Solar
NOVA SCOTIA

Renewable Energy | Conservation | Efficiency

PRICES AND PRODUCTIVITY OF SOLAR ELECTRICITY IN NOVA SCOTIA

2017 DATA

Wayne Groszko
Christie Chaplin-Saunders
Sarah Danielle Miller

EXECUTIVE SUMMARY

From 2015 to 2017, the amount of solar photovoltaic (PV) electricity generating capacity installed in Nova Scotia grew about 59% per year. In this rapidly-growing market, the trends in prices and productivity of PV systems are of interest in the development of policy, programs, and education to support continued and healthy growth.

In this report we update the estimates of prices and electrical productivity of PV electricity generation in Nova Scotia, following on a previous report published in 2014 that was based on 2012 data. In general, prices have decreased since 2012, while PV productivity per unit of installed capacity has remained about the same, resulting in an overall decrease in the Levelized Cost of Electricity (LCOE) for solar power in Nova Scotia.

By surveying PV customers and installers, we have estimated the price and productivity of solar electricity in Nova Scotia as of the end of 2017. The estimates are based on data from 59 PV systems. The results are summarized in Table 1 below:

Table 1: Summary of Key Results

FACTOR	RESULTS 2017	% CHANGE 2012 to 2017	% CHANGE 2013 to 2017
AVERAGE PRICE (INSTALLED)	CAD$ 2.80 ± 0.10 / Watt (DC)	38% DROP*	6.4% DROP*
AVERAGE PRODUCTIVITY	1087 ± 34 kWh/kW per year	NO CHANGE	NO CHANGE
RANGE OF PRODUCTIVITY	841 TO 1248 kWh/kW per year	NO CHANGE	NO CHANGE
LEVELIZED COST OF ELECTRICITY (LCOE) - NOT INCLUDING HST	CAD$ 0.230 ± 0.015 / kWh	26% DROP*	5.7% DROP*

**NOTE: Most of the decrease in price and LCOE occurred from 2012 to 2013. The decrease since 2013 has been modest. See Figure 3 in Section 5.1 for details.*

We found that geographic location has very little effect on PV productivity within Nova Scotia. One region of Nova Scotia in our sample, the region of Annapolis and Digby counties, had about 7% higher productivity than the provincial average. All other regions in our sample had productivity that was not statistically different from the average for the whole province.

1. INTRODUCTION

Following on an earlier (2014) report[1], this is an update of the prices and productivity of solar photovoltaic (PV) electricity generating systems in Nova Scotia. This report is based on price and electricity production data collected from existing PV systems connected to the electricity distribution grid across Nova Scotia that were installed in the years between 2011 and 2017. This data was used to estimate the following:

- Price of solar PV systems, and the trend in that price over time.
- Annual electricity production of PV systems, and its geographic variation in Nova Scotia.
- Seasonal variation in PV electricity production, based on monthly data.
- Levelized cost of solar electricity in Nova Scotia (LCOE), and the trend in that cost over time.

This report is intended to inform the public, government, businesses, and other stakeholders about the value of solar electricity in Nova Scotia, for consideration in project decision-making, policy design, and planning in the solar electricity space.

2. PHOTOVOLTAIC TECHNOLOGIES

The PV generating technologies studied here are those most commonly in use in Nova Scotia in the period from 2014 to 2017. The physical components that most clearly characterize these systems are the PV modules (commonly known as PV panels) and the inverter systems. The types of PV modules and inverters most commonly used in Nova Scotia at this time are described below.

2.1. PHOTOVOLTAIC MODULES

In our sample, the PV modules installed in Nova Scotia to generate electricity today are typically composed of monocrystalline or polycrystalline silicon PV cells. About a half-dozen brands of modules supply the bulk of the PV projects in the province. Typical rated efficiencies of these modules are consistent with the global market, between 15% and 18% (electrical energy output per unit of incoming energy from solar irradiance). All the data reported here is from systems using modules in this category.

2.2. INVERTER SYSTEMS

Inverters convert the direct current (DC) from the PV modules to alternating current (AC) at the correct voltage and frequency, and synchronize this AC with the main electricity supply on the distribution line. The inverter system is an essential element of all the PV projects studied here. We have found three types of inverter systems in use for PV projects in Nova Scotia – string inverters, string inverters with optimizers, and micro-inverters. These systems are described below.

STRING INVERTERS: These are PV systems in which one inverter receives DC input from many PV modules that are connected together in series to form 'strings'. The voltage of the modules adds together when connecting in series, so the number of modules in a string depends on the maximum voltage allowed by the inverter and the electrical code. One common maximum string voltage is 600 Volts DC (VDC), although voltages up to 1000 VDC are beginning to be used in Nova Scotia. Several strings are connected to the inverter, up to the number of strings the inverter can accept.

String inverters on the market today have high efficiency and are economical to install. However, they encounter issues of significantly decreased output if one or more of the PV modules on any string is sometimes shaded, for example with shadows from trees, buildings, or other nearby objects, or partial snow coverage. Therefore, string inverters are used most effectively in situations where there little or no shading will occur during maximum production hours, which are typically between 10 am and 4 pm.

STRING INVERTERS WITH OPTIMIZERS: These are string inverter systems, as described above, but with additional equipment to maximize production. Each PV module (or small group of modules) has an 'optimizer', a device mounted behind the module and connected together in series strings. The optimizer increases the total power output of the array using Maximum Power Point Tracking (MPPT). MPPT measures the voltage and current from each module and adjusts the output voltage to maximize power output. This is advantageous in situations when there is partial shading of a string of modules. If one module is shaded, its power output will decrease, but the optimizer will adjust its voltage to allow it to produce as much power as possible, without decreasing the voltage on the rest of the string. This helps each string perform optimally even if some modules in the string experience sub-optimal conditions.

Optimizers also perform an advanced monitoring function, by measuring and reporting energy output from each module. They also offer a safety feature, by limiting the DC voltage from each module in the array to a safe level when the grid power is down or the system is shut off, for repair or emergency response.

MICRO-INVERTERS: In micro-inverter systems, an inverter is connected behind each PV module (or small group of modules), or integrated into the module itself. This converts the DC power to AC right at the module, and includes the MPPT feature, as described previously. In a micro-inverter system, the power is carried as grid-quality AC power, at the correct voltage, frequency, and synchronization, directly from the module to the distribution grid.

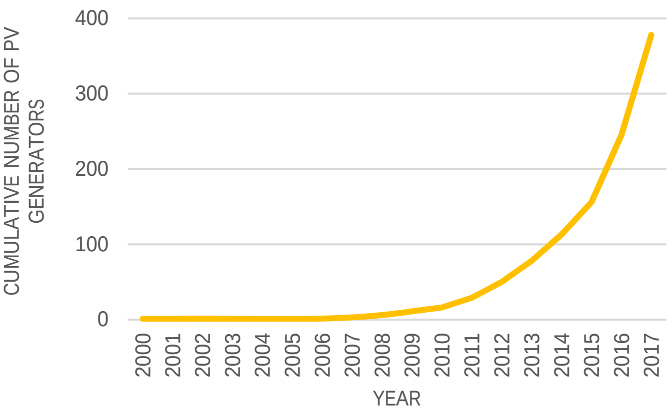
Because AC grid power is more familiar to today's electricians, inspectors, and electrical equipment suppliers, there is a relative simplicity to completing the wiring on a PV array with micro-inverters. And like optimizers, the micro-inverters allow each module to perform as well as possible independently, even if one or more modules is shaded. Micro-inverters also provide safety in the case of a power outage or an emergency, because when the grid is down or the connection to the system is shut off, all the inverters de-activate and there is no high DC voltage in the wires that connect the solar modules.

Most of the PV projects for which we obtained data in our study are using micro-inverters. There are also projects in Nova Scotia with optimizers and string inverters. In this study, we have not collected enough data to measure any possible difference in performance between these types of inverter systems.

3. GROWTH OF PHOTOVOLTAIC ADOPTION IN NOVA SCOTIA

The number of PV systems installed in Nova Scotia grew rapidly in the study period. To assess the pattern and estimate the rate of growth, we used data reported from the Nova Scotia Power Enhanced Net Metering program. The PV projects that are connected to the Nova Scotia Power electrical distribution system each year through the Enhanced Net Metering program are reported by Nova Scotia Power to the Utility and Review Board (UARB). This annual report shows the growth of PV installations in the province over time[2]. By the end of 2017, there were 378 grid-connected PV projects reported to the UARB in Nova Scotia.

Figure 1: Cumulative number of PV generators by year in Nova Scotia.



ANNUAL GROWTH IN NUMBER OF PV GENERATORS:

2015 → 38%
2016 → 57%
2017 → 54%.

Figure 1 above does not include all the PV projects in Nova Scotia, although it likely contains the clear majority of projects. Missing are any projects that are not connected to the electrical distribution system (off-grid systems), any that connect to utilities other than Nova Scotia Power, such as the six municipal electric utilities, and any that are not participating in the Enhanced Net Metering program.

For this last category that are not participants in Enhanced Net Metering, we know that at least one PV array is not included in this list – the largest PV array in Nova Scotia up to 2017 – an 850-kW_{DC} array installed on the roof of a new IKEA store in Dartmouth. With this relatively large array, and others that may follow from other proponents, significant additional PV generation could be installed outside of the Enhanced Net Metering Program in the future. Currently, projects connected without a net metering agreement in Nova Scotia must use and/or store all their solar electricity production on-site in real time, and avoid feeding back to the grid.

The electrical power output capacity of PV projects, also known as 'nameplate capacity', is given as the nominal operating output of AC electrical power from the inverters, in Watts (W), kilowatts (kW), or megawatts (MW). The cumulative capacity of PV projects participating in Enhanced Net Metering over time is shown in Figure 2 below.

Figure 2: Cumulative generating capacity (MW) of PV operating in Nova Scotia over time.

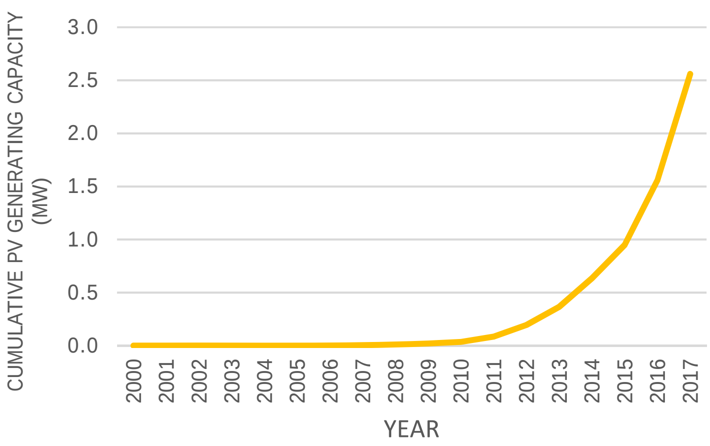


Figure 2 includes only those projects participating in Enhanced Net Metering. PV generating capacity in Nova Scotia now exceeds 3 MW AC at the end of 2017, considering the 2.6 MW reported above, plus the 0.8 MW installed at the IKEA store.

ANNUAL GROWTH IN PV GENERATING CAPACITY:

2015 → 49%
2016 → 64%
2017 → 64%

The development of PV projects in Nova Scotia over this period consists of many relatively small projects, along with a few larger ones. The average capacity per project in 2017 was 7.5 kW AC, and in that year, there was only one net metered project greater than 20 kW of capacity.

4. DATA COLLECTION

We gathered data for this study by two methods – a survey of owners of PV systems, and a survey of companies that install PV systems. We eliminated duplicates between these studies, based on the location of the project. In total, we received usable data for 59 PV systems. Our sample represents approximately 15% of the installed systems in Nova Scotia.

All the PV systems reported in this survey are fixed-mount arrays, with some mounted to buildings and some mounted on stands on the ground. None of the arrays reported here have a tracking system to follow the sun.

4.1. CUSTOMER SURVEY

We invited people who have a PV system at their property to complete a survey that included questions about the number and size of PV modules installed, the type and capacity of inverters, the slope and orientation of the modules, the installed price, and any challenges they encountered in setting up their PV system.

We received 21 responses. For this report, we excluded systems that were not connected to the electrical grid (off-grid systems), and any with incomplete information. With those systems excluded, we were able to use customer data from 9 systems to contribute to the pricing study. Because of this high attrition rate of non-usable survey reports, we focused our efforts on obtaining survey results from the companies that install PV systems.

4.2. INSTALLER SURVEY

We distributed a survey to companies that install PV systems, asking them for information on the prices of their installations over the past 4 years, and for measured electricity production data from PV systems at their customers' sites that have been operating for at least 12 months. We received price data for 50 systems, and production data for 32 systems from installers in response to the survey. We were able to use nearly all this data.

5. RESULTS

IMPORTANT NOTE - DC versus AC ratings:
Accumulated electricity production from a PV array over months or years is most closely related to the nominal (rated) power of the solar modules, known as the DC rated output of the system.

This is different from the discussion in Section 3 above, where the system sizes were reported by the AC nameplate output capacity of the inverters, which is the power generating capacity of the power processing equipment directly connected to the grid.

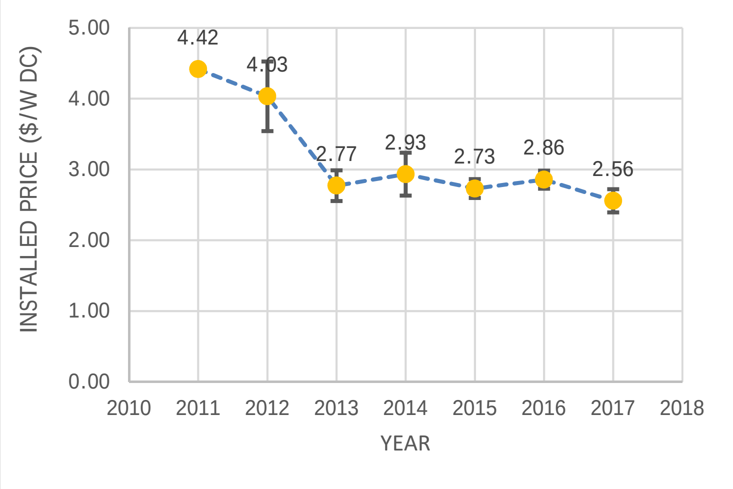
The DC power rating and AC nameplate capacity for a PV array are often different, and typically the DC rating is higher. The reason for the difference is that many PV system designers specify greater DC rated power output (more modules in the array) than the rated capacity of the inverter, often up to 20% more. This causes the inverter to operate closer to its maximum output more of the time, including partly-overcast days and times when the sun is not at optimal angles, while not exceeding the power limit on the inverter. The array will produce more energy over the course of a year, for a given AC nameplate capacity, if there are more DC modules installed.

This tendency to build in extra solar modules is especially strong when legislation or policy places a restrictive limit on the AC power capacity of the system, such as the 100-kW AC limit on net metering projects in Nova Scotia, and the 50-kW AC limit on project size in the Nova Scotia Solar Electricity for Community Buildings Program. A project proponent can produce more electricity on a long-term basis, for the same AC nameplate capacity, by building a larger DC array.

5.1. PRICE

The PV systems in our price survey range in size from 0.6 kW to 100 kW (DC rated output), with an average size of 9.7 kW. The average (mean) installed price of the PV systems in our sample over time is shown in Figure 3 below. To be consistent, in the price and productivity results, all system sizes are based on the DC rated output of the PV modules of the PV array.

Figure 3: Price of photovoltaic systems over time.



NOTES:

-The price is normalized to the size of the system ($/Watt), in terms of nominal (DC) rated power of the array, which is determined by the combined rated power of the PV modules.

-Prices do not include Harmonized Sales Tax (HST).

-The error bars represent the uncertainty, calculated as the 90% confidence interval of the mean.

-For 2011 we have only one data point in our sample, not enough to determine an uncertainty range.

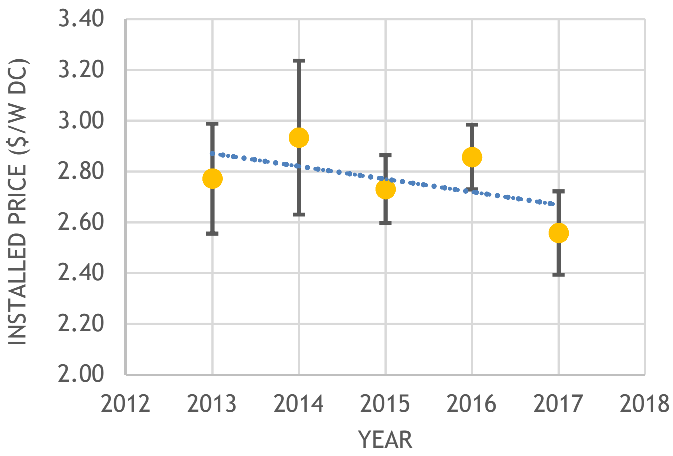
Table 2: PV system prices in Nova Scotia by year.

YEAR	AVERAGE	UNCERTAINTY (±90% CONFIDENCE INTERVAL)
2011	4.42	N/A
2012	4.03	0.49
2013	2.77	0.22
2014	2.93	0.30
2015	2.73	0.13
2016	2.86	0.13
2017	2.56	0.16

The average price of PV systems appears to have dropped dramatically from 2011 to 2013, and then changed relatively little between 2014 and 2017. It is important to recognize that there is very little data in this sample from 2011 and 2012.

To consider the more recent trend, and years for which our sample has more data, Figure 4 shows the best-fit trend line from 2013 to 2017.

Figure 4: PV systems price trend – 2013 to 2017.



Our sample does not show a statistically significant trend in the price of a PV installation since 2013. There appears to be a downward trend visually, but the variation within each year exceeds the trend, and the correlation coefficient of the trend is very low (0.3149). The 2017 prices appear to be anomalously low.

The most solid conclusion from this sample is that the price has varied around a fairly steady average of $2.80 /W (DC), +/- $0.10 between 2013 and 2017.

Nova Scotia average PV price

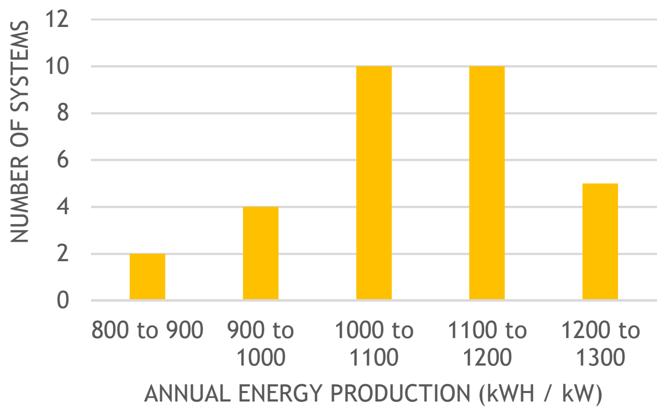
2013-2017:
Between $2.70 and $2.90 per Watt (DC)

2017:
Between $2.40 and $2.72 per Watt (DC)
(Not including HST).

5.2. ANNUAL ELECTRICITY PRODUCTION

Our sample of production data from 31 systems around Nova Scotia showed a wide range of annual electricity production values. To compare different sizes of systems, we normalized the annual production per kilowatt (DC) of installed PV modules. The highest annual value in our sample in Nova Scotia was 1248, and the lowest was 841 kWh/kW.

Figure 5: Distribution of systems by annual production (kWh/kW).



Average annual PV production in Nova Scotia
1087 ± 34 kWh / kW

The uncertainty is the 90% confidence interval. This average includes all systems in the sample, regardless of location, design, module orientation, potential shading issues, or inverter type. It represents an estimate of the bulk average productivity of real systems installed in Nova Scotia to date, not an idealized productivity.

If your site factors are ideal, you may produce more than the average. With ideal conditions and system design, annual production above 1200 kWh/kW is possible. On the other hand, any claims to produce more than 1300 kWh/kW per year in Nova Scotia from a fixed-mount system are unlikely to be true.

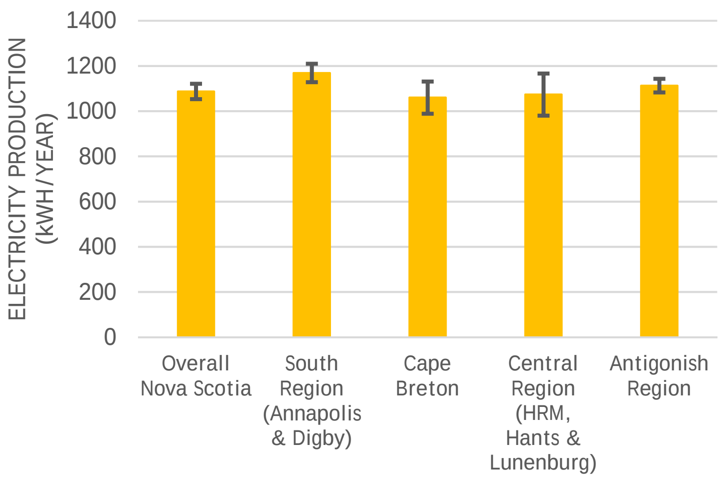
REGIONAL VARIATION: To test for differences between regions, we divided the data in our sample into 4 geographic regions. We defined these regions based on where we had obtained enough data for a significant sample size. The regions and the number of samples are shown in Table 3 below. Some counties are not represented, because we do not have data from those counties.

Table 3: Regions defined in the production data.

REGION	COUNTIES	# OF SYSTEMS	AVERAGE PRODUCTION (kWh/kW/Y)
SOUTH REGION*	ANNAPOLIS & DIGBY	4	1169 +/- 41
CENTRAL	HRM, HANTS, & LUNENBURG	6	1073 +/- 93
ANTIGONISH REGION	ANTIGONISH COUNTY	11	1113 +/- 30
CAPE BRETON	CBRM, VICTORIA, RICHMOND, & INVERNESS	10	1060 +/- 71
OVERALL TOTAL	ALL COUNTIES IN SAMPLE	31	1087 +/- 34

*The only region in our sample that showed a statistically significant higher productivity is the South Region (Annapolis and Digby Counties), with about 7% higher solar productivity than the overall average.

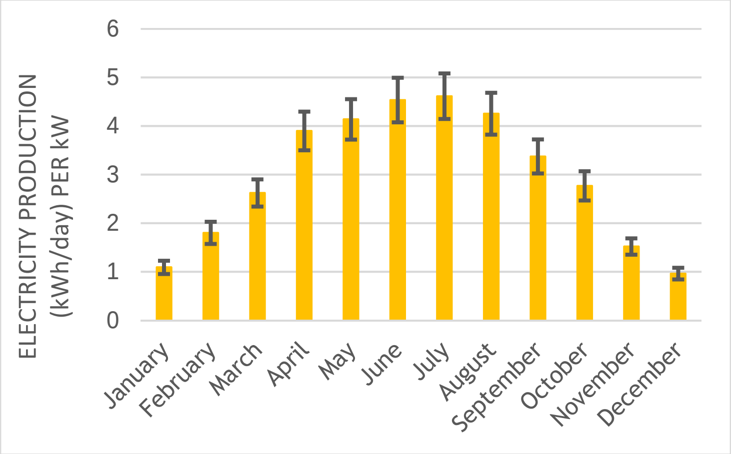
Figure 6: Regional solar electricity productivity.



5.3. SEASONAL VARIATION

We obtained monthly electricity production data for all the systems in our production data set. The seasonal pattern of productivity, averaged over all the systems in our sample, is shown in Figure 7 below. Monthly production in the peak solar months from May through August is over four times higher than in the low months of January and February. This corresponds with expectations based on solar radiation intensity, day length, and cloud cover.

Figure 7: Monthly pattern of solar productivity in Nova Scotia.



5.4. LEVELIZED COST OF SOLAR ELECTRICITY

The levelized cost of energy (LCOE) for solar electricity is an estimate of the amortized cost per kilowatt-hour (kWh) of producing electricity from distributed solar electricity generators. LCOE considers the discount rate, also known as the weighted average cost of capital (WACC). The inputs into the estimate of LCOE are:

- Capital cost of the generator system
- Operating cost of the generator system
- Anticipated output of the generator in each year
- Anticipated operating lifetime of the generator
- Assumed discount rate on future benefits

We have followed the method of the International Renewable Energy Agency to calculate LCOE, as follows[3]:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = levelized cost of electricity generation;

I_t = investment expenditures in the year t;

M_t =operations and maintenance expenditures in the year t;

F_t = fuel expenditures in the year t (this is zero for solar);

E_t = electricity generation in the year t;

r = discount rate;

n = economic life of the system (years).

We used the price and production data from Sections 4.1 and 4.2, along with the following assumptions, to calculate the LCOE of solar electricity in Nova Scotia in 2017. The spreadsheet tool we developed for this calculation is available.

***ASSUMPTIONS*:**

Installed cost:

$2.80 +/- $0.10 per W (not including HST)

This is the 2013-2017 average price.

Annual electricity production in Year 1:

1087 +/- 34 kWh / kW

Economic life of system:

25 years

Annual decrease in PV energy output:

0.6% per year[5]

Discount rate:

6% annual

Annual maintenance and operating costs:

CAD$25 per kW, with 2% annual inflation

Based on the assumptions above, for the average 2013 to 2017 prices, we estimate the LCOE of solar electricity in Nova Scotia as follows:

LCOE for PV in Nova Scotia in 2017:

$0.230 / kWh

Range: $0.216 to $0.245 / kWh

Adding HST raises LCOE by $0.035 / kWh

If the average installed price of PV systems in our sample for just 2017 ($2.56 / W DC), is used in the calculation, the LCOE decreases to $0.213 / kWh (not including HST).

6. DISCUSSION

COST OF SOLAR ELECTRICITY:

The estimated average cost of solar electricity in Nova Scotia for 2017 is lower than in our previous report[1] published in 2014, in which the LCOE was estimated to be between $0.29 and $0.36 per kWh. That figure was based on 2012 price data and included HST. The comparable value for 2017 in this current report is between $0.25 and $0.28 / kWh (including HST), an average drop of $0.06 / kWh. The cost of solar electricity in Nova Scotia has dropped by about 19% over a 4-year period from 2012 to 2016.

The systems sampled in this study represent the typical types and sizes of systems installed in Nova Scotia over the past 4 years, which are relatively small (mostly less than 10 kW) and distributed across a wide spectrum of sites and buildings. There are no systems in this sample greater than 100 kW in size. Therefore, this study represents the price of small-scale, distributed solar energy, not large utility-scale solar energy in Nova Scotia.

PRODUCTIVITY OF SOLAR ELECTRICITY:

We have not seen a significant change in the average electrical productivity of PV systems in Nova Scotia since our earlier 2014 report, which estimated average annual productivity at 1100 +/- 100 kWh/kW. The earlier figure was based on a much smaller sample of 6 systems, compared with 31 in this report. An apparent minor decrease to 1087 +/- 34 kWh/kW is not statistically significant, as the uncertainty ranges overlap.

That an increase in electrical productivity per Watt has not been observed, despite that fact that solar modules on the market have become more efficient, is likely because we are reporting on the average production of all the installed systems for which we could obtain data, not idealized cases where the array orientation and sun exposure are optimized.

Our 2017 productivity estimate represents a realistic sample of the systems that are operating now. Our data show that with ideal siting and orientation it is possible to obtain annual output of over 1200 kWh/kW from a fixed-mount PV array in Nova Scotia, but not more than 1300 kWh/kW.

COMPARISON WITH OTHER PRICE DATA:

Data on the pricing of installed PV systems is also collected by Halifax Regional Municipality (HRM), and can be compared with the results we have found. In November 2017, HRM published a municipal staff report on the previous year of its Solar City program[6]. This program offers municipal financing for property owners to install solar PV, solar water heating, and solar air heating systems. From November 2016 to October 26, 2017, the first year that PV was offered in the program, the participants installed a total of 37 PV systems, with an average capacity of 6.0 kW per installation.

The average installed price of PV systems in HRM Solar City for 2017 was $2.88/W. HRM staff also noted a decline in prices within their program, from $3.10/W in October 2016 to about $2.60/W in October 2017.

The prices reported by HRM for small-scale PV installations are similar to the average price of $2.80 ± $0.10/W we have found across Nova Scotia.

7. CONCLUSION

Based on the results of our survey, we make the following primary conclusions:

PRICE:

According to our sample, the average price of small-scale photovoltaic installations in Nova Scotia fell dramatically in 2013 and has remained close to the level of $2.80 / Watt since then, with some indications of a slower, and not statistically significant, decline in the years from 2014 to 2017.

PRODUCTIVITY:

The annual electricity production of solar PV generators in Nova Scotia in this reasonably representative sample has an average of 1087 ± 34 kWh/kW, and a range between 841 and 1248 kWh/kW. We found one region of Nova Scotia in our sample, the region of Annapolis and Digby counties, with about 7% higher productivity than the provincial average. All other regions in our sample were not significantly different from the provincial average.

LEVELIZED COST OF ELECTRICITY (LCOE):

The average LCOE for small-scale, distributed solar electricity in Nova Scotia in 2017 is estimated to be $0.230 ± 0.015 per kWh (not including HST), or $0.265 ± 0.015 per kWh (including HST).

ENDNOTES

1 Groszko, W. and M. Butler, Solar Photovoltaics in Nova Scotia: Report on Costs and Measured Electrical Productivity, Ecology Action Centre and Province of Nova Scotia, Feb. 2014. Accessed June 12, 2018 at: http://0-nsleg-edeposit.gov.ns.ca.legcat.gov.ns.ca/deposit/b10692939.pdf

2 Nova Scotia Power Inc., Report to the Nova Scotia Utility and Review Board, Regulation 3.6 – 2017 Net Metering Report, January 31, 2018.

3 IRENA (2018), Renewable Power Generation Costs in 2017, International Renewable Energy Agency, Abu Dhabi, page 153. Accessed June 12, 2018 at: http://www.irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017

4 Jordan, D. C., Kurtz, S. R., VanSant, K., and Newmiller, J. (2016) Compendium of photovoltaic degradation rates. Prog. Photovolt: Res. Appl., 24: 978–989. doi: 10.1002/pip.2744.

5 US National Renewable Energy Laboratory (NREL), Distributed Generation Renewable Energy Estimate of Costs, updated February 2016, Table 1. Accessed June 12, 2018 at: https://www.nrel.gov/analysis/tech-lcoe-re-cost-est.html

6 Item 11.1, Information Item No. 2, Report to the Environment and Sustainability Standing Committee, Halifax Regional Municipality, November 20, 2017. Accessed March 15, 2018 at https://www.halifax.ca/sites/default/files/documents/city-hall/standing-committees/180201essc111.pdf

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the Province of Nova Scotia (Department of Energy), and the Atlantic Canada Opportunities Agency (ACOA) for this work. We also express our appreciation to the study's Advisory Team – Sheena Parris, Peter Craig, Matthew Wood, Blake Mann, Dr. Carolan McClarney, Hamish Malkin, David Brushett, and Gord Wilkie. We are especially grateful to the participants in our study who shared their data.

Solar NOVA SCOTIA

Renewable Energy | Conservation | Efficiency

www.solarns.ca