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Shifts in Renewable Energy Consumption Impact Changes in the Composition of Sectoral Energy Consumption

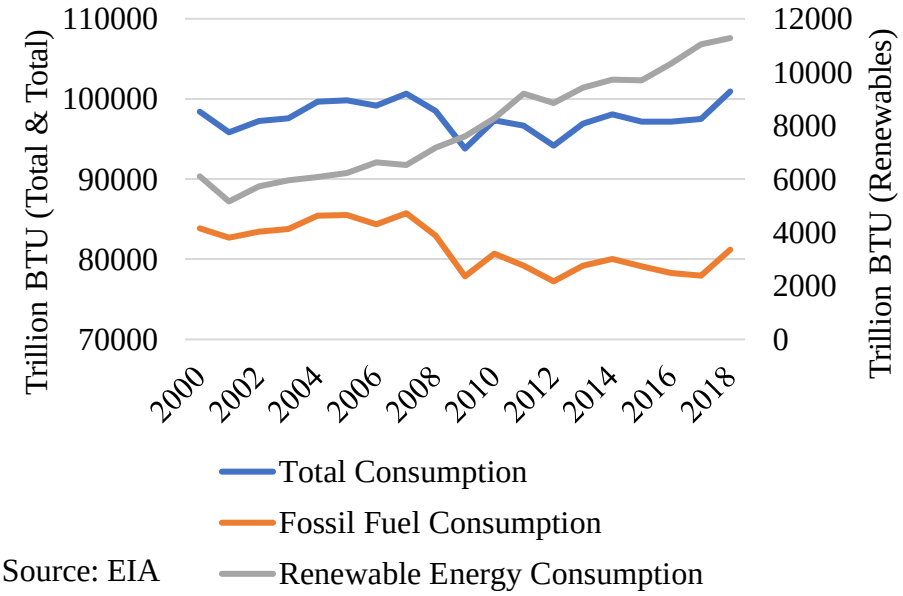
I. Introduction

As calls for improved access to renewable energy grow louder in tandem with concerns over the impact of fossil fuels on the pollution of the ecosystem, the role of energy consumption in the United States is transforming as states investigate the feasibility of powering their citizen's homes and businesses with renewable methods. To obtain energy from fossil fuels like oil, gas, and coal that are stored underground for millions of years, non-renewable energy sources must be extracted and heated to release energy from the carbon molecules in the material. The consequences of this approach loom over not only the local population responsible for burning this type of fuel but also populations across the world as well as future generations since greenhouse gases such as carbon dioxide spread and remain in the atmosphere for hundreds of years. Pollution-induced climate change has devastating environmental and social effects, including warming temperatures that intensify wildfires, droughts, hurricanes and the disappearance of ice caps, animal species extinction, and mass human migration. These issues and more have motivated interest in advancing the innovation and integration of renewable energy technology. Efforts to provide renewable energy to the population vary among the fifty states, leading to discrepancies in how energy is consumed by the four major economic sectors of a given state: residential, industrial, commercial, and transportation. Does a shift in the portion of

renewable energy consumption determine the change in the composition of the energy consumed by each sector?

From 2000 to 2018 the United States experienced a near doubling of renewable energy consumption, rising from 6,102 to 11,279 British Thermal Units. Fossil fuel consumption, on the other hand, has decreased by about 3 percent (see Figure A). Although fossil fuels still make up a majority of energy consumption, renewable energy has steadily increased its portion of total energy consumed in the US.

Figure A. US Renewable, Fossil Fuel, and Total Energy Consumption from 2000 to 2018 (trillion BTU)

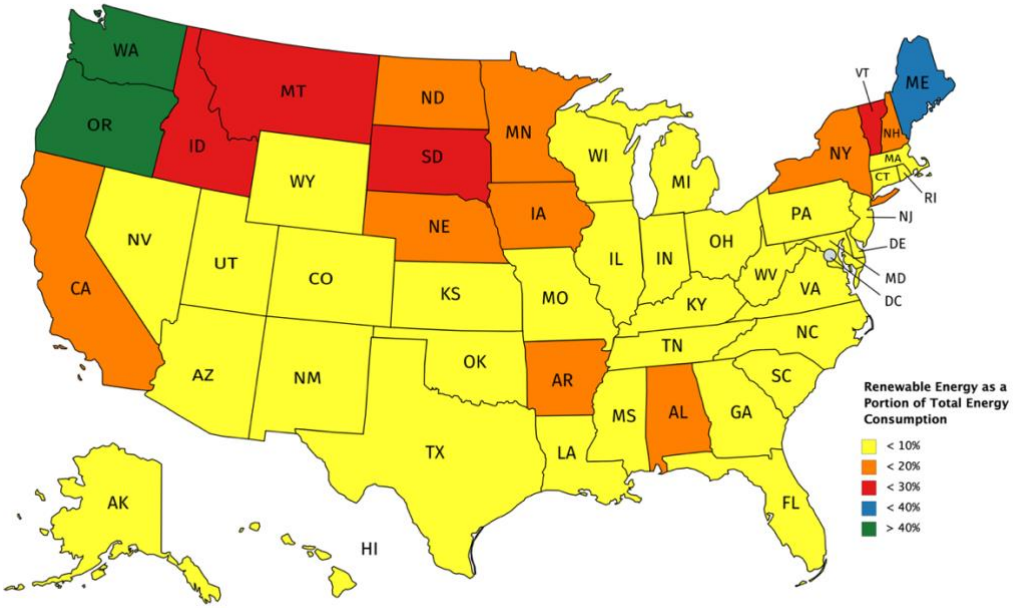


Source: EIA

However, the magnitude of the portion of renewable energy consumption varies among the fifty states. From 2000 to 2018, the average potion of renewable energy consumption has been often higher in northern latitudes (see Figure B). Geographic, political, and economic differences between states have led to this discrepancy in the availability of renewable energy to the population. For instance, Washington and Oregon—the only two states with upwards of 40% of renewable energy as a portion of total energy consumption—benefit from the Columbia River,

where dams and hydropower facilities have provided cheap and reliable renewable energy. Similarly, states in the Midwest have an abundance of wind and unobstructed ranges, ideal conditions for wind power. However, as renewable energy technology improves, such as the efficiency and cost of solar photovoltaics, states in lower latitudes have recently incremented their respective portion of renewable energy consumption.

Figure B. Average Renewable Energy Consumption as a Portion of Total Energy Consumption by State from 2000-2018 (%)



Source: EIA

This research analyzes the annual energy consumption of each state from 2000 to 2018 using a model for the change in each sector's portion of energy consumption. Although the multivariable regression framework builds upon previous research in the literature of energy economics by controlling for the indicator of energy intensity, which measures the amount of total energy consumed per dollar of real GDP, this study differs in two main aspects. The scope of individual states in this paper is narrower than other research in the literature that compare the energy consumption patterns of countries around the world, and the focus on changes in the

portion of sectoral energy consumption has not been approached through the decomposition of energy consumption into its share of renewable and fossil fuel sources.

The results of this study suggest that increases in the portion of renewable energy consumption are significantly related to a decrease in the portion of the amount of energy consumed in the residential and transportation sectors of the economy. Moreover, decreases in the portion of renewable energy indicate an increase in the portion of total energy consumed by the industrial sector. The implications of these relationships may provide energy policymakers, producers, and investors with evidence to understand the condition of their state's renewable energy consumption and how the growth of renewable energy may influence the amount of energy consumption required by the sectors of the economy.

II. Literature Review

Recent studies in the literature on energy economics have placed attention on the change in energy consumption and economic output. Apergis and Payne (2009) employ a heterogeneous panel cointegration test to determine the effect that renewable energy consumption has on economic growth. Their model reveals that an increase in renewable energy consumption by 1 percent leads to an increase in real GDP of 0.76 percent in the long run. Their short- and long-run Granger-causality tests show a positive bidirectional causality between renewable energy consumption and economic output. Another paper (Hirsh & Koomey 2015) find that real GDP grew side-by-side with electricity consumption from 1973 to 1996 with growth rates of 92 percent and 90 percent for GDP and electricity consumption, respectively. Although the authors consider the possibility of a bidirectional relationship between the two economic indicators, the growth rates significantly diverged in 1996, a trend that the authors attribute to the US

government passing of energy efficiency standards in 1987 and 1992 that encouraged advancements in the efficiency of residential appliances like refrigerators and lights.

Apergis and Payne (2010) extend their previous inquiry of energy consumption to a panel of 80 countries over the period of 1990 to 2007 with attention to the proportion of renewable and non-renewable energy consumed. The authors employ a Pedroni multivariate panel cointegration test to measure the equilibrium relationship between real GDP, renewable and non-renewable energy consumption, real gross fixed capital formation, and the labor force. Their results provide empirical evidence for the theory of the feedback hypothesis: the short- and long-term bidirectionality of energy consumption and economic growth.

Other work in the literature of energy intensity has simulated shifts in energy efficiency with a recursive-dynamic computable general equilibrium model and suggests a continued decline in long-run energy intensity (Wind & Eckaus 2007). A recent paper that processed data of a sample of 85 developed and developing economies from 1991 to 2012 with a system general method of moments and observed a positive relationship between reduced carbon dioxide emissions and increased economic output and renewable energy (Bhattacharya, et al. 2016). Capital and non-renewable energy have also been shown to have a positive impact on economic output; however, findings suggest that renewable energy has a higher correlation with economic output than non-renewable sources (Bhattacharya, et al. 2015). This paper analyzes the composition of renewable sources among states and their respective significance to the change in a state's composition of sectoral energy consumption and covers a period that includes a more recent period of technological advancements and enhanced governmental policies to combat the pollution caused by the extraction and consumption of fossil fuels.

III. Data and Methodology

This research considers a sample size of fifty states and the period of 2000 to 2018. For each state, annual data were collected from the energy consumption estimates released by the US Department of Energy's Energy Information Administration (EIA). These data include annual total, renewable, and fossil fuel consumption, real GDP, and total sectoral energy consumption. Measurements for renewable and non-renewable energy as a portion of total energy consumption were calculated for each year. Similarly, residential, industrial, commercial, and transportation sectors' energy consumption as a portion of total energy consumption was calculated on an annual basis. Annual energy intensity in thousand BTU per US dollar was found using total consumption and real GDP for each state. The year-over-year and change in these measurements was found using these data over the relevant period from 2000 to 2018.

Individual annual state-level data were aggregated to obtain estimates for energy consumption levels for the US and the national average of the sectoral composition of total energy consumption.

The multivariable regressions were conducted on the sample size using the independent variables of the change in renewable energy consumption as a portion of total energy consumption along with the control variable of the change in energy intensity, measured in percentage points and percent, respectively. The regressions controlled for energy intensity to account for variations in the connection between energy consumption and economic output between states. For each economic sector, the change in the energy consumption of the sector as a portion of total energy consumption, measured in percentage points, was the dependent variable in the four regressions.

IV. **Results**

The results reveal significant relationships between the change in the portion of renewable energy consumption and the change in the portion of sectoral energy consumption for the residential, industrial, and transportation sectors (see Table A).

Table A. Regression Results for the Change in the Portion of Sectoral Energy Consumption

	Change in Portion of Residential Consumption	Change in Portion of Industrial Consumption	Change in Portion of Commercial Consumption	Change in Portion of Transportation Consumption
Constant	-0.1152	1.6564	0.1996	-1.7418
	(1.1367)	(1.8825)	(0.9742)	(1.1670)
Change in Portion of Renewable Energy	-0.1402*	0.4286***	-0.0897	-0.1988***
	(0.0700)	(0.1159)	(0.0600)	(0.0719)
Change in Energy Intensity	-0.0879**	0.3075***	-0.0575	-0.1622***
	(0.0380)	(-.0629)	(0.0326)	(0.0390)
R-squared	0.2067	0.5095	0.1294	0.4064
Adjusted R-squared	0.1729	0.4886	0.0924	0.3811
No. observations	50	50	50	50

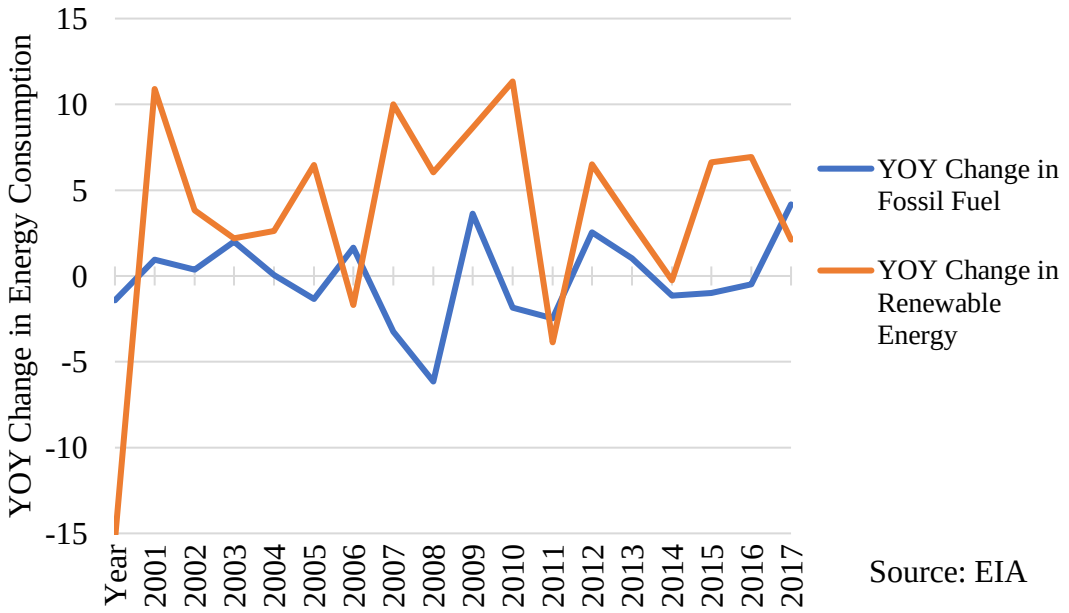
Standard errors are reported in parentheses. *, **, *** indicates significance at the 90%, 95%, and 99% level, respectively. Source: EIA

Specifically, the model predicts that a 1 percentage point increase in the portion of renewable energy consumed leads to a -0.14 percentage point change in the portion of the energy consumed by the residential sector ($p < 0.1$), a 0.43 percentage point change in the portion of the energy consumed by the industrial sector ($p < 0.01$), and a -0.20 percentage change in the portion of the energy consumed by the transportation sector ($p < 0.01$). The results for the change in the portion of commercial energy consumption did not reach a significant p-value. This paper will

primarily focus on interpreting the results of the industrial sector which raise important connections to the portion of renewable energy consumed in a state.

Before discussing the connection between renewable energy and the industrial sector at the state level, it is worth considering the role of each variable in terms of the national economy. In the US, the year-over-year growth rate of renewable energy consumption consistently exceeds the rate of change in fossil fuel energy consumption rates (see Figure C). Despite these changes in the composition of the types of energy resources consumed in the US, sectoral energy consumption as a portion of total energy consumption has remained stagnant between 2000 and 2018. The average proportion of each sector over this period—22% residential, 18% commercial, 31% industrial, and 29% transportation—are nearly identical to the 2000 and 2018 proportions of each sector (see Appendix 1). As a result, observing changes in each sector's energy consumption as a portion of national energy consumption would not provide an accurate depiction of the array of changes occurring within each state.

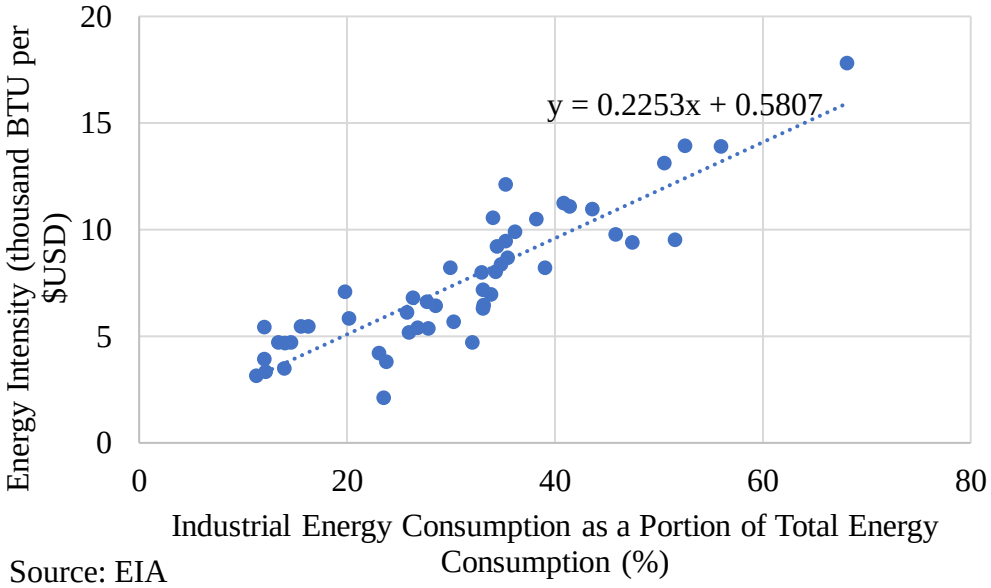
Figure C. YOY Change in US Renewable and Fossil Fuel Energy Consumption from 2000-2018 (percentage point)



Source: EIA

This study controls for energy intensity since this measurement influences each sector of the economy. The portion of the energy consumed by the industrial sector, contrary to the other three sectors, maintains a positive relationship with energy intensity (see Figure D). Each entry in Figure D represents a state, and a state with a greater portion of industrial energy consumption has a higher level of energy intensity. This trend is because manufacturing intensive states require a higher level of energy to produce goods compared to states whose total energy consumption and economic output rely on services (see Appendix 2, 4, and 6 for the relationship between average energy intensity and the portion of the remaining sectors' energy consumption).

Figure D. Average Energy Intensity and the Portion of Industrial Energy Consumption by State from 2000-2018

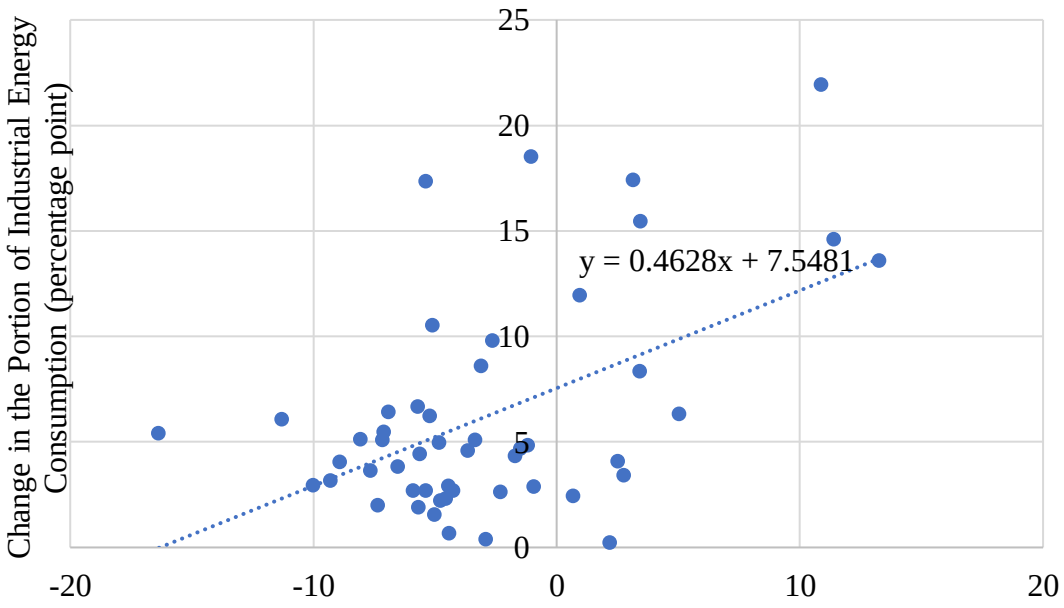


Source: EIA

In each sector besides the industrial sector, as a state increases the rate of change in the portion of renewable energy consumption, the change in the portion of the energy consumed in the sector decreases (see Appendix 3, 5, and 7). For states that experienced an increase in the portion of renewable energy consumption from 2000 to 2018, the change in the portion of the energy consumed in the industrial sector increases. This evidence suggests a state that increases

its share of total energy consumed experiences an increase in the portion of total energy consumed by the industrial sector because renewable energy does not substitute fuels used for manufacturing and other industrial activities in the economy. Instead, the integration of renewable technology decreases the portions of total energy consumed by the residential and transportation sectors (See Figure E). Renewable energy competes with traditional sources of fossil fuels to provide energy to the residential sector, a sector that relies on electricity more than the industrial sector. Similarly, the role of the transportation sector in the model suggests that states with a higher portion of renewable energy consumption require a smaller portion of total energy consumption in transportation than states that have a slower change in the portion of total energy from renewable resources, a trend most likely to continue as consumers have increased access to electric vehicles.

Figure E. Change in the Portion of Industrial Energy Consumption and Change in the Portion of Renewable Energy Consumption by State from 2000 - 2018 (percentage point)



Source: EIA

V. Extensions and Robustness

Further research in the distribution of energy sources for renewable and fossil fuel energy sources may reveal a significant impact of individual types of energy to the change in a state's sectoral composition of energy consumption, in which important sources to analyze may include solar, geothermal, hydro, wind, biomass, and nuclear power, or natural gas, coal, and petroleum.

Other studies may improve the robustness of the model by using a longer or more recent timeframe or investigating the impact of a state's population rates, change in its energy trade balance, energy price fluctuations, or political affiliation.

The annual data collected at the state-level was a robust feature of this study, but additional research may investigate the role of the factors of renewable and sectoral energy consumption between different national economies or geographic regions with emphasis on the primary renewable energy resources consumed by each country or region.

VI. Conclusion

The relationship between the change in the portion of renewable energy consumption and change in the portion of the energy consumption of an economy's four major sectors suggests that the growth of renewable energy has had a significant role in influencing the sectoral composition of a state's energy consumption. As investment and research in renewable energy technology continue to grow, states may observe the portion of the energy consumed by the industrial increase. The reliance of manufacturing on fossil fuels may introduce technological problems of the integration of renewable energy into the industrial sector. The separation of energy consumption into sectors supports findings that service-based economies have lower energy intensities, particularly when comparing industrializing nations compared to developed countries (Hirsh & Koomey 2015).

Similar to previous economic and social disruptions, the worldwide COVID-19 pandemic has impacted the energy consumption patterns of the United States. In the first six months of 2020, non-renewable energy has declined nearly 9% from the level of energy consumption in the same period during 2019 (see Appendix 8). During this transformational period in the role of renewable energy technology in the United States, this paper offers questions about the implementation and effectiveness of different sources of renewable energy, given a state's location and the composition of energy consumption required by each sector.

VII. **References**

Apergis, Nicholas, and James E. Payne. “Renewable Energy Consumption and Economic Growth: Evidence from a Panel of OECD Countries.” *Energy Policy*, Elsevier, 30 Sept. 2009, www.sciencedirect.com/science/article/abs/pii/S0301421509006752?via=ihub.

Apergis, Nicholas, and James E. Payne. “Renewable and Non-Renewable Energy Consumption-Growth Nexus: Evidence from a Panel Error Correction Model.” *Energy Economics*, North-Holland, 16 Apr. 2011, reader.elsevier.com/reader/sd/pii/S0140988311000909?token=8810B5148E9E6F3E1A2018D79F6C968939EF781ED06FF5D535AF0CB53A100D66CB333DEADDE0E88F32F872951E29D70E.

Bhattacharya, Mita, et al. “The Dynamic Impact of Renewable Energy and Institutions on Economic Output and CO2 Emissions across Regions.” *Renewable Energy*, Pergamon, 6 Apr. 2017, www.sciencedirect.com/science/article/pii/S0960148117302987.

Bhattacharya, Mita, et al. “The Effect of Renewable Energy Consumption on Economic Growth: Evidence from Top 38 Countries.” *Applied Energy*, Elsevier, 11 Nov. 2015, www.sciencedirect.com/science/article/pii/S0306261915013318.

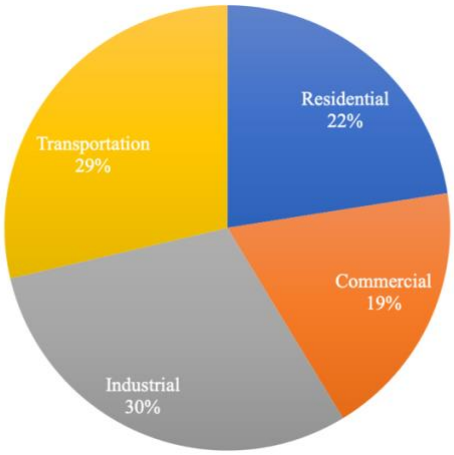
Hirsh, Richard F., and Jonathan G. Koomey. “Electricity Consumption and Economic Growth: A New Relationship with Significant Consequences?” *The Electricity Journal*, Elsevier, 2 Nov. 2015, www.sciencedirect.com/science/article/pii/S1040619015002067.

"State Energy Consumption Estimates 1960 Through 2018." *EIA*, US Energy Information Administration, June 2020, www.eia.gov/state/seds/sep_use/notes/use_print.pdf.

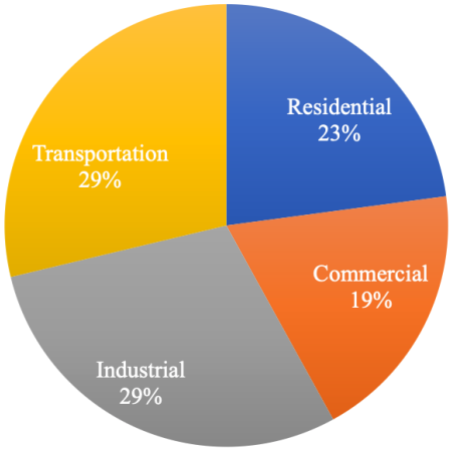
Wing, Ian Sue, and Richard S. Eckaus. "The Implications of the Historical Decline in U.S. Energy Intensity for Long-Run CO2 Emission Projections." *Global Change MIT University*, 2005, globalchange.mit.edu/publication/14562.

VII. **Appendix**

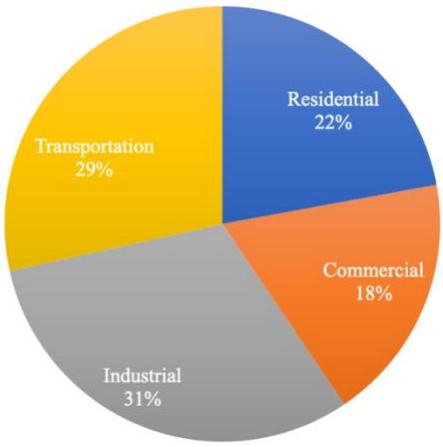
1. **US Portion of Total Energy Consumption by Sector from 2000 to 2018**



2000 Composition



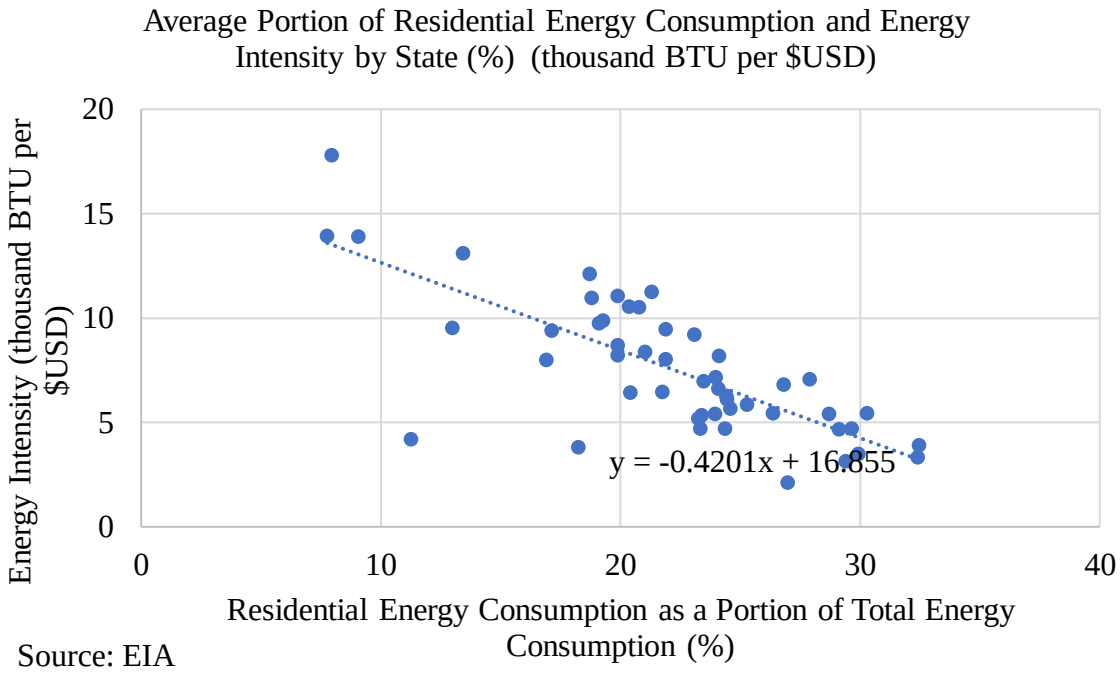
2018 Composition



Source: EIA

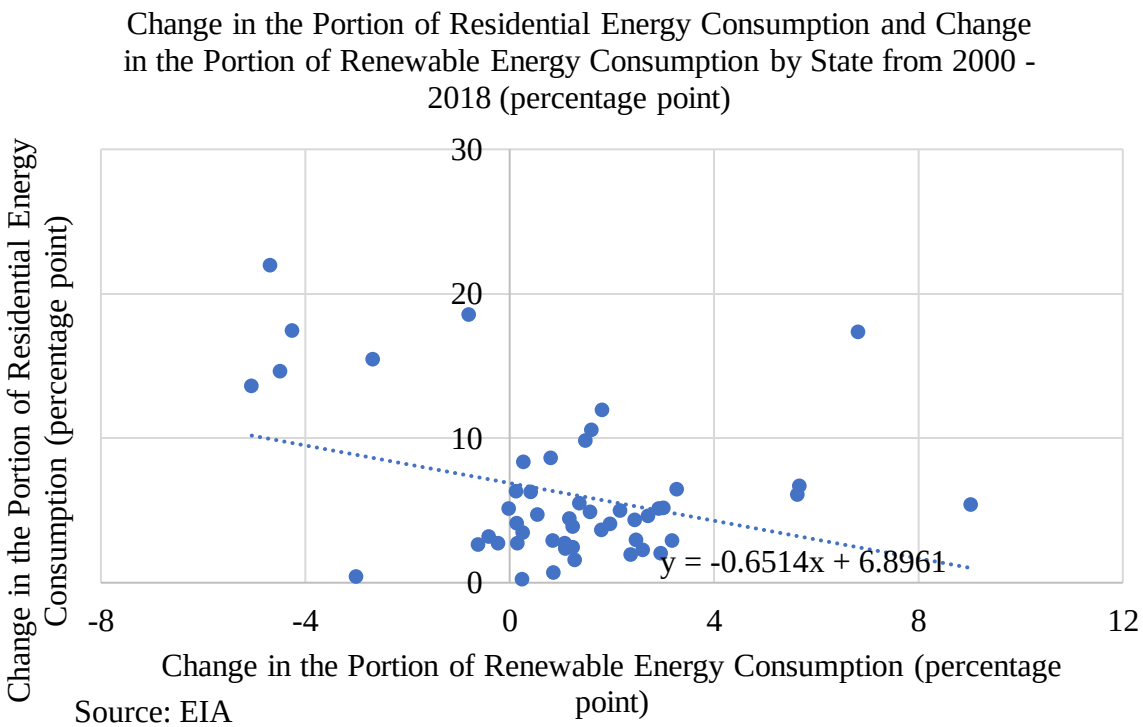
2000-2018 Average Composition

2. **Portion of Residential Energy Consumption and Energy Intensity**



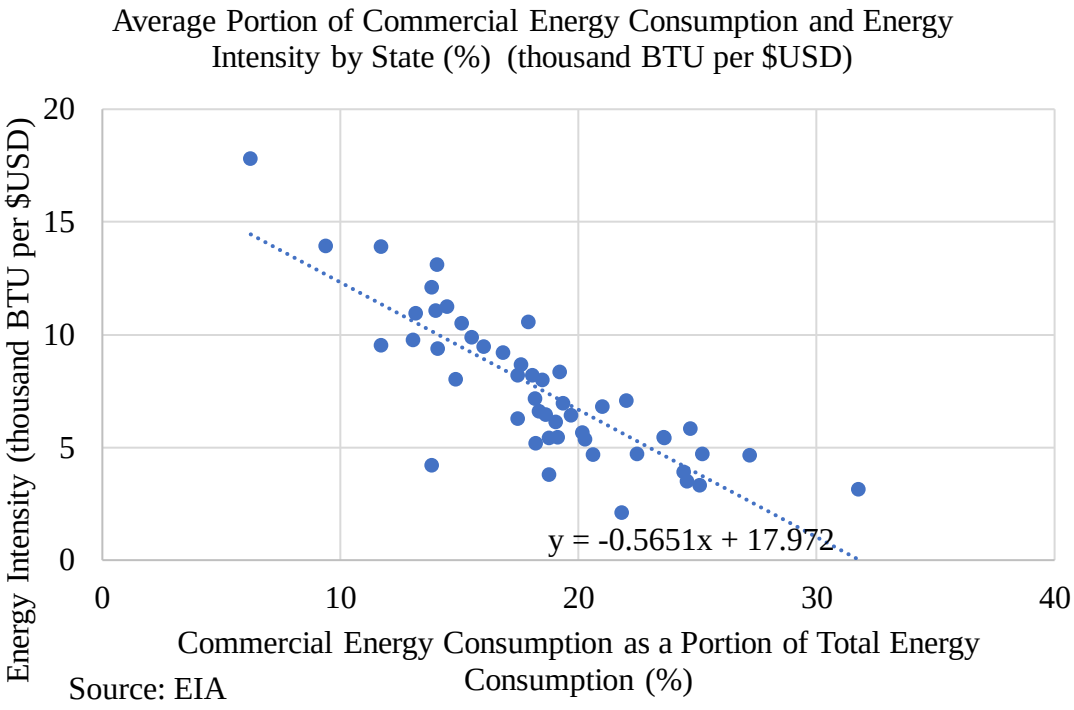
Source: EIA

3. **Change in the Portion of Residential Energy Consumption and Renewable Energy**



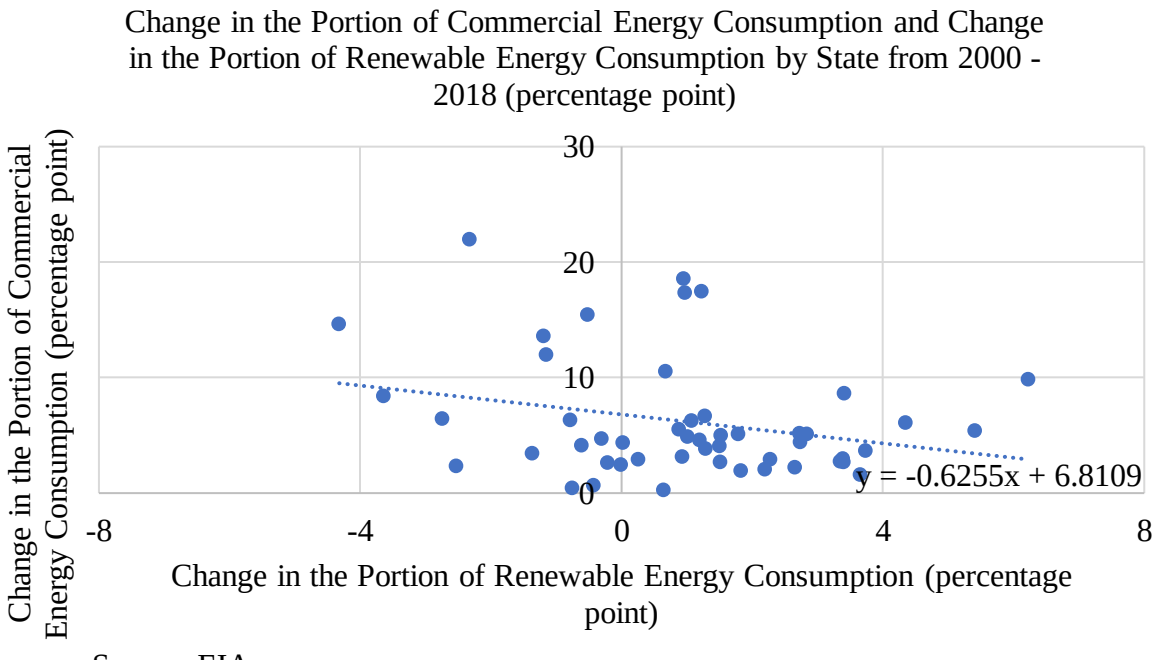
Source: EIA

4. **Portion of Commercial Energy Consumption and Energy Intensity**



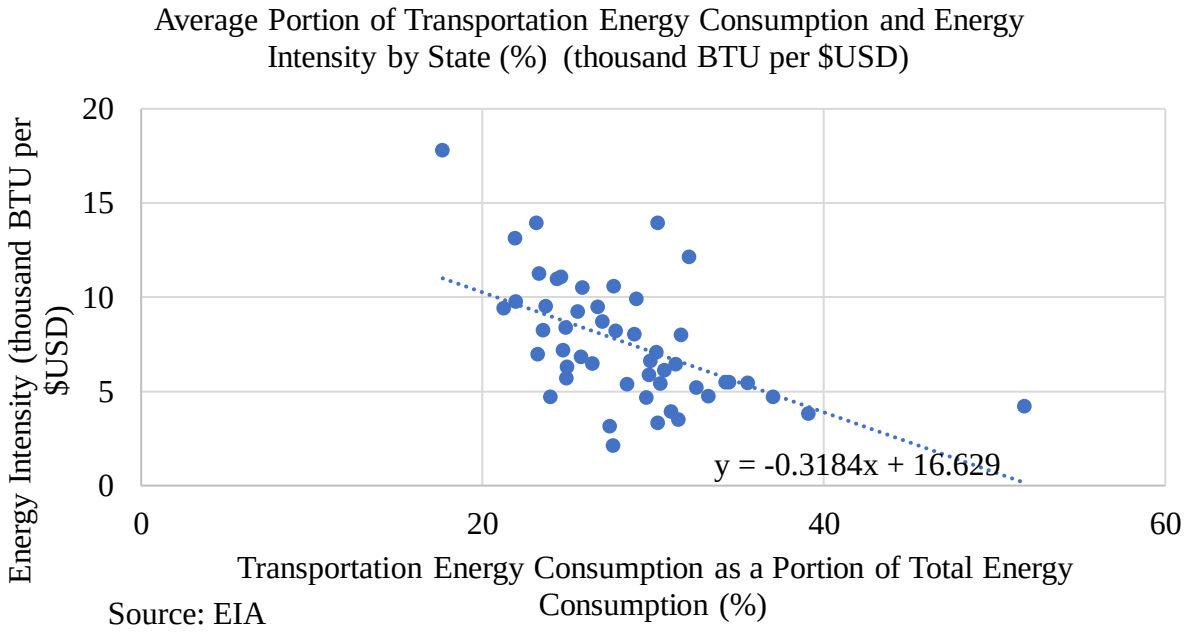
Source: EIA

5. **Change in the Portion of Commercial Energy Consumption and Renewable Energy**



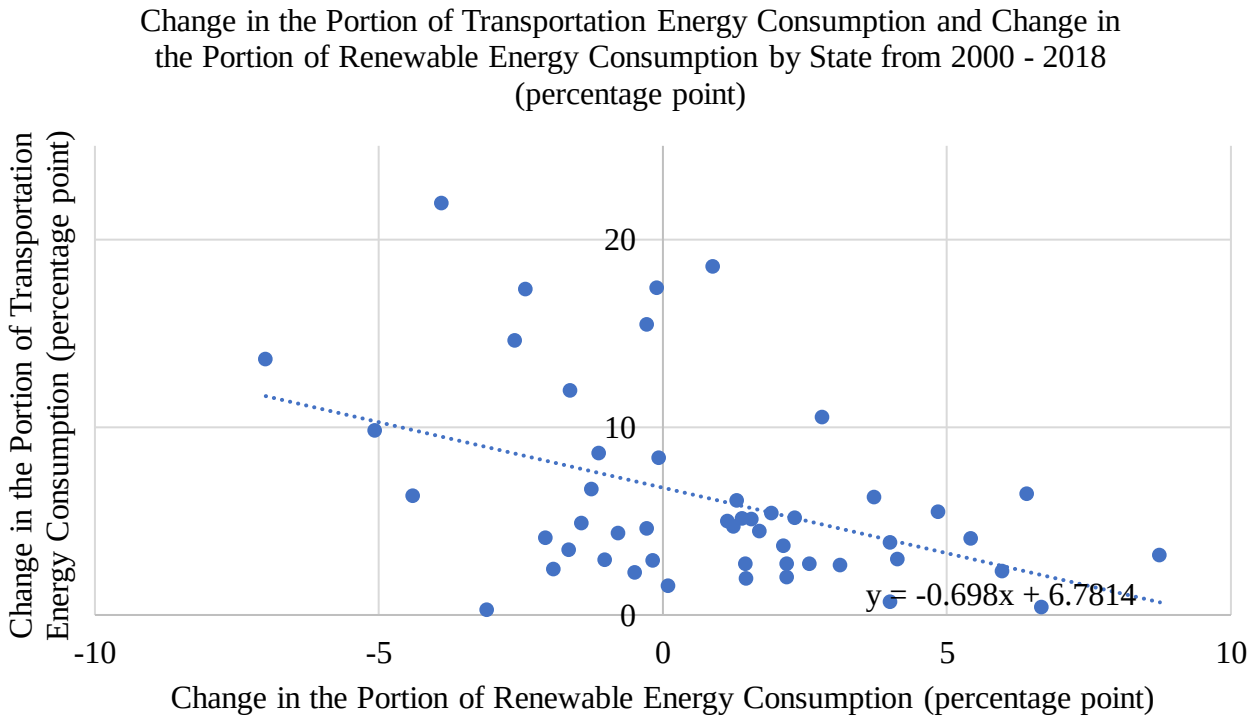
Source: EIA

6. **Portion of Transportation Energy Consumption and Energy Intensity**



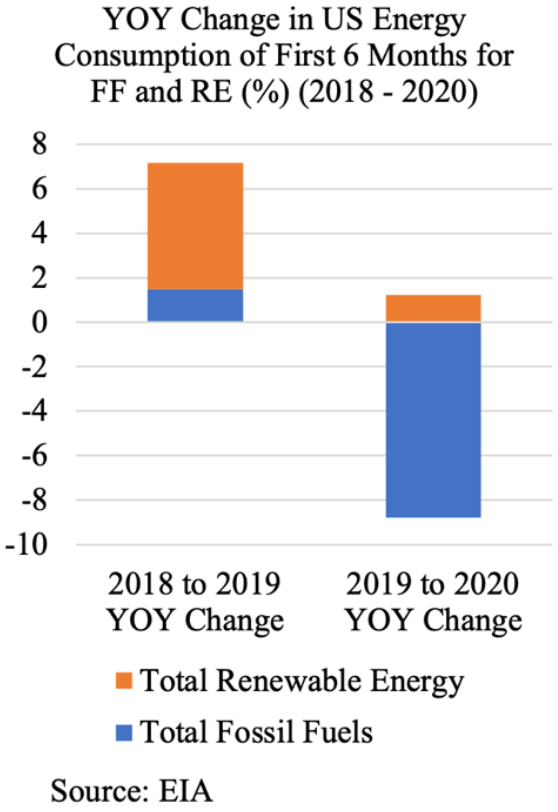
Source: EIA

7. **Change in the Portion of Commercial Energy Consumption and Renewable Energy**



Source: EIA

8. **YOY Change in the Consumption of US Energy Consumption from 2018 to 2020**



Source: EIA