# MICRO-GENERATION IN YUKON

## AN EXAMINATION OF PROGRAM IMPLICATIONS AFTER THREE YEARS OF OPERATION

Energy branch, Department of Energy Mines and Resources, Government of Yukon

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# 1. Introduction and program overview

The *Micro-Generation Policy* was first developed in 2013 and the resulting program was initially funded in the 2014-2015 fiscal year. The policy was a response to the Yukon government's commitment to assisting individuals with connecting renewable energy sources to the grid, as expressed in the 2009 *Energy Strategy for Yukon*.

The scope of the micro-generation program extends to small-scale (less than 50 kW) alternative energy systems in both grid-tied and off-grid communities. The program applies to customers in residential, general service, and industrial classes who want to generate electricity primarily for their own consumption.

When initially launched, the program was expected to attract only nominal participation, with uptake of roughly 1-10 installations per year. As shown in Figure 1-1 however, public appetite for micro-generation has far surpassed these expectations with over 60 systems installed under the micro-generation program to date representing over 400 kW of installed peak capacity.

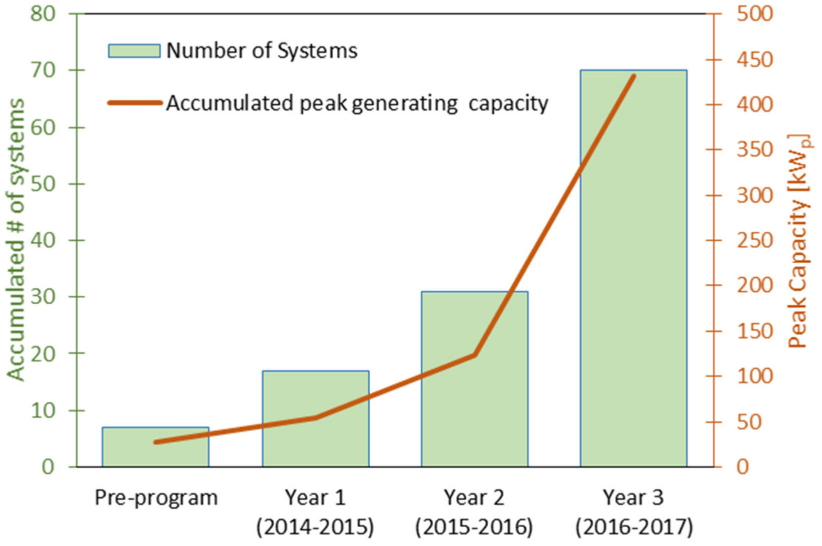

**Figure 1-1 | Micro-generation system uptake in Yukon.** Graph shows the total number of micro-generation systems and their generating capacity for all communities in Yukon.

Although the micro-generation program applies to wind, micro-hydro, biomass, and other emergent technologies, as they become available, all systems installed under the program up to the end of 2016 have been photovoltaic systems. Given the public's interest in and high rate of adoption of solar power, a detailed technical assessment combined with a future outlook for micro-generation in the Yukon is appropriate at this time. In response to this need, this report has been developed to provide technical insight into:

1. The hourly export profiles of typical micro-generation systems throughout the year. Export profile refers to the amount of energy generated by a renewable source that is not consumed on-site, but rather exported to the public electrical grid.
2. The expected future uptake of micro-generation systems, the magnitude of generation capacity represented by this uptake and potential daily and seasonal trends that can be expected.

3. The potential of micro-generation systems to mitigate the use of diesel and natural gas to supplement hydro generation.

This report will focus on solar photovoltaic systems and their implications to the above mentioned points. Adoption of renewable energy generation technologies other than solar photovoltaic systems remains a component of the micro-generation program, but is not expected to contribute to the primary electric grid to the same degree as solar PV.

A detailed discussion of the broader program objectives can be found in the companion report, *Micro-Generation Policy and Micro-Generation Production Incentive Program 2014-2016 Review,* prepared by the Energy branch, Energy Mines and Resources – Government of Yukon, July 28, 2016 available online at www.energy.gov.yk.ca/publications.

The report authors would like to recognize the assistance provided by John Maissan, Michael Lauer, Allan Foster and Anne Middler for providing insights and data related to the performance of PV systems in Yukon.

# 2. Photovoltaic generation and load trends

## 2.1 Photovoltaic system efficiency

Photovoltaic (PV) modules convert energy radiated from the sun into electrical current via the photovoltaic effect. When light strikes the module, electrons in the silicon material are energized and can move freely. These electrons can then be directed into an electric circuit to power electric devices, or loads. The type of current generated by PV panels is direct current (DC), which means that electrons continually flow through a circuit in the same direction to generate power. The type of electric current transmitted through the electric power grid however, is alternating current (AC). Power is transmitted through alternating current not by the continuous flow of electrons but by back and forth oscillations of electrons in a wave-like manner, similar to how sound is transmitted through air or waves through water. Converting the direct current generated by PV panels into alternating current requires a power inverter, a critical component of every grid-tied PV system.

The performance of PV systems depends on many factors, including the efficiency of each of the separate components. PV system efficiency is typically given as the net efficiency of converting energy from the sun into alternating electric current, and accounts for energy lost in each of the system's components (panels, electrical connections, transformer, etc.). The peak power output rating of a PV system is measured under well-defined standard test conditions which makes comparisons between different types of solar panels and different manufacturers possible. These test conditions are summarized in **Table 2-1.**

**Table 2-1 | Photovoltaic module standard test conditions**

| Parameter | Value |
|---|---|
| Module Temperature | 25°C |
| Light Intensity | 1000 W/m$^2$ |
| Light Spectrum | AM 1.5 |

Real-world conditions rarely match these standard test conditions however, which means that actual power output will differ from the rated power output.

The two most significant factors effecting output power are light intensity and temperature. The intensity of the sun varies constantly throughout the day and follows seasonal trends as well resulting in constantly varying power output. Similarly, the temperature variations also affect their efficiency. Photovoltaic panels are less efficient at temperatures above 25ºC and more efficient at temperatures below 25ºC. Furthermore, as sun shines on the panels, they get warmer such that their temperature can be much higher than the ambient air temperature. In such cases, the amount of wind or airflow around the panels can help to keep the panels cool, and so system efficiency is also effected by how windy it is. Other aspects such as snow cover, ice, dirt, clouds, and condensation can further effect the efficiency of a PV system by effecting the amount of light reaching the panels and their temperature.

## 2.2 Annual solar trends

Electricity consumption and PV generation profiles change from month to month, which in turns effects the amount of power exported to the grid. The total amount of sunshine in Whitehorse peaks in May and June when, accounting for weather, the number of hours of sunlight are at a maximum as see in **Figure 2-1**.

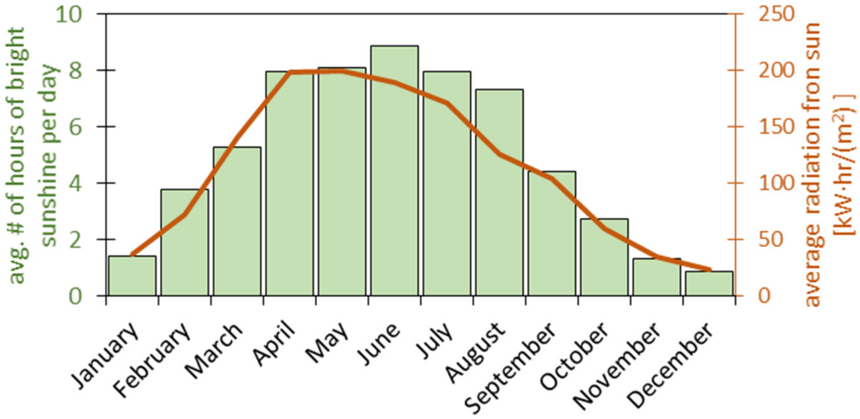

**Figure 2-1 | Number of sunny hours and total sunlight.** The number of sunny hours is based on Environment Canada data for Whitehorse between 1981 and 2010 (http://climate.weather.gc.ca/climate_normals/results_1981_2010_e). Average radiation from the sun is based on direct beam radiation on a plane oriented towards the sun, accounting for historic weather trends, derived using Meteonorm© database and radiation models based on meteorological and satellite data.

### 2.2.1 Effects of solar module tilt

Sunlight collected by solar panels is maximized when the module tracks the path of the sun through the sky so that the module is always facing directly towards the sun. The average amount of sunlight incident on a solar module tracking the sun in Whitehorse is shown in **Figure 2-1**.

Typical PV installations however, will have a fixed tilt angle which results in less overall sunlight collected, but with the benefit of drastically lower cost. A rule of thumb in the industry is that the tilt angle from horizontal should be set to the latitude of the installation location. Seasonal weather patterns however may significantly alter the performance achieved at a given tilt angle. In Whitehorse, for example, optimal sunlight collection for a module occurs with tilt angles around 45°, even though Whitehorse is at a latitude of 60.7°N. This is because tilt angles around 45 degrees optimize sunlight collection during the spring when Whitehorse generally enjoys clearer weather. **Figure 2-2(a)** illustrates the impact that seasonal weather patterns can have on the total sunlight incident on a module. The blue bars show a “blue sky” estimate (not accounting for weather) of annual solar energy collected for various tilt angles showing a maximum 60 degree tilt – corresponding to Whitehorse’s latitude. When weather is accounted for – green bars – the optimal angle is around 45 degrees. **Figure 2-2(b)** further shows a breakdown of the month-to-month solar energy collected for panels at different tilt angles, again illustrating maximum solar energy collection during the sunnier spring months of March, April and May. While 45 degrees is optimal, for practical terms little annual performance improvement is seen with tilt angles ranging from 30-60 degrees.

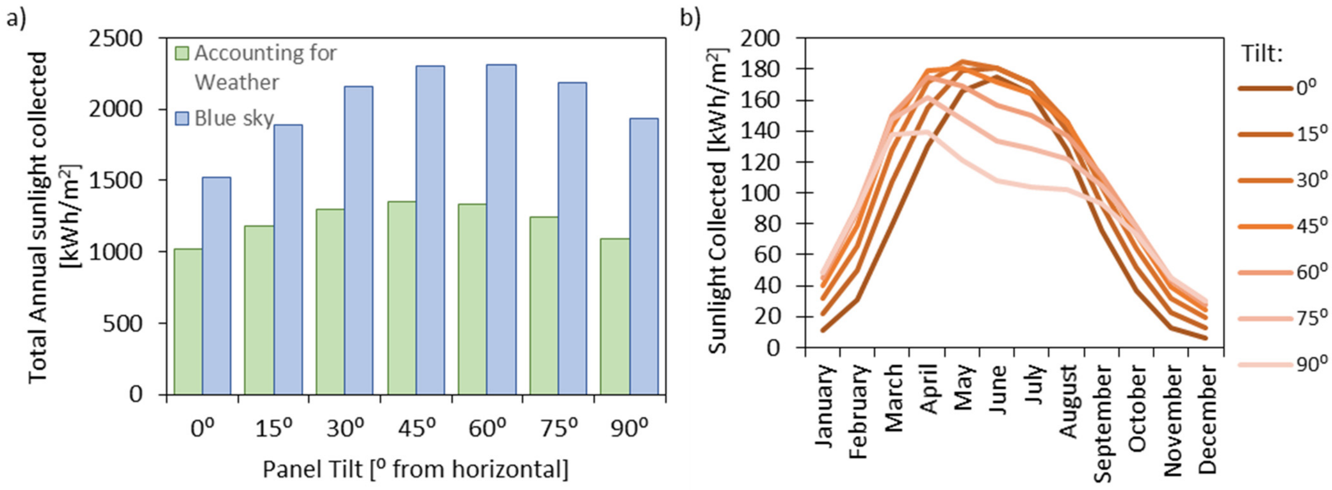

**Figure 2-2 | Solar energy collection by a tilted module. a)** Chart showing the difference between solar energy collected annually with (green bars) and without (blue bars) weather in Whitehorse. Data was calculated using Meteonorm© modeling software incorporating measured meteorological data. **b)** Total monthly radiation collected by modules facing south at different tilt angles in Whitehorse, accounting for seasonal weather patterns.

## 2.2.2 Effects of solar module azimuth

The azimuth of the module can be thought of as the module’s orientation on a compass relative to south. For tilted panels, the azimuth will affect the amount of sunlight harvested by a module. Figure 2-3 shows the impact of changing both the tilt angle and the direction of the module’s facing. The graphs show the relative solar energy harvested compared to a system at 45° tilt facing due south. By increasing the tilt angle, more sunlight can be harvested during the winter months, at the expense of energy harvest during the summer. Azimuths other than due south typically result in reduced sunlight collection at all times of the year.

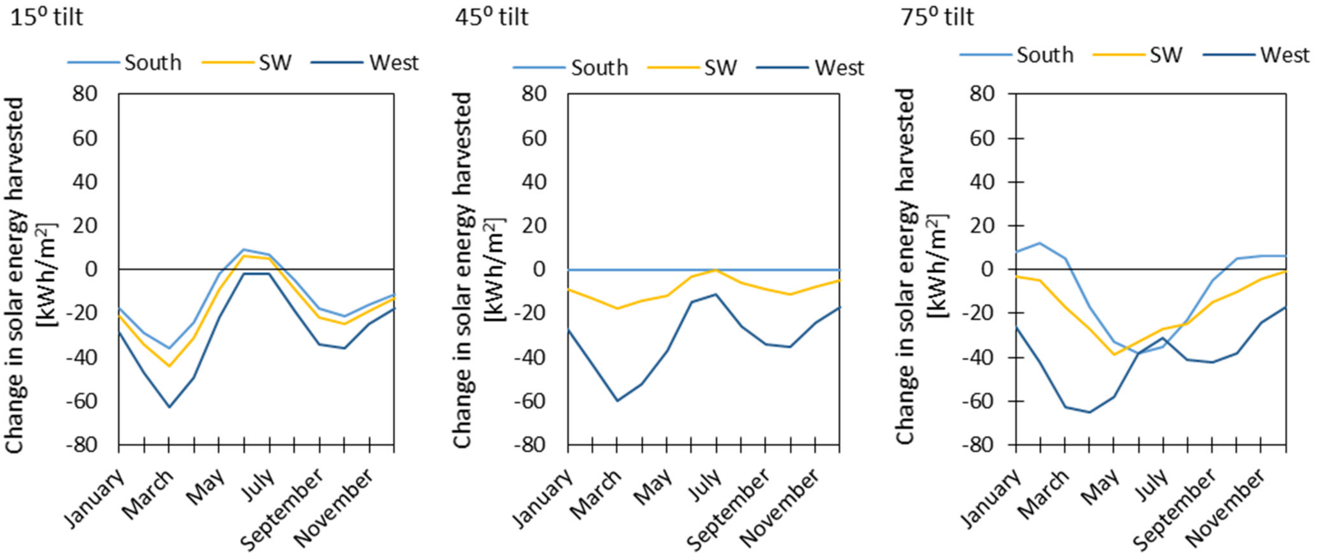

**Figure 2-3 | Effects of module tilt and azimuth on solar energy collected for Whitehorse**. The change in solar energy harvested is relative to a module facing south at a 45° incline. Data was collected using Meteonorm© modeling software incorporating measured meteorological data. Module orientations facing south-east and east are expected to achieve similar results to those shown here for south-west and west facing panels respectively.

### 2.2.3 Effects of cloud cover

Cloud and weather patterns impact the minute-by-minute solar radiation and system performance. Irradiance data collected at Yukon College, plotted in Figure 2-4, shows that the irradiance can be effected by as much as 85% due to cloud cover. This data represents hourly average irradiance, which may not represent the true maximum or minimum irradiance peaks, however, a weather scaling factor of 85% is consistent with published literature and irradiation models. This scaling factor represents a worst-case scenario, and it is not uncommon for PV systems to continue to generate meaningful amounts of energy even during cloudy weather depending on the degree of cloud cover, as can be seen in Figure 2-4.

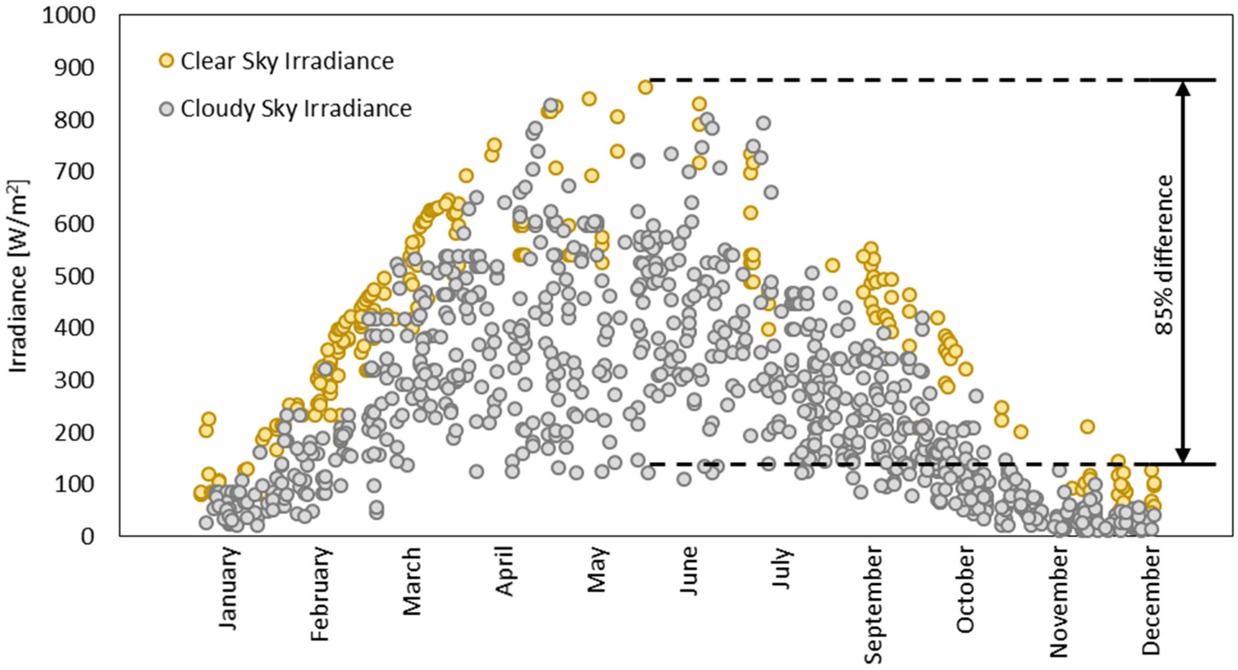

**Figure 2-4 | Average irradiances during cloudy and clear periods**. Hourly data was collected at the Yukon College between 2009 and 2016, and correlated to hourly Environment Canada data for the same time periods. Only data points collected between 11:00 and 13:00 which were designated as either "clear" or "cloudy" by Environment Canada are plotted here to show the variation in irradiance between clear and cloudy weather over the course of the year.

### 2.2.4 Effects of temperature

Solar module temperature impacts their performance. Higher temperatures result in decreased efficiency while lower temperatures result in increased efficiency. The performance factor is a solar module metric that describes how much power a PV system is generating compared to how much it is expected to generate given the amount of sunlight it is exposed to. As discussed in Section 2.1, a PV system's rated output is determined under standard test conditions, and deviations from these standard conditions will effect performance. With 1000 W/m$^2$ of sunlight and cell temperatures of 25°C, a PV system is expected to produce its peak rated power, and will have a performance factor of 1. If the sunlight is halved and the output power also drops by half, the PV system's performance factor will again be 1. The equation for performance factor is:

$$F_p = \frac{\frac{P}{P_{peak}}}{\frac{I}{1000\,W/m^2}}$$

Where P is the power generated by the PV system, $P_{\text{peak}}$ is the rated peak power of the system, and I is the amount of available sunlight. In real-world conditions, temperature, dust, ice, snow, wind, and shadows will all affect the amount of available sunlight that is able to reach the solar panels.

To assess the effect of temperature on Yukon PV systems, the performances of the systems installed at Yukon College and at the Yukon Government Administration Building were analyzed on an hourly basis. These installations were selected since they were not significantly affected by shading and were regularly maintained/cleaned. As can be seen in Figure 2-5, the performance factor of these two installations is inversely related to temperature as expected. Performance increases of up to 40% above the rated peak power can be achieved during cold winter months, and decreases of up to 60% can occur during warmer periods.

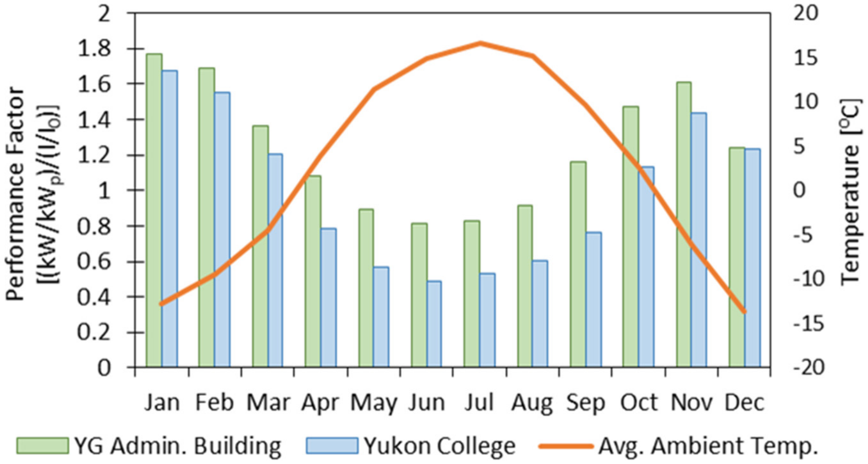

**Figure 2-5 | Yukon PV monthly performances factors**. The rated peak output of a PV system is determined under ideal conditions (1000W/m$^2$ of incident light and 25°C). In the real world, the power produced by a PV system relative to their rated peak power scales with the amount of sunlight falling. The ratio of the power produced by a PV system to its rated peak power divided by the ratio of the intensity of sunlight to ideal sun intensity (1000W/m$^2$) is the performance factor. Average ambient temperature is based on data from Environment Canada for Whitehorse, Yukon from the years 2009-2016.

It is worth noting that the actual cell temperature can differ substantially from the outside air temperature. As the solar panels absorb sunlight, they also heat up. Data collected at the Yukon College demonstrates that the cell temperature can be as much as 40°C warmer than the air temperature, as shown in **Figure 2-6**.

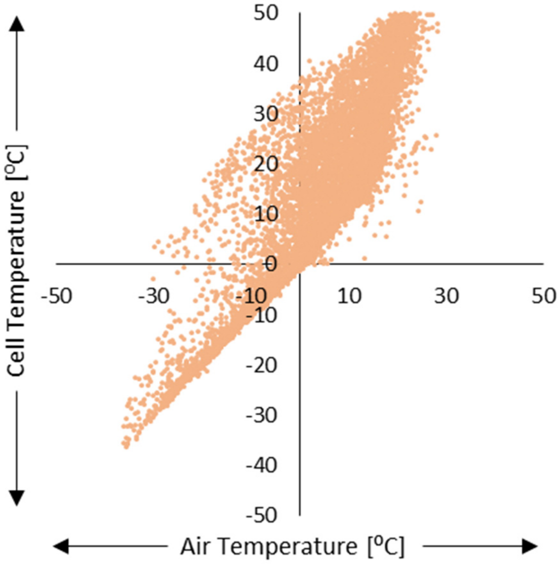

**Figure 2-6 | Air versus cell temperatures**. Cell temperatures are usually higher than the ambient air temperature, with a difference of up to 30° - 40°. Data collected from the Yukon College PV installation between 2009 and 2016.

### 2.2.5 Yukon system performance

All the factors discussed above contribute to varying performance between systems. Actual system data showing the performance of micro-generation program participant's systems located near Whitehorse, **Figure 2-7**, show that on average, energy production rapidly increases during the spring and peaks between April and June. Energy production then gradually tapers off into the winter with only marginal production during December and January.

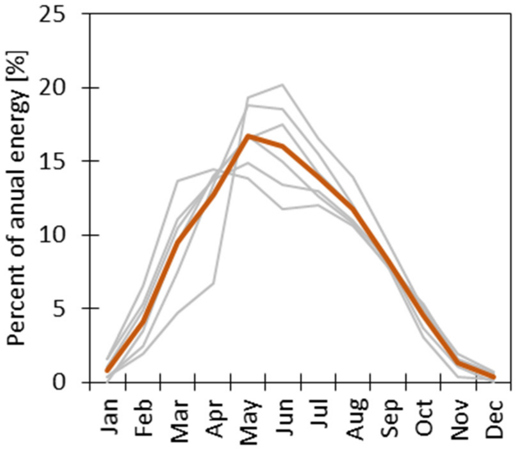

**Figure 2-7 | Monthly performance of Yukon PV systems**. Monthly performance is expressed as a percent of the energy produced in a year by each system. Grey lines represent individual systems, and the red line represents the average.

PV systems at the Yukon College and on the roof of the Yukon Government's main administration building have been in operation since 2008 and provide longer term performance data. **Figure 2-8** shows the year by year performance for these two systems along with the measured solar insolation for the year.

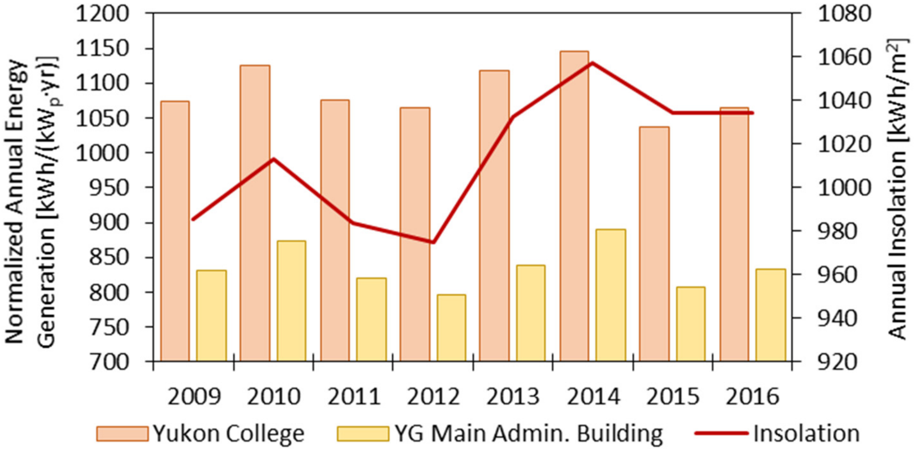

**Figure 2-8 | Annual normalized performance of two Yukon systems and annual solar insolation**. The total energy produced each year by two systems normalized to their system size. The system size for the YG Main admin building is 4.1 $kW_p$ and Yukon College is 1.5 $kW_p$. Insolation was measured at Yukon College on a horizontal plane.

## 2.3 Daily consumption, generation, and export trends

Under the micro-generation program, any electricity generated is first used by the client and any remaining energy is exported to the grid. The amount of power exported to the grid at any given time is the difference between the power generated by the PV system and the power consumed by the client.

### 2.3.1 Typical household power consumption

Hourly power usage for Yukon households is not readily available. As a substitute, modeled data has been used to estimate how Yukon households use energy throughout the day. Average monthly energy usage was set to 875 kWh. Hourly consumption was based off profiles developed for Fairbanks AK, and Anchorage AK, by the US Department of Energy. These profiles were adapted to Yukon households by including electricity loads associated with hot water heating, and calibrated using hourly weighting factors such that the predicted annual power exported from households currently enrolled in the program is well represented by the model.

### 2.3.2 Hourly export patterns

The micro-generation program incents surplus energy exports to the grid by providing an annual reimbursement for exported energy. The amount of energy exported to the grid is the difference between the amount of electricity generated on the property and the amount being used (the electric load) on the property at any given time. Fluctuations in both generation and load occur throughout the day, which requires hourly as well as seasonal insight into both generation and load to understand patterns associated with PV energy exports.

The average rates of power generation and consumption for a typical household with a 5$kW_p$ PV system installed in Whitehorse are shown in **Figure 2-9**. The hourly PV generation profiles shown in **Figure 2-9** are based on the average performance measured for six different systems in the Whitehorse area. Power consumption varies from building to building, but typically peaks during the morning and evening when more lights and appliances are in use, and more hot water is required for showers, baths, and cleaning. On average, solar irradiation peaks around midday when the sun is highest in the sky and has less atmosphere to penetrate before reaching the earth. As a result, exported power peaks during midday when consumption is at a minimum and generation is at its maximum.

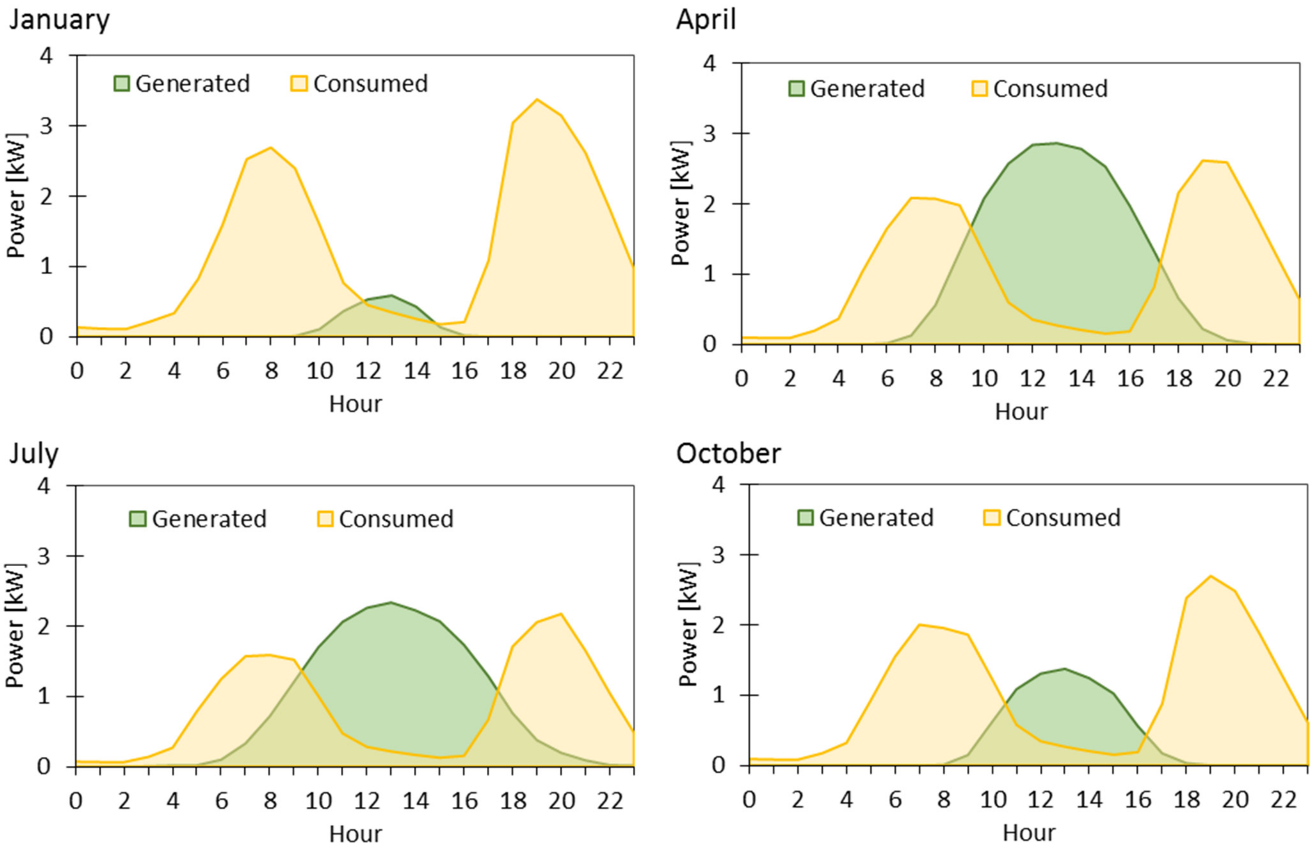

**Figure 2-9 | Power generated versus power consumed** by a typical 5 kWp PV system in Whitehorse. Power generation is based on typical performance observed for PV systems operating in the month of May, and power consumption data is based on a typical residential load model.

## 2.4 Seasonal consumption, generation, and export trends

Seasonally, the amount of exported energy varies substantially, as shown in **Figure 2-10(a)**. The dark red line represents the average annual export during the day while the shaded envelope represents the maximum and minimum exports over the course of a year. It is worth noting that that even though total PV energy generation may fall short of the total energy demand of a building on an annual or monthly basis, energy exports to the grid still occur because of the mismatch between the demand for energy and its supply during the day. **Figure 2-10(b)** illustrates for a 5 kW system that a large fraction >50% of the energy generated by the PV from month to month is exported, even though the total amount generated never exceeds the total demand for energy.

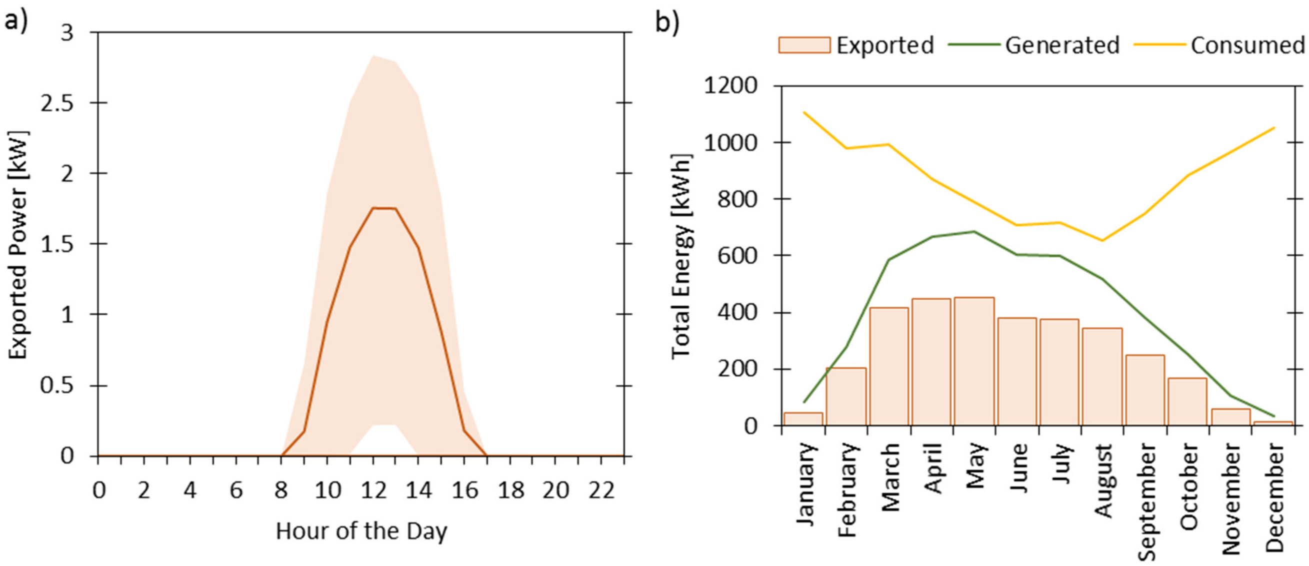

**Figure 2-10 | Power export trends**. **a)** Exported power by a 5 kWp PV system over the course of a typical day. The line shows the annual average exported power and the shaded region shows the range of monthly averages over the course of the year. **b)** Monthly totals for exported, generated and consumed energy. The closer the export bars approach the green generation line, the larger the fraction of generated energy is exported to the grid rather than used to offset internal energy demand. Export data is based on typical PV performance observed in Whitehorse, and simulated household energy consumption.

## 2.5 Annual exports

The micro-generation program issues annual payments for exported power. The chart in **Figure 2-11(a)** shows the total annual energy exported for several micro-generation program clients by system size (blue dots). Also shown are the expected annual exports based on the modelled household energy consumption profile developed in this report, typical PV module performance, and seasonal irradiation and weather patterns. The model agrees well with the data collected to date from micro-generation program participants.

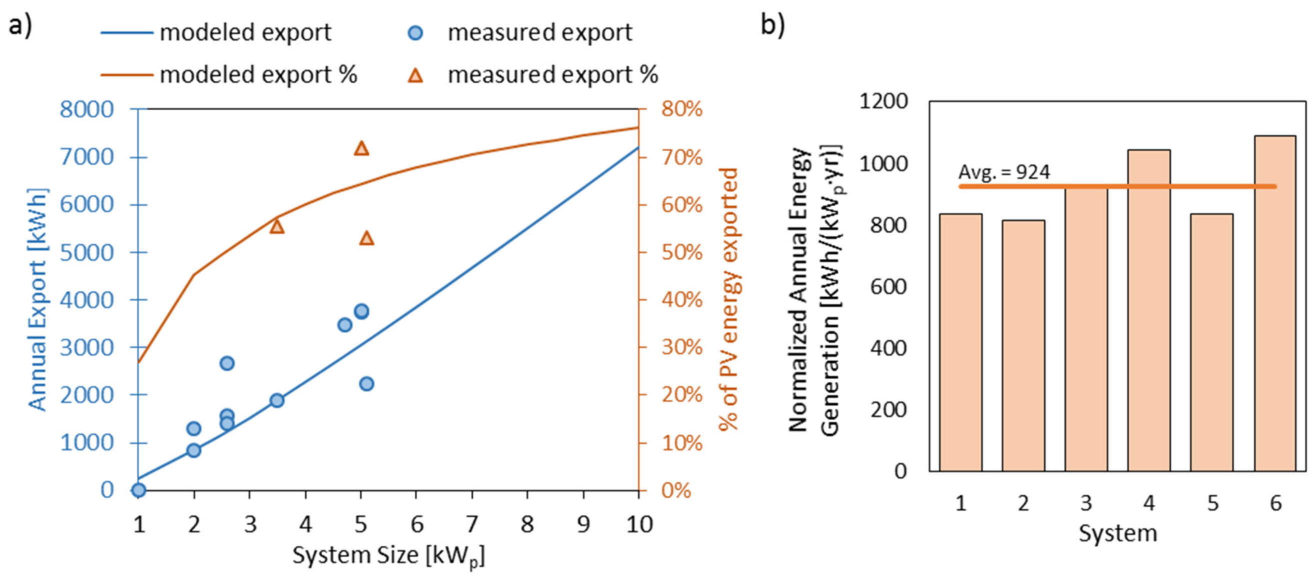

**Figure 2-11 | Annual energy export and generation for Yukon PV systems. a)** Data points represent data collected from micro-generation program participants whose systems have been operational for at least one full year. Solid lines represent modeled data based on a simulated residential load profiles, typical PV module performance, and seasonal irradiation and weather patterns. **b)** Normalized annual energy generation for several Yukon systems.

Based on the modeled energy export, as shown in **Figure 2-11(a)**, typical residential sized systems will export between 40% and 70% of the PV energy they generate, which is consistent with actual data, see red triangles in **Figure 2-11(a)** from micro-generation program participants.

On average, based on data collected from six different PV systems installed in the Whitehorse area, PV systems generate approximates 924 kWh/(kW$_p$·yr). **Figure 2-11(b)** highlights the variation in system performance in this regard.

# 3. Micro-generation forecast

## 3.1 Adoption of PV micro-generation

Consumer adoption of PV in Yukon is accelerating. The data in **Figure 3-1** and **Table 3-1** show an increasing rate of adoption year-over-year since the program began. Growth has been dominated by residential installations in integrated-hydro grid communities, while general service and institutional installations are predominant in diesel communities.

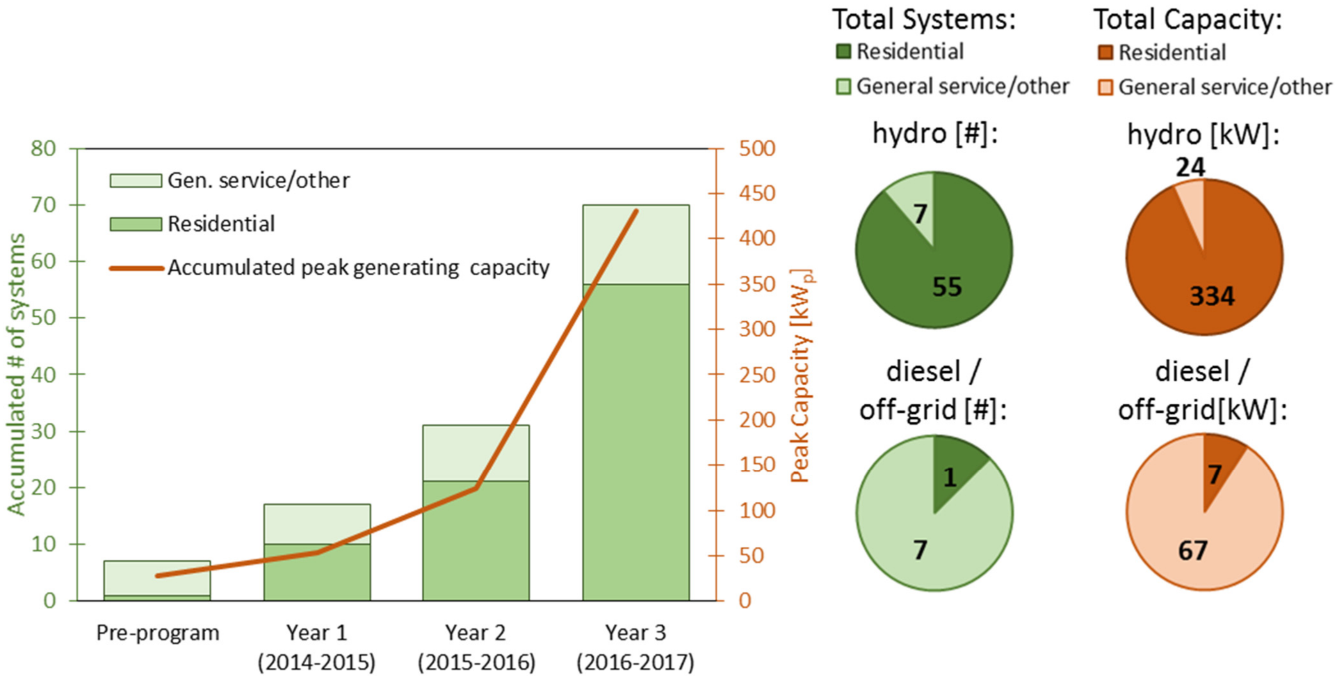

**Figure 3-1 | PV system adoption trends**. Bar graph shows the total number of residential and general service/other installations in Yukon, while the line shows the cumulative peak capacity of these systems. The pie charts to the right show the breakdown of the current PV installations based on their connection to the integrated hydro grid and service classification.

**Table 3-1 | New PV system installations by year**

| | # of systems added | | | Peak generating capacity added [kW$_p$] | | | Average system size [kW$_p$/system] | | |
|---|---|---|---|---|---|---|---|---|---|
| Program year | Residential | Gen. Service/other | **Combined** | Residential | Gen. Service/other | **Combined** | Residential | Gen. Service/other | **Combined** |
| Pre-program | 1 | 6 | **7** | 4 | 24 | 28 | 4.0 | 4.0 | **4.0** |
| Year 1 (2014-2015) | 9 | 1 | **10** | 24 | 2 | 26 | 2.6 | 2.1 | **2.6** |
| Year 2 (2015-2016) | 11 | 3 | **14** | 50 | 20 | 70 | 4.6 | 6.6 | **5.0** |
| Year 3 (2016-2017) | 35 | 4 | **38** | 263 | 45 | 308 | 7.5 | 11.2 | **7.9** |
| TOTAL: | 56 | 14 | **69** | 341 | 90 | **431** | 6.1 | 6.5 | **6.2** |

### 3.1.1 Key drivers of PV adoption

#### 3.1.1.1 Economics

Generation of one's own electricity is attractive for its perceived financial benefit. The cost of installing a PV system has dropped dramatically over the years and the introduction of government incentive programs has made the case for installing a PV system more attractive.

Typical costs for residential PV installations range between $2,000 and $7,500 per kW. Based on the typical usage and export patterns developed in this report, these installed PV system costs translates to payback periods as low as 11 years and as high as 40 years (i.e. beyond the design life of the PV system) – see **Figure 3-2**.

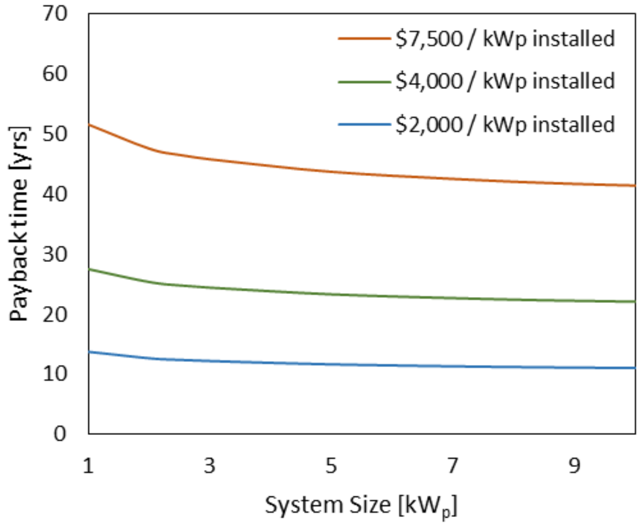

**Figure 3-2 | Simple economic payback of installed PV systems**. Payback is determined using the typical household load profiles and PV performance profiles described in this report, assuming a price of electricity of $0.12/kWh and current reimbursement rate for exported electricity in hydro communities of $0.21/kWh.

#### 3.1.1.2 Environmental stewardship

The desire to reduce greenhouse gas emissions, pollution and environmental footprint is a strong motivation to adopt renewable energy sources. In Yukon, the most significant contribution to greenhouse gas emissions occurs when renewable electricity offsets the use of electricity generated with fossil fuels – either diesel or natural gas.

### 3.1.2 Timescale of adoption – Insight from other jurisdictions

A key aspect of forecasting technology adoption is the timescale in which market saturation occurs. Some insight into this timescale can be gained by looking at other jurisdictions. **Figure 3-3** shows the adoption of PV systems in Australia, Germany, Alberta and California showing both the number of new installations added each year as well as the cumulative total for the added and cumulative generating capacity. In both jurisdictions, adoption of PV systems has been strongly encouraged through rebates or feed in tariffs or both.

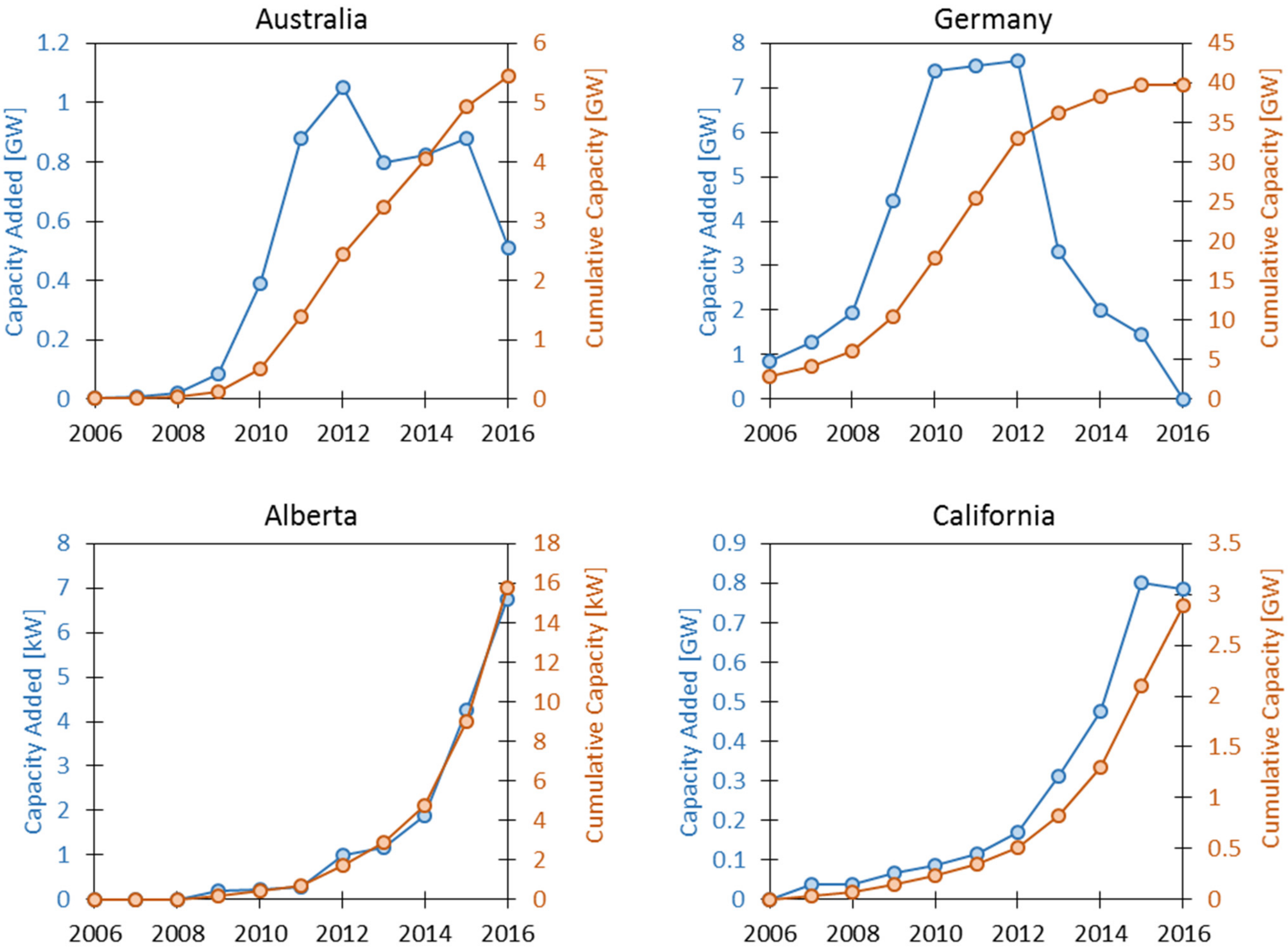

**Figure 3-3** | Adoption of PV systems in other jurisdictions.[1]

From the charts in **Figure 3-3**, PV generation capacity growth in Germany began to saturate after ~10 year and has shown signs of slowing in Australia after a similar amount of time. Alberta, a jurisdiction without significant government incentives for micro-generation, is only beginning to scale up its PV generation capacity. PV systems in California have continued to increase rapidly, growth that is expected to continue for years to come. In Yukon, as in these other jurisdictions, many factors will affect the adoption of new systems, including decreasing price, continued government support for incentive programs, the price of electricity, as well as social and economic factors. These variables will affect both the magnitude and the rate of PV adoption, though the trends observed in **Figure 3-3** can provide insight into how this has played out previously in other jurisdictions.

### 3.1.3 Yukon residential PV market size

In the absence of detailed market research, an estimate of the number of Yukon buildings that will adopt PV systems was determined from the total number of Yukon housing stock. **Table 3-2** shows the number and type of

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[1] Source: a) Australian PV institute (http://pv-map.apvi.org.au/analyses), b) German Federal Ministry for Economic Affairs and Energy (www.bmwi.de/EN/Topics/Energy/Energy-data-and-forecasts/energy-data) c) Alberta Electric Systems Operator (www.aeso.ca), d) California Distributed Generation Statistics, California Solar Initiative (www.californiadgstats.ca.gov)

dwellings in the Yukon according to 2011 Census data from Statistics Canada. Depending on the type of dwelling, a determination was made as to whether or not that dwelling type is amenable to having a PV system installed. For instance, apartments and moveable dwellings such as mobile homes were not considered amenable to PV systems, from an individual residence perspective. This assessment gives an approximation of the total residential market size for PV.

**Table 3-2** | **Number of Yukon dwellings by type***

| Dwelling Type | Yukon | Hydro Communities | Diesel Communities | Amenable to PV |
|---|---|---|---|---|
| Single-detached house | 9,165 | 8,750 | 415 | YES |
| Apartment, five or more storeys | 5 | 5 | 0 | NO |
| Movable dwelling[1] | 1,220 | 1,145 | 75 | NO |
| Semi-detached | 990 | 955 | 35 | YES |
| Row House | 565 | 565 | 0 | YES |
| Apartment - duplex | 480 | 475 | 5 | YES |
| Apartment – less than 5 storeys | 1625 | 1,590 | 35 | NO |
| Other single attached house | 75 | 75 | 0 | NO |
| TOTAL Amenable to PV | 11,200 | 10,745 | 455 | |

1. Includes mobile homes and other movable dwellings such as houseboats and railroad cars.

*Source: Statistics Canada - 2011 Census

The total number of dwellings that will eventually choose to install a PV system will be some fraction of the total number of PV amenable dwellings. **Table 3-3** compares the penetration rates of PV into variety of different jurisdictions. The proportion of amenable households with PV systems ranges between 4% and 18% in the more mature markets of Germany and Australia respectively. California which is continuing to see rapid growth in PV installations is nearly at 3% penetration. These figures include PV systems of all types and sizes, including large scale solar farms. Having a large fraction of generating capacity come from large scale installations instead of residential scale systems is reflected in a lower figure for PV systems per amenable household. As a compliment to this metric, installed PV capacity per capita, shown in **Table 3-3** and **Figure 3-4** , reveals that on a per person basis, Germany is by far the leader with almost 0.5 $kW_p$ per capita installed in spite of its relatively small total system count. In the Yukon context, it is likely that the majority of PV installations connected to the integrated hydro grid will be residential scale in size as opposed to large scale (i.e. > 100kW). Therefore, in developing a forecast of Yukon PV uptake, three levels of household penetration were assessed, 2%, 5%, and 10%, based on residential uptake (as opposed to per capita uptake).

**Table 3-3** | **PV systems per amenable dwelling**

| Jurisdiction | PV Systems per amenable household | Installed PV Capacity per Capita [kW] |
|---|---|---|
| Germany | 4.1% | 0.49 |
| Australia | 17.4% | 0.24 |

| | | |
|---|---|---|
| California | 2.8% | 0.076 |
| Alberta | 0.1% | 0.004 |
| Yukon | 0.5% | 0.011 |

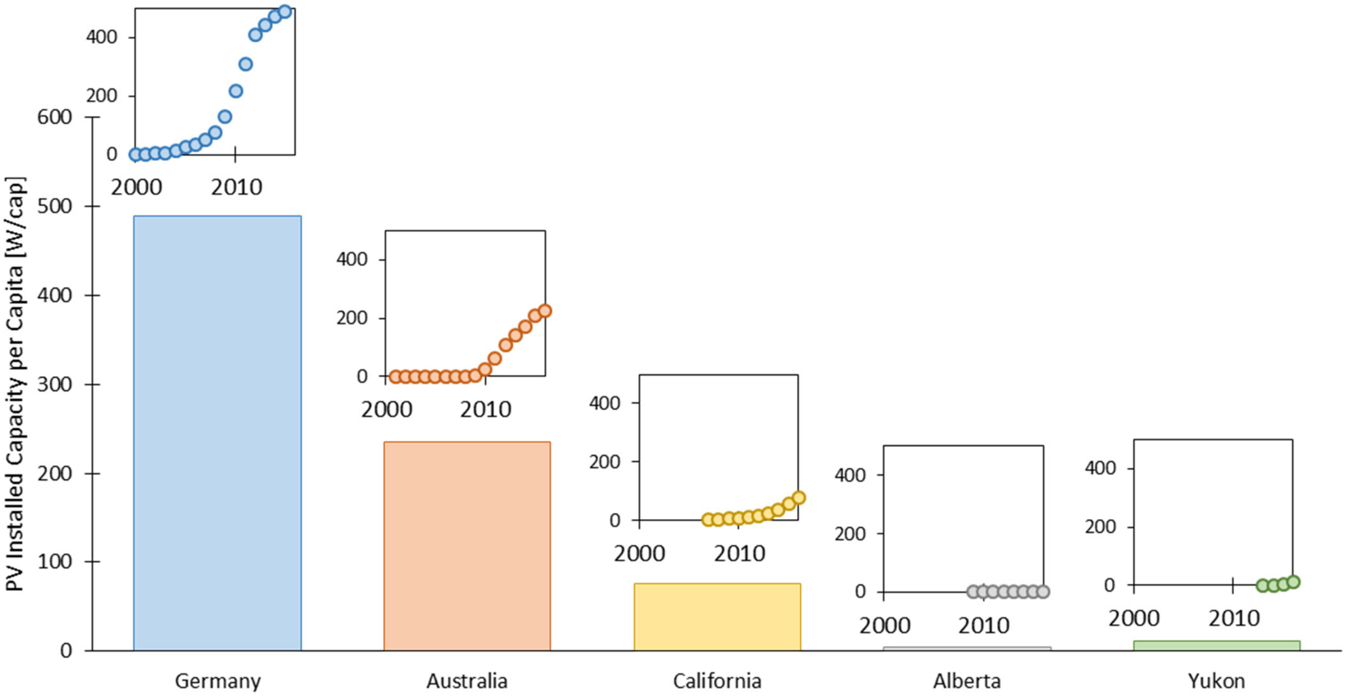

**Figure 3-4 | PV Capacity per capita**. These charts gives an indication of the uptake of PV systems into the market. The insets show for each jurisdiction the rate of increase of PV capacity per capita over time. The values shown are calculated from the total PV capacity in the jurisdiction divided by the population of the jurisdiction.

### 3.1.4 PV system size

The average size of PV installations has increased over time as systems become more affordable, as shown in **Figure 3-5**. Practical limits exist on the size of residential PV systems driven largely by the electrical grid infrastructure to which they are connected, and the amount of space available to install panels. Residential systems are therefore typically limited to less than 10kW. Large scale systems, including institutional systems, community projects, and independent power production facilities (i.e. solar farms), drive up the average size of new systems. Alberta for example, has seen a recent surge in the average size of new builds driven largely by new large scale solar projects. In the future as residential installs become more popular, it is likely that this number will decrease. Based on residential scale PV limitations in size and generating capacity, a conservative annual growth factor of 2% was assumed for the average system size in Yukon, shown as the dashed line in **Figure 3-5**.

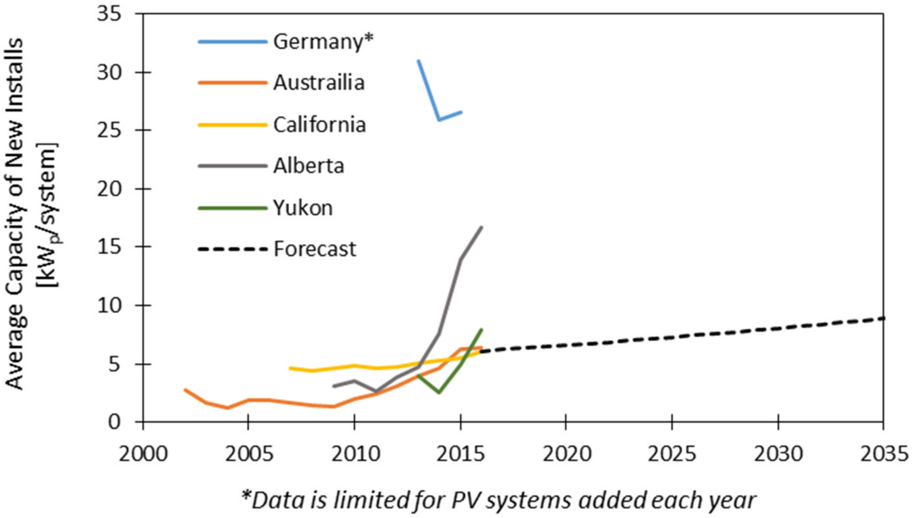

**Figure 3-5 | Average capacity of new systems by year**. The dashed line represents the forecasted average new system size based on a 2% annual increase in size.

### 3.1.5 Forecast of residential hydro-grid PV uptake

A baseline forecast for PV uptake on the hydro grid was generated using a Bass Diffusion Model. The model used the market size assumptions described in Section 3.1.3, and was calibrated against existing installation data. **Figure 3-6** shows the forecasted number of residential hydro-grid tied installations for the next 20 years. The time-scale of adoption is approximately 10 years and is similar to the trends observed in other jurisdictions described in Section 3.1.2.

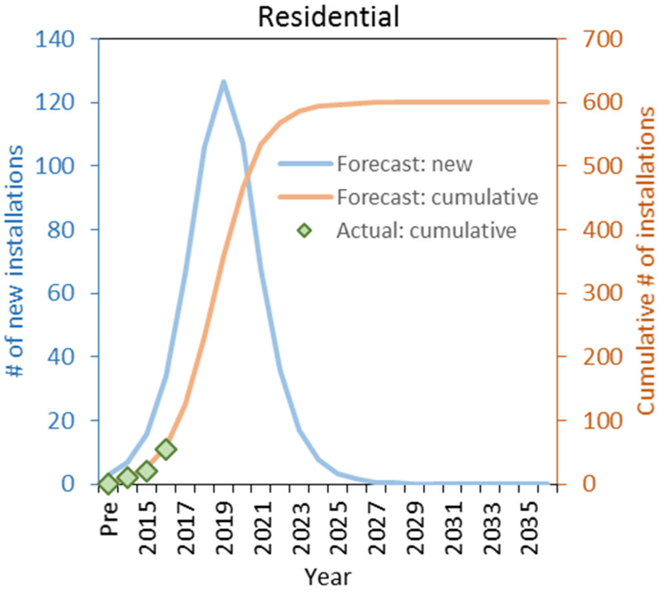

**Figure 3-6 | Forecast of hydro grid tied residential PV system adoption in Yukon.**

The majority of future PV capacity in hydro-grid communities is expected to come from residential installs. Growth of commercial and institutional PV systems in hydro-grid communities has so far has been small (**Figure 3-1**), and does not represent a major component of the long range forecast for hydro-grid PV installations. Based on these projections, integrated hydro-grid tied PV generation could range between 1-8 MW of generation capacity by 2023 (**Figure 3-7**).

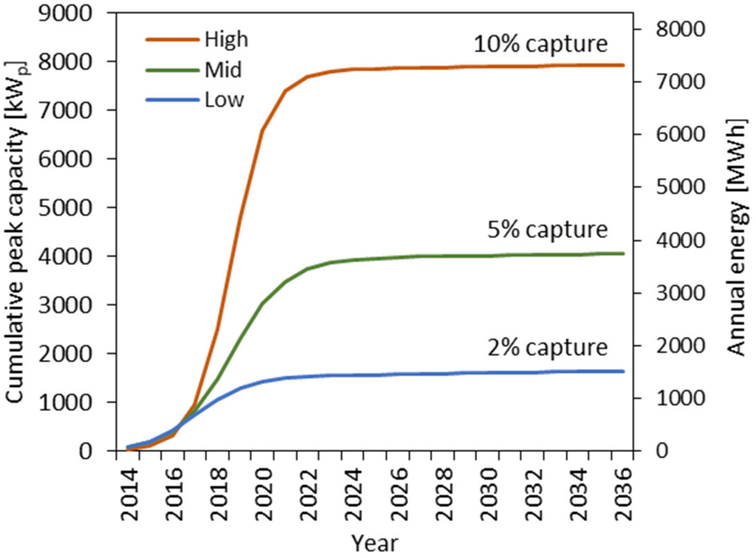

**Figure 3-7 | Forecast of integrated hydro grid installed PV generation**. Left axis shows the forecasted cumulative peak PV capacity based on 2%, 5%, and 10% capture rate of residential buildings adopting PV panels, and 1.8% annual population growth. The right axis reports the forecasted annual energy generated based on the average annual energy generated by a sample of Yukon PV systems, which is 924 kWh/kWp, see Figure **2-11(b)**.

### 3.1.6 PV impact on GHG emissions

Yukon supplements its hydro-electricity with thermally generated electricity in order to deliver reliable electrical service. The degree to which thermally generated electricity is leveraged depends on the demand for electricity, and the availability of hydro generating capacity and resources. Available hydro resources peak during the summer as lakes and reservoirs fill up, and are consumed during the winter when inflows are at a minimum. Maintenance, planned and unplanned, of hydro generation facilities also limits the amount of hydro generating capacity available during these activities. Planned maintenance typically occurs during the summer. The monthly thermal energy generated for the last five years is shown in **Figure 3-8**, and highlights the seasonality for thermal energy generation in the territory.

During periods of low industrial activity, thermal power generation occurs periodically in short bursts of several hours throughout a given month to meet peak electricity demand. Each month, a portion of thermal generation results from mandatory monthly operation of diesel and natural gas turbines to ensure their operability and accounts for approximately 86 MWh of energy each month. During times of high industrial activity, or when maintenance or unplanned outages result in a decrease in hydro generating capacity, the frequency and duration of thermal generation intervals increases. Over the last six years, Yukon has seen periods of both high and low industrial activity as well as several major service interruptions and maintenance activities.

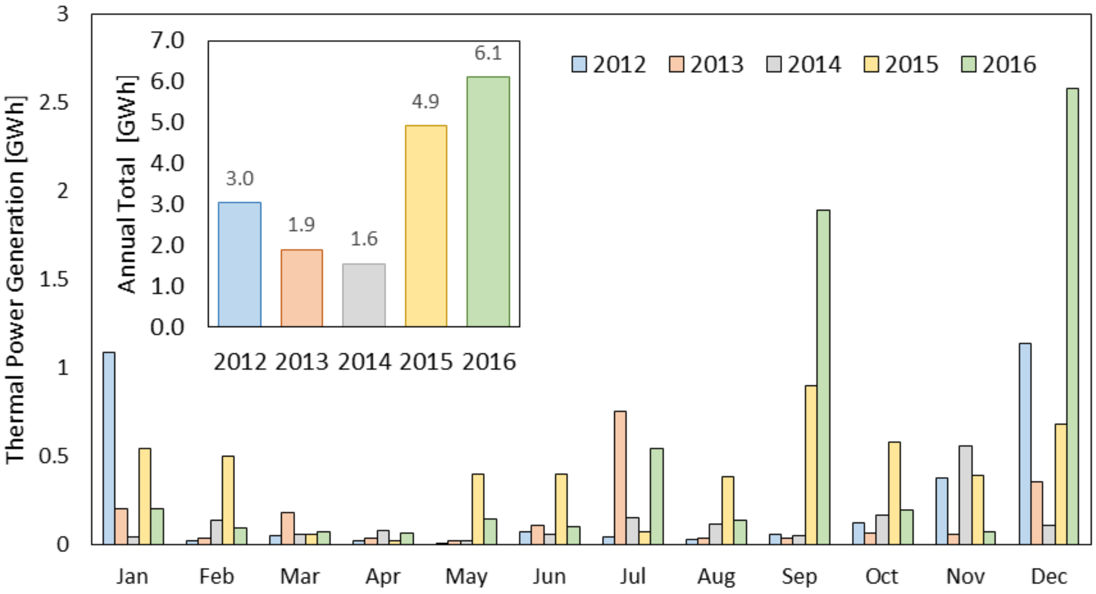

**Figure 3-8 | Thermal energy generation in Yukon.** Bar chart showing the total power generated by burning diesel or natural gas each month for the last five years. The inset shows the total thermal energy generated for the full year.

By comparing hourly thermal generation data from the last six years to hourly PV generation data, a Yukon specific $CO_2$ offset can be calculated. These offsets are listed in **Table 3-4** for 2011-2016. For typical low activity years, PV systems offset between 0.1 and 0.2 $tCO_2/kW_p$. Maintenance activities and unplanned outages, particularly during late spring and summer months when PV generation is at a maximum, result in greater opportunity for PV $CO_2$ offsets, as can be seen in 2015 and 2016. High thermal generation in 2011 to support industrial activity was a major factor in the high $CO_2$ offset for that year. If nothing else, the data in **Table 3-4** highlights the variable nature of PV systems at offsetting $CO_2$ which is related to the intermittent nature of PV combine with the intermittent use of diesel and natural gas for electricity generation. When energy demand is high, or hydro generation capacity is low, the potential to offset $CO_2$ increases. When energy demand is moderate, as has been the case since 2012, the $CO_2$ offset potential of PV is significantly lower, occurring only at times when the both thermal generation and solar generation coincide.

**Table 3-4 | Annual average carbon offset of PV systems**

| **Year** | **PV Carbon Offset [$tCO_2/kW_p$]** |
|---|---|
| 2016 | 0.22 |
| 2015 | 0.28 |
| 2014 | 0.18 |
| 2013 | 0.24 |
| 2012 | 0.1 |
| 2011 | 0.61 |

Future energy demand forecasts for the next 20 years have recently been developed by Yukon Energy as part of their long term resource plan.[2] These scenarios represent low, medium, and high industrial activity, and provide insight into the magnitude of future energy demand. In the high industrial activity scenario energy demand increases by over 70% from 2014 levels. Industrial electricity demand is less variable on an hour-by-hour basis than residential demand, meaning that demand for power is more consistent throughout the day. Under this scenario, PV energy has the highest potential to offset $CO_2$ emission and is likely to be similar to that seen in 2011, between 0.6 and 0.7 $tCO_2/kW_p$.

The low industrial activity forecast prepared by Yukon Energy predicts less than 10% total growth in electrical demand over 2014 levels. Under this scenario, PV $CO_2$ offset potential remains similar to what has been seen in recent years, ~0.2 $tCO_2/kW_p$. As the magnitude of PV generation increases however, the average potential to displace thermal generation will decrease as the net power contributed by PV systems begins to fully displace the need for thermal energy at certain times of the year. In this event, additional PV capacity does not contribute further to offsetting thermal energy. For 4MW of installed PV capacity, the amount forecasted at a 5% participation rate by 2025, the $CO_2$ offset potential on average is reduced to ~0.12 $tCO_2/kW_p$ for the low industrial activity load.

### 3.1.7 Technology advances outlook

Over the next twenty years we will almost certainly see the introduction of new micro-generation technologies that will be attractive to Yukon residents and businesses. Tesla Inc. (www.tesla.com) has generated much interest in their solar shingles concept, though little technical data has been released to provide insight on their performance. Nevertheless, the concept of solar panels playing the dual function as both roofing material and power generation system could make them significantly more attractive to the average consumer – both from a functional and economic perspective, particularly since the lifespan of Tesla's solar shingles has been suggested to be around 50 years.

Presently, urban residential installations are typically limited in size to 5 kW in order to not overload the transformer connecting the property to the main power grid. This puts a limit on the generation capacity of urban residential units, even as new technologies make larger generating capacities more available and affordable. Country residential and rural installations can have more relaxed restrictions and may therefore benefit more from technology advances that allow for larger generation capacities.

As a result, the average generating capacity of new systems is likely to increase over time, though will be moderated by current infrastructure and policy restrictions. Currently, the average system size for residential systems is 6.1 kW. New technologies that make installing PV systems more practical and affordable will result in higher consumer adoption rates, and will push the rate closer to the high (10%) capture rate scenario described in **Figure 3-7** or beyond.

### 3.1.8 Yukon diesel communities

In addition to new solar systems being added to the integrated hydro grid in Yukon, a significant growth opportunity exists in off-grid communities, from both an economic and environmental perspective. Because these communities rely entirely on diesel generation, all the energy generated by PV systems goes towards offsetting thermal generation. A full life-cycle assessment of cost and greenhouse gas emissions of diesel generation in off-grid Yukon communities has not been conducted, but would provide insight into the true impact PV systems would have in Yukon. The intermittency of solar power means that thermal generation will remain a requirement in these communities however in order to consistently meet demand during peak periods and also requires monitoring and management of the local

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[2] http://resourceplan.yukonenergy.ca/more

electric grid to balance generation and demand. Energy storage solutions, both short-term (daily) and long-term (seasonal), could help address these capacity related challenges in the context of increased adoption of renewables in off-grid communities. The optimal mix of renewable generation and energy storage options remains a subject of active research.

## 3.2 Conclusions and recommendations

The adoption of solar power in the Yukon is increasing. Fueled by incentives offered by the Government of Yukon through rebates and feed in tariffs administered through the Energy Solutions Centre, adoption of solar energy is expected to continue and accelerate. By 2025, it is expected that $4\text{MW}_\text{p}$ of generation capacity could be installed in the territory according to mid-level estimates, and as much as $8\text{MW}_\text{p}$ according to high level estimates. On average, PV systems in the Yukon produce 924 $\text{kWh}/\text{kW}_\text{p}$ annually, and export between 40% and 70% of this energy back to the grid.

Recommendations for further work to better understand and prepare Yukon for how our energy landscape will be effected by the growth of distributed, intermittent, capacity include:

1. **Evaluation of long-term and short-term energy storage options in Yukon** – Production of renewable energy usually occurs during times when demand for energy is low, and follows both daily and seasonal cycles. Understanding how energy can be stored when demand is low and used when demand is high would maximize the benefit of renewable generation technology in Yukon. Consideration of the applicability and affordability of storage solutions in Yukon, such as batteries, would help Yukoners weigh the pros and cons of these options and help define the path towards greater penetration of renewables into Yukon's energy mix.

2. **Evaluation of the potential to use time-of-day export premiums** – Electricity generation is at a maximum during periods of low electricity demand. Steps can be taken however to orient solar modules to preferentially generate more power during times of higher demand. This behavior typically comes at the cost of net energy generation and consequently does not make sense under the current flat rate energy reimbursement policy. By increasing the incentive for energy exported to the grid during times of high energy demand, the negative economic implications to the micro-generation participants can be mitigated while encouraging energy saving behavior during those times as well.

3. **End-use study of residential electricity consumption** – Data does not currently exist to describe residential demand on an hour-by-hour basis in Yukon homes. Our understanding of the interplay between micro-generation, residential consumption, energy exports, and greenhouse gas emission offsets, would benefit from a clearer picture of Yukon residential consumption patterns. Current analysis relies on generalized housing models that have not been validated against actual Yukon residential patterns. Collecting hourly data from a cross-section of Yukon homes therefore, would help develop more accurate demand models. Measuring current usage patterns would also establish a baseline which can be used to evaluate the effectiveness of future demand side energy management initiatives.

4. **Life-cycle assessment of diesel power generation in Yukon communities** – Current figures used to represent the greenhouse gas impact and in particular of diesel electricity generation do not take into account the full cradle-to-grave cost of fuel, machinery, and maintenance. For many remote communities these costs can be substantially higher than diesel generation in other locations. Understanding these costs from both an economic and environmental perspective will improve our ability to assess the potential impact of renewable technologies in these communities.