DATA 604: Group Project Report (2023)

Analyzing the Canadian Government's Initiatives to Reduce Carbon Footprint

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1. Introduction

Climate change is a global issue that has been a growing concern for governments worldwide. [ix] Burning of fossil fuels for numerous reasons generates greenhouse gases that will, in turn, act as a blanket wrapped around our planet, trapping the sun's heat and causing a rise in global temperature, commonly called global warming. [i] This causes adverse effects on various ecosystems, rising sea levels, saltwater intrusion, changes in seasonal cycles, etc. Thousands of scientists and government reviewers concurred in several UN reports that keeping the global temperature above 1.5°C would help humanity avoid the worst climate effects and maintain a habitable climate. Regrettably, current strategies predict a 2.8°C rise in temperature by the end of the century. [ii]

In light of these reports, the Canadian Government has targeted net-zero greenhouse gas (GHG) emissions by 2050. [i] Furthermore, the provinces are taking different steps towards the same goal set by the central government. This project aims to analyze the Canadian Government's initiatives toward achieving its net-zero emission goal and the impact of these initiatives on renewable energy production and consumption across provinces.

We analyze energy consumption and emissions by government facilities, industries, and residents. To get to net-zero emissions, renewable energy is the key. Therefore, we compare renewable source usage over the years with non-renewable sources. Lastly, we combine all the data and queries to make a holistic comment on how the sustainability goals are being handled by the Canadian Government so far.

2. Datasets

We will be using three datasets for this project:

2.1 Green House Gases (GHG) by Federal Facilities and Fleets Dataset: [iii] This dataset has 2 CSV files from 2005-2021. The first one provides information on the Canadian Government's facilities which has 4,672 rows, with Energy use (GJ) and Emissions (kt) at Federal organization by Energy type and Province. The second CSV, GHG emissions by fleets, has 1,267 rows, including their emissions and energy consumption by Fleet of each Federal Agency. The dataset was obtained from the Government of Canada's open data portal and is licensed under the Open Government License - Canada. The dataset includes information on emissions, energy consumption, and other factors for different types of facilities and fleets across Canada. We will also utilize Climate Watch Historical Emissions [v] data containing sector-level greenhouse gas (GHG) emissions data for 194 countries and the European Union from 1990-2019, including emissions of the six major GHGs from the most significant sources and sinks with 10,947 rows of data. This dataset was obtained from the Climate Watch portal, which has an open data commitment and provides information free of constraints and restrictions on use.

2.2 Electricity and Gas Consumption Dataset: [ix, x, xi] Electricity and Gas Consumption: This dataset provides information on Canada's total electricity and gas consumption, divided by province and year. The dataset was obtained from the Canadian Centre for Energy Information. The dataset includes information on the total electricity and gas consumption for different provinces and years from 2012 to 2021. It has three columns: Geography, Year and Primary electricity, hydro and nuclear energy usage (terajoules) for residence, industrial and overall electricity consumption, or Natural gas usage (terajoules) for home, industrial and general consumption about Natural gas consumption.

2.3 North American Renewable Integration Study (NARIS) Dataset: [iv] This dataset provides data on North American countries' energy production. It consists of all the locations producing energy, whether renewable such as wind and hydroelectricity or conventional sources, such as thermal and coal power plants. Since the production of energy can lead to a lot of GHG generation, we decided to consider renewable energy as a factor in controlling carbon footprint. Matrices such as capacity, generation output and CO2 emissions while production will be considered. Interestingly, data spans from 2010 to 2050 (showing future predictions). The National Renewable Energy Study website dataset comprises 69,444 rows and is open to public use with proper citations.

3. Data Cleaning

We removed null values from all the datasets. In addition, some of the numeric columns contained removed commas, and columns were converted to the integer type. Further, all the datasets have province columns upon which the tables will be joined. However, different ways of interpreting provinces meant changing the tables to make values consistent over all the tables. We added a new column with two-character abbreviations of provinces to deal with this issue.

To plot the animated gap minder map plots, we used the Geojson library. Our code required numbering the provinces as per requirements, and therefore we added new columns into the tables where needed.

[NOTE: All the SQL queries are uploaded to a GitHub repository and can be accessed using the following link. Jupyter Notebook in the repository is linked with Google Colab and can be directly opened. However, to run the plots with maps, the geojson file (uploaded to the repo) must first be uploaded to the Colab notebook.]

https://github.com/daksh1024/Canadian-Sustainability-Goals/blob/main/DATA_604_canadian_sustainability_goals.ipynb

4. Guiding Questions

4.1 Green House Gases (GHG) Emissions by Federal Facilities and Fleets

Q1. What are the trends in greenhouse gas emissions by facilities over the years?

4.1.1. Greenhouse gas emissions (GHG) by facilities (federal organization)

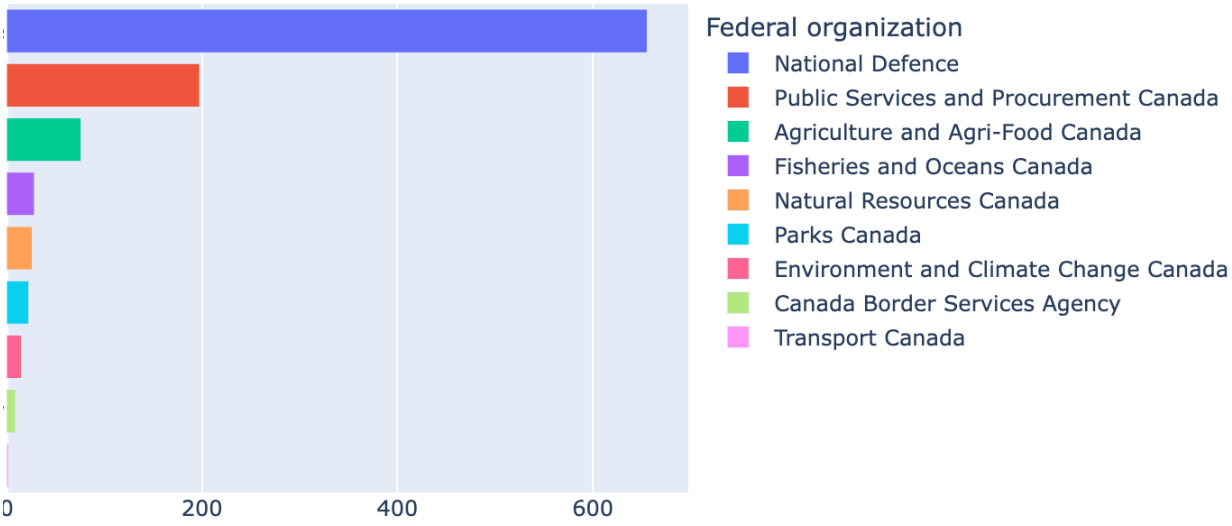
The first query retrieves Greenhouse gas emissions (GHG) by facilities (federal organizations) over the years. This query provides a detailed view of the trends in emissions from government facilities.

	Federal organization	Start_Year	Total_Emissions	Emissions_Percentage_Change
0	National Defence	2011	662.870450	-7.905668
1	Public Services and Procurement Canada	2011	186.710570	-14.560032
2	Agriculture and Agri-Food Canada	2011	74.755980	-9.897338
3	Fisheries and Oceans Canada	2011	30.171040	-2.358620
4	Natural Resources Canada	2011	25.043860	-16.670987
...	...	...	...	...
140	Innovation, Science and Economic Deve…	2021	0.557512	-7.183345
141	Canadian Forces Morale and Welfare Se…	2021	0.455482	-1.754413
142	Crown-Indigenous Relations and Northe…	2021	0.353930	-11.777423
143	National Battlefields Commission	2021	0.205385	1.187674
144	Indigenous Services Canada	2021	0.054320	1588.947948

(Output for Greenhouse gas emissions (GHG) by the federal organization)

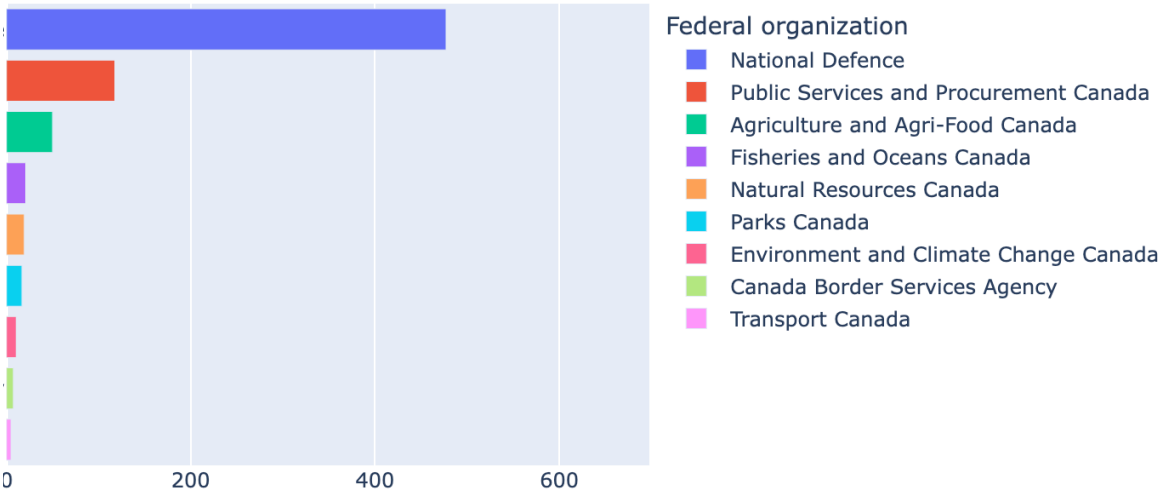
It also details by what percentage the emission increased or decreased compared to the previous year. By identifying the federal organizations with the highest emissions and their changes over time, we can understand which organizations contribute the most to overall emissions and where the most significant reduction efforts are needed.

Below we show plots for the total GHG emissions for different government organizations for 2012 and 2021. We can observe that the pecking order for the number of emissions doesn't change over the years, i.e., National Defence still stays the main contributor to GHG emissions. It produced over 600 kilotons (KT) of emissions in 2012.



(Plot for GHG by the federal organization - the year 2012)

Over time, however, this changes for the good. We see that emissions for all the facilities are declining for 2021. National defence has reduced its GHG emissions by almost 200 KT, which might be due to reform policies taken over by the government.



(Plot for GHG by the federal organization - the year 2021)

Q2. What are the trends in greenhouse gas emissions by fleets and fuel type over the years?

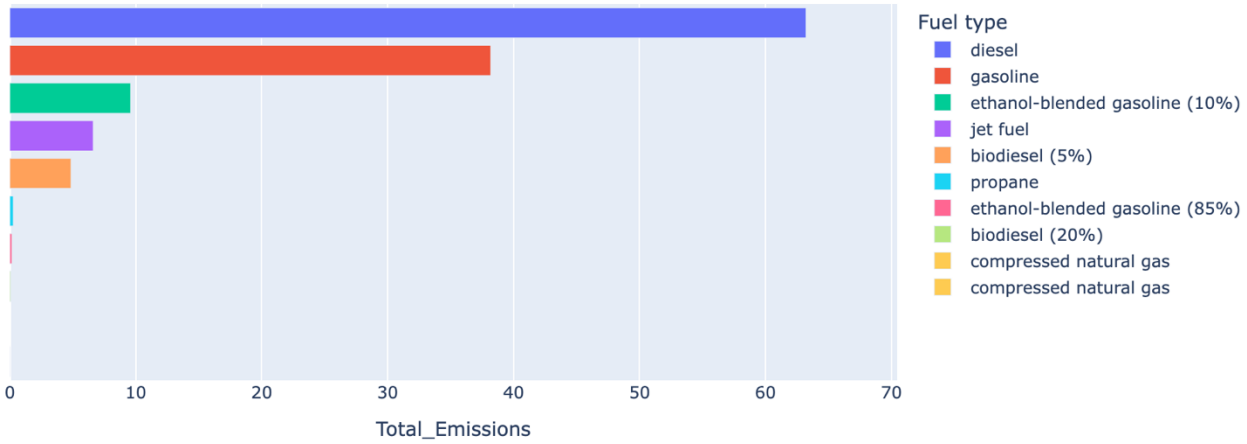
4.1.2. Greenhouse gas emissions across government fleets

The second query retrieves Greenhouse gas emissions across fleets by fuel type over the years. This query shows the trends in emissions from government fleets based on fuel types. Understanding which fuel types contribute the most to the overall emissions can help prioritize the transition to cleaner alternatives, such as electric or hydrogen-based vehicles.

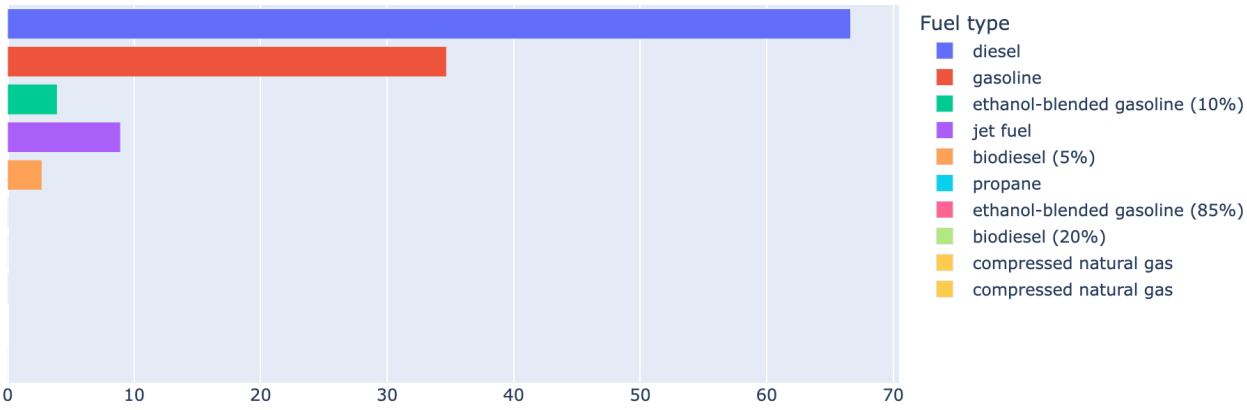
	Fuel type	Start_Year	Total_Emissions	Emissions_Percentage_Change
0	diesel	2011	66.931560	-1.307430
1	gasoline	2011	40.972297	-3.778998
2	ethanol-blended gasoline (10%)	2011	10.787399	-33.178841
3	jet fuel	2011	6.080137	-42.111101
4	biodiesel (5%)	2011	5.865805	53.038943
...	...	...	...	...
96	ethanol-blended gasoline (10%)	2021	3.926482	43.116318
97	biodiesel (5%)	2021	2.715838	16.623568
98	biodiesel (20%)	2021	0.058186	84.280931
99	propane	2021	0.050615	17.845749
100	ethanol-blended gasoline (85%)	2021	0.013246	71.929662

(Output for Greenhouse gas emissions (GHG) by the fuel type)

The plot shows the total GHG emissions produced by fuel type for 2012 and 2021. Diesel contributes most towards the emissions, followed by gasoline.



(Plot for GHG by Fuel type - the year 2012)



(Plot for GHG by Fuel type - the year 2021)

Compared with 2021, diesel and jet fuel emissions have increased over time. On the other end, emissions from different fuels decrease. Interestingly, we can also spot from the plots above

those green fuels such as compressed natural gas and propane; biodiesels contribute significantly fewer emissions showing how big of a different use of such fuels can make.

4.1.3. Total emissions for each energy category

Here, we calculate the total emissions for each energy category by summing the emissions from facilities and fleets over the years 2011 - 2021. The results are then ordered by total emissions in descending order, allowing us to quickly identify which energy categories contribute the most to GHG emissions for government facilities and fleets.

	Energy category	Total_Emissions
0	natural gas	6116.806779
1	electricity	4920.546244
2	fuel oil (1,2,4,5,6, diesel, kerosene)	2148.336883
3	district heating	898.656723
4	Gasoline	533.253841
5	aviation fuel	383.399556
6	district cooling	141.225678
7	liquified petroleum gas	121.079355
8	fuels with renewable content	115.987644
9	biomass	0.000000

(Output for Total emissions for each energy category)

Over the decade, natural gas has been the main contributor to emissions, followed by electricity. Unclean categories contribute the maximum towards the GHG, while cleaner sources contribute the least. We will expand on this more when we combine this query with the generation of energy by renewable sources.

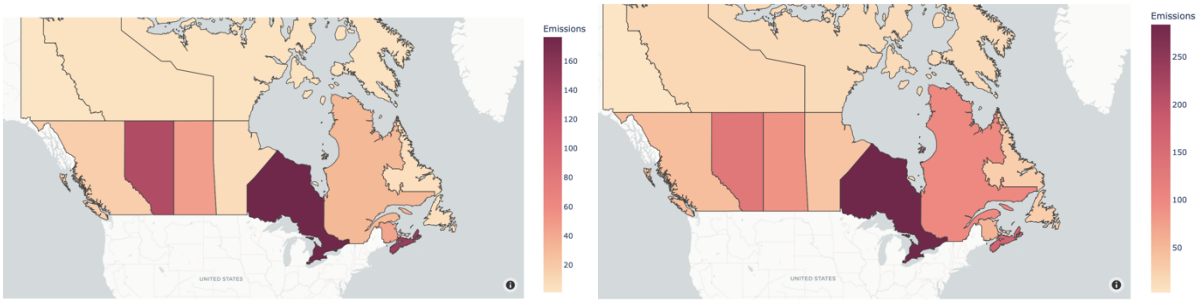
Q3. What are the trends in greenhouse gas emissions in Canada over time and by province/ territory (highest and least)?

4.1.4. Emissions by facilities by province

This query retrieves emissions data from the ghg_by_facility table and groups it by province/territory and fiscal year. This query provides insight into emissions across different provinces and how emissions have changed over time. The results are ordered by emissions in descending order, allowing us to identify the provinces/territories with the highest emissions year-wise.

	Location	Year	Emissions	province_name
0	ON	2010	223.027700	Ontario
1	AB	2010	159.178270	Alberta
2	NS	2010	150.476070	Nova Scotia
3	SK	2010	50.130390	Saskatchewan
4	NB	2010	49.301490	New Brunswick
...	...	...	...	...
151	NL	2021	28.592218	Newfoundland and Labrador
152	NT	2021	19.153805	Northwest Territories
153	NU	2021	15.516358	Nunavut
154	PE	2021	10.013739	Prince Edward Island
155	YT	2021	2.781976	Yukon

(Output for Greenhouse gas emissions (GHG) by the Provinces)



(Plots for Greenhouse gas emissions (GHG) by the Provinces)

We compare the distribution of emissions for provinces over an animated choropleth map plot between 2011 and 2021. The plot on the left shows emissions for 2011 and on the right for 2021. Darker colours and bigger sizes mean higher emissions. GHG emissions increased for most provinces, such as Ontario, New Brunswick, Newfoundland and Labrador, and Quebec. Nova Scotia and British Columbia are the few where emissions decrease.

4.1.5. Highest and lowest emissions by provinces/territories

We use subqueries to fetch the highest and lowest emission by provinces/territories separately and combines the results using UNION ALL. The subqueries calculate the total emissions for each location, order the results by total emissions in descending or ascending order, depending on the query, and limit the results to 1 row. These queries answer the sub-questions of the third guiding question.

	Location	total_emissions
0	ON	2752.588151
1	YT	25.005662

(Output for Provinces with highest and least GHG Emissions)

Ontario has been the leading producer of emissions over the years while Yukon contributes the most minor Another factor to consider here is that Ontario has the highest population in Canada. As a result, it has the most significant number of government facilities, producing the most emissions. Conversely, Yukon, and vice versa, is one of the least populated provinces.

4.1.6. Most emitted GHG in Canada

This query provides information on the gas that contributes the most towards GHG emissions (in KT) in Canada for 2019. This information is crucial in understanding which gases must be reduced to achieve the net-zero emissions target.

	Gas	AvgEmission
0	CO2	216.367667
1	CH4	33.801923
2	Aggregate F-gases	13.490000
3	F-Gas	13.392000
4	N2O	11.524444

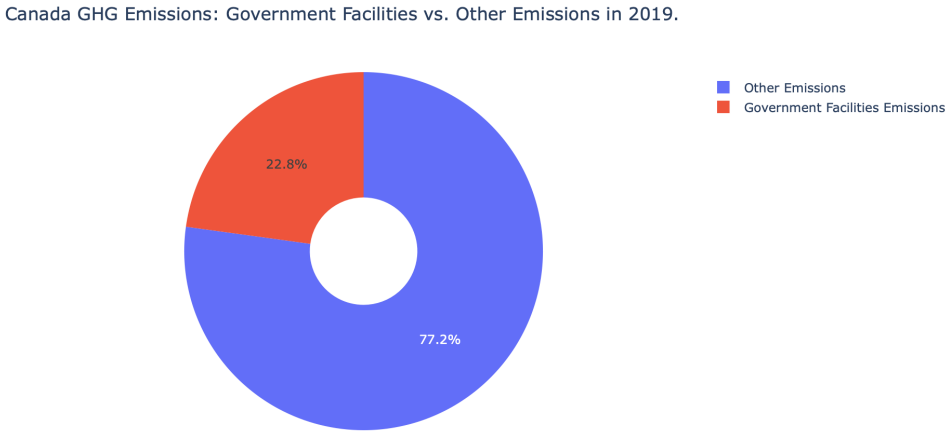
(Output for most emitted GHG)

CO2 leads the way by many folds, followed by CH4. This can explain the specific attention towards reducing these high contributors as they are the major emitters.

Q4. What is the percentage contribution of Canadian government facilities to the country's total GHG emissions in the latest available year in the historical_global_emissions dataset (2019-2020)?

4.1.7. Government v/s country's GHG emissions

This query provides insight into the role of government facilities in Canada's total GHG emissions and can help identify areas where emissions reduction efforts could be targeted. We see that Canadian government facilities produced 22.8% of the country's GHG emissions, which is substantial and hence explains the area of intervention to reduce emissions by the government.



(Plots for Govt Organization's contribution to national GHG Emission)

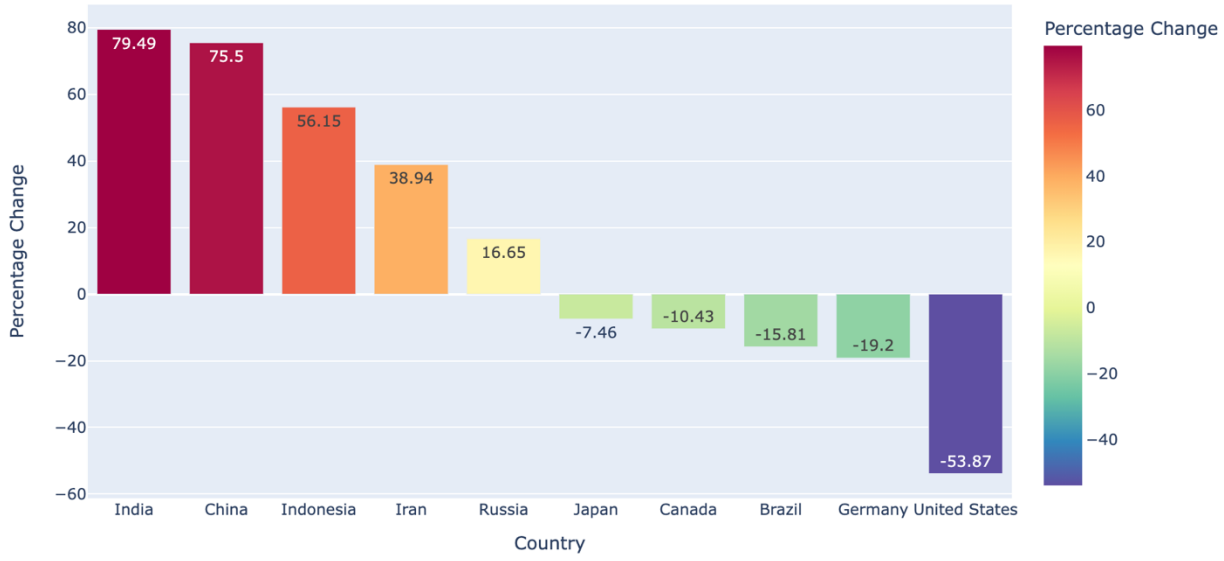
4.1.8. Global comparison of GHG emissions

Here, we retrieve the countries with the highest GHG emissions, which provides a global perspective on emissions and allows for comparisons between Canada and other countries. We calculate the percentage change in emissions for the top 10 emitting countries from 2005 to 2019. This query offers valuable information on the trends in emissions for the top contributors and can be used to benchmark Canada's progress in reducing emissions against other countries.

	Country	Emissions_2005	Emissions_2019	Percent_Change
0	India	6998.99	12562.380000	79.49
1	China	27066.93	47501.320000	75.50
2	Indonesia	3572.11	5577.690000	56.15
3	Iran	2494.86	3466.480000	38.94
4	Russia	7361.43	8587.300000	16.65
5	Japan	4907.43	4541.430000	-7.46
6	Canada	3269.47	2928.460000	-10.43
7	Brazil	5261.14	4429.230000	-15.81
8	Germany	3567.44	2882.410000	-19.20
9	United States	52059.81	24014.806163	-53.87

(Output rate change in emissions for the top 10 emitting countries)

We plot the percentage change from the query result. We can infer from the plot that countries are on both sides of the spectrum. For example, countries such as India, China and Indonesia are leading to an alarming increase in emissions. On the opposite side, more developed countries (including Canada) see a negative change meaning a reduction of emissions from 2005 to 2019.



(Plots for rate change in emissions for the top 10 emitting countries)

4.2 Electricity and Gas Consumption by Non-Government Users

Q1. What is Province's energy consumption trend over the years?

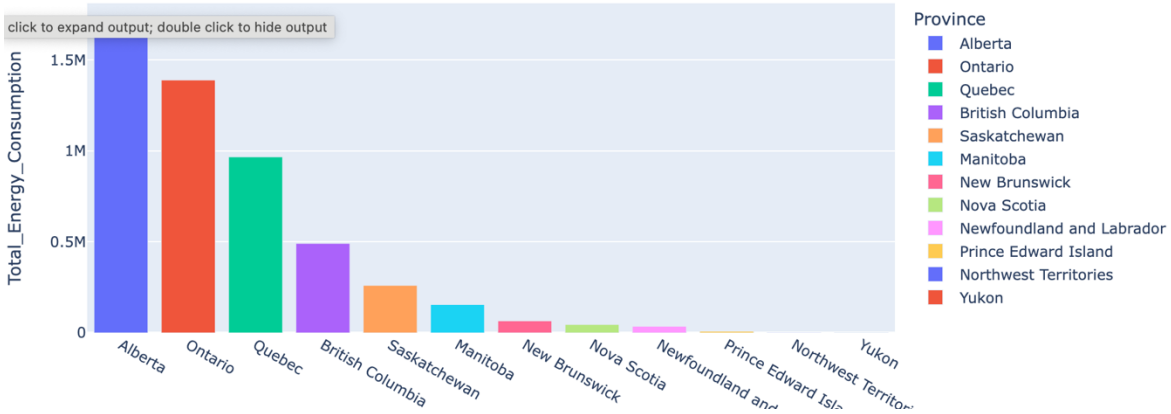
4.2.1. Total energy consumption

We query to get all the provinces' electricity and natural gas consumption over the years.

	Year	Geography	natural_gas_consumption_...	electricity_consumption_Total	Total Energy Consumption
0	2012	Alberta	1069402.0	203237.0	1272639.0
1	2012	British Columbia	238099.0	215167.0	453266.0
2	2012	Manitoba	67369.0	75479.0	142848.0
3	2012	New Brunswick	18063.0	46187.0	64250.0
4	2012	Newfoundland and …	0.0	36346.0	36346.0
...	...	...	...	...	...
115	2021	Ontario	887541.0	501599.0	1389140.0
116	2021	Prince Edward Isl…	2200.0	6457.0	8657.0
117	2021	Quebec	236117.0	730631.0	966748.0
118	2021	Saskatchewan	176745.0	83532.0	260277.0
119	2021	Yukon	1.0	1678.0	1679.0

(Output for Province's energy consumption trend over the years)

It will be easier to summarize this result in a plot. First, we see that total energy consumption for Alberta and Ontario is high. They consume more than half of the country's total energy.



(Plot for Province's energy consumption trend over the years)

4.2.2. Maximum energy consumption by province every year

We sum natural gas and electricity consumption over the years 2012 to 2019. This information helps the government direct their efforts toward the main contributor. To improve, the direction of the steps to reduce consumption must also be effective at lower levels.

We see that Alberta is the leader in energy consumption most years. However, judging by the knowledge that it is not one of the provinces with a high population, this consumption might be explained by industrial activities in the region or the residents of Alberta consuming more energy.[xvi]

	Year	Geography	Total_Energy_Consumption_MAX
0	2012	Alberta	1272639.0
1	2013	Ontario	1359264.0
2	2014	Ontario	1402467.0
3	2015	Alberta	1400702.0
4	2016	Alberta	1362810.0
5	2017	Alberta	1468236.0
6	2018	Alberta	1602740.0
7	2019	Alberta	1646436.0
8	2020	Alberta	1562189.0
9	2021	Alberta	1628084.0

(Output Maximum energy consumption by province every year)

Q2. How does natural gas consumption compare between residential and industrial users?

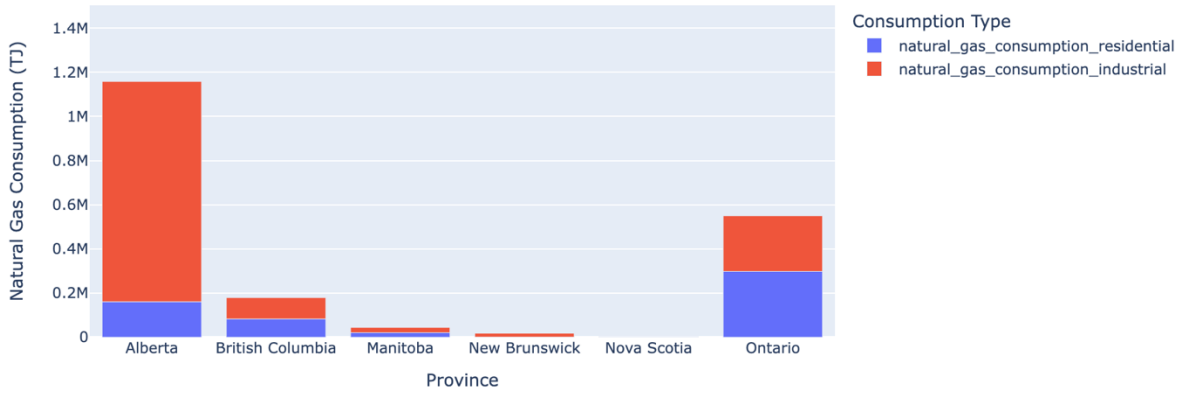
4.2.3. Comparing natural gas consumption between residences and industries

Through this query, we get the natural gas consumption by residential and industrial sources for all the provinces over the years. Government policies can restrict natural gas usage by enterprises. Just like vehicles have emissions regulations, knowing such information can help regulate the rules to control industrial emissions.

	Year	Geography	natural_gas_consumption_residential	natural_gas_consumption_industrial
0	2012	Alberta	168173.0	760275.0
1	2012	British Columbia	78164.0	82458.0
2	2012	Manitoba	19960.0	24573.0
3	2012	New Brunswick	617.0	14882.0
4	2012	Ontario	308741.0	235414.0
...	...	...	...	...
69	2021	New Brunswick	541.0	17228.0
70	2021	Nova Scotia	308.0	2542.0
71	2021	Ontario	297963.0	251524.0
72	2021	Quebec	26809.0	141140.0
73	2021	Saskatchewan	37899.0	77232.0

(Output to show Comparing natural gas consumption between residences and industries)

For better representation, we plot a bar graph. We can see from the plot that our inference from query 2 is correct that Alberta has high levels of industrial activities. High residential consumption in Ontario can be explained by its high population.[xvi]



(Plot for comparison between natural gas consumption between residences and industries)

4.2.4 Maximum and minimum natural gas consumption by Province

In Canada, we have differences in policies between provinces. The same is true for sustainability actions taken by provinces. Although this is a complex topic as we'd have to analyze the demographics, industries, etc., to know why provinces have different approaches towards the same goal, reducing carbon emissions. Hence, as a starting point, we can start by looking at the differences in actions taken by the province with maximum and minimum consumption.

	Year	Geography	naturalgas_consumption_residential	naturalgas_consumption_industrial	total_consumption	Consumption_Type
0	2021	Nova Scotia	308	2542	2850	Lowest
1	2021	Alberta	160589	997561	1158150	Highest

(Output for Maximum and minimum natural gas consumption by province)

Here, we get the province that is the minimum and maximum natural gas consumers. We see a massive difference in natural gas consumption between the highest user (Alberta) and the lowest user (Nova Scotia).

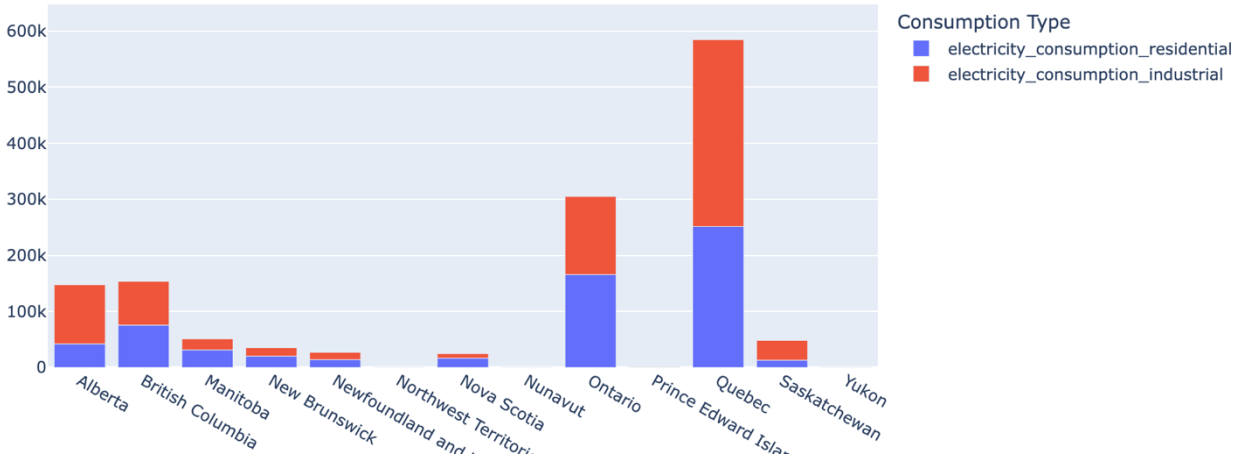
Q3. How does electricity consumption compare between residential and industrial users?

4.2.5. Comparing electricity consumption between residences and industries

Through this query, we get the electricity consumption by residential and industrial sources for all the provinces over the years. Electricity is the backbone of a country, and using this source as efficiently as possible is vital for a country.[xvii] However, it is still mainly generated using un-clean sources (such as coal), as we will discuss further when we analyze renewable energy production.

	Year	Geography	electricity_consumption_residential	electricity_consumption_industrial
0	2012	Alberta	33238.0	101548.0
1	2012	British Columbia	69292.0	82703.0
2	2012	Manitoba	28108.0	26826.0
3	2012	New Brunswick	19266.0	15174.0
4	2012	Newfoundland and L…	13874.0	14034.0
...	...	...	...	...
125	2021	Ontario	165804.0	139064.0
126	2021	Prince Edward Isla…	1027.0	1224.0
127	2021	Quebec	251540.0	333279.0
128	2021	Saskatchewan	13065.0	35371.0
129	2021	Yukon	741.0	199.0

(Output for comparison between electricity consumption between residences and industries)



(Animated Plot for comparison between electricity consumption between residences and industries)

We plot the data to accommodate all the values. Quebec leads in consuming electricity from residential and industrial sources, followed by Ontario. It is interesting to note the difference in the results compared to the natural gas usage we observed in the previous query (query 3).

6. Maximum and minimum electricity consumption by province

As discussed in the above query, knowing which province is doing well in reducing its dependency on energy sources and which is consuming the most is vital. We already compared natural gas, and now we compare electricity usage. Electricity is essential for residential use as well as industrial use. Therefore, electricity is arguably the most critical resource a country can manage.

	Year	Geography	electricity_consumption_residential	electricity_consumption_industrial	total_consumption	Consumption_Type
0	2021	Nunavut	258	2	260	Lowest
1	2021	Quebec	251540	333279	584819	Highest

(Output for Maximum and minimum natural gas consumption by province)

Here, we get the province that is the minimum and maximum electricity consumer. However, we also see a massive difference in electricity consumption between the highest (Quebec) and the lowest (Nunavut).

4.3. Renewable Energy Production

Q1. What is the energy production by Province for each energy source?

4.3.1. Energy Production Capacity by Province

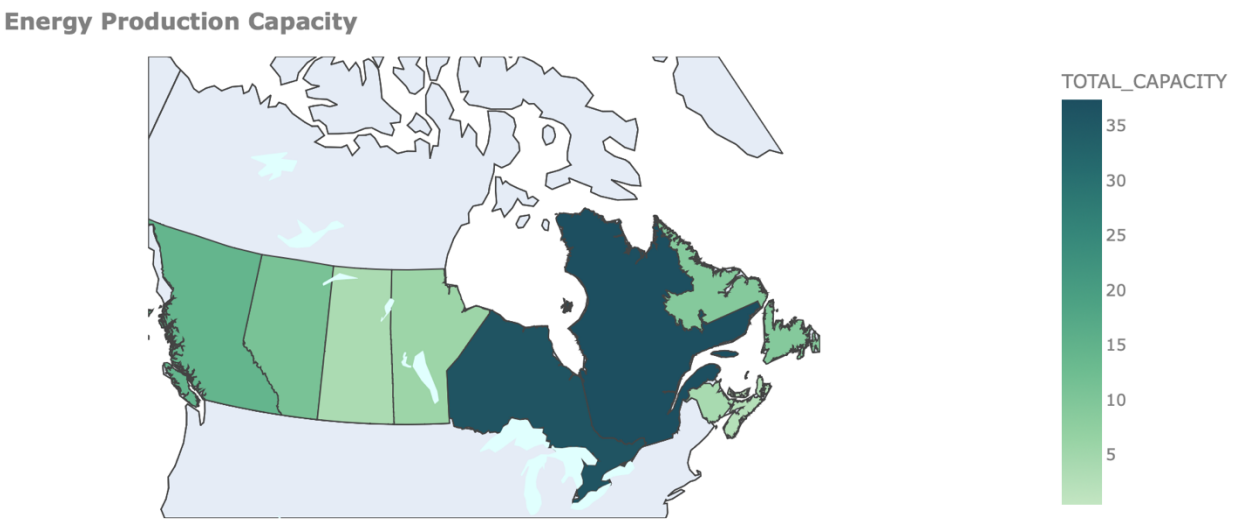
We sum up energy production capacity and filter them by provinces from 2010 to 2022. For an energy source, there is a distinction between capacity and generation.

	Location_Name	year	TOTAL_CAPACITY
0	Alberta	2010	10.979996
1	British Columbia	2010	14.412660
2	Manitoba	2010	5.539872
3	New Brunswick	2010	4.211563
4	Newfoundland and Labrador	2010	9.119056
...	...	...	...
65	Nova Scotia	2022	2.964603
66	Ontario	2022	39.322929
67	Prince Edward Island	2022	0.563712
68	Quebec	2022	42.394476
69	Saskatchewan	2022	4.212216

(Output for energy production capacity by province)

The production output (measured in GW) at full utilization of all available resources, such as wind turbines and solar cells, is called capacity. Yet, regardless of the source's capability, generation refers to the actual product that is seen. Therefore, the total capacity for energy production per province is the result of our initial query.

An animated gap minder map plot can better visualize this.



(Plot for energy production capacity by province - The year 2022)

Darker shade refers to higher production capacity. Ontario and Quebec have the maximum production capacity, while Nova Scotia and New Brunswick have the least. Comparing the power with 2022, we see a similar distribution with a noticeable increase for British Columbia and Alberta.

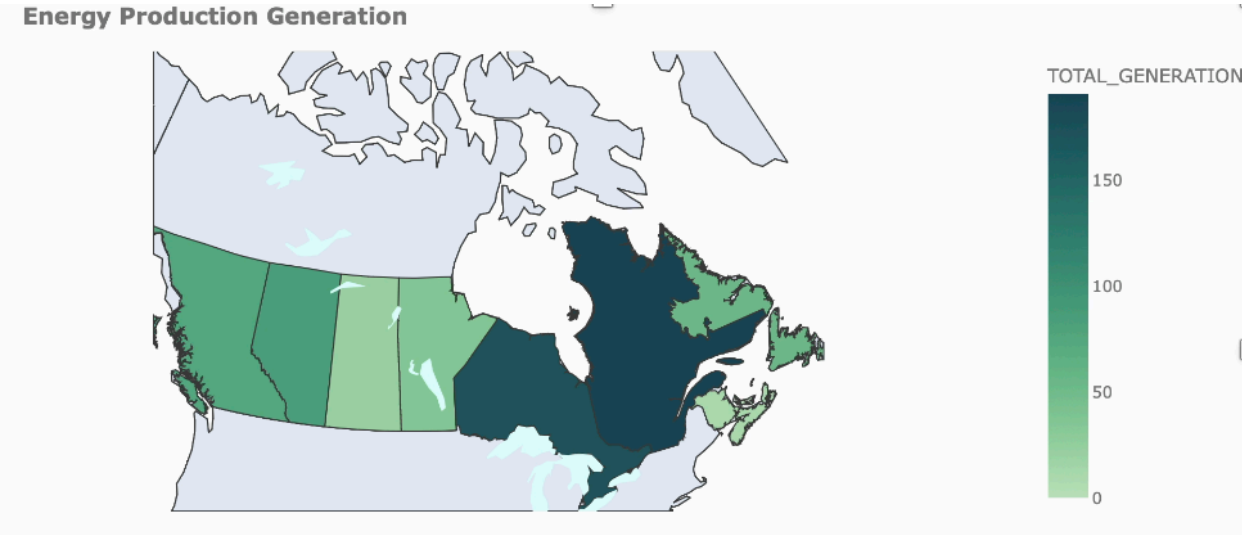
4.3.2. Energy Generation by Province

Building upon the purpose of the previous query, we here calculate the total energy generated by all the sources by individual provinces over the years (in Terawatt hours or TWh). We see an increase in generation as the years pass as the demand increases due to the rise in population and commercial use. We sum up energy generation and filter them by provinces from 2010 to 2022.

	Location_Name	year	TOTAL_GENERATION
0	Alberta	2010	63.550202
1	British Columbia	2010	63.238973
2	Manitoba	2010	31.539256
3	New Brunswick	2010	12.294318
4	Newfoundland and Labrador	2010	49.770459
...	...	...	...
65	Nova Scotia	2022	10.450258
66	Ontario	2022	171.219157
67	Prince Edward Island	2022	0.001143
68	Quebec	2022	190.396980
69	Saskatchewan	2022	22.033790

(Output for energy generation by province - The year 2022)

We plot the results for better understanding. We see a similar trend as capacity. For 2010, Ontario and Quebec generated the highest energy while New Brunswick and Saskatchewan produced the least. Comparing the generation with 2022, we see a similar distribution with a noticeable increase for British Columbia and Alberta.



(Plot for energy production generation by province - The year 2022)

Q2. What is the trend in energy production by energy sources?

4.3.3. Maximum Generation by Source

This search displays the most energy sources, arranged by year. This will show which energy source is most common throughout time and the actual value of energy production.

	year	MAX_Value	SOURCE
0	2010	1909.381521	coal_TWh
1	2012	1474.046784	coal_TWh
2	2014	1704.458085	coal_TWh
3	2016	1447.847544	gas_cc_TWh
4	2018	1310.942403	gas_cc_TWh
5	2020	1325.081282	gas_cc_TWh
6	2022	1343.257397	gas_cc_TWh
7	2024	1334.194824	gas_cc_TWh
8	2026	1303.425907	gas_cc_TWh
9	2028	1298.136260	gas_cc_TWh
10	2030	1362.870870	gas_cc_TWh

(Output for maximum generation by Source- year-wise)

Coal was a significant dependency in the past. But from the year 2016 use of natural gas increased to the top. However, we can see that as years pass, the maximum value decreases. We will try to analyze the reason in the fifth query.

4.3.4. Maximum Used Renewable Energy Source

Again, expanding on query 3, since renewable energy sources are essential for producing carbon-neutral energy, we compare which renewable energy source has been used the most in Canada. This can also reveal patterns between popular sources now and those that will be popular in the future.

Again, hydroelectricity leads in renewable energy generation for a large part of this and the next decade. However, this time we have to go even further to see that after 2038, wind energy generation will be the most used renewable energy source, passing hydroelectricity.

	year	MAX_Value	SOURCE
0	2010	666.651451	hydro_TWh
1	2012	703.853839	hydro_TWh
2	2014	684.070224	hydro_TWh
3	2016	694.575423	hydro_TWh
4	2018	718.904284	hydro_TWh
5	2020	724.004164	hydro_TWh
6	2022	725.307118	hydro_TWh
7	2024	730.651963	hydro_TWh
8	2026	733.392932	hydro_TWh
9	2028	735.185371	hydro_TWh
10	2030	740.091718	hydro_TWh
11	2032	743.575122	hydro_TWh
12	2034	743.898928	hydro_TWh
13	2036	744.646904	hydro_TWh
14	2038	787.476386	wind_TWh
15	2040	870.479683	wind_TWh
16	2042	944.261002	wind_TWh
17	2044	1090.028829	wind_TWh
18	2046	1233.427503	wind_TWh
19	2048	1345.330777	wind_TWh

(Output for maximum used renewable energy source- year-wise)

4.3.5. Analyzing citizen's contribution

With lowering carbon emissions, there are main subjects to consider. The first is the government, which we have been contrasting thus far, and the second is the people or the nation's citizens. The only practical renewable energy source available to the average inhabitant of the country is solar electricity. We will therefore contrast the output of distributed photovoltaic solar (small-scale, personal home use) and utility photovoltaic solar (commercial solar farms). Finally, we compare current levels with the year 2036.

	year	Distributed_Solar	Utility_Solar
0	2022	0.859348	2.631349
1	2036	3.335046	3.252112

(Output for Analyzing Citizen's Contribution)

The positives are that generation of electricity using both sources is increasing. In addition, utility photovoltaic solar sources produce significantly more electricity than distributed sources. Hence,

over time, solar energy for personal use will become more affordable, and awareness of our important cause will also cause people to switch to sustainable sources.

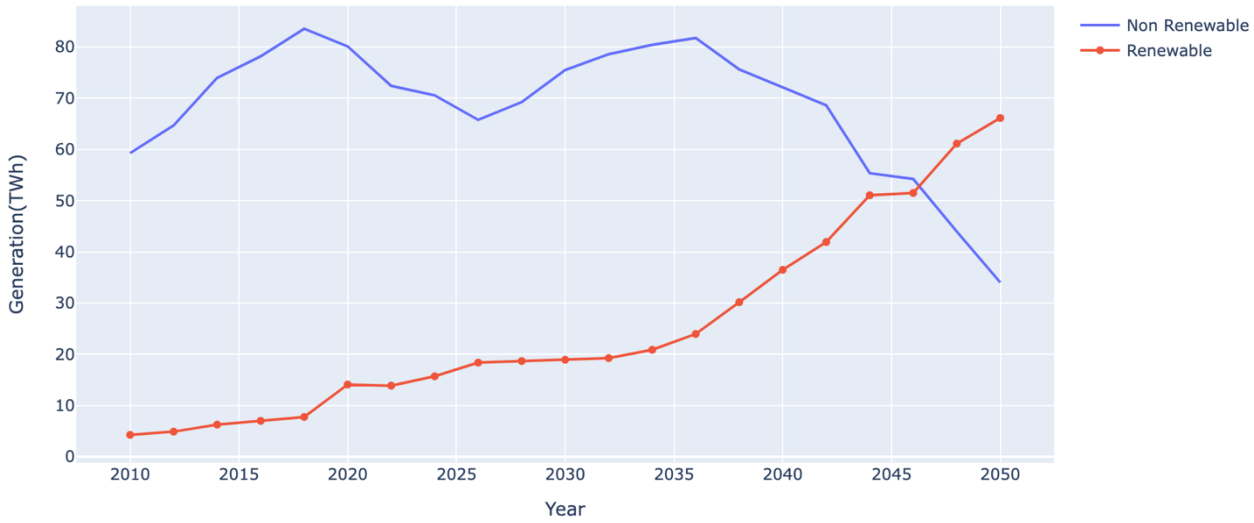
Q3. How does renewable energy production compare to non-renewable energy production?

4.3.6. Comparing Non-Renewable and Renewable Energy Generation

The government must invest in renewable energy sources and work towards making them the primary source of energy generation to achieve the carbon zero target. Hence, we evaluate energy generation between non-renewable and renewable sources to see whether this will be the case. We compare the years 2010 to 2050.

	year	NON_RENEWABLE	RENEWABLE
0	2010	59.280136	4.270066
1	2012	64.684612	4.904435
2	2014	73.964437	6.273801
3	2016	78.177192	7.012001
4	2018	83.557442	7.765152
5	2020	80.120516	14.102954
6	2022	72.407805	13.877950
7	2024	70.555097	15.703892
8	2026	65.770905	18.377459
9	2028	69.236811	18.688944
10	2030	75.510822	18.932401

(Output for Comparing Non-Renewable and Renewable Energy Generation)



(Plot for Comparing Non-Renewable and Renewable Energy Generation)

We plot values to look over all the deals from the table. We see that non-renewable sources start at a considerable high compared to renewable sources. But as government reforms begin taking shape and their investments in renewable energy start to give returns, we see that in the

future, around 2045, renewable energy sources will finally surpass non-renewable energy sources and will continue to rise. The rise in renewable energy can explain the decrease in maximum value in query 3.

4.3.7. Comparing energy generation rate with the corresponding CO2 emission rate

Finally, we compute the rate of rise (%) between 2022 and 2050 to directly see the increase in energy generation from the current year with the final goal year of 2050 established by the government. The percentage change in CO2 emissions for energy production over the same period will be calculated which is more significant. Even if the government's initiatives could enhance energy production, CO2 emissions must decrease in the ideal case.

	Generation_diff	CO2_diff
0	13.867246	39.973246

(Output for comparing energy generation rate with the corresponding CO2 emission rate)

Although energy generation is only up by 13.86%, CO2 generated during the production of energy increases by almost 40%. This means that although the rate of growth decreases over time, as the population rises, to meet the demand, Canada might have to stay dependent on non-renewable sources in the future.

5. Group Guiding Questions

5.1. How does household energy consumption compare to government facilities' consumption?

This query lets us know who consumes more energy- residents or government facilities. This is crucial because we'd learn from this where to direct our efforts to reduce energy consumption and, in turn, reduce carbon emissions.

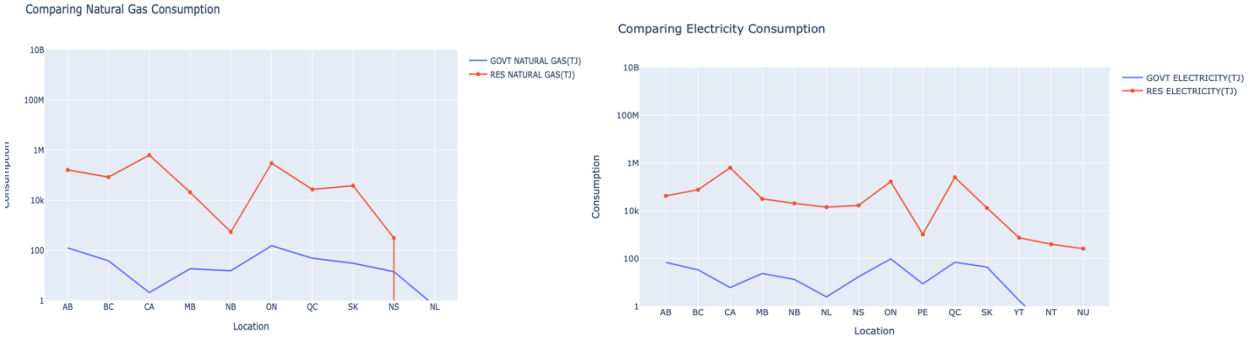
	Year	Geography	electricity_consumption_residential	electricity_consumption_industrial
0	2012	Alberta	33238.0	101548.0
1	2012	British Columbia	69292.0	82703.0
2	2012	Manitoba	28108.0	26826.0
3	2012	New Brunswick	19266.0	15174.0
4	2012	Newfoundland and Labrador	13874.0	14034.0
...	...	...	...	...
125	2021	Ontario	165804.0	139064.0
126	2021	Prince Edward Island	1027.0	1224.0
127	2021	Quebec	251540.0	333279.0
128	2021	Saskatchewan	13065.0	35371.0
129	2021	Yukon	741.0	199.0

(Output for comparing household electricity consumption to government facilities' consumption)

	Year	Geography	natural_gas_consumption_residential	natural_gas_consumption_industrial
0	2012	Alberta	168173.0	760275.0
1	2012	British Columbia	78164.0	82458.0
2	2012	Manitoba	19960.0	24573.0
3	2012	New Brunswick	617.0	14882.0
4	2012	Ontario	308741.0	235414.0
...	...	...	...	...
69	2021	New Brunswick	541.0	17228.0
70	2021	Nova Scotia	308.0	2542.0
71	2021	Ontario	297963.0	251524.0
72	2021	Quebec	26809.0	141140.0
73	2021	Saskatchewan	37899.0	77232.0

(Output for comparing household natural gas consumption to government facilities' consumption)

We have conveyed the difference in how much the residential consumption exceeds the government consumption shows us a vital region to work upon.



(Plot for comparing natural gas and electricity consumption in residential vs that of government facilities)

5.2. What are the total aggregate CO2 emissions of energy production and the historical emissions?

This query shows our final metrics upon which this whole project is based. The final aim is to reduce CO2 emissions; as a result, it is essential to have a measure of it to analyze if the government's actions are helping. We see that the rate of increase of CO2 is reducing, which is a good sign. However, this number will continue to rise until we can reduce consumption levels, non-renewable energy production, and residential and industrial emissions.

	Gas	TOTAL_CO2	Year
0	CO2	60388.597987	2010
1	CO2	60444.473321	2012
2	CO2	60516.953980	2014
3	CO2	60573.971276	2016
4	CO2	60630.686293	2018

(Output for total aggregate CO2 emissions of energy production and the historical emissions)

5.3. How does energy generation change based on the consumption demand?

As years pass, the population increase, new industries are set up, and as a result, the energy consumption rate increases. To meet the demand, governments have to work on increasing the rate at which they generate energy. So, here we compare the rate of increase in consumption so far with the increase in generation by renewable and non-renewable sources. Ideally, to reduce emissions and meet the demand, the growth rate of renewable energy growth has to be relatively high.

nonrenewable_production_rate_of_change	renewable_production_rate_of_change	consumption_rate_of_change
23.863333	187.555125	6.5647

(Output for energy generation changes based on the consumption demand)

This is the data for the past decade. We see that the generation rate is higher than the consumption rate, which is expected. The positive is that renewable energy production has increased by 187% over time while non-renewable energy has increased by 23.8%.

6. Summarizing Results

6.1. Findings on GHG emissions

- Emissions for government facilities have been reduced over the past decade.
- Diesel is the most used fuel, and its use has remained constant.
- Ontario is the province that generates the maximum emissions, while Yukon causes the least, which is in line with their respective populations.
- Government facilities produce 22.8% of the country's GHG emissions.
- Canada is one of the few nations with decreasing emissions when compared globally.

6.2. Findings on energy consumption

- Alberta and Ontario consume the most energy.
- Alberta has the highest industrial natural gas consumption, while Ontario leads for residential natural gas consumption. Nova Scotia has the least combined consumption.
- Quebec has both the highest industrial and residential electricity consumption. Conversely, Nunavut has the least combined consumption.

6.3. Findings on energy production

- Quebec and Ontario lead both total energy production capacity and generation.
- Though high, dependence on Coal to produce energy is reducing as time passes.
- Hydroelectricity is the most used renewable energy, while wind energy will catch up to it by the year 2038.
- The increase in production through renewable energy will cross non-renewable energy by the year 2046.
- By 2036, distributed solar power will have increased by three folds.
- Though the CO2 emissions continue to rise, the rate of increase is decreasing every year.

Conclusion

Over this project, we aggregated the finding on GHG emissions, energy consumption, and energy production to analyze if the initiatives taken by the Canadian government have been effective so far and if they will reach their goal of achieving net zero emissions by the year 2050. We conclude that they are dialling down on their emission and focusing on increasing their dependency on renewable sources. However, consumption rates are high, and the most challenging task they face is to make the country's citizens join them in their sustainability goals. Therefore, this should be their next point of focus. On average, the report finds that G20 nations provided about 2.5 times more support for fossil fuels than renewables, while in Canada, the ratio is 14.5. [xv]

As a future scope of this project, we can deep even deeper into residential consumption and industrial emissions policies to get insights into which reforms have worked and which need to be updated.

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