Evaluation of Gulf Temperature's Effect on Power Plant

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Table of contents

Preface

You are a data scientist for a mid-sized business, in a small group of 3-4 data scientists. You've been tasked with creating a report evaluating a scenario for your business. Your colleagues will also be evaluating the same scenario, and your reports will be used in aggregate to determine a consensus (or lack thereof) on the company's action. The reports will also be used to inform downsizing that is rumored to be coming - you want to ensure your report is better than your peers so that you aren't as easy to cut.

You may talk to your peers who are assigned the same scenario, but you do not want to collaborate too closely, lest you both become targets of the rumored layoffs.

I've scaffolded this report for you to make this process easier - as we talk about different sections of a report in class and read about how to create similar sections, you will practice by writing the equivalent section of your report.

The basic steps for this task are as follows:

- Identify the research question from the business question
- Identify data set(s) which are (1) publicly available (you don't have a budget to pay for private data) and (2) relevant to your task
  - (HW Week 6) Document your data sets in `draft-data-doc.qmd`
- Conduct a statistical analysis to support your answer to your research and business questions
  - Write a methods section for your business report corresponding to your statistical analysis
  - (HW Week 9) Draft of results section of business report with relevant graphics/visual aids in `draft-results.qmd`
- Write your report
  - (HW Week 10) Draft of Intro/Conclusion sections in `draft-intro-conclusions.qmd`

  - (HW Week 11) Draft of Executive summary section in `draft-exec-summary.qmd`

- Revise your report
  - (HW Week 12 – not turned in) Revise your report
  - (HW Week 13) - Rough draft of report due. Create one or more qmd files for your report (you can overwrite or delete intro.qmd and summary.qmd), include the names of each file (in order) in `_quarto.yml`. You should use references (edit references.bib and use pandoc citations). Make sure your report compiles and looks reasonable in both html and pdf.
  - Develop a presentation to go along with your report (Week 13). Create slides for your report using quarto.
- Peer revise reports
  - Peer revise reports
  - (HW Week 14) - Make edits to your report from comments received from peer review
- Final report & presentation due

1 Executive Summary

1.1 Executive Summary

The power plant located at Dauphin Island, Alabama, relies on Gulf of Mexico water to cool its equipment, with an operational limit set at water temperatures below 85°F. Rising ocean temperatures pose significant economic and operational risks, particularly during peak electricity demand in summer.

Historical analysis (2022–2024) of Gulf water temperatures indicates consistent exceedances of the 85°F threshold in July and August, with occasional exceedances in June and September. Forecasted electricity demand for 2024 aligns closely with these periods of elevated temperatures. Thus, increasing the risk of reduced operational capacity precisely when energy demand peaks.

Key findings include:

- Average monthly temperatures in peak summer regularly exceed the plant's cooling threshold.
- Peak energy demand occurs simultaneously with these high-temperature months, increasing the potential for shortages and higher operational costs.

1.1.1 Important Visualizations and Tables

1.1.1.1 Monthly Average Water Temperatures (°F) at Dauphin Island (2022–2024)

The following table presents the average monthly water temperatures for each year between 2022 and 2024.

Month	2022 Avg Temp (°F)	2023 Avg Temp (°F)	2024 Avg Temp (°F)
Jan	54.2	58.5	54.3
Feb	58.4	59.2	58.9
Mar	70.0	64.6	64.2
Apr	81.9	70.7	71.0
May	80.3	78.3	80.6
Jun	86.2	83.0	84.7

Month	2022 Avg Temp (°F)	2023 Avg Temp (°F)	2024 Avg Temp (°F)
Jul	86.0	86.6	87.8
Aug	83.0	89.2	88.3
Sep	83.8	85.7	82.8
Oct	73.5	75.2	75.7
Nov	62.3	64.9	71.3
Dec	58.2	58.2	58.5

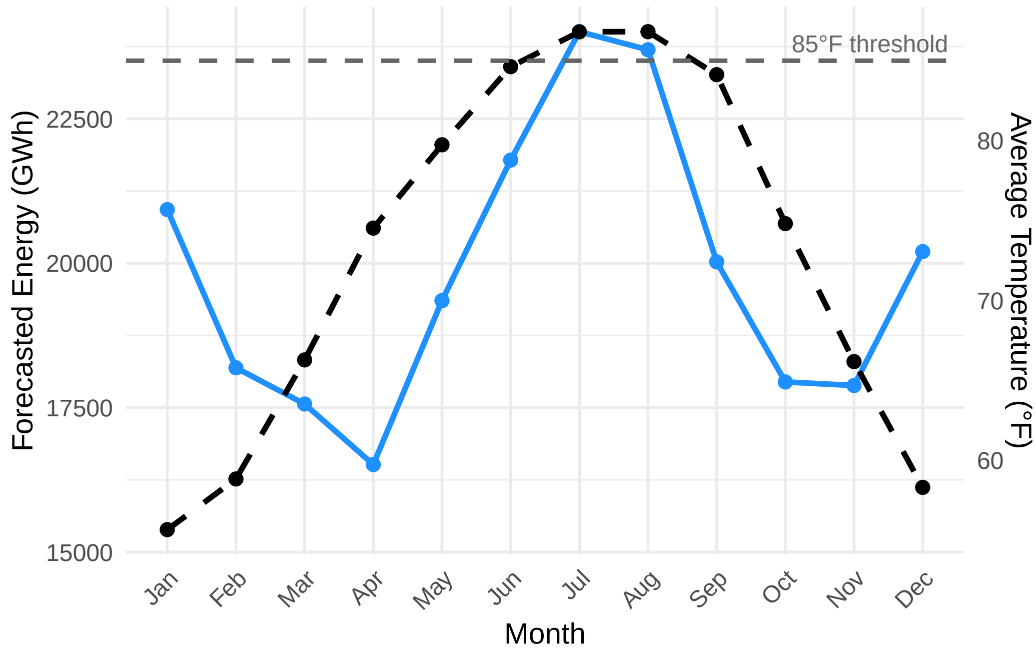
1.1.1.2 Forecasted Net Energy For Load (GWh) by Month for SERC-SE (2024)

This table summarizes the monthly forecasted electricity demand for the SERC-SE region in 2024, showing the seasonal rise in energy needs that aligns with periods of higher temperatures.

Month	Energy (GWh)
Jan	20928
Feb	18190
Mar	17563
Apr	16515
May	19353
Jun	21785
Jul	24007
Aug	23694
Sep	20023
Oct	17945
Nov	17883
Dec	20201

1.1.1.3 Combined Temperature and Energy Usage Graph

The chart below overlays the forecasted 2024 energy usage with the average water temperatures (2022–2024) to reveal a concerning trend: periods of highest energy demand correspond closely with months where water temperatures exceed the 85°F operational limit.



To mitigate these risks, we recommend:

- Evaluating alternative cooling methods to ensure operational stability.
- Investing in additional energy storage or backup generation capabilities.
- Performing detailed economic and predictive analyses to inform strategic planning under various climate projections.

2 Report

2.1 Introduction

Over the past few decades, the demand for reliable electricity has increased steadily, and that trend shows no signs of slowing down. At the same time, global temperatures are rising, which puts extra pressure on power plants—especially those that use water to cool their equipment. Without effective cooling, turbines can overheat, efficiency drops, and unplanned shutdowns become more likely (bergmann 2024). These issues can lead to higher operating costs and potential power shortages during peak demand.

This report examines a mid-sized power plant on Dauphin Island, Alabama, where water from the Gulf of Mexico is drawn. When the plant was built, designers assumed intake water would stay below 85 °F year-round. Recent data show that sea-surface temperatures there occasionally exceed 85 °F—the level engineers originally considered the safe upper limit for cooling intake water. When temperatures climb above this threshold, the plant must scale back capacity to avoid overheating, which can reduce revenue and compromise grid reliability. This analysis aims to assess the operational risk of the plant having to lower production during high ocean temperature periods.

2.2 Methods

2.2.1 Data Sources

Two main datasets were used in this analysis. The first dataset consisted of hourly water temperature readings collected from a buoy located near Dauphin Island, Alabama. These temperature data covered the period from January 2022 through December 2024 and were provided by the National Data Buoy Center ("NDBC - Historical Meteorological Data Search - Station DPHA1," n.d.). The second dataset was an electricity usage forecast for the year 2024, specifically for the Southeastern U.S. (SERC-SE region), focusing on the "Net Energy For Load," provided by the North American Electric Reliability Corporation ("Electricity Supply & Demand (ES&d)," n.d.) .

2.2.2 Temperature Data Preparation

Three separate datasets for temperature, each corresponding to one year (2022, 2023, 2024), were combined into a single dataset. After combining, the dataset was cleaned to retain only relevant information, such as year, month, day, and temperature measurements. Incorrect readings, including placeholder values (temperatures equal to or above 999) and unusually high readings from April 2022 (temperatures above 28.5 °C), were removed.

After cleaning, temperature values were converted from Celsius to Fahrenheit, matching the plant's operational standards. A new date column was also created using a standardized "year-month-day" format for ease of analysis.

Monthly average temperatures were then calculated by grouping daily temperature data. Each month was labeled as either "Above 85 °F" or "Below 85 °F" based on whether the average exceeded the critical threshold of 85 °F. Finally, a long-term average was computed by averaging monthly values across the entire three-year span.

A linear regression model was then created using monthly average temperatures to predict future temperatures, extending the dataset five years beyond the observed period.

2.2.3 Electricity Usage Data Preparation

Electricity forecast data for 2024 was processed separately. The data was initially loaded from a spreadsheet and filtered to include only entries for the SERC-SE region and the "Reporting Year Forecast – Net Energy For Load."

The data initially contained monthly columns for each month from January to December. These monthly columns were reshaped into a long-form dataset, creating individual rows for each month. Energy consumption values were converted to numeric format, and months were organized chronologically from January through December for clearer analysis.

2.2.4 Combined Data Visualization

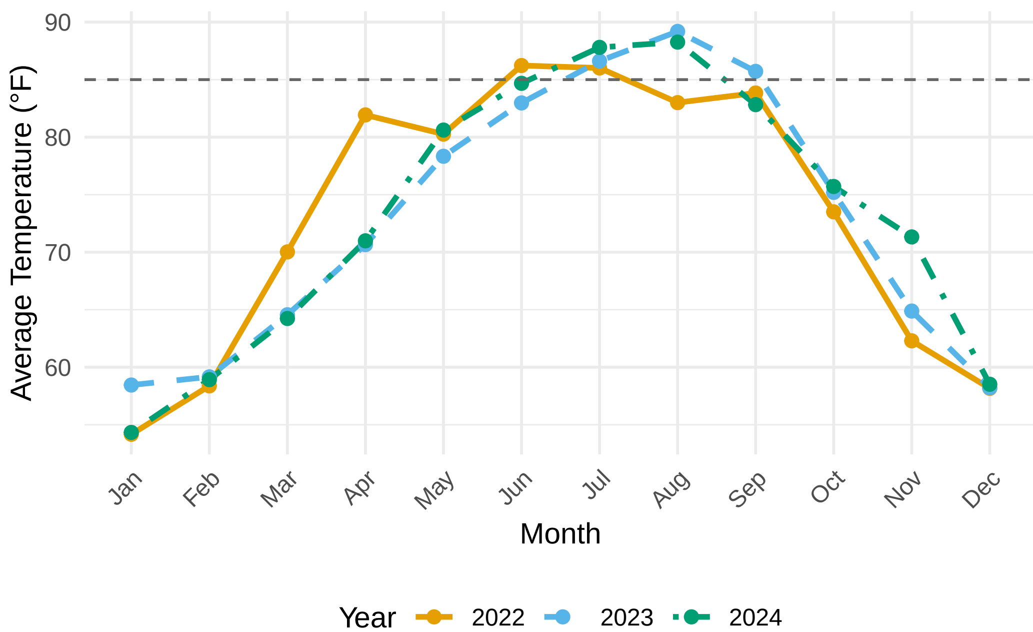
To visualize the relationship between water temperatures and electricity usage effectively, the data required scaling. A scaling factor was calculated by dividing the maximum forecasted energy value for 2024 by the highest average temperature recorded across the three years. This scaling enabled clear and accurate plotting of both temperature and energy data on a single graph.

2.3 Results

2.3.1 Temperature Analysis

Analysis of water temperature data from the Dauphin Island buoy (2022–2024) reveals clear seasonal patterns, with temperatures frequently surpassing the critical threshold of 85 °F during the peak summer months.

Figure 1: Average Monthly Sea-Surface Temperature (2022–2024)
This plot illustrates the monthly average sea-surface temperatures recorded at Dauphin Island, Alabama, from 2022 through 2024. Notably, temperatures exceeded the operational threshold of 85 °F primarily in the months of July and August across multiple years, highlighting potential periods when power plant capacity may need to be reduced.



2.3.2 Predicted Future Temperature Trends

To assess future risks, a linear model was utilized to predict temperature trends based on historical data. This model accounts for interactions between year and month.

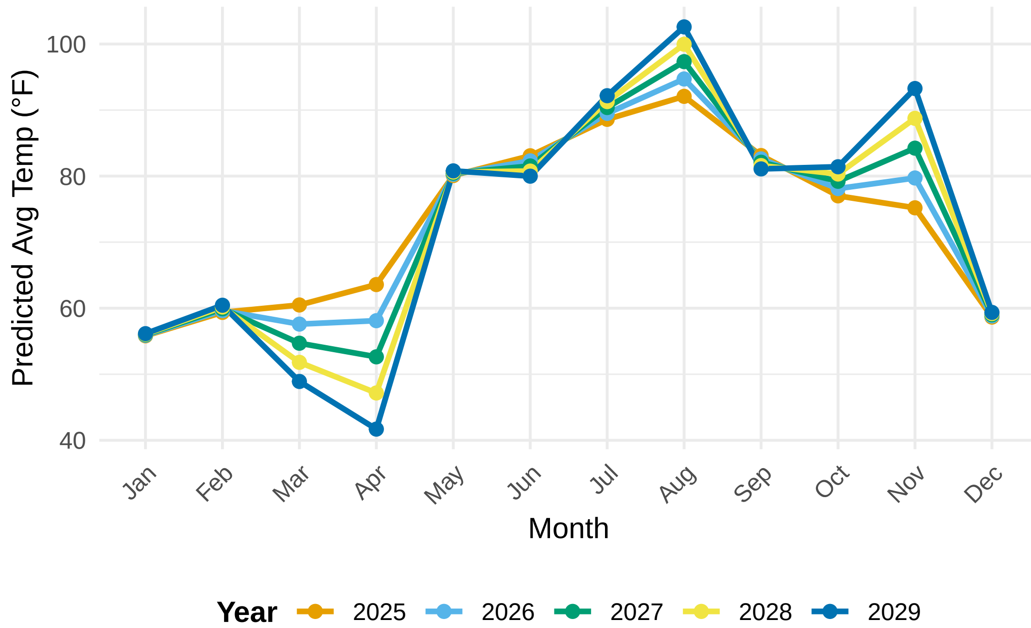


Figure 2: Predicted Average Monthly Temperatures (2025–2029)
This projection uses historical temperature trends from 2022–2024 to predict monthly average temperatures for the next five years (2025–2029). The forecasts indicate continued summertime peaks exceeding 85 °F, suggesting potential operational challenges in future years.

2.3.3 Electricity Usage Forecast (2024)

The 2024 electricity usage forecast for the SERC-SE region indicates significant peaks in energy demand during the summer months, aligning with the observed temperature peaks.

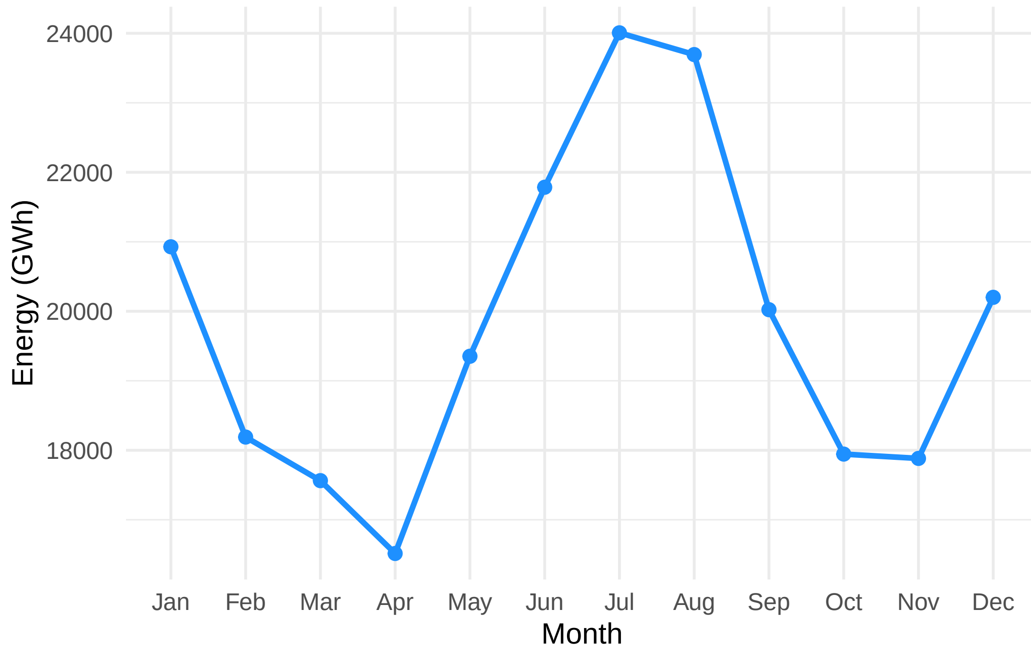


Figure 3: Forecasted Net Energy For Load (2024)
This graph depicts the forecasted monthly electricity usage for the SERC-SE region in 2024. Energy demand is highest during summer months, reflecting increased cooling demands associated with higher temperatures.

2.3.4 Relationship Between Temperature and Electricity Usage

A combined analysis of historical temperature data (2022–2024 averages) and the 2024 electricity demand forecast reveals a correlation between elevated sea-surface temperatures and increased electricity usage.

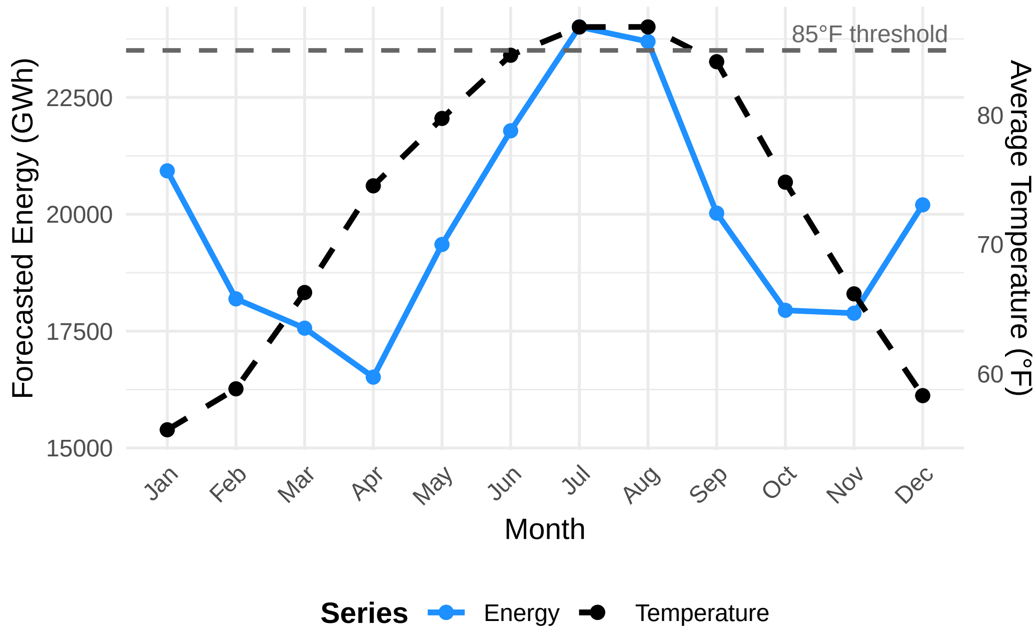


Figure 4: Overlay of Temperature and Electricity Usage
This dual-axis graph overlays average monthly sea-surface temperatures from historical data with the forecasted electricity demand for 2024. It demonstrates that temperature peaks closely align with peaks in electricity demand, particularly during the summer months, emphasizing the operational implications of rising sea-surface temperatures.

2.4 Conclusion

The analysis indicates that rising sea-surface temperatures in the Gulf of Mexico regularly exceed the critical operational threshold of 85°F, particularly in July and August. This trend is expected to continue and potentially intensify over the next five years, increasing operational risks for the Dauphin Island power plant. The synchronization of temperature peaks with periods of high electricity demand creates additional operational challenges, potentially forcing the plant to reduce capacity during peak demand periods. Such scenarios may lead to compromised grid reliability, increased operational costs, and potential economic impacts.

However, there are some limitations to this analysis. The linear regression model assumes historical trends will continue without considering sudden climatic or environmental changes. Additionally, the electricity demand forecast used for comparison is limited to a single year (2024) and may not accurately reflect longer-term fluctuations or future growth.

Some short term solutions are necessary like obtaining electricity from other sources and urging residents to reduce electrical power consumption. Once some short term solutions are in order then the plant can undergo a long term solution to solve the problem of the increasing ocean temperature.

References

bergmann. 2024. "How It Works: Water for Power Plant Cooling." https://www.starcoolingtowers.com/how-it-works-water-for-power-plant-cooling/.

"Electricity Supply & Demand (ES&d)." n.d. https://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx.

"NDBC - Historical Meteorological Data Search - Station DPHA1." n.d. https://www.ndbc.noaa.gov/histsearch.php?station=dpha1&year=2024&f1=wtmp&t1a=gt&v1a=0&t1b=&v1b=&c1=&f2=&t2a=&v2a=&t2b=&v2b=&c2=&f3=&t3a=&v3a=&t3b=&v3b=.

Part I

Appendices

3 Data Documentation

3.0.1 Data Sources

- **Sea-Surface Temperature Data:**
  - **Source:** National Data Buoy Center (Dauphin Island buoy) ("NDBC - Historical Meteorological Data Search - Station DPHA1" (n.d.))
  - **Period Covered:** January 2022 through December 2024
  - **Description:** Hourly water temperature measurements
  - **Variables Used:**
    - Year (V1)
    - Month (V2)
    - Day (V3)
    - Temperature (V15)
- **Electricity Usage Forecast Data:**
  - **Source:** North American Electric Reliability Corporation (NERC) ((**NERC?**))
  - **Document:** 2024 Electricity Supply and Demand (ES&D) Forecast
  - **Focus Region:** Southeastern U.S. (SERC-SE)
  - **Variables Used:**
    - Monthly Net Energy For Load (GWh)

Part II

Drafts

4 Draft: Data Documentation

```
library(readr)
library(purrr)

monthly_files <- list.files(pattern = "gom_A5B7_t\\d{2}mn01\\.csv")

monthly_dfs <- map(monthly_files, ~ read_csv(.x, show_col_types = FALSE))

monthly_dfs <- map(monthly_files, ~ read_csv(
  .x,
  col_names = c("Latitude", "Longitude", "Temp_C"),
  skip = 2,
  col_types = cols_only(
    Latitude = col_double(),
    Longitude = col_double(),
    Temp_C = col_double()
  )
))

dauphin_clean <- function(df, month_num) {
  df %>%
    filter(
      between(Latitude, 29.5, 30.5),
      between(Longitude, -88.5, -87.5)
    ) %>%
    mutate(
      Temp_F = Temp_C * 9/5 + 32,
      Above_85 = Temp_F > 85,
      Month = month_num
    )
}
```

The statistical mean is the average of all unflagged interpolated values at each standard depth level for each variable in each 1° square which contains at least one measurement for the given oceanographic variable. Uses longitude and latitude to tell location.

Source: https://www.ncei.noaa.gov/access/gulf-of-mexico-climate/bin/gomregcl.pl

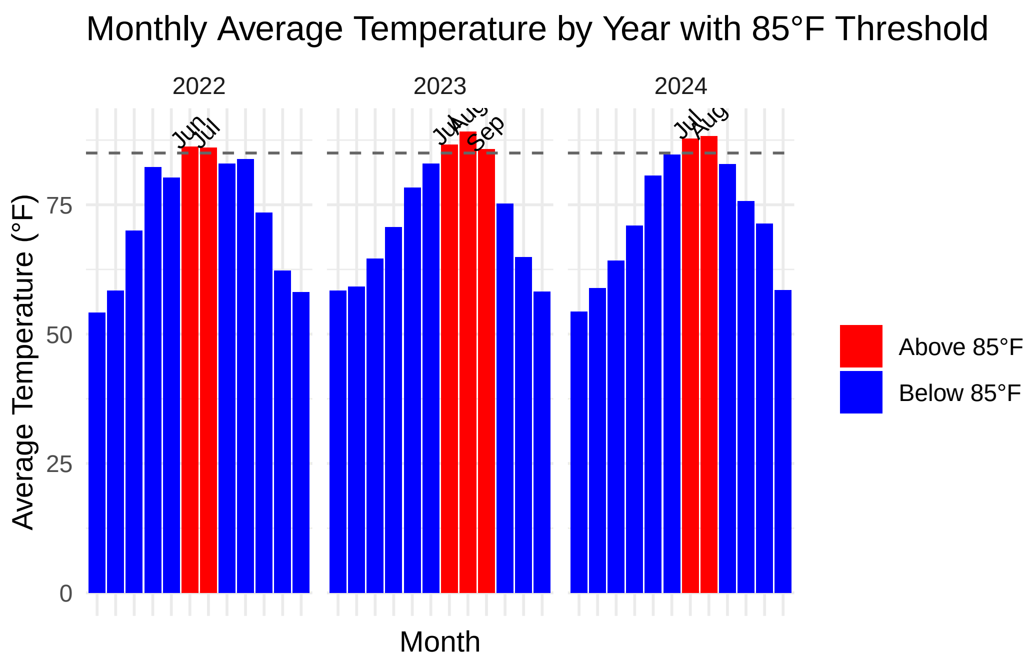
Dauphin Island 30, 88

```
df2 <- readxl::read_xlsx("2024_ESD.xlsx")
```

NERC collects, maintains, and annually publishes the Electricity Supply and Demand (ES&D) database, which includes 10-year projections for the North American bulk power system (BPS). Data are presented for each NERC Region (and subregions where applicable) for years 1990-2010. For years 2011 to present, data are presented for each NERC Assessment Area. Some information in the ES&D has been aggregated to protect sensitive information.

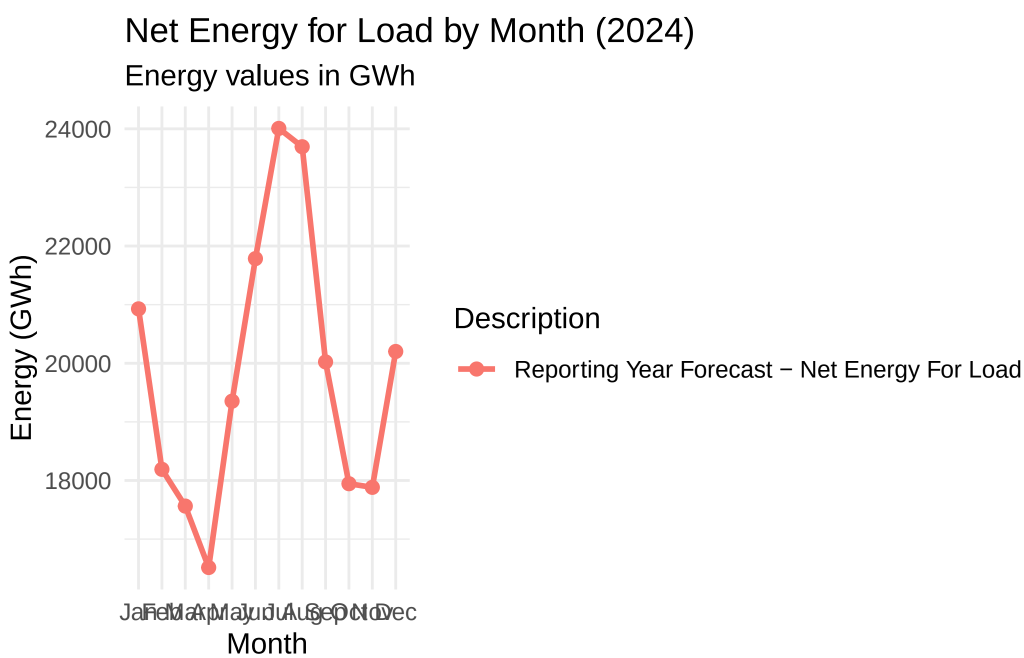
5 Draft: Results

Using Gulf Coast temperature datasets from the National Centers for Environmental Information, we found July, August, and potentially September to be the three months that give our situation trouble. The datasets were monthly records of the average temperature of the gulf from the years 2005-2017 across various depths. The locations were recorded using latitude and longitude which we filtered out to fit what would be most near to Dauphin Island The depth that we elected to look at was a depth of 0 feet assuming the plant pulls water from the surface. Now this data is not ideal since it only goes up to 2017 and is an average of the temperature for that entire month across a span of 12 years. Nonetheless, July had an average temperature of 86 degrees Fahrenheit, August is 86.3, and September is 84.3. Now, data was not able to be found for the past 7 years and we know that global ocean temperature has been rising. However, I could not find conclusive evidence that temperature in the past 7 years has rose enough to say September would be above 85 degrees Fahrenheit.



The other dataset used was from the North American Electric Reliability Corporation, which was much cleaner and easier to filter. The data was filtered get electrical data for the 2024 in the southeast United states region and the Southeast assessment area. Which yielded the table below:

```
# A tibble: 3 x 19
  `Report Year` Country Region Subregion `Assessment Area` Unit  Description
          <dbl> <chr>   <chr>  <chr>     <chr>             <chr> <chr>
1          2024 US      SERC   -         SERC-SE           GWh   Prior Year Act~
2          2024 US      SERC   -         SERC-SE           GWh   Reporting Year~
3          2024 US      SERC   -         SERC-SE           GWh   Year 1 Forecas~
# i 12 more variables: Jan <dbl>, Feb <dbl>, Mar <dbl>, Apr <dbl>, May <dbl>,
#   Jun <dbl>, Jul <dbl>, Aug <dbl>, Sep <dbl>, Oct <dbl>, Nov <dbl>, Dec <dbl>
```



Immediately we can see that July and August have the highest electrical usage which are the two months that sea temperature is above the threshold for full plant operation. From these numbers we can conclude that the plant is under significant risk over the next five years of underperforming during these months.

6 Draft: Intro/Conclusions

7 Intro

Many power plants rely on water for cooling the plant and keeping it stable. The issue with the power plant that is being assessed, located in Dauphin Island, Alabama, is that it uses water from the Gulf of Mexico. Now if a power plant uses the water to cool down the reactor then you would want that water to be as cold as possible right? When the plant being examined was built, it was assumed the temperature of the water extracted from the gulf would not exceed 85 degrees Fahrenheit because if it did the plant would have to operate at reduced capacity. With ocean temperatures rising it is necessary to find out if the plant can remain at capacity. Using ocean temperature and energy demand data this analysis looks into the risk of operating the plant at reduced capacity and when the energy from the plant is needed most.

8 Conclusion

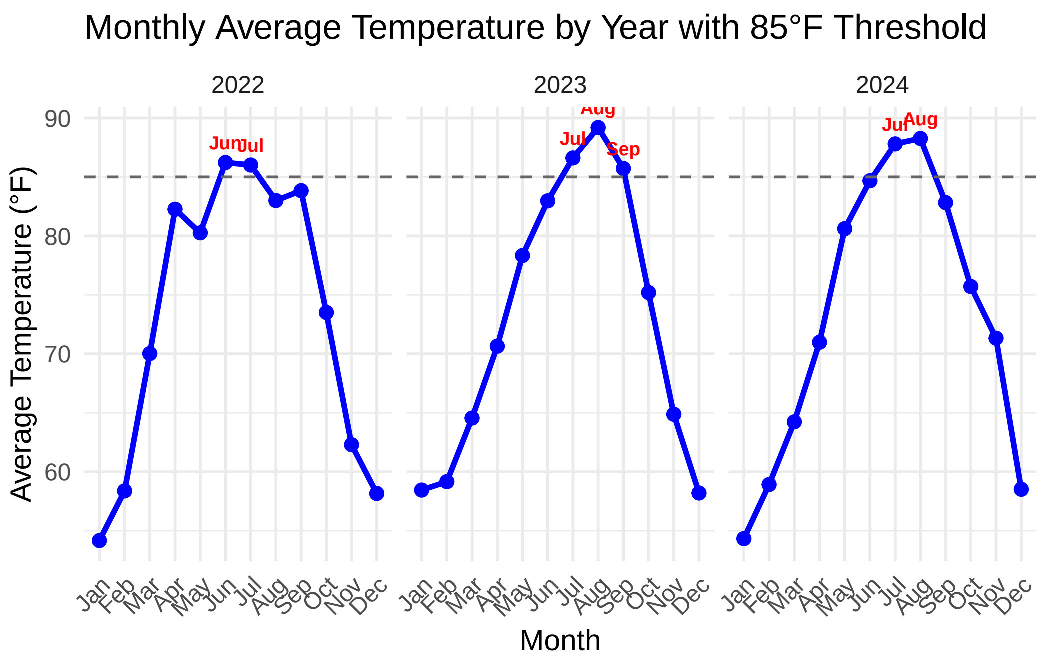
From the analysis we can see that the rising temperature of the water from the Gulf of Mexico is consistently exceeding the limit of 85 degrees Fahrenheit set by the plant, especially during the peak summer months of July and August. We can only assume the number of days where the water is above the threshold is to increase due to rising ocean temperatures. Based upon recent electrical usage data we see that those warm months are the highest for electrical usage. The plant being forced to operate at reduction during the warm months coupled with the fact that those months are the highest in demand for energy show that a solution is necessary for the plant to remain at full operation.

9 Draft: Executive Summary

The analysis reviewed two datasets to evaluate operational risks for the plant over the next five years, given that the plant can only run at full capacity if the Gulf water used for cooling remains below 85°F.

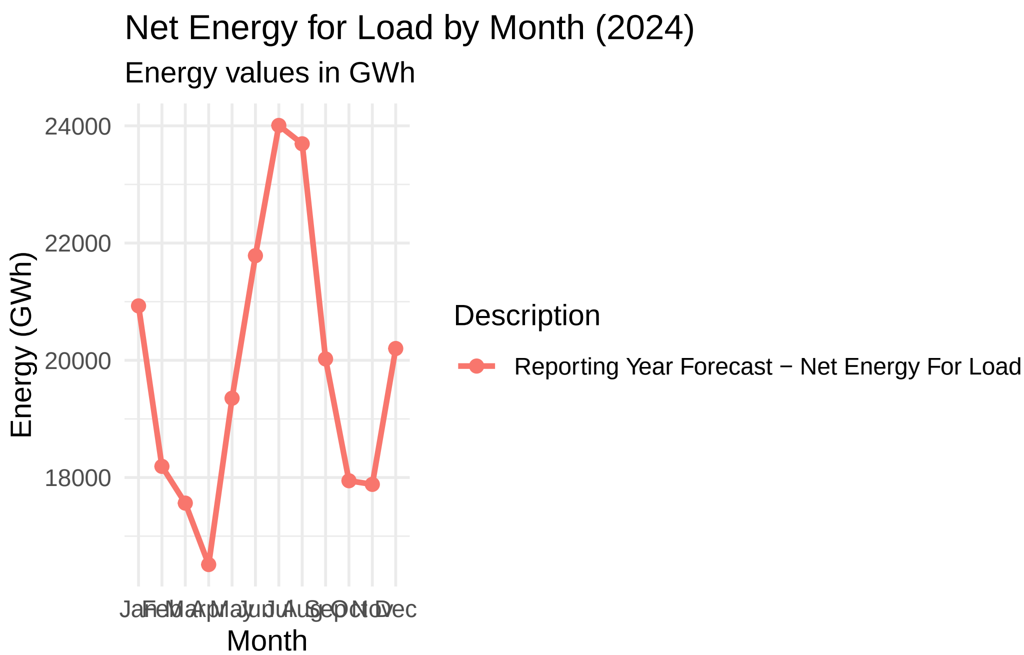
10 Temperature Analysis

According to data from the National Data Buoy Center for the area around Dauphin Island, the average water temperatures in July and August have exceeded 85°F over the past three years, with September also surpassing this threshold in 2023. Also of note, June 2024 recorded an average just below 85°F. Keep in mind that these are monthly averages, meaning that even if a month's average is below the threshold, there could still be individual days when the temperature exceeds 85°F. On those days, the plant must operate at a reduced capacity, supplying less electricity to consumers.



11 Electrical Usage Correlation

Data from the North American Electric Reliability Corporation for 2024 in the Southeast US (SERC-SE area) reveals that electrical consumption peaks in July and August—the same period when sea surface temperatures are above the threshold required for full plant efficiency. This shows that the risk is greatest during these two months.



12 Conclusion

The combined evidence from both temperature and electrical demand data indicates that the plant is at significant risk of underperformance during the peak summer months of July and August. A solution that can get the plant operating at full capacity during these months is vital. Also, efforts to reduce electrical usage or divert some of the demand to other plants in the area could prove effective.