ERCOT Energy Portfolio Optimization

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Goal of this Research

- Develop a quadratic program to determine an optimal mix (portfolio) of energy supplies which minimize the variability of the price of energy in the Texas electricity market.
- I will use the Efficient Frontier concept, a "modern" portfolio theory introduced by Harry Markowitz in 1952.
- When used in Electric Power System optimization Merlin and Back (1975), note that we are interested in both minimizing expected cost and minimizing risk. This is a multi-objective optimization problem and there is always a trade-off between these two objectives.

Background

- My study is focused exclusively on the Texas Electric Grid.
- The Texas Grid is managed by The Electric Reliability Council of Texas (ERCOT).
- ERCOT is a membership-based 501(c)(4) nonprofit corporation, governed by a board of directors and subject to oversight by the Public Utility Commission of Texas and the Texas Legislature.
- (ERCOT) manages the flow of electric power to 24 million Texas customers – representing about 90 percent of the state's electric load.
- ERCOT schedules power on an electric grid that connects more than 46,500 miles of transmission lines and 570+ generation units.

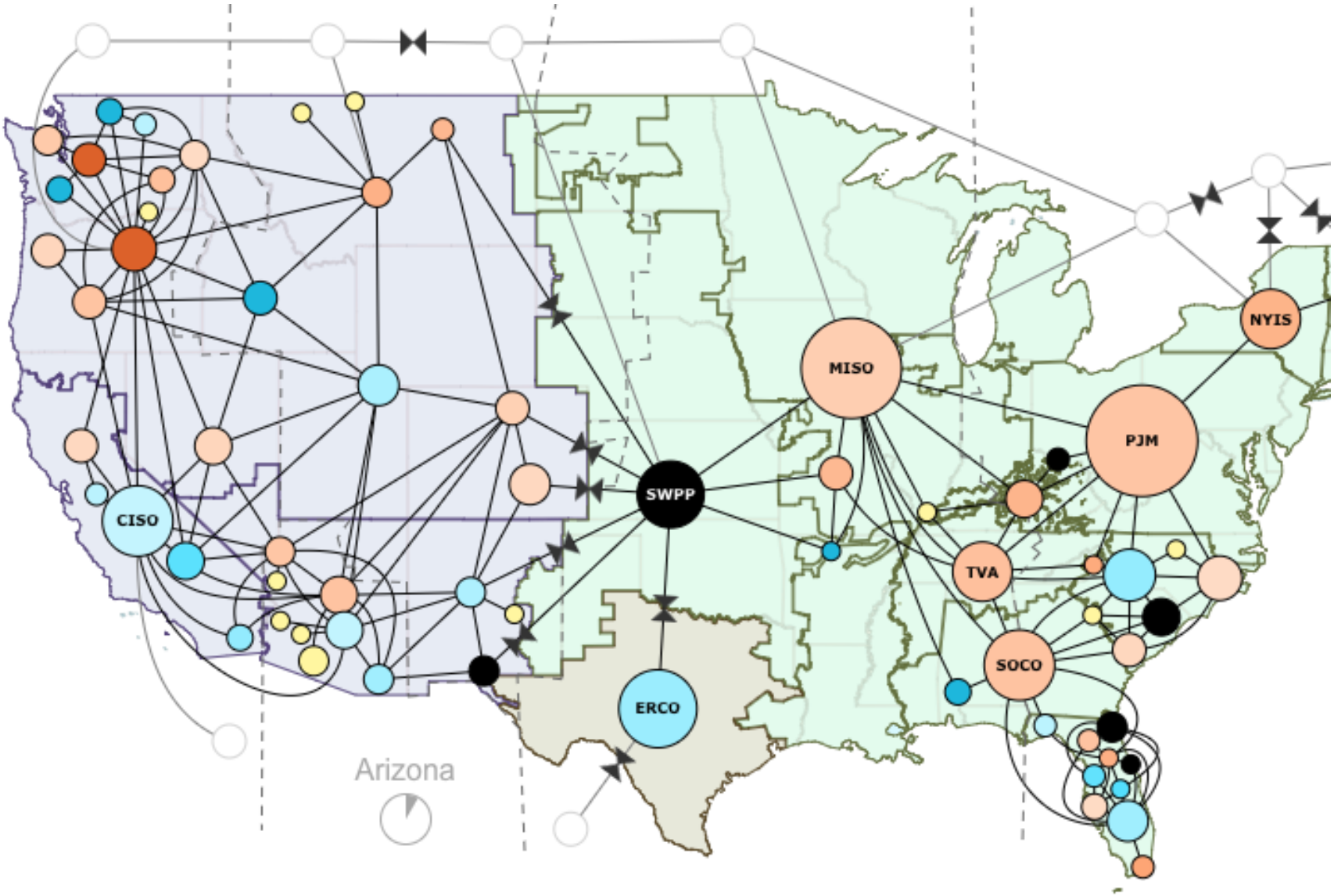
More Background

ERCOT is currently undergoing rapid change in several key areas.

- Demand Increase
- Structural Change
- Changes in Regulatory environment
- Change in ERCOT's Service Territory
- Weather Uncertainty

United States Power Grid

- Western Interconnection, ERCOT, Eastern Interconnection



Demand Increse

- ERCOT Generated Model for Peak Summer Demand

Peak Demand and Energy Forecast Summary

Year	Summer Peak Demand (MW)	Energy (TWh)
2017	72,934	356
2018	74,149	362
2019	75,588	371
2020	76,510	376
2021	77,417	380
2022	78,377	385
2023	79,348	389
2024	80,315	393
2025	81,261	398
2026	82,286	417

Percent Source Data

Table 1: Historical Energy Source Mix in Percentage

Fuel Types	Biomass	Natural_Gas	Gas-CC	Coal	Nuclear	Wind
2008_(%)		43.0		37.1	13.2	4.9
2009_(%)		42.1		36.6	13.6	6.2
2010_(%)		38.2		39.5	13.1	7.8
2011_(%)		40.4		39.0	11.9	8.5
2012_(%)		44.6		33.8	11.8	9.2
2013_(%)		40.5		37.2	11.6	9.9
2014_(%)		41.1		36.0	11.6	10.6
2015_(%)		48.3		28.1	11.3	11.7
2016_(%)		43.7		28.8	12.0	15.1
2017_(%)_10	0.15	5.02	34.62	31.87	10.40	17.21

Gas CC - Combined Cycle Natural Gas
2017 data is incomplete.

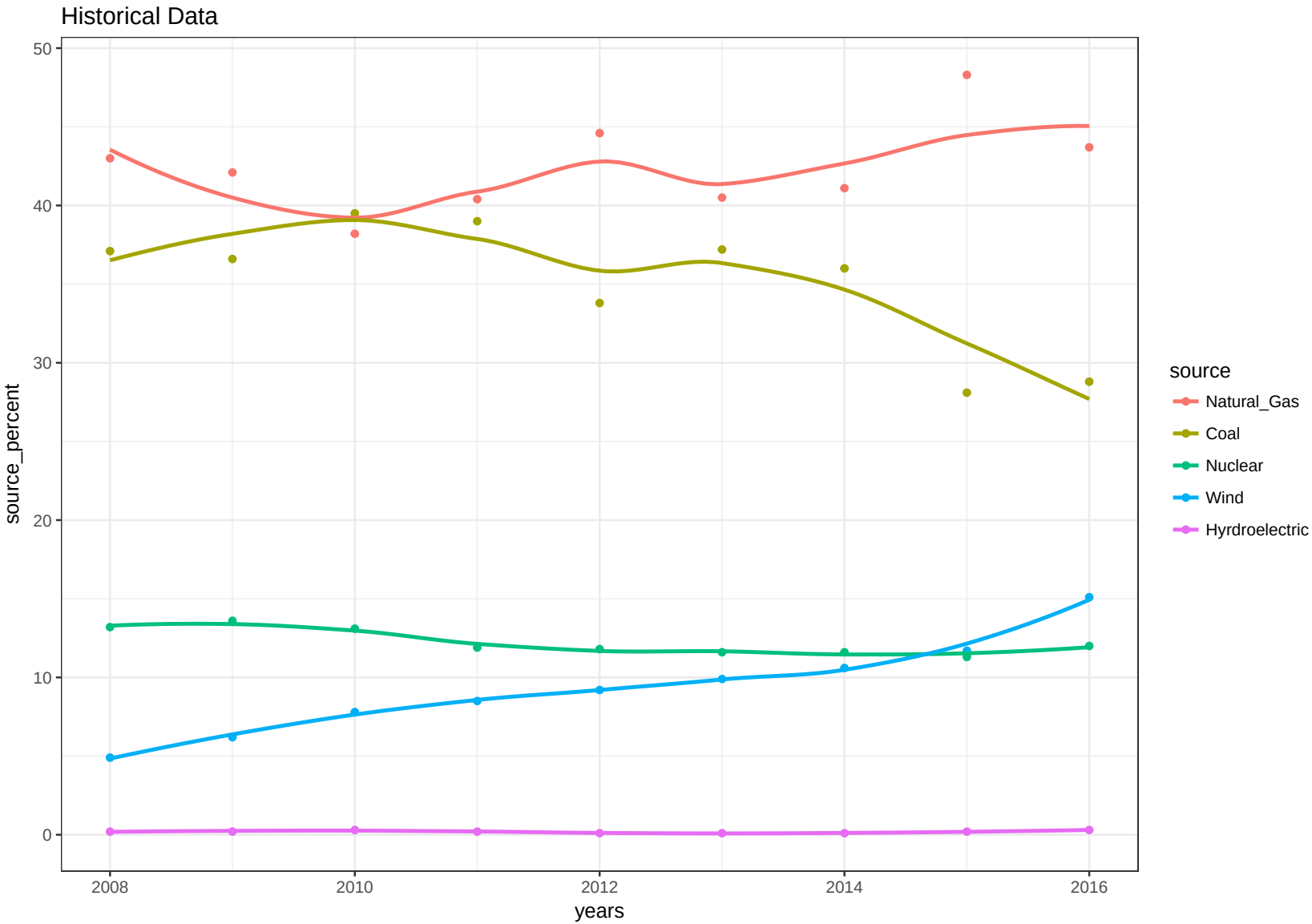
Percent Source Data

Table 2: Historical Energy Source Mix in Percentage

Fuel Types	Solar	Water	Net_DC_BLT	Other	Total_TWh
2008_(%)		0.2000		1.6000	308.9595
2009_(%)		0.2000		1.3000	305.4322
2010_(%)		0.3000		1.1000	316.0463
2011_(%)		0.2000		0.2000	333.8748
2012_(%)		0.1000	0.2000	0.3000	324.8597
2013_(%)		0.1000	0.5000	0.3000	331.6241
2014_(%)		0.1000	0.4000	0.3000	340.0334
2015_(%)		0.2000	0.1000	0.3000	347.5229
2016_(%)	0.2000	0.3000	-0.2000	0.2000	351.5478
2017_(%)_10	0.6400	0.2600	-0.1900	0.0100	302.1717

Other - includes petroleum coke, landfill gas, biomass solids, biomas gases, and any unknown fuel.
A positive value in the 'Net DC/BLT' row indicates import of power, negative indicates export.
2017 data is incomplete.

Percent Source Plot



Structural Change

Energy source portfolio changes

- More Wind and Solar sources online
- More Natural Gas integration
- Coal plant retirement schedules

Demand Shifters

- Electric vehicles have less than 1% market share today
- The future will look very different
- The electricity demands from electric vehicles on the power grid will be non-trivial
- Turns out the future is hard to predict, BUT future demands need to be provisioned for today.

Changes in Regulatory Environment

Electricity Market Reform

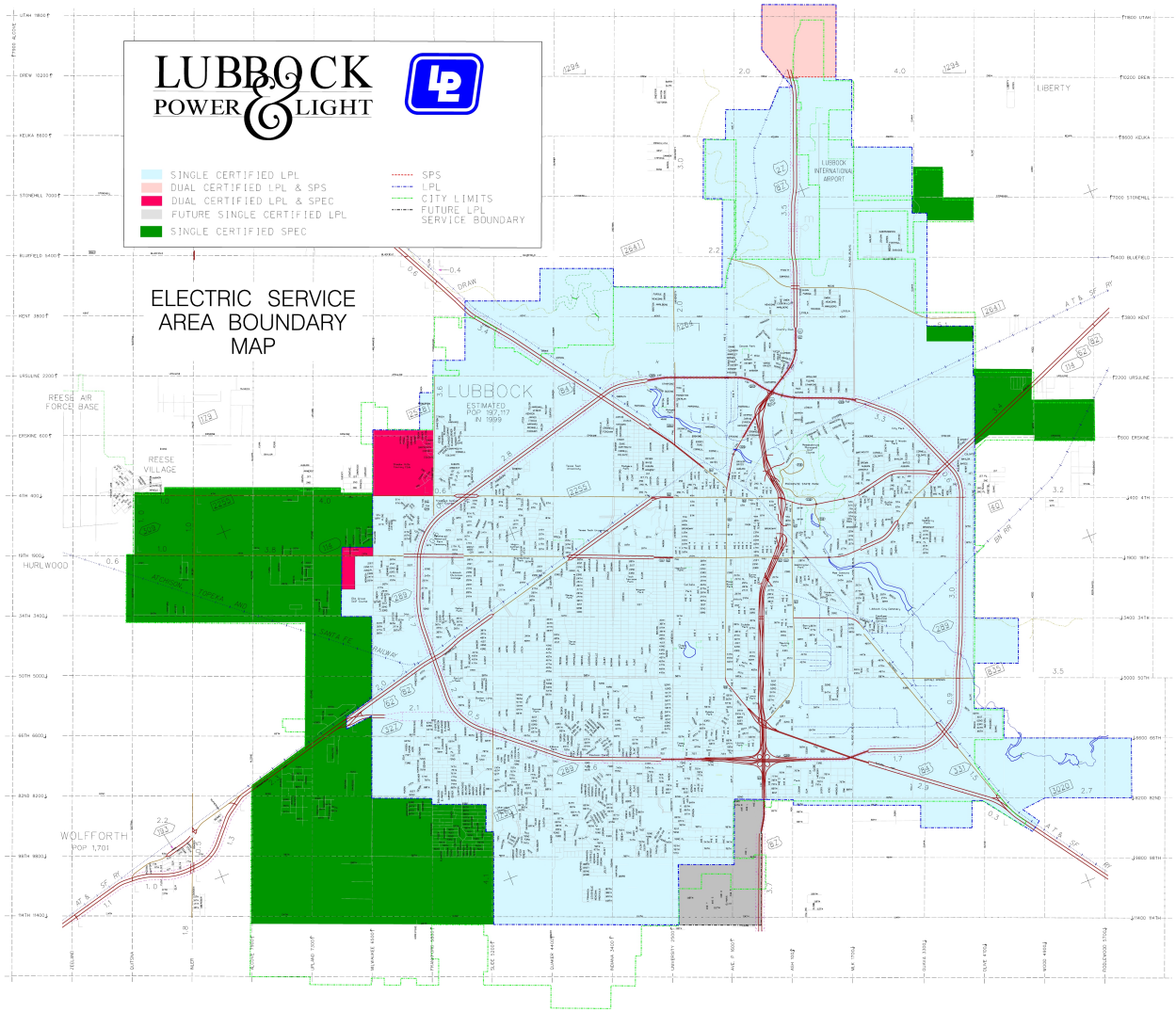
- Move away from vertically integrated electricity markets
- Move toward Investor Owned Utilities (IOU's)
- Development of Spot Market and Day Ahead Transaction Markets
- More sophisticated Cost Plus Pricing Models

Changes in Environmental Regulations

- Move toward renewable energy sources
- Move away from Nuclear

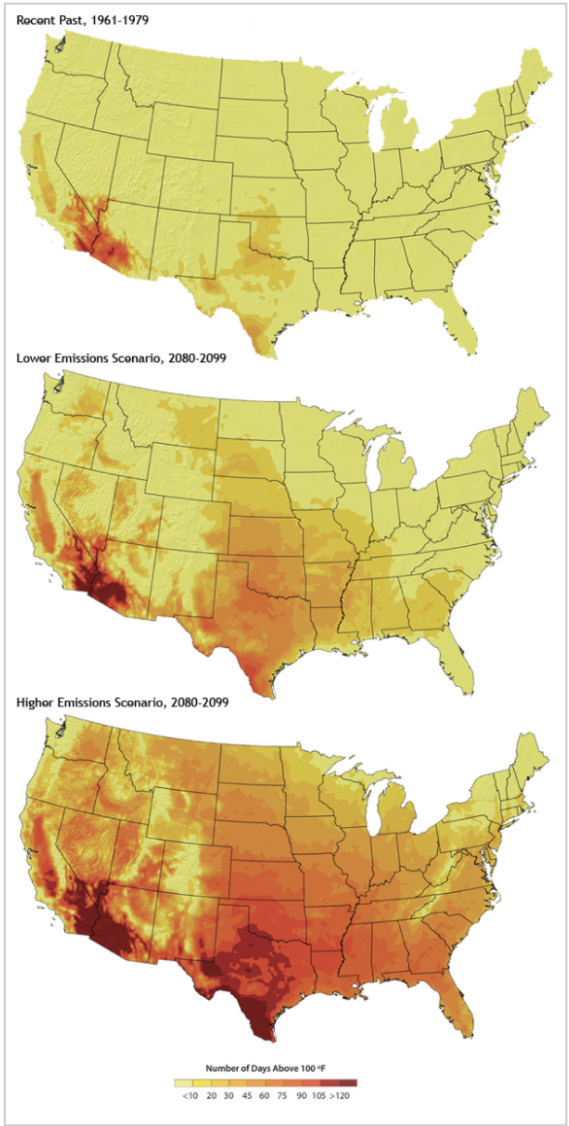
Change in ERCOT's Service Territory

- Lubbock will add 600 MW of demand load



Weather Uncertainty

- Texas summers are always hot!!! and getting hotter???



Optimization Model

Quadratic Programing Model

$$\min_{x_i} \frac{1}{2} x' H x + f' \text{ subject to } \begin{cases} Ax \leqslant b, \\ Aeqx = beq, \\ x \geqslant 0 \end{cases}$$

Optimization Model

Data

- Expected average price of source energy in 20XX
- Data from ERCOT Price Projection Model

Source	Expected Price ($/MWh)
Coal	$E(p_1)$
Hydro	$E(p_2)$
Natural Gas	$E(p_3)$
Nuclear	$E(p_4)$
Biomass	$E(p_5)$
Geo	$E(p_6)$
Solar	$E(p_7)$
Wind	$E(p_8)$

Optimization Model

Data

- Standard deviation of energy source prices in 20XX

Source	σ (\$/MWh)
Coal	σ_1
Natural Gas Combustion Cycle	σ_2
Natural Gas Peaking	σ_3
Nuclear	σ_4
Solar PV	σ_5
Wind	σ_6

Optimization Model

Constraints

- Meet projected demand, ie. 2022 Energy Forecast of 417 TWh
- Keep Texas electricity rates competitive, therefore, ensure expected cost of energy portfolio under XXX $/MWh

Gaol

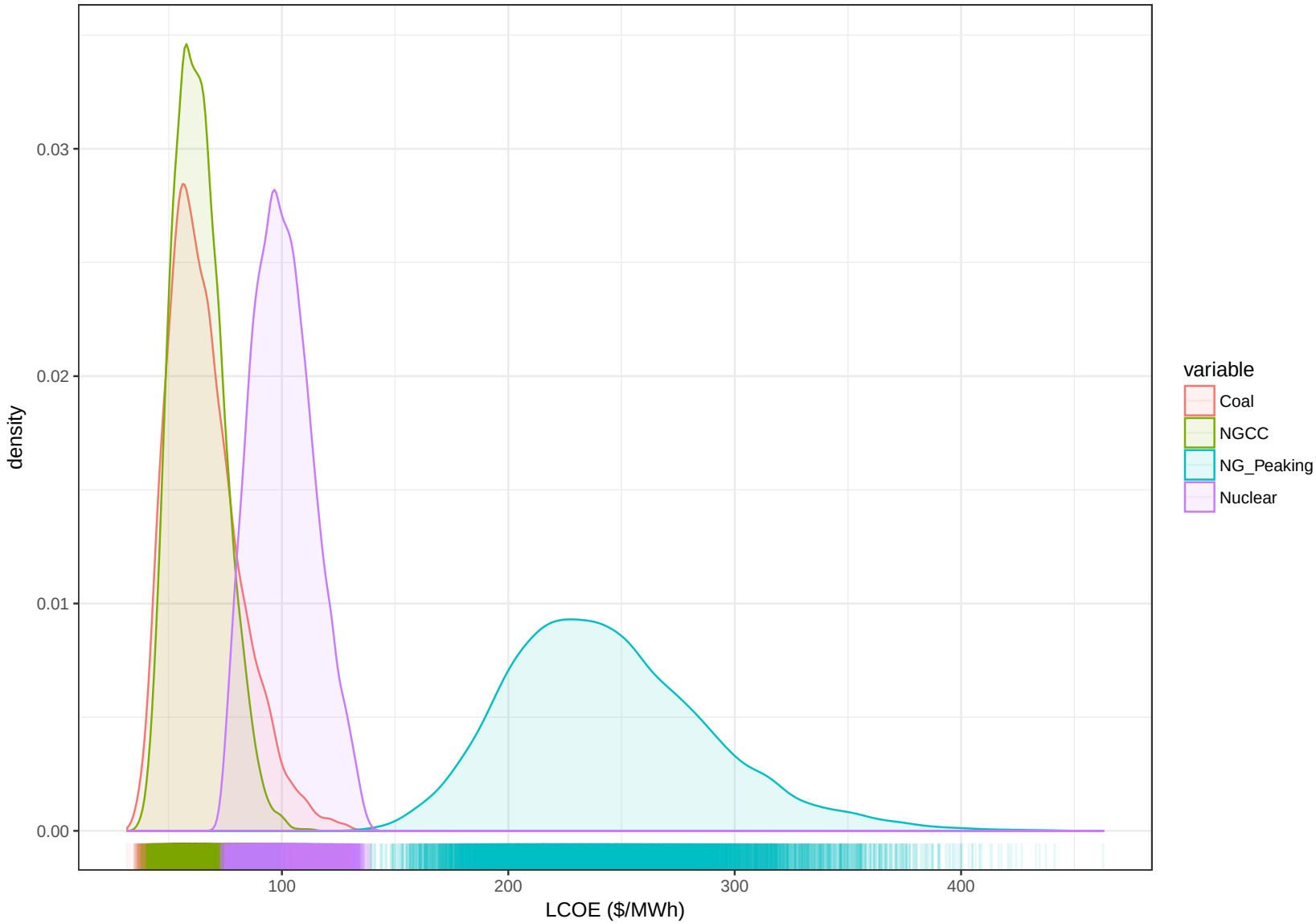
- Formulate a quadratic program to minimize the risk of obtaining energy, while satisfying the maximum expected energy cost constraint described above.

Summary Statistics from Monte Carlo Study

Table 5: Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
Coal	10,000	65.720	15.849	31.683	139.537
NGCC	10,000	63.173	11.154	35.963	113.557
NG_Peaking	10,000	244.178	44.255	136.063	462.787
Nuclear	10,000	100.680	13.269	72.001	139.315
Wind	10,000	86.327	6.624	65.307	115.607
Solar_PV	10,000	201.116	48.828	101.348	430.516

Density Plots from Monte Carlo Study



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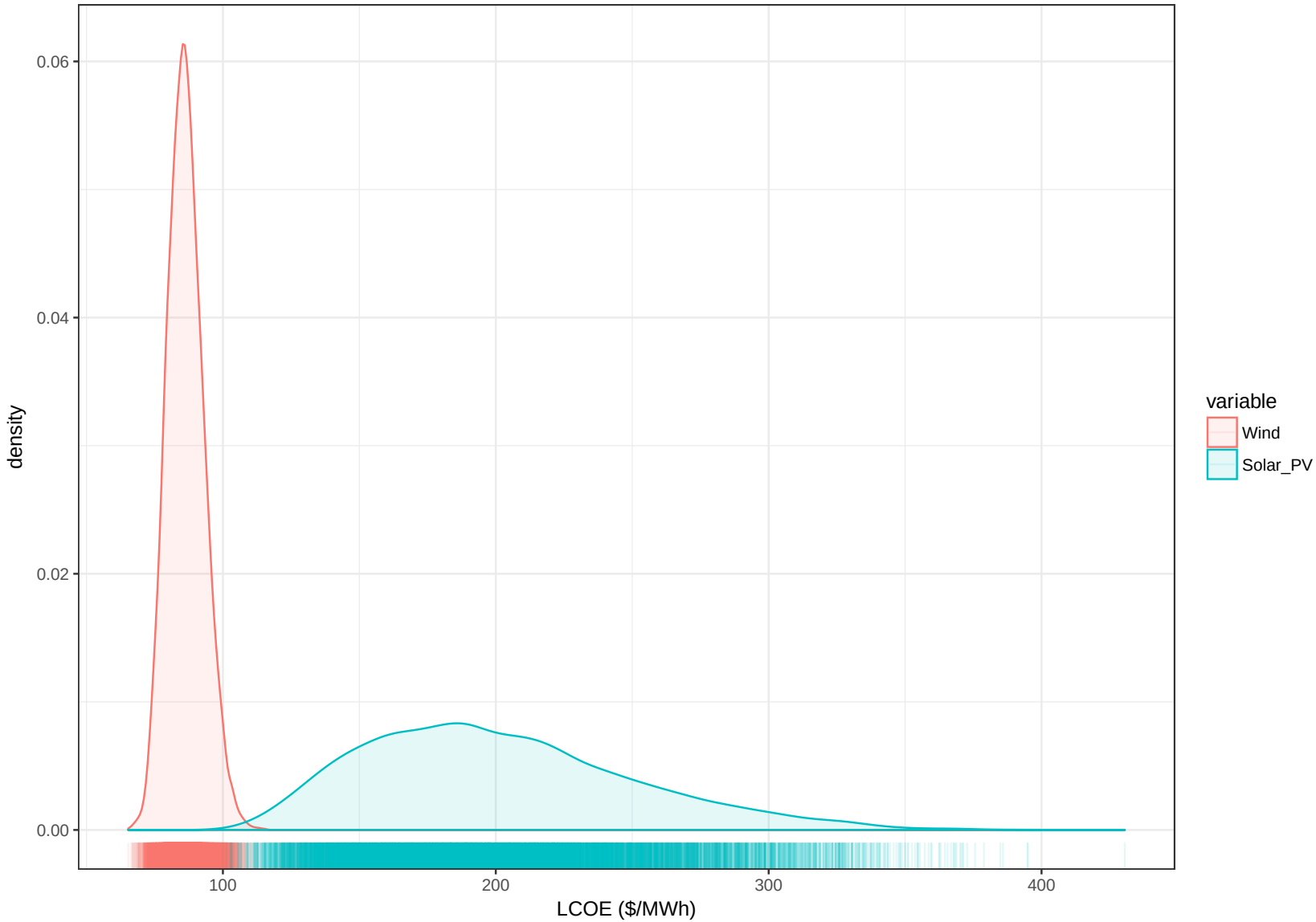

Results

With seed= 12345										
Q1 w/ vcov	id	source	percent	vcov matrix	Coal	NGCC	NG_Peaking	Nuclear	Wind	Solar_PV
coal	1	55.638586	14.451581	Coal	251.1977117	-0.8574479	2.318398	0.6466162	1.2734792	4.2576218
natural_gas_cc	2	111.672017	29.005719	NGCC	-0.8574479	124.4080090	5.086962	2.0653877	-0.5982139	4.0523558
natural_gas_peaking	3	38.500000	10.000000	NG_Peaking	2.3183977	5.0869622	1958.544699	1.1294195	2.2372874	14.3966414
nuclear	4	77.542357	20.140872	Nuclear	0.6466162	2.0653877	1.129419	176.0786624	2.1279467	-0.5545507
wind	5	96.250000	25.000000	Wind	1.2734792	-0.5982139	2.237287	2.1279467	43.8762257	1.0086051
solar	6	5.397041	1.401829	Solar_PV	4.2576218	4.0523558	14.396641	-0.5545507	1.0086051	2384.2161112
Q w/o vcov	id	source	percent	vcov matrix	Coal	NGCC	NG_Peaking	Nuclear	Wind	Solar_PV
coal	1	54.986405	14.282183	Coal	251.1977	0.000	0.000	0.0000	0.00000	0.000
natural_gas_cc	2	111.025482	28.837788	NGCC	0.0000	124.408	0.000	0.0000	0.00000	0.000
natural_gas_peaking	3	38.500000	10.000000	NG_Peaking	0.0000	0.000	1958.545	0.0000	0.00000	0.000
nuclear	4	78.444821	20.375278	Nuclear	0.0000	0.000	0.000	176.0787	0.00000	0.000
wind	5	96.250000	25.000000	Wind	0.0000	0.000	0.000	0.0000	43.87623	0.000
solar	6	5.793292	1.504751	Solar_PV	0.0000	0.000	0.000	0.0000	0.00000	2384.216
with seed= 123										
Q1 w/ vcov										
	id	source	percent	vcov matrix	Coal	NGCC	NG_Peaking	Nuclear	Wind	Solar_PV
coal	1	54.732629	14.216267	Coal	254.2681389	-0.9083444	1.843315	3.998742	1.064627	5.272965
natural_gas_cc	2	110.125665	28.604069	NGCC	-0.9083444	129.8986558	-3.634986	1.427547	1.356694	-3.414447
natural_gas_peaking	3	38.500000	10.000000	NG_Peaking	1.8433148	-3.6349862	1870.958434	-3.327918	1.430276	-31.254010
nuclear	4	79.445819	20.635278	Nuclear	3.9987420	1.4275474	-3.327918	175.262036	1.135800	9.771821
wind	5	96.250000	25.000000	Wind	1.0646272	1.3566943	1.430276	1.135800	43.766321	8.254088
solar	6	5.945887	1.544386	Solar_PV	5.2729654	-3.4144473	-31.254010	9.771821	8.254088	2364.510594
Q w/o vcov										
	id	source	percent	vcov matrix	Coal	NGCC	NG_Peaking	Nuclear	Wind	Solar_PV
coal	1	55.417048	14.394038	Coal	254.2681	0.0000	0.000	0.000	0.00000	0.000
natural_gas_cc	2	108.475254	28.175391	NGCC	0.0000	129.8987	0.000	0.000	0.00000	0.000
natural_gas_peaking	3	38.500000	10.000000	NG_Peaking	0.0000	0.0000	1870.958	0.000	0.00000	0.000
nuclear	4	80.398414	20.882705	Nuclear	0.0000	0.0000	0.000	175.262	0.00000	0.000
wind	5	96.250000	25.000000	Wind	0.0000	0.0000	0.000	0.000	43.76632	0.000
solar	6	5.959284	1.547866	Solar_PV	0.0000	0.0000	0.000	0.000	0.00000	2364.511

Figure 5