AN EVALUATION OF THE POTENTIAL OF BUILDING INTEGRATED PHOTOVOLTAICS IN CANADA

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ABSTRACT

The electricity generation potential of building integrated photovoltaics (BIPV) in Canada is evaluated on a countrywide basis and for each of the provinces, as well as for a few municipalities featuring as case studies. The main goal of this project is to determine the potential of photovoltaics in Canada.

The methodology used was agreed upon by the International Energy Agency (IEA) Photovoltaic Power Systems Programme Task 7 Experts Group. The methodology was applied to Canadian data on ground floor surface areas to evaluate the electricity that can be produced by grid-connected photovoltaic systems integrated into the rooftops and façades of buildings. The electricity production estimates obtained are compared to the corresponding electricity consumption figures, for each building stock/geographical region under consideration. We also evaluate the associated greenhouse gas emissions that would be avoided if photovoltaic systems were used instead of each province's mix of electricity generation sources (thermal, nuclear, hydroelectric, etc.).

Our results illustrate a large, untapped potential for BIPV in Canada. For instance, about 46% of Canada's residential electricity needs could be supplied by BIPV systems. For the combined residential and commercial/institutional Canadian building stock, about 29% of the 246 TWh consumed annually could be supplied by PV, and an associated 23 Megatonnes of greenhouse gas emissions could be avoided.

1. INTRODUCTION

Residential and commercial/institutional buildings accounted for over 50% of total electricity end use in Canada in 2003 and over 30% of total energy end use, producing about 23% of national greenhouse gas emissions [Comprehensive Energy Use Database (CEUD) 2003].

Since photovoltaic (PV) systems generate no greenhouse gases or other emissions during operation, and very little over their entire lifecycle, BIPV can clearly reduce the emissions from electricity use in buildings. In addition, BIPV also offers a means of reducing electricity consumption: the integration of photovoltaics into building designs is closely tied with energy efficiency measures, and often occurs in contexts such as net metering and time-of-day pricing which actively encourage reduced electricity consumption and consumption outside of peak demand hours.

The current cost of electricity produced by PV is relatively expensive. However, costs on average have decreased by 15-20% for each doubling of market size following a standard learning curve [Report IEA-PVPS T1-14:2005]. This is illustrated in Table 1 in the case of Canada. Given the projected cost reductions as well as the environmental benefits associated with BIPV, it becomes relevant to examine the technical potential of BIPV in Canada: how much electricity it can generate, what fraction of electricity demand it can supply, and what greenhouse gas emissions it can avoid.

Table 1: Price of PV modules in Canada over time

Year	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Price (CAD/W)	11.09	10.70	9.41	7.14	6.18	5.53	4.31
Reduction		3.5%	12%	24%	13%	10%	20%

[Source: NRCan, CETC-Varennes, Annual market survey, March 2006]

In section 2, we describe the methodology used to evaluate PV electricity generation potential and associated greenhouse gas reductions. Elements of the methodology common to all cases considered are presented in section 2.1. Specific methods used for the three cases considered in this paper are then presented separately: residential buildings in Canada and the provinces are discussed in section 2.2, commercial and institutional buildings in Canada and the provinces in section 2.3 and buildings within three individual municipalities in section 2.4. The results for these three cases are presented separately in section 3, along with results for the Canadian residential and commercial/institutional buildings combined. Section 4 gives concluding comments.

2. METHODOLOGY

2.1 General Methodology

In order to estimate the electricity generation potential of buildings in Canada, a conservative methodology developed by the International Energy Agency Photovoltaic Power Systems Programme (Task 7) was applied. A complete discussion of the methodology and of the sensitivity of BIPV potential estimates to the assumptions and parameters used can be found in the IEA report [Technical Report IEA-PVPS T7-4: 2002].

The IEA report included an estimate of the electricity production potential for Canadian buildings, classified according to their use: residential, office and service, agricultural, industrial and other. The estimates were based on ground floor areas extrapolated from U.S. figures (Canada did not actively participate in this report). These estimates were re-done in the present study using actual Canadian values for ground floor areas. We were able to obtain data for a subset of residential buildings and commercial/institutional buildings, but not for the other building types, which were therefore excluded.

The methodology is based on a simple rule of thumb: for every m^2 of building ground floor area, there are on average 0.4 m^2 of rooftop area and 0.15 m^2 of façade area with good BIPV potential [Technical Report IEA-PVPS T7-4: 2002]. The areas with good BIPV potential are identified as those which are both architecturally suitable for installing PV systems and receive sufficient yearly insolation. This is defined separately for rooftops and façades as being at least 80% of the respective maximum yearly insolation. The rule of thumb is useful in Canada since statistics on floor areas can generally be obtained or estimated, while data on rooftops and façade areas is not available.

Once the ground floor area of a particular building stock is known, the corresponding annual electricity production (E=Er+Ef) is given by:

Rooftops: $Er = A * 0.4 * Yr * e * I$ (1)

Façades: $Ef = A * 0.15 * Yf * e * I$ (2)

where A is the ground floor area of the building stock, e is the overall PV system efficiency, I is the maximum yearly global insolation received by a fixed surface and Yr/Yf is the solar yield for rooftops/façades, defined as the average over all rooftop/façade surface orientations that are BIPV suitable of the fraction of the maximum yearly insolation received. An overall PV system efficiency of 0.1125 (=0.15*0.75) was used based on a nominal PV module efficiency of 15% and a value of 0.75 for the PV system performance ratio, which is the ratio of the actual system yield (kWh/kW) to the reference or nominal yield, the latter being numerically equal to the insolation in the plane of the PV array (kWh/m^2). The performance ratio takes into account all PV system losses, for instance losses in electrical wires and losses due to operation under non-optimal conditions (temperature-related losses, losses due to shading, reflections, etc.) [Poissant et al., 2003]. The performance ratio value used (0.75) is the most common yearly average value that was reported in a worldwide monitoring of 395 grid-connected PV systems by the International Energy Agency, for systems built between 1996 and 2002 [Report IEA PVPS T2-05:2004]. (In the scope of this paper, off-grid PV systems are excluded, since the performance ratio of 0.75 refers only to grid-connected systems). As for the solar yield, the IEA analysis values for Canada were used: 0.88 for rooftops, and 0.64 for façades.

The only inputs needed in each case are the maximum yearly insolation and the ground floor area of the buildings. The sources used to obtain ground floor areas varied from case to case, and included statistics on heated floor space and number of storeys per building, GIS analyses of aerial maps and direct building measurements. They will be explained in the relevant sections of this paper.

All the insolation data was obtained from the Environment Canada CERES CD (*le disque canadien des énergies renouvelables éolienne et solaire, The Canadian Renewable Energy Wind and Solar Resource CD*), which gives yearly mean daily global insolation values for different surface orientations at 144 meteorological stations throughout the country for the 1974-1993 period. The South-facing surface orientation with latitude tilt obtained the highest yearly insolation values of all the fixed surfaces in the CERES database, so the corresponding values were used to calculate the maximum yearly insolation.

In the case of individual municipalities, insolation data from the nearest meteorological station was used. Meanwhile, for provinces and larger regions, the insolation value was calculated by averaging the insolation value of all the stations in the region weighted by the population associated with each station's municipality (to simplify, meteorological stations/municipalities with populations less than 5% of the region's most populated municipality were excluded). Since building densities and population densities are strongly correlated, this gives a good approximation of the maximum average insolation received by the buildings of the region in question.

After having obtained actual electricity production, this was compared to the corresponding electricity consumption to determine what fraction of the consumption could be supplied by photovoltaics.

Finally, greenhouse gas emissions offsets were estimated by calculating the greenhouse gas emissions that would be avoided if the annual electricity production by photovoltaics replaced an equivalent amount of electricity produced by electricity generation sources currently used in the region in question. The GHG emissions (G) for a given region were calculated using:

$$G = E * g \qquad (3)$$

where E is the photovoltaic electricity generation potential and g is the GHG emissions intensity for electricity production in the region (amount of GHG emitted per electricity generated).

Electricity intensity values for the provinces were taken directly from the Electricity Intensity Tables of Canada's Greenhouse Gas Inventory, 1990-2003 (Annex 9). For groupings of several provinces, electricity intensities were calculated by dividing the total electricity-related GHG emissions for the region by the associated total electricity production. For two municipalities (Calgary and Saskatoon), the electricity intensity of their province was used, since electricity supply is coordinated provincially. In the case of the remote community of Wha Ti, the electricity intensity used was that of a remote grid powered by a diesel generator.

Following the GHG Inventory methodology, PV has a GHG electricity intensity of 0, since PV systems produce no GHG emissions during operation.

2.2 Residential buildings in Canada and the provinces

In order to evaluate the electricity generation potential of BIPV for residential buildings in Canada and its provinces, we combined 2003 data from two Office of Energy Efficiency sources, the first giving the floor space of residential buildings (the total heated floor area on all storeys of a residential building excluding the basement and garage), and the other the average number of storeys per building [Comprehensive Energy Use Database (CEUD 2003); 2003 Survey of Household Energy Use (SHEU 2003)]. We calculated the ground floor area using:

$$\text{Ground floor area} = \frac{\text{Floor space}}{\text{Average number of storeys}} \qquad (4)$$

Apartment buildings were excluded from the analysis since data on the average number of storeys was not available for these. The residential buildings under consideration include single detached, attached and mobile homes. Since photovoltaic systems are very rarely installed on the façades of these buildings in practice, the PV electricity generation potential was estimated for rooftops only using equation (1).

2.3 Commercial and institutional buildings in Canada and the provinces

A similar analysis was carried out for commercial and institutional buildings. Again, data on floorspace was obtained from the CEUD 2003 database, while data on the number of storeys per building was obtained from the Commercial and Institutional Building Energy Use Survey 2000 (CIBEUS 2000**)**. The ground floor area per building was calculated using equation (4), as above. (Note: Floorspace was defined slightly differently in the CEUD 2003 and the CIBEUS 2000, introducing a small source of error). The photovoltaic potential per building was calculated by adding the rooftop and façade contributions from equations (1) and (2), but with a "rule of thumb" value of 0.2 m^2 BIPV façade potential per m^2 of ground floor area instead of 0.15 m^2, as suggested for commercial/institutional buildings in the 2002 IEA report.

2.4 Canadian municipalities

The BIPV electricity generation potential of three Canadian municipalities was also estimated to illustrate the different types of data on building areas currently available at the municipal level, and how these can be used to evaluate BIPV potential. The three municipalities chosen as case studies include two major metropolitan areas, Calgary and Saskatoon, and one remote community in the Northwest Territories, Wha Ti. The evaluation of ground floor areas for each munipality is described below.

<u>Calgary</u>

Like an increasing number of municipalities in Canada and worldwide, the City of Calgary has produced a GIS map of Calgary based on aerial photography, which includes building rooftop outlines, that is the horizontal projection on the ground of the rooftop outline. This data/map has been analyzed by the geomatics group at the City of Calgary [Digital Area Survey, latest data layer: 2005], which has building rooftop outline areas for different building categories. The areas enclosed within building rooftop outlines were used as estimates for ground floor areas. Since rooftop projections include the projection of rooftop overhangs and eaves, rooftop outline areas will overestimate ground floor areas. Electricity consumption data for Calgary was provided by the Alberta Energy Utilities Board [2004 Annual Statistics, personal communication].

<u>Saskatoon</u>

The City of Saskatoon's surveyor's office was able to provide the average heated floor space area for 50,400 residential single unit homes in Saskatoon [personal communication]. The average floor space for these homes was 1090 $ft.^2$, with 23% of units having more than one floor. Under the simplifying assumption that these 23% of units have two floors, the average ground floor area A_{avg} is given by:

$$A_{avg} = \frac{1090\text{ft.}^2 * 0.09290304 \frac{\text{m}^2}{\text{ft.}^2}}{1*0.77 + 2*0.23} = 82.3\text{m}^2 \quad (5)$$

Data on residential electricity consumption was obtained from Saskatoon Light and Power and Sask Power for all residential accounts [personal communication], and the consumption corresponding to the 50,400 attached houses was assumed equal to the fraction (50,400/Number of residential accounts) of the total electricity consumption.

Wha Ti

The case of Wha Ti illustrates an approach that has been used in a number of European cities/municipalities [Report IEA-PVPS T7-4: 2002]: sampling the municipality's building stock to estimate relevant data. Sampling for Wha Ti was conducted in the context of formulating a Community Energy Plan [Bromley et al., 2004]. Building ground floor areas were measured in 2005 for 74 out of 105 residential buildings, and 15 out of 23 non-residential buildings. Electricity consumption data was also gathered previously for several of the sampled buildings [Reference ibid.].

3.DISCUSSION AND RESULTS ANALYSIS

3.1 Residential buildings in Canada and the provinces

The BIPV production potential for residential buildings in Canada and the provinces is presented in Table 2 for the entire residential building stock, and in Table 3 at the level of individual households (the average ground floor area per household was used in this case). The tables also show the corresponding electricity use and the ratio of BIPV production potential to electricity use (as a percentage), as well as the greenhouse gas emissions avoided by producing the yearly BIPV electricity potential with PV instead of currently used energy sources.

Canadian results

On a country-wide level, this analysis suggests that rooftop photovoltaics for residential buildings could supply about 53 TWh out of the 114.8 TWh consumed annually in Canada (6.3 MWh out of 13.6 MWh at the level of individual households). This represents roughly 46% of current residential electricity consumption in Canada. About 16 Megatonnes per year of greenhouse gas emissions would be avoided in the process, or about 1.9 tons per year per household. In terms of power or capacity, the calculated BIPV potential corresponds to installing about 6.2 kW of photovoltaics per household with the module efficiency assumed in this study (occupying about 40 m², or a third of the available rooftop area). This can be compared to the average size of about 3.5 kW [Charron, 2005] for residential grid connected PV systems in Japan, where typical ground floor areas are considerably smaller than in Canada (almost by a factor of 4, [IEA-PVPS T7-4: 2002]). For the roughly 8 million households living in residential buildings other than apartments, this represents a PV potential of about 52,000 MW.

Provincial results

The results vary considerably from one province to another. For instance, the ratio of PV electricity production varies from slighly less than 30% in Québec, New Brunswick and Newfoundland/Labrador to over 100% in the case of PEI and Alberta. Meanwhile, the GHG emissions avoided vary from about 0.1 ton per household per year in Québec, BC and Newfoundland/Labrador to about 6.6 in Alberta and PEI. In terms of electricity production per household, the main source of variation is the difference in insolation, which is considerably higher than average in the Prairies, and lower in Newfoundland/Labrador, the Territories and British Columbia. As far as the ratio of BIPV generation potential to electricity use, the variations derive primarily from considerable differences in electricity use in the different provinces: in Prince Edward Island, electricity use per household (3.2 MWh per year) accounts for only 13% of energy use, while the Québec electricity use per household (22 MWh per year) is about 7 times greater, and accounts for a correspondingly much greater percentage of energy use (59%) [CEUD 2003]. Finally, variations in GHG emissions offsets primarily reflect the difference in electricity production sources used in each province.

Energy-efficient homes

The above results apply to the electricity use of standard Canadian residential buildings. However, integrating photovoltaics into buildings is often part of a broader, twofold approach of reducing energy use and of favouring renewable and decentralized energy production. In fact, a number of projects worldwide now aim for net-zero energy use, i.e. for homes that generate as much energy as they use over the course of a year. (For a review of Canadian and international initiatives, see Charron, 2005).

In terms of building design, the impact of BIPV can be maximized through a number of techniques including super insulation, airtight construction, passive solar design and extracting heat from the PV panels.

From the perspective of homeowners, PV use, especially when combined with net metering and time-of-day pricing, can lead to increased awareness of energy use, to the purchase of energy efficient appliances and to energy saving behaviour. Within the general population, individuals with the "best behaviour" use about 30% less energy than the average [Chiras, 2002]. Meanwhile, energy-efficient appliances can further reduce electricity consumption (by 10-50 % in the case of ENERGY STAR appliances).

Assuming an overall reduction in electricity use of 55%, the ratio of PV production to electricity use would reach 100% for Canada, and climb to about 60% in Newfoundland/Labrador where it is lowest.

3.2 Commercial and Institutional buildings in Canada and the provinces

The results for commercial and institutional buildings are presented in Tables 4 and 5 in the same format that was used for residential buildings, but with provinces grouped according to the CIBEUS and CEUD categories. In the case of commercial and institutional buildings, the total Canadian BIPV electricity generation potential is about 19 TWh out of 131.7 TWh consumed annually (or 78 MWh out of 449 MWh per building). This represents about 15-17% of electricity use (the range reflects slightly different results depending on which database is used). This is considerably lower than in the residential case, and is due to a much higher electricity intensity per ground floor area for commercial/institutional buildings (Canadian average: 0.58 MWh/year/m^2) than for residential buildings (Canadian average: 0.14 MWh/year/ m^2) [CEUD 2003]. In terms of power or capacity, the commercial/institutional BIPV potential corresponds to about 21 000 MW, or 82 kW per building on average. At the level of greenhouse gases, this installed capacity would lead to reductions of about 6.5 Megatonnes per year, or about 16 tons per building.

The electricity production per building for the different regions covers a much wider range of values than in the residential case. This can be attributed to the greater diversity of buildings and the wider range of ground floor areas per building for the different regions.

3.3. Residential and commercial/institutional buildings combined results and the Canadian building stock

Combined results

According to the previous analysis, the combined BIPV potential of the residential and commercial/institutional buildings analyzed for Canada is 72 TWh per year, which represents about 29% of the corresponding electricity use per year (246 TWh) in 2003. This installed capacity would prevent about 23 Megatonnes of GHG per year. In terms of power or capacity, the combined BIPV potential is about 73 000 MW, or about 2300 W per capita. This can be compared to the total installed PV power of 16.75 MW in Canada at the end of 2005, or about 0.5 W per capita [Ayoub et al., 2006]. This represents only about 0.02% of the Canadian BIPV potential as estimated here! Comparing internationally, the 0.5 W per capita value is well below the 8.87 W per capita and 9.62 W per capita reported in 2004 for Japan and Germany respectively, as illustrated in Figure 1 [Report IEA-PVPS T1-14:2005].

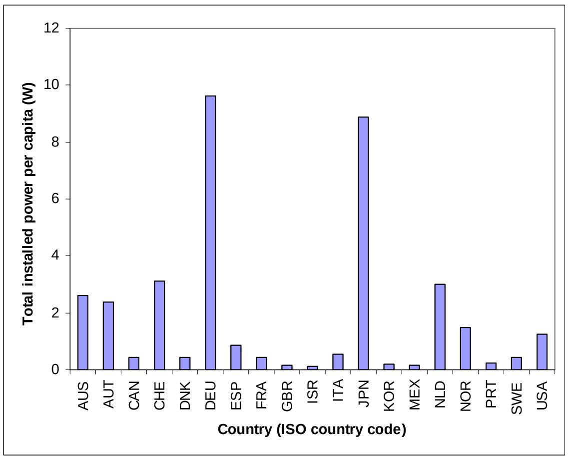

Figure 1: Installed PV power per capita for IEA countries. [Source: Report IEA-PVPS T1-14:2005].

Canadian building stock

Residential and commercial/institutional buildings account for about 54% of electricity end use in Canada (29% for residential buildings and 25% for commercial and institutional buildings), with the remainder of electricity end use coming essentially from industry (44%) and from small contributions by agriculture and transportation (about 2% for the two combined) [CEUD 2003]. (Note: electricity end use excludes the electricity used to generate energy, which is considerable).

Industrial buildings and facilities are much more energy and electricity intensive than their residential and commercial/institutional counterparts. Using IEA ground floor estimates combined with 1998 CEUD data, their electricity intensity is about 1.4 MWh/year/m^2 , or 10 times greater than that for residential buildings (0.14 MWh/year/m^2), with commercial and institutional buildings being roughly midway at 0.58 MWh/year/m^2. In this sense, residential and commercial/institutional buildings are more "BIPV suitable" than industrial buildings and facilities. Thus, for the purposes of the development of PV in Canada, the ratio of PV potential to electricity use can be taken to be about 29% for the relevant building stock (about 46% for the most suitable building stock: residential buildings).

3.4 Canadian municipalities

The results obtained for each of the three municipalities considered are shown in Tables 6, 7 and 8, at the level of individual households (Table 6), of the residential building stock (Table 7) and of the entire buildings stock (Table 8).

At the level of individual households, the results obtained for each municipality can be compared to those of their respective provinces. For Saskatoon, the electricity production per household (6.0 MWh per year) is slightly lower than the Saskatchewan result (7.1 MWh per year) due to a smaller ground floor area per household, as estimated here. Meanwhile, the result for Calgary (9.8 MWh per year per household) is well above the Albertan result (7.2 MWh per year). This reflects the fact that rooftop outline areas include rooftop overhangs and eaves, and that residential garage areas were included for Calgary but excluded at the provincial level, leading to a much larger ground floor area for Calgary (140 m^2) than the Albertan average (105 m^2 , no garages). For Wha Ti, the production potential (6.0 MWh per year) is close to the Northwest Territories value of 5.7 MWh per year per household.

The results obtained for the ratio of BIPV generation potential to electricity use for the residential sector differ from the provincial/territorial values obtained previously, in the case of Calgary (145% vs. 103% provincially) and of Wha Ti (69% vs. 53% provincially). In the case of Calgary, this can be traced to the much larger ground floor area used, while for Wha Ti it reflects electricity use below the North West Territories average.

The results for the entire building stock for Wha Ti and Calgary imply that photovoltaics could meet a substantial fraction of total electricity needs in these two municipalities: 72% in Calgary, and 85% in Wha Ti.

CONCLUSION

The BIPV electricity production potential of residential and commercial/institutional buildings was analyzed for all of Canada, its provinces and territories and three municipalities featuring as case studies.

The analysis shows that photovoltaics could meet a substantial fraction of yearly electricity consumption in Canada, particularly in the residential sector, where about 46% of current needs (53 out of 114.8 TWh per year) could be provided by photovoltaics. For commercial and institutional buildings, photovoltaics could provide about 15-17% of total consumption (131.7 TWh per year). For the combined residential and commercial/institutional building stock, about 29% of the yearly 246 TWh used could be supplied by PV. This corresponds to a total installed capacity of about 73 000 MW, and to about 23 Megatonnes of avoided GHG emissions per year.

The above estimates apply to existing, standard Canadian buildings. The impact of BIPV increases substantially when solar energy and energy efficiency are taken into account in building design and in individual's energy consumption habits.

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TABLES AND FIGURES

Table 2. Total residential BIPV potential for Canada and the provinces

Region	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (km2)	Yearly electricity production (TWh)	Yearly electricity use (TWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (Megatonnes)
Alberta	4.73	99	6.8	6.5	103	0.911	6.2
Saskatchewan	4.99	31	2.3	2.6	88	0.84	1.9
Québec	4.33	172	11	37.8	29	0.0088	0.095
Ontario	4.22	332	20	38.5	53	0.272	5.5
Manitoba	4.55	33	2.2	5	43	0.0305	0.066
PEI	4.06	4	0.26	0.1	181	1.12	0.29
Newfoundland/ Labrador	3.39	17	0.83	3.1	27	0.0211	0.017
Nova Scotia	3.92	28	1.6	3.4	46	0.759	1.2
New Brunswick	4.19	22	1.3	4.6	29	0.433	0.58
British Columbia	3.80	125	6.9	12.9	53	0.0209	0.14
Territories (NWT, Yukon, Nunavut)	3.67	3	0.15	0.3	53	0.255	0.038
Canada		867	53	114.8	46		16

Table 3. Residential BIPV potential per household for Canada and the provinces

Region	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (m2)	Yearly electricity production (MWh)	Yearly electricity use (MWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (tonnes)
Alberta	4.73	105	7.2	7.0	103	0.911	6.6
Saskatchewan	4.99	98	7.1	8.0	88	0.84	6.0
Québec	4.33	102	6.4	22.3	29	0.0088	0.056
Ontario	4.22	102	6.2	11.8	53	0.272	1.7
Manitoba	4.55	100	6.5	15.1	43	0.0305	0.20
PEI	4.06	100	5.9	3.2	181	1.12	6.6
Newfoundland/ Labrador	3.39	97	4.8	17.9	27	0.0211	0.10
Nova Scotia	3.92	97	5.5	11.8	46	0.759	4.2
New Brunswick	4.19	93	5.6	19.3	29	0.433	2.4
British Columbia	3.80	112	6.1	11.5	53	0.0209	0.13
Territories	3.67	107	5.7	10.7	53	0.255	1.5
Canada		103	6.3	13.6	46		1.9

Table 4. Total commercial and institutional BIPV potential for Canada and the provinces

Region	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (km2)	Yearly electricity production (TWh)	Yearly electricity use (TWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (Megatonnes)
BC & Territories	3.79	31.9	2.4	14.5	16	0.024	0.057
Atlantic	3.92	20.3	1.6	8.8	18	0.621	0.97
Quebec	4.33	44.6	3.8	35	11	0.0088	0.033
Ontario	4.22	77.8	6.5	53	12	0.272	1.8
Manitoba	4.55	10.1	0.90	4.2	22	0.0305	0.028
Saskatchewan	4.99	9.1	0.89	3.9	23	0.84	0.75
Alberta	4.73	34.3	3.2	12.3	26	0.911	2.9
Canada		228.2	19	131.7	15		6.5

Table 5. Commercial and institutional BIPV potential per building for Canada and the provinces

Region	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (m2)	Yearly electricity production (MWh)	Yearly electricity use (MWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (tonnes)
BC	3.80	682	51	330	15	0.0209	1.1
Atlantic	3.92	942	73	333	22	0.621	45
Quebec	4.33	948	81	468	17	0.0088	0.71
Ontario	4.22	871	72	485	15	0.272	20
Prairies	4.73	1 095	102	472	22	0.243	25
Canada		915	78	449	17		16

Table 6. Residential BIPV potential per household for certain Canadian municipalities

Municipality	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (m2)	Yearly electricity production (MWh)	Yearly electricity use (MWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (tonnes)
Calgary	4.86	140	9.8	6.8	145	0.911	8.9
Saskatoon	5.05	82	6.0	6.9	87	0.84	5.0
Wha Ti	3.99	104	6.0	8.7	69	0.975	5.9

Table 7. Residential BIPV potential for the entire residential building stock of two Canadian municipalities

Municipality	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (m2)	Yearly electricity production (MWh)	Yearly electricity use (MWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (kilotonnes)
Calgary	4.86	48563200	3410000	2359000	145	0.911	3100
Wha Ti	3.99	11000	630	910	69	0.975	0.62

Table 8. BIPV potential for the entire building stock of two Canadian municipalities

Municipality	Mean daily insolation for latitude tilt (kWh/m2)	Ground floor area (m2)	Yearly electricity production (MWh)	Yearly electricity use (MWh)	Electricity production/ Electricity use (%)	GHG emissions intensity (kg/kWh)	Yearly GHG emissions reductions (kilotonnes)
Calgary	4.86	65024000	5810000	8044000	72	0.911	5300
Wha Ti	3.99	20100	1500	1700	85	0.975	1.4