Review of Photovoltaic System Performance and Financials for Hydro Ottawa

Report 2: Matching of PV to Grid Pricing and Grid Peaks

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Executive Summary

This report is in relation to 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***, provided on November 25, 2013, 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*** contained herein, analysing the revenue streams and optimization of panel orientation to maximize revenues for a potential photovoltaic installation under a number of different scenarios, including fixed feed-in-tariffs, variable market pricing, and peak demand costs.

Executive Summary of Report 2

A model that was a hybrid of theory and real data was developed to serve as a predictive tool for the hourly power and energy generation capability of solar panels. A clear sky model was employed to provide calculated geometric relations between the sun and the panels, with actual production data from 5 HOL installations used to add a power effectiveness or *cloudiness* factor to the model. This approach allowed for simulation of hourly power generation for a wide range of different panel orientations. This was very useful for determining the optimized orientation of panels when non-constant hourly revenues are available.

In particular, the model was employed to study two potential revenue streams that might be available in 2014 in Ontario:

- a constant Ontario FIT3 price
- electricity bill charge reductions that could be available to Ontario Class A electricity customers who build a load-displacement solar project.

For the first, the FIT3 price for roof-mount solar systems <= 500kW is $0.329/kWh, which results in a profitable project, considering we calculate the levelized cost of solar in Ontario to be around $0.19/kWh. For the latter, the dominant costs savings (or revenue as we have called it here) is from a reduction in the global adjustment charges, which relate to electricity use during 5 key hours in the summer when the Ontario grid is at peak. By summing consumption charges, monthly demand charges and global adjustment charges, we find that the load-displacement project is also a financially positive project. Specifically, the FIT3 project had an IRR estimated at 11.9% while the load-displacement project had a 8.7% IRR.

The hybrid PV model was employed to determine the optimal orientation for both types of projects. Naturally, optimal orientation for the FIT3 project is equivalent to maximizing energy production, which was due South and with a tilt of 35°, while the optimal orientation for the load-displacement project was an azimuth 55° West of South and a tilt of 40°. The significant difference in azimuth is because of the effectiveness of solar at producing energy during the peak demand times of summer afternoons, and the global adjustment charges dependence on demand during those periods. Surface plots of revenue vs azimuth and tilt are provided for both types of projects, and both indicate a relatively gradual roll-off from optimal, giving some flexibility for project siting.

It is recommended that large electricity users consider both types of revenue streams for potential solar installations on their properties.

It is also recommended that connection requirements (including allocation of grid capacity and approval procedures) of a load-displacement project be made clear and publically available, such that this model can be fully utilized. Furthermore, regulatory agencies and policy makers should consider incentivizing solar installations oriented West of South so as to offset peak Ontario demand on summer afternoons, for instance by designing a time-of-day dependent FIT for solar.

Table of Contents

Executive Summary of Report 2 2
List of Figures 5
List of Tables 5
Introduction 6
Section 1 – Levelized Cost of Energy 7
Section 2 – The PV model 9
Section 3 – Revenue Streams and Optimization of Panel Orientation 11
    3.1 Fixed price FIT3 revenues 12
    3.2 Class A Load Displacement Revenues 13
    3.3 Comparison and Discussion 17
Section 4 – Project Financial Evaluation 18
Section 5 – Conclusions and Recommendations 22
Acknowledgements 22
References 23

List of Figures

Figure 1 - Power Effectiveness Estimated from Power generated at the 5 non-tracking Ottawa Sites. 10
Figure 2 - HOEP values plotted versus (a) timestamp and (b) hour of the day, for all 2011-2012 data. Red data points and connecting line in the lower graph indicate average price over key solar hours. 11
Figure 3 - Dependence of revenue on tilt and azimuth of PV panels for selling under FIT3 flat-rate pricing, contour plot. 12
Figure 4 - Dependence of revenue on tilt and azimuth of PV panels for selling under FIT3 flat-rate pricing, surface plot. 13
Figure 5 - Variation of HOEP ($/kWh) with hour and month, contour plot. Values are HOEP multiplied by 1.5 to approximately reflect the net sum of electricity charges on an Ontario bill relating to hourly energy consumption in kWh. 14
Figure 6 - Dependence of revenue on tilt and azimuth for a Class A load displacement installation, contour plot. 16
Figure 7 - Dependence of revenue on tilt and azimuth for a Class A load displacement installation, surface plot. 16
Figure 8 - Cash flow worksheet for a FIT3 project. 19
Figure 9 – Cash flow work sheet for a load-displacement project. 20
Figure 10 – Project cash flows for two different types of revenue streams for a 500kW solar installation. 21

List of Tables

Table 1 - Key parameters of four Hydro Ottawa PV installations referenced in this report, along with calculated levelized cost of energy. 8
Table 2 - LCOE sensitivity analysis. 8
Table 3 - Peak hours of Ontario Grid in 2012. 15
Table 4 - Summary of optimal orientation and revenues. 17

Introduction

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. It has successfully enabled the deployment of more than 1GW of solar across the province, via a residential (microFIT) program and multiple rounds of FIT contract offerings. The Ontario government has been 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. Solar is also important outside the FIT program. In particular, on large electricity users' bills, a high percentage of the charges are related to peak power demand, which generally occurs on sunny summer afternoons. Solar generation is well understood to be a good match for these peaks.

In Report 1, provided within the present Sunlab-HOL collaboration, detailed analyses of several HOL solar systems were undertaken. The energy generation values of these systems are employed within calculations herein to provide realistic predictions for energy outputs and thus financial viability. Outputs are thus reflective of the viability of solar in Ottawa. Ottawa is one of the better solar resource regions in Ontario, with a global horizontal irradiance (GHI) of 1379 kWh/m^2/year. This analysis is directly transferable to other regions of Ontario with similar irradiance levels, including all of Eastern Ontario (extending down to Kingston area) and also Southern Ontario (Windsor to London regions) and Western Ontario (Thunder Bay to the border with Manitoba)[1].

In this report, we examine the financial viability of a potential solar project with a size of 500kWdc[*]. Analysis begins in Section 1 with the evaluation of costs for developing a solar project and of producing electricity with solar, via the levelized cost of energy (LCOE) metric.

With the *costs* of solar electricity generation in hand, Section 2 describes a model for estimating how revenue from solar depends on the orientation of the solar panels. Section 3 then considers different potential revenue streams from different tariffs, including the Ontario spot market fluctuating prices for electricity, but in particular undertaking detailed analysis of:

a) the Ontario FIT3 tariffs and the resulting revenue stream for selling power to the grid;
b) reduced electricity bills via a load-displacement installation by a Class A electricity customer.

Note that the latter is a cost savings, put for the sake of simplicity, we will call both FIT revenues and electricity bill cost savings as *revenues* in this report. Analysis includes the optimization of orientation of the solar panels for a maximization of the revenues for each of these scenarios. For cases where the revenues vary with the time of day of solar production, careful consideration is undertaken. If this price varies throughout the year or throughout the day, then the orientation that is optimal for dollar revenue/saving may be different than the orientation that generates the maximum total energy. To undertake this analysis, we developed a model that could predict energy production of a solar

[*] The AC size of the project might also be 500kWac, but often developers build systems with an oversizing of DC to AC equipment by 20% or more. At very high overbuild ratios, the AC equipment will clip power in peak conditions, resulting in minor losses, but generally allow the system to produce more power in off-peak conditions, resulting in a better ROI. Up to a 20 % overbuild the clipping in negligible in Ontario, and thus the system performance should be completely determined by the DC size. Since systems costs are also generally expressed in terms of the DC size, we will stick to using the DC size for this report. Currently with Ontario FIT regulations, up to 20% overbuild it permitted. Thus a 500kWdc system might be a 416kWac system, and 416kWac FIT contract. Should one wish to build a differently sized system, the revenues within this report are scalable, and the comparisons between revenue streams are equally valid. The kWh produced by the systems are AC onto the electricity system.

installation versus a range of orientations; the performance of the HOL systems was employed to calibrate the model to predict realistic performance for a system in Ottawa.

In Section 4, complete 25 year cash flows for projects are undertaken and internal rates of return are deduced.

Section 1 – Levelized Cost of Energy

The levelized cost of energy (LCOE) is a standard energy industry metric defined as the average cost of power, which can be used to compare the relative generation costs of different types of generation sources.[2] The calculation of the LCOE involves summing all costs, both capital and operational, over the life of the power plant, which is then divided by the total energy production of the power plant over its lifetime.[3] Thus, the LCOE is also the price at which electricity must be sold over the plant's lifetime in order for the plant to break even financially.[4] Herein we undertake the calculation of the LCOE for typical solar installations located in Ottawa. We use energy production data from actual sites in combination with costs of a typical installation in 2014.

Values for costs, including installation and maintenance, were determined from reputable sources including peer-reviewed journals such as Renewable and Sustainable Energy Reviews and official government bodies such as the National Renewable Energy Laboratory of the United States Department of Energy.[5] Baseline costs for installation were set at $2.25/Wdc, and maintenance costs were estimated to be $18/kWdc/year.[6] The discount rate was fixed at 7%.[7] Deterioration of the solar panels was assumed to be a linear degradation of 0.5% per year.[8] Furthermore, the lifespans of the solar installations were assumed to be 25 years.[8] Interest expenditures were not taken into account for the LCOE calculation. Thus, it was assumed that loans were not a component of the investment in the solar installations.

In Report 1 from this collaboration, the energy production from six systems owned by HOL was analysed. Since the datasets for two of the systems (MerivaleRoof and RiversideRoof) contain some data gaps, these systems will not be studied in this report. Table 1 contains key parameters of the four systems that will be analysed. The six column, *Energy Produced*, contains the actual smartmeter energy production from 2012 as reported in Report 1, but herein scaled as if each system were 500 kWdc in size. The seventh column contains the *System Performance Ratios,* a measure of the system efficiency at converting the solar panels 'DC electrical production into AC electricity on the grid, as were determined in Report 1. The calculation starts after system orientation is taking into account, so a system with a high PR but non-optimal orientation may produce less energy that a more poorly performing system. The last column contains the LCOE values calculated using these scaled energy production values and the assumed costs from above.

Table 1 - Key parameters of four Hydro Ottawa PV installations referenced in this report, along with calculated levelized cost of energy

Site Name	Size (kWdc)	Mount Type	Tilt (° above horizontal)	Azimuth (° W of S)	Energy Produced (kWh/yr, scaled for a 500kWdc system)	System Performance Ratio	Levelized Cost of Energy ($/kWh)
MerivalePole	1.56	Pole	50	0	510,400	76%	0.20
BankPole	1.56	Pole	45	0	584,490	74%	0.17
GreenbankRoof	11.28	Roof	10	-28	537,000	75%	0.19
Riverdale2Axis	10.5	Full Tracker	Dual-axis tracked		818,750	73%	0.12

The average LCOE for the three fixed tilt systems is $0.19/kWh. This value is higher than typical prices paid for electricity (net rates for residential are ~$0.15/kWh). The performance ratio values here are reasonable for systems installed in 2011, but slightly better values of up to ~0.80 are possible for systems installed in 2013 and beyond, which would lead to proportionately lower LCOEs of around $0.18/kWh.

The 2-axis tracker has a significantly better (i.e., lower) LCOE of $0.12/kWh due to its higher energy production. But this value may be overly optimistic, as no increased costs for tracking equipment and maintenance were included.

Table 2 - LCOE sensitivity analysis.

Installation	Installation Cost ($/W)	Levelized Cost of Energy ($/kWh)
Greenbank Roof	$2.25	0.19
	$2.48	0.21
	$2.70	0.22
	$2.93	0.24
Riverdale 2Axis	$2.25	0.12
	$2.48	0.14
	$2.70	0.15
	$2.93	0.16
Installation	**Maintenance Cost ($/kW/year)**	**Levelized Cost of Energy ($/kWh)**
Greenbank Roof	$18.00	0.189
	$19.80	0.191
	$21.60	0.192
	$23.40	0.194
Riverdale 2Axis	$18.00	0.124
	$19.80	0.125
	$21.60	0.126
	$23.40	0.127

Sensitivity of LCOE for both fixed tilt and tracker systems to the input installation costs and maintenance costs is now undertaken.

As shown in Table 2, as the installation costs increase by 10%, 20%, and 30%, the LCOE values will increase noticeably. At the high end, with an assumed installation cost of $2.93/W, the LCOE is $0.24/kWh for the fixed tilt GreenbankRoof inputs.

For the above calculations, maintenance costs remained steady at $18/kW/year. However, the bottom section of Table2 reveals that as maintenance costs augment by 10%, 20%, and 30% with fixed installation costs, the changes to the LCOE will be much slighter. In fact, the LCOE values were expanded to three decimals to show the minute changes in value.

Thus, solar installation operators should bear in mind that installation costs have a more significant impact on LCOE compared to maintenance costs. Firms looking to attain healthy returns on investment should seek to lower their installation costs as much as possible.

For a solar project to be financially viable, it must be able to sell the electricity at a price greater than its LCOE. The Ontario spot market price, the Hourly Ontario Electricity Price (HOEP) with average value of $0.02437/kWh is clearly much too low to be lucrative on its own. Either incentives, such as a feed-in-tariff program, or other benefits are required. Sections 3 and 4 analyze these possibilities. This analysis will include the optimization of system orientation for maximization of various revenue streams. To undertake this optimization, a model of PV panel performance versus orientation was required, as will be explained in Section 2.

Section 2 – The PV model

A clear sky simulation of solar irradiance incident on PV panels was built in Matlab[9] using the equations developed in Masters[10]. Starting with the extraterrestrial irradiance solar constant of 1.377 kW/m^2, the model calculates the beam, diffuse and reflected sunlight incident on PV panels. The beam portion is computed to a high degree of accuracy using geometric relations of the sun to panel tilt angles through the year. Diffuse and reflected components are more minor in magnitude, and are included using typical industry assumptions for isotropic scattering and reflections. The net irradiance energy on the panels is converted into an AC electrical energy assuming a PV panel efficiency of 0.15 and a system performance ratio of 0.80.

To convert these clear sky values into real, weather-dependent values that include clouds and other effects, we use a factor we call *Power Effectiveness*. We use data from the 5 HOL non-tracking sites to assess actual average output in comparison to the clear sky model. We group the measurements of energy generated according to each hour of each month, where for example the data for “10:00/July” is a set of 31 values for 10am on each of the 31 days during July. Within this subset, we assume that the largest value represents the occurrence of a perfect clear sky condition and is thus equivalent to the clear sky model of above. Then, the average of the subset gives the average kWh generated for a given hour/month and is used to estimate the average “power effectiveness” by comparing it with the maximum. Thus for each hour/month:

Power Effectiveness = (Average kWh) / (Maximum kWh)

Power effectiveness as calculated above is shown in Figure 3. We are essentially estimating atmospheric conditions that will be dominated by "cloudiness". The important parts of the graph to focus on are the high levels of power effectiveness at mid-day and during the summer months when the sun is high in the sky and therefore generating the bulk of the power. These high levels of power effectiveness of 0.5-0.7 form a fairly uniform plateau. The sharp drop-off when the sun is low in the sky seems to be due to higher cloudiness and/or other atmospheric absorption effects near dusk and dawn, which nevertheless occur at times when less power is being generated and therefore have lower impact on our overall analysis within this report.

The power effectiveness curves we developed may be slightly influenced by the characteristics of the input systems, but we believe it to be a minor effect. We have assumed that the cloudiness is independent of system tilt, which should be a good approximation. The systems included in the dataset have a range of tilts, with average tilt of 28 degrees, which is a reasonable representation of a typical system. Furthermore, the power effectiveness of the HOL Riverdale two-axis tracked system showed very similar profiles (not included herein) indicating that the method is a reasonable probe of atmospheric losses. Within this work, we assume the roof has negligible shading for all times of the day (all orientations of panels).

The predictions for hourly solar energy production from the clear sky model are multiplied by the above Ottawa power effectiveness. The modeling is undertaken for a wide range of panel orientations:

- azimuth varying from 30 degrees East to 110 degrees West;
- tilt varying from 10 to 70 degrees.

These hourly energy values will be further multiplied by (time-dependent) revenues in the next section.

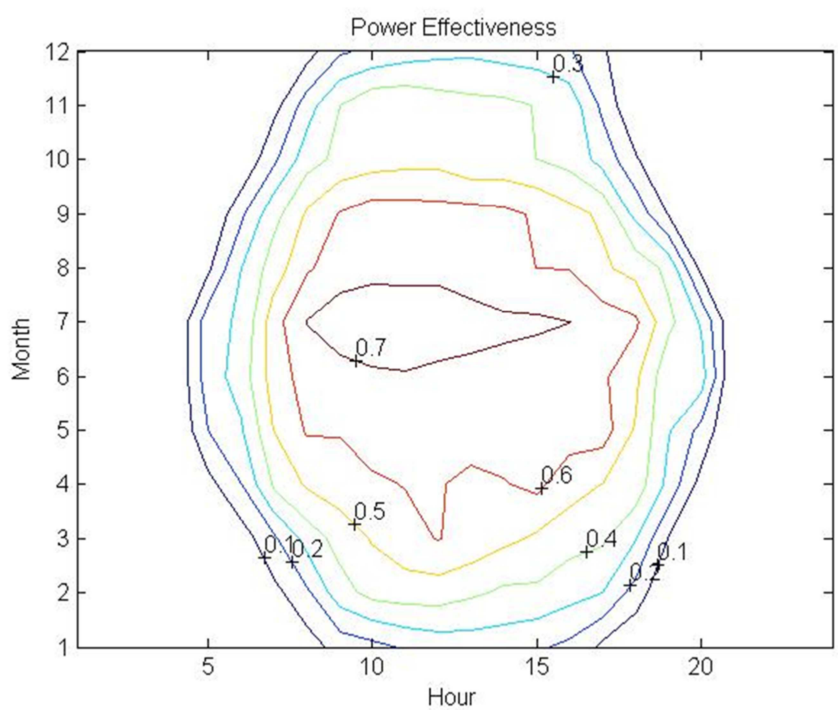

Figure 1 - Power Effectiveness Estimated from Power generated at the 5 non-tracking Ottawa Sites.

Section 3 – Revenue Streams and Optimization of Panel Orientation

Two different types of revenue streams will be examined in this section, a fixed price via a FIT and an hourly varying price based upon a complex set of electricity bill calculations. It might have made sense to also consider the hourly varying spot market price for electricity, which in Ontario is the Hourly Ontario Electricity Price (HOEP),[11] however, it has an average value of $0.02437/kWh, which is only a tenth of the LCOE of solar in Ontario, so clearly this won't be financially profitable on its own. And even though there tend to be higher HOEP values during key solar production times, as can be seen in Figure 2, during the hours of 10am to 6pm the average is still only $0.0308/kWh, which is not significant enough to provide a positive return. But section 3.2 shows that when examining the entirety of electricity costs, at least for certain users, there is a financially viable project possibility.

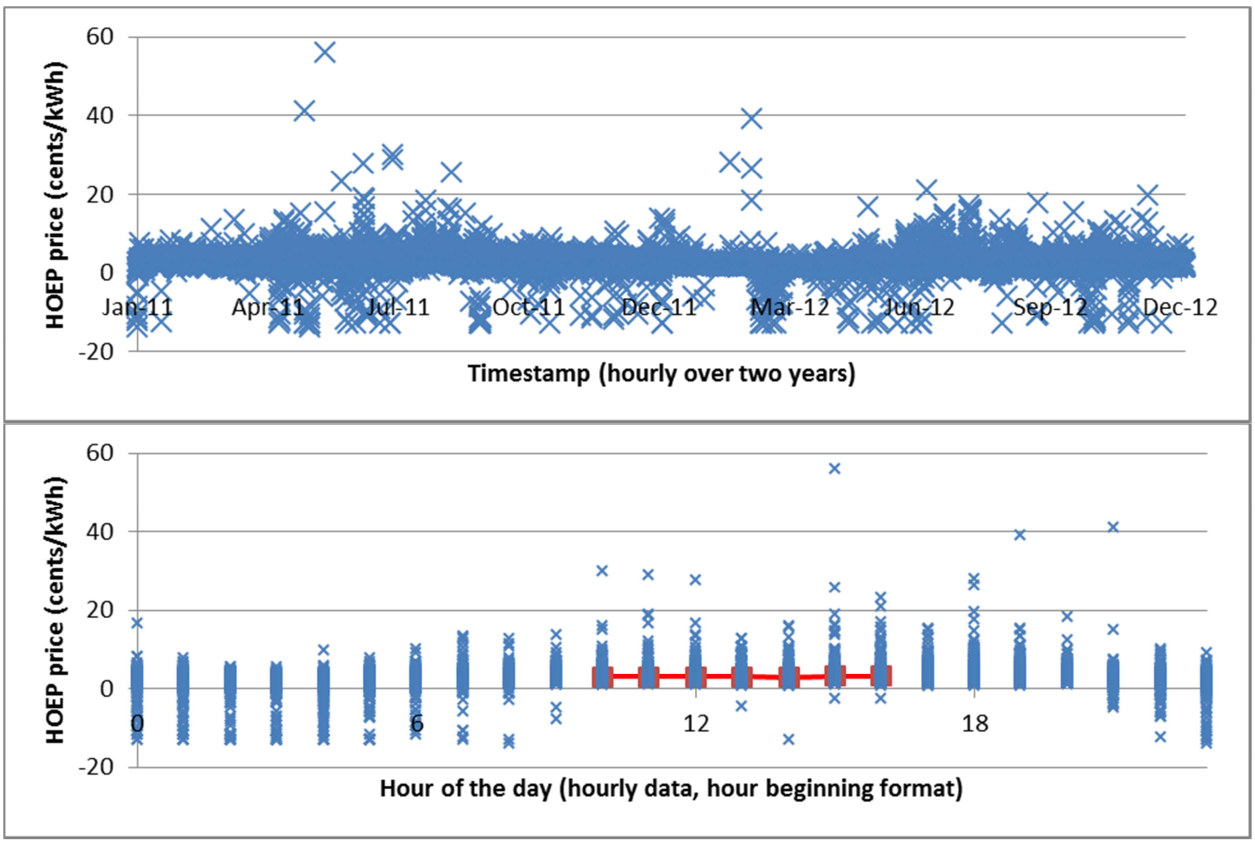

Figure 2 - HOEP values plotted versus (a) timestamp and (b) hour of the day, for all 2011-2012 data. Red data points and connecting line in the lower graph indicate average price over key solar hours.

3.1 Fixed price FIT3 revenues

First we give the base case for a nominal 500 kWdc system*, in which power is sold at a constant price under the Ontario FIT3 price for rooftop mounted solar of $0.329/kWh[12]. The analysis results in yearly revenues for the range of orientations shown in Figures 3 and 4. The yearly revenue has a maximum value of $165K, for an orientation of azimuth = 0 degrees and tilt = 35 degrees. The impact on revenue for non-optimal orientations can be read from the diagrams. For instance, if the site layout requires an azimuth of plus or minus 20 degrees, the revenue is reduced by about 3%.

We also undertook the system optimization calculation *without* the power effectiveness curve, and found that the optimal tilt was slightly higher at 40 degrees, just below the Ottawa latitude of 45.42 degrees. The slightly lower tilt of 35 degrees in the main calculation must be due to a slightly higher power effectiveness in the summer leading to lower tilts.

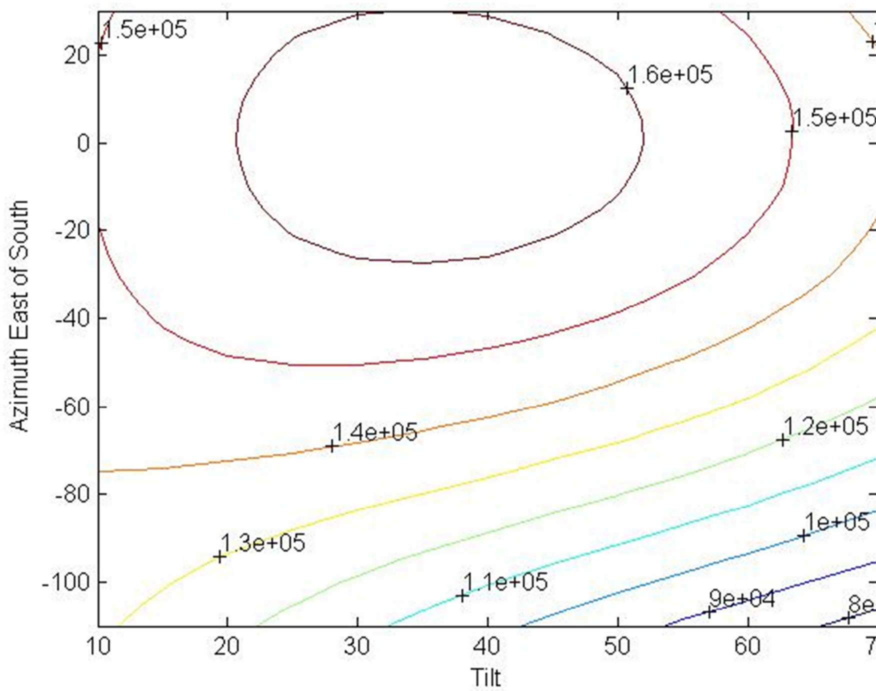

Figure 3 – Contour plot of the dependence of revenue on tilt and azimuth of PV panels for a 500kWdc system selling under FIT3 flat-rate pricing, contour plot, values are revenue in $/yr.

* Note that this means we have, to a certain degree, designed a system that has a DC:AC size of 1:1, whereas the industry often oversizes the DC side of the system because the conditions used for the DC rating are very high sun in cool laboratory setting, which are rarely met in real conditions. Thus for an oversizing of up to 1.2, there is a negligible number of occasions when the DC system power exceeds the inverter's AC rating, and thus the output energy and power can be accurately calculated from the DC size.

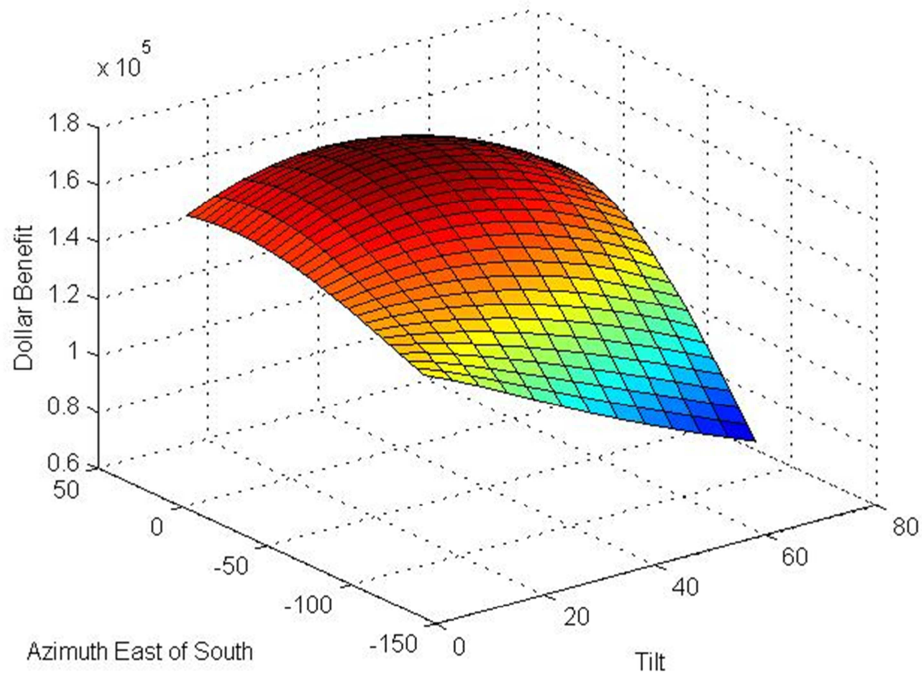

Figure 4 –Surface plot of the dependence of revenue on tilt and azimuth of PV panels for a 500kWdc system selling under FIT3 flat-rate pricing, contour plot, vertical scale is revenue in $/yr.

3.2 Class A Load Displacement Revenues

We examine now a non-FIT revenue stream that has the potential to be financially viable. We wish to examine the case of a self-consumption or ***load displacement system***, which is a solar installation that produces electricity to offset the building's energy consumption and power demand throughout the year. We assume again a 500 kWdc system, and that this size is sufficiently small compared to the load of the customer that all the generated electricity will be consumed by the customer and no electricity will ever reach the main distribution grid. This is different than a net-metered installation, which might sell some electricity back to the grid.

The revenue stream we will examine is not actually a new source of revenue, but a cost savings on electricity bills (although we will continue to use to the term revenue herein). It is thus very dependent on the structure of the electricity bill. In Ontario, large customers with an average peak demand in excess of 5MW (Class A) are subject to an electricity bill which comprises three time varying components:

1. A set of charges based on consumption in kWh.
2. An amount reflecting the customer's peak demand in kW during the billing month, known as "Demand". Customers with very peaked demand profiles will have higher bills than those with flat demand profiles. Peaky demand is harder and more expensive for the grid to manage.
3. An amount called "Global Adjustment", which for Class A users is a reflection of the customer's demand during 5 specific hours (of the previous summer) when the Ontario grid was experiencing peak demand.

The percentage of a customer's electricity bill due to each of these three components depends on the customer's demand profile, and the following analysis is for a hypothetical Ontario customer. We now describe in more detail these three components:

1. The **consumption charges** are predominantly the HOEP, but include additional regulatory and debt retirement charges, which in our analysis of the University of Ottawa's electricity bills had a value of about 50% of the HOEP. Thus, in our analysis, we scale the hourly HOEP up by 50% to take in account these charges. The resulting price (averaged over each day of the month) varies with time of day and month of the year according to Figure 5, with a mean of \$0.02437/kWh and a standard deviation of \$0.00855/kWh. The average of the HOEP in the key solar hours is \$0.0308/kWh, so 1.5 time this is an average value of \$0.00462/kWh, clearly much smaller than the LCOE values calculated in Section 1, and thus not at all a sufficient revenue stream to make a project viable. But the ability to offset demand and global adjustment charges brings additional sources of revenue.

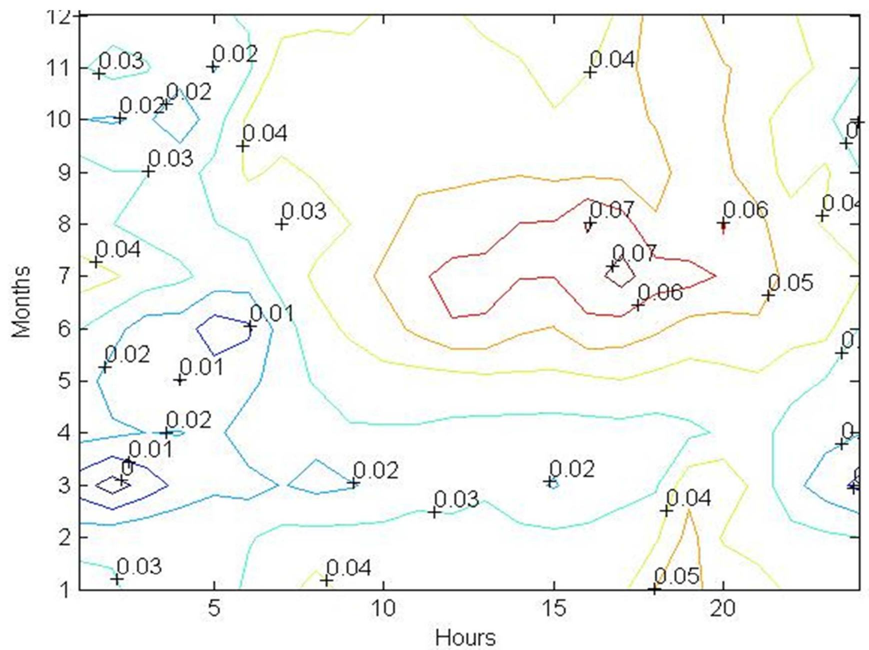

Figure 5 - Variation of HOEP (\$/kWh) with hour and month, contour plot. Values are HOEP multiplied by 1.5 to approximately reflect the net sum of electricity charges on an Ontario bill relating to hourly energy consumption in kWh.

2. The **monthly peak demand** within the billing month. We will assume a demand charge of \$7.62/kW corresponding to the tariff for a Class A customer. We will further assume that the monthly demand charge will be based on demand peaks occurring during the hour ending 14.00 EST from April to October and during the hour ending 10.00 EST during November to March.

3. The **global adjustment** - the Ontario GA program is a collection of different costs that relate to electricity grid operation, maintenance and upgrades, and the difference between contractual power purchase prices and the HOEP. The costs are paid for by all rate payers as a GA charge on every electricity bill: for residential and small accounts it is based on their consumption and is a \$/kWh charge, while for Class A accounts it is based on the customer's demand, as a \$/kWp charge. In particular, it is based on their demand during five specific hours identified by the IESO during the previous year[13]. These hours correspond to demand peaks on the Ontario-wide grid, and typically occur in the summer due mainly to high air conditioning use during the

afternoons of heat waves. Our analysis is based on those hours for 2012, as listed in Table 5. The cost of the global adjustment program totalled $6.4557bn in year 2012, while the total average demand during those 5 hours was 23.883GW, giving a global adjustment charge of $270.30/kWp per year or $22.53/kWp per month.

Table 3 - Peak hours of Ontario Grid in 2012.

Date	Hour ending (EST)
June 20, 2012	16.00
July 4, 2012	17.00
July 6, 2012	16.00
July 17, 2012	16.00
July 23, 2012	14.00

Comparing the demand charge of $7.62/kW per month with the global adjustment charge of $22.53/kW per month gives a ratio of 2.96. The larger global adjustment charge reflects the incentive provided by the IESO for customers to reduce consumption of power at times that are of critical importance to the functioning of the Ontario grid, in terms of both infrastructure and costs. At the GA peak times, the sun is significantly to the west of south. An optimised solar system will therefore need to be oriented towards the west.

Using the PV model to determine the hourly kWh and kW produced by a 500kWdc system, we now calculate the revenue generation from the sum of all three types of charges (consumption, monthly demand and GA). This is done for wide range of different system orientation to find the optimal orientation for a Class A load displacement project, with results plotted in Figures 6 and 7.

Comparing Figures 6 and 7 with the earlier Figures 3 and 4 for optimization against FIT revenues, it is clear that the GA charges significantly affect the optimal orientation of solar panels. The optimal tilt is relatively similar, now at 40 degrees, but the azimuth is substantially changed to 55 degrees west of south. The solar panels are optimally orientated in a direction that is significantly influenced by the position of the sun at the global adjustment times.

At the optimal orientation, the value of the revenues due to HOEP, demand charge and global adjustment charge have a ratio of 20.3%, 14.2% and 65.5%, respectively. In particular, the ratio between global adjustment and demand charge offsets is 4.61 at this optimal orientation, which is even greater than the ratio of the *costs* of these two charges. This is because a solar system is particularly effective during the summer peaks, and thus significantly reduces the high-cost GA charges. Furthermore, this pushes the optimized orientation to be further west and hence derives even more benefit from offsetting the global adjustment than from offsetting the HOEP or demand charge.

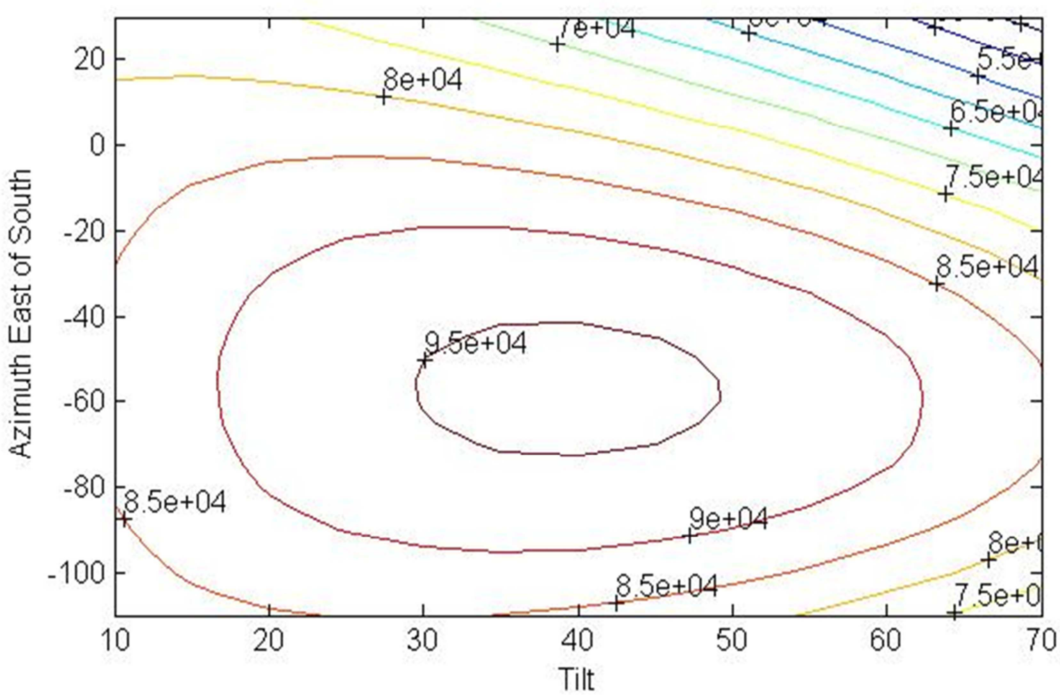

Figure 6 - Dependence of revenue on tilt and azimuth for a Class A load displacement installation, contour plot.

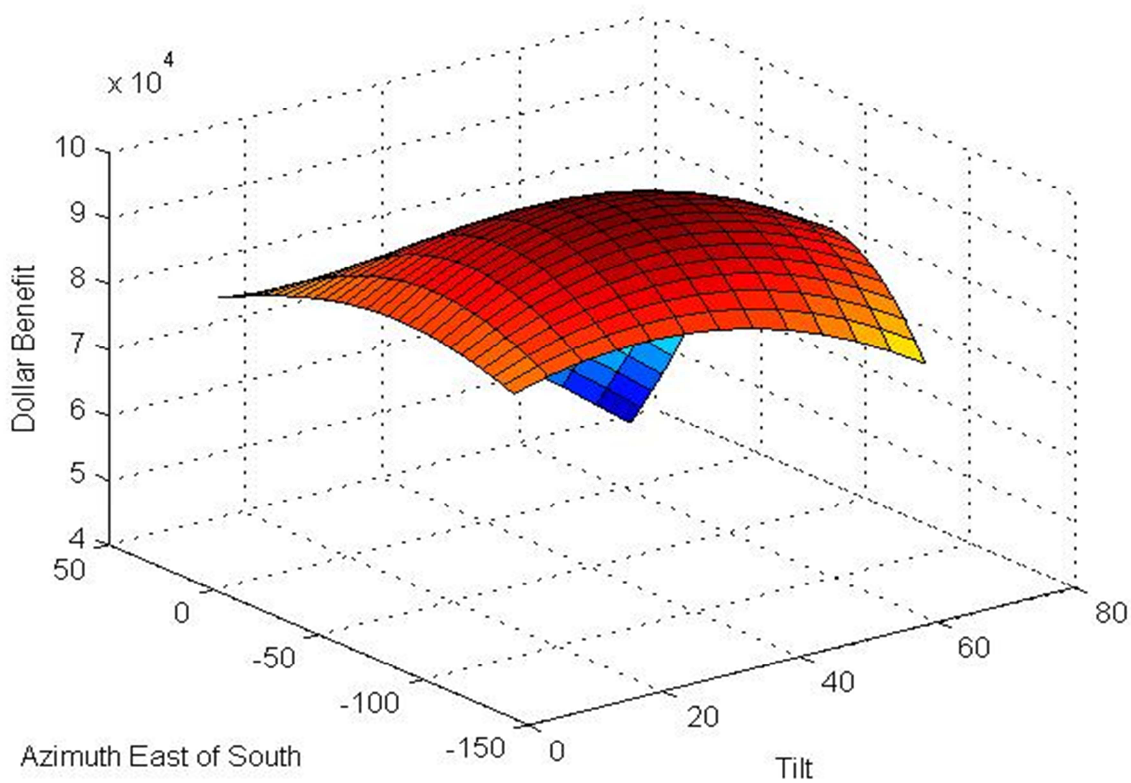

Figure 7 - Dependence of revenue on tilt and azimuth for a Class A load displacement installation, surface plot.

It is also important to consider that in a load displacement situation, all of the electricity charges are likely subject to taxes, which in Ontario is the 13% Harmonized Sales Tax (HST). Thus the net revenue should include this and be multiplied by 1.13.

3.3 Comparison and Discussion

The results of the analysis of the two types of revenue mechanisms for the 500 kWdc system are summarised in Table 1.

Table 4 - Summary of optimal orientation and revenues.

Revenue Stream	Tilt	Azimuth (+ W of South)	Consumption Revenue ($K/yr)	Demand Charge Revenue ($K/yr)	Global Adjustment Revenue ($K/yr)	Total Revenue ($K/yr)
FIT3 contract ($0.329/kWh)	35°	0°	n/a	n/a	n/a	**165**
Class A load displacement	40°	55°	20	14	63	**96 or 109 w HST**

The revenue under the FIT calculation has a maximum of $165,000/yr whereas, that of a Class A load-displacement project has a maximum value of $109,000/yr (including tax). Thus, at present, the FIT program appears more lucrative. Furthermore, a FIT contract is a stable source of revenue whose security is beneficial for long term planning. In contrast, the load displacement project carries risk of higher uncertainty in the revenues, in particular due to changes in the GA program and its dependence on solar production during 5 specific hours Yet, increasing electricity prices seem to be an assured thing, and it is thus reasonable to expect increasing revenues over the life of the project, providing a potential future upside.

Furthermore, an organization may prefer to install solar under a load displacement instead of a FIT contract for some of the following reasons: the logistical and timing constraints imposed within the FIT application process or the FIT contract make it impossible, the competitive process of the FIT program does not guarantee an application will be successful in obtaining a FIT contract, the government may discontinue the FIT program or reduce the tariff significantly, the site service may require extensive upgrades or require lengthy cabling to place the FIT meter at the point of electrical service connection (say for example in a campus environment).

The analysis showed that the *optimal* orientation for the Class A load displacement project is significantly different than that of a standard project. The relatively high tilt and orientation of West of South were significantly influenced by the 2012 GA peak hours. Other analysis (not included here) also considered the peak GA hours for the years 2010, 2011, and 2013, and produced nearly identical results.

While the Class A GA charge structure is perhaps complicated, it is doing an effective job at encouraging demand reduction when it is of prime importance to the grid. In particular to this study, the result was that solar panels oriented towards the west of south would be beneficial to both the Class A customer and to the grid.

It is possible that the peak times of the Ontario grid will shift to other timeslots and then the optimal solar panel orientation would correspondingly change. Three approaches to mitigate this risk include: (a) consider racking that allows the orientation of the PV panels to be changed every few years or (b) install tracking systems, which would completely obviate the orientation optimization aspect of the issue and produce slightly increased revenues, but would carry additional capital and maintenance costs or (c) bias the orientation somewhat towards the more standard orientation to the benefit of the consumption and monthly demand revenues. It is worth noting in Figures 6 and 7 that revenue is only slightly dependent on orientation (tilt in particular): a system with orientation of 30° tilt, 20° azimuth would only have a revenue drop of 6.5%. Furthermore, as is already the case for many commercial solar installations, a lower tilt angle would allow for more panels per square area and reduce the wind loads, both of which may benefit a roof-mounted project in particular, in terms of engineering and financials.

Section 4 – Project Financial Evaluation

Detailed cash flows are now computed for a fixed tilt roof-mount 500kW solar installation under both FIT3 and load displacement revenue scenarios. The same assumptions as in Section 1 are again employed, as tabulated within the calculation windows of Figures 8 and 9. In addition, it is assumed that the inverters will need replacing in year 13, at a cost of $0.16/W, or $80,000.

For the FIT3 revenue project, it is assumed that there is a fixed FIT3 tariff of $0.329/kWh for years 1-20, after which the system owner will be able to sell electricity to the grid at HOEP rates for years 21-25. The HOEP tariff in those is years is an escalated value from 2012 HOEP pricing during daytime hours ($0.0308/kWh in 2014 but escalated by 2%/year).

For the Class A load displacement project, we include a 13% HST on the revenue, and thus use the value of $109,000/yr (=$218/kWdc/yr). The load displacement revenue is assumed to be available for the entire 25 years of the project. We have assumed that cost of electricity is generally going to increase over the lifetime of this project, and for now assign a simple 2% escalation per year to the net revenue of the project[†].

[†] A 2%/yr escalation of total revenues has been confirmed to be reasonable representation of the newly realeased Ontario electricity cost projections, as released in Dec 2013 by the Ontario Power Authority in relation to the 2013 Long Term Energy Plan[14].

					Expenses				Yearly	
	Year	**Capital**	**Energy Prod.**	**Revenue**	**O&M**	**Other**	**Net Income**	**Net Cash Flow**	**Cash Flow**	**HOEP**
0	**2014**	1,125,000						(1,125,000)	-1,125,000	0.0308
1	2015		501,520	165,000	9,000		156,000	(969,000)	156,000	0.0314
2	2016		499,012	164,175	9,000		155,175	(813,825)	155,175	0.0320
3	2017		496,517	163,354	9,000		154,354	(659,471)	154,354	0.0327
4	2018		494,035	162,537	9,000		153,537	(505,934)	153,537	0.0333
5	2019		491,564	161,725	9,000		152,725	(353,209)	152,725	0.0340
6	2020		489,107	160,916	9,000		151,916	(201,293)	151,916	0.0347
7	2021		486,661	160,111	9,000		151,111	(50,181)	151,111	0.0354
8	2022		484,228	159,311	9,000		150,311	100,130	150,311	0.0361
9	2023		481,807	158,514	9,000		149,514	249,644	149,514	0.0368
10	2024		479,398	157,722	9,000		148,722	398,366	148,722	0.0375
11	2025		477,001	156,933	9,000		147,933	546,299	147,933	0.0383
12	2026		474,616	156,149	9,000		147,149	693,447	147,149	0.0391
13	2027		472,242	155,368	9,000	80,000	66,368	759,815	66,368	0.0398
14	2028		469,881	154,591	9,000		145,591	905,406	145,591	0.0406
15	2029		467,532	153,818	9,000		144,818	1,050,224	144,818	0.0415
16	2030		465,194	153,049	9,000		144,049	1,194,273	144,049	0.0423
17	2031		462,868	152,284	9,000		143,284	1,337,557	143,284	0.0431
18	2032		460,554	151,522	9,000		142,522	1,480,079	142,522	0.0440
19	2033		458,251	150,765	9,000		141,765	1,621,843	141,765	0.0449
20	2034		455,960	150,011	9,000		141,011	1,762,854	141,011	0.0458
21	2035		453,680	21,179	9,000		12,179	1,775,033	12,179	0.0467
22	2036		451,412	21,494	9,000		12,494	1,787,528	12,494	0.0476
23	2037		449,155	21,815	9,000		12,815	1,800,342	12,815	0.0486
24	2038		446,909	22,140	9,000		13,140	1,813,482	13,140	0.0495
25	2039		444,674	22,470	9,000		13,470	1,826,952	13,470	0.0505
	Totals	**1,125,000**		**3,234,482**	**216,000**		**2,938,482**	**17,550,361**		
								IRR	**11.9%**	

Inputs used		alternate inputs	Resultant IRR
500	**System Size (kW)**		
$ 2.25	**Capital Costs ($/W)**	$3.00, $2.00	8.1%, 14.4%
$ 330.00	**Revenue year 1 ($/kWdc)**	-10%, +10%	10.6%, 14.1%
-0.005	**Performance changes (/yr)**		
0.02	**HOEP escalation**		
0	**Revenue changes (/yr)**	0.02	13.90%
$ 18.00	**Maintenance costs ($/kWdc/yr)**	$ 24.00	12.00%
0	**Maintenance cost changes /yr**		

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Figure 8 - Cash flow worksheet for a FIT3 project.

				Expenses				yearly
	Year	Capital	Revenue	O&M	Other	Net Income	Net Cash Flow	Cash Flow
0	**2014**	1,125,000					(1,125,000)	-1,125,000
1	2015		109,000	9,000		100,000	(1,025,000)	100,000
2	2016		110,624	9,000		101,624	(923,376)	101,624
3	2017		112,272	9,000		103,272	(820,104)	103,272
4	2018		113,945	9,000		104,945	(715,158)	104,945
5	2019		115,643	9,000		106,643	(608,515)	106,643
6	2020		117,366	9,000		108,366	(500,149)	108,366
7	2021		119,115	9,000		110,115	(390,034)	110,115
8	2022		120,890	9,000		111,890	(278,145)	111,890
9	2023		122,691	9,000		113,691	(164,454)	113,691
10	2024		124,519	9,000		115,519	(48,935)	115,519
11	2025		126,374	9,000		117,374	68,440	117,374
12	2026		128,257	9,000		119,257	187,697	119,257
13	2027		130,168	9,000	80,000	41,168	228,866	41,168
14	2028		132,108	9,000		123,108	351,973	123,108
15	2029		134,076	9,000		125,076	477,050	125,076
16	2030		136,074	9,000		127,074	604,124	127,074
17	2031		138,102	9,000		129,102	733,225	129,102
18	2032		140,159	9,000		131,159	864,385	131,159
19	2033		142,248	9,000		133,248	997,632	133,248
20	2034		144,367	9,000		135,367	1,132,999	135,367
21	2035		146,518	9,000		137,518	1,270,518	137,518
22	2036		148,701	9,000		139,701	1,410,219	139,701
23	2037		150,917	9,000		141,917	1,552,136	141,917
24	2038		153,166	9,000		144,166	1,696,301	144,166
25	2039		155,448	9,000		146,448	1,842,749	146,448
	Totals	**1,125,000**	**3,117,301**	**216,000**		**2,821,301**	**7,944,446**	
							IRR	**8.7%**

Inputs used		alternate inputs	Resultant IRR
500	System Size (kW)		
$ 2.25	Capital Costs ($/W)	$3.00, $2.00	5.7%, 10.1%
$ 218.00	Revenue year 1 ($/kWdc)	-10%, +10%	7.4%,9.9%
-0.005	Performance changes (/yr)		
0.02	Revenue changes (/yr)	0	6.50%
$ 18.00	Maintenance costs ($/kWdc/yr)	$ 24.00	8.40%
0	Maintenance cost changes /yr		

Figure 9 – Cash flow work sheet for a load-displacement project.

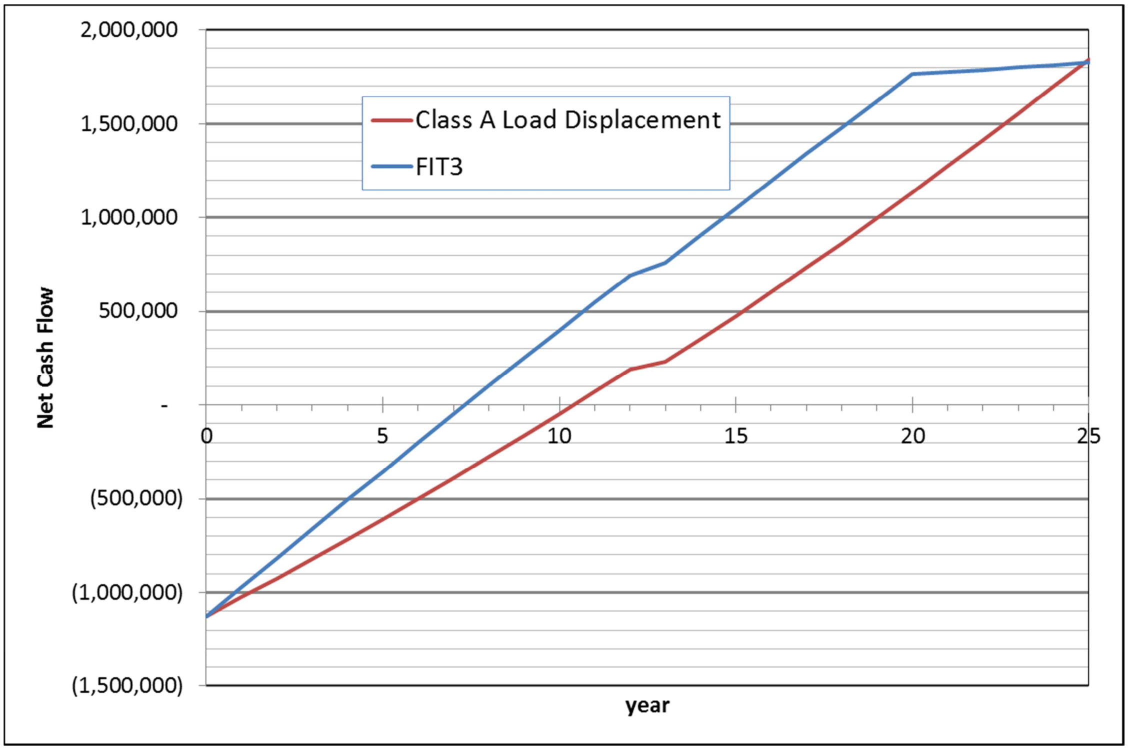

Figure 10 – Project cash flows for two different types of revenue streams for a 500kW solar installation.

The higher yearly revenue for the FIT3 project clearly results in a better IRR, with a value calculated to be 11.9%, versus an IRR of 8.7% for the Class A load displacement project. This is further illustrated with a graph of the cash flows of the two types of projects, with the FIT3 project becoming cash-positive after 7.3 years while the load displacement project only doing so after 10.5 years. This analysis suggests that after 25 years, both projects will have the same net revenues.

Note that in this comparison, we have assumed that *all* costs were exactly equal, which they may not be, as there may be different regulatory and project development costs for one project versus the other. And as discussed in Section 3.3 both revenue approaches may not be available to the same entity in a timely manner. It is of key importance to emphasize that both approaches are financially positive right now, for 2014. It is likely that Feed-in-tariff values are likely to continue to decline whereas electricity costs will continue to rise. Herein, we assumed an overall 2% increase/yr above inflation for the revenue of this load displacement project. A more detailed analysis could be performed using the recently released projected increases in both the HOEP and GA as published by the OPA in January 2014[14]. We can likely expect that future comparative calculations of this nature will be more favourable to the load displacement revenue stream. Furthermore, we assumed a project lifetime of 25 years which is the same length as the warrantees of most PV panels. Yet panels are expected to continue to produce for 30+ years, and evaluation over a longer project life would further benefit the load displacement project's long term financials.

Section 5 – Conclusions and Recommendations

Using actual 2012 production values from a select number of solar installations in Ottawa and estimated build costs for 2014 from a number of sources, we have estimated the LCOE for solar projects in Ottawa to be in the $0.19/kWh range.

A model that was a hybrid of theory and empirical data was developed to serve as a predictive tool for the hourly power generation capability of solar panels which could be calculated at a large range of panel tilt and azimuth orientations. This was very useful for determining the optimized orientation of panels when non-constant hourly revenues are available.

This model was employed to study two potential revenue streams that might be available in 2014 in Ontario:

- a constant Ontario FIT3 price
- a complex electricity bill charge reduction that could be available to Ontario Class A electricity customers who build a load-displacement solar project.

Both revenues streams were sizable and resulted in financially positive projects. The FIT3 project had an IRR estimated at 11.9% while the load-displacement project had an 8.7% IRR.

The optimal orientation for the FIT3 project was due South and with a tilt of 35°, while the optimal orientation for the load-displacement project is an azimuth 55° West of South and a tilt of 40°. The significant difference in azimuth is because of the effectiveness of solar at producing energy during the peak demand times of summer afternoons during which the global adjustment charges are calculated.

It is recommended that large electricity users consider both types of revenue streams for potential solar installations on their properties.

It is also recommended that connection requirements (including allocation of grid capacity and approval procedures) of a load-displacement project be made clear and publically available, such that this model can be fully utilized. Furthermore, regulatory agencies and policy makers should consider incentivizing solar installations oriented West of South so as to offset peak Ontario demand on summer afternoons, for instance by designing a time-of-day dependent FIT for solar.

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