Solar Photovoltaics in Nova Scotia

Report on Costs and Measured Electrical Productivity

Solar photovoltaic array at Nova Scotia Community College, Dartmouth, NS Photo: Wayne Groszko

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1. Introduction

1.1. Statement of Purpose

This report is intended to contribute to an informed discussion about whether and how to promote greater deployment of solar photovoltaic (PV) systems for electricity generation in Nova Scotia. In these pages we examine the following elements of the solar PV landscape in the province:

- The solar resource – measured solar electricity productivity in Nova Scotia;
- Available and developing solar energy technologies;
- Timing of the solar resource with respect to electricity demand in Nova Scotia;
- Prices and price trends for PV systems;
- Trends in feed-in tariff rates and other PV promotion programs in various jurisdictions in Europe and North America;
- The relationship between development of the PV industry and the solar thermal industry in Nova Scotia.

1.2. Background

Photovoltaic electricity systems create electricity directly from sunlight absorbed by semiconductor materials. The use of PV as an electricity supply source is rapidly growing, both globally and in Canada[1,2].

PV produces electricity from renewable solar radiation with no emissions of pollutants to air or water while in operation. When the emissions from the manufacturing, installation and maintenance of a PV system are included, the total life-cycle emissions of greenhouse gases and air pollutants per kilowatt-hour produced are very low in comparison with fossil-fuel fired electricity generation. Total life-cycle emissions of greenhouse gases from PV are estimated to be between 25 and 50 grams of CO_2-equivalent per kilowatt-hour (gCO_{2eq}/kWh)[3], compared with about 900 to 1100 gCO_{2eq}/kWh for coal-fired electricity[4].

Because PV generators are modular, scalable, have no moving parts, and generate no noise or emissions when in use, they are well-suited to being installed in a wide variety of locations throughout a region. PV is effective anyplace in Nova Scotia that has sky exposure to the south and that is not subject to shading. Suitable installation sites include rooftops, walls, on ground mounts and over other compatible infrastructure such as car parking lots. A diversity of PV installations could create a distributed pattern of renewable energy generation and potentially reduce the need for transmission upgrades if they are installed near the points of consumption of the electricity they generate.

The Department of Energy is reviewing the state of solar energy in Nova Scotia to examine its potential in the province. Deploying more solar energy could have a variety of social and environmental benefits in terms of renewability, greenhouse gas emission reduction, diversity and distribution of electricity generation, economic development and community participation. At the same time, since PV-generated electricity is, at present, more expensive in many markets than fossil-fuel-fired electricity, hydroelectricity or wind power, it is important to consider the costs and benefits as well as the appropriate means of developing PV in the Nova Scotia context. Solar PV is also only one of several ways to harvest the solar energy resource, so we will also consider the relationship between solar PV and other solar technologies.

At present the Province and Efficiency Nova Scotia support solar energy development through rebates and zero-interest loans for solar water and air heating systems. Solar PV systems are not eligible for rebates or a feed-in tariff. There is one incentive program for which solar PV systems are eligible – the Nova Scotia Power Enhanced Net Metering Program[5], which offers Nova Scotia Power Inc. (NSPI) customers credit at the retail electricity rate for renewable electricity (including solar PV) that they generate on-site.

Another form of renewable energy incentive, the Nova Scotia Community Feed-In Tariff Program (COMFIT) has been open for applications since September 19, 2011, and has generated considerable interest and numerous renewable energy project applications. The COMFIT offers pre-determined rates for renewable energy generated by eligible facilities owned by eligible entities. The eligible entities are municipalities, First Nations, Community Economic Development Investment Funds (CEDIFs), co-operatives and non-profit organizations[6]. The COMFIT program is currently undergoing its scheduled review, to determine whether any adjustments should be made.

The COMFIT program currently offers tariffs for the following technologies:

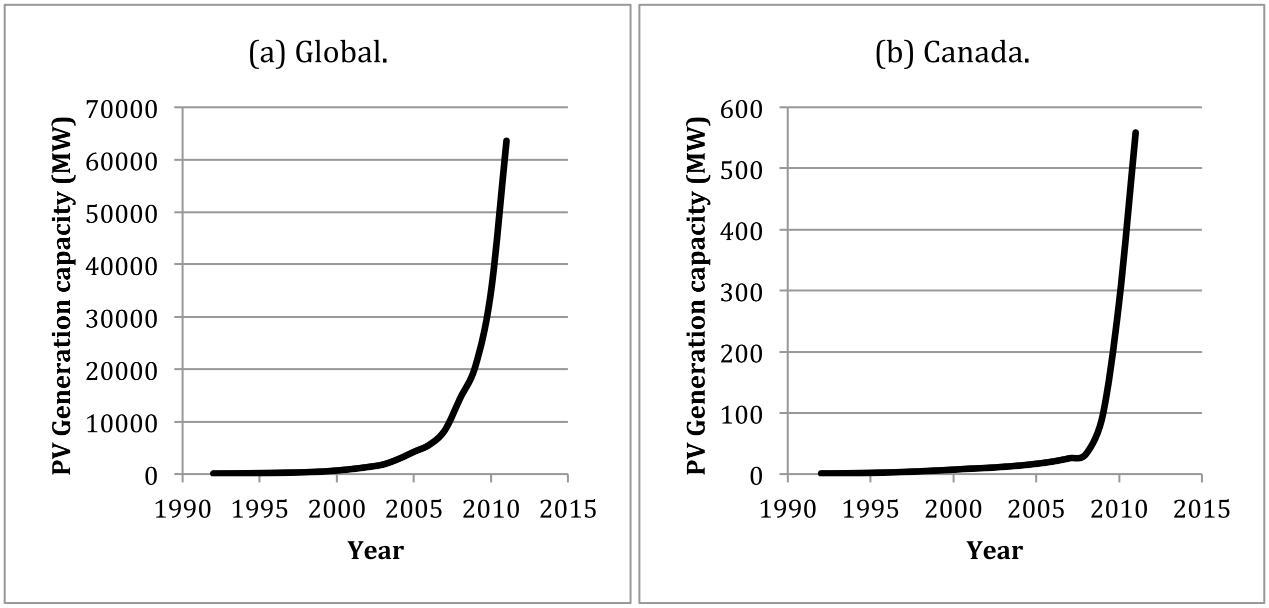
- Small-scale wind energy generators (50kW or less)
- Large-scale wind energy generators (greater than 50kW)
- Small hydroelectric projects
- Biomass Combined Heat and Power projects
- Tidal Electricity projects

Solar energy is not currently included in the COMFIT program. Several stakeholders have expressed interest in expanding the COMFIT program to include solar energy. We include in this report an estimate of the cost of that option.

1.3. Growth of Solar PV Generation

Worldwide, the installed generating capacity of PV is growing quickly. Cumulative installed global PV generating capacity has demonstrated growth rates averaging more than 60% per year for the past 5 years.[7] In Canada over the same period the growth rate of installed PV generation capacity has averaged over 100% per year, including a near tripling in 2009 and more than doubling in 2010.[8] Graphs of the cumulative installed megawatts (MW) of PV generation capacity worldwide and in Canada since 1992 are shown in Figure 1 below.

Figure 1: Cumulative installed PV generation capacity (MW), (a) Global, (b) in Canada.[9]



PV generation is used in both on-grid (grid-connected) and off-grid applications. Off-grid PV is typically used where a grid connection is unavailable or is too far away to be cost-effective. The fastest current growth, both globally and in Canada, is in grid-connected systems, although off-grid PV capacity is increasing steadily as well.[10] The vast majority of the growth in Canada is due to the implementation of the Ontario Green Energy and Economy Act, which established favourable feed-in tariff rates to incentivize the solar PV industry in Ontario.

In Nova Scotia, as of December 2012 there are about 50 grid-connected solar PV arrays with a combined capacity of less than 0.2 Megawatts (MW)[11]. These systems are connected through the Enhanced Net Metering Program of Nova Scotia Power, in which credit is paid at the retail electricity rate for surplus electricity generated.[12]

1.4. Strengths and Weaknesses of Solar PV in the Nova Scotia Context

The Nova Scotia government has adopted ambitious greenhouse gas reduction targets[13] and renewable electricity targets for 2015 and 2020.[14] Significant progress has been made so far towards meeting these goals through energy efficiency and the deployment of wind energy. Moving forward, solar PV could add a new source to the diversity of renewable electricity supply in Nova Scotia.

Table 1: Some strengths and weaknesses of solar PV in the Nova Scotia context.

Strength	Weakness
The price of solar PV is falling rapidly on the global market.	As of 2012, solar PV still has a higher price than several other forms of renewable electricity and energy efficiency.
Solar PV can be widely deployed in a distributed pattern near electrical loads, including in urban areas where wind energy would not be suitable.	Nova Scotia has existing electricity system assets built around a different paradigm – large centralized generation and long-distance transmission.
Solar PV generates in the daytime, when demand is consistently higher than at night. Therefore solar PV will not contribute to night-time over-supply events.	Solar PV output is higher in the summer months than in the winter months, while highest peak electricity demand in Nova Scotia currently happens in the winter months.
Solar PV is feasible for property owners to install at their properties all over the province, thus allowing greater participation, economic development and job opportunities, and support for renewable energy generation.	The existing solar industry in Nova Scotia has strength in solar thermal systems, which homeowners can also install. Too ambitious a program in solar PV could risk moving business away from solar thermal. Hybrid solar PV/ solar thermal may be one of a number of innovative approaches.
Community economic development and jobs would be created in solar PV system design, installation, monitoring and maintenance. Skilled work constitutes a significant portion of solar PV project expenditures.	Nova Scotian industries currently do not manufacture solar PV panels or other major components of PV systems. This may constitute a potential opportunity to begin producing some components here.

2. Solar Energy Technologies

Unless otherwise indicated, information in section 2 is from the International Renewable Energy Agency.[15]

2.1. First Generation PV - Crystalline Photovoltaics (cSi-PV)

Crystalline solar cells (cSi-PV) are the most prevalent form of PV on the world market today, accounting for about 87% of the market in 2010.[16] Formed from wafers of silicon semiconductor, cSi-PV modules that are commercially available typically have a solar energy conversion efficiency of between 14 and 19%.


Photo: Wayne Groszko

Crystalline solar PV is a relatively mature technology that has undergone a major increase in the scale of manufacturing. For example, one of the largest manufacturers of PV modules in the world, Canadian Solar Inc., is capable of manufacturing more than 2000 megawatts of cSi-PV modules annually at its production facilities in China.[17]

During 2012 there was an over-capacity of global production of PV modules, including cSi-PV, and prices on the world market were at all-time lows. While this encouraged continued growth in sales and installations, it also caused a shakedown and consolidation of the PV production industry. A comprehensive market analysis predicts that overcapacity, low prices and consolidation of PV manufacturing will continue through 2014.[18]

2.2. Second Generation PV - Thin Film Photovoltaics (thin-PV)

Thin-film solar cells are made from thin layers of semiconductor successively deposited on a substrate such as glass, plastic or metal. Thin-PV requires much less semiconductor material than crystalline PV, and as such has the potential for lower material and manufacturing costs. These lower costs are partly offset by a generally lower efficiency of solar energy collection.

Another advantage of thin-PV is that the material is more flexible and can therefore be coated onto a variety of curved or oddly-shaped surfaces, facilitating the development of building-integrated photovoltaics (BIPV). Its light weight also allows for innovative applications such as on clothing and backpacks for charging portable electronic equipment.

The three main types of commercially-available thin-film solar modules are:

- Amorphous silicon;
- Cadmium Telluride; and,
- Copper-Indium-Selenide and Copper-Indium-Gallium-Diselenide

Table 2: Summary of features of thin film PV types.[19]

Thin film type	Efficiency	Notable features
Amorphous thin film	4 to 8% (12% in lab)	Most common type of thin film product on the market.
Multi-junction amorphous	14 to 15%	Extra junctions absorb more red and infrared light.
Cadmium telluride	15 to 16%	Low production costs, but cadmium is toxic and tellurium is not highly abundant.
Copper-indium-selenium Copper-indium-gallium-selenium	7 to 16% (20% in lab)	Highest efficiency in thin film, in laboratory tests.

2.3. Third Generation PV – Organic PV, Concentrating PV and other novel PV technologies.

Much work is being undertaken in research institutions and companies around the world to develop new ways of generating electricity with photovoltaic materials, including work now happening at Dalhousie University in Halifax. Dr. Ian Hill of the Department of Physics and Dr. Gregory Welch of the Department of Chemistry, both at Dalhousie University, conduct research into organic photovoltaic materials, one of the types of "third generation PV".

2.3.1. Organic PV

Organic solar cells are composed of polymers and/or smaller organic (carbon-containing) molecules. They have considerable potential to provide low-cost PV materials that are light-weight, thin and flexible, using primarily materials such as carbon that are very abundant and readily available. By adapting commonly available ink printing technologies, some kinds of flexible organic PV cells can be produced quickly and cheaply.

The current disadvantages of organic solar cells are their relatively low efficiencies (4 to 5% commercially and 6 to 8% in the lab), as well as the relative instability of the products. The performance and integrity of organic PV material decreases rapidly with time when exposed to sunlight. Researchers at the Massachusetts Institute of Technology have been working on an organic PV solution that mimics plants by "healing" itself after sun exposure.[20]

2.3.2 Dye-Sensitized Solar Cells

Dye-sensitized solar cells (DSSC) contain a photo-sensitized anode (for example titanium dioxide coated with a light-sensitive pigment), in contact with an electrolyte. The process mimics photosynthesis in plants. Its advantages are in the low cost of the materials and simplicity of manufacture.

Currently available commercial DSSCs have relatively low efficiencies (4 to 5%), and a tendency to degrade with time in UV light. Laboratory demonstration cells have reached an efficiency of 12%. Research is continuing, with thousands of dyes and anodes tested to find those capable of absorbing a greater portion of the solar spectrum and thus increasing efficiency.

2.3.3. Concentrating PV

The idea behind concentrating PV is that if the solar energy from a large area can be concentrated onto a small area of PV material, the cost of PV electricity production will be lower. This idea is based on the fact that highly-efficient multi-junction PV material is expensive, while the materials needed to concentrate light, such as mirrors or plastic Fresnel lenses, are less expensive.

Photo: Morgan Solar (with permission)

Concentrating PV also has the potential to reach higher efficiencies. By using the highest-efficiency triple-junction PV cells currently available, made from combinations of germanium, indium, gallium, arsenic and phosphorous, the efficiency of concentrating solar cells could theoretically reach 59%. In practice, commercial products currently available are in the range of 20 to 25% efficiency, and laboratory cells have reached 40%.

A Canadian example of technology development in concentrating PV is Morgan Solar, which has developed the Sun Simba collector.[21] The cells in this collector consist of acrylic light guide solar optics, which guide the incident light to a multi-junction PV wafer located at the centre of the cell. They claim that modules made from these cells will produce electricity at efficiencies comparable to crystalline modules widely available on the market today, but at lower cost.

An important characteristic of concentrating PV, and all concentrating solar technologies, is that its performance is strongly direction-dependent. The optical mechanisms that concentrate the light energy can accept sunlight from a specific direction only, not indirect or scattered sunlight. This has two implications: (1) The arrays must be mounted on two-axis trackers to point at the sun at all hours of operation, and; (2) their performance will be higher in regions with more days of clear, sunny sky, because they cannot use the indirect light scattered by clouds and particles in the air.

The type of solar radiation that concentrating PV depends on is called direct normal incident (DNI) radiation. As may be expected, global maps of DNI indicate that this solar resource is particularly abundant in arid, desert regions of the world, where cloud cover is infrequent.[22] Concentrating PV will of course work in Nova Scotia, but its relative advantages are not as pronounced in Nova Scotia as they would be in regions with less frequent cloud cover, such as southern Saskatchewan.

2.3.4. Solar Combined Heat and Power

A variant of concentrated solar power, solar combined heat and power technology produces PV electricity and hot water simultaneously. This is an ingenious adaptation to the fact that multi-junction solar cells subjected to solar radiation concentrated to hundreds or thousands of times its ordinary intensity must be cooled to avoid being damaged by high temperatures. The cooling fluid, circulated behind the PV cells, becomes hot and can be used to heat service water and buildings. By combining electricity and useful heat output, the overall efficiency of this system is higher than for PV alone.

Photo: Wayne Groszko

Pictured at right is a prototype solar combined heat and power unit being developed at Menova Energy in Ottawa in 2008, photographed by one of the authors. This technology has since evolved significantly and migrated to California.

Solartron Energy Systems Inc., based in Amherst, Nova Scotia, has developed the SolarBeam, a solar thermal concentrator in the parabolic dish shape. This concentrator can be used to produce hot water or steam. There is not currently a model that produces electricity, but Solartron is offering to sell its concentrator technology to other companies that may wish to develop the electricity-generating capability.

2.4. Concentrating solar thermal electricity

Although not technically considered a photovoltaic system, concentrating solar thermal electricity is another method of producing electricity from the sun. This category includes solar troughs, dishes, and power towers. Nova Scotia's own Prometheus dual-stage concentrator, which was developed at the Lunenburg Foundry, could potentially be used to generate solar thermal electricity.

The basic principle of solar thermal electricity is that sunlight, when concentrated from a great area onto a small collection surface, can heat that surface to many hundreds or even several thousand degrees Celsius. A heat exchanger is used to transfer this heat to a fluid, typically a mineral oil capable of being heated to high temperatures, which is then used in a heat exchanger to produce steam to run a turbine that propels a rotary generator to produce electricity.

Solar thermal electricity has some interesting advantages. It can attain electrical generation efficiencies approaching those of other thermal electricity generating stations, on the order of 30%. The overall efficiency can be even higher through combined heat and power if there is a nearby use for the expelled heat from the steam condenser, such as to heat water or buildings near the generator. Another intriguing possibility, now being demonstrated at several sites in the world, is the ability to store the heated fluid in an insulated container for use during brief cloudy periods and after sunset, thus extending the hours of predictable operation.

Like all concentrating technologies, solar thermal electricity requires dual-axis tracking to ensure that the reflectors to concentrate the sunlight are pointed at the sun. It also depends only on direct normal incident radiation, and therefore has higher performance in regions with less frequent episodes of cloud cover.

2.5. Solar thermal

Solar heating, also referred to as solar thermal, is at present the most widely used solar energy harvesting technique in Nova Scotia. This category refers to solar energy systems that do not produce electricity, but rather collect heat directly for various applications, including:

- ***Heating domestic and service hot water:*** For residential homes, institutions and industries that require hot water, solar water heaters are an effective way to collect a significant fraction of the energy needed to heat water.
- ***Heating ventilation air:*** Cost-effective systems are installed on institutional, industrial and residential buildings around the world to pre-heat the fresh air being drawn in for ventilation.
- ***Heat for buildings:*** Passive designs and active systems that collect heat from the sun to supply a portion of the space heating load for buildings are readily available in Nova Scotia.
- ***Cooling for buildings:*** Heat from solar collectors can be used as the energy supply to absorption chillers that provide cooling for buildings.

As the purpose of this document relates to solar electricity, we will not cover the topic of solar thermal in detail. It is relevant to the discussion of solar PV because solar thermal is a pre-existing solar energy industry in Nova Scotia that offers numerous products and benefits to our province.
The solar thermal and solar PV industries relate to each other directly in several ways.

A clear example of a relationship between solar thermal and solar PV is the fact that a solar water heater, when it displaces electricity that would otherwise have been consumed by an electric water heater, is effectively serving a similar function as a solar PV array, namely the reduction of demand on the electricity grid. The greenhouse gas emission reductions associated with a solar water heater are significant.

Solar thermal systems tend to have higher collection efficiency than PV, on an annual average, because they can absorb a broader portion of the solar spectrum. For a residential household with a suitable domestic hot water demand, installing a solar water heater will typically displace more electricity than would be generated by a solar PV array of the same collection surface area. A comparison between a solar water heater and a solar PV array for a household application is shown in Table 3 below. For this comparison we assume that the solar water heater is displacing electricity consumption in an electric back-up water heater. Production data are from RETScreen[23], and the cost for the solar water heater is estimated from experience in the industry. The cost of the solar water heating system will vary depending on the complexity of the installation. Costs for solar PV systems are discussed in Section 4. Here we have used $4.40/Watt installed as the price for the PV system, which is within the range of recent prices reported in Nova Scotia. The size of the PV system is chosen so as to displace the same amount of electricity annually as the solar water heater, to simplify comparison of the surface area of these two systems. The PV array is over twice as large in surface area to deliver the same amount of energy. The initial capital cost is about 42% higher for the PV system than for the solar water heater in this example.

Table 3: Comparison of a solar water heater and a PV system for household use in Nova Scotia.

	Solar Water Heater	Solar PV System
Usable energy delivered per year	2500 kWh	2500 kWh
Annual GHG emissions avoided[24]	2125 kg	2125 kg
Installed capacity	3.89 kW	2.27 kW
Collector surface area	5.9 m^2	14.2 m^2
Approximate initial capital cost	$7000	$10,000
Energy delivered per collector area per year	422 kWh/m^2	176 kWh/m^2

In principle, a household may invest in both a solar water heater and a photovoltaic array. Indeed, three of the new energy-saving demonstration homes completed in Nova Scotia in 2011 have both solar hot water and PV installed[25,26]. The systems complement and do not interfere with each other, provided there is sufficient sunny space for both sets of collectors. Under the most common circumstances, the normal upper limit on the size of the solar domestic water heater for a family home is a two-collector system that provides about 60% of the family's annual hot water energy consumption, unless an unusually large thermal storage capacity is employed. The upper limit on a solar PV array for a household is either the limit established in the interconnection agreement with Nova Scotia Power or the amount of suitable area available for PV collectors on the property, whichever is less.

Sales of solar thermal collectors in Canada grew steadily from 2001 to 2008, began to show considerable variations in growth rate in 2009, and declined from 2010 to 2011.[27] Data on solar thermal sales for 2012 have yet to be released, so it is unknown at this point whether the decline continued in 2012. Clear Sky Solutions, authors of the solar thermal survey report for Canada, postulate that the decline in solar thermal sales is related to the expiry of the federal ecoEnergy Renewable Heat Incentive in 2010.[28] Several suppliers in Nova Scotia have indicated that they also see an influence holding over from the economic slowdown of 2008/09, and that a downturn in solar thermal sales in Ontario coincided with the Ontario feed-in tariff support for photovoltaic systems.

The solar thermal industry currently represents a significant portion of the solar industry in Nova Scotia, as there are several companies in the province that manufacture solar thermal systems (e.g. Thermo Dynamics and Solartron) and a larger number that work on system design and installation. In consultation, several stakeholders have emphasized the need to consider the benefits of solar thermal and solar PV systems equitably, in keeping with the greenhouse gas emission savings that can be achieved by both technologies.[29,30]

2.6. Hybrid Solar PV / Solar thermal

Hybrid systems have been developed to combine photovoltaic with solar thermal energy harvesting. An example is the SolarDuct™ Hybrid PV/T system made by Conserval Engineering in Ontario. In this system a solar ventilation air preheater is combined with PV modules. The effect of the combination is to enhance the overall efficiency of collecting solar energy.

A solar ventilation air heater is used to preheat the fresh air supply to a commercial, industrial or institutional building. The PV modules absorb some of the solar radiation and convert it a portion of the solar energy to electricity. The remainder of the solar energy is emitted from the PV panels as heat, a portion of which is captured by the ventilation air heater.

Photo: Dalhousie University, with permission.

An advantage of such systems, when applied to buildings capable of using the thermal portion, is that two types of energy supply (heating and electricity) are gained for a single mounting system. This increases the yield of useful energy per dollar invested.

Dalhousie University has a Hybrid PV/T system on the roof of their Computer Science Building (pictured above).

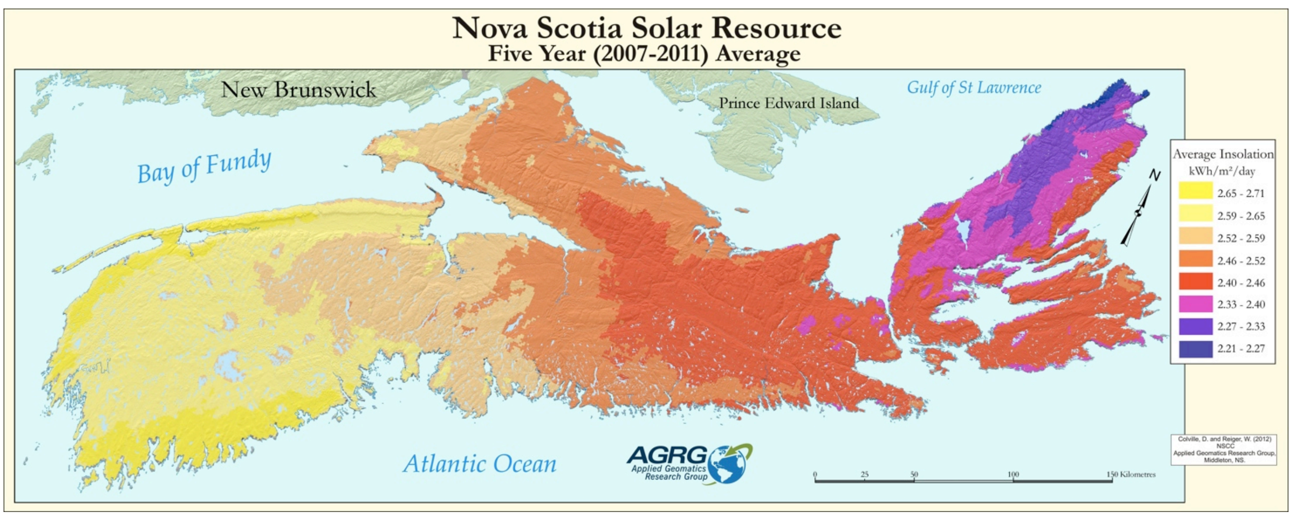
3. Solar Resource Productivity in Nova Scotia

3.1. Modelled solar resource productivity

The approximate incident solar radiation in Nova Scotia has been mapped at coarse resolution by Natural Resources Canada (NRCan), based on irradiance data and modelling. This interactive map, available online, allows the user to estimate the solar resource potential for broad regions of Canada on annual average and for each month of the year, for a suite of six different collector tilt angle configurations.[31] The map represents an approximation of the solar resource that is sufficiently precise for general estimates over large regions. Over the course of a month or a year, solar radiation generally varies less from one site to another in Nova Scotia than wind energy does, provided both sites have clear exposure to the sky and are not shaded by nearby objects. Therefore, a broad-scale map can give a reasonable estimate of the solar resource available in Nova Scotia.

Green Power Labs has developed a higher-resolution solar resource map of Nova Scotia[32], which is more precise for specific site assessments. This high-resolution map shows generally similar, though on average slightly higher solar radiation levels to the NRCan map. The Nova Scotia Community College (NSCC) has also prepared a high-resolution insolation map of the province, based on 5-year averages from 2007 to 2011 (see Figure 2 below). Note that in Figure 2 the lighter colours (yellow) represent the highest solar radiation, and the darker colours (purple) the lowest.

Figure 2: Nova Scotia Solar Resource Map[33]



While the colours of the map are dramatic, it is important to note that the variation in the solar resource from one end of Nova Scotia to the other is actually relatively small as a proportion of the average insolation. The range from dark blue in Cape Breton to bright yellow on the South Shore is from 2.21 to 2.71 kWh/m^2/day, which means the variation from the median value is only +/- 10% across the entire province. The solar resource exhibits much less geographic variability than the wind energy resource, which can vary by a factor of more than 500% from one location in the province to another[34]. The solar map effectively means that all areas in Nova Scotia have similar suitability for solar PV, provided there are no objects in the local area that would cast shadows on the specific proposed location of a solar array.

According to the NRCan map, for a fixed collector surface oriented to the south and tilted up from the horizontal at the angle of the latitude (around 45 degrees), which is the most likely configuration for installed systems, the range of annual average incident solar radiation in Nova Scotia is between 2.5 and 3.3 kWh per square metre per day (kWh/m^2d). The map from Green Power Labs shows a slightly higher range of irradiance levels between 3.3 and 3.6 kWh/m^2d. The map from NSCC shows a lower average, but this is because the values are calculated for horizontal surfaces, which receive less solar radiation at our latitude than a typical tilted solar array would receive. The data for 45 degree tilted surfaces, such as in the Green Power Labs map, are more representative of solar arrays in common practice in Nova Scotia.

For the purposes of this report we will use the irradiance levels from Green Power Labs, from 3.3 to 3.6 kWh/m^2d. These figures are for collectors facing near solar south and inclined 45 degrees from horizontal, and they include direct normal incident radiation and scattered incident radiation.

To estimate the output from a solar PV system, the system efficiency and the surface area are multiplied by the incident energy and the number of days operating in a year. System efficiency consists of module efficiency (typically between 12 and 15% for common monocrystalline PV cells)[35], times inverter/balance of system efficiency (typically around 90%), for an overall efficiency between 10 and 13%. A case study of system performance in Ireland under real conditions showed an overall system efficiency of 12.6%[36], which is in the range of predicted efficiencies. For this report we will use 13% as our standard overall PV system efficiency.

Based on the above figures, we estimate that a PV system of 13% efficiency in Nova Scotia will produce an amount of electricity in the range of 157 to 171 kWh per square metre of PV panels per year (kWh/m^2y). The size of a PV system is usually identified in terms of generation capacity (kW_p), which is the output of the PV panels under standard test conditions of 1000 W m^{-2} incident radiation at a temperature of 25°C.[37] For a typical monocrystalline PV module on the market, one square metre of module represents about 160 W of capacity.[38, 39] Using these figures and the range of output per square metre, we estimate that a PV system in Nova Scotia will produce annually in the range of 981 to 1069 kWh of electricity per installed kW of capacity, with the middle of the range being about 1025 kWh/y. The amount produced by any particular system will depend on its actual location, tilt angle and any obstructions that may shade the collectors.

Modelled annual PV electricity output in Nova Scotia: 981 to 1069 kWh/kW$_p$ installed capacity.*

For comparison, the solar resource rating for Nova Scotia in the NRCan "Atlas of PV Potential" is 900 to 1200 kWh/kW_p, with most of the province in the range from 1000 to 1100 kWh/kW_p.

* The calculation is shown here:

Lower value

$$3.3\ \frac{kWh}{m^2 d}\ x\ 0.13\ x\ 365\frac{d}{y} = 157\ \frac{kWh}{m^2 y}$$

$$\frac{157\frac{kWh}{m^2 y}}{0.160\frac{kW}{m^2}} = 981\frac{kWh}{kW\ y}$$

Higher value

$$3.6\ \frac{kWh}{m^2 d}\ x\ 0.13\ x\ 365\frac{d}{y} = 171\ \frac{kWh}{m^2 y}$$

$$\frac{171\frac{kWh}{m^2 y}}{0.160\frac{kW}{m^2}} = 1069\frac{kWh}{kW\ y}$$

3.2. Measured solar electricity production in Nova Scotia

From Solar Nova Scotia members we have obtained access to measured production data from four grid-connected PV systems operating in Nova Scotia[40]. These systems are monitored automatically on a continuous basis and their performance data are available to their system owners and operators online in real time. The data include daily, monthly and annual electricity production.

Table 4: Measured electricity production from four grid-connected PV arrays in Nova Scotia.

System Location	Rated System Capacity (kW)	1-year production beginning Oct 2011 (kWh)	kWh/kW_p (annual)
Antigonish County	8.28	9409	1136
Richmond County	5.06	5917	1169
Cape Breton Regional Municipality	6.90	7619	1104
Halifax Regional Municipality	2.2	2551	1159
AVERAGE			1142

Measured annual PV electricity output: ***1100 to 1170 kWh/kW_p installed capacity***.

The measured production, averaging 1142 kWh per installed kW_p of capacity, is higher than the modelled range of 981 to 1069 kWh/kW_p. It should be noted that the measured data are a small sample at a few locations that do not represent all the geographic areas of the province. The sample size is not large enough to determine a statistically valid average of real production for the province. Also, these sample systems all use the same inverter type and don't represent the variety of inverter types that are available.

However, the quantity of solar radiation is the most significant variable factor that influences production, and the reported sites are not unusually sunny. They are located in mid-range insolation regions of Nova Scotia, according to the various solar maps mentioned previously, so they are unlikely to represent an over-estimate of the resource. The variation in annual solar radiation across Nova Scotia is about +/- 10%. Therefore, as a cautious estimate of solar PV productivity for Nova Scotia, we will consider average annual production of 1100 +/- 100 kWh/kW$_p$ to be achievable.

Estimated solar PV productivity for Nova Scotia: 1100 +/- 100 kWh/kW$_p$ installed capacity.

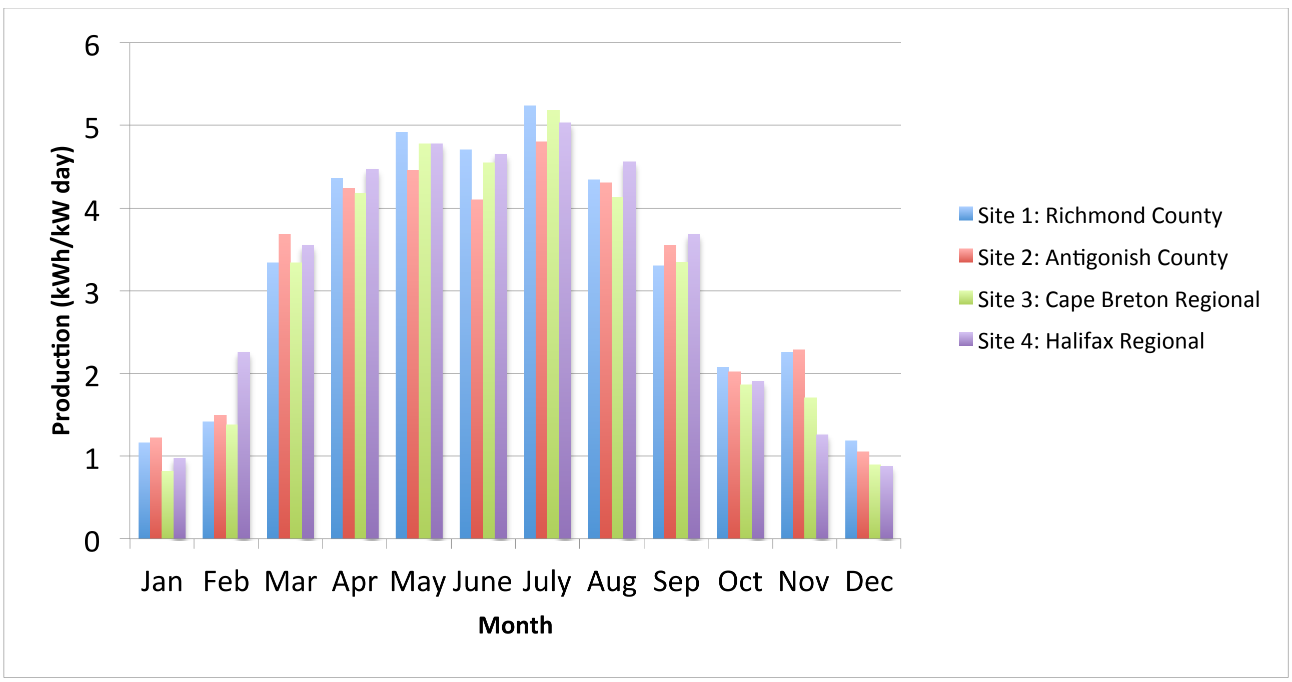
For comparison, Toronto, Ontario rates about 1160 kWh/kW$_p$, Los Angeles, California about 1485 kWh/kW$_p$, and Berlin, Germany, about 850 kWh/kW$_p$.[41]

3.3. Timing of production and electrical demand

3.3.1. Seasonal variation (monthly)

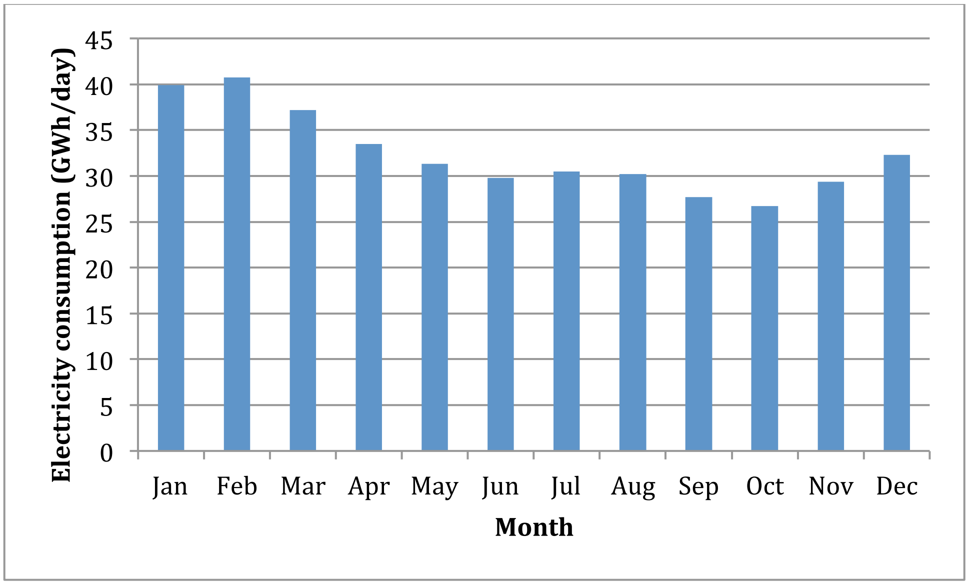
As the day length and maximum angle of the sun above the horizon vary throughout the months of the year, the incident solar radiation varies accordingly in Nova Scotia. This variation in solar radiation can be directly observed in the measured output of the same four PV systems, which varies in a fairly consistent manner from month to month as shown in Figure 3 below.

Figure 3: Monthly measured output of three PV systems in Nova Scotia (2011/2012)



The monthly production of solar energy can be compared with the monthly electricity consumption on the Nova Scotia Power system, as reported in the Open Access Same-time Information System (OASIS) – see Figure 4.

Figure 4: Electricity consumption (gigawatt-hours per day) on the Nova Scotia Power system for each month in 2011.[42]



Figures 3 and 4 show that on a monthly basis the variations in solar electricity generation and total electricity generation were not well correlated in Nova Scotia in 2011. Neither were they consistently anti-correlated. The very low months for solar electricity output were December, January and February. Of these months, January and February were two of the three highest months for total electricity consumption. By March, the third-highest month for total electricity consumption, solar output had tripled, reflecting the longer sunshine days of impending springtime.

The period from May to August yielded high solar electricity output, while total load decreased through April, May and June and then increased slightly to a small summer peak in July and August, presumably due to cooling demand. October was the lowest month for total consumption. November and December saw gradually rising load as heating systems were started up, coinciding with decreasing solar output as the days shortened.

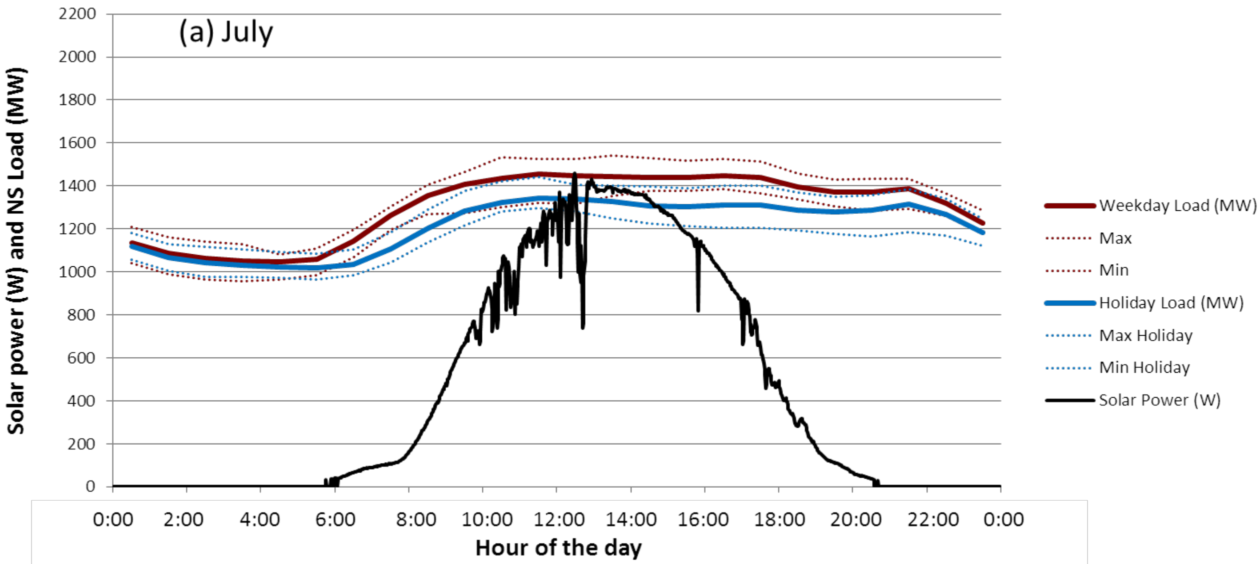
The effect of the lack of seasonal correlation between solar output and total electricity consumption in Nova Scotia is that a given amount of solar capacity will provide a larger portion of the total in the spring, summer and autumn and a lower percentage in winter. For example, if 100 MW of solar PV capacity were installed in Nova Scotia, it would produce about 1% of our annual electricity consumption. The percentage supplied in the lowest solar month (January) would be about 0.3%, while the percentage supplied in the highest solar month (July) would be about 1.6%.

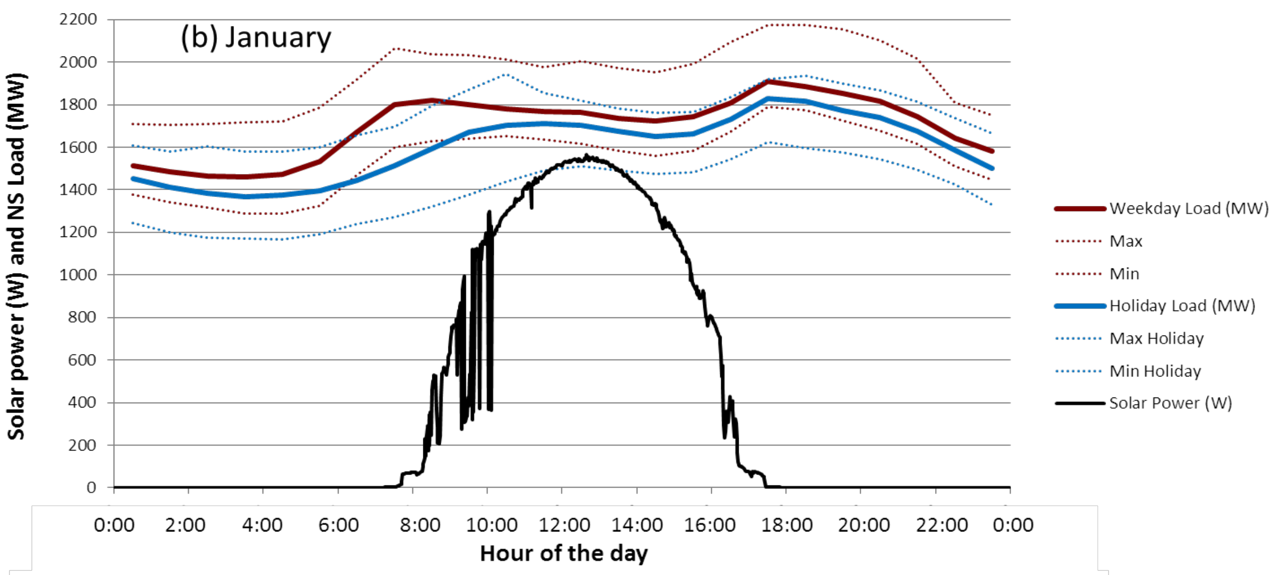
3.3.2. Daily variation

The purpose of this section is to compare the production from a solar array to the Nova Scotia electricity demand curve in the course of the day. Solar electricity production, in the absence of an energy storage system, occurs in a direct and nearly instantaneous relationship with the amount of solar radiation available at the generation site at any given moment.

The hourly load characteristics of the Nova Scotia Power grid are shown in Figure 5(a) for July and 5(b) for January, both in 2011.[43] The average, maximum and minimum hourly loads are shown for weekdays (Monday to Friday), and holidays (Saturdays, Sundays and statutory holidays). Figure 5 also shows the measured output of a 1.5 kW PV array at the Nova Scotia Community College (NSCC) Waterfront Campus in Dartmouth, at one minute intervals on a single day in each of those months. We chose data from sunny, high solar production days to illustrate the full shape of the solar output curve. Figure 5(a) shows solar power output on July 20, 2011, and (b) shows output for January 26, 2012. Solar data for January 2011 were not available in the record. The difference in the year is not significant, as any sunny day in January in any recent year would illustrate a similar solar power profile.

Figure 5: Nova Scotia Power load (MW) and solar power output (W) as a function of the hour of the day for; (a) July, and (b) January.





On the sunny July day (a), the morning rise in electricity demand is followed fairly closely by the increase in solar output as the sun rises in the sky. The mid-day peak in electricity demand occurs at a time of high solar output. In the afternoon and on into the evening, as solar output gradually declines, the system power demand stays level until after the sun has set. The observed pattern suggests there is some correlation between solar output and electricity demand. This correlation is strongest for the morning rise. In the evening, electricity demand continues to be high after the solar output has declined.

The downward spikes in solar output represent passing clouds that cast shadows on the array. The downward spikes are often preceded and followed by small upward spikes, as the cloud edge refracts extra radiation onto the collectors. On a day like this, if multiple arrays were installed in various places across a geographic area the size of a city or a municipality, the cloud shadows would cross the separate arrays at different times, leading to a smoother total output curve for multiple arrays than for this example of one array.

On the sunny January day (b), the peak output of the solar array around 13:00 hours is higher than the peak output in July. This is because, (1) the angle of the array is about 45 degrees from the horizontal, resulting in strong production midday in winter due to a direct sun angle, and (2) crystalline photovoltaic cells produce a higher voltage, and therefore more power, at colder temperatures. Despite the high performance around midday, the total electricity generation (the area under the curve) is smaller in January because the effective solar day length is four hours shorter than in July.

Finally, the highest peak load in January occurs around 18:00 hours, after the PV array has ceased production for the day because of sunset. This means that, in the absence of a short-term storage method or time-shifting of the load, PV generation will not be available for the highest peak of the day in winter, which in Nova Scotia is the highest peak of the year. What PV generation will do is contribute to supplying/decreasing the load in the midday hours, primarily between 11:00 and 17:00 hours.

3.3.3. Correspondence of photovoltaics with daytime load

Grid-connected solar PV systems most often do not have an integrated energy storage capacity, and hence their output varies minute-by-minute with the intensity of solar radiation as detailed in 3.3.2 above. Grid-connected solar PV systems therefore represent a variable, non-dispatchable generation source on the grid. Like other variable generation sources, including wind energy, it is important to consider the relationship between distributed PV generation and the load on each distribution zone as well as across the province, if we are considering installing a significant amount of solar PV capacity.

For non-dispatchable variable generators such as wind turbines and PV systems, the approach to coping with variability thus far in Nova Scotia, particularly with respect to connection of generators to the distribution network, has been to limit the total output capacity of variable renewable generators allowed to be connected to a particular substation to less than the minimum annual load on that substation. This is the general rule in practice for COMFIT projects. The function of this rule is to ensure that all the energy produced by the variable generator is used in its local distribution zone, preventing spill-over of generation through the substation into the transmission network and therefore minimizing the need to consider transmission system impacts.

The rising and variable output from distributed renewable generators will be observed and accounted for as a varying “negative” load (load decrease) on the transmission network. For COMFIT projects, this rule constitutes a fairly simple and rational method for deciding whether a new variable generator, such as a proposed wind turbine, will be accepted on a particular distribution zone.

If we connect more solar PV generators to distribution lines around the province, it may seem that the most obvious assumption would be to apply the same rule, namely that the total of variable generation in the distribution zone should not exceed the minimum annual load in that zone. However, there is a fundamental difference between solar PV and other variable renewable generators that is essential to consider, namely that solar PV will only generate in the daytime. A PV system without storage is capable of producing at nearly its peak power capacity for a period of no more than six hours in the middle of the day, between 10:00 and 16:00. This is a time of day when the electricity load is observed to be consistently higher than the annual minimum load. For this reason, the factor to consider when deciding whether to accept a solar PV array on a distribution zone would be the minimum daytime load on that zone (between 10:00 and 16:00), not the minimum overall load.

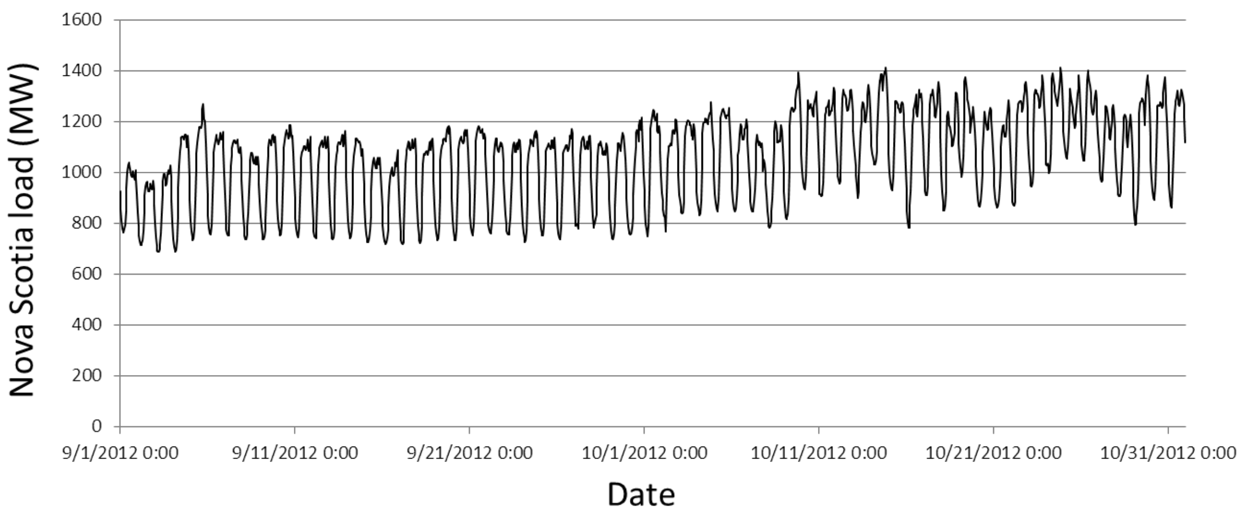
To characterize the output characteristics of a solar PV array, we analysed solar power output data from the NSCC PV system for those months of the year when the minimum load on the power generation and distribution system is most likely to occur (September and October) and found that in those periods the peak output from the solar array always happens between 10:00 am and 16:00 hours. There were no exceptions to this observation. Output near peak capacity never occurred outside of those hours in our sample, and was usually concentrated closer to solar noon (which is at approximately 13:00 hours Atlantic Time in Halifax). As this observation is based on the predictable pattern of the sun in the sky, we expect that this will be true for all PV arrays installed in the province, and particularly for fixed (non-tracking) arrays, which are the most common type and which do not face the sun early in the morning or late in the afternoon.

We defined peak solar power output as a range from 10% below the nameplate (rated) capacity to 30% above the nameplate capacity of the solar array. The reason for this wide range is that the power output from a PV system can sometimes be higher than its nameplate capacity. The rated (or nameplate) capacity is determined under standard test conditions of 1000 W/m^2 of incident solar radiation. Particular conditions can occasionally cause the real incident radiation to be greater than 1000 W/m^2. This can be due to atmospheric conditions, reflection of light from roofs, water, clouds or other surfaces, or refraction around the edges of clouds. However the most common cause of elevated power output is low outdoor temperature, which increases the voltage of solar cells without affecting the electric current, and hence increases power output. In September and October of 2011, the highest observed peak solar power output from the observed PV system was 30% above its nameplate capacity.

The essential question is this: What is the minimum annual “midday” load, during the midday period when solar PV could be producing at its peak, and does this differ from the overall minimum load? To answer this question for the Nova Scotia electricity system as a whole, we analysed load data from the Nova Scotia Power OASIS site for 2010, 2011 and 2012. We extracted the annual minimum load for all hours of the day and the annual minimum load during solar peak hours (10:00 to 16:00 hours) each day.

The difference between minimum load and minimum daytime load is illustrated in Figure 6 below, which shows the load on the Nova Scotia electricity system as a function of time on an hourly basis for two months. The daily high periods (broad peaks in Figure 6) are the load between 6:00 am and about 8:00 pm, and the sharp valleys are the low demand periods from about 2:00 am to 4:00 am. The important point to note is that on any given day, and throughout the whole record, the minimum load during the midday period when solar PV may be producing is always higher than the overall minimum load by a significant margin. This is for the Nova Scotia electricity system as a whole. Most individual distribution zones are likely to display a similar pattern, but in practice each zone would have to be considered individually, as some may show anomalous load patterns, for example due to industries that may run at night.

Figure 6: Nova Scotia electricity system load (MW) as a function of time in Sept/Oct 2012.



In Table 5 we have extracted from the OASIS data set the minimum overall load and the minimum daytime load in Nova Scotia for the years 2010, 2011 and 2012. The reader will note that the load has decreased significantly in each year in the period. From a historical perspective the rate of decrease is unusually large in this period. This is due to a number of factors. Primary among these is the closure of several large industrial facilities during the period. Improved energy efficiency in Nova Scotia is also a factor.

Table 5: Minimum load and minimum daytime load (MW) in Nova Scotia for three years.[44]

Year	**2010**	**2011**	**2012**
Annual minimum load (MW)	1023	741	675
Date of annual minimum load	Dec. 14	Oct. 3	July 1
Time of annual minimum load	03:00	03:00	06:00
Annual ***daytime*** minimum load	1360	1040	935
Date of annual minimum daytime load	Dec. 4	Oct. 2	May 20
Time of annual minimum daytime load	15:00	10:00	14:00
Difference (MW)	**337**	**299**	**260**

The data in Table 5 show that the difference between the minimum load and the minimum daytime load for Nova Scotia as a whole has been at least 260 MW in each of the past three years. This means that on any given day, the load in the daytime can be expected to be at least 260 MW higher than it is on any given night.

When deciding whether to permit a new renewable generation project in a distribution zone, equivalent treatment for solar PV beside other renewable generators such as wind power would take into account the fact that solar PV only produces in the daytime. Therefore, the minimum daytime load should be used as the basis of a calculation to determine whether to permit a new solar PV generator on any particular distribution zone. Essentially, the minimum daytime load on that zone, minus the capacity of any other renewable generators already on that zone, would constitute the permissible solar PV capacity on that zone. A hypothetical example illustrates the calculation:

Hypothetical Case:
Proposed Solar PV Generator (0.3 MW nameplate capacity) in Distribution Zone X

Maximum load on zone X:	5 MW	
Annual minimum load:	1 MW	(from substation load data)
Annual minimum daytime load:	1.5 MW	(from substation load data)
Renewable generators already on that zone:	0.9 MW	(e.g. wind turbines & PV)

Permissible solar PV maximum output = 1.5 MW – 0.9 MW = 0.6 MW
Permissible nameplate capacity of solar PV = 0.6 MW / 1.3 = 0.46 MW*

Conclusion: 0.46 MW of solar PV generation would be permissible in this case.

Therefore, the proposed 0.3 MW solar PV generator would be permissible.

*Factor of 1.3 is because solar PV arrays can generate 30% above nameplate capacity.

If permissible capacity on a distribution zone is calculated as above, this affords equivalent treatment to solar PV alongside other renewable generators, by considering the output of each generator at the time that it could possibly be generating. The example above illustrates the difference from a wind turbine, as a wind turbine of 0.3 MW nameplate capacity would not have been permissible in the above scenario under the current rules, while a 0.3 MW solar PV generator would be.

3.3.4. Grid Integration of Solar PV in Nova Scotia

On any particular distribution zone, if decisions on permitting solar PV generators are guided by the calculation in 3.3.3 above, then in each zone the variable renewable generation will not exceed the load at any time, and all the renewable electricity generated in each zone will be used within that zone. However, if in the aggregate a significant capacity of solar PV generation is added, the reduction in overall load on the transmission system would need to be considered.

The Nova Scotia electricity system now includes a significant and rising number of variable renewable generators. In the near future in Nova Scotia we may have 500 MW of installed capacity of wind energy, plus 100 MW of renewable capacity through the COMFIT program (also mostly wind energy). Nova Scotia Power's system also includes approximately 400 MW of hydroelectric capacity, much of which has relatively little water storage capacity and therefore in rainy seasons must either be used or spilled. In addition, there is a 60 MW biomass electricity generator in Port Hawkesbury that is obligated to run.

The operation of significant generation capacity that is either inherently variable (wind) or has little dispatchability (must-run biomass and low-storage hydro) means that in seasons of the year with relatively low electricity demand such as spring and autumn there will be times when renewable generation in the province has the potential to exceed total load on rare occasions. This can happen a few times per year, particularly during hours when strong winds coincide with a time of low electricity demand. This is a system management challenge that the Nova Scotia System Operator already deals with now in a variety of ways: spilling water from hydro systems, curtailing wind energy, and exporting electricity. These events may become more frequent and more challenging as more variable generators are added. Automated demand response to adjust optional loads, as exemplified by the PowerShift Atlantic project, is one way that the tools available for handling these situations are being expanded.[45]

Adding significant quantities of solar PV generators to the distribution system would have the effect of reducing the daytime load in each distribution zone that has significant PV capacity installed. This reduction would come in the middle of the day on sunny days. If the aggregate reduction in load is large enough, it could have an upstream effect on operations at the transmission level.

If significant amounts of solar PV (for example, say beyond 10 MW of capacity) will be added to the distribution network, it will be necessary to work with the Nova Scotia Power System Operator and/or a consultant to prepare a transmission system impact study. The purpose of the system impact study would be to model and estimate the impact on overall system operations of adding a proposed amount of solar PV generation capacity at various points in the distribution grid. A transmission system impact study is beyond the scope of this report.

The location of additional solar PV generators is also significant. If those generators are distributed in areas with high daytime electricity load, such as within cities and towns, they will have the effect of supplying nearby loads and reducing the need to transmit electricity from more distant generators. This will be more beneficial to the electricity system than locating large solar PV generators far from the areas of high daytime load. From this perspective, a few examples of favourable locations for solar PV installations include dense urban areas such as the cities of Halifax, Dartmouth, and Sydney and towns like Kentville, Wolfville, etc. The denser urban areas within these communities include zones too densely populated to allow a wind turbine with normally-accepted setback distances, but where solar PV generators could be installed on rooftops, parking lots, etc. These dense urban areas also have large daytime electrical loads, which make them a good fit for adding solar PV to the distribution grid. Solar PV could give people and community groups (community centres, municipal buildings and churches, for example) in denser urban zones an opportunity to participate in renewable electricity generation through the COMFIT program.

3.3.5. Forecasting Day-Ahead PV Generation

As mentioned in the previous section, if the capacity of PV generation on the Nova Scotia system grows to significant levels, it will be necessary for the system operator to forecast the available solar resource at least one day ahead, to be able to plan to have enough dispatchable generation available to meet the net load on the following day, including any arrangement for imports or exports to other jurisdictions in our region. The need to forecast both load and supply is already an existing operating condition of the Nova Scotia electricity system. Solar PV would add another variable to that system, with its own characteristics that will have to be forecast as accurately as possible.

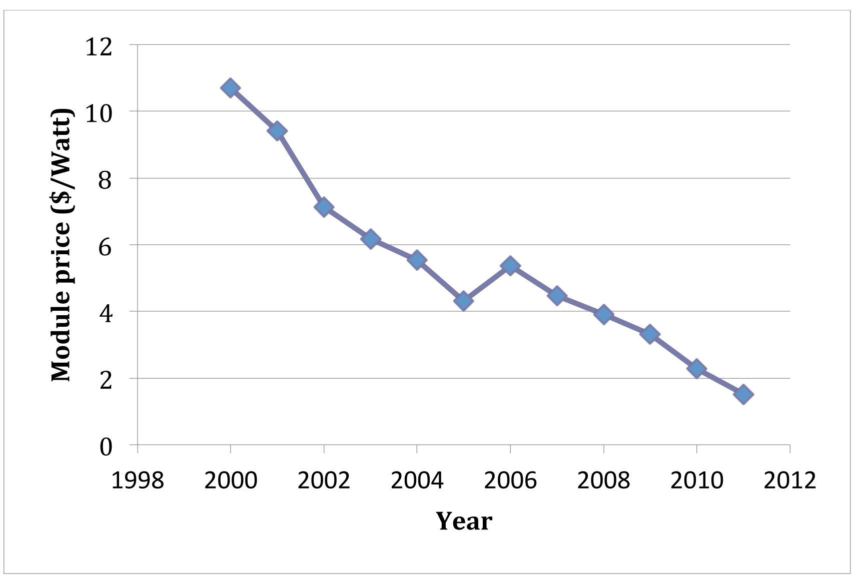
While it is beyond the scope of this report to explore the topic of solar energy forecasting in any detail, it is important that all parties be aware that if significant solar PV generation (without energy storage) is added to the grid, forecasting the solar resource a day ahead will become an integral part of our electricity system operation, just as forecasting the available wind power has become important in the Nova Scotia electricity system of today. Several other jurisdictions are already working with significant quantities of solar PV generation on their systems, including Ontario, Massachusetts, California, and Germany. Therefore we would not expect to have to work alone in adding forecasts and planning for solar PV to our electricity system operations.

4. Prices and costs of solar electricity

4.1. Global price trends for PV

Solar PV modules typically account for about 50% of the installed cost of a PV system. The price of solar PV modules decreased significantly between 2001 and 2011, the last year for which annual average data are currently available. Figure 6 shows the trend in module prices in Canada. The rate of decline of module prices in Canada since the year 2000 has been about $0.72/W per year.

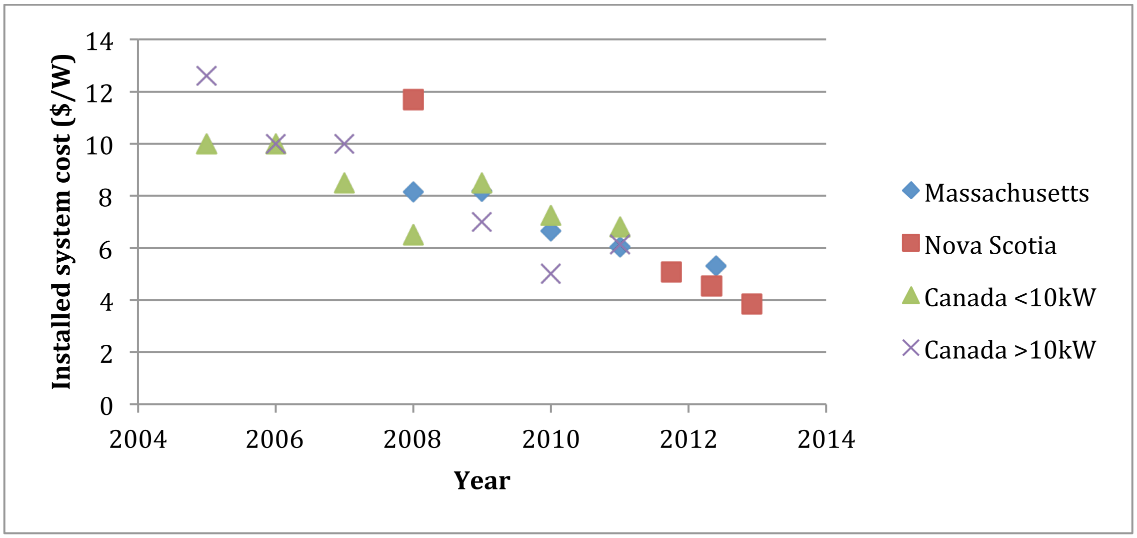
Figure 6: Trend in module prices in Canada (CAD$)[46]



The International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) have both published global compilations of installed PV system costs. The IEA global report for 2011 states that globally, installed system prices in 2011 averaged US$3.6/Watt (range 2.6 to 4.4).[47] For the same year, the country report from Canada states turnkey installed system prices of CAD$6.79/W for systems 10 kW capacity and lower, and $4.38/W (range 3.50 to 5.27) for systems larger than 10 kW.[48]

The trend in PV system cost for three jurisdictions is shown in Figure 7 below. The prices and the trend are remarkably consistent among the three. The data for Canada is largely influenced by prices in Ontario, as the majority of installations have happened there. The Nova Scotia data is described in greater detail below. The best-fit linear trend in the whole data set is a decrease in installed cost of $0.87/W per year.

Figure 7: Trend in total installed PV system cost in three jurisdictions.[49]



4.2. Installed costs and trends for PV in Nova Scotia

In response to a request for information to Solar Nova Scotia members, we have received data on actual installed prices of PV systems in Nova Scotia. An example from this data is shown below:

System size (rated capacity)	8.28 kW	
Installation date	September 2011	
Location	Rooftop in Antigonish County	
Total installed cost	$36,587	(+HST = $42,075)
Installed total cost per watt	$4.42/Watt	(+HST = $5.08/Watt)
PV modules retail price in project	$2.62/Watt	(+HST = $3.01/Watt)
PV modules as % of installed cost	59%	

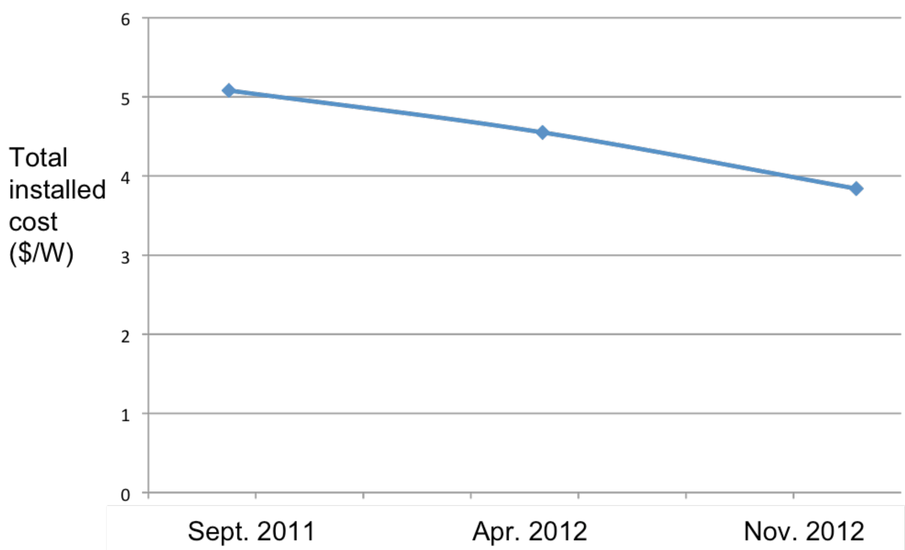
The breakdown of costs for this system is shown in Table 6.

Table 6: Cost categories for example PV system installed in Nova Scotia in Sept. 2011.

Modules	Inverters	Roof Mount	Cables & Other	System Monitor	Permits	Labour	Total	HST
59.2%	19.2%	8.9%	4.2%	1.7%	0.8%	6.0%	100.0%	+15.0%

Installers have reported that the cost of PV modules has decreased in 2010, 2011 and again in 2012. The other costs of a system have remained steady. Based on the observed change in module prices since 2010, the observed trend in the price of the example system above is shown in Figure 8 below. The trend line represents an average decline of $1.06 / W per year.

Figure 8: Trend in total installed cost in Nova Scotia, including HST:



4.3. Estimate of the levelised cost of PV electricity in Nova Scotia

We have created a simple spreadsheet tool to calculate the levelised cost of electricity (LCOE) for PV systems. This tool is available from the authors. We have calculated the LCOE as follows, in the same manner as the International Renewable Energy Agency.[50]

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

Where:

LCOE = the average lifetime levelised cost of electricity generation;
$\mathbf{I_t}$ = investment expenditures in the year **t**;
$\mathbf{M_t}$ = operations and maintenance expenditures in the year **t**;

$\mathbf{F_t}$ = fuel expenditures in the year **t** (this is zero for solar);
$\mathbf{E_t}$ = electricity generation in the year **t**;
r = discount rate; and
n = economic life of the system.

Using the formula above and the spreadsheet tool, for the example PV system given above, we have estimated the LCOE under the following assumptions:

Installed cost: $4.50 / W (including HST) – represents mid-year 2012 pricing
Economic life of system: 25 years
Annual decrease in PV energy output: 0.5% per year[51]
Discount rate: 6%
Maintenance costs: $50 per year, with 2% inflation
Periodic capital investment: $500 in years 10, 15 and 20 (replacement of inverters)

Under those assumptions, we estimate the LCOE for this example system to be 33 cents/kWh.

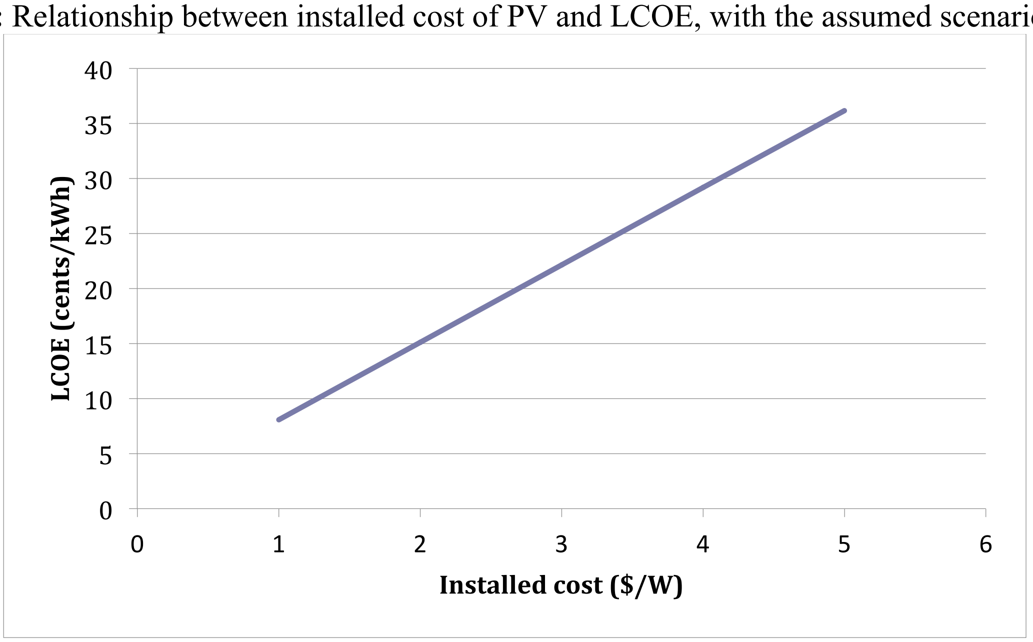
To test the sensitivity of this result to varying assumptions, we calculated LCOE for a range of input parameters. For example, an installed cost of $4.00/W instead of $4.50 brings the LCOE down to 29 cents/kWh. A decrease in the discount rate from 6% to 5% (all other factors unchanged) yields an LCOE of 30 cents/kWh. The range of total installed costs from $4/W to $5/W yields a range of 29 to 36 cents/kWh.

Estimate of levelised cost of PV electricity in Nova Scotia ***(2012): 33 (29 to 36) cents/kWh***

If the observed decline in installed cost of about $1.06/W per year continues in 2013, then we project the LCOE for 2013 to be in the following range:

Estimate of levelised cost of PV electricity in Nova Scotia ***(2013): 25 (22 to 29) cents/kWh***

Figure 9: Relationship between installed cost of PV and LCOE, with the assumed scenario above.



We acknowledge that the costs estimated in this report do not include provision for: grid integration, owner insurance, unexpected permitting costs, site acquisition, roof strengthening or repairs. The estimates are based on simple projects on the owner's property with simple installation and operating conditions. We also have not accounted for possible trade tariffs on imported PV modules in the case of trade disputes. See the notes below for more details on the limitations of this estimate.

Note 1 - Financing: The cost of financing a PV system, such as interest on a loan for the system, has not explicitly been included in this calculation of LCOE, except to the extent that the discount rate implies a return on the investment. The LCOE would be slightly different if an interest-bearing loan were used to purchase the system. To test sensitivity to the financing method, we also calculated the LCOE under a scenario in which the owner of the system made a 10% down payment and financed the rest with a ten-year loan at 5% interest (comparable with interest rates available for a home renovation loan in early 2013). With this financing scenario, the LCOE was 32 cents/kWh, comparable with the first scenario in which the owner pays up-front (33 cents/kWh). In this case there is no significant difference in LCOE with loan financing because of the effect of the value of spending later instead of spending now, as accounted for by the discount rate.

Note 2 – End-of-Life Recycling: This estimate does not include the cost of end-of-life recycling of the PV modules or other system components. An important issue to consider going forward will be the volume of PV modules to be recycled about 25 to 30 years from now when the growing quantity of solar PV modules being installed globally today will come to the end of their economic life. Effective recycling processes are in place for solar PV modules today, however the cost of recycling the modules exceeds the value of the recovered materials and the avoided landfill costs at today's prices, making the recycling of solar PV modules economically unfavourable today.[52] Extended producer responsibility legislation or mandated recycling fees (such as exist for tires and electronic equipment in Nova Scotia today) may be necessary in the future as this industry grows, and could add an up-front capital cost to PV systems. We are not able to estimate accurately the cost of this responsibility at this time. McDonald and Pearce (2010) put the net cost of recycling the most common kind of PV module at about $24 per module. If a typical module is 200W, that would add about $0.12 per Watt to the installed cost if paid up-front as an environmental handling fee. These figures should be considered very approximate at this time.

Note 3 – Building Maintenance: The estimate of LCOE does not include a provision for repairs to or strengthening of a roof to which the solar panels may be affixed. The reason we did not include this is because there are many different types of installation structures, including ground mounts, pitched roofs and flat roofs, and the implications of each type for structural integrity of a building and future roof repair costs are different. On a pitched roof, the solar panels may need to be temporarily removed the next time the roof shingles are replaced. On a flat, commercial rooftop, future roof repairs may be completed with the array in place. For a ground mount, there is no interaction with a roof. Also, for a roof mounted system the shade of the solar panels may lengthen the lifetime of the roof membrane by decreasing exposure to sunlight, thus possibly decreasing maintenance costs. With so many variables the cost implications of the type of mounting system on future building maintenance are best considered on a case-by-case basis.

Note 4 – Grid integration: All the LCOE estimates calculated above represent the cost to the owner of the PV system. They do not include costs external to that owner, except those that are charged directly to the owner, such as interconnection fees. For example, the estimates do not include any system cost that may be incurred by the electric utility to integrate solar PV electricity into the distribution or transmission system. Some of the possible future grid integration issues include: forecasting and adjusting for variable solar PV power generation, maintaining voltage and frequency, coping with power harmonics, power factor correction, and the possible implications for the use of under-frequency load protection (a form of blackout protection). Initially, if solar PV systems are small in scale, distributed geographically near daytime loads on the distribution system, and moderate in number, we believe the integration cost would be insignificant in the early stages. Distributed PV systems at a modest scale would be evident on the distribution grid only as a modest reduction in load during the midday period on sunny days. If much larger numbers of PV systems are installed, and particularly if large PV farms are installed on the transmission network, system integration costs could become a significant factor for consideration.

5. Case studies and prices of solar PV feed-in tariffs in other jurisdictions

5.1. Ontario Feed-in Tariff and micro Feed-in Tariff (FIT and microFit)

The Ontario Government launched the Renewable Energy Standard Offer Program in November 2006. The program offered $0.42/kWh for solar electricity. Two years later, solar had the second largest contract capacity at 515 MW, behind wind energy. However by 2008 only 36 MW of that PV capacity had been commissioned.[53] In the following years, a portion of the contracted capacity was built.

In 2009, as a key program of the Green Energy and Economy Act, Ontario launched its renewable energy feed-in tariff with the goal of creating a clean energy manufacturing base, new jobs and cleaner air. The program offered some of the highest rates for solar PV in the world, which were differentiated by project size and whether the project was ground-mounted or roof-mounted (see Table 1 below). The Ontario FIT program is the primary reason for the large increase in photovoltaic installations in Canada since 2009, as shown in Figure 1.

In October 2011, the Ontario Government launched the two-year review of the FIT program with the goal in part to reduce rates to reflect reduced costs. Reporting in March 2012, the Deputy Minister of Energy recommended a reduction in rates of more than 20% for solar, 15% for wind, and no change for the other energy sources. The new Ontario FIT rates for PV in 2012 are also show in Table 7 below.

The Ontario FIT rates also have an “adder” (an additional supplementary rate) if the project is partly or wholly owned by a First Nation or a defined community group such as a co-operative. These adders range from 0.5 to 1.5 cents/kWh, with the range depending on the percentage of community or First Nations equity. The adder applies to all FIT categories except rooftop solar.

Table 7: Ontario FIT prices for PV, original prices (2009) and new prices (2012).[54]

<table>
<tr><th>Type</th><th>Project Size Tranche</th><th>Original FIT Price (¢/kWh)</th><th>New FIT Price (¢/kWh)</th><th>% Change from Original FIT Price</th></tr>
<tr><td rowspan="6">Solar Rooftop</td><td>≤ 10 kW</td><td>80.2</td><td>54.9</td><td>-31.5%</td></tr>
<tr><td rowspan="2">> 10 ≤ 100 kW*</td><td>71.3</td><td rowspan="2">54.8</td><td rowspan="2">-23.1%</td></tr>
<tr><td>< 250 kW</td></tr>
<tr><td rowspan="2">> 100 ≤ 500 kW*</td><td>63.5</td><td rowspan="2">53.9</td><td rowspan="2">-15.1%</td></tr>
<tr><td>> 250 ≤ 500 kW</td></tr>
<tr><td>> 500 kW</td><td>53.9</td><td>48.7</td><td>-9.6%</td></tr>
<tr><td rowspan="4">Solar Groundmount</td><td>≤ 10 kW</td><td>64.2</td><td>44.5</td><td>-30.7%</td></tr>
<tr><td>> 100 ≤ 500 kW*</td><td>44.3</td><td>38.8</td><td>-12.4%</td></tr>
<tr><td>> 500 kW ≤ 5 MW*</td><td rowspan="2">44.3</td><td>35.0</td><td>-21.0%</td></tr>
<tr><td>> 5 MW</td><td>34.7</td><td>-21.7%</td></tr>
</table>

* New size category.

5.2. Feed-in Tariffs in Germany

Germany introduced its current FIT regime in 2000 through the Renewable Energy Sources Act (EEG). The government reviews the rates on a regular basis. The rates have dropped annually and they are now about one third to one quarter of the year 2000 rates. Depending on the size and type of the PV installation, FIT rates for PV in Germany in late 2012 now range from a low of 16.2 CAD cents/kWh for large ground-mounted arrays to 23.4 CAD cents/kWh for small roof-mounted systems.

The program has been successful in kick starting a massive increase in PV capacity in Germany, from 186 MW in 2001 to over 17,000 MW in 2010 and still growing by about 3,000 MW per year. With the large-scale uptake of the program in Germany, the additional charge to electricity rates for all the FIT payments for all eligible renewable electricity generators is estimated to be 4.6 CAD cents/kWh[55], on an average retail electricity rate of about 31.9 CAD cents/kWh.

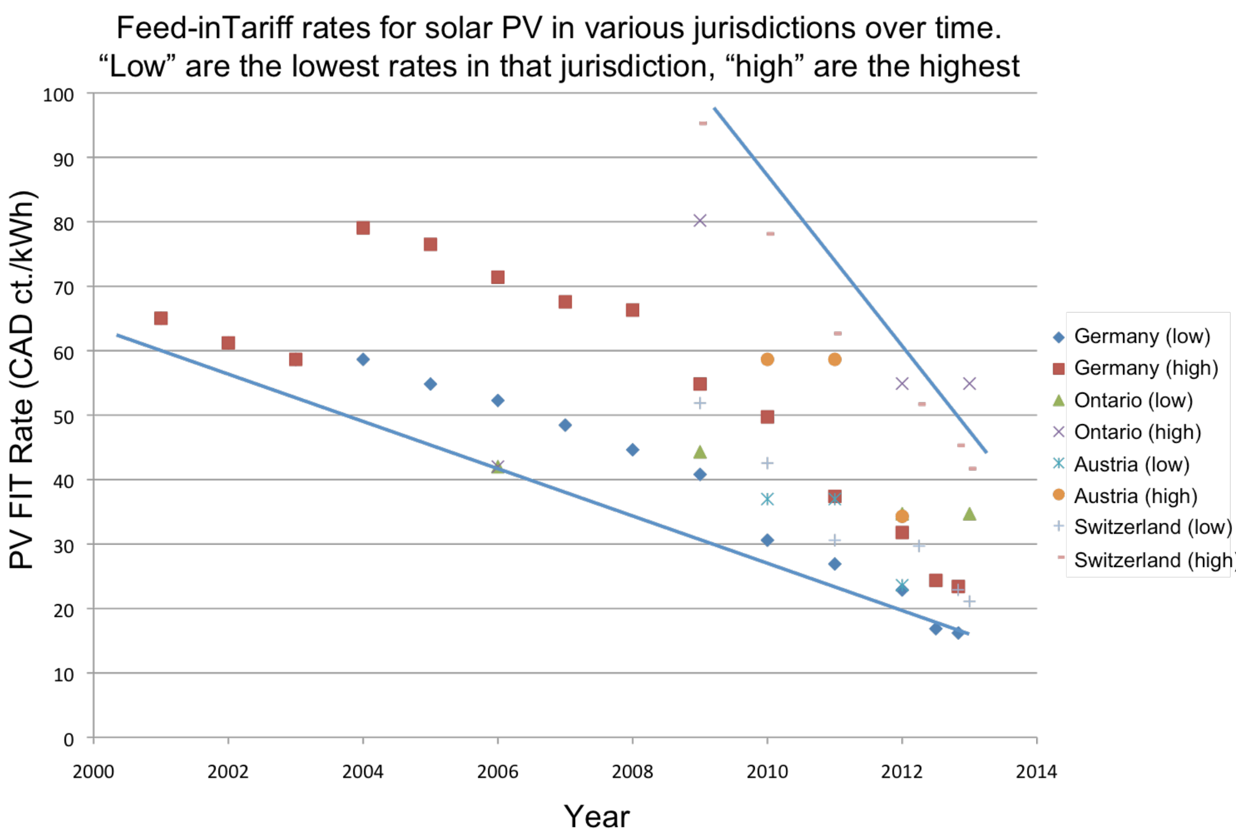
Since 2009 the government offers increasing tariffs if the electricity produced is consumed on site. This is to encourage demand side management and to address the variability of solar energy. As very large quantities of solar arrays have been installed in Germany, they have learned lessons about directing solar PV development to appropriate land spaces and coping with episodic excess PV generation. As the amount of solar PV installed in Nova Scotia increases, we can learn from the German experience.

5.3. Trends in Feed-in Tariff rates

Feed-in tariffs are intended to offer higher rates for projects completed in early years and decreasing rates for those installed in later years, as the solar PV industry gains experience in the region and costs decrease. Feed-in tariff rates for PV have been trending downward for the past 3 years in all jurisdictions that we have investigated. Germany provides the best example, where FIT rates for PV have been steadily decreasing since 2004. Several countries, including Germany and Switzerland, have designed their programs with automatic annual or monthly digression rates, specifying the rate of decrease over time. Even so, PV costs have fallen so quickly in 2011 and 2012 that these countries have decreased their FIT rates even faster than originally planned.

Trends in PV FIT rates in a set of jurisdictions in Europe and Canada since 2001 are shown in Figure 9 below. The graph shows the highest and lowest rates in each jurisdiction. The clear downward trend is evident. The general pattern is that a jurisdiction will start an effective FIT program at a relatively high rate, usually higher than in other jurisdictions with longer experience in PV FITs. After a few years gaining experience, the rates tend to fall dramatically and to converge with those of other jurisdictions.

Figure 10: Trends in PV FIT rates in one Canadian and three European jurisdictions



Taken together, this set of trends suggests that PV FIT rates in Northern European and Canadian jurisdictions with FIT experience are tending in 2012/2013 towards the range between 17 CAD cents/kWh for large ground-mounted arrays and 45 CAD cents/kWh for small rooftop arrays. Within programs in individual jurisdictions, the difference in FIT rate between large and small systems is decreasing over time.

The data suggest that jurisdictions starting a new FIT program for PV often start with rates approximately equal to what they were 3 to 4 years prior in the most experienced jurisdiction

(Germany). By this approximate measure, if Nova Scotia were to add PV to the list of eligible technologies in the COMFIT in 2014, it would be consistent with the trend in the data to choose COMFIT rates in the range that they were in Germany in about 2010, namely from 30 cents/kWh for large ground-mounted installations (>100 kW) to 50 cents/kWh for small roof-mounted installations (≤ 10 kW). At the beginning, to allow time for the local industry to organize, the starting rates could be in effect for 2014.

In this scenario, it would also be common practice to have an automatic digression of the tariff in each year, so that the contracted rate for projects to be installed in 2015, 2016 and subsequent years would be lower by an amount pre-determined in the regulations. The slope of the trendline in Germany since 2004, by least-squares regression, is a decrease of about 6.6 CAD cents/year, however since 2008 the slope has been steeper, at about 8.8 cents/year. It would therefore be consistent with this sample of the experiences of other jurisdictions if Nova Scotia were to implement a COMFIT rate ranging between 30 and 50 cents/kWh for contracts signed in 2014 and decreasing automatically by about 9 cents/kWh annually in 2015 and 2016. It would be normal practice to expect to change the formula after 2016, based on the market conditions at that time. These rates are summarized in Table 8 below.

Table 8: Approximate COMFIT rates (¢/kWh) for PV in Nova Scotia that would correspond with observed patterns of past experience in Northern Europe and Ontario.

Size category	Contract Year		
	2014	2015	2016
≤ 10 kW	50	41	32
> 100 kW	30	21	12

6. Solar PV FIT or COMFIT rates and cost for Nova Scotia

6.1. Factors in choosing a rate

If the Province of Nova Scotia chooses to set a FIT or COMFIT rate for solar PV, we expect that the Nova Scotia Utility and Review Board will be tasked with ruling on the appropriate rates. It is not our intention to propose or set feed-in tariff rates in this report. However, the purpose of this report includes estimating the cost of incentivizing solar PV. To make an estimate of the cost it is necessary to construct a scenario that includes plausible rates. In this section we consider the factors in setting these rates.

In section 4.3 we estimated the levelised cost of electricity (LCOE) from solar PV in Nova Scotia, at mid-2012 module prices, to be in the range of 29 to 36 cents/kWh. This estimate is for a residential roof-top system with a capacity of about 8 kW, which would be in the small category (<10 kW) in most FIT programs. The calculation assumes a discount rate of 6%, which essentially represents the return on the owner's investment. As module prices have continued to decrease in 2012, the LCOE would be lower for systems commissioned in 2013. If we assume a continued linear decline, the range in LCOE for a small system (<10 kW) would be 22 to 29 cents/kWh.

In Table 8 we have shown estimates of FIT rates that would correspond with normal observed practice for jurisdictions like Nova Scotia that do not yet have a highly developed solar PV industry. We observe that FIT rates for solar PV are normally higher when they are first introduced in a new jurisdiction than in jurisdictions that have had a solar PV FIT for a long time.

It should also be noted that in several jurisdictions that recently started with a high FIT rate, Switzerland and Ontario in particular, there was a large number of applications that could not all be processed in a timely way, due to the high level of interest in the program. If in Nova Scotia we choose a more moderate approach in order to have a more gradual uptake, lower rates than the observed practice may be considered appropriate.

If the province were to choose rates based on the low end of the range of the estimated LCOE, with three size categories, and with an automatic 20% annual digression in price (consistent with the long-term trend in Germany), a plausible set of FIT or COMFIT rates for Nova Scotia would be as shown in Table 9 below.

Table 9: A scenario for FIT or COMFIT rates (¢/kWh) for PV in Nova Scotia based on LCOE.

Size category	**Contract Year**		
	2014	**2015**	**2016**
≤ 10 kW	30	24	19
10 to 100 kW	26	21	17
100 to 250 kW	22	18	14
250 kW to 1000 kW	20	16	13

In choosing the size categories we have given the scenario a maximum allowable project size of 1000 kW. This corresponds with the current maximum for self-generation projects to connect to the Nova Scotia Power system under the Enhanced Net Metering Program.[56]

Simple scenario: We will also consider a simplified scenario with a single rate. The simple average (mean) of all the rates in the scenario in Table 9 is 20 cents/kWh. For the purpose of estimating the FIT cost, we will use this average rate in the simplified scenario in 6.2 below.

6.2. Simple Scenario – Cost of program to ratepayers for a simple PV COMFIT rate

The cost to ratepayers of having a solar PV FIT or COMFIT offering in Nova Scotia would depend on the FIT rate(s) and the total capacity installed at each rate. First we consider a simple scenario in which a single rate is chosen for all solar PV installations. Based on the cost research in Sections 4, 5 and 6 above, we have chosen to illustrate the impact of a range of single rates from 20 to 40 cents/kWh. The chart in Figure 11 below shows the resulting costs to ratepayers for the solar electricity generated from a range of installed solar PV capacity between 0 and 100 MW.

Figure 11: Cost of solar electricity payments (% of retail rate), for single-price scenarios, as a function of capacity installed (MW). Five chosen prices are shown between 20 and 40 cents/kWh.

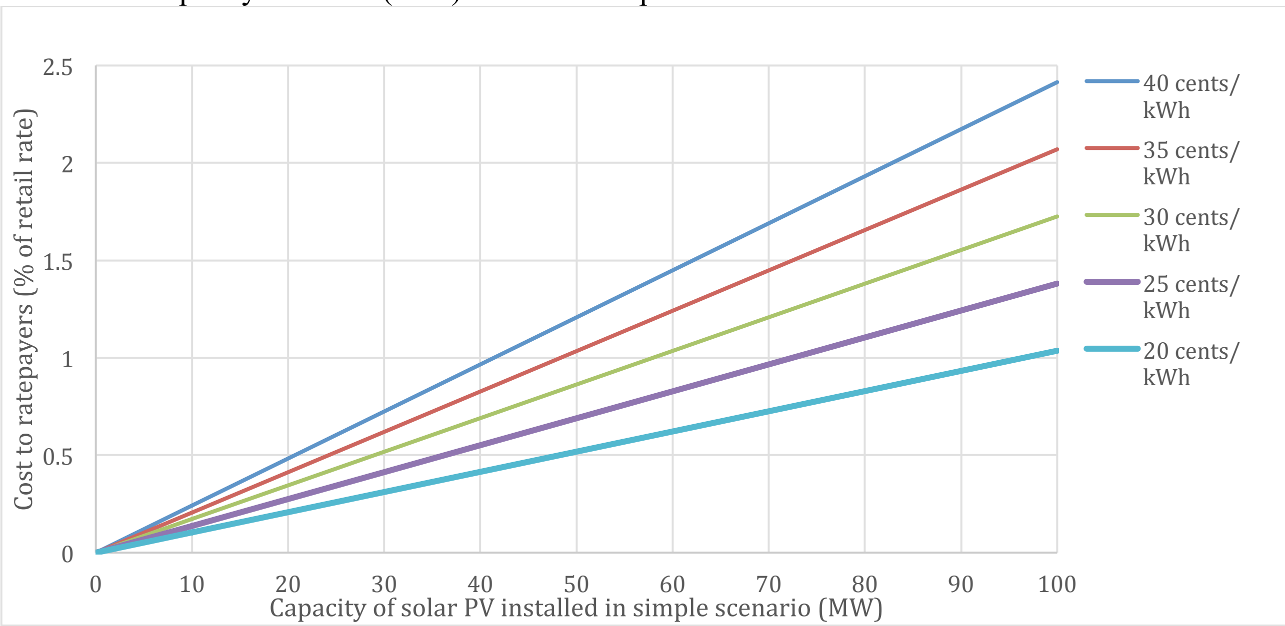


Figure 11 serves as a quick reference to estimate the cost to ratepayers of payments for solar PV electricity generated in a range of scenarios. For example, if a goal is to stimulate the solar PV industry in Nova Scotia at a cost of not more than 1% to ratepayers, we can see from the chart how much solar PV can be installed and still stay below that cost. At a price of 40 cents/kWh, over 40 MW of solar PV could be added and still be below 1% (not including any grid integration costs). At 30 cents/kWh, the 1% cost would be reached at around 50 MW, and at 20 cents/kWh it would be reached at over 90 MW.

Table 10: Net Cost of payments for electricity generated, per 10 MW installed capacity, for a range of simple COMFIT prices.

PV Rate (cents/kWh)	Net cost - $ million /year/10 MW capacity	Net cost spread across ratepayers	Net cost as a % of retail rates.
20 ¢/kWh	$ 1.65 million	0.0145 ¢/kWh	0.103 %
25 ¢/kWh	$ 2.20 million	0.0193 ¢/kWh	0.138 %
30 ¢/kWh	$ 2.75 million	0.0241 ¢/kWh	0.172 %
35 ¢/kWh	$ 3.30 million	0.0290 ¢/kWh	0.207 %
40 ¢/kWh	$ 3.85 million	0.0338 ¢/kWh	0.241 %

At 30 cents/kWh, COMFIT payments for the electricity production from each 10 MW of installed capacity of solar PV would have a net cost of $2.75 million per year, which is about 0.0241 cents/kWh when divided across all ratepayers, or equivalent to about 0.17% of 2013 retail electricity rates. The range from 20 to 40 cents/kWh results in a range of $1.65 million to $3.85 million in net payments per year, for each 10 MW of installed solar PV, which is a range from

0.0145 to 0.0338 cents/kWh when spread across all ratepayers, or can be expressed as 0.10% to 0.24% of current retail rates. In calculating the net cost we have subtracted out an avoided cost of 5 cents/kWh that would otherwise be incurred to generate the electricity.

This simple scenario does not include any grid integration costs.

6.3. A Tiered Scenario – Cost of program to ratepayers for structured rates with size classes

We have also constructed a more structured hypothetical scenario in order to estimate the cost to ratepayers for a set of tiered solar PV COMFIT rates based on project size, using the size categories and rates from Table 9 above.

If the rates given in Table 9 were used, and if a program cap of 1% of total Nova Scotia electricity generation were set for PV, and if the program were fully subscribed by 2016, the totals would be as follows:

Total annual electricity generated in 2011 in Nova Scotia: 11,400 GWh.
1% of total: 0.01 x 11,400 GWh = 114 GWh = 114,000 MWh
Measured annual solar PV productivity in NS: 1100 kWh/kW (= 1100 MWh/MW)
PV Generation capacity to produce 1% = 114,000 MWh/1100 MWh/MW = 104 MW

Total installed PV capacity: 100 MW (rounded down from 104 MW for simplicity)
Total solar PV production: 110 GWh/year

It may not be necessary to define a total program cap or a project size cap for PV installations on the distribution grid. The decisions about which installations to allow could be made based on the minimum daytime load on the distribution zone, as previously described in Section 3.3.3.

In this more detailed scenario we have chosen the fraction of the total capacity installed in each size category and year. The scenario is not a prediction, but serves as a basis for estimating the cost. We have assumed based on the experience in Ontario that a large number of small systems will be implemented, and relatively few large systems. For the timing, we have assumed that the majority of the contracts would be signed in 2015, allowing time for the local industry to ramp up. Table 10 details the deployment scenario we have constructed.

Table 11: Scenario of the portion of projects in each size category and year.

Size category	**Contract Year**		
	2014	**2015**	**2016**
≤ 10 kW	10% (10 MW)	35% (35 MW)	15% (15 MW)
10 to 100 kW	8% (5 MW)	10% (15 MW)	9% (5 MW)
100 to 250 kW	2% (5MW)	4% (15 MW)	4% (5 MW)
250 to 1000 kW	0% (0 MW)	1% (1 MW)	2% (2 MW

When calculating the net cost to ratepayers, it is necessary to subtract the cost that would otherwise have been incurred to supply the electricity from other generators. For the purpose of this calculation we have used Nova Scotia Power's estimate of the average marginal cost of electricity of 5 cents/kWh[57]. This cost varies depending on the year and how it is calculated.

Under the set of assumptions made above and using the FIT rates from Table 9, for 100 MW of installed solar PV by the end of the third year the total net cost of solar electricity sales to the grid would amount to $18.8 million per year. When spread across the total electricity generation in Nova Scotia (11,400 GWh in 2011), this amounts to a net cost of about $0.00165 / kWh system-wide for all ratepayers, or roughly 1.2% of current retail electricity rates. For the purpose of this report we are using current retail electricity rates of $0.14 / kWh.

To estimate the range of possible costs in this scenario, we also calculated the cost in a scenario of very rapid uptake, if all contracts were signed in the first year, which has higher rates. The net cost for 100 MW in that case is $0.00220 / kWh, which is about 1.6% of current retail rates. At the lower-uptake end, if all projects were contracted in the third year at the lowest rates, the net cost would be $0.00123 / kWh (0.88% of current retail rates).

The cost is linear, in the sense that for the same basic set of assumptions, a program that resulted in half as much (50 MW) of installed PV capacity under otherwise the same conditions would lead to a distributed cost of about half as much, or $0.000826/kWh (0.6%). An even smaller program resulting in 10 MW under the same conditions would cost ratepayers about $0.000165/kWh (0.12%).

Tiered Scenario Results:

Estimated cost of 100 MW solar PV feed-in-tariff: $0.00165/kWh (1.2%) Range 0.9 to 1.6%

Estimated cost of 10 MW solar PV feed-in-tariff: $0.000165/kWh (0.12%) Range 0.09 to 0.16%

Figure 12 shows the cost to ratepayers for solar electricity in this scenario, as a percentage of 2013 retail electricity rates, for a range of total installed solar PV capacity.

Figure 12: Cost of solar electricity payments (% of retail rate), for this scenario, as a function of solar PV capacity installed (MW).

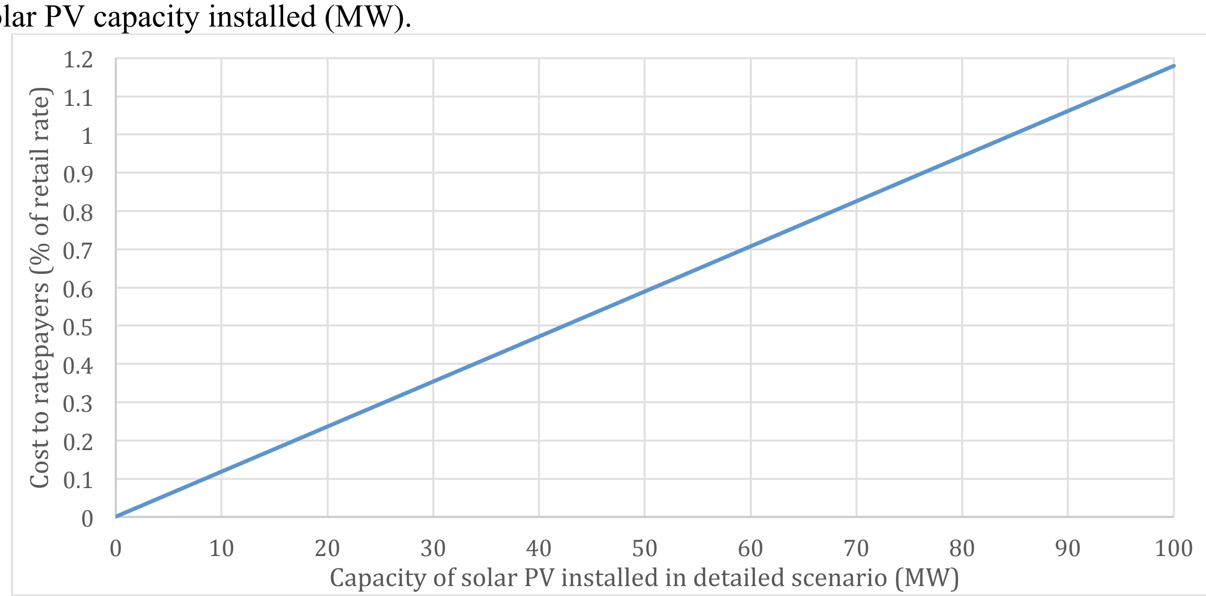


Figure 12 demonstrates that for this scenario each addition of 10 MW of solar PV generation adds about 0.12% (about $0.000165) to current electricity rates. The results are very similar to the simple scenario from Figure 11. Comparing the simple and detailed scenarios reveals that the detailed scenario has about the same cost as a single rate of about 23 cents/kWh. While it requires more complexity, one advantage of a more detailed rate structure is that it would incentivize projects of a variety of sizes, since smaller projects typically have higher per-unit costs.

Assuming 20-year contracts, the annual payments would remain constant for 20 years, while the avoided cost of generation would increase due to inflation and fuel price increases. As a result, the net cost as a percentage of the going electricity rate would decrease over time.

Note: This estimated cost to ratepayers does not include any transmission or distribution system integration costs for solar PV.

7. Examples of other PV incentive programs in North America

7.1. Alberta

Alberta Agriculture

Alberta Agriculture and Rural Development, a provincial government department, through its "Growing Forward" partnership with the federal government, offered a "Solar PV Equipment Pilot" capital rebate program for eligible registered farms in 2011 and 2012.[58] The goal of the pilot project is to collect data on installation cost and energy productivity of solar PV systems on farms in Alberta. Grants of between $1.50 and $2.50/W were offered to cover a portion of the installed cost, up to a maximum of $19,500. The incentive was tiered by system size, with the first 3000W receiving $2.50/W, the next 3000W receiving $2.00/W, and any portion above 6000W receiving $1.50/W. The minimum project size was 2.2 kW. There was no maximum project size, although the maximum project grant set an effective cap of 10 kW for a single project, above which no further grant was available.

The farmers who installed the systems applied to interconnect under the Alberta Micro-Generation Regulation[59] and are therefore eligible for payment for surplus generation from their PV array at the retail electricity rate, which in Alberta in 2012 ranged between 8 and 10 cents/kWh.[60] Distribution fees are not counted in the credit.

The pilot program was quickly oversubscribed and closed to further applications, due to "tremendous interest".[61] Fourty-six projects were approved, for a total installed capacity of 352 kW.[62] The pilot program ends March 31, 2013, though it is effectively closed now due to being fully subscribed. The Government of Alberta has expressed interest in continuing and expanding the program in 2013 if it is deemed successful.[63]

ENMAX Generate Choice Program[64]

A private electrical utility company based in Calgary, ENMAX is offering to lease PV systems to residential customers. The duration of the lease is 15 years, after which the customer can choose to purchase the system for an additional $350 or pay $950 to have it removed. Each PV system is sized at 1.3 kW, and there are three payment options, as shown in Table 3 below. Parts and labour are warranteed for the duration of the lease.

Over the lifetime of the system, the levelized cost the lessee is paying for the electricity can be estimated based on the up-front fee, the monthly fees, buy-out fee and electricity production. A 1.3 kW PV array can be expected to produce about 1690 kWh annually in southern Alberta. The lease is for 15 years, however if the user elects to buy the system for $350 at the end of 15 years, they can expect ten more years of useful production after the end of the lease. The estimated levelized cost of solar electricity in these systems is also shown in Table 12.

Table 12: Payment plans for 1.3 kW PV systems in the ENMAX Generate Choice program

Fees	Zero Down	Standard	Low Monthly
Initial Fee	$ 0	$1500	$3500
Monthly Fee	$59.99	$39.99	$16.99
LCOE*	38 ¢/kWh	33 ¢/kWh	29 ¢/kWh
Net cost to lessee	28 ¢/kWh	23 ¢/kWh	19 ¢/kWh

*Levelised Cost of Electricity (estimated from the fees under a set of assumptions). The net cost to the user of the solar electricity is about 10 ¢/kWh less than the LCOE, because they will receive credit at the retail rate for all the electricity they generate.

ENMAX received a grant of $14.5 million from the Climate Change and Emissions Management Corporation (CCEMC) to support offering this program as an immediate way to reduce greenhouse gas emissions and build capacity in the distributed renewable sector. The program goal is to install 9000 distributed renewable energy systems, 8300 of them solar PV and the other 700 being micro wind turbines, for a total generation capacity of 12,470 kW. If all of the systems are installed, the grant represents a subsidy of approximately $1.16/W across the whole program.

As of November 2012, the program has facilitated the installation of over 450 kW of renewable capacity, including both wind and solar. The ratio of solar to wind in the installations was not specified. If the ratio installed is equal to the ratio of the program targets, the solar portion would represent about 92%, or 414 kW.

Alberta Municipal Solar Showcase

Twenty municipalities across Alberta are demonstrating highly visible grid-connected solar PV projects at public buildings. Each participating municipality installed a grid-connected PV system of at least 1 kW of capacity. Real-time output for the 20 projects is available on the project website. Funding for the project comes from the municipalities, Alberta's Climate Change Central and the Federation of Canadian Municipalities' Green Municipal Fund. The purpose is to raise awareness amongst the public, the trades, governments and industry.[65]

7.2. Saskatchewan Net Metering Demonstration Program[66]

From 2006 to 2012 the Saskatchewan Research Council (SRC) offered a 35% rebate incentive up to $35,000 per project for environmentally preferable customer-installed electricity generation systems with capacity under 100 kW. In exchange, the customer/generator agreed to provide production data from their system for 10 years. Wind energy and PV systems were both eligible for the same incentive. The program was originally intended to run for five years and was extended for one year. Registrations were accepted up to January 2012.

The program resulted in 250 systems being installed in the first five years and an additional 179 systems in the extended year. Among these there were 190 PV systems for a total of 1530 kW of installed PV capacity. Data collected in the project so far has found that the PV systems are producing 29% more electricity than that predicted by RETScreen[67] software modelling. The lifetime cost of electricity production by the PV systems in the study (after the rebate) is estimated at 13 ¢/kWh.[68] At current prices of $4 to $5/W installed, the 35% rebate represents an incentive of $1.40 to $1.75/W.

SaskPower announced in February 2013 that the net metering rebate program will continue. The renewed program is now operated by the utility company and offers 20% rebates of capital cost for eligible net-mtered PV systems, up to a maximum rebate of $20,000.[69]

7.3. Efficiency New Brunswick – Net zero homes incentive and PV

Efficiency New Brunswick's Residential Energy Efficiency Program offers incentives to improve the energy efficiency of residential buildings, and it includes an optional bonus incentive for net zero retrofits, in cases where the building owner agrees to make the building site produce as much energy as it uses. The idea is that the owner will first upgrade energy efficiency as much as practicable and then install a renewable energy system to produce annually as much energy as the building uses. This in effect is an incentive available for PV systems, because installing PV is one of the more common ways to bring a building to a net zero energy position.

For a single family home, the Net Zero Bonus is $4000, and for a multi-unit building it ranges from $4000 to $20,000. To estimate the value of this as an incentive for PV, consider a scenario in which a single family home has been retrofitted with upgraded insulation and a heat pump, bringing its total energy consumption down to 7000 kWh per year (all electric). In New Brunswick, a 6 kW PV array would produce about this much electricity annually, with a small surplus, and would cost between $24,000 and $30,000. An incentive of $4000 then represents approximately a 13 to 17% capital cost rebate, or about $0.67/W.

This program has been offered for retrofits of existing homes and for new homes in New Brunswick. The entire new homes incentive program, including the net zero option, was suspended in the spring of 2013. In the two years that the new homes net zero incentive operated, 12 homes in New Brunswick completed a net zero system, most of which would include solar PV. This represented roughly 0.6% of participating households in the new homes incentive program who went for net zero status.[70]

7.4. Massachusetts, USA – Solar Renewable Energy Certificates

Since 2010 the state government of the Commonwealth of Massachusetts has established a Renewable Portfolio Standard (RPS) with targets for renewable electricity supply. Within the RPS, solar PV has a specific "carve-out". The goal for Massachusetts is 400 MW of installed capacity of PV with distributed projects of a variety of sizes up to 6 MW each.[71]

To facilitate growth in solar PV capacity there is a legislated requirement that all retail utilities selling electricity in the state source a percentage of their electricity from a certified solar energy source. The required percentage is adjusted year-by-year to achieve growth. The utilities may install PV systems of their own or purchase Solar Renewable Energy Certificates (SRECs), which are promissory instruments or contracts with an independent power producer (IPP) to supply the specified amount of solar electricity.

The sale of SRECs is the primary revenue source for IPPs, on which they can base their business and financing plans for new solar PV installations. The solar electricity itself is sold primarily through net metering, power purchase agreements or spot pricing, at between 6 and 10 US¢/kWh. On the other hand, the SRECs are sold to electricity retailers on an open market, with the price floating within a range of 28.5 and 50.0 US¢/kWh set by the government. Individuals with small residential systems typically participate in this market by pooling their SRECs through an aggregator company. The government has set up an auction clearinghouse to facilitate the sale of any unsold SRECs, but in 2011 no SRECs were deposited in the auction, suggesting that all who wanted to sell their SRECs were able to do so without needing to put them up for auction.

The combined value of solar electricity in this scenario, including the sale of the energy and the SRECs, is between 34.5 and 60 US¢/kWh, which is comparable with feed-in-tariff prices in Ontario and other jurisdictions. The US dollar has traded within +/- 5 cents of par with the Canadian dollar for all of 2012[72]; therefore in this context US currency is equivalent to Canadian currency.

Interestingly, the retail utilities have an alternative of paying a "compliance fee" if they do not obtain the necessary SRECs. The compliance fee is 55 US¢/kWh in 2012 for the solar portion that they fail to obtain, to decline gradually over the next 10 years to 34.7 US¢/kWh. Given the recent drop in installed solar PV costs, it seems likely that utilities will spend significantly less if they purchase SRECs or install PV systems rather than paying the compliance fee.

The legislated market for SRECs makes commercial solar electricity development very attractive in Massachusetts at this time. SRECs can be sold by anyone, including individuals who install solar PV systems on their own properties and interconnect them with the grid. The Massachusetts SREC system has a similar effect as having a FIT or COMFIT rate of between 30 and 60 CAD¢/kWh.

Since 2008, over 3700 solar PV projects under 6 MW have been installed in Massachusetts, for a current installed PV capacity of 138 MW. In the year 2012 alone, up to the end of October, over 2000 PV systems were installed, for a total of 86 MW of capacity. If that rate were to continue year-over-year, the 400MW goal would be reached in 3 more years. Being well on track towards meeting the current target soon, the state government is beginning considerations in 2013 about whether to increase the goal.[73]

8. Relationship between solar PV and solar thermal industries in Nova Scotia

As mentioned previously in Section 2.5, solar thermal technologies such as solar water heaters also represent economic development opportunities and an effective means of harvesting renewable energy and reducing greenhouse gas emissions. In Nova Scotia, where the solar industry includes significant activity in solar thermal, the question of the relationship between solar thermal and solar PV technologies is worthy of consideration.

The government of the UK has taken an interesting approach by offering two incentives – a feed-in tariff for solar electricity and a renewable heat incentive for solar thermal systems. The renewable heat incentive is now open in Phase 1 to commercial, institutional and non-profit agency solar thermal installations and offers payments of 8.9 pence (13.8 CAD cents) per kWh of heat energy produced by a solar thermal array[74]. Payments are based on the real measured heat output of the system, and are made every three months for as long as the system produces, or 20 years, whichever comes first. The payments are an additional benefit on top of the savings in energy that accrue to the system owner.

For the small solar water heater described in Section 2.5 of this report, which produces 2500 kWh annually, the UK renewable heat incentive would pay the equivalent of CAD$345 annually. This would be in addition to the approximately $350 that the owner would save on electricity bills, for an annual return of nearly $700 on the investment in a solar water heater, or about 28 cents/kWh. By comparison, the solar PV feed-in-tariff in the UK is structured such that the value of solar electricity is about 45 cents/kWh[75]. The ratio of the value of solar electricity to solar thermal energy in this comparison is 1.6:1, which is similar to the difference in capital cost between the solar heater and the solar PV system described in Section 2.5, which is a ratio of 1.4:1.

The Province of Nova Scotia could consider a similar approach to the UK government, by offering both a renewable heat incentive based on measured production, and a feed-in tariff for solar electricity production. The rates may differ here, but the concept would allow for equitable treatment of solar technologies. An alternative approach could be to tailor a solar PV incentive in the form of a rebate or capital grant that models existing solar thermal incentives in Nova Scotia. There are also new combinations being developed in the market, such as solar PV used exclusively for domestic water heating[76]. As the price of solar PV continues to decrease, the feasibility of a variety of uses for solar PV is increasing.

An interesting aspect of the UK system is that in order to be eligible for either of the incentives, a homeowner must demonstrate that their home meets a defined standard for energy efficiency. This prioritizes energy efficiency in the hierarchy of actions to reduce greenhouse gas emissions.

9. Summary

The main points of this report are summarized as follows:

- The solar resource in Nova Scotia is fairly uniform across the province and amounts to about 1100 kWh of annual electricity production per installed kilowatt of PV generation capacity. This is about normal for southern Canada and intermediate on the global scale.
- On a seasonal basis, solar PV output in Nova Scotia corresponds well with the small secondary peak in electricity demand that occurs during July for cooling load, but it does not correlate with the maximum winter peak demand in January associated with heating.
- On a daily basis, in summer (July) the peak output from solar PV on sunny days is observed to occur during the typical daily demand peak. However in winter (January), PV will not be available at the time of the typical daily demand peak, which occurs after sunset.
- A key difference between solar PV and other variable renewable electricity generators is that peak power output from solar PV always occurs in the daytime, and particularly near midday. Daytime minimum load in Nova Scotia is consistently higher than the overall minimum load by a significant margin. This means there will be many days when the demand for power will absorb incremental solar PV output. Equivalent treatment of solar PV in distribution-level interconnection agreements would mean basing the interconnection permit decision on minimum *daytime* load, rather than overall minimum load.
- We have not estimated the transmission system impact or system costs to the Nova Scotia Power System Operator for grid integration of PV generators. Analysing the transmission system impact and cost of grid integration of PV is beyond the scope of this report. This will require a system impact study if large amounts of solar PV (e.g. above 10 MW) are proposed.
- We find that the capital cost of installed solar PV systems has decreased steadily over the past decade, at about $0.87/W per year, and the installed prices in Nova Scotia show the same pattern. More recently, in the past two years (2011/2012) the rate of decline in installed prices appears to be closer to $1.06/W per year. Installed prices in Nova Scotia in 2012 were in the range from $4.00 to $5.00/W.
- Under a chosen set of assumptions, we estimate that the levelised cost of solar PV electricity in Nova Scotia is about 33 (29 to 36) cents/kWh for 2012 prices, and about 25 (21 to 29) cents/kWh for projected 2013 prices. We acknowledge that there are several factors that could make the real levelised cost higher than this.
- Feed-in tariffs have been used in many jurisdictions to effectively encourage deployment of solar PV systems. FIT rates in Ontario and in northern European jurisdictions have declined steadily and dramatically over the past three years, and now range from 17 to 55 cents/kWh, depending on the jurisdiction and the category and size of the PV system.
- We constructed two scenarios – simple and tiered – to estimate the cost of solar PV to ratepayers if Nova Scotia offered a FIT or COMFIT rate for solar PV. We used hypothetical COMFIT rates based on the levelised cost of electricity for solar PV.

- ❖ In the simple scenario, at a hypothetical solar PV COMFIT rate of 30 cents/kWh, for each 10 MW of installed solar PV capacity the net cost of payments for solar electricity generation would be $2.75 million per year. When divided across all ratepayers, this would represent about 0.0241 cents/kWh, or about 0.17% of current retail electricity rates. For a range of simple COMFIT rates from 20 to 40 cents/kWh, the net cost of payments ranges from $1.65 to $3.85 million per year for each 10 MW of solar PV capacity. This represents a range of 0.0145 to 0.0338 cents/kWh when spread across all ratepayers, or can be expressed as 0.10% to 0.24% of current retail rates, per 10 MW of solar PV capacity. This does not include any system integration costs.
- ❖ For the tiered scenario described in section 6.3, each 10 MW of added solar PV capacity would cost ratepayers about 0.12% (net) on the current retail electricity rate, with a range of 0.09% to 0.16% depending on the rate of uptake. This does not include any system integration costs.
- ❖ There are several other kinds of incentive programs that have been implemented for solar PV in other jurisdictions, including grants, rebates, leasing programs and tradable Solar Renewable Energy Certificates. These are detailed in section 7.
- ❖ Stakeholder input and the existing conditions of the Nova Scotia solar market indicate the importance of considering how to encourage the solar thermal industry and solar PV industry together. To contribute to this discussion, in Section 8 we have described an example from the United Kingdom of a system that encourages both solar thermal and solar PV in a relatively equitable manner by including both a renewable heat incentive for solar thermal and a feed-in tariff for solar PV.

10. Conclusion

We respectfully submit this report to the Province of Nova Scotia. We would also like to express our appreciation to the many stakeholders and reviewers who participated in its production. We hope this work will contribute to the discussion of solar photovoltaic generation in Nova Scotia.

Note that the spreadsheets for calculating the levelized cost of electricity are available.

APPENDIX

Example spreadsheet calculation of Levelised Cost of Electricity (LCOE) (from Section 4.3)

Installed	Annual	Installed	Maintenance	Discount		
Cap. (kW)	output	cost	inflation	rate		
10	decrease	$/W				
PV potential	0.005	4.5	0.02	0.06		
1100						
kWh/kW y						
Year	E(t) (kWh)	I(t)	M(t)	(1+r)^t	Numerator	Denominator
1	11000	45000	50.00	1.00	45050.00	11000
2	10945	0	51.00	1.06	48.11	10325
3	10890	0	52.02	1.12	46.30	9692
4	10835	0	53.06	1.19	44.55	9097
5	10780	0	54.12	1.26	42.87	8539
6	10725	0	55.20	1.34	41.25	8014
7	10670	0	56.31	1.42	39.70	7522
8	10615	0	57.43	1.50	38.20	7060
9	10560	0	58.58	1.59	36.76	6625
10	10505	500	59.75	1.69	331.32	6218
11	10450	0	60.95	1.79	34.03	5835
12	10395	0	62.17	1.90	32.75	5476
13	10340	0	63.41	2.01	31.51	5139
14	10285	0	64.68	2.13	30.32	4822
15	10230	500	65.97	2.26	250.33	4525
16	10175	0	67.29	2.40	28.08	4246
17	10120	0	68.64	2.54	27.02	3984
18	10065	0	70.01	2.69	26.00	3738
19	10010	0	71.41	2.85	25.02	3507
20	9955	500	72.84	3.03	189.33	3290
21	9900	0	74.30	3.21	23.17	3087
22	9845	0	75.78	3.40	22.29	2896
23	9790	0	77.30	3.60	21.45	2717
24	9735	0	78.84	3.82	20.64	2549
25	9680	0	80.42	4.05	19.86	2391
				SUMS	46500.86	142293
				LCOE	0.327	$/kWh

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