SSIE 516 WESTERN INTERCONNECT – TOWARDS SENATE BILL 100

By Group 5

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AGENDA

Introduction

Western Interconnect Overview

Motivation

Data Preprocessing and Exploratory Data Analysis

Methodology

Results Analysis

Future Work

INTRODUCTION

OBJECTIVE

- Explores the structure, regulation, and characteristics of the energy sector in the Western Interconnect region of the United States.
- Examine generation mix, transmission networks, energy demand, and key policies shaping the region's energy landscape.

WECC

- Western Electricity Coordinating Council
- Maintains a reliable electric power system in Western Interconnect
- Support effective competitive power markets
- Assures open and non-discriminatory transmission
- WECC control areas have signed RMS (Reliability Management System) agreement

WESTERN INTERCONNECT OVERVIEW

809,018 GWh
Total generation

156,000
Miles of transmission lines

299.5 GW
Total installed capacity

15 GW
New resources

90 Million People

Covers 14 western states, parts of Texas, Mexico and Canada

167,745 MW
Interconnection peak demand

893 Million MWh
2023 Annual demand

163,746 MW
2023 Peak demand

20% increase
Annual demand 2023 – 2024

SECTORAL ENERGY CONSUMPTION

Residential Sector

- Percentage of total electricity consumption: 37.4%
- Seasonal variation:
    - Higher in summer and winter
    - Extreme climates
- Key factors influencing consumption:
    - Temperature extremes
    - Humidity
    - Household income and size

Commercial Sector

- Percentage of total electricity consumption: 33.4%
- Key areas: California, Nevada, Seattle and Portland
- Significant sectors:
    - Services (e.g., finance, healthcare, and tourism)
    - Retail and hospitality

Industrial Sector

- Percentage of total electricity consumption: 24.1%
- Key states: California, Arizona, Nevada, Utah, Oregon, and Washington
- Major industries:
    - Technology and manufacturing
    - Mining

Transportation Sector

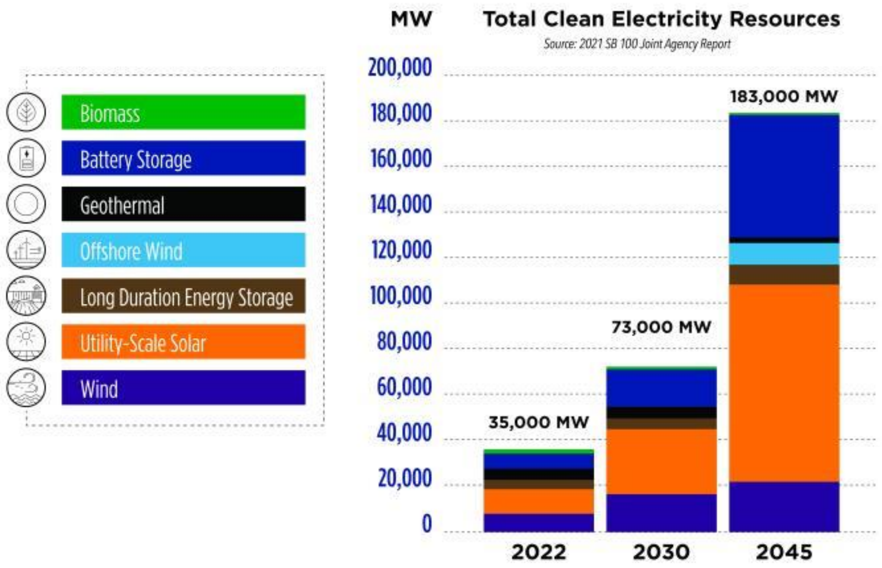
- Percentage of total electricity consumption: 3.1%
- Key factors driving growth:
    - Increasing electric vehicle (EV) adoption
    - Expansion of public charging infrastructure
    - Government incentives and policies supporting EV adoption
- States with high EV adoption:
    - California, Oregon, Washington

CALIFORNIA SENATE BILL 100

2021 SB 100 Joint Agency Report

- Policy requires renewable energy and zero-carbon resources supply **100 percent of electric retail sales by 2045**
- Takeaways from Electricity System Modeling:
  - "Diversity in energy resources and technologies lowers overall costs."
  - "Increased energy storage and advancements in zero-carbon technologies can reduce natural gas capacity needs."

Total Clean Electricity Resources Forecast



Source: https://www.energy.ca.gov/sb100

PROBLEM STATEMENT

Cost Optimization

Minimize the **total system cost**, including:

- **Fixed Costs**:
  - Generation, storage, and transmission
- **Variable Costs**:
  - Generation and non-served energy costs

Renewable Integration

Maximize the utilization of renewable energy sources such as solar, wind, and hydro power to reduce reliance on fossil fuels

CO2 Emission Reduction

Significantly decrease carbon dioxide emissions by optimizing energy production and promoting renewable energy adoption

WHY IS IT IMPORTANT?

- Electric Grid:
  - Reliable 100% zero-carbon electricity by 2045
  - Grid modernization and reliability in Westen Interconnect
- Environmental Benefits:
  - Reduced greenhouse gas emissions
  - Improved air and water quality
- Economic Advantages:
  - Accelerated research in storage technologies
  - Increased job creation

ASSUMPTIONS

- Geographic diversification scenario – “Expanded regional transmission allowing for greater energy exchanges between California and the rest of the WECC” – is considered
- Dataset as part of SR01 is sufficient for the capacity expansion model
- RPS eligible resources for California are biomass, small hydroelectric, geothermal, wind, and solar
- RPS target value is set to 1 in alignment with SB100 policy for the year 2045

SOURCE: https://www.energy.ca.gov/sb100

LET'S TALK ABOUT DATA

Datasets
Fuels_data
Generators_data
Generators_variability
Load_data
Network

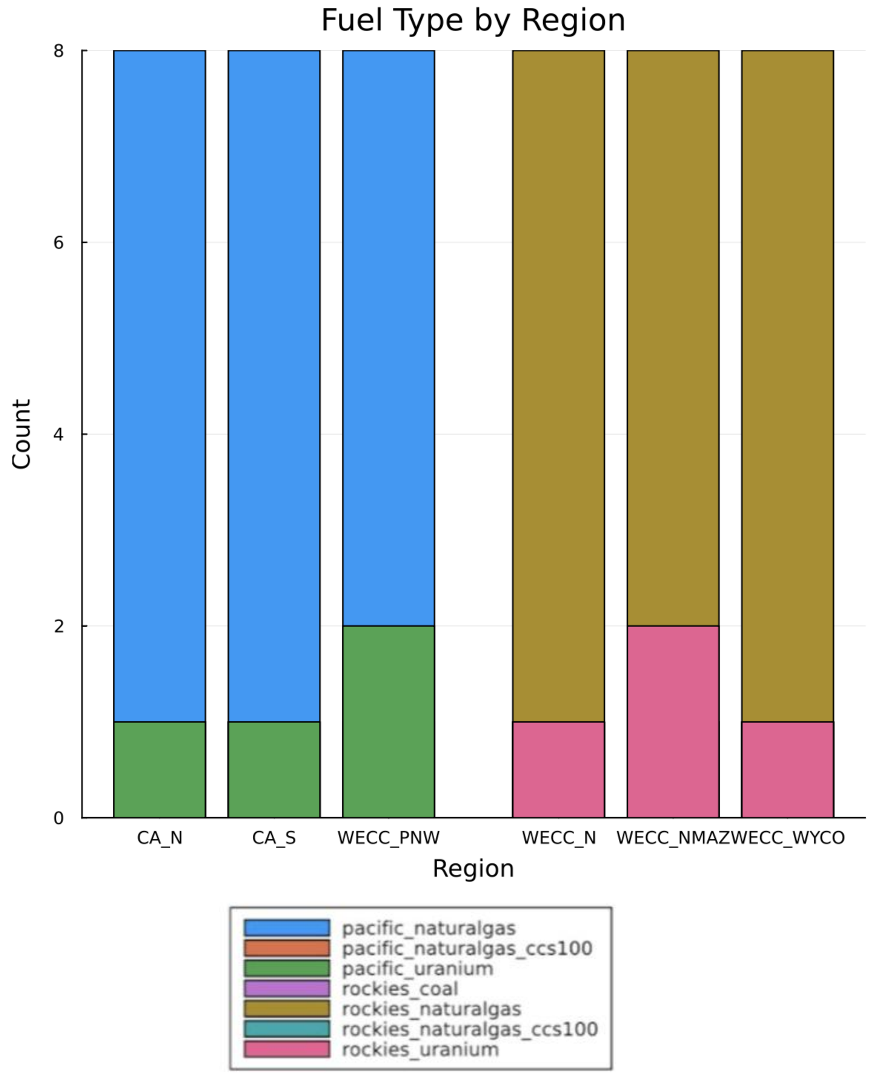
→ Collect required attributes → Add more data (RPS eligible resources) ↓

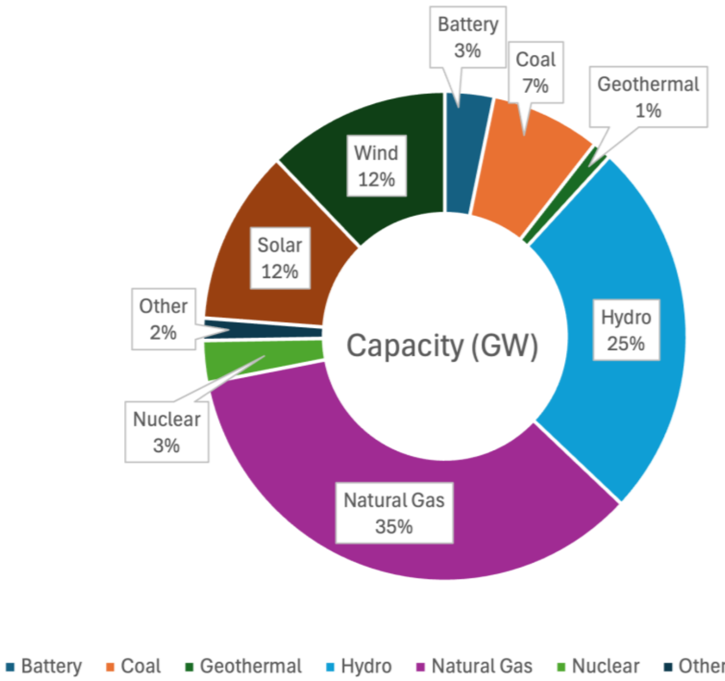
Generators: 297×30 DataFrame
Demand: 672×6 DataFrame
Variability: 672×297 DataFrame
Fuels_data: 8×3 DataFrame
Lines: 6×12 DataFrame

- **Generators:** Describes different technologies used with respect to each region along with the various costs and cap
- **Demand:** Describes demand for various zones at each time index
- **Variability:** Describes time-series data for capacity factor and resource availability
- **Fuels data:** Describes cost and CO2 content for each fuel type
- **Lines:** includes data on transmission fixed costs, capacity parameters, and loss parameters

ENERGY STATISTICS

[24]:



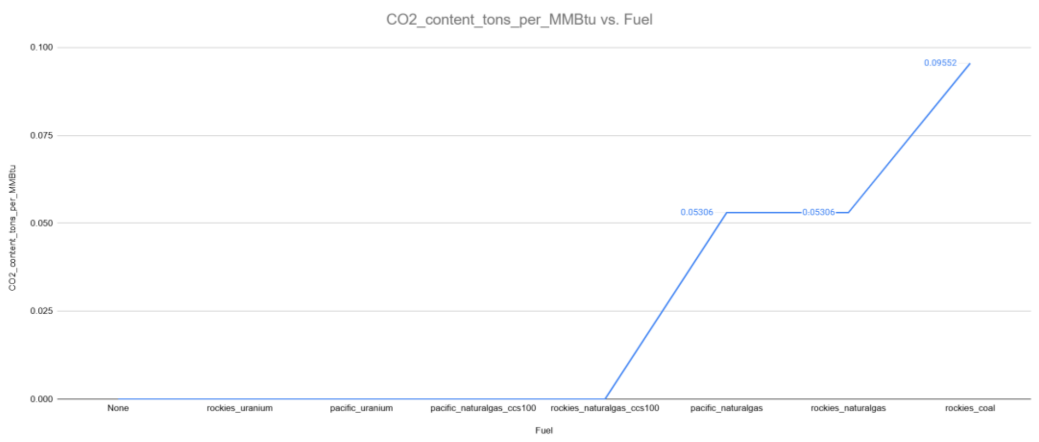


Resource	Capacity (GW)
Battery	9.8
Coal	22
Geothermal	3.8
Hydro	75.2
Natural Gas	104.7
Nuclear	8.3
Other	4.4
Solar	34.7
Wind	36.6

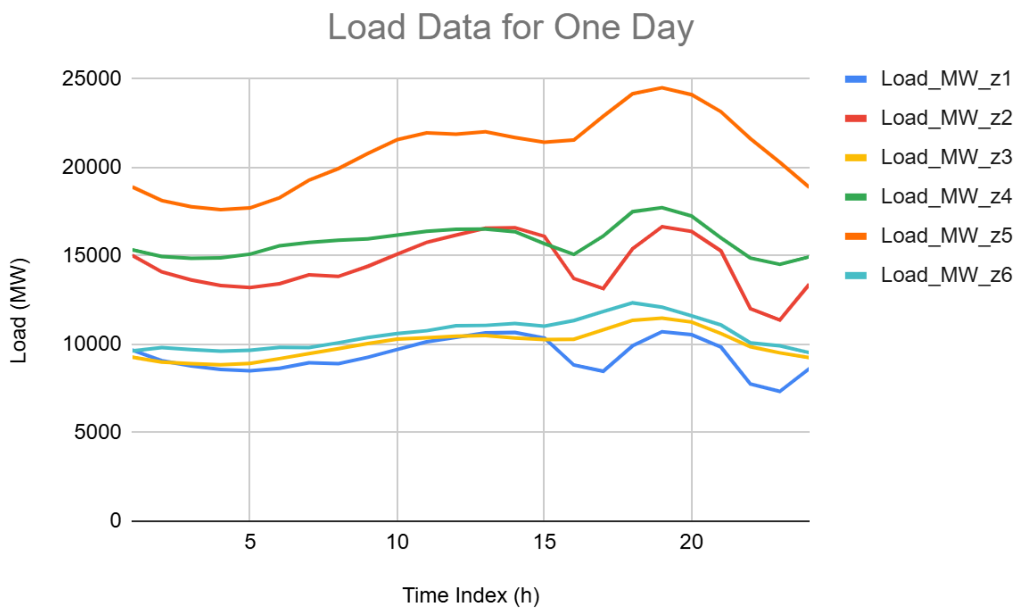
2023 Total Installed Capacity (GW)

DATA VISUALIZATION

Fuel_data for CO2 Content



Load Data for One Day in January



METHODOLOGY

Western Interconnect Dataset (4w)

julia

Base Model

CT Model

RPS Model

Constraints

- Supply-demand balance constraint for all time steps and zones
- Max power, charge, SOC, NSE constraints for all time steps and all generators/storage
- Max and min flow constraints for all time steps and all lines
- Total capacity constraints for all generators/storage
- Ramp up and down constraints along with storage SOC for normal and sub-wrapping

- Inclusion of total CO2 emission transmitted cap constraint (CT Model)

- Inclusion of Renewable Portfolio Standard (RPS) constraint

Z = **Minimize** fixed cost for generation, storage, and transmission, variable costs, and NSE costs

MODEL 1 – BASE MODEL

OBJECTIVE FUNCTION

- Minimize the total cost, increase renewable sources

CONSTRAINTS

- **Demand Balance**:
  - Ensures that generation, storage, and transmission meet demand in every time step and zone
- **Capacity Limits**:
  - Restricts generation, storage, and transmission within their maximum capacities
- **Storage Constraints**:
  - Limits on charging, discharging, and state-of-charge (SOC) of storage units
- **Transmission Flow**:
  - Ensures flows on transmission lines respect capacity and directionality
- **Ramp Constraints**:
  - Limits how quickly generators can increase or decrease their output between time steps
- **Coupling of Time Periods**:
  - Links variables across time steps to account for ramp rates, storage SOC, and sub-period wrapping

MODEL 2 – CT MODEL

OBJECTIVE FUNCTION

- Minimize the total cost, increase renewable sources, decrease CO2 emission

CONSTRAINTS

CO2 emissions rate = fuel CO2 content * heat rate
Start-up CO2 emissions = fuel CO2 content * start up fuel use

$$Total\_CO2\_emission = \sum_{t\in T, g\in G} sample\_weight[t] * \left(vGEN[t,g] \cdot generators.CO2_{Rate[g]} + vSTART[t,g] * generators.CO2\_Per\_Start[g]\right)$$

$$Total\ CO2 \leq Cap\ Value$$

Set the Cap Value as necessary, our model assumes 0% CO2 emission!

```
@expression(Expansion_Model, Total_CO2,
    sum(sample_weight[t] * (vGEN[t,g] * generators.CO2_Rate[g] +
    vSTART[t,g] * generators.CO2_Per_Start[g]) for t in T, g in G)
)

@constraint(Expansion_Model, Total_CO2 <= 0)
```

MODEL 3 – RPS MODEL

OBJECTIVE FUNCTION

- Minimize the total cost, increase renewable sources, decrease CO2 emission with RPS policy

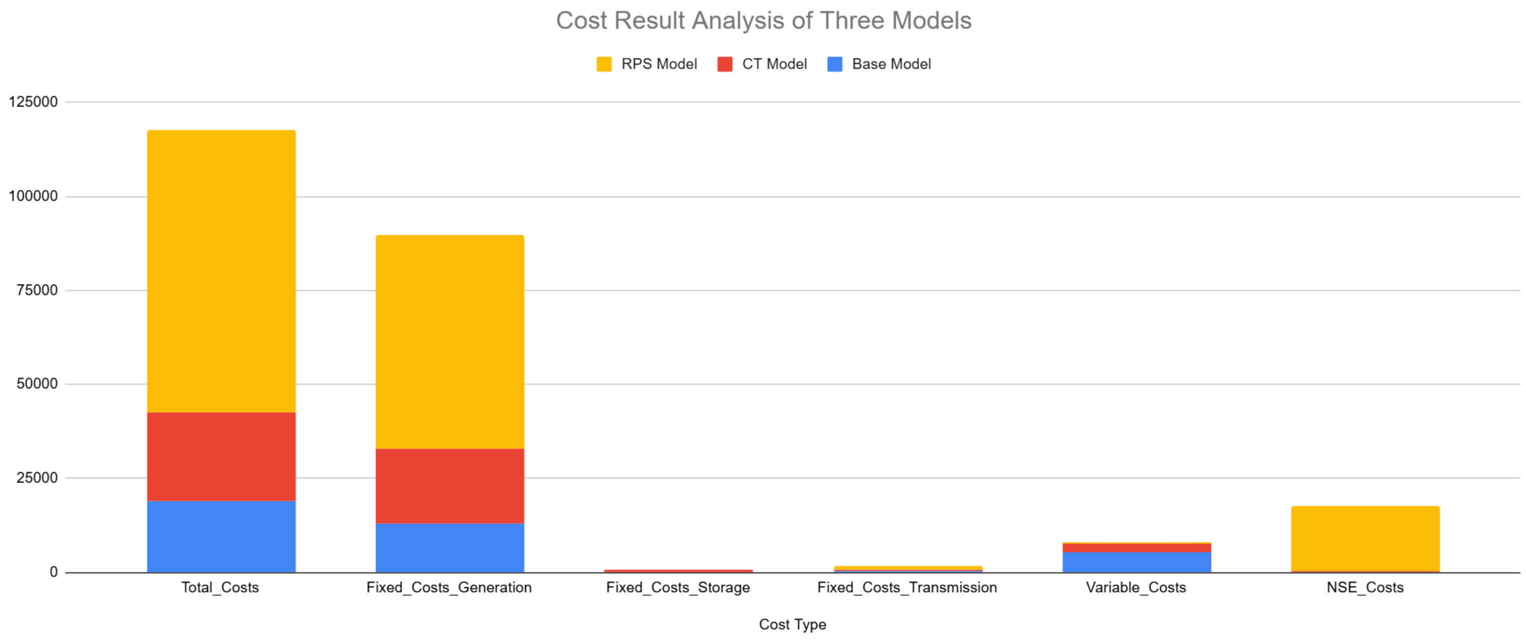
CONSTRAINTS

- Added new constraint for RPS

$$\frac{\sum_{g \in RPS} GEN_{t,g}}{\sum_{g \in G} GEN_{t,g}} \geq RPS_{target_t}, \forall t \in T$$

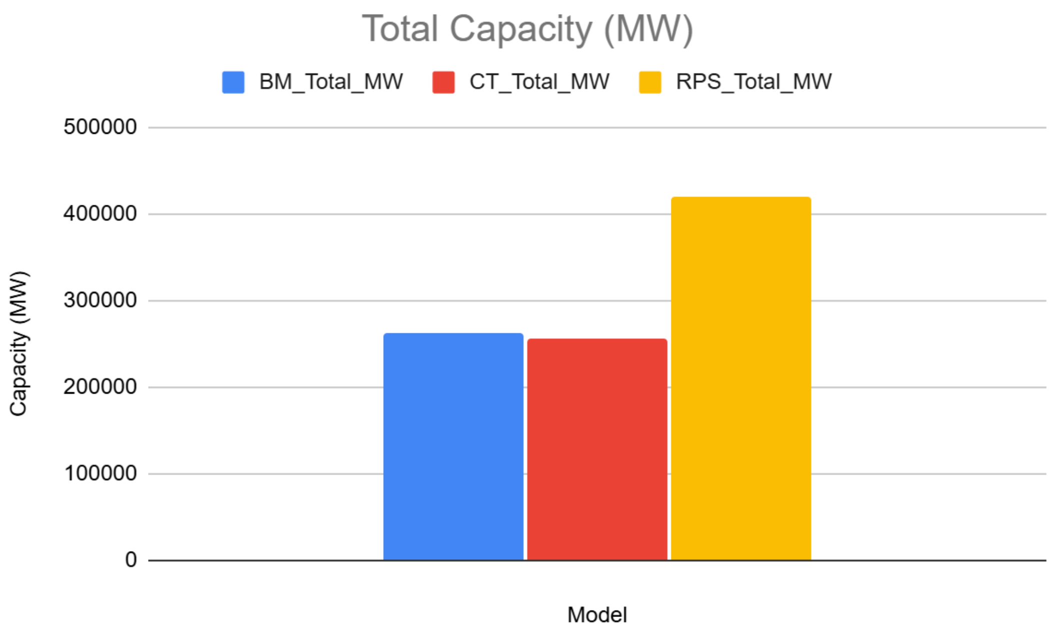
```
# Now let us try to add the RPS constraint. For carbon neutrality, we w
rps_target = 1
@constraint(Expansion_Model, cRPS[t in T],
    sum(vGEN[t,g] for g in RPS) >= sum(vGEN[t,g] for g in G)
)
```

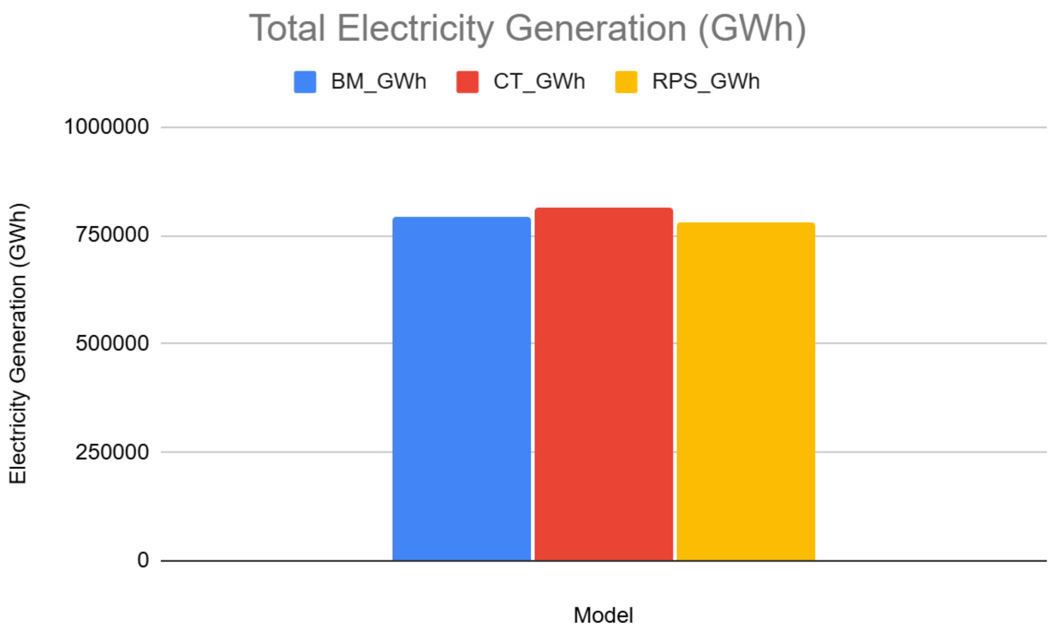
COST RESULT ANALYSIS



- Base Model minimizes total costs through lower fixed generation and NSE costs
- CT Model incurs higher fixed costs for generation and storage
- RPS Model has high fixed generation costs and high NSE costs, leading to the highest total costs

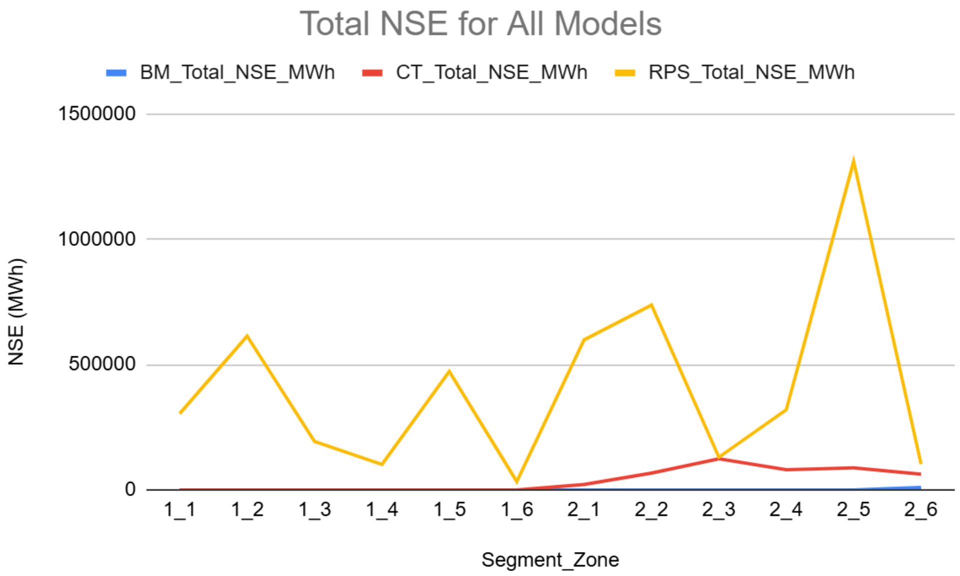
GENERATORS RESULT ANALYSIS

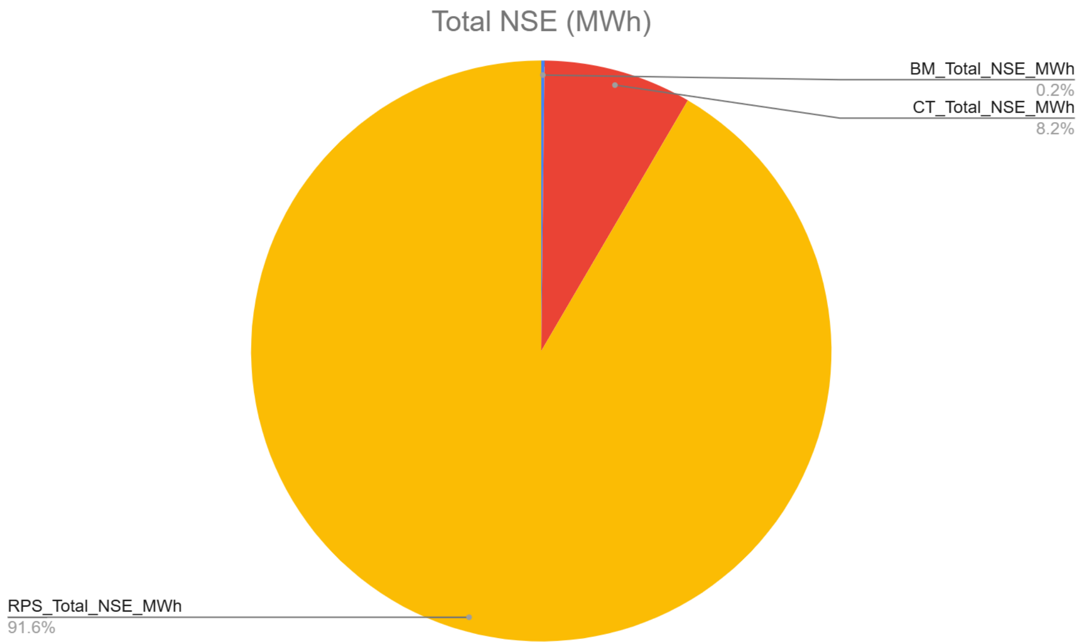




- The RPS Model generates significantly higher total MW but achieves lower total GWh, indicating inefficiency in energy utilization due to renewable integration.
- The CT Model balances moderate MW and the highest GWh, suggesting improved operational efficiency compared to the Base Model.

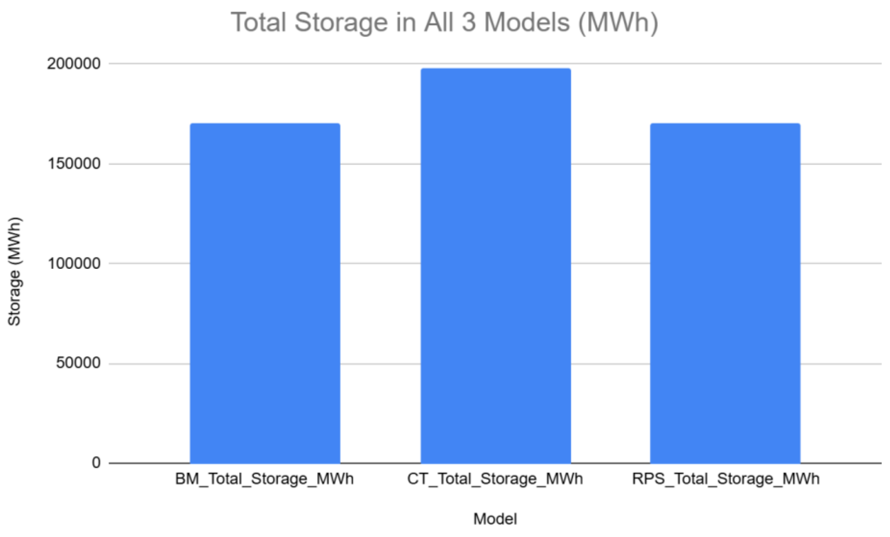
NSE RESULTS ANALYSIS

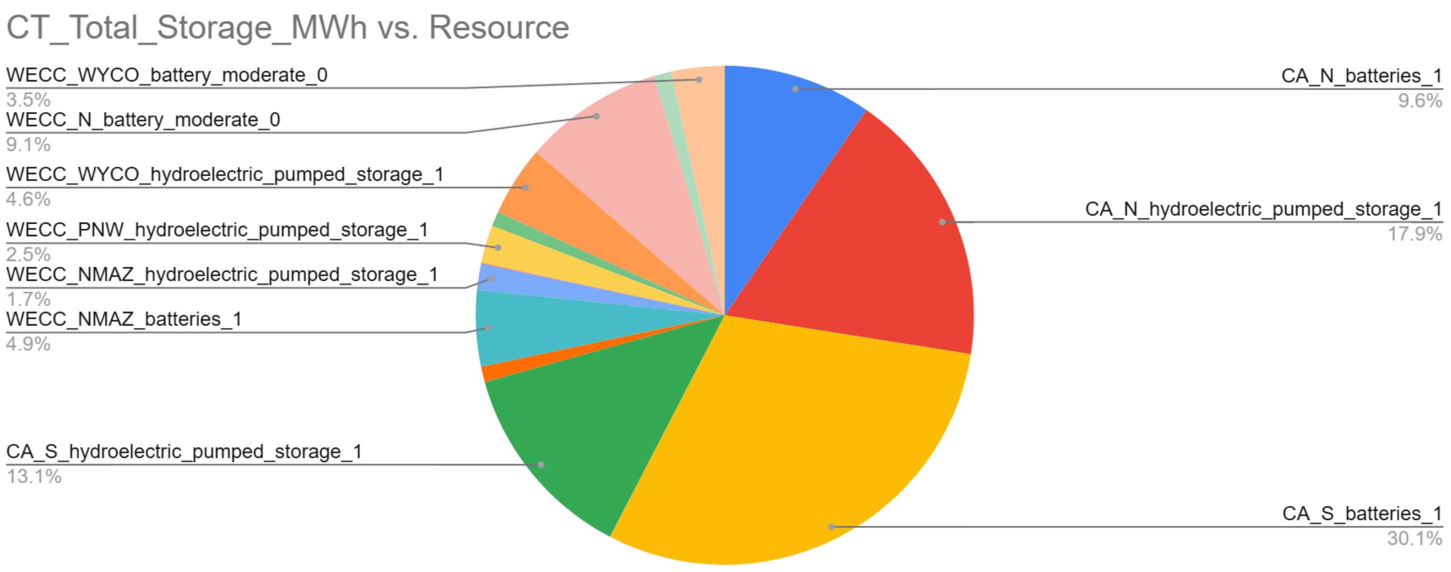




- The RPS Model has highest NSE across all segments indicating challenges in meeting demand despite higher MW capacity
- Base Model demonstrates reliable energy delivery, achieving near-zero NSE

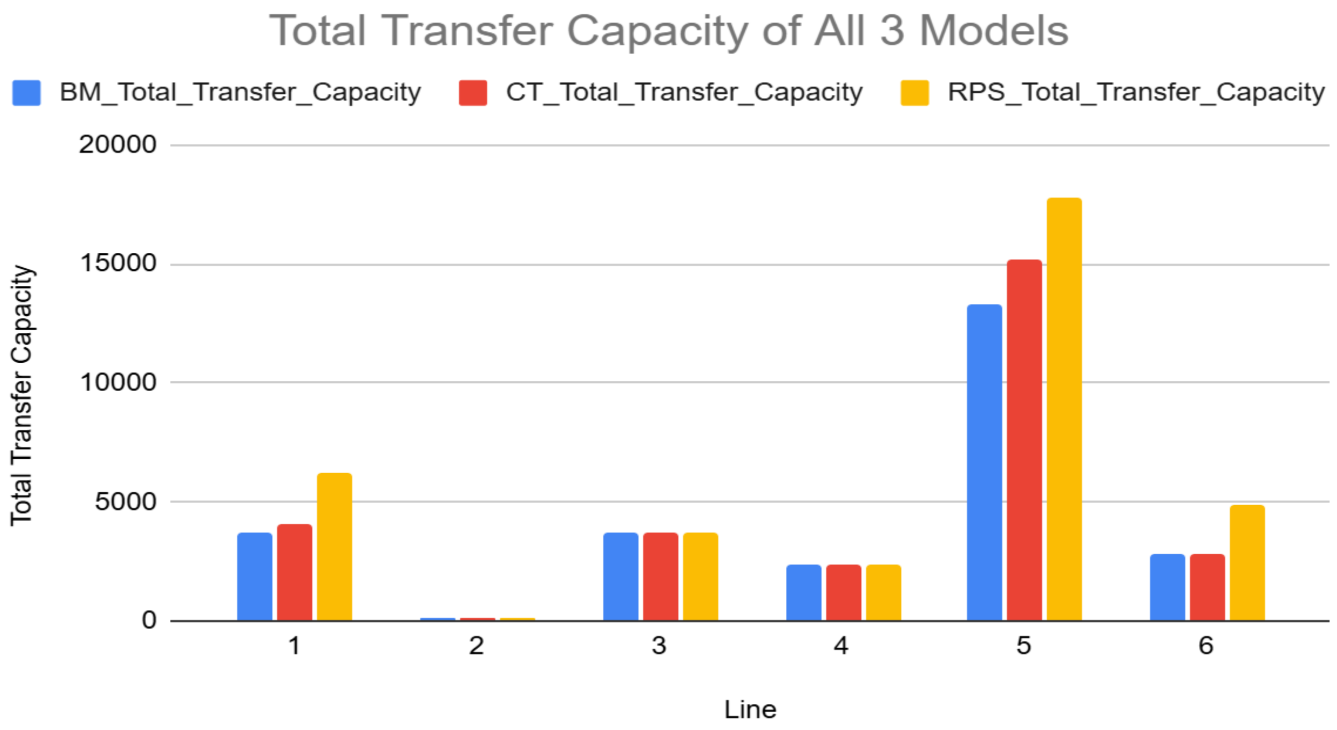
STORAGE RESULTS ANALYSIS





- The CT Model increases total storage utilization compared to the Base Model and RPS Model, balancing emissions trading with storage strategies
- RPS does not utilize additional storage despite its higher NSE

TRANSMISSION RESULTS ANALYSIS



- The RPS Model has highest transfer capacity inferring importance of a reliable transmission infrastructure to meet the standard

LIMITATIONS

Ignored socioeconomic factors

- The model does not consider the social or economic impacts of policies, such as job creation, regional equity, or energy access

Limited emissions scope

- The focus is only on CO_2 emissions from the power sector, ignoring other greenhouse gases (e.g., methane) or emissions from other sectors (e.g., transportation, industry)

Absence of consumer behavior

- The model does not incorporate the potential impacts of demand-side management or consumer behavior changes in response to carbon pricing or renewable policies

Limited policy interactions

- The interactions between cap-and-trade and a clean electricity standard are not analyzed in detail, which may overlook potential synergies or conflicts between these policies

FUTURE WORK

- Run model for 1 year
- Run sensitivity analysis on storage resources to explore impact on total NSE
- Explore inclusion of Cap-and-Trade policy as constraint to examine effect on total costs

REFERENCES

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THANK YOU

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