Energy Modelling Initiative
Bringing the Tools to Support Canada's Energy Transition

Electrification and deep decarbonization of Canada's energy system with small-scale residential prosumers: A case study of Ontario

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POLYTECHNIQUE MONTRÉAL

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- Household model
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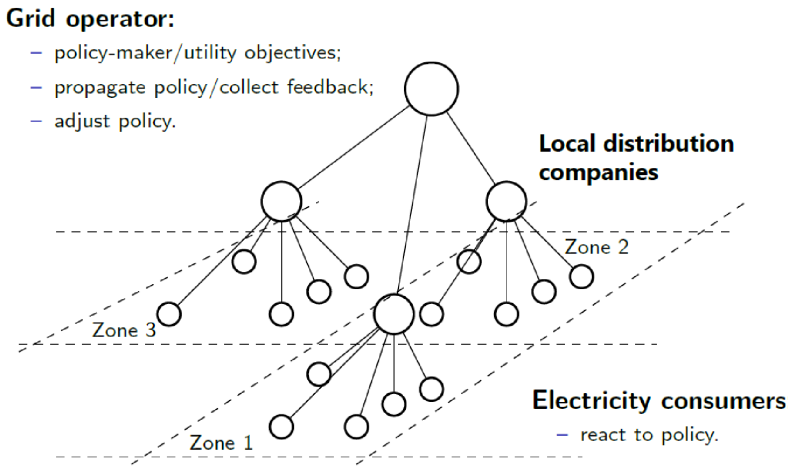
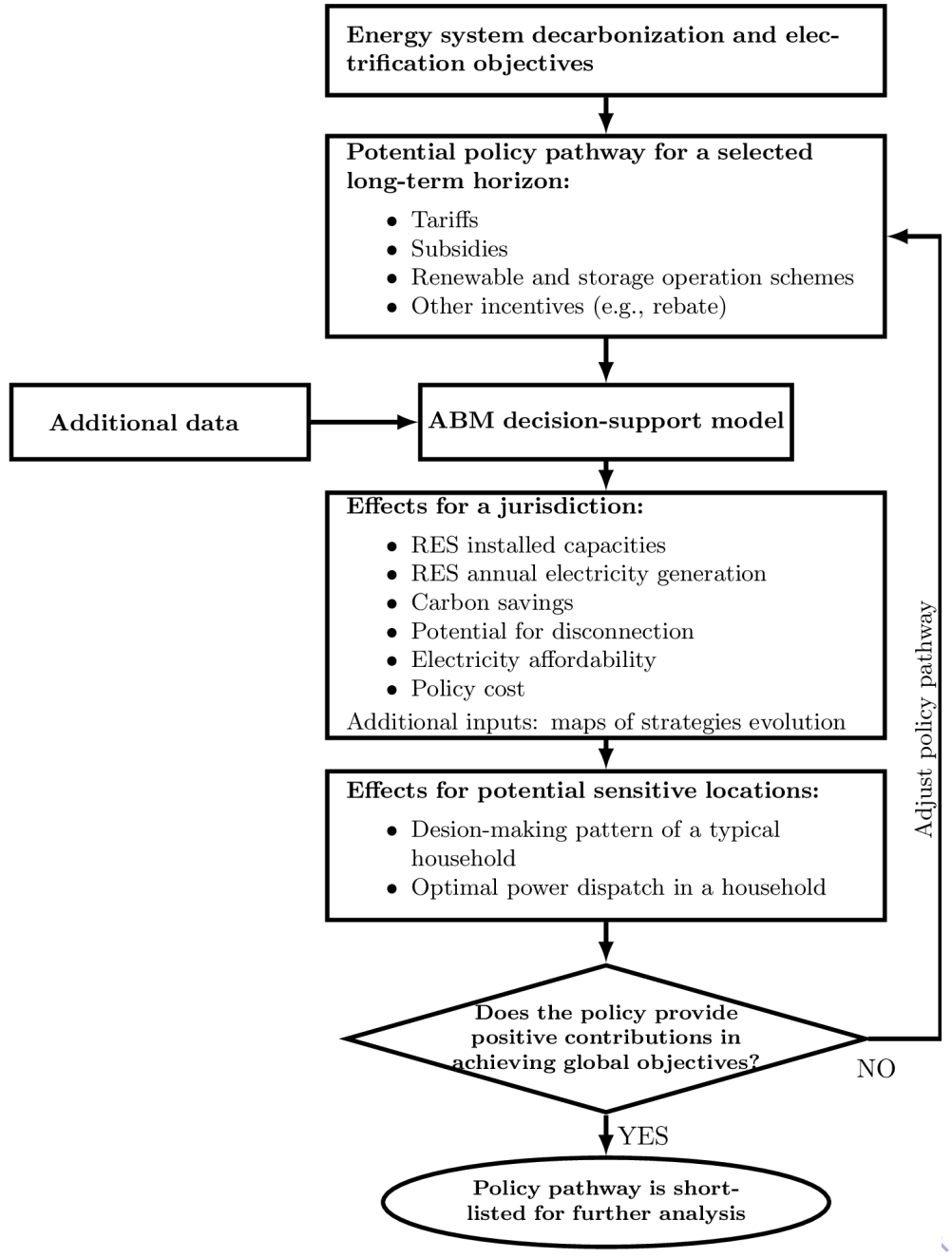
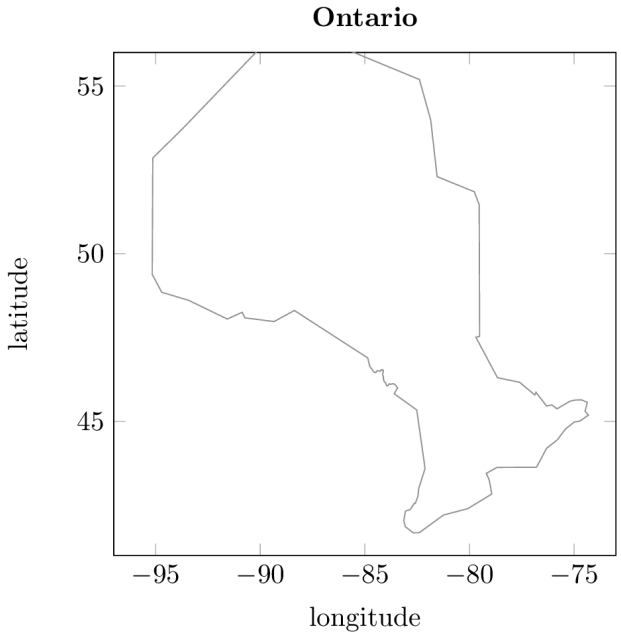
- Model analysis and future developments

Policy-maker decision-support framework

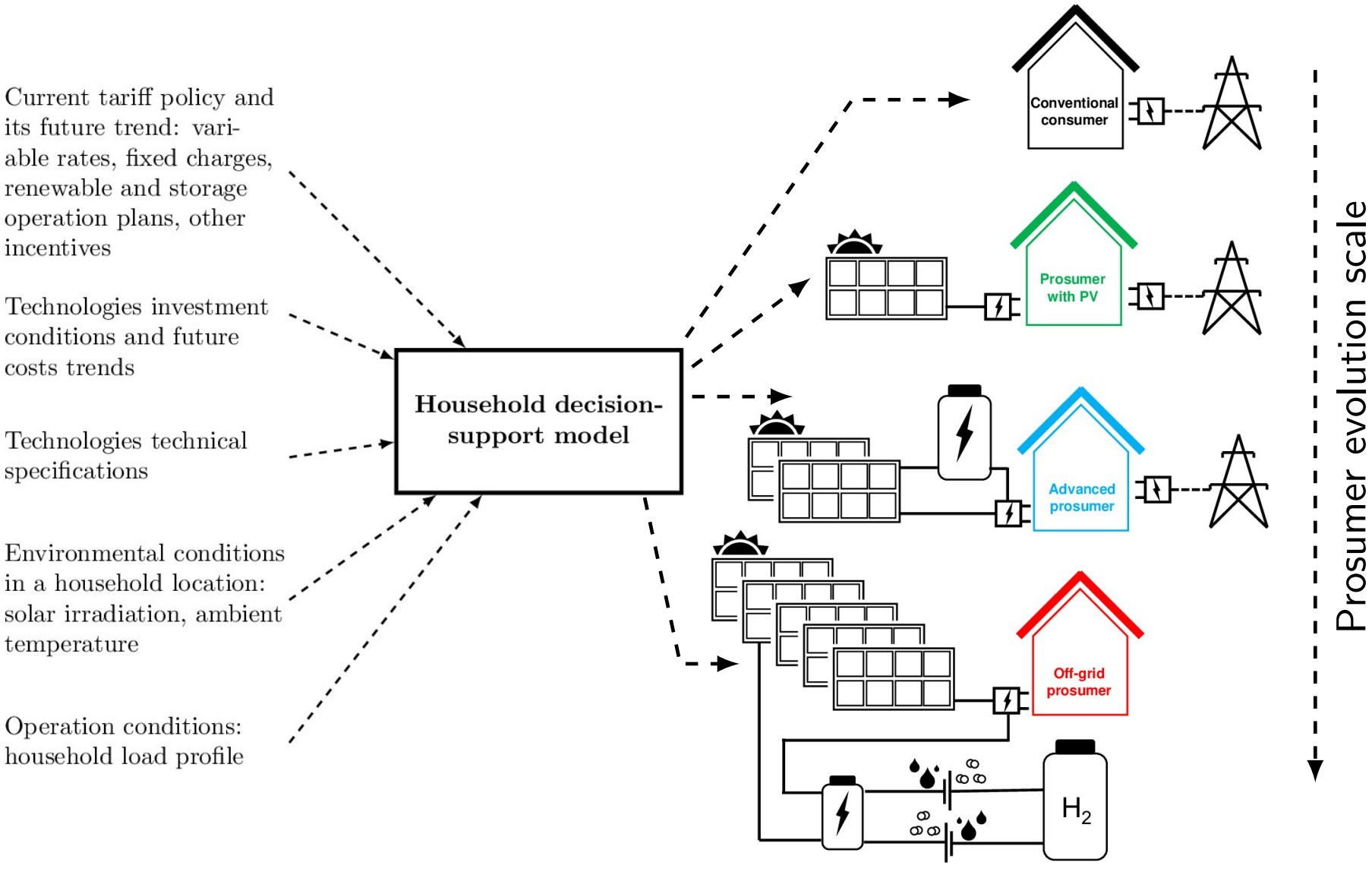




- Application:



Household decision-support model



Household decision-support model

- Minimize Net Present Value of future cash flows (expenses)

$$\sum_{y \in Y} \frac{\left[CAPEX_y + REPLACE_y + OPEX_y + Electricity\ Bill_y - Avoided\ cost_y \right]}{(1 + Discount\ rate)^{-y}}$$

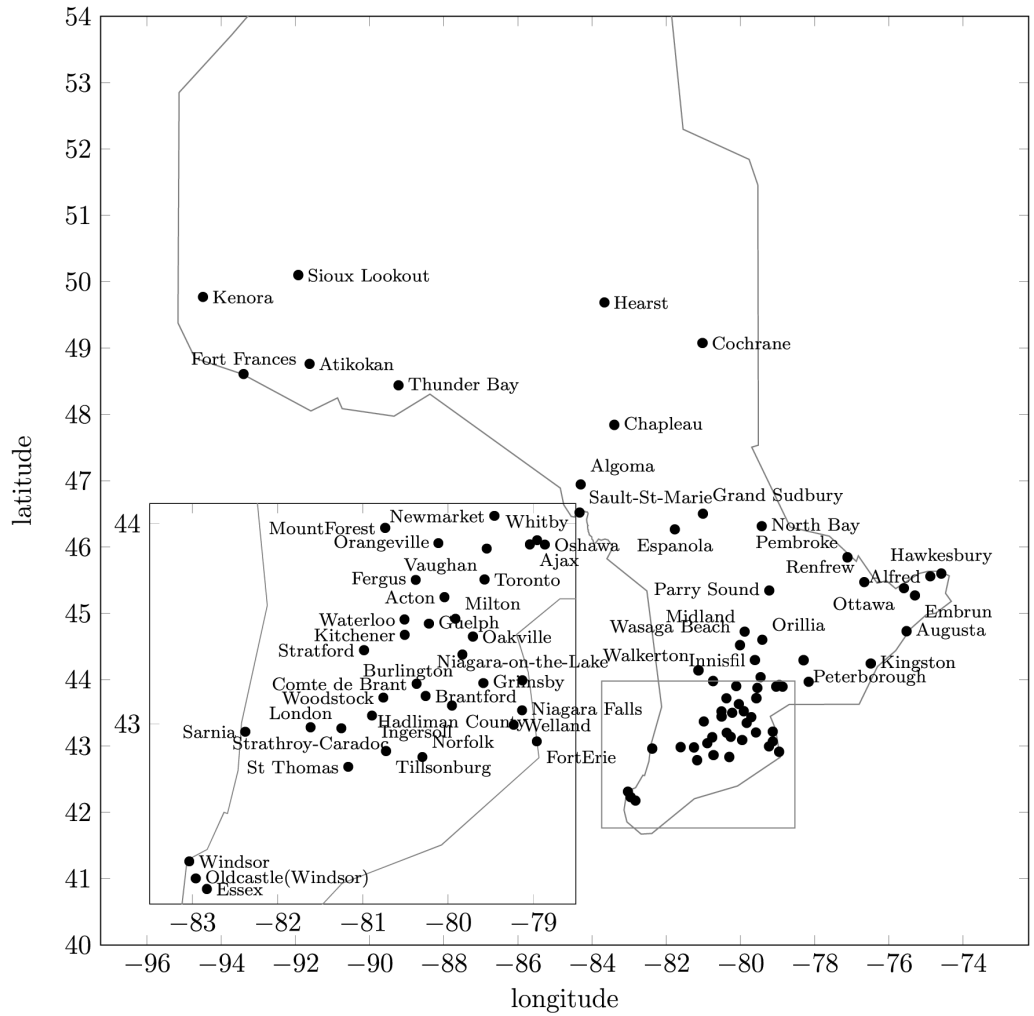
s.t.

  - $CAPEX_y$ - installed costs of PV and storage technologies
  - $OPEX_y$ - maintenance costs of PV and storage technologies
  - $REPLACE_y$ - replacement costs in case of PV and storage technologies fail outside their warranty period
  - $Electricity\ bill_y$ - electricity bill paid to the grid based on variable rates and fixed charges
  - $Avoided\ cost_y$ - avoided costs due to self-generation and self-consumption (avoided part of the electricity bill)

- Allows to simulate a progressive expansion of RES system
- Integrates the model for optimal power dispatch in a household in presence of RES generators (here only PV), residential electric battery and seasonal storage based on power-to-H_2-to-power technology

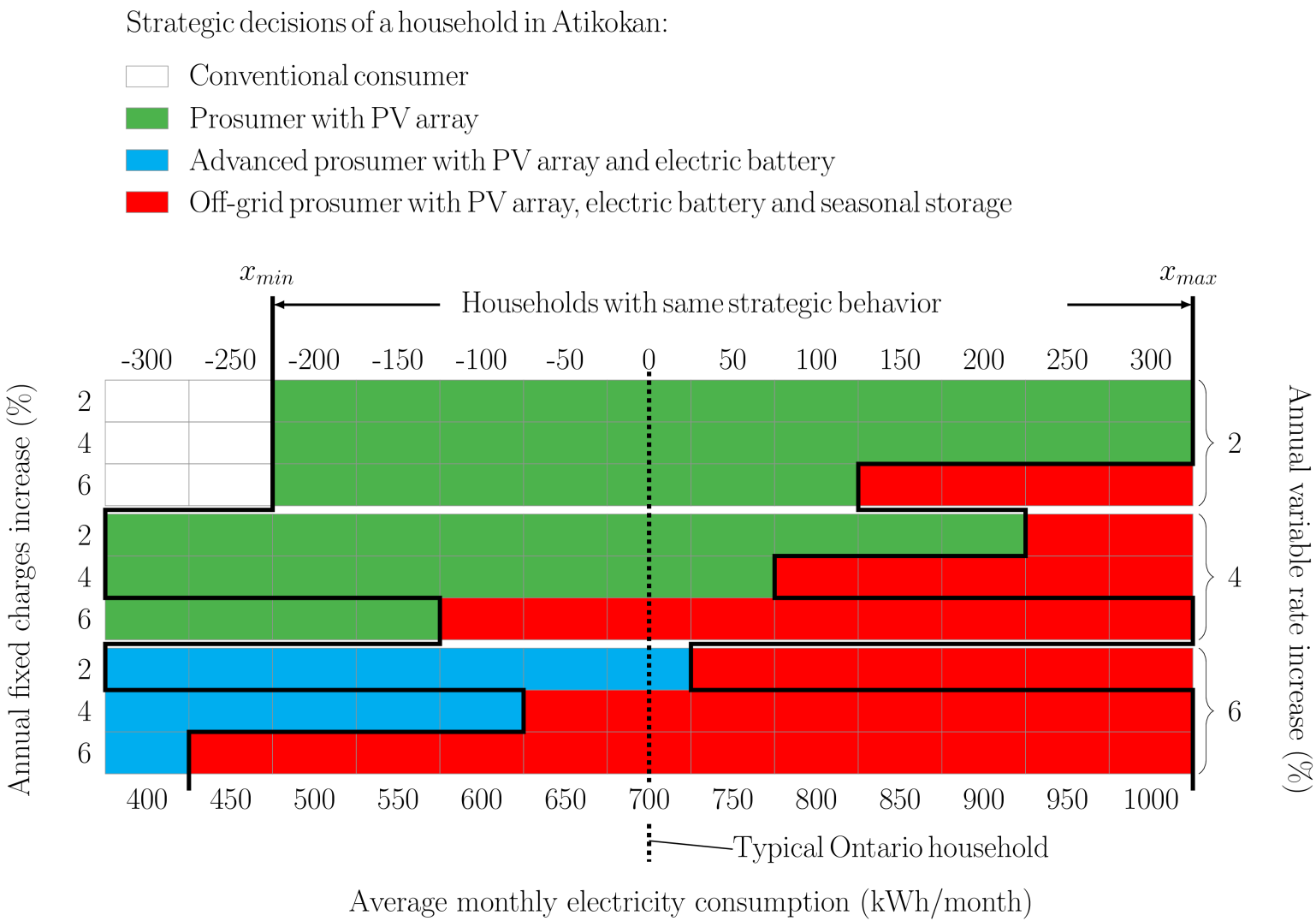
Representation of a jurisdiction - Number of intelligent households' agents

- How many agents for a given jurisdiction?
- Must be representative of areas with
  - different tariffs
  - different environmental conditions
  - type of appliances used in a household (consumption patterns)
- For Ontario
  - 67 consumer agents representing 67 distribution areas
  - each agent is a typical household with average electricity consumption of 700 kWh/month



Representation of a jurisdiction - Households with the same strategic behavior

- How many households with the same strategic behavior in a given jurisdiction?



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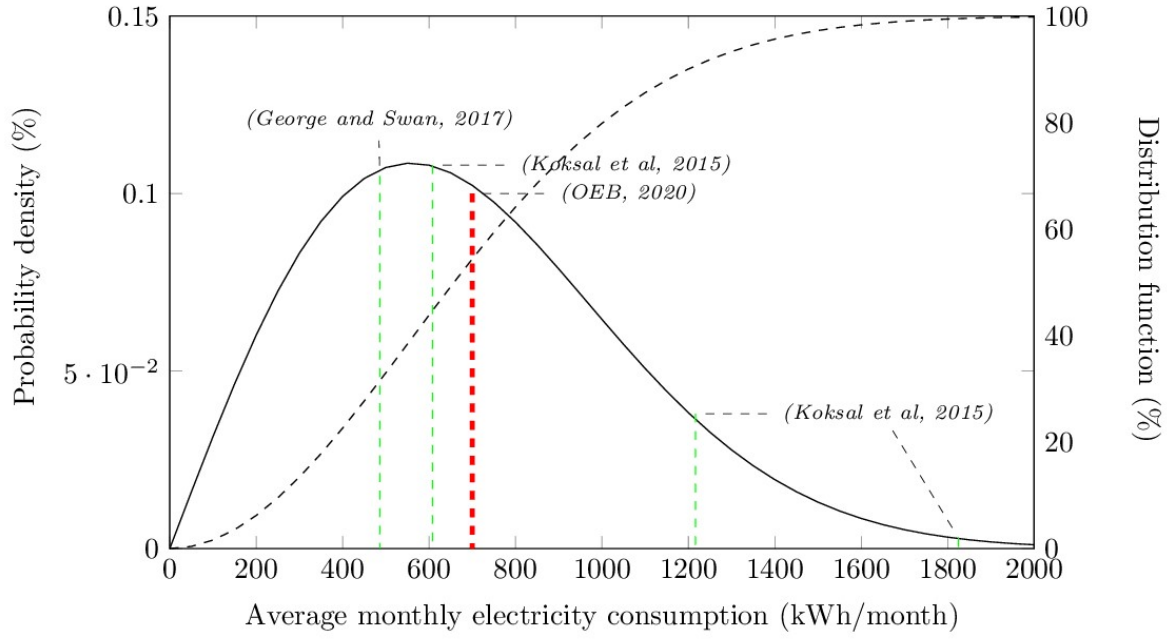


- For Ontario
  - No access to the consumption measurements
  - Rely on Weibull PDF (study of electricity use in detached houses in Sweden) and few available studies for Ontario
  - From the cumulative distribution function $F(x_{min})$ and $F(x_{max})$ - around 40% of households will have similar strategic behavior
  - 1,122,744 of single-detached households for all Ontario

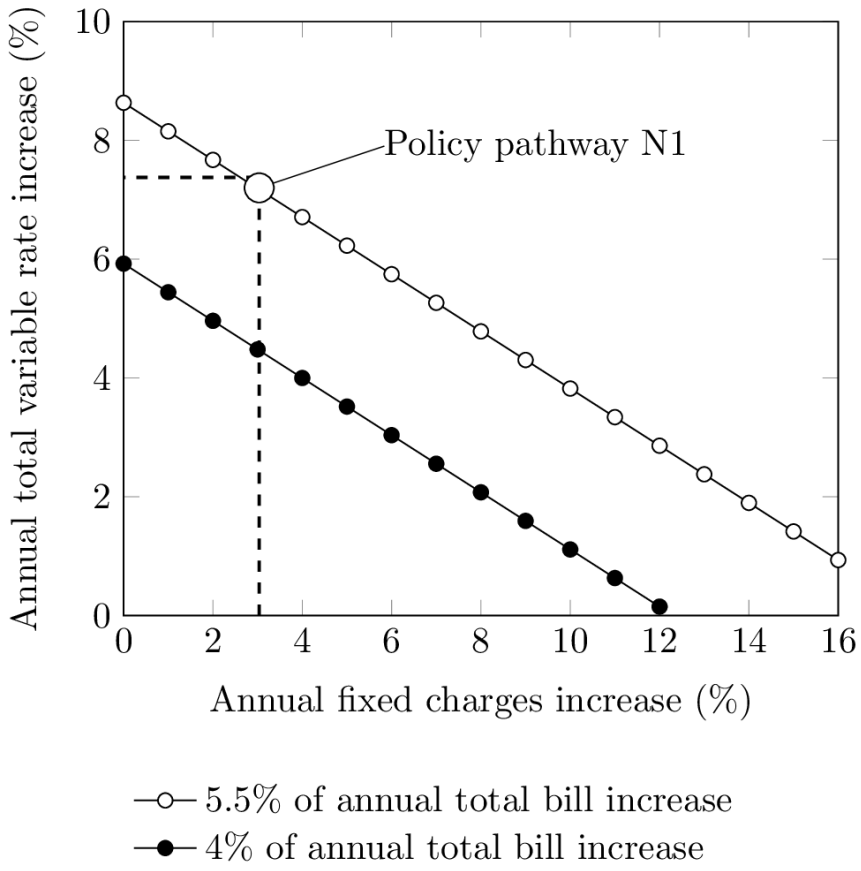
Framework application - Step 1. Potential policy pathways

- Major assumptions:
  - household under residential tariff plan
  - natural gas heated household (the majority of Ontario households)
  - bill structure remains unchanged over a planning period
  - RES are connected under net metering
  - electricity rates are at their pre pandemic level
- Policy pathways refer here to economic and financial measures:
  - total variable rate
  - fixed service charges
  - rebate

$$\textit{Electricity bill} = \Big[\textit{Consumption} \cdot \underbrace{(\textit{Electricity rate} + \textit{Transmission rate} + \textit{Distribution rate})}_{\textbf{total variable rate}} + \textbf{Fixed service charges} - \textbf{Rebate}\Big] + \textit{Taxes}$$

Framework application - Step 1. Potential policy pathways

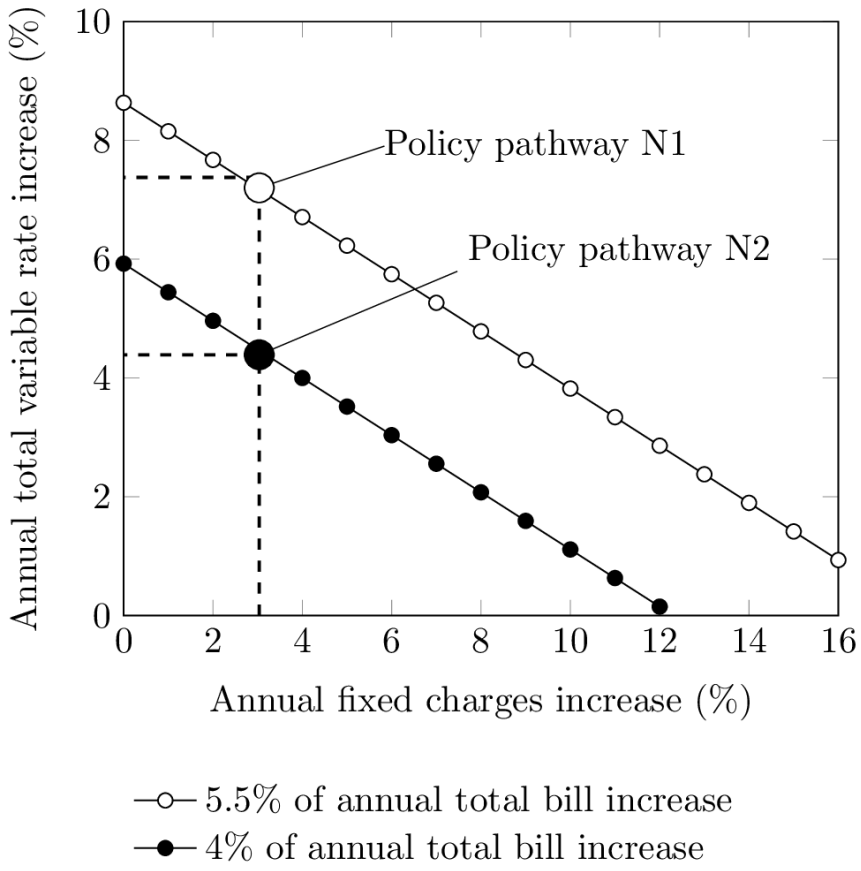
- 2021-2050 planning horizon



- Policy pathway N1 - Actual pricing with rebate:
  - total bill increases without rebate by 5.5% annually
  - annual tariff increases: by 3% for fixed charges & by 7.19% for total variable rate
  - rebate at least 21.2% of the total bill, 2% of annual increase, 5 years duration

Framework application - Step 1. Potential policy pathways

- 2021-2050 planning horizon



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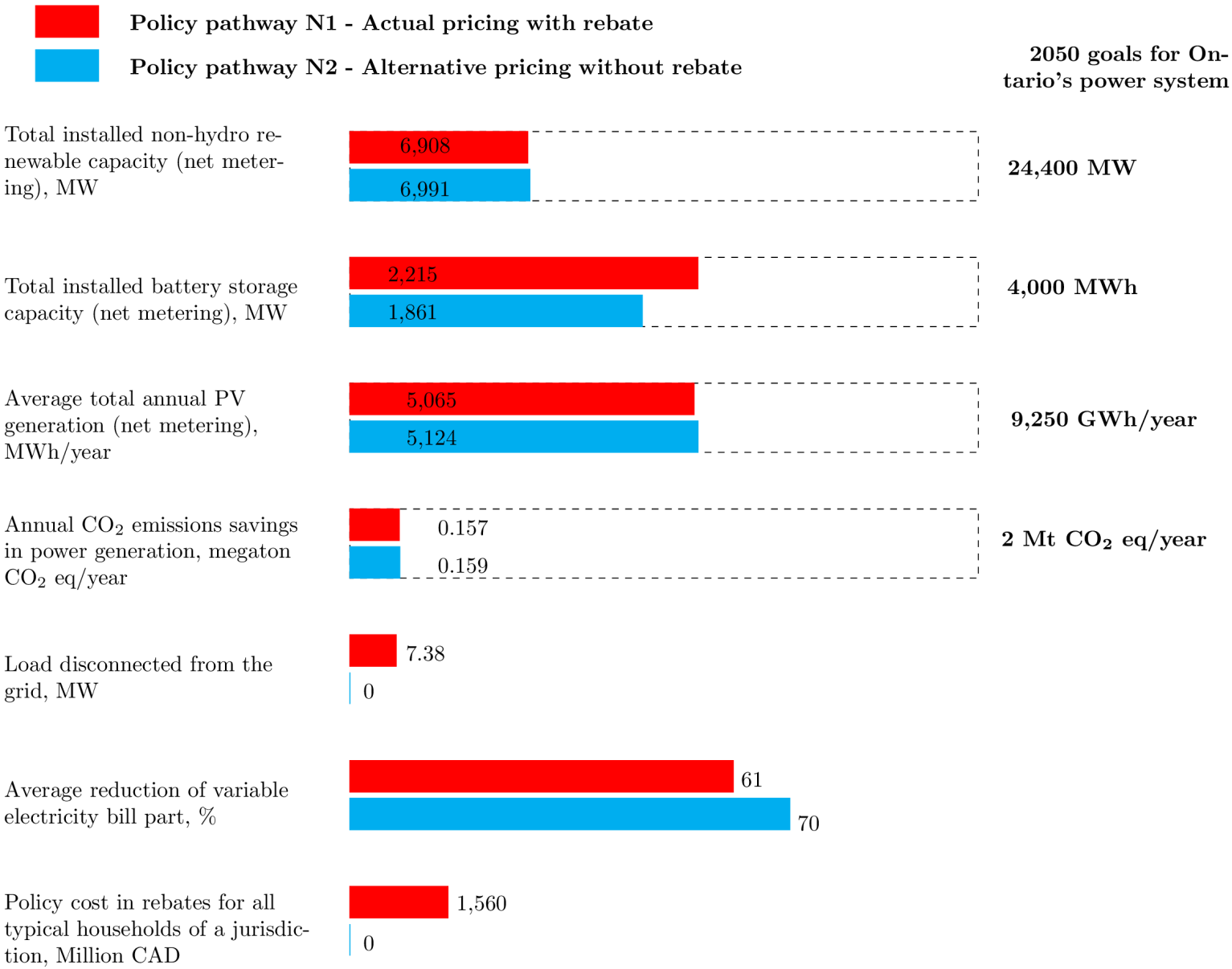
  - annual tariff increases: by 3% for fixed charges & by 7.19% for total variable rate
  - rebate at least 21.2% of the total bill, 2% of annual increase, 5 years duration
- Policy pathway N2 - Alternative pricing without rebate:
  - total bill increases by 4% annually
  - annual tariff increases: by 3% for fixed charges & by 4.48% for total variable rate
  - no rebate

Framework application - Step 2. Data collection

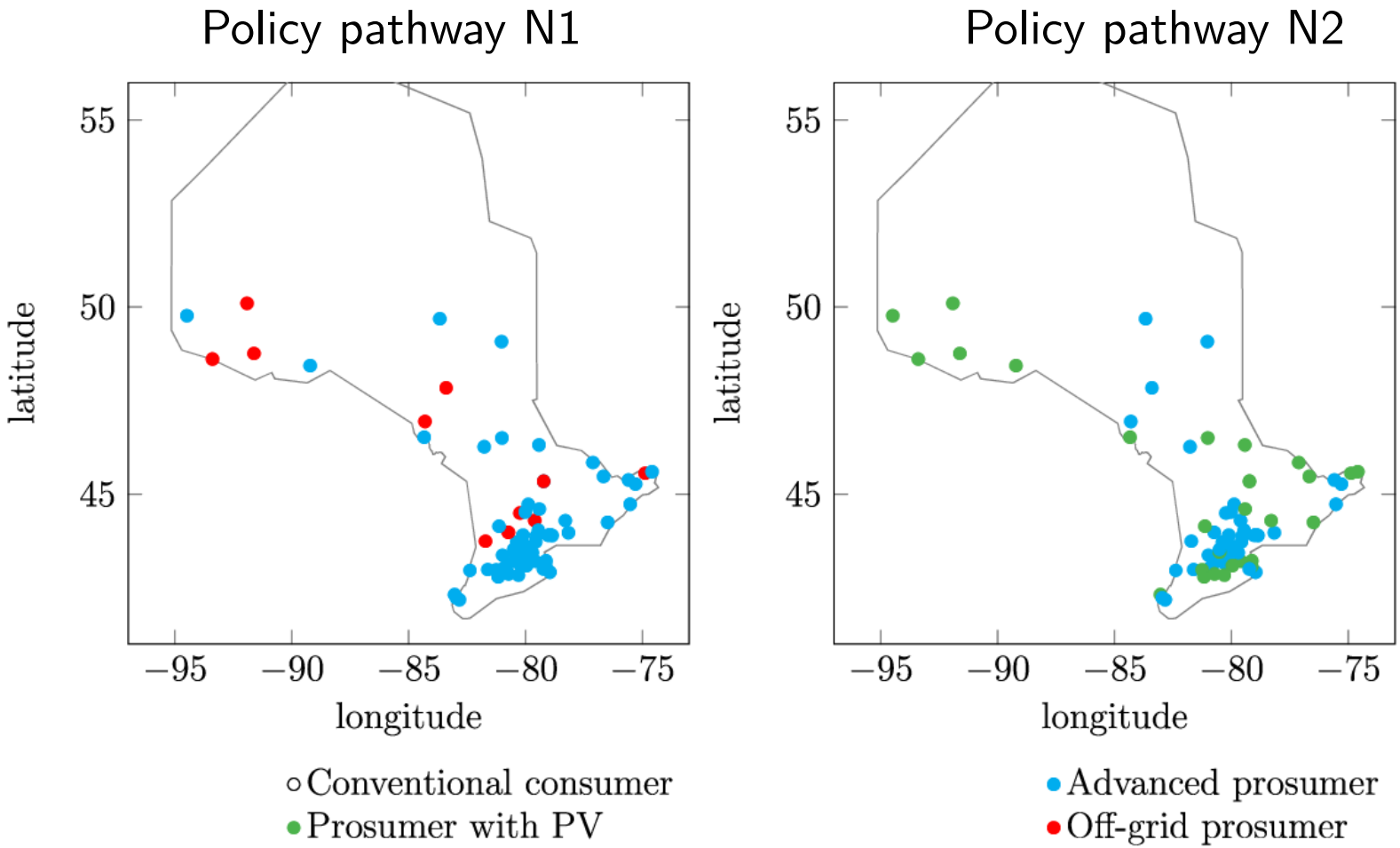
- All data is taken from available online sources:
  - OEB, IESO, local distribution companies
  - Government of Canada, Government of Ontario
  - Research councils, institutes and agencies: NRC, NREL, IRENA
  - Technology manufacturers and distributors, experts
  - Media and resources focused on green tech: Energy Sage, Energy Hub, GTM
  - Weather datasets: Weatherstats, CERES
  - Scientific publications in specialized journals
- Operational conditions (modeling toolboxes):
  - Mathematical model of PV array accounting for the technical characteristics of the panels, the solar irradiation and the loss of module efficiency with the increase of ambient temperature
  - Household load profile is simulated with a top-down approach, based on detailed chronological collection of overall electricity demand over a year

Framework application - Step 3. Global effects for Ontario



Framework application - Step 3. Global effects for Ontario

- Consumption strategies of Ontario's households illustrated for the year 2050



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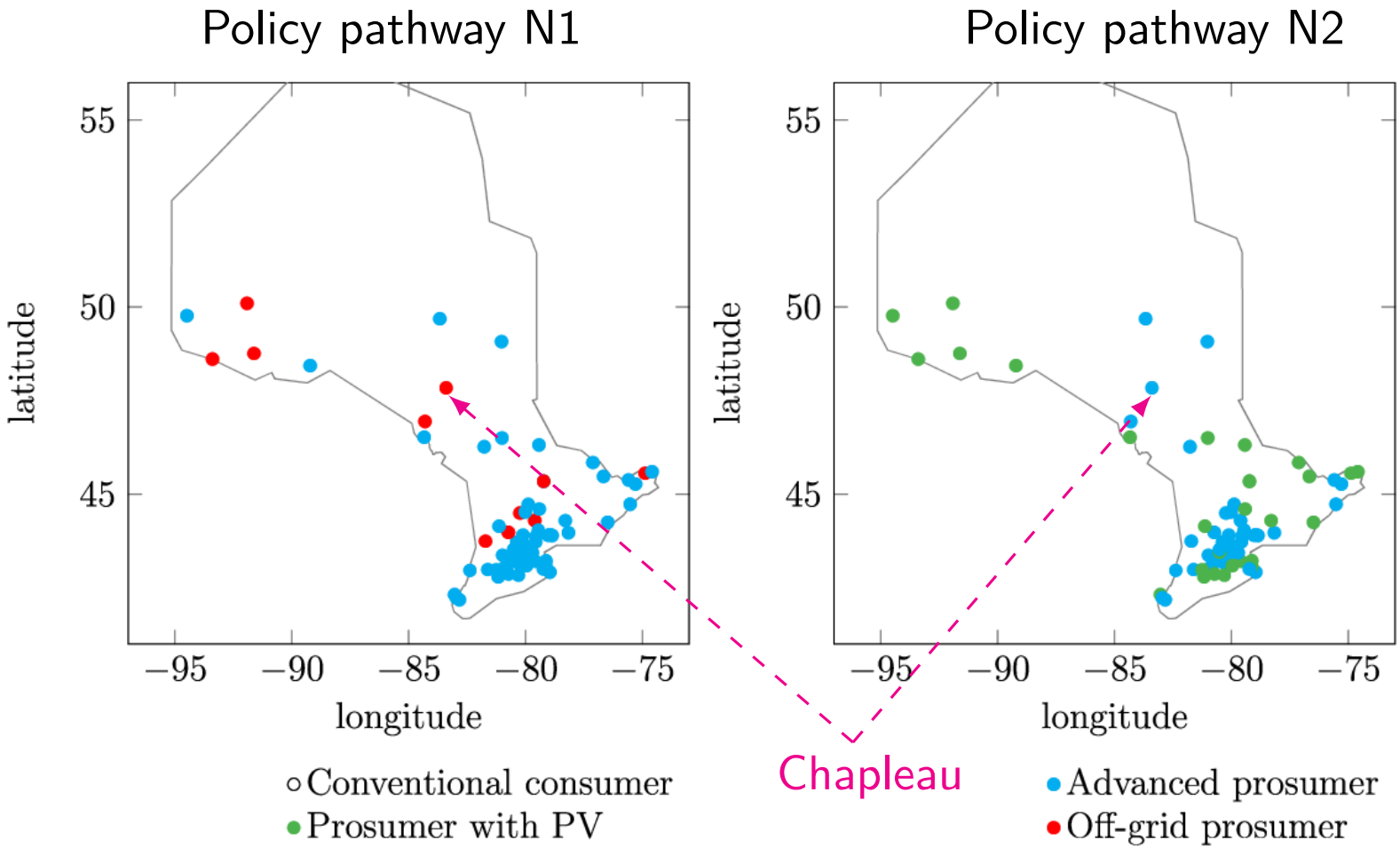
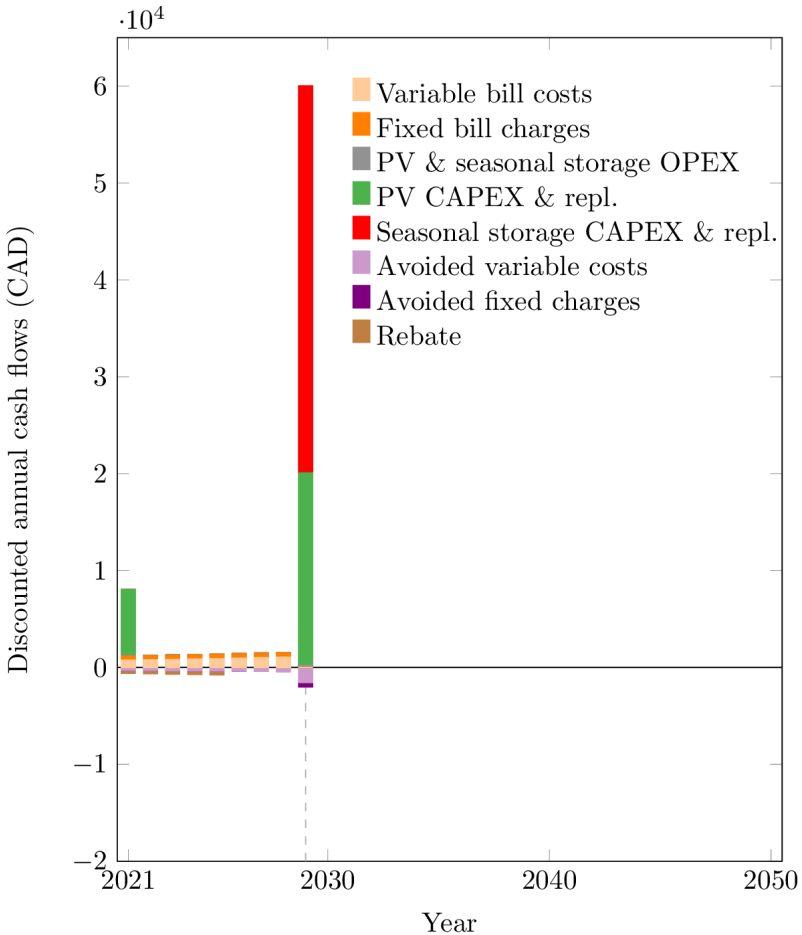
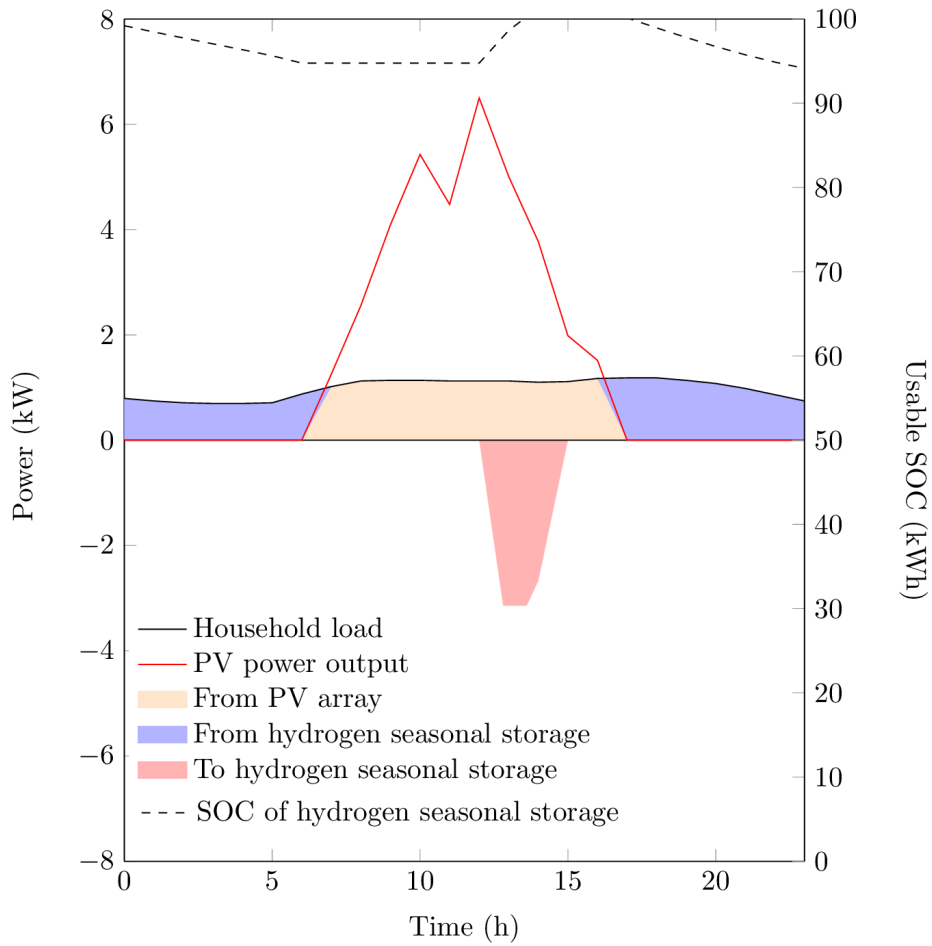


Framework application - Step 4. Effects for sensitive location

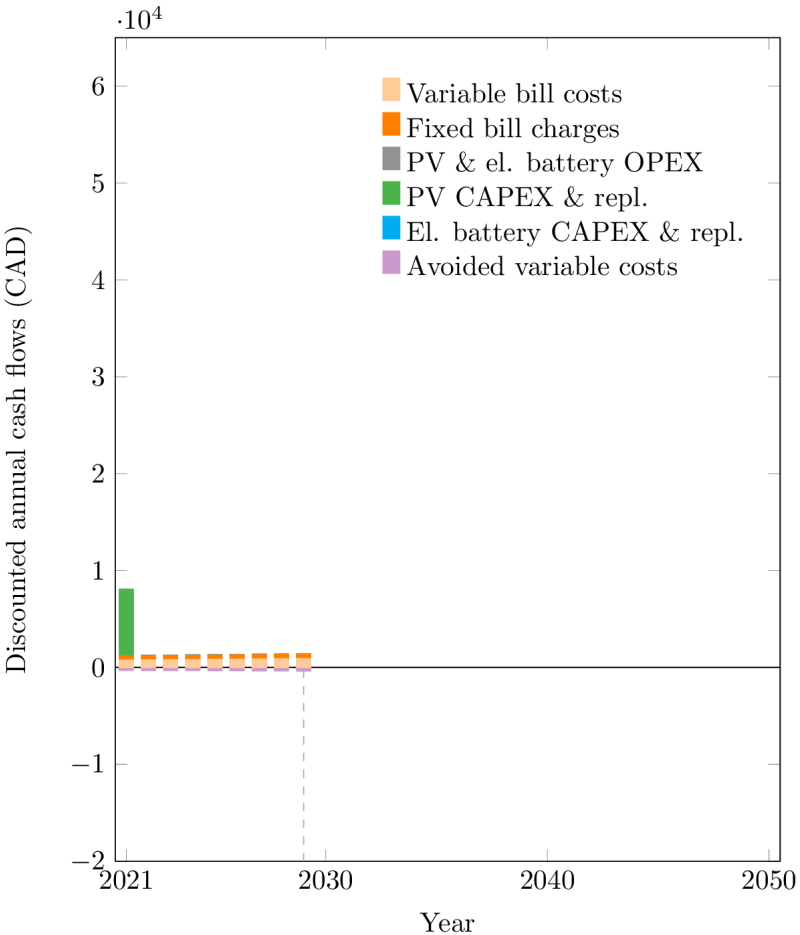
- Policy pathway N1 - Actual policy with rebate - Chapleau township

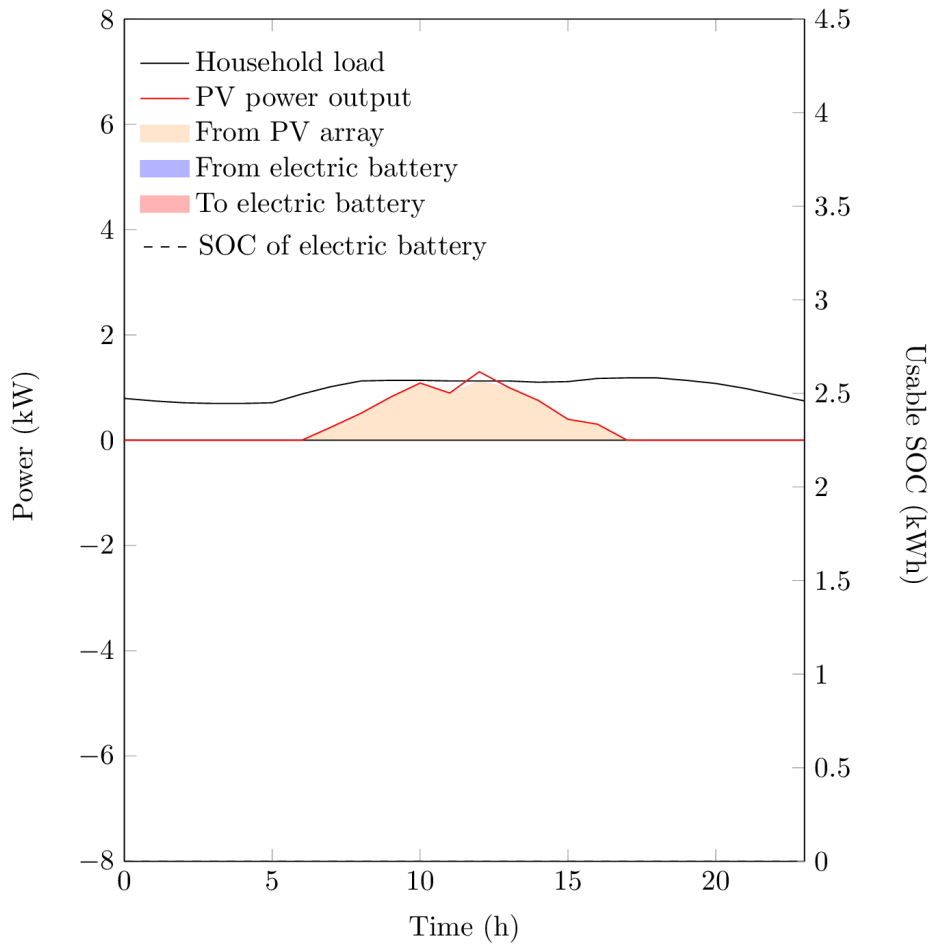




Framework application - Step 4. Effects for sensitive location

- Policy pathway N2 - Alternative policy without rebate - Chapleau township





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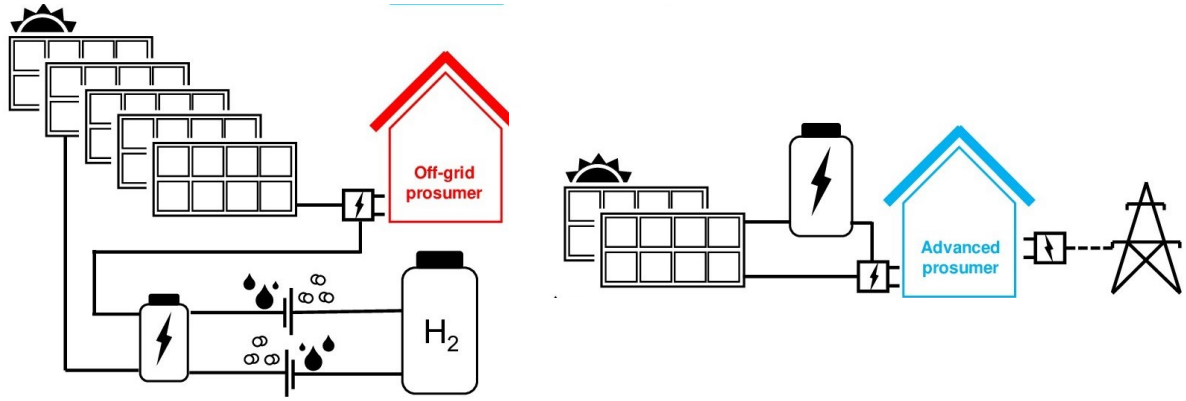

Details	Policy pathway n1 - Actual pricing with rebate	Policy pathway n2 - Alternative pricing without rebate
Prosumer total cash flows over 2021-2050 period		
Electricity bill, 10^3 CAD	10.64 (8 years)	38.5
Investments, 10^3 CAD	102.76[1]	27.49[1]
Avoided costs, 10^3	75.9[2]	22.3
Balance, 10^3 CAD	**37.5**	**43.7**
Benchmark - conventional consumer over 2021-2050 period		
Electricity bill, 10^3 CAD	**120.56**	**83.6**

[1] Installed, maintenance and replacement costs.

[2] Including rebates.

Framework application - Step 5. Policies implication

- Implications of policies N1 & N2:
  - Both policies may contribute to the global energy system goals
  - System reliability - policy N1 may stimulate physical disconnection of prosumers
  - Policy cost - policy N1 requires important investment for rebates
- Potential policy directions:
  - To explore measures to mitigate the total bill increase, to help distribution companies diversify their service offers, to develop new business models to stimulate the local RES and storage markets, and to involve prosumers in demand response
  - To rethink the use of power-to-H_2-to-power storage - may be included in low-carbon hydrogen strategy
  - To reconsider the definition of "typical" household for policy effect evaluation - households with different monthly consumption react differently to policies

Model analysis and future developments

- Model features:
  - Applicable to different jurisdictions (size and location)
  - Model inputs may be defined "manually" or come from other models
  - Deterministic, no uncertainty related to future conditions variability, emergence of new technologies or other events
  - Accounts only for PV model (for Ontario case), but other technologies (such as wind power) may be also included
- Future developments
  - Scientific communications (Energy Modelling Platform for North America (EMP-NA) - Open Modelling Projects, a special issue of Energy Strategy Reviews)
  - Model licensing and technology transfer (looking for collaborative opportunities with policy-makers)
  - Model and algorithm improvements (automatic policy search with deep reinforcement learning, development of user interface)

Thank you!