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Merit Order Dispatch and Flexibility in Canada's Low-Carbon Electricity System

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The Canadian electricity system has a total installed capacity ranging between 152 and 193 GW, dominated by hydropower (103 GW), which represents the main source of electricity generation in the country. The generation fleet also includes approximately 29 GW of nuclear power, 33 to 36 GW of natural gas-fired power plants, 12 GW of coal, 13 to 19 GW of wind power, 1.8 to 6.5 GW of solar power, as well as around 3 GW of biomass and other renewable sources. Despite this large generation capacity, peak winter demand is significantly lower than the available capacity. Indeed, the maximum peak recorded during the winter of 2022–2023 reached a historical level of approximately 43,124 MW (43.1 GW), representing only 22 to 28% of total installed capacity. This large margin is explained by the strongly hydro-based structure of the Canadian system, the diversity of generation resources, interprovincial and international electricity exchanges, as well as the reserves required to ensure supply security during periods of high demand.

Merit Order Curve of the Canadian Electricity System

The first figure (Figure 1) presents the merit order curve of the Canadian electricity generation fleet. This representation classifies different generation technologies according to their marginal cost of production, from the least expensive to the most expensive. The horizontal axis represents cumulative installed capacity (MW), while the vertical axis indicates the different generation technologies.

The curve begins with hydropower, which is the main source of electricity generation in Canada with an installed capacity of approximately 103 GW. This technology appears first in the merit order due to its very low operating marginal cost. Once dams are built, the variable costs associated with electricity production are extremely low, which explains their priority dispatch to meet demand.

The second technology is nuclear power, representing approximately 29 GW of installed capacity. Although initial investment costs are high, marginal operating costs remain low due to inexpensive fuel. Nuclear plants typically operate in baseload mode, which justifies their position immediately after hydropower in the economic dispatch order.

Next come wind turbines (16 GW) followed by solar photovoltaic plants (4 GW). These two technologies use free natural resources (wind and solar radiation) and therefore have nearly zero marginal cost. Their position in the curve reflects their economic priority when available. However, their production is intermittent and depends on weather conditions.

Biomass (3 GW) appears next. This technology has a slightly higher marginal cost than previous renewables due to fuel supply costs, but remains cheaper than fossil fuel thermal plants.

The last two technologies correspond to dispatchable fossil fuel generation. Natural gas plants (35 GW) occupy the second-to-last position. Their marginal cost is mainly driven by fuel prices, and they are typically used to respond to demand fluctuations or during periods when renewable generation is insufficient.

Finally, coal-fired power plants (12 GW) close the merit order curve. They have the highest marginal costs among the technologies represented, along with significant CO emissions. They are therefore only used when other generation sources are insufficient to meet demand.

The width of each colored rectangle represents the installed capacity of the corresponding technology. The total cumulative capacity reaches approximately 202 GW, illustrating the diversity of the Canadian generation fleet and the large reserve margin available compared to peak system demand.

This representation clearly highlights the strong dominance of hydropower in the Canadian electricity mix as well as the relatively low contribution of fossil fuel-based generation in total installed capacity.

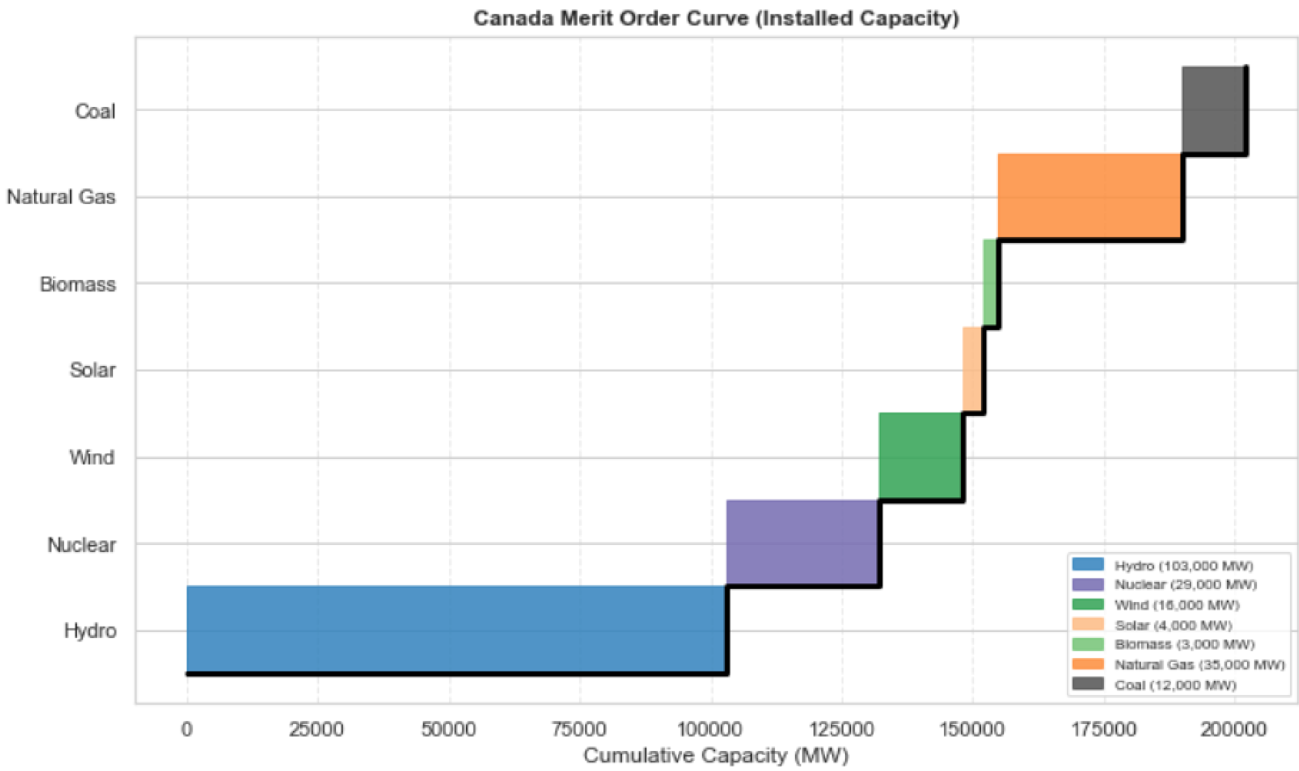

Figure 1: Merit order curve of the Canadian electricity system based on installed capacities (2024). Generation technologies are ranked in ascending order of marginal cost, from hydropower and nuclear (low marginal costs) to natural gas and coal-fired power plants (higher marginal costs). The width of each segment represents the installed capacity associated with each technology, illustrating the strongly hydro-dominated structure of the Canadian electricity mix as well as the diversity of generation resources. Source: Own elaboration.

Daily Electricity Generation Profile (Dispatch Stack Plot)

The second figure (Figure 2) illustrates the hourly electricity generation profile during a representative winter day in Canada under a simplified residual load model.

The horizontal axis represents the 24 hours of the day, while the vertical axis indicates electrical power in MW.

The black curve corresponds to total system electricity demand. It follows a typical winter daily pattern: relatively low consumption during the night, gradual increase in the morning with economic activity, and a peak in the early evening when heating, lighting, and residential consumption are simultaneously high. In this simulation, peak demand reaches approximately 43,124 MW, consistent with the record observed during winter 2022–2023.

The colored areas represent the contribution of each generation technology.

Hydropower, shown in blue, is the main source of electricity throughout the day. Thanks to the high flexibility of reservoirs, production is adjusted slightly to follow demand fluctuations. This feature is one of the main advantages of the Canadian electricity system.

Nuclear generation, shown in purple, remains almost constant throughout the day. Nuclear plants operate mainly as baseload units and are rarely used to follow rapid load variations. They therefore provide a stable output close to their nominal capacity.

Wind generation, shown in green, fluctuates continuously depending on wind availability. These variations are independent of electricity demand and illustrate the intermittent nature of this energy source.

Solar photovoltaic generation, shown in light orange, is zero during the night. It increases after sunrise, reaches a maximum around midday, and decreases until sunset. This follows the natural daily solar cycle.

Biomass, shown in light green, provides nearly constant output throughout the day. It serves mainly as a dispatchable renewable source.

After accounting for all renewable and nuclear generation, the corresponding residual load is covered by thermal power plants.

Natural gas plants, shown in dark orange, are only dispatched when other generation sources are insufficient to meet demand. Their output increases mainly during periods of high consumption, particularly during the evening peak.

Coal-fired power plants, shown in dark grey, are only activated when gas plants reach their limits or when demand exceeds the remaining available capacity. Their contribution remains relatively limited, reflecting the current low reliance on coal in Canada.

The sum of all colored areas equals the system load at each moment in time. This representation highlights the fundamental principle of electricity dispatch: generation resources are called progressively according to their marginal cost to continuously balance supply and demand.

It is also observed that the large hydroelectric capacity absorbs a significant portion of daily demand variability, thereby reducing reliance on fossil fuels. This configuration contributes to lowering greenhouse gas emissions while ensuring high operational flexibility of the Canadian electricity system.

Finally, the figure shows that despite a national installed capacity well above 190 GW, simulated peak demand reaches only about 43 GW, indicating a large reserve margin required to ensure supply security, manage weather variability, account for generation outages, and support interprovincial and cross-border electricity exchanges with the United States. This large reserve margin is one of the key characteristics of the Canadian electricity system.

Can Canada transform its surplus electricity into a lever for green hydrogen production?

The large installed electricity generation capacity in Canada, significantly exceeding peak national demand, offers substantial opportunities for valorizing surplus generation, particularly from low-carbon electricity sources such as hydropower, nuclear, wind, and solar (Figure 2). These electricity surpluses, especially during periods of low demand or high renewable availability, can be converted into green hydrogen or low-carbon hydrogen through water electrolysis. This strategy represents a major lever for the energy transition by enabling the decarbonization of sectors that are difficult to electrify directly, such as heavy transport (trucks, buses, trains, maritime transport, and in the longer term aviation) as well as energy-intensive industries, including steelmaking, chemicals, refining, ammonia and methanol production, and cement manufacturing. Hydrogen can also serve as a seasonal energy storage medium, thereby improving the flexibility and resilience of the power system in the face of renewable variability. Furthermore, given Canada's abundant energy resources and its proximity to North American and European markets, part of this hydrogen, or its derivatives such as ammonia or synthetic fuels, could be exported.

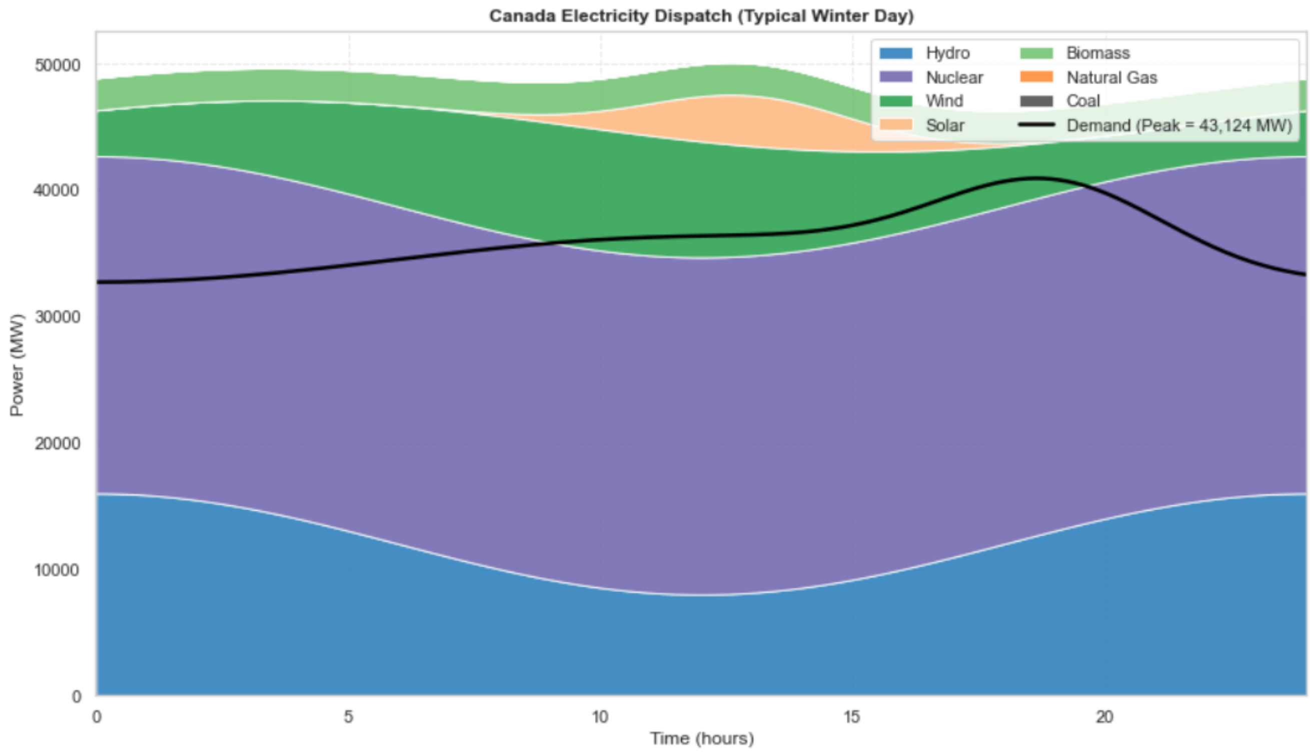

Figure 2: Dispatch Stackplot (Winter Day). Simulation of the daily electricity dispatch of the Canadian system during a representative winter day. Generation is broken down by technology according to a residual load model, where demand is primarily met by low marginal cost sources (nuclear, hydropower, wind, solar, and biomass), while natural gas and coal-fired power plants are used to cover peak demand. The black curve represents total electricity demand, with a peak of approximately 43 GW in the evening. The figure highlights the central role of hydropower in system balancing and demonstrates the flexibility of the Canadian generation fleet. Important Note: The apparent absence of generation from natural gas and coal-fired power plants in the stackplot is explained by the structure of the dispatch model used, in which electricity demand is fully covered or even exceeded at certain times by the sum of so-called priority generation sources, namely nuclear, hydropower, wind, solar, and biomass. In this type of representation based on a simplified merit order, fossil thermal generation is defined as residual capacity that is only dispatched when low marginal cost resources are insufficient to meet demand. However, under the chosen parameters, the combination of nearly constant nuclear generation, significant and flexible hydropower contribution, and a substantial share of variable renewable energy leads to a structural situation of relative overproduction compared to simulated demand. As a result, the residual load variable becomes zero or nearly zero over the entire simulated period, which mechanically implies no dispatch of natural gas and coal-fired power plants in the system. This result does not reflect an absence of these technologies in the real system, but rather a calibration of generation and demand profiles that limits their activation. To make these technologies visible in the graphical representation, it would be necessary either to increase peak demand or to reduce baseload generation, thereby reintroducing a residual deficit that justifies the dispatch of thermal power plants in the system balancing model. Source: Own elaboration.