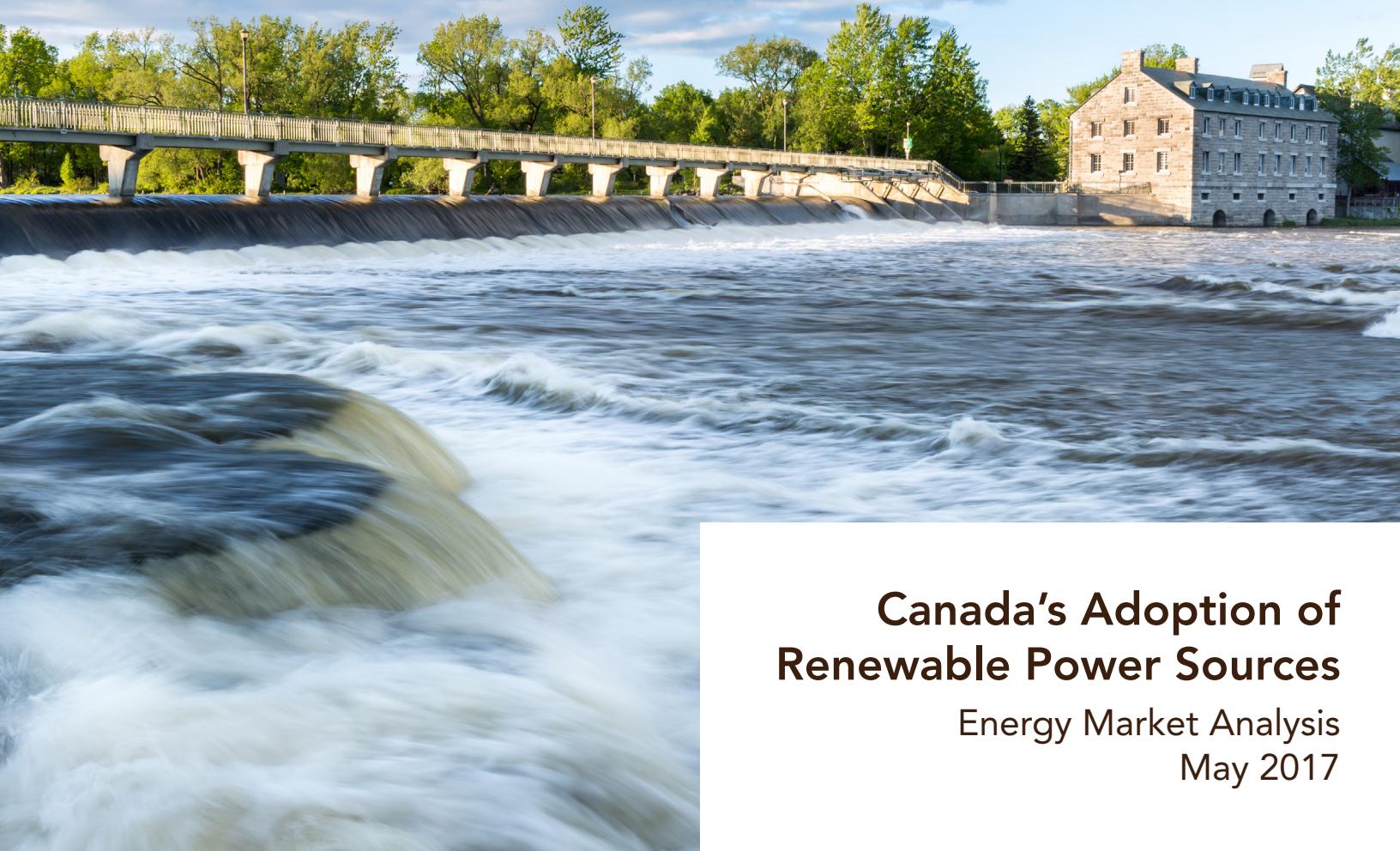




National Energy
Board

Office national
de l'énergie



Canada's Adoption of Renewable Power Sources

Energy Market Analysis
May 2017



Canada

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About the NEB

The National Energy Board (NEB or Board) is an independent national energy regulator. Its role is to regulate, among other things, the construction, operation and abandonment of pipelines that cross provincial or international borders, international power lines and designated interprovincial power lines, imports of natural gas and exports of crude oil, natural gas liquids, natural gas, refined petroleum products, and electricity, and oil and gas exploration and production activities in certain areas. The NEB is also charged with providing timely, accurate and objective information and advice on energy matters.

The NEB's strategic outcome states: The Regulation of pipelines, power lines, energy development and energy trade contributes to the safety of Canadians, the protection of the environment and efficient energy infrastructure and markets, while respecting the rights and interests of those affected by NEB decisions and recommendations.

The Board's main responsibilities include regulating:

- the construction, operation, and abandonment of pipelines that cross international borders or provincial/territorial boundaries;
- associated pipeline tolls and tariffs;
- the construction and operation of international power lines and designated interprovincial power lines;
- imports of natural gas and exports of crude oil, natural gas, natural gas liquids, refined petroleum products, and electricity; and
- oil and gas exploration and production activities in specified northern and offshore areas.

About this Report

The Board monitors energy markets and assesses Canadian energy requirements and trends to support its regulatory responsibilities. This report, *Canada's Adoption of Renewable Power Sources*, is one of a series of publications on energy supply, demand, and infrastructure that the NEB publishes regularly as part of its ongoing market monitoring.

Contributors to this report include: Natalia Lis (project manager), Josephine DeLeon, Ingrid Ektvedt, Ryan Quan, Alison Taylor, Sara Tsang, and Cassandra Wilde.

Questions or comments? Email renewables@neb-one.gc.ca.

Executive Summary

Canada generates a large share of its electricity from renewable sources, including hydro generation, compared to other countries. In 2015, renewables accounted for 66% of generation, up from 60% in 2005. Only five countries¹ produce a similar or larger share of electricity from renewable sources: Norway, New Zealand, Brazil, Austria, and Denmark.

In 2015, Canada was a global leader in total hydroelectricity production, second only to China. Canada is also a major producer of wind power; Canadian generation from solar and biomass sources is more modest. China, the United States, and Germany lead the world in total wind, solar, and biomass production.

About 60% of Canadian electricity came from hydro power in 2015, typically from large facilities with reservoirs. This type of hydro power is a valuable part of Canada's generation mix, since it economically stores energy and moderates fluctuations from more intermittent renewable sources. Run-of-river projects do not require reservoirs and are less disruptive to water flows, but operate on a much smaller scale.

Wind power capacity in Canada increased twenty-fold from 2005 to 2015. However, the intermittency of wind generation is still a challenge for widespread adoption. One way of overcoming this difficulty is by trading electricity with neighbouring jurisdictions to help moderate generation fluctuations. This strategy allows Denmark to generate 50% of its electricity from wind sources.

Biomass provided about 2% of Canada's electricity generation in 2015. It can be integrated into the grid easily but requires suitable supply to be economic. For this reason, projects are often integrated with operations that produce appropriate waste for fuel, such as the forestry, pulp and paper industries, and landfills.

Solar is a relatively small component of Canada's electricity. About 98% of all Canadian solar capacity is installed in Ontario, where it represented 5% of total capacity in 2015. The primary hurdles for more solar adoption are intermittency and its relatively high cost. Solar capacity grows faster in jurisdictions which offer incentives, such as the feed-in tariff programs in Ontario and Germany.

Other renewable technologies, such as offshore wind, tidal power, and geothermal energy, have not experienced significant uptake in Canada, but still have potential. Offshore wind projects are being proposed on Canada's west and east coasts, and a 20 MW tidal power facility already exists in Nova Scotia. Large scale geothermal energy [may be possible on Canada's west coast](#) by harnessing the "Ring of Fire" around the Pacific Ocean. Geothermal projects are also being [considered in isolated northern communities](#), which would benefit from combined heat and power.

Many factors influence the adoption of different power sources, including installation and generation costs, reliability, and environmental considerations. Collectively, renewables such as wind and solar are becoming more cost competitive. The low carbon emissions associated with renewables have also aligned them with current policy priorities. As a result, the increased adoption of renewables is expected to continue in Canada and abroad.

¹ International electricity capacity and generation numbers in this report come from [BP World Energy Statistical Review](#) which contains data for 71 countries. Some countries that use renewable sources to produce most of their electricity are very small and not included in the dataset (e.g., Iceland).

Introduction

The electricity industry around the world is moving towards increased renewable generation, including hydro, biomass, wind, and solar. Although these forms of generation have also increased substantially in Canada, further growth is not without challenges.

Canadian electricity prices are among the lowest in the world, making it difficult for relatively expensive non-hydro renewable sources to compete. Renewable power projects can also face public criticism and approval delays. As shown in Figure 1, Canadian electricity demand was relatively flat from 2005 to 2015. The [NEB's latest long-term energy outlook](#) projects electricity demand to grow at an average of 0.7% per year from 2015 to 2040.

TABLE 1

Renewable Electricity in Canada - Key Statistics

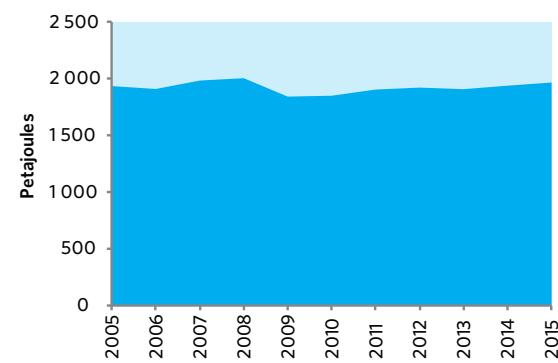
Key Statistics (2015)	Renewables
Installed capacity	94 929 MW
Share of Canada's capacity	65.6%
Share of Canada's generation	65.7%
Electricity generated	429 229 GW.h
Generation growth from 2005 to 2015	17%

Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

FIGURE 1

Canadian Electricity Demand



Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

Description:

This graph shows Canadian electricity demand from 2005 to 2015. Over this period, demand was relatively flat at just under 2 000 PJ.

For more information on historical growth rates for renewable power in Canada, including data for each province and territory, please see [Canada's Renewable Power Landscape](#).

This report, *Canada's Adoption of Renewable Power Sources*, discusses major renewable technologies in greater detail, with emphasis on factors influencing their adoption rates. These include costs, technological advancements, environmental considerations, and regulatory issues. This report also compares renewable generation growth in Canada to developments in other countries.





TABLE 2

Renewable Electric Capacity and Generation in Canada

		Capacity in MW and %		Generation in GW.h and %	
		2005	2015	2005	2015
Hydro	🌊	72 859 59.7%	79 313 54.8%	358 387 59.0%	385 500 59.0%
Wind	风电	557 0.5%	11 072 7.7%	1 453 0.2%	28 561 4.4%
Biomass	生物质能	1 789 1.5%	2 408 1.7%	7 875 1.3%	12 161 1.9%
Solar	太阳能	17 0%	2 135 1.5%	0 0%	3 007 0.5%
All renewable sources		75 222 61.6%	94 929 65.6%	367 716 60.6%	429 229 65.7%
All sources		122 065	144 608	607 007	653 183

Source: [Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)



Hydro electricity comes from the energy in water flowing over reservoir dams or through run-of-river projects.



Wind power is captured by the blades of wind turbines which spin a shaft connected to a generator.



Biomass power comes from burning organic waste.



Solar energy comes from photovoltaic (PV) cells converting sunlight into electricity at the atomic level.

Electric capacity vs generation

Capacity is the maximum amount of power that a device can generate, use, or transfer. It is usually expressed in megawatts.

Generation is the process of producing electric energy by transforming other forms of energy. In this report, generation is commonly used to refer to the amount of energy actually produced.

International Comparisons

Canada is a world leader in renewable electricity production and generates a larger share of its electricity from renewable sources, including hydro, than most developed economies.

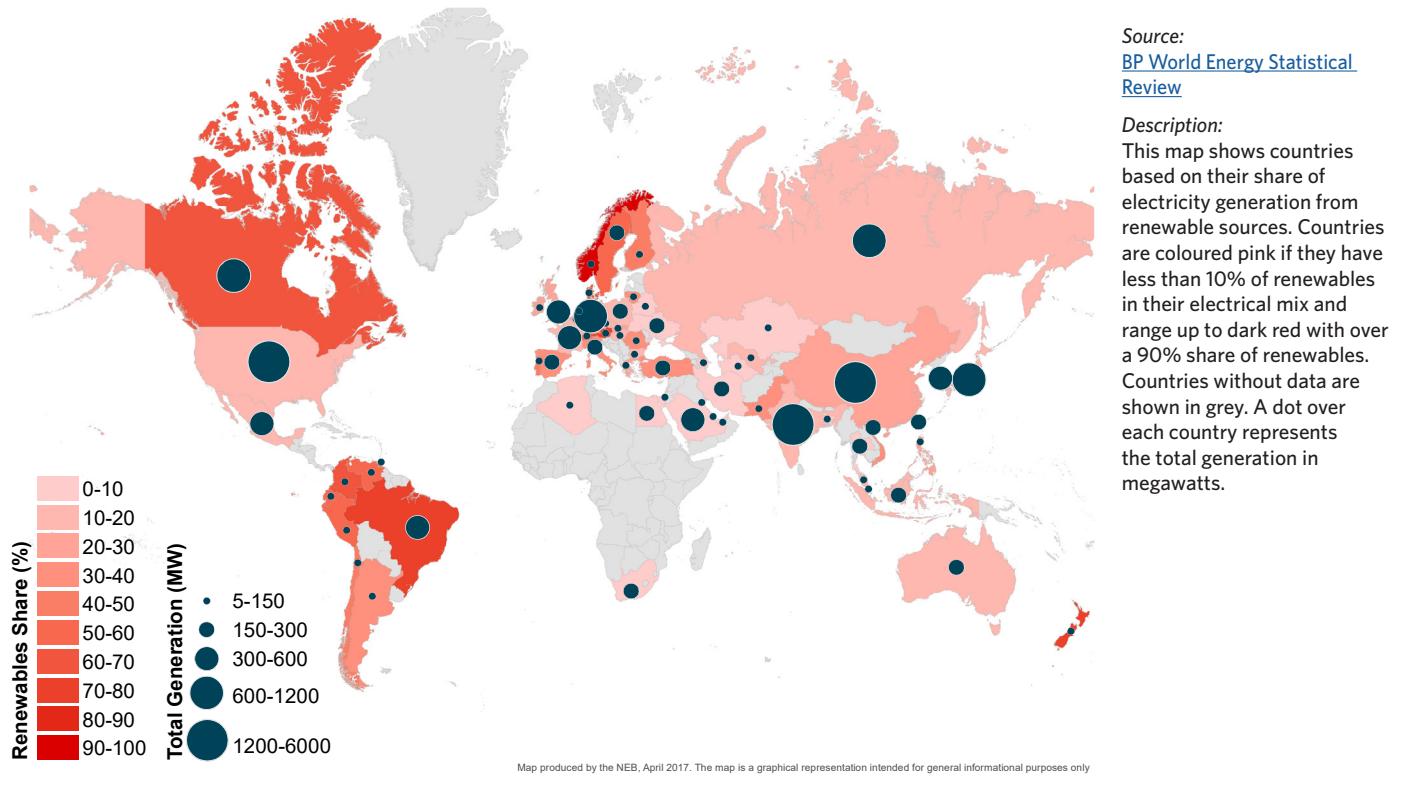
In 2015, Canada generated about 66% of its electricity from renewable sources. Canada's renewable power sector relies mostly on hydro. Wind and solar, which have grown tremendously across the globe, play a much smaller role in Canada than in some other countries.

Only 12 countries generate more than half of their electricity from renewable sources. Like Canada, most of them rely heavily on hydro, but Denmark is a significant outlier. Denmark produces a small amount of hydro but generates two-thirds of its electricity from wind, biomass, and solar.

Canada's electricity generation per capita is relatively high. With over 600 TW.h of electricity production in 2015, Canada generates as much electricity as some countries with much higher populations, including Brazil, Germany, and France.

FIGURE 2

Electricity Generation & Share of Renewables in Electricity Generation



In 2015, Canada generated about 10% of the world's hydroelectricity – second only to China. Hydroelectricity accounts for about 60% of Canada's production. Only two countries generate a higher proportion of their electricity from hydro sources: Norway and Brazil. (See Figure 2)

In the same year, Canada accounted for about 3% of global wind production, which placed it 7th in the world (See Figure 11). However, wind generation only accounts for a small proportion (4%) of Canada's production. In other countries, wind production plays a much larger role in the electricity mix, including Denmark (50%), Ireland (23%), and Portugal (22%). (See Figure 2)



FIGURE 3

Countries with Highest Share of Renewables

Share of renewable sources in 2015

Total Renewable Electricity

Norway	97%
New Zealand	80%
Brazil	75%
Austria	73%
Denmark	66%
Canada	66%
Colombia	60%
Sweden	60%
Venezuela	60%
Switzerland	57%

Hydro

Norway

Brazil

Canada

Venezuela

Colombia

Austria

New Zealand

Switzerland

Ecuador

Peru

Wind

Denmark

Ireland

Portugal

Spain

Lithuania

Germany

United Kingdom

Romania

Sweden

Greece

Solar

Italy

Greece

Germany

Spain

Belgium

Romania

Japan

Bulgaria

Czech Republic

Australia

Biomass and geothermal

New Zealand

Finland

Denmark

Philippines

Lithuania

Italy

Brazil

United Kingdom

Belgium

Germany

Source:

[BP World Energy Statistical Review](#)

Note:

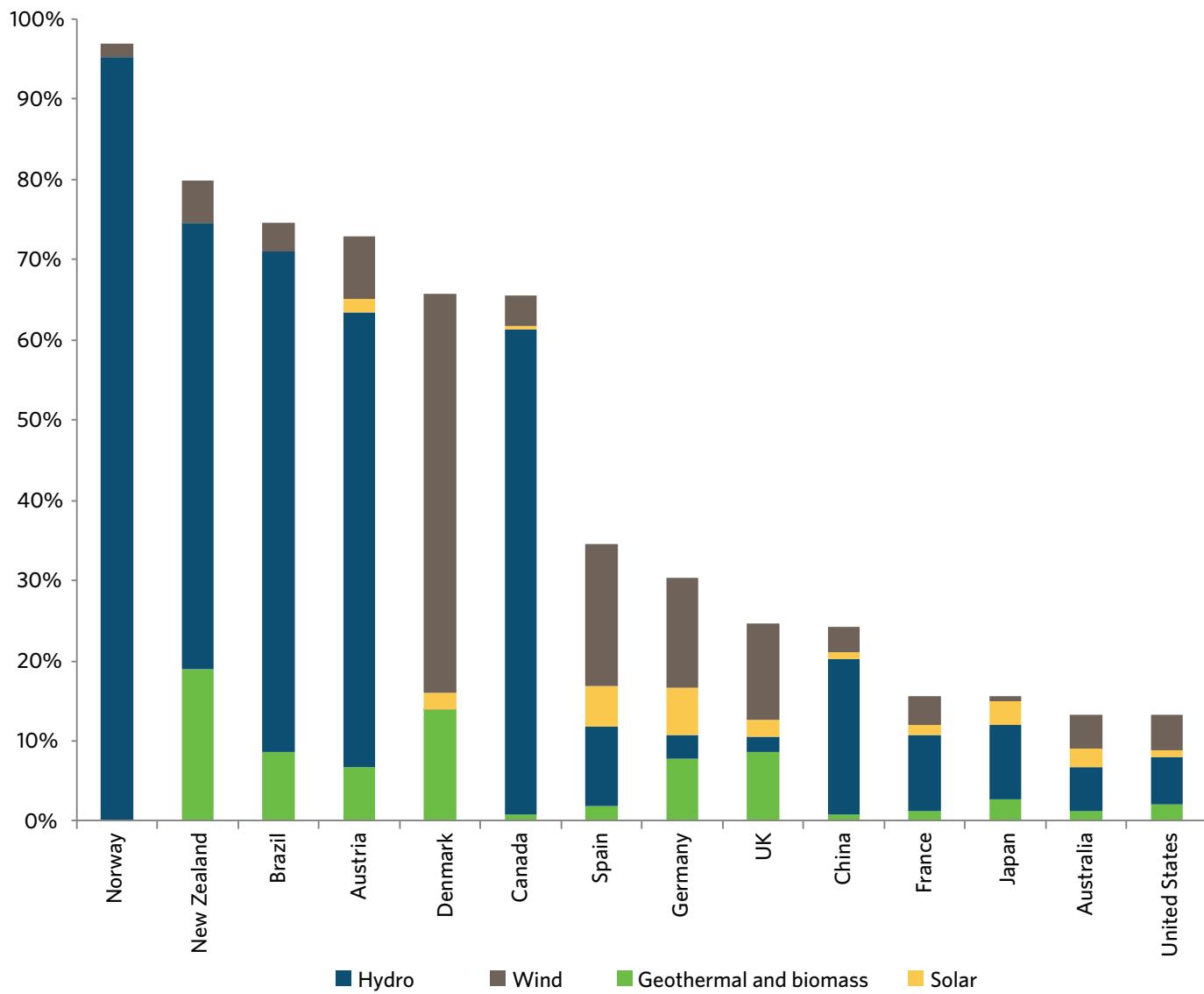
BP World Energy generation numbers for Canada are slightly different than NEB numbers but they are used in international comparisons for consistency.

Solar plays a modest role in Canada's electricity mix (0.5%), but is used heavily in a number of other countries. In 2015, four countries generated 5% or more of their electricity from solar: Italy (9%), Greece (7%), Germany (6%), and Spain (5%).

Similarly, geothermal² and biomass energy account for about 2% of Canadian electricity generation but more than 10% of electricity generation in New Zealand, Finland, Denmark, the Philippines and Lithuania. (See Figure 2 and 3)

FIGURE 4

Renewables in Electricity Mix: Selected Countries



Source: [BP World Energy Statistical Review](#)

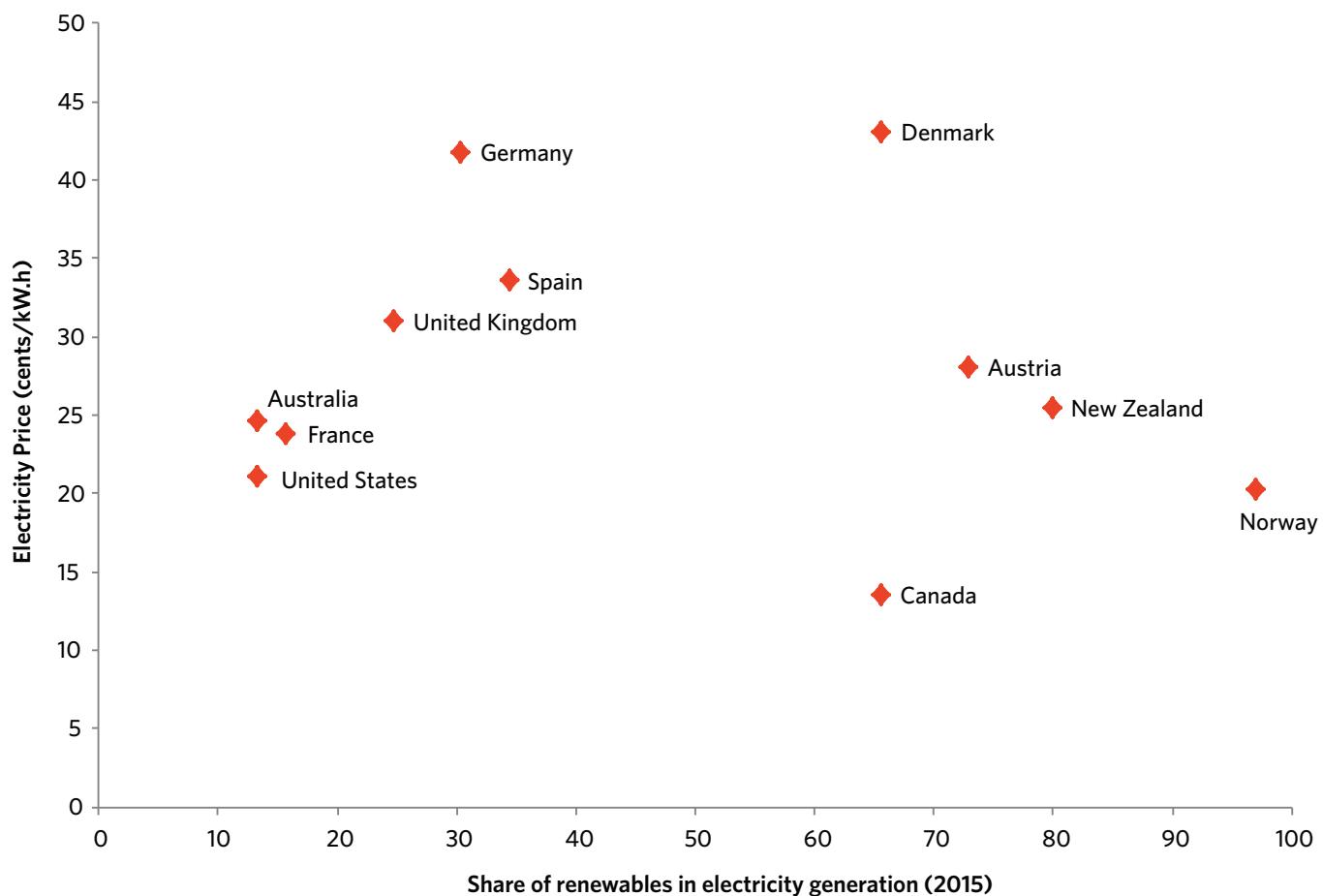
Description: The stacked column graph shows the percentage of electricity generated from wind, solar, hydro and biomass sources in fourteen select countries, including Canada. In this selection, Norway relies the most on renewable sources and the United States, the least. In 2015, Norway produced 97% of its electricity from renewable sources and the United States produced 13%.

² [BP World Energy Statistical Review](#) combines data on biomass and geothermal sources. The only country that uses geothermal sources to generate a significant share of electricity is New Zealand.

Canada's electricity prices are relatively low compared to many other countries. Consumers in Germany and Denmark pay more than twice as much as Canadians for each kW.h of electricity. However, consumers in those countries use less electricity per capita than in Canada, so their total electricity bills are not necessarily much higher. (See Figure 5)

FIGURE 5

Share of Renewables and Electricity prices: Selected Countries



Sources (Price):

[Canada and the US - Hydro Quebec: Comparison of Electricity Prices in Major North American Cities \(2015\)](#)

[European countries - Eurostat](#)

[Australia - Australian Energy Market Commission: 2015 Residential Electricity Price Trends](#)

[New Zealand Ministry of Business, Innovation and Employment - Sales based Electricity Costs](#)

Sources (Share of renewable generation):

[BP World Energy Statistical Review](#)

Note: Prices include energy, distribution, taxes and other fees. American and Canadian prices are a simple average of regional prices.

Description: The graph plots the share of renewable generation, on the x axis, and residential electricity prices, on the y axis, for 11 selected countries. In most cases, prices are higher when the share of renewable generation is higher. Canada and Norway are the outliers. They have the lowest prices but generate more electricity from renewable sources than the other countries in the selection. Canada and Norway mostly use hydro, which is usually the cheapest form of renewable generation.

Hydro

Hydropower harnesses energy from moving water to activate a turbine connected to a generator. The amount of energy produced depends on water volume and speed: the more water moving at a fast rate, the more energy produced.

Hydropower plants vary in size and type. Projects are tailored to local conditions, and the technical feasibility of a potential hydroelectric site depends on the specific topography and climate.

Reservoir hydropower uses a dam to capture river water, which is then stored in a reservoir for release when needed. A deep, narrow valley with constructed walls and a dam that can support large volumes of water is an attractive site for this type of generation.

Reservoir hydropower can serve base load and peak demand through its ability to be shut down and started up at short notice. It can also offer enough storage capacity to operate independently of natural water flows for weeks, and even years. However, hydropower ultimately depends on precipitation patterns, which can be unpredictable.

Run-of-river hydro is built on an existing stream or river. Facilities are usually located where water naturally falls, for example, off a cliff or over rapids.

Recently developed turbines make it possible to operate run-of-river projects in sites with low flow and no height differences. The size of run-of-river facilities in Canada varies from less than 1 MW to almost 1 900 MW.

Pumped-storage hydropower moves water between reservoirs at different elevations. When electricity demand is low, electricity is used to pump water into a high reservoir. When demand peaks, water is released back into the lower reservoir through a turbine. The only pumped-storage facility in Canada is the [Sir Adam Beck Pump Generating Station](#) in Niagara Falls, Ontario.

Canadian Adoption

Hydroelectricity has been the main source of power generation in Canada for more than a century. British Columbia (B.C.), Manitoba, Quebec, Ontario, and Newfoundland and Labrador use hydro to meet most of their electricity demand. All provinces and territories produce hydroelectricity with the exception of Nunavut and PEI.

Several large hydroelectric projects are currently under construction. These include the 1 100 MW [Site-C](#) in B.C., the 695 MW [Keeyask Project](#) in Manitoba, two new generation units with a combined capacity of 640 MW at [La Romaine](#) in Quebec, and the 824 MW [Muskrat Falls](#) project in Labrador.

TABLE 3

Hydro Electricity in Canada: Key Statistics

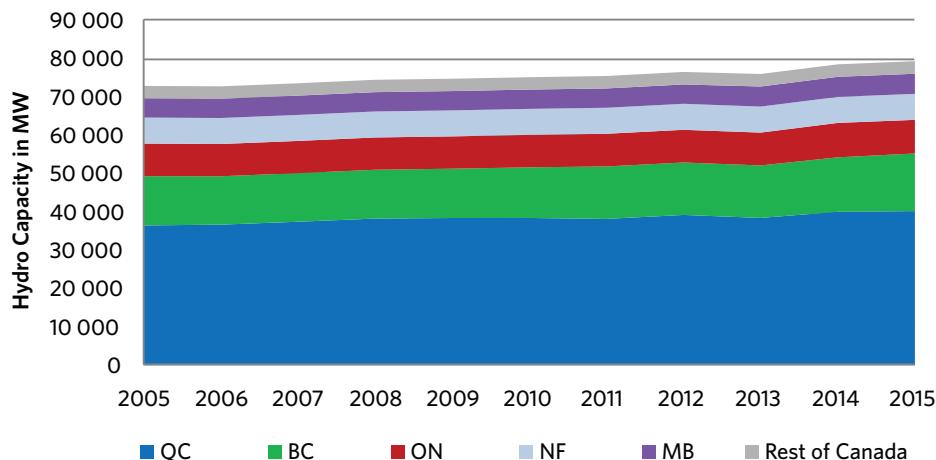
Key Statistics (2015)	Hydro
Installed capacity	79 313 MW
Share of Canada's capacity	54.8%
Share of Canada's generation	59.0%
Electricity generated	385 500 GW.h
Generation growth from 2005 to 2015	8%

Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

FIGURE 6

Hydro Capacity in Canada

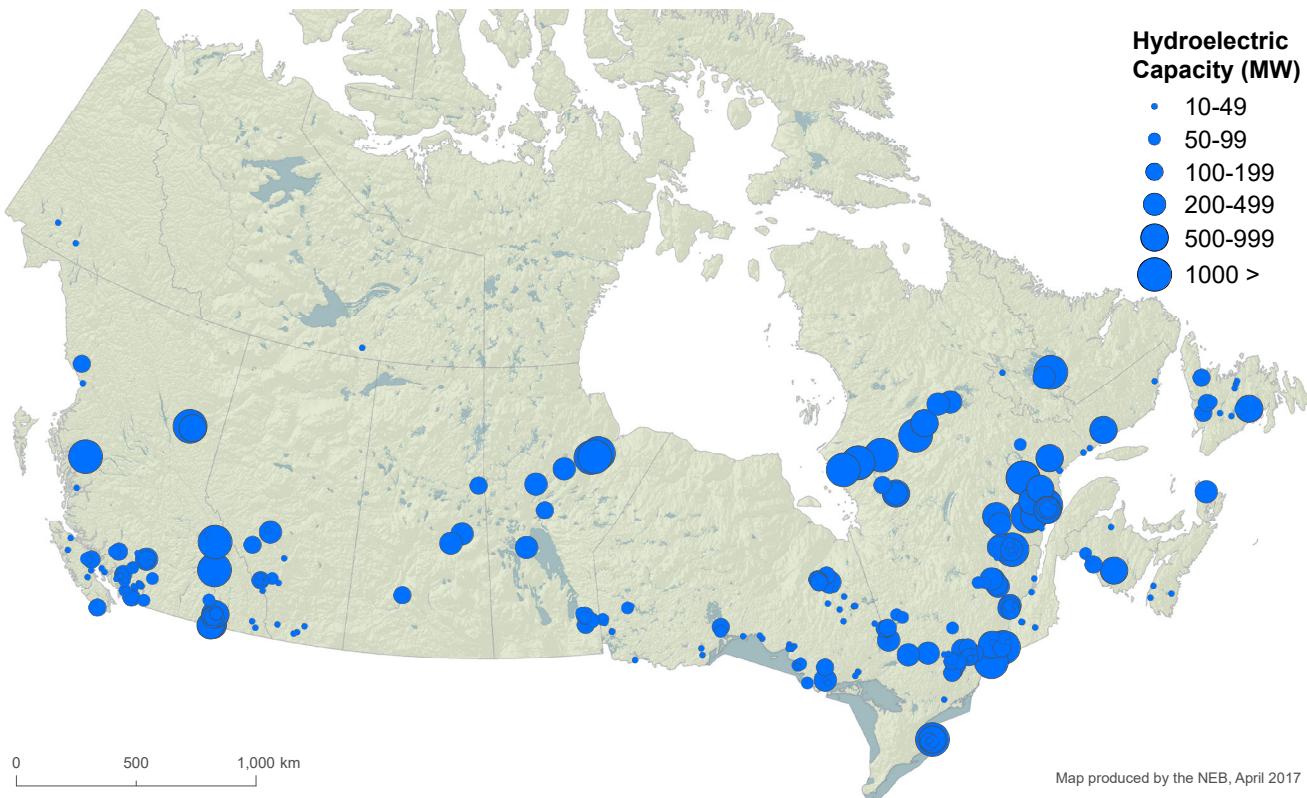


Source: [Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

Description: The stacked area chart shows hydroelectric capacity in five Canadian leading provinces and the rest of Canada between 2005 and 2015. The five provinces with the largest hydroelectric capacity are Quebec, B.C., Ontario, Newfoundland and Manitoba. In all those regions and the rest of Canada, hydroelectric capacity remained stable or grew slightly between 2005 and 2015.

FIGURE 7

Map of Hydro Power Plants in Canada



Source: [Natural Resources Canada, Renewable Energy Power Plants, 1 MW or more - North American Cooperation on Energy Information](#)

Description: This map shows the location and approximate capacity of hydro power plants with a capacity of at least 10 MW across Canada. Hydro facilities of this size can be found in every province and territory with the exception of PEI and Nunavut. Largest hydro facilities are located in B.C., Manitoba, Quebec, Ontario and Labrador, often in northern parts of those provinces.

International Adoption

Hydropower is used in over 150 countries and provided 16% of worldwide electricity in 2015. According to the [International Hydropower Association](#), 33.7 GW of new capacity was installed in 2015 and 31.5 GW in 2016. This includes 6.4 GW of pumped storage, which is nearly twice the amount installed in 2015. China was the largest hydropower producer in the world, followed by Canada, Brazil, and the United States. Together, those four countries are responsible for about 50% of global hydropower output.

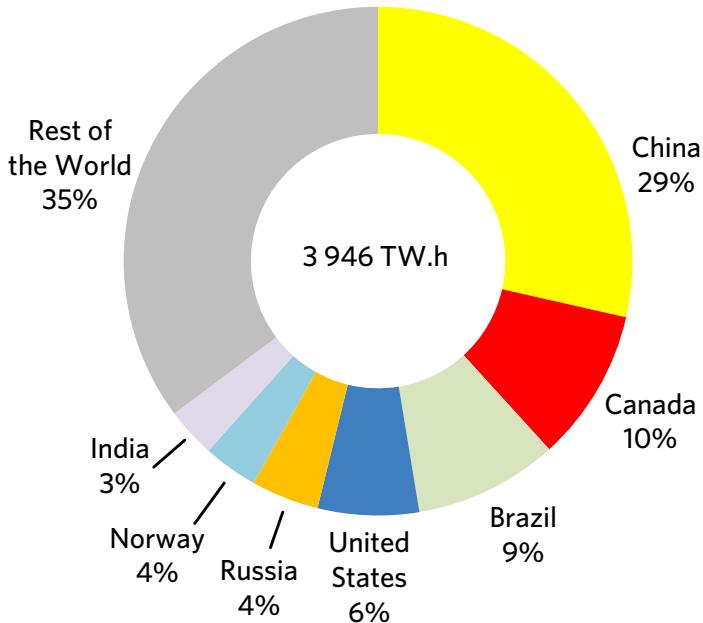
Environmental Considerations

Hydropower can help to balance intermittent renewable sources in an electricity grid, such as solar and wind, which allows for greater penetration of low GHG sources. It generates electricity without combusting fossil fuels. However, dams have [fragmented nearly two-thirds of the world's largest rivers](#), including many in Canada. Dams can [interfere with fish migration](#), [deplete oxygen in reservoirs](#), mobilize contaminants, and trap sediment that are important for maintaining downstream habitats including protecting deltas from erosion. New reservoirs typically create GHG emissions. However, this varies greatly depending on the vegetation, soils and preparation in the flooded area.

Because they do not use dams, [run-of-river facilities cause fewer disturbances](#) to fish and natural water flow when installed and operated according to specified limits.

FIGURE 8

World Hydro Electricity Production in 2015



Source: [BP World Energy Statistical Review](#)

Description: The donut chart shows hydro generation of the top seven producers and the rest of the world. The top seven hydro producers are China, Canada, Brazil, the United States, Russia, Norway and India. Together, they produce more than half of world's hydroelectric energy. Total global hydroelectric production in 2015 was 3 946 TW.h



Market Issues

Hydropower, especially large hydropower, is financially competitive with other electricity sources. Advantages include no fuel cost, low operating costs, and a very long and reliable service life. Hydropower also converts over 90% of available energy into electricity, whereas the most efficient combined cycle natural gas plants achieve approximately 60% efficiency.

On the other hand, hydropower projects can involve long construction periods and large upfront capital costs. Returns on investment may also vary greatly from year to year, depending on precipitation. These factors make it difficult for the private sector to invest in large hydro facilities, which is why they are usually built in Canada by provincial Crown Corporations (although smaller privately owned facilities do exist). The Canadian federal government has also provided financial support to hydroelectric projects, including a [\\$6.3 billion loan guarantee](#) for the Muskrat Falls generating station and associated transmission lines.

A major benefit of hydroelectricity is its reliability. In contrast to intermittent sources of renewable energy such as wind and solar, hydroelectric plants can produce electricity on demand and are recognized as system management assets capable of ensuring reliable supply.

Hydropower as an international supplement to wind

Norway generates about 95% of its electricity from hydro, the highest percentage among developed countries. With 29 GW of installed hydroelectric capacity, over half of Europe's hydropower is located in Norway. This hydropower is partially used as a "battery" to balance generation from intermittent renewables in other European countries. [Norway trades electricity](#) with Sweden, Finland, the Netherlands, and Denmark. Two additional interconnections in advanced stages of development will enable the exchange of surplus wind and solar power generated in [Germany](#) and the [UK](#) with hydroelectric power produced in Norway.

Similar examples of combining hydro and wind exist in North America. For example, the Quebec government recognizes the [complementary nature](#) of these sources, where hydro can support wind's intermittency and wind can be dispatched to preserve energy stored in large hydroelectric reservoirs. The province already has significant hydroelectric capacity and through recent developments has installed [3 262 MW of wind capacity](#) as of December 2015.



Wind

Wind power is captured by turbine blades that spin a shaft connected to a generator. The blades of wind turbines work on the same principle as airplane propellers. In the case of wind turbines, the wind passes over the blades and the rotor turns because the pressure difference between the upper and lower surfaces creates lift.

Modern wind turbines are increasingly cost-effective, reliable, and powerful. Turbine nameplate capacity, height, and rotor diameter have all increased significantly. Wind turbines can now generate electricity for 20-25 years, and can run for as many as 120 000 hours over their lifetime.

Canadian Adoption

In 2015, Canada produced 4.4% of its electricity from wind, and every Canadian province and territory (except Nunavut) generated some power from wind. Canada has ample wind resources because of its diverse geography, but its cold climate poses challenges related to working conditions, road access in winter, and turbine technology impacts.

In 2015, Canada had over 11 000 MW of total installed wind capacity and was the 7th largest wind energy producer in the world (See Figure 10). Between 2010 and 2015, Canada's installed wind capacity grew by 24% per year.

This capacity could grow further due to provincial and federal initiatives. For example, Alberta's government unveiled a new climate strategy in November 2015 that pledges to generate 30% of Alberta's electricity from renewable sources such as wind, hydro and solar by 2030.

TABLE 4

Wind Electricity in Canada: Key Statistics

Key Statistics (2015)	Wind
Installed capacity	11 072 MW
Share of Canada's capacity	7.7%
Share of Canada's generation	4.4%
Electricity generated	28 561 GW.h
Generation growth from 2005 to 2015	1 866%

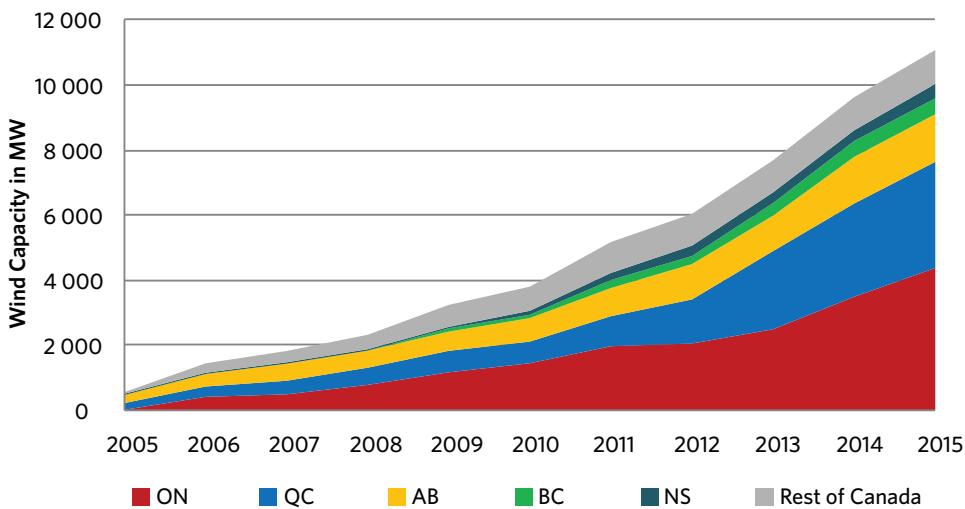
Source:

[Canada's Energy Future 2016:
Update - Energy Supply and Demand Projections to 2040](#)



FIGURE 9

Wind Capacity in Canada



Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

Description: The stacked area chart shows wind capacity in five Canadian leading provinces and the rest of Canada between 2005 and 2015. The five provinces with the largest wind capacity are Ontario, Quebec, Alberta, B.C. and Nova Scotia. Wind capacity grew strongly between 2005 and 2010 and even more sharply between 2010 and 2015.

FIGURE 10

Map of Wind Power Plants in Canada



Source:

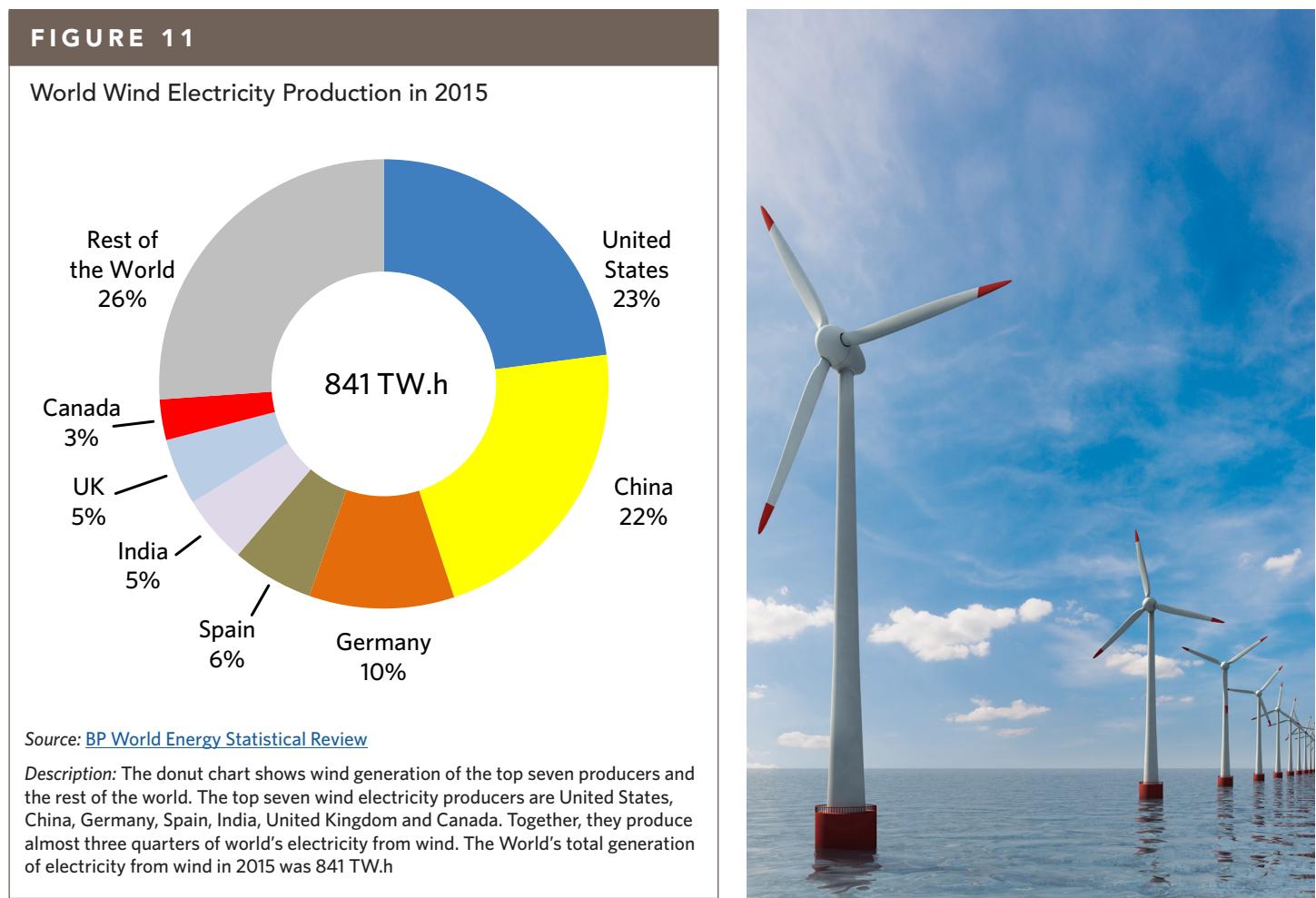
[Natural Resources Canada, Renewable Energy Power Plants, 1 MW or more - North American Cooperation on Energy Information](#)

Description: This map shows the location and approximate capacity of wind power plants with a capacity of at least 10 MW across Canada. Wind farms of this size can be found in every province but not in the territories. Most wind farms are located in Ontario, Quebec, Alberta, B.C. and the Maritime provinces.

International Adoption

Global wind capacity grew by 17.2% in 2015, or a record 63.7 GW, bringing total global wind capacity to 435 GW. China, the second largest wind energy producer in the world, registered the highest increase with 33 GW of new wind capacity installed in 2015.

Three countries, the United States, China, and Germany, produced over 50% of global wind energy in 2015. Canada accounted for 3% of global wind production that year.



Environmental Considerations

Wind energy is essentially emission-free and wind facilities generate electricity without polluting air or water resources. Wind farms also use as little as 1% of total acreage for turbines and access roads, which means that the remaining land can often still be used for farming or ranching.

Common environmental concerns associated with wind farms include [noise and visual disturbance](#), [impacts on birds and bats](#), and [land use concerns](#). Some GHGs are also produced during the manufacturing, transportation, assembly, and maintenance of wind turbines.

Market Issues

Wind energy is now among the lowest-cost options for new electricity supply in most Canadian provinces. Policymakers and utilities are increasingly recognizing it is a cost-competitive and scalable option for low carbon electricity, but slow electricity demand growth in most provinces means that growth in wind energy will likely depend on a combination of domestic and export growth and specific policies to replace other forms of generation with wind.

Optimal wind sites are often in locations distant from major populations so they require construction of transmission lines to connect to markets. Further, developing a wind farm in a cold climate requires consideration of the impact of ice on its installation, operation, and maintenance. Adaptations include using different materials and lubricants, additional heating for certain components, and adding de-icing technologies to rotor blades.

A major drawback of wind technology is intermittency. In recent years, the Independent Electricity System Operator (IESO) in Ontario adopted a series of initiatives to improve wind dispatch, or the ability of wind plants to modify production at the request of the electricity system operator. Thanks to those initiatives, wind generation facilities in Ontario now help balance the system and prevent nuclear shutdowns during periods of surplus base load generation. [Wind dispatch helped avoid 19 of these shutdowns in 2015.](#)

Wind leader - Denmark

In 2015, Denmark generated 50% of its electricity from wind, the highest proportion in the world. This creates substantial intermittency challenges, but Denmark has developed methods for managing this.

Denmark has the capacity to transfer 6.4 GW of power to Norway, Sweden and Germany. This is greater than Danish peak demand of 6 GW. This allows Denmark to sell electricity during times of high wind production, and to import electricity in times of low wind production.

Denmark also devoted significant effort to increasing the operational flexibility of its conventional power plants. Coal plants have been optimized to start quickly and on a short notice, and to vary output over a wide range during the day. In addition, Danish regulations were restructured to reduce the use of fossil fuel plants during periods of high wind generation.



Biomass

Power generation from biomass is the creation of power from organic material such as solid wood or wood residues, agricultural crop residues, aquatic plants, animal wastes, and dedicated energy crops including tree farms.

Biomass can be directly burned to generate power or gasified then sent to a boiler where electricity is generated. Biomass can also be co-fired with coal to reduce overall greenhouse gas emissions from a coal plant.

Canadian Adoption

As of 2014, Canada had approximately 70 biomass generating power plants with total installed capacity of 2 408 MW. Most of these facilities rely on wood, wood by-products, and landfill gas.

Provinces with high biomass use tend to have active pulp, paper, and forestry industries. Canada has a large supply of renewable forest biomass, as well as access to forest industry by-products and residues. B.C., Ontario, Alberta, Quebec, and New Brunswick are the provinces with the largest biomass capacity and generation.

Very few Canadian landfills recover methane emissions for energy purposes. However, some Canadian municipalities (e.g. Edmonton, Nanaimo, and Vancouver/Burnaby) actively produce energy from waste, either from landfills or from large-scale anaerobic digesters. Increasingly, Canadian landfills and waste to energy facilities generate electricity for nearby utilities and industries, or convert landfill gas to natural gas to be moved in natural gas pipelines.

International Adoption

In 2015, biomass generation reached 518 TW.h, which is about 2% of global power generation. Five countries generated more than half of this electricity: the United States, China, Germany, Brazil, and the United Kingdom. (See Figure 14)

Globally, biomass generation is mostly attributed to solid biomass in the form of wood pellets and chips. Biogas, municipal solid waste, and biofuels are also used but less common.

TABLE 5

Biomass Electricity in Canada: Key Statistics

Key Statistics (2015)	Biomass
Installed capacity	2 408 MW
Share of Canada's capacity	1.7%
Share of Canada's generation	1.9%
Electricity generated	12 161 GW.h
Generation growth from 2005 to 2015	54%

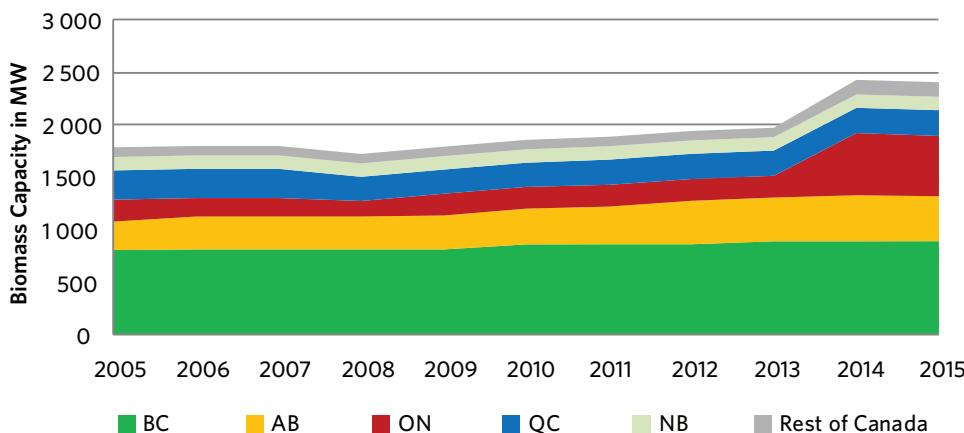
Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)



FIGURE 12

Biomass Capacity in Canada



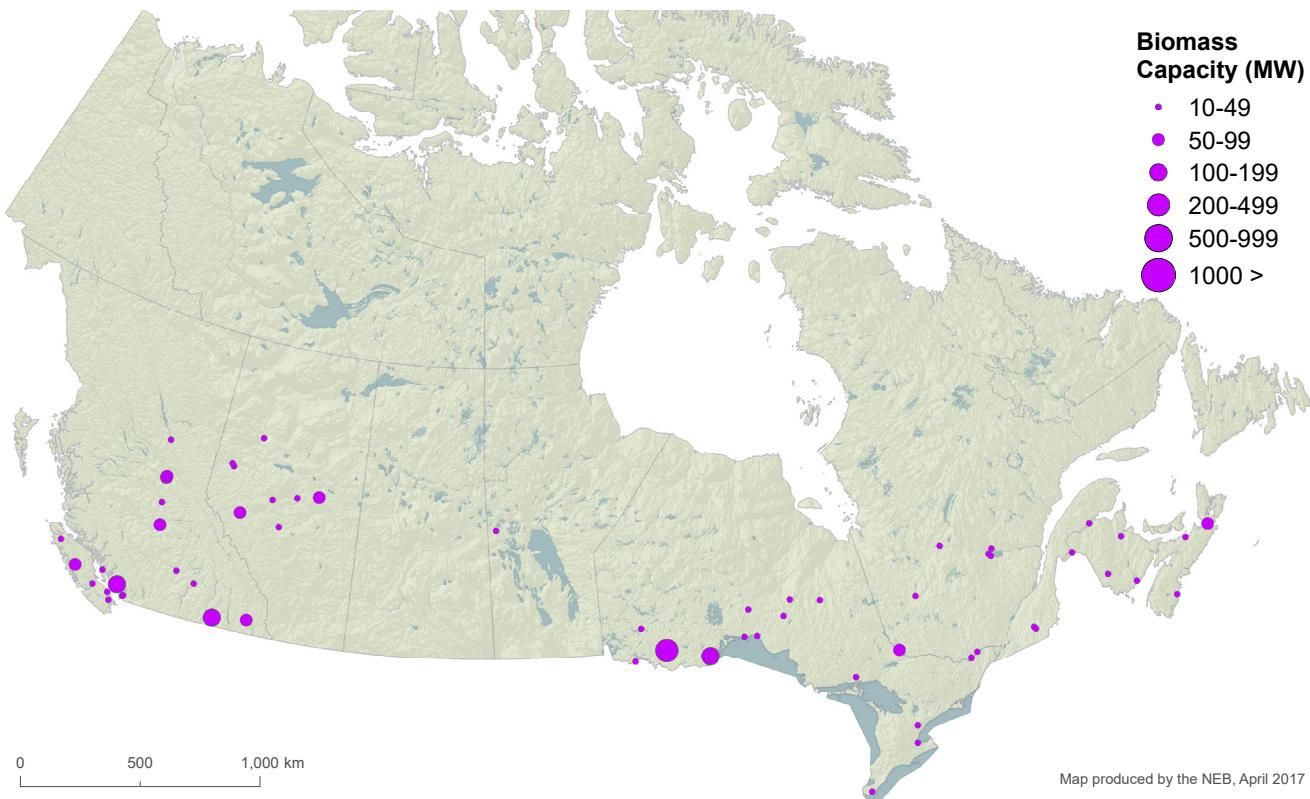
Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

Description: The stacked area graph shows biomass capacity in five Canadian leading provinces and the rest of Canada between 2005 and 2015. The five provinces with the largest biomass capacity are B.C., Alberta, Ontario, Quebec and New Brunswick. Biomass capacity fluctuates slightly between 2005 and 2013 and increases sharply in 2013 following a large addition in Ontario.

FIGURE 13

Map of Biomass Power Plants in Canada



Source:

[Natural Resources Canada, Renewable Energy Power Plants, 1 MW or more - North American Cooperation on Energy Information](#)

Description: This map shows the location and approximate capacity of biomass power plants with a capacity of at least 10 MW across Canada. Most biomass facilities are located in B.C., Alberta, Ontario, Quebec, New Brunswick and Nova Scotia. One biomass facility is located in Manitoba. There are no biomass facilities with a capacity of at least 10 MW in Saskatchewan, PEI, Newfoundland and Labrador and the Territories.

Environmental Considerations

Biomass is generally considered carbon neutral because the carbon dioxide (CO_2) released from either burning or decomposing biomass approximately equals the CO_2 that trees or plants take in from the atmosphere during their lives. If the trees harvested as biomass are replanted as fast as the wood is burned, new trees take up the CO_2 produced by the combustion or decomposition. However, [burning biomass results in air pollution](#) and incremental carbon is emitted from cultivating, harvesting, processing, and transporting biomass.

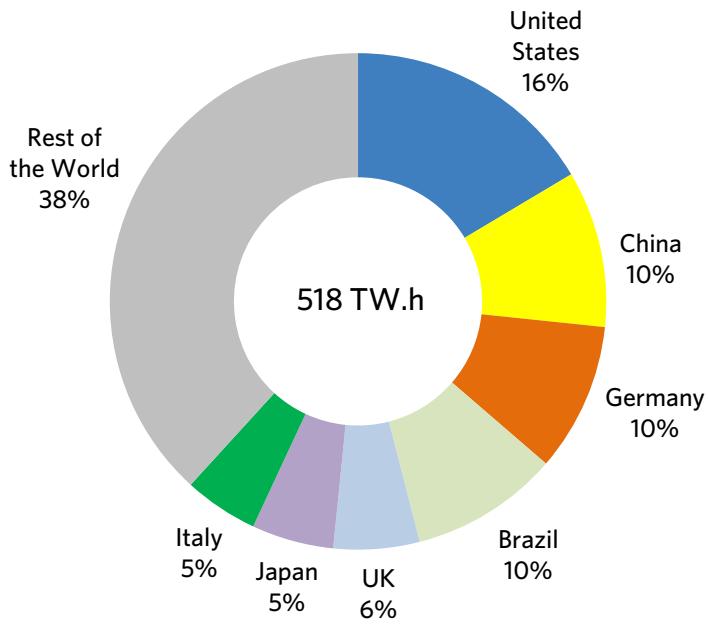
Market Issues

A major advantage of biomass plants is that they generate power on demand and can be used for base load generation, unlike other renewables that generate intermittently. However, fuel availability and transportation costs are major factors impacting the financial viability of biomass plants.

Sawmills typically convert about 45% of each log into lumber. The remaining sawmill waste (wood chips, shavings, and sawdust), can be used as feedstock in biomass plants, but can also be consumed by the pulp and paper industry or converted into wood pellets or fibreboards. This competition between users can limit the amount of wood biomass available for electricity generation.

FIGURE 14

World Biomass Electricity Production in 2015



Source: [BP World Energy Statistical Review](#)

Description: The donut chart shows biomass and geothermal generation of the top seven producers and the rest of the world. The top seven biomass and geothermal electricity producers are the United States, China, Germany, Brazil, the United Kingdom, Japan and Italy. Together, they produce almost three quarters of the world's electricity from biomass and geothermal which reached 518 TW.h in 2015.



Biomass plants can use standing timber (whole trees that have not yet been harvested for another purpose) provided they are cut in compliance with applicable permits. This requires the power generator to cover all costs of logging and transportation. According to BC Hydro estimates, the cost of producing electricity from wood waste in B.C. varies between \$107 and \$134/MW.h, while the cost of producing electricity from standing timber is \$208/MW.h.

Transporting biomass feedstock over large distances is challenging. Biomass has lower energy density than coal or petroleum, which means that more biomass is needed to generate one unit of electricity. Biomass is usually transported by trucks, which is more costly than using trains or pipelines.

Because of these challenges, biomass plants are most economic when located close to fuel supplies. The economics can also be improved by using cogeneration units which produce both heat and electricity.

Collaboration with Finland for Biomass Expertise

Finland is one of the world leaders in biomass power. In 2015, it generated 11.3 TW.h of electricity from biomass (17% of total generation) compared to 3.7 TW.h in B.C. (6% of total generation). The main drivers for the use of biomass in Finland are its lack of alternative energy sources, cold climate, and the availability of waste biomass from the country's sizeable forestry, wood products and paper industries. The wood used consists mostly of waste from those industries and is low quality wood with no competing uses.

Finland's biomass power sector benefits from support programs such as research funding, tax relief, and production subsidies. Finland is also keen to promote

energy efficiency. Most of its biomass power plants are cogeneration plants which supply energy for heating as well as electricity. About 80 of them have a capacity of 20 MW or larger.

Forests cover about 60% of Finland, and the country is comparable to B.C. in terms of population, climate, and size of the forestry industry (based on annual volume of wood harvested). In June 2016, FP Innovations, a B.C. research agency, in conjunction with the University of British Columbia's Forest Science Centre, proposed a [partnership](#) with Finland's biomass industry to gain expertise in bioenergy best practices.



Solar

The most common method of converting solar energy into electricity is through photovoltaic (PV) cells, which convert sunlight into electricity that can be used, stored or added to the grid.

A PV panel is an array of cells, comprised of either crystalline silicon wafers or thin films of silicon and metal.

The amount of electricity generated depends on the intensity of sunlight reaching the panel face. Power output is reduced by cloud cover, seasonal variation in daylight hours, and panel obstruction by snow and dust, and by hail damage. Solar is also an intermittent power source, as its availability fluctuates with weather conditions and is not available during nighttime.

PV cells are being installed at both the residential and commercial scale. Household rooftop projects are typically less than 10 kW, while the capacity of utility-scale farms can reach hundreds of megawatts.

Continuous improvements in PV panel manufacturing have reduced production costs over time, including for conventional crystalline silicon cells, the most prevalent cell across the world. PV module costs have fallen from **\$6.18/watt in 2004 to \$0.85/watt in 2014**. Despite this, solar energy is still costly compared to conventional sources of power generation and those costs remain a barrier to the technology's widespread adoption.

TABLE 6

Solar Electricity in Canada: Key Statistics

Key Statistics (2015)	PV Solar
Installed capacity	2 135 MW
Share of Canada's capacity	1.5%
Share of Canada's generation	0.5%
Electricity generated	3 007 GW.h
Generation growth from 2010 to 2015	2 344%

Source:

[Canada's Energy Future 2016:
Update - Energy Supply and Demand Projections to 2040](#)

Note:

There was zero generation from solar in 2005, so 2010 was used as the base year to calculate generation growth. In 2010, Canada generated 123 MW from solar power.

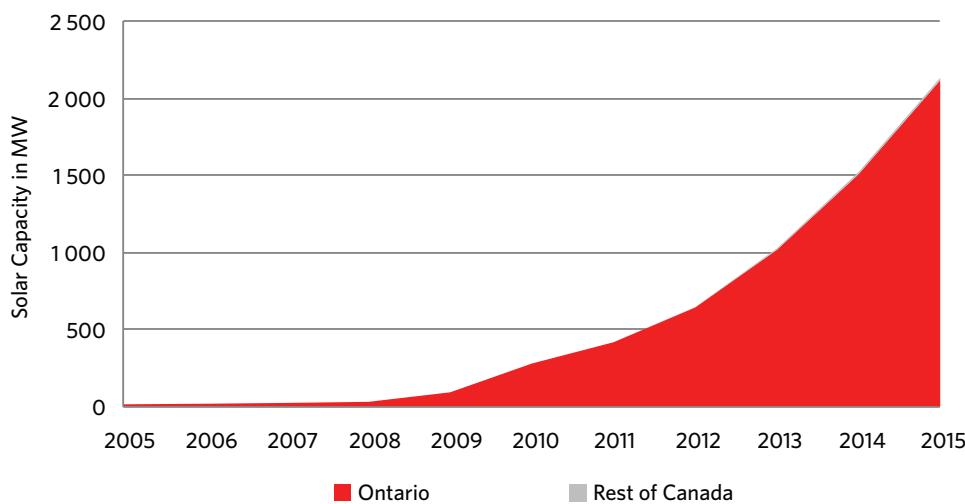
Canadian Adoption

Solar power is a small but rapidly growing source of electricity for Canadians. In 2015, Canada had over 2 100 MW of installed solar capacity generating 3 TW.h annually. Although this represents only about 0.5% of national electricity generation, solar projects have been developing rapidly, with close to 2 000 MW of capacity added since 2013. Over 98% of Canada's solar power generation capacity is located in Ontario.



FIGURE 15

Solar Capacity in Canada



Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

Description: The stacked area chart shows solar capacity in Ontario and the rest of Canada from 2005 to 2015. Solar capacity in Ontario increases rapidly between 2008 and 2015. In 2015, it represents more than 98% of solar capacity in Canada. Solar capacity growth in the rest of Canada is marginal in comparison and difficult to see visually on the graph.

FIGURE 16

Map of Solar Power Plants in Canada



Source:

[Natural Resources Canada, Renewable Energy Power Plants, 1 MW or more - North American Cooperation on Energy Information](#)

Description: This map shows the location and approximate capacity of solar power plants with a capacity of at least 10 MW across Canada. All solar facilities of that size are located in Ontario.

International Adoption

Global solar capacity has increased tremendously in the last few years. In 2015, about 50 GW of solar capacity was installed across the world for an estimated total of 227 GW. The top countries for solar generation are China, the United States, Germany, Japan, and Italy, which combined account for close to 70% of the world's solar output.

Environmental Considerations

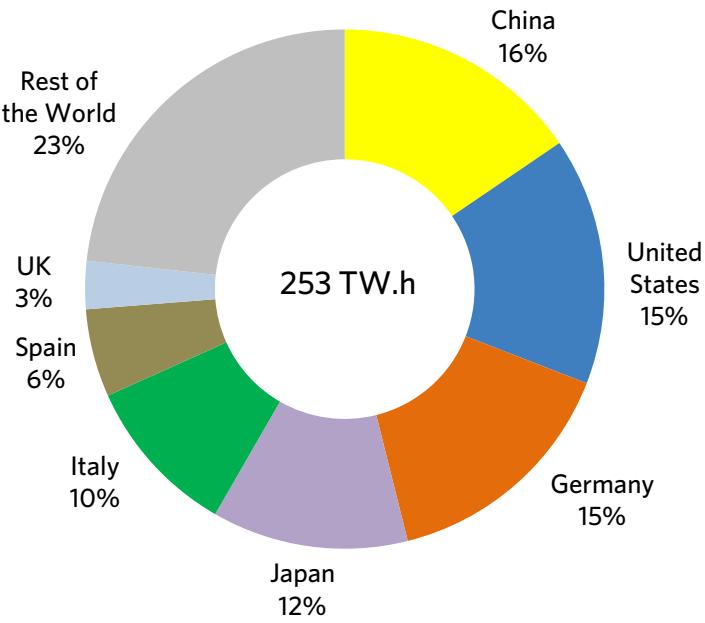
The primary benefit of solar generation is that it emits no pollutants or GHGs, and unlike wind turbines, is non-disruptive to bats and migratory birds. However, as with wind turbines, some GHGs are released during the production, transportation, and assembly of PV cells. Using land for solar farms also raises concerns about [land degradation and habitat impacts](#), and combining solar farms with agricultural use is more challenging than with wind energy. Finally, solar panels can create waste when they become defunct, as few places recycle old solar panels.

Market Issues

The primary impediment to widespread adoption of PV generation is cost. The average lifetime cost of PV power in Canada was around 23 cents per kW.h in 2016 (See Figure 18), far higher than other renewable alternatives, such as wind, and generally higher than market prices. Because of this, solar relies overwhelmingly on incentive programs for development.

FIGURE 17

World Solar Electricity Production in 2015



Source: [BP World Energy Statistical Review](#)

Description: The donut chart shows solar generation of the top seven producers and the rest of the world. The top seven solar electricity producers are China, the United States, Germany, Japan, Italy, Spain and the United Kingdom. Together, they produce about three quarters of world's electricity from solar. World's total generation of electricity from solar in 2015 was 253 TW.h.



Ontario's feed-in tariff (FIT) program provides the largest incentives for solar power in Canada which is why 98% of Canadian PV capacity is located in Ontario. FIT pays [PV generators 22.5 to 31.3 cents per kW.h](#) as of June 2016 for every grid-connected kW.h of generation, although prices can vary depending on the project's scale and development timing.

PV accounted for about 5% of Ontario's capacity in 2015, and some growth is expected, including in [larger transmission-connected solar farms](#). However, substantial new penetration in Ontario and beyond will be determined by future prices, incentives, and cost reductions.

Across Canada, some electricity retailers offer [net metering](#) to households with residential solar projects. This allows households to sell excess electricity back to the power grid.

Finding the Right "FIT" for Solar Development

Globally, Canada is a small developer of solar resources. In 2015, Canada [ranked 10th in the world](#) for annual PV installations by adding 600 MW of PV capacity; in the same year, China ranked 1st by adding 15 200 MW of capacity. As of 2015, solar contributed 0.5% to Canada's electricity generation (See Table 6). In comparison, Italy, Greece and Germany led the world for PV penetration with 8%, 7.4% and 7.1% of total electricity demand, respectively.

Germany's *Renewable Energy Sources Act* implemented a feed-in-tariff (FIT) for renewable power. The growth in

German PV generation can be explained by generous FIT prices, which are recovered through higher consumer bills. The German solar FIT varies by project size and year, starting at 57-45 euro cents per kW.h in 2004 and declining over time to 9-13 cents in 2014. Since 2014, FIT prices have been determined by auction in order to encourage competition.

Both Ontario and Germany have reduced their respective FIT prices over time. The programs successfully encouraged new PV development, but are being scaled down to control costs.



Emerging Technologies

Several renewable technologies currently have little or no market penetration in Canada's power sector, but have made significant breakthroughs elsewhere and have the potential to play a larger role in the Canadian energy mix. Those technologies include tidal, offshore wind, and geothermal energy.

Tidal

Electricity can be generated from tidal movements in four ways: tidal streams, tidal barrages, tidal lagoons and dynamic tidal power.

Tidal stream generators use underwater turbines to capture energy from tidal currents. Tidal stream systems extract the kinetic energy (energy in motion) from moving water generated by the tides without altering the environment. This technology has been deployed around the world, mostly in demonstration projects of less than 10 MW.

A tidal barrage is similar to a reservoir hydro dam except that it is built across a tidal estuary. The gates of the barrage are opened as the tide rises into the estuary and closed during high tide to capture a reservoir of water. Water is then released through a turbine generator during low tide to produce power. The largest tidal barrage in the world, in Korea, has a capacity of 254 MW.

A tidal lagoon is an enclosed ring wall that encircles an area of sea, forming an artificial lagoon. Like a tidal barrage, a tidal lagoon captures a reservoir of water at high tide, and releases water through turbines built into the wall during low tide to generate power. The 320 MW Tidal Lagoon Swansea Bay in the United Kingdom is the first proposed facility of its type and is planned to be commissioned in 2019.

Dynamic tidal power is a conceptual technology based on a long dam built out to sea from the coast, with many turbines embedded along its length. As the tide cycles, water would flow from one side of the T-like structure to the other, passing through the embedded turbines. Dynamic tidal power is still being researched and no facility has been constructed.

The only tidal power plants in North America are in Nova Scotia. The Annapolis Tidal Station was installed in Nova Scotia in 1984. The station has an installed capacity of 20 MW and generates 29 to 37 GW.h of electricity per year, depending on tides. Cape Sharp Tidal began testing the first turbine of a 4 MW project in the Bay of Fundy in late 2016. The project consists of two 2 MW in-stream tidal turbines, which, once operational, are estimated to reduce Nova Scotia's CO₂ emissions by 6 000 tonnes per year. Other projects planned for Nova Scotia are Black Rock Tidal Power (5 MW), Minas Tidal Limited Partnership (4 MW), Atlantis Operations Canada Limited (4.5 MW), Halagonia Tidal Energy Limited (4.5 MW), and Fundy Tidal Inc. (2.95 MW).

South Korea, France and the United Kingdom lead Canada in installed tidal capacity. Much of South Korea's capacity comes from its 254 MW Sihwa Lake project, which is situated on the west coast of South Korea and is connected to a 43.8 km² artificial lake. By opening the gates twice a day when the West Sea is at high tide, the power plant is able to generate about 552.7 GW.h of electricity annually.

TABLE 7

Top Five Countries for Tidal Capacity in 2015

Country	Tidal Power Capacity (MW)
South Korea	511
France	246
United Kingdom	139
Canada	40
Belgium	20

Source:

Ocean Energy Systems Annual Report 2015

Offshore Wind

Efforts to improve the efficiency of wind farms led to the installation of wind turbines offshore, where wind speeds are generally faster and larger turbines with higher capacity factors³ can be used. Offshore turbines are essentially the same as their land based counterparts, but are modified so that they can be installed in water. Shallow water turbines have a base fixed to the seafloor, while deep water turbines are attached to a floating base that is tethered to the seafloor.

[Offshore wind](#) is a proven technology that has operated in many parts of Europe for over 25 years. In 2015, Europe had approximately 11 GW of offshore wind capacity. [Wind Europe](#) set a target of 40 GW to be installed by 2020 and 150 GW by 2030. In contrast to Canada, Europe has a higher incentive to pursue offshore renewables due to higher energy and electricity costs, higher coastal population density, and a shortage of available land.

No offshore wind farms exist in Canada, but projects totaling more than 3.6 GW have been proposed. The 400 MW [NaiKun Project](#) in Hecate Strait, B.C. is the only West Coast proposal. Five projects totaling more than 3 200 MW, are planned by [Beothuk Energy](#) for Atlantic Canada: two off the coast of Newfoundland and Labrador, and one each off the shores of Nova Scotia, Prince Edward Island, and New Brunswick.

Environmental issues related to offshore wind are similar to those for onshore wind, but with concerns about marine ecosystems replacing concerns about primarily birds and bats. Because offshore wind farms are often located beyond the sight and reach of most onshore residents, they can minimize objections related to noise, recreation, and visual disturbances.

Offshore wind farms are more costly than onshore installations. Constructing in deep water is expensive, requires different materials, takes longer, and is more dependent on weather. Due to more extreme temperature shifts and corrosion issues, materials do not last as long and facilities require more operation and maintenance. Collisions with icebergs and motorized water craft can be additional risks.

On the other hand, [winds blow harder and more consistently offshore](#), producing up to 50% more electricity. Offshore winds also blow harder during the day, when electricity demand is highest, while [onshore wind typically blows stronger at night](#), when demand is low. Finally, capacity factors for offshore wind are approximately 45%, as opposed to 30% for onshore.

Geothermal

[Geothermal energy](#) is produced from heat in the earth, whether from magma, hot rocks, hot water, or steam. Adding fluid into hot areas creates steam which can then be used to generate electricity. Although the technology to generate power from geothermal energy has existed for over 100 years, no geothermal power plants operate in Canada.

At the end of 2015, world levels of installed capacity were 13.2 GW. The countries with most geothermal power capacity in 2015 were the [United States, the Philippines, Indonesia, Mexico, and New Zealand](#).

All of Canada has geothermal energy. However the principal areas showing the most promise are B.C., Alberta, the Yukon, the Northwest Territories, and Saskatchewan. Canada's west coast, on the eastern periphery of the [Ring of Fire](#) around the Pacific Ocean, is suited for larger-scale commercial power production. Isolated northern communities are exploring synergies between geothermal heat and power, even at smaller scales, in order to displace comparatively high energy costs for electricity and heat.

Primary factors determining whether a site is economically viable are how hot the water or steam is, and the speed and pressure at which it reaches the surface. Additional factors include how close the resource is to the surface, and proximity to transmission lines and markets. Unlike the majority of renewables, geothermal power is suited for base load generation as, once operational, it has a 98% reliability rate. Fuel costs are extremely low, as are operational and maintenance costs.



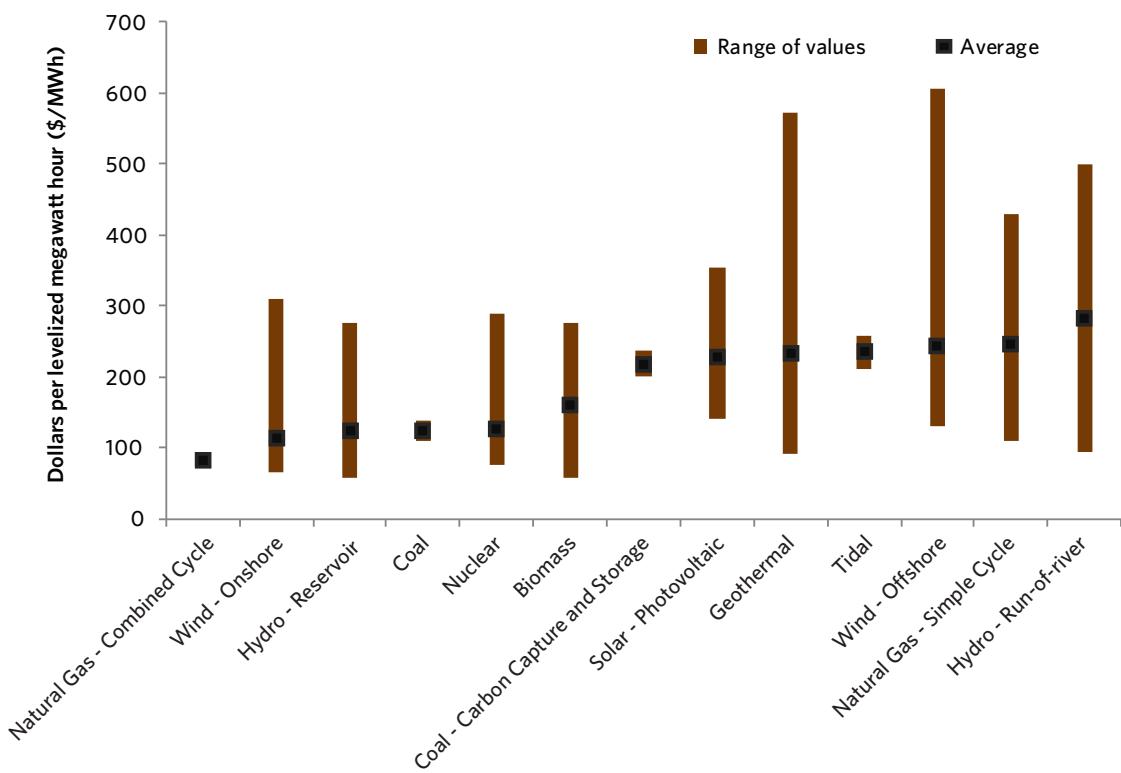
Costs and Trade-Offs

The financial cost of generating power from different sources or fuels varies. For example, power generated by PV solar tends to cost more than power generated by reservoir hydro. In addition, costs vary greatly between different solar projects and different hydro projects.

Generation projects can have vastly different sizes, power outputs, efficiency levels, and other operational variables. Financially, the cost of initial investment, ongoing operations, maintenance, and fuel vary greatly. Tax regimes and subsidies also affect project costs.

FIGURE 18

Levelized Cost of Electricity



Sources:

NB Power, AESO, Nova Scotia Power, OPG, IESO, Manitoba Hydro, BC Hydro

Description: The chart shows, leveled costs of various types of power plants. The leveled cost is the average price an electricity generator must receive for each unit it generates over its lifetime to financially break even. For each type of electricity generation, a column indicates the range of values reported in the provincial sources and the square indicates the average value. Combined cycle natural gas plants, onshore wind farms and reservoir hydro projects have the lowest average leveled costs. Offshore wind farms, simple cycle natural gas plants and run-of-river hydro plants have the highest average leveled costs.



One measure used to directly compare costs between technologies with such different characteristics is the leveled cost of electricity. This is the average price an electricity generator must receive for each unit it generates over its lifetime to financially break even. The leveled cost is often presented in cents per kW.h and calculated in today's dollars.

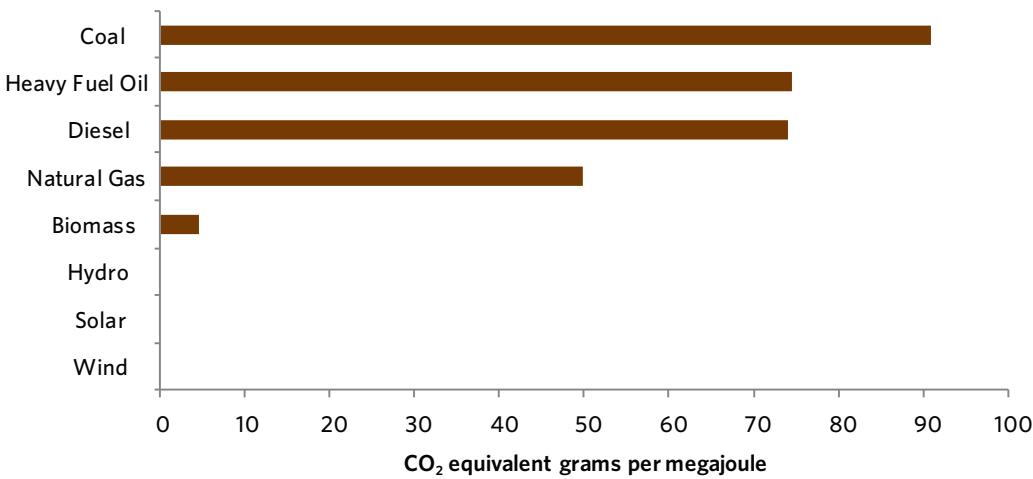
Most utility boards are concerned about the total cost consumers pay for electricity, including the impact on low-income consumers. Price is a large factor in decisions about which sources of generation to build or to run on a given day, and system operators typically build or run low-cost generators first.

Many additional factors must be balanced when making decisions about what sources to use to generate electricity. Reliability is a major concern, as system operators are mandated to ensure supply meets demand at all times. Intermittent sources of power, such as wind and solar, must be backed up by other sources of generation.

Different electricity sources also have different environmental costs. The world is currently focused on carbon emissions and greenhouse gasses (GHGs), often presented in tonnes of CO₂ equivalent. Operating hydro, wind, and solar generation create few or no emissions, whereas other types of generation can produce substantially more.

FIGURE 19

Emissions by Fuel Type



Source:

[Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040](#)

[Environment and Climate Change Canada](#)

Note: Greenhouse gases include: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), sulphur hexafluoride (SF₆), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and nitrogen trifluoride (NF₃).

Description: This chart shows estimated CO₂ emissions by fuel type, where emissions are presented in CO₂ equivalent grams per megajoule (g/MJ). Emissions from coal contribute the most at 90.87g/MJ, followed by heavy fuel oil at 74.58g/MJ, diesel at 74.08g/MJ, natural gas at 49.88g/MJ, and then biomass at 4.59g/MJ. There are no emissions from operating hydro, wind, or solar.

Every method of generating electricity has an environmental cost, even if there are no emissions from generation. Emissions are produced throughout the lifecycle of facilities. Raw materials must be gathered or mined and manufactured into the required components, which must then be transported to the generating site and assembled. Emissions are also generated by ongoing operations and maintenance. Beyond emissions, the construction, operation, and decommissioning of power facilities can have significant environmental impacts on the land, air, and water ecosystems around them.

Power generation policies balance these various costs and trade-offs in different ways. Current encouragement of wind, solar, and hydro reflects the prioritization of low emission generation. As technologies, costs, and environmental concerns evolve, the relative strengths and weaknesses of various fuels may shift.



Data challenges

Data in this report was derived from:

- Statistics Canada
- Open Government (a portal that provides access to the Government of Canada's searchable open data and open information)
- Provincial agencies
- Provincial utilities and system operators

Accurate and detailed data on renewables is difficult to obtain. When values are small, the data might be aggregated for ease of reporting or omitted from

reports for confidentiality. For example, when only one or two biomass facilities or wind facilities operate in an area, the generation data is not published.

The NEB used the best available data for this report, but it is likely that some data is absent. When necessary, estimates or older data was used.

The NEB is working with other federal and provincial organizations to reconcile and improve the quality of renewable power data in Canada.

For data questions or suggestions, please e-mail renewables@neb-one.gc.ca