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Assessing the photovoltaic potential of the Canadian building stock

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January 10, 2024

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1 Introduction

The Canada Energy Regulator predicts that electricity demand in Canada will more than double between now and 2050, with increasing electrification and the need for clean electricity in order to meet the 2035 and 2050 net-zero electricity and energy targets, respectively. [1]. For the electricity sector, this will require a substantial buildout of technologies like solar photovoltaics (PV), which convert the sun's energy into electricity.

In 2006, Pelland and Poissant analyzed the potential of PV systems that could be installed on Canada's residential, commercial, and institutional buildings [2]. They estimated that such systems could generate each year enough electricity to meet 29 % of these buildings' electricity needs. Since then, the price of PV modules (also known as solar panels) has decreased by about 90 % [3] [4], and they have become more efficient, requiring less area to generate the same power. The Canadian building stock has also grown considerably.

The current report revisits, improves upon, and updates the estimates of PV potential on Canadian buildings from [2]. It focuses on technical potential [5], meaning that all building surfaces that can support PV are included, irrespective of financial viability, hosting capacity of the electricity grid, or matching of supply and demand in real time. Such technical potential is the starting point for studies of the market potential, i.e., the contribution that PV on buildings could make to Canada's future electricity supply, once economic, grid integration and other factors are considered.

This report is structured as follows: Section 2 details the methodology used to generate PV potential estimates. Section 2.1 describes the development and application of a new statistical method for estimating rooftop PV technical potential in Canada. Section 2.2 discusses other statistical methods that yield quasi-economic PV potential by limiting this to surfaces that meet certain requirements in terms of orientation, shading, solar resource, and area. Technical potential and quasi-economic potential results are presented and discussed in Section 3, and Section 4 provides concluding comments.

2 Methodology

The goal of this analysis is to estimate PV technical potential on buildings (capacity and electricity generation) for Canada, and each of its provinces and territories. The method used for the earlier estimates in [2] is based on statistical rules derived by the International Energy Agency Photovoltaic Power Systems Programme Task 7 (IEA PVPS Task 7) in [6]. However, the statistical methods used in [6] and in more recent analyses in Canada [7] and the U.S. [8] [9] include criteria that are more properly construed as financial rather than technical, such as excluding areas based on shading losses and on solar resource. Considering for instance the case of building integrated photovoltaics (BIPV), these constraints on shading and solar resource are not appropriate since PV materials replace traditional roofing materials over the entire roof surface, regardless of these factors.

A new statistical method was therefore developed to estimate rooftop PV technical potential in Canada, as described in Section 2.1. It is based on a detailed analysis of PV technical potential in 11 Canadian municipalities, using Light Detection and Ranging (LiDAR) and building footprint data. The LiDAR-based analysis was not used for all of Canada due to data availability limitations: LiDAR data and especially building footprints are not yet available for every Canadian municipality. This type of analysis is also very computationally intensive compared to statistical methods.

2.1 New statistical method

2.1.1 Technical PV potential on rooftops for selected municipalities

The new statistical method was developed using LiDAR [10] and building footprint [11] data. Airborne LiDAR data are gathered by aircraft that emit laser pulses travelling toward the ground, with GPS used to track their position. The travel time of the laser pulses is used to obtain elevation values as a function of location on the Earth's surface, generating what is known as a LiDAR point cloud. The LiDAR-based analysis was performed for the 11 municipalities shown in Fig. 1. These were selected based on the availability of both the building footprint and LiDAR data, the density of the LiDAR points (with a median of 14.4 points/m^2 and a range of 4.7 to 90.8 points/m^2), and the computational time of the simulations. As such, in larger municipalities, only a portion of the municipality was included in the analysis. When possible, at least one municipality was selected per province or territory to sample from a broad range of Canadian climates and building stocks.

The analysis was completed in Python and QGIS. QGIS was used for visualization of the data. Fig. 2 describes the process for the LiDAR analysis and lists the Python packages and modules used in specific steps. WhiteboxTools Open Core v1.4.0 (WBT) [12] was used to:

1) Create digital surface models (DSMs) that represent municipalities as surfaces in 3D, with pixels corresponding to the highest-elevation objects for each location. This was completed with WBT functions LiDARDigitalSurfaceModel and Mosaic, using a DSM resolution of 0.5 m.

Fig. 1: Location of the 11 municipalities across Canada included in the LiDAR-based analysis made with QGIS [13]

2) Divide rooftops into segments (polygons) with associated characteristics such as area, tilt (or slope), and azimuth (or aspect). This was done with WBT function LiDARRooftopAnalysis and Python package gdal v3.4.3 to rasterize the file.
3) Estimate shading of the direct normal or beam component of irradiance with an hourly timestep over one year, using WBT function TimeInDaylight. Direct shading was first computed for each DSM pixel, and then averaged over all pixels within a given rooftop segment.

Hourly meteorological data for a Typical Global Year were obtained from the U.S. National Solar Radiation Database (NSRDB) international dataset [14] for municipalities other than Yellowknife, and from the Canadian Weather Year for Energy Calculation (CWEC) dataset [15] for Yellowknife. Plane-of-array (POA) irradiance without shading was modelled for each segment using the Hay-Davies model as implemented in pvlib v0.8.1 function get_total_irradiance [16]. This was then multiplied by the hourly shading from WBT to obtain hourly POA with shading for each segment.

Table 1 summarizes the assumptions made for PV system configuration and performance. To calculate the PV capacity of each segment, the following equation was used:

$$P_{segment} = A_{segment} * U_{F1} * \eta_{PV} * CR * \ kW/m^2 \tag{1}$$

$P_{segment}$ = Segment PV capacity (kW)
$A_{segment}$ = Segment area (m^2)
U_{F1} = Utilization factor applied to determine the PV-suitable area (-)
η_{PV} = Module efficiency at Standard Test Conditions (-), which is numerically equivalent to module power density (kW/m^2)
CR = Coverage Ratio, i.e., ratio of module area to roof area (-)

The module efficiency in Table 1 was selected as representative of the more efficient monocrystalline silicon PV modules currently on the residential market, to anticipate continued upward trends in efficiency. CRs in Table 1 were derived for flat and tilted roofs based on an assumed module area of 2 m^2, and 1.27 cm [9] space between modules in both directions. For flat roofs, spacing between rows of modules was also taken into account following [17], leading to a lower CR.

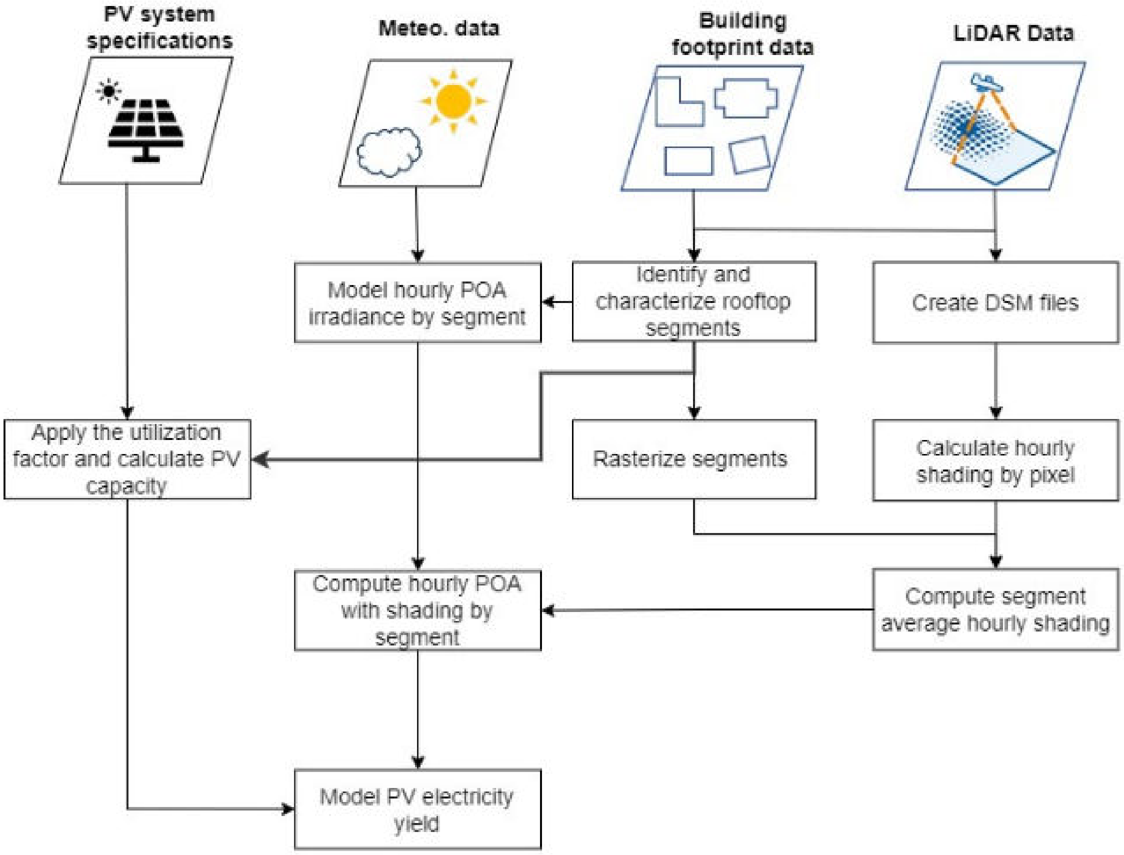

Fig. 2: Process for the municipal analysis using LiDAR data

Table 1: PV system specifications and assumptions for PV modelling

PV system specification	Sloped roofs	Flat roofs
Tilt	Equal to segment tilt	10˚
Azimuth	Equal to segment azimuth	180° (south-facing)
Coverage Ratio (CR)	0.96	0.66
PV module efficiency	22.5 %	
Performance ratio	0.75	
Utilization factor U_{F1}	1.01	

A utilization factor (U_F) is simply a coefficient that multiplies raw surface areas to derive PV-suitable areas. The utilization factor U_{F1} was applied to account for two factors: obstructions on a rooftop and a segmentation correction factor. This analysis assumed that rooftop obstructions such as chimneys and vents account for 10 % of the rooftop area according to [18][19], or to a U_F of 0.9. Meanwhile, a segmentation correction factor of 1.12 was used to correct for an artefact of the segmentation process that artificially reduces the overall rooftop area. It was calculated from the ratio of the total building footprint area to the total area of the horizontal projections of the rooftop segments. Multiplying these two factors leads to a U_{F1} value of 1.01.

To calculate the electricity generated annually, the following equation was used:

$$E_{segment} = P_{segment} * H * PR * \ m^2/kW \tag{2}$$

$E_{segment}$ = Annual segment PV electricity generation (kWh)
H = Annual POA insolation for the segment (kWh/m^2)
PR = Performance ratio (-)

The performance ratio accounts for overall system losses with respect to operation at the rated module efficiency under Standard Test Conditions[1]. The value of 0.75 is representative of lifetime-average performance for well-functioning PV systems.

The total capacity and total annual electricity generation for a given municipality were obtained by summing over all the rooftop segments.

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[1] Standard Test Conditions include cell temperature of 25 °C, irradiance of 1000 W/m^2, normal incidence angle, and air mass of 1.5.

2.1.2 Statistical method for Canada based on the municipal analysis

A new statistical method for estimating Canada-wide PV technical potential on rooftops (henceforth called the CanmetENERGY method) was developed from the results in the previous section. The method follows the same logic as the IEA method [6], but with two coefficients developed in Python from the 11-municipality LiDAR analysis. The two coefficients, U_{F2} and Y_r, are defined in equations (3) and (4):

$$P_{rooftops} = A_{ground\ floor} * U_{F2} * \eta_{PV} * \ GW/km^2 \tag{3}$$

$$E_{rooftops} = P_{rooftops} * H_{optimal} * PR * Y_r * \ m^2/kW \tag{4}$$

$P_{rooftops}$	=	Total rooftop PV capacity (GW)
$A_{ground\ floor}$	=	Ground floor area of the building stock (km^2)
U_{F2}	=	Utilization factor to derive PV-suitable area from ground floor area (-)
$E_{rooftops}$	=	Total rooftop annual PV electricity generation (GWh)
$H_{optimal}$	=	Annual insolation for an optimally oriented, unshaded surface (kWh/m2)
Y_r	=	Solar yield, or weighted-average fraction of $H_{optimal}$ received by the rooftop surfaces (-)

The coefficients U_{F2} and Y_r for the CanmetENERGY method are averages of the calculated coefficients over all the municipalities in this analysis. They are listed in Table 2. To assess the uncertainty in the coefficients, a cross-validation approach was used: coefficients were developed using 10 municipalities and applied to the remaining municipality, calculating the error for each municipality in turn. Fig. 3 shows box plots of the resulting errors, which are all within ±8 % for both U_{F2} and Y_r. The standard uncertainty associated with the coefficients of the new method was estimated from the standard deviation of these errors to be about 3.6 % for U_{F2}, and 4.9 % for Y_r.

Table 2: Coefficients of the new statistical method for determining rooftop PV technical potential

	Developed coefficient
U_{F2}	0.81
Y_r	0.70

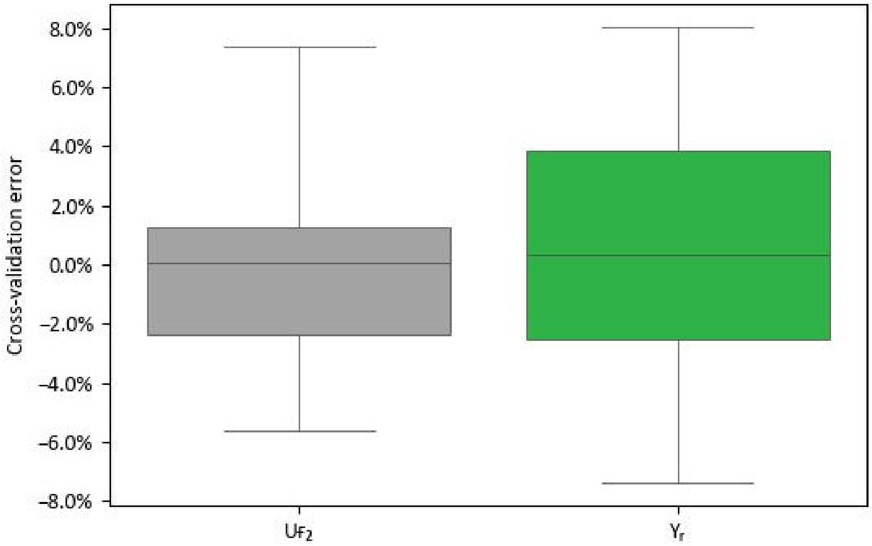

Fig. 3: Box plots of the cross-validation errors in the coefficients UF2 and Yr across the 11 municipalities

2.1.3 Estimating technical rooftop PV potential for Canada and its provinces and territories

The CanmetENERGY statistical method discussed in the previous sections was used to estimate the technical PV potential on rooftops for Canada and its provinces and territories via equations (3) and (4) and the province-or territory-specific inputs $H_{optimal}$ and $A_{ground\ floor}$. The optimum annual insolation for each region ($H_{optimal}$) was obtained from [2]. The total ground floor area ($A_{ground\ floor}$) was derived from total floor space data from the 2019 Comprehensive Energy Use Database (CEUD) [20] and 2019 Survey of Commercial and Institutional Energy Use (SCIEU) [21]. Total ground floor area was estimated from the total floor space by dividing by the number of stories as described in [2], with the number of stories for residential buildings provided by the 2019 Survey of Household Energy Use (SHEU) [22]. Apartment and industrial buildings were excluded from this study as the data were insufficient (apartments) or not available (industrial buildings). Other sources have similar data in Canada such as the SHEU, which has a higher uncertainty than CEUD, and the Canadian Building Footprints (CBF) [23] database. Unlike the CEUD and SHEU, CBF can provide ground floor area and number of buildings directly, rather than requiring estimates using the number of stories (for ground floor area) or the number of households (for number of buildings). However, preliminary analyses of the CBF data indicated some uncertainty regarding the data accuracy, with instances of a field and a portion of a water body misclassified as buildings.

Technical potential results are presented in Section 3.1. The uncertainty associated with these results was estimated by propagating input data uncertainties through equations (3) and (4), assuming uncorrelated inputs. The sources of uncertainty for the capacity are total floor space, average number of stories, and the coefficient U_{F2}. An upper bound of 16.6 % for the standard deviation of the error was assumed for the total floor space based on the SHEU data quality indicator. No such uncertainty estimate is available for the CEUD, so 16.6 % was used for this as well since CEUD data are designed to be of higher accuracy than SHEU. Meanwhile, uncertainty of U_{F2} was estimated at 3.6 % in Section 2.1.2. Propagating these uncertainties via equation (3) led to a combined standard uncertainty of the capacity estimates of 24 %.

The electricity uncertainty was derived using equation (4) optimum insolation $H_{optimal}$, and solar yield Y_r. A standard uncertainty of 5.9 % was estimated for $H_{optimal}$ from the analysis of McKenney et al. [24], while an uncertainty of 4.9 % was estimated for Y_r in Section 2.1.2. Propagating these uncertainties via equation (4) leads to a combined standard uncertainty of 25 % for the electricity estimates.

2.2 Quasi-economic PV potential from other statistical methods

While the previous section focused on PV technical potential from the CanmetENERGY method, this section examines other statistical methods that incorporate additional criteria to qualify surfaces as PV-suitable. Since statistical methods are sensitive to the characteristics of the building stocks on which they were trained, only those with an international, Canadian or U.S. training set were considered: 1) NREL 2016 - adapted [9], 2) NREL 2008 [8], and 3) IEA [6]. These methods are referred to here as quasi-economic since their criteria often reflect underlying financial considerations. The criteria applied by each method to select PV-suitable rooftop surfaces are listed in Table 3.

Like the CanmetENERGY method described in Section 2.1, the NREL 2016 method was developed using LiDAR and building footprint data for 128 U.S. municipalities, with the LiDAR-based analysis feeding statistical models for municipalities without LiDAR. It was used notably in the North American Renewable Energy Integration Study (NARIS) [7] to estimate a rooftop PV potential of over 160 GW for Canada. The NREL 2016 method was applied to Canada using the input data described in Section 0. Two adaptations to the method were made for small buildings: the number of buildings was estimated from CEUD and SCIEU data, and a US-average value was used for the fraction of suitable buildings, since the associated regression models require U.S.-specific inputs.

Table 3: Criteria used by the quasi-economic methods to select PV-suitable rooftop surfaces

Criteria	NREL 2016 - adapted	NREL 2008	IEA
Orientation	Allowed orientations must satisfy: 67.5° ≤ Azimuth ≤ 292.5° (South = 180°) Tilt ≤ 60°	Raw surface areas multiplied by a utilization factor (U_F) of 0.3 or 1 depending on building type	Allowed orientations must satisfy: Annual POA ≥ 80 % of unshaded POA for optimum orientation
Shading losses	Allowed surfaces must have shading losses less than 20 %	Raw surface areas multiplied by a U_F of 0.59 to 0.81 depending on climate and building type	Raw surface areas multiplied by U_F = 0.85
Other	Projection of suitable contiguous plane to horizontal must be at least 10 m^2	Raw surface areas multiplied by a U_F of 0.8 or 1 for structural adequacy, depending on climate and building type	Raw surface areas multiplied by U_F = 0.75 for construction elements, U_F = 0.9 for historical elements

NREL 2008 is an approach completed by industry experts, who estimated utilization factors to account for the fraction of rooftop surfaces that are PV-suitable once shading, orientation and structural adequacy are considered. The IEA method is based on utilization factors derived from international estimates and data. It was used in 2006 to estimate PV potential on buildings in Canada [2]. One benefit of using the IEA method is that it includes façades, whereas the other two methods and the CanmetENERGY method include only rooftops.

It is worth noting that the IEA report [6] explicitly mentions that its PV potential estimates roughly double if its constraint on suitable orientations is removed, while it is roughly halved if the associated threshold is changed from 80 % to 90 %. Since such thresholds are somewhat arbitrary, and since they will map to different financial thresholds depending on local costs and solar resources, it is more appropriate to include only thresholds that reflect physical limitations on where PV can be installed, as was done in the CanmetENERGY model.

3 Discussion and results

3.1 PV potential results for Canada and its provinces and territories

The estimated PV potential on rooftops for Canada and its provinces and territories is presented in detail for two methods: the CanmetENERGY method (technical potential) and the IEA method (quasi-economic potential), which is limited to surfaces meeting criteria outlined in Table 3. The IEA method was selected out of the quasi-economic methods in Section 2.2 for ease of comparison with estimates in [2], and because it is the only method that includes façades. Results are presented in Table 4 for the technical potential (CanmetENERGY method) and in Table 5 for the IEA method. Uncertainty and sensitivity of these results to input parameters are discussed in Section 3.2.

Table 4: Rooftop PV capacity and electricity technical potential results from the CanmetENERGY method

	Residential		Commercial/ Institutional		Total	
	PV Capacity (GW)	PV Electricity (TWh)	PV Capacity (GW)	PV Electricity (TWh)	PV Capacity (GW)	PV Electricity (TWh)
Canada	210	173	90	74	300	247
BC	29	21	12	9	41	30
ON	88	71	35	28	122	99
QC	37	31	20	17	58	48
AB	25	22	10	9	35	32
SK	7.1	6.8	2.8	2.7	9.9	9.5
MB	7.2	6.3	3.3	2.8	10.5	9.1
NS	6.4	4.8	2.3	1.7	8.7	6.5
NB	5.0	4.0	1.9	1.5	6.9	5.5
NL	4.0	2.6	1.2	0.8	5.3	3.4
PEI	1.03	0.80	0.38	0.29	1.41	1.09
NT	0.25	0.17	0.11	0.08	0.36	0.25
NU	0.21	0.15	0.09	0.06	0.30	0.21
YK	0.22	0.16	0.10	0.07	0.32	0.23

Table 5: Rooftop PV capacity and electricity potential results from the IEA method

	Residential		Commercial/ Institutional		Total	
	PV Capacity (GW)	PV Electricity (TWh)	PV Capacity (GW)	PV Electricity (TWh)	PV Capacity (GW)	PV Electricity (TWh)
Canada	100	104	36	38	136	142
BC	14	13	5	5	19	17
ON	42	42	14	14	56	57
QC	18	19	8	9	26	27
AB	12	13	4	5	16	18
SK	3.4	4.1	1.1	1.4	4.5	5.4
MB	3.4	3.8	1.3	1.4	4.7	5.2
NS	3.0	2.9	0.9	0.9	4.0	3.8
NB	2.4	2.4	0.7	0.8	3.1	3.2
NL	1.9	1.6	0.5	0.4	2.4	2.0
PEI	0.49	0.48	0.15	0.15	0.64	0.63
NT	0.12	0.10	0.04	0.04	0.16	0.14
NU	0.10	0.09	0.04	0.03	0.14	0.12
YK	0.11	0.09	0.04	0.04	0.15	0.13

On a country scale, this analysis suggests that up to 300 GW of PV can be installed on building rooftops, with a corresponding annual electricity generation of up to 247 TWh. With the more restrictive IEA method (Table 5), the rooftop PV capacity is reduced by 51 % to 136 GW, while electricity generation is reduced by 43 %, to 142 TWh. Façades can increase the quasi-economic potential by 59 GW and 45 TWh, as seen in Table 6. To put these numbers into context, the total capacity of electric generators in Canada is about 154 GW [25], while total annual electricity consumption from all sectors is roughly 546 TWh [20], with about 60 % of this attributable to the residential and commercial/institutional (C&I) sectors. In other words, PV technical potential on Canadian buildings is substantial compared to the current total capacity of Canada's electrical generation fleet.

The results indicate a greater potential in the residential sector than in the C&I sector: it accounts for 64 % to 70 % of the overall capacity and electricity generation in Canada for either method. For an average single detached house in Canada, the technical potential translates to installing a 21 kW PV system on a suitable rooftop area of 110 m^2 and to generating around 17.4 MWh per year (825 kWh/kW). With the IEA method, installed capacity is reduced to 10 kW, with a yield of 10.8 MWh per year (1042 kWh/kW). As expected, the specific yield in kWh/kW is higher for the IEA method, since it restricts surfaces to those meeting a minimum insolation threshold. However, this is at the expense of lower absolute yield.

Table 7 shows rooftop PV potential electricity generation as a percentage of building electricity consumption[2] for residential and C&I buildings using both methods (electricity usage data is from CEUD [20]). The result for the technical potential in Canada suggests that installing PV on building rooftops could generate an amount of electricity per year equivalent to 76 % of the current electricity demand in these buildings, with 100 % in the residential sector and 49 % in the C&I sector. The quasi-economic potential (IEA) amounts to 44 % of overall building electricity use, with 60 % for residential buildings and 25 % for C&I buildings. This number could increase by 18 percentage points if façades were included. Results for the residential sector vary widely by province.

Table 6: Façade PV capacity and electricity potential results from the IEA method

	Residential		Commercial/ Institutional		Total	
	PV Capacity (GW)	PV Electricity (TWh)	PV Capacity (GW)	PV Electricity (TWh)	PV Capacity (GW)	PV Electricity (TWh)
Canada	38	29	22	16	59	45
BC	5.2	3.5	2.9	1.9	8.1	5.4
ON	16	12	8.3	6.2	24	18
QC	6.7	5.1	4.9	3.7	12	8.8
AB	4.5	3.7	2.5	2.1	7.0	5.8
SK	1.3	1.1	0.7	0.6	2.0	1.7
MB	1.3	1.0	0.9	0.6	2.1	1.7
NS	1.2	0.8	0.6	0.4	1.7	1.2
NB	0.9	0.7	0.4	0.3	1.3	1.0
NL	0.72	0.43	0.30	0.18	1.02	0.61
PEI	0.19	0.13	0.09	0.06	0.28	0.20
NT	0.04	0.03	0.03	0.02	0.07	0.05
NU	0.04	0.02	0.02	0.01	0.06	0.04
YK	0.04	0.03	0.02	0.02	0.06	0.04

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[2] Note that these percentages do not consider the need for real-time matching of supply and demand. To be realized, they would require exchange with a flexible electricity grid and/or energy storage.

Table 7: Rooftop PV annual electricity generation potential as a percentage of building electricity consumption[2] by province and sector

	Technical Potential – CanmetENERGY			Quasi-Economic Potential – IEA		
	Residential	Commercial/ Institutional	Residential and C&I	Residential	Commercial/ Institutional	Residential and C&I
Canada	100%	49%	76%	60%	25%	44%
BC	105%	51%	80%	63%	26%	46%
ON	159%	52%	101%	95%	27%	58%
QC	44%	42%	43%	26%	22%	25%
AB	204%	49%	106%	122%	25%	61%
SK	191%	45%	100%	115%	23%	57%
MB	71%	50%	63%	43%	26%	36%
PEI	320%	45%	121%	192%	23%	70%
NS	101%	43%	74%	61%	22%	43%
NB	70%	46%	62%	42%	24%	35%
NL	61%	37%	53%	37%	19%	31%
NT	134%	49%	88%	80%	25%	50%
NU	133%	49%	88%	80%	25%	50%
YK	131%	49%	87%	79%	25%	50%

Provinces where PV technical potential amounts to less than 100 % of current electricity needs typically have a ratio of electricity demand to total secondary energy use in residential buildings of over 0.6. In contrast, the provinces that have the highest percentages in Table 7 only have a corresponding ratio of about 0.2.

The percentages presented in Table 7 are for current estimates of the electricity and energy usage. However, electricity use is predicted to more than double in the next 30 years [1] because of the electrification of space heating, transportation and other electrical applications. Installation of PV on buildings can provide an additional electricity source and help achieve the goal of doubling the electricity generation.

3.2 Comparison of methods, sensitivity, and uncertainty

Fig. 4 presents the rooftop PV capacity results for Canada from the three quasi-economic methods presented in Section 2.2, and the NARIS study. Estimates vary widely, from a total of 104 GW (NREL 2016 – adapted) to over 160 GW (NARIS). This is particularly surprising given that these two results are both based on NREL 2016 [9]. The breakdown by building sector suggests that the discrepancy is primarily due to differences in input data for C&I buildings (the source is not specified in the NARIS study, nor the assumed PV module efficiency). As expected, all the quasi-economic potential values are significantly lower than the rooftop technical potential of 300 GW for Canada estimated with the new CanmetENERGY method. These differences in results highlight the lack of agreement in the definition of the PV potential concept as it is currently used. Similar discrepancies between the results of different methods were pointed out by Walch et al. for Switzerland [26], with the biggest source of discrepancies being the criteria for PV-suitable surfaces analogous to those in Table 3. The development of the CanmetENERGY method was prompted in part by the aim to separate purely technical constraints from quasi-economic constraints.

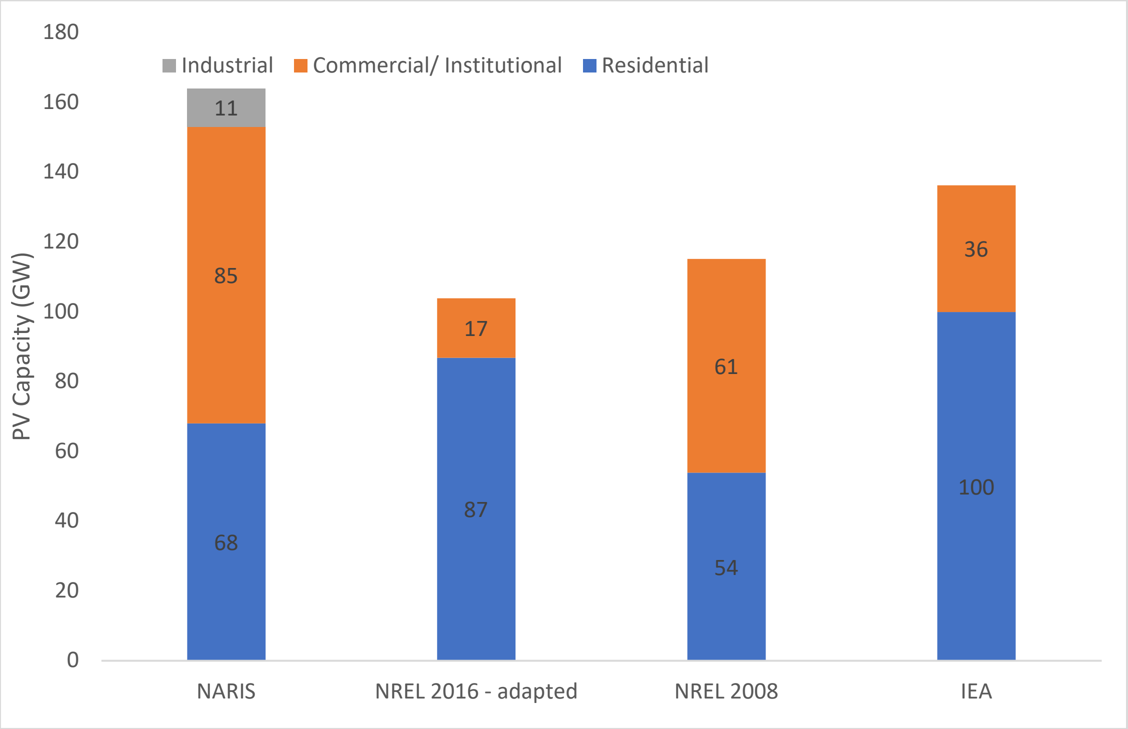

Fig. 4: Rooftop PV capacity potential by building sector for each quasi-economic statistical method

As discussed in Section 2.1.2, a standard uncertainty in the range of 24 to 25 % applies to the technical potential estimates in this report, reflecting the uncertainty in the CanmetENERGY method inputs such as ground floor area, insolation, and coefficients. This uncertainty does not cover the sensitivity of the results to selected parameters such as PV module efficiency, performance ratio, coverage ratio or the utilization factor for construction elements. Similarly, PV potential will evolve in time as the building stock grows, PV modules become more efficient and performance ratios increase. Comparing for instance the IEA results (rooftops and façades) to those obtained with the same method almost two decades ago [2] shows an increase in capacity from 73 GW [2] to 196 GW, or more than double. This increase is attributable to both the growth in the Canadian building stock, and to the increased PV module efficiency (22.5 % in the current estimate vs. 15 % in [2]). Similarly, the electricity generation potential estimated for both rooftops and façades in [2] corresponded to 29 % of electricity use in residential and C&I buildings at the time, while the current IEA estimate amounts to 58 % of electricity use from Table 7 andTable 8.

Table 8: Façade PV annual electricity generation potential as a percentage of building electricity consumption^2 by province and sector

	Quasi-Economic Potential - IEA		
	Residential	Commercial/ Institutional	Residential and C&I
Canada	22%	14%	18%
BC	26%	17%	22%
ON	36%	16%	25%
QC	10%	12%	10%
AB	41%	13%	23%
SK	36%	11%	21%
MB	15%	14%	14%
PEI	74%	14%	31%
NS	24%	14%	19%
NB	16%	14%	15%
NL	17%	14%	16%
NT	34%	17%	25%
NU	34%	17%	25%
YK	34%	17%	25%

4 Conclusion

A new statistical method for assessing rooftop PV technical potential in Canada and its provinces and territories was developed from a training set of 11 municipalities across the country with good quality LiDAR and building footprint data. The method differs from the other statistical methods considered in that it excludes only surfaces that are not technically available for installing PV, namely rooftop obstructions such as chimneys. This analysis shows that rooftop PV could generate 247 TWh per year, which amounts to 76 % of the current electricity needs in residential and C&I buildings in Canada. For Canada as a whole, rooftop PV on residential buildings can supply as much electricity per year as is consumed in these buildings. For C&I buildings, this number drops to 49 % of annual needs. These figures apply to current building counts and electricity demand in Canada and will necessarily change as the number of buildings and the electricity demand increase, and as PV system efficiency and performance evolve. While PV on façades is less common (especially for residential buildings), it could boost potential electricity generation by 45 TWh or more per year. Other applications in the built environment such as PV carports and PV on industrial and apartment buildings could further increase this number but could not be included in this study.

The new CanmetENERGY method indicates a potential of up to 300 GW for rooftop PV on residential and C&I buildings. Other statistical methods that include additional constraints yield lower PV capacities in the range of 104 GW to 160 GW. While these results differ, they are all comparable to or greater than Canada's total electric power capacity of about 154 GW [25]. In other words, PV technical potential on Canadian buildings is significant and can play a role in Canada's energy transition. To determine the extent to which PV technical potential will be realized, financial criteria and market adoption will need to be considered, as well as the ability of electricity grids to host this capacity.

Acknowledgements

The authors would like to thank former and current CanmetENERGY colleagues for assistance with this project: Negar Salimzadeh for helping to develop the LiDAR-based methodology, Benjamin Roy for exploring data sources and doing preliminary validations of WhiteboxTools shading results, Véronique Delisle for project management, and Marc Provost and Yves Poissant for feedback on this report. The authors would like to acknowledge the helpful information and data provided by Jean-Samuel Proulx-Bourque, Guillaume Légaré-Couture and Charles Papasodoro from the Canada Centre for Mapping and Earth Observation (CCMEO) and Ian Gibson, Monika Forgo and Peter Greenberg from the Office of Energy Efficiency. Thank you to John Lindsay from the University of Guelph who provided guidance on the use of Whitebox Tools. Thanks also to Kyle Edginton from

Canadian Solar Inc. who provided valuable insight on common rooftop PV installation practices.

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