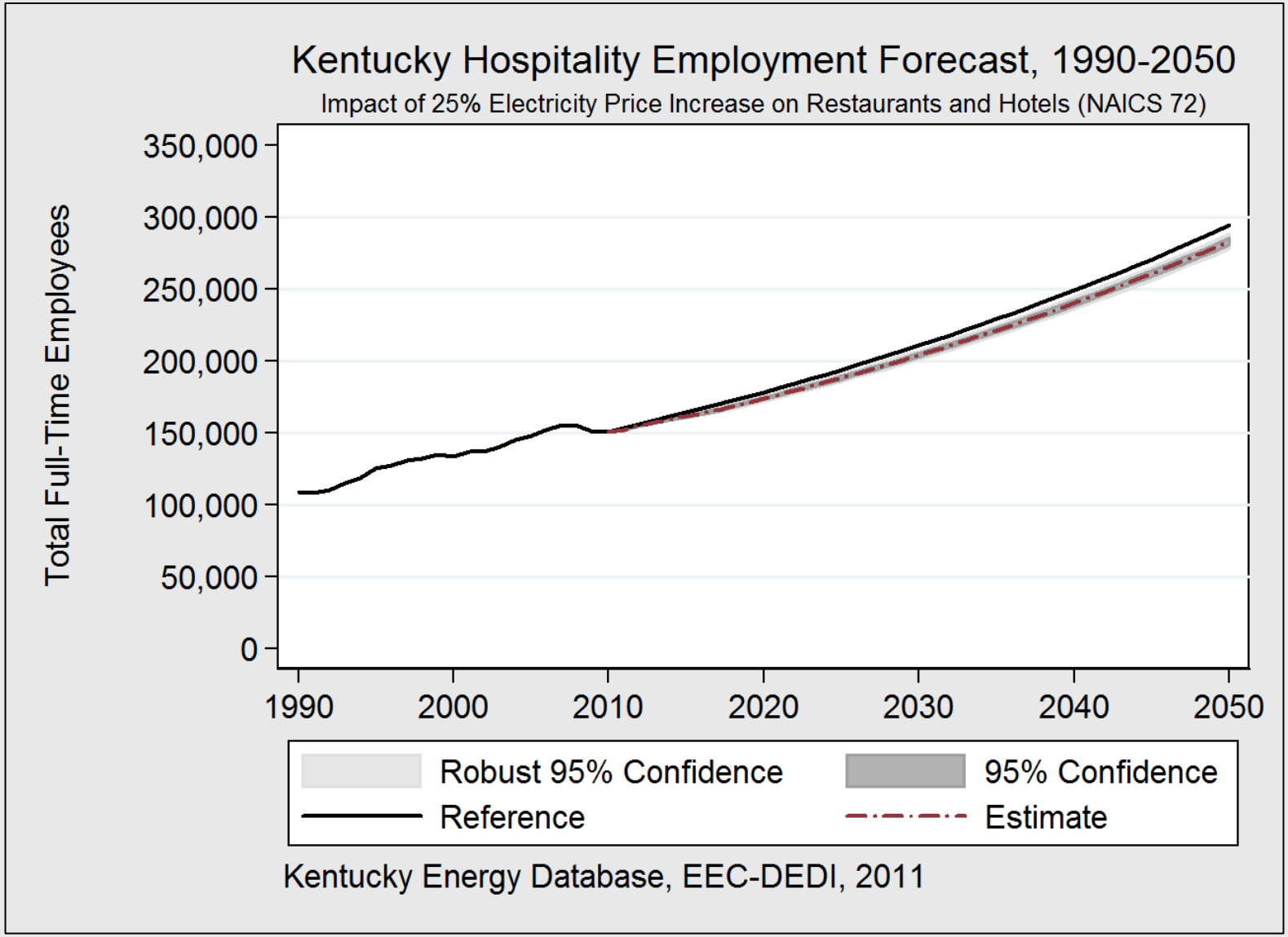
The complete List of all manufacturing sectors is available on page of 4 of the associated white paper: http://energy.ky.gov/Programs/Documents/Vulnerability%20of%20Kentucky's%20Manufacturing%20Economy.pdf



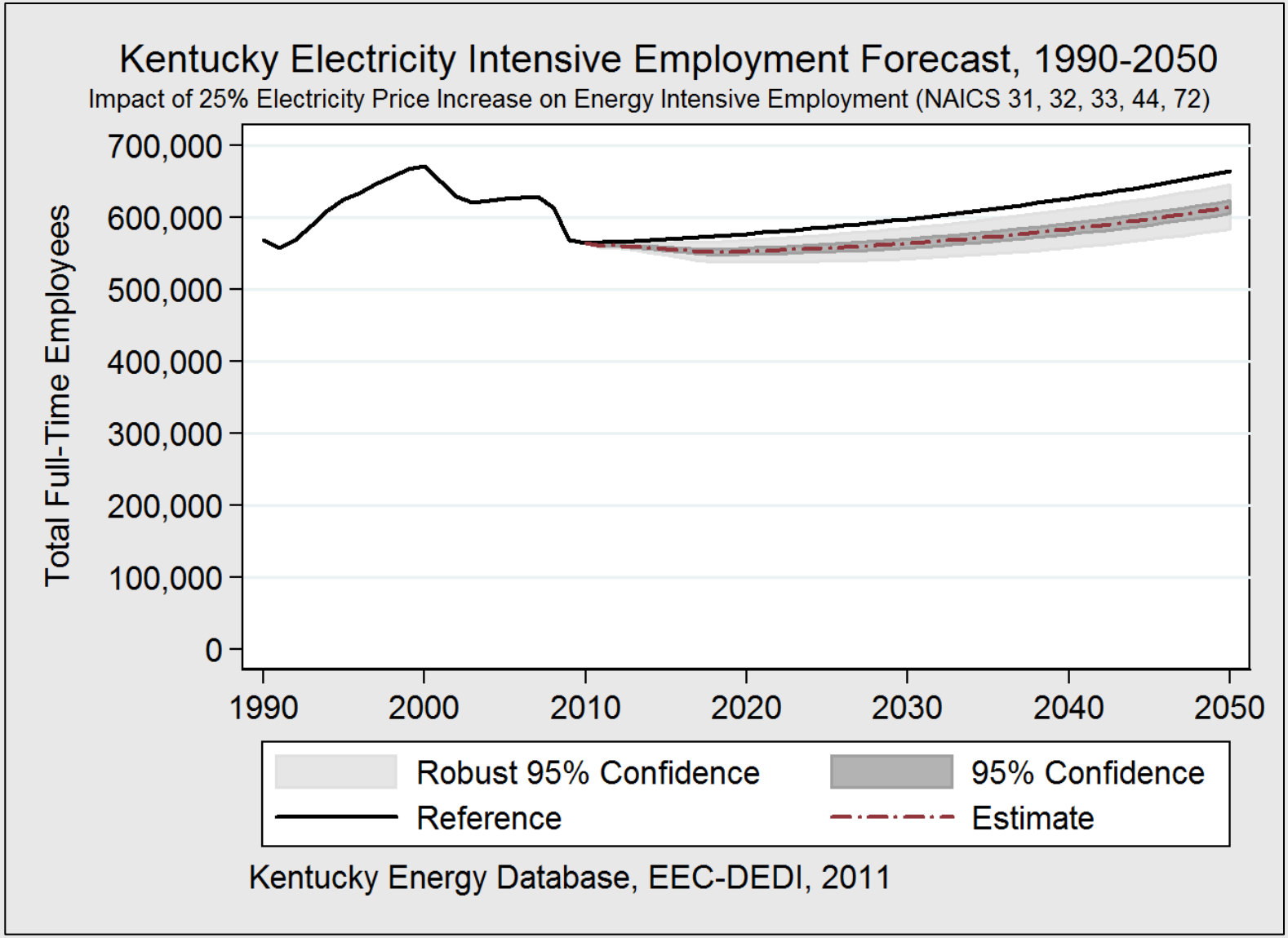
Manufacturers are the Most-Responsive to Electricity Prices - Given a 25% increase in real electricity prices by 2025, manufacturing establishments in Kentucky would be expected to permanently shed an additional **17,660** full-time jobs long-run as a direct result of price increases, and with 95% confidence using robust standard errors between **5,764** and **31,022** full-time jobs, *ceteris paribus*.



Retail Stores are Much Less Responsive - Given a 25% increase in real electricity prices by 2025, retail establishments in Kentucky would be expected to fail to create **7,225** full-time jobs long-run, and with 95% confidence using robust standard errors, between **3,916** and **12,160** full-time jobs, *ceteris paribus*.



Restaurants and Hotels are Even Less Responsive - Given a 25% increase in real electricity prices by 2025, restaurants and hotels in Kentucky would be expected to shed **5,352** full-time jobs long-run, and with 95% confidence using robust standard errors, between **2,940** and **7,765** full-time jobs, *ceteris paribus*.



Combined Impact of Electricity-Intensive Sectors - Given a 25% increase in real electricity prices by 2025, Kentucky's most electricity-intensive economic sectors, (manufacturing, retail trade, restaurants, and hotels) could be expected to shed a combined total of **30,237** full-time jobs and with 95% confidence and robust standard errors between **12,620** and **50,947**.

Significance of Electricity to Kentucky

- **Low and stable electricity prices have fostered the single-most electricity intensive manufacturing economy in the United States.**
- **Half of the electricity consumed in Kentucky goes to manufacturing.**
- **Manufacturing is Kentucky's largest source of GDP and leading source of employment.**
- **Kentucky's economy is vulnerable to electricity price increases.**
- **Price elasticity of employment should be taken into consideration, when trying to understand such impacts.**

Download the Full Report

"The Vulnerability of Kentucky's Manufacturing Economy to Increasing Electricity Prices"

A Quick Peek at Some of the

The Mathematics behind the Forecasts

Model of Electricity Prices & Employment by Sector

A multiple regression of panel data model using fixed effects was estimated for each of the top five employment opportunities in Kentucky, both with and without robust standard errors, for a total of ten models. Fixed effects were used to control for the numerous factors inherently affecting sector-specific employment as well as electricity prices from state to state that have not been accounted for in the independent variables included in this study. The result is a conservative estimate of the isolated national effect of the variable of interest, real electricity prices on employment by industry.

The 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, employment by industry, in state i in year t, β_0 is the constant y intercept across all states, X is a k by 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.

Read the Complete Report on this Model

Model of Electricity Prices & Employment by Sector

A multiple regression of panel data model using fixed effects was estimated for each of the top five employment opportunities in Kentucky, both with and without robust standard errors, for a total of ten models. Fixed effects were used to control for the numerous factors inherently affecting sector-specific employment as well as electricity prices from state to state that have not been accounted for in the independent variables included in this study. The result is a conservative estimate of the isolated national effect of the variable of interest, real electricity prices on employment by industry.

The multiple regression of panel data model with fixed effects can be generally given by,

Predicted Employment by Industry in State (i) and Time (t)

Stochastic Error Term (~ $N(0, \sigma^2)$)

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

Constant Intercept Across States

Fixed Effect for State (i)

Sum of the product of the observation for each independent variable *j* through *k* for state *i* in year *t* and the coefficient of *Xj*

Where *i* and *t* index states and years, such that y_{it} is the dependent variable of interest, employment by industry, in state *i* in year *t*, β_0 is the constant *y* intercept across all states, *X* is a *k* by 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.

Read the Complete Report on this Model

Model of Electricity Prices & Employment by Sector

Logged Variables	Manufacturing Employment	Retail Employment	Hospitality Employment	Healthcare Employment	Government Employment
Price of Electricity	**-0.337** ***	**-0.158** ***	**-0.142** ***	**-0.0426** **	**0.00084**
(Real 2010 US$)	(-0.0307)	(-0.0136)	(-0.0152)	(-0.0158)	(-0.0101)
	0.0249	-0.108	-0.0679	-0.536 ***	-0.14 **
Educational Attainment	(-0.146)	(-0.065)	(-0.0728)	(-0.0758)	(-0.0482)
State GDP	0.744 ***	0.509 ***	0.318 ***	0.17 ***	0.253 ***
(Real 2010 US$)	(-0.0514)	(-0.0228)	(-0.0255)	(-0.0265)	(-0.0169)
Population	0.166 **	0.26 ***	0.129 ***	0.37 ***	0.258 ***
	(-0.0532)	(-0.0236)	(-0.0264)	(-0.0275)	(-0.0175)
Year	-76.05 ***	-11.31 ***	21.11 ***	55.21 ***	3.801 *
	(-5.536)	(-2.457)	(-2.752)	(-2.861)	(-1.819)
Constant	579.4 **	88.85 ***	-153.9 ***	-413.5 ***	-22.72
	(-41.38)	(-18.36)	(-20.57)	(-21.39)	(-13.6)
R-Squared	0.7776	0.956	0.9219	0.8885	0.9344
Observations (*N x t*)	1069	1071	1069	1071	1071
Number of States (*N*)	51	51	51	51	51

Standard Errors in Parentheses

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

All variables were transformed to their natural logarithms, such that their coefficients may be interpreted as elasticities.

Model of Electricity Prices & Employment by Sector

Index of Coefficients β_j

Logged Variables	Manufacturing Employment	Retail Employment	Hospitality Employment	Healthcare Employment	Government Employment
Price of Electricity	β_1 → **-0.337** ***	**-0.158** ***	**-0.142** ***	**-0.0426** **	**0.00084**
(Real 2010 US$)	(-0.0307)	(-0.0136)	(-0.0152)	(-0.0158)	(-0.0101)
Educational Attainment	β_2 → 0.0249	-0.108	-0.0679	-0.536 ***	-0.14 **
	(-0.146)	(-0.065)	(-0.0728)	(-0.0758)	(-0.0482)
State GDP	β_3 → 0.744 ***	0.509 ***	0.318 ***	0.17 ***	0.253 ***
(Real 2010 US$)	(-0.0514)	(-0.0228)	(-0.0255)	(-0.0265)	(-0.0169)
Population	β_4 → 0.166 **	0.26 ***	0.129 ***	0.37 ***	0.258 ***
	(-0.0532)	(-0.0236)	(-0.0264)	(-0.0275)	(-0.0175)
Year	β_5 → -76.05 ***	-11.31 ***	21.11 ***	55.21 ***	3.801 *
	(-5.536)	(-2.457)	(-2.752)	(-2.861)	(-1.819)
Constant	β_0 → 579.4 **	88.85 ***	-153.9 ***	-413.5 ***	-22.72
	(-41.38)	(-18.36)	(-20.57)	(-21.39)	(-13.6)
R-Squared	0.7776	0.956	0.9219	0.8885	0.9344
Observations (*N x t*)	1069	1071	1069	1071	1071
Number of States (*N*)	51	51	51	51	51

Sign of Coefficients = Direction

Standard Errors in Parentheses

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

Stars = Significance Levels

All variables were transformed to their natural logarithms, such that their coefficients may be interpreted as elasticities.

Electricity Prices and Economic Output

GDP Model Summary

Purpose – This model estimates the responsiveness of state Gross Domestic Product (GDP) to changes in real electricity prices, while controlling for the numerous factors inherently affecting GDP, including population, education, health, employment, and other fuel prices.

Results – This study indicates that higher electricity prices, holding all other factors constant, are associated with lower levels of economic output. Specifically, a 10% increase in the real price of electricity, would, on average, be associated with a 1.1% reduction in state GDP, and with robust 95% confidence, between 0.6 and 1.6%.

Accuracy – The preliminary version of this model 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%.

Limitations – This model is intended 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 and are traditionally more closely related to the business cycle than long-run economic growth. While the model is able to explain past variations in economic output, some of its inputs, such as employment, are difficult to extrapolate into the future and therefore decrease the predictive ability of the model forwards in time.

Kentucky Electricity Portfolio Model v.2.0 Design Plan

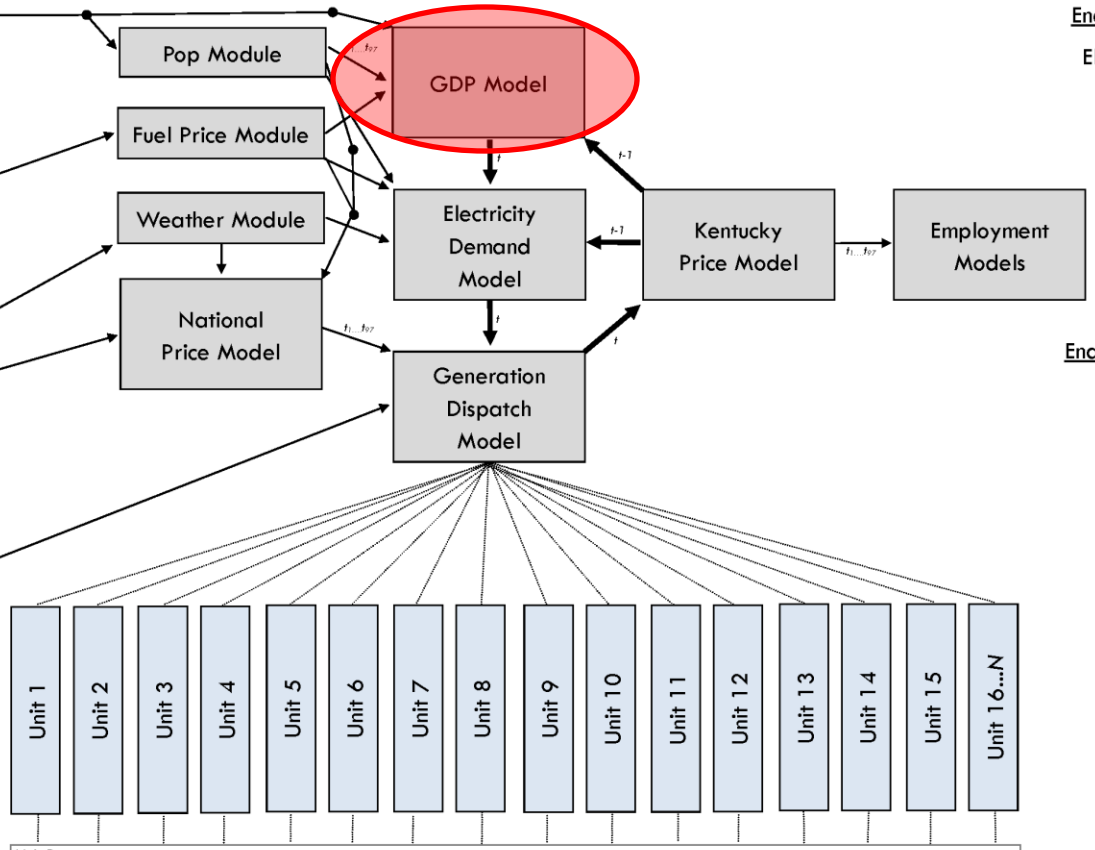
Historical Data Inputs, 1895-2013

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 & Pricing
- Unit-Level Emission Standards
  - CO2, SO2, HG, NOX, PM



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.

LEGEND
- *Complete One-Time Data Transfer*
- *Annual Data Loop*
- *Control*
- *Programming or Statistical Module*
- *Generating Unit*

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

Foundations in Economic Theory

Neoclassical Growth Model

$$Y = f\ (K, L, t)^*$$

- **Benefits:**
  - Is the first flexible model that identified the basic determinants of growth.
  - Includes diminishing returns to scale.
  - Utilizes productivity, capital accumulation, population growth, and technological progress to explain economic growth.
- **Shortcomings:**
  - Assumes productivity growth as exogenous.
  - Combines factors.
  - Cannot account for Total Factor Productivity (up to 60% of growth).

*Where Y denotes GDP (total production), K represents Capital, L is labor, and t is an exogenously determined level of technology such that gross output is a function of inputs of capital and labor given a specific level of production.

Endogenous Growth Model

$$Y = AK^*$$

- **Benefits:**
  - Includes positive spillover effects.
  - Technological change is endogenous to the model.
  - Allows for the inclusion of policies/institutions.
- **Shortcomings:**
  - Includes a multitude of variables.
  - Growth is considered perpetual.

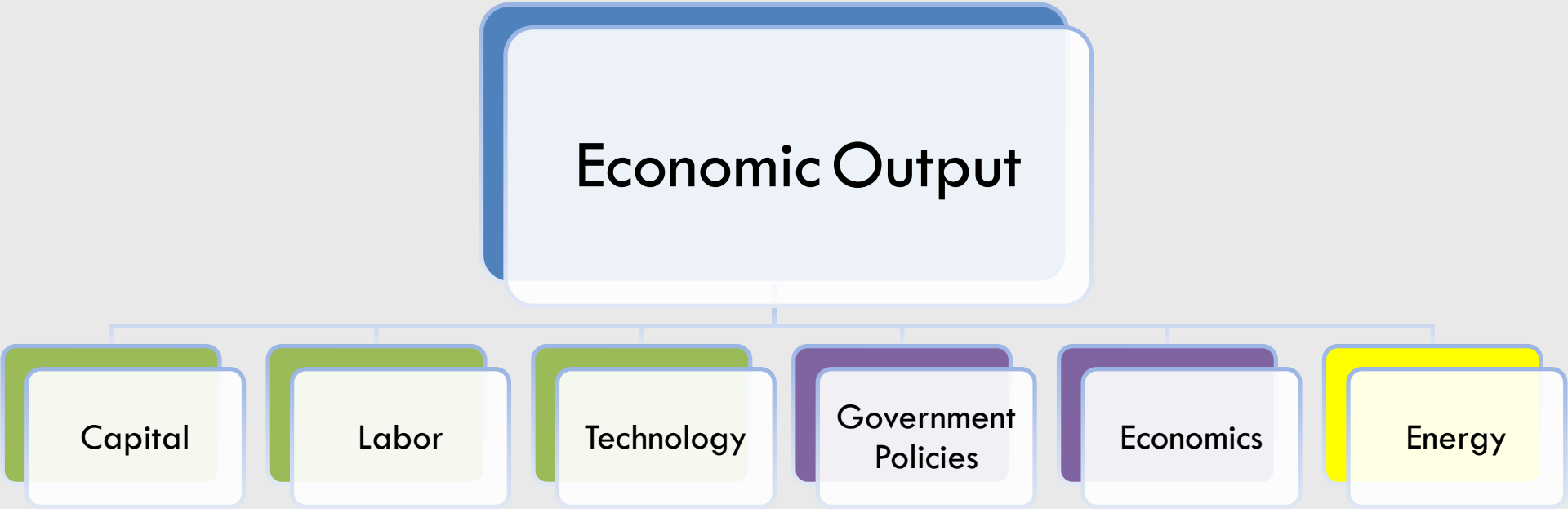
*Where Y denotes GDP (total production), K represents Capital, and A is a positive constant reflecting the level of technology.

Energy and Efficiency Growth Theory

"Electricity use and gross national product have been, and probably will be, strongly correlated."
– U.S. Department of Energy, 1986

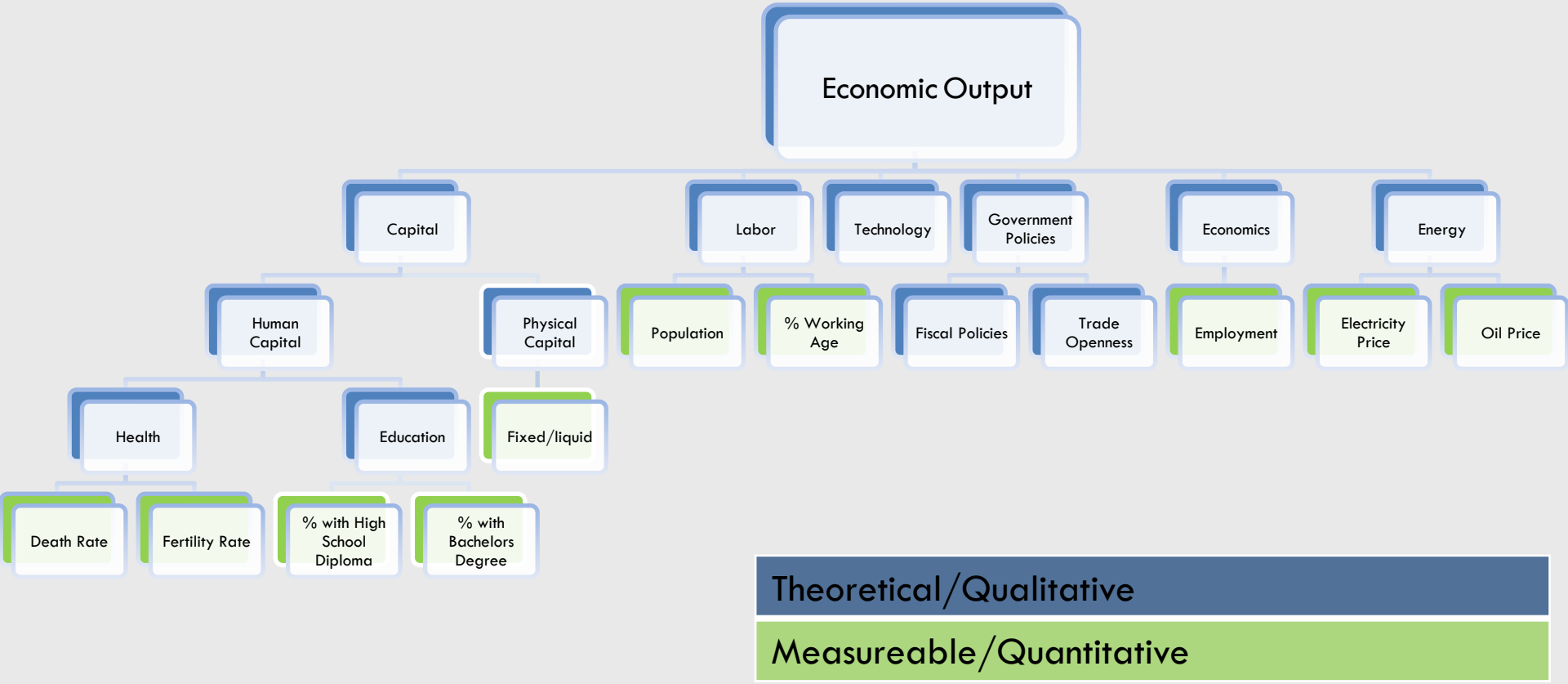
- Energy efficiency and consumption are central to economic growth.
- Ideas incorporated in the theory date back at least to William Jevons in 1862.
- The theory brings in the study of physics and attempts to understand the role of electricity power consumption and energy in an economy by utilizing the first two laws of thermodynamics.
- Is utilized in studies of "peak" resource use, among other topics.

Determinants of Economic Output (non-exhaustive)

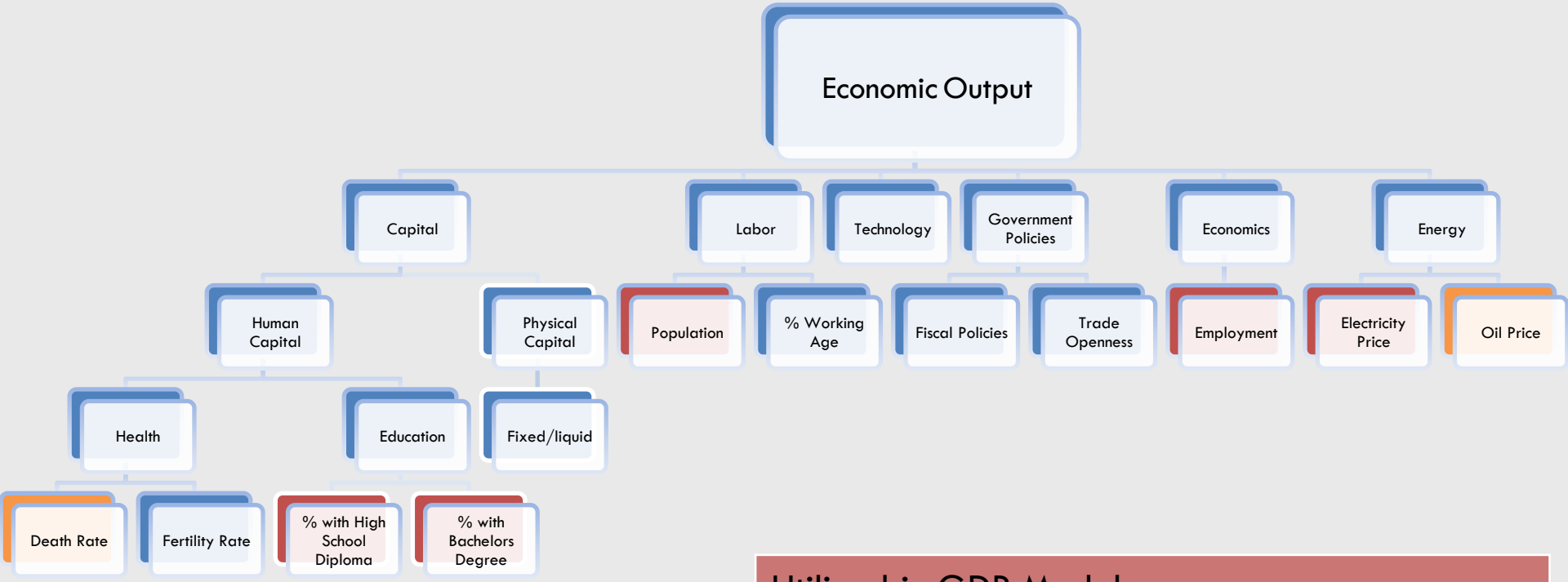


Neoclassical Growth Model
Endogenous Growth Model
Energy and Efficiency Growth Theory

Determinants of Economic Output (non-exhaustive)



Determinants of Economic Output (non-exhaustive)



Utilized in GDP Model

Included in Preliminary GDP Model, Discarded

Other Components of GDP

Fixed Effects Model

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

$$i = 1, \ldots, 48 \ (state)$$
$$t = 1970, \ldots, 2010 \ (year)$$
$$k = 8$$

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.

Fixed Effects Model

This model uses a statistical analysis technique called multiple regression of panel data with fixed effects, which builds upon Ordinary Least Squares (OLS) regression by isolating the time-independent constant difference in Gross Domestic Product (y_{it}) between cross-sectional units (states or i) that are correlated with the explanatory variables (X_{jit}).

This model uses a statistical analysis technique called multiple regression of panel data with fixed effects, which builds upon Ordinary Least Squares (OLS) regression by isolating the time-independent constant difference in Gross Domestic Product (y_{it}) between cross-sectional units (states or i) that are correlated with the explanatory variables (X_{jit}).

Therefore, as with OLS, the resulting coefficients are homogenous—uniform across all states and times. However, since a custom fixed effect for GDP is calculated for each state, GDP forecasts are significantly improved versus OLS by adjusting to best fit the model to historical data.

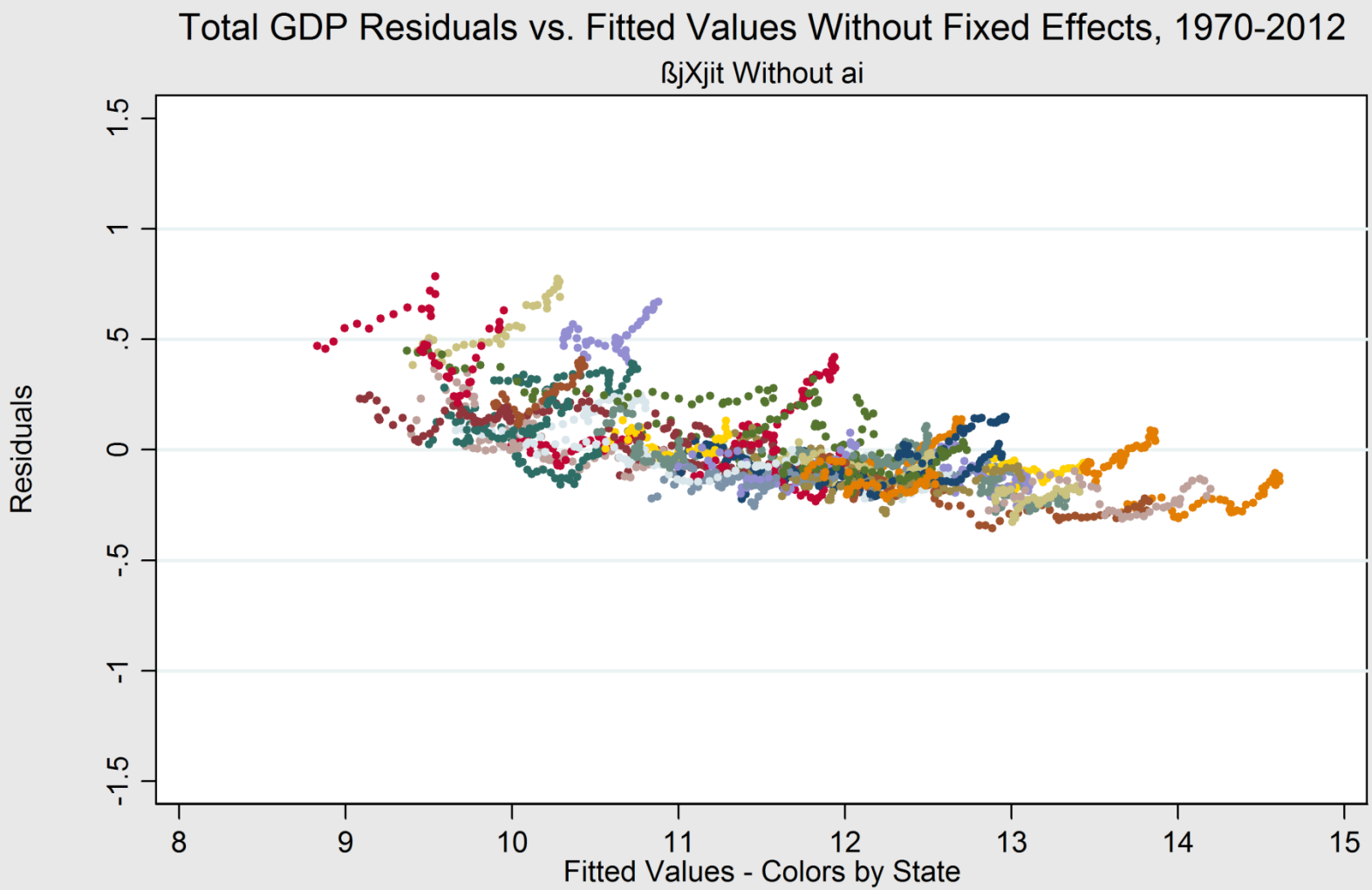
GDP Model

Logged Variables	Proposed Model	Other Models Evaluated 1	2	3	4	5	6	7	8
Real Electricity Price	**-0.111*** **	-0.111***	-0.199***	-0.183***	-0.453***	-0.424***	-0.436***	-0.367***	-0.769***
	(0.0255)	(0.0249)	(0.0267)	(0.0281)	(0.059)	(0.537)	(0.0585)	(0.0496)	(0.107)
Population	**1.185*** **	1.181***	1.115***	1.169***	1.485***	1.510***	1.538***	1.631***	
	(0.0514)	(0.0486)	(0.0539)	(0.0616)	(0.126)	(0.128)	(0.122)	(0.123)	
Real Petroleum Price		0.0963***	0.0725***	0.0955***	0.106**		0.156***		
		(0.0170)	(0.0230)	(0.0218)	(0.0378)		(0.0369)		
Real Natural Gas Price		-0.0810***	-0.0916***	-0.0891***	0.0871**	0.133***			
		(0.0151)	(0.0177)	(0.0182)	(0.0308)	(0.0307)			
Education Index	**0.370*** **	0.421***	0.7776***	0.791***					
	(0.0604)	(0.0577)	(0.0568)	(0.0642)					
Health Index			-0.4021***						
			(0.0890)						
Employment	**1.312*** **	1.297***							
	(0.129)	(0.0577)							
Constant	**-7.963*** **	-8.187***	-7.205***	-8.511***	-9.974***	-10.21***	-10.75***	-11.89***	13.44***
	(0.659)	(0.636)	(0.7962)	(0.780)	(1.917)	(1.956)	(1.847)	(1.896)	(0.247)
R-Squared (Overall)	**.9801**	.9578	.9512	.9546	.9288	.9313	.9256	.9258	.0045
R-Squared (Within)	**.9536**	.9578	.9470	.9438	.8727	.8673	.8688	.8542	.1953
R-Squared (Between)	**.9839**	.9811	.9530	.9571	.9432	.9470	.9418	.9258	.0351
AIC	**-5237.2**	-5410.4	-4946.8	-4828.3	-3181.7	-3096.6	-3126.4	-2917.1	753.3
N	**2050**	2040	2040	2040	2090	2090	2100	2150	2150

Coefficients with robust standard errors in parentheses at the following significance levels: * p<0.05, ** p<0.01, *** p<0.001

All variables have been 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 after controlling for all other included independent factors. The models were run using robust standard errors, calculated using the Huber-White Sandwich estimator, in order to prevent biased estimation that could be caused by the presence of outliers in the natural logarithm of GDP, such as the District of Colombia, as well as inherent serial autocorrelation and the presence of the residual heteroscedasticity as identified by the Breusch–Pagan post estimation test. The state-specific fixed effects are not listed above.

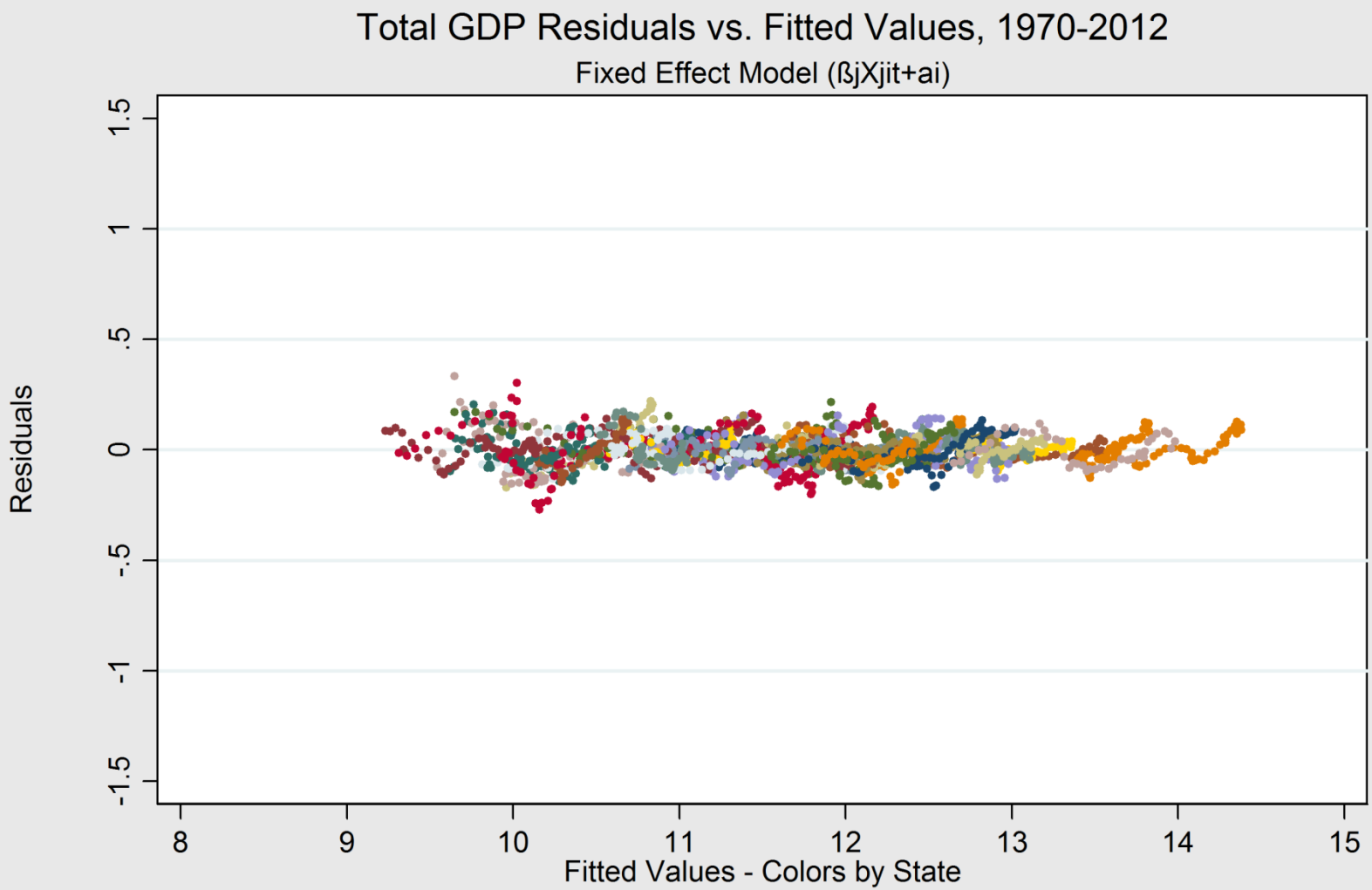
Residuals vs. Fitted Values (without Fixed Effects)



Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

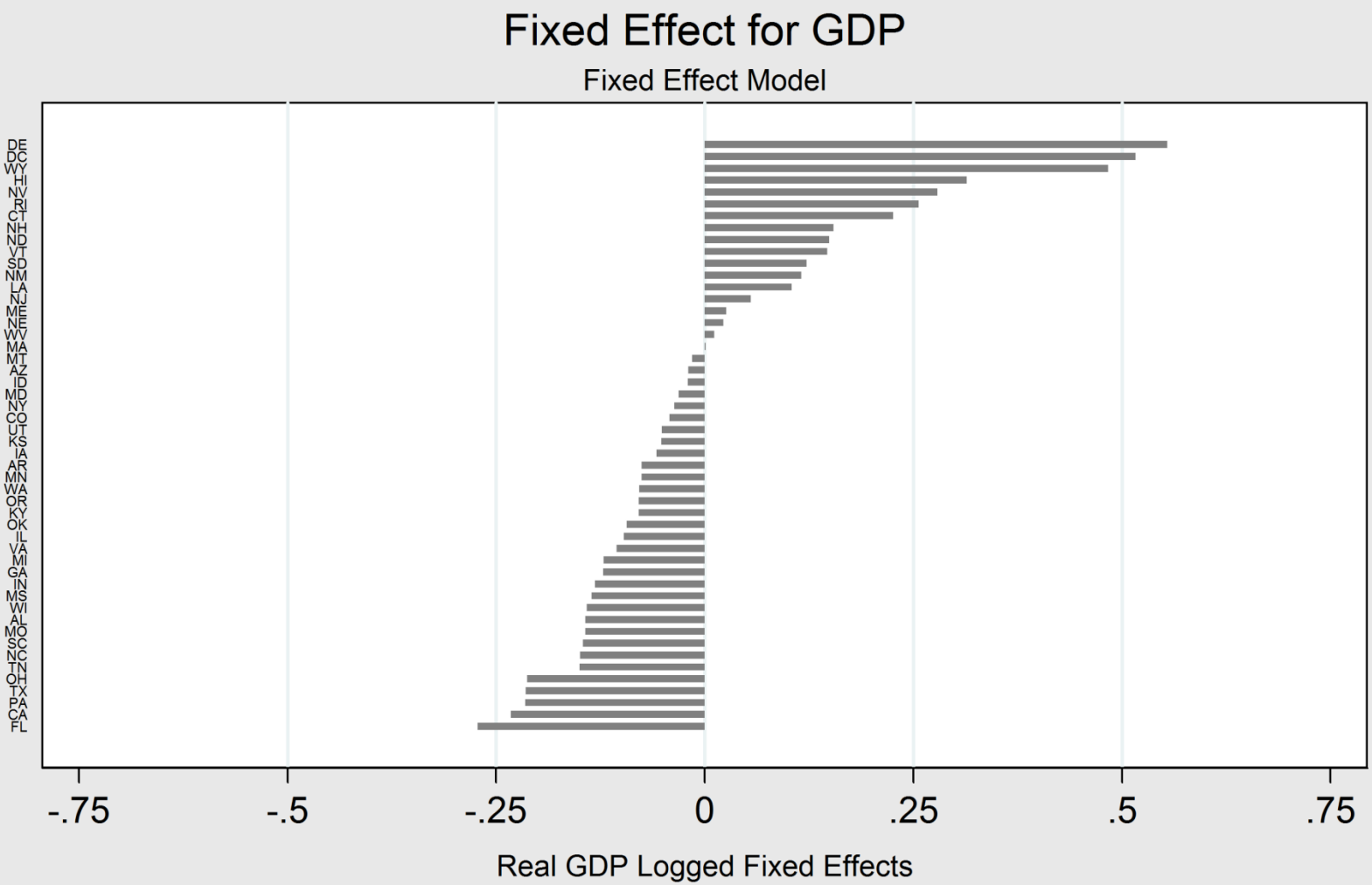
Residuals vs. Fitted Values (with Fixed Effects)



Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

Fixed Effects for Demand (α_i)

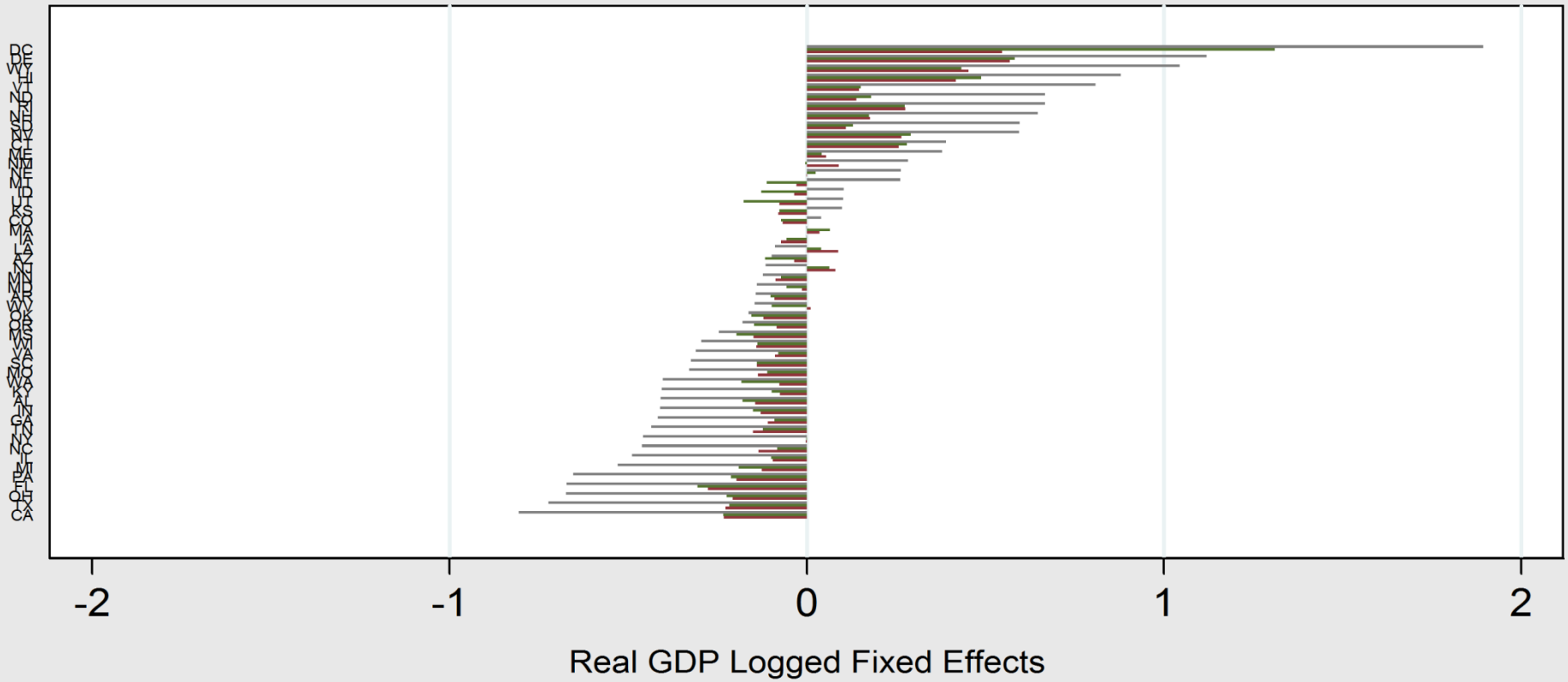


Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

Unobserved Variable Bias Explained by Education and Employment

Fixed Effect Model



Without Education Index and Percent Employed

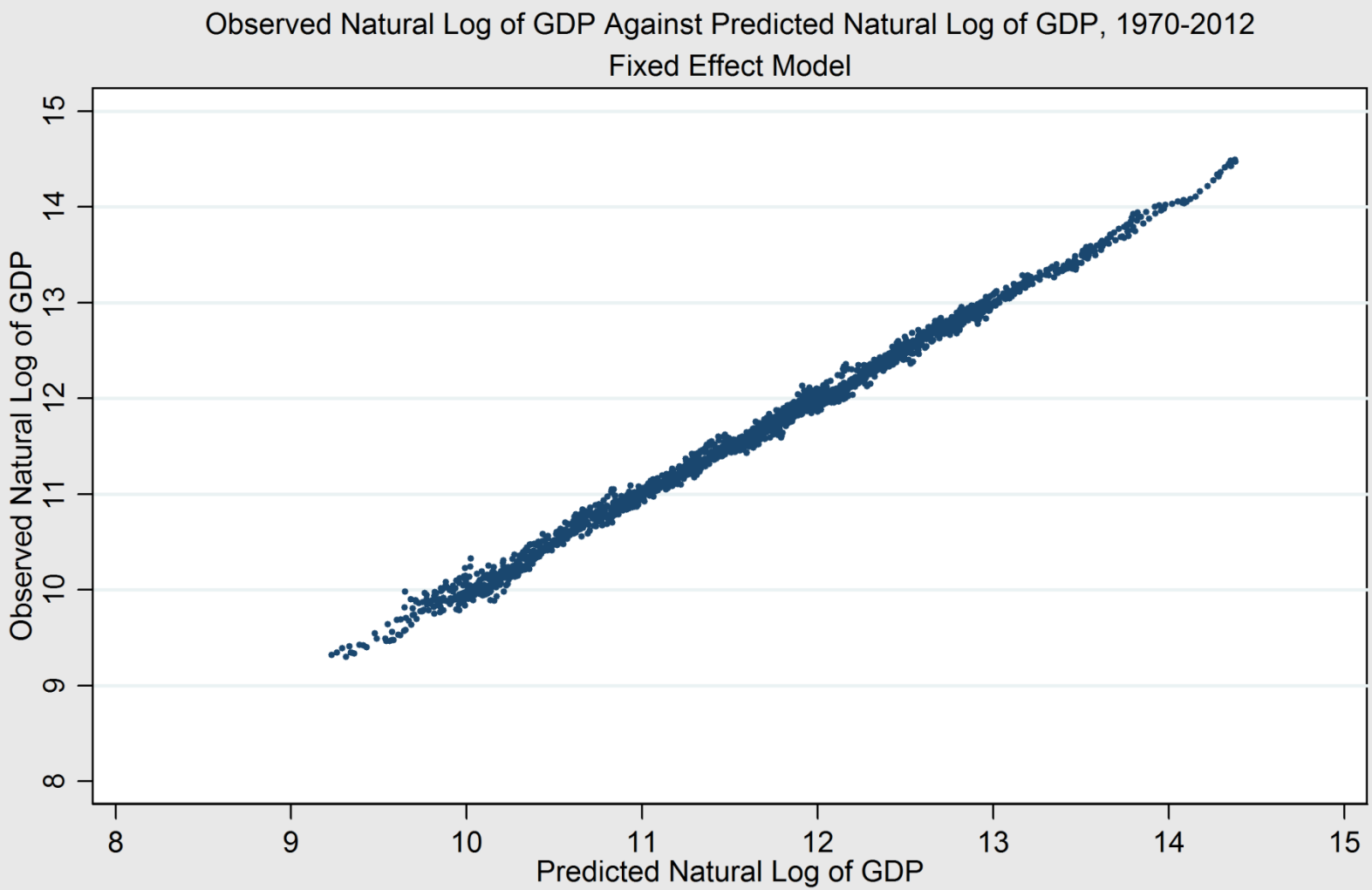
With Education Index

With Education Index and Percent Employed

Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

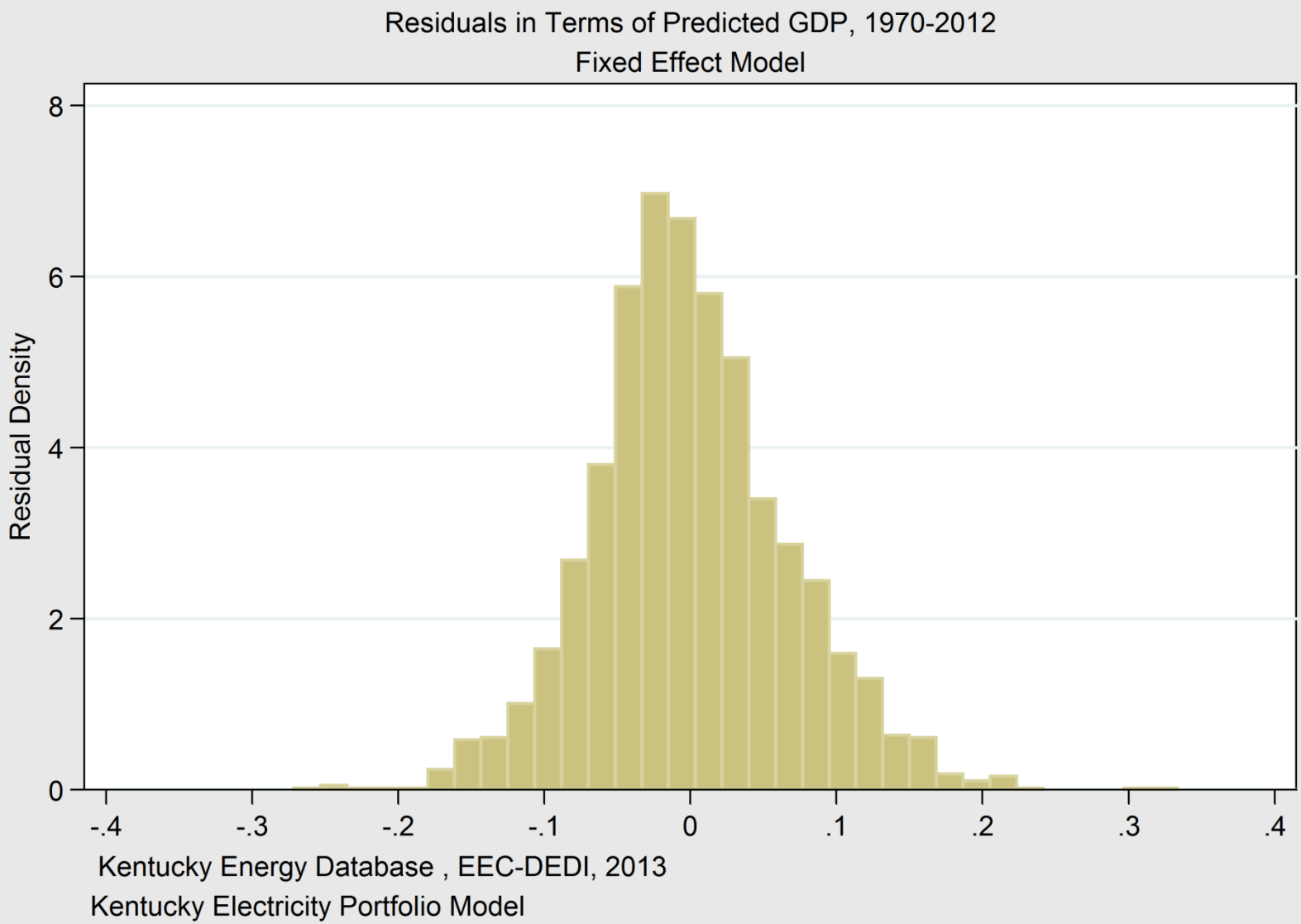
Observed vs. Predicted



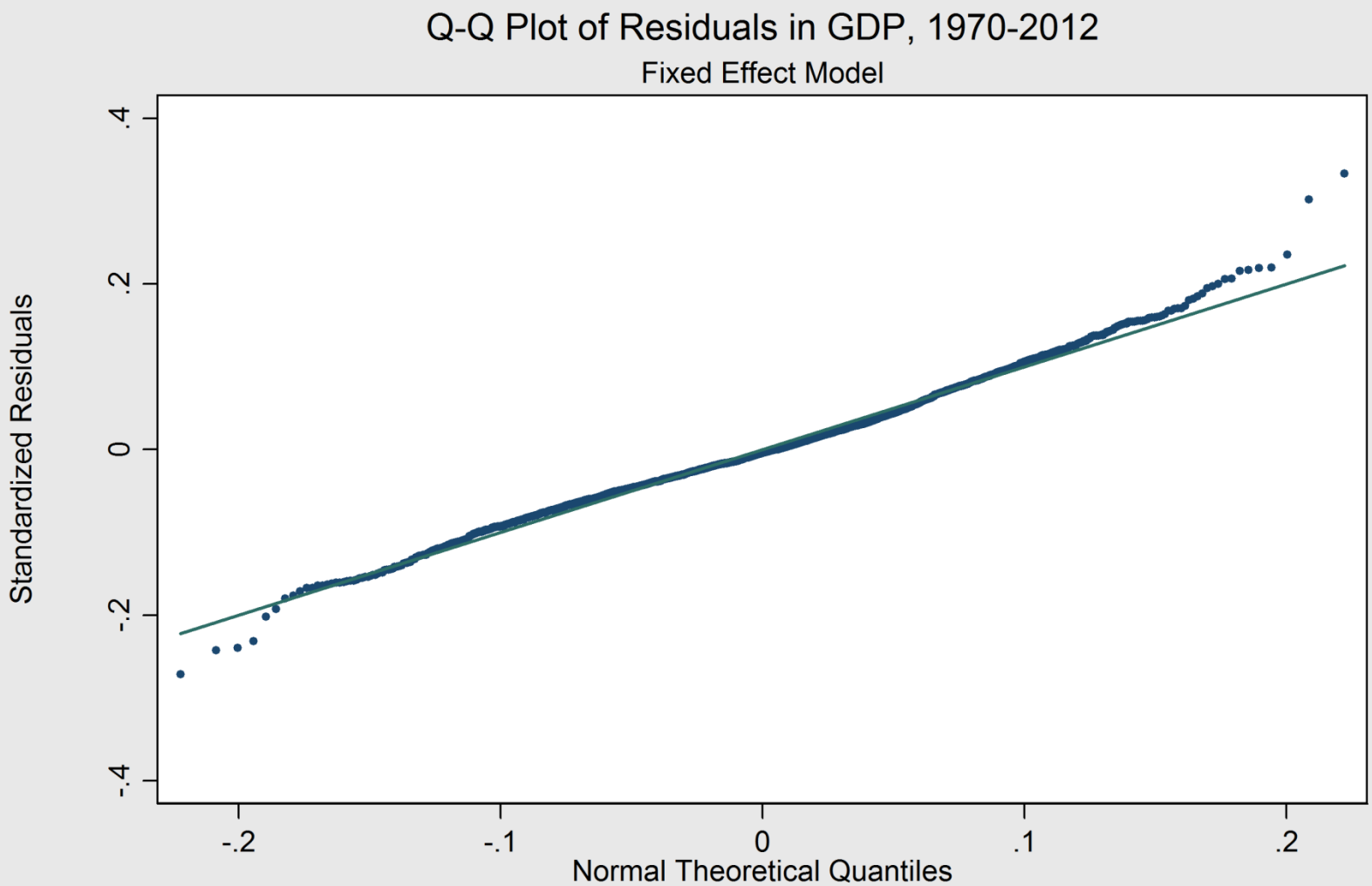
Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

Distribution of Residuals



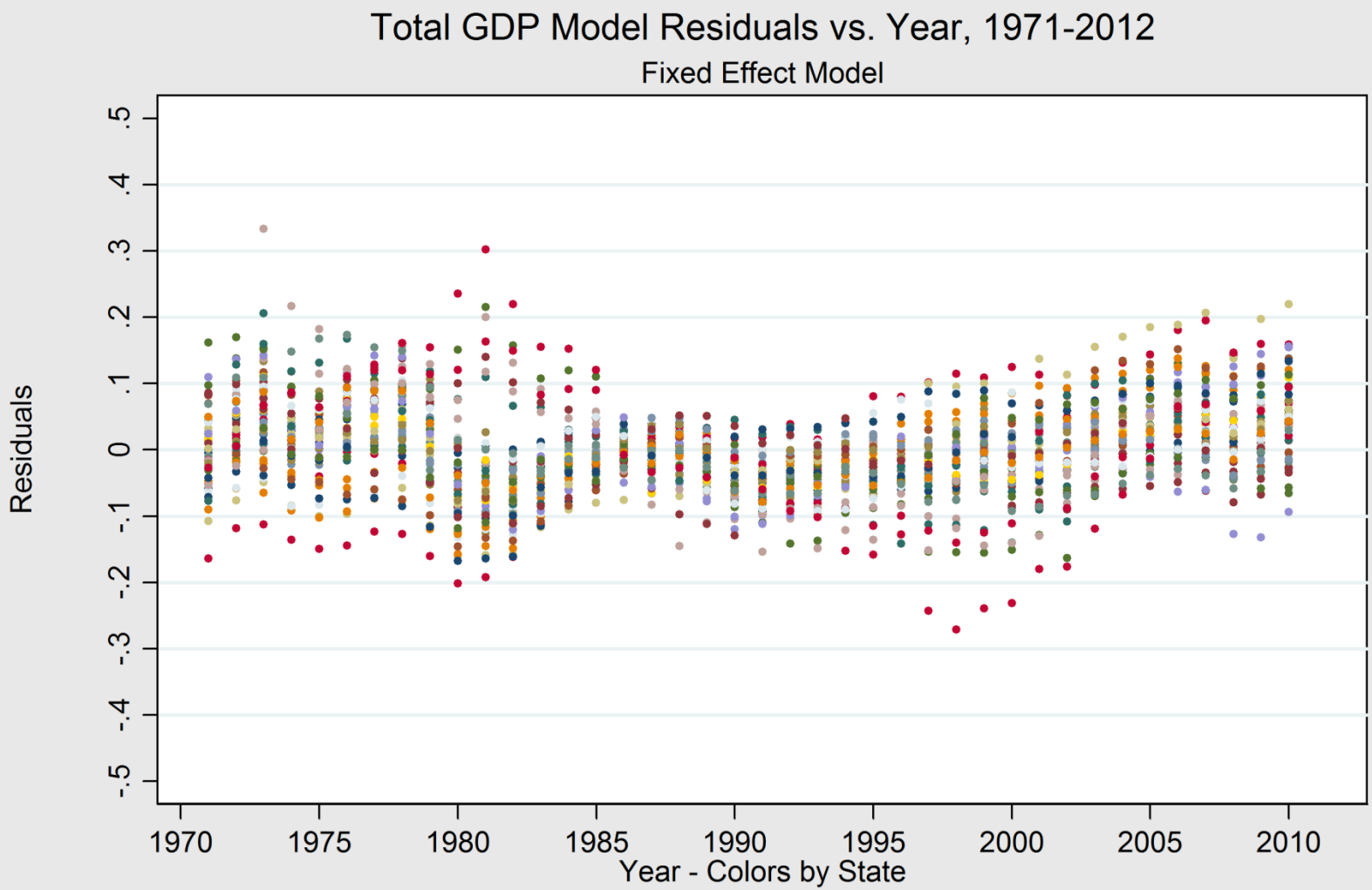
GDP Model Q-Q Plots



Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

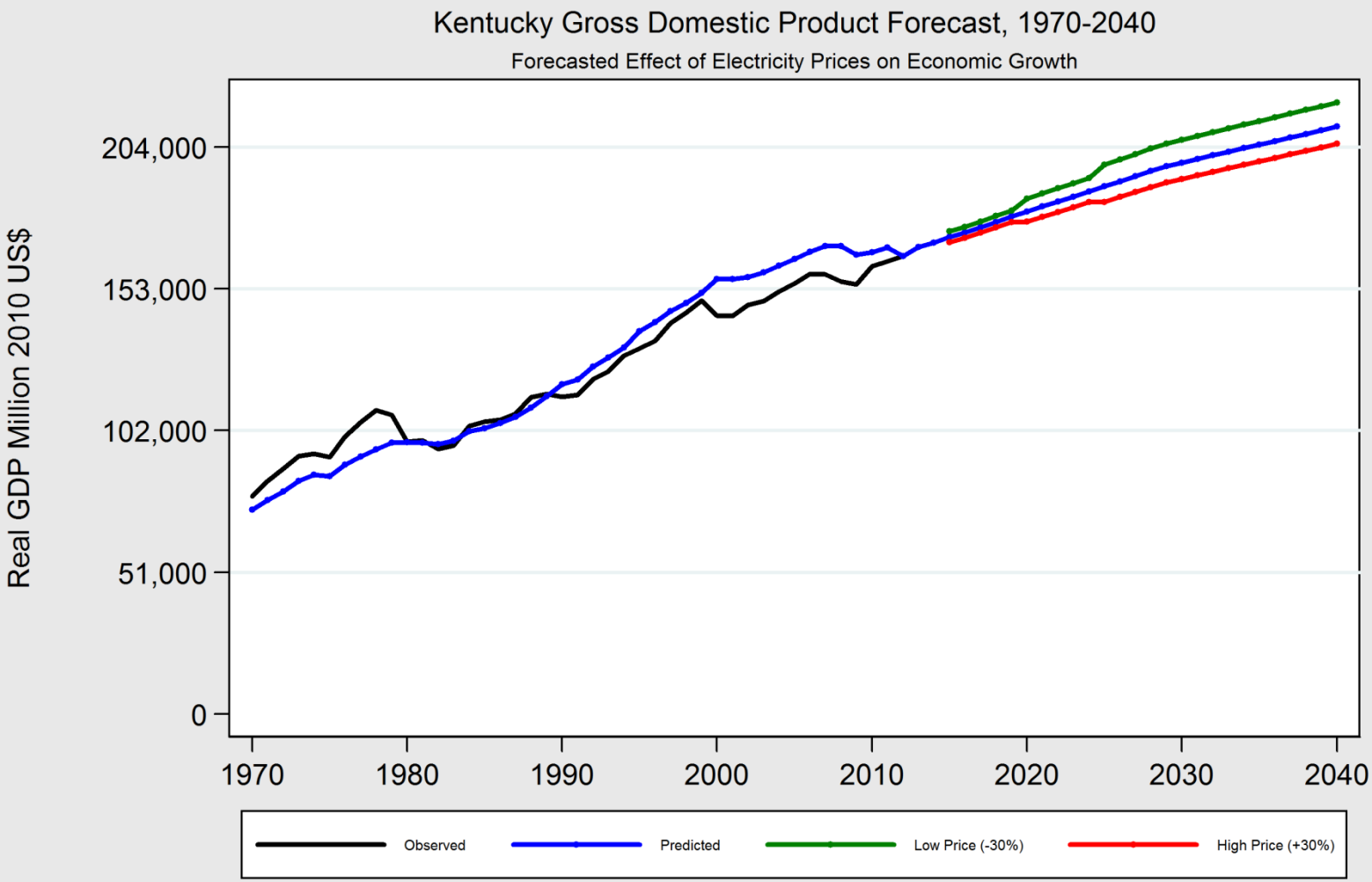
Residuals vs. Time



Kentucky Energy Database, EEC-DEDI, 2013

Kentucky Electricity Portfolio Model

Model Validation



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

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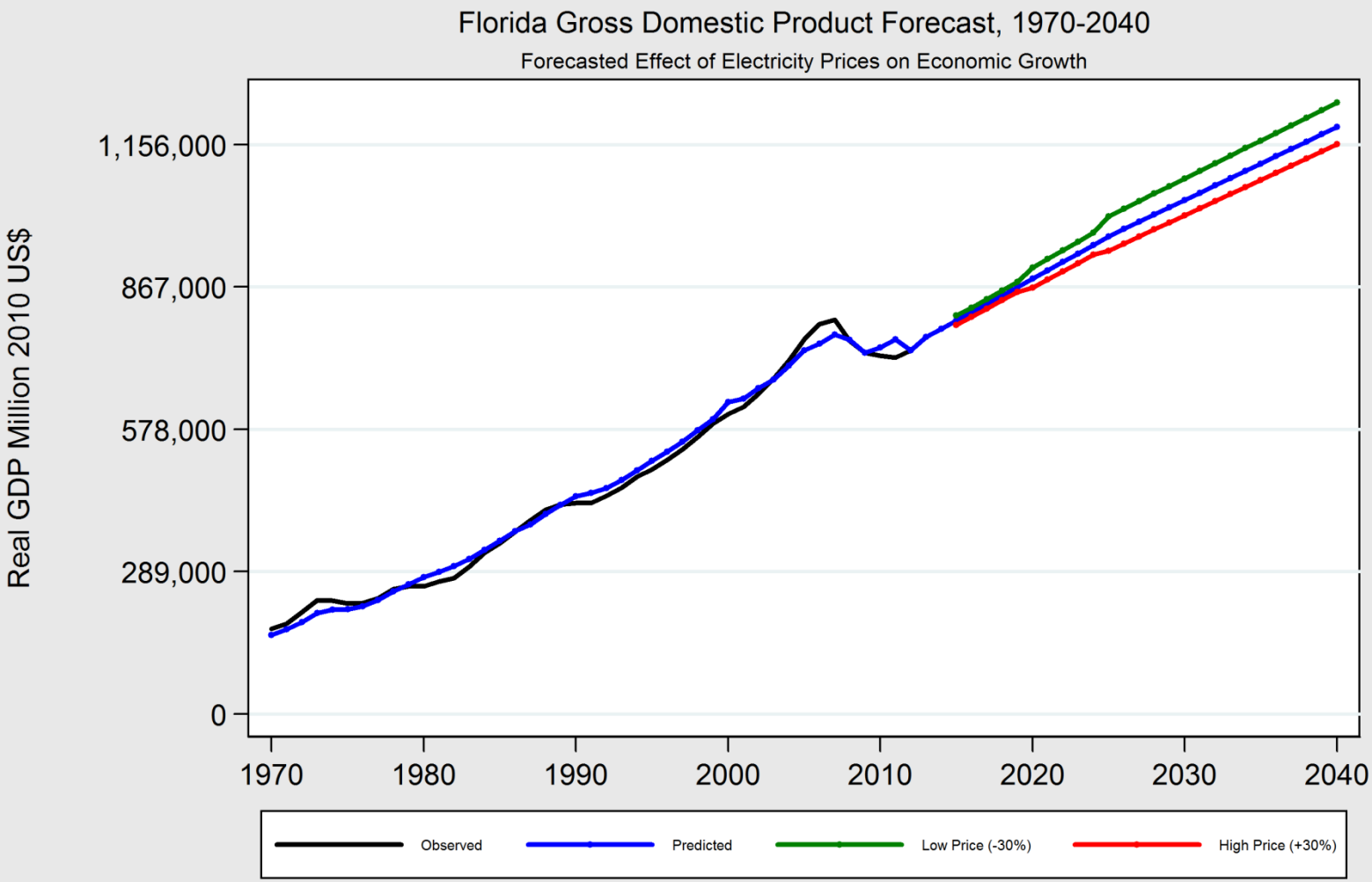

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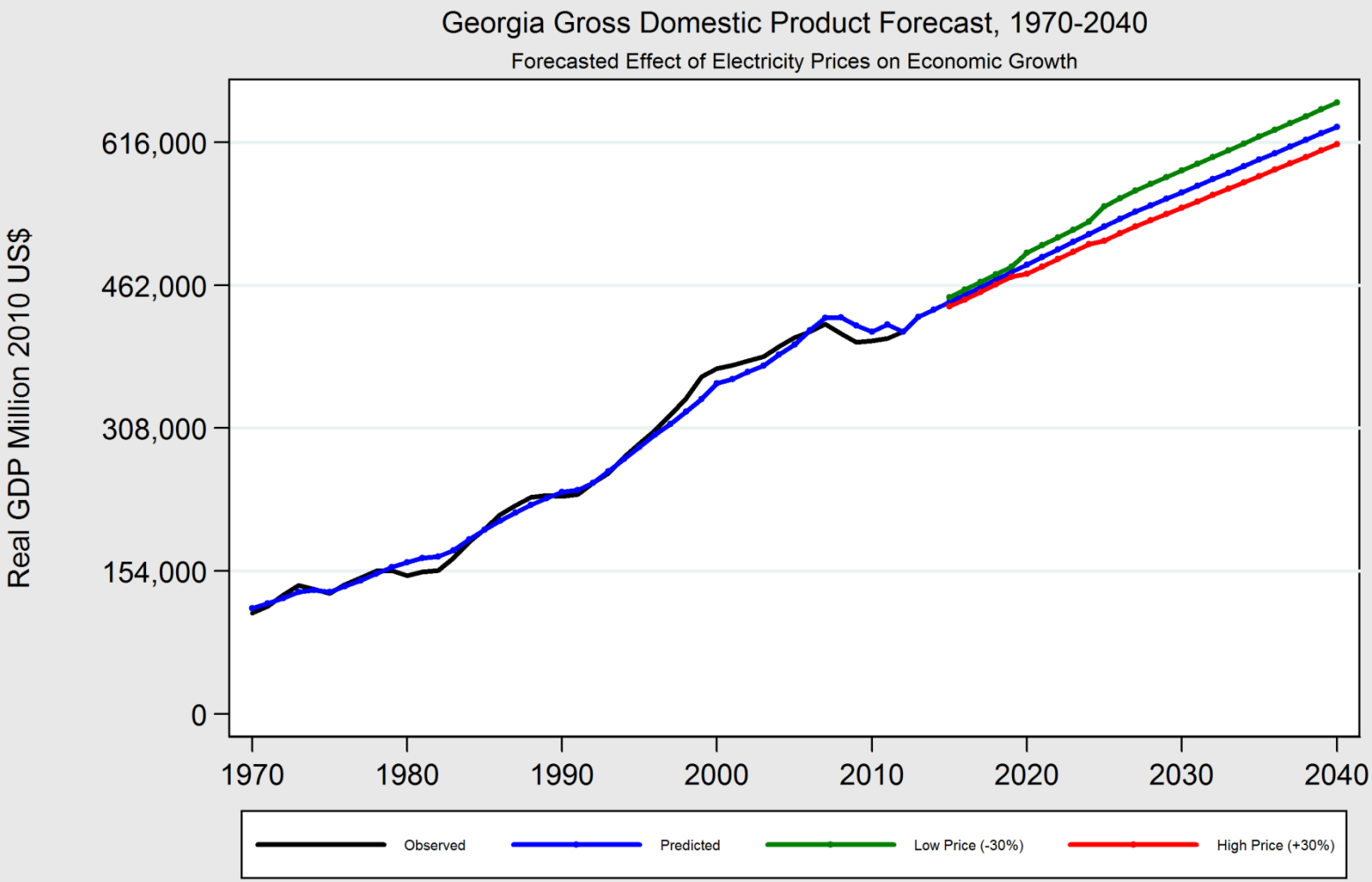

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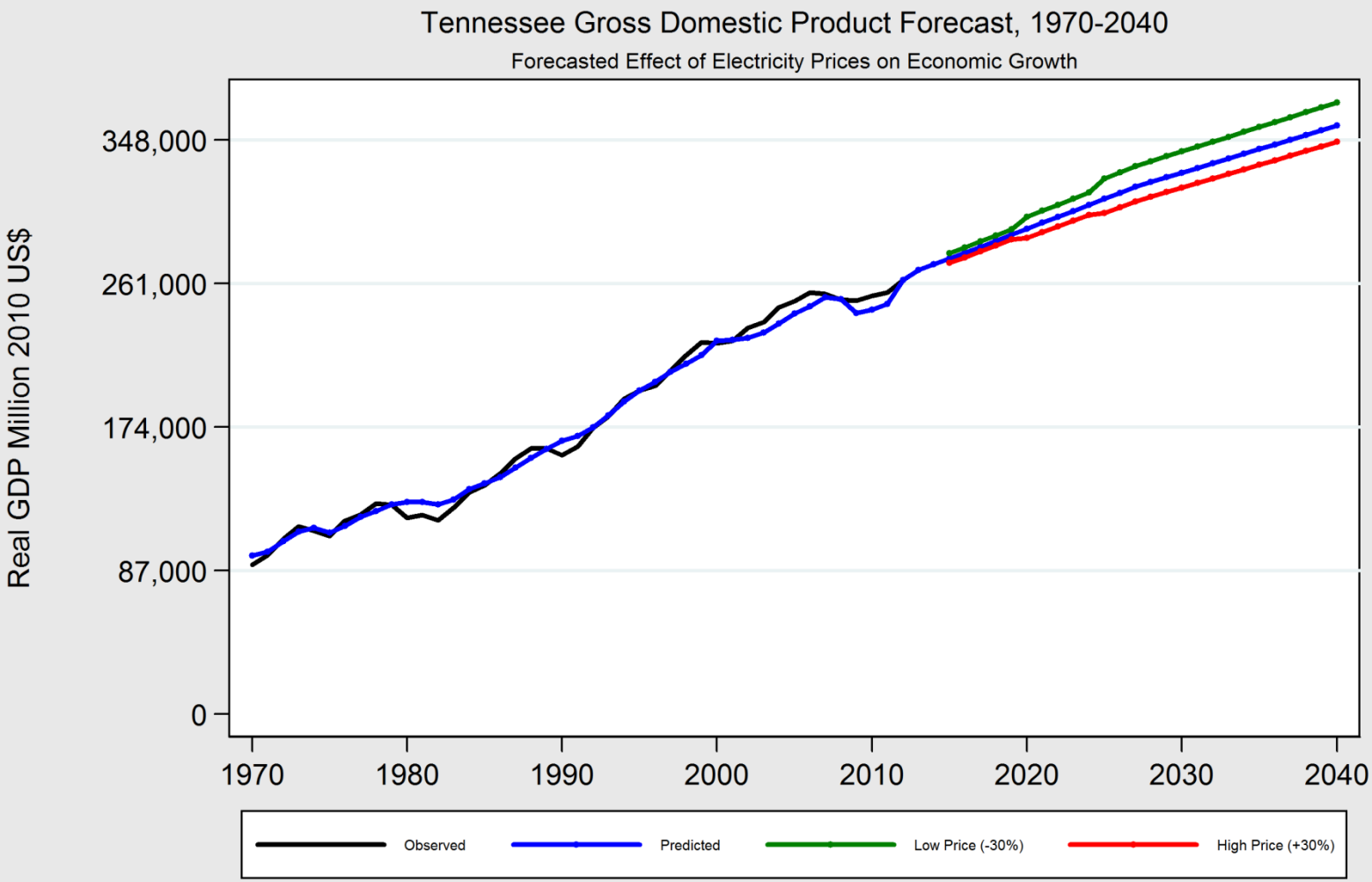

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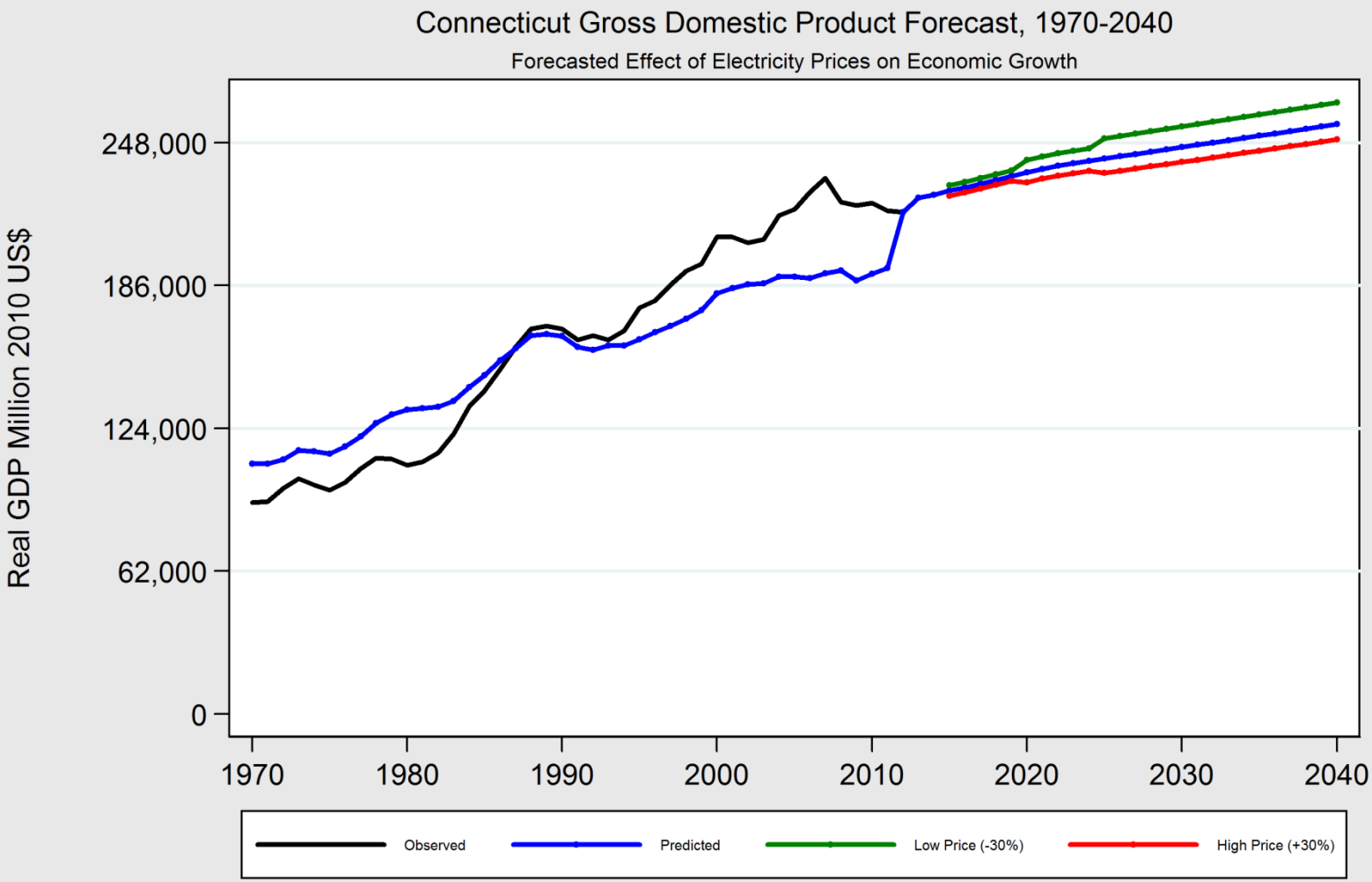

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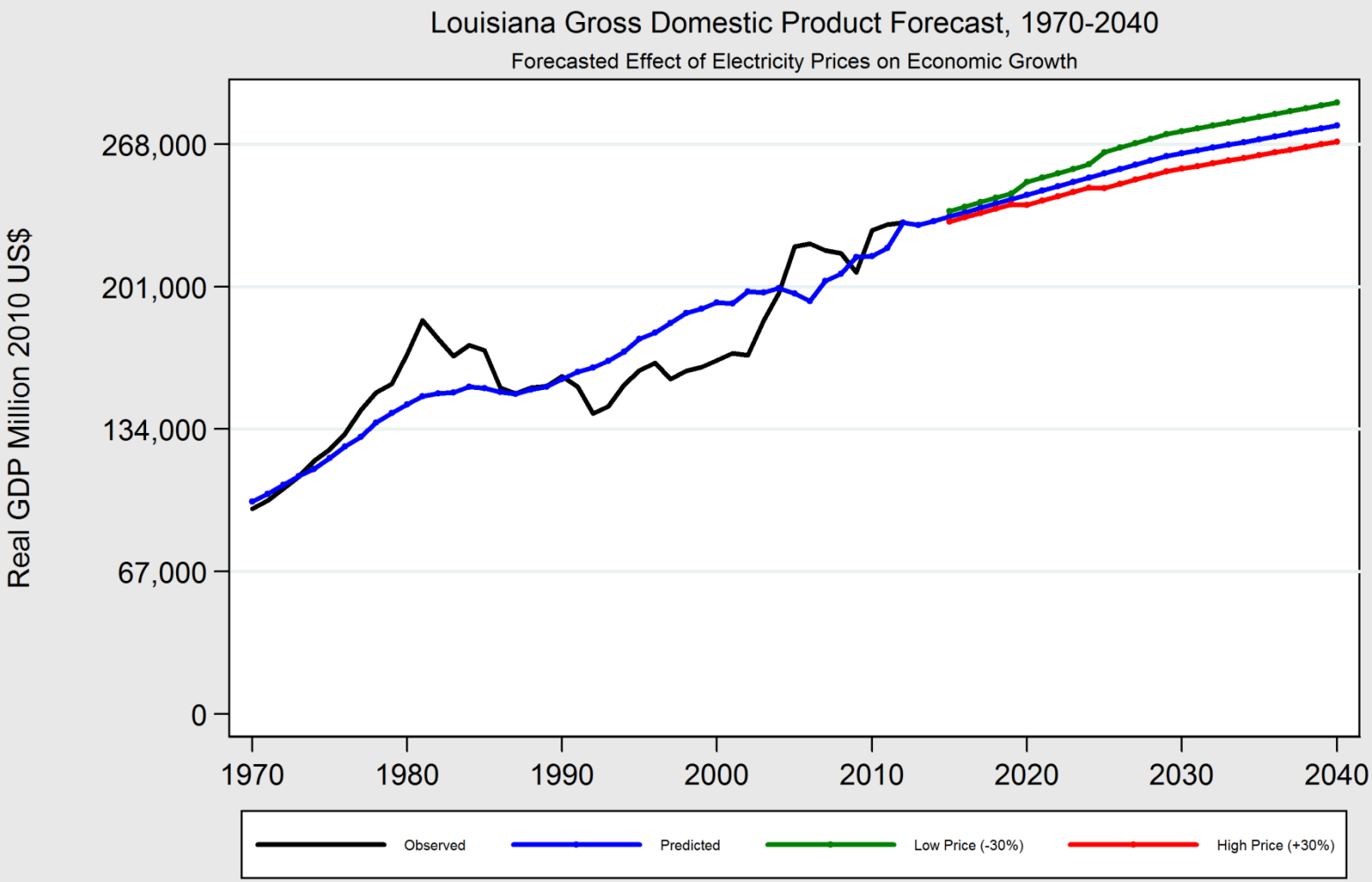

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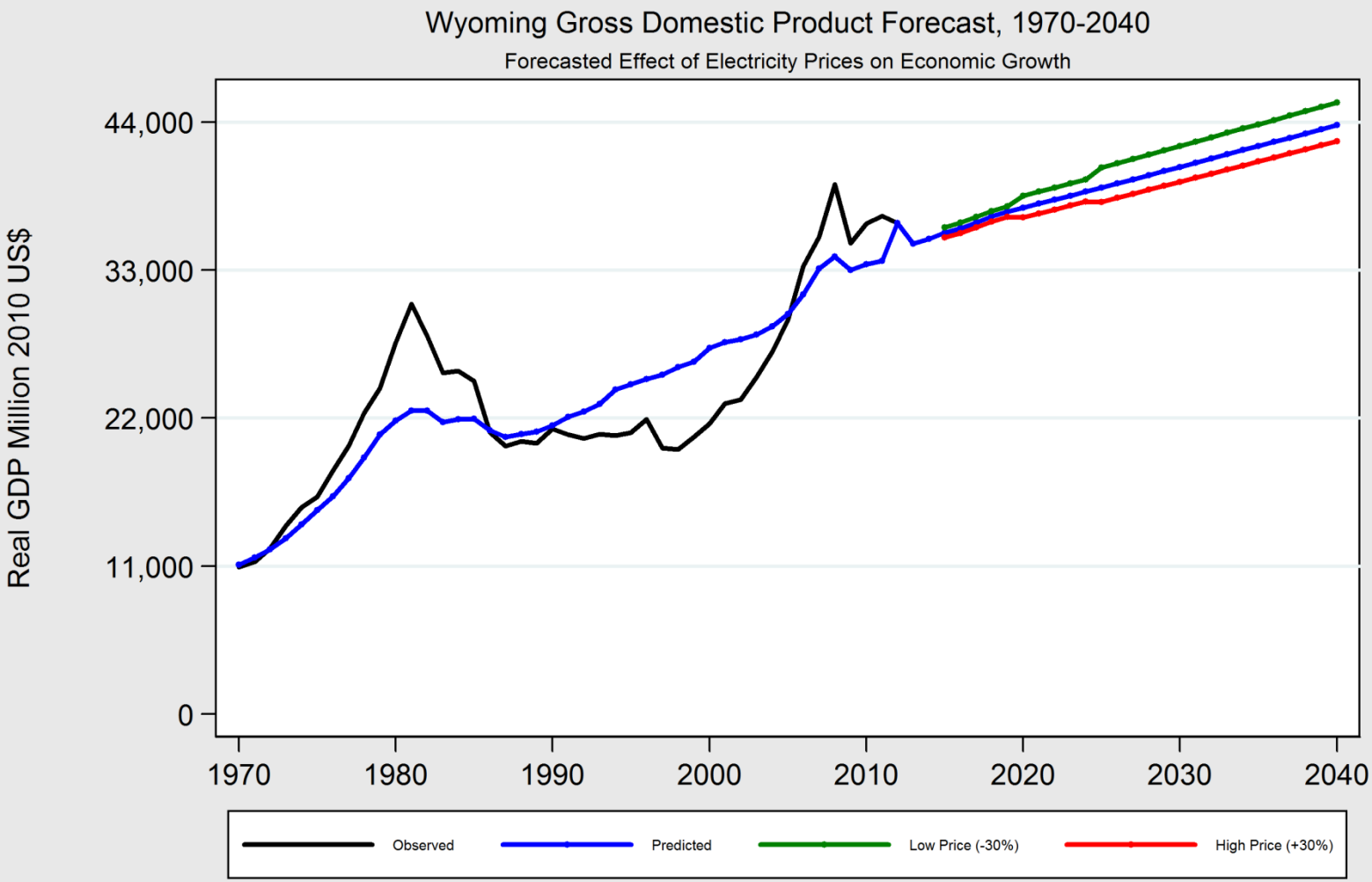

Kentucky Energy Database, EEC-DEDI, 2013
Kentucky Electricity Portfolio Model

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