Submission to the Ontario Ministry of Energy in response to its request for feedback on the IESO's *Pathways to Decarbonization* study (ERO #019-6647)

May 12, 2023

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This submission to the Ontario Ministry of Energy is supplementary to the May 10, 2023, submission by the Boltzmann Institute in response to the Ministry's request for feedback. The present submission reinforces elements of the Boltzmann Institute's main submission. It contains material that was unavailable at the time of preparation of the main submission or could not otherwise be fitted readily into that submission.

What follows provides additional information on and analysis concerning two related matters:

(1) Estimates of the peak demand for electric power in 2050. This section concludes that the estimates in the IESO's *Pathways* document are too low on account of the way in which transport electrification may have been considered. Proper treatment of this factor, as well as the proper treatment of heating electrification indicated in the main Boltzmann Institute submission, could raise the winter peak demand for electricity in 2050 from the 60 GW expected by the IESO to about 103 GW. (The current peak is about 25 GW.) Extending the IESO's cost estimates to the required additional increase in electricity infrastructure indicates a required expenditure by 2050 that could total some $900 billion in 2022 Canadian dollars, i.e., just short of Ontario's trillion-dollar, annual gross domestic product.[1*]

(2) Lengths of long periods of cold weather. These were determined for seven Ontario locations. The longest periods during which the outside air temperature remained below -10°C ranged between 84 hours in Sarnia and 340 hours in Thunder Bay. The possible continued occurrence of long periods of cold during the decades ahead strengthens the need for reliable and affordable means of space heating.

As in the main Boltzmann Institute submission, there are indications in what follows that widespread deployment of district heating would avoid or greatly alleviate many of the challenges resulting from the extensive electrification of space heating that is a central feature of the IESO's *Pathways* study. A very preliminary estimate suggests that investment of $64 billion to achieve 70% penetration of district heating across Ontario could reduce needed investment in electricity infrastructure by several hundred billion dollars.

[*] Superscript numbers in the text point to source and other notes beginning on Page 8.

1. Further consideration of estimates of peak demand for electric power in 2050.

In the *Pathways* report, the IESO began the introduction to its "pathway to decarbonization" as follows:

> In the development of a pathway to a decarbonized grid, the IESO adopted a more aggressive electrification demand forecast. The Pathways scenario illustrates a system designed to meet winter peaks that are almost three times higher than those we experience today. As a result, the system would likely require an additional 69,000 MW of non-emitting supply and 5,000 MW in demand reductions from conservation.[2]

By contrast, the IESO anticipated that summer peaks – now a little higher than winter peaks – would rise at a much lower rate than winter peaks. This is illustrated in Table 1.

Table 1. Anticipated Ontario electric power peak demands, 2024 and 2050, total and per-capita.

	2024 (GW)[3]	2050 (GW)[3]	GW increase (2024-2050)	2024 (kW/capita)[4]	2050 (kW/capita)[4]	kW/cap increase (2024-2050)
Summer peak	24.68	36.44	48%	1.58	1.75	11%
Winter peak	22.67	59.82	164%	1.45	2.87	98%

Table 1 suggests that the summer peak is expected to rise at an average of 1.5% per year, a third higher than the 1.1%-per-year increase expected for population growth.[5] The annual increase in the winter peak is expected by the IESO to be a much higher 3.8% – several *times* more than would be expected from population growth. What accounts for this extraordinary growth in the winter peak and the comparatively low rate of growth of the summer peak?

To deal with the summer peak first: Apart from a list of demand assumptions in the IESO's *Pathways* report's Appendix A,[2] there's no indication from IESO as to how the summer peak in 2050 was estimated. Review of the list suggests that road transport electrification could be the main contributor to the to the increase in summer peak demand noted in Table 1, beyond the 8.51 GW that could be expected if per-capita electricity consumption were to remain unchanged. Other potential increases (e.g., from electrification of manufacturing activity) could be offset by system-wide energy efficiency. If so, the contribution to the 2050 Ontario peak of full electrification of light-duty vehicles would be 3.51 GW. Is this a plausible estimate?

Almost all light-duty vehicles are currently fuelled by gasoline, which has few other uses. In 2020, their energy consumption in Ontario was close to 100 TWh.[6] Allowing for population growth, full electrification of these vehicles could require about 54 TWh of electrical energy in 2050.[7] Using the *Pathways* report's link between energy use and peak demand,[8] the energy use could correspond to an increase in peak demand of 11.04

GW. This is a much higher estimate than the increase of 3.51 GW for transport electrification derived in the previous paragraph. What might account for the discrepancy?

The IESO could have pointed to two things that may reduce peak demand resulting from electrified transportation. One is **time-of-use pricing of electrical energy**. In Norway, a cold country that has the world's highest EV (electric vehicle) ownership per capita,[9] over 80% of the charging of EV batteries occurs at owners' homes, almost all overnight, almost all under the control of smart meters.[10] Overall, such pricing has been found to reduce overall electricity demand by less than 3% during high-price periods. For households with an EV (18% of those studied) this was the most prominent measure.[11]

A reasonable preliminary conclusion from work in Norway could be that time-of-use pricing can have a certain but small effect on when EVs are charged. A similar conclusion has been made about the effect of time-of-use pricing in Ontario,[12] although not for charging EV batteries. Of course, if peak prices were, say, 20 times off-peak prices rather than the roughly double that applies in Norway and Ontario, the effect on charging could well be stronger.

Another contribution that electrified transportation might make to reducing peak demand could be through **vehicle-to-grid (V2G)** arrangements, whereby electricity stored in vehicle batteries can be made available to the grid, mostly to avoid expensive development of infrastructure used only during peak periods.

A March 2023 account of attempts since the early 20th century to use vehicle batteries to solve grid management problems and of V2G's current prospects concluded, "the idea of an off-the-shelf energy storage unit that also provides transportation and pays for itself is likely to remain attractive enough to sustain ongoing interest. Who knows? The electric car might still one day become a power plant on wheels."[13] The point to be made here could be that such an important matter as electricity planning should not rest on a technology whose prospects for widespread use seem so unproven.

A final factor to be mentioned in discussion of the summer peak estimate is the reduced vehicle battery performance when temperatures are high. Ontario's hot weather would appear to be friendlier to vehicle batteries than its cold weather – to be discussed below. The driving range at +30°C is about 10% below the near +20°C "perfect temperatures" at which "the existing literature on EV-power and grid studies assumes that EVs are used."[14] Thus, the above estimate that Ontario's summer peak could rise by about 11 GW by 2050 on account of transport electrification could be considered conservative, even after allowing for the (modest) effect of widespread time-of-use pricing.

It may be a coincidence, but also close to 11 GW is the allocation for demand savings in the IESO's pathway to decarbonization; where demand savings includes "savings from energy efficiency and demand response."[2] The quotation on Page 2 above indicates that 5 GW is to come from energy efficiency, leaving 6 GW to come from demand response. No further details are given, including as to whether the expected demand response could increase emissions. The above discussion suggests that it would be a mistake if the IESO were to assume that all or a substantial portion of this allocation could be directed towards reducing the impacts of transport electrification on peak demand.

Thus, subject to more details of the IESO's pathway to decarbonization being made available, **it may be reasonable to conclude that the IESO's estimate of the summer peak for 2050 should be close to 44 GW rather than near 36.5 GW** (i.e., 7.5 GW [11 GW less 3.5 GW] above what is projected).

Now to turn to what may be transport electrification's contribution to winter peak demand – perhaps more significant because of the IESO's anticipation of a much increased winter peak: The most substantive reference to transport electrification in the *Pathways* report is on Page 27: "The system becomes winter peaking by 2030, largely as result of increased electrification of transportation – i.e., evening or overnight charging – and of heating requirements in buildings."[2] This is the only suggestion in the report that transport electrification may have a substantial impact – again without details.

Unless otherwise indicated, the following discussion of EVs in cold weather is based on material and conclusions in a comprehensive and authoritative review published on April 20, 2023.[14]

There are two reasons to expect transport electrification to add to the winter peak. One is that winter driving uses electricity less efficiently, in terms of energy use per kilometre travelled. This happens because the battery and the vehicle's cabin must be heated, because of adverse road conditions, and because of battery chemistry. At -10°C, the overall effect on range seems to be a reduction by 30-50% from that at about +20°C. The effect varies with vehicle type and driving style, and with whether there is preheating of the cabin and battery before driving. Battery chemistry – an extraordinarily complex matter – seems to be responsible for a winter reduction in range of about 25%. (For some vehicle batteries, the manufacturer does not advise operation below +15°C.)

The other reason is that charging EV batteries is less efficient when batteries are cold. This seems to be particularly true of fast charging – which involves delivery of high-voltage direct current at a charging station, capable of charging an EV's battery in about 25 minutes at +20°C but requiring much longer at low temperatures. The efficiency of

fast changing (energy stored as a percentage of the charging energy) can fall from near 100% at "perfect temperatures" to below 40% at very low temperatures, with a consequent further contribution to peak demand.

Slower charging, as may be done at home, is much less affected by temperature, although one battery manufacturer recommends that *no* charging be done below +10°C. Regenerative braking, an appealing feature of EVs and a form of charging, is often switched off by battery management systems during cold weather.

(Not pursued here is another potential challenge posed by fast charging of EV batteries. It's been found that despite the large exchanges of electrical energy involved, "harmonic limitation is a much more significant issue [for fast charging] than power limitation." Such implications for power harmonics have been described as "an untouched area in the existing literature.")

Compounding the above two reasons is the phenomenon that batteries age more quickly when exposed to low temperatures and that a battery's ability to accept and supply charge declines with age. Exposure of a lithium-ion battery pack to a winter total of 21 days at -10°C degrades battery performance by about 20%, whereas degradation would be negligible at 20°C. Thus, there is good reason to keep EVs in heated garages (or at least to arrange that their batteries are warm), providing a further possible contribution to peak demand.

Taking all the above impacts of cold-weather driving and cold-weather charging into account, it may be reasonable to expect that transport electrification in Ontario will result in an increase in the order of 50% in the winter peak demand for electricity compared with its effect on the summer peak.

However, the scant available data suggest that about 24% less driving occurs in Canada in winter than in summer,[15] which could bring the effect on the peak down to a 14% increase, i.e., the winter peak would be close to 12.5 GW.

Again subject to more details of IESO's pathway to decarbonization being made available, it may be reasonable to conclude that the IESO's estimate of the winter peak should be increased by about 12.5 GW on account of transport electrification. This increase would be in addition to the increase of about 31 GW identified in Appendix 2 of the main Boltzmann Institute's submission. Thus, **it may be reasonable to conclude that the IESO's estimate of the winter peak for 2050 should be near 103 GW rather than near 60 GW** (i.e., 31 GW more for heating plus 12.5 GW more for transportation above what is projected).

The IESO estimated that providing for an increase in peak electricity demand from about 25 GW to about 60 GW by 2050 would cost about $400 billion in 2022 Canadian dollars. It may be reasonable to suggest that providing for an increase that is about 125% higher – from an increase of 35 GW to an increase of 78 GW – could cost about $900 billion. The further increase for transportation identified here greatly increases the need to reduce peak electricity demand, and thus reduce these massive costs.

Experience of other countries suggests that 70% penetration would be a reasonable Ontario target for district heating by 2050. For example, Finland and Sweden have overall population densities and winter climates not unlike Ontario, and current district heating shares above 60%.[16]

An assessment for Mississauga,[17] extrapolated to Ontario, suggests that 70% penetration of district heating by 2050 would require investment of about $64 billion. The peak electricity demand for heating could perhaps be reduced by a similar percentage, reducing the costs of required electrical infrastructure by several hundred billion dollars. Such costing is urgently in need of substantiation, to be provided by a Boltzmann Institute-led project being conducted in collaboration with McMaster University's Faculty of Engineering. The project's results should be available in early 2025.

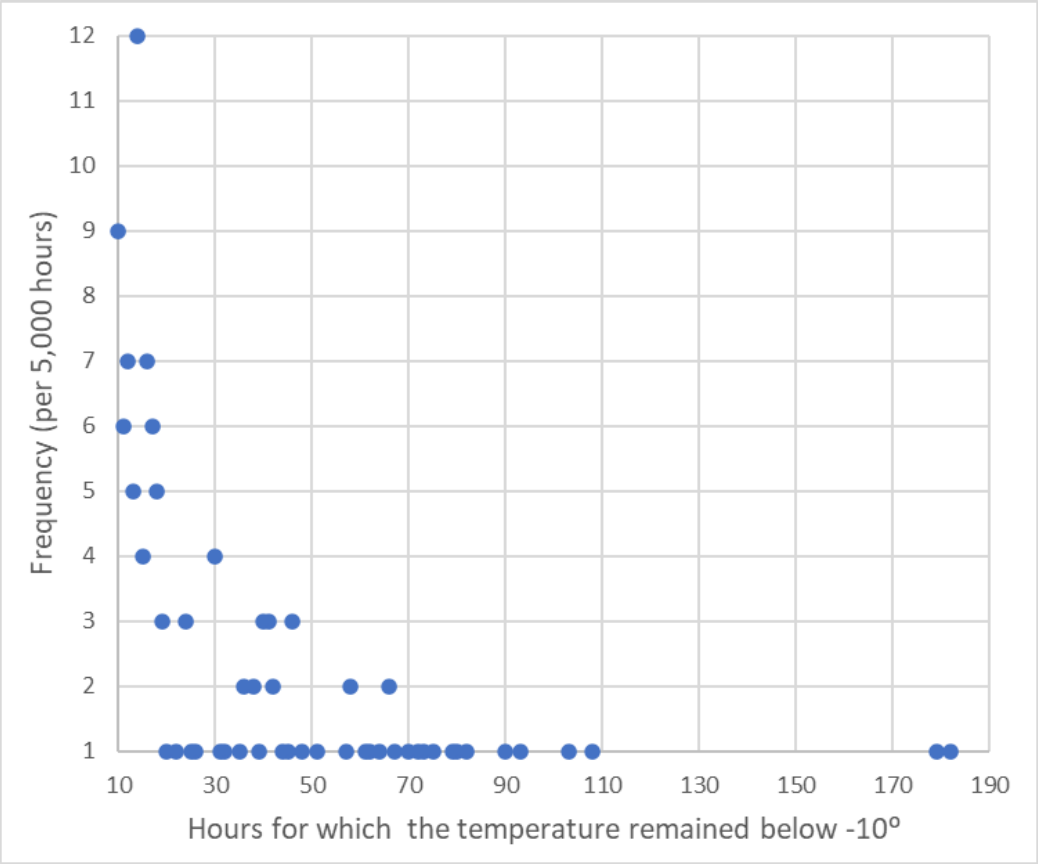
2. Consideration of the durations of cold-weather spells

This section concerns Ontario weather during the period from 2017 to 2023. Weather in 2050 may well be very different, although it's hard to know today if more or fewer periods of extreme cold can be expected. The IESO, in elaborating its "pathway to decarbonization," included the following: "The demand scenario is based on an assumption of normal weather patterns and does not consider extreme weather events or the projected increase in overall temperature."[18] The same approach is used here.

The Boltzmann Institute examined hourly data from seven weather stations – Thunder Bay, Sudbury, Ottawa, Kingston, Toronto, London and Sarnia – across 5,000 hours from 9 pm on August 2, 2017, to 4 am on April 17, 2023, noting the distributions of durations of particular kinds of weather.

Data from Ottawa, the third coldest of the seven locations, is used to illustrate the kind of results obtained. The distribution of periods when the temperature remained below -10°C is shown in Figure 1 on the next page. Across the 5,000 hours, spanning six winters, there were 120 occasions when the outside temperature remained below -10°C for 10 hours or more. 69 of these were for 10-24 hours; 51 were for longer than 24 hours. The two longest such periods were for 182 and 179 hours, ending at 5:00 am on

Figure 1. Frequencies of lengths of periods below -10°C in Ottawa



December 26, 2017, and at 1:00 am on January 20, 2022, both having lasted more than a week. The most frequent length was 14 hours, which happened 12 times.

The lengths of the longest cold periods varied with the annual mean temperature of the location. The longest cold period was recorded in Thunder Bay (340 hours below -10°C). The location among the seven with the shortest of the longest cold periods was Sarnia (84 hours).

The temperature of -10°C was use as an analysis point because it is a temperature below which there are severe impacts of cold on EV battery operation and charging, as noted above. This is also a temperature at which regular air-source heat pumps (ASHPs) typically have low efficiency, i.e., a coefficient of performance (COP) of 1.0 or close to 1.0.[19] Indeed, Manitoba Hydro recommends regular ASHPS not be used when outside air temperatures are below -10°C.[20]

Cold-climate ASHPs meeting a US standard recommended by Natural Resources Canada[21] maintain a COP of 1.45 to 1.75 or higher at -15°C when they are new, properly

installed, and operating at their maximum output. They cost substantially more than regular ASHPs.[22] Manitoba Hydro suggests that "cold climate heat pumps can still provide heat to −25°C or −30°C, depending on the manufacturer's specifications."[20]

However, a Winnipeg installer suggests that even with a cold-climate ASHP "you will typically need a secondary source of heat if temperatures go below 10 degrees Fahrenheit [-12.2°C]. This could include a dual-fuel system with a gas furnace. Heating alternates between the two to deliver the most energy-efficient heating comfort across your home."[23] Using a natural gas furnace would not be consistent with attainment of net-zero greenhouse gas emissions. Electric resistance heating would be the likely alternative, adding to peak demand in the coldest weather.

The data for Ottawa in Figure 1 point to what may be surprisingly long periods of cold weather, and thus the need for reliable and robust sources of heating. Electric heating – whether using heat pumps or resistance heating and subject to interruption on account of inadequate anticipation of peak demand – increases the risk of life-threatening outages. Although deaths associated with hot weather have been more in the news, it may well remain the case that mortality rates in Canada associated with cold weather are many times the rates associated with hot weather.[24]

District heating, using hot water available at all outside air temperatures, whether from waste heat or summer heat stored seasonally, can provide reliable heating throughout the deepest Ontario cold weather.

Source and other notes

1. Ontario's GDP in 2022 was $1.04 trillion (link). If the required investment of $900 billion were to be spread across the 26 years from 2024 to 2050, it would amount to about $35 billion per year. This rate of investment can be contrasted with the current annual rate of investment in new electricity infrastructure by Ontario Power Generation Inc., which owns close to half of Ontario's grid-connected generation capacity (see link, and Table 7 at link) and by Hydro One Limited, which owns 98% of Ontario's distribution capacity (link). OPG's capital investment in 2022 was $2.6 billion (link). Hydro One's was $2.1 billion (link).All data here are in Canadian dollars.
2. The IESO's *Pathways to Decarbonization* report and its five appendices are at link. This quotation is from Page 2 of the report.
3. The 2024 and 2050 summer and winter peaks are taken from Figures 8 and 9 of Appendix D to the *Pathways* report (see Note 2).
4. The per-capita conversions made use of the population estimates for 2024 to 2046 by the Ontario Ministry of Finance at link, extrapolated to 2050.
5. In 2021, the IESO had predicted a steady growth in consumption of electrical energy of 1.7% per year between 2023 and 2042 (link). In Appendix D of the *Pathways*

report (Note 1), the rate of growth in consumption of electrical energy between 2024 and 2050, with full decarbonization, is anticipated to be to be 2.7% per year. The growth rate of peak demand for electrical power between summer 2024 and winter 2050, with full decarbonization, is anticipated to be 3.5% per year.

[6] 2020 data on gasoline consumption are from Natural Resource Canada's Comprehensive Energy Use Database at link.

[7] The estimate of 54 TWh assumes the energy consumption of light-duty vehicles would be 140 TWh in 2050 if they were still fuelled by gasoline and the per-person rate of use of them remained the same. The estimated electricity consumption if they will all be battery electric vehicles assumes an average efficiency of 35% for gasoline vehicles, and 10% charging and other losses associated with summertime electric traction. (Battery electric vehicles are typically 30-50% heavier than equivalent gasoline-fuelled vehicles. The energy required to move the extra weight is assumed here to be offset by efficiency improvements.) Full electrification of these vehicles would thus consume 18% of Ontario's total electrical energy use in 2050 (see the Appendix D source in Note 2 for an estimated total). This share may be compared with a corresponding estimate for Germany: 16% of total electrical energy use (link).

[8] As indicated in Note 5, the IESO anticipates that the rate of growth of peak power demand will be 30% higher than the rate of growth of energy consumption.

[9] For Norway's pre-eminence in EV ownership, see the source at link.

[10] For information about home charging and other aspects of electric vehicles in Norway, see link.

[11] See Matthias Hofmann and Karen Lindberg, Evidence of households' demand flexibility in response to variable electricity prices – Results from a comprehensive field experiment in Norway (March 24, 2023). Available at SSRN (link).

[12] A 2017 study (link) of time-of-use (TOU) electricity pricing in Ontario concluded, "TOU reduced usage during the summer peak by 3.26% in the pre-2012 period, 2.27% in 2012, 2.00% in 2013, and 1.18% in 2014, relative to what usage would have been in the absence of TOU."

[13] See Matthew Eisler, "False starts: the story of vehicle-to-grid power," *IEEE Spectrum*, March 11, 2023, at link.

[14] See Figure 16 of Mukat Senol et al, "Electric vehicles under low temperatures: a review on battery performance, charging needs, and power grid impacts," *IEEE Access*, vol 11, 2023, 39879-39912 (link). The quotations are from the abstract of this paper.

[15] For an insurance industry estimate of the lower driving rate in winter, see the article at link.

[16] Sweden's country-wide district heating share seems to be about 63% (extrapolated to 2023 from data in Figure 1 of Sven Werner, District heating and cooling in Sweden. *Energy*, vol 126, 2017, 419-429). Finland's seems to be above 65% (see Page 24 of the report at link). The respective population densities are 23 and 17 persons/km^2; Ontario's is 13/km^2. The highest district heating share – about 90% of all floor space – appears to be in Iceland (link), which has an even lower population density than Ontario (4/km^2), but extensive geothermal resources.

[17] The March 22, 2023, report by FVB Energy Inc., *City of Mississauga District Energy in the Downtown: Feasibility Study*, may be the best available indication of the current costs of district heating in Ontario (link). Details of how the costing in that report have been extrapolated to 70% pene-

tration of district heating throughout Ontario are available from the author of this submission (who stresses that the extrapolation and subsequent costing are very preliminary in nature).

[18] The quotation about weather is on Page 26 of the report detailed in Note 2.

[19] A COP of 1.0 means that the ASHP has the same heating efficiency as electric resistance heating. A COP of 2.0 means that it is twice as efficient, i.e., half the energy is used to provide the same heat output as resistance heating.

[20] The advice is in Manitoba Hydro's document at link.

[21] On Page 23 of the Natural Resources Canada document, *Air-source heat pump sizing and selection guide : procedure for mechanical designers and renovation contractors* (link), it's suggested that cold-climate ASHPs are required "for most climate zones in Canada." This document points to the U.S. Northeast Energy Efficiency Partnerships' *Cold Climate Air-Source Heat Pump Specification* for information. The January 2023 version of the *Specification* is at link. This version appears to have introduced a less stringent COP requirement for some cold-climate equipment. It now allows COP values as low as 1.45 at -15°C, whereas the 2021 version spoke only to 1.75 as the minimum coefficient of performance at this temperature.

[22] Comparative prices for conventional and cold-climate ASHPs are hard to secure. A March 2022 BC Hydro document at link suggests that cold-climate versions may cost about 25% more.

[23] The quotation is from the website of Winnipeg Supply at link.

[24] See Antonio Gasparrini et al, Mortality risk attributable to high and low ambient temperature: a multi-country observational study. *The Lancet*, vol, 386, 2015, 369-375. Data for the Canadian element of this study are from 1986-2009. Deaths in Canada during this period attributed to cold weather were about nine times the number of deaths attributable to hot weather.