Cities and Smart Grids in Canada

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IISD
International Institute for Sustainable Development

September 2017

Published by the International Institute for Sustainable Development

International Institute for Sustainable Development

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Acknowledgements and Disclaimers

The authors wish to thank Natural Resources Canada for their generous support of the underlying research that contributed to this report. The authors would also like to thank staff at Natural Resources Canada, Canadian Electricity Association and Manitoba Hydro for their constructive feedback.

Acronyms

CEA	Canadian Electricity Association
CEP	Community Energy Plan
FCM	Federation of Canadian Municipalities
FIT	feed-in tariff
GHG	Greenhouse Gas
ICT	information and communication technology
IEA	International Energy Agency
kW	kilowatts
kWh	kilowatt hour
MW	megawatts
NEB	National Energy Board
NERC	North American Electric Reliability Corporation
NRCan	Natural Resources Canada
PV	photovoltaic
QUEST	Quality Urban Energy Systems of Tomorrow
StatsCan	Statistics Canada
TWh	terawatt hour

Executive Summary

Canada's electricity sector plays a central role in supporting the country's economic, social and environmental needs. In order to meet emerging trends, including supply and demand pressures, and to remain competitive in a world that is becoming increasingly carbon constrained, Canada's electricity sector must modernize and make appropriate investment decisions. To this end, coming decades will be critical and lock-in effects in the electricity sector that can undermine mid-century decarbonization objectives should be avoided.

This report looks specifically at smart grids within the context of grid modernization and urban settings in Canada. In this context, we note that the rapidly aging electricity infrastructure provides a unique opportunity to achieve synergies found between grid modernization and climate objectives. A central pillar of these efforts must be deployment of smart grid solutions. These solutions will have an important role in enhancing decarbonization opportunities, especially in the transportation and heating sectors—two of Canada's largest sources of greenhouse gas emissions. Second, they provide value for costumers by supporting energy efficiency and by allowing consumers to sell back to the grid. Finally, they can address supply-side pressures, especially in the context of agglomeration trends in Canada.

The following context has informed the research's conclusions and recommendations:

- **Canada's cities are growing both in terms of population and geographic space.** This is leading to the dual challenge of addressing increased demand in city core areas while simultaneously having to supply residential and commercial areas in ever growing suburban areas.
- **Traditionally, electricity generation has consisted of major facilities** (e.g., coal plants, hydro dams, nuclear facilities) connected to demand sources through high-voltage transmission lines running over long geographical areas.
- **Going forward, a shift in energy production and distribution is anticipated**. This will be driven by a number of factors, including: reliability and security concerns (vulnerability of long transmission lines to extreme weather); policies that incentivize low-carbon energy production (solar panels and wind turbines); increasing social resistance to large power projects; and a growing desire for alternative approaches to energy generation and distribution sources (e.g., district heating and prosumers).
- **Climate change mitigation policies will affect business decisions in the electricity sector**. Coal phase-out and carbon pricing were already mentioned, but there are additional factors at play. Recent commitments of the government in Budget 2017 to fossil fuel subsidy reform and renewable energy investment will act as lubricant to the existing trend to cleaner energy. Increasing energy prices will drive investment decisions, but also consumption decisions. An example is the growth in electric vehicles, which is driving electricity demand, particularly in urban settings. Interviews indicate that this demand is manageable thus far, but it is driving uncertainty in long-term planning.
- **Climate change will have an impact on demand and resources**. Temperature changes, and associated water accessibility challenges, can affect energy production efficiency, while demand for electricity in summer months will increase. There is potential for some areas of Canada to shift dramatically from winter-peaking utilities to summer-peaking ones. Given that electricity supplies the massive demand for air conditioning, while a great deal of heating is provided by natural gas, this can fundamentally shift the energy system in Canada.
- **Consumers' expectations of utilities is changing**. Consumers' expectations are likely to increasingly include economic, social and environmental impacts of energy production. Some consumers want greater information about their power use; others want the ability to become early adopters of new, clean technology; while still others are most concerned about access to energy in light of increased costs associated with fossil fuel sources. ***This has led to the need for utilities to adopt new business models***. We note four emerging business models in the smart grid-enabled electricity systems (see Table ES1).

Table ES1. Business models emerging in the smart-grid enabled energy system

Energy Service Provider	Customer Energy Marketplace
This model provides power and heat from renewable electricity to homes. It does not suggest replacement of, for example, natural gas furnaces, but rather provides flexibility that is acknowledged at the home level.	This model changes the consumer relationship from one-dimensional business-to-customer low-cost, reliable energy provision toward a partnership model. This business model is rooted in two-way generation distribution and demand.The intent is to provide two-way flows of power and grid services to and from the customer.
Local Balancing Authority	**Smart City**
This model moves away from simply a bulk power system level. At the distribution level, utilities will operate "virtual power plants" or, in some cases, even microgrids (which can island to provide back-up power during outages) embedded within the city to balance supply and demand using aggregated distributed energy resources (demand response, distributed generation and storage).	This model integrates energy systems. Heat, power, transportation and water all are able to balance energy supply and demand needs through integrated systems and markets. It includes more efficient systems and greater flexibility.

It is critical to note that there is no emergent "winner" model of these four models. They are each evolving differently in different jurisdictions across Canada. For example, in provinces with large-scale renewable resources and single public sector utilities, such as Manitoba and Quebec, the large-scale model has emerged dominant. Ontario undertook a major initiative to support local energy provision, and government and a large number of utilities have provided models for potential for flexibility and optimization of efficiency (e.g., the Green Button Program). In the North (where the climate is harsh and energy prices are in some cases a factor of 10 times higher than they are in the south), the foremost issue is how to provide energy access to residents above all else and ensure efficiency, given the high cost of fuels. **It is important to recognize that, while there are some issues that can be addressed nationally and a national vision on smart grids is required, *there is no unified business model* and approaches to smart grids will mean very different things in the regions across the country**.

To concretely explore ways to support grid modernization and meet urban needs, next steps should include the development of a refreshed vision for smart grids and low-carbon electricity in Canada. This vision should include increased exchange of intelligence and coordination on smart grid technology deployment clusters that include utilities, governments and the public. In addition, it is important to provide targeted support for smart grid technologies in areas where implementation is currently flagging, as well as broader education and capacity-building efforts that include utilities, policy-makers, associations and the general public.

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1.0 Introduction

Canada's urban population is an estimated 81 per cent (from 2011 figures), a significant change from the early 1950s, when only 62 per cent of the population resided in cities (Statsistics Canada, 2011). Similar to the trend in urban demographics, electricity use patterns have changed in the recent past. Today's modern electricity consumption has evolved from heating and cooking needs to a more complex use of electricity services, and has evolved into complex urban electricity networks. Figure 1 illustrates Canada's electricity transmission grid.

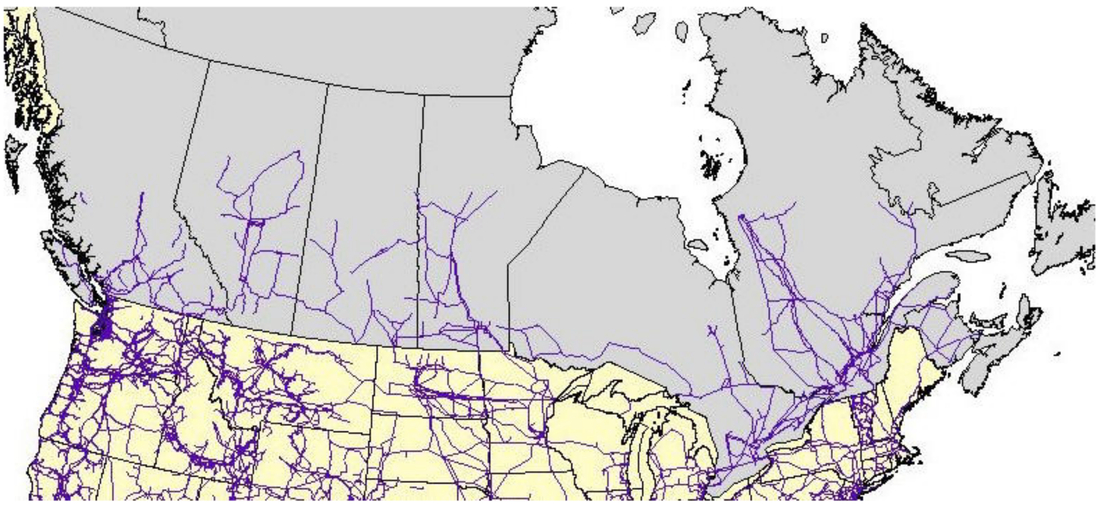

Figure 1. National Electricity Transmission Grid of Canada

Source: Global Energy Network Institute (n.d.)

Through continual technological advances coupled with urban agglomeration and changing sectoral needs, a perpetual evolution in the electricity sector is all but inevitable. As the electricity sector serves as the backbone for society, constant need for change requires forward-thinking investments and understanding of socioeconomic and environmental trends, working within political frameworks, anticipating challenges and minimizing risks, and where technological advancements are an essential tool in transitioning the sector to better service its customers. To this end, this paper takes a look at the agglomeration trends in Canada, explores the state of the current electric power system in the country, identifies challenges within the value chain, and identifies the risks and opportunities in modernizing the electrical grid through smart grids.

1.1 Urban Agglomeration Trends in Canada

In Canada, urban agglomeration has been low-density, automobile-dependent expansion, primarily led by the construction of suburban centres at the edges of city centres (Sustainable Prosperity, 2012). This agglomeration into suburban centres has been driven in part due to low-cost housing and office space, but has led to silos within cities, notably as suburban population hubs are becoming increasingly geographically connected to, but also structurally separate from, major city centres (such as the situations between Markham or Vaughan and Toronto, or Burnaby and Vancouver). This has led to an increased dependency on cars and traffic congestion, expropriation of agricultural lands, and increases in smog and greenhouse gas (GHG) emissions (Sustainable Prosperity, 2012; Gurin, 2003). The landscape of the city has been changing in turn, where, for example, garage doors now replace front porches on many streets, shopping malls replace downtown shopping, and airports, rather than railway stations, are the travel hubs (Gurin, 2003). Moreover, there is higher dependence on fossil fuels due to longer travelling distances, particularly in cities where there are limited geographic barriers to suburban expansion and where the population is expanding faster than existing rapid mass-transit networks (e.g., Winnipeg) (Gurin, 2003).

Apart from real-estate and economic conditions, policies and public incentives have enabled the urban sprawl, including through subsidization of transportation infrastructure, water, sewage and electricity and gas utilities. Replacement of streetcars with buses and reduction of sidewalks have also enabled the use of vehicles on the road and residing away from city centres (e.g. reduction of sidewalk widths, one-way traffic, zoned and timed parking) (Gordon & Shirokoff, 2014). The agglomeration trend has led Canada to become an increasingly auto-dependent, suburban nation, where suburban areas are home to two thirds of the population (Gordon & Shirokoff, 2014). To demonstrate the agglomeration trend, Figure 2 illustrates rural versus urban population growth, noting that rural population has plateaued since the 1940s, while urban population has increased four fold in the same period.

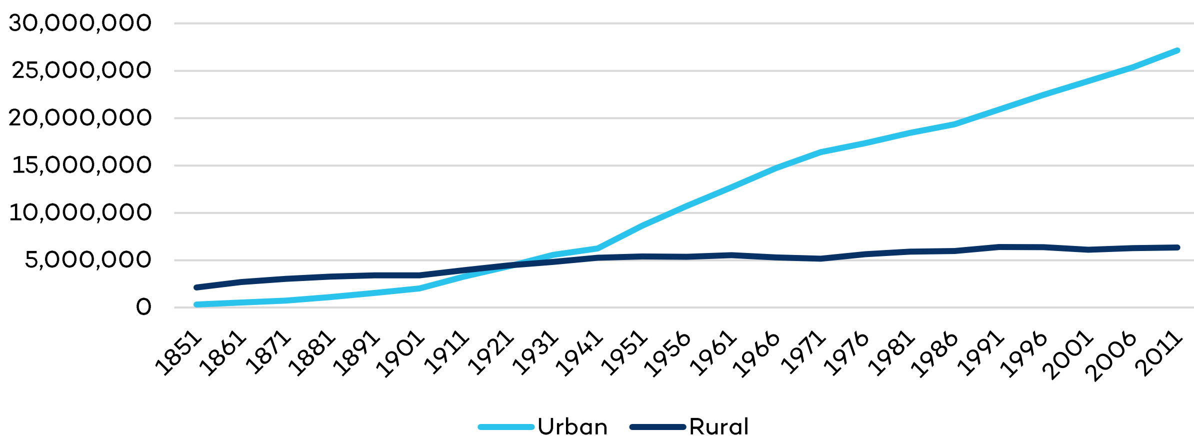

Figure 2. Urban and rural population trends, 1851–2011

Source: StatsCan (2011)

The fastest growing major urban centres are Toronto, Edmonton, Vancouver, Calgary and Ottawa, with Edmonton and Ottawa experiencing the largest growth rate. Overall, Kelowna has seen the largest growth rate of cities included in the Statistics Canada (StatsCan) survey: 1,433 per cent growth between 1971 and 2011 (StatsCan, 2016).

Although not all cities are equal, the agglomeration trend is a continued movement of people to urban centres, and these urban centres are growing both in terms of density and geographic size (i.e., more people and more space). This is changing small rural communities into bedroom communities, converting the landscape into suburban areas with new homes and usage of advanced technologies, and consequently increasing electricity usage, vehicle dependency and longer commuting times. This agglomeration trend also places stresses on provision of basic services, including the need for new and expanded schools, fire stations, policing services and other basic services that all draw heavily on the energy network, both at the outskirts of cities and in the city centre as density increases.

As noted, this trend has made Canada to an auto-dependent nation; however, use of vehicles versus use of public transportation depends largely on the location of residences. Residents located closer to the city centre tend to use public transportation to go to work more than those living in neighbouring (suburban) municipalities (StatsCan, 2016). The national average commute time is 23 minutes. Toronto has the highest commute time, estimated at 33 minutes, while Saguenay is the lowest commute time of 17 minutes (based on 2011 figures). The vast majority of the commute is done in single occupancy vehicles or carpooling (84 per cent), while on average only 8 per cent of the commuting population of the national average used public transportation to go to work, and alternative (walking, bicycle) transportation is about 7 per cent. Statistics Canada data indicates that the cities with greater public and alternative transportation are Edmonton, Quebec City, Winnipeg, Calgary, Halifax, Vancouver, Victoria, Ottawa-Gatineau, Toronto and Montreal.

With an understanding of trends in agglomeration, the next section looks at the current electricity system, and how this is, or is not, equipped to address the challenges that agglomeration presents.

1.2 Structure of the Current Energy System

The electricity sector directly supports an estimated 78,270 jobs across Canada (2015 figures), and contributes an estimated 1.9 per cent to Canada's GDP (2015 figures) (NRCan, 2017). Moreover, it serves as the backbone for other sectors in the economy, including oil and gas, manufacturing, mining and emerging clean technology (Canadian Electricity Association [CEA], 2013). In terms of the type of electricity generated, Canada generates some of the cleanest electricity in the world. Canada produced a total of 639 TWh in 2014 (NRCan, 2017), with 80 per cent of the electricity generation derived from non-fossil fuels, such as hydro and nuclear power (NRCan, 2017; National Energy Board [NEB], 2016; CEA, 2012, 2016b). Remaining energy generation came from coal (9.5 per cent), and other fossil fuels (10.2 per cent) (NRCan, 2017). Canada's current electricity generation is illustrated in Figure 3 and generation by province is presented in Figure 4. Figure 4 in particular shows that while the majority of Canada's electricity comes from non-fossil sources, there are wide provincial/territorial discrepancies, from almost 100 per cent non-emitting in Quebec and PEI, to 100 per cent fossil fuels in Nunavut.

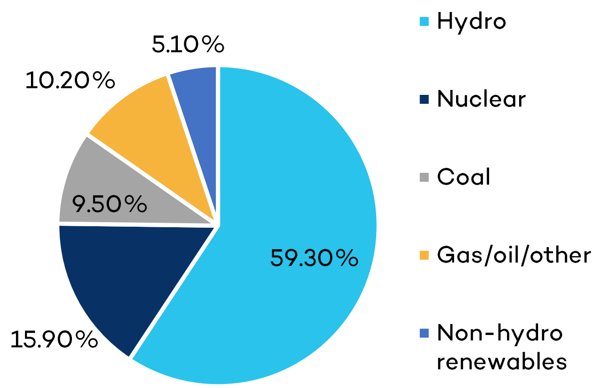

Figure 3. Canada's energy mix, 2014

Source: NRCan (2017)

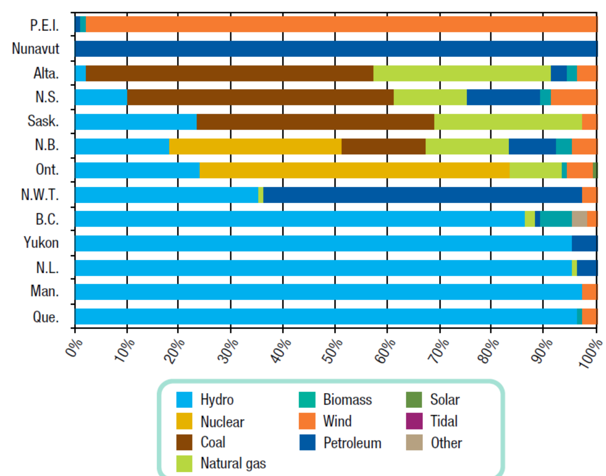

Figure 4. Electricity generation by province

Source: NRCan (2017)

With urban agglomeration, previously small towns are now becoming part of the urban sprawl (StatsCan, 2017). This urban growth dictates the electricity demand, where electricity generators and distributors need to address growing and changing demands, and make necessary adjustments in their business models, while still ensuring energy access to smaller rural communities.

In addition, as economic sectors are evolving, there is a high demand for advancements in the electricity sector to manage high volumes of electricity data. Much of this demand has been driven by cities, where the use of renewables and decentralized forms of energy generation have been implemented to support the supply of the ever-growing energy demand (CEA, 2013). This illustrates the perpetual change, where grid owners adapt and need to be agnostic about supply, increasing their capacity in integrating various forms of generation, enabling prosumers to access the grid, open work with external retailers, extend their customer services and support (e.g., microgrids), and, most importantly, improve grid efficiency and enhance reliability, resilience and safety (GridWise Alliance, 2014).

Taking a closer look at the trends in the current system, and with an understanding of how agglomeration is driving these trends, the following section provides insight on jurisdiction over electricity in Canada and how this is relevant to the opportunities for modernization examined later in the paper.

1.3 Jurisdiction Over Electricity in Canada

As owners of its energy resources, provinces and territories have jurisdiction over electricity, as legislated by the Constitution Act 1982. Depending on the jurisdiction, electricity generation, transmission and distribution are either privately controlled or publicly owned by provincial or municipal governments, with the majority of utility companies under public ownership. In recent history, the Canadian electricity industry has been composed of integrated companies that own the entire electricity value chain; however, some integrated companies are unbundling to accommodate wholesale competition. For example, in Newfoundland and Labrador, generation and transmission are owned by one company, while distribution and retail are owned by a separate entity; in Ontario and Alberta independent power producers are emerging (CEA, 2017).

Though electricity is under provincial/territory jurisdiction, responsibility for environmental stewardship, management, protection and assessment are shared by federal, provincial and territorial governments. In addition, electricity infrastructure projects fall under the review and approval of various national and subnational legislations and regulations. The regulation of provincial utilities falls under the responsibility of quasi-independent bodies, with the exception of Alberta and Ontario, which have independent regulating bodies (CEA, 2017).

The federal government also has a central coordination and convening role between different levels of government. The benefits of these responsibilities, when it comes to modernization of the electricity sector and deployment of, for example, smart grid solutions, should not be discounted.

1.4 Smart Grids

Smart grid technologies can support different policy objectives and impact utilization, but will play a central role in electricity sector modernization. The role of smart grids will especially be important in the context of above-described supply and demand pressures as well as prioritization of environmental and climate objectives.

How we define smart girds matters (Beaulieu, 2016). If the focus is on technological solutions, demand-side management can result in passive or reactive solutions, where the utility company applies a particular technology to control demand directly or change behaviour indirectly. However, if the focus is on social problems (i.e., energy access and poverty), more participatory approaches and bottom-up solutions are applied.

How governments have defined smart grids is also noteworthy. The U.S. Department of Energy (2017) defines smart grids as “the digital technology that allows for two-way communication between the utility and its customers, and the sensing along the transmission lines.” It refers to technologies that digitally interact with the electrical grid to adjust for changes in electricity demand. The European Commission (2017) defines smart grids as “energy networks that can automatically monitor energy flows and adjust to changes in energy supply and demand accordingly.” From a technical point of view, the Institute of Electrical and Electronics Engineers (2017), an international electrical standards body, defines the smart grid as “a next generation electrical power system that is typified by the increased use of information and communication technology (ICT) in the generation, delivery and consumption of electrical energy.”

When speaking about smart grid technologies, it is also important to understand their role in integrating renewable energy. One study notes that “in the US, the expectation is one of improvement, while in the European definition, integration is the aim. A focus on definitions can therefore orient us to particular ambitions and goals” (Beaulieu, 2016, p. 2). The goals of smart grid technology deployment depend on local politics and priorities. Nevertheless, this means that an increase in the use of ICT to manage grids, as opposed to traditional system management tools, is a common feature across the world.

In the Canadian context, a definition of smart grids should have elements of both modernization and integration of renewables to align with the challenges of agglomeration and climate change, and the policy requirements for a decarbonized energy grid. The Pan-Canadian Framework on Clean Growth and Climate Change specifically notes the role of smart grids in helping to "make better use of renewable energy, facilitate the integration of energy storage for renewables, and help expand renewable power capacity" (Government of Canada, 2016). The framework is the most recent policy document that should provide guidance on objectives that should be incorporated in definitions used by both provincial and federal levels of government in Canada going forward. Other priority areas for Canada may include consumer participation (including opportunities for prosumers, as well as basic information and communication improvements), decentralizing and modernizing an aging system, and improving resilience. Examples of the types of specific technologies and applications that are already in practice in Canada and would be covered under this type of definition are highlighted in Box 1.

Box 1. Examples of smart grid technologies

Examples of smart grid applications that can have a net positive impact (Navigant, 2015), and that can be prioritized in the Canadian context:

- **Advanced metering infrastructure** to detect overload and decrease duration of outages.
- **Automated voltage controls** to enhance voltage that can help to reduce usage with potential new demand sources (e.g., electrification of transportation).
- **Distributed Energy Resources Monitoring and Control** to improve reliability (especially in light of increased renewable generation) and demand response.
- **Energy storage** to minimize the impact of intermittent energy through hardware and software controls.
- Self-healing grids to automate the isolation and rerouting of power to areas where faults are detected, reducing downtime and costs.
- **Green Button** to access standardized electricity data which can support customers in making energy conservation and management decisions (see Box 2).
- **Microgrids** to integrate distributed generation and improve resiliency.

2.0 The Evolution of Electricty Systems

Canada has an aging infrastructure that is fast approaching the end of its life cycle (CEA, 2015). Much of Canada's energy infrastructure was built over half a century ago, with a second large investment in the 1980s. The 1980s investments supported a centralized model, establishing infrastructure far from cities and towns, a design used to exploit large hydro resources situated away from cities. Due to this design, most of Canada's transmission system is made up of a small number transmission lines that run at extremely high capacity over long geographical networks, connecting generation lines to consumers (CEA, 2012). However, recent changes have been implemented over the past decade resulting in a push for modernization and decentralization of the electrical grid, particularly for the distribution of electricity due to urban growth spurts through the agglomeration process (CBC News, 2011).

It is important to remember that these **major expansions and developments in the energy sector took place before widespread growth in understanding of issues like climate science** and prediction models. Increasing knoweldge in these areas have led to much greater understanding about the potential threats to resiliency and security that increased temperatures and increased instances of extreme weather events present to the Canadian electricity system. **In addition, these developments also took place before policy priorities to reduce and eliminate GHG emissions and fossil fuels**.

These dynamics, coupled with the growth of cities outlined in Section 1, drive a need for increased generation, increased efficiency, and new and upgraded technologies to distribute and manage this energy. To this end, with current urban population growths and increasing electricity dependence, **the need to modernize the electrical grid presents both challenges and opportunities for increasing reliability and resiliency to the grid, diversifying the electrical mix, and introducing technologies that will support low-carbon transition** and strengthening of the electrical grid.

2.1 The Evolution of Canada's Electricity System

The historical structure of the energy system is outlined in Section 1.2; however, **today's utility companies are moving outside "poles and wires" and demand-driven models**. Recent changes have been spurred by consumer needs and choices, climate change impacts, aging infrastructure, environmental regulations, advancements in technology and evolving economic sectors (Singh, Roy, Spiess, & Venkatesh, 2015). Based on these drivers, the changes have manifested throughout the entire electricity value chain: generation, distribution, usage and control. Distribution systems are shifting from purely centralized to more decentralized systems, shortening the distance between generation points and end-users in urban areas in particular. Supporting decentralization of the electrical across Canada is the number of microgrids emerging through the various feed-in tarrif (FIT) and microFIT programs. For example, Saskatchewan launched Net Metering and Small Power Producers Programs for renewable energy generation produced by consumers (SaskPower, 2017). Other provinces have launched similar programs that are not only decentralizing the system, but also giving rise to the prosumer (see Section 2.5 for more information).

This change has been led through diversification in the electricity mix, which is creating a more prominent space for renewables and modern technologies, such as smart meters, to meet the growing electricity demand and to manage responsive loads (CEA, 2015). This diversification also has an added resiliency benefit, providing enhanced redundancy and less reliance on single high-generation sources. Although these major sources will remain a key part of the network for the next several decades, they will increasingly be complemented by diversified and decentralized energy sources.

Between 2011 and 2013 the CEA Corporate Utility Members invested over CAD 22 billion on transmission and distribution infrastructure, each year with a significant investment increase from the year previous indicating their focus on modernization (CEA, 2015). **The shift in electricity generation and distribution is creating a more active space for municipalities to promote local generation and renewable energy**, where local policies (e.g., creating enabling regulatory environments) can foster favourable environments for prosumers and partnerships with utility companies (Singh et al., 2015). For example, Ontario has a dedicated Renewable Energy Facilitation Office and has developed a guide for municipalities across the province to develop renewable energy projects, both large and small scale (Ontario Ministry of Energy, 2017).

Despite these investments, much more is needed. In 2012 the Conference Board of Canada completed a study estimating that CAD 350 billion needs to be invested over the next 20 years (CEA, 2012, p. 3; CEA, 2013). CEA expects that, out of the CAD 350 billion, 20 per cent should be directed toward distribution infrastructure, while 13 per cent should be invested in transmission infrastructure, with the rest to generation (Hiscock, 2015, p. 12). Modernization with a focus on investments in smart grid technologies may amount to an estimated CAD 70 billion (Hiscock, 2015). **What this means is that the financing gap for smart grids is still very significant**. Looking at these large numbers it becomes clear that there is no one party (provincial governments, federal governments, private sector) that has the resources to meet these needs. Collaboration in financing smart grid investments will be key, with different levels of governments each having a role to play. **Like the jurisdictional issue, in financing, every party has a role to play, and efforts must be coordinated to ensure effective implementation of smart grid technologies**.

Meeting growing energy demand is one side of the multifaceted areas of concern. Climate change mitigation and adaption are other concerns to address. On the adaptation side, climate change impacts heighten the vulnerability throughout the (vastly aging) electrical grid and threaten its resiliency and reliability in an era of high electricity dependency (see sections 2.3 & 2.4). The impact of climate change mitigation policy articulated through Canada's national and international commitments is outlined in the next section.

2.2 The Impact of GHG Emissions Mitigation Policy on the Electricity System

Canada's electricity profile will change with the country's new mandate to phase out coal fired electricity emissions. An estimated 93 per cent, from its 2010 capacity, will be shut down by 2030 (CEA, 2016b). This creates a functional space for renewables to replace coal-fired electricity generation. Other climate and energy policies will also play a role in shaping Canada's electricity sector, including the implementation of pan-Canadian carbon pricing (which will affect the cost of coal and natural gas) and fossil fuel subsidy reforms like those outlined in Budget 2017 (Department of Finance, 2017). Subnationally, provinces are moving towards greater cooperation in clean growth, including the creation of Canadian Council on Renewable Electricity, the release of Canadian premiers' Canadian Energy Strategy and the signing of the Vancouver Declaration on clean growth and climate change (Clean Energy Canada, 2016). All of these events contribute to Canada's low-carbon future vision, especially when coupled with the provincial climate change and carbon pricing strategies that are being implemented across the country.

In addition, from the industry perspective, **in the past 10 years the electricity sector has already lowered its emissions, both in terms of absolute emissions and emissions intensity** (CEA, 2016b). Moreover, CEA notes that "Canada's electricity sector is aligned with [a low-carbon, climate-resilient development] approach. We are clean technology; we are green infrastructure; and we are green jobs" (CEA, 2016b, p. 2). This illustrates that a vast majority of electricity sector players are already aligned with the objectives of lowering emissions and increasing climate resiliency.

Pressures to reduce emissions will have the following impacts (among others) on the electricity sector over the next decade:

- The coal phase-out will lead to increased renewables in the grid, as well as a shift to natural gas.
- Increased cost of fossil fuel energy sources that remain post-coal (e.g., natural gas, diesel in the North) will lead to increased pressure for renewables and energy efficiency, and will also lead to increased focus on ensuring affordable energy access, especially in the North where electricity rates are already far higher than in the rest of Canada.
- Fossil fuel subsidy reforms will have dual impacts, increasing the price of fossil fuels (accelerating conversation mentioned directly above, but also opening up fiscal space for investment in efficiency and renewable technologies), while also levelling the competitiveness playing field for the debate between renewables and fossil fuel energy sources.
- In addition, the high-profile focus on climate change impacts and the need to reduce emissions, coupled with increased energy prices, will lead to consumers demanding increased accountability from their utilities on these issues, as well as increased ability to understand and change their own energy usage profiles to reduce emissions or reduce their energy cost.

2.3 Extreme Weather Events and Grid Resiliency

Extreme weather events are one of the main factors in electricity disruption. **Events that used to happen every 40 years are now occurring every six years**, and are expected to become more frequent and intense in the future (CEA, 2016a). Increasing grid resiliency is paramount to secure many essential services to cities as well as to support reliability in electricity generation, transmission and distribution (CEA, 2015). For example, in December 2013, an ice storm in Toronto left approximately 300,000 customers without power (CEA, 2015), while an ice storm in Quebec in 1998 still stands as a major example of the damage that can occur, leaving almost 1.5 million people without power (*The Ottawa Citizen*, 2016). To enable a proactive approach toward increasing infrastructure resilience, policy may move toward greater innovation (see Section 5).

Utilities are already attuned to the need to enhance reliability and energy security. They are building their own projection models and increasing resiliency of their electricity networks. This is one area where there is already a strong investment in smart grid technologies, but where increased vigilance is required to ensure security of supply.

2.4 Gradual Climate Change Challenges to Grid Resiliency

When looking at Canada's present and future electricity generation, it is important to consider climate change impacts that can affect production, supply and consumption. Climate change models project changes in both annual and seasonal averages, as well as changes in variability (CEA, 2016a). **Warmer days, precipitation extremes and drought are climate hazards that present major challenges to infrastructure, particularly for hydropower generation**, which is not only vulnerable to impacts to its infrastructure, but also vulnerable to reduced water availability (Fields et al., 2014).

The CEA released an adaptation to climate change paper in 2016, which focused on the impacts of climate change on the electricity sector's value chain. On electricity demand, increased numbers of hot days may result in a higher demand in electricity for cooling, particularly during summer months. **The heat island effect from densely populated cities will drive this demand even higher (CEA, 2016a), despite efforts such as urban forestry to mitigate some impacts**. Higher temperatures could actually change the dynamics of power demand to such an extent that it changes power peaking patterns from winter to summer demand peaks in cold climates such as Manitoba. This shift can have substantial impacts, especially if the fuels for heating (i.e., natural gas) differ from the fuels for cooling (e.g., electricity).

Increases in air and water temperatures may limit various forms of thermal (coal, oil and gas) energy generation due to changes in ambient and combustion temperatures. Nuclear generation may also be affected due to reduction in thermal efficiency (CEA, 2016a), an assertion that is also backed by European studies indicating that a 1 per cent rise in ambient air temperature can reduce nuclear power output by 0.5 per cent (Linnerud, Mideksa, & Eskeland, 2011). In periods of drought and heat waves, this loss can exceed 2 per cent (Linnerud et al., 2011).[1] These losses are driven by physical laws, environmental regulations and reduced access to water.

Lower water availability can lead to infrastructural changes in hydropower plants as environmental licences are based on historical water levels. As **a cross-sectoral resource, reduced water availability can negatively affect energy resource extraction, power plant cooling and operation** (noted above). This may call for water diversion from a greater distance, potentially needing electricity to operate necessary machinery and tools (CEA, 2016a).

For electricity transmission, distribution and infrastructure, increases in temperatures can reduce transmission and distribution efficiency, including de-rating or failure for air cooled transformers. Moreover, distribution systems can be overstressed through increased electricity demand during heatwaves. **To mitigate stressed distribution systems, distributors, system planners and operators will need to monitor energy demand in real time, increasing system redundancy and revising maintenance and component replacement strategies** (CEA, 2016a).

All these climate change hazards increase vulnerability in existing infrastructure. It is clear that **the coming decades will have to focus on risk assessments and preventative measures that can be taken to build resiliency** in power generation, distribution and consumption. The ever-growing electricity demand requires that these solutions be long-lasting and forward-looking, particularly as infrastructure has a life cycle of at least 30 years. With expected climate change driven impacts, usage of historic data will not suffice to ensure grid resiliency and reliability. It is imperative to study how climate change is affecting the electricity sector, both generally and provincial/territory specific, and what impacts it will have in the future.

2.5 Responses to Grid Resiliency and Reliability Challenges

Taking into consideration some of the challenges presented above, responses are already emerging to minimize power insecurity. Below are three examples of current responses in Canada that are part of the drivers in grid changes, including the use of renewables and decentralizing power generation.

2.5.1 Community Energy Plans

Cities are taking meaningful steps toward reducing their vulnerability to electrical black outs through a proactive approach in designing Community Energy Plans (CEPs). Municipalities are playing a more active role in introducing renewable energy into the urban electrical mix through new cost-effective technologies and incentives for residents to become prosumers (Singh et al., 2015). There are many actors supporting CEPs; one of the main supporters is the Federation of Canadian Municipalities (FCM), whose support is financed through the federal Gas Tax Fund (Infrastructure Canada, 2016). FCM support includes funds for retrofits and new construction that aims to increase energy efficiency and reduce municipal facilities and residential energy use by 30 per cent and 10 per cent, respectively. Other types of projects include energy recovery or district energy using thermal energy from residual or renewable sources to reduce energy consumption by 40 per cent for one or more existing facilities within three years of implementation (FCM, 2017). Moreover, as part of the community projects, FCM requires that a

[1] In thermal and nuclear stations the need for water cooling may rise as air and water temperatures increase. If the need for greater water discharges grows, these may be restricted by regulations in terms of the water use and discharge, which could jeopardize the plant's existence (CEA, 2016a).

large portion of the community members are engaged and "seek maximum energy reduction at a reasonable cost" (FCM, 2017).

To-date over 200 communities across Canada, representing more than 50 per cent of the Canadian population, have CEPs (Community Energy Association et al., 2016), and have changed the dynamics of electricity generation, distribution and usage. Though these municipalities have CEPs, the degree of implementation varies, with 43 per cent having more than 75 per cent of their actions implemented, 30 per cent with only 25–50 per cent of their actions implemented and 27 per cent of the municipalities with less than 25 per cent of their actions implemented (2015 figures) (Quality Urban Energy Systems of Tomorrow [QUEST], 2015).[2] Figure 5 illustrates the locations of these communities across the country.

Municipalities, real estate developers and consumers become essential in the energy planning for cities (Singh et al., 2015). One of the provinces with a significant number of CEPs is Ontario, with Toronto as one of these communities. According to Toronto Hydro, toward the end of 2015, 834 microFIT interconnections (each under 10kW capacity) were installed. This totals more than 5.1 MW of generation. During the same period, Toronto Hydro enabled a total of 377 FIT interconnections (each greater than 10kW capacity) totalling more than 59.5 MW of generation (City of Toronto, 2015). In ideal circumstances this would be enough power for roughly 70,000 Canadian homes (Evans, 2011).

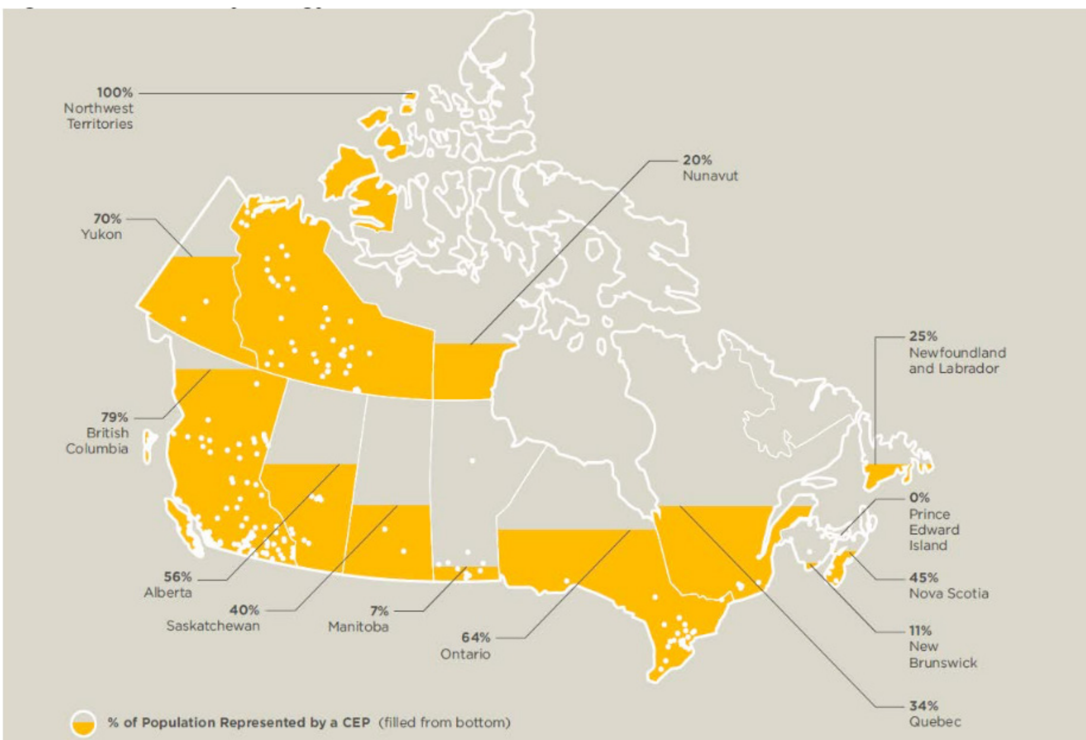

Figure 5. Community energy plans across Canada, 2015

Source: Community Energy Planning: Getting to Implementation in Canada initiative (2017)

[2] The main actions being implemented include solid waste diversion and landfill gas, energy efficiency in existing buildings, and planning and policy measures (QUEST, 2015). For information on CEPs' implementation stages see QUEST's Smart Energy Atlas of Canada at http://www.questcanada.org/hub/atlas

CEPs feed into communities' sustainable development through environmental, social and economic benefits. Environmentally, CEPs help communities mitigate climate change by reducing GHG emissions and improving air and water quality. Economically, they provide communities with energy security, new revenue streams, lower energy costs, job creation and local economy stimulation. By working together, communities strengthen their social ties, improve their livability and create healthier communities (Rizi, 2012). Moreover, under the 2016 *Pre-Budget Submission to The House Of Commons Standing Committee On Finance*, CEPs are noted to be instrumental to meeting Canada's climate change commitment (Community Energy Association et al., 2016).

On the social spectrum, the intrinsic relationship between human and natural environment will play a vital role within urban energy planning, where CEPs become instrumental. IISD's study of Ontario's coal phase-out found that public health and climate change concerns were the primary drivers for this fundamental shift in the provincial electricity system (Harris, Beck, & Gerasimchuk, 2015). With ever-growing urban centres, the trends in urban design have focused on compact and modular spaces, such as in Toronto, where high rises are becoming the preferred design, and this trend will continue in the future (Singh et al., 2015).

As a way to integrate sustainability in the planning process, in particular in mega cities, efficiency in land use, energy, water and materials are at the centre of reducing ecological footprint while addressing the needs of residents and businesses. More and more we are witnessing the use of small-scale renewable energy, the integration of net-zero designs in buildings, increasing efficiencies and minimized footprints through waste reduction, energy efficiency and demand-side management. In addition, there is a greater shift from large centralized power plants toward distributed electrical power systems, and the promotion and use of sustainable transportation (Singh et al., 2015). CEPs are one of the instruments used in sustainable planning and addressing a municipality's specific energy and sustainability needs. A challenge in CEPs is that IISD was not able to identify a comprehensive, publicly available database for examination, information sharing and collaboration across CEPs. This would be helpful to ensuring broader successes in implementation.

2.5.2 Brightfields

Large-scale renewable energy projects require a significant amount of land—a commodity that is already scarce in cities. Brownfields, previously developed land that is underused or abandoned due to contamination, have the potential to be reused for renewable energy projects. These lands include vacant lands, closed landfills, ex-military sites and abandoned commercial areas such as parking lots and gas stations (Singh et al., 2015). By using existing infrastructure, such as roads and energy grids, this land could be turned towards energy generation and provide a cost-effective way to not only reuse land, but also to locate renewable energy closer to urban centres (Singh et al., 2015). This redevelopment of brownfields is known as brightfields. As noted by Singh et al. (2015), some of the benefits in converting brownfields into brightfields include:

- Remediation of contaminated site and protection of public health and safety
- Renewable energy generation and reduction of GHG emissions
- Neighbourhood renewal and revitalization
- Disappearance of eyesore, nuisance and blight, and elimination of social stigma
- Leveraging of existing infrastructure and restoration of tax base
- Reduction of development pressure on greenfield sites

In general, by placing generation physically closer to consumption of energy, brightfields reduce transmission costs and risks.

Despite several benefits, there are also challenges in using brownfields, primarily the contamination in the area. This creates further challenges in technical feasibility, and financial, regulatory and social implications (Singh et al., 2015). Competing uses are also among the challenges, where landowners may not want to lock the use of their land for 20 years and miss out on other development opportunities. The latter may be easier to address if the land is owned by the municipality (Singh et al., 2015). By creating an inventory of brownfields, noting which brownfields are privately and publicly owned, municipalities may be able to easily identify viable lands to use for renewable energy sites or brightfields. Under the FCM's support toward CEPs, funding is provided to standalone renewable energy projects that are implemented in brownfields sites, under FCM's brownfields capital project funding window (FCM, 2017).

2.5.3 Reliability Standards

There are North America-wide reliability standards specific to the bulk electricity transmission system. These standards, which are mandatory and enforceable across jurisdictions, provide a level of uniformity in energy trade despite the different entities and private/public sector utility models across borders. The North American Electric Reliability Corporation (NERC) is the regulatory authority with the mission to assure reliability across the North American electricity system (NERC, 2017a, 2017b).

To strengthen reliability by harmonizing standards, the NERC monitors the power system and develops and enforces standards, acting across Canada and the United States (and Baja California, Mexico). Oversight to the NERC is provided by the Federal Energy Regulatory Commission in the United States; in Canada it is provided by the National Energy Board and individual provincial governments, recognizing the decentralized electricity sector mandate in Canada (NERC, 2017a, 2017b).

These are only three examples of current responses across Canada. Given that each utility and government in Canada has its own responses, an opportunity exists to increase sharing and collection of this type of information to support investments and decision making by learning from best practices and lessons learned.

2.6 Renewables: Current Capacity and a Low-Carbon Pathway

Most of the renewable energy generated in Canada comes from hydropower; British Columbia, Manitoba, Quebec and Newfoundland and Labrador are among the leading producers (CEA, 2012). Through the decreasing costs and improved reliability in solar and wind technologies, their penetration into the energy mix has been increasing in the past few years (Bataille, Sawyer, & Melton, 2015).

The use of distributed electrical power is improving electrical efficiency and grid resilience, and lowering GHG emissions. Solar power has been on the rise in recent years, primarily driven by FIT contracts, renewable energy standards, environmentally friendly consumers and reduction in costs (CEA, 2015). Figure 6 demonstrates the levelized cost of solar power compared to other energy sources since 2000. What this indicates is that **renewables are already achieving parity with other energy sources in many cases**. Based on the International Energy Agency's (IEA) *2016 Energy Outlook*, globally, **solar photovoltaic (PV) is projected to have an eleven-fold increase by 2040 relative to 2014 levels**. Together with wind, solar PV accounts for one third of global growth in power generation, accounting for 15 per cent of power generation across the globe (IEA, 2016).

At the end of 2015, Canada's solar capacity was estimated at 2,517 MW of installed capacity across the country, a 37 per cent increase from 2014, estimated at 1,837 MW (NRCan, 2017). Overall, in the past five years Canada has experienced a gradual upward growth in its clean energy capacity, with wind, solar and biomass as the largest non-hydro increases since 2011 (Clean Energy Canada, 2016).

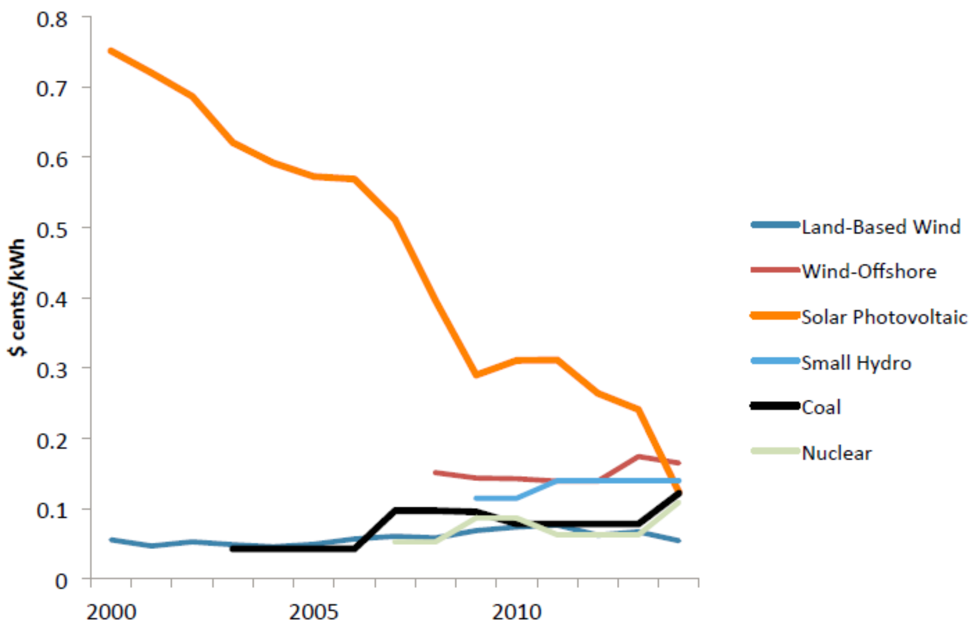

Figure 6. Levelized cost of energy (world average)

Source: World Economic Forum (2016, p. 6)

Many cities are supporting the use of solar energy on rooftops, as well as the use of community energy co-ops, which are strengthening the distributed generation model (Singh et al., 2015). It has a higher consumer uptake due to its manageable integration into building structure with a life span of 25 or more years requiring little maintenance. The uptake has increased based on public incentives, such as FIT programs, for example Toronto Hydro's FIT programs (Toronto Hydro, 2017) and Manitoba Hydro's Solar Energy Program (Manitoba Hydro, 2017b).[3]

With the emergence of microgrids across Canada, particularly in urban centres, there are opportunities for utility companies to connect with existing infrastructure, but also provide utility companies two-way services: reduce peak loads and outage impacts (GridWise Alliance, 2014). Moreover, it further illustrates the need to modernize the grid to improve information exchange between transmission and distribution systems in real time, necessitating greater coordination between these systems through the development of standard data structures and adequate storage for the information flowing throughout the value chain (GridWise Alliance, 2014). More specifically, **the more complex the grid becomes, the greater the need to have in place "self-learning systems, balancing systems (on supply-side and load-side) and coordination of the information they provide**" (GridWise Alliance, 2014, p. 9).

There are some projections of what Canada's electricity future will look like, particularly in light of carbon pricing. Coming back to the aforementioned IEA (2016) statistic, imagine the impact that an eleven-fold increase in solar power would have in Canada by 2020—essentially growing from roughly 2,500 MW to 28,000 MW (almost the equivalent of all of the coal and natural gas generation **combined** in 2014) (CEA, n.d.). This is a speculative global estimate, but it does highlight the massive changes that the Canadian electricity grid will experience over the next 30 years.

[3] Not all FIT programs are designed equally or intended to be economically competitive. For example, Manitoba Hydro's solar energy program is a pilot project, and based on its current measures the program is not cost competitive with other sources of energy in Manitoba.

More conservatively, and more directly applicable to Canada, **the National Energy Board (NEB) projects that by 2040 there will be an increased capacity from wind, solar and biomass of 17 GW combined** (NEB, 2016), a figure higher than all nuclear generation capacity on the Canadian grid as of 2014 (CEA, n.d.). Natural gas is expected to have an estimated 17 GW of increased capacity by 2040 (NEB, 2016). Figures 7 and 8 illustrate the NEB's projections in biomass, wind and solar power generation.

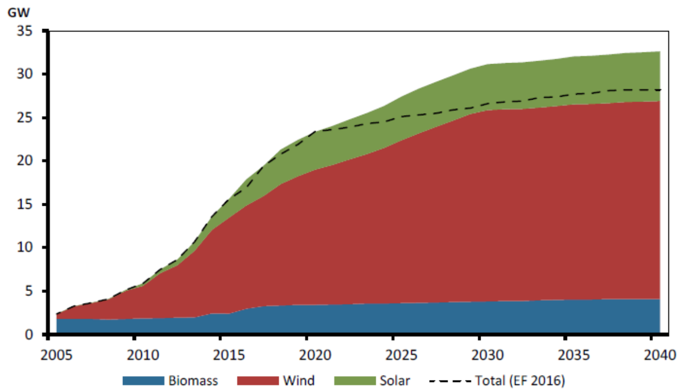

Figure 7. Projections in biomass, wind and solar power generation to 2040

NEB (2016, p. 30)

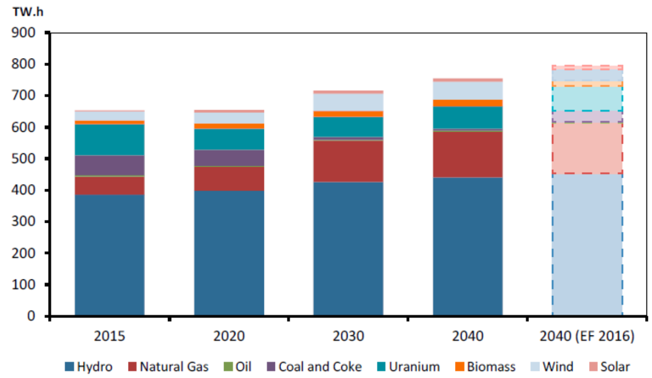

Figure 8. Generation by fuel, projections to 2040*

** EF in the figure means energy forecast.*
Source: NEB, 2016 p. 30

These trends and figures indicate that **the shift to lower-carbon energy sources is already well underway and will shape the growth of energy supply to meet increasing demand, particularly from urban centres. The pressing challenge for utilities, provinces/territories, and the federal government is managing this transition, ensuring it is done in a way that efficiently integrates these new sources of energy that does not compromise security of supply, access to affordable energy (i.e., avoiding energy poverty) or the environmental goals of energy transition**. The transition must also accommodate the desires of consumers for more accountability, flexibility and responsiveness from their utilities. The following section looks at emergent business models responding to this transition.

2.7 Business Models

The evolution of the electricity sector, including changing dynamics from centralized to decentralized value chains, the rise of renewables into the energy mix and the introduction of modern technology, moves business toward more customer-service centric models. In addition, consumers are playing a more active role through choice and control over their energy use. This new market dynamic is enabling alternative models, and affects the operational complexity within the electricity sector (GridWise Alliance, 2014). Development of energy resources is primarily a provincial jurisdiction, although this differs greatly across provinces with everything from publicly owned Crown corporations that are subject to direct oversight and reviews to more private markets that are still subject to regulatory oversight and reviews on elements such as electricity rates. We note four emerging business models in the smart grid-enabled electricity systems:

- **Energy Service Provider:** This model provides power and heat from renewable electricity to homes. It does not suggest replacement of, for example, natural gas furnaces, but rather provides flexibility that is acknowledged at the home level.
- **Customer Energy Marketplace:** This model changes the consumer relationship from a one-dimensional business-to-customer low-cost, reliable energy provision toward a partnership model. This business model is rooted in two-way generation distribution and demand. The intent is to provide two-way flows of power and grid services to and from the customer.

- **Local Balancing Authority:** This model moves away from simply the bulk power system level. At the distribution level, utilities will operate "virtual power plants" or in some cases even microgrids (which can island to provide backup power during outages) embedded within the city to balance supply and demand using aggregated distributed energy resources (demand response, distributed generation and storage).
- **Smart City:** This model integrates energy systems. Heat, power, transportation and water all are able to balance energy supply and demand needs through integrated systems and markets. It includes more efficient systems and greater flexibility.

It is critical to note that there is no emergent "winner" future business model. They are each evolving differently in different jurisdictions across Canada. For example, in provinces with large-scale renewable resources and single public sector utilities, such as Manitoba and Quebec, the large-scale model has emerged dominant. Ontario undertook a major initiative to support local energy provisions, and governments and a large number of utilities have provided models for potential for flexibility and optimization of efficiency (e.g., the Green Button program).

In the North, where the climate is harsh and energy prices are in some cases a factor of 10 higher than they are in southern Canada (electricity in Montreal and Winnipeg is 7–8 cents per kWh (Manitoba Hydro, 2017a); in Nunavut the pre-subsidy rate ranges between 60 cents per kWh [Qualliq Energy Corporation, 2017] to over 1 dollar per kWh) the foremost issue is how to provide energy access to residents above all else, and ensure efficiency, given the high cost of fuels. It is important to note that while there are some issues that can be addressed nationally, and a national vision on smart grids is required, there is no unified business model, and approaches to smart grids will mean very different things in regions across the country.

While there is no emergent "dominant" model at this point, these models will guide how utilities evolve, and this can differ across jurisdictions as priorities differ across cities, provinces and utilities. The overall trend in energy systems and business models has been to focus on integration of new technologies that increase reliability and efficiency, incorporate new energy sources, and focus on greater service and interaction for consumers. There are several opportunities for greater integration of smart grids, but also some associated risks, examined in the next section.

3.0 Smart Grids

This report so far has explored the current state of Canada's electric power system. It is undergoing a modernization process, moving toward the integration of smart grid technology to address challenges arising from agglomeration trends and climate change, while seizing opportunities to reduce emissions and improve energy production, consumption and efficiency. Based on IISD's interviews, industry's question is not whether a change should include greater integration of renewables and grid decentralization, but how best to carry out this change, where smart grid technologies are part of the answer.

Many of the policy levers related to electricity production and distribution are at the subnational level in Canada. Provincial efforts on smart grids have varied across the country and may include (Hiscock, 2015, p. 8–11):

- **British Columbia:** Microgrids, reliability and electric vehicle integration.
- **Alberta:** Integrating renewable generation, which will likely continue to be a priority given the province's rapid phase-out of emissions from coal-fired electricity facilities (currently highest in Canada) combined with mandates for renewable energy.
- **New Brunswick:** Low energy prices, reliability, supporting regional efforts in integrating renewable generation.
- **Nova Scotia:** Integrating wind power and enabling customer participation.
- **Ontario:** Enabling consumer participation and performance improvements, and capitalizing on commercial opportunities.
- **Saskatchewan:** Provincial efforts have been reversed since eight meters caught fire. Given the provincial utility companies renewable energy targets, smart grids will likely be necessary going forward.

Box 2. The Ontario Green Button Program

Green Button is designed to provide users with the access to information required to make these shifts (i.e. electricity use data), while respecting privacy.

The 2012 introduction of the Green Button Program in Ontario was an effort to take advantage of modern technologies to allow energy users to take more control of their energy use. The goal is to take advantage of the shift to "smart home" technologies that will manage energy based on consumer preferences.

As an example, users could identify when they are using energy most across the day, and in cases with time of use pricing, could adapt their practices to see exactly the impact that these changes have on their energy bills.

Green Button Download My Data (DMD) allows users to download their energy data by clicking a button on their utility's website.

Despite early adopters in smart grid technologies, the uptake is still in its early stages. To identify solutions to support the electricity industry to test and adopt smart grid technologies, it is important to identify the current barriers and risks inhibiting industry from taking a greater leap. The following section starts by looking at some of the barriers to smart grids with suggested responses. Following that is a look at opportunities for achieving policy objectives and building the business case for smart grids.

3.1 Risks and Barriers

Smart grid technology is still in its infancy, and as it is with any emerging technologies, there are barriers to buy-in, investment and deployment of smart grid technologies. While technology-related risks can be overcome, the principle challenge will be cultural and financial obstacles. Below are some of these barriers with suggested responses.

Table 1. Barriers and risks to smart grid deployment

Barrier	Response
Technical	
Complexity: Smart grids promise to automate the management of generators and consumers offering greater sophistication but also greater complexity. This complexity creates new risks. For example, an ICT-driven system now relies not only on the performance of the electricity grid but also on the telecommunications networks to communicate supply and demand data in real time. Until the technology matures, control algorithms and systems may prove to be unstable under certain circumstances, potentially leading to unexpected system failures (Navigant, 2015). The technical risks to the system create a barrier to adoption as regulators and operators struggle to identify and mitigate the risks of these new technologies.	Standards and practices have to be put in place to ensure reliability of communications tools and networks. New technology will have to be subject to rigorous testing. Best practice sharing and communication across utilities can provide better lessons for technology implementation, help optimize further testing and accelerate technology maturity.
Cyber/Privacy Security: Building ICTs into the electricity system and using signals from users to inform system operations also opens up the system to the possibility of nefarious activities. Hackers could attempt to bring down the system for political reasons or criminals could attempt to manipulate the power market for financial advantage. This can create significant privacy, security, and reliability risk that can act as barriers to achieving buy-in. Even just one incident of compromization of cyber security can set buy-in back significantly.	Strict regulatory controls about the use and protection of information have to be established and enforced in line with the requirements of the Federal Energy Regulatory Commission. Training and capacity building on cyber security threats should be promoted for utilities. This includes for all staff, as attacks like phishing schemes can target areas of weakness. Upgrading legacy systems has to occur at rapid rates, increasing sufficient monitoring and detection of threats (National Cybersecurity Institute, 2016). Development, rehearsal and implementation of incident response plans (Idaho National Laboratory, 2016). Utilities need to think long term about security strategy and incorporate continued improvement (Wall Street Journal, 2015). Increased intelligence sharing between governments and utilities about potential threats.
Industry Cautiousness: The above risks can also lead to excess caution in adoption of new technologies. Utility companies may approach the adoption of these technologies with caution and may limit their installation and usage within their existing infrastructure.*	Promoting information and best-practice sharing across utilities and governments. Requirements for development of public-facing results documents as part of government-funded research initiatives. Support for innovation by governments, in terms of funding, public communication and generation of a culture of innovation can help de-risk activities for utilities that may be afraid of failure in terms of technology development and testing.

* This sentiment was backed up by our interviews, as companies are picking specific approaches to focus on, and looking to how other utilities are testing/piloting alternative options.

Barrier	Response
Standards: To integrate distributed control systems which may be owned and operated by a range of actors requires technical standards to allow communication between systems. To support this there are a raft of protocols and standards that are in development and subject to revision (Habash et al., 2013), but have not yet been adopted.	The standardization of protocols will eventually enable interoperability between the different vendors and higher adoption rates.
Intermittent Power: When considering the current and projected growth of renewable energy in Canada, increased renewable electricity generation could result in intermittent power that, when coupled with demand from new sources, will require automated response across the system to ensure system reliability.	Intelligent integration of resources across a larger network and enhanced load management will be critical in developing the electricity infrastructure of the future.
Proprietary Concerns: The use of proprietary communication protocols threatens to limit the communication between systems and the applications of the technology (Navigant, 2015).	Installation of requirements through regulation for communications across systems.
Increased Demand/Consumption Risks: Increased electrification demand from new sources (e.g., electrification of the transport sector), as well as intermittency from prosumers have the risk to lead to instability or generation gaps and increased power peaking.	Improved data can enhance demand management, providing tools that can address demand risks from new sources and from production. On the latter, smart grids can provide intelligent systems feedback necessary to address fluctuations from non-baseload and microgeneration.
Financial and regulatory	
Lack of Human Capital: In addition, utility companies will need to invest in human capital with different sets of skills than previously utilized. Smart grid technologies require professionals within the areas of IT, advanced control systems, and data analytics. Without these professionals, the benefits of smart grid technologies will not be fully realized. Medium and small distributors might have a greater challenge than larger ones as allocation of resources will conflict with other high-priority projects (such as replacing aging infrastructure), or may not have the available finances to expand their workforce (Navigant, 2015).	Supports for training and education in fields related to smart grid technologies; this includes educational programming for existing staff, as well as training programs for new workforce members. Collaborations between utilities, associations and governments for international training opportunities (e.g., conferences and exchange programs).
Financial Constraints: Utilities are obtaining financial capital from deferred earnings, such as municipal and provincial shareholders, that choose to reinvest dividends in the sector rather than to collect them. Though positive in terms of allocating investment capital, there is a limit on how much utility companies and the sector can grow through these means (Navigant, 2015). Additional financial sources will be necessary to properly invest in grid modernization (Navigant, 2015).	The advent of carbon pricing opens up a revenue source for development and implementation of smart grids. This is particularly applicable as sales of traditional energy/electricity sources (coal/natural gas) will be one of the primary sources of carbon pricing revenue. Reforms of subsidies for traditional infrastructure (e.g. fossil fuel subsidies) can open up fiscal space to support. Pricing models under current regulatory measures will need to evolve along with the shifts in distributors' business models toward the provision of multiple services such as demand response, energy storage, and distributed energy resources, to name a few (Navigant, 2015).

Barrier	Response
Regulatory Frameworks: For example, in Ontario the Ontario Energy Board categorizes smart grid investments as traditional infrastructure investments. This presents complications to the utility companies as they develop their business case for investments given that grid modernization is complex, particularly in the lack of understanding in benefits and risks associated in smart grid investments (Navigant, 2015). Given this limitation, lack of understanding may favour leaning toward better-understood traditional infrastructures investments, where financial approval may be easier to obtain (Navigant, 2015).	Regulatory reviews can incorporate "green tape" assessments, looking specifically at regulatory barriers to smart grid or other green, renewable or low-carbon technologies, or even just areas where regulations can be revised to be more supportive of smart grid implementation.
Cultural barriers	
Technology Infancy: The relative infancy of smart grid technology, lack of sharing lessons learned, and risk-averse behaviour can limit the large-scale adoption of smart grid technologies in Canada.	On the other hand, there is a small but committed group of early adopters that could be motivated to be a "leading wave" for these technologies, working with utilities and policy-makers. A smart grid community of practice on lessons learned and best practices is not well established in Canada, but could be greatly beneficial to motivation and culture change. The International Smart Grid Action Network is already looking at developing such communities and could be a source of information (Clean Energy Ministerial, 2017).
Fear of Failure: Utility companies may not wish to share confidential information due to market competition and fear of being discredited due to failed initiatives. This lack of sharing information creates a barrier toward faster adoption rates in grid modernization.	Communities of practice can help break down these barriers. Requiring cross-sectoral, cross-utility and cross-jurisdictional collaboration as part of government-funded research is also a tool to promote collaboration, as is public reporting requirements for research projects.
Risk Aversion: Risk-averse behaviour can further limit the appetite to invest in smart grid technology when both utility companies and its shareholders (municipalities and provincial governments) jealously guard secure, reliable energy generation and distribution, as well as seek low-risk investments (Navigant, 2015).	The electricity sector, through the need to increase reliability and resiliency, needs to test out solutions (technological, response, risk reduction and contingency strategies) to better adapt to anticipated and unanticipated challenges from climate change. As the CEA notes, needs will be different across Canada, and it will be necessary to identify what are the adequate solutions for climate modelling and system vulnerability analysis (CEA, 2015).
Inward Schematics: The current trend in updating the grid has been a provincial approach creating inward schematics and promoting self-sustaining and sufficient electricity supply to own customers (CEA, 2012).	Taking a broader approach to syncing and modernizing the electrical grid will require a cross-jurisdictional approach, putting in place long-term contracts for energy generation. Moreover, lessons should be learned from previous contractual agreements between provinces, such as Newfoundland and Labrador and Quebec on their electricity trading, as well as the Maritime Link between Newfoundland and Labrador and Nova Scotia and contract sales between Canadian utilities and U.S. states.

Despite the risks and barriers identified above, modernizing the electricity sector by integrating smart grids will be critical in enhancing grid resilience, especially in the context of a changing climate and with the foresight of climate policy objectives. The suggested responses can help mitigate some of these barriers and risks.

3.2 The Business Case

Though barriers and risks exists, there is a business case to be made for smart grid technologies. For starters, despite high upfront costs to many smart grid technologies, some policy mechanisms are available to help overcome this and other barriers for integration of smart grids. As the responses indicate above, all of the potential risks come with mitigation options.

The business case for smart grid technologies is already present and is steadily improving as technologies mature. Fundamentally, **smart grids can reduce the cost of electricity production, consumption and distribution by identifying and reducing wasteful consumption; matching demand and supply to reduce the costs of dealing with short term peaks; operating electricity networks to minimize transmission and distribution losses; and pooling demand to match availability of resources and operate generators closer to their maximum efficiencies. In addition, they can provide information back to consumers, which can result in behavioural changes that reduce energy costs.**

Starting in 2012, Canada, and Ontario in particular initiated major policy initiatives that have supported rapid growth in smart grids. The business case is further enhanced by policy signals and market conditions. The underlying emerging domestic and international trend is climate policy.

On the economics and environment argument, smart grids will be instrumental in the energy transition toward meeting national and international climate and energy commitments. However, to fully function, the appropriate policy incentives need to be in place to enable stakeholders (producers, distributors, end-users) to adopt the use of smart grid technologies (Rutter & Keirstead, 2012). Integration of renewable sources into the energy supply is opening the way for cities to not only become consumers of clean energy, but also producers to improve energy reliance, create job opportunities and reduce energy costs (Singh et al., 2015). **Smart grids, by the way of their design in responding to changes to variable generation and demand, can contribute to better integration of renewables into the energy mix**. They can also increase energy efficiency by providing better information to consumers, maximizing usage of existing assets by rerouting energy from where it is available to where it is needed. In the process, they can reduce energy costs.

The Pan-Canadian Framework, coupled with Canada's international climate commitments, provide clear policy signals that will require further decarbonization of the electricity system. Although some provinces benefit from access to large-scale hydro electricity generation, rapidly decreasing costs of wind and solar generation will stand to compete with the existing business models that have incentivized large-scale centralized generation. Not all provinces have hydro resources and will have to shift to distributed renewable generation. With the right market conditions, consumers may also demand enabling policies and technologies in order to benefit from electricity generation. Appropriate smart grid investment can enable increased renewable penetration, prosumers and achieving climate objectives.

Electricity infrastructures, and related smart grid investment decisions, can have a lock-in impact. It can either enable or hinder longer-term policy objectives. **Appropriate decisions over the next 5–10 years will have a direct impact on Canada's longer-term climate objectives for decades, including mid-century goals.**

Smart grid deployment will be critical in achieving climate objectives. Despite the higher initial capital costs, smart grids are longer-term investments with benefits that can be quickly realized. For example, in Ontario, "Navigant estimates that the cumulative investment from 2005 through 2045 will be [CAD] $12.0 billion" with costs peaking between 2022 and 2023 (Navigant, 2015, p. 30). At the same time, Navigant estimates that benefits will significantly offsets costs, with benefits (mainly reliability and economic) expected to rise to CAD 1.5 billion per year by 2045. Distribution will take on the highest costs, which are expected to be only partially offset. The benefits will be primarily for generation and consumers. Navigant estimates that the net benefit of investment in smart grid could reach CAD 6.3 billion by 2045, through enhanced deployment through 2035 (Navigant, 2015).

Finally, Canadian leadership on smart grids can unlock demand for smart grid technologies and provide export opportunities for Canadian technology innovators. It can create domestic opportunities through asset investments that translate into skilled labour jobs. It can also help to reduce energy costs over the longer term and/or provide a new source of income, which increases free capital that can be invested in other sectors of the economy.

3.3 Opportunities for Canada

While a centralized energy system, structured around major investments like the Maritime Link, will continue to be a fixture in the energy system for decades, **Canada's energy system is rapidly evolving into one that is much more decentralized than it has been in the past**. Movement within the sector with a greater focus on the generation of energy that is consistent with environmental goals as well as economic (i.e., low-cost energy) and social (i.e., provision of energy access) goals will be critical. With these two parallel shifts, the following looks at how the current structure and data holdings of the sector can be strengthened. We also look at roles of local, subnational, national and international governments in enhancing decentralized generation of low-carbon energy, as well as leveraging technologies to reduce the cost and enhance reliability of this energy.

Across utilities, there is a deep knowledge of different aspects of the electric energy system, particularly in the area of reliability and security. This research has found that utilities have prioritized understanding of technologies and processes that can enhance reliability and security of energy for clients, given that access to energy is the primary concern for utilities and their ratepayers. Data records are deep and utilities have a great understanding of demand, consumption and provision of electricity to customers. **One of the attractions of smart grid technology for utilities is the enhanced collection and storage of reliability data that these technologies offer.** This appears to be a consistent motivation for adopting and implementing smart grids for utilities.

In the area of low-carbon technology, and the opportunities that smart grid technologies present for the provision of low-carbon electricity, this appears to be a more piecemeal approach. **Utilities are interested in these technologies, but it can be difficult to make the economic case for their adoption if conventional energy sources (e.g., natural gas) present more economical sense for electricity provision for customers**. This is understandable: it is difficult to make the case for research into solar, wind and geothermal power if natural gas and large-scale hydroelectricity provide energy to ratepayers at a lower cost. The result has been a system where individual utilities have dabbled in renewable energy, but only in cases where it makes economic sense in the short term, or, for cases when short-term electricity rates for a low-carbon source are higher than the market rates, only in small pilot projects that are intended not to have an outsized impact on overall electricity rates (e.g., Manitoba Hydro's Solar Energy Program) (Manitoba Hydro, 2017b).

While all utilities have often robust data on their customer base and potential to enhance reliability, and most utilities have developed an understanding of potential for lower-carbon energy technologies, this data is often held within the utilities. It is not broadly shared for the public good, despite the potential this could have for cross-country implementation of smart grid and low-carbon technologies. Utility A may have experience in potential for solar energy, Utility B may have experience with geothermal, and Utility C may have experience on district heating systems; however, they may not be motivated to share this information despite mutual benefit for all of these technologies for each utility.

This highlights that **there is a good basis of knowledge on clean energy and smart grid technologies, but that while there have been some efforts to share this knowledge, they have not been as extensive as they could be if the goal is widespread implementation of smart grids and low-carbon technology.**

Additionally, given the growing number of prosumers in the Canadian electricity system, **resources on clean energy and smart grid technology that are accessible to the general public, as opposed to utilities, could help generate a greater or at least more informed base of prosumers into the Canadian electricity grid**. There are also opportunities for Canada to benefit from international experience, although this has come across as an uncoordinated approach at the utility level based on our research. The CEA and Electric Power Research Institute were both cited by multiple sources for their role in bringing utilities together and driving collaboration, through leadership and sharing of best practices.

In relation to North America, given the connectivity of the grid across borders (see Figure 1), there is potential for more fundamental collaboration for reliability, and implementation of smart grid technologies. Alignment of energy models and sharing of data on reliability and low-carbon energy technologies is a good start. **Identification of opportunities to foster greater cross-border energy trade, given the interconnectedness of the cross-border grid can also assist in motivating clean energy implementation. Seeking regulatory alignment on clean energy, reliability standards and other areas—like clean/renewable standards, clean energy credit trading and GHG reduction policy—can create greater potential for smart grid technologies to achieve alignment across North America (Resources for the Future, 2016).**

There are also "softer" areas where alignment across borders could facilitate clean energy development such as shared monitoring and enforcement systems, research initiatives, reporting, and strengthening and refocusing bilateral and trilateral institutions.

In addition to collaborating with utilities and other levels of government, **it is important for governments to ensure that the views and interests of consumers are also respected**, which helps achieve a balanced approach to integration of smart grids and new technologies. This can be achieved by including civil society in collaborative efforts and ensuring that energy consumers have their interests reflected in government initiatives.

Several of these themes can be incorporated into revised national and international roadmaps for smart grid technologies that take into account emergent processes that will influence the energy sector in the coming decades, including the Pan-Canadian Framework on Clean Growth and Climate Change and the Paris Agreement.

4.0 Conclusion

This study has resulted in a number of key findings related to smart grids and other technologies in the electricity sector that can contribute to low-carbon development, particularly in urban areas.

Table 2. Policy context

Climate Change and Climate Policy	• Climate change impacts and policies are a growing influence on Canada's electricity infrastructure, at a time when a majority of this infrastructure currently requires, or will soon, update, refurbishment and modernization. • Influences include adaptation and resiliency challenges, with utilities predicting and trying to adapt to how projected changes in climate will impact reliable generation and distribution of electricity. • Policies to mitigate climate change, including coal phase-out plans and carbon pricing approaches are also influencing long-term electricity generation decisions.
Urban Agglomeration & Smart Grids	• Urban centres are getting larger and more spread out, and utilities are facing increased pressure to be more efficient, reliable and reduce the amount of carbon in their generation and distribution networks.
Emerging Trends in the Sector	• The evolution of the electricity sector, including changing dynamics from centralized to decentralized value chains, the rise of renewables into the energy mix and the introduction of modern technology, is moving business to new and emergent business models. • These include a focus on energy as a service provider, emphasizing small- and large-scale low-carbon electricity generation, and/or focus on flexibility models, allowing people to feed into, and form, the grid in a more dynamic fashion than in the past.

In addition to the differing business models, we have identified several potential barriers to, and opportunities for, increased smart grid integration.

Table 3. Risks and opportunities for smart grid integration

	Risk/Opportunity
Financial	**Most investments are carried out in the distribution segment of the power system**, in collaboration with industry partners. Canadian utilities are contributing to innovation in Canada where the return on investment isn't always available through their own rates.
Financial/ Regulatory	Regulatory frameworks also present **financial barriers** to the investment of smart grid technologies. For example, in Ontario, the Ontario Energy Board categorizes smart grid investments as traditional capital infrastructure investments. This presents complications to the utility companies as they develop their business case for investment.
Cultural	The relative **infancy of smart grid planning and management within utilities, lack of sharing lessons learned and risk-averse behaviour** can limit large-scale adoption of smart grid technologies. On the other hand, there is a small but committed group of early adopters that could be motivated to be a "leading wave" for these technologies.
	A smart grid **community of practice on lessons learned and best practices is not well established in Canada**, but could be greatly beneficial to motivation and culture change.
	Risk-averse behaviour can further limit the appetite to invest in smart grid technology when both utility companies and their shareholders (municipalities and provincial governments) jealously guard internal information, as well as seek low-risk investments.
Technical	Utility companies are approaching new technologies with caution due to **lack of confidence in the new business models and cases associated with them**, coupled with general mandates to place customer reliability through capital infrastructure investments and affordable electricity rates as the highest priority.
	Slow development and adoption of smart grid standards is also a barrier hindering integration efforts across provinces and utility companies. While Canada is active in smart grid standards development, relatively little progress has been reported with regard to the Smart Grid Standards Roadmap published in 2012. Greater effort on this front could accelerate market development and adoption rates.
	Smart grid technologies require **professionals with new skillsets** including areas of IT, advanced control systems, costumer relations and data analytics.

A **review of smart grid technologies** with the focus on grid modernization and low-carbon energy development could be beneficial. This would include working with utilities to determine which technologies are already undergoing significant research, development and implementation testing, and those where the knowledge base is much less developed. By better integrating with utilities, the CEA and others, governments could focus research efforts, demonstration projects, and funding supports on areas where technologies are less developed, for example because of their current lack of commercial viability. This could also include **joint initiatives with other countries** to share best practices, including missions, personnel exchanges or technology sharing.

We also echo CEA's recommendation on **flexible regulatory environments** to allow for innovation and stimulate research and development within utilities (CEA, 2013) and the general public (e.g., early adopters of smart grid technologies), including the ability for prosumers to integrate their energy generation to the grid.

Canadian cities are getting bigger in terms of space and population. This alone is driving a need for modernization of the electricity grid. In addition, the grid is also more at risk from climate change, and there are pressures to reduce GHG emissions. Consumers are also demanding more services and options from their utilities, including, most notably, the chance to generate their own energy and feed it into the grid. These pressures and demands are combining to generate motivation for a cleaner, more modern grid, but also one that can serve more dynamic business models.

With the motivation for modernization established, there are a number of opportunities for smart grid integration in Canada. There are associated risks and barriers, but there are easily identifiable response measures to these that can be implemented. What is missing more than anything is a national vision pulling together all of the relevant stakeholders and providing guidance for the development of smart grids in Canada.

We believe, a new a **National Vision on Grid Modernization** is necessary, and that such a vision should have at its core climate and sustainable development objectives. Moreover, we believe in order to achieve Canada's 2030 and mid-century climate objecties, it will be critical for different levels of government to improve coordination and information sharing on best practices while increasing policy, technical and program efforts that focus on grid modernization and low-carbon energy development.

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Published by the International Institute for Sustainable Development.

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