Chair in Energy Sector Management
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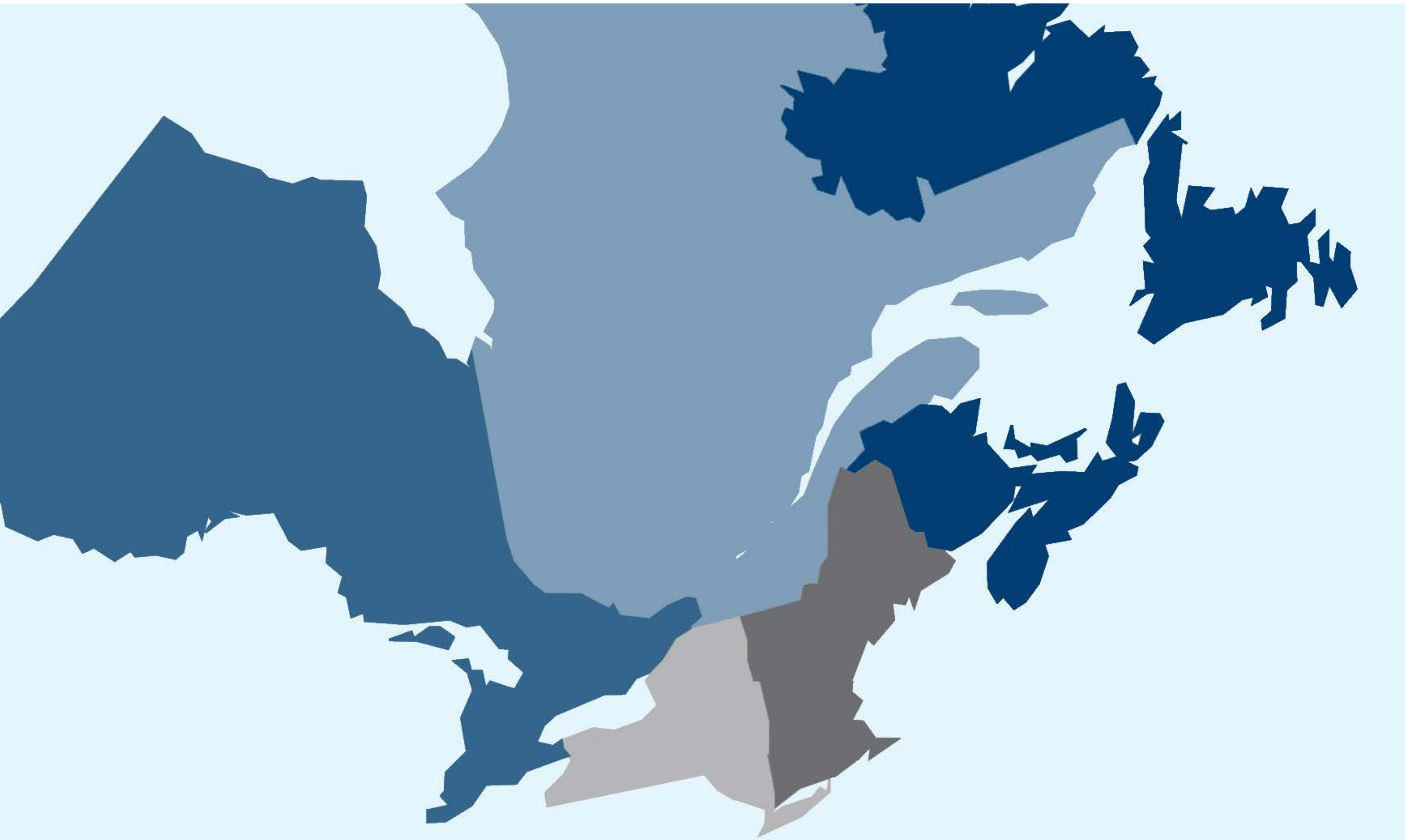
NORTHEAST DECARBONIZATION

OPPORTUNITIES AND CHALLENGES OF REGIONAL ELECTRICITY SECTOR INTEGRATION FOR HIGH RENEWABLE PENETRATION



NORTHEAST ELECTRIFICATION AND DECARBONIZATION ALLIANCE

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NORTHEAST DECARBONIZATION

OPPORTUNITIES AND CHALLENGES OF REGIONAL ELECTRICITY SECTOR INTEGRATION FOR HIGH RENEWABLE PENETRATION

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ABOUT THE NORTHEAST ELECTRIFICATION AND DECARBONIZATION ALLIANCE

The Northeast Electrification and Decarbonization Alliance (NEDA) promotes collaboration among jurisdictions in the North American Northeast to achieve deep reductions in greenhouse gas (GHG) emissions through almost 100% renewable energy systems.

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The mission of the Chair in Energy Sector Management is to advance knowledge of energy issues in support of sustainable development, resource optimization and the achievement of an adequate balance between energy sources and societal needs. The Chair's activities are made possible through the support of its partners: Boralex, Brookfield Renewable, Enbridge, ENERCON, Énergir, Hydro-Québec, Valero Energy, WSP.

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Executive Summary

Deeper regional integration in the electricity sector across the North American Northeast can bring substantial benefits in reducing greenhouse gas (GHG) emissions through the deployment of renewable energy. In this region, as elsewhere in the world, GHG emission reduction targets imply the dual challenge of electrifying many energy needs and decarbonizing electricity production. The electricity sector will play a central role in decarbonization. This report argues that better coordination in planning and operating the Northeast electricity sector could greatly facilitate decarbonization.

Disparities in production and consumption levels – particularly the availability of existing inexpensive low-carbon resources – already lead to fruitful electricity trade. Much more is however achievable. After providing some general background information on the Northeast region electricity profile, this report provides information on three key aspects of the issue:

1. What are the subnational jurisdictions' (i.e., states and provinces) goals and current tools with respect to reducing GHG emissions?
2. What does the current scientific literature say about the need for collaboration in the electricity sector – both in generic terms and more specifically in the context of deep penetration of renewables?
3. What barriers must be overcome to foster such collaboration?

Despite putting forward several ambitious GHG reduction and renewable deployment targets, policy efforts by subnational jurisdictions across the Northeast are falling short, and prospects for meeting renewable penetration levels required by long-term targets appear dim. Even the more promising policy initiatives' chances of success may be undermined by various barriers unless they are accompanied by measures to overcome them. Upscaling GHG reduction efforts through measures targeting the electricity sector and more aggressively fostering the use of renewables requires giving significantly more attention to integration strategies across the region.

Regional integration in the electricity sector can help these efforts in various ways. Electricity sector integration can be defined as increased coordination and collaboration among adjacent jurisdictions. Integration involves different aspects such as physical infrastructure (e.g., interties), institutional and regulatory cooperation and harmonization (e.g., shared regulation, market design, and systems operation rules), and commercial integration (e.g., level of trade). There is an important academic consensus on the benefits of electricity market integration. Academic and engineering studies have demonstrated how aggressive decarbonization goals can be achieved while maintaining current levels of reliable electricity service. Indeed, to meet the challenges of progressively increasing the penetration of renewables in the electricity mix across the region, increased integration is essential. Recent political initiatives in the Northeast seem to recognize these benefits, and early efforts could lead to calls for an even greater coordination.

To achieve such coordination and collaboration, significant institutional, political and social barriers must be overcome.

- Institutional barriers imply a need for subnational jurisdictions to give special attention to regulatory discrepancies across jurisdictions – such as price levels or market access, for instance. This is necessary to ensure that regional collaboration leads to a streamlining of efforts to harmonize and facilitate integration of grids across subnational jurisdiction borders.

- Political barriers often take the form of combining renewable deployment efforts with local industrial policy and job creation objectives. By adding unrelated constraints, they prevent more rapid and extensive penetration of renewables in the electricity mix. Although this type of policy rationale can foster public support for such renewable policy, this strategy seems to have reached its limits, and often works against achieving higher penetration levels for renewables across the region.

- Finally, social barriers materialize through opposition to projects (e.g. wind farms, dams, transmission lines). The failure to address such concerns results in lower renewable penetration and sub-optimal investments, either from the perspective of a single jurisdiction or for the region as a whole. A viable path to regional integration must consider both the legitimate concerns in local areas and the regional goals to accelerate renewable energy deployment.

Reaching medium- and long-term targets for GHG emission reduction and renewables deployment necessitates an urgent intensification of policy efforts. In the electricity sector, regional integration presents opportunities in this regard. If both technical and non-technical difficulties can be managed, this integration will provide significant benefits in terms of sharing renewable resources across the region and meeting the challenges associated with attaining higher shares of renewables in the electricity mix.

Introduction

The North American Northeast includes six Canadian provinces and seven American states (collectively referred to as the "Northeast" in this report). Their electricity systems are interconnected, and their reliability standards are overseen by the Northeast Power Coordinating Council (NPCC). Figure 1 displays the region.

As for all countries in the world, meeting ambitious greenhouse gas (GHG) emission reduction targets probably implies the dual challenge of electrifying many energy needs (e.g., heating, transportation, industry) and decarbonizing electricity production. Despite variation among plans laid out so far on how to reach aggressive GHG reduction targets, the electricity sector will play a central role in all cases.

Better coordinating the planning and operation of the Northeast electricity sectors could facilitate decarbonization. This document provides information on three key aspects of the issue:

1. What are the subnational jurisdictions' goals and current tools with respect to reducing GHG emissions?
2. What does the current scientific literature say about the need for collaboration in the electricity sector – both in generic terms and more specifically in the context of deep penetration of renewables?
3. What barriers must be overcome to foster such collaboration?

FIGURE 1 | MAP OF THE NPCC REGION

Source: NPCC, 2018.

[1] Throughout this report, the term "state" is used predominantly to refer to U.S. subnational jurisdictions and "province" for Canadian ones. To avoid confusion, the term "jurisdiction", unless otherwise specified, refers to subnational jurisdictions across North America (i.e., states and/or provinces).

[2] Only New Brunswick and Nova Scotia (the two largest provinces) are part of the NPCC, out of the four Canadian Atlantic provinces (New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland and Labrador, referred to here as "AT").

Before getting into the specifics of these questions, we provide some general background information on the Northeast region and its electricity consumption and generation. Table 1 shows that New York is by far the most populous jurisdiction, with close to 20 million people. Ontario comes second (14 million), followed by Quebec (8 million) and Massachusetts (almost 7 million). However, electricity generation and consumption are dominated by Quebec, with 212 TWh of generation in this province, almost entirely from hydroelectric production. Given the availability of low-cost hydroelectric power in Quebec, consumption per capita is close to 21,000 kWh per year, while it is below 8,000 kWh in New York and New England.

TABLE 1 | NPCC POPULATION IN 2018 AND TOTAL ELECTRICITY CONSUMPTION AND PRODUCTION IN 2017

		Population (2018)	Generation TWh (2017)	Consumption TWh (2017)	*Surplus (Deficit) (TWh)*	(kWh/person) in 2017 Generation	(kWh/person) in 2017 Consumption
New England	**NE**	**14,853,290**	**105.23**	**115.46**	***–10.22***	**7,085**	**7,773**
Connecticut	CT	3,572,665	34.56	28.14	*6.43*	9,674	7,875
Maine	ME	1,338,404	11.26	11.21	*0.05*	8,416	8,378
Massachusetts	MA	6,902,149	32.20	52.51	*–20.31*	4,666	7,608
New Hampshire	NH	1,356,458	17.45	10.79	*6.66*	12,862	7,953
Rhode Island	RI	1,057,315	7.61	7.38	*0.23*	7,202	6,984
Vermont	VT	626,299	2.14	5.42	*–3.28*	3,419	8,660
New York	**NY**	**19,542,209**	**128.07**	**144.99**	***–16.93***	**6,553**	7,419
Quebec	**QC**	**8,356,699**	**212.09**	**173.72**	***38.37***	**25,380**	**20,788**
Ontario	**ON**	**14,246,035**	**150.96**	**133.72**	***17.24***	**10,597**	**9,386**
Atlantic	**AT**	**2,403,044**	**63.08**	**35.91**	***27.16***	**26,249**	**14,945**
Nova Scotia	NS	955,708	10.07	10.29	*–0.22*	10,540	10,766
New Brun.	NB	768,865	13.23	13.03	*0.20*	17,202	16,945
Prince Ed. Isl.	PE	152,009	0.61	2.13	*–1.52*	4,008	14,017
NF. & Lab.	NL	526,462	39.17	10.47	*28.70*	74,399	19,878

Source: U.S. Census Bureau, 2018; Statistics Canada, 2019a and b; EIA, 2019a.

Table 2 shows installed generation capacity by fuel type and location. Notably, more than 45,000 MW of installed capacity is in Quebec, which accounts for 25% of the Northeast installed capacity, but only 14% of the region's population.

TABLE 2 | INSTALLED CAPACITY BY FUEL IN 2017, IN MEGAWATT

	NE	**NY**	**QC**	**ON**	**AT**	**Total**
Coal/Petroleum/Biomass	9,132	6,239	675	5,512	3,893	25,452
Hydroelectric	1,951	4,684	40,438	9,122	8,099	64,294
Natural Gas	16,592	23,169	824	5,153	1,069	46,807
Nuclear	4,075	5,709		13,328	705	23,817
Other	377	265			20	662
Pumped Storage	1,571	1,240				2,811
Solar	785	161		2,296	0	3,242
Wind	1,408	1,830	3,432	5,077	1,166	12,914
	35,891	43,298	45,369	40,489	14,953	179,999

Source: EIA, 2019a; Statistics Canada, 2019c.

Note: Fuel categories have been modified from the sources to allow for a uniform presentation of U.S. and Canadian data.

Electricity trade is already very important in the Northeast, allowing Massachusetts, for instance, to obtain about 20 TWh of electricity from its neighbors (40% of its consumption), while New York is a net importer of close to 17 TWh (12% of its consumption). Canadian provinces, through their excess generation, are important sources of power for New York and importing New England states (MA and VT).

The diversity among jurisdictions, further detailed in section 1, is a source of potential complementarity gains (as detailed in section 2), but is also a difficulty in and of itself, as each jurisdiction is different and operates independently on its own terms (section 3 further discusses these issues, which impose barriers to further coordination). To answer the three questions above, we begin in the next section with a careful look at how jurisdictions across the Northeast have approached efforts to meet GHG emission reduction targets and accelerate the deployment of renewables in the electricity sector.

SECTION 1 | Overview of climate targets and electricity policies

This section presents GHG emissions trends in the electricity sector and compares GHG emission reduction targets and related goals and initiatives put forward by various jurisdictions in the Northeast.

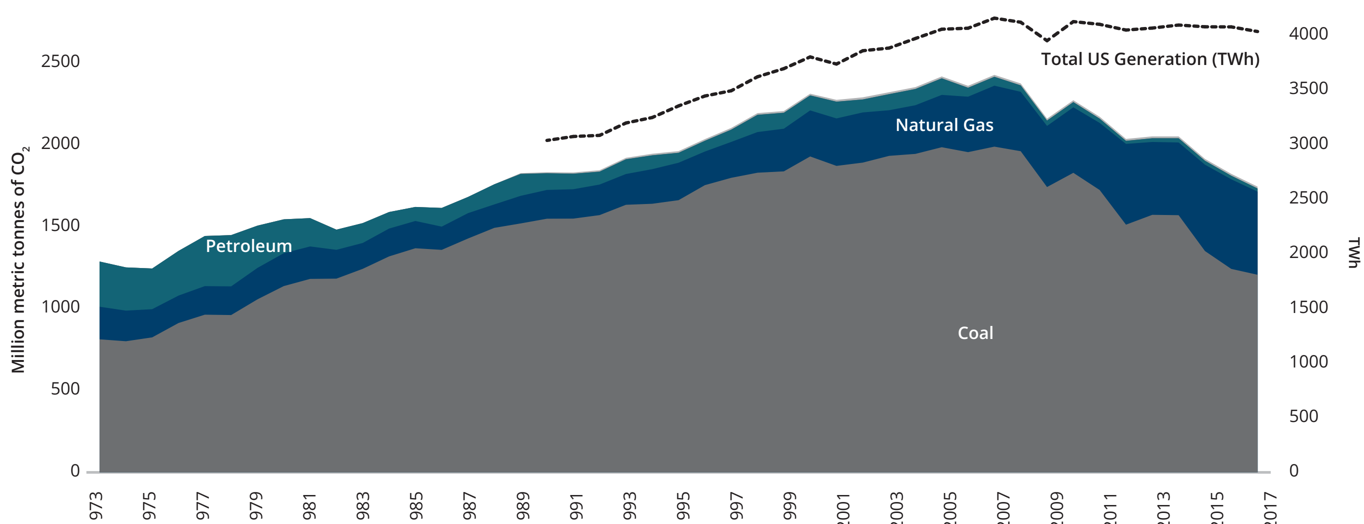
SECTION HIGHLIGHTS |

- GHG emissions from the electricity sector in the Northeast have declined over the past decade, following the replacement of coal by natural gas and renewables.
- All Northeast jurisdictions have set forth ambitious targets to further reduce their emissions, and many have aggressive targets to increase the share of renewables in the electricity mix.
- Current policies to help reach medium- and long-term GHG targets are unlikely to be sufficient.
- Coordinated regional strategies in the electricity sector have been very limited, jeopardizing higher penetration for renewables and compromising the realization of GHG reduction targets.

GHG Trends in the Electricity Sector

While total U.S. power generation has been stable since 2005 (around 4,000 TWh of generation per year, Figure 2), direct electricity sector emissions of CO_2 have been declining at the same time – from a 2007 peak of 2,400 million tonnes to about 1,700 in 2017 (28% decrease). This is because coal is in effect being displaced by natural gas and renewable energy sources (not shown in Figure 2 because they do not emit GHGs).

FIGURE 2 | U.S. ELECTRICITY SECTOR CO2 EMISSIONS, 1973-2017 AND U.S. TOTAL GENERATION, 1990-2017

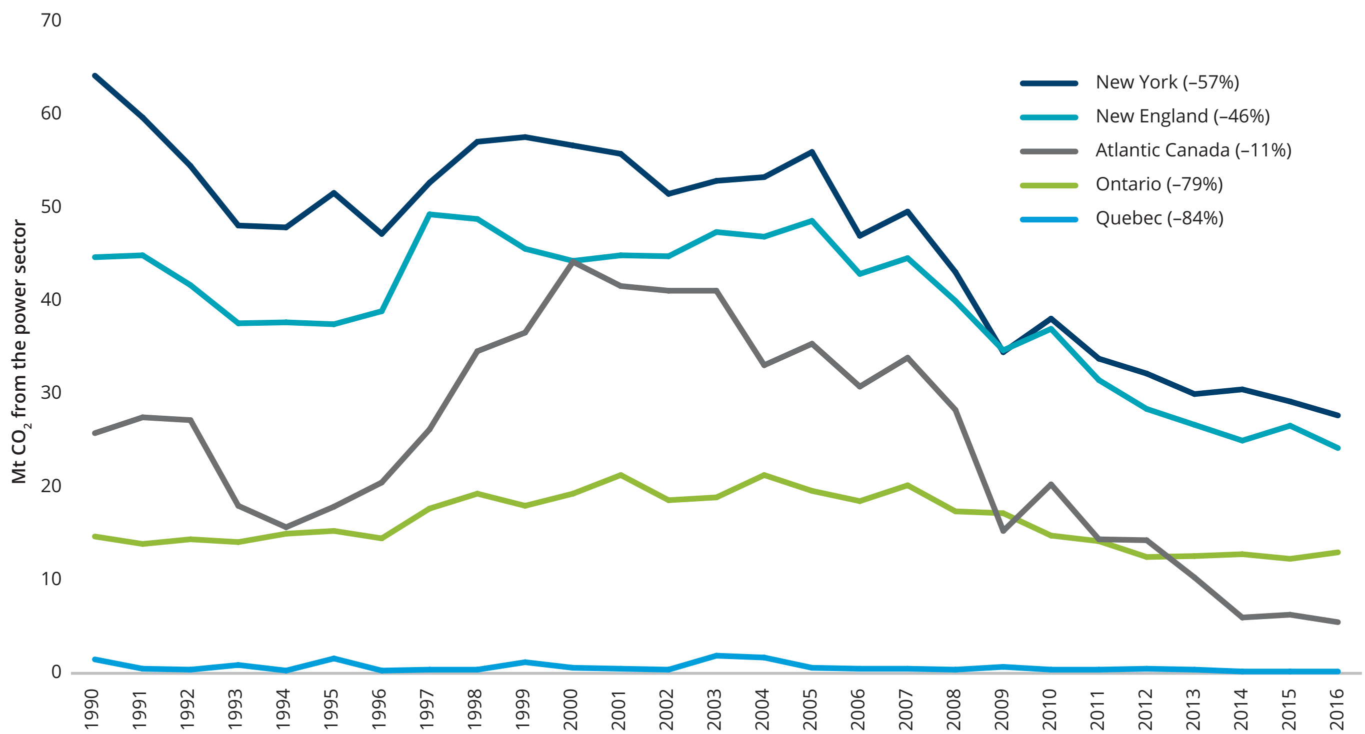


Source: EIA, 2019a and b.

[3] Most GHG emissions from the combustion of energy are CO_2 emissions, and these are the emissions most commonly reported by the U.S. EIA and the International Energy Agency for the energy sector. However, small amounts of CH4 and N2O, which are also GHGs, are also emitted in the energy sector, but are less reported.

Northeast jurisdictions have been on the same trend: declining electricity sector emissions in New York, New England and Ontario, in particular. Figure 3 shows the drastic decline in electricity sector CO_2 emissions from 1990 to 2016 in New York (-57%), New England (-46%) and Ontario (-79%), achieved by virtually eliminating coal and petroleum generation from their electricity mix (Figure 3). In the case of Ontario, this was achieved through an official coal phase-out policy (Ontario, 2019).

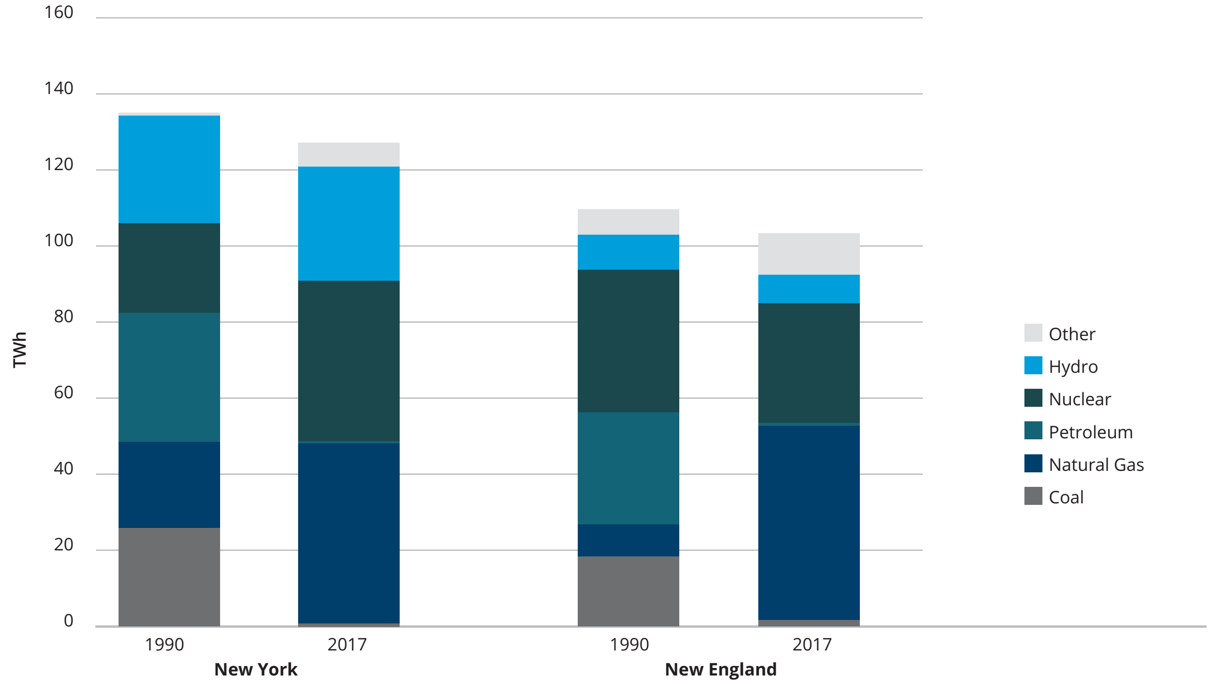
FIGURE 3 | NEW YORK, NEW ENGLAND, ONTARIO, QUEBEC AND ATLANTIC CANADA ELECTRICITY SECTOR CO_2 EMISSIONS, 1990-2016



Source: EIA, 2019b; ECCC, 2018.

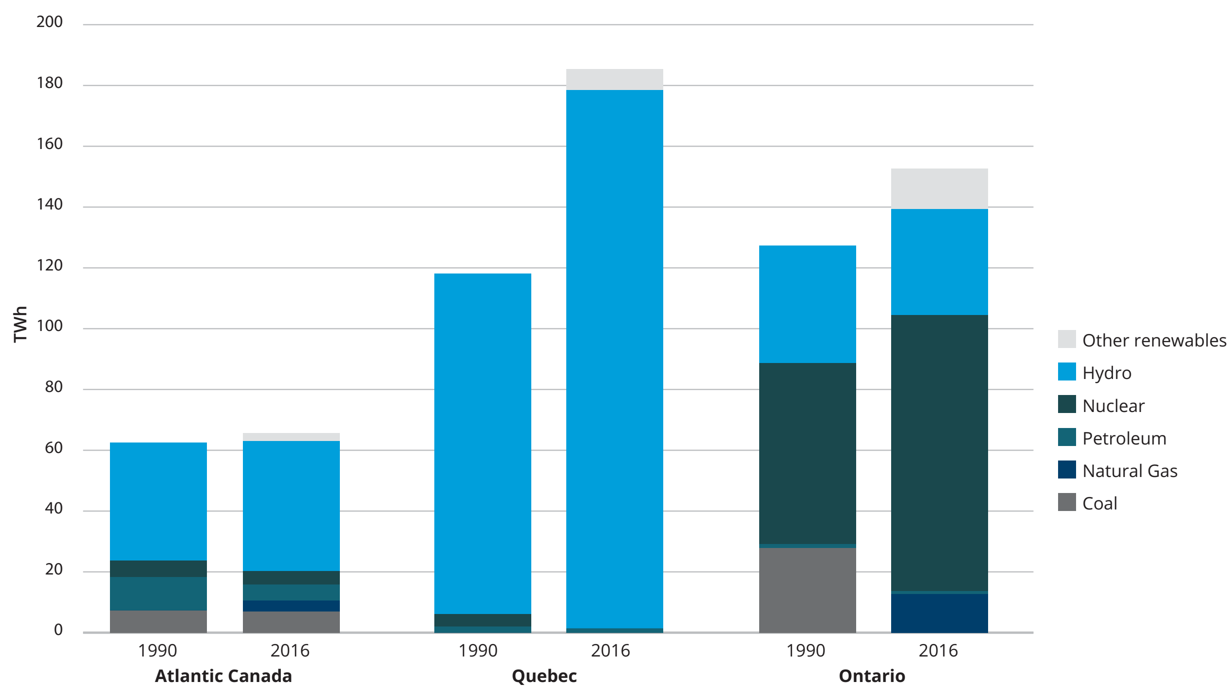
Figure 3 shows how CO_2 reductions have resulted from coal and petroleum being practically eliminated between 1990 and 2017, with natural gas, nuclear and, more modestly, renewable sources being used instead. While generation went down in New York and New England over the 1990-2017 period (Figure 4), it grew in the Canadian provinces, especially in Quebec, with important additions in hydroelectric and wind generation (Figure 5).

FIGURE 4 | NEW YORK AND NEW ENGLAND POWER GENERATION BY SOURCE IN 1990 AND 2017



Source: EIA, 2019a.

FIGURE 5 | ONTARIO, QUEBEC AND ATLANTIC CANADA POWER GENERATION BY SOURCE IN 1990 AND 2016 (CANADA)

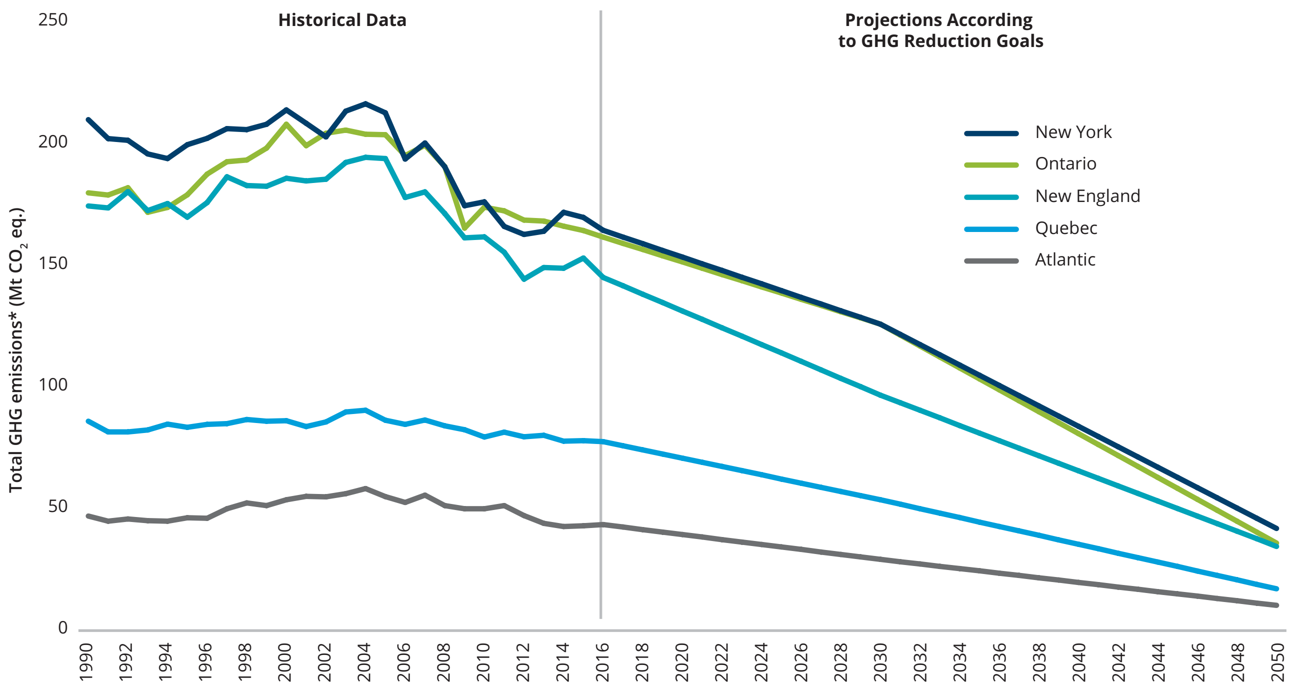


Source: ECCC, 2018.

GHG Targets and Policies

Most jurisdictions in Northeast have three timeframes for GHG emission reduction targets: 2020, 2030 and 2050, each with increasingly stringent objectives. For most of these, the most rapid increases are between the 2030 and 2050 targets, which require an intensification of efforts compared to earlier objectives: targets for 2030 correspond more or less to reductions in the order of 30-40%, whereas those for 2050 require an 80% reduction in emissions.

FIGURE 6 | HISTORICAL TOTAL GHG EMISSIONS* FROM 1990 TO 2016 WITH PROJECTIONS TO 2050 ACCORDING TO GHG REDUCTION GOALS (TABLE 3)



Source: EIA, 2019b and ECCC, 2018.

* For US states, only CO_2 emissions are available at the state level, not all GHG emissions (including CH_4, N_2O and other GHG). CO_2 represent about 80% of total GHG emissions. Real total emissions for New York and New England are therefore higher than what appears on the Figure.

In order to achieve these targets, jurisdictions across the Northeast have put forward a varying set of initial measures and initiatives, summarized in the last column of Table 3. Some of these are more typical across subnational jurisdictions: for instance, several governments set targets for the decarbonization of certain sectors of the economy, often the electricity sector.

The main initiatives are the following ones, even if they vary substantially across jurisdictions:

- **Renewable Portfolio Standards (RPS)**, which require utilities to have a progressively larger share of the electricity they sell to end-use customers come from renewable sources;
- **Cap-and-trade systems** such as the Regional Greenhouse Gas Initiative (RGGI) and the Quebec Western Climate Initiative (WCI, a joint cap-and-trade system with California), which requires large CO_2 emitters to acquire allowances from the government or from other allowance owners in an amount equal to their emissions, with a progressively decreasing cap on the total number of allowances available in the region covered;
- **Clean energy funds** of various forms, through which jurisdictions support efforts to decrease emissions toward the stated targets by financing eligible projects that are expected to lower GHG emissions.

[4] The reference year from which emission reductions are measured varies among different jurisdictions. Typical reference years include 1990, 2001, or 2005 (see Table 3). Judging from Figures 2 and 6, the reference year used could make achieving a reduction target more or less challenging.

In addition, a few less common policy initiatives exist, such as specific objectives for increasing the market share of electric vehicles (New Brunswick, Quebec), attempts to decarbonize more rapidly through securing large hydroelectricity purchases from Canadian provinces, notably Hydro-Quebec (for instance, through Massachusetts' 83D Clean Energy request for proposals), or the grouping of various objectives in more comprehensive energy strategies. In this latter category, New York is putting together a comprehensive regulatory and policy reform of the electricity sector through its Reforming the Energy Vision (REV) initiatives. REV, however, is primarily oriented towards an internal (or "New York only") approach to decarbonization, never explicitly mentioning the current and possible future gains from regional collaboration.

Some of the common measures nevertheless illustrate a significant degree of collaboration across the region. The RGGI, for instance, includes not only all New England states and New York, but also a few other neighboring states (Maryland and Delaware). New Jersey, which participated in the program in its early years before leaving in 2012, is also set to re-enter in 2020. Through the RGGI, participating jurisdictions commit to reducing GHG emissions from large emitters in the electricity sector, by setting a regional cap for emissions, which declines over time (currently at a rate of 2.5% per year). Each participant then allocates allowances for their share of this cap, the vast majority of which are distributed through auctions. Between 2020 and 2030, electricity sector emissions in RGGI participating jurisdictions should decrease by 30%.

The RGGI represents a credible measure to curb emissions. The constraints it imposes on members are stable over time, and the reduction in emissions is controlled by the declining cap on emission allowances across the entire region subject to the program, which ensures that the targets are reached. Moreover, the rules for compliance and allocation of allowances are clear and transparent, and revenues from the auctions are overwhelmingly assigned to other measures dedicated to reducing emissions, for instance energy efficiency, community-based renewable energy projects, or other greenhouse gas reduction measures.

Nevertheless, as a closer look at the overview presented in Table 3 makes clear, the RGGI remains an exception in the set of measures adopted across the Northeast in recent years. Clean energy funds, for instance, rarely have specific GHG reduction targets attached to their performance requirements and funding, and a result it is often difficult to assess whether they constitute a satisfactory contribution to GHG mitigation for a given level of funding.

Most importantly, despite the urgency associated with addressing these shortcomings if short- and medium-term targets are to be reached, the failure of matching the intensity of efforts with the requirements of these targets becomes even more difficult for achieving the longer term and more aggressive 2050 GHG reduction objectives. As Figure 6 shows, the required decline in GHG emissions between 2030 and 2050 is steeper in the largest Northeast jurisdictions. As a result, it is important to remember that meeting the 2050 targets will be more challenging, because earlier and less costly reductions in GHG emissions will have already been made.

The bottom line is that upscaling GHG reduction efforts through measures targeting the electricity sector and more aggressively fostering the use of renewables requires giving significantly more attention to the credibility and effectiveness of associated programs and initiatives. As we turn to in the next section, the integration of such efforts across the region is a strategy presenting significant benefits in this regard.

[5] See the Massachusetts Clean Energy website (https://macleanenergy.com), dedicated to the "collaborative efforts of the Massachusetts Department of Energy Resources, Eversource Energy, National Grid and Unitil to procure Clean Energy for the Commonwealth of Massachusetts."

TABLE 3 | OVERVIEW OF TARGETS AND INITIATIVES FOR REDUCING GHG EMISSIONS AND INCREASING THE DEPLOYMENT OF RENEWABLES IN NORTHEAST SUBNATIONAL JURISDICTIONS (SOURCES IN APPENDIX 1)

Jurisdiction	GHG targets	Other targets and initiatives
New Brunswick	• –10% by 2020, from 1990 • –35% by 2030, from 1990 • –80% by 2050, from 2001	• 2,500 electric vehicles on the road in New Brunswick by 2020 and 20,000 by 2030
Newfoundland and Labrador	• –10% by 2020, from 1990 • –75–85% by 2050, from 2001	
Nova Scotia	• –10% by 2020, from 1990 • –45–50% by 2030 from 2005 • –80% by 2050, from 2009 • 25% cap–induced reductions in emissions from electricity sector by 2020, 55% by 2030	• 40% renewables in the electricity mix by 2020 • Cap–and–trade program (emitters above 50,000 tonnes, petroleum product suppliers, natural gas distributors, and electricity importers)
Ontario	• –30% by 2030, from 2005 • –80% by 2050, from 1990	• Increase ethanol content to 15% by 2025
Prince Edward Island	• –30% by 2030, from 2005	
Quebec	• –20% by 2020, from 1990 • –37.5% by 2030, from 1990 • Between –80% and –95% by 2050, from 1990	• –40% oil products consumption by 2030, from 2013 • +25% renewable energy production by 2030, from 2013 • +50% 2013 bioenergy production by 2030 • Elimination of thermal coal • Cap–and–trade program (Western Climate Initiative, WCI) covering all sectors except waste and agriculture. • Revenues of auctions from the cap–and–trade program go into the "Fonds vert", a green funds for projects linked to GHG reduction efforts • 3.5% of EV (or PH or hydrogen) for new vehicles sales for 2018, increasing progressively to 22% in 2025 • 100 000 EVs by 2020, 1 000 000 by 2030
Connecticut	• –10% by 2020, from 1990 • –45% by 2030, from (legislated) • –80% by 2050, from 2001 (legislated)	• RPS 40% renewables by electricity providers by 2030 (of which hydro includes only run–of–the–river) • Comprehensive Energy Strategy 2018 • Participation in RGGI • Participation in Transportation emission cap regional initiative
Maine	• –10% by 2020, from 1990 • –75-80% from 2003 ("sufficient to eliminate any dangerous threat to the climate")	• Participation in RGGI • Participation in Transportation emission cap regional initiative • Biennial report to legislature on progress toward reduction targets
Massachusetts	• -25% by 2020, from 1990 • -80% by 2050, from 1990	• Clean Energy Standard 16% for 2018 and 2% yearly increase until 80% in 2050 (minimum percentage of electricity sales that utilities and competitive retail suppliers must procure from clean energy sources) • RPS: Class I requirement increases by one percent annually with no established end date • RPS: Class II (for older facilities) + Waste energy • Alternative Energy Portfolio Standard (similar to the RPS: requires a certain percentage of the state's electric load to be met by CHP, flywheel storage, and efficient steam tech): increase by -0.25% per year indefinitely • Clean Energy and Climate Plan 2020 (updated in 2015) • Clean Energy solicitations: 83D (state purchase Canadian hydropower through a 20-year contract) and 83C (offshore wind) • Participation in RGGI • Participation in Transportation emission cap regional initiative

TABLE 3 | (CONTINUED)

Jurisdiction	GHG targets	Other targets and initiatives
New Hampshire	• –20% by 2025, from 1990 • –80% by 2050, from 1990	• RPS: 25.2% by 2025 (large hydro ineligible) • Renewable Energy Fund (finances renewable energy projects) • Renewable Energy Rebates (several incentive programs for PV, wind, solar water heating, as well as other types of installations) • Participation in RGGI • Participation in Transportation emission cap regional initiative
New York	• –40% by 2030, from 1990 in the energy sector (including power generation, industry, buildings and transportation) • –80% by 2050 for total carbon emissions (1990 implied as reference year) • –80% by 2050, from 1990 in New York City	• 100% clean electricity by 2040 • Clean Energy Standard: 50% renewable sources in electricity by 2030, announced 70% in Cuomo's new plan • 600 trillion Btu increase in statewide energy efficiency • 1.5 GW of energy storage by 2025 • Green New Deal proposed in 2019 budget (not passed yet): – Offshore wind target raised to 9,000 megawatts by 2035, up from 2,400 megawatts by 2030 – Distributed solar deployment increased to 6,000 megawatts by 2025, up from 3,000 megawatts by 2023 – Deploying 3,000 megawatts of energy storage by 2030 • Reforming the Energy Vision (REV) initiative: uses a two–track process to reorient the electricity industry: (1) focus on (1) markets and on (2) ratemaking reform • Participation in RGGI • Participation in Transportation emission cap regional initiative
Rhode Island	• –45% by 2035, from 1990 • –80% by 2050, from 1990	• Energy 2035: Rhode Island State Energy Plan • Renewable Energy Standard: 38.5% by 2035 • Participation in RGGI • Participation in Transportation emission cap regional initiative
Vermont	• –40% by 2030, from 1990 • –80-90% by 2050, from 1990	• Comprehensive Energy Plan 2016 • RES (reaching 75% by 2032 from 55% in 2017; also by 2032 10% of each utility's electricity must come from in–state renewable generators under 5MW • Reduce total energy consumption per capita by 15% by 2025, and by more than one third by 2050. • 25% of the remaining energy need from renewable sources by 2025, 40% by 2035, and 90% by 2050 • Three end–use sector goals for 2025: 10% renewable transportation, 30% renewable buildings, and 67% renewable electric power. • Clean Energy Development Fund • Participation in RGGI • Participation in Transportation emission cap regional initiative

SECTION 2 | Benefits from greater coordination and collaboration in renewable energy deployment

SECTION HIGHLIGHTS |

- There is a consensus on the benefits of **electricity market integration** and of regional collaboration for **deep renewable integration in electricity systems**.
- Regulatory policy changes, market design innovation, and flexible operating procedures are critical to achieving technical potential.
- Current policies do not seriously consider regional collaboration.
- The scope of the GHG challenge and the electricity system context of the Northeast calls for a greater coordination between New England, New York and Canadian provinces.

Electricity Sector and Renewable Integration: Two Related Challenges

Electricity sector integration can be defined as increased coordination and collaboration among adjacent jurisdictions. Integration involves different aspects such as physical infrastructure (e.g., interconnections), institutional and regulatory cooperation and harmonization (e.g., shared regulation, market design, and systems operation rules), and commercial integration (e.g., level of trade). In the following, "integration" has no specific implication on the extent to which additional coordination and collaboration is involved on each of these dimensions – but to meet the challenges of progressively increasing the penetration of renewables in the electricity mix across the region, increased integration is essential.

Renewable integration in the electricity sector is a different, but related concept. It covers the challenges of adding large amounts of renewable electricity production sources in a power system. It has been studied in many context – see for instance Holttinen et al. (2019) for the final summary report of the IEA Wind Task 25, providing many insights on the design and operation of power systems with large amounts of wind power.

In a nutshell, integrating different electricity systems can bring some benefits, even if no renewable capacity is added. If significant increases of renewable capacity are considered, regional integration of electricity system is even more beneficial.

Generic Benefits of Electricity Sector Integration

Even without considering the addition of renewable capacity, there is an important consensus on the benefits of electricity market integration. The UN has published many reports on the subject (see in particular UNECA, 2004; and UN, 2006), and so have the World Bank (ESMAP, 2010), the World Energy Council (WEC, 2010), the Organization of American States (OAS, 2007) and even the Commission for Environmental Cooperation (CEC, 2002). This latter organization is a North American organization established in 1994 along with the North American Free Trade Agreement (NAFTA). This literature identifies a series of potential technical benefits that can be achieved through increased integration. Basically, benefits derive from efficiency gains obtained through trade and increased productive efficiency. These benefits, in the context of electricity markets, are summarized in Table 4.

[6] This section draws partly from Pineau (2013).

TABLE 4 | POTENTIAL TECHNICAL BENEFITS FROM ELECTRICITY SECTOR INTEGRATION

Improving reliability and pooling reserves	With access to the production facilities of its neighbours, each region gains access to much greater resources to meet the demand in the case of an incident. This increases reliability and reduces the need for local reserves of production capacity.
Reduced investment in generating capacity	Thanks to pooling, each region can avoid costs of adding further capacity on its own.
Improving load factors and increasing demand diversity	Greater geographic reach often provides a more diverse demand, where peak periods do not coincide. This helps to avoid operating generating plants only for peak periods, and it uses the generator fleet in a more constant and efficient manner.
Economies of scale in new construction	With guaranteed access to a much larger market, larger generating stations can be installed, making some economies of scale accessible.
Diversity of generation mix and supply security	With more types of generation producing electricity, over a larger territory, the system is less exposed to events that affect a particular source of energy (low rainfall, lack of fuel, etc.). This increases the overall security of the integrated system.
Economic exchange	With a more diversified generating fleet and production costs, it is possible to use less costly technologies, situated in other regions, to meet various energy needs. It becomes possible to use lower cost, but distant, energy resources if equivalent local resources are not available. This reduces the overall operating costs of the system.
Environmental dispatch and new plant siting	With a larger territory in which to choose the location of generation facilities, the best sites can be chosen (for example, areas with less fragile ecosystems or zones with the most favourable winds for wind power).
Better coordination of maintenance schedules	Greater flexibility and reduced impact can be obtained with a more extensive production fleet.

Source: CEC, 2002; UN, 2006; ESMAP, 2010; see also Pineau, 2012.

Assessing Integration Benefits in a context of Increased Renewable Penetration

In the North American context, different studies have looked at how more electricity sector integration could help achieve different goals, notably increasing the penetration of renewable energy sources or reducing cost.

The benefits and needs for increased transmission capacities, in particular high-voltage direct current (HVDC) lines, have been recently studied by the EIA (2018) and Weiss et al. (2019), and in a Canadian context, the Standing Committee on Natural Resources (2017). Transmission lines are needed to help transmit electricity generated from remote intermittent power sources to load centers. More detailed studies of the challenges related to additional renewable capacity in the generation portfolio are also conducted by NREL – see for instance the NREL (2016a) and the forthcoming *North American Renewable Integration Study*. See also GE (2016) for a Canadian study on wind integration. In the context of the Eastern North American grid, NREL (2016a) identifies how old and new generation capacity can be used when renewable penetration is on the rise. It points, however, that "regulatory policy changes, market design innovation, and flexible operating procedures are critical to achieving technical potential" (NREL, 2016b). These issues have more institutional components than technical ones, stressing the importance of increased discussions and coordination among jurisdictions.

Beyond transmission and technical aspects, different studies have tried to assess some of the economic gains that could be achieved through increased integration, in the Northeast region:

- Hatch (2018) modeled the Atlantic region of Canada and assessed the various generation and transmission options to minimize the procurement cost of lower carbon-intensive electricity. Quebec and United

[7] See https://www.nrel.gov/analysis/naris.html.

States interconnections and projects were, however, excluded from the scope of this study, which was financed by Natural Resources Canada through its Regional Electricity Cooperation and Strategic Infrastructure Initiative (NRCan, 2019).

- Dolter and Rivers (2018) modeled the entire Canadian electricity system to assess the cost of decarbonization – but without including the United States.
- Williams et al. (2018), in a study commissioned by Hydro-Québec, explored different electricity sector coordination scenarios between Quebec and New England and New York. These scenarios illustrate various gains from coordination in a deep decarbonization context, where loads would significantly be higher than current ones. However, they excluded other Canadian provinces and the scenario approach adopted did not optimize investment across various possible technologies and transmission line configurations.
- Bouffard et al. (2018) presented gains from greater integration in the Northeast region, derived from a capacity expansion model similar to the one of Dolter and Rivers (2018). It is the only regional study that models large hydropower reservoirs available in the Northeast to examine how they could help reduce the cost of decarbonization in the region.

While these studies all point towards the significant benefits of increased integration, especially when renewables penetration is pursed for deep decarbonization goals, they have not yet fully made their way to energy policy makers and electricity system planners. There are promising signs, however, as detailed in the next subsection.

Political Recognition of Electricity System Integration Benefits

Some initial steps have been taken by New England Governors and Eastern Canadian Premiers (Quebec and Atlantic provinces), through their annual discussions in the context of the *Conference of New England Governors and Eastern Canadian Premiers*. In August 2018, they have taken the following resolutions (CAP, 2018):

> "system planners and operators should strengthen and diversify the generation resource mix and storage capabilities to reduce energy cost pressures and for greater system resilience during periods of extended temperature extremes" (Resolution 42-2, Resolution Concerning Energy Security and Affordability)
>
> "governors and premiers encourage ongoing dialogue among elected officials, businesses and stakeholder groups in Canada and the United States to further promote cross-border trade, trade liberalization and North American cooperation" (Resolution 42-4, Resolution Concerning the NAFTA and the Benefits of Cross-Border Trade)

Following the resolution 42-2 from the 2018 conference, the Northeast International Committee on Energy (NICE) has been created (Coneg, 2019a). Clearly, goals pursued in these resolutions are related to the potential benefits brought by electricity market integration. When GHG targets are considered, higher renewable penetration becomes required and the electricity system integration and renewable energy integration become joint challenges.

In March 2019, the New England Governors have taken a further step in their commitment towards energy collaboration through the release of the statement "New England Governors' Commitment to Regional Cooperation on Energy Issues" (Coneg, 2019b), which declares that:

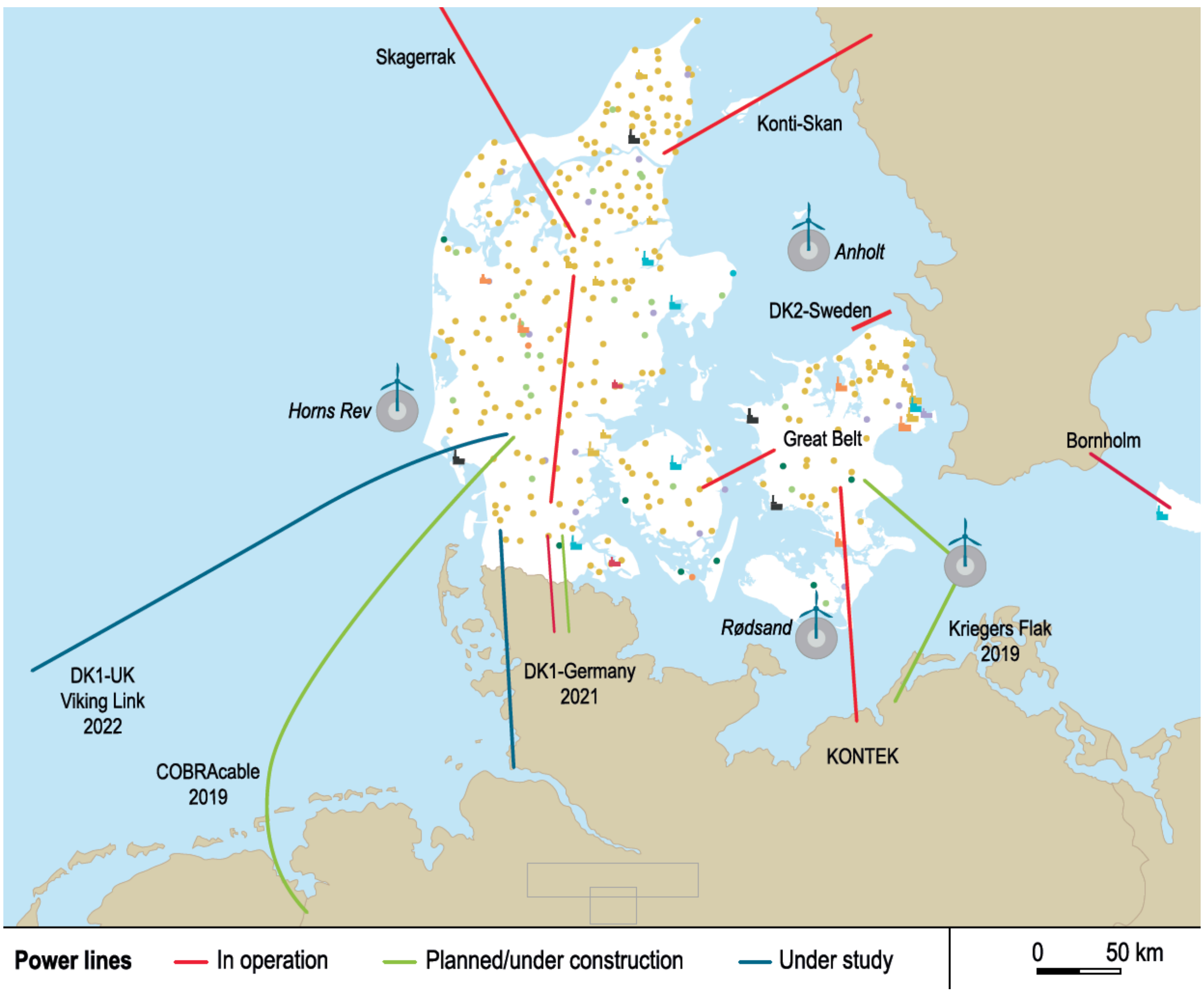
"the New England Governors commit to work together, in coordination with ISO New England and through the New England States Committee on Electricity (NESCOE), to evaluate market - based mechanisms that value the contribution that existing nuclear generation resources make to regional energy security and winter reliability. In addition, to the extent a state's policies prioritize clean energy resources, those states commit to work together on a mechanism or mechanisms to value the important attributes of those resources, while ensuring consumers in any one state do not fund the public policy requirements mandated by another state's laws."

If increased coordination in the New England power system goes in the direction of greater electricity system integration, the scope of the challenge (detailed in section 1) and the electricity system context of the Northeast calls for an even greater coordination, beyond New England, including Eastern Canadian provinces, as well as Ontario and New York.

International Examples

The case of Denmark is also particularly telling. As Figure 7 illustrates, that country is highly interconnected with its neighbors: it has 4,500 MW of such interconnectors with a peak load of 5,600 MW in 2017. This makes possible almost 100% imports, in the worst local supply situations (IEA, 2017). This capacity to trade allowed that country to go from a 100% coal and oil electricity production system in 1990 to a 66% renewable system in 2016 – with wind and biomass accounting for the renewable energy production. Wind intermittency is managed through the ability to export and import electricity with a wide variety of neighbors.

FIGURE 7 | DANISH INTERCONNECTORS THAT EXIST, ARE PLANNED OR ARE UNDER STUDY



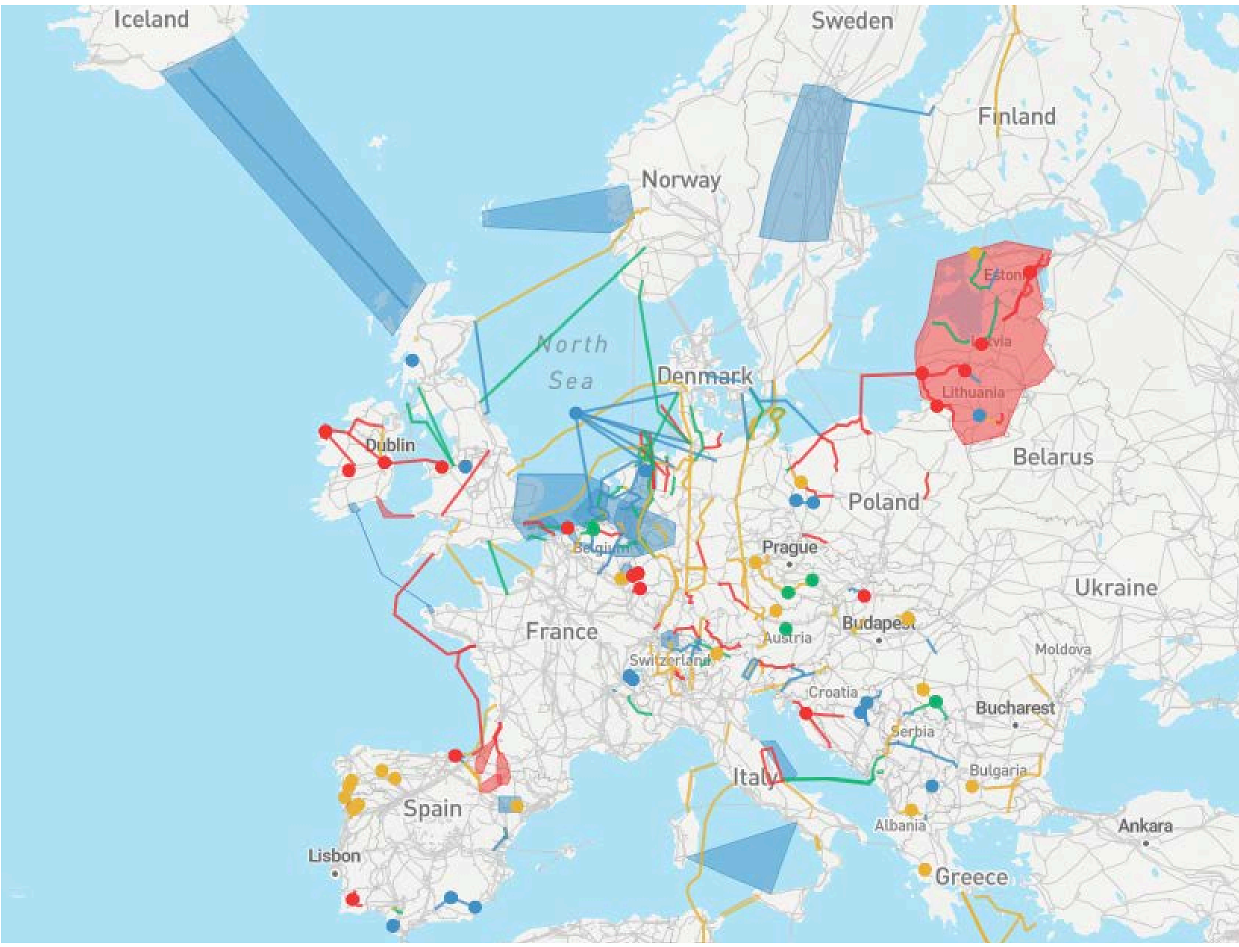
Source: IEA, 2017.

[8] With the already existing power trade and agreements and shared reliability institution, the Northeast Power Coordinating Council, NPCC (https://www.npcc.org/).

Part of the coordination in planning is done through the Nordic Energy Regulators forum, the Nord Pool (wholesale market owned by Nordic transmission system operators), the Nordic Regional Security Coordinator and of course through European Union organizations such as the European Network of Transmission System Operators for Electricity (ENTSO-E).

In the Europe, this ENTSO-E was formed in 2009 to support the "setting up the internal energy market and ensuring its optimal functioning, and of supporting the ambitious European energy and climate agenda" (ENTSO-E, 2019a). It is in charge of Europe's Network Development Plan to 2025, 2030 and 2040, which studies and tests various transmission and storage projects, as illustrated in Figure 8. Such coordinated approach in planning allows, for instance, to better establish the importance of some particular transmission projects.

FIGURE 8 | EUROPEAN TRANSMISSION PROJECTS FROM THE TEN-YEAR NETWORK DEVELOPMENT PLAN 2018



Source: ENTSO-E, 2019b.

SECTION 3 | Identification of barriers to greater regional cooperation and coordination in the electricity sector

Increased integration requires meeting some technical challenges, such as the need for transmission infrastructure or managing dispatch and reliability over greater areas. Although these obstacles may be important, this section highlights additional and often overlooked non-technical challenges. Combined with technical challenges, they prevent or complicate efforts to coordinate the electricity sector across the Northeast. More specifically, institutional, political and social barriers prevent, slow down, or increase the cost of, regional cooperation and coordination to achieve GHG reduction and greater renewable energy take-up.

SECTION HIGHLIGHTS |

- While some technical challenges remain to be solved, non-technical barriers complicate regional integration.
- These barriers prevent or hinder both regional integration and the most effective deployment of renewable sources in the electricity mix, required to reach GHG reduction targets.
- Political barriers dim the prospects for integration across the Northeast electricity sector, through the conflation of industrial policy objectives and climate-related ones.
- Decision-makers should give special attention to these barriers, notably by addressing social acceptance issues and by harmonizing electricity regulation and policies across jurisdictions.

Institutional and organizational barriers

A first type of non-technical barrier to regional integration comes from the organization of regulatory and other overseeing governmental institutions. Both in the U.S. and in Canadian provinces, primary regulatory authority is in the hands of state- or province-based utility commissions, which have a mandate that requires they look over the costs and benefits for customers in their home jurisdiction. As a result, there is, by design, little incentive for these institutions to consider integration from a regional perspective. The U.S. Federal Energy Regulatory Commission (FERC) has however authority over interstate trade and favors the creation of Regional Transmission Organizations (RTOs), which compels greater electricity-sector integration among RTO-member states. Between 2001 and 2005, the FERC even pushed for the mandatory creation of RTOs across the U.S., all organized under a Standard Market Design – but this initiative was received with a lot of resistance and eventually failed.

Subnational authority over electricity markets, as opposed to a more central or federal control, can create a barrier to integration for a variety of reasons. Regulatory clustering across states or provinces, notably, makes integration difficult as it adds administrative and operational costs to collaborative arrangements between firms or governments from different jurisdictions. This is because this clustering often results in substantially different

[9] States with lower regulated prices (resulting from favorable access to hydropower or coal) indeed resisted the concept of exporting more electricity to higher cost markets, with the consequence of experiencing higher local prices. Such change was unpopular among consumers groups and led to the rejection of RTO, mostly to protect local lower cost electricity. See Sullivan et al. (2003) for a detailed account.

regulations and standards: as a result, regional collaboration requires their harmonization, which in turns involves political and regulatory actors from all jurisdictions involved.

This is further complicated by constitutional issues: for instance, Canadian provinces may be reluctant to pursue interprovincial transmission projects in order to avoid involving the federal government's participation through the National Energy Board approval process, which applies to designated interprovincial power lines. Favorable low-price regulation in some provinces, such as Quebec (made possible by the abundance of low-cost hydropower) can also complicate regional integration given the diverging pricing approaches.

In the U.S., the prospect of federal pre-emption may make Northeastern states and their regulatory agencies hesitant to pursue collaborative arrangements on a regional basis (Craig 2010). Moreover, regulatory preferences on tariff practices make it more difficult for large utilities to benefit from economies of scale following the integration of their operations across jurisdictions, as the definition of public interest applied by regulatory agencies in evaluating rate proposals varies across jurisdictions (Brown and Rossi 2010).

These difficulties come in addition to variation in the importance and role of electric utility companies, which have a government-sanctioned monopoly over certain aspects of the services they provide. This variation reflects distinctions in regulatory and political approaches that may be difficult to reconcile in regional collaboration efforts. For instance, some jurisdictions across the Northeast have fully deregulated wholesale markets, whereas others see a single state-owned enterprise dominate. Therefore, the prospects for integrating these markets raises questions about how to treat and resolve concerns over competitivity among public monopolies and private actors of various sizes.

For such reasons, these barriers prevent or hinder the regional integration of efforts related to achieving GHG reduction targets and increasing the share of renewables in the electricity mix, even when this integration would be more effective at achieving these objectives.

Political Barriers: Regional cooperation conflicting with industrial policy

In subnational jurisdictions, industrial policy is designed to achieve objectives such as job creation, expansion of certain sectors of economic activity, or technological innovation and leadership. With regard to fostering the deployment of renewable energy technologies, the political rationale has long been to couple the climate-related benefits with such industrial policy concerns. The electricity sector is often impacted by such policies, for instance when subnational governments encourage the development of wind and solar energy as a way to increase employment and innovation within its own jurisdiction – such as how New York's REV is largely designed. Ontario and Quebec, in Canada, also largely justified their wind and, to a lower extent, solar investments in the name of local economic development.

In some instances, these objectives shape policy design, which may act as a barrier to a more effective expansion of renewables installed capacity, as it can raise the cost of achieving the targets by incorporating local industrial development or job creation concerns. In this situation, the objectives of GHG policy and industrial policy are conflicting, leading to suboptimal policies to achieve the former (Langlois-Bertrand et al. 2015). One example is Ontario's Green Energy and Green Economy Act of 2009, which contained feed-in tariff support for renewable energy technologies like wind and solar, but which required developers to respect minimum domestic content requirements. The stated objective was to use the legislation not only to increase the share of renewables in the electricity mix, but also to develop a manufacturing sector within the province and create "green" jobs. This had the effect of raising the price of renewables, thereby diminishing the rate of installations. A similar wind investment program took place in Quebec, requiring some "local" content for contracted wind farms, that had to be of course located in the province.

[10] The domestic content requirement was eventually removed after being successfully challenged at the World Trade Organization by Japan and the European Union.

Another example is the RPS program in New Hampshire, which was designed to be a key tool in reducing the state's emissions, by requiring utilities in the state to procure a steadily increasing share of their electricity from renewable sources. Under the program's rules, meeting RPS goals can be achieved in a variety of ways, and the general approach was to rely on the market to determine the most cost-effective options to meet the requirements. However, in the RPS legislation, the definition used by New Hampshire for eligible renewable sources specifically excluded large-scale hydropower. In practice, this results in making imports of low-emission electricity from neighboring Canadian provinces ineligible to meet RPS requirements, even when cost would be lower than other options. By design, New Hampshire-based producers are preferred over clean energy imports, at a higher cost linked to a significant expansion of local production from sources like wind, solar and local hydropower. Concerns related to job creation and promoting local industry, in particular, made the New Hampshire authorities – like several other jurisdictions in the region – very hesitant to procure large amounts of electricity from North of the border.

A third example is New York using its hydropower to foster development in some regions of the state. The New York Power Authority's ReCharge NY program, for instance, provides qualifying businesses with arrangements to get guaranteed access to specifically allocated hydropower at below-market prices. In return, the businesses must make commitments to expand their operations and/or to create jobs. Here as well, the result in terms of pushing for cost-effective GHG reduction strategies may be less than optimal, given that this low-carbon electricity is sold at a cheaper rate than the state could otherwise get. This results in a disincentive to increase efficiency in its use, or to develop the fleet of low-carbon resources, since below-market prices make it less attractive for utilities and renewable energy developers to install additional renewable resource capacity.

Therefore, political barriers also dim the prospects for integration across the Northeast electricity sector, through the conflation of industrial policy objectives and climate-related ones.

Social Acceptance Barriers

Given that regional integration often requires the building of new transmission lines, social acceptance barriers add to the difficulties of fostering collaborative efforts to achieve GHG reduction targets. Local opposition to infrastructure projects often comes from local populations concerned by the project's economic, environmental, social or sometimes simply visual impacts. In the energy sector, if opposition is strong enough, it can derail valuable regional integration projects. This opposition is often simplified in terms of Not-in-my-Backyard (NIMBY) arguments, although the rationales are often more varied (Komendantova and Battaglini 2016; Nelson et al. 2018)

In the specific case of transmission lines, opposition coalitions often consist of actors with very different interests and perspectives. In Maine, for instance, recent opposition to Central Maine Power's construction of a transmission line as part of the New England Clean Energy Connect to import hydropower from Quebec to Massachusetts (Clean Energy 83D solicitation) is composed of environmental groups (the Natural Resources Council of Maine (NRCM), the Sierra Club), local renewable energy producer associations (Maine Renewable Energy Association, ReEnergy Biomass Operation) and notably the New England Power Generators Association (NEPGA), a Boston-based trade group that represents mostly natural gas generators in the region. This coalition is made possible by the multiple concerns regarding the project, including environmental and tourism impacts (e.g., destruction of habitats, impact on landscape, uncertain impact on GHG emissions), local business concerns (e.g., crowding out of small local renewable producers, unfair advantage given to one large utility over other players), and, finally, local opposition from towns closest to the planned path with specific siting concerns (e.g., land property value, health risks).

Given the frequent presence of organized social opposition to transmission line projects, the failure to address such concerns results in a lesser take-up of renewables from a regional perspective, as it prevents the sharing of renewable resources across jurisdictions.

Overcoming barriers and the way forward

Realizing deeper integration across the Northeast electricity sector can result in higher penetration of renewables and increase effectiveness in efforts to reach GHG reduction targets. However, achieving this integration requires overcoming or eliminating institutional, political, and social acceptance barriers that add to technical challenges.

The examples above suggest a few points in moving forward. One is that institutional barriers imply a need for subnational jurisdictions to give special attention to regulatory discrepancies across jurisdictions. This is necessary to ensure that regional collaboration leads to a streamlining of efforts to harmonize and facilitate integration of grids across subnational jurisdiction borders. A second point is that combining renewable deployment efforts with industrial policy and job creation objectives appears to prevent more rapid and extensive penetration by renewables in the electricity mix. Although this type of policy rationale can help in selling government support for renewables to the public, this strategy seems to have reached its limits, and often works against achieving higher penetration levels for renewables across the region. This, in addition to providing a legitimate process for addressing citizens concerns over transmission line projects, must be a key concern for governments so that they manage to convince their constituents of the merits of regional integration and more aggressive renewable energy deployment.

Conclusion

The Northeast has ambitious economy-wide GHG reduction targets for 2030 and 2050. It already enjoys a low-carbon electricity sector, with declining emissions. However, given the decarbonization aspirations and likely increase of electricity demand, related to the decarbonization of transportation, heating and industrial processes, important changes will have to take place in the electricity sector to achieve GHG reduction targets.

The literature and the current disparities in the supply and demand clearly show that there would be significant benefits in integrating electricity sectors across the Northeast, especially if increased renewable penetration is required. These benefits derive from the increased efficiency at which the sector can operate if optimal collaboration and cooperation can be achieved and sustained. These efficiency gains would come from trade, pooling capacity, economies of scale, demand diversity, among others.

However, there are significant technical, institutional, political and social barriers that must be overcome to achieve the level of integration needed to efficiently and effectively achieve GHG reduction targets.

A first step toward addressing these barriers, which has already been largely recognized, is to strengthen regional collaboration through additional dialogue, sharing of information and data, and further technical and economic studies on the gains of and approaches to greater integration.

Bibliography

Bouffard F., Debia S., Dhaliwal N. and Pineau P.-O. (2018) *A Decarbonized Northeast Electricity Sector: The Value of Regional Integration*, Northeast Electricity Modelling Project Scoping Study, Montreal: Chair in Energy Sector Management. http://energie.hec.ca/npcc/

Brown, A.C. and J. Rossi (2010) "Siting Transmission Lines in a Changed Milieu: Evolving Notions of the Public Interest in Balancing State and Regional Considerations", *University of Colorado Law Review* 81: 705–70

CAP (2018) *NEG/ECP Resolutions*, Halifax: Council of Atlantic Premiers. Webpage accessed on May 5, 2019. https://www.cap-cpma.ca/about/new-england-governors-and-eastern-canadian-premiers-annual-conference-negecp/negecp-resolutions/

CEC (2002) *Environmental Challenges and Opportunities in the Evolving North American Electricity Market*, Secretariat report to council under article 13 of the North American agreement on environmental cooperation, Montréal: Commission for Environmental Cooperation of North America.

Coneg (2019a) *Northeast International Committee on Energy (NICE)*, Washington DC: Coalition of the Northeastern Governors. Webpage accessed on May 5, 2019. https://www.coneg.org/neg-ecp/committees/northeast-international-committee-on-energy-nice/

Coneg (2019b) *Published articles referencing the New England Governors' Commitment to Regional Cooperation on Energy Issues*, Washington DC: Coalition of the Northeastern Governors. Webpage accessed on May 5, 2019. https://myemail.constantcontact.com/Governors--Regional-Commitment-to-Energy-Issues--House-Passes-Climate-Action-Legislation--Save-the-Date-for-New-England-Governor.html?soid=1125796069643&aid=szx4SO7hd6k

Craig, R.K. (2010) "Constitutional Contours for the Design and Implementation of Multistate Renewable Energy Programs and Projects", *University of Colorado Law Review* 81: 771–833

Dolter B. and Rivers. N. (2018) "The cost of decarbonizing the Canadian electricity system" *Energy Policy*, vol. 113, 135-148.-

ECA (2010) The Potential of Regional Power Sector Integration – Literature Review, London: Economic Consulting Associates.

ECCC (2018) Canada's Official Greenhouse Gas Inventory. Gatineau: Dataset accessed on March 24, 2019. http://data.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/

EIA (2018) *Assessing HVDC Transmission for Impacts of Non-Dispatchable Generation*. Washington: Energy Information Administration.

EIA (2019a) Electric Power Annual. Washington: Energy Information Administration. Dataset accessed on March 24, 2019. https://www.eia.gov/electricity/annual/

EIA (2019b) State Carbon Dioxide Emissions Data. Washington: Energy Information Administration. Dataset accessed on May 21, 2019. https://www.eia.gov/environment/emissions/state/

ENSTO-E (2019a) *ENTSO-E Objectives,* Brussels: European Network of Transmission System Operators for Electricity. Webpage accessed on June 3, 2019. https://www.entsoe.eu/about/inside-entsoe/objectives/

ENSTO-E (2019b) *TYNDP 2018 - Project Sheets,* Brussels: European Network of Transmission System Operators for Electricity. Webpage accessed on June 3, 2019. https://tyndp.entsoe.eu/tyndp2018/projects/

ESMAP (2010) Regional Power Sector Integration: Lessons from Global Case Studies and a Literature Review, Regional Energy Integration Strategies Program – Solving Energy Challenges through Regional

Cooperation, Briefing Note 004/10, Energy Sector Management Assistance Program (ESMAP), Washington, DC: The World Bank.

GE (2016) *Pan-Canadian Wind Integration Study*, Published by the Canadian Wind Energy Association (CANWEA), General Electric International Inc. Available on-line at: http://canwea.ca/wind-energy/wind-integration-study/.

Hatch (2018) *Nova Scotia Power Inc. Atlantic RECSI*, Final Report for the Study - Atlantic Regional Electricity Cooperation and Strategic Infrastructure Initiative (RECSI).

Holttinen H., Kiviluoma J., Levy T., Jun L., Borre Eriksen P., Orths A., Cutululis N., Silva V., Neau E., Dobschinski J., von Roon S., Dillon J., Flynn D., Maria E., Terna C., Tanabe R., Yasuda Y., Ramirez M., Rueda Torres J., Kristian Vrana T., Korpås M., Estanqueiro A., Couto A., Gomez Lazaro E., Söder L., Pudjianto D., Strbac G., Hodge B.-M., Smith J.C., Lew D. and Fraile D. (2019) *Design and operation of power systems with large amounts of wind power*, Final summary report, IEA WIND Task 25, Phase four 2015-2017, VTT Technical Research Centre Of Finland.

IEA (2017) *Energy Policies of IEA Countries Denmark 2017 Review*, Paris: International Energy Agency.

Komendantova, N. and A. Battaglini (2016) "Beyond Decide-Announce Defend (DAD) and Not-in-My-Backyard (NIMBY) models? Addressing the social and public acceptance of electric transmission lines in Germany", *Energy Research & Social Science* 22: 224–31.

Langlois-Bertrand, S., M. Benhaddadi, M. Jegen and P.-O. Pineau (2015) "Political-institutional barriers to energy efficiency", *Energy Strategy Reviews* 8: 30–8.

Nelson, H.T., B. Swanson and N.L. Cain (2018) "Close and Connected: The Effects of Proximity and Social Ties on Citizen Opposition to Electricity Transmission Lines", *Environment and Behaviour* 50(5) : 567–96

NPCC (2019) *2019 Business Plan and Budget*, New York: Northeast Power Coordinating Council, Inc. (NPCC).

NRCan (2019) *Clean Energy and Electricity Infrastructure*, Ottawa: Natural Resources Canada. Webpage accessed on May 5, 2019. https://www.nrcan.gc.ca/node/21294/

NREL (2016a) *Eastern Renewable Generation Integration Study*, Technical Report NREL/TP-6A20-64472, Golden: National Renewable Energy Laboratory.

NREL (2016b) *Eastern Renewable Generation Integration Study*, Golden: National Renewable Energy Laboratory. Webpage accessed on May 5, 2019. https://www.nrel.gov/grid/ergis.html

OAS (2007) Regional Electricity Cooperation and Integration in the Americas: Potential Environmental, Social and Economic Benefits, Washington, D.C.; Organization of American States.

Ontario (2019) *The End of Coal*, Toronto: Government of Ontario. Webpage accessed on May 21, 2019. https://www.ontario.ca/page/end-coal

Pineau, P.-O., Hira A. and Froschauerc, K. "Measuring international electricity integration: a comparative study of the power systems under the Nordic Council, MERCOSUR, and NAFTA", *Energy Policy*, vol. 32 (2004) 1457–1475.

Pineau, P.-O. (2012) Integrating Electricity Sectors in Canada: Good for the Environment and for the Economy. The Federal Idea, Montreal.

Pineau, P.O. (2013) "Fragmented Markets: Canadian electricity sectors' underperformance (Ch. 13)" in F.P. Sioshansi (Ed.), Evolution of Global Electricity Markets: New Paradigms, New Challenges, New Approaches, Elsevier (2013)

Standing Committee on Natural Resources (2017) *Strategic Electricity Interties - Report of the Standing Committee on Natural Resources*, Canada House of Commons.

Statistics Canada (2019a) Table 17-10-0009-01 Population estimates, quarterly. Ottawa: Statistics Canada.

Statistics Canada (2019b) Table 25-10-0030-01 Supply and demand of primary and secondary energy in natural units. Ottawa: Statistics Canada.

Statistics Canada (2019c) Table 25-10-0022-01 Installed plants, annual generating capacity by type of electricity generation. Ottawa: Statistics Canada.

Sullivan M.A., Bell J.C., and Lilyestrom J.R. (2003) "Standard Market Design: What Went Wrong? What Next?" *The Electricity Journal*, vol. 16 (6) 11-17.

UN (2006) Multi Dimensional Issues in International Electric Power Grid Interconnections, Department of Economic and Social Affairs, Division for Sustainable Development, New York: United Nations.

UNECA (2004) Assessment of Power Pooling Arrangement in Africa, Addis Ababa: United Nations Economic Commission for Africa.

U.S. Census Bureau (2018) Table 1. Annual Estimates of the Resident Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2018 (NST-EST2018-01).

WEC (2010) Interconnectivity: Benefits and Challenges, London: World Energy Council.

Weiss J., Hagerty J.M. and Castañer M. (2019) *The Coming Electrification of the North American Economy: Why We Need a Robust Transmission Grid*, Prepared for Wires, The Brattle Group.

Williams J.H., Jones R., Kwok G. and Haley B. (2018) *Deep Decarbonization in the Northeastern United States and Expanded Coordination with Hydro-Québec*, A report of the Sustainable Development Solutions Network in cooperation with Evolved Energy Research and Hydro-Québec.

Appendix 1 | References for Table 3

New Brunswick

New Brunswick. 2016. Transitioning to a low-carbon economy: New Brunswick's Climate Change Action Plan. Province of New Brunswick.

New Brunswick. 2017. Update on New Brunswick Climate Change Actions. Province of New Brunswick.

Newfoundland and Labrador

Newfoundland and Labrador. 2007. Provincial Energy Plan. Newfoundland and Labrador.

Newfoundland and Labrador. 2011. Climate Action Plan. Newfoundland and Labrador.

Newfoundland and Labrador. 2011. Energy Efficiency Action Plan. Newfoundland and Labrador.

Nova Scotia

http://Climatechange.novascotia.ca

Ontario

https://www.ontario.ca/page/climate-change

Prince Edward Island

https://www.princeedwardisland.ca/en/publication/pei-climate-change-action-plan

Quebec

MDDELCC. 2018. Engagements du Québec: Nos cibles de réduction d'émissions de GES. Québec : Développement durable, environnement et lutte contre les changements climatiques. Online, http://www.mddelcc.gouv.qc.ca/changementsclimatiques/engagement-quebec.asp (accessed January 31 2018)

Québec. 2016. L'énergie des Québécois: Source de croissance. Politique énergétique 2030. Gouvernement du Québec.

Connecticut

https://www.ct.gov/pura/cwp/view.asp?a=3354&q=415186

Maine

http://www.mainelegislature.org/legis/statutes/38/title38sec576.html

https://www.maine.gov/dep/sustainability/climate/reducing-impacts.html

Massachusetts

https://www.mass.gov/service-details/energy-generation-and-distribution

New Hampshire

https://www.georgetownclimate.org/adaptation/state-information/new-hampshire/overview.html

http://www.puc.state.nh.us/Sustainable%20Energy/Renewable_Portfolio_Standard_Program.htm

https://www.puc.nh.gov/sustainable%20energy/RenewableEnergyFund.html

https://www.puc.nh.gov/sustainable%20energy/RenewableEnergyRebates.html

New York

https://rev.ny.gov/

https://www1.nyc.gov/site/sustainability/codes/80x50.page

https://www.greentechmedia.com/articles/read/new-york-names-100-carbon-neutral-electricity-as-priority#gs.pLPKxoqT

https://www.greentechmedia.com/articles/read/new-york-cuomo-green-new-deal-clean-energy#gs.qUKPOjcR

Rhode Island

http://climatechange.ri.gov/

Vermont

https://climatechange.vermont.gov/

https://publicservice.vermont.gov/publications-resources/publications/energy_plan/2015_plan

https://outside.vermont.gov/sov/webservices/Shared%20Documents/2016CEP_Final.pdf

RGGI

Additional information on the Regional Greenhouse Gas Initiative and the Transportation Emission Cap Regional Initiative

https://www.rggi.org/

https://www.transportationandclimate.org/