Econ 216 Exploratory Data Analysis

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Introduction

In this project we aim to examine the geographic distribution and capacity characteristics of wind turbines in the United States using the US Wind Turbine Database (USWTDB). We plan to do this by analyzing the placement and various attributes of wind turbines in the US in hopes of finding insights into the wind energy landscape over all 50 states.

Using the data from the dataset we believe we can investigate the impact of local vs federal policies on wind energy development through two methods. The first is by the geographic mapping of wind turbines in the US; this can visually display where these turbines are located on a map which in turn can show us various clusters of the turbines distributions. This visualization can be used to identify areas of high wind energy concentration and relate these areas to geographic and policy factors of certain local or state governments.The second way is visualizing the number of wind turbines per each US state. This data can be compared with certain state policies or with federal wind energy incentives in each region. This can be all combined to show us which states are leading in wind energy production and possibly find patterns of wind energy adoption nationally.

Using the data set we can also investigate the capacity distribution and also win turbine hub height of all the wind turbines in the US. This data would let us discover insights on the range, efficiency, and sizes of the turbines in terms of their power output and hub height. This could possibly allow us to look at technological trends nationally for wind turbine and even see how many advanced wind projects have been made.

Background

The dataset we are using is the United States Wind Turbine Database (USWTDB). We retrieved this from: https://eerscmap.usgs.gov/uswtdb/. What follows is the details about the dataset:

Dataset Structure:

- **Observation Level:** Each observation represents a single wind turbine within the United States.
- **Variables Included:** Here are the key variables contained in the dataset:

1. **case_id:** Unique stable identification number for each turbine.
2. **faa_ors, faa_asn:** Unique identifiers for cross-reference to FAA digital obstacle files and FAA obstruction evaluation airport airspace analysis dataset.
3. **usgs_pr_id:** Unique identifier for cross-reference to the 2014 USGS turbine dataset.
4. **t_state:** State where the turbine is located.
5. **t_county, t_fips:** County and state FIPS code where the turbine is located.
6. **p_name:** Name of the wind power project the turbine is a part of.
7. **p_year:** Year that the turbine became operational.
8. **p_tnum:** Number of turbines in the wind power project.

9. **p__cap:** Cumulative capacity of all turbines in the project (in MW).
10. **t__manu, t__model:** Turbine manufacturer and model.
11. **t__cap:** Turbine rated capacity (in kW).
12. **t__hh:** Turbine hub height (in meters).
13. **t__rd:** Turbine rotor diameter (in meters).
14. **t__rsa:** Turbine rotor swept area (in square meters).
15. **t__ttlh:** Turbine total height from ground to tip of a blade (in meters).
16. **retrofit, retrofit__year:** Indicator and year of partial retrofit, if applicable.
17. **t__conf_atr, t__conf_loc:** Confidence levels in turbine attributes and location.
18. **t__img__date, t__img__srce:** Date and source of image used to visually verify turbine location.
19. **xlong, ylat:** Longitude and latitude of the turbine point.
20. **eia__id:** Plant ID from the Energy Information Administration (EIA).

Important Variables for Analysis:

1. **t__state:** Allows for analysis based on geographical location and comparison between states.
2. **p__year:** Provides insight into the temporal distribution of wind turbine constructions.
3. **p__tnum:** Helps in understanding the scale of wind power projects.
4. **p__cap:** Indicates the total power capacity of wind projects, crucial for assessing energy generation potential.
5. **t__hh, t__rd, t__rsa, t__ttlh:** These dimensions are essential for understanding turbine design and efficiency.

The phenomenon under study is the geographic distribution and various attributes of wind turbines in the United States. The dataset being used for this Exploratory Data Analysis (EDA) is the United States Wind Turbine Database (USWTDB), which tracks the current locations and pertinent information of both land-based and offshore wind turbines across the country. This dataset includes a wealth of data points on over 70,000 wind turbines.

To effectively analyze and interpret the data, one must consider the interplay between the column attributes and external factors such as economic incentives, technological advancements, environmental considerations, and policy changes. The goal of the EDA would be to use visualizations like maps, scatter plots, histograms, and time series charts to uncover patterns, correlations, and trends that could inform stakeholders and guide policy and investment decisions in the wind energy sector.

Data Wrangling

```r
# Load necessary libraries
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v dplyr     1.1.4     v readr     2.1.5
## v forcats   1.0.0     v stringr   1.5.1
## v ggplot2   3.4.4     v tibble    3.2.1
## v lubridate 1.9.3     v tidyr     1.3.1
## v purrr     1.0.2
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```r
library(lubridate)
library(ggmap)
```

```
## Warning: package ’ggmap’ was built under R version 4.3.1
```

```
## i Google’s Terms of Service: <https://mapsplatform.google.com>
##   Stadia Maps’ Terms of Service: <https://stadiamaps.com/terms-of-service/>
##   OpenStreetMap’s Tile Usage Policy: <https://operations.osmfoundation.org/policies/tiles/>
## i Please cite ggmap if you use it! Use ‘citation("ggmap")‘ for details.
```

```r
library(dplyr)

us_map <- map_data("state")


# Load the data
data <- read.csv("uswtdb_v4_3_20220114.csv")

# Inspect the first few rows of the data
head(data)
```

```
##   case_id   faa_ors          faa_asn usgs_pr_id eia_id t_state     t_county
## 1 3072661                                  5149  52161      CA  Kern County
## 2 3072695                                  5143  52161      CA  Kern County
## 3 3072704                                  5146  52161      CA  Kern County
## 4 3063272 19-028134 2014-WTE-4084-OE         NA     NA      IA Story County
## 5 3053390 19-028015 2015-WTE-6386-OE         NA     NA      IA Boone County
## 6 3063269 19-028130 2016-WTE-5934-OE         NA     NA      IA Story County
##   t_fips                  p_name p_year p_tnum p_cap t_manu    t_model t_cap
## 1   6029                251 Wind   1987    194 18.43 Vestas               95
## 2   6029                251 Wind   1987    194 18.43 Vestas               95
## 3   6029                251 Wind   1987    194 18.43 Vestas               95
## 4  19169 30 MW Iowa DG Portfolio   2017     10 30.00 Nordex AW125/3000  3000
## 5  19015 30 MW Iowa DG Portfolio   2017     10 30.00 Nordex AW125/3000  3000
## 6  19169 30 MW Iowa DG Portfolio   2017     10 30.00 Nordex AW125/3000  3000
##   t_hh t_rd    t_rsa t_ttlh retrofit retrofit_year t_conf_atr t_conf_loc
## 1   NA   NA       NA     NA        0            NA          2          3
## 2   NA   NA       NA     NA        0            NA          2          3
## 3   NA   NA       NA     NA        0            NA          2          3
## 4 87.5  125 12271.85    150        0            NA          3          3
## 5 87.5  125 12271.85    150        0            NA          3          3
## 6 87.5  125 12271.85    150        0            NA          3          3
##   t_img_date    t_img_srce      xlong     ylat
## 1   5/8/2018 Digital Globe -118.36376 35.07791
## 2   5/8/2018 Digital Globe -118.36441 35.07744
## 3   5/8/2018 Digital Globe -118.36420 35.07764
## 4  4/24/2017 Digital Globe  -93.43037 42.02823
## 5   6/1/2017 Digital Globe  -93.70042 41.97761
## 6  7/23/2017 Digital Globe  -93.63284 41.88248
```

```r
# Summarize the data to understand its structure
summary(data)
```

```
##     case_id          faa_ors            faa_asn            usgs_pr_id   
##  Min.   :3000001   Length:70808       Length:70808       Min.   :    1  
##  1st Qu.:3032230   Class :character   Class :character   1st Qu.:18626  
##  Median :3050978   Mode  :character   Mode  :character   Median :28598  
##  Mean   :3058490                                         Mean   :27524  
##  3rd Qu.:3090448                                         3rd Qu.:38720  
##  Max.   :3118671                                         Max.   :49135  
##                                                          NA's   :32545  
##      eia_id        t_state            t_county             t_fips     
##  Min.   :   90   Length:70808       Length:70808       Min.   : 2013  
##  1st Qu.:56763   Class :character   Class :character   1st Qu.:19081  
##  Median :57752   Mode  :character   Mode  :character   Median :35057  
##  Mean   :57878                                         Mean   :32244  
##  3rd Qu.:60338                                         3rd Qu.:48141  
##  Max.   :65270                                         Max.   :72133  
##  NA's   :5793                                                         
##     p_name              p_year         p_tnum          p_cap       
##  Length:70808       Min.   :1981   Min.   :  1.0   Min.   :  0.05  
##  Class :character   1st Qu.:2008   1st Qu.: 56.0   1st Qu.: 99.00  
##  Mode  :character   Median :2012   Median : 85.0   Median :158.00  
##                     Mean   :2012   Mean   :104.4   Mean   :170.18  
##                     3rd Qu.:2018   3rd Qu.:121.0   3rd Qu.:211.22  
##                     Max.   :2021   Max.   :731.0   Max.   :525.02  
##                     NA's   :613                    NA's   :4482    
##     t_manu            t_model              t_cap           t_hh       
##  Length:70808       Length:70808       Min.   :  50   Min.   : 19.00  
##  Class :character   Class :character   1st Qu.:1500   1st Qu.: 80.00  
##  Mode  :character   Mode  :character   Median :2000   Median : 80.00  
##                                        Mean   :1964   Mean   : 81.06  
##                                        3rd Qu.:2300   3rd Qu.: 87.00  
##                                        Max.   :6000   Max.   :131.00  
##                                        NA's   :5480   NA's   :6180    
##       t_rd            t_rsa           t_ttlh        retrofit      
##  Min.   : 13.40   Min.   :  141   Min.   : 30.4   Min.   :0.00000  
##  1st Qu.: 82.00   1st Qu.: 5281   1st Qu.:121.0   1st Qu.:0.00000  
##  Median :100.00   Median : 7854   Median :130.1   Median :0.00000  
##  Mean   : 95.66   Mean   : 7619   Mean   :129.1   Mean   :0.08454  
##  3rd Qu.:110.00   3rd Qu.: 9503   3rd Qu.:145.1   3rd Qu.:0.00000  
##  Max.   :155.00   Max.   :18869   Max.   :199.6   Max.   :1.00000  
##  NA's   :5934     NA's   :5934    NA's   :6180                     
##  retrofit_year     t_conf_atr      t_conf_loc     t_img_date       
##  Min.   :2015    Min.   :1.000   Min.   :1.000   Length:70808      
##  1st Qu.:2018    1st Qu.:3.000   1st Qu.:3.000   Class :character  
##  Median :2019    Median :3.000   Median :3.000   Mode  :character  
##  Mean   :2019    Mean   :2.767   Mean   :2.884                     
##  3rd Qu.:2020    3rd Qu.:3.000   3rd Qu.:3.000                     
##  Max.   :2020    Max.   :3.000   Max.   :3.000                     
##  NA's   :64822                                                     
##   t_img_srce            xlong              ylat      
##  Length:70808       Min.   :-171.71   Min.   :13.39  
##  Class :character   1st Qu.:-103.04   1st Qu.:34.43
##  Mode  :character   Median : -99.39   Median :39.05
##                     Mean   :-100.09   Mean   :38.48
##                     3rd Qu.: -95.20   3rd Qu.:42.81
##                     Max.   : 144.72   Max.   :66.84
##
```

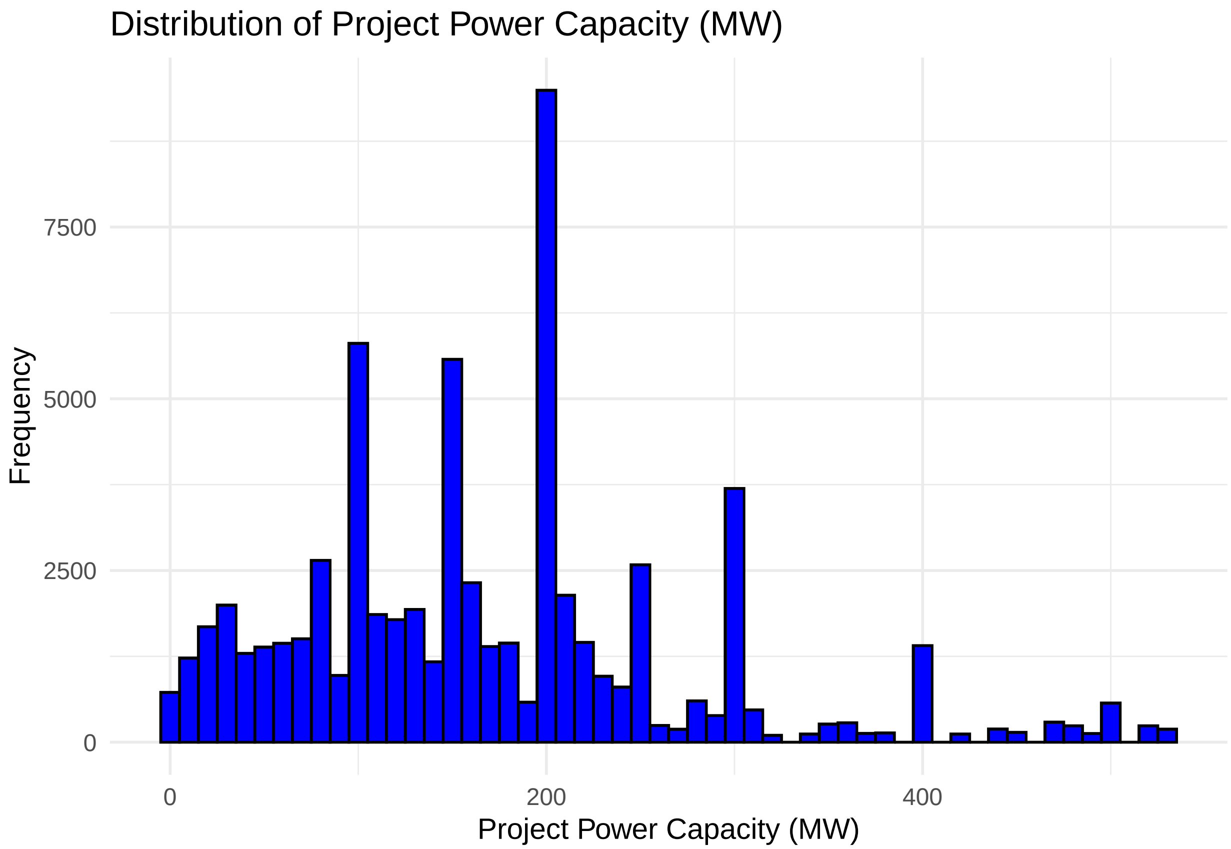
```r
# Convert date to Date format
## We want it in the Date format since it allows us to do easier modifications to the variables
data$t_img_date <- as.Date(data$t_img_date, format = "%m/%d/%Y")


## Data pre-2015 seems very unreliable pre-2015 so I am cutting off before then.
data_after_2015 <- data %>%
  filter(t_img_date > as.Date("2014-12-31"))


# Aggregate data by month
## Data is very noisy so collecting by month makes the data bit easier to parse.
monthly_data <- data_after_2015 %>%
  group_by(month = floor_date(t_img_date, "month")) %>%
  summarise(count = n())

## Need to establish bounding boxes on geographic areas for the maps
continental_bbox <- c(left = -125, bottom = 24, right = -66, top = 49)
alaska_bbox <- c(left = -170, bottom = 52, right = -130, top = 72)
hawaii_bbox <- c(left = -160, bottom = 18, right = -154, top = 23)

## Grabbing all numeric data for a rough analysis
numeric_data <- data %>% select_if(is.numeric)
```

Exploratory Analysis

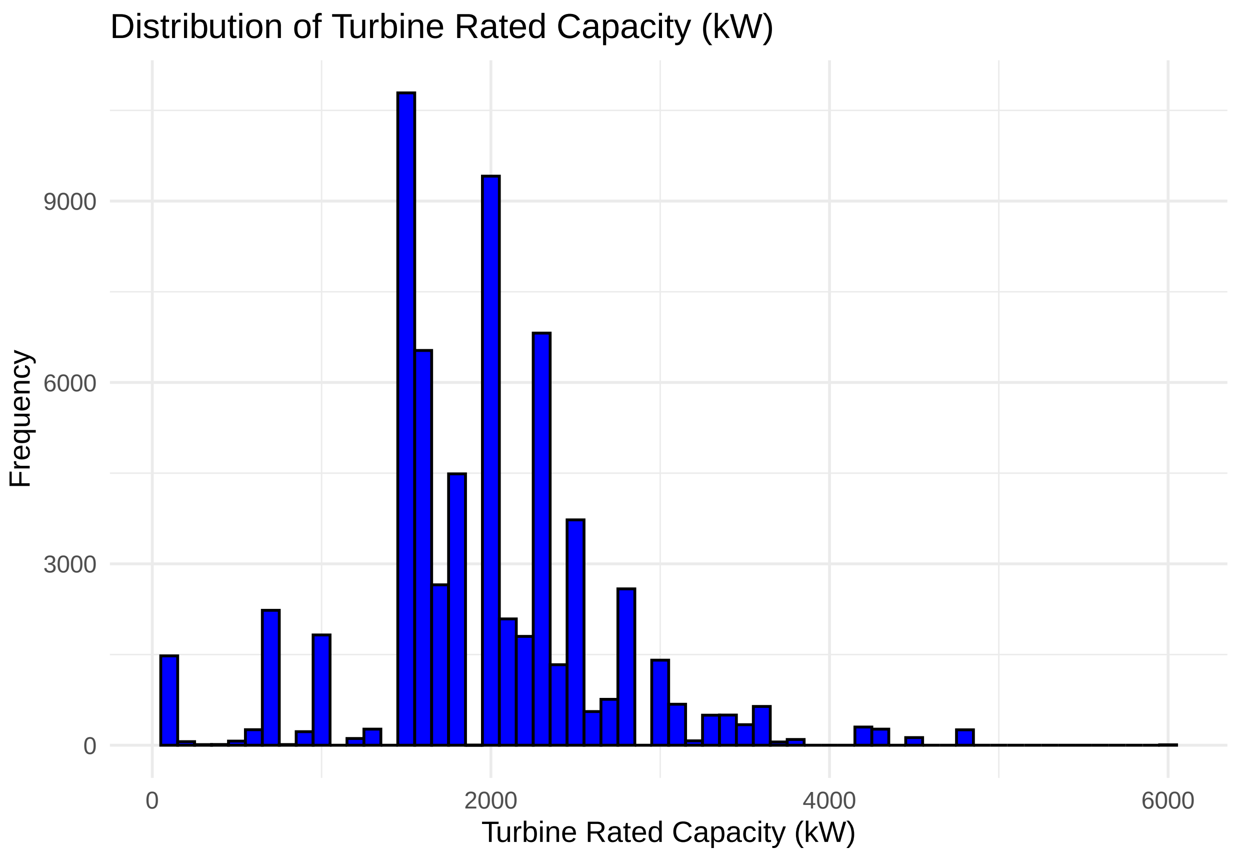
```r
# Histograms for continuous variables
continuous_vars <- c("p_cap", "t_cap", "t_hh", "t_rd", "t_rsa", "t_ttlh")
continuous_titles <- c("Project Power Capacity (MW)", "Turbine Rated Capacity (kW)",
                       "Turbine Hub Height (m)", "Turbine Rotor Diameter (m)",
                       "Turbine Rotor Sweep Area (sq m)", "Total Turbine Height (m)")

binwidths <- c(10, 100, 5, 2.5, 500, 5)


for (i in 1:length(continuous_vars)) {
  var <- continuous_vars[i]
  title <- continuous_titles[i]
  binwidth <- binwidths[i]

  print(ggplot(data, aes_string(x = var)) +
          geom_histogram(binwidth = binwidth, fill = "blue", color = "black") +
          labs(x = title, y = "Frequency", title = paste("Distribution of", title)) +
          theme_minimal())
}
```

```
## Warning: ‘aes_string()‘ was deprecated in ggplot2 3.0.0.
## i Please use tidy evaluation idioms with ‘aes()‘.
## i See also ‘vignette("ggplot2-in-packages")‘ for more information.
## This warning is displayed once every 8 hours.
## Call ‘lifecycle::last_lifecycle_warnings()‘ to see where this warning was
## generated.
```

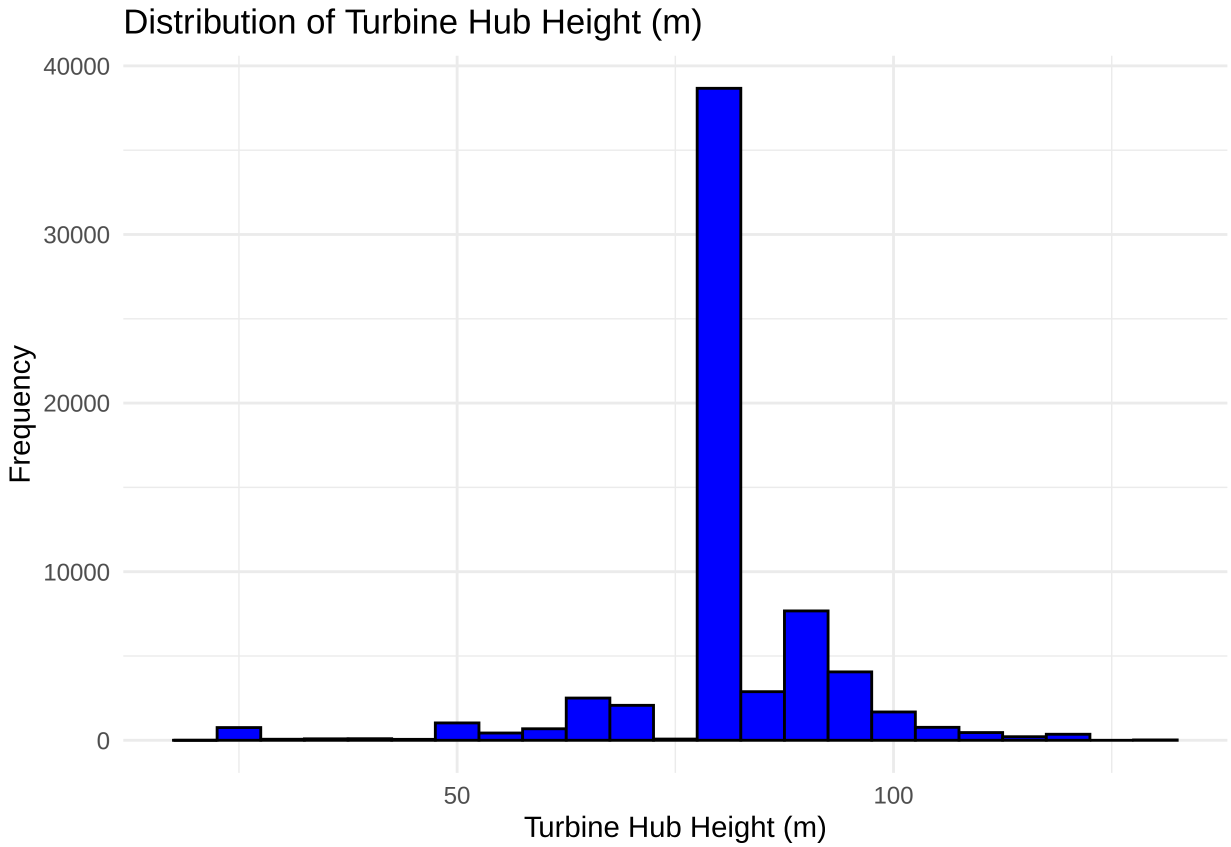
```
## Warning: Removed 4482 rows containing non-finite values (‘stat_bin()‘).
```



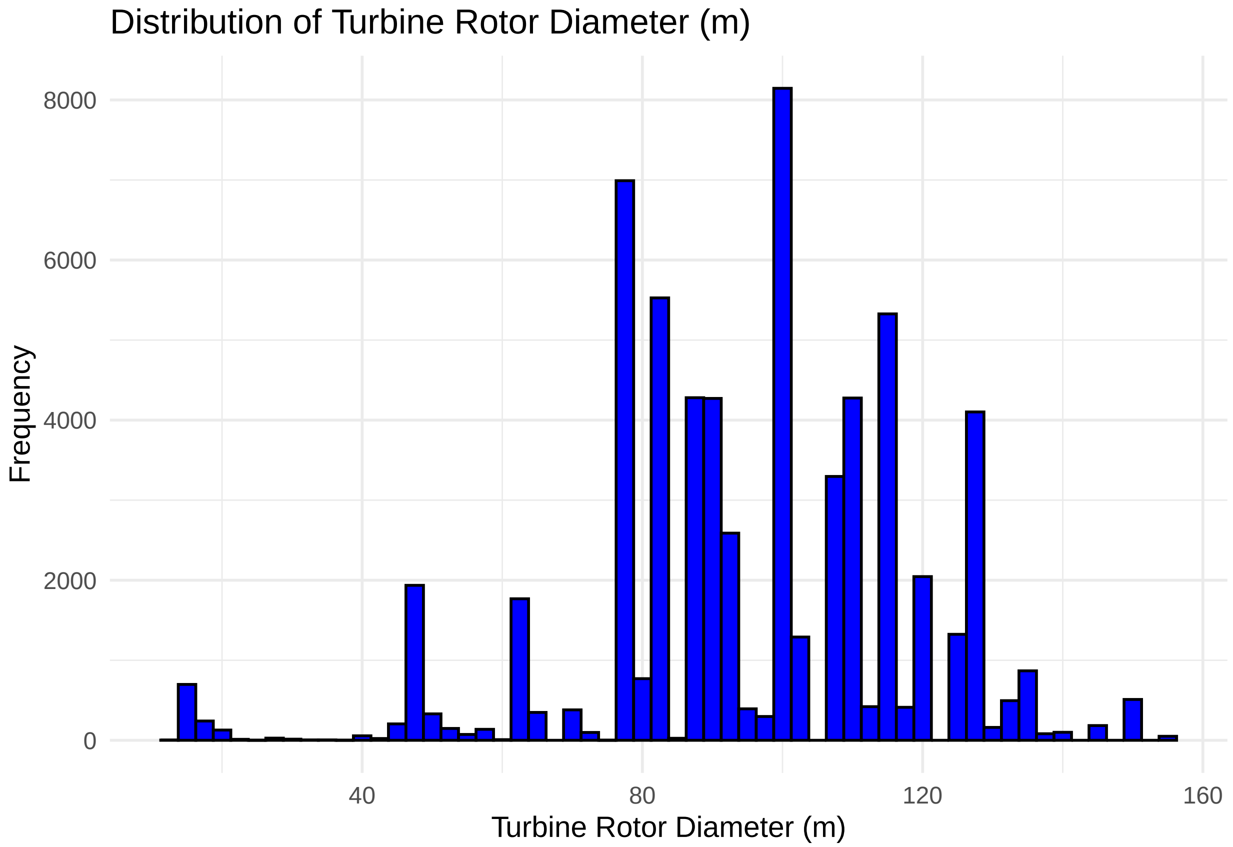
```
## Warning: Removed 5480 rows containing non-finite values (‘stat_bin()‘).
```



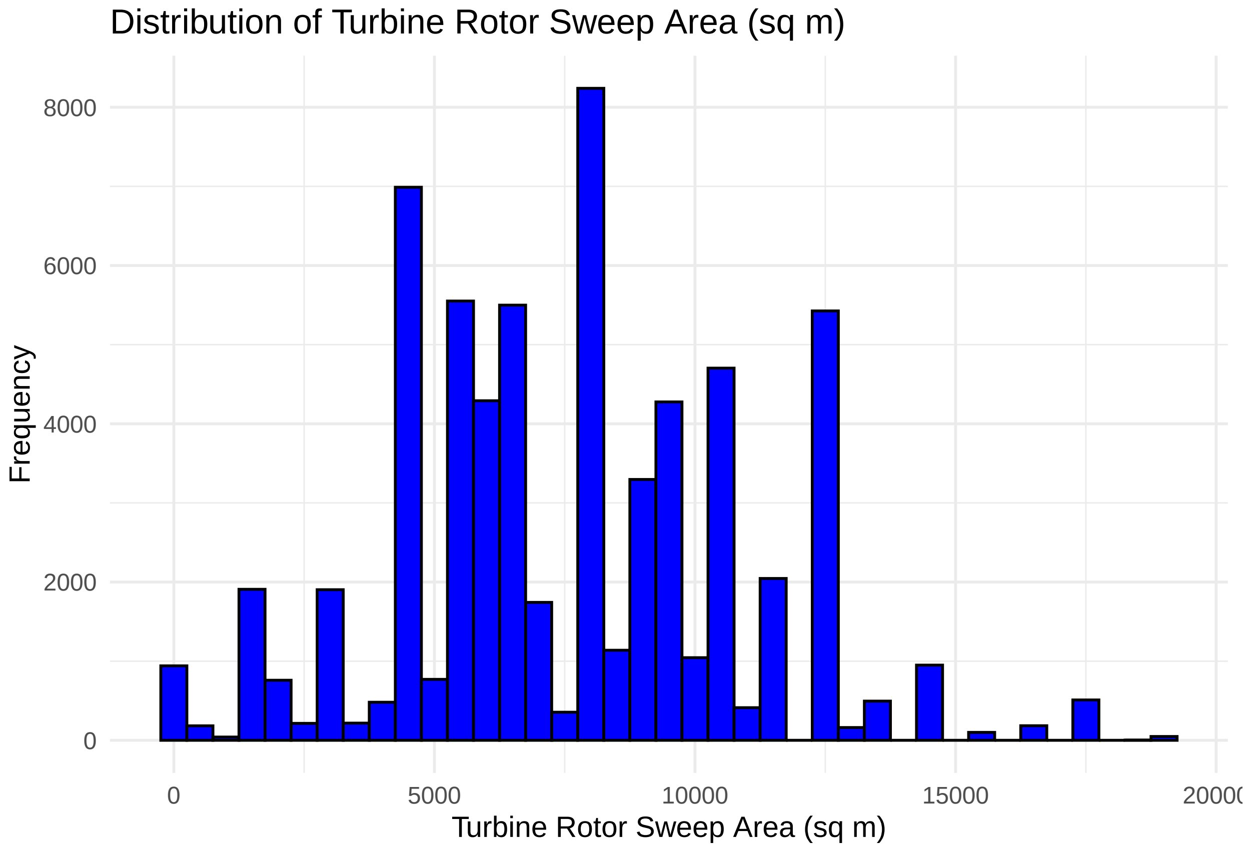
```
## Warning: Removed 6180 rows containing non-finite values (‘stat_bin()‘).
```



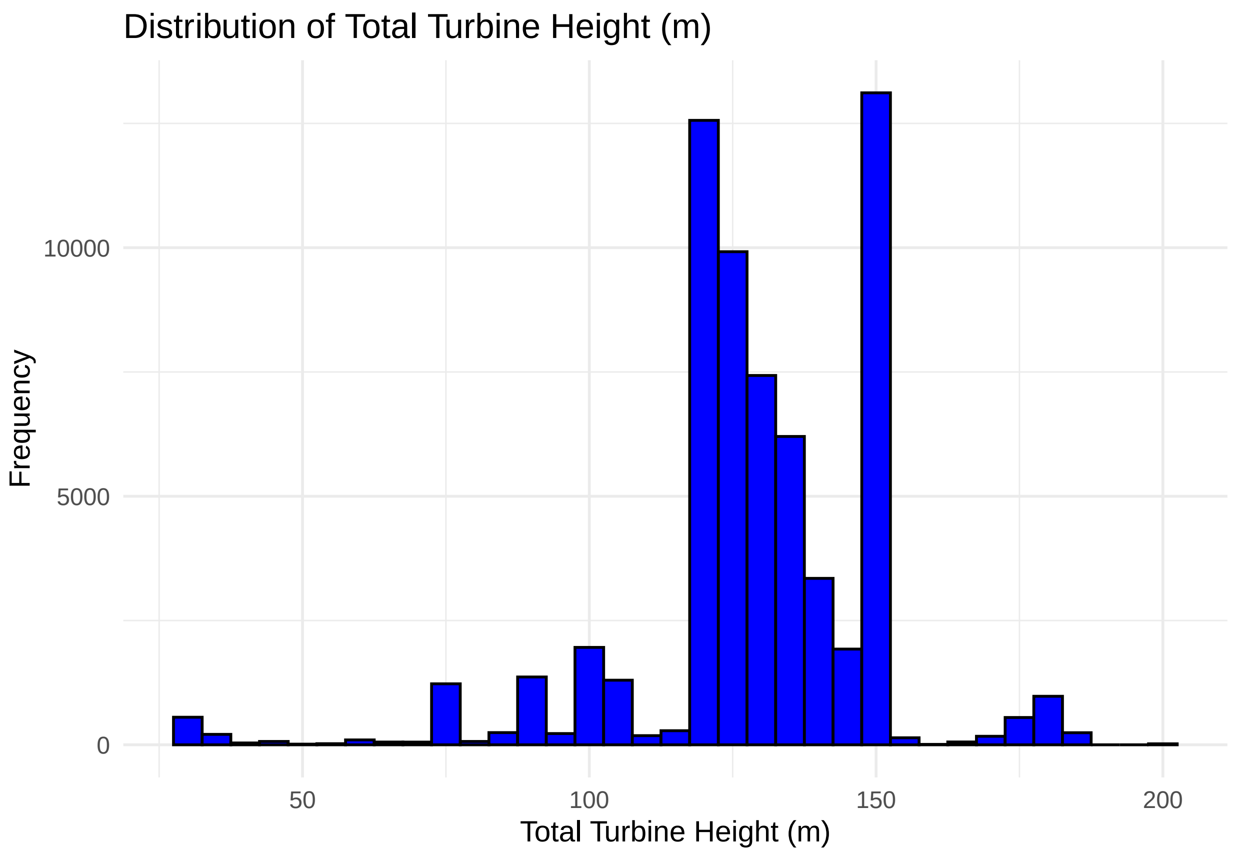
```
## Warning: Removed 5934 rows containing non-finite values (‘stat_bin()‘).
```



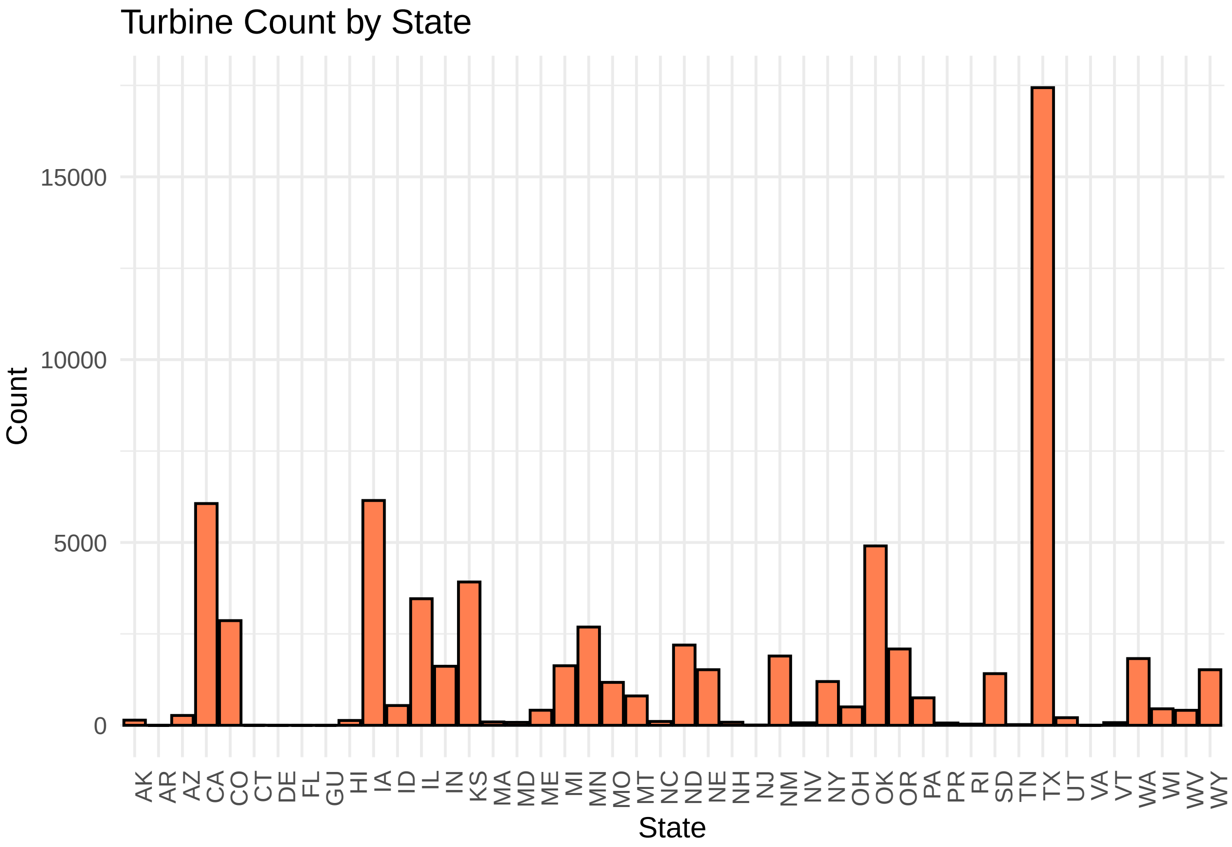
```
## Warning: Removed 5934 rows containing non-finite values ('stat_bin()').
```

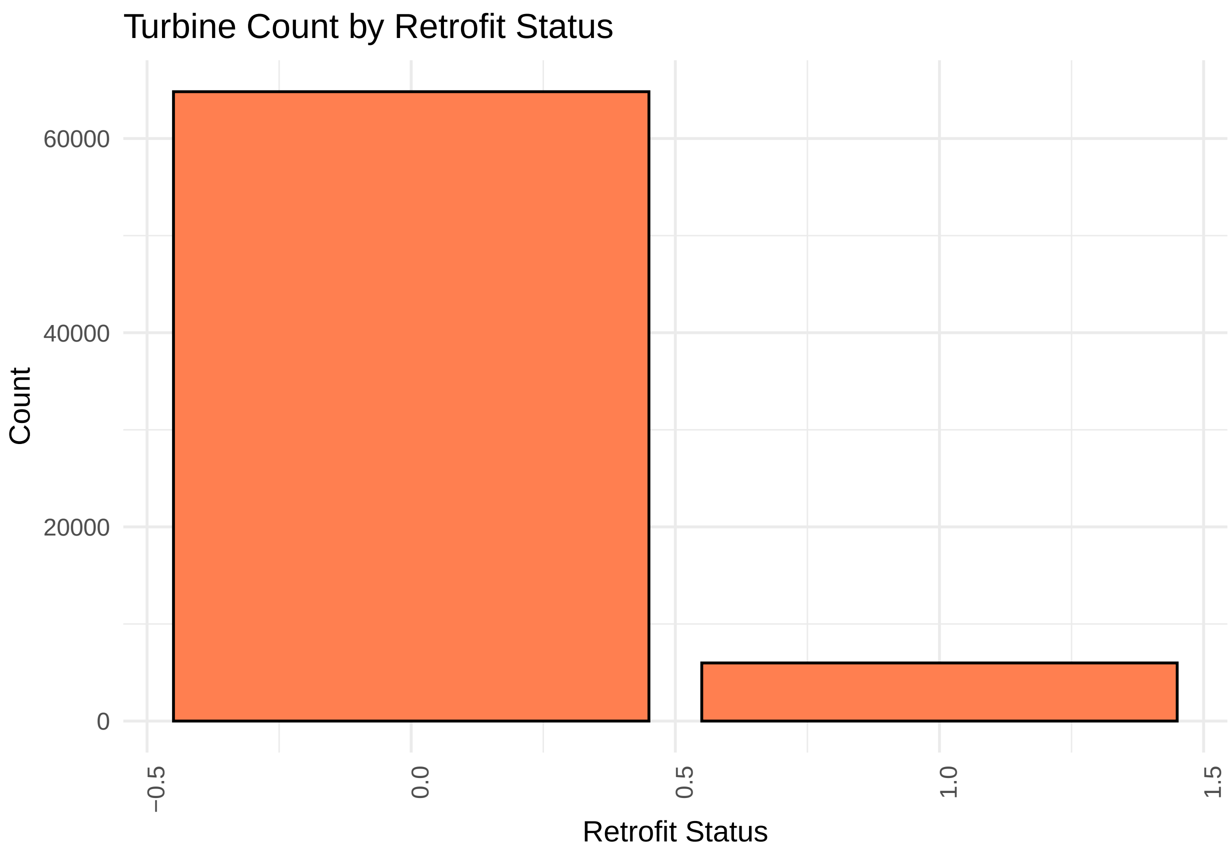


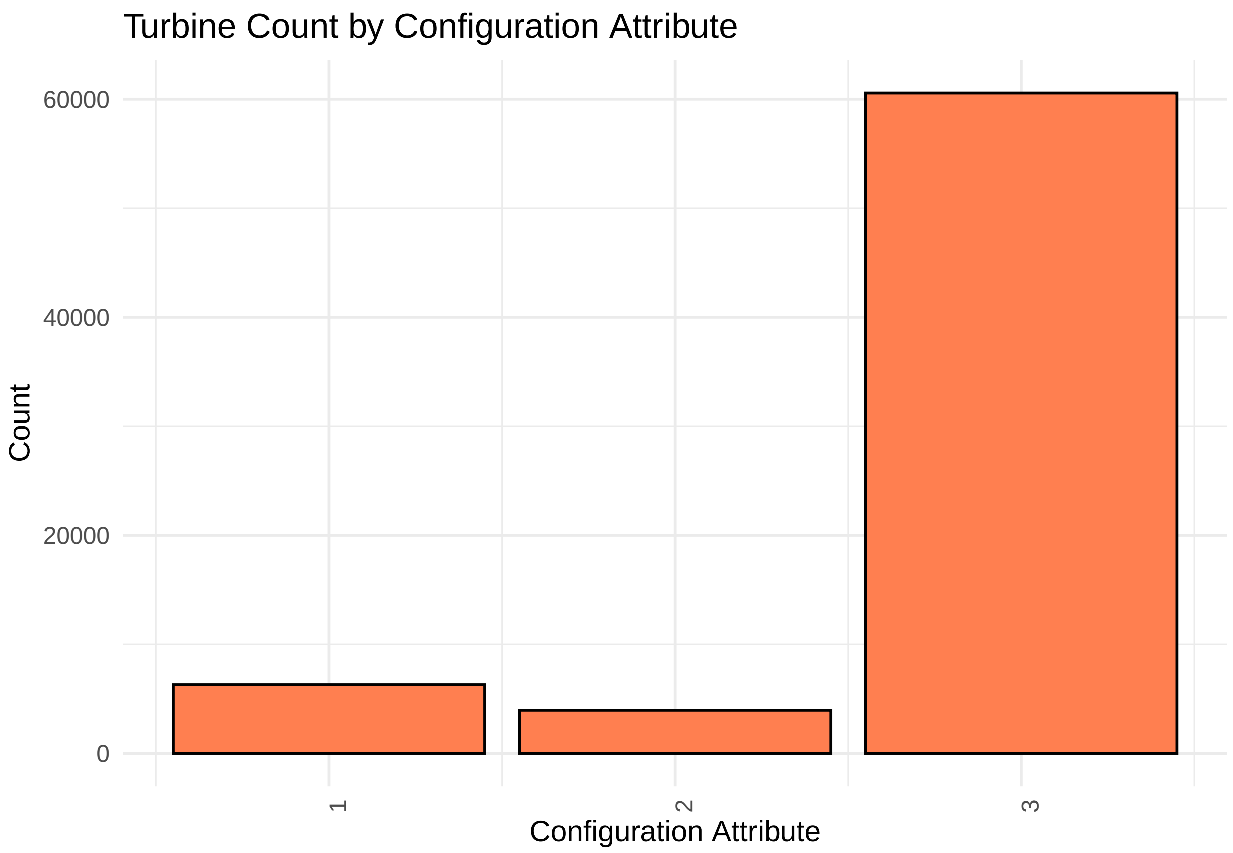
```
## Warning: Removed 6180 rows containing non-finite values (‘stat_bin()‘).
```

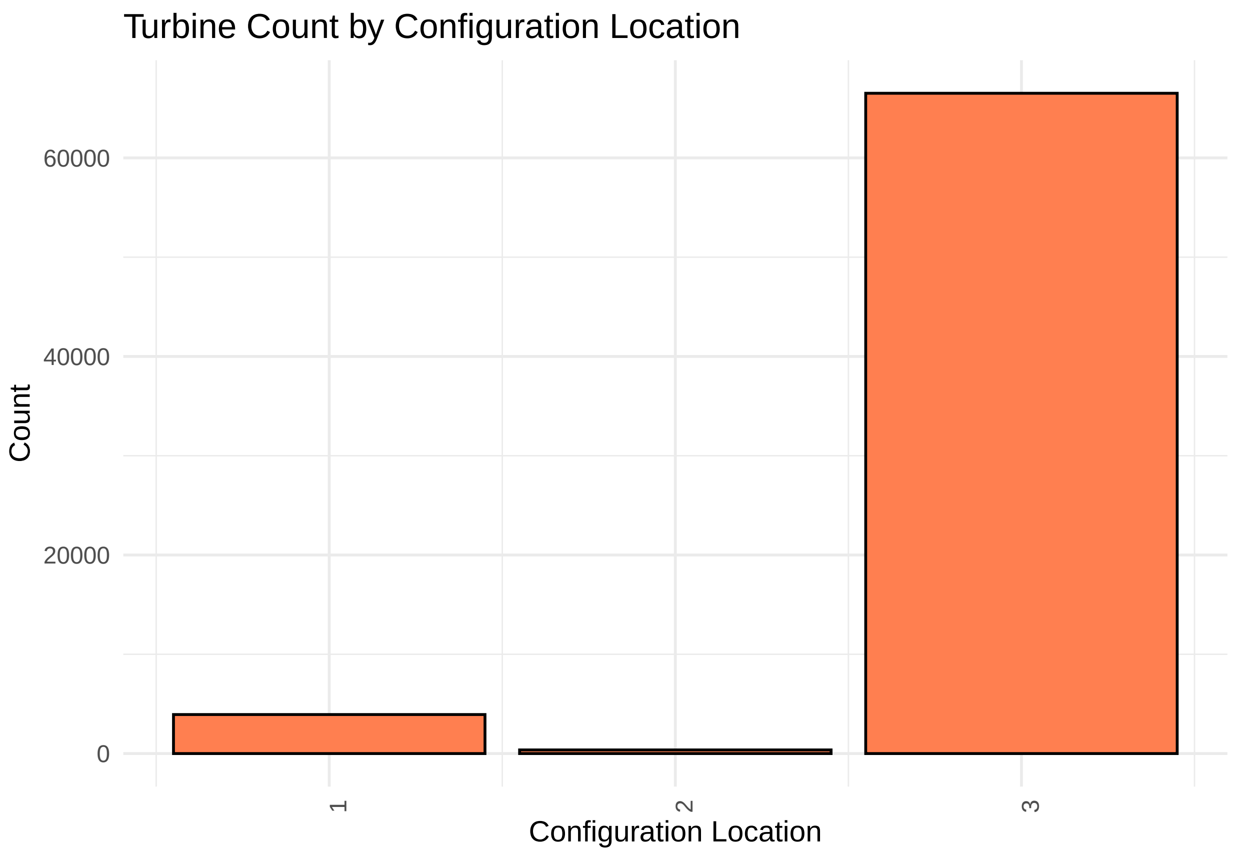


```
# Bar plots for categorical variables
categorical_vars <- c("t_state", "retrofit", "t_conf_atr", "t_conf_loc")
categorical_titles <- c("State", "Retrofit Status", "Configuration Attribute", "Configuration Location"

for (i in 1:length(categorical_vars)) {
  var <- categorical_vars[i]
  title <- categorical_titles[i]

  print(ggplot(data, aes_string(x = var)) +
          geom_bar(fill = "coral", color = "black") +
          labs(x = title, y = "Count", title = paste("Turbine Count by", title)) +
          theme_minimal() +
          theme(axis.text.x = element_text(angle = 90, hjust = 1)))
}
```

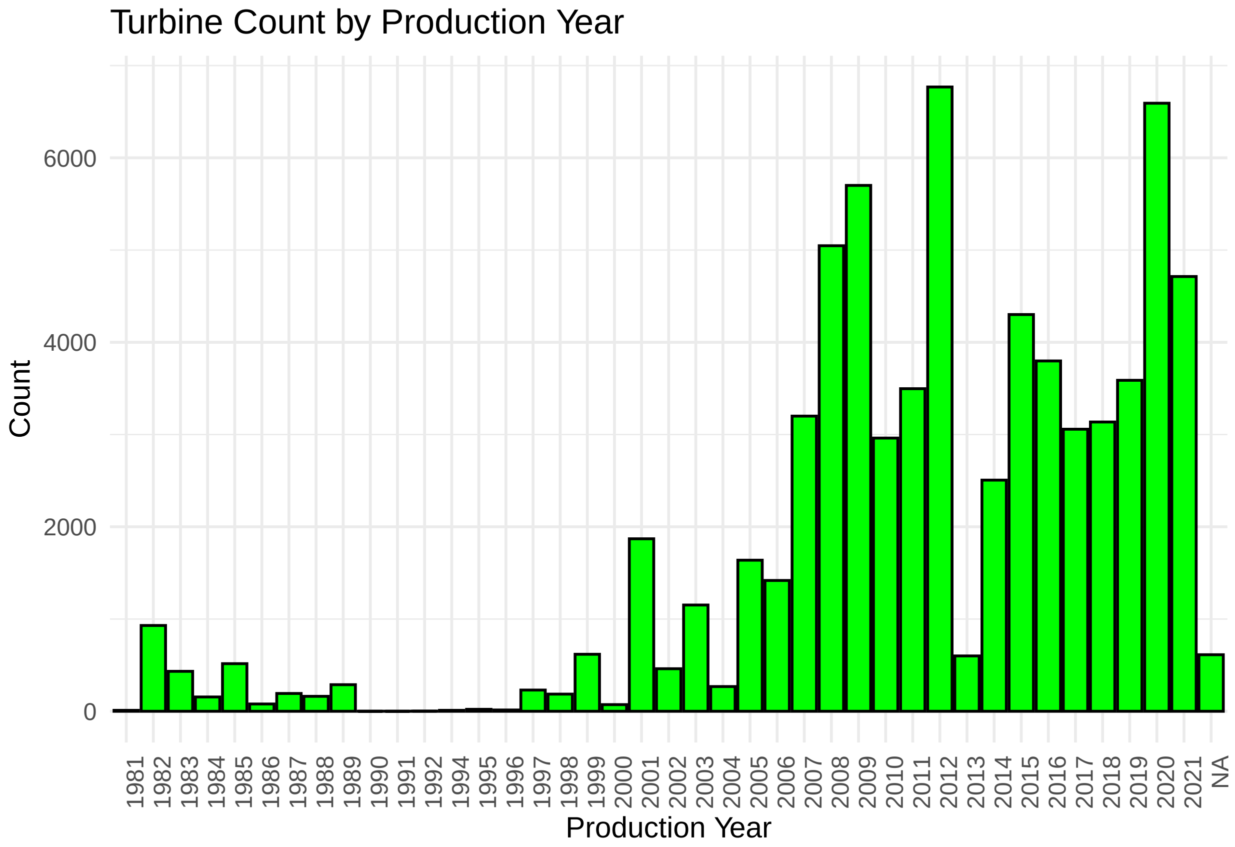

Turbine Count by State
Count
15000
10000
5000
0
State
AK
AR
AZ
CA
CO
CT
DE
FL
GU
HI
IA
ID
IL
IN
KS
MA
MD
ME
MI
MN
MO
MT
NC
ND
NE
NH
NJ
NM
NV
NY
OH
OK
OR
PA
PR
RI
SD
TN
TX
UT
VA
VT
WA
WI
WV
WY

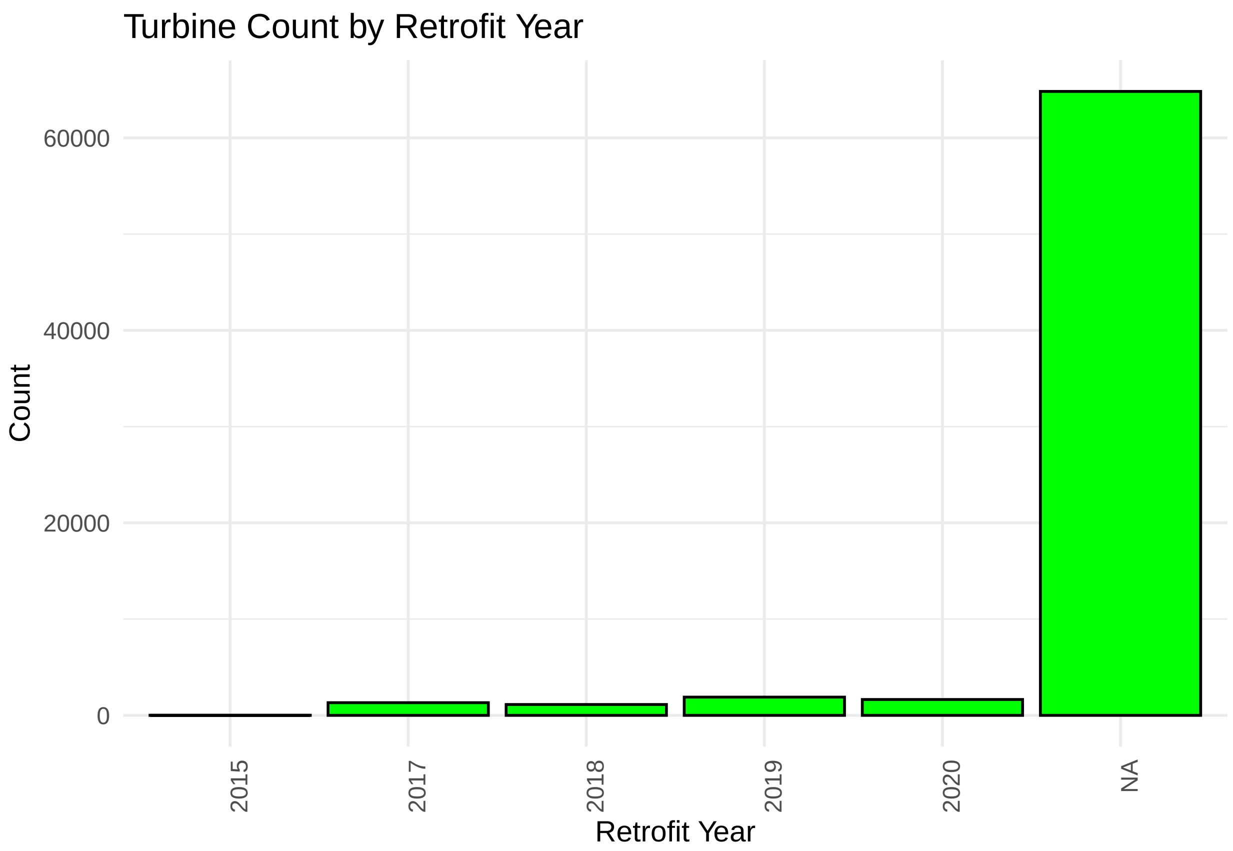

Turbine Count by Retrofit Status
Count
60000
40000
20000
0
−0.5
0.0
0.5
1.0
1.5
Retrofit Status


Turbine Count by Configuration Attribute
60000
40000
20000
0
Count
1
2
3
Configuration Attribute



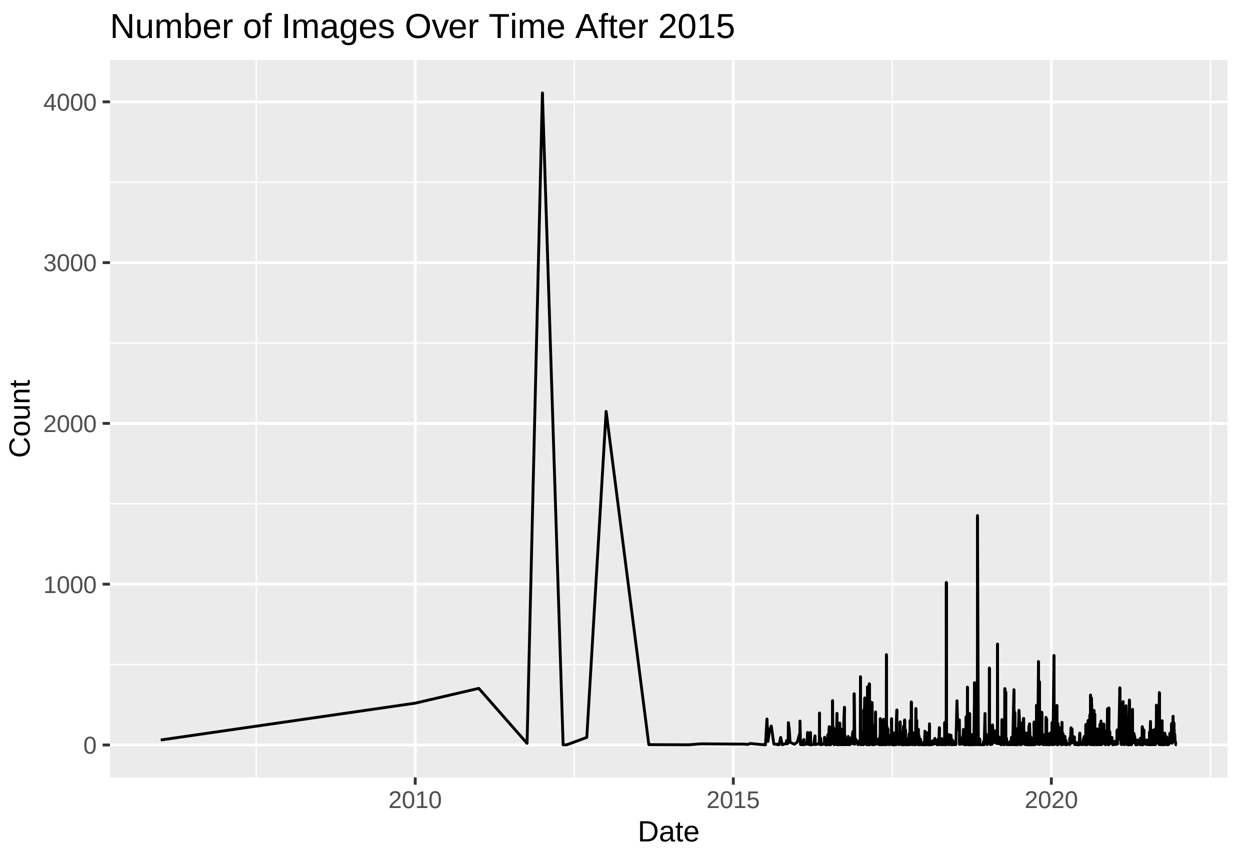
```
# Bar plot for year variables
year_vars <- c("p_year", "retrofit_year")
year_titles <- c("Production Year", "Retrofit Year")

for (i in 1:length(year_vars)) {
  var <- year_vars[i]
  title <- year_titles[i]

  data[[var]] <- as.factor(data[[var]])

  print(ggplot(data, aes_string(x = var)) +
          geom_bar(fill = "green", color = "black") +
          labs(x = title, y = "Count", title = paste("Turbine Count by", title)) +
          theme_minimal() +
          theme(axis.text.x = element_text(angle = 90, hjust = 1)))
}
```


Turbine Count by Production Year
Count
6000
4000
2000
0
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
NA
Production Year

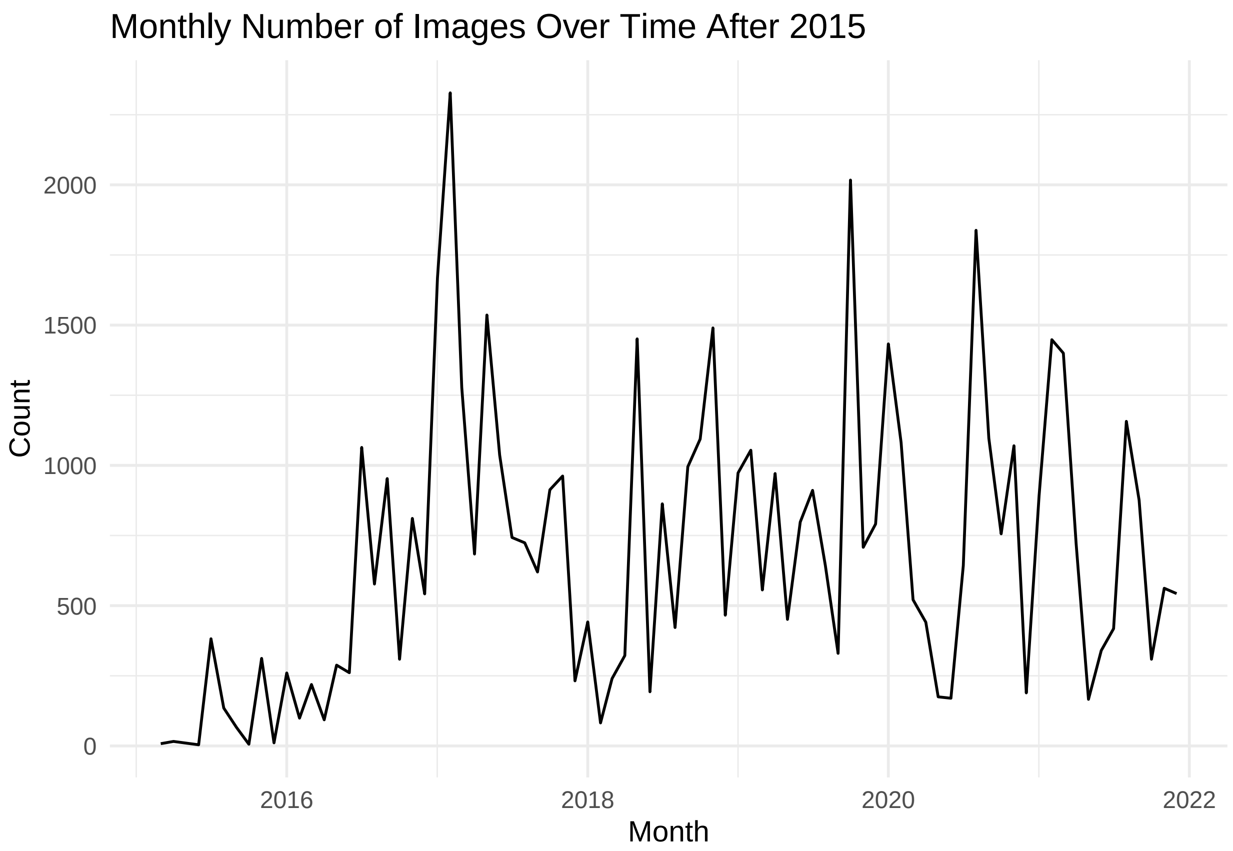


```
ggplot(data, aes(x = t_img_date)) +
  geom_line(stat = "count", aes(group = 1)) +
  labs(x = "Date", y = "Count", title = "Number of Images Over Time After 2015")
```

```
## Warning: Removed 8316 rows containing non-finite values (‘stat_count()‘).
```



```r
ggplot(monthly_data, aes(x = month, y = count)) +
  geom_line() +
  labs(x = "Month", y = "Count", title = "Monthly Number of Images Over Time After 2015") +
  theme_minimal()
```



```
register_stadiamaps("f94c64ea-35d9-425f-af7a-e139e3bd6242", write = TRUE)
```

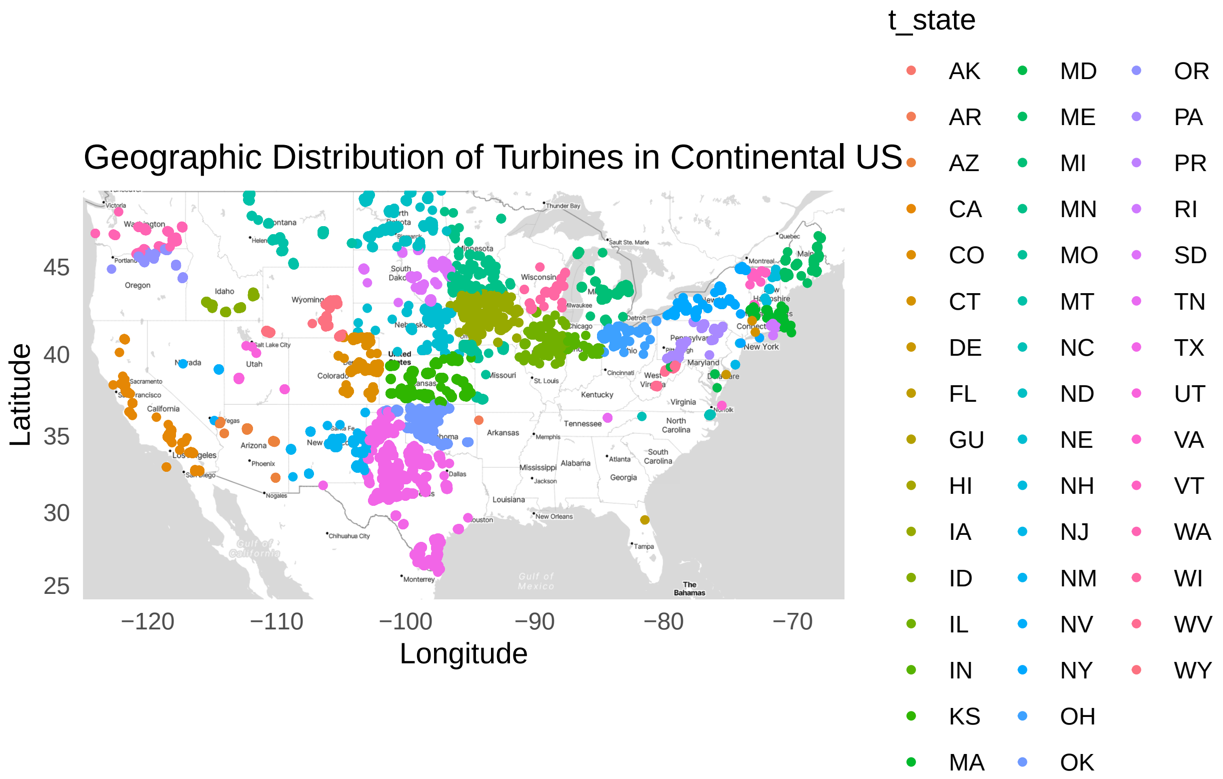
```
## i Replacing old key (f94c64ea) with new key in /Users/kyler/.Renviron
```

```
continental_map <- get_stadiamap(bbox = continental_bbox, zoom = 5, maptype = "stamen_toner_lite")
```

```
## i © Stadia Maps © Stamen Design © OpenMapTiles © OpenStreetMap contributors.
```

```
ggmap(continental_map) +
  geom_point(data = data, aes(x = xlong, y = ylat, color = t_state), size = 1) +
  labs(x = "Longitude", y = "Latitude", title = "Geographic Distribution of Turbines in Continental US"
  theme_minimal()
```

```
## Warning: Removed 337 rows containing missing values (‘geom_point()‘).
```

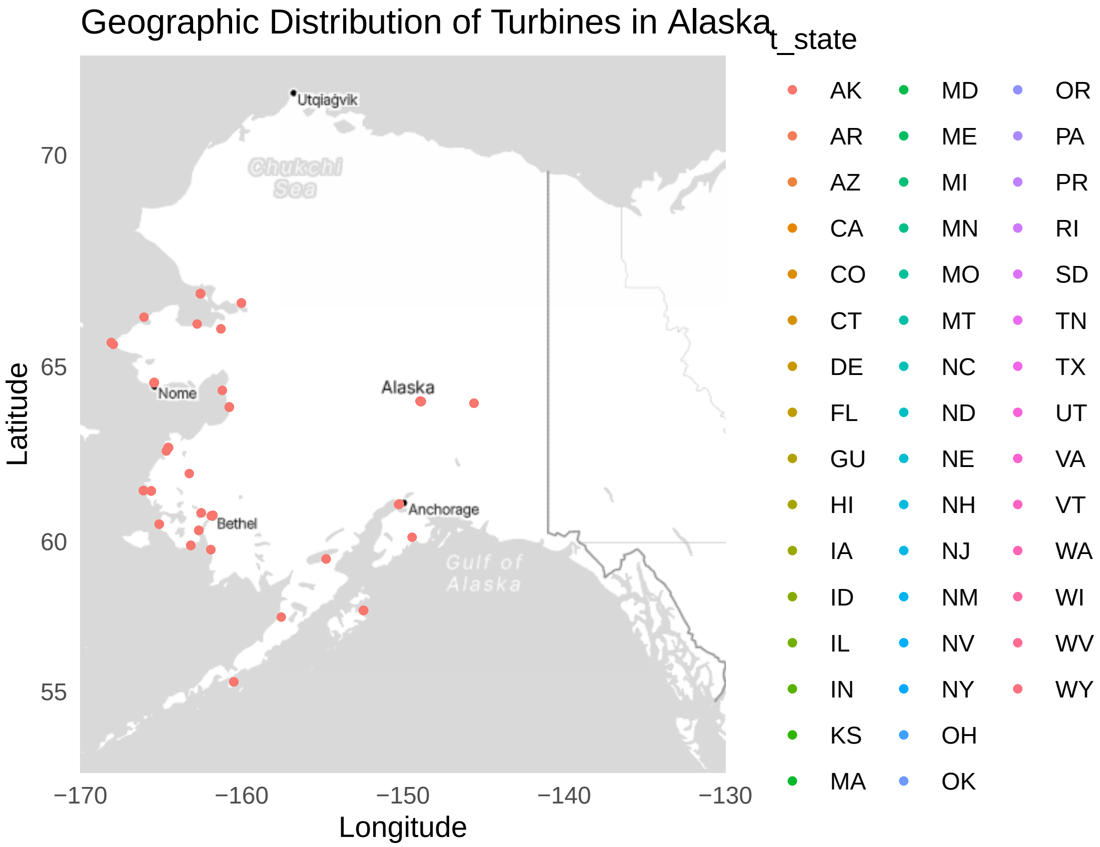


```r
alaska_map <- get_stadiamap(bbox = alaska_bbox, zoom = 4, maptype = "stamen_toner_lite")
```

```
## i © Stadia Maps © Stamen Design © OpenMapTiles © OpenStreetMap contributors.
```

```r
ggmap(alaska_map) +
  geom_point(data = data, aes(x = xlong, y = ylat, color = t_state), size = 1) +
  labs(x = "Longitude", y = "Latitude", title = "Geographic Distribution of Turbines in Alaska") +
  theme_minimal()
```

```
## Warning: Removed 70675 rows containing missing values (‘geom_point()‘).
```

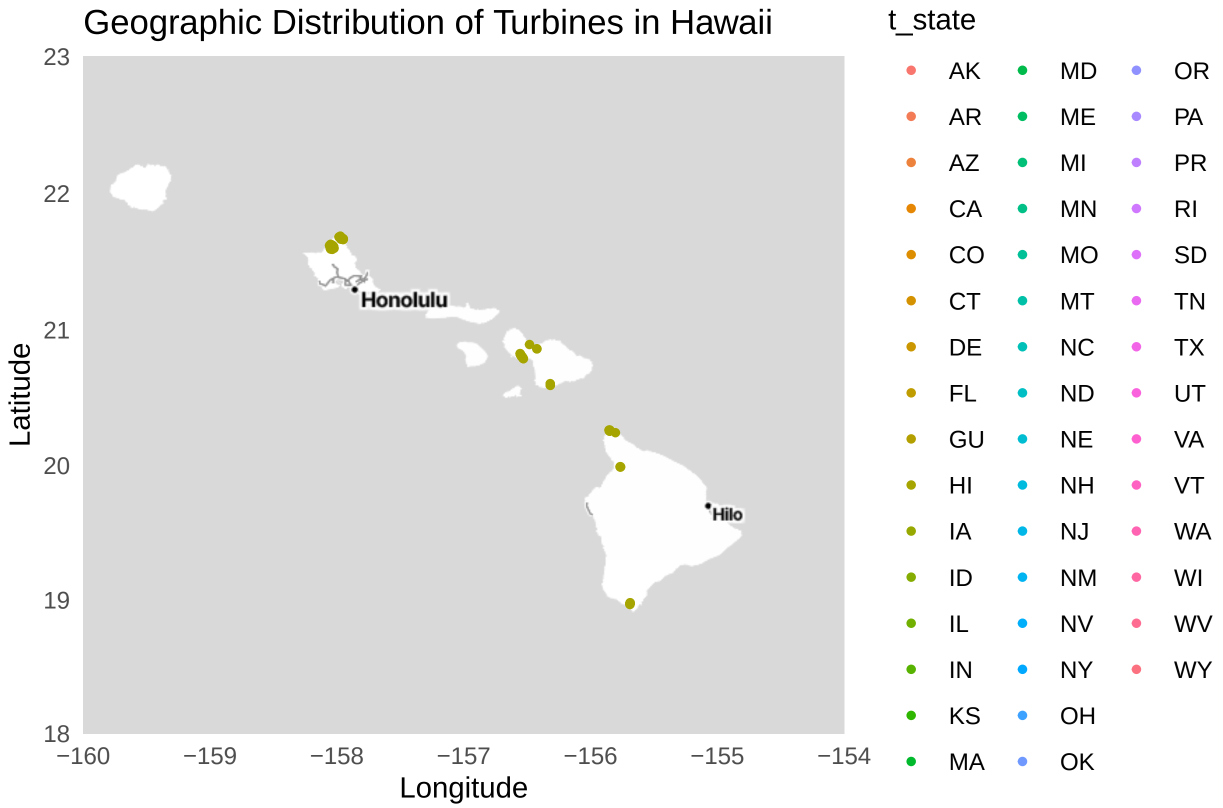


```
hawaii_map <- get_stadiamap(bbox = hawaii_bbox, zoom = 7, maptype = "stamen_toner_lite")
```

```
## i © Stadia Maps © Stamen Design © OpenMapTiles © OpenStreetMap contributors.
```

```
ggmap(hawaii_map) +
  geom_point(data = data, aes(x = xlong, y = ylat, color = t_state), size = 1) +
  labs(x = "Longitude", y = "Latitude", title = "Geographic Distribution of Turbines in Hawaii") +
  theme_minimal()
```

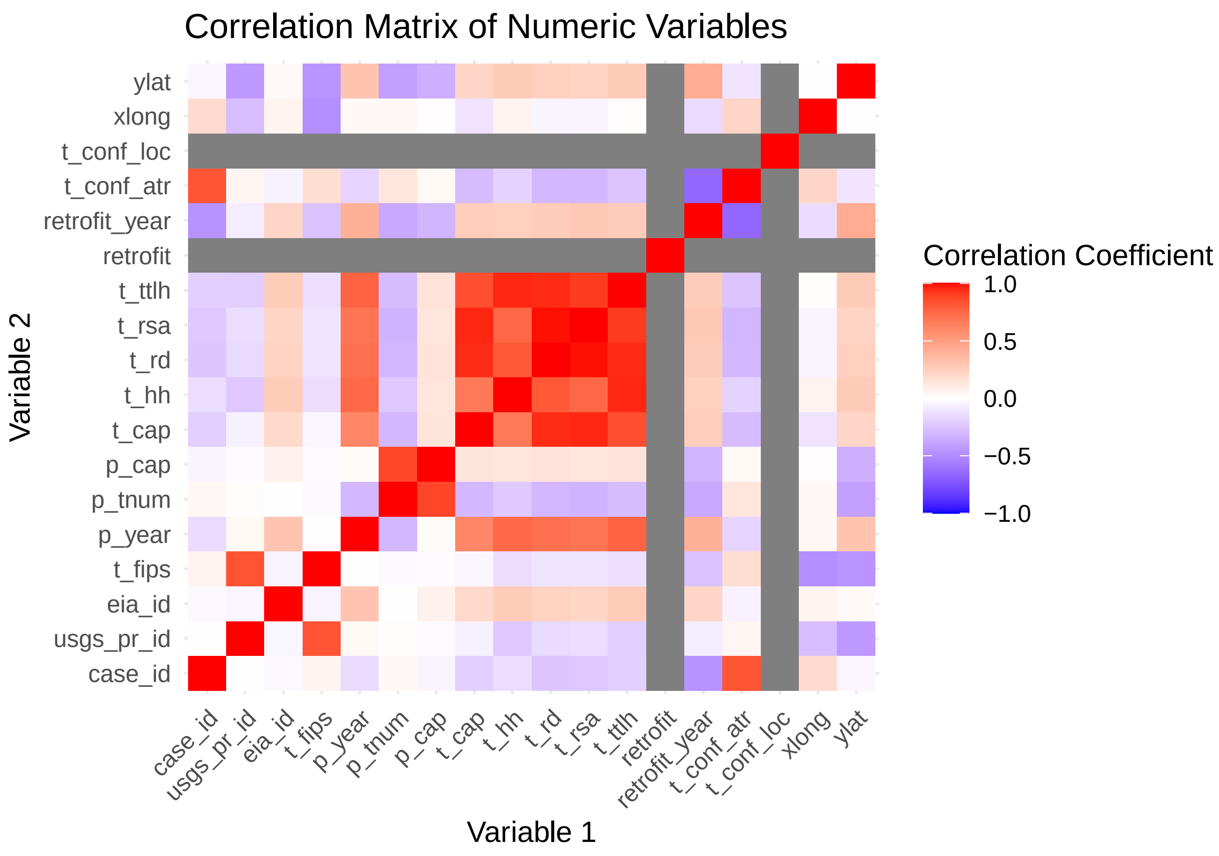
```
## Warning: Removed 70676 rows containing missing values (‘geom_point()‘).
```



```r
# Correlation plot if there are multiple numeric variables
correlation_matrix <- cor(numeric_data, use = "complete.obs")
```

```
## Warning in cor(numeric_data, use = "complete.obs"): the standard deviation is
## zero
```

```r
print(ggplot(data = as.data.frame(as.table(correlation_matrix)),
       aes(x = Var1, y = Var2, fill = Freq)) +
  geom_tile() +
  scale_fill_gradient2(low = "blue", high = "red", mid = "white", midpoint = 0, limit = c(-1,1)) +
  labs(title = "Correlation Matrix of Numeric Variables",
       x = "Variable 1",
       y = "Variable 2",
       fill = "Correlation Coefficient") +
  theme_minimal() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)))
```



```r
# End of EDA section with session information
sessionInfo()
```

```
## R version 4.1.2 (2021-11-01)
## Platform: aarch64-apple-darwin20 (64-bit)
## Running under: macOS 14.2.1
##
## Matrix products: default
## BLAS:   /Library/Frameworks/R.framework/Versions/4.1-arm64/Resources/lib/libRblas.0.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/4.1-arm64/Resources/lib/libRlapack.dylib
##
## locale:
## [1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] ggmap_4.0.0     lubridate_1.9.3 forcats_1.0.0   stringr_1.5.1
##  [5] dplyr_1.1.4     purrr_1.0.2     readr_2.1.5     tidyr_1.3.1
##  [9] tibble_3.2.1    ggplot2_3.4.4   tidyverse_2.0.0
##
## loaded via a namespace (and not attached):
##  [1] Rcpp_1.0.12       highr_0.9         plyr_1.8.9        pillar_1.9.0
##  [5] compiler_4.1.2    bitops_1.0-7      tools_4.1.2       digest_0.6.29
##  [9] timechange_0.3.0  evaluate_0.14     lifecycle_1.0.4   gtable_0.3.0
## [13] png_0.1-8         pkgconfig_2.0.3   rlang_1.1.3       cli_3.6.2
## [17] rstudioapi_0.15.0 curl_5.2.0        yaml_2.2.1        xfun_0.29
## [21] fastmap_1.1.0     httr_1.4.7        withr_3.0.0       knitr_1.37
## [25] maps_3.4.2        generics_0.1.3    vctrs_0.6.5       hms_1.1.3
## [29] grid_4.1.2        tidyselect_1.2.0  glue_1.7.0        R6_2.5.1
## [33] jpeg_0.1-10       fansi_1.0.2       rmarkdown_2.11.12 farver_2.1.0
## [37] tzdb_0.4.0        magrittr_2.0.3    scales_1.3.0      htmltools_0.5.2
## [41] colorspace_2.0-3  labeling_0.4.2    utf8_1.2.2        stringi_1.7.6
## [45] munsell_0.5.0     crayon_1.4.2
```