Comparing State Energy Consumption in the Power Sector

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Introduction

The State Energy Data System is an important Database provided by the U.S Energy Information Administration (EIA) that allows us to determine the Energy Consumption and Production Statistics of each American State.

For the purpose of this analysis, four states in the Southern bottom of the country are considered. These states are - Texas, Georgia, Florida and California. All states present different energy landscapes with different potentials in their adoption of renewable energy sources. For instance, we find that all four states have a high potential to construct Solar Energy Projects. We find that in the last five years, Florida has undertaken rapid strides to achieve the sum such as through Orlando's Community Solar Program. On the other hand, Texas has started to tap into its potential for Wind Energy Systems. The following metrics for each of these States and the United States as a whole will be considered ➖

- Visualizing Trends: Patterns of Energy Consumption for Power Generation based on Fuel Sources
- Distribution of 2020 Energy Consumption in the Electric Power Generation Sector across different fuel sources amongst the five geographic entities
- Understanding Emissions from each State based on Using Carbon Dioxide Emissions Coefficients provided by the Environmental Protection Agency

Mnemonic Series Name Codes

The SEDS data is organized based on Mnemonic Series Name Codes (MSN Codes). These codes allow the user to understand factors including Fuel Source, Consumption Sector and Energy Units. The following MSN Codes are considered for this analysis➖

CLEIB	Coal	GEEGB	Geo-Thermal
NGEIB	Natural Gas	HYEGB	Hydro-Electric
DFEIB	Distilled Fuel	RFEIB	Residual Fuel
WYEGB	Wind	PAEIB	All Petroleum
WWEIB	Wood & Waste Fuel	WDEIB	Wood Fuel
SOEGB	Solar	SFEIB	Gaseous Fuel
PCEIB	Petroleum Coke	NUEGB	Nuclear Energy

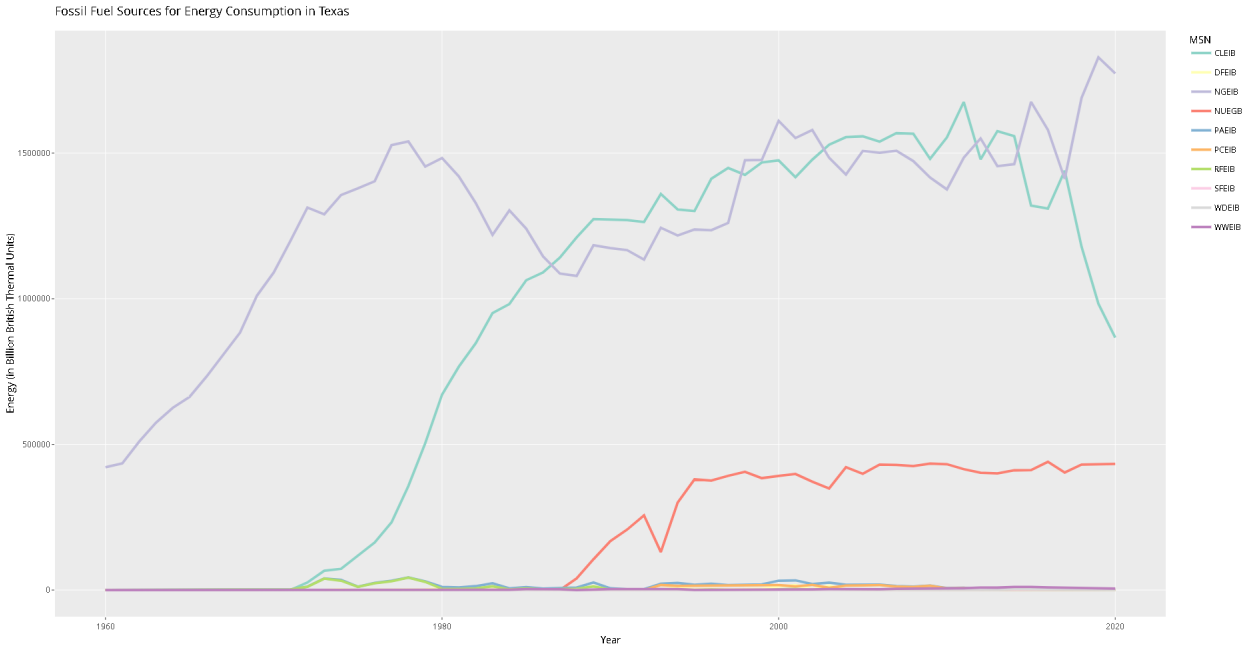
Time Series Data

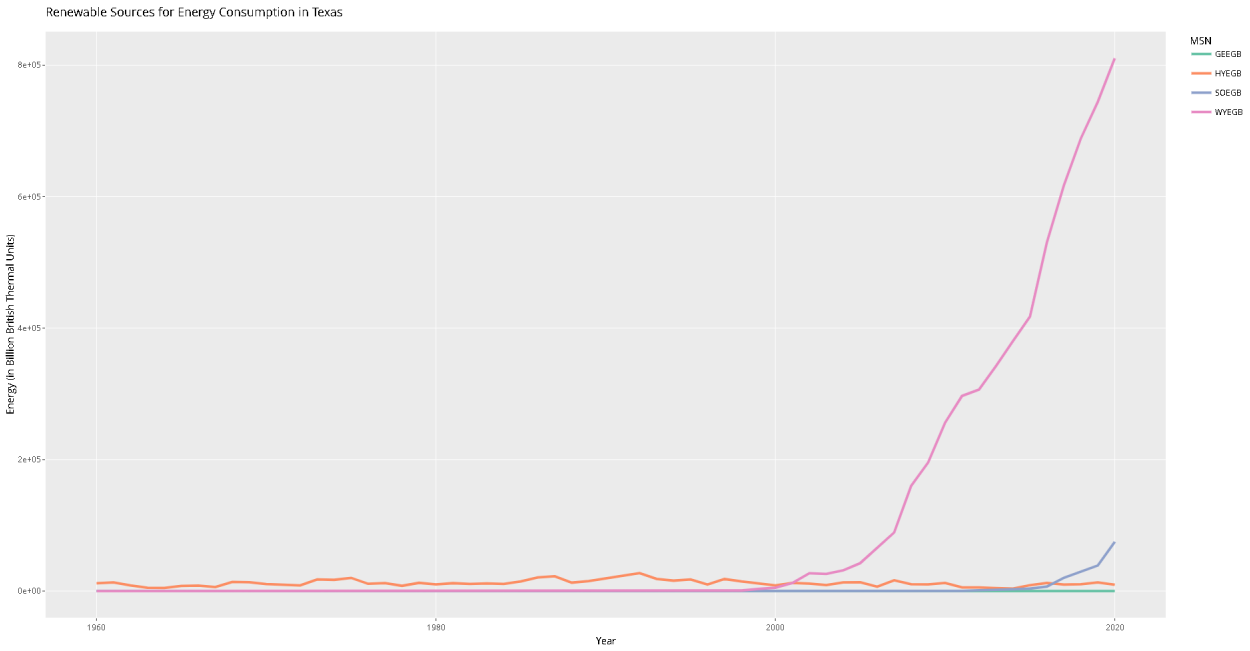
The following Charts showcase the Energy Consumption Patterns in the Electric Power Generation Sector for each State during the period 1980 - 2020.

Texas

In the plots below we see that Texas has a high consumption of Natural Gas & Coal although Coal has tapered off in the last half of the previous decade. This has been accompanied by an increase in Natural gas Consumption. One remarkable trend is the almost 10x increase in the use of Wind Energy since 2000. Solar Energy has begun to be adopted more widely since 2015.

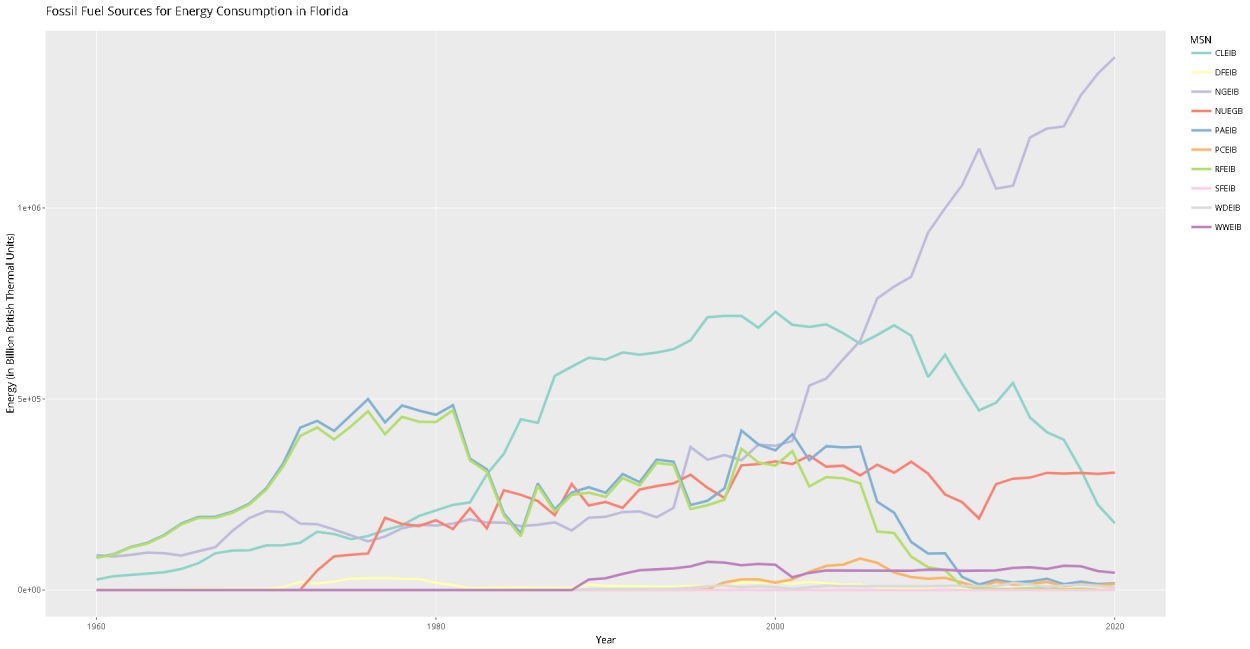
Nuclear Energy Utilization has remained constant more or less since the 1990's.

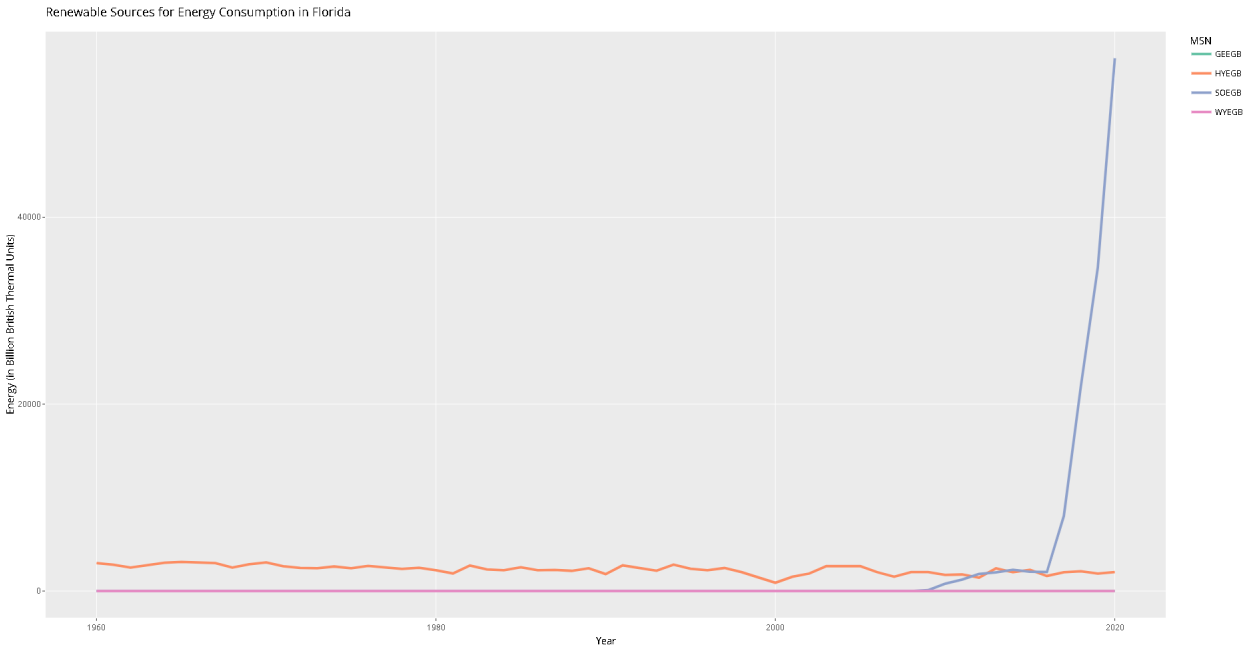




Florida

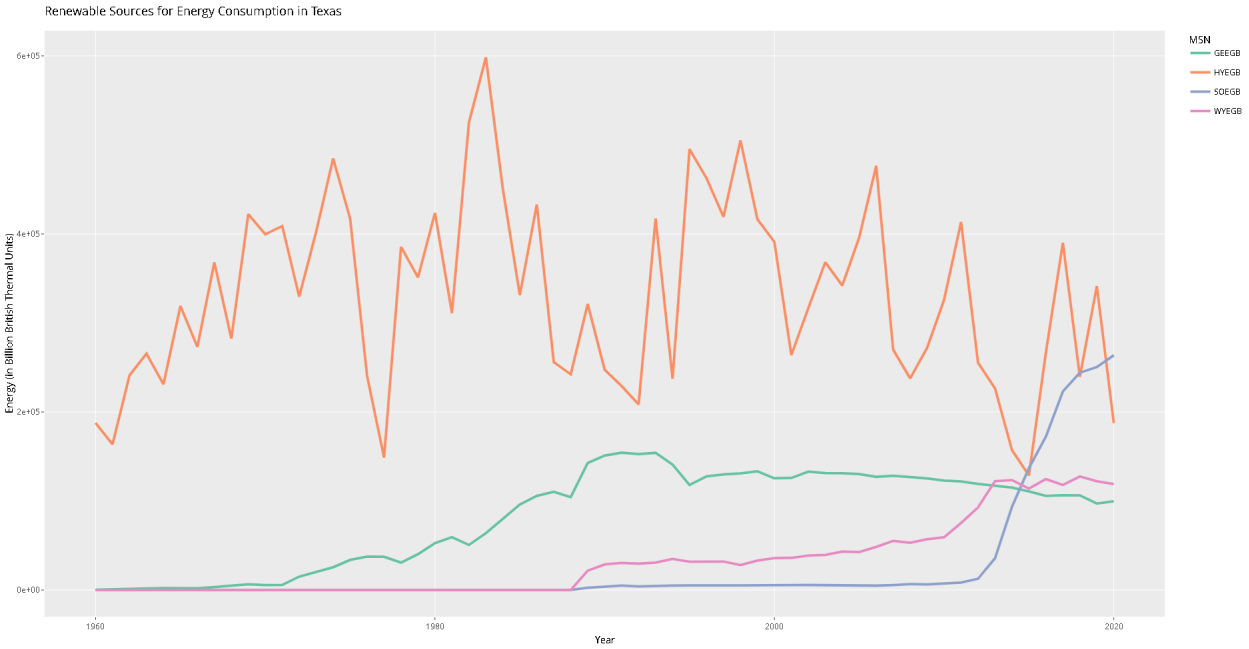
We find that Florida has a diversified Energy Portfolio although its Renewable Energy usage is strictly limited to Solar which has particularly picked up since 2015. Natural gas forms a major part of its portfolio and continues to increase while Coal has tapered off. It sees a high use of Petroleum Coke and Residual Fuel from 1980 through to 2010. These are highly polluting sources.

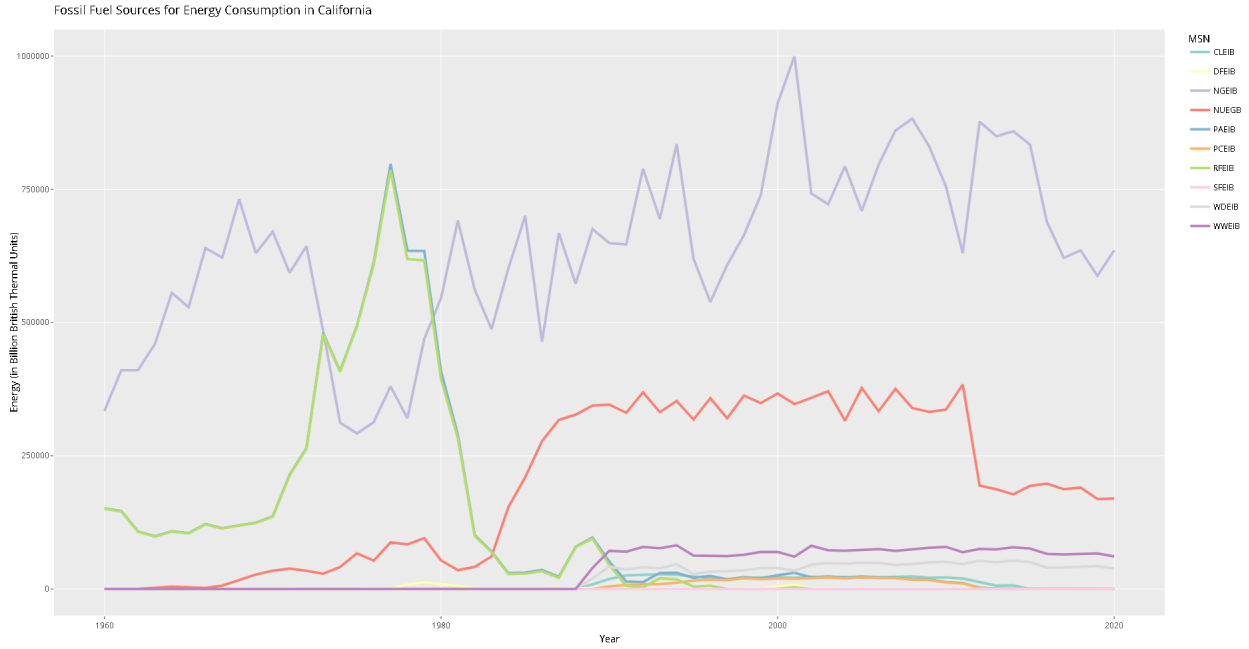




California

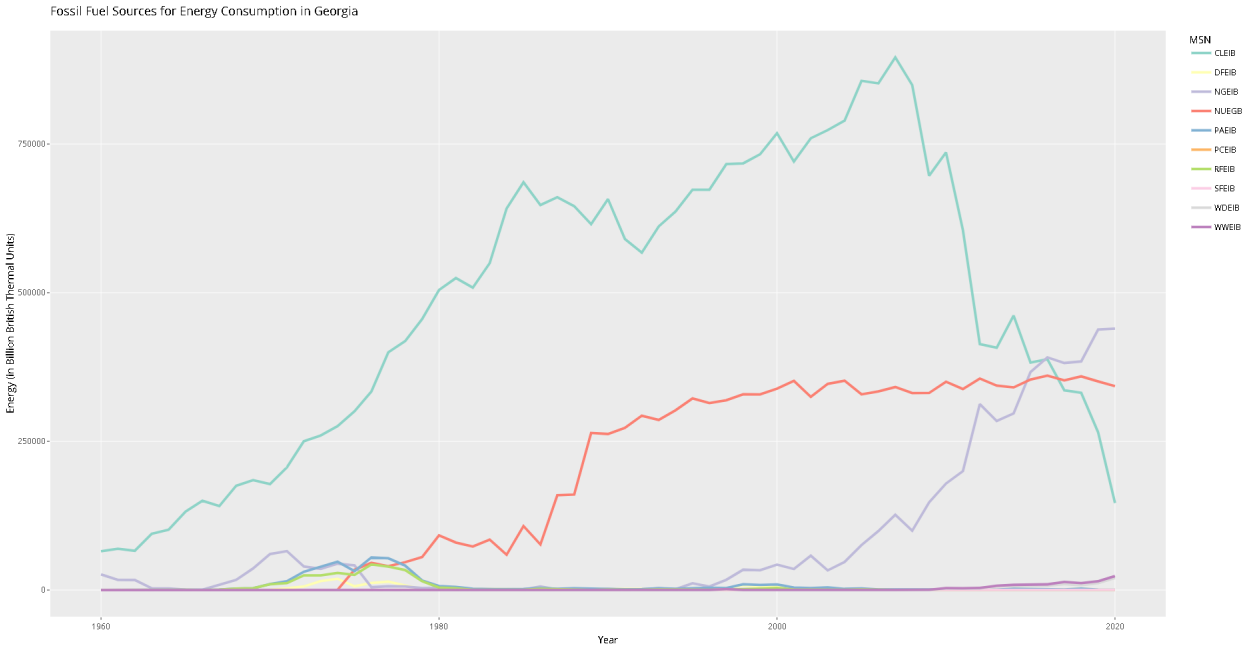
California has a more diversified Renewable Energy Portfolio as compared to the other states. They see a high adoption of Hydro -electric power generation with inputs from Solar Energy becoming the highest generator recently. On the fossil front, Natural Gas is the highest consumed fuel. There is a remarkable drop in Coal Consumption since 1975 making the source almost negligible. There is also a drop in nuclear power generation in 2010 that points towards reactor decommissioning .

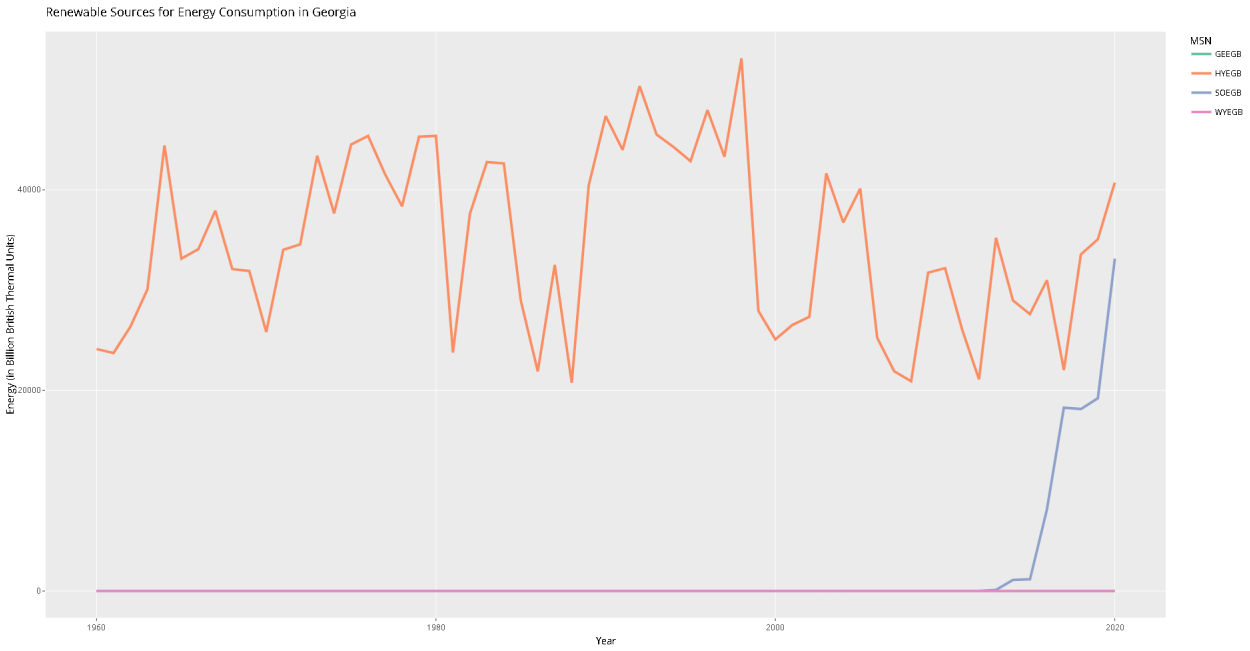




Georgia

Georgia has traditionally been reliant on coal as an energy source, but in the last decade Nuclear Energy and Natural Gas have surpassed the dirty fuel as the mainstay. This is a good trend as Nuclear is one of the least polluting fuels in terms of carbon emissions although there are other dangers such as radiation disposal. With the commissioning of the Vogel Nuclear Reactor, Georgia can potentially continue to rely on nuclear power for its increasing population. Georgia's renewable portfolio largely consists of Hydro-Electric and Solar Power, the latter of which has picked up steadily in the last decade.





Two common trends from all the states are the increases in alternative fuel sources such as Residual Fuel, Distillate Fuel and Petroleum Coke in the 1970's concurrent with the Global Oil Crisis. Additionally, it is to be noted that Renewable Energy still forms a smaller portion of the overall energy consumption as seen in the **table below which shows percentage share of sector.** Natural Gas is the predominant energy sector supplier. Only in California does Solar Power form a significant contributor. Texas's energy consumption is still largely coal and natural gas dependent with similar contributions by Nuclear Energy and Wind Power. Georgia's Nuclear contribution is significant and is double that of Coal.

📢 Note: For the total United States energy values, a summation of all the individual state values have been undertaken. It is found that using this summed value provides a larger consumption amount than the entry in the SEDS table. Therefore to account for this discrepancy, the more conservative estimate has been selected.

StateCode	CLEIB	DFEIB	GEEGB	HYEGB	NGEIB	NUEGB	PCEIB
Description	Coal	Distillate Fuel	Geo-Thermal	Hydro-Electric	Natural gas	Nuclear Energy	Petroleum Coke
CA	0.00	0.02	6.49	12.20	41.35	11.05	0.00
FL	8.75	0.08	0.00	0.10	69.77	15.37	0.78
GA	14.25	0.06	0.00	3.97	42.81	33.38	0.00
TX	21.81	0.01	0.00	0.24	44.62	10.89	0.00
USA	23.20	0.12	0.38	7.03	33.86	23.25	0.25

StateCode	RFEIB	SFEIB	SOEGB	WDEIB	WWEIB	WYEGB
Description	Residual Fuel	Gaseous Fuel	Solar Energy	Wood	Wood & Waste	Wind Energy
CA	0.00	0.00	17.16	2.50	3.98	7.75
FL	0.03	0.00	2.85	0.32	2.26	0.00
GA	0.00	0.02	3.23	1.98	2.29	0.00
TX	0.00	0.02	1.88	0.02	0.13	20.39
USA	0.15	0.03	2.19	0.52	1.21	8.34

Comparisons of Energy Consumption and CO2 Emissions of Power Sector

💡 The Findings from the analysis of the Energy Consumption patterns of the Four States of Georgia, Florida, California & Texas and the United States as a whole are presented below. For the purposes of this analysis, the Emissions Coefficient of Wood is taken to be 75% higher than that of Natural Gas as per current research. The EPA has not included wood as a carbon dioxide source in its emissions information as burning wood pellets is a rather recent phenomenon.

The following table shows the Energy Consumption by the Electric Power Sector in Billion British Thermal Units.

StateCode	CLEIB	DFEIB	GEEGB	HYEGB	NGEIB	NUEGB	PCEIB
Description	Coal	Distillate Fuel	Geo-Thermal	Hydro-Electric	Natural gas	Nuclear Energy	Petroleum Coke
CA	0	359	99718	187491	635462	169773	0
FL	174940	1605	0	2033	1394330	307197	15565
GA	146279	594	0	40720	439637	342766	0
TX	866717	523	0	9462	1773446	432703	0
USA	16458284	88333	270923	4984105	24021950	16495828	174853
CO2 Emissions Coefficients	95.77	74.14	0	0	52.91	0	102.12

StateCode	RFEIB	SFEIB	SOEGB	WDEIB	WWEIB	WYEGB	Total BTU
Description	Residual Fuel	Gaseous Fuel	Solar Energy	Wood	Wood & Waste	Wind Energy	
CA	0	0	263718	38432	61194	119069	1536784
FL	603	0	57008	6346	45148	0	1998429
GA	0	237	33134	20340	23480	0	1026847
TX	0	721	74868	904	5181	810501	3974122
USA	105392	23186	1553019	370750	855146	5915686	70946705
CO2 Emissions Coefficients	72.93	66.73	0	92.5925	92.5925	0	557.1925

The following table discusses the Co2 Emissions in Mega Metric Tonnes per Quadrillion British Thermal Units

StateCode	CLEIB	DFEIB	GEEGB	HYEGB	NGEIB	NUEGB	PCEIB

StateCode	CLEIB	DFEIB	GEEGB	HYEGB	NGEIB	NUEGB	PCEIB
Description	Coal	Distillate Fuel	Geo-Thermal	Hydro-Electric	Natural gas	Nuclear Energy	Petroleum Coke
CA	0.00	0.03	0.00	0.00	33.62	0.00	0.00
FL	16.75	0.12	0.00	0.00	73.77	0.00	1.59
GA	14.01	0.04	0.00	0.00	23.26	0.00	0.00
TX	83.01	0.04	0.00	0.00	93.83	0.00	0.00
USA	1576.21	6.55	0.00	0.00	1271.00	0.00	17.86

StateCode	RFEIB	SFEIB	SOEGB	WDEIB	WWEIB	WYEGB
Description	Residual Fuel	Gaseous Fuel	Solar Energy	Wood	Wood & Waste	Wind Energy
CA	0.00	0.00	0.00	3.56	5.67	0.00
FL	0.04	0.00	0.00	0.59	4.18	0.00
GA	0.00	0.02	0.00	1.88	2.17	0.00
TX	0.00	0.05	0.00	0.08	0.48	0.00
USA	7.69	1.55	0.00	34.33	79.18	0.00

Energy Consumption Per Capita in kilowatt hour is shown below. kWh is a better unit for per capita consumption analysis as it is a better indicator of how people use and conceive energy.

StateCode	CLEIB	DFEIB	GEEGB	HYEGB	NGEIB	NUEGB	PAEIB
CA	0.0	2.7	739.9	1391.1	4714.8	1259.6	2.7
FL	2376.9	21.8	0.0	27.6	18944.7	4173.9	241.5
GA	3996.8	16.2	0.0	1112.6	12012.4	9365.5	16.2
TX	8693.6	5.2	0.0	94.9	17788.6	4340.2	5.2
USA	7275.2	39.0	119.8	2203.2	10618.6	7291.8	162.9

StateCode	PCEIB	RFEIB	SFEIB	SOEGB	WDEIB	WWEIB	WYEGB
CA	0.0	0.0	0.0	1956.7	285.1	454.0	883.4
FL	211.5	8.2	0.0	774.6	86.2	613.4	0.0
GA	0.0	0.0	6.5	905.3	555.8	641.6	0.0
TX	0.0	0.0	7.2	751.0	9.1	52.0	8129.7
USA	77.3	46.6	10.2	686.5	163.9	378.0	2614.9

The highest per capita consumption in each fuel cateogry has been shown above. It is consistent with our expectations. All the states have the highest consumption in Natural gas. Wind in Texas, Nuclear in Georgia, Hydro-Electric & Solar in California are the promising trends in Renewable Energy.

A Summary of the Information is Provided Below:

StateCode	Total CO2 Emissions	Total Population	Tonnes Per Capita	Per Capita Energy in kWh
CA	39.32	39500000	1.00	814.44
FL	96.46	21570000	4.47	1939.47
GA	39.50	10726000	3.68	2004.07
TX	177.41	29218000	6.07	2847.32
USA	2960.03	663003000	4.46	2240.07

📢 Note: PAEIB and WDEIB have been neglected in calculation of final averages because they are constituent to other categories - viz. WWEIB & PCEIB. They have been included in the categories to provide a breakup of how the different fuel sources compare for the user's convenience.

Summary

We find that Texas has a greater Emissions Output Per Capita than the national average at 177 Mega Metric Tonnes per Quadrillion British Thermal Units. This is largely due to their increased share of Coal based Power Generation. While GA and CA have almost equal emissions, at the per capita level, the average Georgian emits three times the amount of data as a Californian. Floridians have a higher Per Capita Emissions Output than either of those states. Increased Share of Natural Gas based production is the reason for this rise. Georgia's increased share of Nuclear Energy Consumption reduces the potential higher emissions level that could have risen from a Fossil Fuel based economy. It is clear that all the states need to move towards a zero-carbon economy. But based on the different differential start points, each State will have to pursue policies that are designed to suit their particular patterns of consumption. Especially so since energy transitions have very high socio-economic implications.

An important factor to be noticed is the increase Wood Pellets in Energy Generation, highly prominent in Georgia due to its abundant forest reserves (see graph). This is largely due to European legislation as a response to Russian sanctions. Seeing wood as a renewable resource justifies logging forest reserves for energy generation. But this argument is flawed since **forest logging also reduces carbon sequestration capacities**. Therefore, there is double impact. Additionally, **trees cannot grow back at the rate at which it is logged for power generation**. This policy needs to be discussed with considerable expert input to understand what detrimental impacts similar US legislation can result in.

Appendix

```
library(tidyverse)
library(readxl)
library(sf)
library(tmap)
library(RColorBrewer)
library(viridis)
library(plotly)
library(htmlwidgets)
library(writexl)
library(dplyr)

setwd("C:/Users/ssivakumar60/OneDrive - Georgia Institute of Technology/Climate_Change_Resources/Climate_Change_Project")
getwd()

# The SEDS Worksheet is loaded for Investigation. This is done in order to understand what are the
# necessary data columns to be considered. The MSN Code Data set is also to be loaded for reference.
# Another Data set to be loaded is the Information Sheet on State Data and Nomenclature.

SEDS <- read_csv("Complete_SEDS.csv")
excel_sheets("Codes_and_Descriptions.xlsx")

MSN <- read_excel("Codes_and_Descriptions.xlsx", sheet = "MSN Descriptions", skip = 9)

State_Info <- read_excel("stateinfo6.xls", col_names = TRUE)

State_Shape <- st_read("cb_2018_us_state_20m.shp")

# We manipulate loaded data files to only consider the Contiguous United States in the Visual Presentation.

State_Shape <- State_Shape %>%
  mutate(stateabbr = STUSPS) %>%
  left_join(State_Info) %>%
  filter(NAME != 'Puerto Rico' &
           NAME != 'Hawaii' &
           NAME != 'Alaska')

# Having prepared the Shapefile, Let us now consider the SEDS Database for Analysis. We first consider
# the different fuels that are available and used by the electric power sector.
# THE MSN Codes under Consideration are:

SEDS_Categories <- SEDS %>%
  filter(StateCode == 'GA' |
         StateCode == 'FL' |
         StateCode == 'CA' |
```

```
         StateCode == 'TX') %>%
  filter(MSN %in% c("CLEIB","DFEIB","GEEGB","HYEGB","NGEIB","NUEGB","PAEIB","PCEIB","RFEIB","SFEIB","SOEGB","WDEIB","TPOPP","WWEIB","WYEGB"

SEDS_Categories_USA <- SEDS %>%
  filter(MSN %in% c("CLEIB","DFEIB","GEEGB","HYEGB","NGEIB","NUEGB","PAEIB","PCEIB","RFEIB","SFEIB","SOEGB","WDEIB","TPOPP","WWEIB","WYEGB"

# Output:1 First we want to compare the Consumption of Each Fuel By State over the years

SEDS_Combo <- SEDS_Categories %>%
  left_join(State_Shape, by = c("StateCode" = "stateabbr"))


#Testing the Time Series Outcomes

SEDS_GA_ <- SEDS_Combo %>%
  filter(StateCode == 'GA')

ggplot(data = SEDS_GA) +
  geom_line(aes(x = Year, y = Data, col = MSN)) +
  scale_color_brewer(palette = "Set3") +
  ggtitle("Fuel Sources for Energy Consumption in Georgia") +
  xlab("Year") + ylab("Energy (Billion Btus")

#We find that the consumption of Fossil Fuels & Nuclear is much higher than the others.
#We segment the data into Renewable & Non-Renewable Sources to get greater insight.
#_____________________________________________________________________________#
#TIMESERIES
#GEORGIA

SEDS_GA_Fossil <- SEDS_Combo %>%
  filter(StateCode == 'GA') %>%
  filter(MSN %in% c("CLEIB","DFEIB","NGEIB","NUEGB","PAEIB","PCEIB","RFEIB","SFEIB","WDEIB","WWEIB"))

gaf <- ggplot(data = SEDS_GA_Fossil) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set3") +
  ggtitle("Fossil Fuel Sources for Energy Consumption in Georgia") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
gaf <- ggplotly(gaf)
saveWidget(gaf, file = paste0(getwd(),"/GAFossilsTS.html"))

SEDS_GA_Renewable <- SEDS_Combo %>%
  filter(StateCode == 'GA')%>%
  filter(MSN %in% c("GEEGB","HYEGB","SOEGB","WYEGB"))

gar <- ggplot(data = SEDS_GA_Renewable) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set2") +
  ggtitle("Renewable Sources for Energy Consumption in Georgia") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
gar <- ggplotly(gar)
saveWidget(gar, file = paste0(getwd(),"/GARenewableTS.html"))

#FLORIDA

SEDS_FL_Fossil <- SEDS_Combo %>%
  filter(StateCode == 'FL') %>%
  filter(MSN %in% c("CLEIB","DFEIB","NGEIB","NUEGB","PAEIB","PCEIB","RFEIB","SFEIB","WDEIB","WWEIB"))

flf <- ggplot(data = SEDS_FL_Fossil) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set3") +
  ggtitle("Fossil Fuel Sources for Energy Consumption in Florida") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
flf <- ggplotly(flf)
saveWidget(flf, file = paste0(getwd(),"/FLFossilsTS.html"))

SEDS_FL_Renewable <- SEDS_Combo %>%
  filter(StateCode == 'FL')%>%
  filter(MSN %in% c("GEEGB","HYEGB","SOEGB","WYEGB"))

flr <- ggplot(data = SEDS_FL_Renewable) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set2") +
  ggtitle("Renewable Sources for Energy Consumption in Florida") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
flr <- ggplotly(flr)
saveWidget(flr, file = paste0(getwd(),"/FLRenewableTS.html"))

#TEXAS
```

```
SEDS_TX_Fossil <- SEDS_Combo %>%
  filter(StateCode == 'TX') %>%
  filter(MSN %in% c("CLEIB","DFEIB","NGEIB","NUEGB","PAEIB","PCEIB","RFEIB","SFEIB","WDEIB","WWEIB"))

txf <- ggplot(data = SEDS_TX_Fossil) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set3") +
  ggtitle("Fossil Fuel Sources for Energy Consumption in Texas") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
txf <- ggplotly(txf)
saveWidget(txf, file = paste0(getwd(),"/TXFossilsTS.html"))

SEDS_TX_Renewable <- SEDS_Combo %>%
  filter(StateCode == 'TX')%>%
  filter(MSN %in% c("GEEGB","HYEGB","SOEGB","WYEGB"))

txr <- ggplot(data = SEDS_TX_Renewable) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set2") +
  ggtitle("Renewable Sources for Energy Consumption in Texas") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
txr <- ggplotly(txr)
saveWidget(txr, file = paste0(getwd(),"/TXRenewableTS.html"))

#CALIFORNIA

SEDS_CA_Fossil <- SEDS_Combo %>%
  filter(StateCode == 'CA') %>%
  filter(MSN %in% c("CLEIB","DFEIB","NGEIB","NUEGB","PAEIB","PCEIB","RFEIB","SFEIB","WDEIB","WWEIB"))

caf <- ggplot(data = SEDS_CA_Fossil) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set3") +
  ggtitle("Fossil Fuel Sources for Energy Consumption in California") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
caf <- ggplotly(caf)
saveWidget(caf, file = paste0(getwd(),"/CAFossilsTS.html"))

SEDS_CA_Renewable <- SEDS_Combo %>%
  filter(StateCode == 'CA')%>%
  filter(MSN %in% c("GEEGB","HYEGB","SOEGB","WYEGB"))

car <- ggplot(data = SEDS_CA_Renewable) +
  geom_line(aes(x = Year, y = Data, col = MSN), lwd = 1) +
  scale_color_brewer(palette = "Set2") +
  ggtitle("Renewable Sources for Energy Consumption in Texas") +
  xlab("Year") + ylab("Energy (in Billion British Thermal Units)")
car <- ggplotly(car)
saveWidget(car, file = paste0(getwd(),"/CARenewableTS.html"))

#_____________________________________________________________________________#

#Output 2: Total Energy Consumption by Energy Category

SEDS_Combo_State <- SEDS_Combo %>%
  filter(Year == "2020") %>%
  select("MSN","StateCode","Data","NAME","geometry") %>%
  pivot_wider(names_from = MSN, values_from = Data)

SEDS_US <- SEDS_Categories_USA %>%
  filter(Year == "2020") %>%
  select("MSN","StateCode","Data") %>%
  group_by(MSN, StateCode) %>%
  summarize(Total_Energy = sum(Data)) %>%
  pivot_wider(names_from = "MSN", values_from = "Total_Energy")

#Let us Calculate the Sum Per Capita Emissions
# First we need to understand the Unit Conversions.
# Our End Goal is to understand Per Capita Energy Consumption in kilo-Watt Hour.

# 1 kilo Watt-Hour = 3412.14 British Thermal Units
# Our Measures are in Billion BTU's.
# Our Population measure TPOPP, needs to be multiplied by a 1000.
# We also Omit PAEIB & WDEIB to restrict Superfluousity in the Data as it is a summation value.
# Since this particular measure is more easily made in excel, I am exporting the tables to develop the same.
# Let us now Convert the Consumption to Emissions using the Emissions Coefficients.
# We need to convert the kWh to 1000 BTu's to assess grams of CO2

write_xlsx(SEDS_US, "SEDS_US.xlsx")
write_xlsx(SEDS_PC, "SEDS_PC.xlsx")
write_xlsx(SEDS_Combo_State, "SEDS_State.xlsx")
```

```
write_xlsx()

pop <- SEDS_Combo_State %>%
  select(StateCode,TPOPP)

SEDS_4State <- SEDS_Combo_State %>%
  pivot_longer(CLEIB:WYEGB, names_to = "MSN", values_to = "Energy") %>%
  filter(MSN != "TPOPP" |MSN != "PAEIB" |MSN != "WDEIB") %>%
  left_join(pop, by = "StateCode") %>%
  mutate(percapitainkwh = (Energy/(TPOPP*1000)/3412.14)*10^9)

SEDS_PC <- SEDS_4State %>%
  select("MSN","StateCode","percapitainkwh","geometry")%>%
  pivot_wider(names_from = MSN, values_from = percapitainkwh)

#Let us visualize this on a chart

energy <- ggplot(SEDS_4State, aes(x = StateCode, y = MSN, color = percapitainkwh, size = percapitainkwh)) +
  geom_point(alpha = 0.7) +
  scale_size(range = c(.1, 24), name="Energy")

energy <- ggplotly(energy)
saveWidget(energy, file = paste0(getwd(),"/State_Energy.html"))
SEDS_Emissions <- read_excel("SEDS_PC.xlsx")

#_____________________________________________________________________________#
```