CS2545 - Term Mini-Project

CS2545 - Data Science

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UNB, Fredericton

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Introduction

This report looks at how electricity is made, used, and traded in different parts of Canada. The focus is on the mix of renewable's and fossil fuels, and how geography, infrastructure, and policy shape the results.

The analysis addresses two major challenges: significant regional disparities in energy sources and the absence of a unified national energy strategy. Using data from 2005 to 2050, including historical and projected values, this study examines electricity generation and capacity, sectoral demand, pricing differences, and import/export trends at both provincial and national levels.

Public datasets from Natural Resources Canada (NRCan), Statistics Canada, and the Canadian Energy Regulator (CER) were analyzed using Python tools in Jupyter Notebooks. Key metrics include per capita energy use, generation efficiency, and trade balances. Data was normalized to enable meaningful cross-provincial as well as national level comparisons, and visualizations were used to highlight trends and disparities. This project ultimately aims to identify where energy systems are efficient, where improvements are needed, and how better integration across provinces could benefit Canada's energy landscape.

In [3]:
```python
# Imports & Pip Installs if needed
# comment out if not required :
# %pip install matplotlib
# %pip install pandas
# %pip install plotly
# %pip install seaborn
# %pip install openpyxl

# Importing all the goodies
import pandas as pd

# ploting imports
import matplotlib.pyplot as plt
import seaborn as sns
# i wanted this for the money formating on our charts
import matplotlib.ticker as ticker

# All Data to import using dataframes
population_Data_Path = "../data/population.csv"
Electricity_Generation_Data_Path = "../data/Electricity_Generation.xlsx"
Electricity_Interchange_Data_Path = "../data/Electricity_Interchange.xlsx"
Electricity_Capacity_Data_Path = "../data/Electricity_Capacity.xlsx"
End_Use_Demand_Data_Path = "../data/End_Use_Demand.xlsx"
End_Use_Prices_Data_Path = "../data/End_Use_Prices.xlsx"
energy_trade_canada_path = "../data/energy_trade_canada.xls"
```

Legend

- `power_generation_df` - DataFrame for power generation data post cleaning
- `power_capacity_df` - DataFrame for power capacity data post cleaning
- `power_interchange_df` - DataFrame for power interchange data post cleaning
- `power_prices_df` - DataFrame for power prices data post cleaning
- `power_demand_df` - DataFrame for power demand data post cleaning
- `canada_population_df` - DataFrame for Canada population data post cleaning

Approach

The data was collected and then analyzed using Python and its associated libraries within a Jupyter Notebooks environment. Key libraries included Pandas and Matplotlib, which was used for data wrangling, visualization, and analysis. One of the primary goals was to evaluate the electricity generation mix across Canada's provinces. This provided insights into each province's individual contribution, as well as their role in Canada's national energy production. Additional analysis included provincial and federal data on population, electricity pricing, and import/export activity, to identify both strengths and areas for improvement in the energy sector.

Data was sourced from publicly available, trusted government portals and energy agencies. Unlike prior coursework datasets, these files required cleaning and preprocessing. Collected files included both .csv and .xlsx formats. To ensure consistency, datasets were primarily acquired from a single source, allowing for more standardized formatting. Where applicable, each province's data was organized into their own tables, which allowed for reusability of a number of data cleaning functions. This design allowed for parsing of fields such as province, year, energy type, energy output and energy consumption.

Sector-specific energy demand data was also analyzed. The dataset, provided by the Canadian government, was split into energy use across residential, commercial, industrial, transportation, and total demand sectors. The data could then be processed into a dataframe with columns: sector, year, energy type, and energy quantity in petajoules (PJ). We had to convert PJ to gigawatt-hours (GWh) for ease of use later on. Provincial energy pricing was also processed, showing the difference power prices throughout Canada. E.g. Quebec's low-cost hydro power compared to Alberta's higher-cost fossil fuel generation.

Cleaning Data

The following six Jupyter Notebooks code blocks were used to clean the data:

Power Generation Data

In [4]:
```python
# power Generation Data
generation_df = pd.read_excel(Electricity_Generation_Data_Path)

# function for cleaning generation data - used across multiple data sets
def clean_generation(df, start_row, province_name, num_rows = 8):
    header_row = start_row + 1
    data_rows = start_row + 2

    headers = df.iloc[header_row]
    block = df.iloc[data_rows : data_rows + num_rows].copy()
    block.columns = headers

    block = block.dropna(subset=[block.columns[0]])
    block = block.rename(columns={block.columns[0]: "Energy_Type"})
    block = block.melt(id_vars="Energy_Type", var_name="Year", value_name="GWh")

    block["Province"] = province_name
    block["Year"] = pd.to_numeric(block["Year"])
    block["GWh"] = pd.to_numeric(block["GWh"])

    block = block.dropna(subset=["Year", "GWh"])
    block["Year"] = block["Year"].astype(int)

    return block

# dictionary to get the proper rows for each table in teh dataset
provinces_generation = {
    "Canada": 5,
    "Newfoundland and Labrador": 16,
    "Prince Edward Island": 27,
    "Nova Scotia": 38,
    "New Brunswick": 49,
    "Quebec": 60,
    "Ontario": 71,
    "Manitoba": 82,
    "Alberta": 93,
    "British Columbia": 104,
    "Saskatchewan": 115,
    "Yukon": 126,
    "Northwest Territories": 137,
    "Nunavut": 148,
}
all_province_data = []
```

```python
for province, start_row in provinces_generation.items():
    cleaned = clean_generation(generation_df, start_row, province)
    all_province_data.append(cleaned)

gen_clean = pd.concat(all_province_data, ignore_index=True)
power_generation_df = gen_clean
```

Power Capacity Data

In [5]:
```python
capacity_df = pd.read_excel(Electricity_Capacity_Data_Path)

provinces_cap = {
    "Canada": 5,
    "Newfoundland and Labrador": 16,
    "Prince Edward Island": 27,
    "Nova Scotia": 38,
    "New Brunswick": 49,
    "Quebec": 60,
    "Ontario": 71,
    "Manitoba": 82,
    "Alberta": 93,
    "British Columbia": 104,
    "Saskatchewan": 115,
    "Yukon": 126,
    "Northwest Territories": 137,
    "Nunavut": 148,
}

all_province_cap_data = []
for province, start_row in provinces_cap.items():
    cap_cleaned = clean_generation(capacity_df, start_row, province)
    all_province_cap_data.append(cap_cleaned)

cap_clean = pd.concat(all_province_cap_data, ignore_index=True)
power_capacity_df = cap_clean
```

Power InterChange Data

In [6]:
```python
interchange_df = pd.read_excel(Electricity_Interchange_Data_Path)
provinces_interchange = {
    "Canada": 4,
    "Newfoundland and Labrador": 13,
    "Prince Edward Island": 22,
    "Nova Scotia": 31,
    "New Brunswick": 40,
    "Quebec": 49,
    "Ontario": 58,
    "Manitoba": 67,
    "Alberta": 76,
    "British Columbia": 85,
    "Saskatchewan": 94,
}

all_province_interchange_data = []
for province, start_row in provinces_interchange.items():
    clean_interchange_block = clean_generation(interchange_df, start_row, province)
    all_province_interchange_data.append(clean_interchange_block)

interchange_clean = pd.concat(all_province_interchange_data, ignore_index=True)
power_interchange_df = interchange_clean
```

End User Price Data

In [7]:
```python
prices_df = pd.read_excel(End_Use_Prices_Data_Path)

prices_provinces = {
    "Canada": 0,
    "Newfoundland and Labrador": 5,
    "Prince Edward Island": 11,
    "Nova Scotia": 17,
    "New Brunswick": 23,
    "Quebec": 29,
    "Ontario": 35,
    "Manitoba": 41,
    "Alberta": 47,
```

```
    "British Columbia": 53,
    "Saskatchewan": 59,
    "Yukon": 65,
    "Northwest Territories": 71,
    "Nunavut": 77,
}
year_filter = 2025
all_province_price_data = []

for province, start_row in prices_provinces.items():
    clean_block = clean_generation(prices_df, start_row, province, num_rows=3)
    all_province_price_data.append(clean_block)

prices_clean = pd.concat(all_province_price_data, ignore_index=True)
power_prices_df = prices_clean

#  function was used in both provincial and national data
def get_prices(df_prices, df_energy, filter_import_export="Total_Exports", year=2025):
    total_dollars = df_prices[(df_prices["Year"] == year) & (df_prices["Energy_Type"] == "Electricity")].copy()
    total_dollars["Cost_per_GWh"] = total_dollars["GWh"] * 1000

    total_dollars = pd.merge(total_dollars, df_energy, on="Province", how="inner")
    total_dollars["Total_Profit"] = total_dollars["Cost_per_GWh"] * total_dollars[filter_import_export]
    return total_dollars[["Province", "Total_Profit"]]
```

Population Data

In [8]:
```
def clean_population_database_format(filepath):

    df = pd.read_csv(filepath)
    df = df[["REF_DATE", "GEO", "VALUE"]].rename(columns={
        "REF_DATE": "Date",
        "GEO": "Province",
        "VALUE": "Population"
    })

    df = df.dropna(subset=["Population"])
    df["Date"] = pd.to_datetime(df["Date"])
    df["Year"] = df["Date"].dt.year

    df_yearly = (
        df.groupby(["Province", "Year"], as_index=False)
        .agg({"Population": "mean"})
    )

    return df_yearly

population_yearly_df = clean_population_database_format(population_Data_Path)
canada_population_df = population_yearly_df
```

End Use demand Data

In [9]:
```
demand_df = pd.read_excel(End_Use_Demand_Data_Path)

sector_blocks = {
    "Residential": 15,
    "Commercial": 25,
    "Industrial": 35,
    "Transportation": 45
}

def clean_end_use_demand(df, sector_blocks):
    all_sectors = []

    for sector, start_row in sector_blocks.items():
        row_index = start_row + 3
        row = df.iloc[row_index].tolist()

        cols = ["Label"] + list(range(2005, 2051))
        data = pd.DataFrame([row[:47]], columns=cols)

        toReturn = data.melt(id_vars="Label", var_name="Year", value_name="PJ")
        toReturn["Sector"] = sector
        toReturn["Energy_Type"] = "Electricity"
        toReturn["Year"] = pd.to_numeric(toReturn["Year"])
        toReturn["PJ"] = pd.to_numeric(toReturn["PJ"])
```

```python
        toReturn = toReturn.dropna(subset=["Year"])
        toReturn = toReturn.dropna(subset=["PJ"])
        all_sectors.append(toReturn)

    return pd.concat(all_sectors, ignore_index=True)

demand_clean = clean_end_use_demand(demand_df, sector_blocks)
demand_clean["GWh"] = demand_clean["PJ"]* 277.778
power_demand_df = demand_clean
```

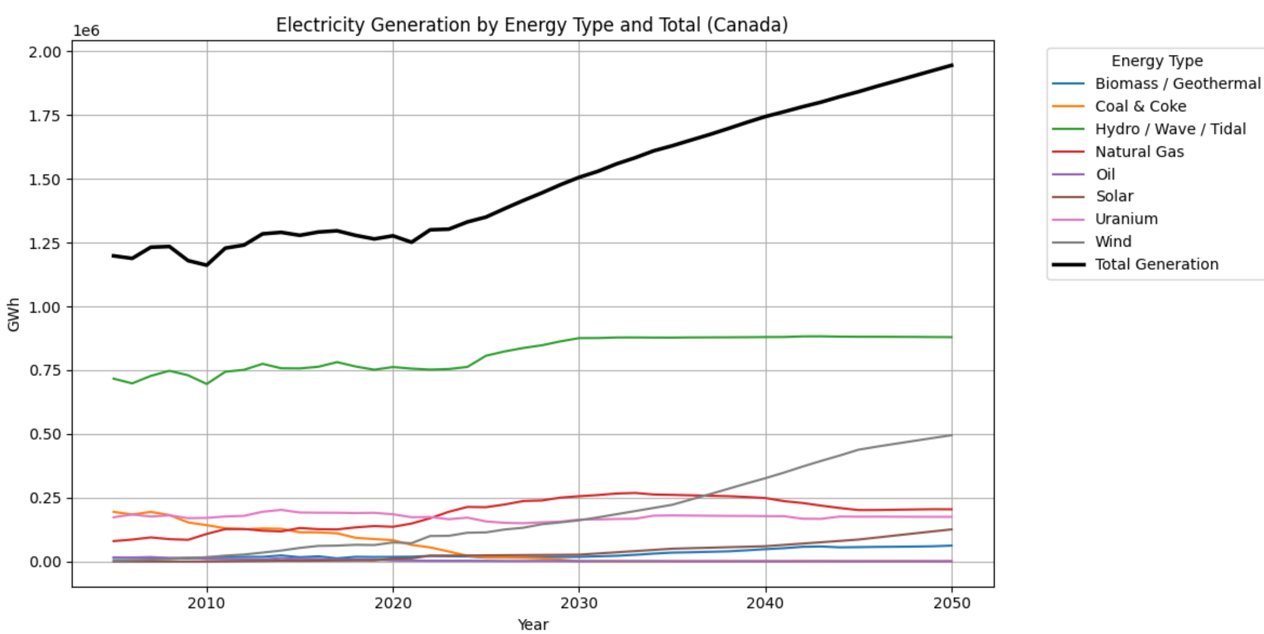
Data Manipulation

Power Generation Types, Generation & Capacity

Generation by Canada as a whole

In [10]:

```python
total_generation = (
    power_generation_df.groupby("Year", as_index=False)
    .agg({"GWh": "sum"})
    .rename(columns={"GWh": "Total_GWh"})
)

generation_by_type = (
    power_generation_df.groupby(["Year", "Energy_Type"], as_index=False)
    .agg({"GWh": "sum"})
    .pivot(index="Year", columns="Energy_Type", values="GWh")
)

ax = generation_by_type.plot(
    figsize=(12, 6),
    title="Electricity Generation by Energy Type and Total (Canada)",
    linewidth=1.5
)

ax.plot(total_generation["Year"], total_generation["Total_GWh"], color="black", linewidth=2.5, label="Total Gene
ax.set_xlabel("Year")
ax.set_ylabel("GWh")
ax.grid(True)
ax.legend(title="Energy Type", bbox_to_anchor=(1.05, 1), loc="upper left")

plt.tight_layout()
plt.show()
```

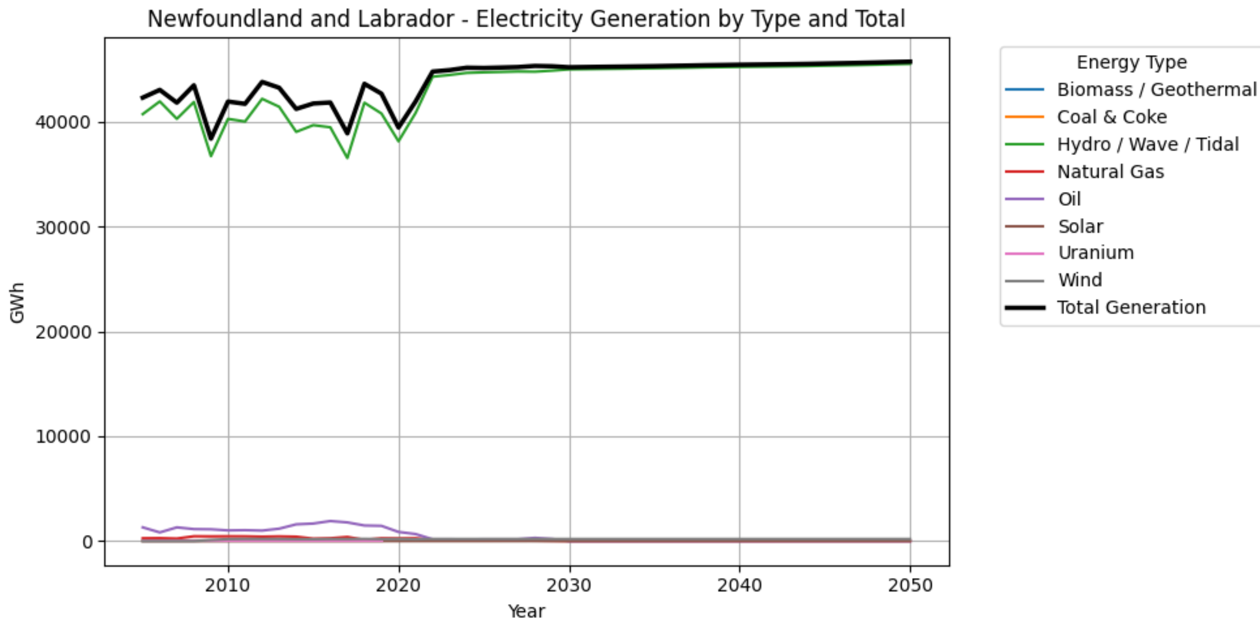


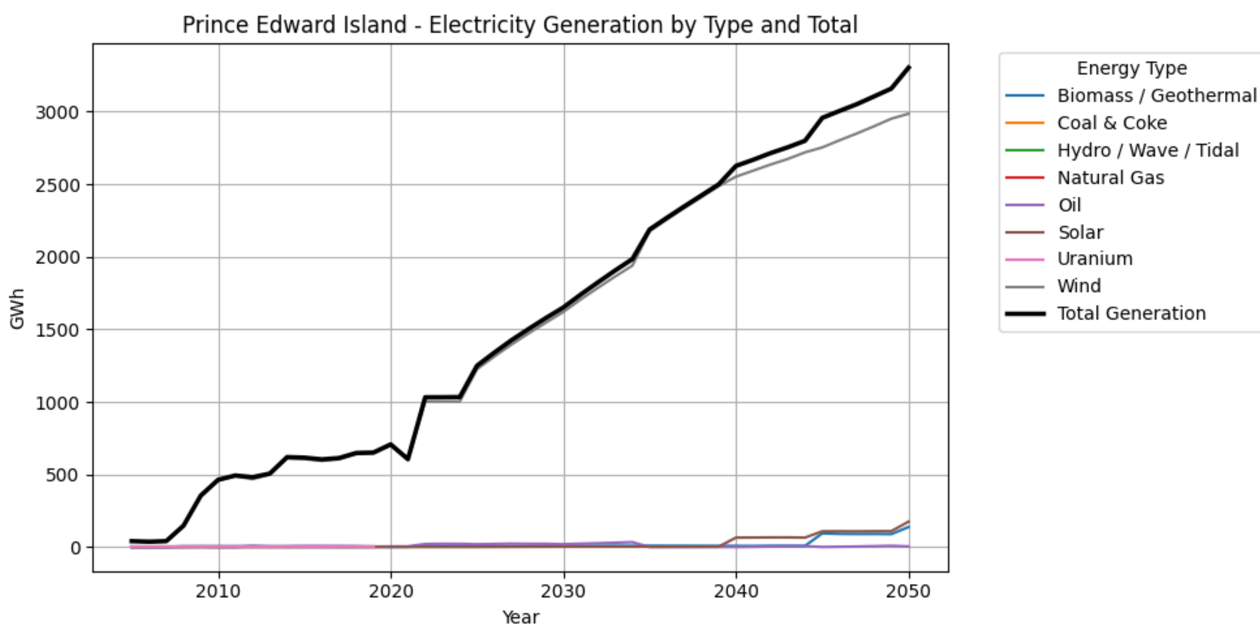
Results

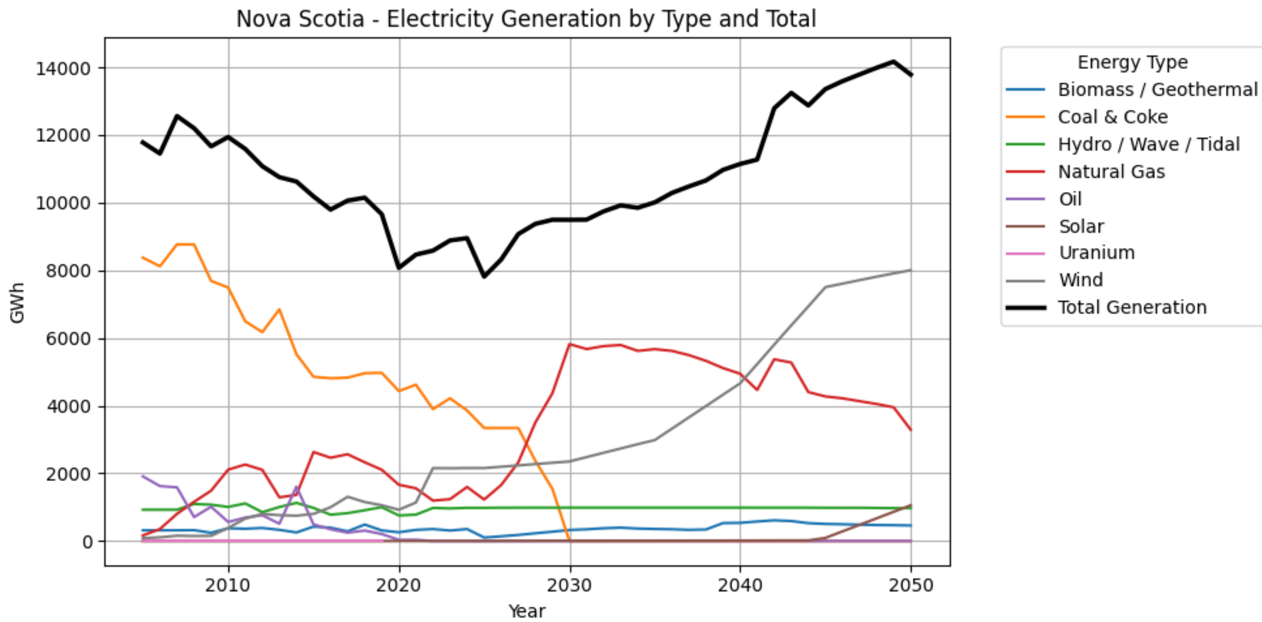
As seen in the `Electricity Generation by Energy Type and Total`, showing the energy production type from 2005 to 2050. The data shows that hydro electric power is biggest source of power generation across Canada as well as being the most stable over time. Wind appears to be a significant long-term strategy interprovincially. The data also shows that Natural gas will peek around 2032 and then drop off as more eco-friendly sources are used. Coal will also be nearly completely phased out by 2029.

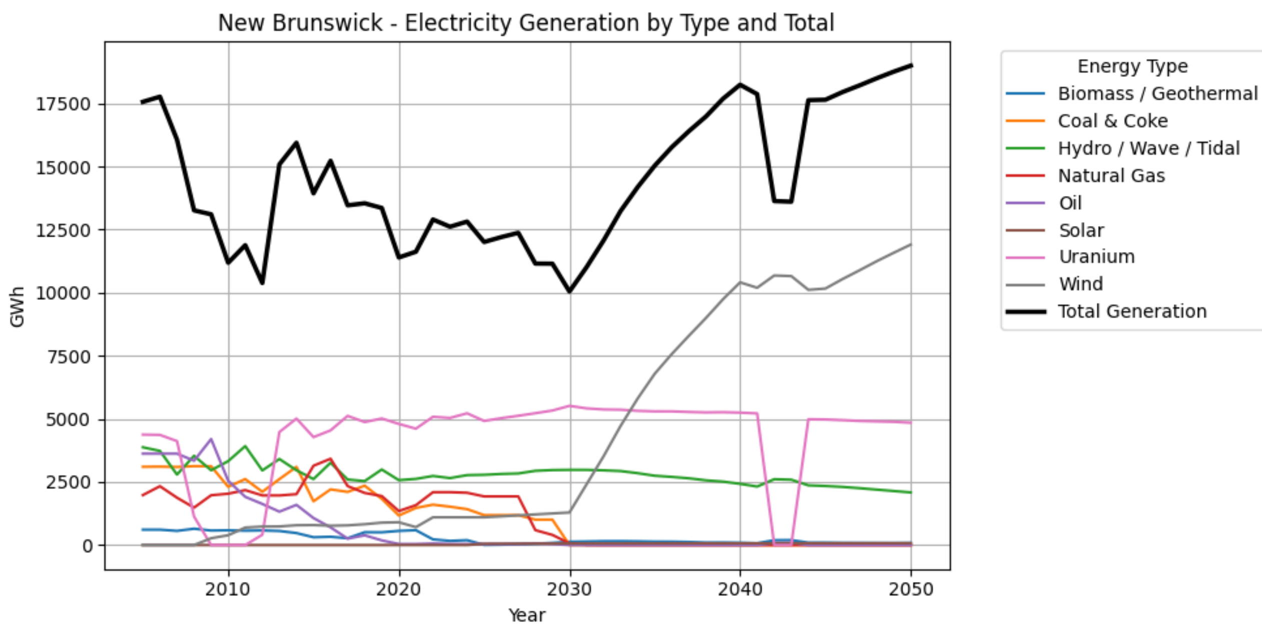
Generation by every province

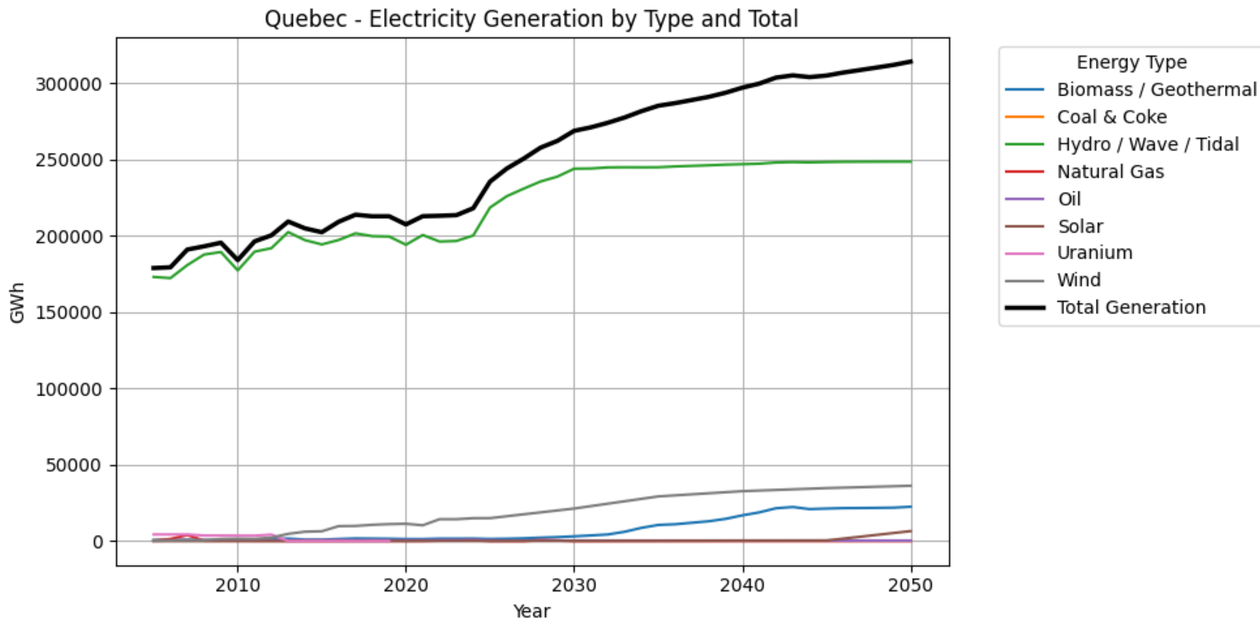
In [11]:
```
provinces_to_plot = [
    "Newfoundland and Labrador",
    "Prince Edward Island",
    "Nova Scotia",
    "New Brunswick",
    "Quebec",
    "Ontario",
    "Manitoba",
    "Alberta",
    "British Columbia",
    "Saskatchewan",
    "Yukon",
    "Northwest Territories",
    "Nunavut",
    # "Canada",
]

for province in provinces_to_plot:
    province_df = power_generation_df[power_generation_df["Province"] == province]

    # generation per year
    total = (
        province_df.groupby("Year", as_index=False)
        .agg({"GWh": "sum"})
        .rename(columns={"GWh": "Total_GWh"})
    )

    # by energy type
    by_type = (
        province_df.groupby(["Year", "Energy_Type"], as_index=False)
        .agg({"GWh": "sum"})
        .pivot(index="Year", columns="Energy_Type", values="GWh")
    )

    # plotting
    ax = by_type.plot(
        figsize=(10, 5),
        title=f"{province} – Electricity Generation by Type and Total",
        linewidth=1.5
    )

    ax.plot(total["Year"], total["Total_GWh"], color="black", linewidth=2.5, label="Total Generation")
    ax.set_xlabel("Year")
    ax.set_ylabel("GWh")
    ax.grid(True)
    ax.legend(title="Energy Type", bbox_to_anchor=(1.05, 1), loc="upper left")

    plt.tight_layout()
    plt.show()
```


Newfoundland and Labrador - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation

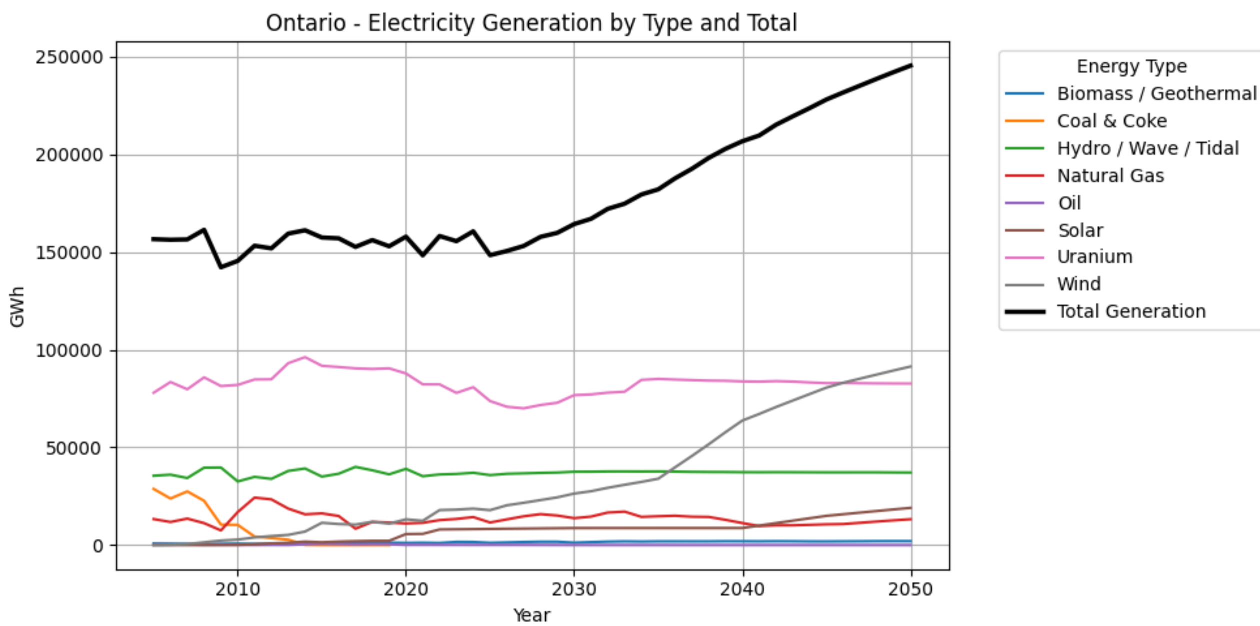

Prince Edward Island - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation


Nova Scotia - Electricity Generation by Type and Total
GWh
Year
0
2000
4000
6000
8000
10000
12000
14000
2010
2020
2030
2040
2050
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation

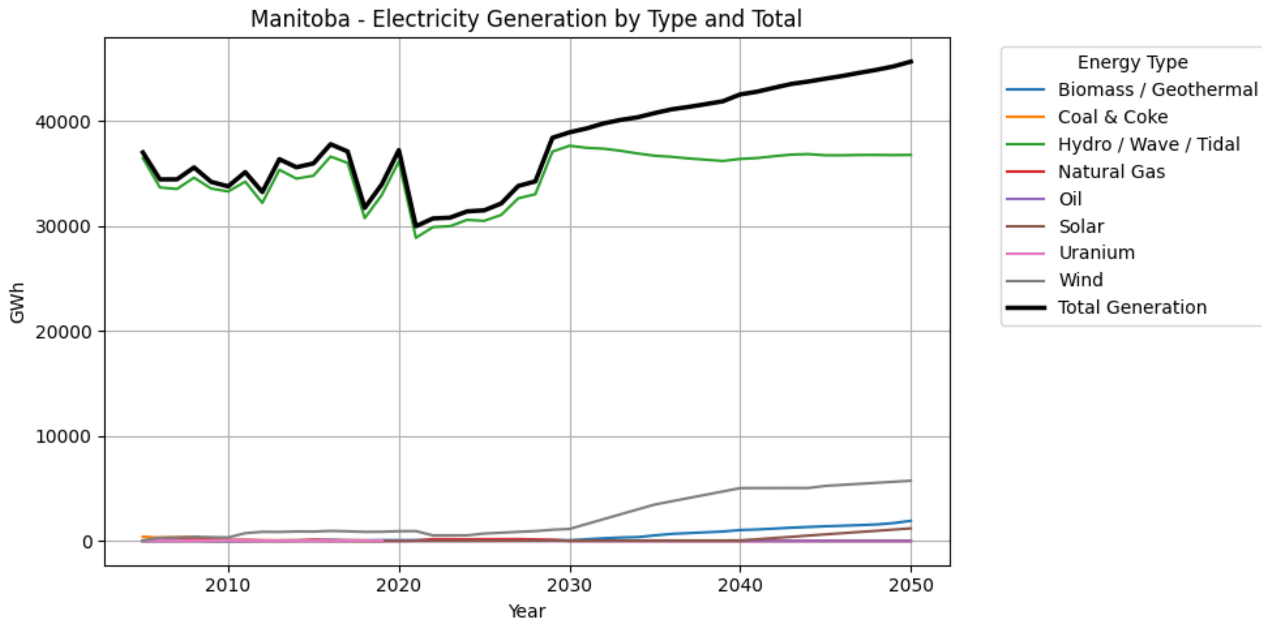

New Brunswick - Electricity Generation by Type and Total
GWh
Year
0
2500
5000
7500
10000
12500
15000
17500
2010
2020
2030
2040
2050
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation

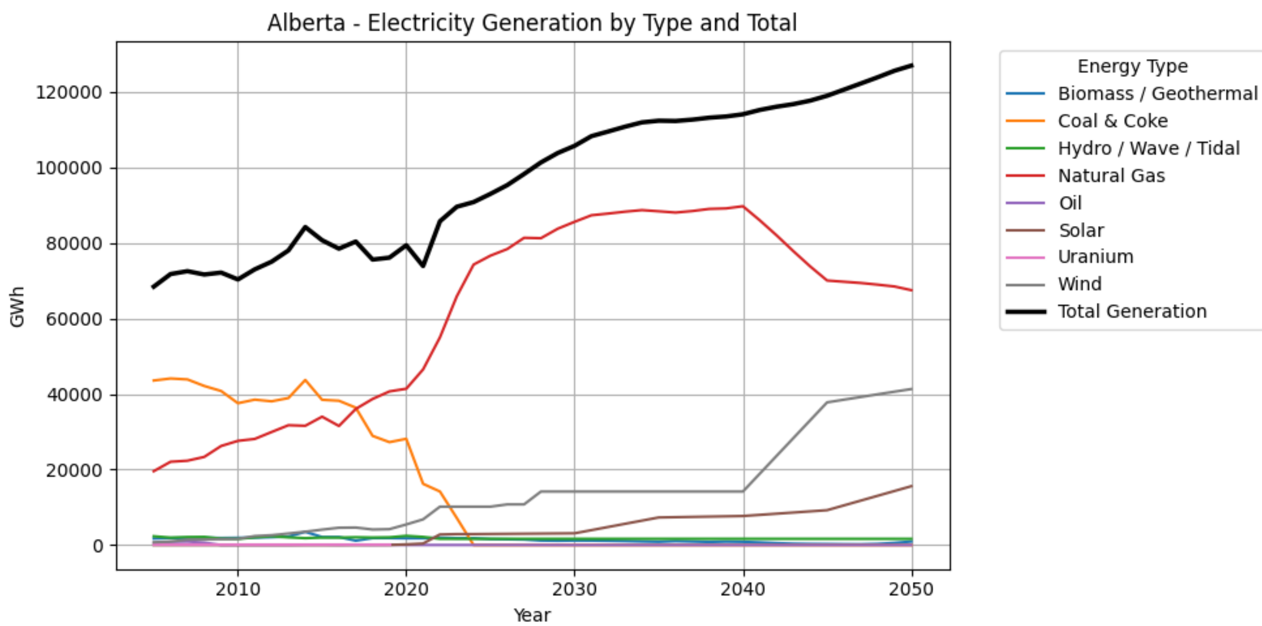


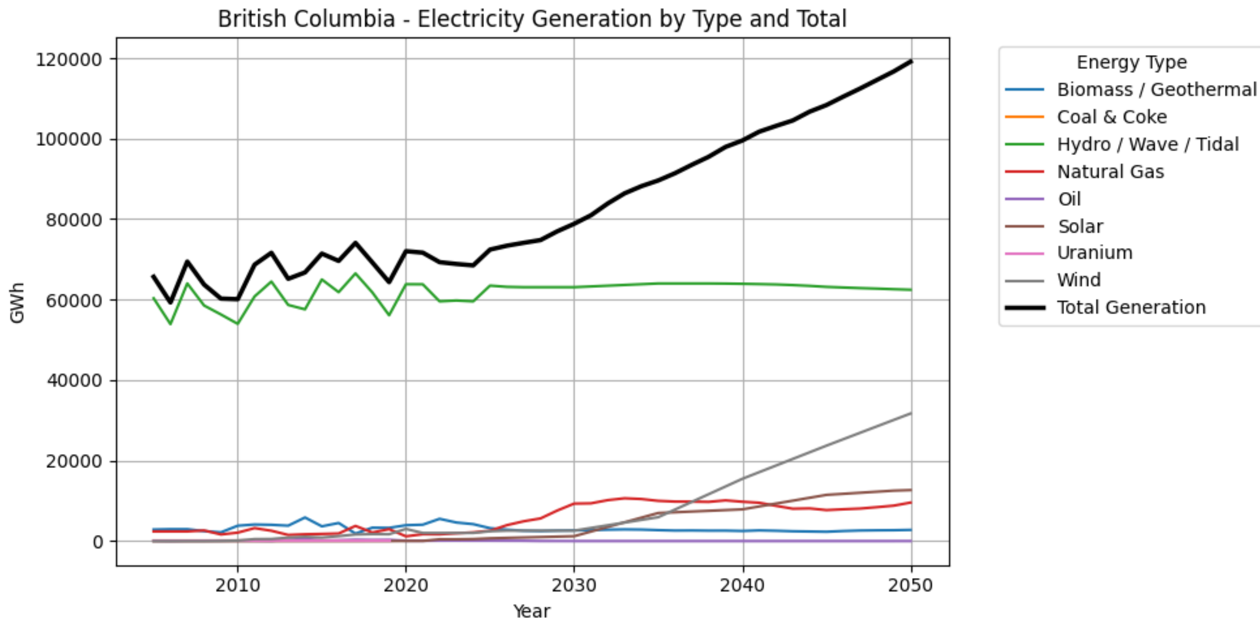
Quebec - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation

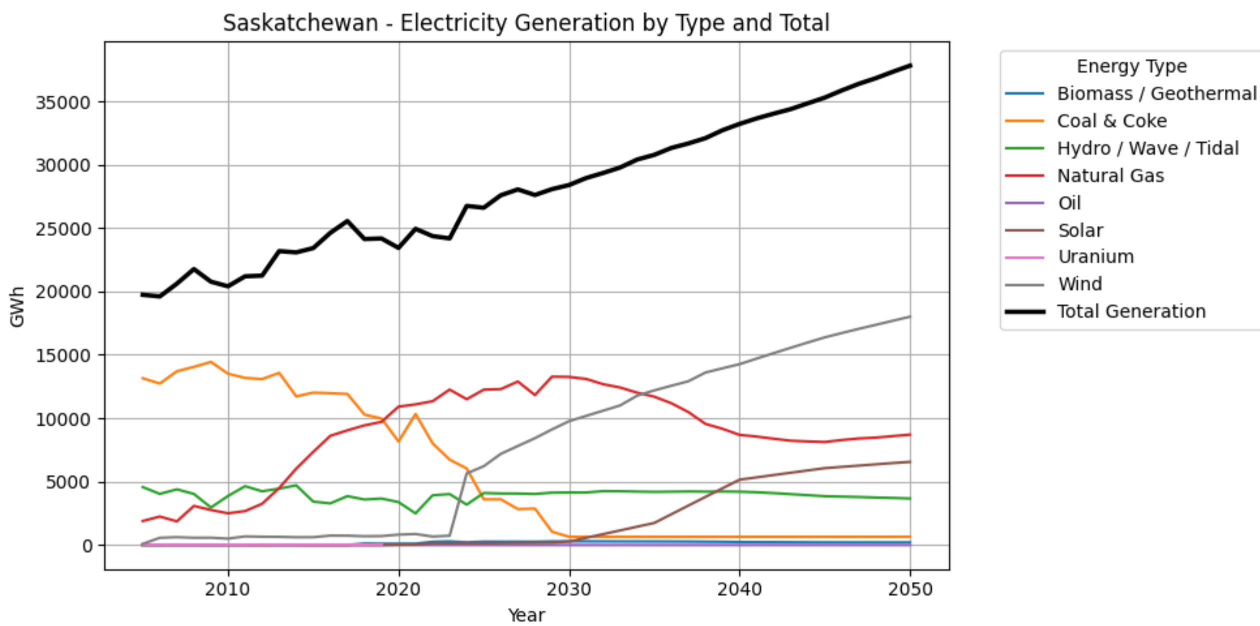


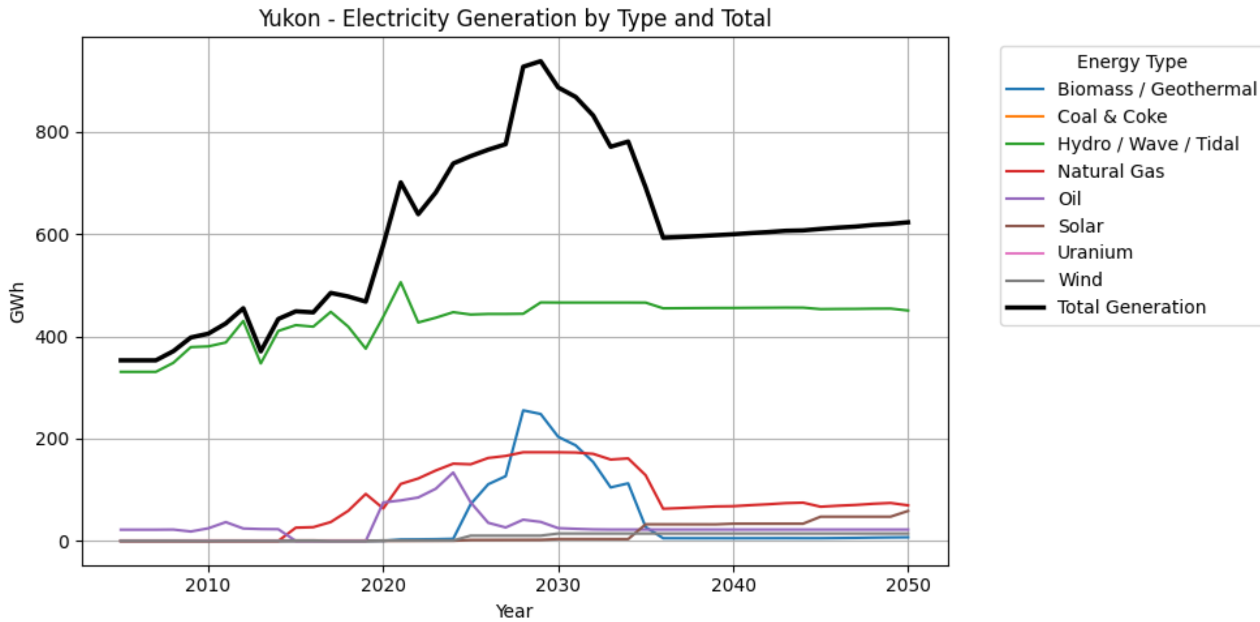
Ontario - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation

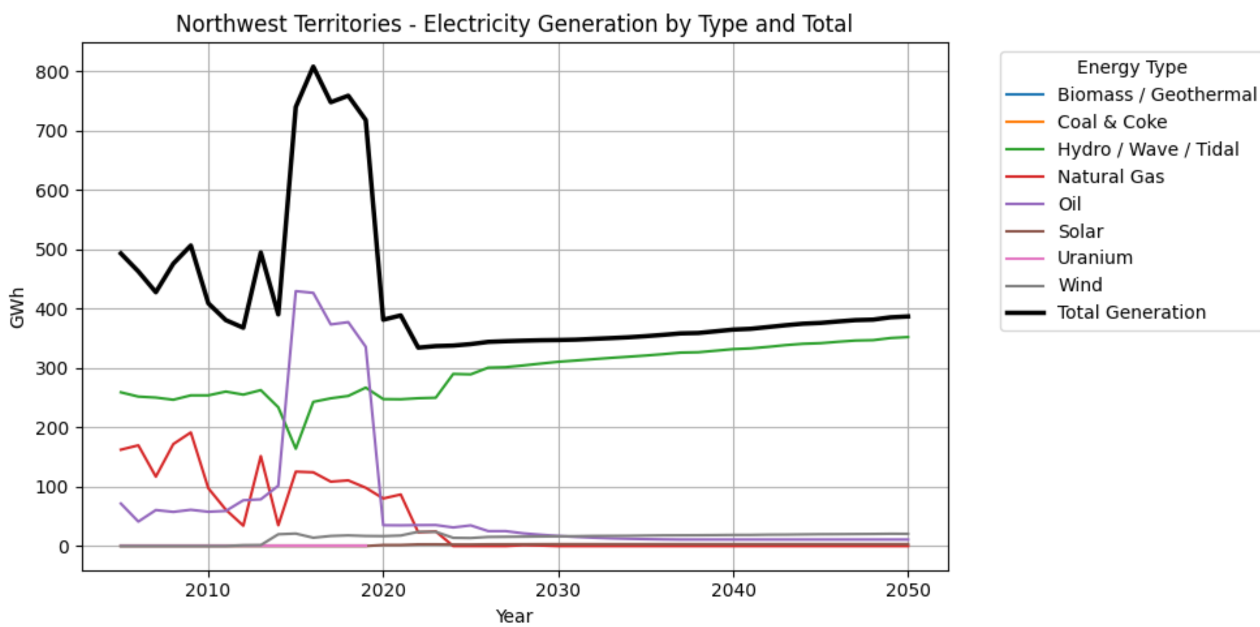

Manitoba - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation

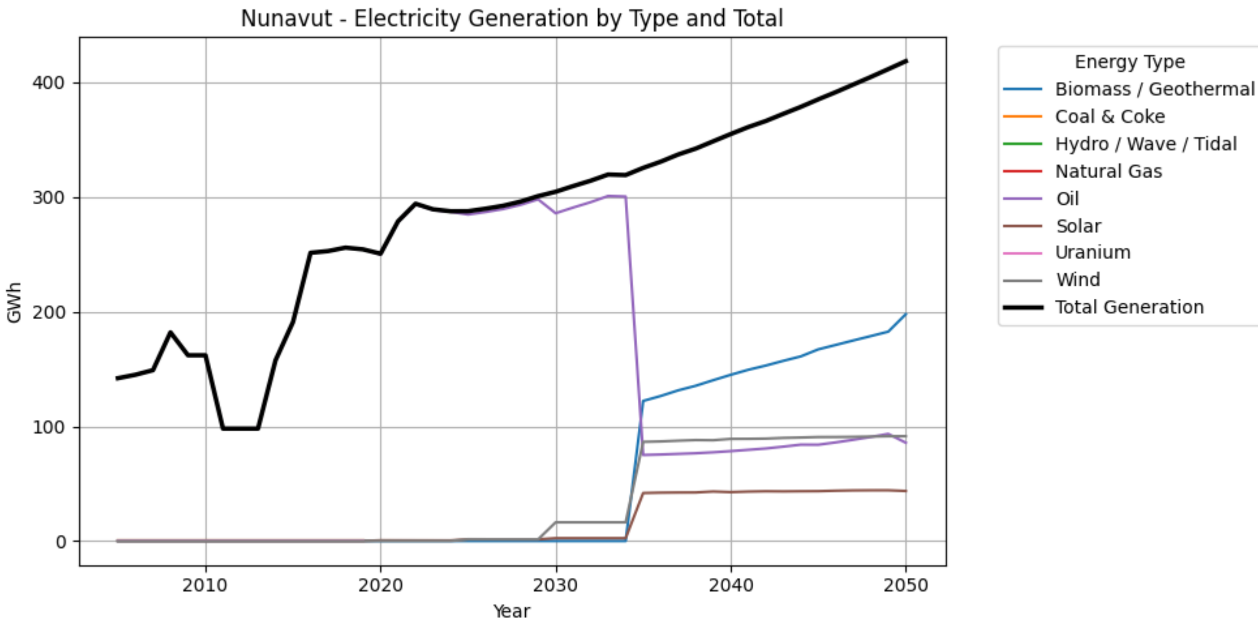

Alberta - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation


British Columbia - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation


Saskatchewan - Electricity Generation by Type and Total
GWh
Year
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation


Yukon - Electricity Generation by Type and Total
GWh
Year
0
200
400
600
800
2010
2020
2030
2040
2050
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation


Northwest Territories - Electricity Generation by Type and Total
GWh
Year
0
100
200
300
400
500
600
700
800
2010
2020
2030
2040
2050
Energy Type
Biomass / Geothermal
Coal & Coke
Hydro / Wave / Tidal
Natural Gas
Oil
Solar
Uranium
Wind
Total Generation



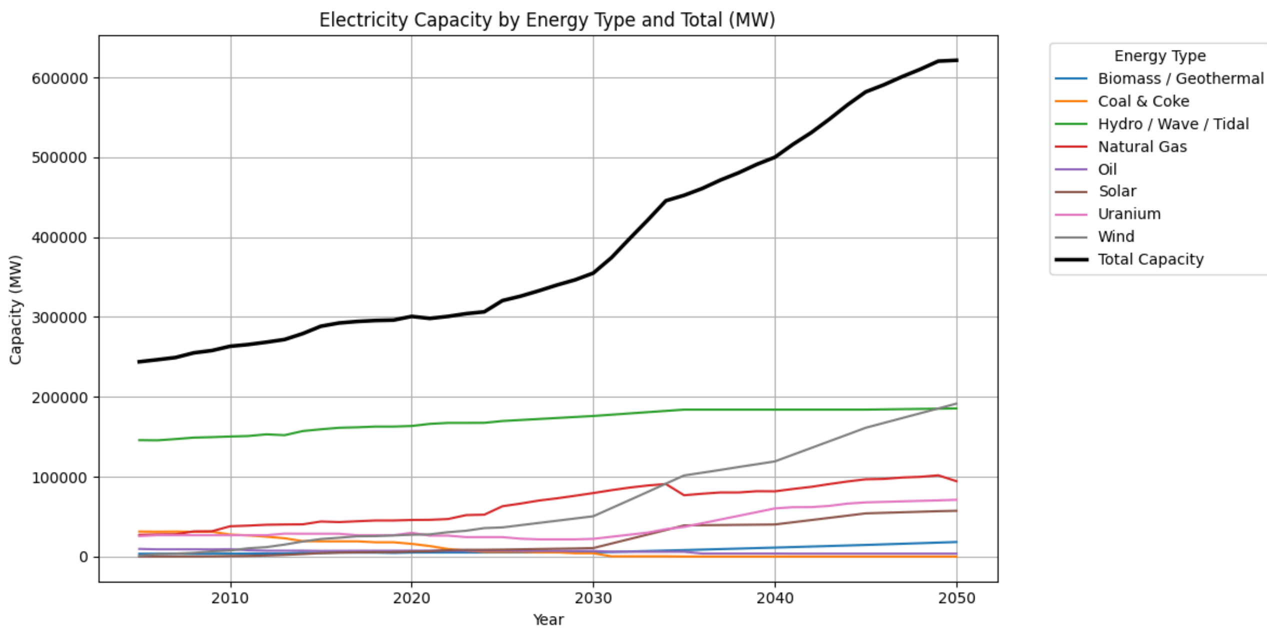
Results

The results show each province's generation by energy type. The data shows that BC, Quebec, Manitoba and Newfoundland and Labrador rely almost entirely on hydro. It shows a mixture on energy sources in Ontario and New Brunswick such as nuclear, hydro and wind. The territories offer a mixed variety of power generation sources with a phasing out of oil in Nunavut and a strengthening of geothermal and biomass. Alberta and Saskatchewan are heavily reliant on coal and natural gas, with a small amount of wind and hydro.

Power Capacity

In [12]:

```
total_capacity = (
    power_capacity_df.groupby("Year", as_index=False)
    .agg({"GWh": "sum"})
    .rename(columns={"GWh": "Total_MW"})
)
capacity_by_type = (
    power_capacity_df.groupby(["Year", "Energy_Type"], as_index=False)
    .agg({"GWh": "sum"})
    .pivot(index="Year", columns="Energy_Type", values="GWh")
)
# plot
ax = capacity_by_type.plot(
    figsize=(12, 6),
    title="Electricity Capacity by Energy Type and Total (MW)",
    linewidth=1.5
)

ax.plot(total_capacity["Year"], total_capacity["Total_MW"], color="black", linewidth=2.5, label="Total Capacity'
ax.set_xlabel("Year")
ax.set_ylabel("Capacity (MW)")
ax.grid(True)
ax.legend(title="Energy Type", bbox_to_anchor=(1.05, 1), loc="upper left")
plt.tight_layout()
plt.show()
```



Results

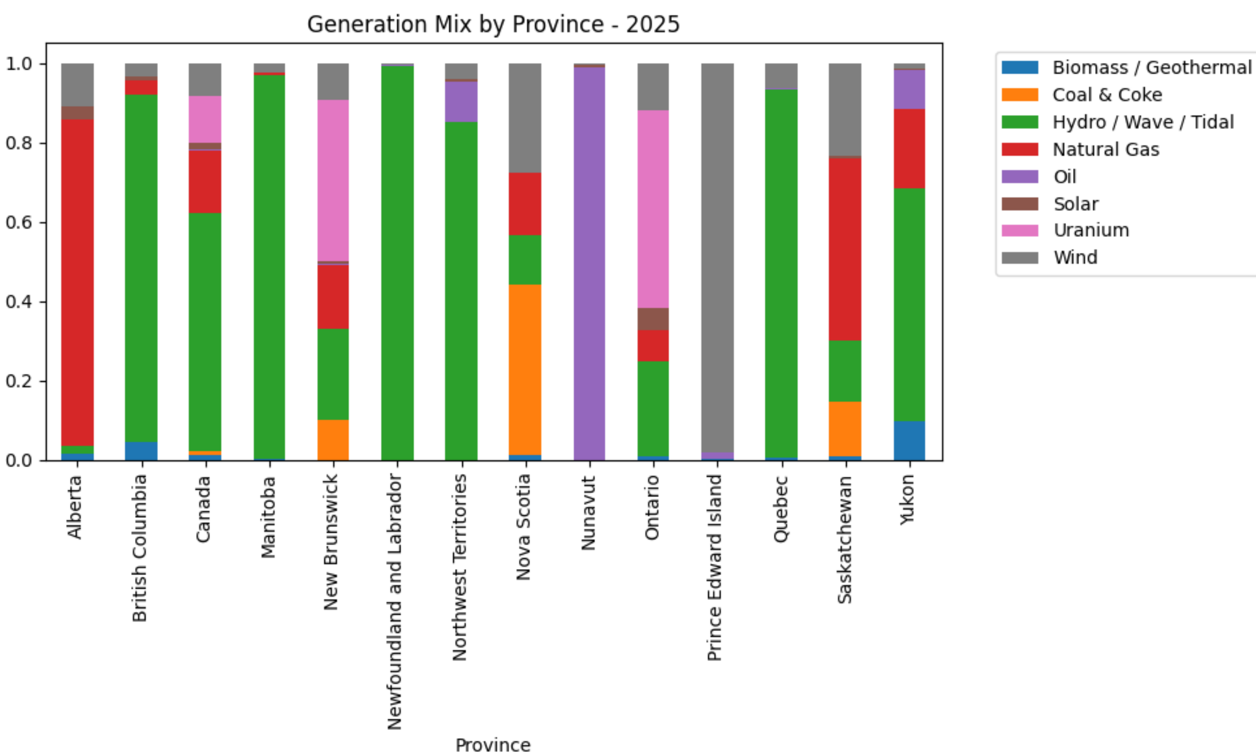
The data shows that hydro is currently the biggest source of power capacity up until the year 2048. In 2048 wind powered electricity generation is anctipated to surpass the total for hydro genearation. The data also shows that coal is being phased out and will be completely phased out by 2030.There is an a menial increase in anticipated Nuclear power generation, but it is not significant enough to be a major player in the energy mix, despite its long history of sustainable, cost-effective energy generation.

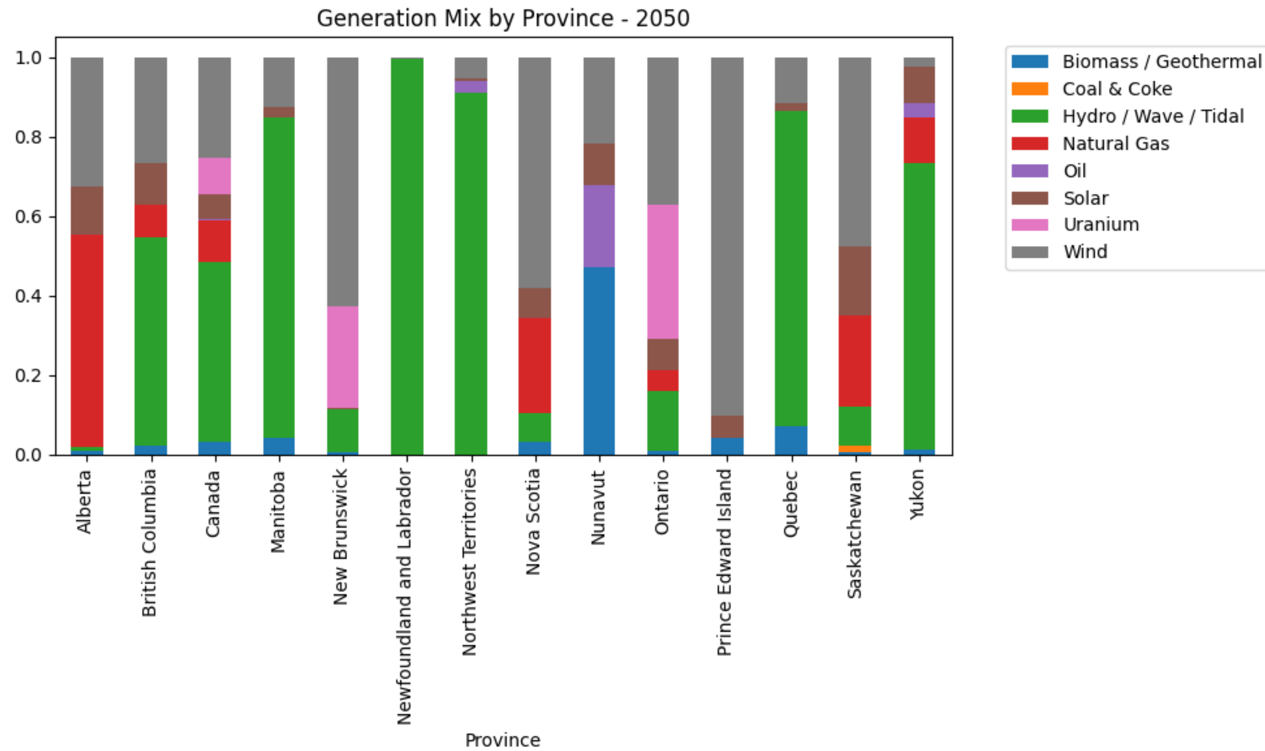
Analyze energy production in different regions of Canada

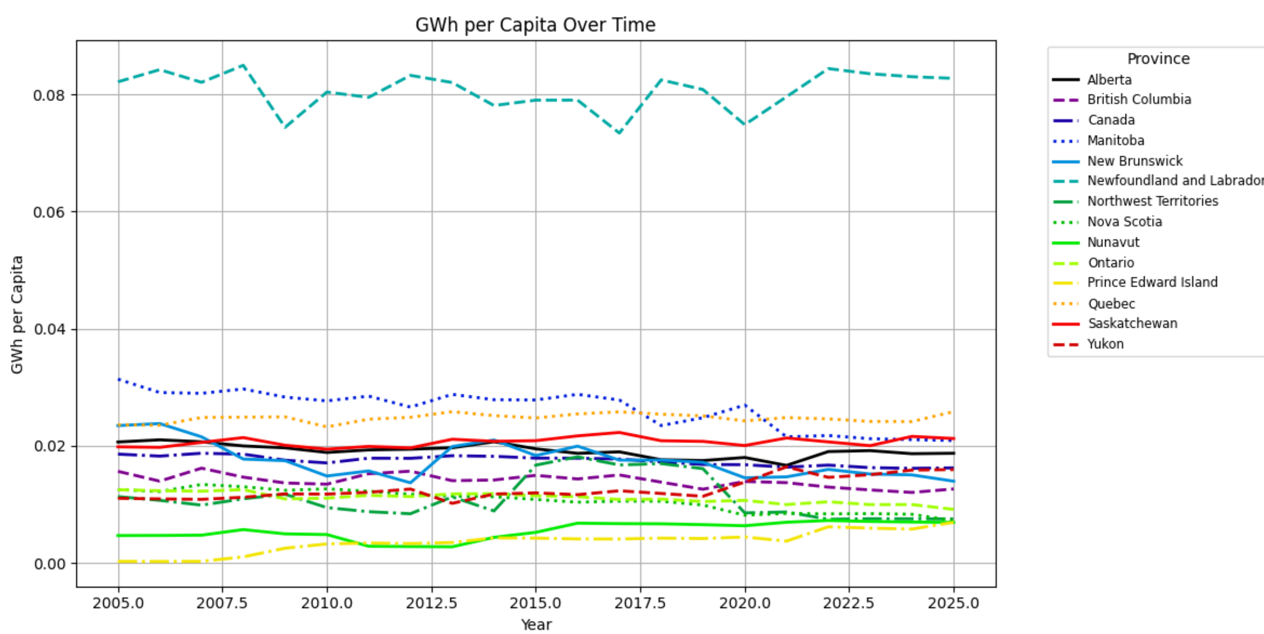
In [13]:

```python
def get_total_gwh_per_province(df):
    return df.groupby(["Province", "Year"], as_index=False).agg({"GWh": "sum"})

def get_per_capita_GWh(df_gwh, df_population):
    merged_df = pd.merge(df_gwh, df_population, on=["Province", "Year"], how="inner")
    merged_df["GWh_per_Capita"] = merged_df["GWh"] / merged_df["Population"]
    return merged_df[["Province", "Year", "GWh_per_Capita"]]

def get_per_GWh_MW(df_gwh, df_mw):
    total_mw = df_mw.groupby(["Province", "Year"], as_index=False).agg({"GWh": "sum"})
    total_mw = total_mw.rename(columns={"GWh": "MW"})
    merged_df = pd.merge(df_gwh, total_mw, on=["Province", "Year"], how="inner")
    merged_df["GWh_per_MW"] = merged_df["GWh"] / merged_df["MW"]
    return merged_df[["Province", "Year", "GWh_per_MW"]]

total_gwh_per_province = get_total_gwh_per_province(power_generation_df)
per_capita = get_per_capita_GWh(total_gwh_per_province, canada_population_df)
per_capita = get_per_GWh_MW(total_gwh_per_province, power_capacity_df)

def get_generation_mix(df):
    generation_mix = df.groupby(["Province", "Year", "Energy_Type"], as_index=False).agg({"GWh": "sum"})
    generation_mix["GWh"] = generation_mix["GWh"] / generation_mix.groupby(["Province", "Year"])["GWh"].transfor
    return generation_mix

generation_mix = get_generation_mix(power_generation_df)
display_stacked_barChar_GHw_per_Prov = True
display_lineChar_GHw_per_Capita = True
years_wanted = [2025, 2050]

if display_stacked_barChar_GHw_per_Prov:
    for year in years_wanted:
        mix_year = generation_mix[generation_mix["Year"] == year]
        mix_pivot = mix_year.pivot(index="Province", columns="Energy_Type", values="GWh")
        mix_pivot.plot(
            kind="bar",
            stacked=True,
            figsize=(10, 6),
            title=f"Generation Mix by Province - {year}"
        )
        plt.legend(bbox_to_anchor=(1.05, 1), loc="upper left")
```

```
        plt.tight_layout()
        plt.show()

if display_lineChar_GHw_per_Capita:
    per_capita_line = get_per_capita_GWh(total_gwh_per_province, population_yearly_df)
    pivot = per_capita_line.pivot(index="Year", columns="Province", values="GWh_per_Capita")
    provinces = pivot.columns
    num_provinces = len(provinces)
    cmap = plt.get_cmap("nipy_spectral")
    colors = [cmap(i / num_provinces) for i in range(num_provinces)]
    linestyles = ['-', '--', '-.', ':']
    fig, ax = plt.subplots(figsize=(12, 6))
    for i, province in enumerate(provinces):
        ax.plot(
            pivot.index,
            pivot[province],
            label=province,
            color=colors[i],
            linestyle=linestyles[i % len(linestyles)],
            linewidth=2
        )
    ax.set_title("GWh per Capita Over Time")
    ax.set_xlabel("Year")
    ax.set_ylabel("GWh per Capita")
    ax.grid(True)
    ax.legend(bbox_to_anchor=(1.05, 1), loc="upper left", fontsize="small", title="Province")
    plt.tight_layout()
    plt.show()
```







Results

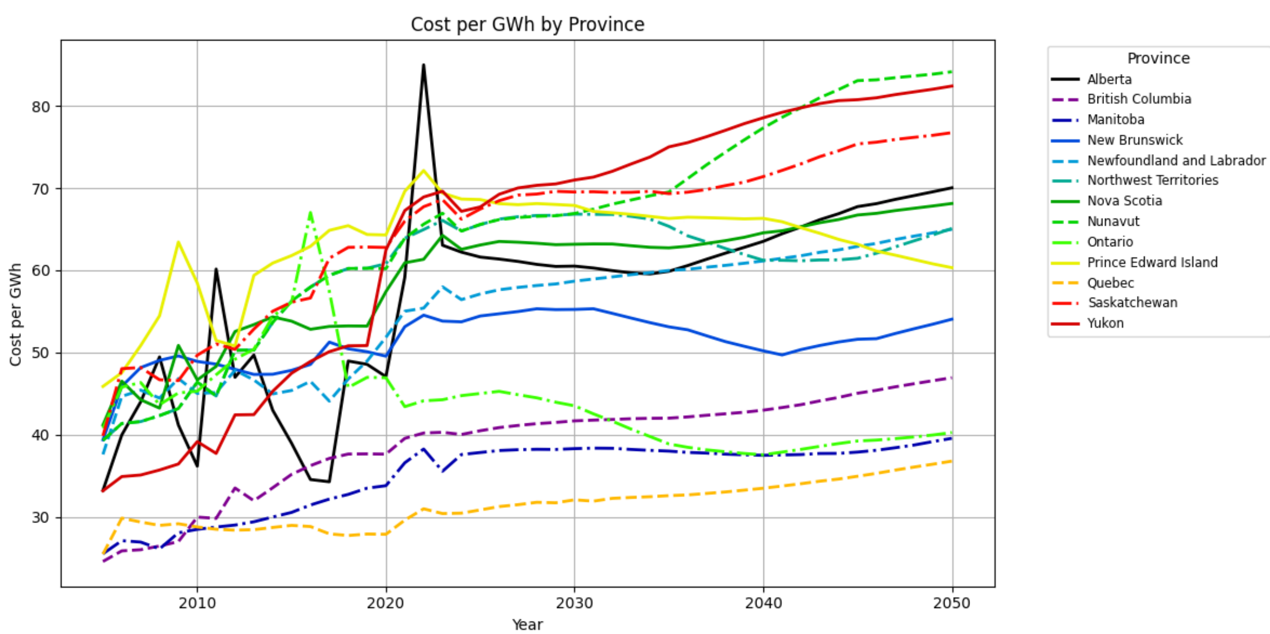
The data shows the energy production in each region of Canada. Both in the year 2025 and 2050 to see trends of renewable energy sources across Canada. In 2025 hydro is the biggest source of energy in almost all regions. By 2050 wind is anticipated to be the biggest source of energy in almost all provinces. The data also shows that natural gas is being phased out in all regions. The figure of the GWh (Gigawatt hour) of energy per capita, shows that the North West Territories consistently uses the most energy while PEI and Ontario use the least. This is mostly due to climate and population density of these provinces.

Power Interchange (Both With Canda and US and By provinces)

National Interchange (Canada Importing and Exporting with the USA)

In [14]:
```
# get the total exports by province
def get_total_national_imports(df, year=2025):
    total_imports = df[df["Year"] == year].copy()
    total_imports = total_imports[total_imports["Energy_Type"] == "Imports"]
```

```
    total_imports = total_imports.groupby("Province", as_index=False).agg({"GWh": "sum"})
    total_imports = total_imports.rename(columns={"GWh": "Total_Imports"})
    return total_imports

# get the total imports by province
def get_total_national_exports(df, year=2025):
    total_exports = df[df["Year"] == year].copy()
    total_exports = total_exports[total_exports["Energy_Type"] == "Exports"]
    total_exports = total_exports.groupby("Province", as_index=False).agg({"GWh": "sum"})
    total_exports = total_exports.rename(columns={"GWh": "Total_Exports"})
    return total_exports

national_exports = get_total_national_exports(power_interchange_df, year=year_filter)
national_imports = get_total_national_imports(power_interchange_df, year=year_filter)
national_import_export = pd.merge(national_exports, national_imports, on="Province", how="outer")

# per province prices (cause some provinces produce cheaper energy like quebec)
def get_Price_by_Province(df_prices, year=year_filter):
    total_dollars = df_prices[df_prices["Energy_Type"] == "Electricity"].copy()
    return total_dollars
province_energy_prices = get_Price_by_Province(power_prices_df, year=year_filter)
pivot = province_energy_prices.pivot(index="Year", columns="Province", values="GWh")

num_provinces = len(pivot.columns)
cmap = plt.get_cmap("nipy_spectral")
colors = [cmap(i / num_provinces) for i in range(num_provinces)]
linestyles = ['-', '--', '-.']
fig, ax = plt.subplots(figsize=(12, 6))
for i, province in enumerate(pivot.columns):
    ax.plot(
        pivot.index,
        pivot[province],
        label=province,
        color=colors[i],
        linestyle=linestyles[i % len(linestyles)],
        linewidth=2
    )
ax.set_title("Cost per GWh by Province")
ax.set_xlabel("Year")
ax.set_ylabel("Cost per GWh")
ax.grid(True)
ax.legend(bbox_to_anchor=(1.05, 1), loc="upper left", fontsize="small", title="Province")
plt.tight_layout()
plt.show()
```

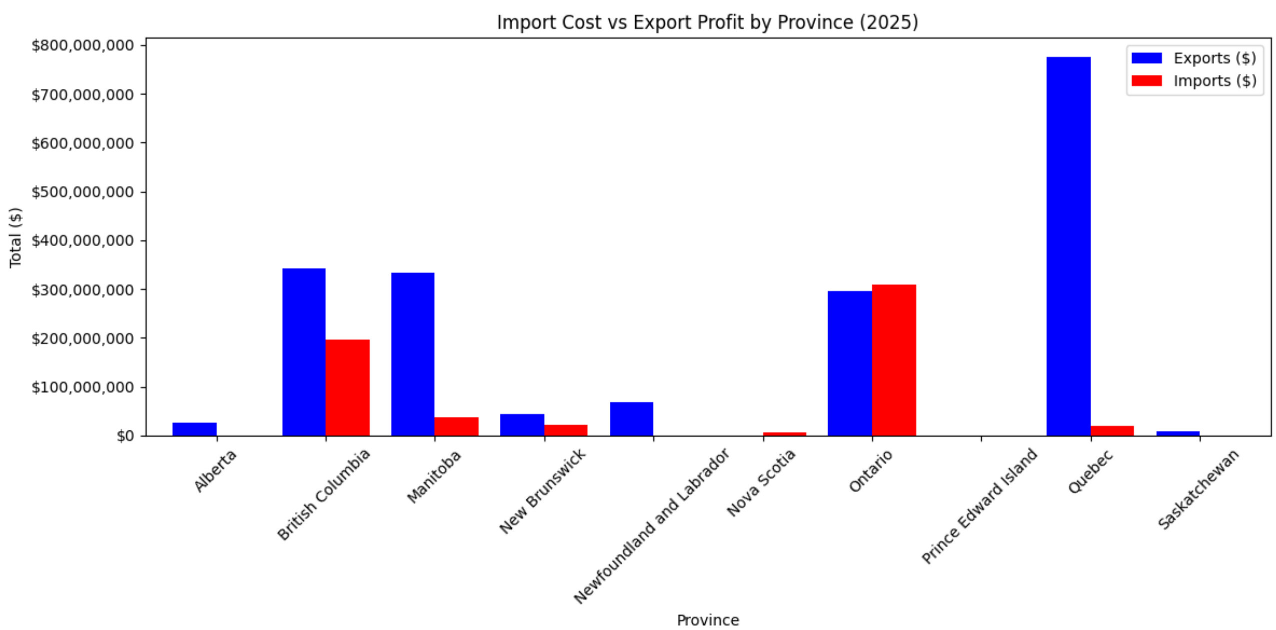


Results

The data reflected electricity prices are lowest in Quebec and highest in Nunavut and Yukon. Most provinces see prices go up from 2025 to 2050, especially in the northern territories and Saskatchewan.

Provincial Import and Export Totals

In [15]:
```
exports_total_profit = get_prices(power_prices_df, national_import_export, filter_import_export="Total_Exports", 
imports_total_cost = get_prices(power_prices_df, national_import_export, filter_import_export="Total_Imports", y
combined_trade = pd.merge(
    exports_total_profit.rename(columns={"Total_Profit": "Exports ($)"}),
    imports_total_cost.rename(columns={"Total_Profit": "Imports ($)"}),
    on="Province",
    how="outer"
).fillna(0)

# canada was shown didnt want it
combined_trade = combined_trade[combined_trade["Province"] != "Canada"]
ax = combined_trade.plot(
    x="Province",
    kind="bar",
    figsize=(12, 6),
    color=["blue", "red"],
    width=0.8,
    title="Import Cost vs Export Profit by Province (2025)"
)
plt.ylabel("Total ($)")
ax.yaxis.set_major_formatter(ticker.StrMethodFormatter('${x:,.0f}'))
plt.xticks(rotation=45)
plt.tight_layout()
plt.show()
```



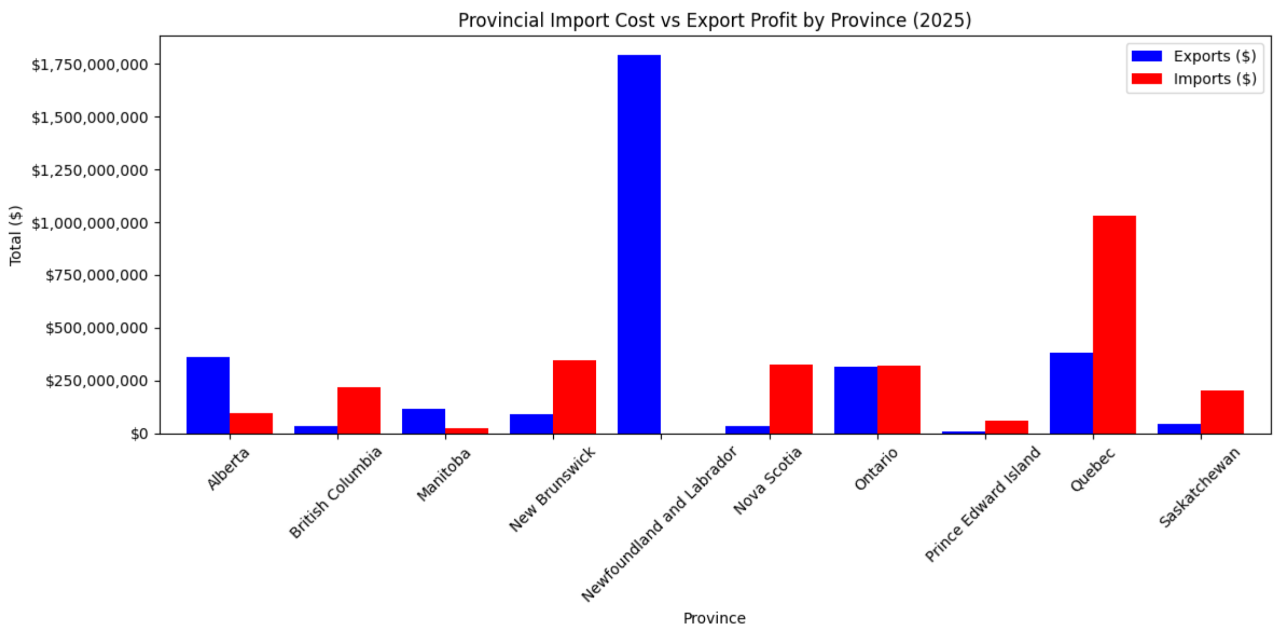
Results

In 2025, Quebec had the highest export profit, earning over $700 million. Ontario, B.C., and Manitoba also made strong gains from exports. In 2025, Quebec and Ontario export the most. Alberta and Atlantic Canada import more than they export. Hydro provinces send power to places with less supply or higher costs. Import costs were highest in Ontario and B.C., showing that even large producers still rely on imports to meet demand. Quebec had the biggest gap between export profit and import cost, highlighting its role as a major net exporter. Smaller provinces like PEI and Newfoundland had minimal import/export activity, indicating their reliance on local generation and consumption.

Power Interchange between provinces

In [16]:
```
def get_total_provincal_totals(df, year=2025, filter_import_export="Interprovincial Out-Flows"):

    total_exports = df[df["Year"] == year].copy()
    total_exports = total_exports[total_exports["Energy_Type"] == filter_import_export]
    total_exports = total_exports.groupby("Province", as_index=False).agg({"GWh": "sum"})
    return total_exports.rename(columns={"GWh": filter_import_export})

provincial_exports = get_total_provincal_totals(power_interchange_df, year=year_filter, filter_import_export="Ir
provincial_imports = get_total_provincal_totals(power_interchange_df, year=year_filter, filter_import_export="Ir
provincial_imports_exports = pd.merge(provincial_exports, provincial_imports, on="Province", how="outer")
```

```python
provincial_exports_profit = get_prices(power_prices_df, provincial_imports_exports, filter_import_export="Interp
provincial_imports_cost = get_prices(power_prices_df, provincial_imports_exports, filter_import_export="Interpro
combined_provincial_trade = pd.merge(
    provincial_exports_profit.rename(columns={"Total_Profit": "Exports ($)"}),
    provincial_imports_cost.rename(columns={"Total_Profit": "Imports ($)"}),
    on="Province",
    how="outer"
).fillna(0)

combined_provincial_trade = combined_provincial_trade[combined_provincial_trade["Province"] != "Canada"]
ax = combined_provincial_trade.plot(
    x="Province",
    kind="bar",
    figsize=(12, 6),
    color=["blue", "red"],
    width=0.8,
    title=f"Provincial Import Cost vs Export Profit by Province ({year_filter})"
)
plt.ylabel("Total ($)")
ax.yaxis.set_major_formatter(ticker.StrMethodFormatter('${x:,.0f}'))
plt.xticks(rotation=45)
plt.tight_layout()
plt.show()
```



Results

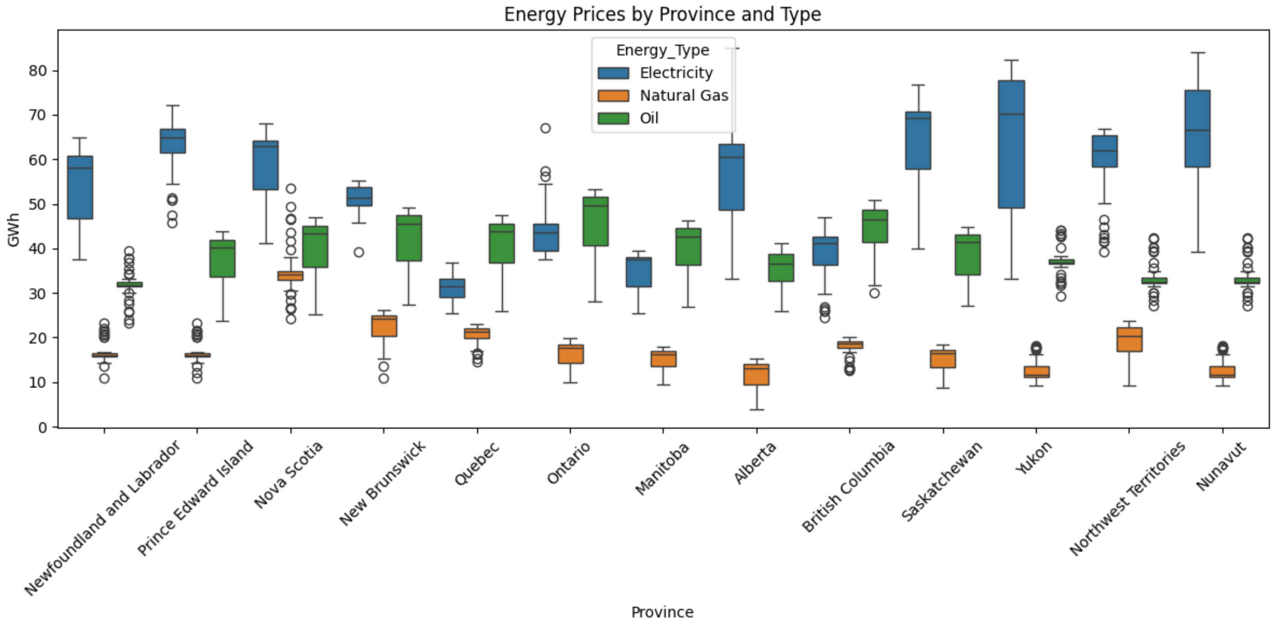
Even though Quebec are the biggest producer of energy in Canada, they import more provincially then they export. This is due to the selling of energy to the States. Canada in the middle with an export of 1.8 billion is the amount of energy that is exchanged yearly within Canada.

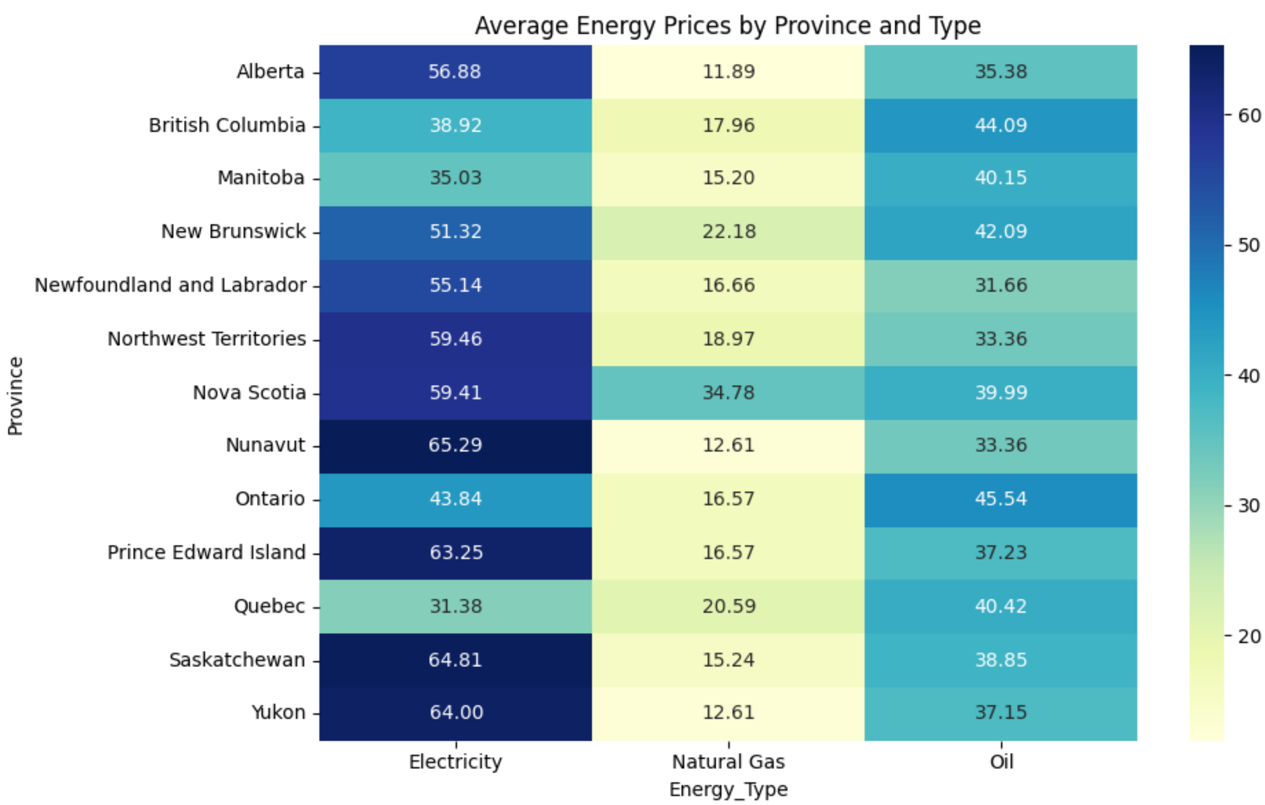
Prices Across Canada

Analysis of Prices Across Canada

In [17]:
```python
def get_avg_price_by_province(df):
    return df.groupby(["Province", "Year", "Energy_Type"], as_index=False).agg({"Price": "mean"})

display_price_boxplot = True
display_price_heatmap = True

if display_price_boxplot:
    plt.figure(figsize=(12, 6))
    sns.boxplot(data=power_prices_df, x="Province", y="GWh", hue="Energy_Type")
    plt.title("Energy Prices by Province and Type")
    plt.xticks(rotation=45)
    plt.tight_layout()
    plt.show()
```

```
if display_price_heatmap:
    pivot = power_prices_df.pivot_table(index="Province", columns="Energy_Type", values="GWh", aggfunc="mean")
    plt.figure(figsize=(10, 6))
    sns.heatmap(pivot, annot=True, fmt=".2f", cmap="YlGnBu")
    plt.title("Average Energy Prices by Province and Type")
    plt.tight_layout()
    plt.show()
```



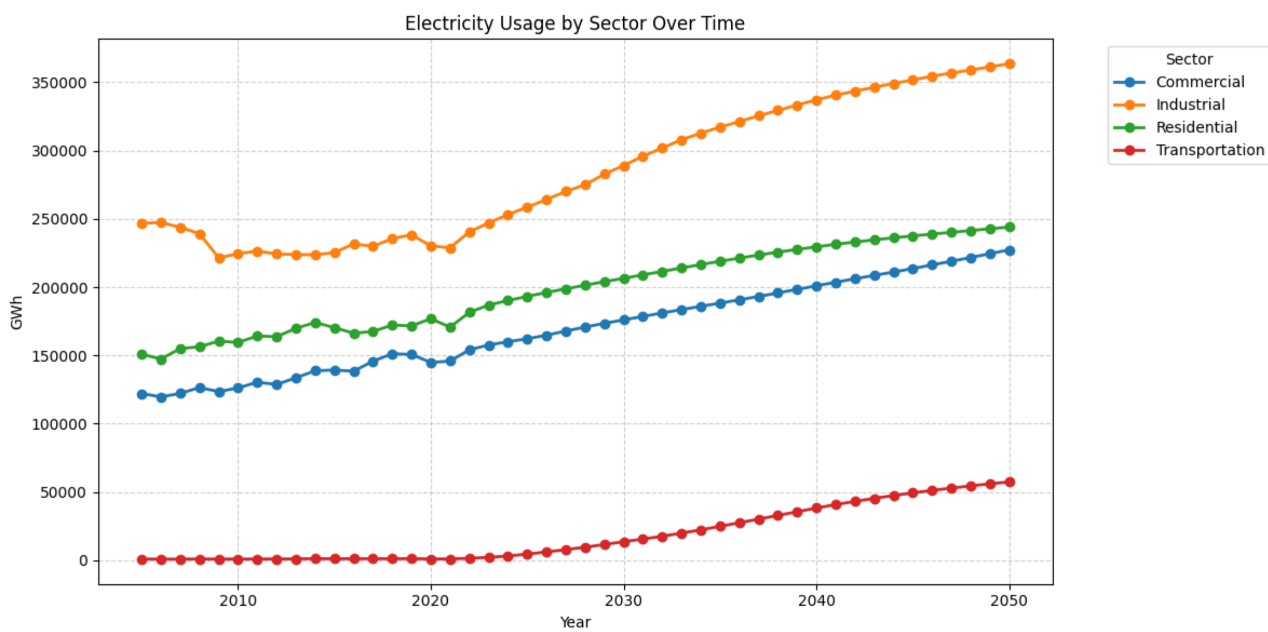


Results

The data shows electricity is cheapest in Quebec and Manitoba, and most expensive in Nunavut, Yukon, and Saskatchewan. Natural gas is lowest in Alberta and Yukon. Oil prices are pretty even, with some higher in Nova Scotia and Ontario. The boxplot shows more price swings in electricity, especially in the 3 Territories. The heatmap makes it easy to spot where energy is more or less expensive across types.

Analyze Energy Usage in Different Sectors in Canada

In [18]:
```
# we only want electricity
power_demand_df = power_demand_df[power_demand_df["Energy_Type"] == "Electricity"]

def get_sector_trends(df):
    return df.groupby(["Sector", "Year"], as_index=False).agg({"GWh": "sum"})

sector_trend = get_sector_trends(power_demand_df)
sectors = sorted(sector_trend["Sector"].unique())

plt.figure(figsize=(12, 6))
for sector in sectors:
    sector_data = sector_trend[sector_trend["Sector"] == sector]
    plt.plot(
        sector_data["Year"],
        sector_data["GWh"],
        marker="o",
        label=sector,
        linewidth=2
    )

plt.title("Electricity Usage by Sector Over Time")
plt.xlabel("Year")
plt.ylabel("GWh")
plt.grid(True, linestyle='--', alpha=0.6)
plt.legend(title="Sector", bbox_to_anchor=(1.05, 1), loc="upper left")
plt.tight_layout()
plt.show()
```



Results

In the data its seen that Industrial is always the biggest energy consumer in Canada, which is a given. Looking at commercial and residential they are very similar. In 2020 there is a decently sized dip in the Industrial power use, this is due to Covid causing the lockdown and moving people at home, hence the power power consumption in residential. The Transport sector not much happens until 2026, more electric vehicles are being used, increasing the power consumption.

Conclusion and Discussion

To Conclude the analysis provided a clear view of how energy is produced, consumed, and priced across Canada, both provincially and federally. The results show stronger and weaker provinces when it comes to energy production, like Quebec and BC produce mostly clean cheap hydro energy. At the same time, Alberta and Saskatchewan are more fossil-fuel dependent. Prices vary widely across Canada and are heavily affected by the types of energy produced.

The analysis also shows that Canada is a net exporter of energy with the US. With the datasets, there is also a projected energy types per province and the demand for energy. The results show a strong movement of wind and hydro throughout Canada.

Using real government data made the project more realistic but required more cleaning and preprocessing. The setup with Jupyter made it easier for multi-user work and had individual cells for each type of analysis, allowing for an easier process to come to these results.