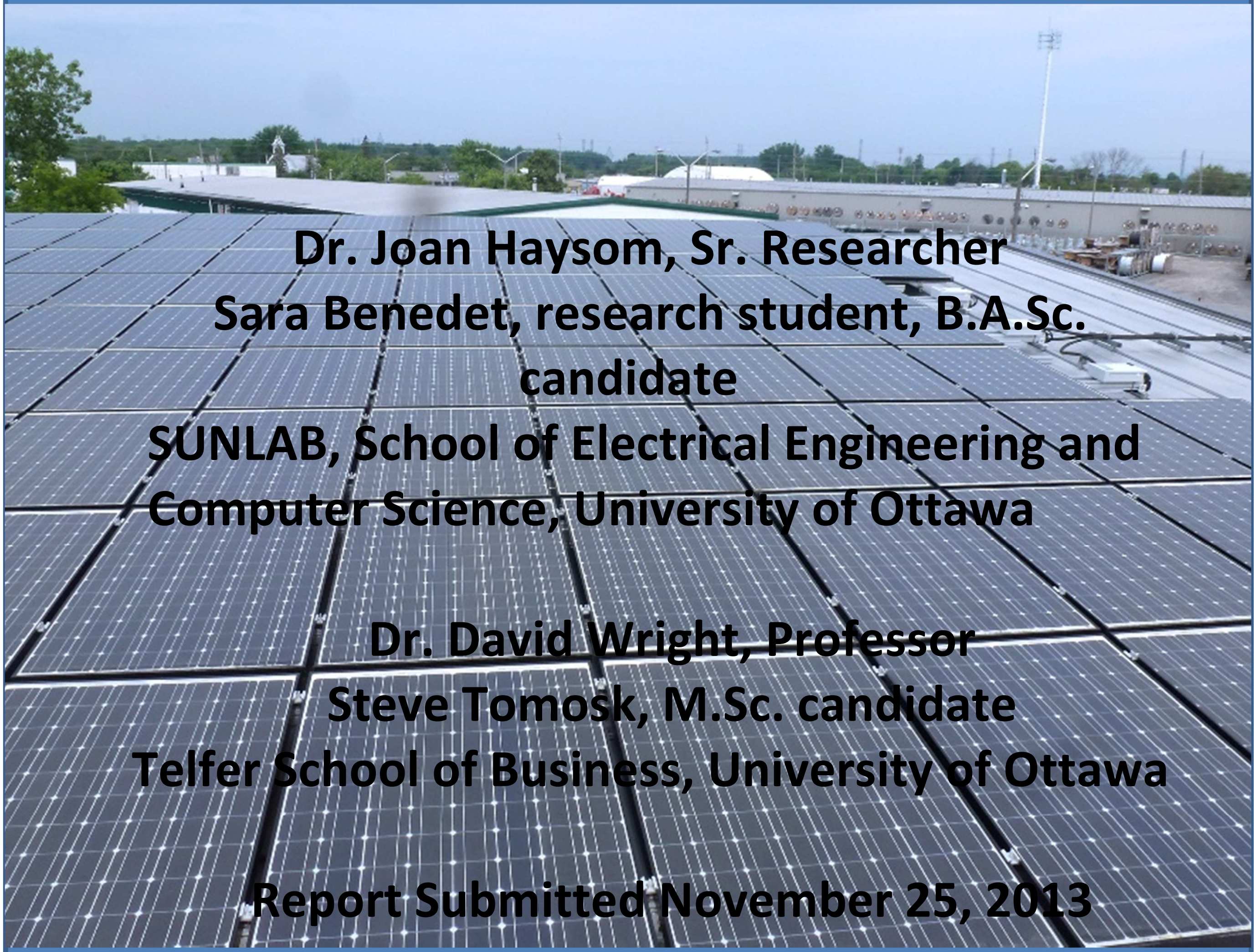
Review of Photovoltaic System Performance and Financials for Hydro Ottawa

Report 1: Energy Yield Analysis of Installed Systems



Dr. Joan Haysom, Sr. Researcher
Sara Benedet, research student, B.A.Sc. candidate
SUNLAB, School of Electrical Engineering and Computer Science, University of Ottawa

Dr. David Wright, Professor
Steve Tomosk, M.Sc. candidate
Telfer School of Business, University of Ottawa

Report Submitted November 25, 2013

Pictures from three Hydro Ottawa photovoltaic installations: *preceding page* - view of Merivale Roof 20 kW array; *above* - Bank St. pole-mounted 1.56kW system, with Sara Benedet (Sunlab) on ladder taking shadow measurements, Al Lemay (Hydro Ottawa) assisting, and Sasha McCollough (Energy Ottawa) in background; bottom – Riverdale 2 axis tracker 10kW, with Allan Morton (Energy Ottawa), Sara Benedet, David Wright (uOttawa), Al Lemay, and Joan Haysom (uOttawa).

Executive Summary

This report is in relation to a collaboration on photovoltaics (PV) systems between Hydro Ottawa Limited (HOL) and the University of Ottawa's Sunlab funded by an Engage grant from the Natural Sciences and Engineering Research Council (NSERC) of Canada. The goals of the collaborative project were multifold - at the highest level, as is typically intended for an NSERC Engage project, one goal was to build a new research partnership between the two Ottawa institutions. The collaborative partnership has started with research on standard PV systems, with the intent to extend the partnership into future collaboration in the domain of renewable energy integration onto the grid.

As a result of the NSERC funding and additional Sunlab in-kind contributions, two reports have been written which are now being shared with HOL:

1. ***Report 1: Energy Yield Analysis of Installed Systems***, contained herein, on the performance of six of HOL's photovoltaic installations and methodologies for detailed study of PV system performance factors, and
2. ***Report 2: Matching of PV to Grid Pricing and Grid Peaks -*** analysing the financial viability of photovoltaic installation under a number of different scenarios, including variable market pricing, time-of-use and peak demand costs.

Executive Summary of Report 1

At present, within the burgeoning growth of PV deployment in Ontario, there is a research opportunity for an aggregated performance evaluation of PV systems. Such a study would be a guide to both policy-makers, existing players in the industry, and those new to the field. Such a study would be best done on a large number of systems, but that is then a sizeable undertaking. Thus, a small study was undertaken to evaluate methodologies, while also providing analysis of value to HOL. The specific objectives undertaken in research contained with Report 1 are:

- Using six PV systems owned by HOL, analyse hourly performance datasets and summarize figures of merit for those systems.
- Confirm general performance expectations for systems deployed in Ottawa, with a goal of public dissemination of the results.
- Evaluate methodology for high-accuracy simulation of system performance, for comparison to actual performance, in order to accurately examine system losses, and consider if snow losses can be deduced with methodologies examined here.
- Evaluate if the smartmeter and/or simulation analysis can be applied to a future HOL and Sunlab studies of a large number of systems.
- Confirm the applicability of smartmeter data for these studies.

Datasets & systems

As of the end of 2012, HOL had six photovoltaic systems under operation, for which smartmeter data had been collected for a period of more than one year. For simulation work, solar irradiance and ambient temperature data for 2011 and 2012 are used as inputs, and the results are compared with smartmeter values. Datasets with different timestamp formats were converted into hourly datasets with hour beginning, GMT-5 timestamps. Efficient methods were developed to manipulate and screen the data for validity. The major issue with the dataset however, was the existence of appreciable gaps, primarily related to maintenance events on the PV systems and irradiance meters. Analysis from the calendar year of 2012 was the most useful, while some months of data from 2011 was of use in the simulation studies with monthly granularity.

Annual Energy Production

The smartmeter ***annual energy production*** for the six systems for the years 2011 and 2012 are shown in Figure 3. The values vary greatly due to system size, as expected. It should be noted that the 2011 smartmeter data was low due to an incomplete year of operation.

Annual Specific Energy Yields

The annual specific energy yield is the total energy produced by a system, divided by the rating of its panels (DC nameplate rating), and is a commonly used metric for system performance comparisons. For the calendar year 2012, **the BankPole system achieved the best specific energy yield of 1192 kWh/kWdc/yr** (in-line with expected performance for optimally oriented systems in Ottawa), while GreenbankRoof and Riverdale2Axis systems also performed well against the expected outputs for their orientations: 1066 and 1623 kWh/kWdc/yr. The MerivalePole, MerivaleRoof and RiversideRoof all had low yearly specific energy yields, believed to be largely due to system availability issues. The portfolio average for the five fixed-tilt systems was 1035 kWh/kWdc/yr for 2012. Note **that the Riverdale2Axis was able to achieve a 41% increased energy harvest due to dual axis tracking**, in comparison to the BankPole system.

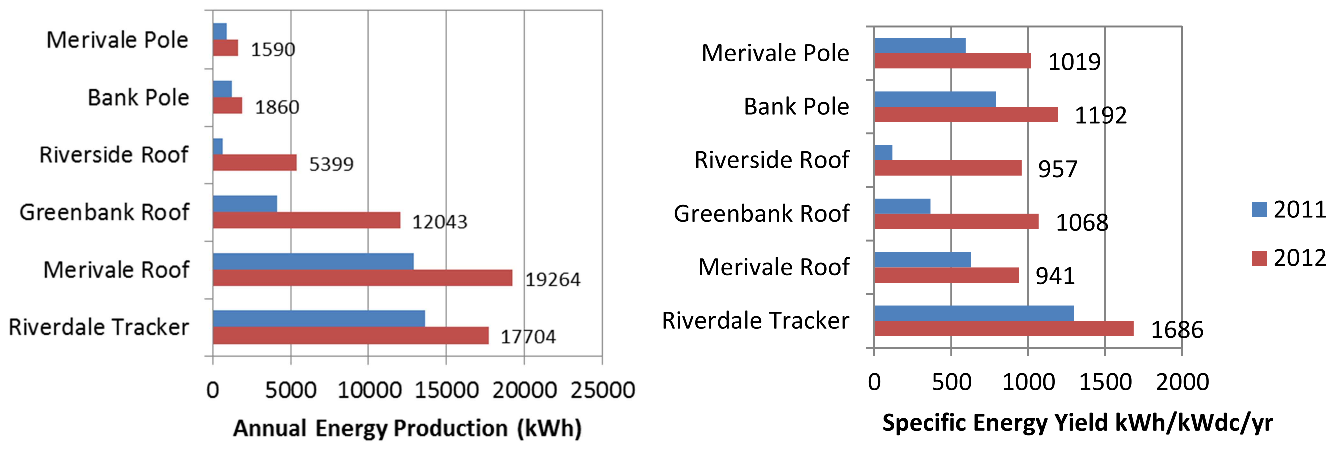


Figure 1: Annual energy yields and annual specific energy yields for the six HOL systems studied, for the years 2011 and 2012 (the latter is the annual energy yield divided by the total dc power rating of all the PV panels of the system)

PV System Simulation Accuracy

A concerted effort was undertaken to develop an accurate and detailed description of the PV systems for input into the simulation software PVSyst. Actual ground measured irradiance data for 2011 and 2012 was provided through a separate collaboration with the National Research Council (NRC) Institute for Research in Construction. These inputs are used together to provide predicted performances for 2011 and 2012 which are then compared with the actual smartmeter energy output.

First, annual energy yields were studied. Once scaling of the results was undertaken (justified by known issues with the irradiance dataset) **agreement within ~±2% was obtained between predicted and actual energy production for two of the systems with good availability** (BankPole, GreenbankRoof), and we likely also achieved the same accuracy for a third system (RiversideRoof), although poor smartmeter availability made it hard to confirm, except through an estimation. Second, the performance ratios of the system were studied: it is the ratio of a system's AC energy output divided by the energy harvestable by its panels, and is a measure of a *system's* total efficiency. For the above three systems, **the performance ratios were found to be 74-76%** from simulations. This is in-line with expectations for systems built in the time period of 2005-2011,[1,2,3] although it is lower than present best-in-class installations (built in 2012 and later). For the three other HOL systems, particular system inputs (shading and transformer losses) were identified as probably being set too high and thus the likely main sources of discrepancies. Furthermore, if more complete or more extensive datasets were studied (for example, adding data for 2013) one could likely further calibrate and verify the simulation inputs to produce a simulation tool with high accuracy prediction capability.

The analysis of monthly results (actual versus predicted) indicated snow losses were significant for some systems in the months of January and February, but data was too sparse to deduce any generalized trends. Quantification of snow loss in the Canadian climate is an area of PV performance research recently identified as needing more study. It appeared that the methodology developed here could provide useful insights if a larger, more complete dataset were obtained. Although this method requires a substantial analysis effort, it does not require the building of specific test sites. Thus, the HOL smartmeter database for solar connected systems has a wealth of information that could be employed to great advantage in future studies.

Final Recommendations and Next Steps

A joint meeting is requested to discuss how best to disseminate various aspects of this report to the public and other audiences. The proposed avenues include publication of a white paper, media releases, and presentations to conferences or various industry associations.

The methodology of using PVSyst performance predictions in comparison with actual performance proved to be intensive but very powerful. It can provide a detailed understanding of the actual losses of an existing system and likely be calibrated to provide high-accuracy predictor of new systems. Site visits with shading loss measurements provide the highest accuracy, but are also time consuming.

The HOL smartmeter data was instrumental to this analysis, and their use in future studies is highly recommended. Analysis using a larger dataset could be undertaken, using either HOL systems and/or PV systems owned by others. Additional information about new systems (tilt, orientation, estimation of shading, electrical losses) would be required, likely requiring a campaign to get system owners to share this information. However, direct site visits of each system of a larger study would prove too onerous. Thus, an expanded study which would provide more substantiated correlations between system parameters (including tilt, soiling and snow) and performance outcomes could take two approaches:

- the continued study of these six HOL systems, described with high accuracy, or
- the study of a large number systems connected to the HOL grid, described with a lower level of fidelity.

Either would be publishable in the scientific community. It should be mutually discussed whether further collaborative research efforts are applied to these possibilities, or if efforts should move into other areas of research on renewable energy integration on the grid.

Table of Contents

List of Figures

List of Tables

Introduction

Background

On May 14, 2009, the Province of Ontario introduced the first renewable energy “feed-in tariff” (FIT) program in North America. The program provided a premium price for energy produced by various types of renewable energy generation, with contract being allocated by the Ontario Power Authority, but connection to the grid and payments being administered by local distribution companies (LDCs). As such, early on in this program, Hydro Ottawa Limited (HOL) and Energy Ottawa undertook the deployment of several installations on their facilities in the City of Ottawa all under initial FIT1.0 tariffs.

For HOL and Energy Ottawa, the deployments provide key learning opportunities that help them in their ability to support their customers who decide to invest and install PV generation systems. The undertaking also has an outreach aspect to encourage others to become adopters of renewable energy generation and other sustainable energy practices. As FIT projects, they will also be a (small) source of revenue for Energy Ottawa; this revenue is dependent on the system performance and on the climatic conditions of the particular year. **Thus a review of the performance of the systems after 1 to 2 years of operation was desired, with the likely result of public dissemination of major results to further customer support.** A surprisingly small number of research papers exist on system performance (for example, from Europe[2,4,5] and Canada[1]). Since the technology and system designs are changing and improving, regular reviews, in particular in hot markets such as Ontario, are of interest to many in the industry.

The Ontario government is reducing tariff prices of FIT contracts in successive roll-outs of contract offerings, primarily to keep tariffs in-line with the declining costs of equipment. Eventually, PV electricity production will be financially viable without incentives or special tariffs. With deployment costs continuing to decline and costs of electricity expected to increase, the point at which the cost of PV energy matches the grid electricity costs (generally described as “grid parity”) is forecast to be 2018 for Southern Ontario[6]. Whether it due to decreasing subsidies, or desire to develop solar outside of the FIT program, it will become more common in future years for PV systems to be installed where the electricity produced has a value equivalent to the grid prices. Furthermore, on large electricity users’ bills, a high percentage of their bills are related to peak power demand, which generally occurs in sunny summer afternoons. **Thus, the deployment of PV systems can be a good match to reduce peak demand, and a study on the extent of this was desired, as will be covered in Report 2 - Matching of PV to Grid Pricing and Grid Peaks. Should non-FIT scenarios prove to be financially viable, means of public dissemination of the results should also be considered.**

Project Goals

The goals of the entire collaborative project were multifold. At the highest level, as is typically intended for an NSERC Engage project, one goal was to build a new research partnership between Hydro Ottawa and the Univeristy of Ottawa’s Sunlab. This collaboration partnership has started with research on typical photovoltaic systems, such as HOL and its customers already own. Our intent is to extend the partnership into future collaboration in the domain of renewable energy integration onto the grid. The specific objectives undertaken in this project were:

As examined in Report 1:

- Using six PV systems owned by HOL, analyse hourly performance dataset and summarize figures of merit for those systems, while making use of direct measurements of irradiance.
- Confirm general performance expectations for systems deployed in Ottawa, with a goal of public dissemination of the results.
- Evaluate methodology for high-accuracy simulation of system performance, for consideration towards future studies of a large number of systems.
- Examine the sources of losses, and consider if parameters for losses due to snow can be deduced.

As examined in Report 2:

- Evaluate trends between solar generation, grid peaks and grid pricing within Ontario
- Evaluate revenues that are obtainable from different types of sales of the solar generation: feed-in-tariff pricing, spot-market electricity prices, and use of additional peak demand offsets.
- Evaluate savings that may be obtained by certain class A large electricity users, who are greatly incentivised (through Global Adjustment calculations on their electricity bills) to reduce their peak demand
- Design an optimal system design for best return-on-investment for an installation for the above financial advantages

Acknowledgements

Great appreciation is given to Raed Abdullah from Hydro Ottawa, for his support throughout this project. During the site visits we also received wonderful support from Al Lemay from Hydro Ottawa Ltd, and Sasha McCulloch from Energy Ottawa Ltd.. Furthermore, we appreciated the support from Adam Frey and Mike McGahern from Ottawa Solar Power, who kindly lent us the Solar Pathfinder plus time in their offices to convert shadow images into horizon data files. Finally, thank you to Mike Swinton and Marianne Armstrong for sharing the irradiance data from their research facilities at the Canadian Centre for Housing Technoligy (National Research Council) and reviewing and discussion our comparative studies with the irradiance meter at uOttawa.

Standard Formatting Used in this Report

Throughout this report, tables which contain summaries relative to the six HOL systems are shaded in red, whereas tables which contain monthly parameters are shaded in green.

Within the text, certain key points are highlighted in bold font.

Section 1 - Datasets Used in Analysis

1.1 Introduction

The technical analysis included the performance analysis of six solar PV installations and used data coming from a range of sources provided by HOL and other SUNLAB partners and Environment Canada datasets. This data included energy outputs, irradiance, ambient temperature, and wind speed, each with hourly granularity. Thus each dataset had 8760 values for the year 2011 and 8784 for the year 2012, which was a leap year.

It is worth noting here that when combining our datasets, it was critical to understand the defined timestamps, using the following terminology:

- hour beginning – value N is representative of the hour N to N+1 (these datasets have hourly timestamps from 0:00 to 23:00) This is the convention to which we converted (if required) all the data.
- hour ending – value N is representative of the hour N-1 to N (these datasets have hourly timestamps from 1:00 to 24:00).
- if daylight saving time shifts were contained within the time series - in one case it was – it was manually removed such that all our datasets were Greenwich mean time minus five hours (GMT-5)
- leap year – the year 2012 was a leap year with an extra 24 datapoints, and was analysed as such.

In some cases, multiple datasets for the same parameter were available and some early steps were required to understand and vet the datasets. In order to not make this report too long, only brief mention of this vetting will be included within the discussion of key inputs below.

The technical computing language Matlab was used to aid in the manipulation of datasets. For example, a script was created in order to import all the data and easily clean the irradiance data. It was also used to find the availability of the data and convert formats as desired (can easily convert an array of annual data to monthly and consider leap years).

1.2 HOL Solar Installations

The six HOL systems analyzed were located within Ottawa: two pole-mounted systems, three roof top systems, and 1 dual-axis tracker. A summary of the systems and their sizes is shown in Table 1. All six installations used PV panels comprised of 60 cell silicon mono or polycrystalline technology, with nominal power ratings between 195W and 235W. See Appendix A for complete system details.

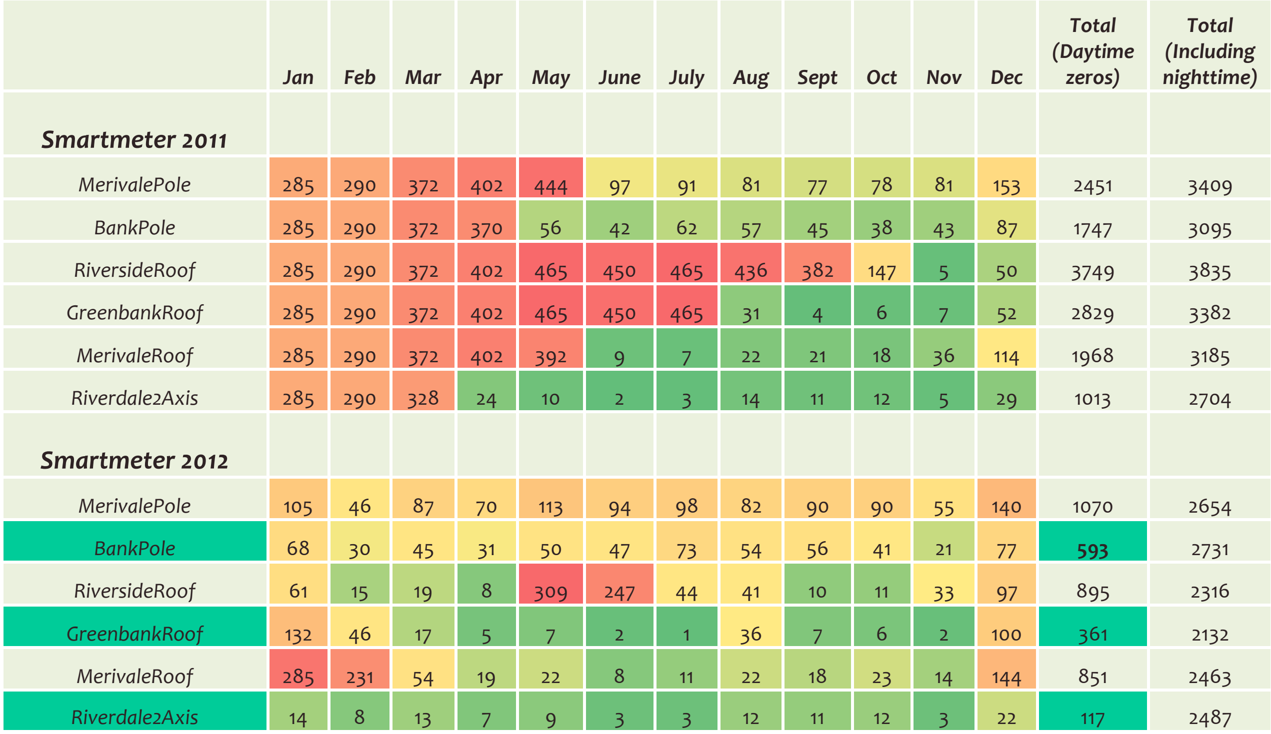
Table 1: HOL System Equipment Summary

Site Name	Size (kW, DC)	Mount Type	Tilt	Azimuth	Inverter
MerivalePole	1.56	Pole	50	0	SMA SB3000
BankPole	1.56	Pole	45	0	SMA SB3000
RiversideRoof	5.64	Roof	30	-6	Enphase D380
GreenbankRoof	11.28	Roof	10	-28	Enphase M190
MerivaleRoof	20.48	Roof	5	-60	3 x SMA 7000
Riverdale2Axis	10.5	Full Tracker	Dual-axis tracked		Enphase D380

Hourly energy outputs were obtained directly from smartmeters, as extracted from HOL's historic database, **which was confirmed to employ an hour beginning GMT-5 timestamp**. In the case of two of the systems, we also had the option of using energy output data from the inverter company's on-in portal (SMA). Some downloads of this data were undertaken, but there were significant gaps in the datasets for unknown reasons. In addition, since this type of inverter data was not available for all six systems, these SMA inverter datasets were not further employed.

Table 2 shows the monthly "system availability" of the six systems. The availability comes from our screening of the dataset: values represent the number of hours in which there are daytime zeros (the colour scheme highlights the severity of the missing data). The algorithm employed cannot distinguish between legitimate daytime zeros (due to shading or snow or sun being behind the plane of the panels) and actual missing data due to systems being off-line.

Table 2: Smartmeter Data Availability for the six HOL systems for years 2011 and 2012.



	Jan	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Total (Daytime zeros)*	*Total (Including nighttime)*
Smartmeter 2011														
MerivalePole	285	290	372	402	444	97	91	81	77	78	81	153	2451	3409
BankPole	285	290	372	370	56	42	62	57	45	38	43	87	1747	3095
RiversideRoof	285	290	372	402	465	450	465	436	382	147	5	50	3749	3835
GreenbankRoof	285	290	372	402	465	450	465	31	4	6	7	52	2829	3382
MerivaleRoof	285	290	372	402	392	9	7	22	21	18	36	114	1968	3185
Riverdale2Axis	285	290	328	24	10	2	3	14	11	12	5	29	1013	2704
Smartmeter 2012														
MerivalePole	105	46	87	70	113	94	98	82	90	90	55	140	1070	2654
BankPole	68	30	45	31	50	47	73	54	56	41	21	77	**593**	2731
RiversideRoof	61	15	19	8	309	247	44	41	10	11	33	97	895	2316
GreenbankRoof	132	46	17	5	7	2	1	36	7	6	2	100	361	2132
MerivaleRoof	285	231	54	19	22	8	11	22	18	23	14	144	851	2463
Riverdale2Axis	14	8	13	7	9	3	3	12	11	12	3	22	117	2487

It should be noted that the beginning of 2011 had very sparse data, as the HOL PV systems were only connected onto the grid during 2011. As well, MerivaleRoof had known down time due to connection reconfiguration at the site during December 2011 through to February 2012, and RiversideRoof was turned off during May and June 2012. Months highlighted in orange and red (# of hours with more than 100 zeros) will be disregarded or screened in some of the further analysis in section 3.4. **The three datasets that have the best availability for 2012 are: the BankPole, GreenbankRoof and Riverdale2Axis.**

One trend that is clearly visible in this availability chart is that both MerivalePole and BankPole systems have is relatively high number of hours with zeros throughout the year, which is surely related to their system design. We believe this is due to solar geometry: the higher tilt angles of these systems means that there are hours early and late in the day when the sun is behind the plane of the panels. In contrast, the tracked system shows the best availability.

1.3 Irradiance Datasets

It was of interest to simulate systems using actual ground measurements of irradiance for the years of study. Surprisingly, Environment Canada does not have free publically available sources for recent years (2005 being the last year available), thus we looked to SUNLAB collaborators for support.

The irradiance data that was used in the simulations comes from the Canadian Centre for Housing Technology at the National Research Council (NRC), who is a partner of SUNLAB's and who agreed to share the dataset on an exclusivity basis. The dataset is of global horizontal irradiance (GHI), measured using an Eppley Precision Spectral Pyranometer, a thermopile-type pyranometer, which is mounted horizontally on the roof of one of the research houses. A thermopile is a very accurate type of pyranometer, rated at 1-2% accuracy when well maintained and calibrated at least bi-annually; in this case, the unit was last calibrated on July 2010 and was not cleaned during the two year period of analysis. **From the outset, it was clearly understood by both NRC and SUNLAB that this was an "unqualified" data with possibly deficiencies, but that with careful interpretation by the SUNLAB, the datasets could still be of use.** The dataset had a granularity of 5 minutes, which was converted into hourly and monthly values for analysis. Monthly values are contained in Table 3.

In addition to this dataset, the BankPole PV system did have a silicon pyranometer installed at the same tilt angle as its panels (45° tilt), and the data was available through the inverter manufacturer's portal. This dataset was reviewed, but it contained a large section of missing data for an unknown reason, so was not analysed further.

A further ground-based measurement was available - at SUNLAB's outdoor test site, a new GHI thermopile pyranometer identical to NRC's was installed in January 2013. This time period clearly was not useful for the present study, however, some comparative work of NRC's and uO data was undertaken to confirm accuracy/agreement of the pyranometers. For a five months overlap between February and May 2013 (both without any datagaps), analysis showed that the NRC pyranometer read 4% lower than the uOttawa device. Soiling of the NRC unit versus the regularly cleaned uOttawa unit was an obvious possible reason for the discrepancy, but cleaning of the NRC unit on June 2013 revealed no increase in output. Calibration accuracy is the next most likely source of error. The units are supposed to be accurate to <1%, but require recalibration every 1-2 years (NRC's hadn't been recalibrated in 2.5yrs). Final reason for the discrepancy is still unknown; **in this analysis we make use of the NRC dataset as is, but we assume it is reading slightly low. Thus, some scaling of simulation results may be required, and we assume a 4% low reading of all values.**

Before being used in any calculations, the NRC GHI dataset went through a cleaning process to remove negative values and noise: based off of sunrise and sunset times, night time values were set to zero. Furthermore, after consideration of a few algorithms for dealing with daytime negative values, we opted for the simplest approach, that these were also simply set to zero.

Columns four and five of table 3 summarise the number of zeros found in the resultant dataset, which we call "availability". It represents both spurious issues as well as legitimate downtime, the latter being much more significant. In fact, it is apparent that **there is a significant amount of data missing for May 2011 and May 2012. Note that any simulations done with this data will produce erroneously low predictions for those two months.**

Table 3: Summary of monthly irradiance values.

	NRC		% missing		CWEC	Scaled Irradiance	
	2011	2012	*2011*	*2012*	TMY	2011	2012
January	44.0	39.5	0.00	0.80	45.8	45.7	41.5
February	64.5	68.8	0.00	0.18	74.8	67.0	71.7
March	112.3	103.4	0.00	0.00	120.8	116.7	107.5
April	127.3	134.5	1.08	0.00	139.0	133.9	139.9
May	126.8	82.2	13.63	52.21	169.8	155.0	174.1
June	170.8	176.8	0.00	0.78	182.6	177.6	185.3
July	198.9	197.9	0.30	2.28	187.4	207.4	210.1
August	148.0	147.3	0.22	2.99	150.5	154.2	157.7
September	117.4	110.1	0.28	0.00	112.7	122.4	114.5
October	66.2	61.7	0.00	0.00	74.4	68.9	64.2
November	42.3	45.8	0.14	0.71	40.0	44.0	47.9
December	28.7	26.2	0.06	0.00	40.3	29.8	27.3
Yearly Total	**1247.1**	**1194.2**			**1338.2**	**1322.9**	**1341.6**
Amount different					**10.7% vs NRC2012**	**6.1% vs NRC2012**	**12.3% vs NRC2012**

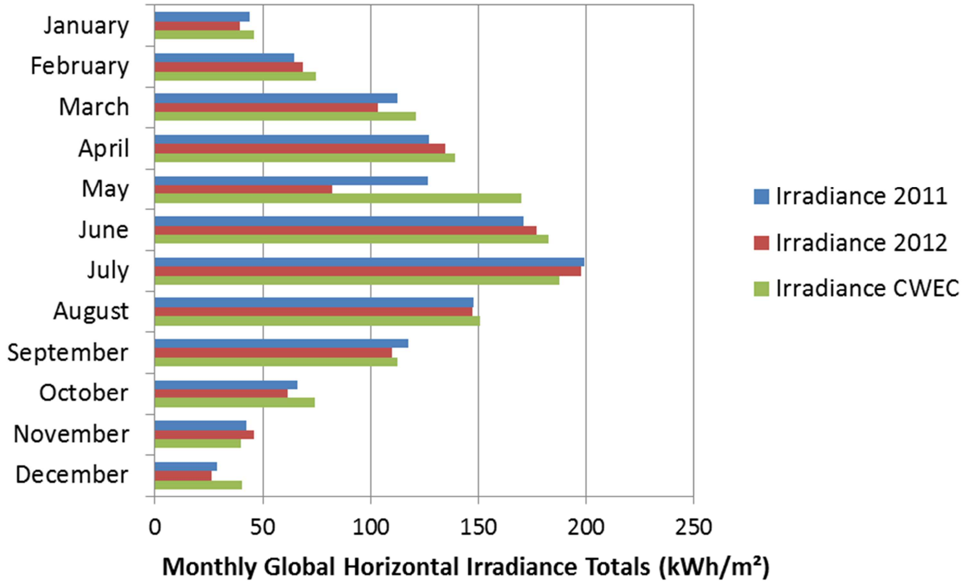


Figure 2: Plot of monthly irradiance values used in simulations.

One further GHI dataset was employed in our analysis. This is the dataset for a “typical” Ottawa year, as provided by Environment Canada’s datasets called Canadian Weather for Energy Calculations (CWEC). These have hourly predicted GHI values, composed of actual historic measurements from months deemed to be “typical” from 50+ years of historic data; it is often call a Typical Month Year (TMY), meaning that typical months as added up to make a year. **Note that the CWEC totals are substantially higher that the NRC totals (6.8% and 10.7% for 2011 and 2012 respectively)** presumably due to a combination:

1. possible low readings of the NRC pyranometer – assessed as 4%,

2. missing data in the NRC dataset, as assessed by month in Table 3, and
3. normal year-to-year variability of the solar resource – difference CWEC to 2011 or 2012 is presently unknown.

Since we can quantify the first two effects, we can **produce a scaled NRC dataset**; i.e. we can scale NRC data by +4% to account for the fact the pyranometer readings are thought to be low, and then further scale month-by-month by the amount of missing data (adding that percentage missing x CWEC monthly value). The last two columns of Table 3 contain the results of these calculations. In particular, for the year 2012 which we will analyse in later sections, **the yearly scaled total irradiance is 12.3% higher than the NRC2012 data we will use as an input in our PVSyst analysis.**

Incidentally, the SMA irradiance dataset discussed above had datagaps at different time periods than those of NRC's dataset, so it could have been possible, with sufficient effort and use of commercial simulation tools, to convert the SMA dataset into a global horizontal dataset and cross-compare and fill in gaps of the NRC GHI dataset. Conversion does involve some assumptions as to percentage of diffuse versus direct beam irradiance though. Use of other dataset without any datagaps would have been the preferred option, and thus none were acquired within the timeframe of this project. Collaborations with outside companies would be required.

1.4 Temperature and Wind Data

Hourly temperature data was provided by HOL for Ottawa (measurement location unspecified). We did not have access to wind speed measurements for the years under study (wind speed is a factor in simulations due to wind cooling effects), so the wind speed values available in the CWEC files were appended to the 2011 and 2012 NRC datasets. Naturally, this will introduce a minor source of error since it will be different that the actual wind conditions during 2011 and 2012, but it was better than assuming no wind.

Section 2 - Analysis of Smartmeter Data

In this section, we will analyse the performance of the six HOL installations using their actual energy production results as per their smartmeter data. Using Matlab scripts to manipulate the datasets, the energy yield was computed on daily, monthly and annual basis for each of the PV systems.

2.1 Smartmeter Annual Energy Yields

The smartmeter ***annual energy production*** for the six systems for the years 2011 and 2012 are shown in Figure 3. The values vary greatly due to system size, as expected. It should be noted that the 2011 smartmeter data was significantly lower than a typical year due to system availability (i.e the systems were not connected throughout all of 2011), as was discussed in earlier section.

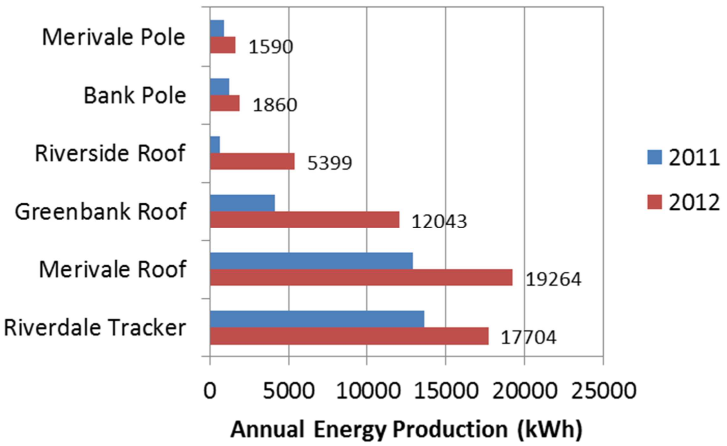


Figure 3: Annual Energy Yield of Each System (from Smartmeter data). Numerical values for 2012 are provided.

2.2 Smartmeter Specific Energy Yield

The next figure below shows the ***specific energy yield***, which divides the actual energy yield by the system's DC nameplate capacity (nameplate capacity is the size of the system in kWdc, as per the rated power for the panels as tested at standard test conditions). The units are kWh/kWdc/year and shown in Figure 2. It is one of the more useful "quick" metrics for comparing performance of different systems, although the value will depend slightly on the orientation of the system (panels facing south and with optimal tilt are able to harvest more solar irradiance than those at different orientations. Again, 2011 has low values due to being connected for less than a full year.

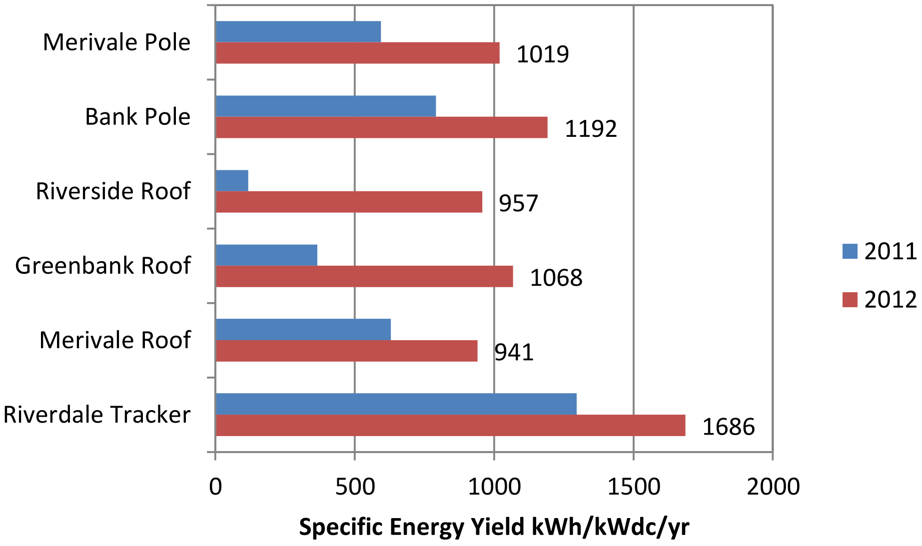


Figure 4: Annual specific energy yield of all 6 systems for calendar years 2011 and 2012, taken from smartemeter data

In Ottawa, the "rule-of-thumb" value for specific energy yield is 1200 kWh/kWdc/yr for a system with ~ 30-40° tilt and facing south, with perhaps slightly higher values now being observed for best system designs[7]. **The average of the five fixed-tilt systems is only 1035 kWh/kWdc/yr**. The one system comes close to achieving the “rule-of-thumb” value: **the BankPole system achieves 1192 kWh/kWdc/yr**. Table 4 tabulates the results and compares them with a quick simulation using PVWatt, which takes in account the specific system orientations, and assumes a typical solar year, using CWEC irradiance data. For all systems, total system losses in PVWatt, or system derate factors are set to 79.1%; this number was chosen such that the BankPole system’s predicted performance is identical to its actual, i.e. 1192 kWh/kWdc/yr. The table thus shows that the **GreenbankRoof and RiverdaleTracker systems both performed well within expectations, but the MerivalePole, MerivaleRoof and RiversideRoof all had low yearly specific energy yields, which is believed to be largely due to system availability**, although other site specific losses may also be contributing factors.

Note though, that 2012 may have been a “good” solar year, with total irradiance being 1-2% above the CWEC typical year. So this analysis doesn’t quite provide the complete conclusion as to how well the systems actually did do.

As a point of comparison, a collection of similar age of systems in Toronto with range of orientations were analysed by the SolarCity Partnership for year 2011 of operation[8] and showed a range of 1000 to 1250 and average value of 1109 kWh/kWdc/yr (keeping in mind that Toronto’s solar resource is slightly weaker than Ottawa’s).

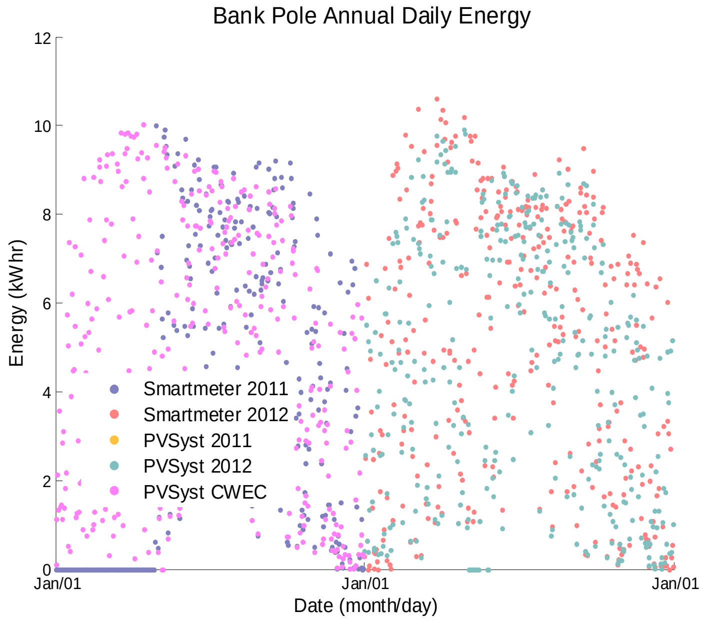
The Riverdale2Axis tracker system achieves a value 1686 kWh/kWdc/yr, which is 41% higher than the BankPole system because the tracking is able to harvest the maximum amount of solar energy possible. This 41% is a very good percentage increase: typically predictions for dual-axis trackers are in the 30-35% range.

Table 4: Summary of HOL Systems yearly smartmeter totals for energy production, and compared with a simple simulation of performance uisng PVWatt, which accounts for effects of orientation (system derate set such that BankPole outcome was 1192).

	Panel Orientation		2012 SmartMeter Measured kWh/kWdc	PVWatt CWEC Predicted kWh/kWdc	Difference meas – pred.
	Tilt	Azimuth			
MerivalePole	50	0	1019	1178	-13%
BankPole	**45**	**0**	**1192**	**1192***	**0%***
RiversideRoof	30	-6	957	1187	-19%
GreenbankRoof	**10**	**-28**	**1068**	**1066**	**0%**
MerivaleRoof	5	-60	941	1009	-7%
RiverdaleTracker	**Dual-axis tracked**		**1686**	**1623**	**4%**
Portfolio Avg (fixed tilt)			1035	1126	-8%

2.3 Seasonal Trends

On the topic of system orientation, there is a well understood **relationship between system tilt and seasonal performance**. This can be nicely observed with a plot of the daily energy output of all the data, as shown in figure 3. A system with steep tilt (such as BankPole with tilt of 45°) will be best aligned with the sun’s position in the sky at the solar equinoxes (spring and fall), leading to peak performance at these times, and an overall double hump curve over the course of a year. Minor dependencies on temperature and seasonal weather affect the exact date of the two peaks. In contrast, a system with low tilt (such as MerivaleRoof with tilt of 5°) is most optimally aligned for the summer sun when the sun is high in the sky and has a wide sweep, but performs poorly in the winter when the sun is low. Snow build up on panels with low tilts may further reduce their winter performance. These different profiles imply that there are some tilts that may be better suited certain local grid seasonal demand patterns.



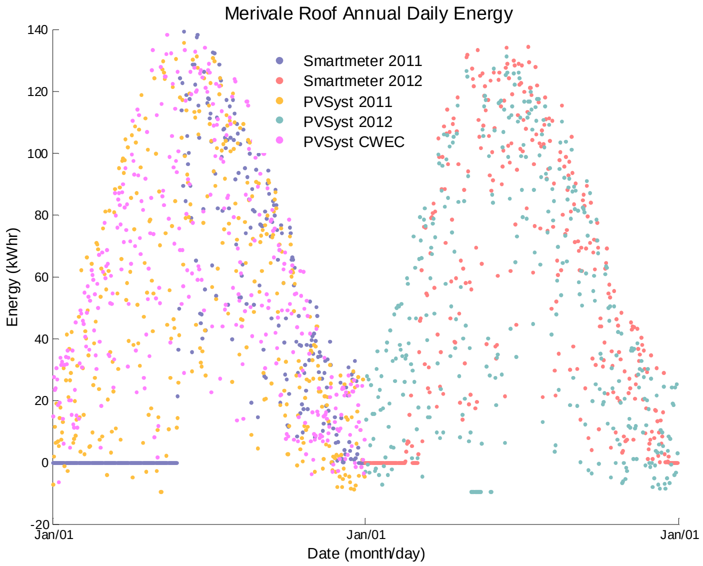


Figure 5: Daily energy production from smartmeter data, plotted versus time over the full 2 year period for (a) the BankPole, and (b) the MerivaleRoof system. The very different seasonal patterns of the two systems relate to the large difference in their tilt angles: 45° and 5°, respectively.

Section 3 - PVSyst Simulations

3.1 Introduction to PV System Simulations

All six HOL systems were simulated in high detail using a well-recognized commercial software package PVSyst version 6.08. It is a substantive software package allowing users to simulate just about every detail of a solar system's design and performance.

As discussed previously, the purpose of this aspect of the research was multifold:

1. To further evaluate the HOL systems' performance using the actual irradiance measurements for the specific years of study (as opposed to a typical year in the above work).
2. To evaluate loss factors and other performance metrics
3. To develop the methodology for system performance analysis in-house at SUNLAB and to evaluate how accurately a system could be modeled.

The relatively large number of data gaps in both the irradiance datasets and the smartmeter datasets somewhat impacted our abilities to achieve all of these objectives, although use of scaling and screening is employed to still achieve some worthwhile conclusions.

3.2 PVSyst Inputs and Resultant Losses

The main input parameters to this software package are:

1. the meteorological data (consisting of irradiance, temperature and wind)
    - o three different dataset were considered: NRC 2011, NRC 2012 and CWEC. The first two had to be created into .MET files, while the last already a default dataset available within PVSyst
2. the exact panel and inverter product number, from extensive PVSyst database which contains most available solar modules and inverters, including their data specifications
    - (d) In several cases we had to create new panel and inverter descriptions, as well as modify specifications of existing descriptions
3. panel orientation and string configuration
4. shading profile (description of the entire horizon, thus describing any objects that may shadow the modules)
    - (e) shading measurements were taken using a Solar Pathfinder unit (loaned to us by Ottawa Solar Power) and used to create "horizon" profiles
5. soiling and snow losses
    - (f) soiling losses were set at a fixed monthly value of -3%, as recommended from various references[9], with no seasonal variations and no losses due to snow (it is possible to provide monthly values as inputs)
6. electrical losses
    - (g) wiring losses fixed at -1%
    - (h) transformer losses included for the two Merivale systems.

To get complete system information, a visit to each of the test sites was organized, confirming exact model number of equipment, system sizes as well as analysis of the shading at each site. For all panel descriptions, datasheets were used and interpreted to give the best description of the panel specifications. In particular, the power tolerance values for some panels were edited and light-induced degradation of -2% at start of life was assumed to have occurred for all panels.

For each and every hour of the irradiance data, PVSyst simulates the currents and voltages from the strings of panels, the performance of the inverters given those inputs, and then calculates the hourly energy output. The main outputs of PVSyst include:

1. predicted effective net losses of energy production due to various factors
2. predicted energy production on hourly and monthly granularity
3. predicted performance ratios

With respect to *1 – Effective net losses of energy production*, these losses are broken down by PVSyst into a few main categories, and are tabulated for each of the six simulated HOL systems in the Table 5. There are three parameters that are quite dependent on the user inputs (highlighted in blue font), and these are thus a main potential source of error in our simulations.

Table 5: Summary of loss factors for the PVSyst simulations.

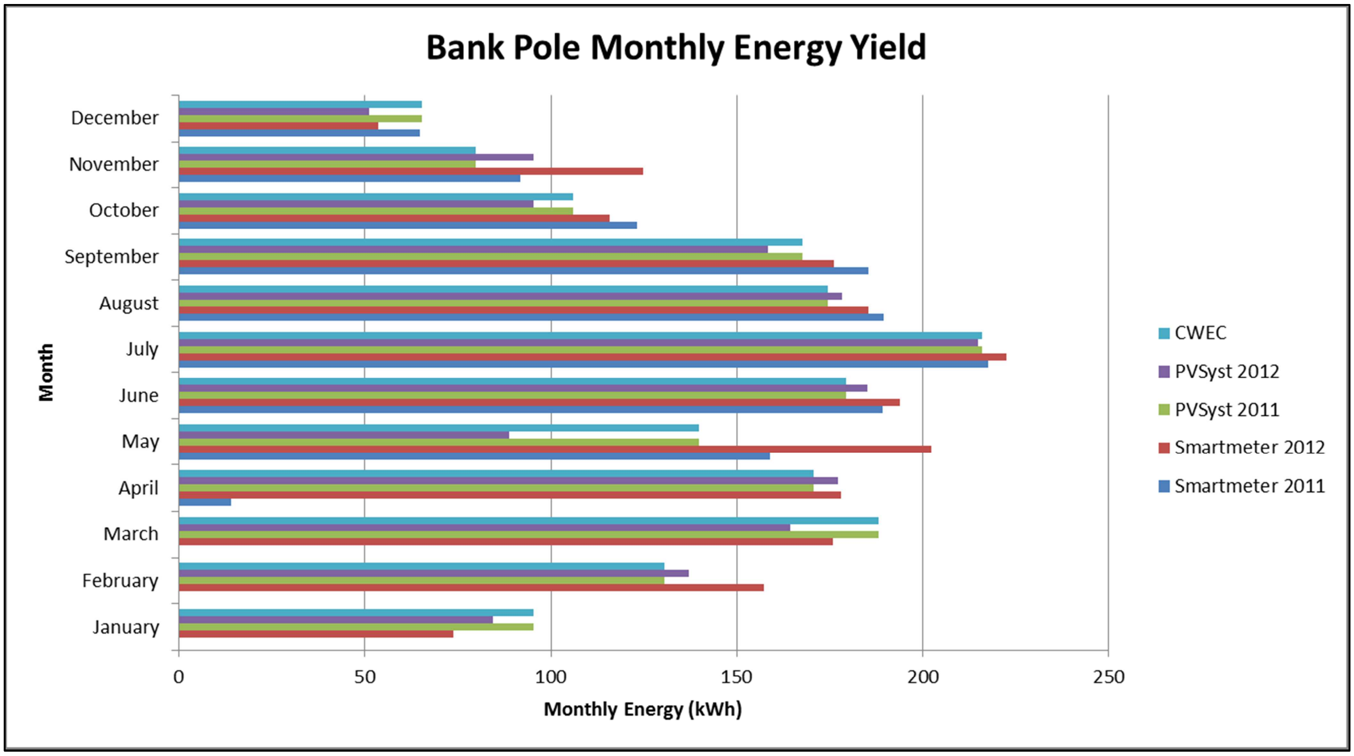
		Merivale Pole	Bank Pole	Riverside Roof	Green-bank Roof	Merivale Roof	Riverdale 2Axis	Type	Description
Irradiatne Factors	Global irradiance in the plane of the panels (relative to GHI, on net yearly basis)	+13.7	+15.3	+16.1	+7.0	+3.9	+46.3	Calc	Actual total irradiation in the plane of array (i.e. for the panels orientation). Because panels are inclined towards the sun, this is higher than the horizontal value.
	Shading loss	-4.4	-8.3	-4.3	-3.7	-1.7	-7.7	User input	based on horizon profile
	Incidence Angle Modifier factor on Global	-2.7	-2.1	-2.4	-2.7	-3.4	-1.5	Calc	When there is a high angle between the sun and the panels, there are higher reflection losses at the surface of the panels
	Soiling loss	-3.0	-3.0	-3.0	-3.0	-3.0	-3.0	User input	input fixed value
Module & Array Factors	PV Conversion (% efficiency at Standard Test Conditions)	16.82	16.82	14.19	14.19	16.82	13.65	from panel specs	From panel specifications
	PV loss due to irradiance level	-2.2	-2.3	-2.4	-2.8	-2.6	-1.2	Calc	Panel efficiency decreases at low irradiances
	PV loss due to temperature	-3.0	-5.5	-5.5	-5.0	-2.9	-7.3	Calc	ΔP/ΔT from panel specifications plus temperature (T) from input weather files are used to calculate.
	Module quality loss	+0.5	+0.5	-1.5	-1.5	+0.5	-0.6	from panel specs	If manufacturer has a positive power tolerance (e.g. 0 to +1%), then on average power is +0.5%.
	Light induced degradation (LID)	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	from panel specs	Silicon cells undergo light-induced oxidation process in first few days in the sun.
	Module array mismatch loss	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0	from panel specs	Array power will be constrained to weakest panels of a string.

	Ohmic wiring loss	-0.9	-0.9	-0.9	-0.8	-0.8	-1.1	Calc	From a user input.
Inverter Factors	Inverter loss during operation	-4.1	-4.2	-5.5	-5.5	-4.9	-5.4	from inverter specs	Accounts for matching of panels' actual hourly DC power to inverter's variable efficiency depending on input power. Inverters will typically have a maximum efficiency of 96%+, and an slightly lower effective operating efficiency.
	Inverter loss over nominal inverter power	0.0	0.0	0.0	0.0	0.0	0.0	Calc	If the array I,V inputs are below inverter minimum thresholds
	Inverter loss due to power threshold	-0.9	-0.1	0.0	0.0	0.0	0.0	Calc	
	Inverter loss over nominal inverter voltage	0.0	0.0	0.0	0.0	0.0	0.0	Calc	
	Inverter loss due to voltage threshold	0.0	0.0	0.0	0.0	0.0	0.0	Calc	
	External transformer loss	-15.6	0.0	0.0	0.0	-16.6	0.0	Calc	Based on user inputs, there is need for review of this parameter.

3.3 Simulated Monthly Energy Production

Figure 6 contains bar graphs of the output energy yields (summed into monthly totals) for three different irradiance data inputs (NRC 2011, NRC 2012 and CWEC) and compared with the actual measured smartmeter values from Section 2.1. Graphs for two of the strong performing systems: - BankPole 1.56kWdc and GreenbankRoof 11.26kWdc - are shown. One can see that in general there is decent agreement between smartmeter and our simulated energy yield outputs although there some are obvious areas of disagreements. Recall that since the irradiance inputs had missing data for May 2011 and 2012, those predictions are expected to be erroneous, while months without Smartmeter data at the start of 2011 for the GreenbankRoof are not included.

A summary of the differences between yearly totals for all 6 systems for the year 2012 is contained in Table 6. Looking at the second column, the **smartmeter measurements are on average 11% higher than our simulations using NRC2012.** This overall portfolio discrepancy of +11% for can perhaps be reasonably well explained giving the known low input values of the NRC2012 irradiance dataset. Recall that a net scaling factor of +12% was deduced in section 1.3. Thus we can then scale our yearly PVSyst predictions by +12%, resulting in results that are closer to actual smartmeter values, as summarized in the third column of Table 6. Recall that **BankPole and GreenbankRoof systems** had good availability and good performance relative to simple PVWatt predictions in section 2.1, and we see here that again we **get good agreement (to within ±2%) with this more intensive PVSyst simulation**.



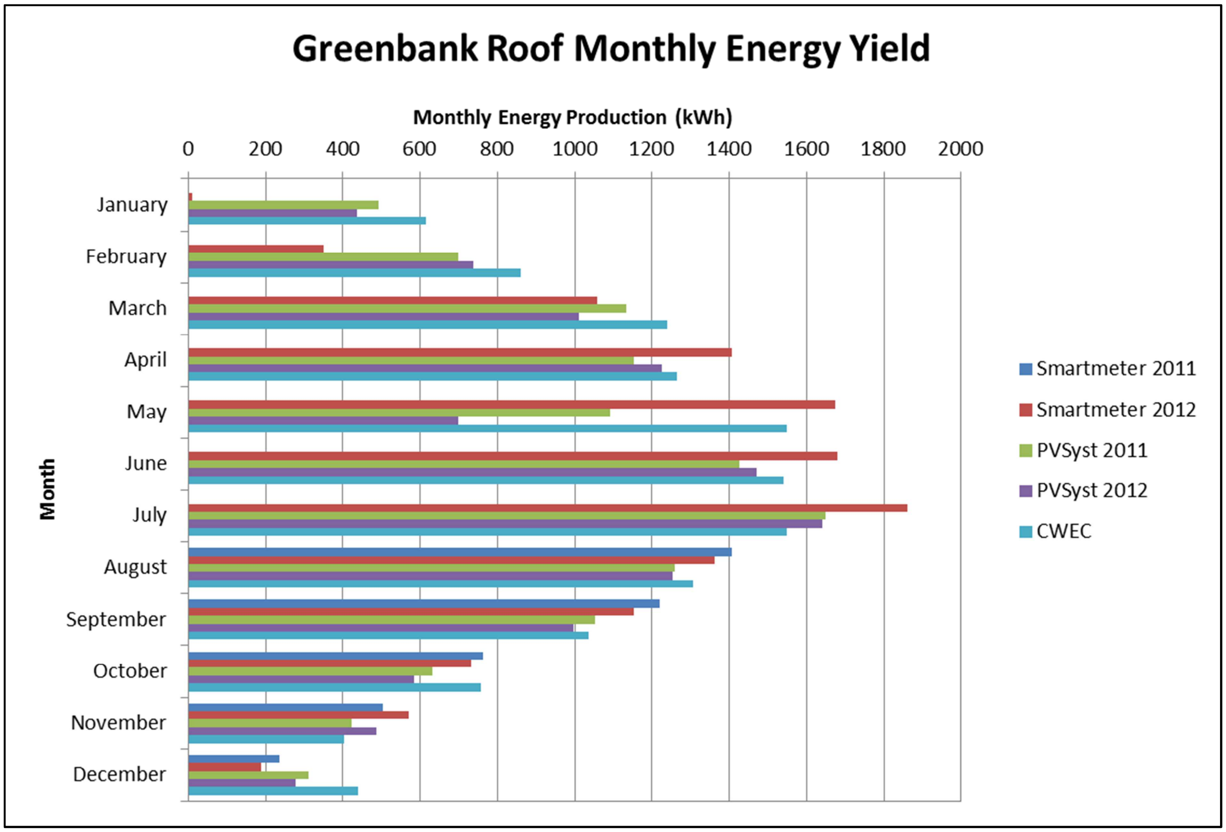


Figure 6: Monthly energy production for (a) BankPole and (b) GreenbankRoof systems, including both actual measurements from smartmeter data and simulated outputs using PVSyst software with irradiance inputs from 2011, 2012 and CWEC typical year data.

Table 6: Summary of the difference between datasets for the calendar year 2012.

	Smartmeter2012-PVSyst2012	Smartmeter2012-PVSys2012(scaled)	Comments about the result
MerivalePole	10%	-1%	Expected be more negative due to smartmeter availability issues.
BankPole	**12%**	**2%**	**Good agreement**
RiversideRoof	**-8%**	**-21%**	**In agreement with Section 2.2**
GreenbankRoof	**10%**	**-1%**	**Good agreement**
MerivaleRoof	10%	-1%	Expected to be more negative due to smartmeter availability issues.
Riverdale2Axis	19%	9%	Tracker outperforms simulations
Portfolio average	11%	0%	

However, for the remaining systems there are surprising results. First, the Riverdale2Axis smartmeter data outperformed the PVSyst2012 simulation by 9%. Perhaps the shading input into PVSyst was too high (7.7% as per Table 5), which is possible because the horizon profile was taken from the bottom edge of the tracker

Furthermore, there is good agreement for the MerivalePole and MerivaleRoof systems but the poor availability of their smartmeter data would presuppose we should be over predicting energy production with PVSyst2012, not matching it as we have. This makes our assumptions for high transformer losses look suspect. In fact, the values of 15.6 and 16.6% in Table 5 are surely too high.

And finally, the huge difference in the RiversideRoof system (-21%) is in close agreement with our earlier approximate PVWatt – TMY prediction of performance in Section 2.2 (smartmeter was -19% of PVWatt prediction). This must clearly relate to the low availability during the months of May and June 2012 tabulated in Table 2. This nominally suggests we have accurately simulated this system to within 2%, although further verification would of course be desirable.

3.4 Sources of discrepancies in simulations

One aim of this study was to see if we could tease out seasonal patterns in performance. Thus, the same metric as above, namely SM2012-PVSyst2012(scaled), but now in monthly granularity is analysed in Figure 7. Data has been screened such that months with insufficient data in either system availability or irradiance are omitted, which should eliminate data relating to the issues of above.

The following observations can be made:

- There is a dip in the months of January and February 2012, likely indicating that snow coverage on the panels has decreased the actual output. Note that there is no dip in December, either because snowfall was not significant and/or because irradiance was so low during periods of snow coverage that it didn't actually result in a measurable loss of production.
- The reason for the peak in June 2012 is unclear, but seems to suggest there were further issues with the irradiance datasets that month.
- The fact that smartmeter exceeds prediction in the months of November and December is curious. We speculate it is indication that too large of a shading horizon profile used in the simulation (a relatively course, conservative profile was interpreted from the SolarPathfinder images.

It was hoped that this data would allow for the study of snow losses in more detail, and perhaps lead to analysis of snow losses versus system tilt, but at this point the data is too sparse (only 6 valid data points for the months of Jan and February) to allow for any solid conclusions. The research effort does seem to indicate that the method looks useful should more comprehensive datasets be obtained. Though there is obviously a fair amount of effort to undertaking this type of detailed PVSyst simulation of actual systems, the methodology does have the advantage of not requiring a specifically built test site. Furthermore, it is possible to study either a large number of years and large number of systems in one location to get rigorous data trends for snow in that location, or to cover a range of locations which may have differing snow types and snow losses.

Note that although the differences shown here are huge on a % scale, they amount to only a few % of annual energy total on an absolute scale.

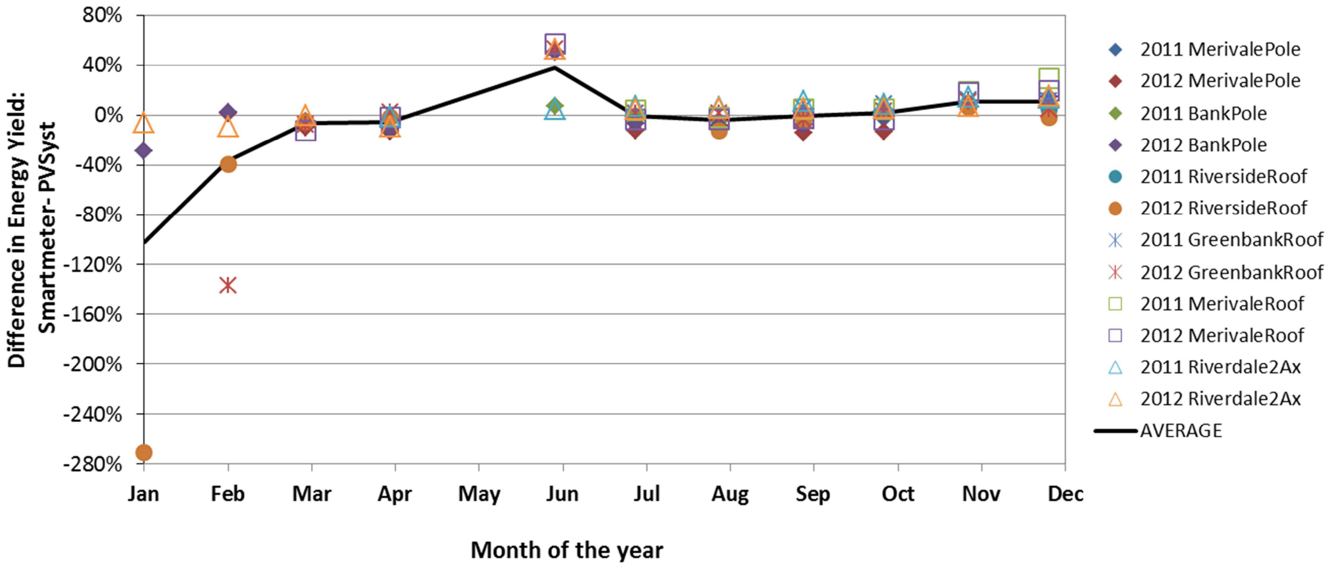


Figure 7 - Comparison between actual energy yield (smartmeter data) and energy yield predictions using PVSyst software with NRC irradiance data inputs. Data for all 6 HOL systems are included, screened for months with good data availability in both smartmeter and irradiance datasets.

3.5 PVSyst: Performance Ratios

Progressing further into the performance analysis of these systems, the performance ratio (PR) is a very useful tool in describing how well a system has performed, as it normalizes for the actual irradiance for the system orientation. In PVSyst, it is calculated as the predicted energy delivered to the grid divided by the nameplate rating AND the irradiance in the plane-of-the-array. Thus it can be used for a direct comparison of different systems with different orientations; differences in PR are simply related to the equipment's efficiency in converting irradiance into electricity, and can indicate various sources of losses in the system.

Note that since irradiance values are now "normalized-out" so to speak, the data gaps and scaling issues in our irradiance datasets have no impact. Instead, the results are very dependent on our inputs into the simulation, as per Table 5, so the PR values are accurate only if our simulations inputs were accurate (as discussed in Sections 3.2 and 3.3).

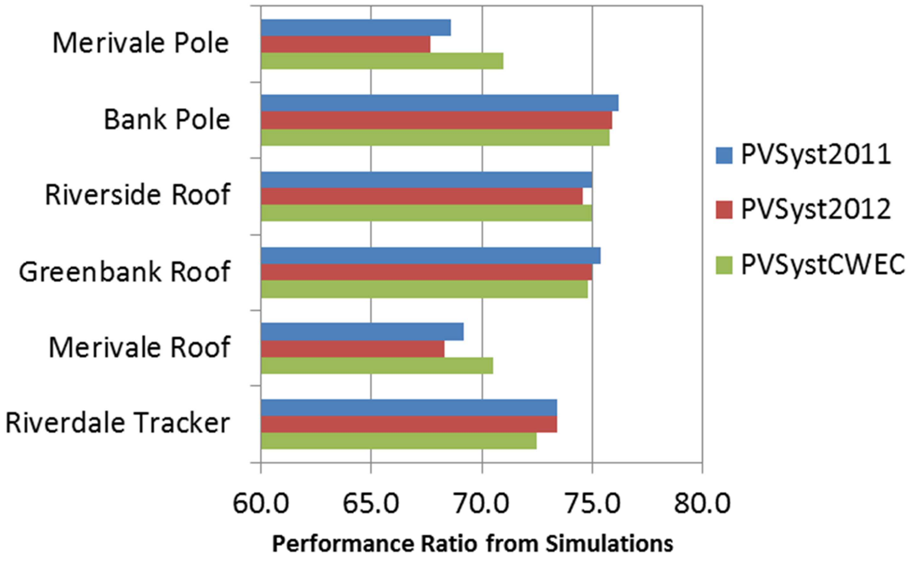


Figure 8: Annual performance ratios from PVSyst simulations for all 6 HOL systems.

As captured in Figure 8, the PR of the whole portfolio ranges between 67.7% and 76.2%, and with an average value of 72.9. **Because the total energy predictions for BankPole, RiversideRoof and GreenbankRoof were in good agreement with smartmeter data, the PR values for these three systems are legitimate at 76%, 74% and 75%, respectively.** The variation between the 2011, 2012 and CWEC bars for a given system essentially capture the level of uncertainty, which on average is +/- 3%. Rule-of-thumb values for the industry are currently in the 75% to 80% range,[3] and have been recently increasing above 80% along with the improvements in module rating accuracy, reduction of panel mismatch, inverter efficiencies, and minimized ohmic losses, to name the most common targets for losses. **Thus these three systems appear to have reasonable performance efficiencies.**

3.6 PVSyst: Performance Analysis using Hourly granularity

The consideration of hourly datasets can be undertaken to look for degradation of performance due to particular events, including shadows, snow and temporally varying conditions. The best would be a comparison of actual vs predicted, such as was undertaken with monthly data in section 3.4. However, because in this study the irradiance meter was not co-located with the panels, variations in localized cloud cover would dominate any other effects, and nothing of interest with respect to the systems could be concluded.

Yet, as a matter of curiousity, a small effort was included by looking at only the simulation results using hourly PR values as deduced from PVSyst. Variations in hourly performance are mostly related to soiling, shading, and high temperature losses. Only the two well modeled systems will be included here, although the analysis for the remaining four systems appeared similar.

Figure 9 plots the hour PR values versus time of year. The major trend to be observed is that droop during the summer months, known to be related to poorer performance at higher temperatures. The difference between summer and winter PR is more than 0.10. Furthermore there are a few points clearly falling significantly below a PR 0f 0.70: looking carefully, most of these create diagonal lines that are nominally symmetric about the summer solstice, and we conclude they are mostly due to small shadows (from poles and trees) moving across the arrays. Figure 10 indicates that these low PR values are only occurring at relatively low irradiance levels, which we further assume would be at the start and ends of the day, which correlates with when shadows are most prevalent. Although one might look for low performance in winter months due to snow, recall that this data is ONLY simulated data, so doesn't incorporate the possibility of snow or temporary soiling.

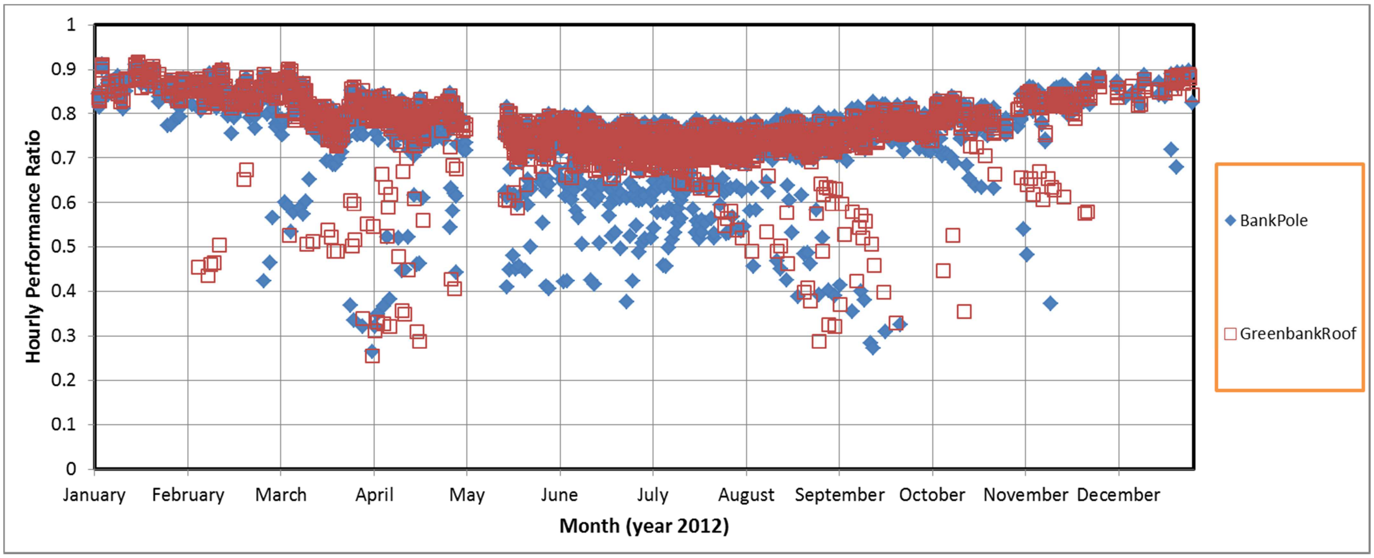


Figure 9: Hourly performance ratios from PVSyst simulations for the BankPole and GreenbankRoof systems, plotted versus month for the calendar year 2012. (screened for GHI>200 kW/m2).

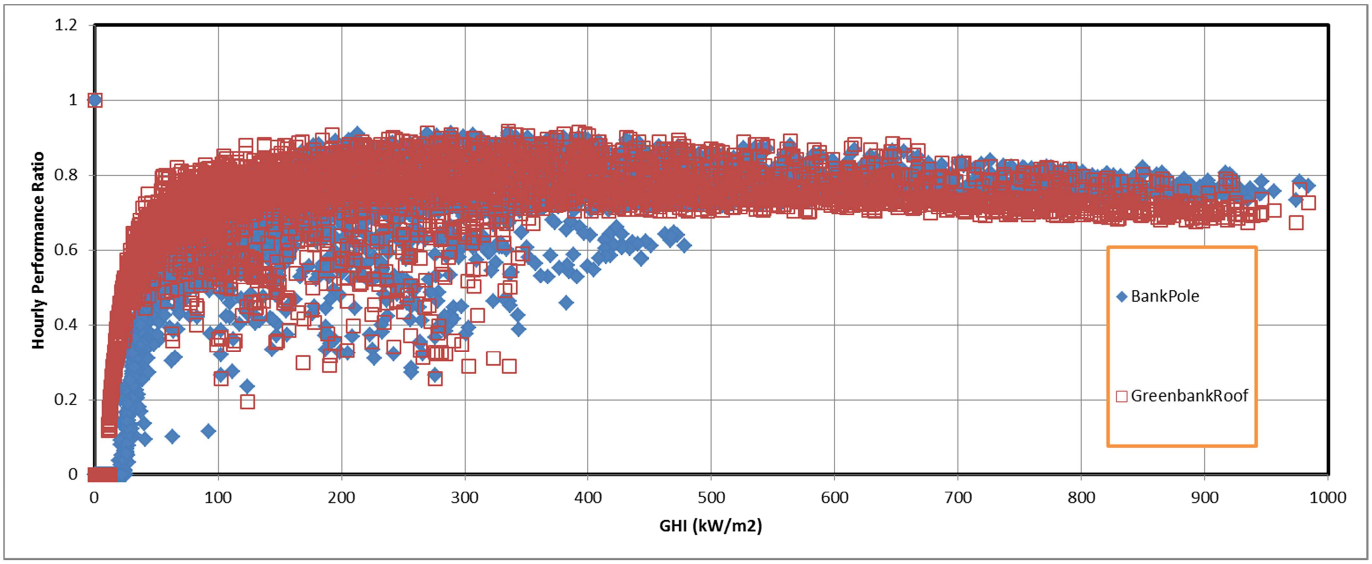


Figure 10: Hourly performance ratios from PVsyst simulations for the BankPole and GreenbankRoof systems, plotted versus GHI for the calendar year 2012.

Section 4 - Conclusions

There were some clear challenges in managing conventions and quality of the datasets used in this study. At the start, it took time to confirm the timestamps formats and the best way to proceed; the end results was that all datasets were converted into hourly datasets with hour beginning, GMT-5 timestamps. Efficient methods were developed to manipulate and screen the data for validity. The major issue with the dataset however, was the existence of appreciable gaps in the datasets. The gaps primarily related to maintenance events on the PV systems and irradiance meters.

The smartmeter ***annual energy production*** for the six systems for the years 2011 and 2012 were calculated; the values vary greatly due to system size, as expected. The ***annual specific energy yields*** is a more useful metric for comparison of different systems. For the calendar year 2012, the BankPole system achieved the best specific energy yield of 1192 kWh/kWdc/yr (in-line with expected performance for optimally oriented systems in Ottawa), while GreenbankRoof and Riverdale2Axis systems also performed well against the expected outputs for their orientations: 1066 and 1623 kWh/kWdc/yr. The Riverdale2Axis was able to achieve a 41% increased energy harvest due to dual axis tracking. The MerivalePole, MerivaleRoof and RiversideRoof all had low yearly specific energy yields, believed to be largely due to system availability issues. The portfolio average for the five fixed-tilt systems was 1035 kWh/kWdc/yr for 2012.

A concerted effort was undertaken to develop an accurate and detailed description of the PV systems for input into the simulation software PVSyst. Actual ground measured irradiance data, as provided by the NRC was also used as an input. The predicted performances from the simulations were compared with the actual smartmeter energy.

First, annual energy yields were studied. Once scaling of the results was undertaken (justified by known issues with the irradiance dataset) agreement within ~±2% was obtained between predicted and actual energy production for two of the systems with good availability (BankPole, GreenbankRoof), and we likely also achieved the same accuracy for a third system (RiversideRoof), although poor availability meant a need to compare with estimated. For these systems, the performance ratios, which are a measure of a *system's* total efficiency, were found to be 74-76% from simulations. This is in-line with expectations for systems built in the time period of 2005-2011,[10,11] although lower than best-in-class installations for 2012 and later. For the three other systems, particular system inputs were identified as probably being set too high (shading and transformer losses) and thus the likely main sources of discrepancies. With additional effort, a second iteration on the simulations would likely produce better agreement for all six systems. Furthermore, if more complete or more extensive datasets were studied (for example, adding data for 2013) one could likely further calibrate and verify the simulation inputs to produce a simulation tool with an even more accurate prediction capability.

The analysis of monthly results (actual versus predicted) indicated snow losses were significant for some systems in the months of January and February, but data was too sparse to deduce any generalized trends. Quantification of snow loss in the Canadian climate is an area of PV performance research recently identified as needing more study. It appeared that the methodology developed here could provide useful insights if a larger, more complete dataset were obtained. Although this method requires a substantial analysis effort, it does not require the building of specific test sites, and can be applied to a range of locations and system types. The HOL smartmeter database for solar connected systems has a wealth of information that could be employed.

Section 5 - Final Recommendations and Next Steps

A joint meeting is requested to discuss how best to disseminate various aspects of this report to the public and other audiences. The proposed avenues include publication of a white paper, media releases, and presentations to conferences or various industry associations.

The methodology of using PVSyst proved intensive but very powerful. Its ability to take detailed user inputs and predict with hourly granularity make it a useful tool for PV system performance analysis. The HOL smartmeter data was instrumental to this analysis, and their use in future studies is highly recommended. There have been several lessons learned on proper performance assessment protocol, which can be used as a foundation for future studies.

Additional analysis using a larger dataset could be undertaken, using either HOL systems and/or PV systems owned by others. A larger study would provide more substantiated correlations between system parameters (including tilt, soiling and snow) and performance outcomes. This would be publishable in the scientific community. It should be mutually discussed whether further collaborative research efforts are applied to this topic, or if efforts should move into other areas of research on renewable energy integration on the grid. The tools and expertise developed in this research project could be applied to topics such as optimization of solar orientation for matching to dialy and seasonal load profiles, and/or quantifying intermittency of PV output in relation to integration with energy storage and mitigation of stresses on electrical grid equipment, to name just a few possible topics.

Lastly, it is recommended that for further studies, new irradiance dataset be obtained, preferably from a pyranometer that is cleaned and calibrated regularly to provide high quality irradiance dataset. Ideally, it would be co-located with the PV systems.

Appendix A – HOL system summary

		MerivalePole	**BankPole**	**RiversideRoof**	**GreenbankRoof**	**MerivaleRoof**	**Riverdale2Axis**
Connection	**Gen ID**	GE0018	GE0100	GE0204	GE0142	GE0019	GE0087
	Contracted KW (AC)	1.56	1.56	10	10	20.48	10
	Meter No.	OTT904948	OTT904950	OTT910177	OTT910190	OTT516478	OTT904583
	Address	1970 MERIVALE	4565 BANK	1695 RIVERSIDE (Queens)	910 GREENBANK (Barrhaven)	1970 MERIVALE	39 RIVERDALE
	Energization Date	11/03/2010	11/03/2010	11/10/2011	27/07/2011	21/04/2011	28/03/2011
	Connection Voltages	347/600	120/208	120/240	120/240	347/600	120/240
	Connection Phases	3PH	3PH	1PH	1PH	3PH	1PH
System	**Installer**	Ottawa Solar Power	Ottawa Solar Power	Ottawa Solar Power	Ottawa Solar Power	Ottawa Solar Power	Sentinel Solar
	Mount	POLE-FIXED	POLE-FIXED	ROOF-FIXED, flat roof	ROOF-FIXED, sloped roof	ROOF-FIXED	POLE-DUAL AXIS
	Tilt (deg)	50	45	30	10	5	TRACKED
	Azimuth (deg)	0	0	-6	-28	-60	TRACKED
	Lattitude	45.32	45.33	45.40	45.28	45.32	45.40
	Longitude	-75.72	-75.60	-75.67	-75.75	-75.72	-75.68
	Site ground Altitude (m)	93	105	65	95	93	65
Panels	**Panel brand, model**	Sanyo HIP-195BA3	Sanyo HIP-195BA19	Conergy ON235P-60	Conergy 235P-60	Sanyo HIP-195BA3	Solgate SG225P
	# panels	8	8	48	48	105	50
	Panel Rating (W)	195	195	235	235	195	210
	DC rating (kW)	1.560	1.560	11.280	11.280	20.475	10.500
Inverter	**Inverter Model**	SMA SB3000US	SMA SB3000US	Enphase D190	Enphase M190	3xSMA SB7000	Enphase D380
	Inverter Line Voltage	240		240		208	
	Inverter Data	SunnyPortal	SunnyPortal	EnlightenPortal	EnlightenPortal	SunnyPortal	EnlightenPortal
	String Config	2 strings of 4 panels	2 strings of 4 panels			5 strings x 7 panels per inverter	
Transformer	**kVA rating**	6kVA				30kVA	
	voltages	120/240-600V				208Y/120 - 600Delta	

Appendix B – Horizon Profiles used in PVSyst Simulations

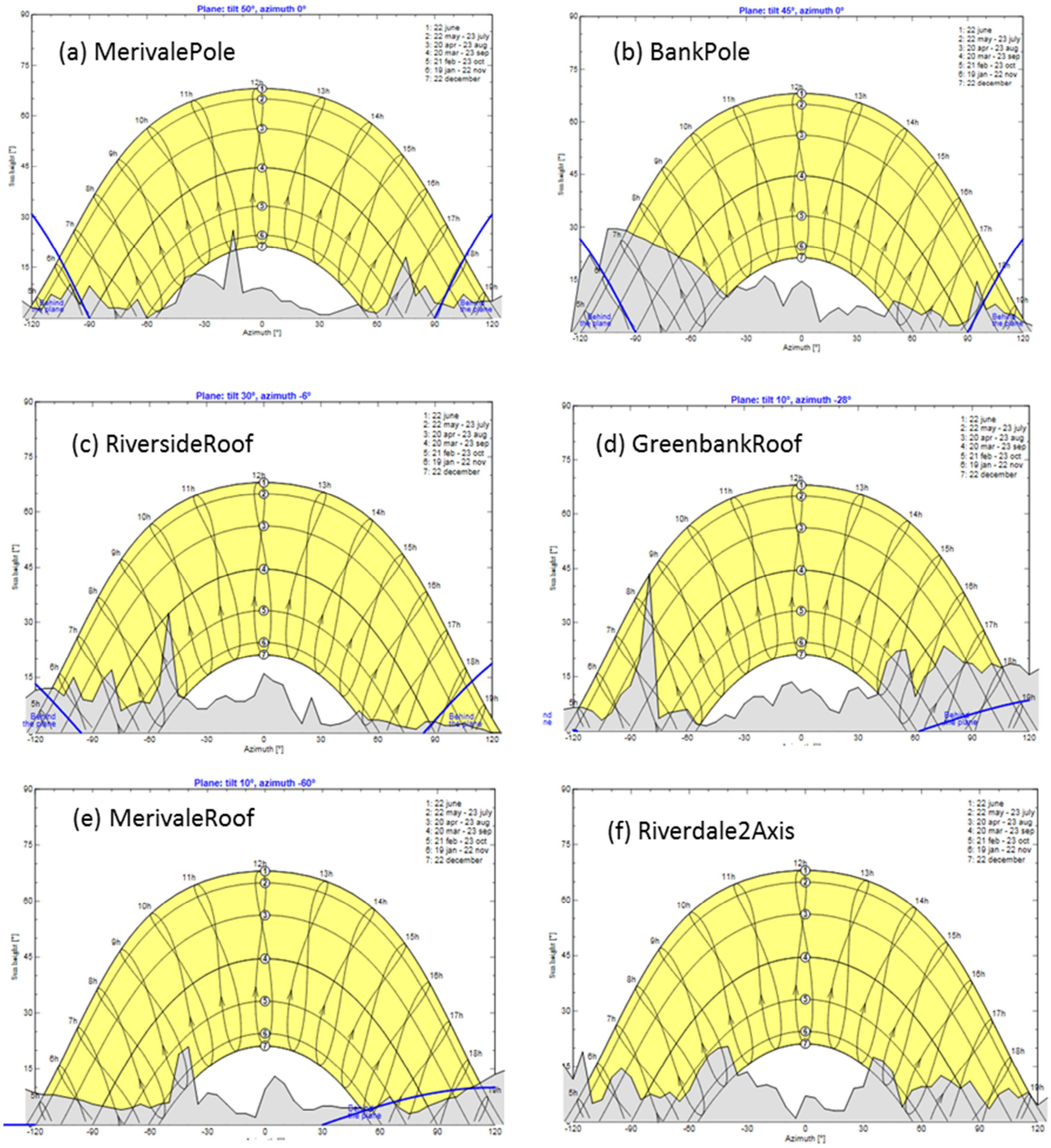


Figure 11: Horizon Profiles taken from SolarPathfinder shading analysis tool, used as inputs to PVSyst.

References

[1] Didier Thevenard, Sophie Pelland, “Estimating the uncertainty in long-term photovoltaic yield predictions”, Solar Energy, May 31, 2011.

[2] Ulrike Jahn, “PV module and System Performance” IEA Task 13 report presented in Hangzhou, November 6, 2012.

[3] PVWatts, “A Performance Calculator for Grid-Connected PV Systems”, produced by the US National Renewable Energy Laboratory, version 1 for international sites. <http://rredc.nrel.gov/solar/calculators/pvwatts/version1/.

[4] Hans Georg Beyer, Georgi Hristov Yordanov, Ole-Morten Midtgård, Tor O. Saetre, Anne Gerd Imenes, Contributions to the knowledge base on PV Performance: Evaluation of the Operation of PV Systems using different technologies installed in Southern Norway”, report for the IEA Task Force number 13, June 2011.

[5] N. M. Pearsall, K. M. Hynes, C. Martin, and M. Munzinger , “Analysis of Performance Parameters for UK Domestic PV Systems”, Conference Record of the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion, Vols 1 and 2 Pages: 2300-2303, 2006.

[6] Yves Poissant, “Status and Trends of PV Technology in Canada 2013”, Next Generation Solar Conference 2013, Hamilton, Ontario, May 8, 2013.

[7] Based on J. Haysom’s exposure in developing solar PV systems for the Ottawa Renewable Energy Cooperative, and also through discussions with other solar researchers such as Sophie Pelland of the Distributed Energy Program at Canmet Energy, Natural Resources Canada.

[8] SolarCity Partnership (Toronto Atmospheric Fund, Toronto and Region Conservation Authority, and City of Toronto), “Performance Review of Rooftop Solar Photovoltaic Projects in the Greater Toronto Area: Technology, Monitoring and Best Practices”, white paper, January 2012.

[9] John T A Miller, Jaya Jackson, Impact of Soiling and Pollution on PV Generation Performance”, CH2MHILL and Sandia National Laboratories Technical Memorandum, Oct 8, 2009.

[10] Didier Thevenard, Sophie Pelland, “Estimating the uncertainty in long-term photovoltaic yield predictions”, Solar Energy, May 31, 2011.

[11] Ulrike Jahn, “PV module and System Performance” IEA Task 13 report presented in Hangzhou, November 6, 2012.