Optimizing the Grid

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Agenda

The Climate Challenge

Unchecked, the crisis presents heightened risks of

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Water & Food Insecurity

Extreme Weather Events

Mass Displacement

Competition for Resources

The Climate Challenge

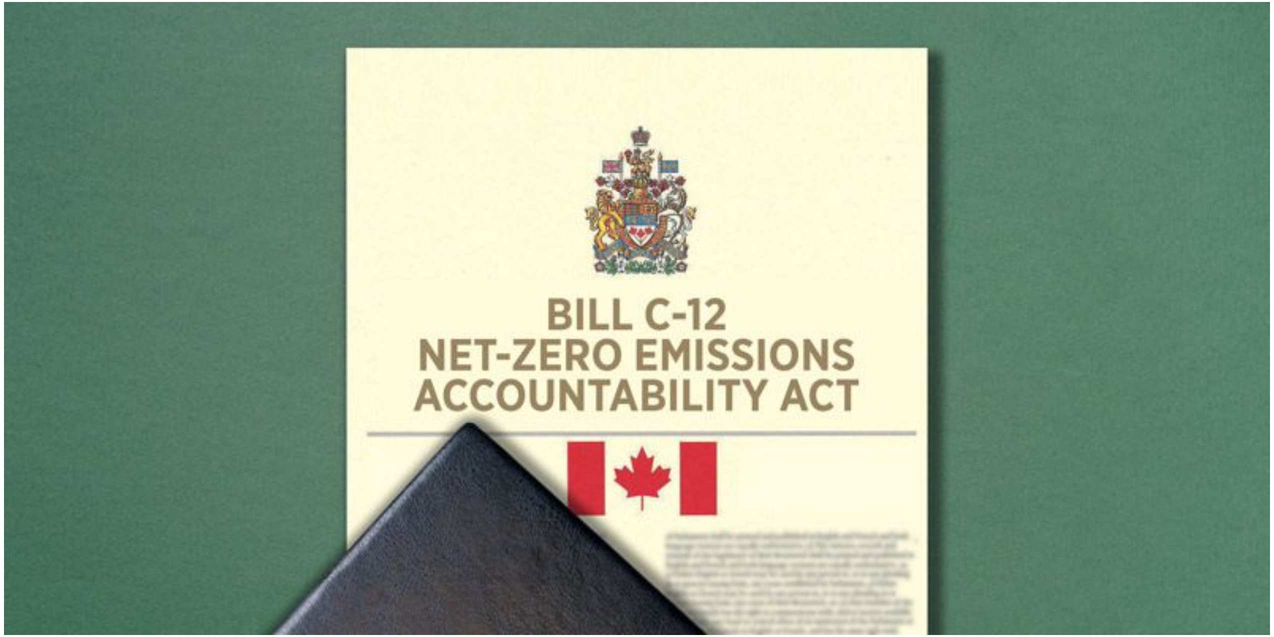
PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

ipcc
INTERGOVERNMENTAL PANEL ON
climate change
WMO UNEP

GREEN
CLIMATE
FUND

United Nations
Framework Convention on
Climate Change

The Climate Challenge



The Climate Challenge

broad-based changes across our economy

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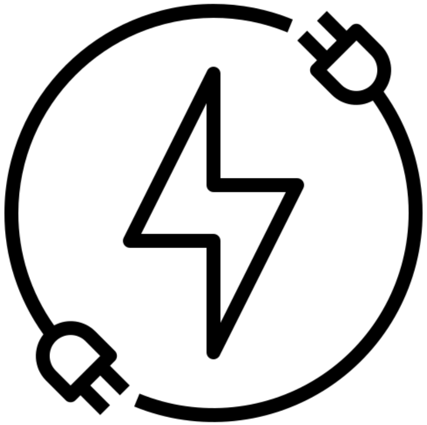

Why Electricity?

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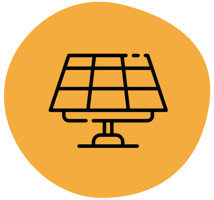
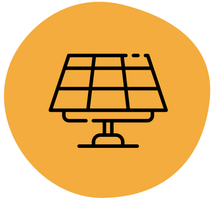


Cornerstone energy source

for a net-zero energy system, as per Energy Regulator's 2023 Energy Futures Report

Why Electricity?



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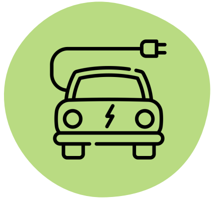
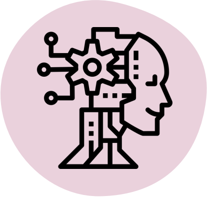


Broader low-carbon transition

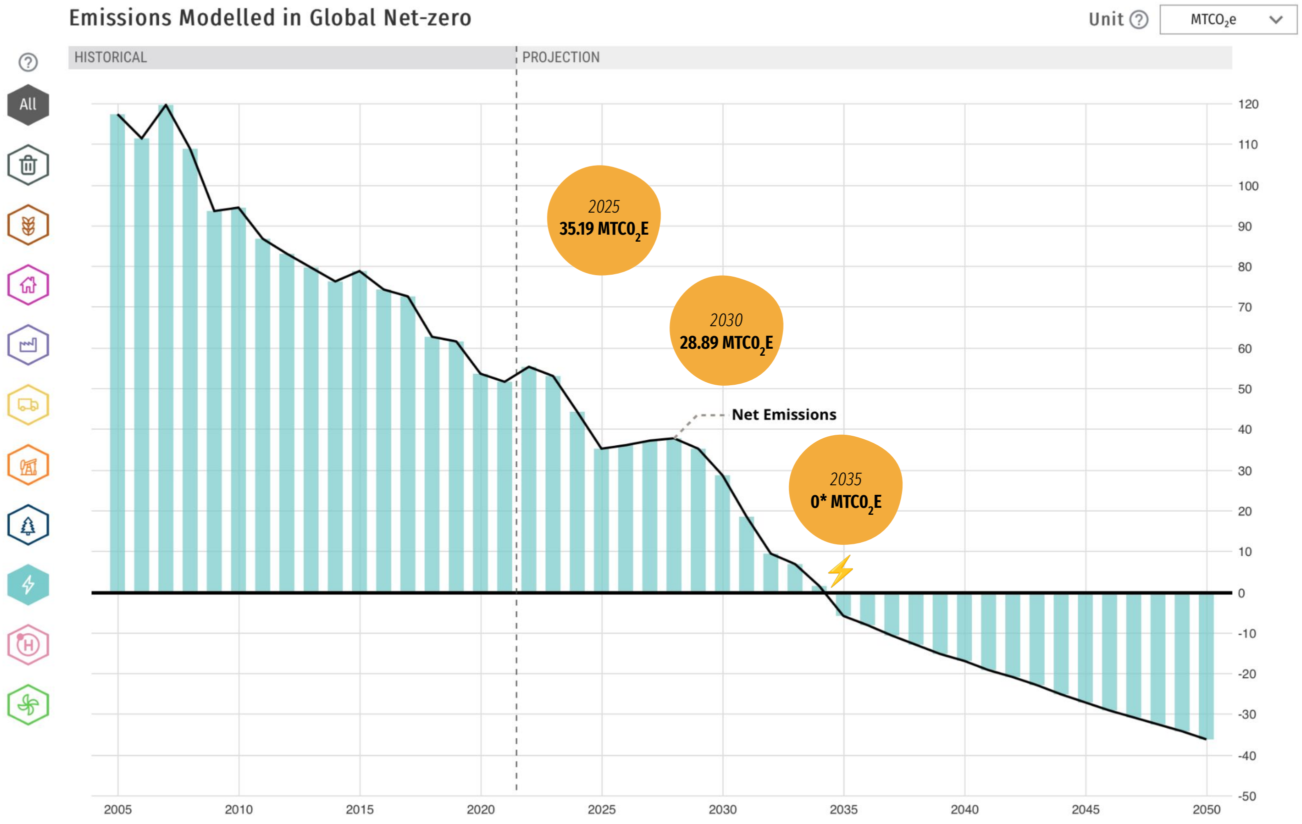
through electrification of technologies currently reliant on non-renewables



Accounting for disruptive tech

with X-times the energy-intensity of incumbent tech

Why Electricity?



The Grid as a Portfolio

Hydro
57.9% of 2022 generation

Nuclear
13.4% of 2022 generation

Natural Gas
13.1% of 2022 generation

Wind
7.7% of 2022 generation

Coal
4.3% of 2022 generation

Solar
1.8% of 2022 generation

Geothermal
1.7% of 2022 generation

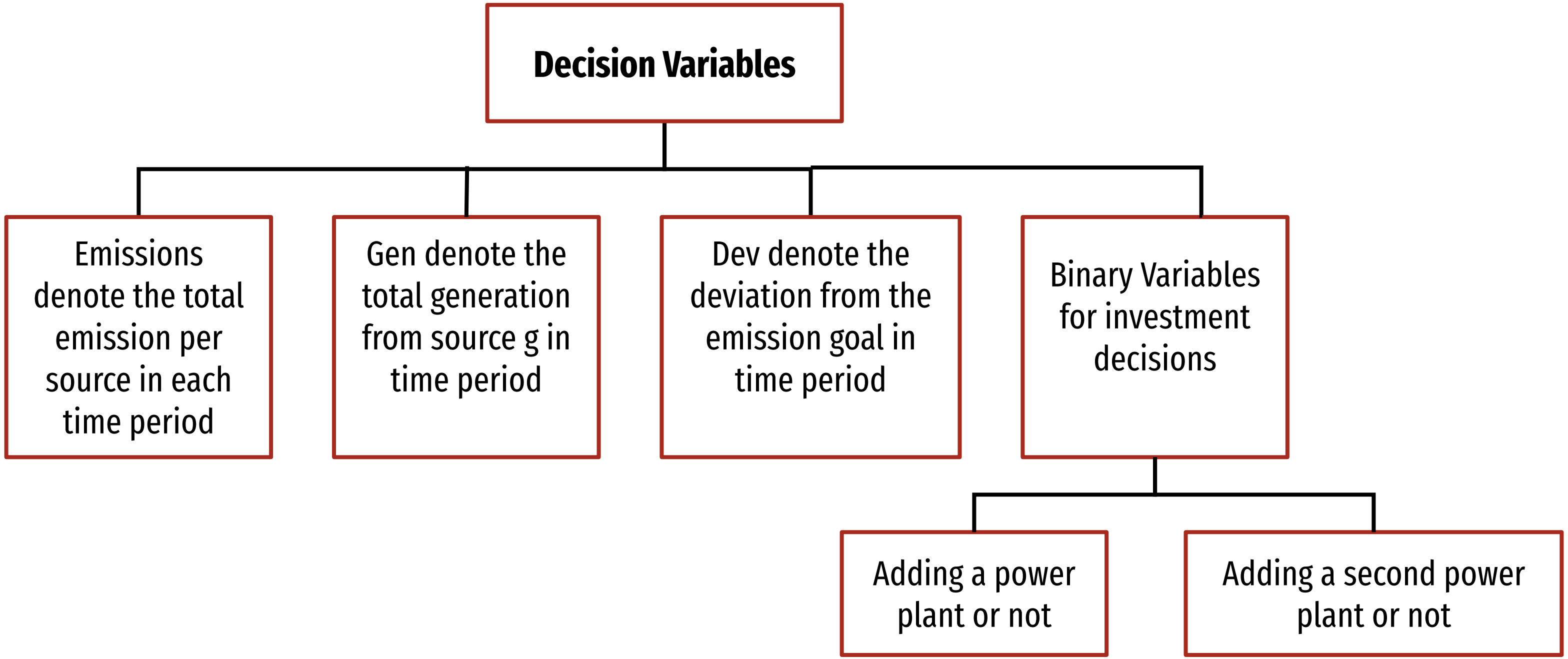
Oil
0.1% of 2022 generation

Base Model Formulation

Minimize total deviation from emissions targets

Minimize total cost

Base Model Formulation



Base Model Formulation

Objective Function

- **Primary**

$$\min \sum_{t \in T} Dev_t$$

- **Secondary**

$$\min Total\_Cost = \sum_{g \in G} \sum_{t \in T} C_{g,t} \cdot Gen_{g,t} + \sum_{g \in \{\text{Wind,Solar,Nuclear}\}} \sum_{t \in \{2030,2035\}} (Increase\_Cost_{g,t} \cdot B^{(1)}_{g,t} + Increase\_Cost_{g,t} \cdot B^{(2)}_{g,t})$$

Base Model Formulation

Constraints

- **Emission Calculation**

$$\sum_{g\in G} Emissions_{g,t} \leq Goal_t + Dev_t \quad \forall t \in T, \forall g \in G$$

$$Emissions_{g,t} = E_{g,t} \cdot Gen_{g,t} \quad \forall t \in T, \forall g \in G$$

- **Demand Satisfaction**

$$\sum_{g\in G} Gen_{g,t} \geq D_t \quad \forall t \in T$$

- **Phase Out Non-Renewable Energy Sources**

$$Gen_{\text{Coal \& Coke},2030} = 0, \quad Gen_{\text{Oil},2035} = 0$$

Base Model Formulation

Constraints

- **Maximum Generation and Capacity Decision Added Constraints**

$$
\begin{aligned}
&\text{In 2025:} && \text{Gen}_{g,2025} \leq F_{g,2025} \quad \forall g \in G \\
&\text{In 2030:} && \text{Gen}_{g,2030} \leq F_{g,2025} + I_{g,2030} \quad \forall g \in \{Wind, Solar, Nuclear\} \\
& && \text{Gen}_{g,2030} \leq F_{g,2025} \quad \forall g \in G \setminus \{Wind, Solar, Nuclear\} \\
&\text{In 2035:} && \text{Gen}_{g,2035} \leq F_{g,2025} + I_{g,2030} + I_{g,2035} \quad \forall g \in \{Wind, Solar, Nuclear\} \\
& && \text{Gen}_{g,2035} \leq F_{g,2025} \quad \forall g \in G \setminus \{Wind, Solar, Nuclear\}
\end{aligned}
$$

$$
I_{g,t} \leq B^{(1)}_{g,t} \cdot \text{Capacity\_Added}_{g,t} + B^{(2)}_{g,t} \cdot \text{Capacity\_Added}_{g,t} \quad \forall g \in \{Wind, Solar, Nuclear\}, \forall t \in \{2030, 2035\}
$$

Base Model Formulation

Constraints

- **Continued**

$$Gen_{g,t} - \text{Utilization\_Threshold} \cdot \left(F_{g,2025} + \sum_{\tau<t} I_{g,\tau}\right) \leq M \cdot (1 - y_{g,t}) \quad \forall g \in \{\text{Wind, Solar, Nuclear}\}, \forall t \in T$$

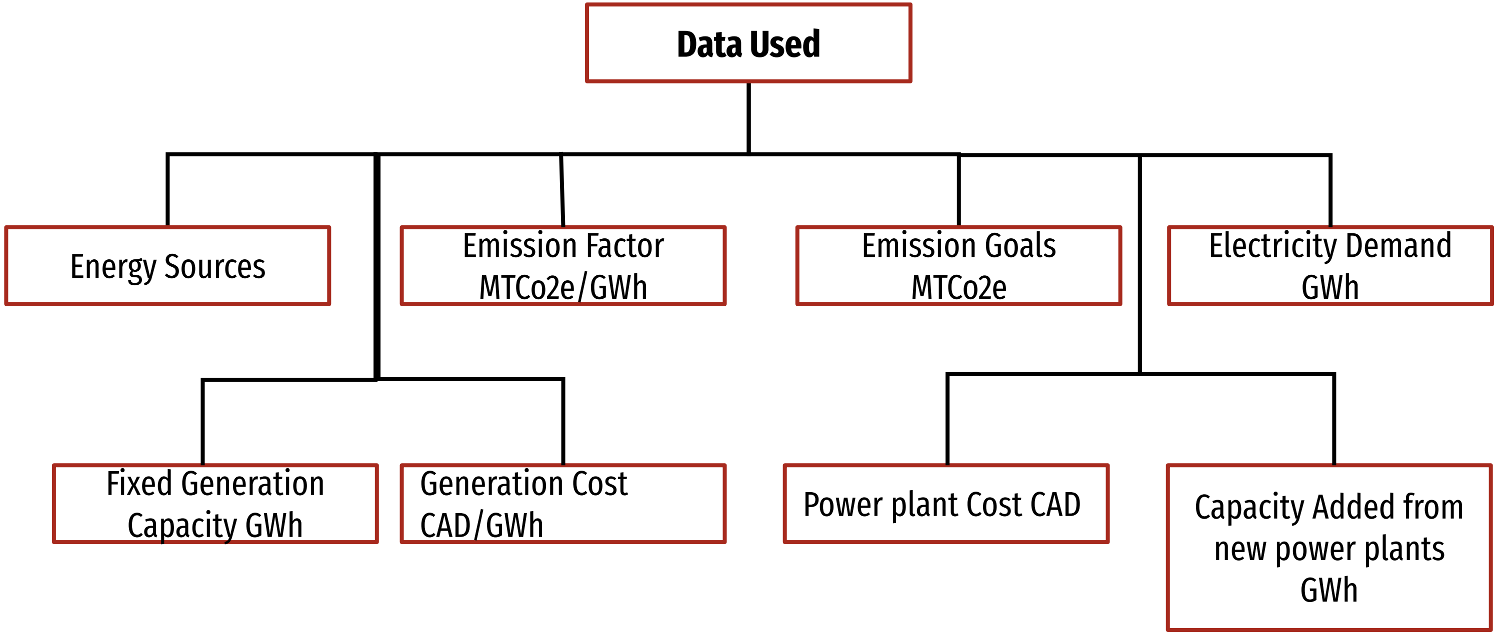
Where y is a binary variable and M is a large number

$$B^{(1)}_{g,t} + M \cdot y_{g,t} \geq 1 \quad \forall g \in \{\text{Wind, Solar, Nuclear}\}, \forall t \in T \tag{3}$$

$$Gen_{g,t} - \text{Utilization\_Threshold} \cdot \left(F_{g,2025} + \sum_{\tau<t} I_{g,\tau} + \text{Capacity\_Added}_{g,t}\right) \leq M \cdot (1 - y^{(2)}_{g,t}) \quad \forall g \in \{\text{Wind, Solar, Nuclear}\}, \forall t \in T \tag{4}$$

$$B^{(2)}_{g,t} + M \cdot y^{(2)}_{g,t} \geq 1 \quad \forall g \in \{Wind, Solar, Nuclear\}, t \in T$$

Base Model Formulation



Results

Results: 2025

- 0.001 MTCO2e deviation with total emission of 35.19 MTCO2e
- Results can inform the optimal pathway towards net-zero for Canada.
- Portfolio predominantly contains hydro, nuclear, and wind.

Results: 2030

- Total emission of 14.49 MTCO2.
- Two wind plants and two nuclear plants were opened with a cost of $27 billion.
- The energy mix geared more towards clean energy with nuclear, nuclear, and wind making up an even larger portion of it.

Results: 2035

- Deviation of 13.50 MTCO2e.
- $15 billion to reduce emission from 14.49 MTCO2e to 13.50 MTCO2

Extension: Canada’s Demand Satisfaction Leeway

- How much leeway does Canada have in demand satisfaction?

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- How much leeway does Canada have in demand satisfaction?

$182,000 / GWh

Goal Programming Extension

Goal Programming Overview

•An extension of multiobjective linear programming

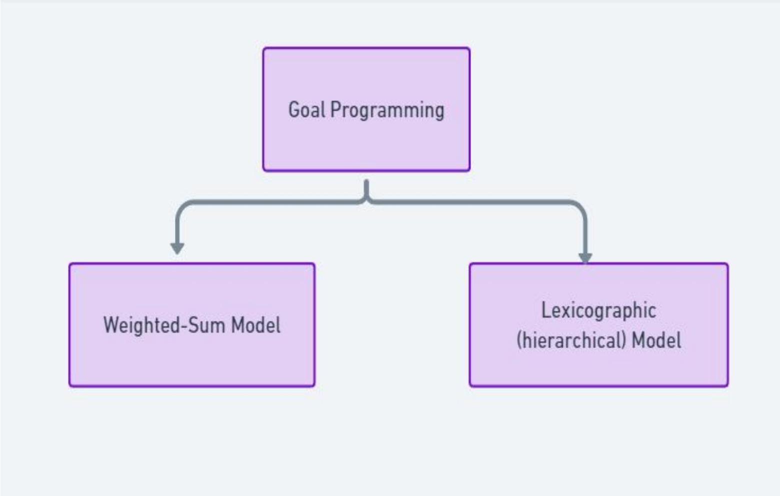
•Two basic models: lexicographic(hierarchical) model and the weighted-sum model.

•Incorporates positive and negative deviation variables with bounds

•The objective function of a goal programming model requires us to always minimize the deviations from the goals.

•Goals are specified for a set of constraints, the non-achievement of these don't make the model unfeasible

•No optimal solution, we want a solution that satisfies our criteria

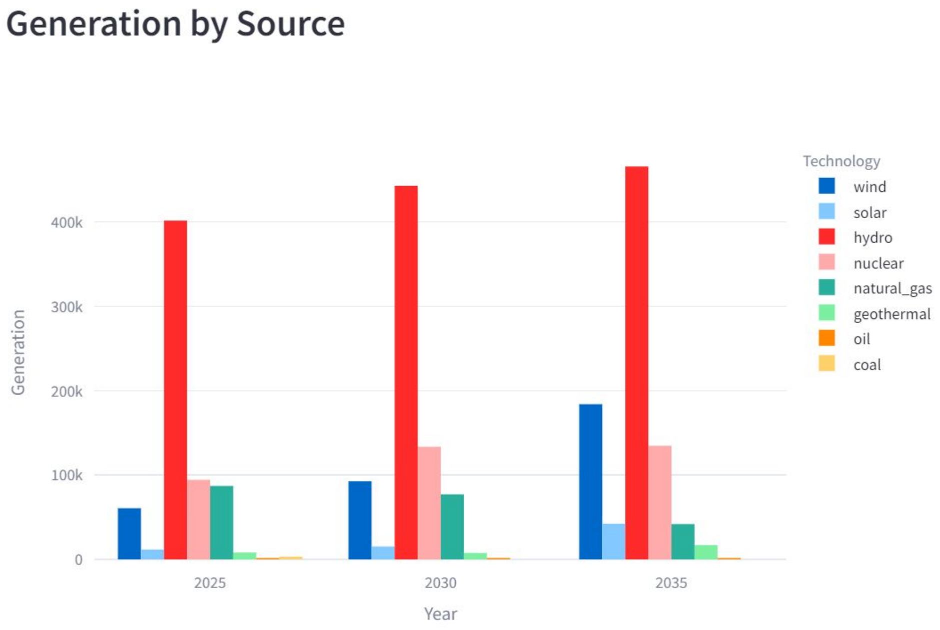


Goal Programming Model

- Our model spans the years **2025**, **2030**, and **2035**
- Prioritizes four main objectives with distinct targets in this order: minimizing emissions deviations (highest priority), generation output, generation capacity, and associated costs.
- It incorporates decision variables and 5% deviation variables for measuring performance against predetermined targets.
- Constraints ensure meeting forecasted demands, avoiding technology capacity exceedance, and staying within defined limits for all goals stated above

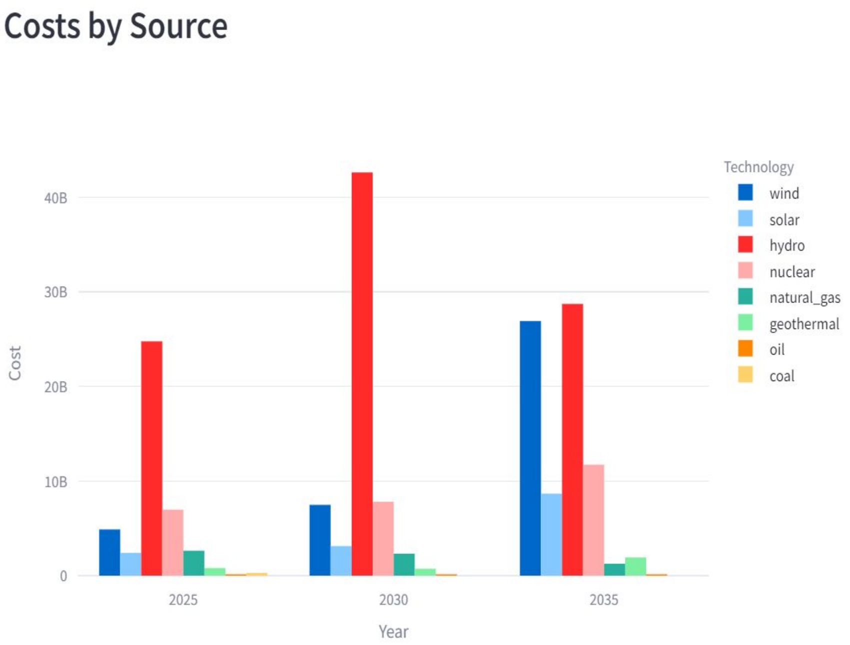
Goal Programming Model Results

- Shift towards renewable energies like wind, nuclear and hydro + hydroelectric power leading in generation and costs.
- **2030** - increased generation for wind and solar and coal phases out
- **2035** - renewable sources reach peak generation and higher costs, particularly for wind energy.
- Hydroelectric and nuclear power maintain high outputs, with geothermal showing potential for growth



Goal Programming Model Results

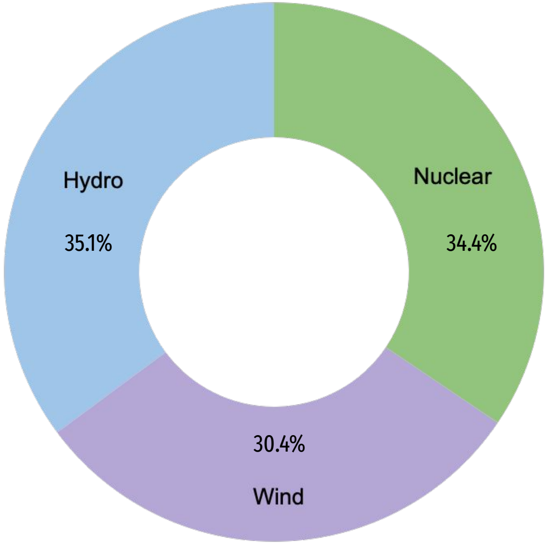
- Critical deviations from the targets, in costs and capacities as we move towards renewable sources by 2035
- Wind energy shows a significant cost increase to CAD 26 billion, highlighting larger-than-expected financial investments.
- Hydroelectric power also sees rising costs, emphasizing the financial challenges in scaling renewables.
- **Overall model indicates a transition towards cleaner energy, though not achieving net zero, due to lifecycle emissions and the absence of carbon capture technology in our model**



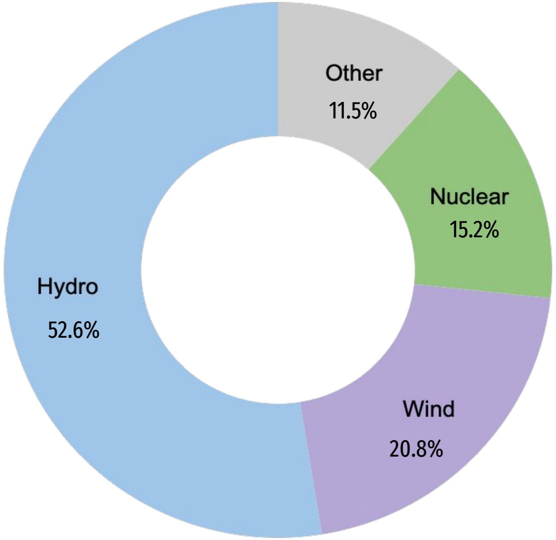
Recommendations

Recommendations

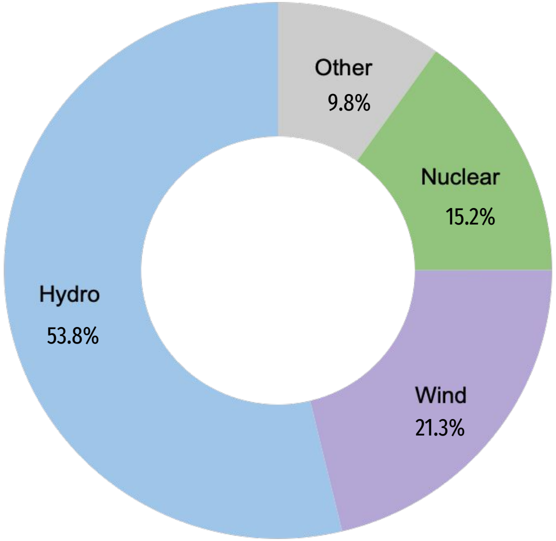
A grid dominated by hydroelectric, wind, and nuclear power



2035, Base Model



2035, Goal Programming Extension

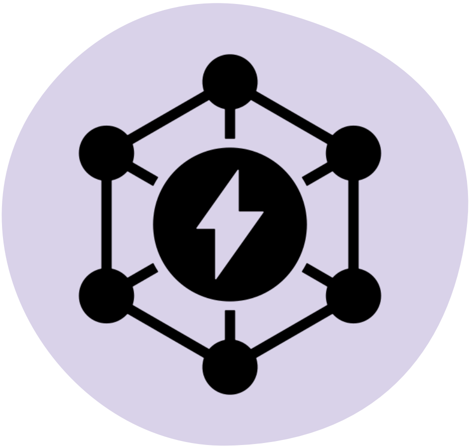


2035, Canada Energy Futures Global Net Zero

Share of Generation by Source

Recommendations

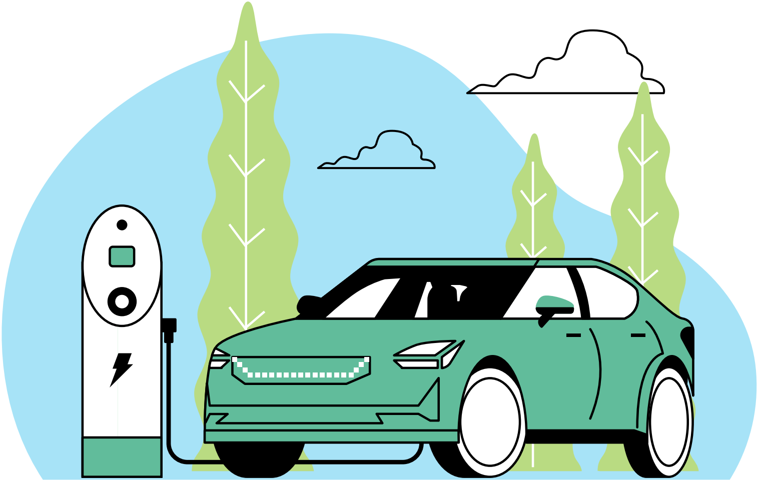
Key Considerations



National Interties

Public Acceptance

Summary & Takeaways



Project Summary, Takeaways, and Lessons Learned

Summary:

- The project develops two models with a hierarchical approach to examine Canada's path to net-zero electricity by 2035 - a MIP model minimizing emissions and costs and a GP model balancing emissions, generation, capacity, and cost.
- MIP enables focused optimization, but GP allows flexibility for complex multi-objective scenarios.

Takeaways:

- Achieving net-zero electricity will require major investments in wind, nuclear and hydro energy while phasing out fossil fuels.
- Also, policy support for renewable sources is key to a viable transition path.

Lessons Learned:

- No model can perfectly predict the future. Uncertainties around costs, technology, demand etc. mean outputs should be considered estimates.
- Models support but don't dictate policy; they are one input for decision making.

Q&A