Chair in Energy Sector Management

HEC MONTRÉAL

Modelling Decarbonized Electricity Markets in Northeastern North America

Pierre-Olivier Pineau

May 18th 2022 – 10h30-12h

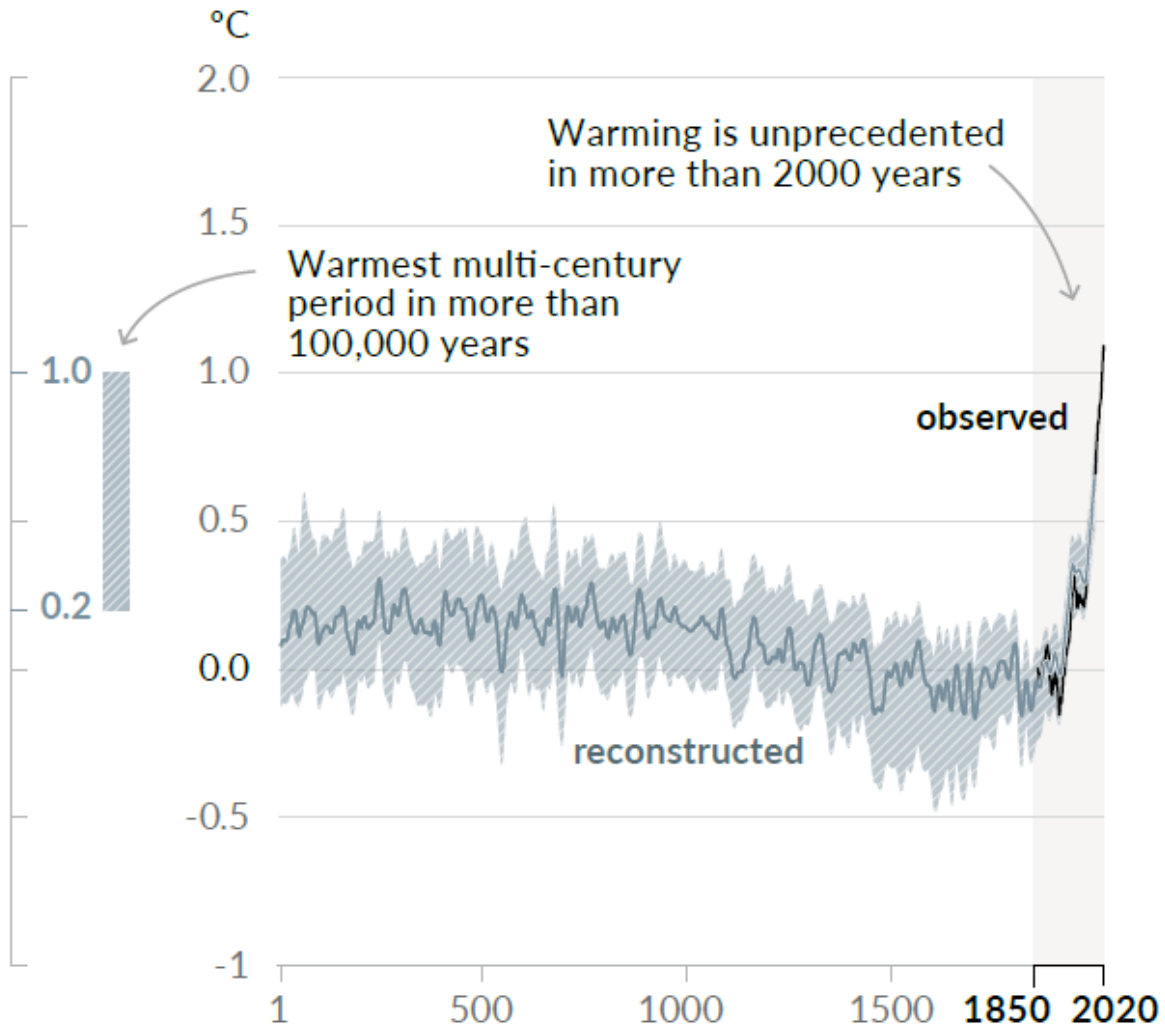
WA1 - Tutorial IV – Optimization Days / Journées de l'optimisation 2022

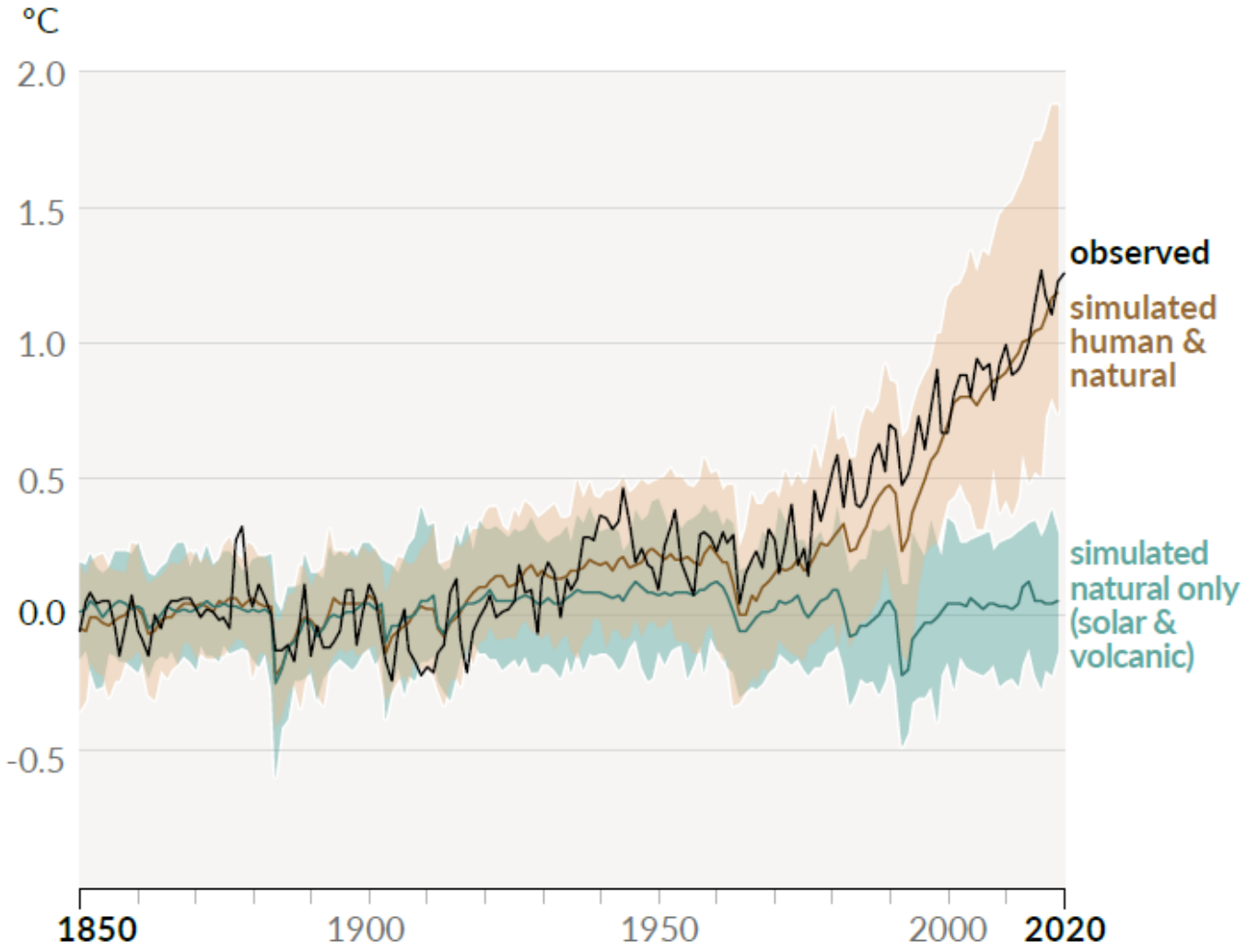
Walter Capital (bleu) (ex-BDC), HEC Montréal

Outline

1. Context
2. Models
3. Some of our results
4. Challenges & Opportunities

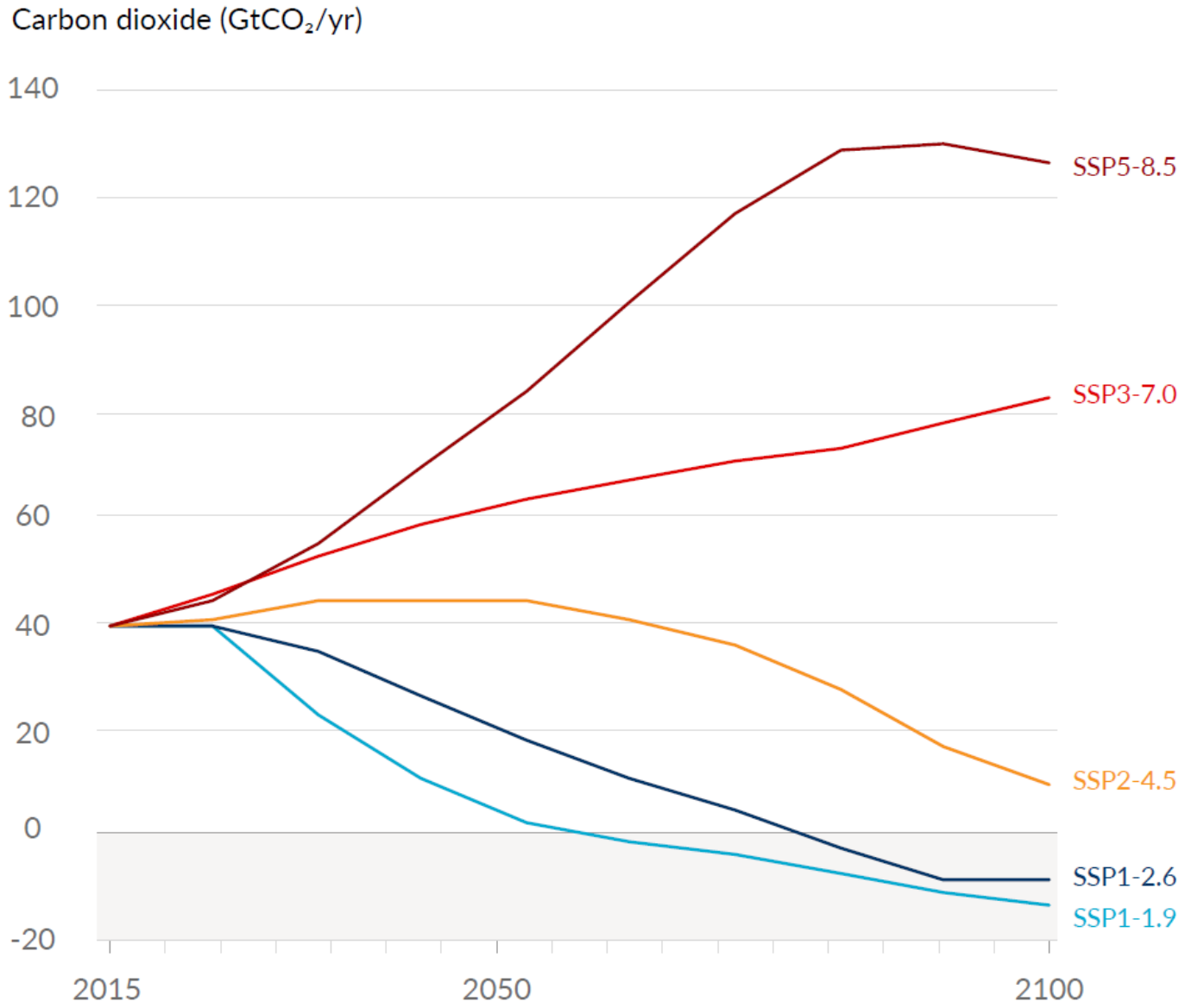
Global Temperature Change (°C) relative to 1850-1900



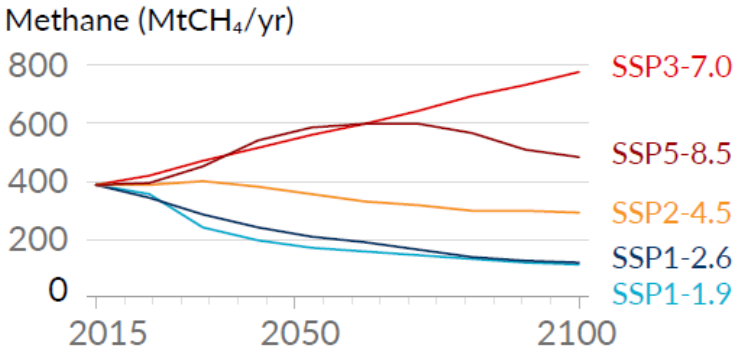


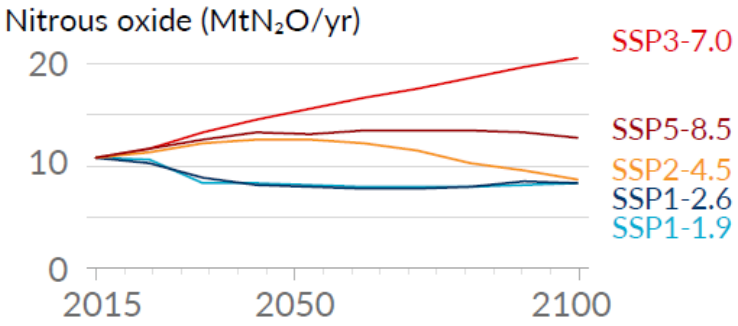
IPCC (2021)

Emission Scenarios (CO_2 and other GHG)

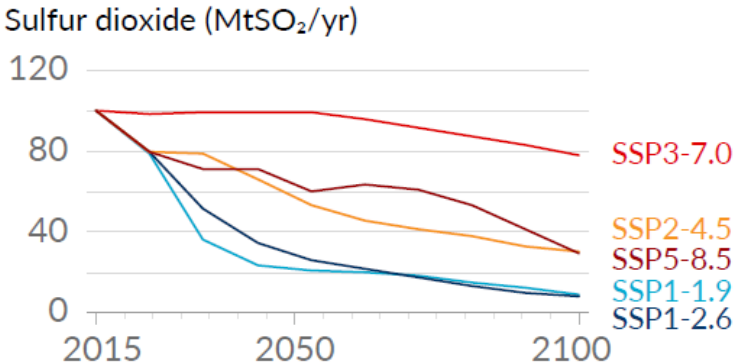


Selected contributors to non-CO_2 GHGs



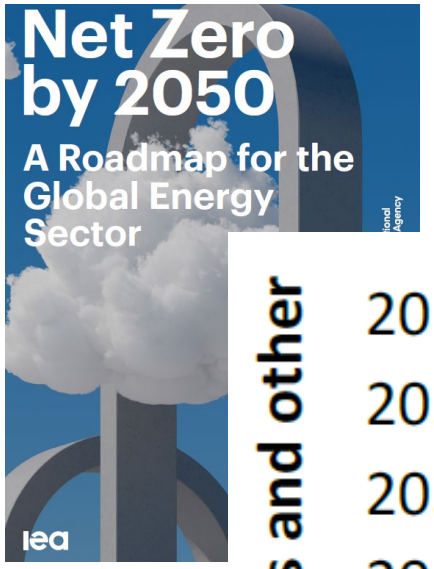


One air pollutant and contributor to aerosols



IPCC (2021)

SSP = Shared Socioeconomic Pathways



Global total final consumption by fuel in the Net-Zero Emissions by 2050 Scenario

Fuels and other
2010
2020
2030
2040
2050
Oil
Natural Gas
Coal
Bioenergy
H_2

Electricity use
2010
2020
2030
2040
2050
Wind & Solar

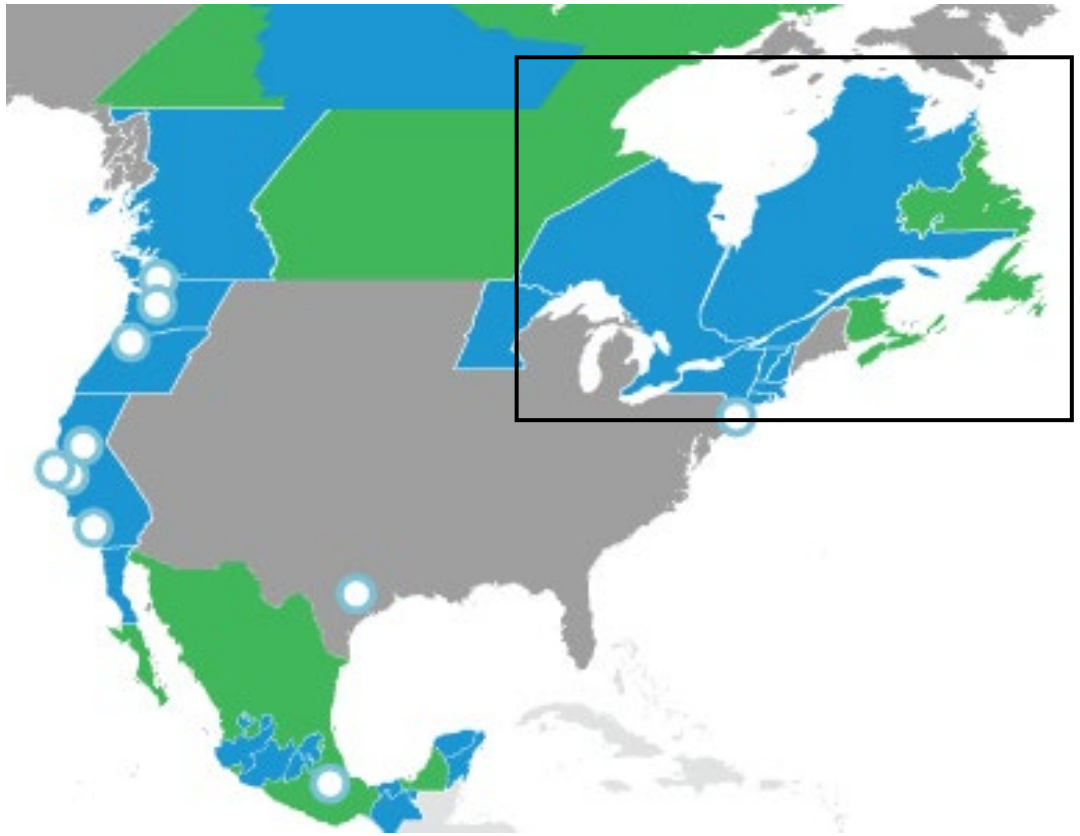
Reduced by 150 EJ (45%)

Grows by 95 EJ (2.25x)

50 100 150 200 EJ 250 300 350

IEA (2021)

Northeast Decarbonization



Under 2° Coalition: 80-95% GHG reduction below 1990 level by 2050 + real policies

Real policies in the Northeast:

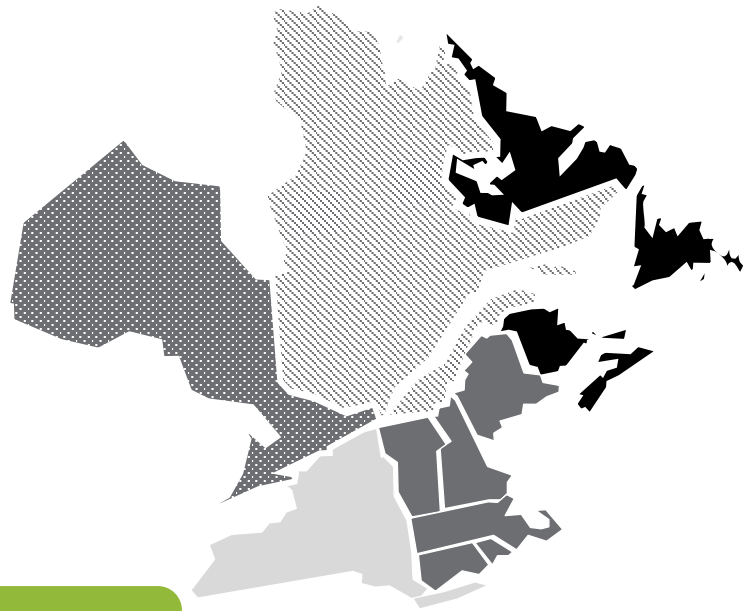
- Renewable Portfolio Standards (RPS)
- Cap-and-trade: RGGI + WCI
- Clean energy funds
- New York's Reforming the Energy Vision (REV)
- Massachusetts Clean Energy RFP
- …

Under2mou (2017)

GHG Emissions Reduction Targets 2030 / 2050

Quebec
37.5% / Net-zero

Ontario
37% / 80%



New York
40% / 85%

Note: GHG emissions targets are measured below 1990 levels except for * (below 2002 levels) and ** (below 2005 levels)

Atlantic provinces

NB: 35% / 80%*
NL: 30%** / 75%*
NS: 53%** / Net-zero
PEI: 40%** / Net-zero

New England

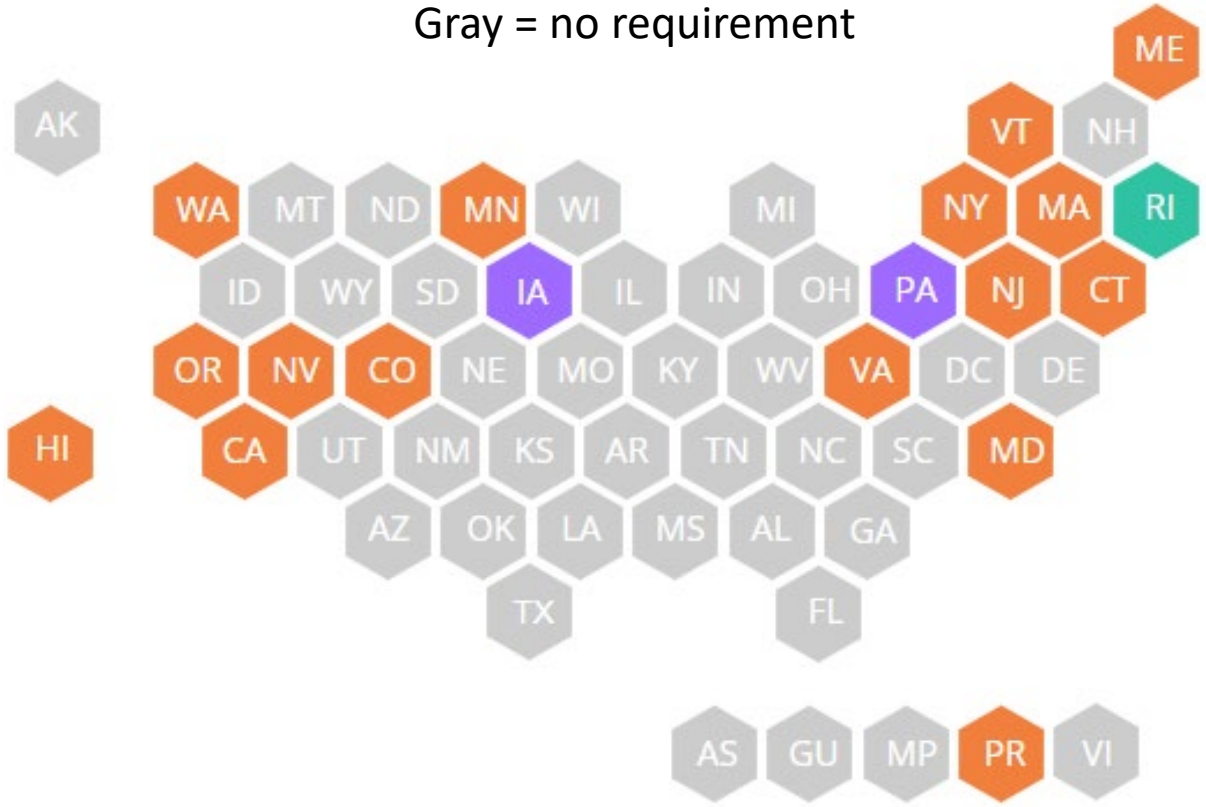
CT: 45%* / 80%*
MA: 50% / Net-zero
ME: 45% / Net-zero
NH: 20% / 80%
RI: 45% / 80%
VT: 40% / 85%

Sources: C2ES - the Center for Climate and Energy Solutions - for US and Canada GHG Emissions Targets (2021); Energyhub - Clean Energy Targets Canada (2021); National Conference of State Legislatures (NCSL) - State Renewable Portfolio Standards and Goals (2021)

States with Statutory GHG Reduction and Reporting Requirements and Market-Based Policies

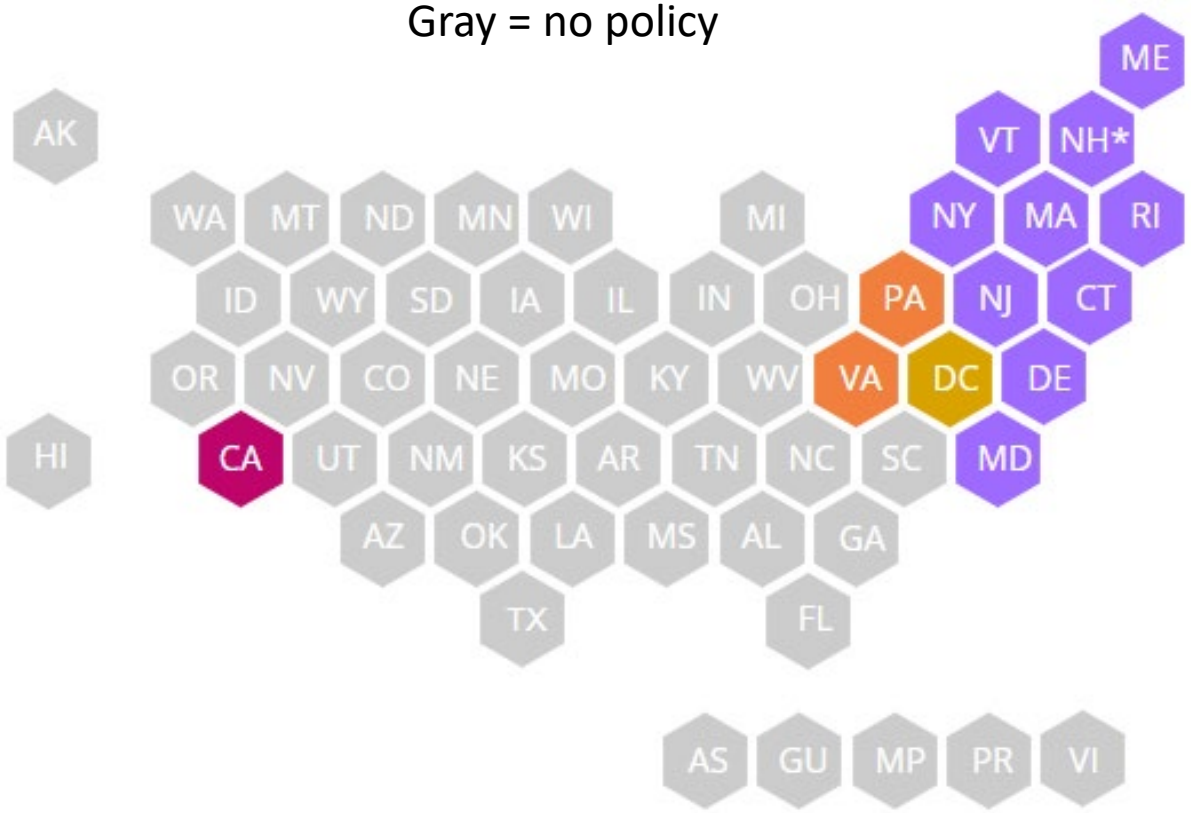
Reduction and Reporting Requirements

Gray = no requirement



Market-based Policies

Gray = no policy

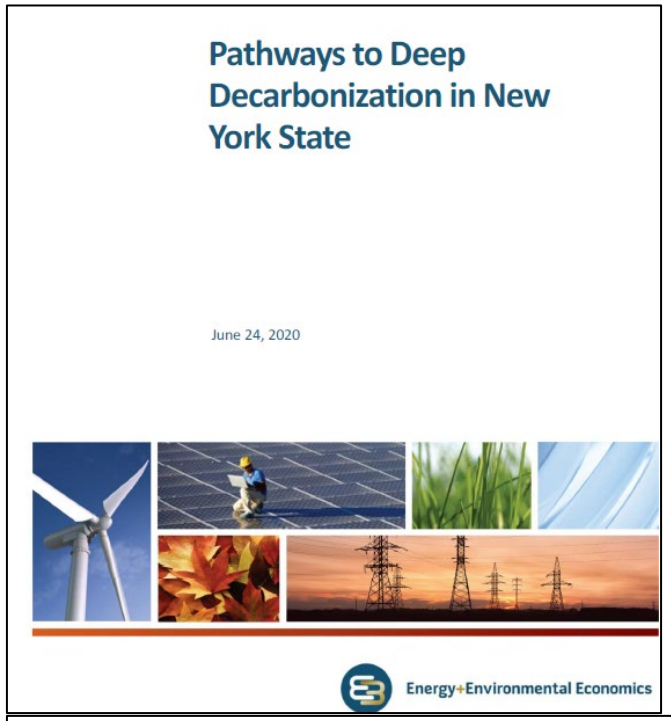


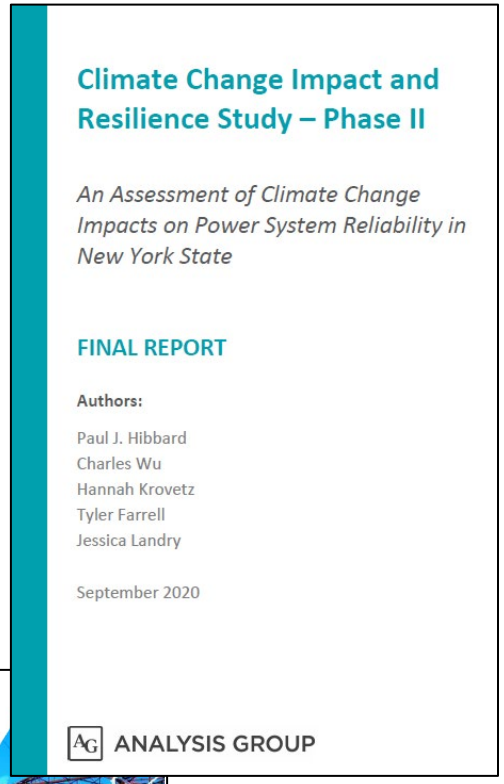
Shields (2021)

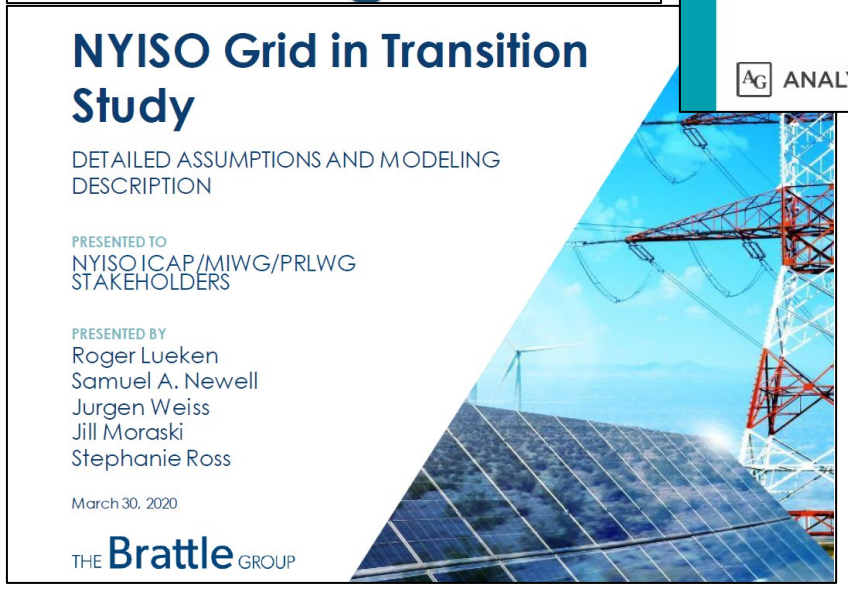
How are we going to decarbonize and electrify?
(Nobody has done it!)

2. Models

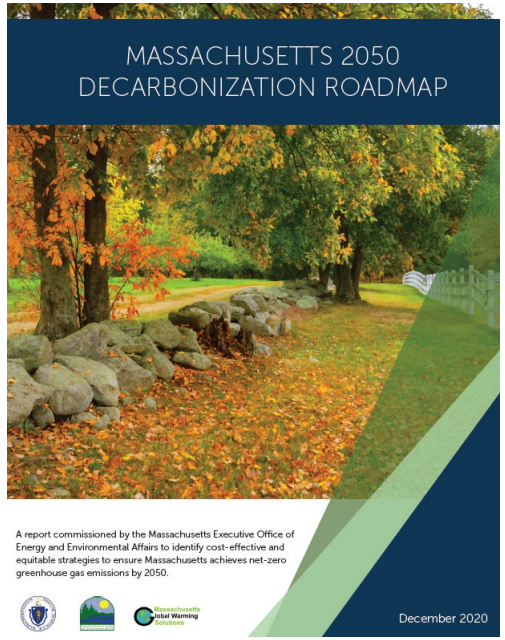
New York

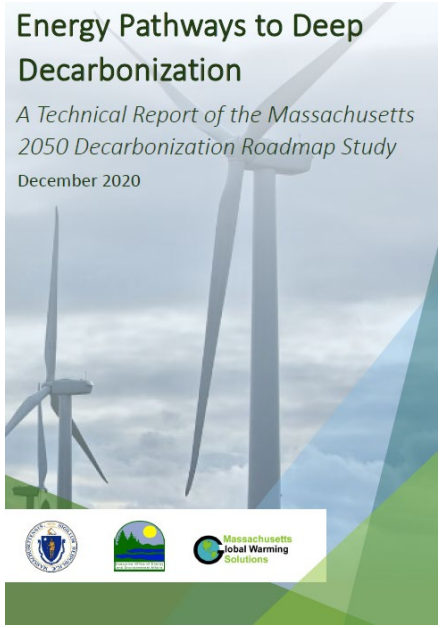




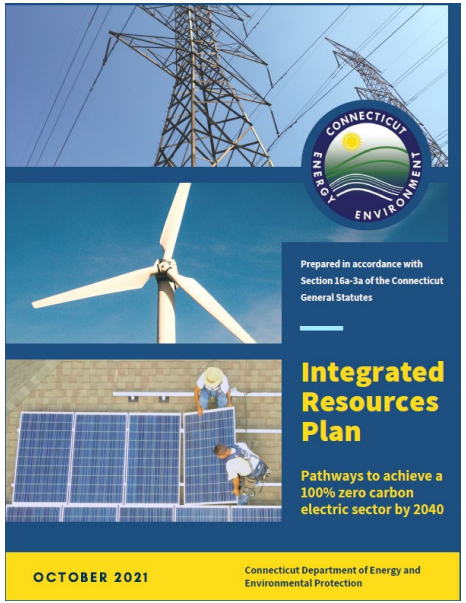


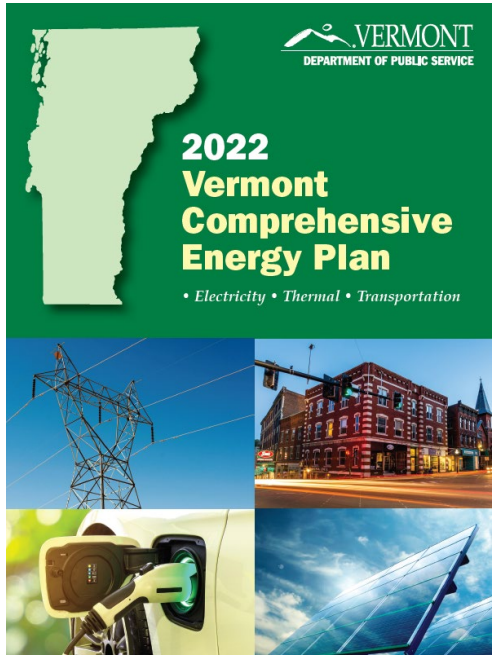
Massachusetts



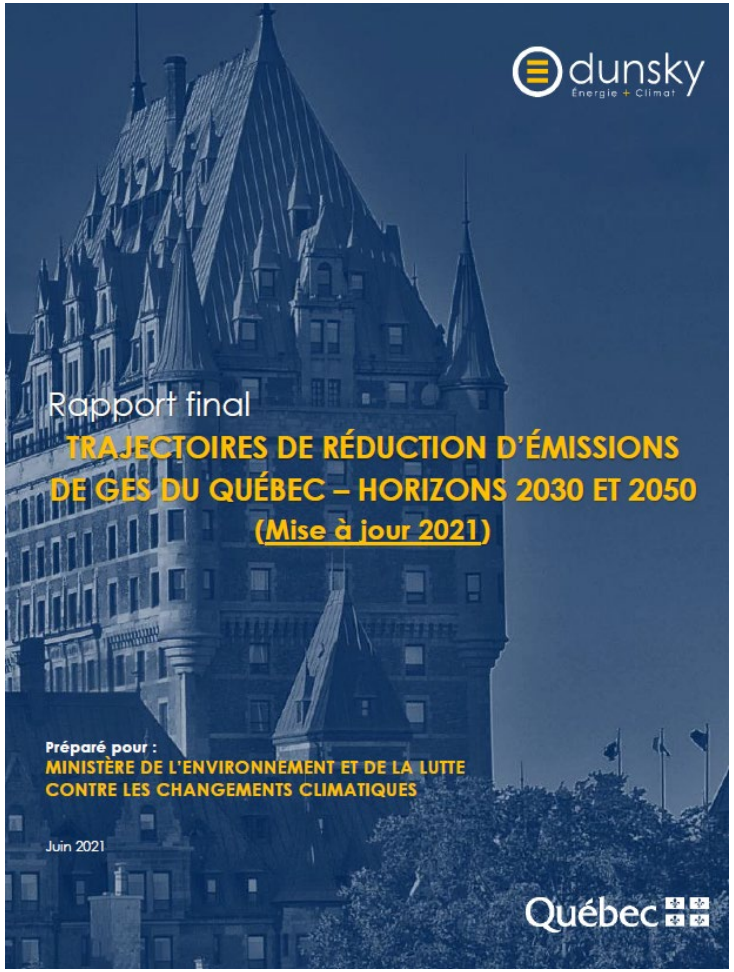


Connecticut

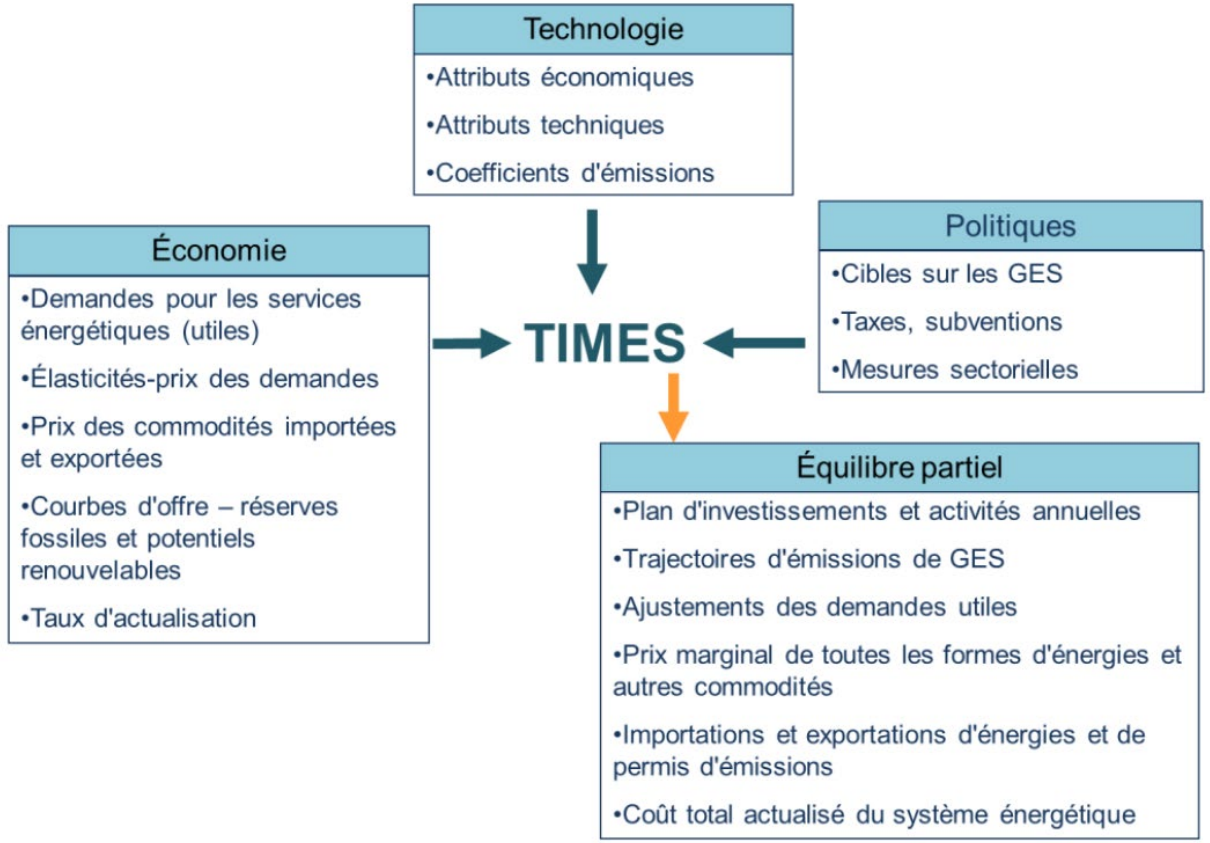




Québec

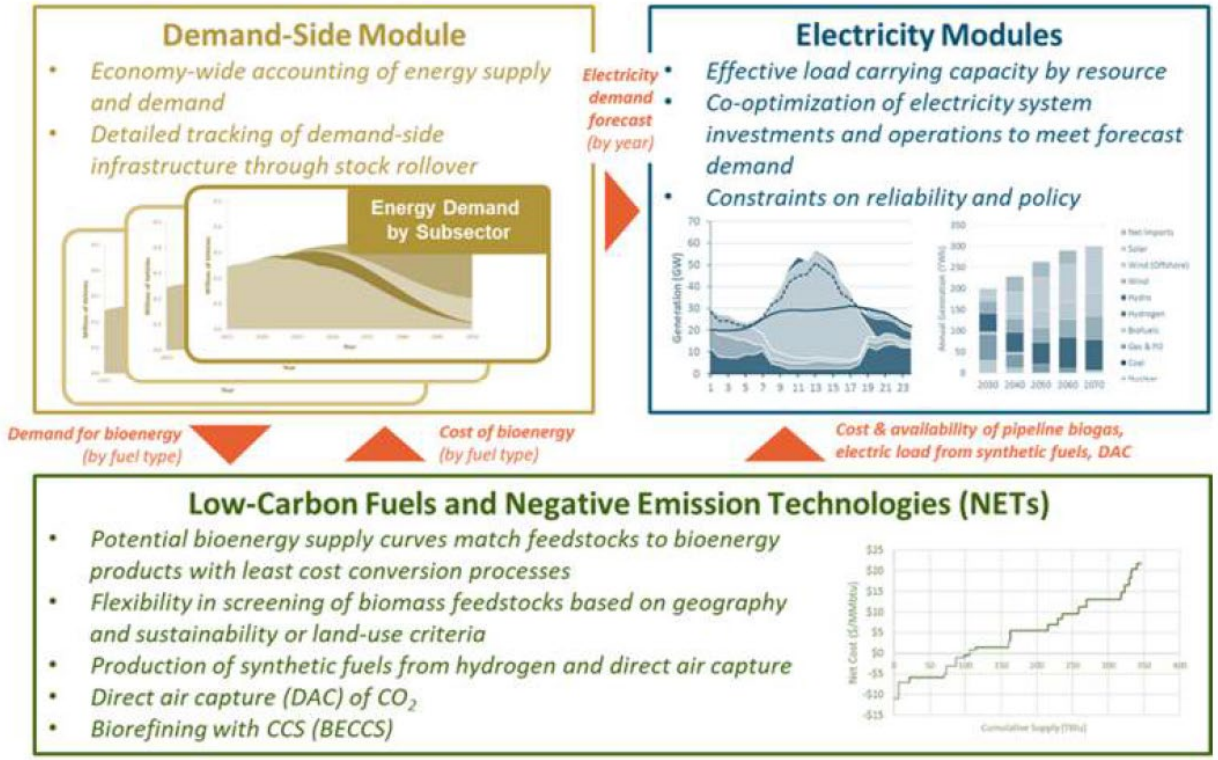


Dunsky & ESMIA (2021)
Trajectoires de réduction d'émissions de GES du Québec – Horizons 2030 et 2050 (Mise à jour 2021) – NATEM model

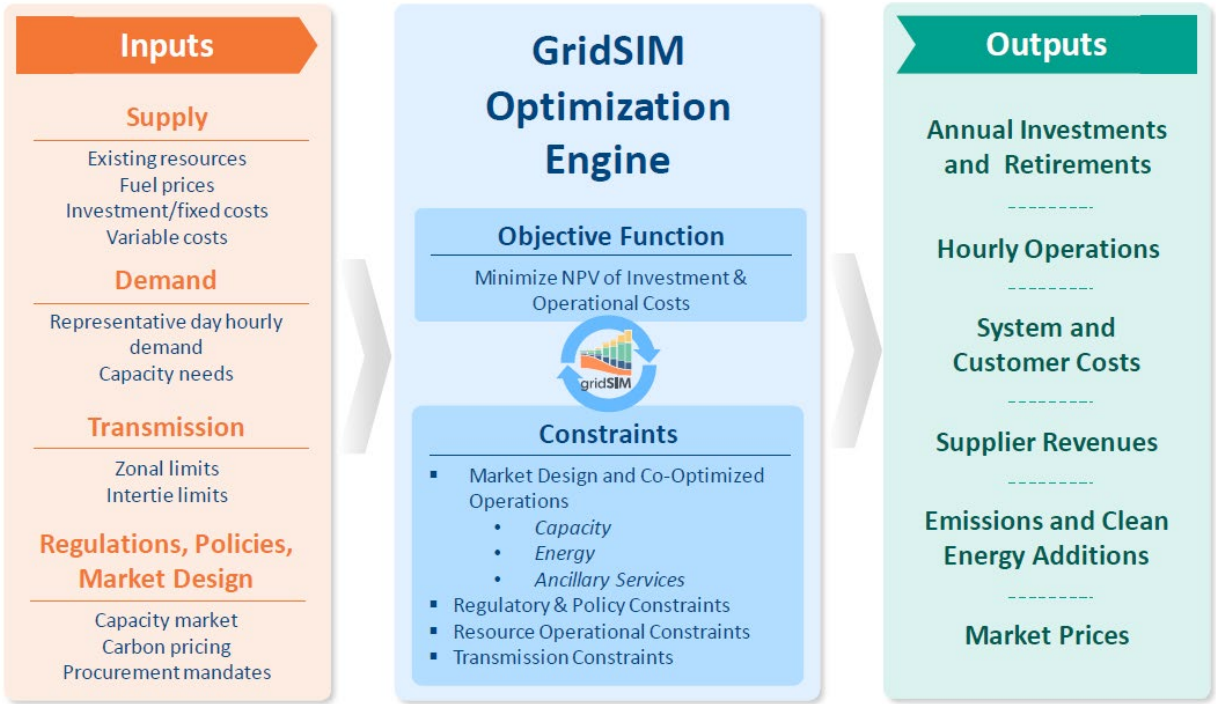


+ Hydro-Québec's Supply Plan 2022-2029
+ QC Environment Ministry's "Green Economy Plan 2030" (*Plan pour une économie verte 2030*)

Energy and Environmental Economics (2020)
Pathways to Deep Decarbonization in New York State – PATHWAYS model

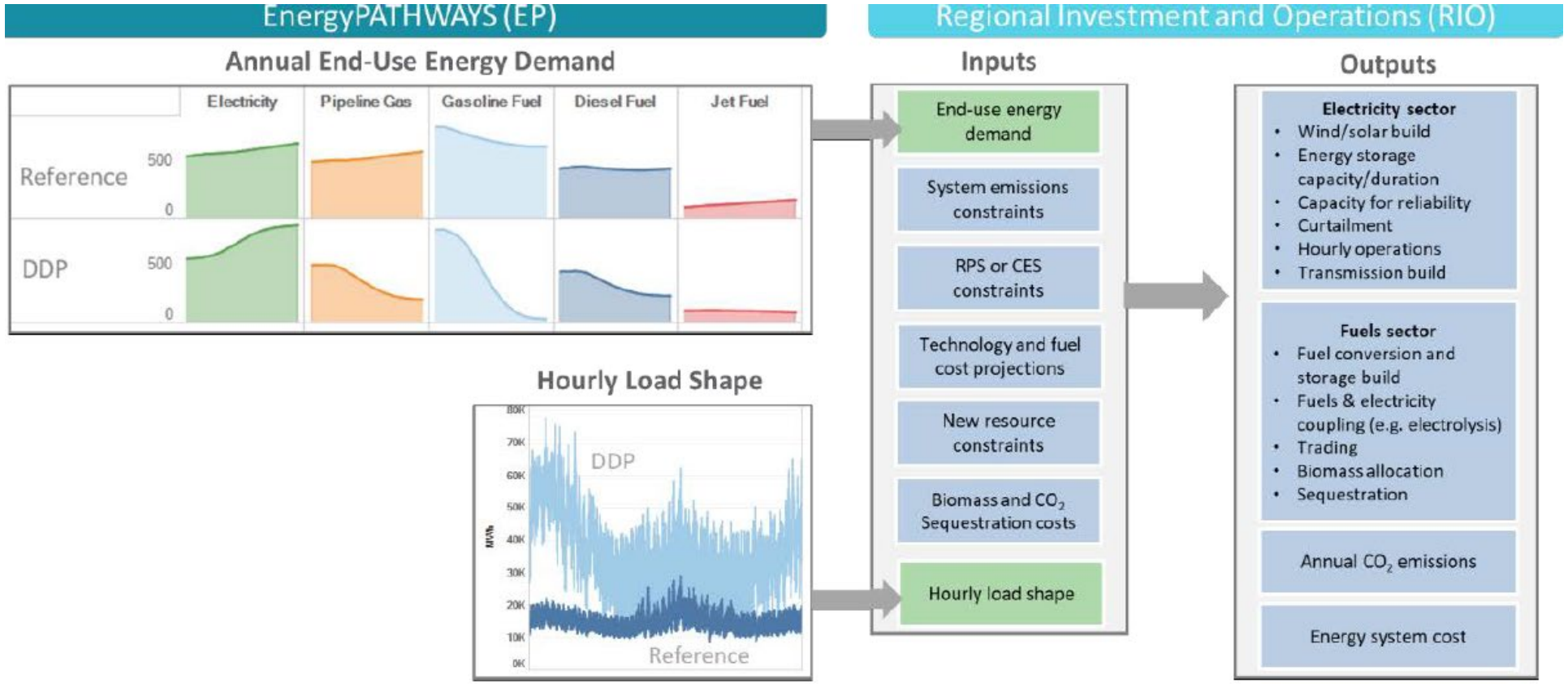


Brattle Group (2020)
NYISO Grid in Transition Study - GridSIM



Evolved Energy Research (2020)

Energy Pathways to Deep Decarbonization – Energy Pathways model



North America

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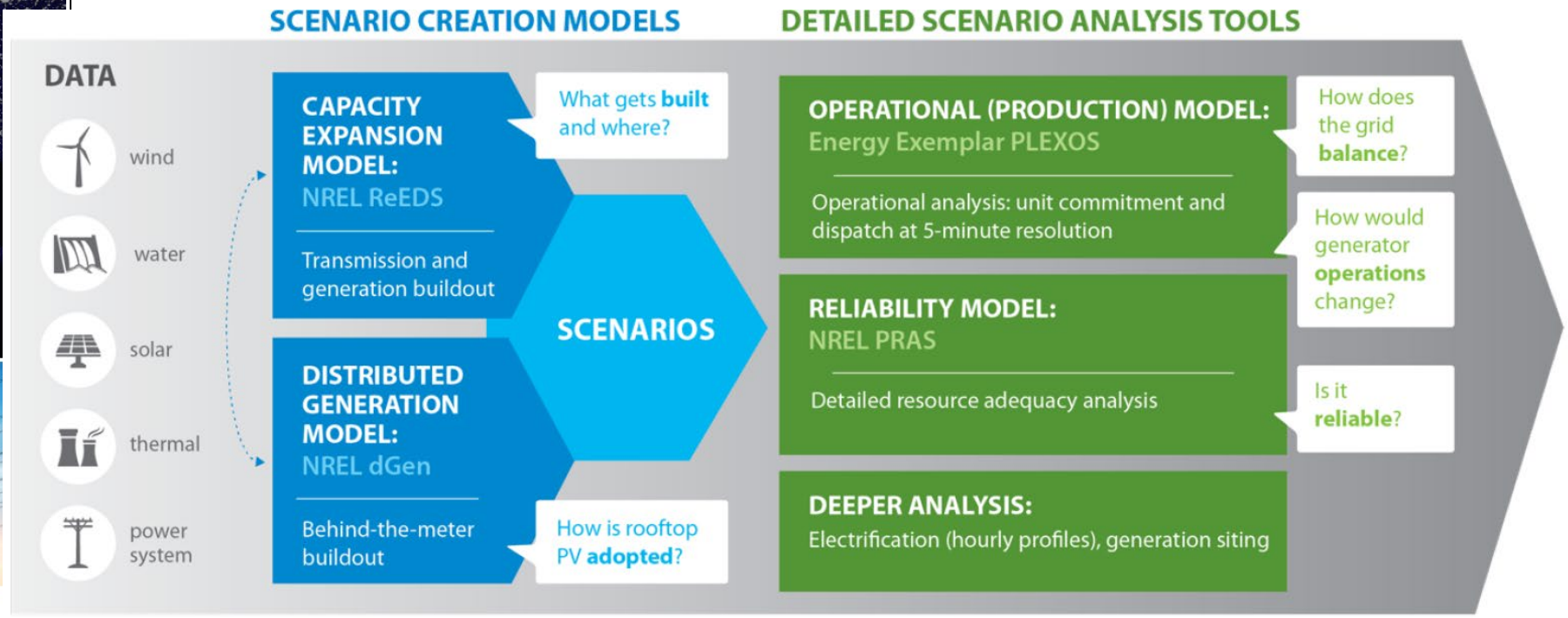
[1] National Renewable Energy Laboratory
[2] GE Energy
[3] Evolved Energy Research

2021

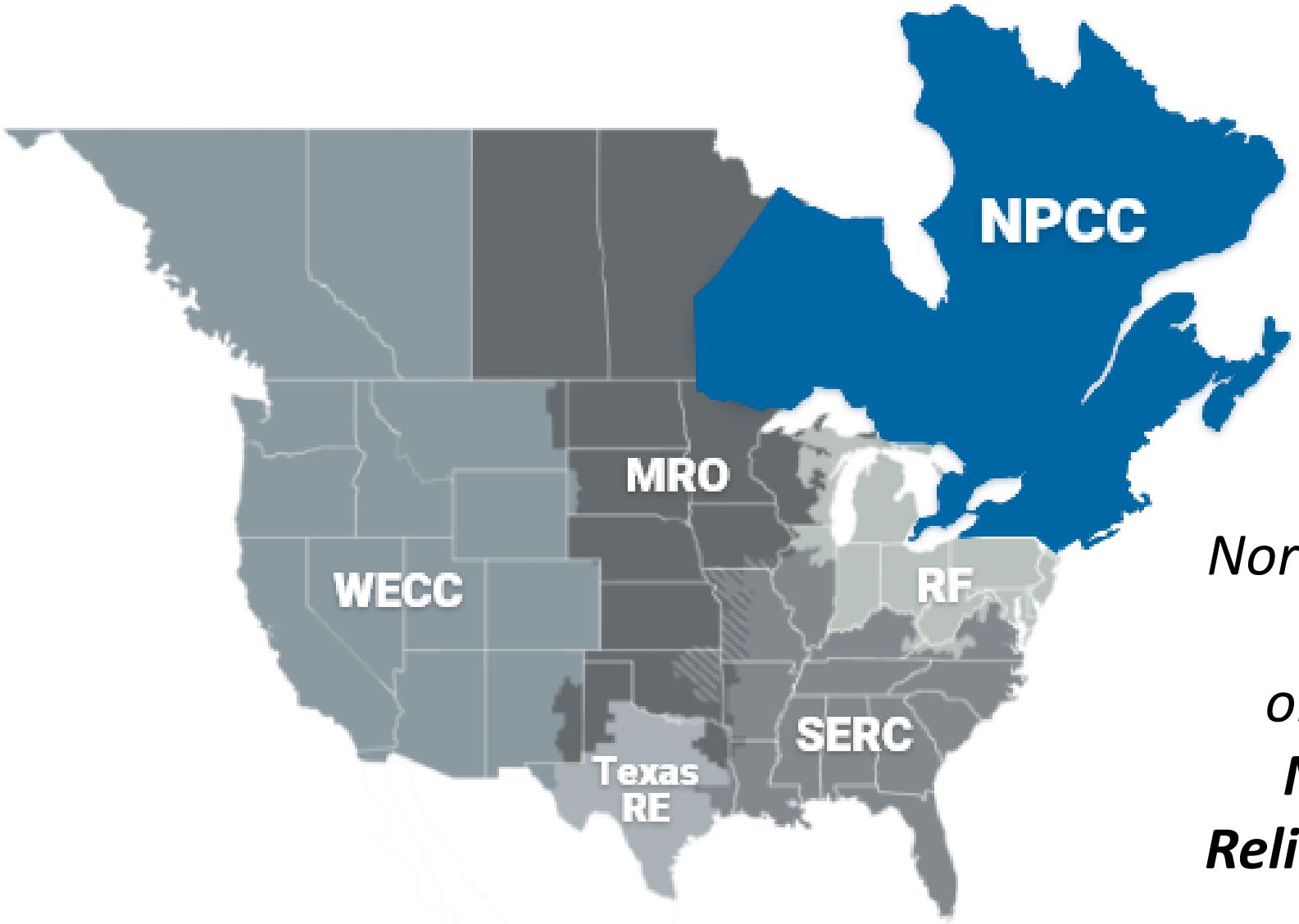


Key Features to Consider

- **Region of interest**: city, state/province, region, country, continent?
- **Demand profile**:
  - How are heating, water heating, cooling, EV charging, industry consumption, etc. going to evolve?
  - How to make demand price responsive?
- **Renewable generation costs and profiles**:
  - How will future cost evolve?
  - What wind/solar profile should be used?
- **Storage**: short-term, long-term? Hydro reservoirs?
- **Network representation**:
  - Level of details (transmission / distribution)?
  - Simple transportation network representation or real physical constraints (Kirchhoff's laws)?
- **Objective?** Cost minimization? Current or future? Equilibirum solution?

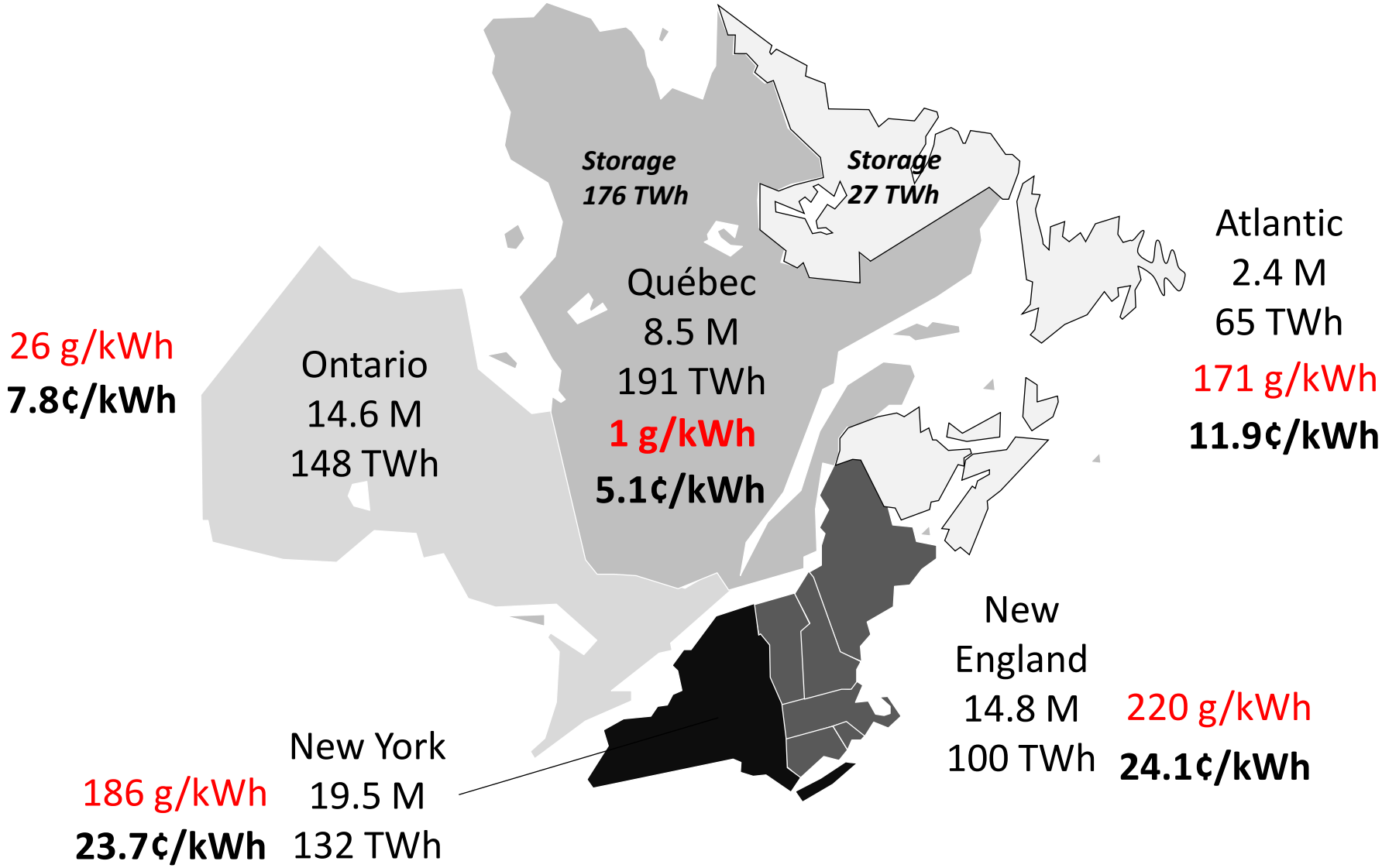
My own insatisfactions with previous approaches

- **Region of interest**: not regional enough (e.g. Canadian + US Northeast)
- **Demand profile**: energy efficiency impacts largely unexplored
- **Renewable generation costs and profiles**: little sensitivity analysis
- **Storage**: Hydro reservoirs not always included
- **Network representation**: Role of transmission interties often overlooked
- **Objective:** Decarbonization costs not presented or highlighted. Cost allocation not discussed.

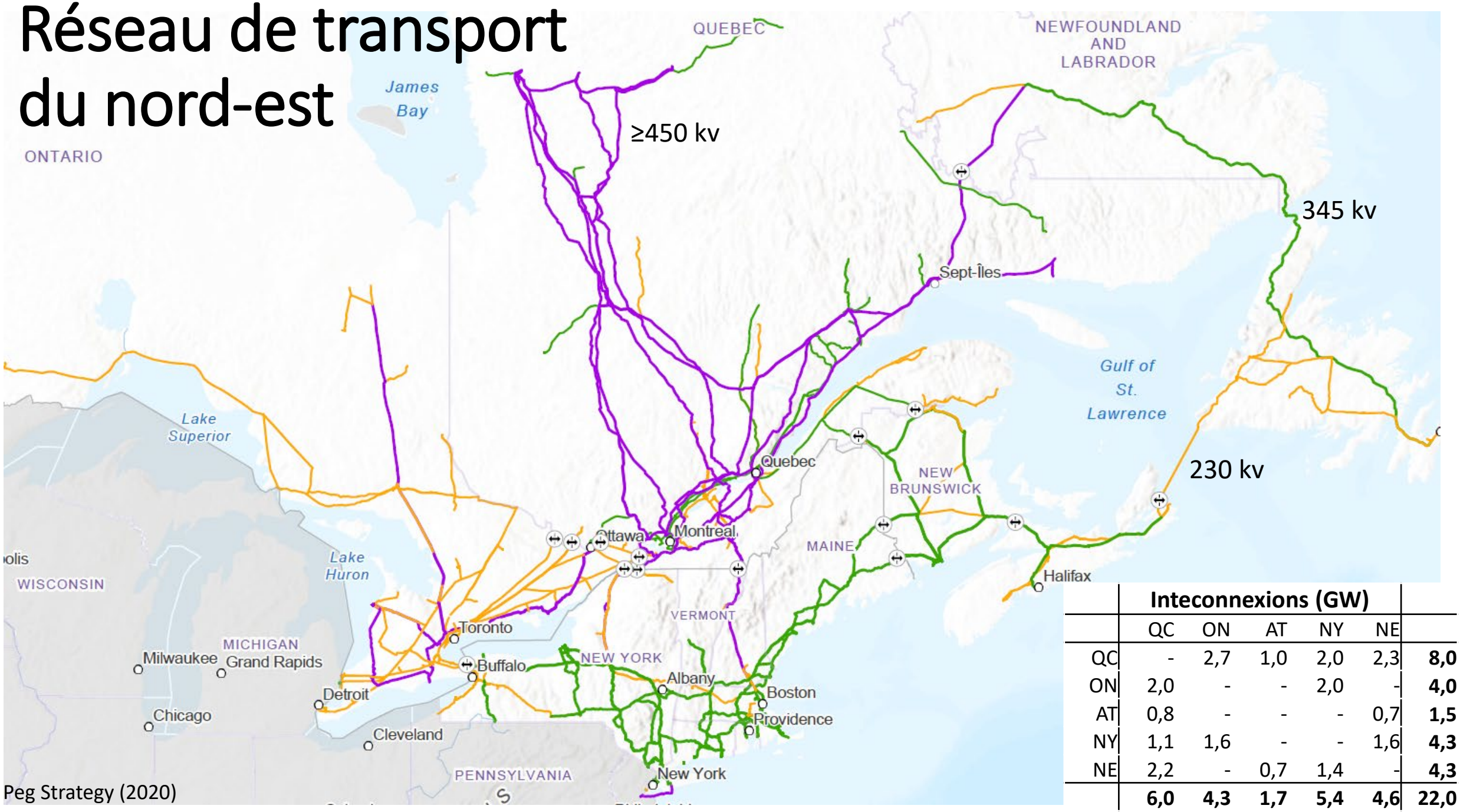


Northeast Power Coordinating Council (NPCC):
one Regional Entity of the
North American Electric Reliability Corporation *(NERC)*

Northeast: Population, Generation, carbon intensity and residential price (US$)

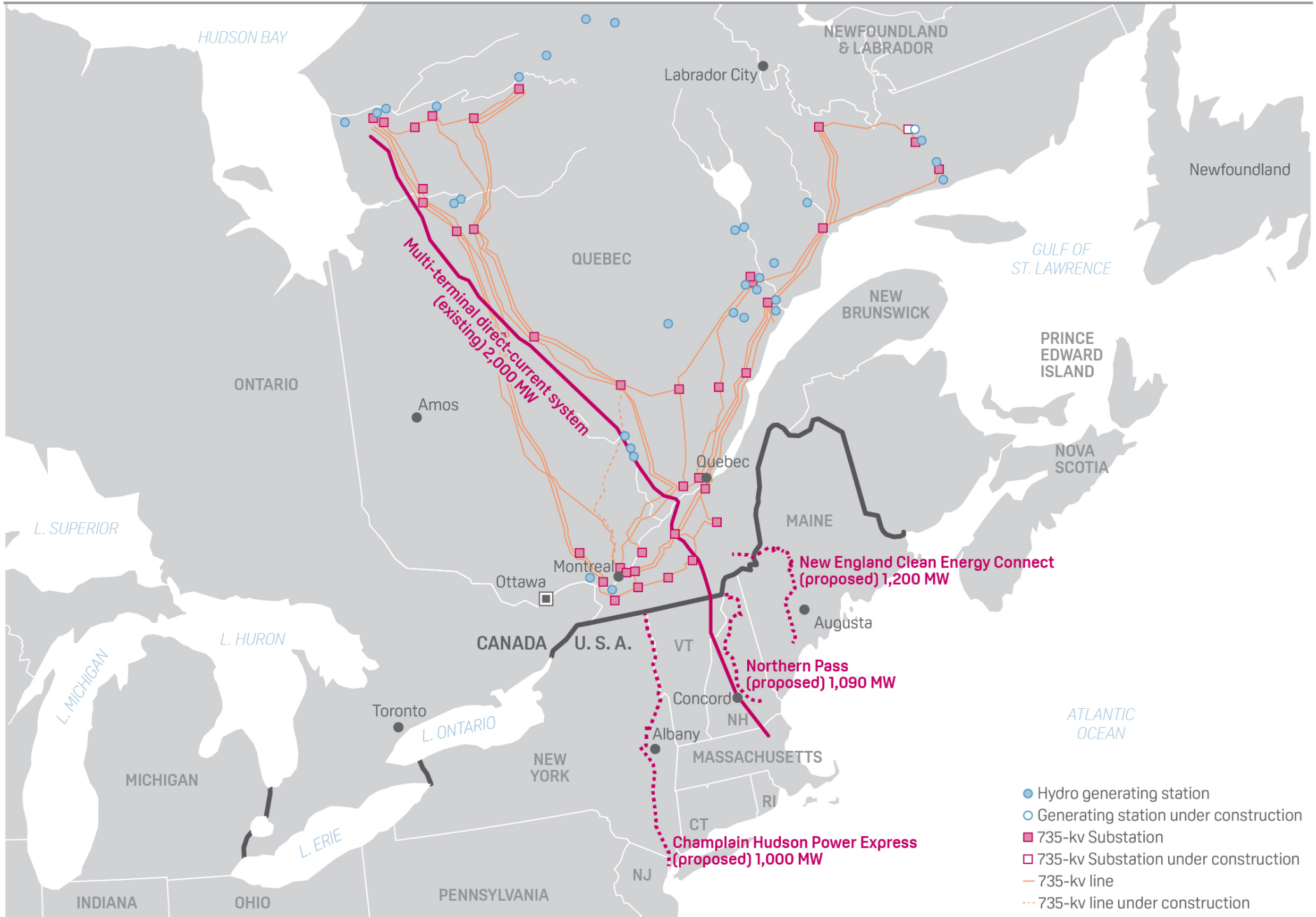


Réseau de transport du nord-est



	Inteconnexions (GW)					
	QC	ON	AT	NY	NE	
QC	-	2,7	1,0	2,0	2,3	**8,0**
ON	2,0	-	-	2,0	-	**4,0**
AT	0,8	-	-	-	0,7	**1,5**
NY	1,1	1,6	-	-	1,6	**4,3**
NE	2,2	-	0,7	1,4	-	**4,3**
	6,0	**4,3**	**1,7**	**5,4**	**4,6**	**22,0**

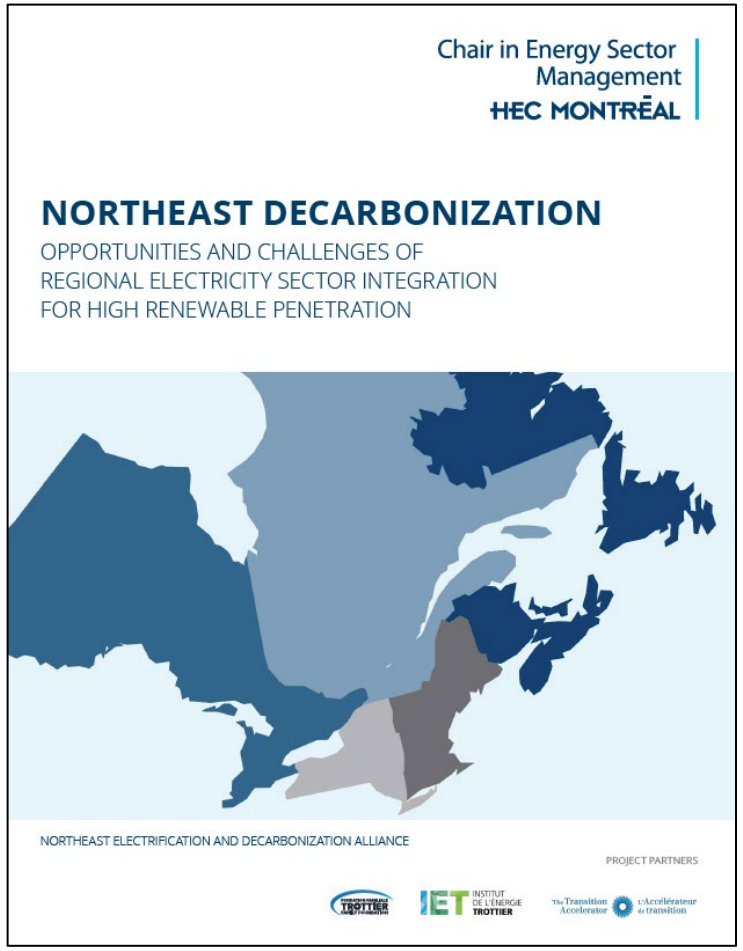
Peg Strategy (2020)



S&P Global Platts (2019)

3. Some of our results

Some publications



https://transitionaccelerator.ca/northeast_decarbonization/
https://energie.hec.ca/npcc-2/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journal homepage: http://www.elsevier.com/locate/enpol

Deep decarbonization in Northeastern North America: The value of electricity market integration and hydropower

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Decarbonization
Hydropower
Northeastern North America

ABSTRACT

In several countries, electricity systems are under strong decarbonization pressure. In particular, the Canadian provinces of Quebec and Ontario as well as the states of the northeastern United States have committed to cut their greenhouse emissions by more than 70% (with respect to emission levels of 1990). Increased collaboration and integration between jurisdictions could decrease such decarbonization costs, especially when important hydropower resources are available.

Using a capacity expansion and dispatch model of the Northeastern North American electricity sector, we analyze the impact of emission reduction targets, load levels and availability of power technologies in a range of scenarios, in order to assess the benefits of regional cooperation. Our results show that for deep decarbonization, the electricity system costs can be significantly reduced through integration, especially by adding more interconnection capacity. These costs savings and benefits are however not evenly allocated between jurisdictions, creating potentially difficult collaboration incentives.

1. Introduction

Emission pathways consistent with 1.5 °C (or 2 °C) global warming require reaching net zero emissions by 2050 (or 2070), according to IPCC (2019). Such level of decarbonization will require profound changes in the energy systems and a greater role for electricity (Williams et al., 2012). Key sub-national governments in Northeastern North America committed to limiting emissions to 80–95% below 1990 levels by 2050 by joining the Under2 Coalition: New York and all New England states (except Maine) in the United States and Ontario and Quebec in Canada (Under2 Coalition, 2019). In addition to state-level clean energy policies in New York, Maine and Connecticut, several local governments in New England have committed to 100% clean or renewable energy (Trumbull et al., 2019). Such decarbonization initiatives are supplemented with regional carbon cap-and-trade markets covering the electricity sector in the Northeastern states of the U.S. (RGGI, 2019) and in the Canadian provinces of Quebec and Nova Scotia (WCI, 2019). However, cooperation in the North American northeast electricity sector has been mostly limited to bilateral trade of surplus power (CEA, 2016). While the region includes five areas (New York, New England, Ontario, Quebec and the Atlantic provinces), there are currently more than five very different electricity market designs. They share one reliability coordinating institution, the Northeast Power Coordinating Council (NPCC, 2019), but they otherwise plan their respective power systems in almost complete disregard of integration benefits and regional resources potential.

In this multi-region setting, electricity market integration and cooperation can occur in multiple ways, for example, through coordinated capacity planning, pooled capacity resources or electricity trade. Such cooperative actions can support the transformation of power systems to achieve decarbonization goals, through:

- Access to low-cost renewable energy across regions.
- Economies of scale in large capacity investment projects.
- More efficient power dispatch (Newbery et al., 2016).
- Load balancing and smoother generation in a wider territory (Bahar and Sauvage, 2013).
- Greater economic value of renewable generation, by reducing electricity curtailment (Newbery et al., 2016).

This paper illustrates the value of electricity market integration in a context of a region strongly committed to deep decarbonization. It also explores the enabling role of hydropower in such decarbonization, as the large hydropower capacity in Quebec (40.44 GW, corresponding to 22%

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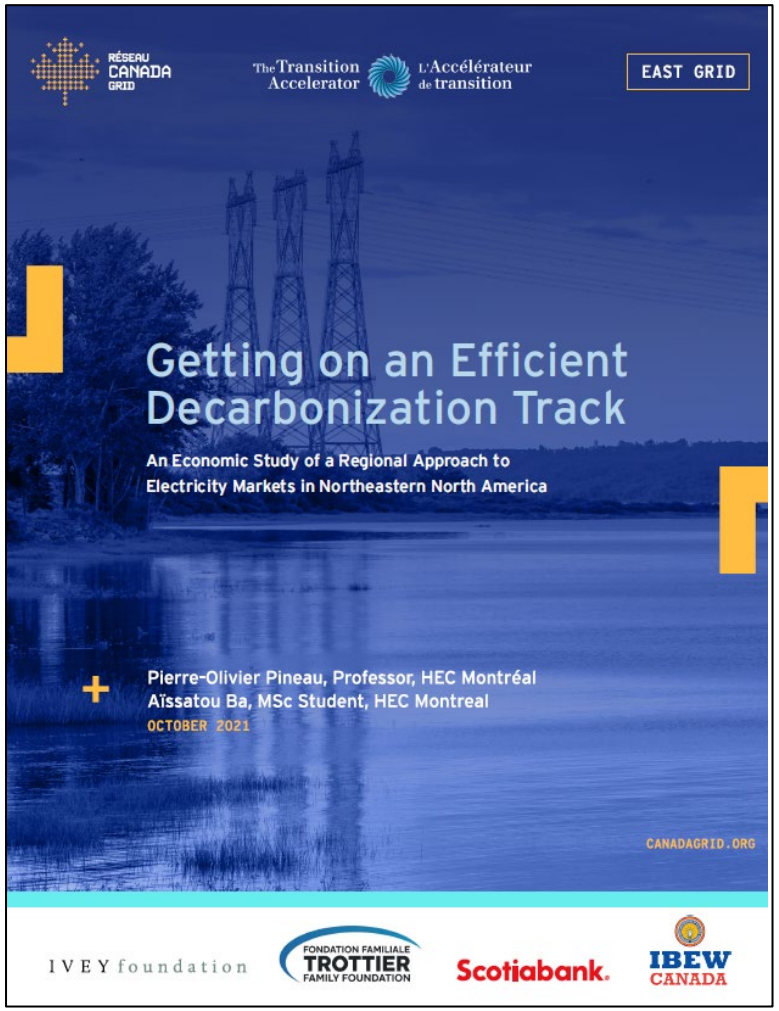
Energy Policy April 2021 paper
https://www.sciencedirect.com/science/article/abs/pii/S0301421521000793



https://www.canadagrid.org/

Modelling Approach (1)

- Capacity expansion and dispatch linear model
- 8,760 hours of a representative year
- Investment decisions: generation + transmission capacity
- Operational decisions: power production for each type of generator, power exchanges between jurisdictions, electricity curtailment + energy storage and discharge, demand response and load shedding levels

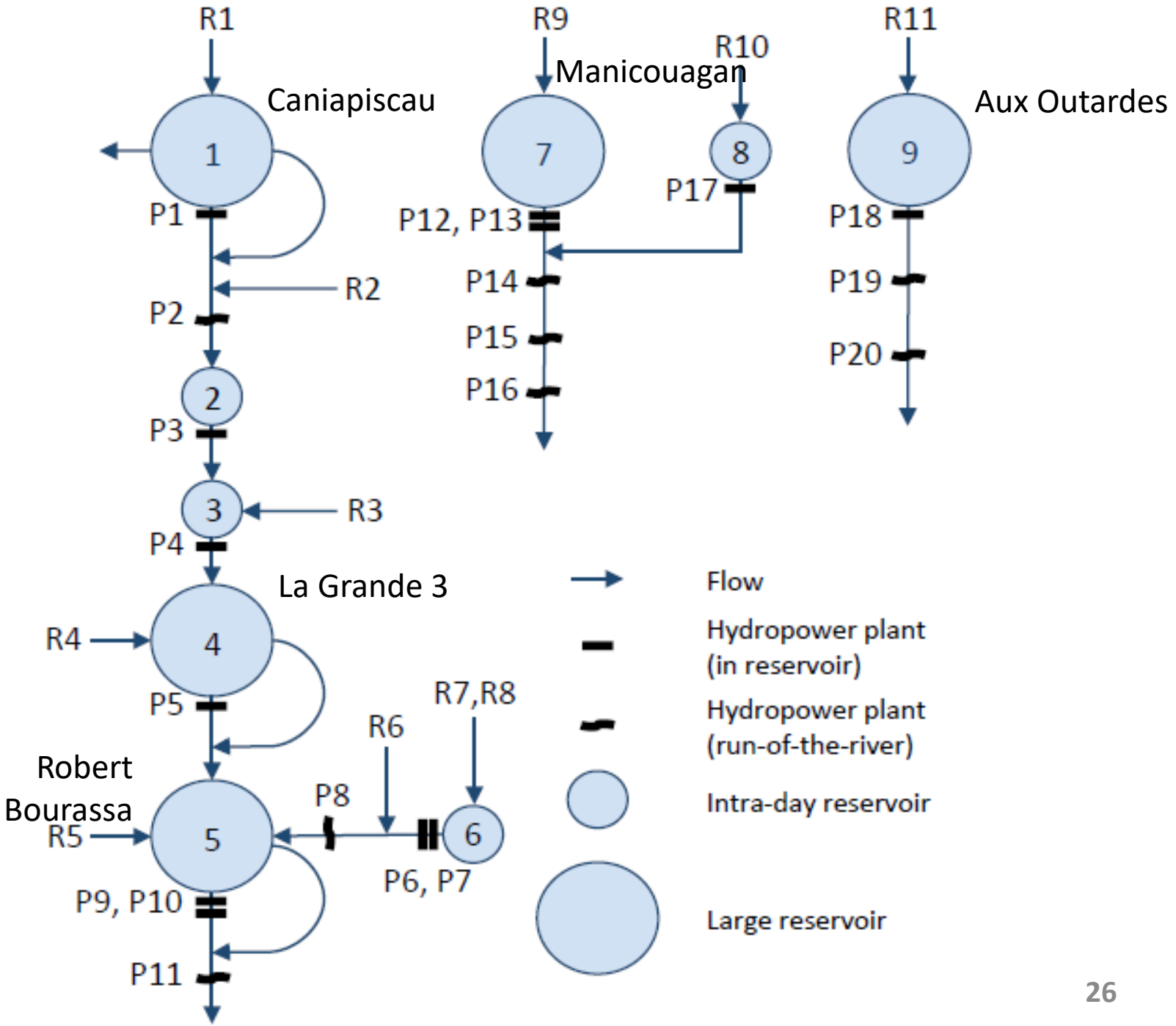
Modelling Approach (2) – Power Technologies

- **Intermittent renewable** (solar & wind) with real local generation profiles
- **Nuclear power**.
- **Natural Gas**: CT and CGGT, with carbon-neutral fuel possible
- **Hydropower**: Flow-of-the-river + Intra-day reservoirs + Large reservoirs (yearly cyclic storage capacity)
- **Energy Storage**
- **Transmission**: cross-border interconnections

Modelling Approach (3) – Quebec Hydropower

Number	Name	Capacity [Billion m^3]	
		Min.	Max.
1	Caniapiscau	39.0	52.6
4	La Grande 3	25.2	60.0
5	Robert Bourassa	19.4	61.7
7	Manicougan	35.2	137.9
9	Aux Outardes	10.9	24.5

Table 13: Storage capacity of large reservoirs in Quebec

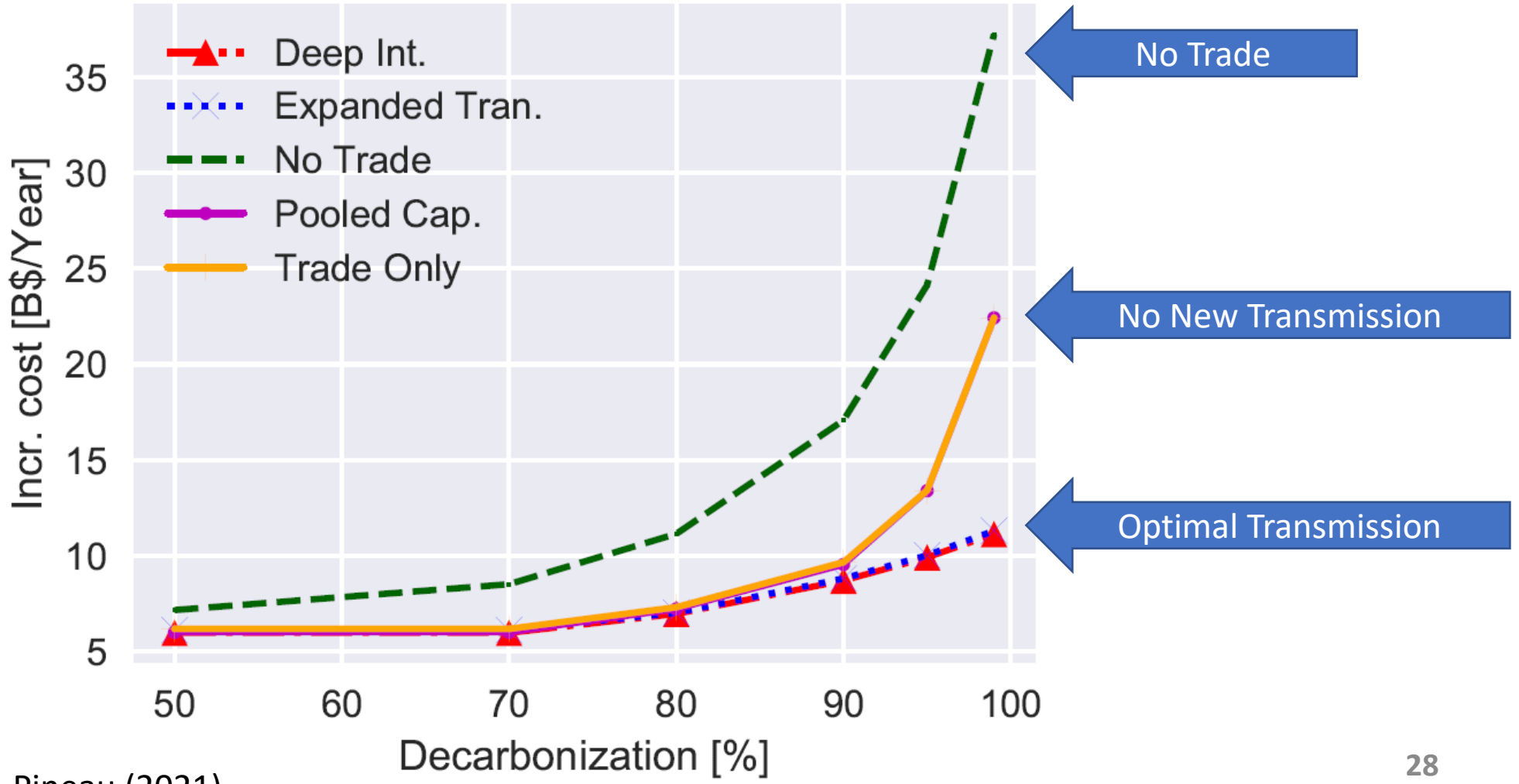


Scenarios of interest

- **Decaronization level** (electricity generation): from 50 to 99%
- **Interconnections**: without, same or as much as needed?
- **Shared capacity (or local capacity constaint)?** Yes / no
- **Nuclear**: Yes / no
- **Emission-free natural gas**: Yes / no
- **Demand**: x1, x1.25, x1.5

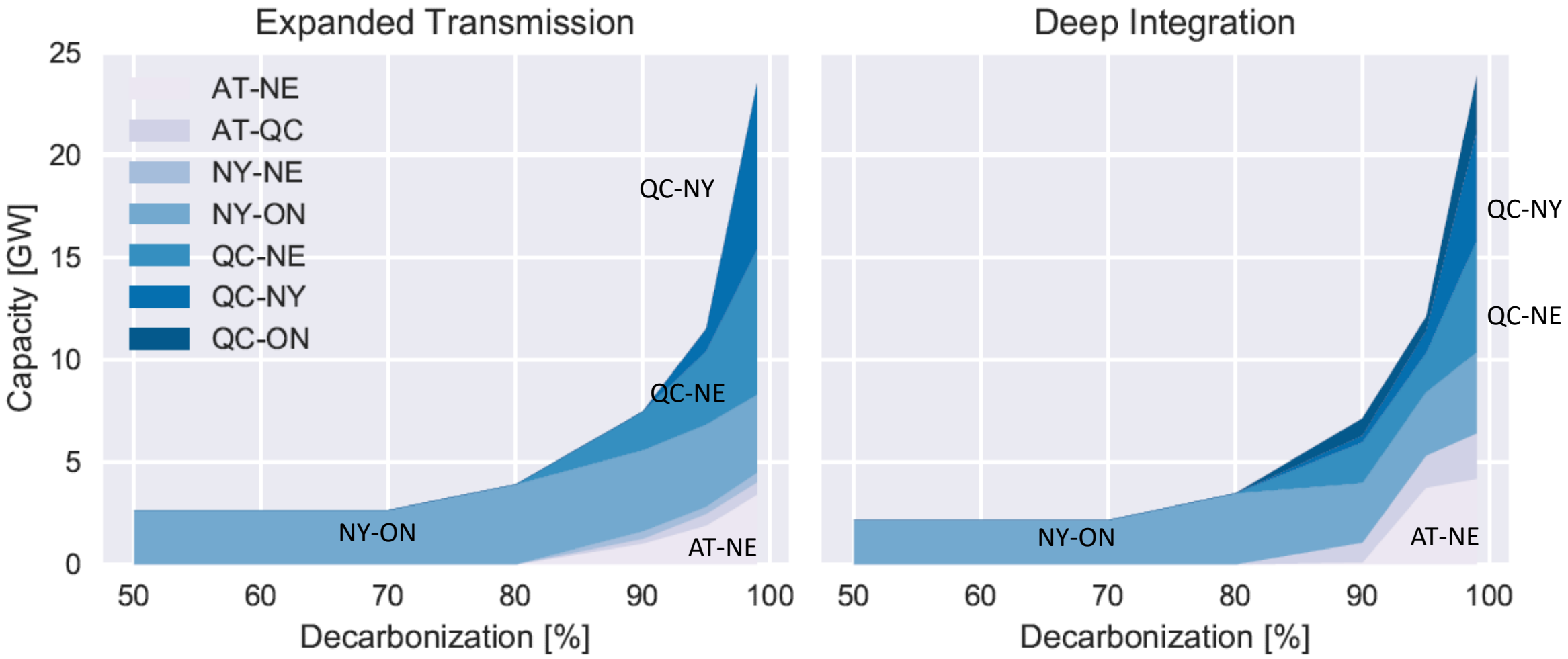
Annual decarbonization cost

No Trade / No New Transmission / Optimal Transmission

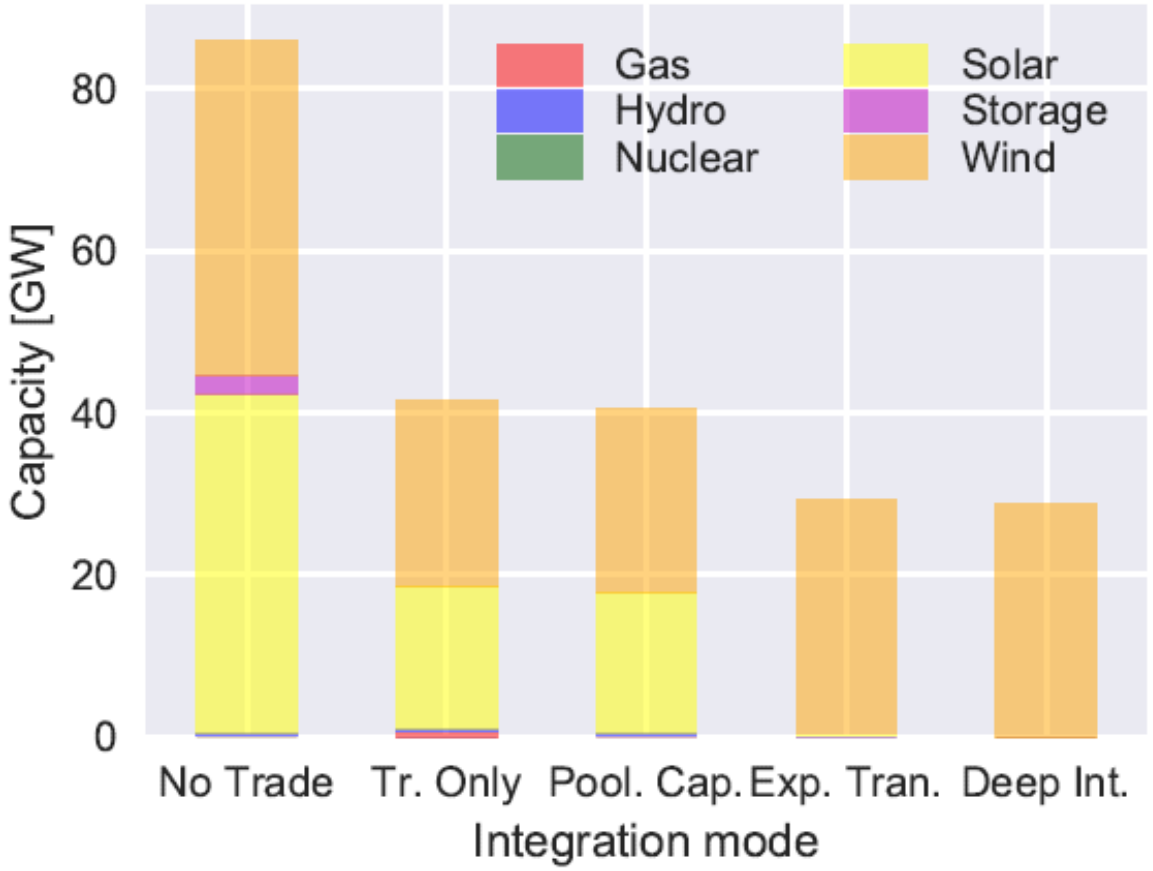


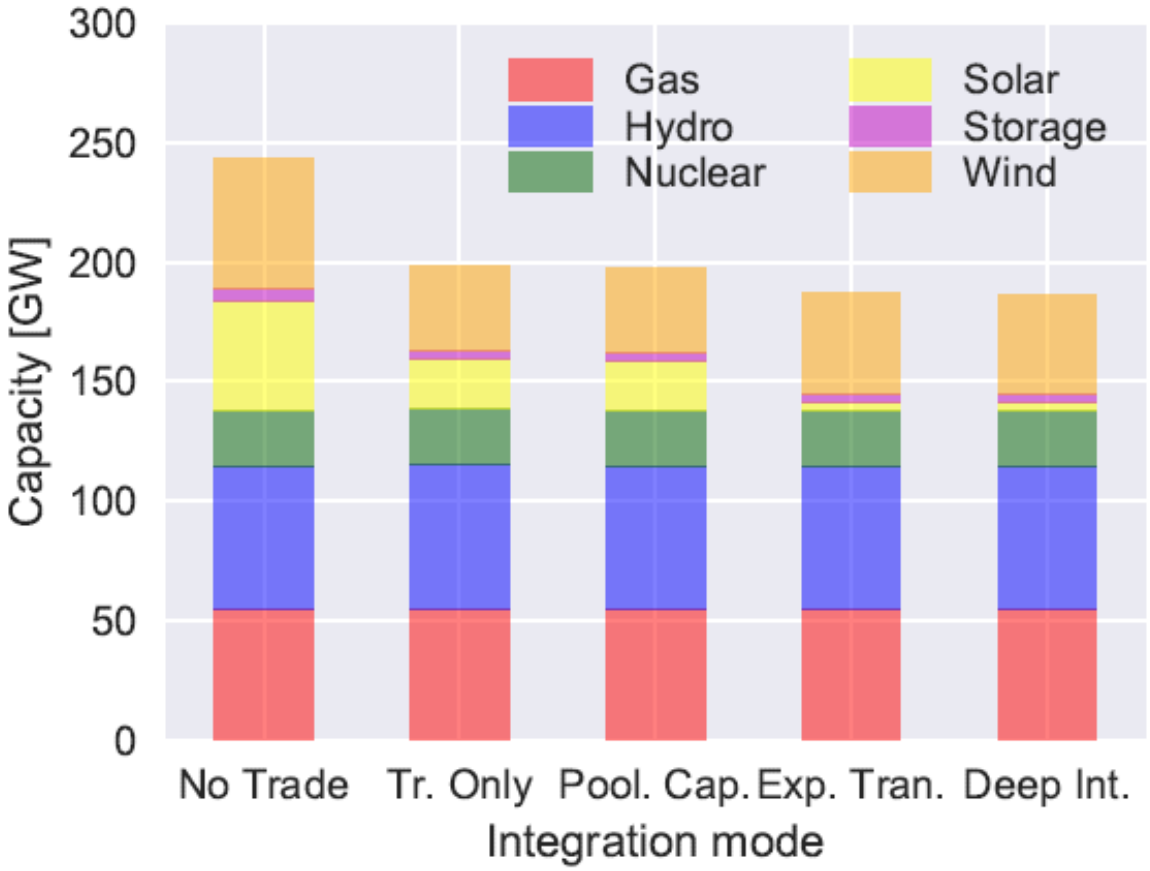
Rodríguez-Sarasty, Debia, Pineau (2021)

Interties are critical



Important Wind and Solar requirements (90% decarbonization)





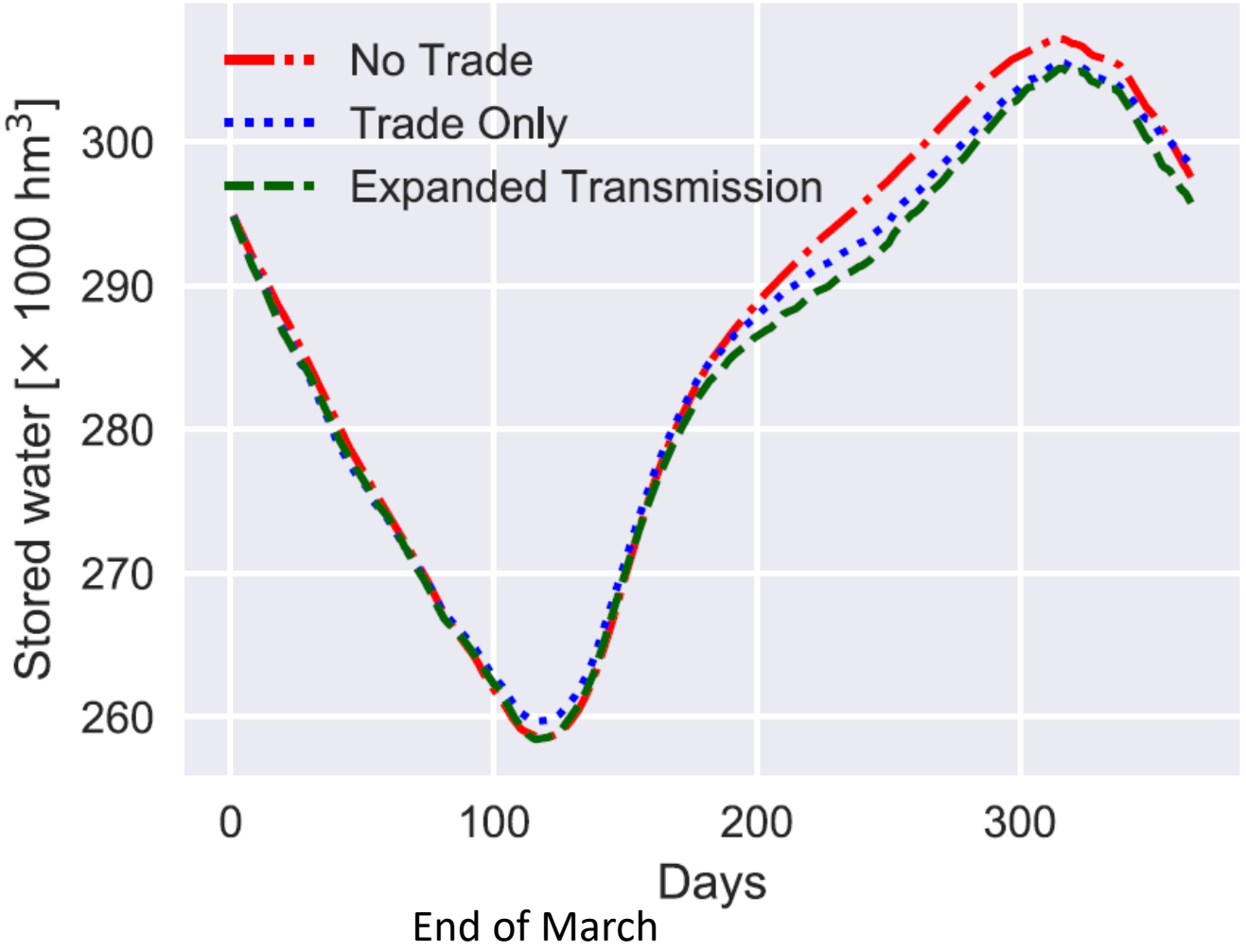
More interies = More wind

With Optimal Transmission :

- Hydro-Wind correlation: from -0,06 to **-0,28**
- Wind generation: from 102 to **120 TWh**
- Wind curtailment: from 1,5 % to **0,1 %**

Rodríguez-Sarasty, Debia, Pineau (2021)

Changes in reservoir levels

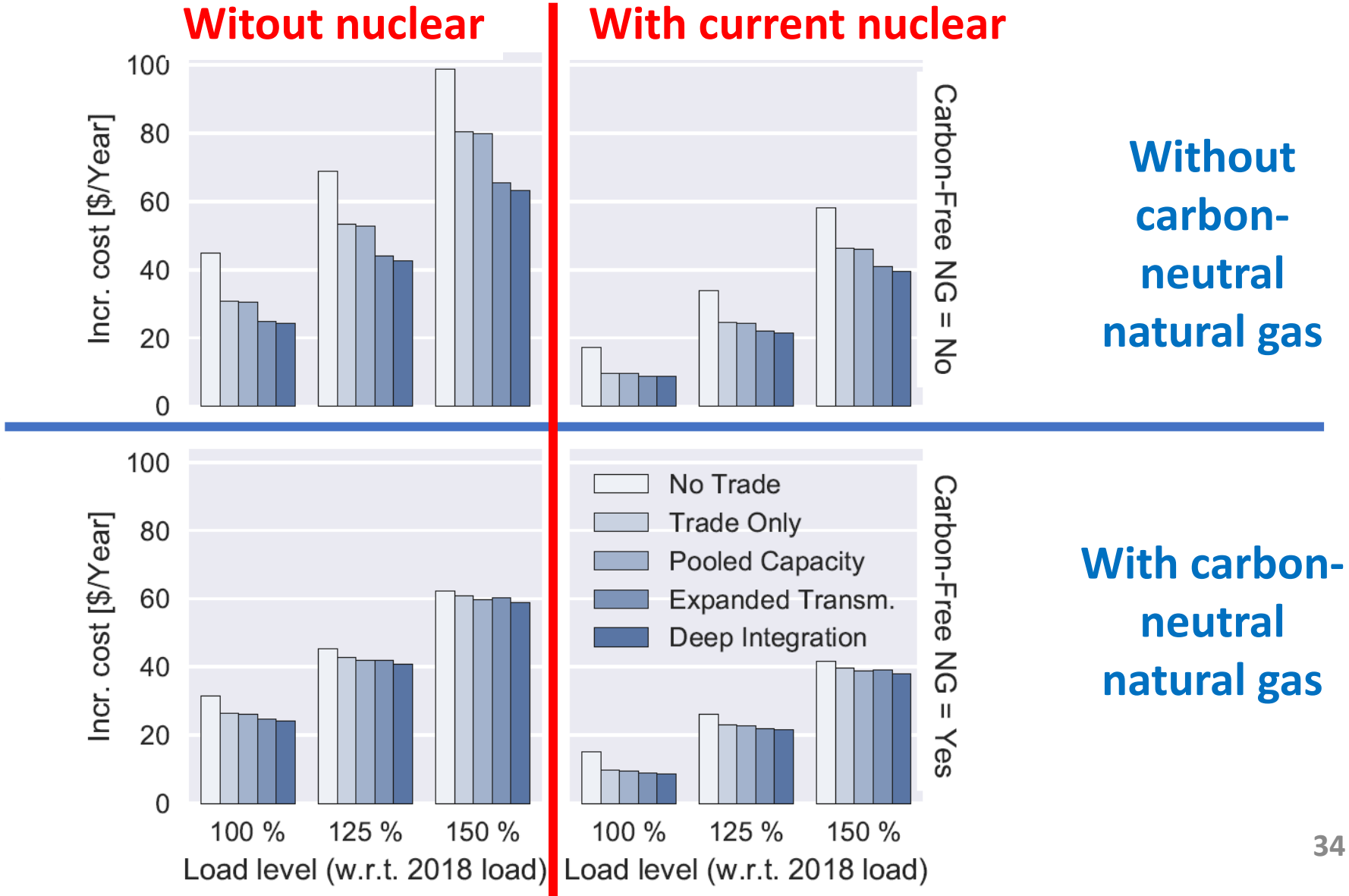


Rodríguez-Sarasty, Debia, Pineau (2021)

Price converge with integration

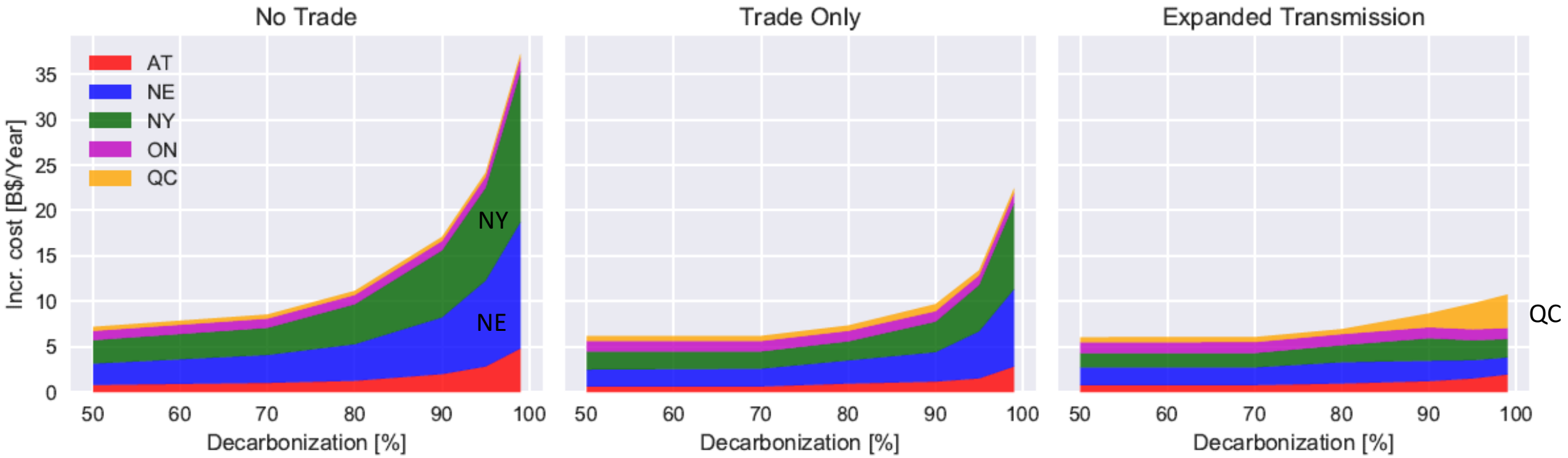
Cost for different scenarios: Nuclear, GHG-free natural gas and demand growth (100%, 125% and 150%)

Annual cost 90% decarbonization



Regional Cost Impacts

Annualized cost of operation and incremental investments by decarbonization level

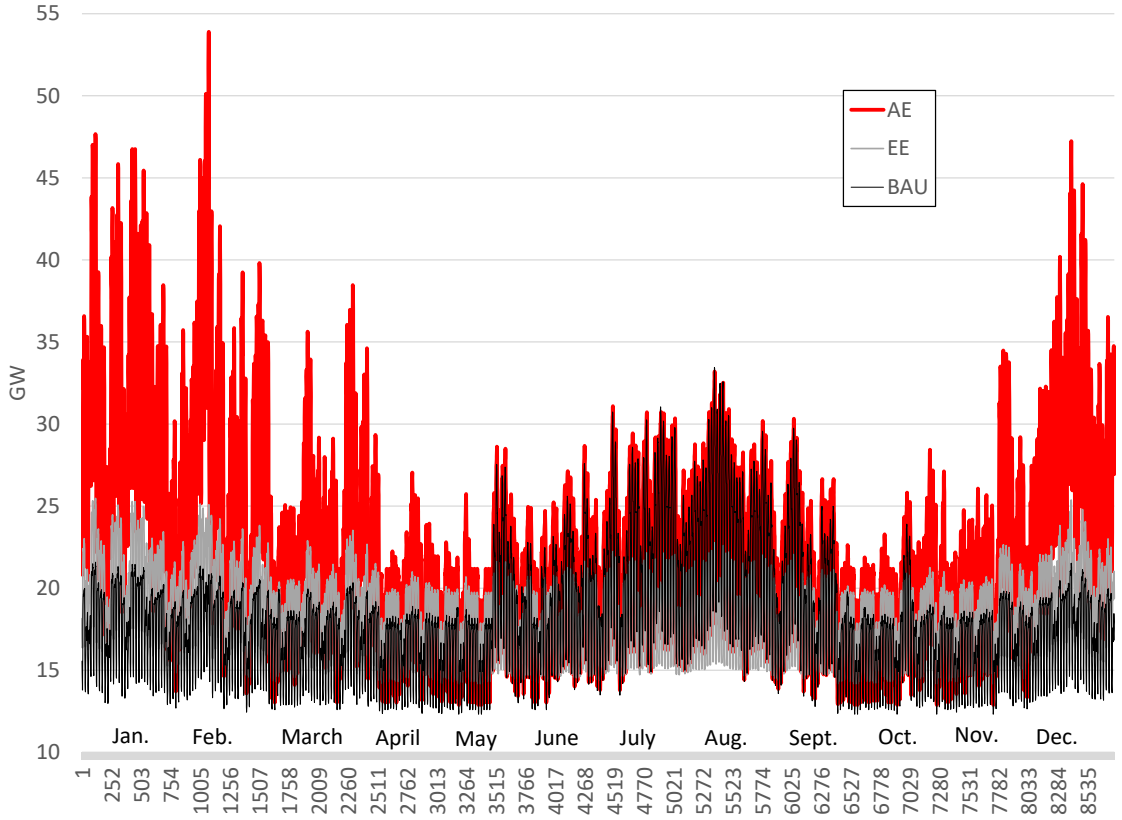


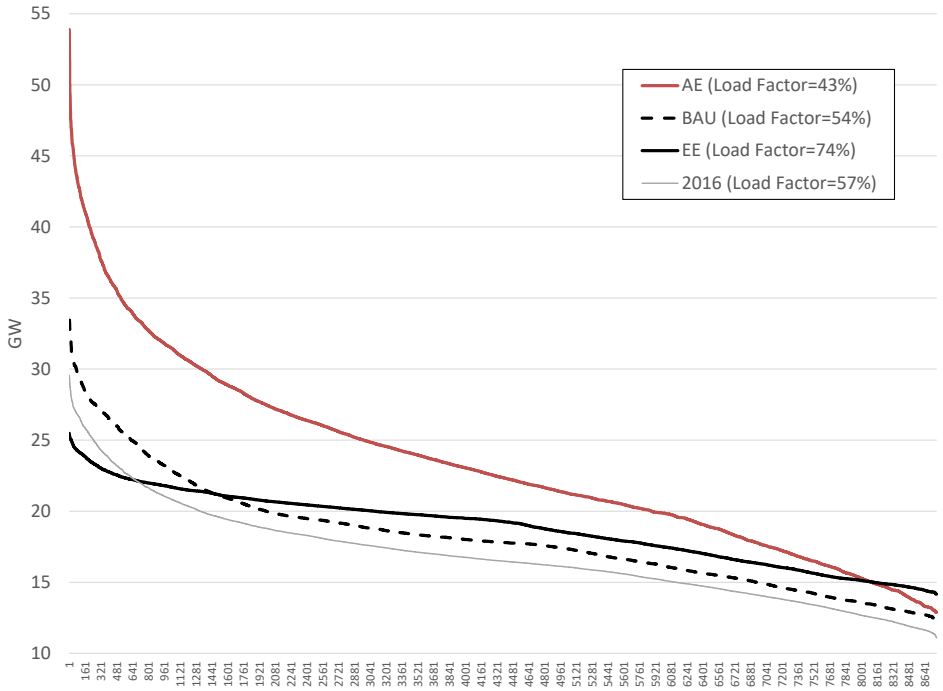
Ongoing work

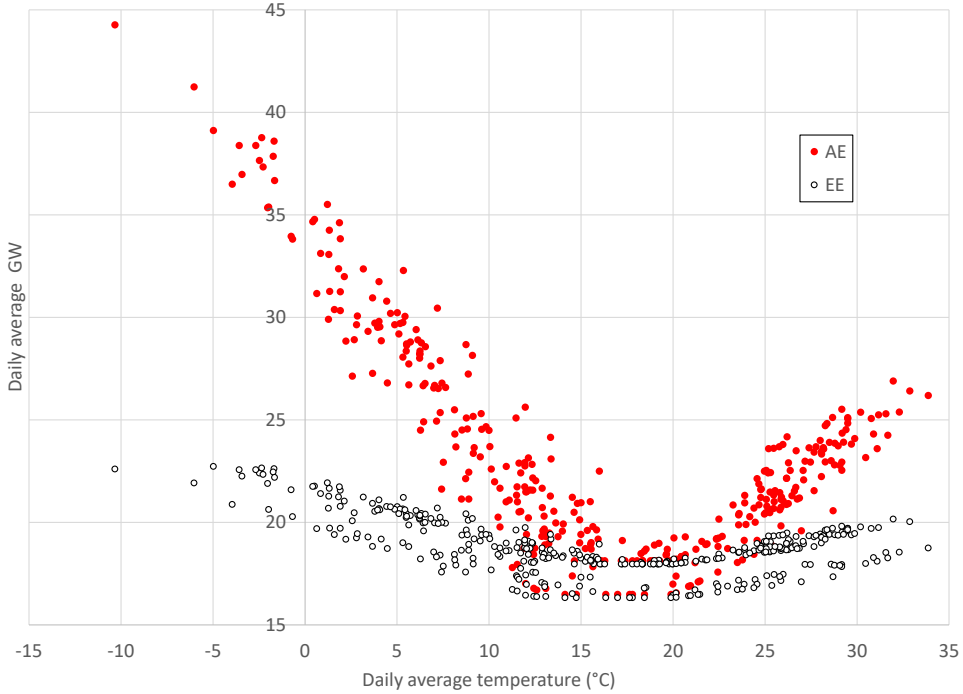
- **Sébastien Debia**: cooperative game theory analysis of coalitions
- **Aïssatou Ba**: robustness of the integration value to (low) short-term storage cost and (high) transmission cost
- **with Florian Mitjana and Michel Denault** (Jopt2022 MB2) : Multi-stage stochastic problem + myopic vision (or not) + nuclear impact
- **with Hydro-Québec**: hourly demand generator (to create demand scenarios)

4. Challenges & Opportunities

Electrification or efficient electrification?

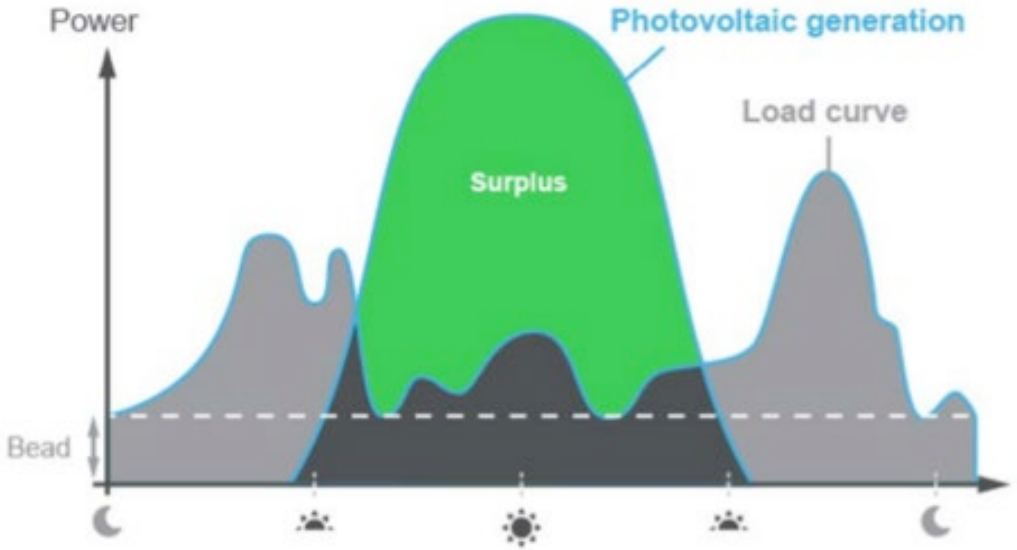




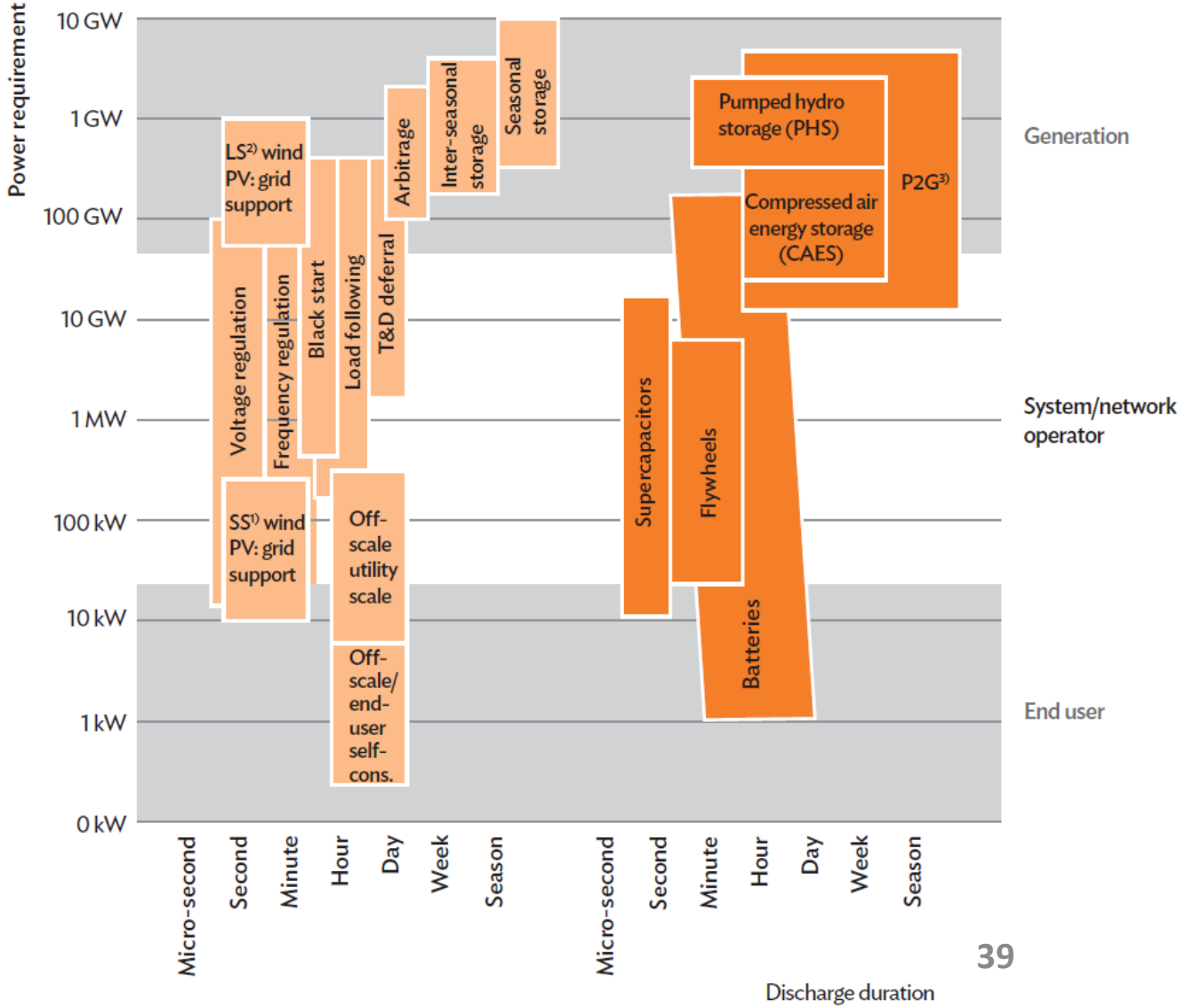


Pineau et al. (forthcoming)

Storage: the weak link of electricity markets



Value of storage = fct (cost, load flexibility/DR, generation cost, network costs)



ADB (2018)

Hydrogen Analysis

- Value for the electricity system (storage)
- Value for the energy system (sectors hard or impossible to electrify)
- Additional generation & transmission capacity assessment

Market Analysis

- Reconciliate **individual** value/cost and **system** value/cost
- Contract design
- Transfer payments

+ political and social analysis

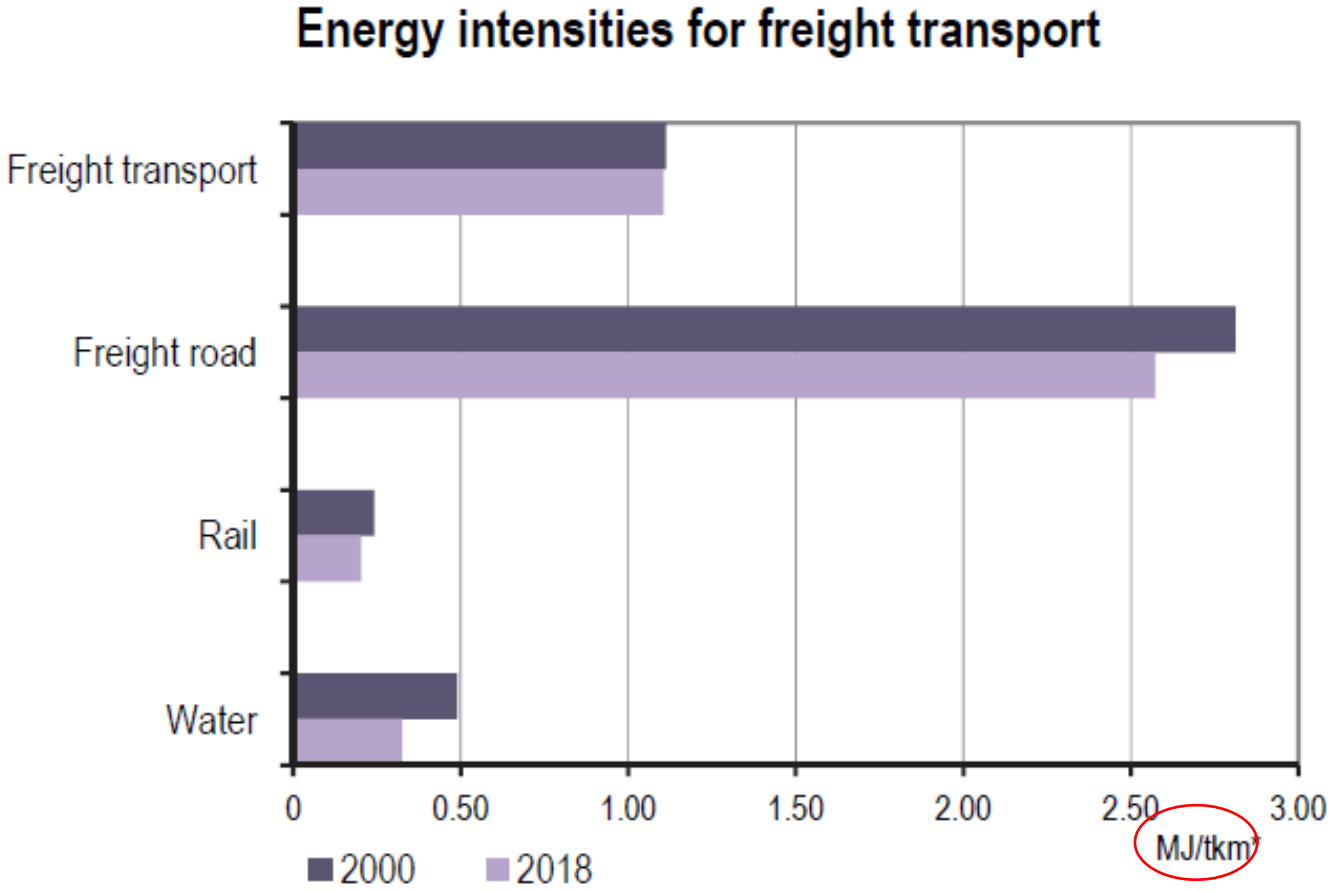
ADB (2018)

Hydropower modelling

- Value of a detailed hydro system model in technico-economic studies?
- Flexibility analysis of hydropower generation:
  - Wind/solar balancing versus hydro generation optimization
  - Integration of river management constraints
- Impact on turbines of increased ramps up/down
- System impacts of low multi-year water intakes, in a context of (much) more solar and wind

Transportation: Electrification or modal shift?

Canada



IEA (2020)

Conclusion

- Lots of areas to study
- Sadly, there is limited institutional capacity to adequatly use models and their results
- This is where people like me can (maybe) help bridge the gap between OR models and their use to support decision making and policy

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