Identifying Ideal Renewable Alternatives to Coal-Fired Electricity Production in Texas and West Virginia

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Abstract

Coal-fired electricity generation is one of the largest sources of air pollution in the United States. Finding an alternative, sustainable source of electricity production is necessary. We intend to quantify the environmental impacts of coal and identify alternative energy sources in states which are most reliant on coal. We use Texas and West Virginia as case studies. Texas utilizes the greatest amount of coal in terms of absolute value, while West Virginia relies most on coal for energy production over other sources.

We discover that Texas and West Virginia are best suited to invest in wind-generated electricity as the coal price increases. We achieved through a careful statistical analysis of the relationship between the historical percentage consumption of 6 types of renewable energy types and the price of coal over time.

The implications of our research suggest that using wind as an alternative source of energy to coal, accounting for future decreases in the costs associated with renewable energy production and an increase in price-competitiveness relative to traditional methods of electricity production such as coal and coal-coke, can be advantageous both economically and environmentally.

1 Technical Exposition

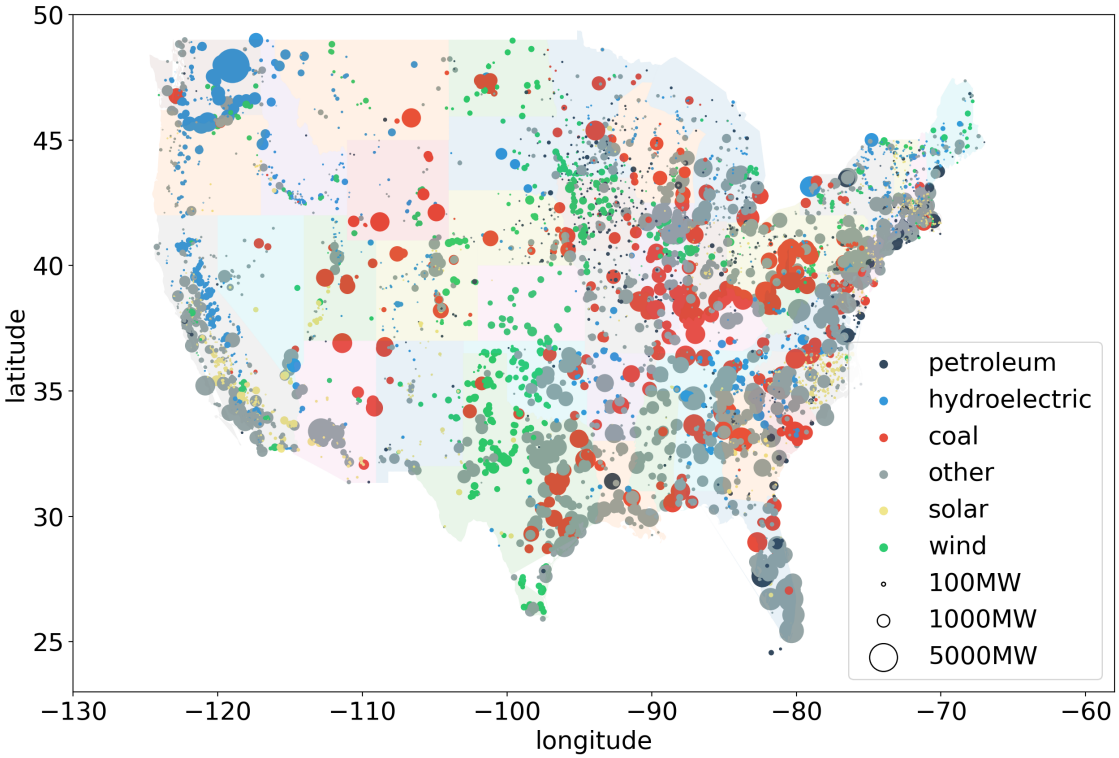

Figure 1: Spatial Map of U.S. power plants from *power plant* dataset. We see that different regions prefer different sources.

Using the latitude and longitude coordinates of power plants in the United States, we digitally mapped them to identify the relationship between location and primary source of electricity production per plant.

The map reveals some interesting findings:

- Hydroelectric power plants are mostly near coasts.
- Solar power plants are mostly in Western states California, Arizona, and Nevada.
- Wind power plants are dispersed in the Central United States
- Coal-fired power plants are concentrated in Texas, Indiana, Kentucky, Pennsylvania, etc.

1.1 Research Questions

After considering existing research and conducting basic visualizations of the datasets, we come up with the following research questions:

- What is the impact of coal-fired power plants on air pollution?
- What is the ideal renewable energy source replacement for Texas and West Virginia?

If we replace coal with renewable sources, how much can we offset the various environmental impacts of coal-fired power plants? This last question is beyond the scope of this paper, but we hope that the implications of our research can yield meaningful insights to answer it in the future.

Table 1: top 10 states with largest coal power plant capacity

States	Coal power plants capacity (MW)	Coal capacity percentage
Texas	25696.5	21.4%
Indiana	16267.1	64.2%
Ohio	15322.0	53.2%
Illinois	14902.8	32.8%
Kentucky	13299.7	66.1%
West Virginia	12969.0	84.9%
Pennsylvania	12809.4	29.1%
North Carolina	11130.4	34.4%
Florida	10694.0	17.5%
Missouri	9820.0	54.5%

1.2 Preprocessing

We cleaned and tidied the data in R Studio and Python to extract the variables of interest: those related to coal and coal-coke and renewable energy. Additionally, we munged the geospatial data to assist in creating the maps. We used average temperature change variables to see whether there is a warming impact in the 10 states. In order to find the relationship between the amount of coal consumption and its environmental impact on air pollution, we select the variables of the annual concentration of sulphur dioxide and nitrogen dioxide in the atmosphere in top 10 states. Using the total coal consumption over time from 1960 to 2017, we find which top 10 states consume the coal most. Averaging the price of coal across time helps to see whether there is a higher correlation between the price of coal and coal consumption.

1.3 Methods

To identify the alternative renewable energy sources that states used to compensate for the increasing cost of using coal and the ensuing air pollution, For each state, we first calculate the percentage of the energy consumption for six types of renewable energy (solar, wind, hydroelectric, wood and biomass, nuclear) relative to the total energy consumption from years 1970 to 2016. The percentage were averaged across all sectors. We then calculated the average price of the coal in units of dollars per million btu across all sectors. We used a lasso regression to select the one most important predictor of the coal prices. Since we only have limited data samples $N = 47$, instead of using a cross-validation procedure, we used a permutation procedure to test for the significance of the lasso regression. In each step, we scrambled the coal price variable across time points and performed the lasso regression between the permuted coal price variable and the 6 energy consumption predictors. We repeated this step 5000 times to get a empirical null distribution of the r^2 value. Then we compared the observed r^2 value against this null distribution to computed the p-value.

1.4 Definitions

Renewable Energy Sources: solar, wind, geothermal, hydroelectric, biomass, and nuclear sources of electricity production.

2 Results

2.1 Power Plants

We grouped American power plants by states and by their primary energy sources of electricity production. We identify the top ten coal culprits: Texas, Indiana, Ohio, Illinois, Kentucky, West Virginia, Pennsylvania, North Carolina, Florida, Missouri. 1.

Texas consumes the most coal by volume and so the state was a candidate for our analysis on mitigating coal reliance. However, surprisingly, West Virginia's electricity production relies almost 85% on coal. We decided to look at these two states in closer detail.

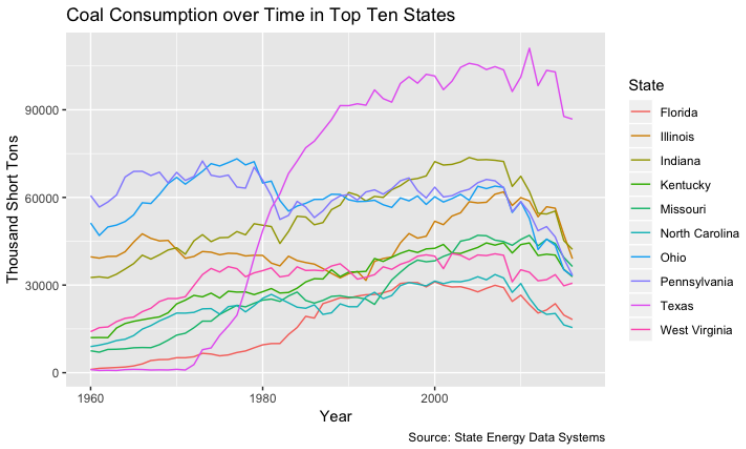

Figure 2: The time-series graph shows the consumption of coal for electricity production in the ten states

2.2 Air Pollution

We examined the *air concentrations* dataset and aggregated the data by year and state code. Sulfur dioxide (SO_2) and nitrous oxides (including NO_3) are two of the main gases emitted by coal-firing, and are associated with significant health risks and environmental damage to the ecosystem. Research from American journal of medical sciences shows that high concentration of sulfur dioxide and nitrogen dioxide in the atmosphere could increase the chances of having lung cancer, worsen existing heart disease,and asthma attacks. The variables of interest are total emissions of SO_2 and NO_3. We plotted the trends in total emissions over time.

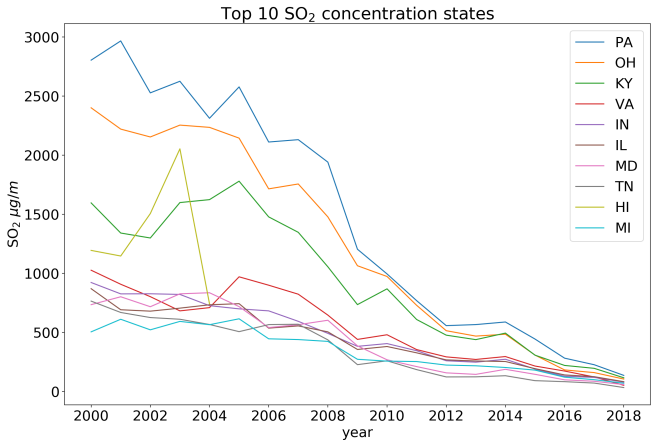

Figure 3: We show top 10 states with highest SO_2 concentration. Overall the trend is decreasing with time. The top three states are PA, OH and KY, as the same as NO_3.

The downward trends in NO_3 and SO_2 emissions may incite hope, but on closer examination, coal-fired plants still produce significant amounts of air pollutants.

Among the ten states with largest coal power plant capacity, 6 (Indiana, Ohio, Illinois, Kentucky, Pennsylvania, Missouri) are also identified as having highest the SO_2 concentration. Similarly, 7 states (Indiana, Ohio, Illinois, Kentucky,Pennsylvania, North Carolina,Missouri) are identified as having the highest NO_3 concentration.

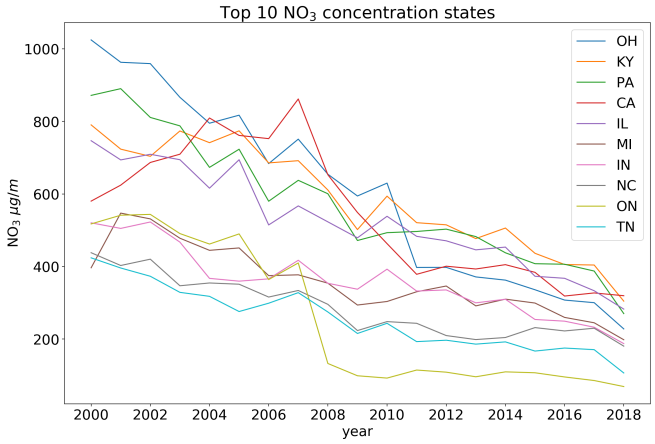

Figure 4: We show top 10 states with highest NO_3 concentration. Overall the trend is decreasing with time. The top three states are OH, KY and PA, as the same as SO_2.

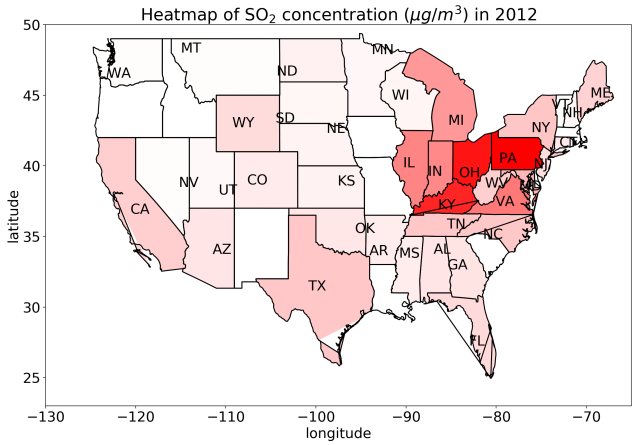

Figure 5: A heat-map of SO_2 emissions in the United States. It is clear that the top ten coal-reliant states also demonstrate increased emissions in SO_2

2.3 Identifying Alternative Renewable Energy Sources

As shown in Fig. 6, the average coal price across all states and all sectors has increased over the past two decades. This is likely due to increasing global consumption of energy. The price increase exerts an economic pressure on states whose power plants rely on coal as the primary source of electricity production.

In order to offset the increasing costs of coal use, and at the same time reduce air pollution from burning coal thus offsetting the external costs of energy production, we argue that these states must divest to renewable energy sources, such as solar or wind.

To validate our hypothesis, we analyzed the relationship between the consumption of different renewable energy sources and rising coal prices in the two states selected for analysis : Texas and West Virginia. We picked these two states for two reasons: (1) Among all states, Texas utilizes the largest volume of coal in electricity production and West Virginia's electricity production is overwhelmingly homogeneous in its coal reliance.

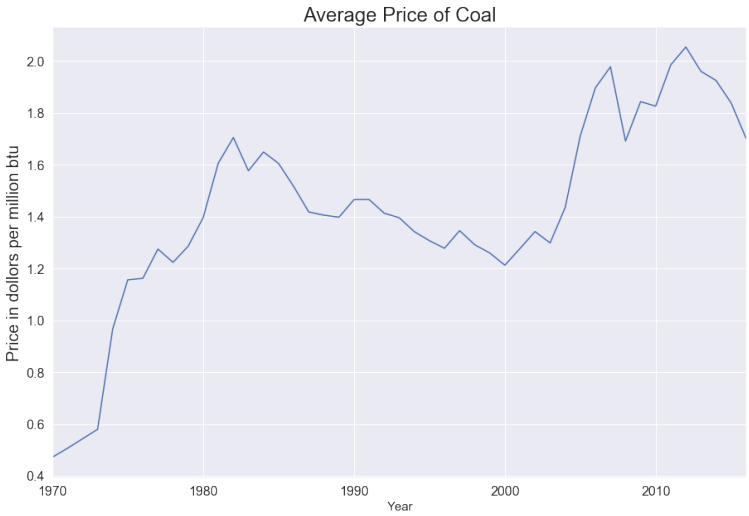

Figure 6: The average coal price (price in dollars per million Btu) across all states and all sectors over years.

As shown in Fig. 7, Texas shows an increase in the percentage of energy consumption for wind, wood and biomass, and nuclear in the past decade when the coal price also increased. Similarly, in West Virginia, the percentage of energy consumption for wind, wood and biomass, and hydroelectric increases in the past decade as the price of coal goes up (Fig. 8). To select the features for our analysis, we performed a lasso regression to select the most correlated energy source with the price of coal. The lasso regression suggests that in both Texas ($r^2 = 0.68, p = 0.02$) and West Virginia ($r^2 = 0.7, p = 0.005$), the percentage of wind consumption correlates positively with the price of coal over time (Fig. 9). Therefore, as the coal price increases, both states increase their consumption in wind as an alternative energy source to the coal.

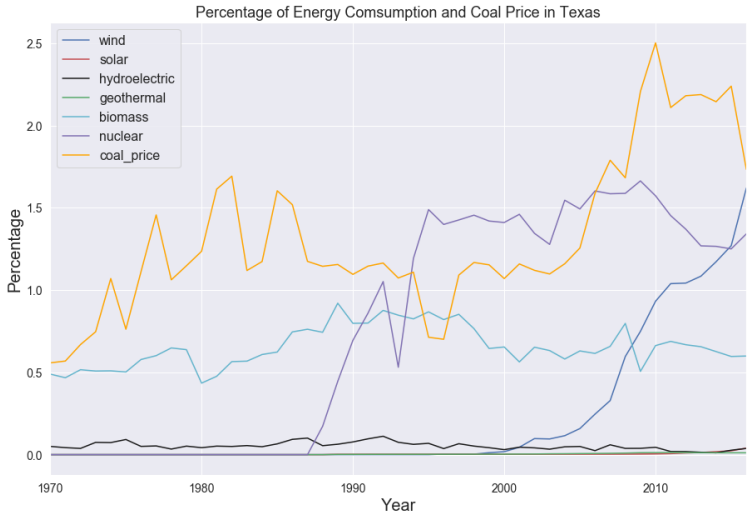

Figure 7: The percentage of energy consumption over time for six renewable energy types and the average coal price over time.

This suggests that wind-sourced electricity is the most likely alternative to traditional coal-fired electricity production in Texas and West Virginia as the regressions suggest that this trend will continue.

3 Conclusion

In conclusion, we find that improving electricity production efficiency by de-carbonizing can be achieved through regression analysis that is specific to the geographical specificities of states. This is ultimately necessary for lowering the waste and cost of power plant.

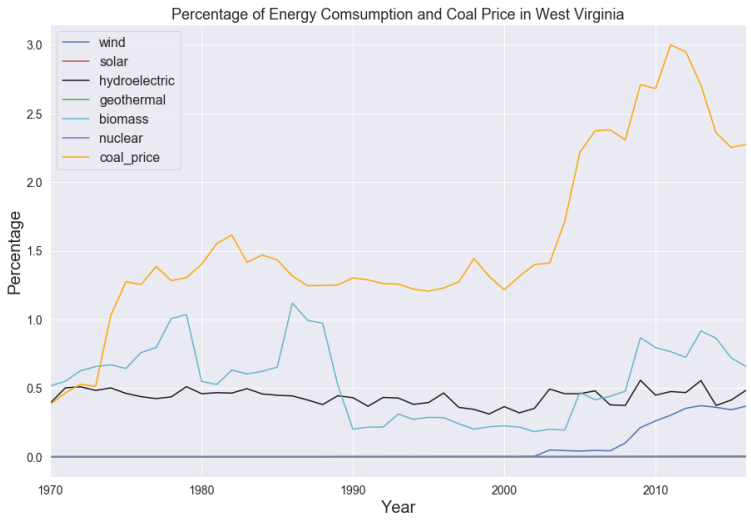

Figure 8: The percentage of energy consumption over time for six renewable energy types and the average coal price over time.

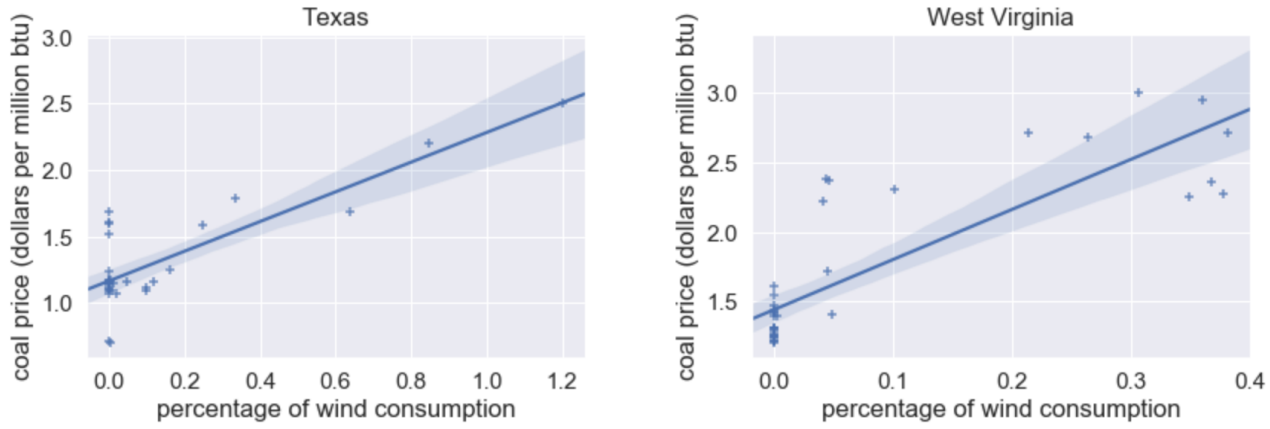

Figure 9: The linear relationship between the percentage consumption in wind and the average price of coal for Texas and West Virginia.

4 Appendix

4.1 Future research

Based on the findings from this research, we believe that state governments should allocate the renewable energy power plants based on the demand of energy type in the market and the geographical advantages of the region. In our case, Texas and West Virginia are suited towards adopting wind-sourced electricity. However, this conclusion may differ on a state-by-state basis.

In future, we would like to expand our analysis beyond analyzing existing trends in consumption to include other factors like price-competitiveness of solar or geothermal sources.

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