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Chaire de gestion du secteur de l'énergie
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The Benefits of Integrating Electricity Markets – *Why and How Canadian Provinces Should Reform their Electricity Sector*

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DEPARTEMENT OF DECISION SCIENCES

Department of Economics: Visiting Speaker Series
November 20th, 2015 – 3 to 4:30pm
Room A2065 Arts and Administration Building
Memorial University
St-John's

PRESENTATION BASED ON TWO PAPERS

- "Fragmented Markets: Canadian Electricity Sectors' Underperformance" (Chapter 13), in *Evolution of Global Electricity Markets: New paradigms, new challenges, new approaches*, ed. by F.P. Sioshansi, Elsevier, 2013.
- "Integrating Thermal and Hydro Electricity Markets: Economic and Environmental Costs of not Harmonizing Pricing Rules" (open access article), Billette de Villemeur E. and Pineau P-O*., The Energy Journal*, vol. 37 (1) 77-100, 2016.

OUTLINE

1. Introduction: Energy in Canada and Regional Power Integration
2. Model
3. Calibration
4. Results
5. Discussion

1. INTRODUCTION: CANADA AND ENERGY PRODUCTION

Oil	Natural Gas	Coal	Hydropower
1. Saudi Arabia 2. Russia 3. US 4. China **5. Canada** (2013)	1. US 2. Russia 3. Qatar 4. Iran **5. Canada** (2011)	1. China 2. US 3. India 4. Indonesia 5. Australia … 11. **Canada** (2013)	1. China 2. Brazil **3. Canada** 4. US 5. Russia (2012)

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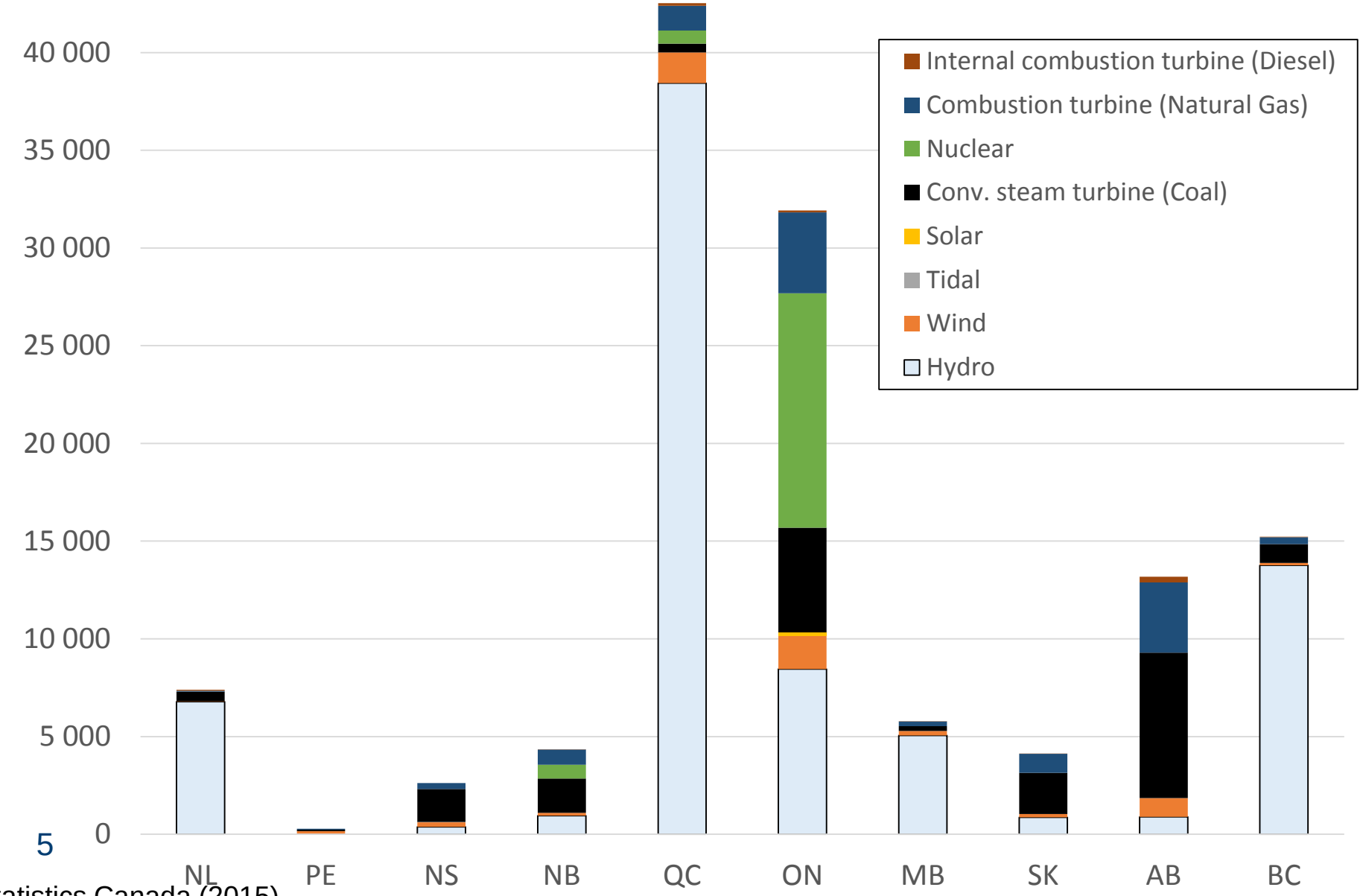
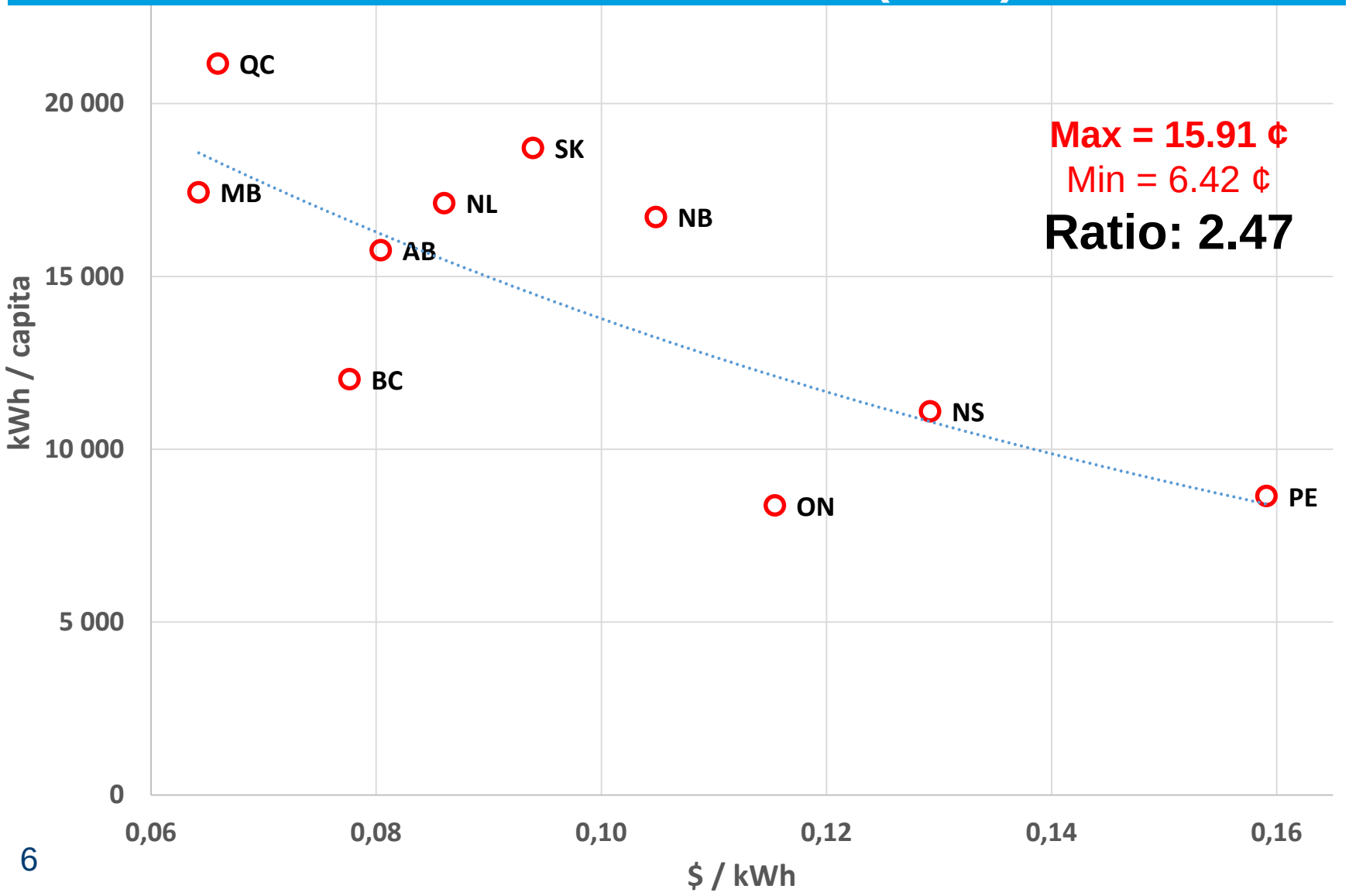
IEA (2014)

INSTALLED CAPACITY, 2013 (MW)



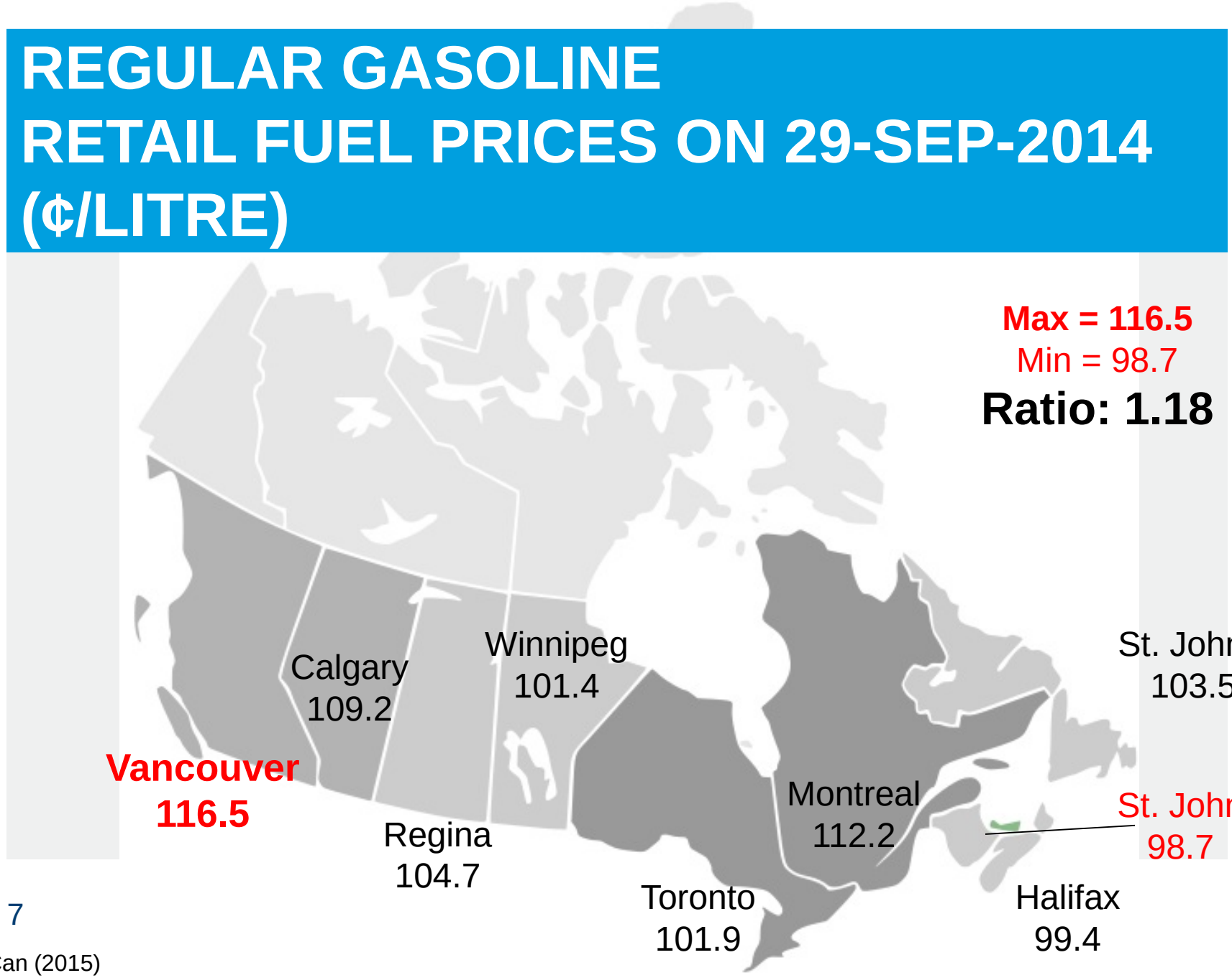
Statistics Canada (2015)

TOTAL ELECTRICITY SALES PER CAPITA BY AVERAGE ELECTRICITY VALUE (2013)



Statistics Canada (2015)

REGULAR GASOLINE
RETAIL FUEL PRICES ON 29-SEP-2014 (¢/LITRE)



NRCan (2015)

NATIONAL ENERGY PROGRAM (1980-1984)

Main elements of the program:

- **a blended "made-in-Canada" price of oil consumed in Canada:**

  $18.50 versus $35 (Sept. 1980 world price)

- a petroleum and gas revenue tax of 8% on all production of oil and gas in Canada
- a federal share of petroleum production income rising from 10 to 24%

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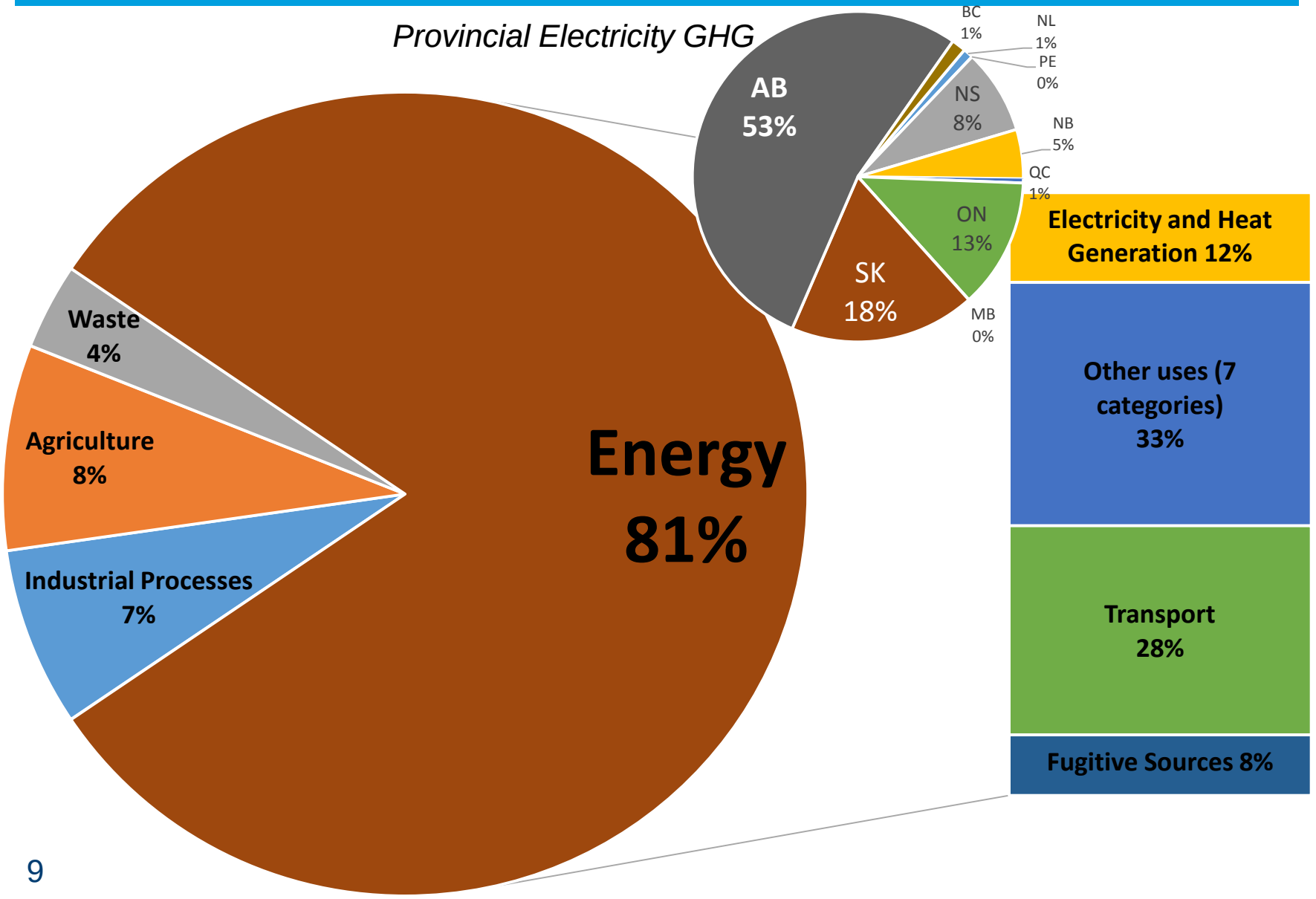
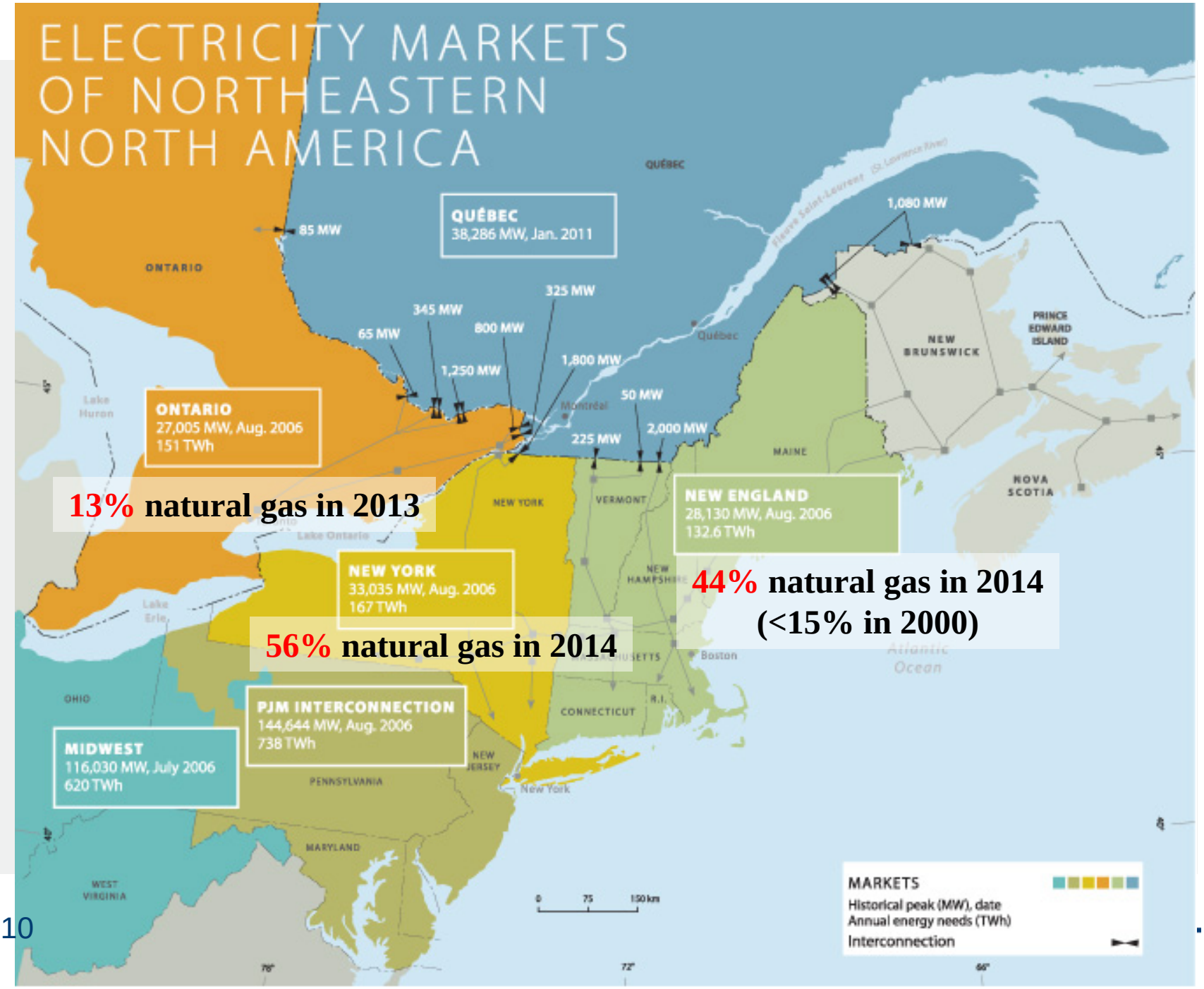
Scarfe (1981) and Bregha (2013)

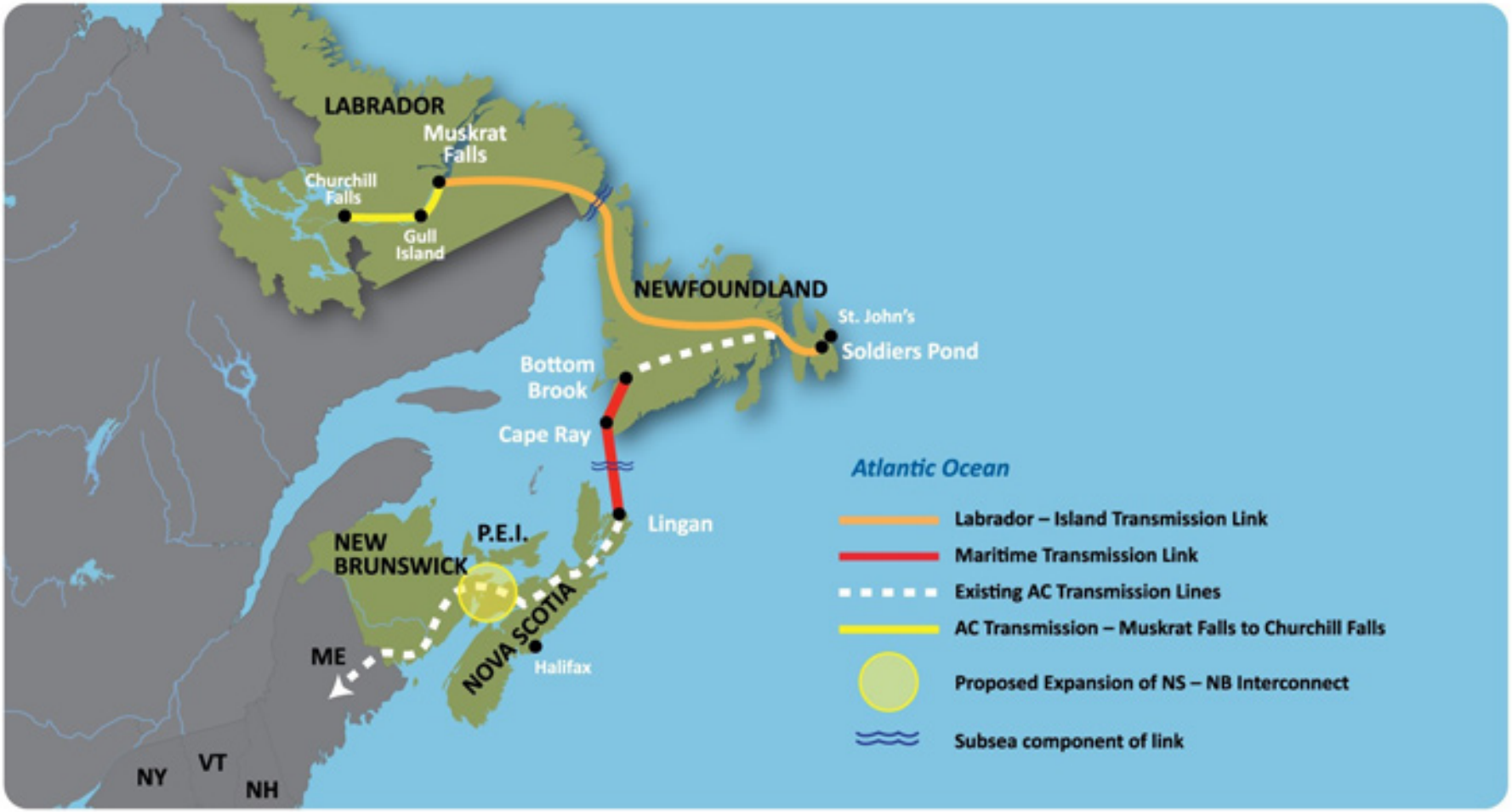
GHG EMISSIONS IN CANADA BY SECTOR (2013)



Environment Canada (2015)


ELECTRICITY MARKETS OF NORTHEASTERN NORTH AMERICA
QUÉBEC
38,286 MW, Jan. 2011
85 MW
65 MW
345 MW
800 MW
325 MW
1,250 MW
1,800 MW
50 MW
225 MW
2,000 MW
1,080 MW
ONTARIO
27,005 MW, Aug. 2006
151 TWh
13% natural gas in 2013
NEW YORK
33,035 MW, Aug. 2006
167 TWh
56% natural gas in 2014
NEW ENGLAND
28,130 MW, Aug. 2006
132.6 TWh
44% natural gas in 2014
(<15% in 2000)
PJM INTERCONNECTION
144,644 MW, Aug. 2006
738 TWh
MIDWEST
116,030 MW, July 2006
620 TWh
MARKETS
Historical peak (MW), date
Annual energy needs (TWh)
Interconnection

WHEN ABSURDITY DEFEATS ECONOMICS



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GENERIC BENEFITS OF ELECTRICITY MARKET INTEGRATION

1. Improving reliability and pooling reserves
2. Reduced investment in generating capacity
3. Improving load factors and increasing demand diversity
4. Economies of scale in new construction
5. Diversity of generation mix and supply security
6. Economic exchange
7. Environmental dispatch and new plant siting
8. Better coordination of maintenance schedules

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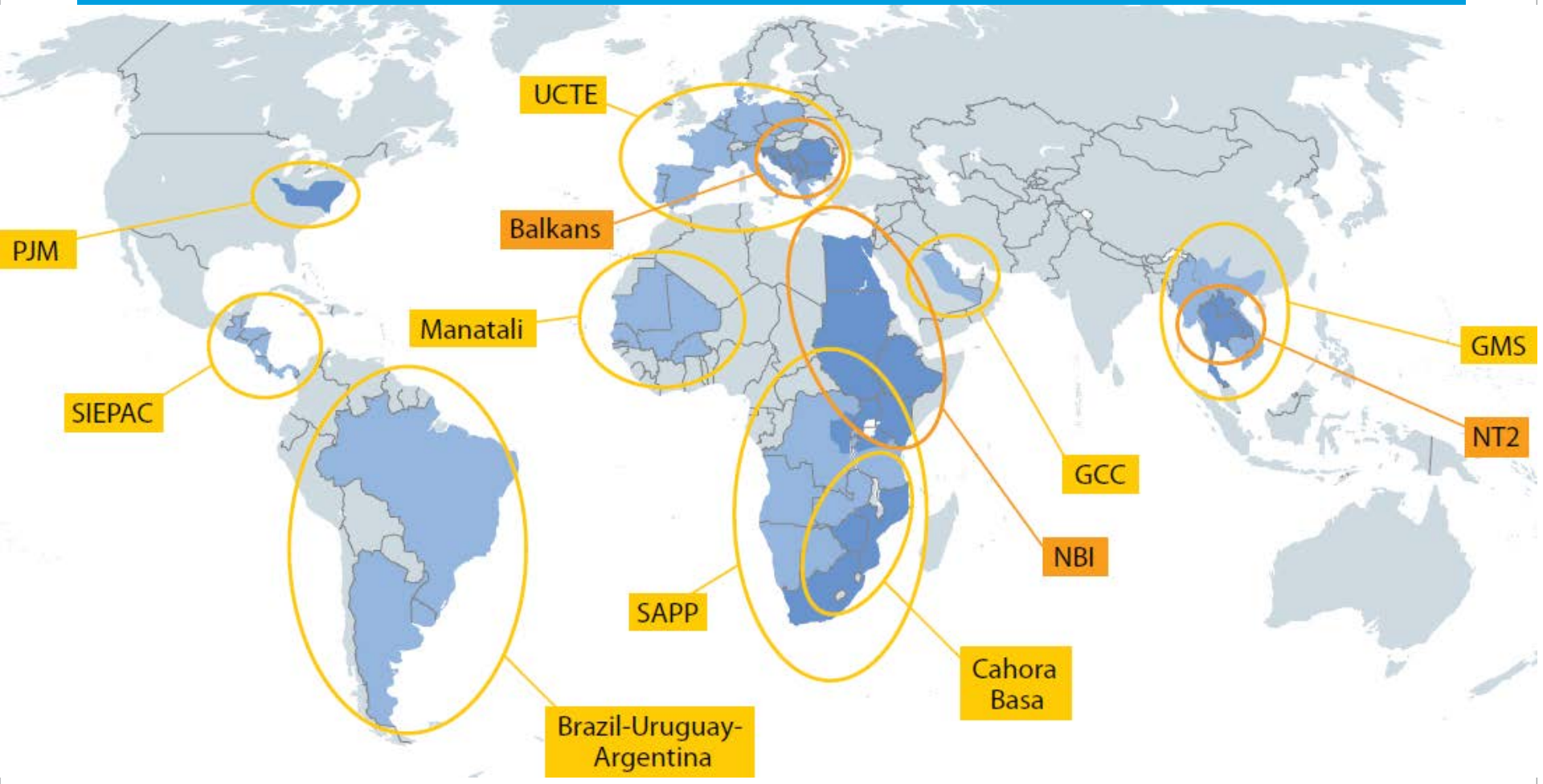
CEC (2002), UN (2006) and ESMAP (2010)

REGIONAL POWER INTEGRATION



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World Bank / ESMAP (2010)

REGULATORY BARRIERS

- Few unified markets or “deep integration”
- Mostly bilateral trade agreements
- Many regulatory challenges:
  - Possibility to trade interconnection capacity day-ahead and intraday
  - Technical features (e.g. technical losses) properly modelled in the allocation process
  - Gate closure time as close to real time as possible
  - Integration of electricity balancing markets

(Teusch et al., 2012)

LITERATURE REVIEW FINDINGS

"It was notable in carrying out the literature review that many of the papers on regional power are ***descriptive rather than analytic***. There are comparatively few academic studies which have real theoretical depth."

Research gap: "theoretical analysis of the way in which benefits are distributed"

ECA (2010) *The Potential of Regional Power Sector Integration: Literature Review*

Billette de Villemeur and Pineau (2012) "Regulation and electricity market integration: When trade introduces inefficiencies", *Energy Economics*

2. MODEL

Th	thermal jurisdiction, marginal cost
H	hydro jurisdiction, average cost
e_t^{Th}	hourly production, in MWh at t
$C_{Th}(e_t^{Th})$	cost of producing e_t^{Th} in Th at t
p_t^{Th}	price in Th at t ($= C'_{Th}(e_t^{Th})$)
x_t^{Th}	export from Th into H at t
$\bar{x}_t^{Th}$, $\bar{x}_t^{H}$	transmission capacity at t
$D_t^{Th}(p_t^{Th})$	demand in Th $\boldsymbol{D_t^{Th} = e_t^{Th} + x_t^{H} - x_t^{Th}}$

THREE REGIMES

Regime 1: No transmission, competitive market in *Th* and regulated in *H*

Regime 2: Transmission and trade, competitive market in *Th* and regulated in *H*

Regime 3: Transmission, competitive market in both *Th* and *H*

PROBLEM FORMULATION FOR R1&R2

$$\max_{\{e_t^{Th},x_t^{Th},x_t^H\}_{t=1..8760}} \left\{ \sum_{t=1}^{8760} \int_0^{e_t^{Th}+x_t^H-x_t^{Th}} p_t^{Th}(q)\,dq - C_T\left(e_t^{Th}\right) - c^\tau x_t^{Th} - c^\tau x_t^H \right\}$$

Transmission cost

$$s.t. \begin{cases} \sum_{t=1}^{8760} \left(x_t^H - x_t^{Th}\right) \le W - \sum_{t=1}^{8760} D_t^H\left(p_R^H\right) \\ \sum_{t=1}^{8760} e_t^H \le W \end{cases}$$

Shadow value of water

λ

$$-\overline{x}_t^{Th} \le x_t^H - x_t^{Th} \le \overline{x}_t^H,$$

Shadow value of transmission capacity

μ_t

$$all\ t = 1..8760.$$

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REGIME 2 PRICES

- When *Th* exports, $p_t^{Th} = \lambda - c^{\tau} - \mu_t$

  and is at most $\overline{\boldsymbol{p^{Th}}} = \boldsymbol{\lambda - c^{\tau}}$

With p_R^H at average cost

- When *Th* imports, $p_t^{Th} = \lambda + c^{\tau} + \mu_t$

  and is no less than $\underline{\boldsymbol{p^{Th}}} = \boldsymbol{\lambda + c^{\tau}}$

- When $x_t^{Th} = x_t^H = 0$,

$$\overline{p^{Th}} < p_t^{Th} = C'_t\,(e_t^{Th}) < \underline{p^{Th}}$$

PROBLEM FORMULATION FOR R3

$$\max_{\left\{e_t^{Th}, e_t^H, x_t^{Th}, x_t^H\right\}_{t=1..8760}} \left\{ \begin{array}{l} \sum_{t=1}^{8760} \int_0^{e_t^{Th}+x_t^H-x_t^{Th}} p_t^{Th}(q)\,dq - C_{Th}\left(e_t^{Th}\right) - c^\tau x_t^{Th} - c^\tau x_t^H \\ \sum_{t=1}^{8760} \int_0^{e_t^H+x_t^{Th}-x_t^H} p_t^H(q)\,dq - C_H \end{array} \right\}$$

$$s.t. \quad \sum_{t=1}^{8760} e_t^H \leq W$$

Shadow value of water

λ

$$-\overline{x}_t^{Th} \leq x_t^H - x_t^{Th} \leq \overline{x}_t^H,$$

Shadow value of transmission capacity

μ_t

$$all\ t = 1..8760.$$

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REGIME 3 PRICES

- When *Th* exports, $p_t^{Th} = p_e^H - c^\tau - \mu_t$

  and is at most $\overline{\boldsymbol{p^{Th}}} = \boldsymbol{p_e^H - c^\tau}$

With $p_e^H = \lambda$

- When *Th* imports, $p_t^{Th} = p_e^H + c^\tau + \mu_t$

  and is no less than $\underline{\boldsymbol{p^{Th}}} = \boldsymbol{p_e^H + c^\tau}$

- When $x_t^{Th} = x_t^H = 0$,

$$\overline{p^{Th}} < p_t^{Th} = C'_t\ (e_t^{Th}) < \underline{p^{Th}}$$

3. CALIBRATION

- We calibrated the *Th* and *H* jurisdictions unsing 2007 hourly data from Ontario and Quebec
- Linear demand curve with a -0.15 elasticity (at the observed price-quantity pair)
- Marginal cost is linear, from observed price-quantity pairs

3. CALIBRATION

- *H* has 184.705 TWh of hydropower (but also imported from *Th* to meet its demand)
- *Th* exports were limited to 720 MW and *H* exports to 1,295 MW. These capacities have been adjusted to reflect actual trade
- Transaction cost of $2/MWh

4. PRICE RESULTS

Average price **$/MWh**	2007 Data*	R1	R2	R3
p^{Th}	47.81	47.96	48.52	46.79
p^{H}	27.90	29.02	27.90	30.91
Export from Th	37.15	–	38.84	22.80
Export from H	67.20	–	71.00	53.88
Min p^{Th}	−0.4**	4.60	4.60	4.60
Max p^{Th}	436.53	167.66	165.39	165.39

4. QUANTITY RESULTS

TWh	2007 Data	R1	R2	R3
$\sum D_t^{Th}$	162.25	162.39	161.94	162.85
$\sum D_t^{H}$	185.82	184.70	185.82	182.823
Total Demand	348.083	347.09	347.77	345.67
$\sum e_t^{Th}$	n.a.	162.39	163.06	160.96
$\sum e_t^{H}$	n.a.	184.70	184.70	184.70
Share of Trade*	n.a.	0%	0.79%	0.83%

*Sum of exports and imports over overall demand.

4. WELFARE IMPACTS

Million $	2007 Data	R1	R2	R3
Change of Consumer Surplus *Th*	n.a.	+61	–	+275
Change of Consumer Surplus *H*	n.a.	−208	–	−554
Change of Profit *Th*	n.a.	−63	–	−275
Change of Profit *H*	n.a.	+198	–	+601
Transaction cost		–	5.47	5.76
Export Revenues *Th*	n.a.	–	74.3	11.2
Export Revenues *H*	n.a.	–	56.5	126.0
Coal Emissions (million t)		28.74	29.29	28.60
NG Emissions (million t)		8.86	8.90	8.31
Total Emissions (million t)	34	37.60	38.19	36.92

4. WELFARE IMPACTS (2)

Change in Million $	R1	R2	R3
Th CS + Profit	−2.41	–	+0.30
H CS + Profit	−10.28	–	+47.12
Total CS+Profit	−12.70	–	+47.42
Marginal Damage Th (@20$/t)	−11.80	–	−25.52
Marginal Damage H (@20$/t)	−11.80	–	−25.52
Total Damage (@40$/t)	−23.61	–	−51.05
Total Welfare (CS+Profit-Damage)	+10.91	–	+98.47

4. DOUBLING TRANSMISSION / PRICE

Average price **$/MWh**	R2	R3	R2 x2	R3 x2
p^{Th}	48.52	46.79	48.41	45.80
p^{H}	27.90	30.91	27.90	32.48
Export from Th	38.84	22.80	37.60	24.97
Export from H	71.00	53.88	65.24	52.91
Min p^{Th}	4.60	4.60	4.60	4.60
Max p^{Th}	165.39	165.39	163.12	163.12

4. DOUBLING TRANSMISSION / QUANTITY

TWh	R2	R3	R2 x2	R3 x2
$\sum D_t^{Th}$	161.94	162.85	161.81	163.20
$\sum D_t^{H}$	185.82	182.823	185.82	181.25
Total Demand	347.77	345.67	347.64	344.46
$\sum e_t^{Th}$	163.06	160.96	162.93	159.75
$\sum e_t^{H}$	184.70	184.70	184.70	184.70
Share of Trade*	0.79%	0.83%	1.53%	1.62%

*Sum of exports and imports over overall demand.

4. DOUBLING TRANSMISSION / WELFARE IMPACTS

Million $	R2	R3	R2 x2	R3 x2
Change of Consumer Surplus *Th*	–	+275	+54	+466
Change of Consumer Surplus *H*	–	−554	0	−840
Change of Profit *Th*	–	−275	−84	−458
Change of Profit *H*	–	601	32	931
Transaction cost	$5.47	$5.76	$10.62	$11.17
Export Revenues *Th*	$74.3	$11.2	$118.6	$26.0
Export Revenues *H*	$56.5	$126.0	$135.4	$235.4
Coal Emissions (million t)	29.29	28.60	29.67	28.53
NG Emissions (million t)	8.90	8.31	8.62	7.82
Total Emissions (million t)	38.19	36.92	38.34	36.36

4. DOUBLING TRANSMISSION / WELFARE IMPACTS

Change in Million $	R2	R3	R2 x2	R3 x2
Th CS + Profit	–	+0.30	−29.39	+8.02
H CS + Profit	–	+47.12	+32.00	+90.94
Total CS+Profit	–	+47.42	+2.61	+98.96
Marginal Damage Th (@20$/t,	–	−25.52	+3.00	−36.75
Marginal Damage H (@20$/t,	–	−25.52	+3.00	−36.75
Total Damage (40$/t,	–	−51.05	+6.00	−73.5
Total Welfare (CS+Profit-Damage)	–	+98.47	−3.38	+172.45

CONCLUSION

- Model to study regime change and trade between two jurisdictions – *our main contribution.*
- Welfare gains + environmental gains
- Shortcomings:
  - Only 2 jurisdictions are included
  - Perfect knowledge is assumed (e.g. hourly demand)

5. DISCUSSION: RECOGNIZING OBSTACLES

1. Structure of political and electoral incentives in the provinces and the federal government
2. Redistribution of the gains from a partial or complete integration
3. Lack of recognition of the environmental benefits resulting from integration

5. DISCUSSION
WORKING TOWARDS INTEGRATION

- Awareness and information
- Redistribution and compensation
- Inspiration from the Canada Health Act
- Expand the concept of the “Atlantic Energy Gateway”
- Bi-lateral agreements (as QC and ON are currently exploring)
- Agreement on Internal Trade
- A credible Federal approach on GHG