TECHNICAL-ECONOMIC FEASIBILITY AND SIMULATION OF ÉTS' ELECTRICITY SAVING WITH PHOTOVOLTAIC SYSTEM AND BATTERIES

by

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FOREWORD

This report represents 30 out of 45 credits of the Master of Science in Renewable and Efficiency Energy, which was presented at École de Technologie Supérieure, under the supervision of the professor Louis A. Dessaint from Electrical department. The goal of this research is to make a technical-economic feasibility study and a yearly simulation of École de Technologie Supérieure's electricity expenses and savings with and without Solar Photovoltaic System, Battery Energy Storage System, financial incentives or demand response scenarios, taking into account the Quebec and Ontario electricity rates.

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Faisabilité technique-économique et simulation d'économie d'électricité d'ÉTS avec de système photovoltaïque et des batteries

Fernando DIAS DA CRUZ

RÉSUMÉ

L'objectif de ce mémoire est de réaliser une étude de faisabilité technico-économique et une simulation annuelle des dépenses et des économies d'électricité de l'École de Technologie Supérieure avec et sans système solaire photovoltaïque, système de stockage d'énergie par batterie, d'incitations financières ou de réponse à la demande, en tenant compte des facteurs suivants: les tarifs d'électricité du Québec et de l'Ontario en 2017.

Six scénarios sont proposés et simulés dans un intervalle de 5 minutes avec les données de puissance électrique de l'ÉTS en 2017, l'irradiance solaire et la température de Montréal et l'ensemble des charges d'électricité du Québec et de l'Ontario pour un client de 5 MW comme l'ÉTS. Toutes les simulations ont été réalisées avec le logiciel MATLAB SimScape Power System, où chaque système a été analysé séparément et / ou ensemble, comme suit:

0) Scénario de base: L'ÉTS en Ontario et au Québec avec des tarifs standard d'électricité;
1) l'ÉTS en Ontario avec incitatif financier et au Québec avec réponse à la demande;
2) l'ÉTS en Ontario avec incitatif financier et de système photovoltaïque (150 kW) ainsi qu'au Québec avec les tarifs standards et de système photovoltaïque;
3) l'ÉTS en ON avec incitatif financier, de système photovoltaïque (150 kW) et des batteries (250 kW), ainsi qu'au QC avec la réponse à la demande, de système PV et des batteries;
4) ÉTS en Ontario avec incitatif financier et des batteries (250 kW) ainsi qu'au Québec avec réponse à la demande et des batteries;
5A / 5B) l'ÉTS en Ontario avec incitatif financier, des batteries avec tarification à l'utilisation (250 kW) (5A) et avec des panneaux photovoltaïques (150 kW) (5B);
6) l'ÉTS en ON avec incitatif financier, de système photovoltaïque (500 kW) et des batteries (250 kW), ainsi qu'au QC avec la réponse à la demande, de système PV et des batteries;

Premièrement, la simulation a montré que les panneaux photovoltaïques réduisaient le pic de puissance de 5 MW et la consommation d'énergie dans les deux provinces, tandis que les batteries réduisaient le pic de puissance et permettaient la participation au programme de réponse à la demande, GDP, au Québec. Deuxièmement, le coût de l'énergie et de puissance représentent environ 93% et 7% de la facture annuelle en ON, respectivement et 61% et 39% au QC. De plus, les résultats de la simulation indiquent que la différence de prix de l'électricité entre les deux provinces est énorme. C'est autour quatre fois plus cher en Ontario qu'au Québec, soit environ 0.27 $/kWh et 0.057 $/kWh, respectivement. La simulation a également montré que le prix par kWh avait été réduit de 13.77% en Ontario, passant de 0.3025 $/kWh à 0.2608 $/kWh et au Québec, de 6.08%, passant de 0.0571 $/kWh à 0.0536 $/kWh, après avoir ajouté des systèmes PV, des batteries, d'incitation financier ou de réponse à la demande.

En outre, la simulation indiquait une économie d'énergie annuelle de 412,77 MWh sur MATLAB SimScape et de 260.53 MWh dans RETScreen pour 'l'électricité exportée vers le réseau' en utilisant des panneaux photovoltaïques de 150 kW (3% de 5 MW de l'ÉTS). En outre, MATLAB a réalisé des économies d'énergie annuelles de 1,376.95 MWh et dans RETScreen de 868.42 MWh en utilisant des panneaux photovoltaïques de 500 kW (10% de 5 MW de l'ÉTS). La variance d'environ 50% inférieure dans RETScreen indique une méthode plus précise que MATLAB, par l'économie d'énergie, avec différentes données des inputs (d'irradiance solaire, température) et des coefficients de perte plus élevés dans RETScreen.

La faisabilité technico-économique indiquait que le système solaire photovoltaïque était réalisable sur le plan économique en Ontario, où une économie annuelle de $151,574.73 avait été réalisée pour un MPP de 150 kW, avec un investissement de $873,050, un TRI et une VAN élevé et une période de retour sur investissement basse. Sur la base de cette économie d'électricité potentielle liée à l'utilisation de panneaux photovoltaïques, un MPP supérieur aléatoire de 500 kW a été simulé. Les chiffres suivants ont ainsi été obtenus: une économie annuelle de 493,515.15 dollars canadiens pour un investissement de 2,773,435 dollars, une VAN et un TRI supérieurs et une période de retour d'investissement plus basse, en raison des économies d'échelle. En raison de son faible prix de l'électricité, aucun système solaire photovoltaïque n'était économiquement réalisable au Québec. En outre, le BESS de 250 kW n'est économiquement réalisable ni à l'ON ni au Québec, en raison d'un investissement élevé, d'une basse économie d'énergie annuelle et de retour d'investissement haut.

En Ontario, l'ÉTS devrait utiliser un système de panneaux photovoltaïques de 500 kW (10% de 5 MW requis) ou plus, sans aucune batterie, afin de réduire considérablement la valeur de la facture annuelle et le prix par kWh avec un faible retour sur investissement. Les TRI et VAN sont élevés pour l'investissement requis. En plus de cela, participez également au marché de gros détenu par IESO via des enchères visant à réduire le coût de l'électricité / kWh, payez le Global Adjustment par consommation ou en PDF (9% de réduction de facture annuelle) et participez à l'enchère de réponse à la demande de IESO.

Au Québec, l'ÉTS devrait utiliser un système BESS de 250 kW sans aucun système photovoltaïque pour réduire le pic de puissance de plus de 5 MW et participer au programme de réponse à la demande, GDP, de HQ, uniquement s'il existe une incitation financière ou un don pour acquérir l'équipement auprès d'un fournisseur ou du gouvernement, selon le cas (à l'ÉTS). Autrement, ni système photovoltaïque ni groupe de batteries ne sont recommandés.

Mots-clés: Système solaire photovoltaïque, batteries, simulation, faisabilité technico-économique, écrêtage

Technical-Economic Feasibility and Simulation of ÉTS' Electricity Saving with Photovoltaic System and Batteries

Fernando DIAS DA CRUZ

ABSTRACT

The goal of this Master's thesis is to make a technical-economic feasibility study and a yearly simulation of École de Technologie Supérieure's electricity expenses and savings with and without a Solar Photovoltaic System, Battery Energy Storage System, financial incentives or demand response, taking into account the Quebec and Ontario electricity rates in 2017.

Six scenarios are proposed and simulated in a 5-minute interval with 2017 ÉTS power data, Montreal's solar irradiance and temperature and all Quebec and Ontario's electricity charges for a 5 MW customer as ÉTS. All simulations were obtained with Matlab SimScape Power System, where each system was analyzed separately and/or together, as followed:

0) Baseline Scenario: ÉTS in Ontario and Quebec with electricity standard rates;
1) ÉTS in Ontario with financial incentive and in Quebec with demand response;
2) ÉTS in Ontario with financial incentive and Photovoltaic Arrays (150kW) as well as in Quebec with standard rates and PV Arrays;
3) ÉTS in Ontario with financial incentive, PV Arrays (150 kW) and Batteries (250 kW) as well as in Quebec with demand response, PV Arrays and Batteries;
4) ÉTS in Ontario with financial incentive and Batteries (250 kW) as well as in Quebec with demand response and Batteries;
5A / 5B) ÉTS in Ontario with financial incentive, batteries with Time of Use pricing (250 kW) (5A) and also with Photovoltaic Panels (150 kW) (5B);
6) ÉTS in Ontario with financial incentive, PV Arrays (500 kW) and Batteries (250 kW) as well as in Quebec with demand response, PV Arrays and Batteries;

First, the simulation showed that PV System reduced the 5 MW peak power and energy consumption in both provinces, while battery energy storage system reduced the peak power and allowed the participation in the demand response program, GDP, in Quebec. Secondly, Energy and Power costs represented around 93% and 7% of a yearly bill in ON, while 61% and 39% in QC, respectively. Also, the simulation results indicated that the electricity rate variance between both provinces is huge, where it is around four times more expensive in ON than in QC, around 0.27 $/kWh and 0.057 $/kWh, respectively. The simulation also showed that the price per kWh was reduced up to 13.77% in ON from 0.3025 $/kWh to 0.2608 $/kWh and up to 6.08% in QC, from 0.0571 $/kWh to 0.0536 $/kWh, after adding PV systems, Batteries and financial incentives or demand response program.

Furthermore, the simulation indicated a yearly energy saving of 412.77 MWh from MATLAB SimScape Power System and 260.53 MWh from RETScreen for electricity exported to the grid, by using a 150 kW PV Arrays (3% of 5MW from ÉTS). Also, 1,376.95 MWh yearly energy savings from MATLAB and 868.42 MWh from RETScreen, by using a 500 kW PV

Arrays (10% of 5MW from ÉTS). The variance around 50% lower on RETScreen indicates a more accurate method for energy saving, with some different input data (solar irradiance and temperature) and higher loss coefficient on RETScreen.

The technical-economic feasibility indicated that a Solar PV System is economically feasible in Ontario, where an annual saving of $151,574.73 was reached for a 150 kW MPP, with a $873,050 investment, high IRR, high NPV and low payback period. Based on this potential electricity saving using a PV System, a random higher MPP of 500 kW was simulated, where an annual saving of $493,515.15 for $2,773,435 Investment, higher NPV, higher IRR and a lower payback than 150 kW were reached, due to economies of scale. No PV System was economically feasible in QC, due to its low electricity price. Also, the 250 kW BESS is not economically feasible neither in ON nor in QC, due to a high investment, low annual energy saving and a high payback period.

In Ontario, ÉTS should utilize a system of 500 kW of Photovoltaic System or higher, without any batteries, in order to achieve a considerable reduction in the yearly bill and on the price per kWh, with a low payback period and high IRR and NPV. Also, the participation of the Wholesale market held by IESO through bids to reduce the electricity cost/kWh, pay the GA by consumption or PDF (9% of yearly bill reduction) and participate of the Demand Response Auction by IESO.

In Quebec, ÉTS should utilize a 250 kW BESS without any Photovoltaic Arrays, to reduce the peak power over 5 MW and participate of the GDP's demand response program by HQ, but only if there is a financial incentive or donation to acquire the equipment from a supplier or the government, as it is going to occur to ÉTS. Otherwise, neither Photovoltaic system nor batteries banks are recommended.

Keywords: solar photovoltaic system, batteries, simulation, technical-economic feasibility, peak shaving

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AB	Canadian province of Alberta
AC	Alternating Current
AM1.5	Air Mass 1.5 Spectrum – 48.2º is the angle between the Sun & Earth under STC
BC	Canadian province of British Columbia
BESS	Battery Energy Storage System
DC	Direct Current
DR	Demand Response Program
ÉTS	École de Technologie Supérieure
EV	Electrical Vehicles
FF	Fill Factor – ratio between P_{max} generated by a solar cell and product V_{oc} * I_{sc}
FI	Financial Incentive
GA	Global Adjustment charge in ON
GDP	Gestion de la Demande de Puissance - a Demand Response Program HQ
GRÉPCI	Groupe de Recherche en Électronique de Puissance et Commande Industrielle
HO	Hydro One – Electric power Utility chosen in Ontario
HOEP	Hourly Ontario Energy Price – Wholesale market average hourly energy price
HQ	Hydro Québec – Electricity Generation, Transmission and Utility in Quebec
IEEE	Institute of Electrical and Electronics Engineers
IESO	Independent Electricity System Operator – Electrical Power Operator in ON
I_{mp}	Optimum Operating Current
I_{sc}	Short Circuit Current
IRR	Internal Rate of Return – Economic indicator of project feasibility

JB	Junction Box
L_{panel}	Length of Panel
MARR	Minimum Attractive Rate of Return
MPP	Maximum Power Point
N/A	Not Applicable
NA	North America
N_{blocks}	Number of blocks
NG	Natural Gas
NL	Canadian province of Newfoundland and Labrador
MB	Canadian province of Manitoba
NPV	Net Present Value – Economic indicator of project feasibility
NREL	National Renewable Energy Laboratory of the U.S. Department of Energy
ON	Canadian province of Ontario
OEB	Ontario Energy Board
p.a.	from Latin "per annum"
PDF	Peak Demand Factor – rate to calculate the percentage contribution of GA
P_{in}	Incident Power – for STC, P_{in} = 1000 W/m^2
P_{max}	Nominal Maximum Power
$P_{parallel}$	Number of Panels in parallel
P_{serie}	Number of Panels in serie
PP / PP^0	Payback Period / Minimum Acceptable Payback Period set by a Company
PV	Photovoltaic cell technology that converts solar energy in electricity

QC	Province of Quebec
REN21	Renewable Energy Policy Network for the 21st Century
RETScreen	Clean Energy Management Software developed by Natural Resources Canada
SOC range	State of Charge range. Used to protect a battery and increase its lifetime
SO	System Operator
SS	Sous-Sol – Under ground level
SSS	Standard Supply Services – electricity power charge in Ontario
STC	Standard Test Conditions – Irradiance:1000 W/m^2, T=25 ^oC, Spectrum AM1.5
STD	Standard
T	Temperature
TMY	Typical Meteorological Year data from NREL
ToU	Time-of-Use rates - variable price per kWh according to the hour of the day
TRI	Taux de Rentabilité Interne - indicateur economique primaire
U.S.	United States of America
VAN	Valeur Actuelle Nette – indicateur economique primaire
V_{mp}	Optimum Operating Voltage
V_{oc}	Open Circuit Voltage
W_{panel}	Width of Panel
W/	With
WO	Without
WMSC	Wholesale Market Service Charge - electricity energy charge in Ontario

LIST OF SYMBOLS AND UNITS OF MEASUREMENT

Ah	Ampere hours
Ca$	Express the amount in Canadian Dollars currency
^{o}C	Degrees Celsius
¢/kWh	Cents per kilo Watt hour of electricity
$/kWh	Price per kilo Watt hour of electricity
€	Express the amount in Euro currency
H_2SO_4	Sulphuric Acid
kPa	Kilopascal equal to 101.97 kg/m^2
Mtoe	Million tonnes oil equivalent: large scale unit of energy = 7.33 Million barrels
MW	Mega Watt
m	Meter
m^2	Squared Meter
mm	Millimeter
η	Conversion Efficiency of a solar cell
PJ	Peta joules – the International System of unit of work or energy
Pb	Lead
TWh	Tera Watt-Hour
US$	Express the amount in U.S. Dollars currency
W	Watt

INTRODUCTION

Canada is considered one of the best examples of a country that generates a large quantity of electricity and where a significant amount of energy is produced from renewable sources. For instance: a total of 648 TWh was produced in 2016, with 66 % (sixty-six per cent) from Hydropower, Wind Power, Photovoltaic Systems and other renewable sources. Thus, the country was positioned as the sixth largest electricity producer and second largest electricity exporter in the world [19].

Despite this wealth of electrical power generation and matrix, prices per kWh among Canadian provinces are very different from each other. Also, there is a high potential for Peak Shaving with Solar Photovoltaic System, Battery Energy Storage System and Demand Response program.

Based on the figures above, the goal of this Master's thesis is to evaluate the yearly electricity bill, savings and price per kWh of a 5 MW consumer, École de Technologie Supérieure, during the course of 2017 in Ontario and Quebec. A 5 (five) minute simulation will be obtained with MATLAB Simscape Power System and will take into account all electricity standard rates in each province. These will be compared to the scenarios with financial incentives or demand response program, photovoltaic systems and/or batteries energy storage system, individually and together. Following this, a technical and economic feasibility study will be presented for the photovoltaic systems and battery energy storage systems, where the main economic indicators will be evaluated and compared.

All simulation results will be based on the following scenarios:

0) ÉTS University Complex in Ontario and Quebec with electricity standard rates (baseline);
1) ÉTS University Complex in Ontario with financial incentives (GA by PDF - Global Adjustment by Peak Demand Factor) and in Quebec with demand response (GDP – "Gestion de la Demande de Puissance");

2) ÉTS University Complex in Ontario with financial incentives and Photovoltaic Arrays (150kW) as well as in Quebec with standard rates and PV Panels;
3) ÉTS University Complex in Ontario with financial incentives, Photovoltaics Arrays (150 kW) and Batteries (250 kW) as well as in Quebec with demand response, PV Panels and Batteries;
4) ÉTS University Complex in Ontario with financial incentives and Batteries (250 kW) as well as in Quebec with GDP and Batteries;
5) ÉTS University Complex in Ontario with financial incentives, batteries with Time of Use pricing (250 kW) and with (5B) / without (5A) Photovoltaics Panels (150 kW); Note: this scenario will be run just in Ontario.
6) ÉTS University Complex in Ontario with financial incentives, 500 kW of Photovoltaics Panels and Batteries (250 kW) as well as in Quebec with demand response, PV Arrays and Batteries;

All algorithms, data inputs, process, outputs and simulation will be obtained with MATLAB SimScape Power System, which is one of many tools provided with MATLAB [1], in order to allow a reliable and accurate simulation on an easily accessible and user-friendly page.

CHAPTER 1

CONTEXTUALIZATION

1.1 Contextualization and steps of the research

Nowadays, governments, companies and people seek ways to use energy more efficiently. In Canada, for example, electrical power providers like Hydro Québec and system operators like the IESO in Ontario, afford some interesting financial incentives for large clients that agree to reduce the peak of energy during periods of high demand. All nations must keep an electricity reserve margin in relation to peak demand; otherwise, a sudden blackout may occur and leave the related cities without electricity for some minutes, hours or even days. If a peak of power occurs simultaneously by a number of large companies during a - 35^{o} C winter season in Quebec or + 35^{o} C summer season in Ontario, for example, it means that more investment in electrical infrastructure will be required very soon. In consequence, the population will have to pay more taxes directly or indirectly, in order to pay this long-term investment. Therefore, this research will focus on this attempt to save both energy and money.

The main contribution of this Master's thesis is to simulate in a 5-minute interval the data from the entire year 2017. It will generate the yearly and monthly electric bill, savings and price per kWh in Ontario and Quebec, with and without financial incentives or demand response credit, photovoltaic systems and/or battery energy storage system. The 2017 ÉTS power data, electricity utility unit price for power, energy and fixed rates in both provinces will be used, as well as the 2017 Montreal weather and solar irradiance data. In addition, a technical-economic study will be presented, in order to evaluate the feasibility of installing solar photovoltaic panels and battery energy storage systems in both provinces.

Firstly, this study will provide an overview of Canada energy consumption and the electrical power generation matrix per province, in order to provide an overview of the origin of their electrical power generation and consumption.

Secondly, Ontario's electrical power system and monthly billing will be presented as well as Quebec's, so that all power, energy and fixed rates of both provinces are known, to better analyze the reason why the unit price of electricity is so different between neighboring provinces.

Thirdly, the MATLAB Simscape power system will be introduced together with all main premises, information and data utilized in the proposed scenarios, in order to understand how the MATLAB SimScape Power system works and all parameters used in the simulation.

Fourthly, a technical-economic feasibility study will follow, where solar photovoltaic system and battery energy storage system will be evaluated technically and economically in both Ontario and Quebec. This includes the Maximum Power Point dimensioning for Photovoltaic System, required surface areas, modules in series and in parallel, DC-AC Inverters, where all these should be positioned within specific ÉTS buildings and the main economic indicators with an in-depth analysis. A similar technical-economic feasibility study will be presented for the batteries.

Fifth, the simulation results will be presented with an in-depth analysis of yearly and monthly bill amounts, $/kWh prices and percentages differences for each scenario.

Finally, the conclusion and recommendation will address the results obtained in the simulation and they will be compared with the real and historical data of each province. Also, a system for each Province will be recommended, based on MATLAB SimScape Power System Model simulation, RETScreen Economic Feasibility study for the Photovoltaic System and Economic Feasibility in Excel for the Battery Energy Storage System.

CHAPTER 2

OVERVIEW OF CANADA'S ENERGY MATRIX

2.1 World and Canada's Primary Energy Consumption

The 2016 world primary energy consumption was 13,276.31 Mtoe, where just 10% came from renewable energy sources. Canada consumed 329.71 Mtoe, 2.48% of total, where 30% came from renewable sources, mainly hydropower. The graphs below show the mix per fuel.

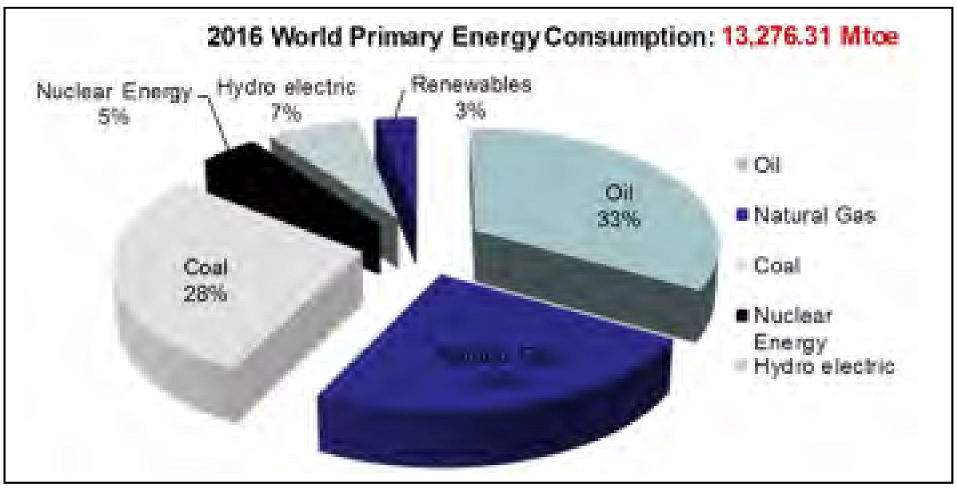


Figure 2-1 World Primary Energy Consumption in 2016
Taken from BP Statistical Review of World Energy – all data (2017)

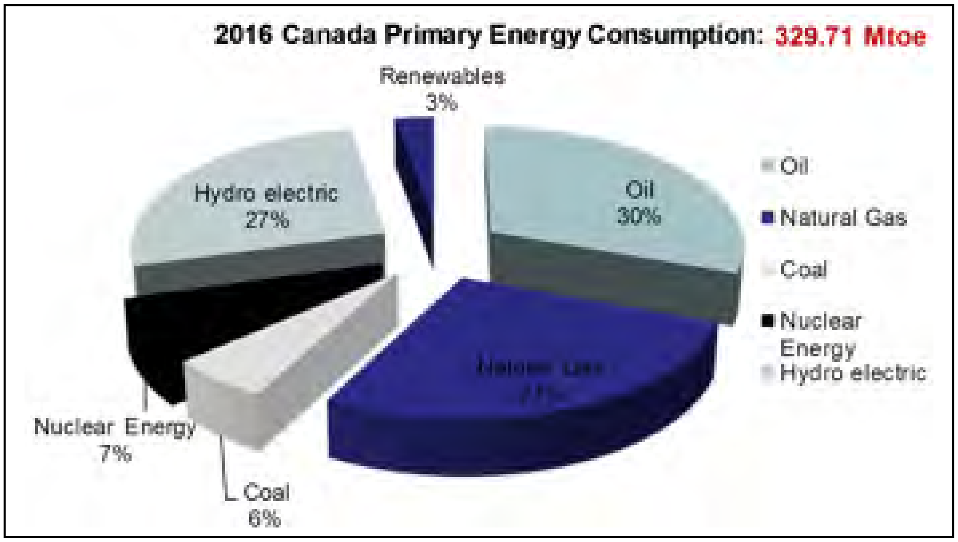


Figure 2-2 Canada's Primary Energy Consumption in 2016
Taken from BP Statistical Review of World Energy – all data (2017)

2.2 Canada's Electrical Power Generation Matrix

Canada generated 648.4 TWh of electricity in 2016, 66% out of 100% from Renewables sources, with 59% and 7% from Hydropower and Non-Hydro, respectively. The Hydropower is present in 23% and 95% of provincial share electricity supply in Ontario and Quebec, respectively. In addition, Wind Power is present in 4.7% out of 100% of Canada electricity generation, with 7.7% and 3.6% of electricity production mix in Ontario and Quebec, respectively. Finally, Solar Photovoltaic makes up 0.5% of Canada's electricity generation, with 1.9% of electricity production mix in Ontario and less than 0.1% in Quebec [19].

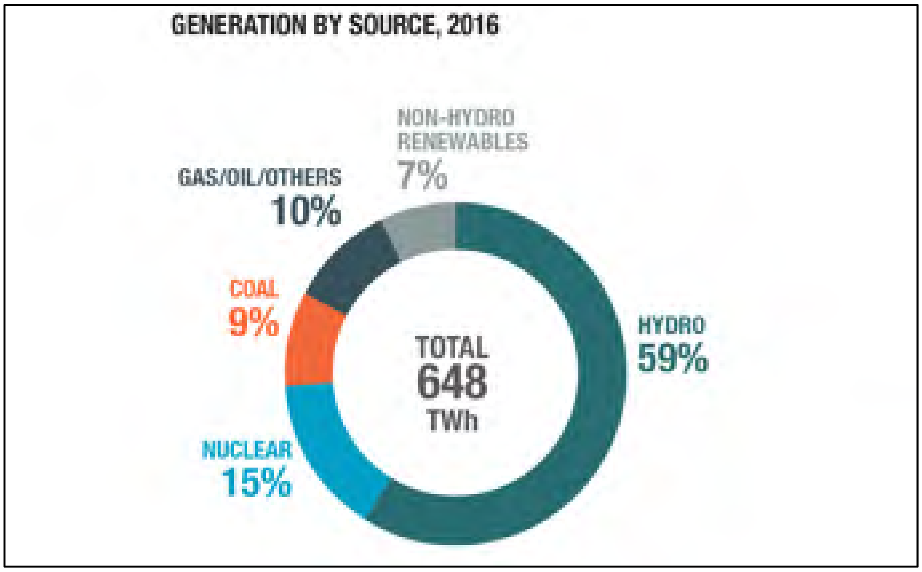


Figure 2-3 Canada Energy Electricity Generation by Source in 2016
Taken from Natural Resources Canada - Electricity Facts (2018)

The electricity world generation was 25,082 TWh in 2016, 2.6% out of 100% from Canada, as the 6th largest world electricity producer. In addition to it, Canada was ranked as the second largest world electricity exporter, 10% out of 100% total world exports – 724 TWh. The tables below describe in more details the world generation and exports figures.

Table 2-1 World and Canada Electricity Generation in 2016
Taken from Natural Resources Canada - Electricity Facts (2018)

World production | World exports

World generation – 25,082 TWh (2016)

Rank	Country	Percentage of Total
1	China	25%
2	United States	17%
3	India	6%
4	Russia	4%
5	Japan	4%
6	**Canada**	3%
7	Germany	3%
8	Brazil	2%

Table 2-2 World and Canada Electricity Export in 2016
Taken from Natural Resources Canada - Electricity Facts (2018)

World production | World exports

World exports – 724 TWh (2016)

Rank	Country	Percentage of Total
1	Germany	11%
2	**Canada**	10%
3	France	8%
4	Paraguay	7%
5	Switzerland	4%

2.3 Electricity Energy Use

The 2015 Canada's electricity energy use was 1,784 peta joules (PJ), where the industry consumed 39.9% out of the whole energy. Therefore, this sector always requires more attention in terms of energy consumption and greenhouse gas emission. The energy use by sector is shown below.

Table 2-3 Canada Electricity Energy Use by Sector in 2015
Taken from Natural Resources Canada - Electricity Facts (2018)

Sector	Energy use (PJ)	% of the total
Residential	608.5	34.1%
Commercial	425.2	23.8%
Industrial	711.3	39.9%
Transportation	3.3	0.2%
Agriculture	35	2.0%
Total	**1,783.8**	**100%**

The 2015 electrical energy use by province shows a curious reality: QC (35%) uses more electrical energy than ON (28%). It is explained by having plentiful and cheap electricity from large scale electricity projects [19]. In ON, NG is the principal energy source for residential heating system (62%) [48], which is cheaper [49] than electricity. However, it is air pollutant.

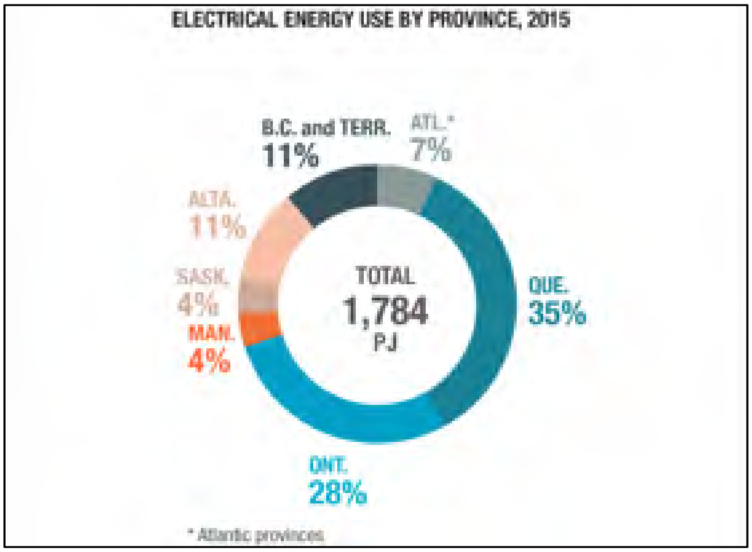


Figure 2-4 Electrical Energy Use by Province in 2015
Taken from Natural Resources Canada - Electricity Facts (2018)

The 2015 distribution of residential energy use in Canada shows that 62% is for space heating, followed by water heating (19%) and appliances (13%), as shown below. Therefore, Ontario seeks to reduce its residential electrical use by replacing it to Natural Gas. But, it is pollutant.

Figure 2-5 Canada's Distribution of residential energy use
Taken from Natural Resources Canada – Heating equipment for residential use (2018)

2.4 Canadian Provinces Power Generation

The chart below shows the Canadian provinces generation energy matrix. In general, provinces where the Hydropower generation is predominant, owns a lower price/kWh than others that depend on other sources, such as petroleum and nuclear. Thus, the lowest rates are concentrated mainly in QC & MB, after in BC and NL. Except for AB, based on air pollutants Coal and NG.

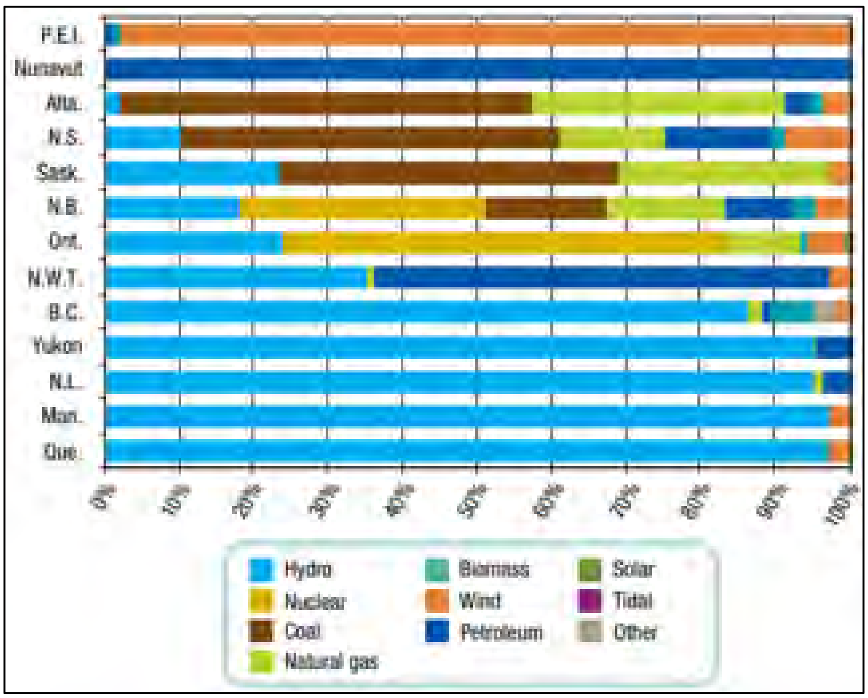


Figure 2-6 Provincial Power Generation Matrix in 2015
Taken from Natural Resources Canada – Energy Fact Book 2016-2017 (2017)

2.5 Average Price for residential and 5 MW Large Customers by Cities in 2017

The maps below bring the cents/kWh for both residential and a 5 MW large-power customers.

Figure 2-7 Average Price for Residential Customers in 2017
Taken from Hydro Québec – Comparison of Electricity Prices in Major NA Cities (2017)

Figure 2-8 Average Price for 5 MW Large-Power Customers in 2017
Taken from Hydro Québec – Comparison of Electricity Prices in Major NA Cities (2017)

As noted, QC presented the lowest 2017 residential price, 7.07¢/kWh, in NA and the 2nd lowest price for a 5 MW client, 5.18¢/kWh. ON's price were 16.3¢/kWh and 14.6¢/kWh, respectively.

CHAPTER 3

ONTARIO'S ELECTRICAL POWER SYSTEM AND BILL

3.1 Contextualization

Undoubtedly, Ontario owns the higher electricity rates in Canada. Despite being so high for Canadians, it's considered competitive when compared to the 2017 United States and some European countries rates, such as France 0.17 €/kWh [50] or 0.25 Ca$/kWh [51] and United Kingdom 0.19 €/kWh [52] or 0.28 Ca$/kWh [51]. Or even cheap, when compared to Germany, 0.30 €/kWh [53] or 0.45 Ca$/kWh [51] or Italy, 0.21 €/kWh [54] or 0.32 Ca$/kWh [51].

Below, an overview of the Ontario's electrical power system will be provided with all applicable billing charges for residential, small business and mid to large-power consumers.

3.2 Regulated Electricity in Ontario

The first step is to understand why and how the former Ontario Hydro was split out into five companies and what occurred after that. Thus, a general overview of Ontario's electricity system from 1997 to 2017 will be displayed below:

- Until 1997 – Ontario Hydro – Electricity Generation, Transmission and Distribution;
- 1998: Energy competition Act signed – restructure of the electricity market;
- 1998: Ontario Hydro divided up into 5 Companies:
  - Hydro One – Electricity Transmission;
  - Ontario Power Generation (OPG) – half of province's power generation;
  - IESO – Independent Electricity Systems Operator;
  - Electrical Safety Authority;
  - Ontario Electricity Financial Corporation.
- 1998: Ontario Energy Board (OEB) – Licenses, Rules and Energy Rates;
- 1999: Debt of $38.1 billion;

- 2002: Official opening of the new electricity market;
- 2006: Regulated Price Plan;
- 2015-2017: Competitive Energy Market.

The Hydro-Electric Power Commission of Ontario established in 1906, was re-named as Ontario Hydro in 1974 and it was a single government agency in charge of managing the entire Ontario's Generation, Transmission and Distribution system [33] . By the mid-1990's, Ontario Hydro was collapsing due to its massive debt, monopoly status and management issues. Thus, the Premier Mike Harris appointed in 1995, an "Advisory Committee on Competition in Ontario's Electricity System". Soon thereafter, the task force recommended the opening of the electricity market, in order to lead in lower prices and more choice to provincial power users.

In 1998, The Energy Competition Act was signed, in order to restructure the Ontario's electricity market by opening a wholesale electricity market, retail choice at the consumer lever offered by retailers and access to the power transmission grid for new competitors in generation. As a result of this Act, the former Ontario Hydro was divided up into 5 new entities, each focusing on a different subject: Ontario Power Generation (OPG) - focused on generation; Hydro One: focused on transmission and distribution; Independent Electricity System Operator (IESO) - focused on managing the operation of the power system among generators and consumers; Ontario Electrical Safety Association (ESA) - focused on safety and Ontario Electricity Financial Corporation (OEFC) - focused on debt retirement.

In addition, in 1998, the Ontario Energy Board (OEB) was proclaimed as the regulator of the new market by regulating prices and overseeing the wholesale and retail markets to protect the public against uncompetitive practices.

In 1999, the Ontario Electricity Financial Corporation became responsible for a debt of Ca$38.1 billion from Ontario's hydro, where $30.3 billion of this debt would be re-payed by consumers through Hydro One, IESO, Ontario Power Generation and its local municipalities [55] and the rest allocated as stranded debt. In 2001, the government set the debt retirement charge at 0.7 cents per kWh of electricity consumed, which was taken off just in April 1st 2018 [56].

In 2002, it occurred the Official opening of the new electricity market, which did not go smoothly due to lack of expertise. From 2003 on, the Province started to import power to meet its needs, upgrading aging infrastructure, commissioning new natural gas plants, starting to close down some coal-fired power plants through replacing then by a wind and solar plants parks and making a 20–year long-term contract with private companies to build a new electricity park. Thus, a period of high investment in electricity infrastructure started together with a high debt retirement, mainly from the 1980s and 1990s over budget nuclear construction projects and other projects. In addition, a long-term contract with private companies to guarantee a minimum source of revenue, even if the province did not use that generated electricity, culminated in a very high electricity rate in Ontario. In 2006, a regulated price plan was issued by OEB, whose more details are mentioned below. Almost a decade later, a very competitive energy market is set [33].

3.3 Ontario Energy Board (OEB)

The Government of Ontario, through the Ministry of Energy, sets the overall policy for the energy sector. It does this mainly through laws and regulations.

The Ontario Energy Board regulates Ontario's energy sector. It ensures that electricity companies follow the rules. As an independent government agency, its goal is to promote a sustainable, reliable energy sector that helps consumers get value from their electricity services.

- Definition: OEB: Ontario Energy Board - Ontario's independent energy regulator.
- Objectives:
  - Set the rules for energy companies operating in Ontario;
  - Establish energy rates that are reasonable;
  - License energy companies;

- Monitor the wholesale electricity market and energy companies;
- Develop new energy policies and provide unbiased advice to government;
- Provide timely and helpful information about energy matters for residential consumers and small businesses;
- Take the complaints;
- Help to resolve client's issues with a particular energy company;
- Clamp down on energy companies that don't follow the rules [57].

3.4 Independent Electricity System Operator (IESO)

A System Operator (SO), is in charge of managing operation of the power system so as to maintain stability and the security of supplies from minute to minute [58]. In Ontario, the Independent Electricity System Operator (IESO) is in charge of that, which it is a government agency that manages the province electrical system supply and demand. Its goal is to make sure that the electrical energy supply meets the demand today, tomorrow and in the future. Also, to intermediate all relation between large dispatchable generators and load customers, connected directly to transmission through bids, in the wholesale market.

- Definition: IESO: Independent Electricity System Operator.
- Objectives:
    - Managing the power system in real-time;
    - Planning for the province's future energy needs;
    - Enabling conservation and designing a more efficient electricity marketplace;
    - Balance of Energy supply and demand [18].

Figure 3-1 IESO Website with hourly Demand, Supply and Price 24 hours a day
Taken from IESO Website (2018)

The site of IESO informs 24 hours a day, on an hourly basis, which is the current demand and supply of electricity in the province, the projected demand for the next hour and the peak demand hour of the day. In addition, it informs the price of the Hourly Ontario Energy Price (HOEP), which the average of the twelve 5-minute price negotiated in the Wholesale market, the Global Adjustment charge by consumption and the average weighted price, for customers that do not own a smart meter. The HOEP and Global Adjustment will be detailed on the following sections.

A baseload demand in Ontario is regarded between 11,000 and 15,000 MW, where Hydropower generators and Nuclear power plants are working and price of energy is lower.

- Baseload demand (11,000 – 15,000 MW) – Mainly Hydropower and Nuclear power. Also, some Wind and Solar power (intermittent).

A peak demand is regarded from 15,000 MW on, which it may reach up to 10,000 MW in addition of it. In this case, the price of electricity will be higher, because it will be necessary to activate also the gas and biofuel fossil fueled thermal generating stations and the intermittent wind and solar power with a high supply. Unfortunately, this strategy is not clean for a peak demand period in Ontario.

- Peak demand (from 15,000 MW on and up to 10,000 MW in addition) – Hydropower, Nuclear power, Fossil Fueled thermal generating stations, Wind power and other sources.

In summary, IESO is in charge of the electrical system and market operator in Ontario, where it directs the flow of electricity across the grid and administer the wholesale electricity market, which will be detailed below.

An overview of Electricity Generation, Transmission and Utilities will be provided on the chapter below, before moving on electrical power Criteria for residential and business consumers in Ontario.

3.5 Electricity Generation, Transmission and Utilities

Electricity is generated at power plants and moves through the *grid*, of electricity substations, transformers, and power lines that connect electricity producers and consumers.

The entire electricity grid consists of thousands of kilometers of high-voltage power lines (Transmission) and thousand of kilometers of low-voltage power lines with distribution transformers (Distribution) that connect power plants (Generation) to millions of electricity final customers [29]. A schematic of a general electrical system is shown below.

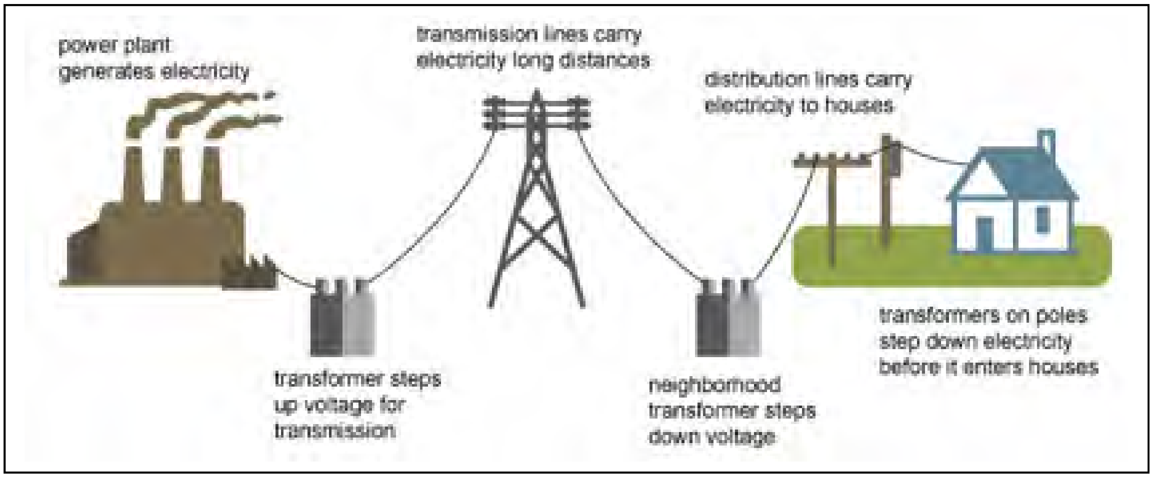


Figure 3-2 Electricity Generation, Transmission and distribution
Taken from U.S. Energy Information Administration – How Electricity is Delivered to Consumers (2018)

3.5.1 Generators

Generators produce the electricity we use. They include facilities powered by nuclear, hydro, natural gas, wind and solar sources. In ON, the largest generator is Ontario Power Generation.

3.5.2 Transmitters

Once electricity is generated, it travels across Ontario on high-voltage transmission lines. These lines, which are mostly owned and operated by Hydro One, take power from the generator to the doorsteps of local utilities. There, it is put through transformers that convert it to low-voltage power. It is then sent out on distribution lines.

3.5.3 Distributors

Local utilities (also known as distributors) own and operate the low-voltage lines that deliver power to home or business. They are also responsible for billing all final consumers [59].

3.5.4 Overview and Electricity Production Mix

The electricity production mix in the province changed a lot from 2005 to 2016. In 2005, it was strongly depended on coal (19%), nuclear (51%), Natural Gas (8%) and hydropower (22%). The renewables sources, such as Solar, Wind and Bioenergy represented less than 1% of it. After closing the coal-fired power plants and replacing then by wind and solar plants parks through a 20–year long-term contract with private companies, the production mix improved so much, in terms of renewables energy generation and reduction of greenhouse gas emission. In 2016, the nuclear power generation was responsible for 58.5% of electricity, followed by Hydropower (23.3%), Renewable sources (9.5%, with Wind 6.8%, Solar 2.2% and Biomass 0.5%) and Natural Gas (8.2%).

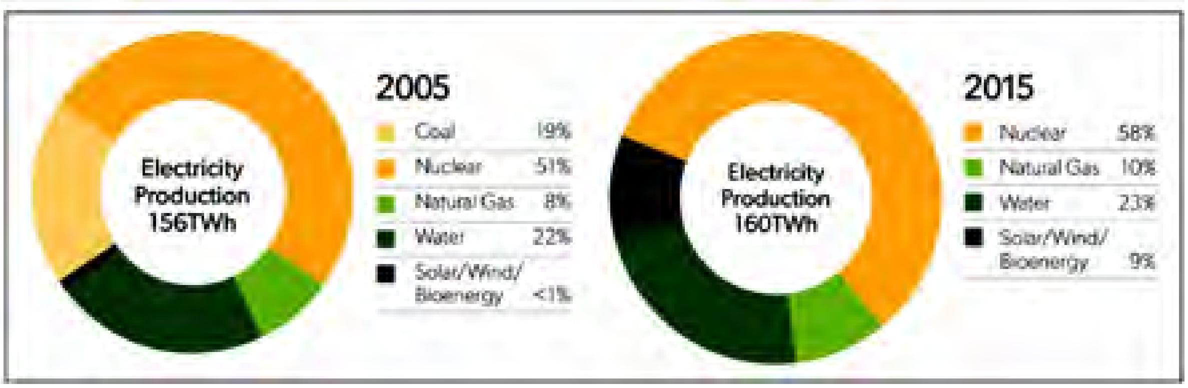


Figure 3-3 2005 and 2015 Electricity Production Mix in Ontario
Taken from Ministry of Energy, Northern Development and Mines of Ontario – 2005 and 2015 Electricity Production Mix (2017)

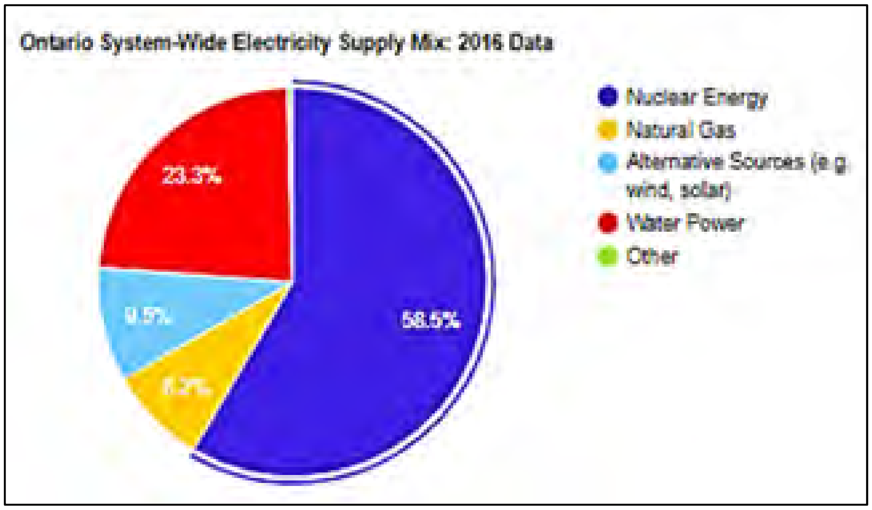


Figure 3-4 2016 Electricity Production Mix in Ontario
Taken from Ontario Energy Board – 2016 Electricity Production Mix (2018)

3.6 Criteria and Billing for Residence, Business and the Global Adjustment

In ON, the electricity rate is determined by the quantity of electrical power a consumer uses. Residential consumers and small businesses, for the most part, pay time-of-use (ToU) rates, while mid to large businesses pay the wholesale price [32].

3.6.1 Criteria and Billing for Residences and Small Businesses

Most of residential and small business costumers pay time-of-use (ToU) rates, which means there is a variable price per kWh according to the hour of the day. Thus, consumers pay higher prices when electricity is more expensive and lower prices when it is less expensive. It is divided in 3 layers: off-peak, mid-peak and on-peak, whose rates are shown in the picture below.

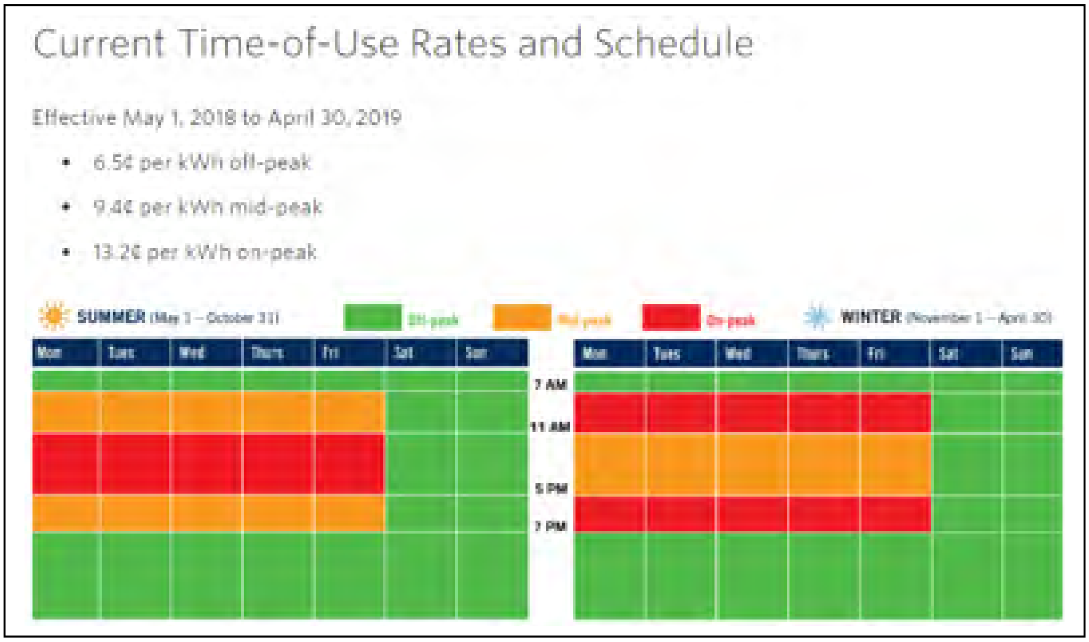


Figure 3-5 Ontario's Current Time-of-Use Rates and Schedule
Taken from IESO – Electricity Pricing for Residents and Small Businesses (2018)

Off-peak rate is 6.5¢/kWh, mid-peak 9.4¢/kWh and on-peak 13.2¢/kWh, which are applicable in different hours during the summer and winter season: The summer time goes from May 1st to October 31st of each year, whose on-peak period is from 11:00h am to 05:00h pm, due to high air conditioning use during this time. On the other hand, the winter season is from November 1st to April 30th, whose on-peak period is in the morning, 7:00 to 11:00h am and in the late afternoon, 5:00 to 7:00h pm, due to the necessity of more lighting during shorter days. Off-peak periods are from 7:00h pm to 7:00h am, weekends and holidays.

A consumer can choose from whom to buy the electricity. The vast majority (about 95%) buy electricity from their local utility. If the residential or small business does not do anything, it will be automatically charged from local utility and the electricity rate will be set by OEB.

However, a consumer may choose to buy electricity from a private company that sells electricity under contract (called an electricity retailer). In this case, an agreed price is set between the consumer and the retailer in the contract [59]. In this case, the consumer must also pay the Global Adjustment by consumption, which covers the cost of building new infrastructure and providing conservation programs to ensure enough electricity supply in the ON, together with the agreed price with the retailer. The Global Adjustment is already incorporated in ToU rate. Residents and small businesses consumers who do not own a smart meter (which track and capture electricity consumption on an hourly basis) pay the tiered rates:

Table 3-1 Residential and Non-Residential tiered rate
Taken from Ontario Energy Board – Residential and Small Business Tiered rates in Ontario (2018)

Residential (effective May 1, 2018)

When	How much electricity you use	Rate (¢ per kWh)
Summer (May 1 - Oct 31)	Up to 600 kWh	7.7
	More than 600 kWh	8.9
Winter (Nov 1 - Apr 30)	Up to 1,000 kWh	--
	More than 1,000 kWh	--

Non-Residential (effective May 1, 2018)

When	How much electricity you use	Rate (¢ per kWh)
All seasons	Up to 750 kWh	7.7
	More than 750 kWh	8.9

As displayed below, a ToU residential and small business monthly bill statement is divided up in three prices/kWh, together with delivery price from utility, regulatory (for the reliable management of power system approved by OEB) and only federal tax.

Figure 3-6 Sample of ToU rate Monthly Bill Statement
Taken from Ontario Energy Board – Residential and Small Business Consumers Monthly Bill Statement (2018)

The Province really encourages the consumer to use the demand response in their routine, which is a change in end-user electricity consumption patterns due to fluctuating in market prices [60]. The smart meters show the energy consumption on an hourly basis to assist customer to save energy on the current and future hour. Also, The Province encourages clients to follow the energy conservation/efficiency programs [61], where it gives some money back for each energy saving equipment installed at home or smart devices and controller, for instance: Smart Thermostat - $100 back, Heating & Cooling incentive (up to $850.00 rebate) and Whole home conservation program with an energy advisor inspection [62].

3.6.2 Criteria and Billing for Mid to Large Businesses

Businesses with a peak demand over 50 kW pay the Wholesale price for electricity, also called as HOEP – Hourly Ontario Energy Price, in one of these 3 ways:

- Business with an interval meter: pay the Hourly Ontario Energy Price
- Business without interval meter: pay the Average Weighted Price
- Business may choose to enter a fixed-price contract with an electricity retailer

The HOEP covers the cost of producing electricity. Business also pay the global adjustment rate on their monthly consumption, which covers the cost of building new infrastructure and providing conservation programs in ON. A summary of these costs are presented at IESO website:

Figure 3-7 IESO 's Current Electricity Demand, Supply and Price
Taken from IESO - Website with hourly electricity demand, supply and price 24 hours a day (2018)

An update status of it is shown on an hourly basis, which brings the current demand and supply of electricity in the province, the projected demand for the next hour and the peak demand hour of the day [63]. In addition, it informs the price of the Hourly Ontario Energy Price (HOEP), which is the average of the twelve 5-minute market clearing price (bid price) set in each hour, negotiated in the Wholesale market operated by IESO.

Business also pay the following charges:

- Transmission Network (power cost);
- Transmission Connection (power cost);
- Distribution Charge (power cost);
- Wholesale Market Service (WMSC) (energy cost);
- Debt Retirement (energy cost); Note: used in 2017 Simulation, but taken off in 2018.
- Standard Supply Services (fixed cost);
- Monthly Service Charge (fixed cost).

Both HOEP and Global Adjustment Charge are considered as Energy cost and they will be added together with the charges above, for mid to large business monthly bill. Main Definition:

HOEP: The Hourly Ontario Energy Price is the average of twelve market clearing prices set in each hour. Based on real-time bids of electricity offer & demand in the wholesale market, IESO issues an average price each 5 minutes, which depends on the electricity demand in ON. The price also takes into account factors such as weather, time of day, day of week and economic conditions. A business also has the option of buying electricity through its local utility and paying the HOEP or paying a fixed rate through an energy retailer licensed by the OEB.

Global Adjustment: The Global Adjustment covers the cost of building new generation and other forms of supply to ensure enough electricity supply is available over the long term. The charge accounts for the difference between the market price of electricity and the rates paid to various contracted and regulated generators and other suppliers across Ontario [39].

The global adjustment is set monthly to reflect:

- The differences between the wholesale market price for electricity, known as Hourly Ontario Energy Price (HOEP) and:
    - Regulated rates for Ontario Power Generation's nuclear and hydroelectric generating stations;
    - Payments for building or refurbishing infrastructure such as gas-fired and renewable facilities and other nuclear, as well as the contracted rates paid to a number of generators across the province;
- The cost of delivering conservation programs.

<u>Global Adjustment by Monthly Consumption:</u>

The Global adjustment by consumption is mandatory for Residents, all small and medium businesses customers (up to 499.99 kW), which pays it directly or indirectly in their monthly bill. It is a monthly value (¢) per kWh, which is multiplied by the monthly consumption (kWh) of the customer.

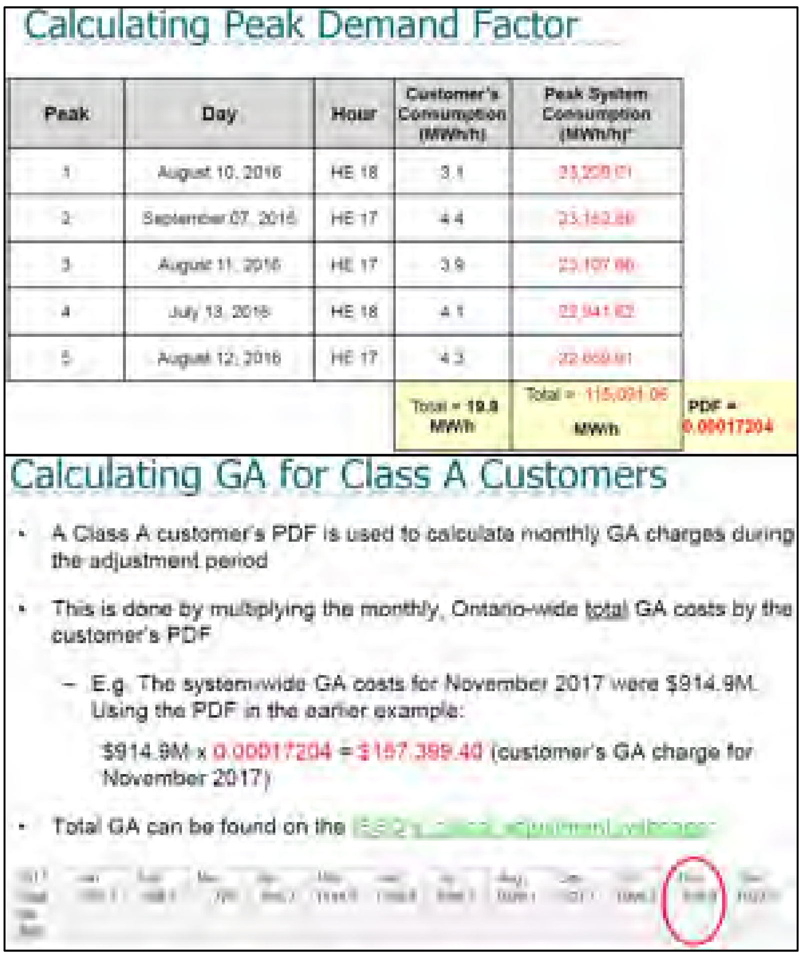
All consumers in ON pay the global adjustment, even residential and small business, whose charge is already incorporated indirectly in the ToU or tiered rates. Except for retail contracts, which is paid directly. Consumers with a peak demand over 50 kW are referred as Class B and pay it directly on their monthly bill. Consumers over 500 kW under the Industrial Conservation Initiative (Business classified as a large energy user [39]), is referred as Class A [64].

<u>Global Adjustment by Peak Demand Factor:</u>

The Global Adjustment (GA) by Peak Demand Factor (PDF) is based on Percentage Contribution to the top five coincident peaks in Ontario during a 12-month period and they are charged for the per cent of total GA costs through the next adjustment, or billing period. [42]. It is eligible for clients from 500 kW and up (conditions apply), where consumers over five MW are automatically joined to the program.

For example, if a Class A customer is assessed to be responsible for one per cent of Ontario's coincident peak demand for the five highest hours of a set base period; they will be charged for one per cent of total GA costs on the following 12-month period. The breakdown of calculus is shown below.

Table 3-2 Global Adjustment per Percentage Contribution or Peak Demand Factor
Taken from IESO - Calculating Peak Demand Factor for Global Adjustment per Percentage Contribution (2018)



Calculating Peak Demand Factor

Peak	Day	Hour	Customer's Consumption (MWh/h)	Peak System Consumption (MWh/h)*	
1	August 10, 2016	HE 18	3.1	23,208.01	
2	September 07, 2016	HE 17	4.4	23,162.89	
3	August 11, 2016	HE 17	3.9	23,107.86	
4	July 13, 2016	HE 18	4.1	22,941.62	
5	August 12, 2016	HE 17	4.3	22,669.61	
			Total = 19.8 MWh	Total = 115,091.06 MWh	PDF = 0.00017204

Calculating GA for Class A Customers

- A Class A customer's PDF is used to calculate monthly GA charges during the adjustment period
- This is done by multiplying the monthly, Ontario-wide total GA costs by the customer's PDF
  - E.g. The system-wide GA costs for November 2017 were $914.9M. Using the PDF in the earlier example:

    $914.9M x 0.00017204 = $157,399.40 (customer's GA charge for November 2017)
- Total GA can be found on the IESO's global adjustment webpage:

Participation in the Electricity Wholesale Market:

Large consumers connected to the Transmission Grid buy electricity through IESO-administered market. They are non-dispatchable, if they do not participate of the electricity supply and demand bids of the Wholesale Market. In this case, they pay the HOEP. On the other hand, they are dispatchable loads, if they can adjust their energy use in response to five-minute dispatch instruction from IESO. In this case, they participate of the Wholesale Electricity Market administrated by IESO [32].

In the IESO-administered market, the HOEP is charged to local distribution companies and it is also the basis for regulated rates charged to residential and small business consumers [65].

Wholesale Electricity Price:

The electricity wholesale market occurs through bids between dispatchable generators and large load consumers in a real-time operation, with IESO between them to manage the province's power demand & supply and, consequently, the applicable price in each 5 minutes. Thus, HOEP is the average of the twelve market clearing prices set in each hour.

The wholesale price is dynamic and changes hourly based on demand & available electricity supply. Everyday, IESO issues expected demand forecast for days ahead w/ 1,400 MW reserve.

Generators submit offers to IESO indicating the amount of energy to supply and desirable price to receive, while large consumers submit bids into the market with the amount of energy to be acquired and desirable price to pay. IESO accepts the lowest-cost offers to supply electricity until sufficient power is available to meet ON's demand. Then, IESO dispatches generators and importers to provide more electricity with a different price depending on generator source. In consequence, the wholesale price of electricity rises as more expensive forms of generation are brought online to meet demand. A new market clearing price is set each 5 minutes [66].

Figure 3-8 IESO's Control Room of Wholesale Market in real-time
Taken from IESO – Control Room System and Market Operator (2018)

Real-time Energy Market:

The IESO's real-time energy market matches the supply and demand of electricity in Ontario. Every 5 minutes, a market-clearing price is set based on the bids and offers that are settled in the wholesale electricity market.

Role of Dispatchable generators:

Dispatchable generators submit offers to supply electricity in specific quantities and prices for each hour of the day. Each 5 minutes, they adjust the amount of electricity they generate as instructions by IESO.

Role of Dispatchable loads:

Large energy consumers (or loads), can submit bids to buy electricity. They adjust their power consumption in response to instructions from IESO each 5 minutes. If the Ontario energy price is higher than the price they desire to pay, instructions will be sent to the load, in order to reduce its consumption.

Role of Importers and exporters:

The Ontario electricity market is interconnected with five other districts: Manitoba, Minnesota, Michigan, New York and Quebec. Market Participants can export, import and move energy through Ontario from one jurisdiction to another. In order to export or import, the market participants will make a bid in the IESO-administered market to purchase or sell energy, in a scheduled time [67].

Monthly Billing for Mid to Large Businesses:

There are 09 (nine) different charges of the electricity monthly bill for mid to Large Business in ON. Each charge was already mentioned in the chapter: "3.6.2 Criteria and Billing for Mid to Large Businesses" and HOEP and GA already explained. A summary of each charge and its electricity rate values are presented below:

Table 3-3 Monthly Bill Charges for Mid to Large Business
Adapted from IESO – The Bottom Line of Energy Management (2017)

Item	Kind of Cost	Kind of Charge	2017 Rate ($)	Unit
1	Energy Cost	Hourly Ontario Energy Price	Variable	$/kWh
2	Energy Cost	Global Adjustment Price	Variable	$/kWh
3	Energy Cost	Regulatory Wholesale Market Service	0,0057	$/kWh
4	Energy Cost	Debt Retirement	0,007	$/kWh
5	Fixed Cost	Standard Supply Services	0,25	$
6	Fixed Cost	Delivery: Monthly Service Charge	85	$
7	Power Cost	Delivery: Distribution Charge	4	$/kW
8	Power Cost	Delivery: Transmission Network	3,65	$/kW
9	Power Cost	Delivery: Transmission Connection	2,45	$/kW

1) Energy Cost: HOEP: is the average of the twelve market clearing prices set in each hour.
2) Energy Cost: Global Adjustment (GA) covers the cost of building new infrastructure and providing conservation programs. GA by Consumption: monthly value, cents (¢) per kWh, multiplied by the monthly consumption (kWh) of the customer. GA by PDF is according to the calculus presented on table: “3-2 GA by PDF”. The 2017 monthly fees are shown below.

Table 3-4 Global Adjustment by Consumption
Adapted from IESO – Global Adjustment by Consumption (2018)

Global Adjustment by Consumption	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Actual Rate (¢/kWh)	8.23	8.64	7.14	10.78	12.31	11.85	11.28	10.11	8.86	12.56	9.7	9.21

3) Energy Cost: Regulatory: Wholesale Market Service (WMSC) of 0.0057$/kWh is charged to provides the reliable management of the power system and the wholesale electricity market. It is approved by the OEB.
4) Energy Cost: Debt retirement fee of 0.007$/kWh is charged to pay down the residual stranded debt of the former Ontario Hydro. This charge was removed from all customers from April 1st 2018 on [56], but it was considered in the simulation which occurred in 2017.
5) Fixed Cost: Standard Supply Services of $0.25 to cover a portion of the administrative cost that the Utility incurs.
6) Fixed Cost: Delivery: Monthly Service Charge of $85.00 to cover administrative costs such as meter reading, billing and customer services.
7) Power Cost: Delivery: Distribution Charge of 4.00 $/kW to cover the cost of delivering electricity from the transmission system to the business. This charge is used to build and maintain distribution lines, towers and poles. Distribution rates vary according to each Utility rate contract and local municipality. It is a variable rate, which is regulated by OEB.
8) Power Cost: Transmission Network of 3.65 $/kW, which allows the electricity Transmission company to recover costs of operating and maintaining high-voltage system

that carries electricity from generation stations to local Utility. Transmission rates vary according to each Transmission company contract and local municipality. It is a variable rate, which is regulated by OEB.

9) Power Cost: Transmission Connection of 2.45 $/kW, which allows the electricity Transmission company to recover costs of operating and maintaining high-voltage system that carries electricity from generation stations to local Utility. Transmission rates vary according to each Transmission company contract and local municipality. It is a variable rate, which is regulated by OEB.

Power factor - Power factor is the measure of how effectively equipment converts electric current into useful power output, such as light, heat or mechanical motion. In the sample of Mid to Large Business Monthly Bill Statement, 93.2% was utilized; Real Power (kW) = Apparent Power (kVA) x Power factor [39].

Loss Adjustment Factor – Losses from high-voltage transformers to low-voltage are paid by the business for HOEP, GA and WMSC charges, calculated as: metered consumption + loss adjustment factor. Except for Debt retirement charge, based on the real metered consumption.

The largest part of electricity bill comes from the GA (cost of building new infrastructure and providing conservation programs) and HOEP (cost of producing electricity). Also, the quantity of charges are related to a large electrical system in ON, with OEB, IESO, public and private power generators, transmitters and utilities. In addition, the power generation mix based on Nuclear, Gas, Hydropower, Wind and Solar, some of them with a long term contract with a minimum revenue stream, a huge deficit of Ontario Hydro from nuclear plants projects, coal power plants closure, high investment in infra-structure and a surplus of electricity available.

A Sample of a mid to Large Business Monthly Bill Statement in ON is shown below.

MANUFACTURING COMPANY XYZ

Billing Date: [illegible]
Your Service Type: [illegible]
Your Local Hydro Company

Account Number: [illegible]
Meter Number: [illegible]

HOW WE CALCULATED YOUR CHARGES

Metered Values	
Metered Consumption	45,000 kWh
Metered kW Demand	150 kW
Metered kVA Demand	161 kVA
Loss Adjustment Factor	4.8%

Calculated Values	
Adjusted Consumption	47,160 kWh
Power Factor	93.2%
Billing Demand	150 kW

Line Item	Rate($)	Amount	Total
Hourly Ontario Energy Price	0.03	47,160 kWh	$1,414.80
Global Adjustment	0.08	47,160 kWh	$3,772.80
Regulatory: Wholesale Market Service	0.0057	47,160 kWh	$268.81
Debt Retirement	0.007	45,000 kWh	$315.00
Standard Supply Services	0.25	—	$0.25
Delivery: Monthly Service Charge	85.00	—	$85.00
Delivery: Distribution Charge	4.00	150 kW	$600.00
Delivery: Transmission Network	3.65	150.0 kW	$547.50
Delivery: Transmission Connection	2.45	150.0 kW	$367.50

Total Monthly Electricity Charges **$7,371.66**

Figure 3-9 Sample of Mid to Large Business Monthly Bill Statement in ON
Taken from IESO – The Bottom Line of Energy Management (2017)

3.7 Demand Response Auction

DR includes all intentional electricity consumption pattern modifications by end-use customers that are intended to alter the timing, level of present demand or total electricity consumption [60].

The (DR) Auction from IESO provides a transparent and cost-effective way to select the most competitive providers of DR, while ensuring that all providers are held to the same performance obligations. The DR Auction occurs annually starting on the first Wednesday of December.

Pre-Auction Report Requirements:

- Key Milestone Dates, including submission of capacity qualification documents, payment of auction deposit, and date of auction;
- Target Capacity;
- Maximum and Minimum Clearing Prices;
- Capacity Limits and Zonal Constraints.

IESO will process all submitted demand response auction offers, determine clearing price and quantities. The results will be published, as follow:

- DR Auction clearing price;
- Amount of MW cleared for each electrical zone;
- List of successful DR Auction Participants and their DR capacity obligations;
- Qualified demand response capacity, by participant.

Post DR Auction Report:

The successful participants will be required to become authorized, as Demand Response Market Participants, which will enable them to register resources to deliver on their DR Capacity Obligations. The participants will receive availability payments for providing DR Capacity, subject to non-performance charges [68].

3.8 Peak Demand, Energy Grid Output and Available Capacity vs. Demand

The main Peak Demand of the province occurs in the summer, mainly from air conditioning system use at its highest, where it may reach up to 25,000 MW. During 2016-2017 period, the first peak demand was 23,213 MW in September 2016, followed by 21,168 MW in June 2017. During the winter, the peak was around 20,500 MW, which was lower than in the summer, because most of residential heating system is fed by Natural Gas (instead of electricity) [48].

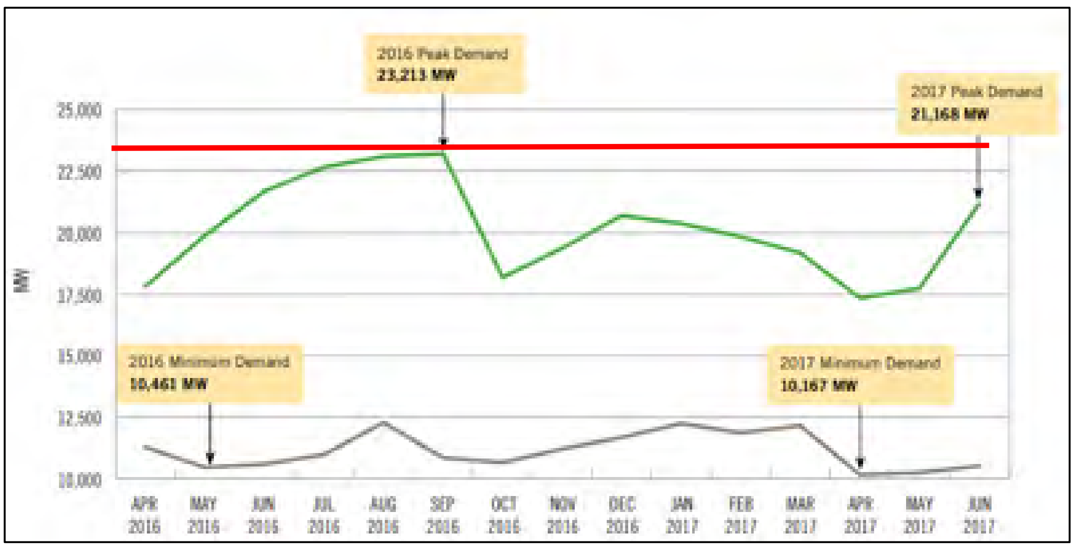


Figure 3-10 Ontario's Monthly Peaks Power and Minimums
Taken from Ontario Energy Report Q2 2017 (2017)

The 2016 Monthly Energy grid output by Fuel type below, reveals that gas power plants work in higher capacity in summer time during the peak power in the province. In addition, the wind power plants produce more energy during the winter, where a cold weather together with continuous period of wind contribute to a higher generation of electricity from this renewable source.

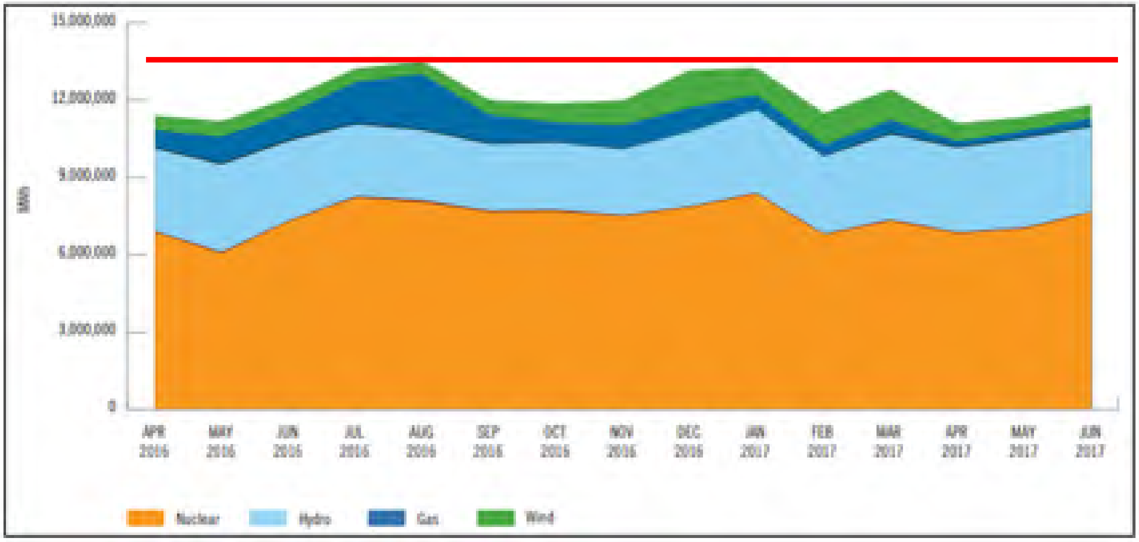


Figure 3-11 Ontario's Monthly Energy Grid Output by Fuel Type
Taken from Ontario Energy Report Q2 2017 (2017)

The chart below shows the Ontario's available capacity versus actual demand from 2009 to 2014. It reveals that the 2014 peak power demand was around 23,000 MW, the average baseload demand around 15,500 MW and there is around 30,000 MW of available resources to be utilized anytime. Thus, a surplus around 30 % over the peak demand is available.

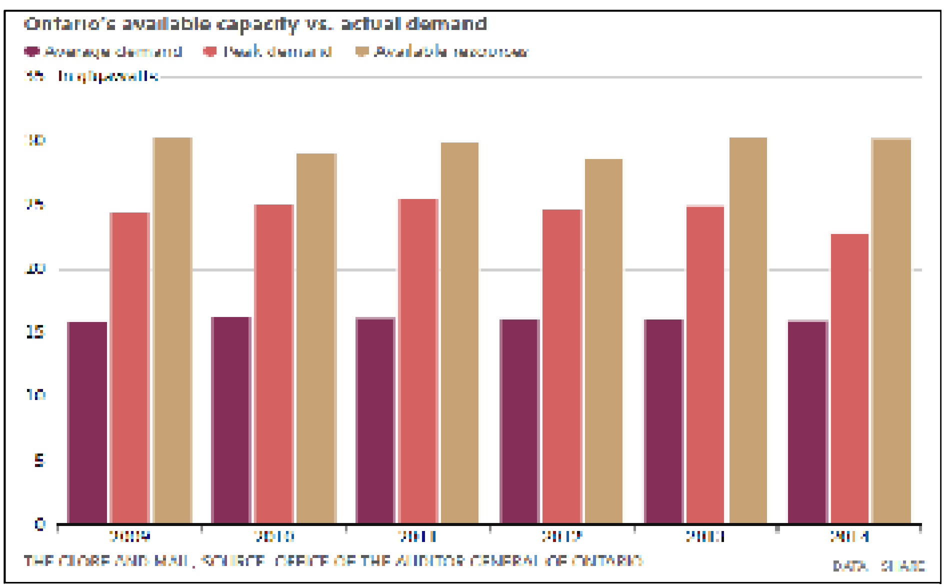


Figure 3-12 Ontario's available capacity vs. actual demand
Taken from The Globe and Mail Website (2017)

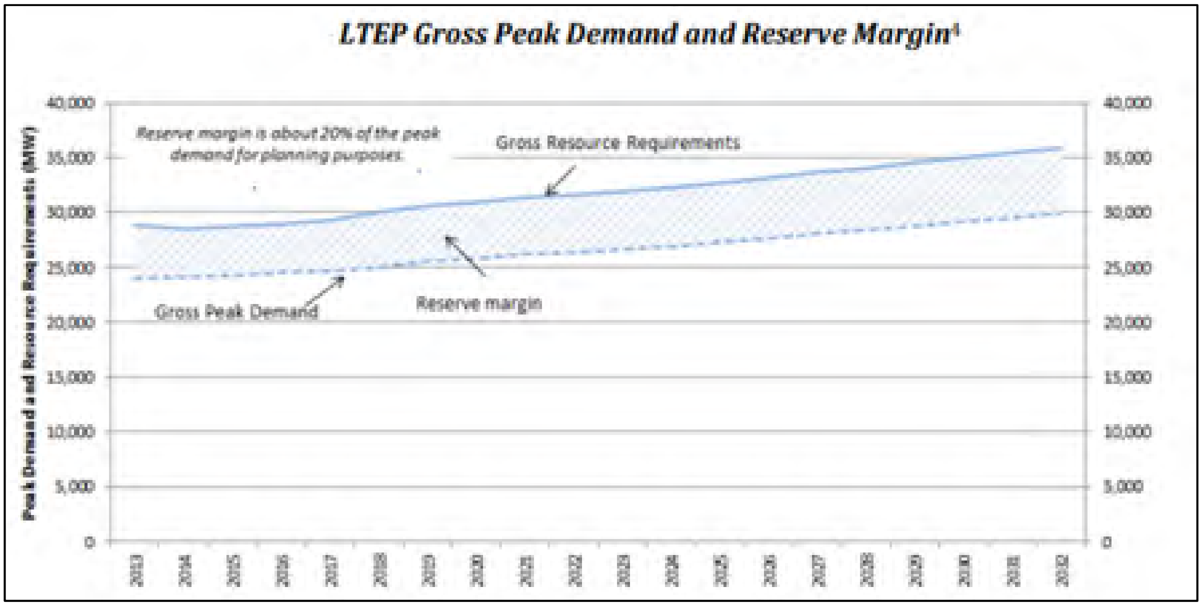


Figure 3-13 LTEP Gross Peak Demand and Reserve Margin
Taken from IESO – LTEP Gross Peak Demand and Reserve Margin (2018)

The 2013 Long Term Energy Plan and Reserve Margin chart above forecasted a gross peak demand around 25,000 MW and reserve margin of 30,000 MW for 2016 and 2017. Due to an excellent encouragement from local utilities, IESO, OEB and province advertisements to participate in energy efficiency programs and ToU demand response initiative for residential and financial incentives together with demand response auction for large consumers, the peak power demand was reduced from 25,000 MW to 23,000 MW in 2016. Therefore, a surplus of around 30% over the peak demand is present, which is over the 20% recommended for planning purposes. On the other hand, this extra electrical energy available is linked to a 20-year contract with a minimum revenue stream with private companies from Wind Power and Solar Photovoltaic farms, no matter if the production is sold or not. Thus, this bill is paid by all consumers in ON as Global Adjustment charge.

3.9 Percent of Installed Energy Capacity versus Actual Annual Supply

The 2014 installed energy capacity versus actual annual supply chart informs that 35% Ontario's electrical capacity is nuclear, however around 60% of electricity consumed in ON comes from Nuclear power plants. So, it means that they are running non-stop (over capacity), while some other power sources, such as: Wind, Solar and Gas power plants are under capacity.

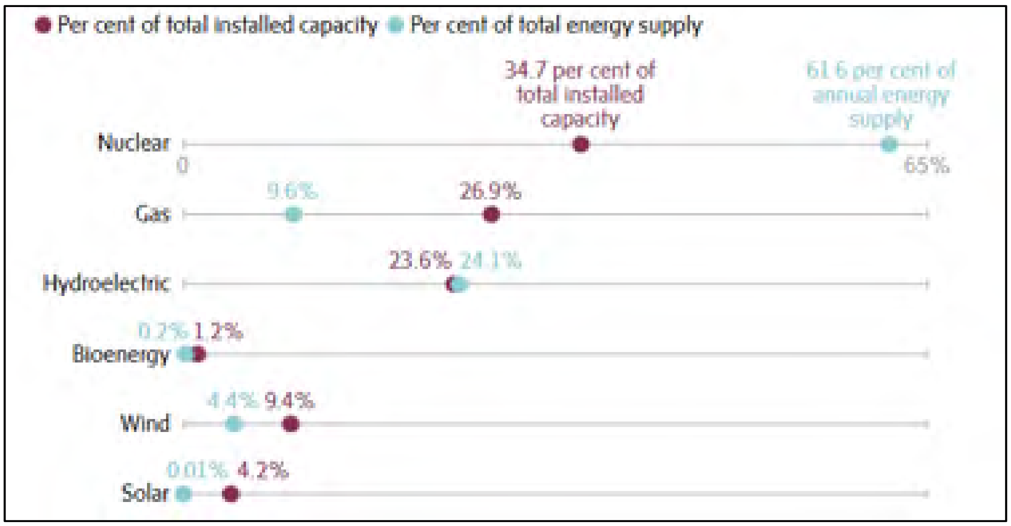


Figure 3-14 Ontario's 2014 Installed Energy Capacity vs. Actual annual supply
Taken from The Globe and Mail Website (2017)

3.10 Cost Components of Ontario's Electricity System

The breakdown of 2014 Ontario's electricity system cost components shows that 62.1% of overall costs belong to Generation, followed by Distribution 17.9% and Transmission 8.4%. The rest, 11.6% to cover Conservation programs and other extra fees imposed by the Province electrical system.

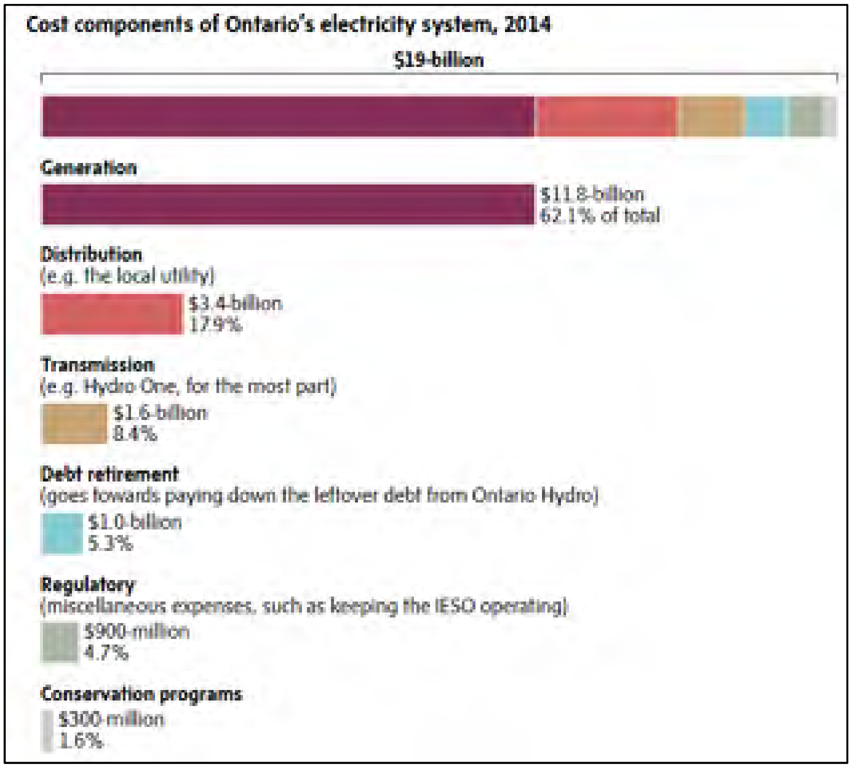


Figure 3-15 Cost Components of Ontario's Electricity System Taken from The Globe and Mail Website (2017)

3.11 Greenhouse Gas Emission for Ontario's Electricity Sector

Ontario's greenhouse gas (GHG) emissions have declined significantly over the past 10 years from 33 Megatonnes (MT) of carbon dioxide equivalent (CO_2e) in 2005 to approximately 4 MT in 2017 [38]. Approximately 30 megatonnes of Greenhouse Gas Emission was removed from the phase out of coal as a fuel source of the electricity generation sector. It is equivalent of removing 7 million cars from Ontario's roads. The fall of around 80% between 2005 and 2015 was mainly from the closure of coal thermal power plants as well as the leftover is mostly from Natural Gas thermal power plants generation. The chart below illustrates this fall.

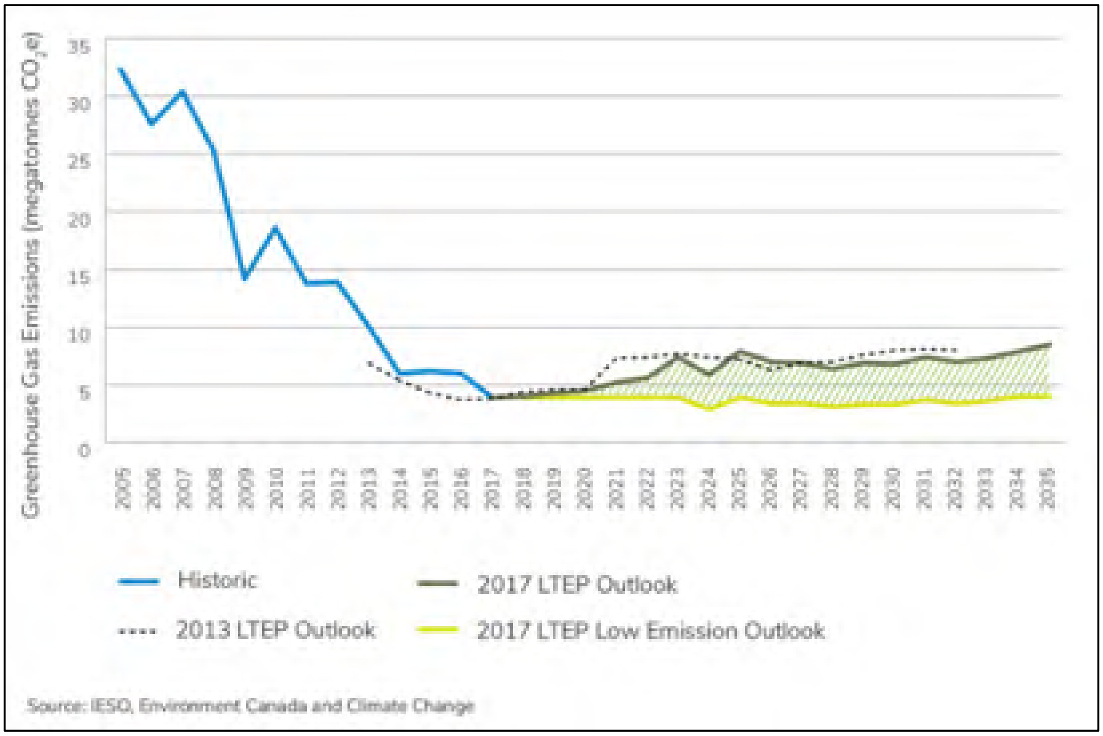


Figure 3-16 Greenhouse Gas Emission for Ontario Electricity Sector
Taken from Ministry of Energy, Northern Development and Mines of Ontario – Greenhouse Gas Emission for the Ontario Electricity Sector (2017)

Ontario's investments in clean generation sources - water, nuclear, wind, solar, bioenergy - along with the elimination of coal-fired electricity generation, have significantly reduced GHG emissions.

Ontario's electricity sector is forecasted to account for only about two per cent of Ontario's total GHG emissions in 2017 and the emissions are forecast to be more than 80 per cent below 1990 levels. Emissions are expected to remain well below historical levels and to be relatively flat over the planning period of 2017-2035.

Ontario will continue to look for ways to keep GHG emissions in the electricity sector low, and work with carbon-free generators to meet the province's emissions reduction targets [38].

CHAPTER 4

QUEBEC'S ELECTRICAL POWER SYSTEM AND BILL

4.1 Contextualization

Undoubtedly, Quebec owns the lower electricity rates in Canada. An excellent geography to generate electricity from Hydropower stations, responsible for 94.5 % out of 99.8% of power delivered from renewable sources in Quebec, together with a long term benchmark business management [17].

Below, an overview of the Quebec's electrical power system will be provided with all applicable billing charges for residential, small business and mid to large-power consumers.

4.2 Hydro Québec Electricity System

Hydro Quebec is one of the few energy producers in the world that produces and delivers 99.8% (ninety-nine and eighty per cent) of renewable power supply. With low Hydropower station operation costs, large volume of available electricity and reservoirs' ability to support intermittent energy sources, it strongly contributes to achieve a low-carbon economy collectively in the world [17].

94.5% (ninety-four and fifty per cent) of Hydro Québec electricity generation comes from hydroelectric power, where it owns the 9th (largest) and has a participation of 34.2% [69] on the 10th largest hydroelectric power plants in the world [70], Robert-Bourassa and Churchill falls (Labrador), respectively. HQ takes advantage based on its geography and successful management to produce a huge quantity of electricity from clean and renewable energy, to export it and still produce one of the cheapest electricity in NA, due to its low hydropower operational costs. A schematic of a Hydropower generation power plant is shown below.

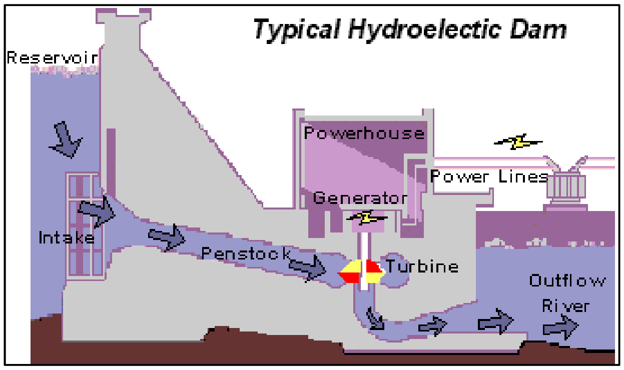


Figure 4-1 Schematic of a Hydropower station
Taken from U.S. Geological Survey's –
Hydroelectric power: How it works (2016)

A hydroelectric generating station is a plant that produces electric power by using water to propel the turbines, which, in turn, drive the alternators [22]. In summary, the water intake from a Dam is used to turn a propeller-like piece, a turbine. Then, it turns a metal shaft in an electric generator, which is the motor that produces electricity. When the rotor turns, it causes the field poles (electromagnets) to move past the conductors mounted in the stator. This, in turn, causes electricity to flow and a voltage to develop at the generator output terminals [7].

In 1971, the James Bay Project was initiated between HQ and the Quebec government, to build a series of hydroelectric-power plants on the east cost of James Bay, with a potential installed capacity of 16,000 MW, divided up into phases [71].

Nowadays, James Bay is responsible for the majority of QC's electricity production [70, 72], where it counts on 11 (eleven) Hydropower stations with a total of 17,418 MW of installed capacity. A summarized table and a map of their hydropower plants location are shown below.

Figure 4-2 Map of James Bay Hydropower stations in QC
Taken from Hydro Québec – Map of 11 Hydropower stations at James Bay in Quebec (2016)

Table 4-1 James Bay Hydropower plants summarized information
Taken from Hydro Québec – Hydroelectric Generating Stations (2018)

Hydropower plant	Name	Watersheds	River or other watercourse	Type	Installed capacity (MW)	Number of units	Head (m)	Commissioning Date	Tours
1	Robert-Bourassa (formerly La Grande-2)	La Grande	Grande Rivière	Reservoir	5616	16	137.16	1979-1981	Yes
2	La Grande-2-A	La Grande	Grande Rivière	Reservoir	2106	6	138.5	1991-1992	
3	La Grande-4	La Grande	Grande Rivière	Reservoir	2779	9	116.7	1984-1986	
4	La Grande-3	La Grande	Grande Rivière	Reservoir	2417	12	79	1982-1984	
5	La Grande-1	La Grande	Grande Rivière	Run-of-river	1436	12	27.5	1994-1995	Yes
6	Laforge-1	La Grande	Laforge	Reservoir	878	6	57.3	1993-1994	
7	Eastmain-1-A	La Grande	Rivière Eastmain	Reservoir	768	3	63	2011-2012	
8	Eastmain-1	La Grande	Rivière Eastmain	Reservoir	480	3	63	2006	
9	Brisay	La Grande	Caniapiscau	Reservoir	469	2	37.5	1993	
10	Laforge-2	La Grande	Laforge	Run-of-river	319	2	27.4	1996	
11	Sarcelle	La Grande	Rivière Eastmain	Run-of-river	150	3	8.7 à 16.1	2013	
	Total				**17 418,00 MW**				

The 7,722 (5,616+2,106) MW Robert-Bourassa Hydropower Generating Facility at James Bay in the heart of Taiga, ranks as the world's 9th (ninth) biggest hydropower plant, the largest in NA and the world's largest underground generating station [70, 72]. A picture is shown below.

Figure 4-3 Robert-Bourassa (formerly La Grande-2) Hydropower Generation station
Taken from Hydro Québec – Robert Bourassa Generating Facility (2018)

4.3 Electricity Supply in QC

The Renewables Energy sources was responsible for 99.78% of the Electrical generation in Quebec, while 0.22% came from non-renewables. The Non-Renewable sources were made up in two categories: Fossil Fuel: 0.04% (composed by Gas, Coal and fuel oil) and Nuclear: 0.18%. The Other Renewables 5.31% was made up in three categories: Wind: 4.38%, Biomass: 0.87% and Biogas, waste and solar: 0.06% [28]. The chart below displays it in more details.

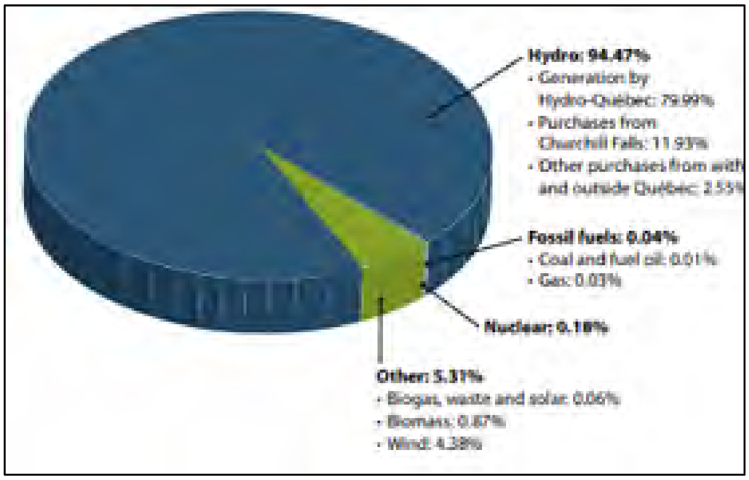


Figure 4-4 2017 Electricity Supply mix in QC
Taken from Hydro Québec – Hydro Québec's Electricity Facts (2018)

The Total electrical energy generated and purchased by Hydro Québec in 2017 was 221,097 GWh, which is represented better by the chart below, from 2014 to 2017.

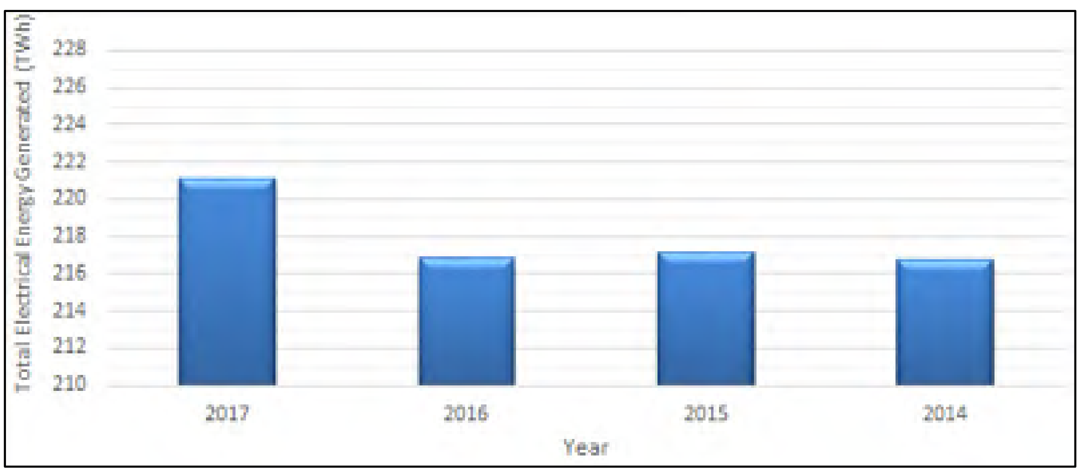


Figure 4-5 Total Electrical Energy Generated and Purchased by HQ (TWh)
Taken from Hydro Québec – The Sustainability Report 2017 (2018)

The breakdown of the electrical energy generated and purchased in GWh is displayed below.

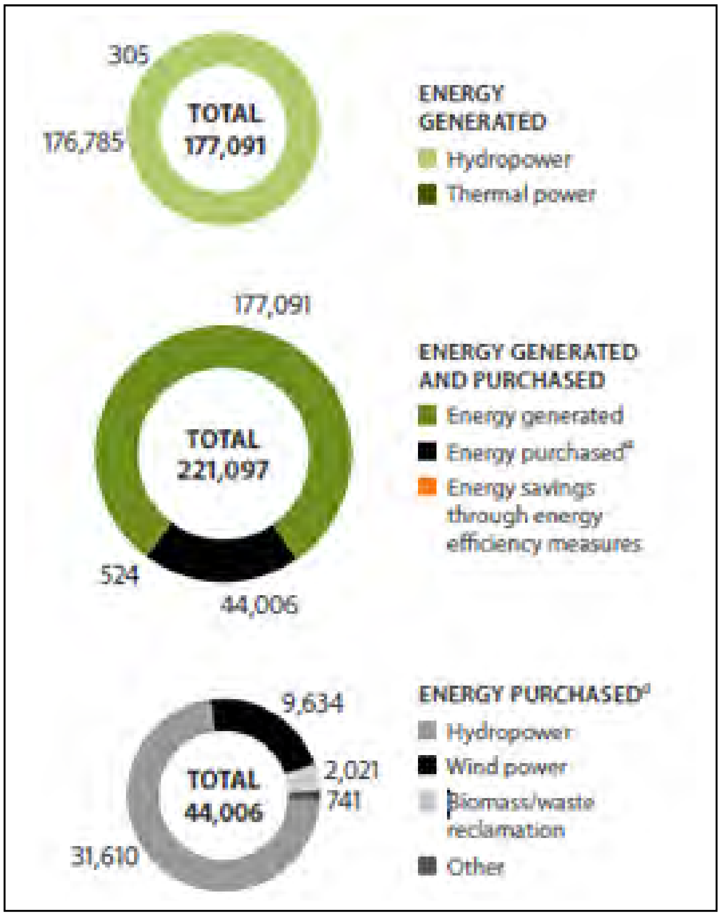


Figure 4-6 2017 Breakdown of electricity generated and purchased by HQ (GWh)
Taken from Hydro Québec – The Sustainability Report 2017 (2018)

Hydro Québec has generated by its own, 177,091 GWh, which corresponds to 80% of total. The biggest part of the purchased electrical energy comes from the Churchill Falls (Labrador) Corporation Limited Hydropower station, where HQ owns 34.2% of it and has the right to acquire almost all of its output until 2041.

4.4 Criteria and Billing for Residential and Business Consumers

The electricity rate in Quebec is determined by the quantity of electrical power a consumer uses and its category. Hydro Québec owns a huge list with different rates and categories for residences, farms, small, medium, commercial, industrial, service large, industrial large, off-grid and other customers, whose complete breakdown is included in the Appendix I – 2017 HQ Electricity Rates for Residence and Business. In this thesis, two rates will be studied: the Domestic rate or D rate for residence and Service LG rate for a five MW consumer as ÉTS.

4.4.1 Criteria and Billing for Residences

D rate is usually applied to domestic, which includes residences and farms (crop and animal farming). In most cases, the electricity supplied is metered separately or bulk metering (whose total amount is divided up among its users).

D rate is divided up in a fixed charge and a variable amount reflecting energy consumption, divided into two tiers: First tier (1^{st} tier) is billed at a lower price than Second tier (2^{nd} tier) [46].

From the end of 70s up to March 31, 2017, the first tier was set at 30 kWh a day, or 900 kWh a month. On April 1^{st} 2017, it was raised from 30 to 33 kWh a day and updated again on April 1^{st} 2018, where it was raised to 36 kWh.

It represents an estimated saving of 90 kWh a month and up to 18% of saving in 2017, as well as 180 kWh a month and up to 35% saving from 2018 on. It is excellent for small costumers that use electricity for heating during winter season.

A summary of each charge and its electricity rate values are presented below.

Table 4-2 Monthly Bill Charges for a D Consumer
Adapted from Hydro Québec – Rate D – Rate for residential and farm customers and 2017 Electricity Rates & Conditions of service (2018 and 2017)

Item	Kind of Cost	Kind of Charge	2017 Rate ($)	Unit
1	Energy Cost	Price of energy for energy consumption up to 33 kilowatthours (kWh) times the number of days in the consumption period (1st tier)	0.0582	$/kWh
2	Energy Cost	Price of energy for the remaining energy consumption (2nd tier)	0.0892	$/kWh
3	Fixed Cost per day	Fixed charge per day in the consumption period	0.4064	$/Day

1) Energy Cost: First tier pays a lower amount, 0.0582/kWh up to 33 kWh of consumption per day, according to the 2017 rates.
2) Energy Cost: Second tier pays a higher amount, 0.0892/kWh from what exceeds 33kWh per each day, according to the 2017 rates.
3) Fixed Cost per day: Fixed charge of 0.4064 $/day in the consumption period, according to the 2017 rates.

These residential electricity rates represented the lowest in North America in 2017. The comparison prices for a 1,000 kWh monthly bill residential consumer among the largest cities in NA are displayed below.

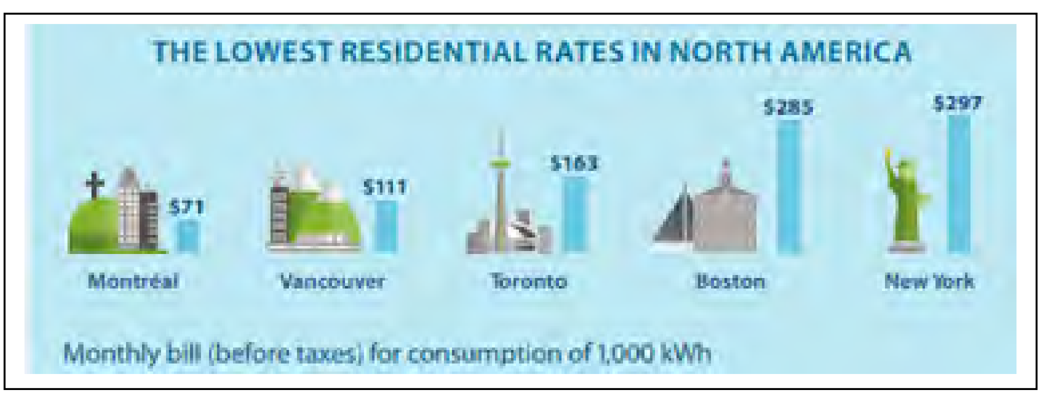


Figure 4-7 The lowest Residential in North America in 2017
Taken from Hydro Québec – 2017 Annual Report (2018)

A sample of a residential Monthly Bill Statement in QC is shown below.

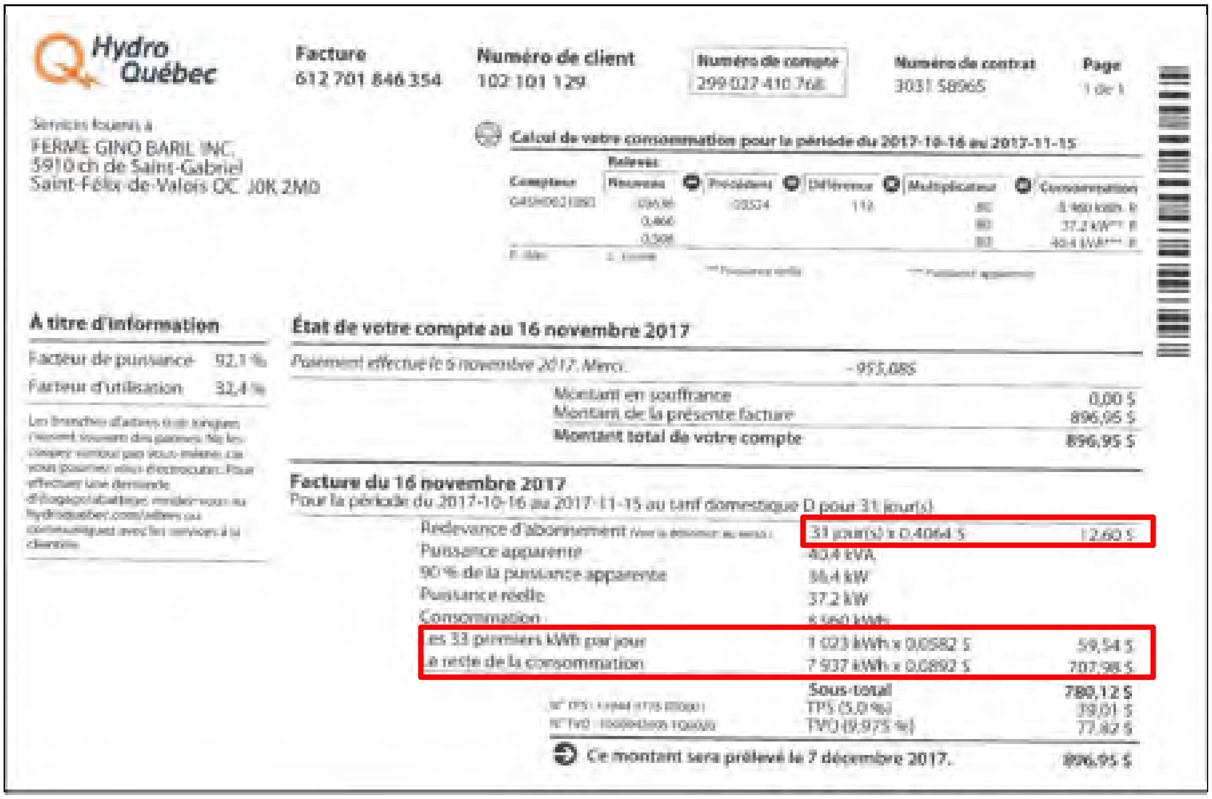


Figure 4-8 Sample of a Residential Monthly Bill in QC
Taken from Presentation of the course ENR810 ÉTS by D. Rousse (2018)

4.4.2 Criteria and Billing for a Large Service Businesses as ÉTS

The LG Rate is applied for an annual subscription with a minimum power demand of 5 (five) MW or more and that is not related to an industrial activity.

An amount for energy in kilowatt-hours (kWh) is consumed during the period and an amount for the power demand in kilowatts (kW). The LG rate is a monthly rate, which means that the amount billed for power and consumption are based on a 30-day period [73].

Thus, there are 02 (two) different charges of the electricity monthly bill for a 5 MW LG Service Consumer, as ÉTS. A summary of each charge and its rate values are presented below.

Table 4-3 Monthly Bill Charges for a LG Service Consumer
Adapted from Hydro Québec – Large-power Client Service LG rate and 2017 Electricity Rates & Conditions of service (2018 and 2017)

Item	Kind of Cost	Kind of Charge	2017 Rate ($)	Unit
1	Energy Cost	Energy Consumption	0.0342	$/kWh
2	Power Cost	(+) Demand Charge	13.11	$/kW
3	Power Cost	(-) Feed Credit	-0.98100	$/kW
4	Power Cost	(-) Adjustment for Transformation Losses	-0.17760	$/kW
5	Fixed Cost	No Fixed Cost	0	$

1) Energy cost: The Real Monthly Consumption is multiplied by 3.42 ¢/kWh. In June 2017, ÉTS consumption was: 2,800,656.0 kWh * 0.0342 $/kWh = $95,782.44.
2) Power Cost: The Monthly Power Demand is multiplied by 13.11 $/kW (*). The Power Demand will be explained in details on the next page.
3) Power Cost: The Feed Credit rate of 0.98100 $/kW is deducted from the Demand Charge of 13.11 $/kW.

   Feed Credit: Hydro-Québec rates are set for low-voltage electricity service. If the business owns the equipment that allows lowering the voltage of electricity supplied by HQ or if the business uses the electricity at medium voltage or high voltage, it avoids costs to HQ. A monthly credit applicable to the price of the power is then, granted to the business. This credit varies according to the voltage of the electricity delivered [73].
4) Power Cost: The Adjustment for Transformation Losses rate of 0.17760 $/kW is deducted from the Demand Charge of 13.11 $/kW. After deducting all losses of Feed Credit of 0.98100 $/kW and Adjustment for Transformation Losses rate of 0.17760 $/kW, the Real Demand Charge is multiplied by 11.9514 $/kW.

   The Adjustment for Transformation Losses: Hydro-Québec only charges the customer for the electricity it actually receives. Therefore, it intends to assume that the transformation losses is associated with the delivery of electricity. In some cases, the measurement is carried out before the transformation; the electricity billed is then to include the energy lost at the stage of the transformation, and therefore not received by the customer. This is why a compensation on billing power is granted to the customer so that lost energy is not his responsibility [73].

5) Fixed Cost: No fixed cost are presented in Quebec.

(*) Power Demand

In order to find out the Power Demand value, which will be multiplied by 13.11 $/kW or 11.9514 $/kW (after deducting the Feed Credit and The Adjustment for Transformation Losses), Hydro Québec does the following analysis for a 5 MW LG Service Contract:

1) Calculates the power demand in each 5 (five) minutes in a 30-day period.
2) Calculates the average for each 15 (fifteen) minutes and picks up the maximum value of a 15-minute average in a month, which is the peak power demand. In June 2017, the real power was 5,894.4 kW, as indicated in red in the chart below.
3) After, HQ takes the apparent power of the same period, which was 6,248.5 kVA in June 2017 and multiplies by its optimal power factor of 95%, to convert it to the real power [73]. This value was 5,936.1 kW in June 2017 (marked in a yellow dotted line in the Monthly Bill Statement).
4) Then, HQ peaks the highest value between 5,936.1 kW and 5,894.4 kW and multiplies by 11.95 $/kW (13.11 - 0.98100 - 0.17760), which is equal to $70,944.71.
5) If the peak demand is lower than 5,000 kW, such as 4,800 kW, the consumer will pay for 5,000 kW, which is the minimum, according to the LG Service Contract.

The Peak Demand Chart and a Sample of a 5 MW LG Monthly Bill in QC are shown below.

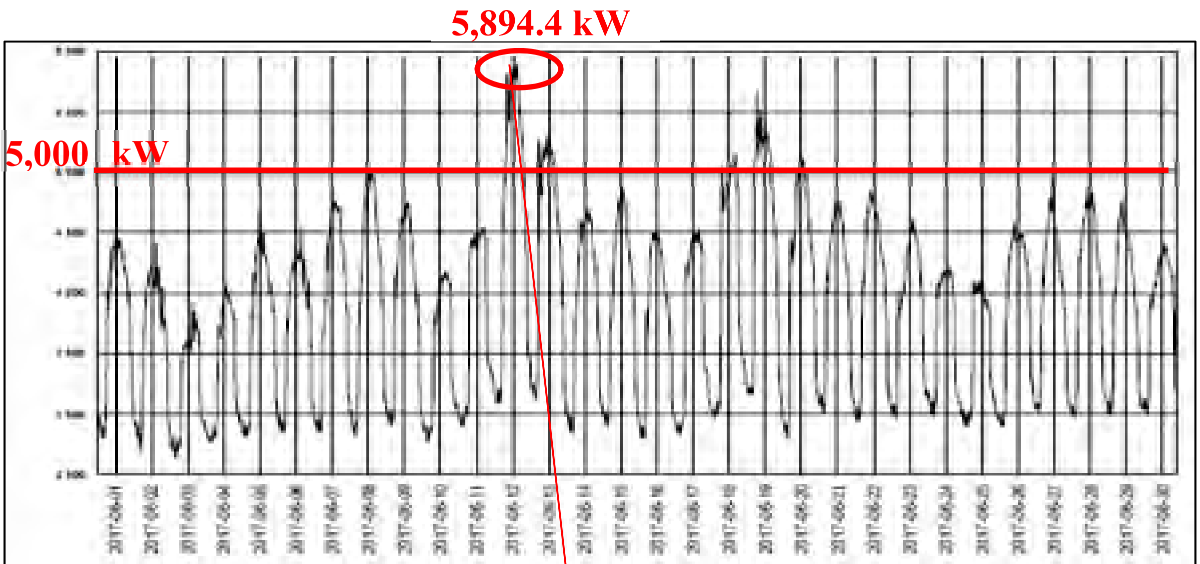
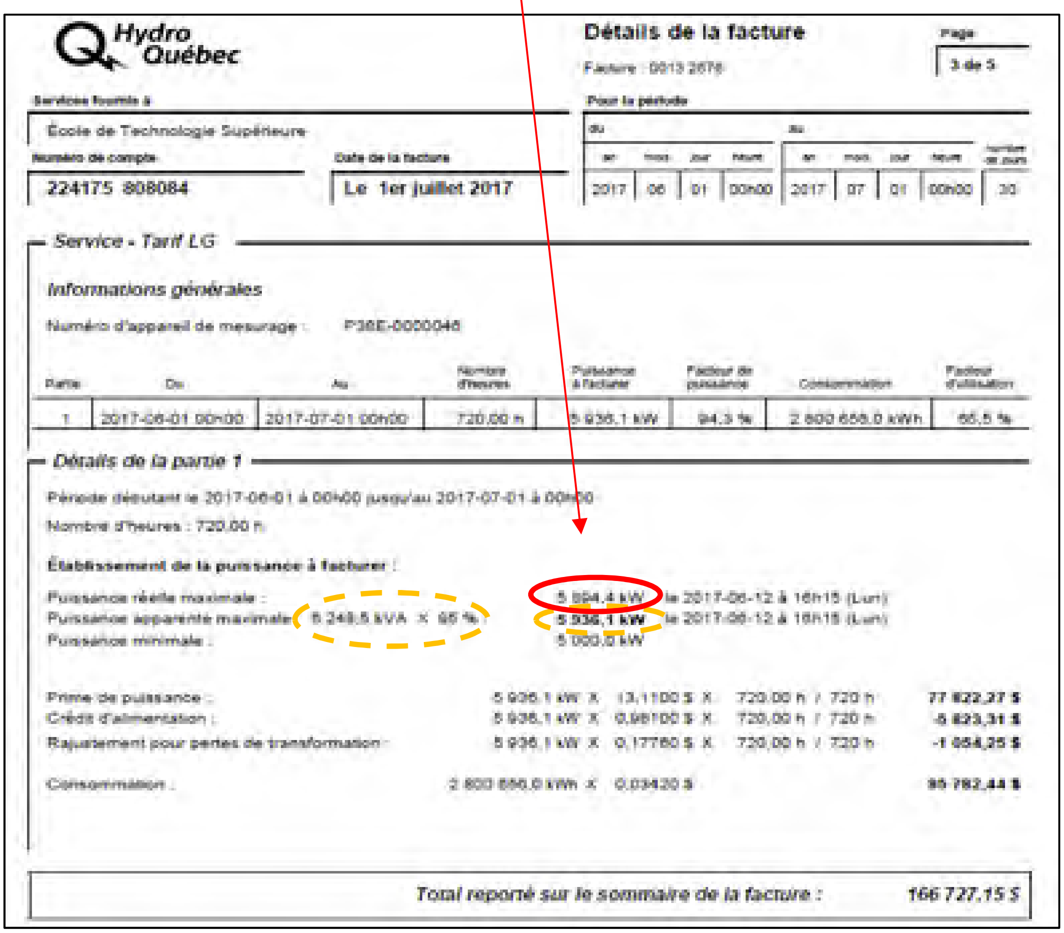


Figure 4-9 Chart of Peak Power Demand for a LG Service Consumer
Taken from ÉTS Monthly Bill in 2017 (2017)



Hydro Québec

Détails de la facture

Facture : 0013 2676

Page 3 de 5

Services fournis à : École de Technologie Supérieure

Numéro de compte : 224175 808084

Date de la facture : Le 1er juillet 2017

Pour la période

du an	mois	jour	heure	au an	mois	jour	heure	nombre de jours
2017	06	01	00h00	2017	07	01	00h00	30

Service - Tarif LG

Informations générales

Numéro d'appareil de mesurage : P36E-0000046

Partie	Du	Au	Nombre d'heures	Puissance à facturer	Facteur de puissance	Consommation	Facteur d'utilisation
1	2017-06-01 00h00	2017-07-01 00h00	720,00 h	5 936,1 kW	94,3 %	2 800 656,0 kWh	65,5 %

Détails de la partie 1

Période débutant le 2017-06-01 à 00h00 jusqu'au 2017-07-01 à 00h00

Nombre d'heures : 720,00 h

Établissement de la puissance à facturer :

Puissance réelle maximale : 5 894,4 kW le 2017-06-12 à 16h15 (Lun)
Puissance apparente maximale : 6 248,5 kVA × 95 % 5 936,1 kW le 2017-06-12 à 16h15 (Lun)
Puissance minimale : 5 000,0 kW

Prime de puissance :	5 936,1 kW × 13,1100 $ × 720,00 h / 720 h	77 822,27 $
Crédit d'alimentation :	5 936,1 kW × 0,98100 $ × 720,00 h / 720 h	-5 823,31 $
Rajustement pour pertes de transformation :	5 936,1 kW × 0,17760 $ × 720,00 h / 720 h	-1 054,25 $
Consommation :	2 800 656,0 kWh × 0,03420 $	95 782,44 $

Total reporté sur le sommaire de la facture : *166 727,15 $*

Figure 4-10 Sample of a Large-Power as ÉTS Consumer in QC
Taken from ÉTS Monthly Bill in 2017 (2017)

4.5 Installed Capacity and Peak Power Demand

The installed capacity of HQ is great. It owned 47,612 MW in 2017, where 78% or 37,309 MW was operated directly by HQ Production or Distribution [8]. The rest was operated by independent power producers, such as: 39 wind farms with 3,508 MW, 8 biomass and 4 biogas cogeneration plants with 272 MW and Other suppliers with 988 MW. The exception is Churchill Falls (Labrador) Corporation, which HQ owns 34.2% of it [69] and has the right to buy almost all the output until 2041. The Churchill Fall Generating is the 2nd largest hydropower in Canada with 5,428 MW of installed capacity [70]. A total summary is below.

INSTALLED CAPACITY — 37,309 MW

63 HYDROELECTRIC GENERATING STATIONS[a] — 36,767 MW

Robert-Bourassa	5,616	Eastmain-1-A	768	Paugan	226
La Grande-4	2,779	Carillon	753	Rapide-Blanc	204
La Grande-3	2,417	Romaine-2	640	Shawinigan-2	200
La Grande-2-A	2,106	Toulnustouc	526	Shawinigan-3	194
Beauharnois	1,900	Outardes-2	523	Manic-1	184
Manic-5	1,596	Eastmain-1	480	Rapides-des-Îles	176
La Grande-1	1,436	Brisay	469	Chelsea	152
René-Lévesque	1,326	Romaine-3	395	Sarcelle	150
Jean-Lesage	1,229	Péribonka	385	La Gabelle	131
Bersimis-1	1,178	Laforge-2	319	Première-Chute	131
Manic-5-PA	1,064	Trenche	302	Les Cèdres	113
Outardes-3	1,026	La Tuque	294	Rapides-des-Quinze	109
Sainte-Marguerite-3	882	Romaine-1	270	Rapides-Farmer	104
Laforge-1	878	Beaumont	270	Other (18 generating stations rated less than 100 MW)	771
Bersimis-2	845	McCormick	235		
Outardes-4	785	Rocher-de-Grand-Mère	230		

24 THERMAL GENERATING STATIONS[b] — 542 MW

Bécancour (gas turbine)	411
Other (23 diesel plants on off-grid systems)	131

a) 62 operated by Hydro-Québec Production and 1 by Hydro-Québec Distribution.
b) 1 operated by Hydro-Québec Production and 23 by Hydro-Québec Distribution.

OTHER SOURCES OF SUPPLY — 10,303 MW

Churchill Falls generating station (Churchill Falls (Labrador) Corporation Limited)[a]	5,428
39 wind farms operated by independent power producers[b]	3,508
8 biomass and 4 biogas cogeneration plants operated by independent power producers[c]	272
7 small hydropower plants operated by independent power producers[b]	107
Other suppliers[d]	988

a) Hydro-Québec has access to almost all the output until 2041.
b) Hydro-Québec purchases all the output.
c) Hydro-Québec purchases almost all the output.
d) Hydro-Québec has access to the output of these suppliers.

Figure 4-11 Hydro-Quebec Installed Capacity in 2017
Taken from Hydro Québec – The Sustainability Report 2017 (2018)

Table 4-4 Installed Capacity and Peak Power demand in 2017
Taken from Hydro Québec – 2017 Annual Report (2018)

	2017	2016	2015	2014	2013
MW					
Installed capacity					
Hydroelectric	**36,767**	36,366	36,370	36,100	35,364
Thermal	**542**	542	542	543	704
Total installed capacity	**37,309**	36,908	36,912	36,643	36,068
GWh					
Total energy requirements	**226,824**	223,143	222,172	222,045	226,576
MW					
Peak power demand in Québec	**38,204**	36,797	37,349	38,743	39,031

The Peak Power Demand in the province of Quebec was 38,204 MW in 2017, as shown below.

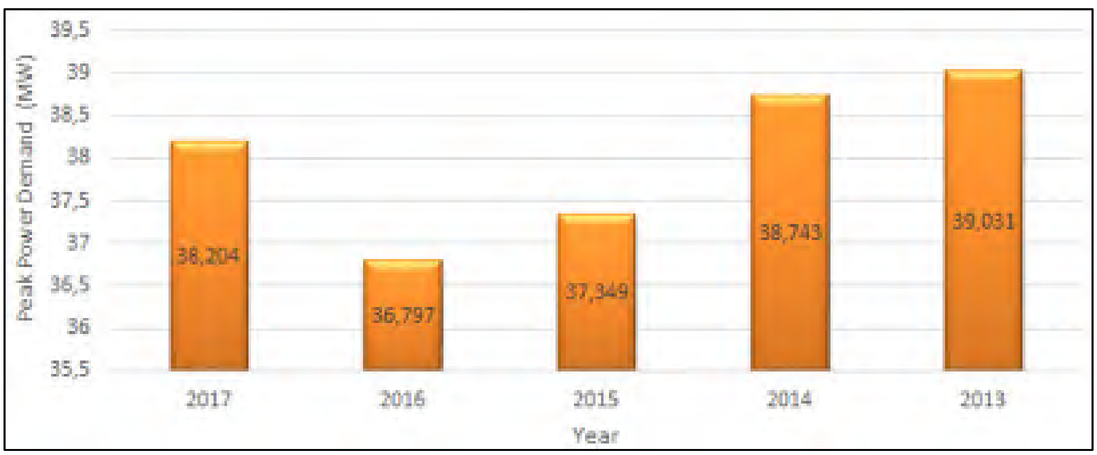


Figure 4-12 Peak Power Demand in Quebec (MW)
Taken from Hydro Québec – 2017 Annual Report (2018)

The Peak Demand Figures in 2017 was issued on February 16, 2018. The highest values indicated correspond to the needs for the winter, including interruptible power. The peak for a given period is based on measurements at fixed intervals. The 2017–2018 winter peak was 38,204 MW and occurred on December 28, 2017, at 5:00 p.m. [8]. HQ owns a Demand

Response for mid to large-power business consumers, in order to encourage them to reduce the peak demand during winter season and get some financial assistance from the DR program.

4.6 2017 Project Portfolio and Long-term Non-Heritage Supply

The 2017 Project Portfolio of HQ is shown below, according to sustainability & annual report.

Table 4-5 2017 Project Portfolio of Hydro Québec
Adapted from Hydro Québec – 2017 Annual Report and The Sustainability Report 2017 (2018 and 2018)

Project Number	Project Name	Scope of Work	Region	Period	Status	Installed Capacity (MW)	Planned Annual Output (TWh)	Investment ($)
1	Romaine Complex	Hydropower Station Construction - Romaine-3 (395 MW) commissioned in 2017; Romaine-4 (245 MW) planned to 2020	Côte-Nord	2009-2020	Under Construction	1 550	8.0	6,5 billion
2	735-kV Chamouchouane–Bout-de-l'Île Project	Construction of more than 400 km of 735-kV lines between Chamouchouane substation in Saguenay–Lac-Saint-Jean and the metropolitan loop, in addition to the relocation of a short existing 735-kV line to Bout-de-l'Île substation in Montréal; and the construction of 735/120/25-kV Judith Jasmin substation in Terrebonne (Lanaudière)	Saguenay–Lac-Saint-Jean; Mauricie; Lanaudière; Laurentides; Montréal	2015-2018	Under Construction	xxx	xxx	1,3 billion
3	Dismantling Parent dam	Dismantling Parent dam and Restore the site	Parent	2018	In Progress	xxx	xxx	xxx
4	Decommissioning Gentilly-2	Decommissioning Nuclear Power Station of Gentilly-2	Bécancour	2017-2066	In Progress	xxx	xxx	xxx
5	Rehabilition of Robert-Bourassa Hydropower	Rehabilitation of most powerful Hydroelectric facility - Robert Bourassa for efficiency performance	James Bay	xxx	In Progress	xxx	xxx	xxx

Also, HQ has currently 75 contracts from 15 to 25 years for delivery of generated electricity by a variety of sources and also other signed agreements to secure future supply, with independent power producers [17].

Table 4-6 Long-term Non-Heritage Supply Under Contract
Taken from Hydro Québec – The Sustainability Report 2017 (2018)

			ANNUAL ENERGY (TWh)	
ENERGY SOURCE	NUMBER OF CONTRACTS SIGNED ✓	PEAK CAPACITY (MW) ✓	2018	2026
Biomass	21	338	1.8	2.5
Wind power	38	1,484	11.2	11.3
Cogeneration	1	8	0.1	s.o.
Small hydro	9	122	0.5	0.7
Other sources	3	600	3.1	4.5
Hydro-Québec Production	3	500	s.o.	0.2
TOTAL	**75**	**3,053**	**16.6**	**19.2**

Table 4-7 Current and Planned Capacity Under Supply Contracts (MW)
Taken from Hydro Québec – The Sustainability Report 2017 (2018)

	IN OPERATION ✓	UNDER CONSTRUCTION ✓	PLANNED	TOTAL
Wind farms	3,520.5	147.2	42.8	3,710.5
Cogeneration plants	766.8	9.8	78.8	856.4
Hydroelectric generating stations	703.4	0.0	44.0	747.4

4.7 Demand Response Program – Gestion de la Demande de Puissance

Demand Response refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices) [60].

In Quebec, firstly, a Pilot Project was implemented in some different kind of business, such as a bank, a school, some stores and administrative buildings, in order to test a potential power demand fall by implementing some demand response measures. After obtaining a successful result, HQ implemented the Demand Response Program in 41 administrative and service centers. As a Result, the buildings' power demand dropped by an average of 35% to 50% during the winter peak [17]. The name of this DR program is "Gestion de la Demande de Puissance" or GDP.

In both 2018 and 2017, HQ is offering a financial assistance of $70/kW by reducing the power demand during Hydro-Québec's winter peak times through prescheduled DR events [74]. It means, that HQ will establish some specific days and period of time, which registered medium and large-power businesses may participate of the DR events. In addition, the business must save a minimum of 200 kW per hour of event, in order to be eligible to gain the financial assistance. Finally, it will be provided based on the average power reduction during all GDP events, which will take place in different days and times during winter season.

Benefits of the Program: A substantial amount in recurring financial assistance each year, minimal investment, streamlined registration, voluntary participation, no contract to sign, no penalty if reduction target not met and a minimum amount granted if Hydro-Québec issues no Demand Response notice during the winter season [74].

A summary of the GDP Program Participant's Guide Report will be provided below:

- GDP Program: Reduction of the power demand of buildings during a winter's period of high peak demand in Quebec.
- Target Market: Commercial and institutional markets as well as small and medium industrial enterprises.
- Eligible Clients: Any Customer having a communicating meter and whose subscription is subject to the service: DP, DM, G, G-9, M or LG.
- Minimum Required Power to be eligible to the program: 200 kW.
- Financial assistance: The unit amount of $70/kW is multiplied by the Eligible Power (kW), which is the average of power reductions of all GDP Events.
- Eligible Power (kW): It is calculated based on the average of saved power in all GDP events.
- Period of the Program: From December 01st to March 31st.

- Payment period: By May 31st, the Participant receives an email from HQ that provides him with the Calculation of Financial Support and asks him to send the invoice for it.
- A GDP Event may occur during any of Hydro-Québec's Winter Peak Periods, which are from 6:00 am to 9:00 am and from 4:00 pm to 8:00 pm, or during these two periods, unless weekends and holidays
- The maximum number of hours per Winter Period covered by GDP Events is 100.
- A minimum four-hour notice period for which the participant is asked in advance by HQ to decrease the power demand recorded by the meters linked to the project. This notice will be provided by registered e-mail. [75].

A practical example of the GDP calculus is shown in the section 5.2.8 – Algorithm Description.

4.8 Export Market

Hydro Québec produces an extra volume of electricity from Hydro electricity, which is available to Export Market. While Quebec’s residential consumers paid 0.07 $/kWh in 2017 (with all HQ generation, transmission and distribution costs included), Boston and New York paid 0.28 $/kWh and 0.30 $/kWh [25], respectively (with all electricity purchase price, transmission and distribution cost paid by U.S. utilities included) [21].

In 2017, HQ exported 34.9 TWh, mainly to New England region (52%) and New York City (23%) in the U.S., as well as to Ontario (15%) and New Brunswick (6%) in Canada, as displayed below.

It is important to note that a relevant yearly profit from Hydro Québec comes from this export market. Also, it contributes to the environment by exporting electricity from a renewable energy source.

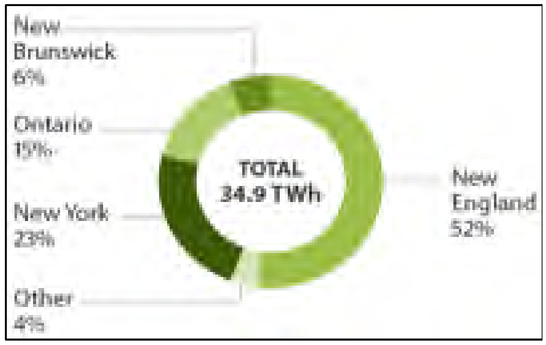


Figure 4-13 Hydro Québec Electricity Sales Outside Quebec - 2017
Taken from Hydro Québec – Export Markets in 2017 (2018)

New England region corresponded to 52 % of HQ's Export market. This region is located in the northeast corner of the U.S. and comprised by six states: Maine, Vermont, New Hampshire, Massachusetts, Rhode Island and Connecticut [2]. The map of New England is shown below.

Figure 4-14 Map of New England States
Taken from New England Network (2018)

Over the year, emissions avoided by net electricity exports totaled 8.4 Mt Co_2 eq [17].

4.9 Greenhouse Gas Emission for Quebec's Electricity Sector

An audit was conducted through the bureau de normalisation du Québec (BNQ) in 2018, to assure the Electricity Supply and Air Emissions of HQ's energy generation and purchases in 2017. The atmospheric emissions of greenhouse gas (GHG) and others gases emission were analyzed and audited. Based on the materiality thresholds established for this mandate, the audit conducted by the BNQ served to attest that the targeted declarations are accurate and reliable and that they comply with the principles of standard ISO 14064- 1:2006 [28]. HQ emitted 0.26% or 558 out of 210,944 metric tonnes/TWh of carbon dioxide equivalent of greenhouse gas, in comparison to the regional average, with 0.01% from HQ generation.

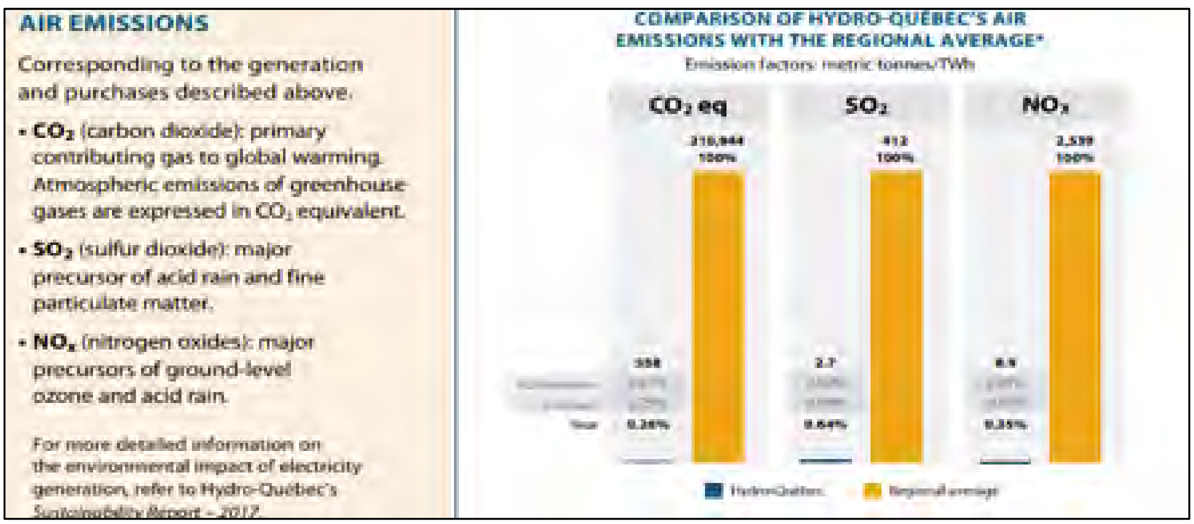


Figure 4-16 Comparison of Hydro Québec Gas Emission with Regional Average
Taken from Hydro Québec – Hydro Québec's Electricity Facts (2018)

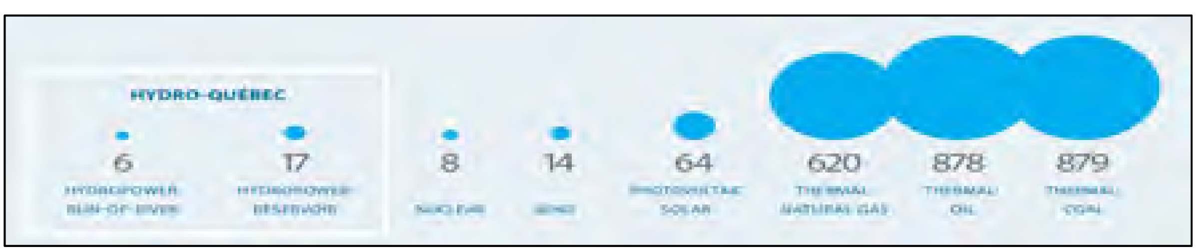


Figure 4-15 GHG Emissions by Generating Option (g CO_2 eq./kWh) in 2017
Taken from Hydro Québec – 2017 Annual Report (2018)

CHAPTER 5

MATLAB SIMSCAPE POWER SYSTEM SIMULATION

5.1 The MATLAB SimScape Power System

The MATLAB SimScape Power System model: Smart Micro-Grid was developed by Nicolas Mary and Professor Louis Dessaint, from the Chair on Electrical Network Security of the GRÉPCI (Groupe de Recherche en Électronique de Puissance et Commande Industrielle) [76]. This research group of the Electrical Engineering department from École de Technologie Supérieure worked in a partnership with Hydro-Québec for the Mathworks. In addition, it was modified by the author's of this master thesis, where it was added 08 new algorithms to work with Ontario's electricity power system and billing, which is completely different from Hydro-Québec.

The model represents a Smart Micro Grid, which is a group of interconnected loads and distributed energy resources acting as a single controllable entity [77], composed of a Photovoltaic Solar panels farm, electrical vehicles charging stations, a Battery Energy Storage System (BESS) and Generics load representing commercial or industrial buildings. All these components work together with the help of a smart controller supported by load and meteorological forecasting. Using 'Phasor' Mode for simulation, it allows yearly simulations and economical studies of a smart micro-grid in few minutes [78]. A Phasor mode is known as frequency-time equation formulation, that leads to accurate simulation of AC models with larger time steps [79].

Results are saved both in Matlab Workspace and in Excel files to be easily exploitable.

The main objectives of this model are:

1) Simulate a smart micro grid composed of a renewable energy source and battery energy storage system (BESS);

2) Simulate a full year with resolution up to 5 minutes in less than 10 minutes using Simulink Simulation “Phasor” Mode;
3) Use public data for meteorological and load demand and allow user to use custom data;
4) Use Simulink library “Battery” block with phasor mode;
5) Allow testing of smart control algorithms for the BESS based on forecasts in order to:
   - Optimize use of photovoltaic panels’ production.
   - Achieve peak shaving on load consumption.
   - Reduce overall energy costs of the building.
   - Compute economic study to estimate costs and benefits of Smart Micro-Grid Projects [78].

An overview of its main screen and blocks parameters are shown below.

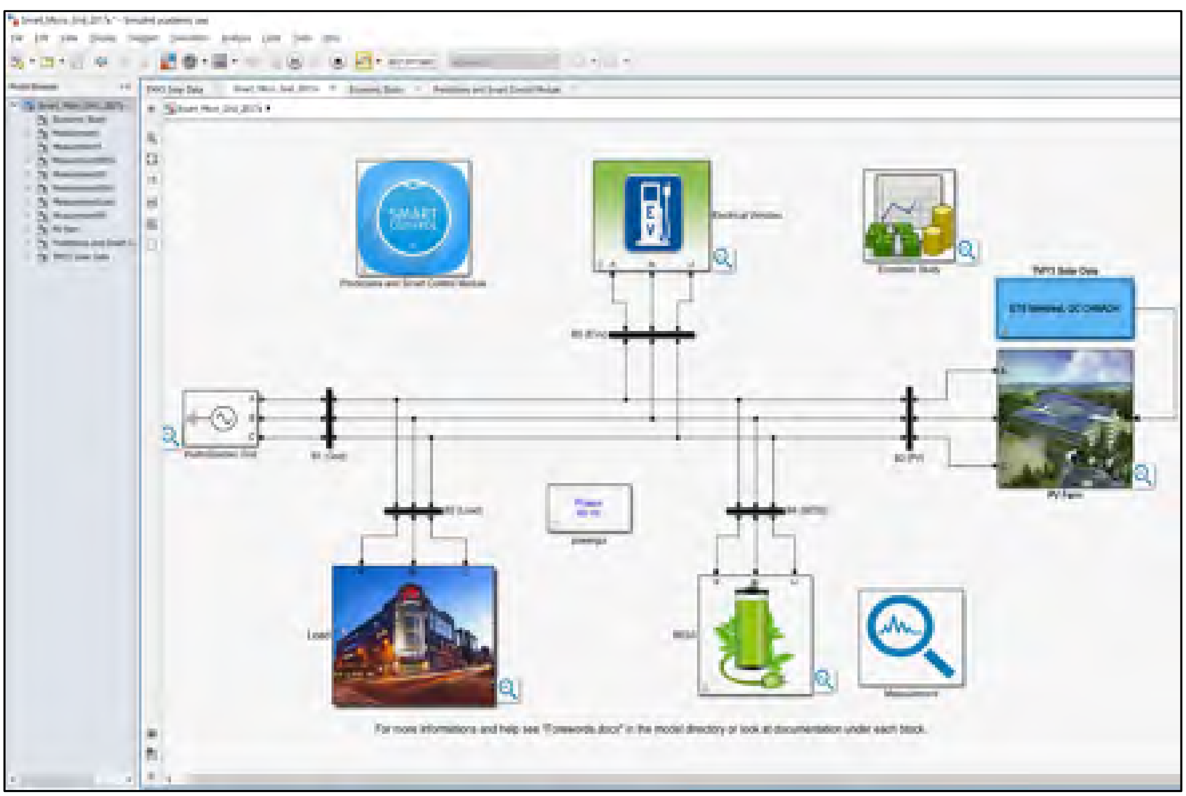


Figure 5-1 Main screen of Smart Micro Grid in Simulink
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

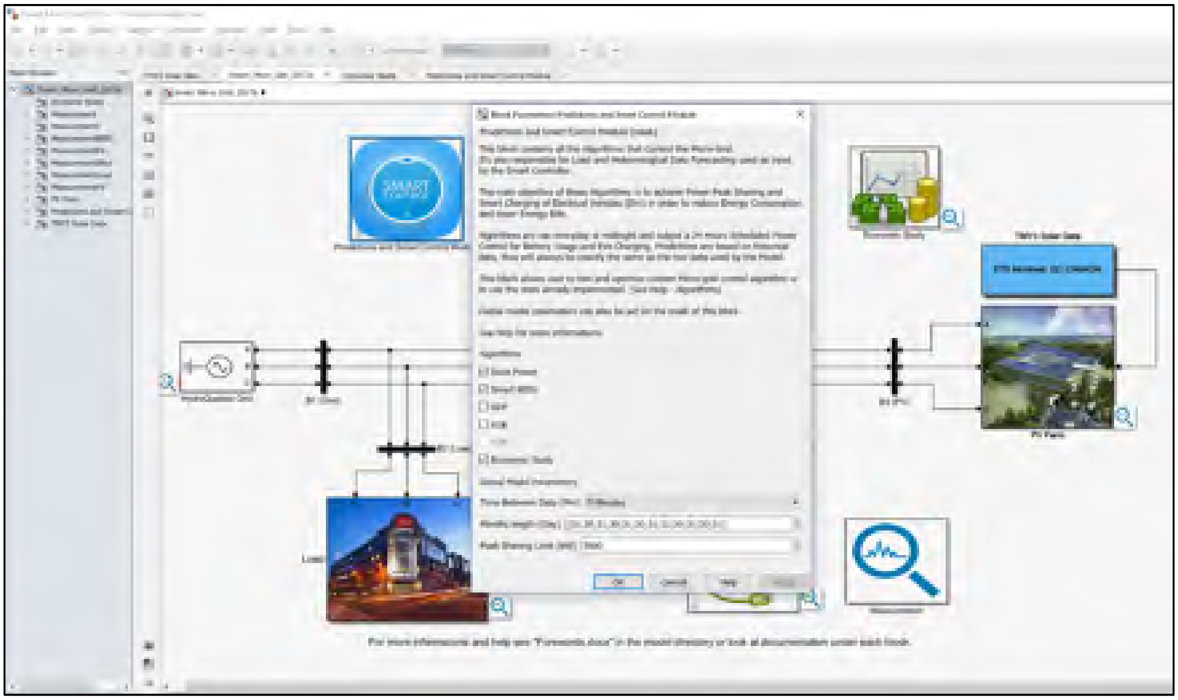


Figure 5-2 Prediction and Smart Control Module / Block
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

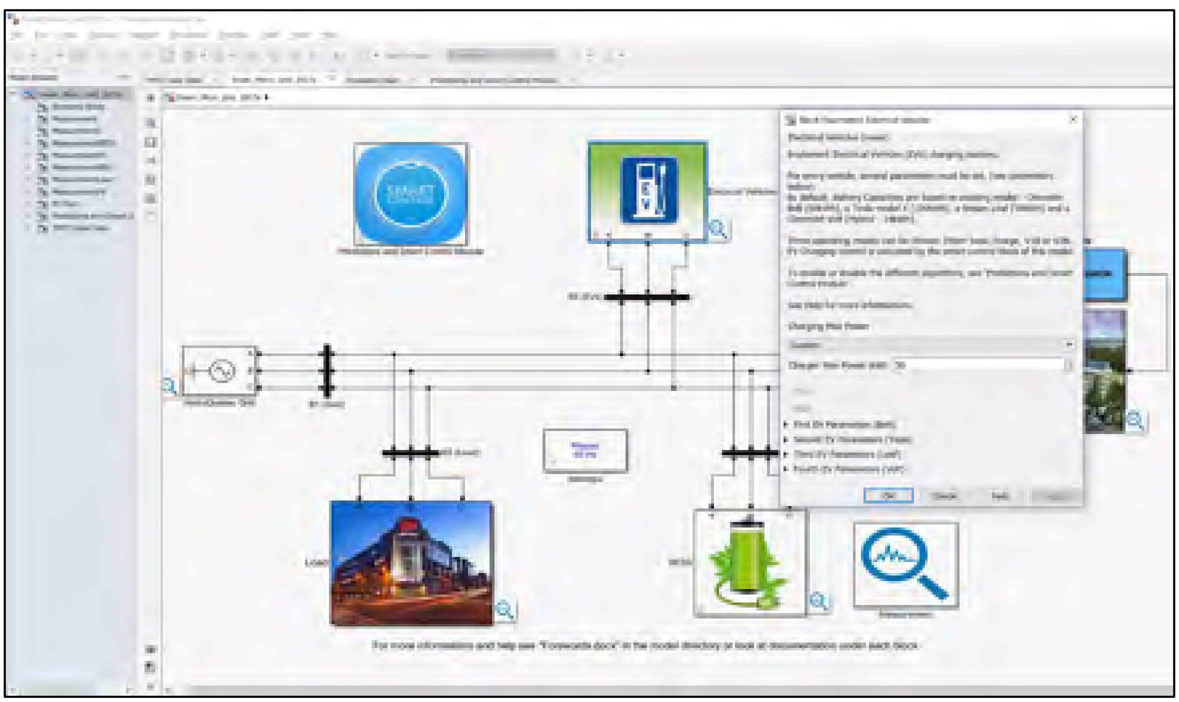


Figure 5-3 Electrical Vehicles Module / Block
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

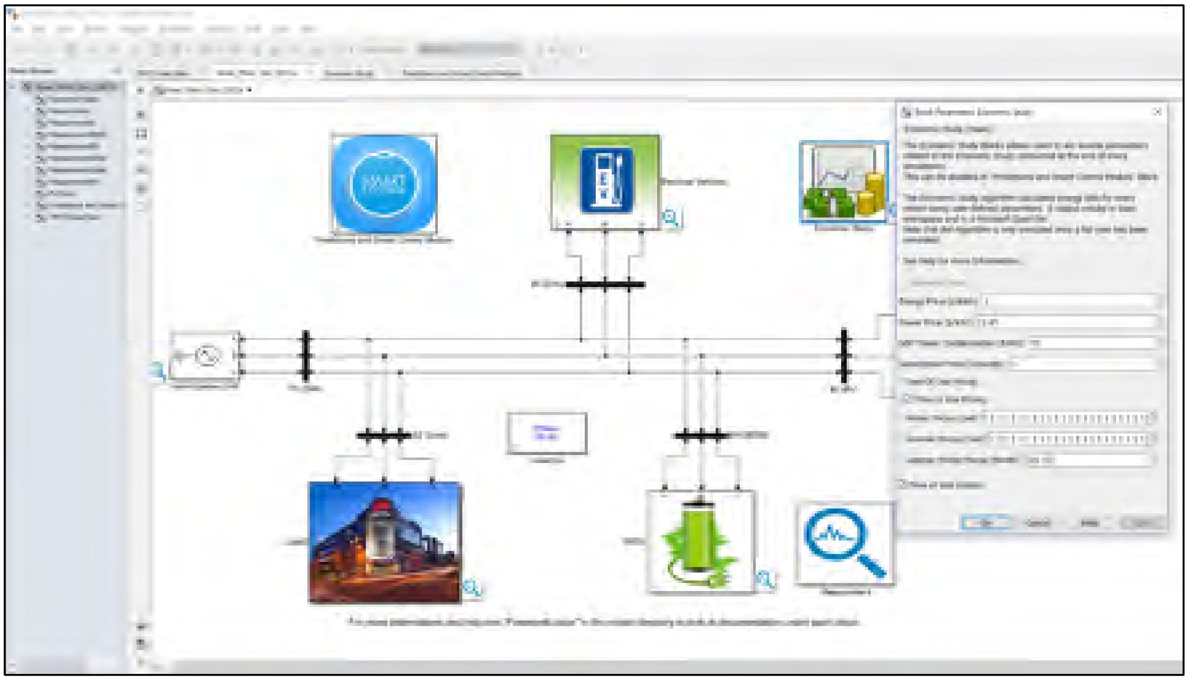


Figure 5-4 Economic Study Module / Block
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

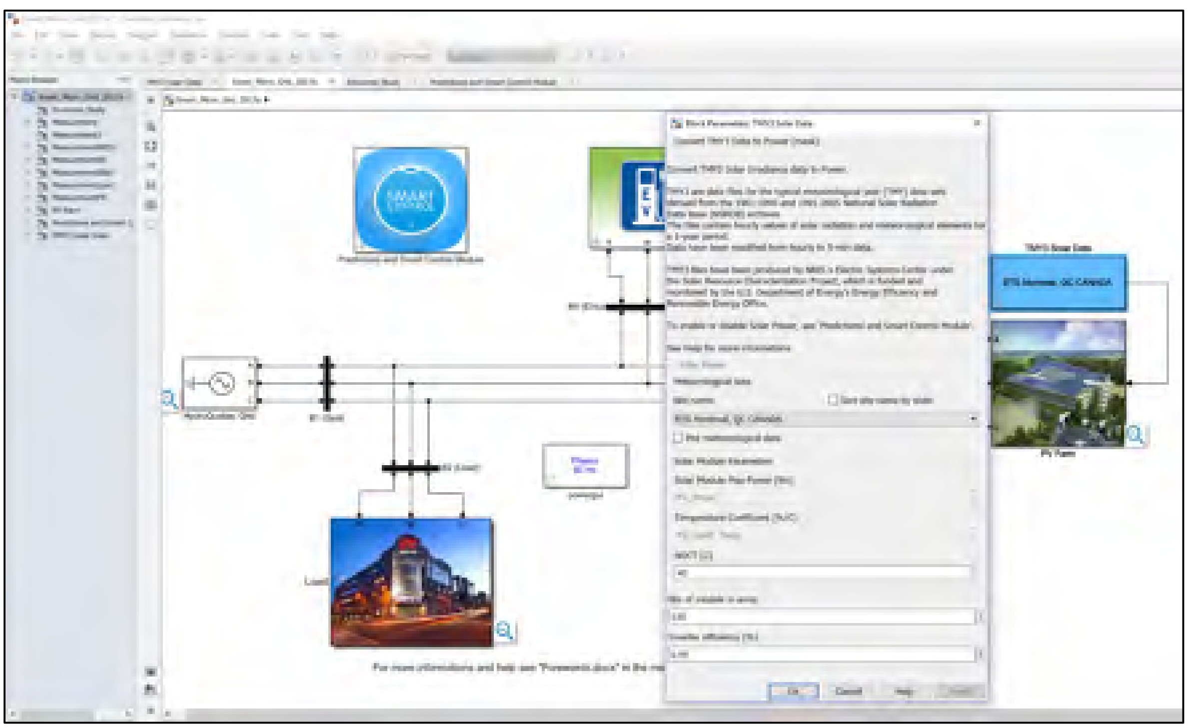


Figure 5-5 TMY3 Data to Power Module / Block
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

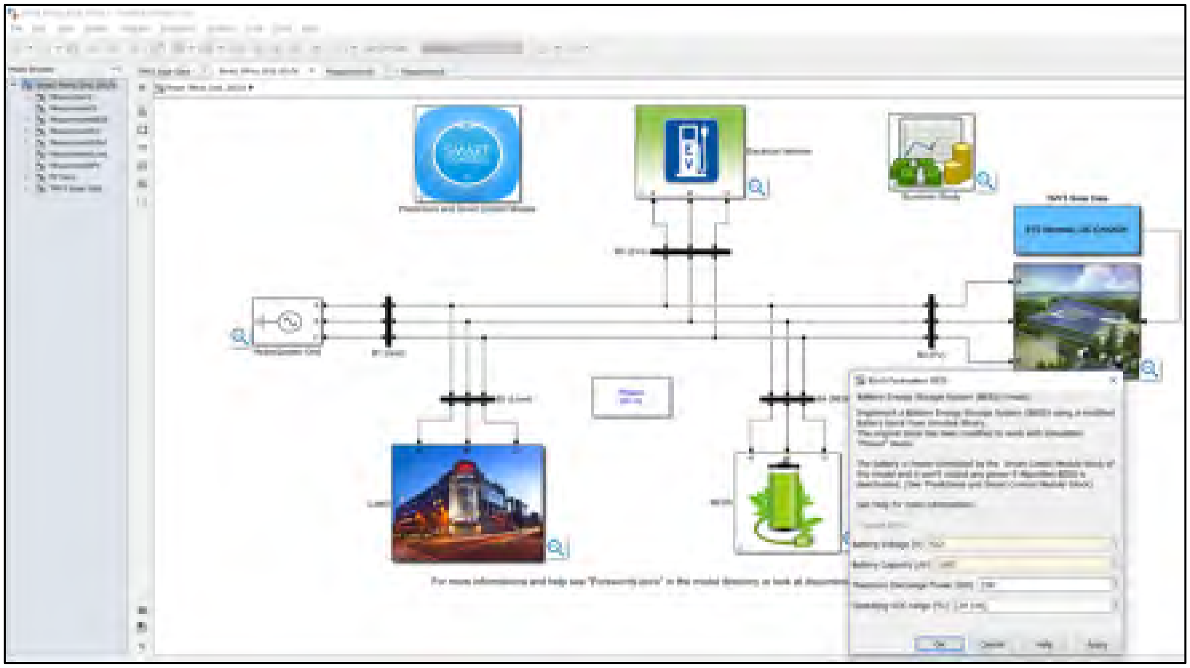


Figure 5-6 Battery Energy Storage System Module / Block
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

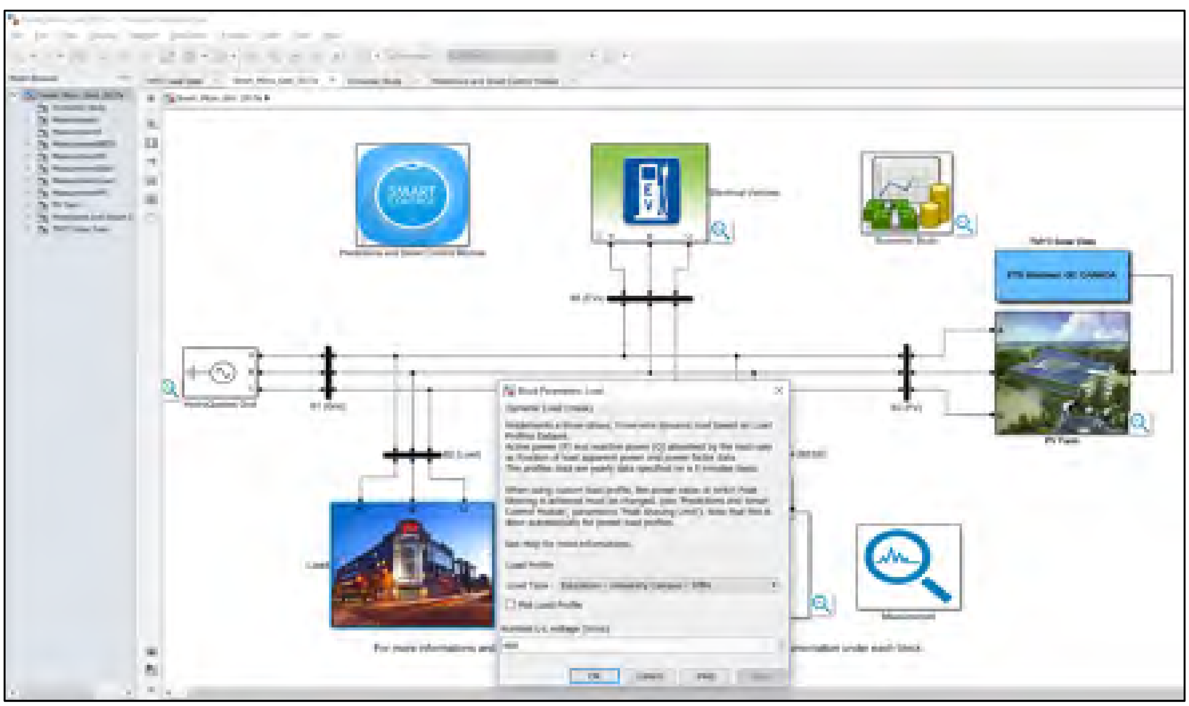


Figure 5-7 Dynamic Load Module / Block
Taken from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

5.2 Assumptions of the Simulation

The assumptions utilized in this simulation and an overview of each block is presented below, in order to calculate the yearly and monthly electricity expenses of the ÉTS at MATLAB Simscape:

5.2.1 Load:

Represented by a 5MW Educational Building, Commercial, Light Industry and Custom loads, this block is a three-phase, three-wire dynamic load based on their load Profiles dataset. Active power (P) and reactive power (Q) absorbed by the load vary as function of load apparent power and power factor data. The profiles data are yearly data specified on a 5 minutes basis [1].

In this master's thesis simulation, it was utilized ÉTS's active power, power factor and apparent power data for each 5 minutes from 2015, 2016 and 2017 annual period [80].

5.2.2 Photovoltaics Panels

The Solar Photovoltaic System represented the renewable energy source generation in this simulation. The Power of one module is multiplied by the number of modules in the array, giving the Array Power. In addition, the Power value output by the 'TMY3 Solar Data' block serves as input for the 'PV Farm' block, which output three phase AC current into the micro grid. For the ÉTS's simulation, the following Solar Module specification, quantity and other related parameters were utilized:

- Maximum Power Point (MPP) of array: 150 kW;
- Number of Modules in array: 535 units;
- Photovoltaic Module type: Canadian Solar CS6X-280M (Datasheet is attached in Appendix II);
- Nominal Maximum Power per module: 280.08 W;

- Photovoltaic Cells per module: 72 units;
- Cell Type: Mono-Crystalline 156 x 156 mm;
- Module dimension: 1954 x 982 x 40 mm (76.93 x 38.7 x 1.57 in);
- Normal Operating Cell Temperature (NOCT): 45o C;
- Inverter efficiency: 95% (DC/AC Conversion Loss Coefficient).

5.2.3 BESS (Battery Energy Storage System):

A Battery Energy Storage System (BESS) is used to store electricity in the form of chemical energy and to convert to electrical energy when required [81]. It was implemented by using a modified Battery block from Simulink library. The original block has been modified to work with Simulation "Phasor" mode. The battery is Power-controlled by the Smart Control Module block [1]. Below is a summary of ÉTS' parameters used in this simulation:

- Battery Type: Lead-Acid;
- Battery Module type : BAE SECURA OGi 250kW Battery (Datasheet is attached in Appendix III);
- Battery Voltage: 512 V;
- Battery Capacity: 1,953 Ah;
- Maximum Discharge Power: 250 kW;
- Two lead-acid battery banks plugged with 2 inverters of 125 kW AC Output Power;
- DC-AC Power Inverter and Battery Controller Module type : GTIB-480-125 (Datasheet is attached in Appendix IV);
- Operating State of Charge (SOC) range: 20 – 100%;

5.2.4 Electrical Vehicles (EV):

No electrical vehicles simulation were held in this research.

5.2.5 Prediction and Smart Control Module:

This block contains all the Algorithms that control the Micro-Grid. The Algorithms' goal is achieve Peak Power Shaving in order to reduce Energy Consumption and lower Energy Bills.

- Predictions are based on historical data, thus will always be the same as the real data used by the Model;
- Algorithms available: Economic Study, Solar Power, Smart Bess, GDP ("Gestion de la Demande de Puissance"), a Demand Response program from Hydro Quebec and EV;
- Global Model Parameters: each 5 minutes;
- Peak Shaving limit: 5,000 kW [1]. Note: Peak Shaving is the process of reducing the amount of energy purchased from the utility during peak demand hours [82].

5.2.6 Temperature and Solar Data:

Solar irradiance and Temperature from Montreal, QC, in hourly basis and modified to 5 minute data for 2015, 2016 and 2017 annual period.

Data downloaded from Weather Stats website [83], whose data were obtained from Environment and Climate Change Canada [84] and from the Citizen Weather Observer Program [85].

5.2.7 Economic Study:

Economic Study Algorithm calculates energy bills for every month using user-defined parameters in a 12 months period for ÉTS. It outputs results in base workspace and in a Microsoft Excel file.

The Algorithm is only executed once a full year (365*24*3600 Sec) has been simulated.

All unit prices from Hydro Québec are described below [47]:

- 2017 Energy Price ($/kWh): Price of one kWh: 0.0342$/kWh;
- 2016 Energy Price ($/kWh): Price of one kWh: 0.0339$/kWh;
- 2015 Energy Price ($/kWh): Price of one kWh: 0.0335$/kWh.

- 2017 Gross Power Price ($/kW): Price per kW (+): 13.11$/kW;
- 2016 & 2015 Gross Power Price ($/kW): Price per kW (+): 13.05$/kW.

- 2017, 2016 & 2015 Feed Credit: ($/kW): Price per kW (-):0.98100$/kW;
- 2017 Adjustment for transformation losses: Price per kW (-): 0.17760$/kW;
- 2016 & 2015 Adjustment for transformation losses: Price per kW (-): 0.1767$/kW.

- 2017 Net Power price: ($/kW): 13.11$/kW – 0.98100$/kW - 0.17760$/kW = $11.95;
- 2016 & 2015 Net Power price: ($/kW): 13.05$/kW – 0.98100$/kW - 0.1767$/kW = $11.89.

- 2017, 2016 & 2015 GDP Power Compensation ($/kW): Price per kW credited to participant of GDP demand response program: (-) 70$/kW during winter season.

- Subscription Price ($/month): Fixed part of the monthly energy bill: 0 (zero) [1].

- Time of Use (ToU) Pricing: Some Energy Providers change Energy Price during the day to account for Peak Demand and encourage customers to postpone some energy-consumption to off-peak period, where the price/kWh is lower.

5.2.8 Algorithm Description:

The Economical Study Algorithm is based on a custom generic pricing strategy inspired by Quebec, Ontario, France and California's energy providers.

The Electricity Bill is divided in three parts: Energy Cost, Power Cost and Subscription, which are then summed to create the Monthly Energy Bill.

- Energy Cost = sum (Energy Demand* Energy Price);
- Explanation: For every hour, Energy (kWh) consumed by the load is multiplied by the corresponding Energy Price. Every hour are summed to obtain Month's total Energy Part of the Bill. Thus, Energy Cost is equal to the sum of Energy Demand from the first hour up to last hour of the month (kWh) multiplied by the Energy Price (2017 example: 0.0342$/kWh).
- Power Cost = Billed Power * Power Price ($).
- Explanation: The Billed Power is the highest mean Power Demand recorded during 15 minutes during the month. Billed Power cannot be inferior to the Contract Power (by default 5000kW for ÉTS). If the Load peak at 5100kW for 15 minutes with a contract power of 5000kW, the Billed power for the month will be 5100kW. However, if the Load peaked at 4800kW, the Billed Power will be equal to the contract Power: 5000 kW.

This Power Part is the main reason why Peak Shaving is interesting for Consumers. By reducing a Peak from 5500kW to 5000kW for example, using a Net Power Price value of 11.95$/kW it allows consumer to save 500 kW*11.95$/kW = 5,975$ for the month. Thus, Power Cost is equal to the billed power (kW) multiplied by Gross Power Price (2017 example: 13.11$/kW), minus the product of the same billed power (kW) by Feed Credit (2017 example: 0.98100$/kW) and Adjustment for transformation losses (2017 example: 0.17760 $/kW).

Subscription: Fixed part of the monthly bill, accounts for several costs that charge utilities to provide electricity to customers [1].

GDP Credits: it consists of credits given to customers that accepts to reduce their consumption during winter peaks.

Energy Provider emits some GDP alerts during winter and participant responds:

- First: Morning Event (6am-9am): participant is able to reduce by 300kW his power demand.
- Second: Evening Event (4pm-8pm): Participant is able to reduce by 250kW his power demand. At the end of the winter, a mean value of reduced power is calculated.
- Here it would be Mean_Reduced_Power = 300 + 250 /2 = 275 (kW) Then, this value is multiplied by the GDP Power Compensation Value to calculate total credits customer will receive: Credits ($) = Mean_Reduced_Power (kW) * GDP_Power_Compensation ($/kW).
- In our example, GDP_Credits = 275 * 70 = 19250$. The Participant will receive 19250$ at the end of the winter period.

The Final monthly bill is calculated as follow : Monthly Bill = Energy Bill + Powerball + Subscription - GDP_Credits [1].

5.3 Scenarios

All algorithms created to simulate the monthly and yearly electricity expenses and savings scenarios for a 5 MW large customer as ÉTS in Ontario are described below:

5.3.1 Scenario 00: ÉTS in ON and QC with electricity standard rates (baseline);

Algorithm's name: Algo_Economic_Study_Ontario2017_GA_by_Consumpt_Scenario_00.

Description:
This Algorithm calculates the total monthly and yearly electricity charges in Ontario with the HOEP (Hourly Ontario Energy Price), Global Adjustment by consumption and with the other following rates:

The Hourly Ontario Energy Price (HOEP) fee is multiplied by ÉTS' active power data in a 5-minute interval period. In fact, the HOEP was obtained on an hourly basis and modified to a 5-minute interval for an accurate simulation. In addition, its data was downloaded from IESO: http://www.ieso.ca/en/power-data/data-directory.

The Global adjustment by consumption is mandatory for Residents all small and medium businesses customers (up to 499.99 kW), which pays it directly or indirectly in their monthly bill. The Global Adjustment covers the cost of building new infrastructure and providing conservation programs in Ontario's Province. It is a monthly value, cents (¢) per kWh, which is multiplied by the monthly consumption (kWh) of the customer. The 2017 monthly fees are described below:

Table 5-1 Global Adjustment by Consumption
Adapted from IESO – Global Adjustment by Consumption (2018)

Global Adjustment by Consumption	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Actual Rate (¢/kWh)	8.23	8.64	7.14	10.78	12.31	11.85	11.28	10.11	8.86	12.56	9.7	9.21

Two fixed rates were utilized: Standard Supply Services ($0.25) and Delivery: Monthly Service Charge ($85.00).

A Debt retirement fee of 0.007$/kWh is charged to pay down the residual stranded debt of the former Ontario Hydro. This charge was removed from all customers on March 31st 2018, but it was considered in our simulation that occurred in 2017.

A Regulatory: Wholesale Market Service charge (WMSC) of 0.0057$/kWh is charged to cover the reliable management of the power system and the wholesale electricity market in Ontario.

The others charges are regarded to Delivery: Distribution (4.00$/kW), Transmission Network (3.65$/kW) and Connection (2.45$/kW).

This Algorithm simulated the baseline scenario, called as "00", which will be compared to another six algorithms: Scenario 01, 02, 03, 04, 05A, 05B and 06.

5.3.2 Scenario 01: ÉTS in ON with financial incentives and in QC with demand response;

Algorithm's name: Algo_Economic_Study_Ontario2017_GA_by_PDF_Scenario_01.

Description:
There is just an important change in the monthly bill charges, where the Global adjustment by consumption will be replaced by the Global adjustment by Peak Demand Factor. It is a

percentage contribution to the top five peak in Ontario over a 12 month period, which is available for large customers over 500 kW (conditions are applied) and considered as a financial incentive. A summary of the calculus is shown below.

Table 5-2 Global Adjustment per Percentage Contribution or Peak Demand Factor
Taken from IESO - Calculating Peak Demand Factor for Global Adjustment per Percentage Contribution (2018)

Calculating Peak Demand Factor

Peak	Day	Hour	Customer's Consumption (MWh/h)	Peak System Consumption (MWh/h)*	
1	August 10, 2016	HE 18	3.1	23,208.01	
2	September 07, 2016	HE 17	4.4	23,162.88	
3	August 11, 2016	HE 17	3.9	23,107.80	
4	July 13, 2016	HE 18	4.1	22,941.62	
5	August 12, 2016	HE 17	4.3	22,669.91	
			Total = 19.8 MWh	Total = 115,091.06 MWh	PDF = 0.00017204

Calculating Peak Demand Factor

Peak	Day	Hour	Customer's Consumption (MWh/h)	Peak System Consumption (MWh/h)*	
1	August 10, 2016	HE 18	3.1	23,208.01	
2	September 07, 2016	HE 17	4.4	23,162.88	
3	August 11, 2016	HE 17	3.9	23,107.80	
4	July 13, 2016	HE 18	4.1	22,941.62	
5	August 12, 2016	HE 17	4.3	22,669.91	
			Total = 19.8 MWh	Total = 115,091.06 MWh	PDF = 0.00017204

* LDCs must use the Coincident Peak data from the IESO's website when calculating a customer's peak demand factor. It is available

5.3.3 Scenario 02: ÉTS in ON with FI and Photovoltaic Arrays (150 kW) as well as in QC with standards rates and PV Arrays;

Algorithm's name: Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_noBess_Scenari_02.

Description:
This algorithm will add a 150 kW MPP (Maximum Power Point) of Photovoltaics Arrays in the simulation, in order to reduce the electricity bill. The 150 kW PV Arrays represent just 3% of the 5MW power required to supply ÉTS and the energy produced will be injected in the electrical consumption of the buildings. The financial savings will be analyzed after the simulation.

5.3.4 Scenario 03: ÉTS in ON with FI, PV Arrays (150 kW) and Batteries (250 kW) as well as in QC with DR, PV Arrays and Batteries;

Algorithm's name: Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_wBess_Scenario_03.

Description:
This algorithm will add a 250 kW Maximum discharge power battery energy storage system (BESS) in the simulation, in order to reduce even more the electricity bill. Two lead-acid battery banks plugged with 2 inverters of 125kW each will be simulated for 4 hours up to 20% of battery discharge (to preserve the battery lifetime) and they will be fed by grid energy.

The battery capacity will be 1,953 Ah and it will be in charge of peak shaving any time the Electrical Power of ÉTS is over 5MW as well as it will attend the Demand Response program, "Gestion de la Demande de Puissance"(GDP) during winter season in Quebec. In Ontario, it will be used for the peak shaving over 5MW as well, in order to reduce the peak demand factor

(Global Adjustment by Peak Demand Factor charge) and consequently, the monthly and year electricity bill. The financial savings will be analyzed after the simulation.

5.3.5 Scenario 04: ÉTS in ON with financial incentives and Batteries (250 kW) as well as in QC with DR and Batteries;

Algorithm's name: Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_wBess_S_04.

Description:
This algorithm will add a 250 kW Maximum discharge power battery energy storage system (BESS) in the simulation, in order to reduce the electricity bill. Two lead-acid battery banks plugged with 2 inverters of 125kW each, will be simulated for 4 hours up to 20% of battery discharge.

As already mentioned above, the battery capacity will be 1,953 Ah. It will be in charge of peak shaving any time the Electrical Power of ÉTS is over 5MW as well as it will attend the Demand Response program, "Gestion de la Demande de Puissance"(GDP) during winter season in Quebec. In Ontario, it will be used for the peak shaving over 5MW as well, in order to reduce the peak demand factor (Global Adjustment by PDF charge) and consequently, the monthly and year electricity bill.

5.3.6 Scenario 05: ÉTS in ON with FI, Batteries with Time of Use Pricing (250 kW) and with and / or without PV Arrays (150 kW);

Algorithm's name:
Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_woptmBess_S_05A;
Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_woptmBess_S_05B.

Description:

This simulation will take place just in Ontario, where there is a variable price per kWh according to the hour of the day, night and dawn. The goal of using batteries with Time of Use pricing is to get them charged at night, where the $/kWh is lower and to use them during the day.

The Algorithm 5A will simulate just the batteries with Time of Use pricing (250kW) and the algorithm 5B will add 150kW MPPT of Photovoltaic Modules in the simulation, to reduce even more the electricity consumption.

5.3.7 Scenario 06: ÉTS in ON with FI, 500 kW PV Arrays and Batteries (250 kW) as well as in QC with DR, 500 kW PV Arrays and Batteries;

Algorithm's name: Algo_Economic_Study_Ontario2017_GA_by_PDF_w1MWPV_wBess_S_06.

Description:

The last algorithm will replace the 150 kW to a 500 kW MPP of Photovoltaic Arrays and consider the same battery capacity in the simulation. This random number of 500 kW is to evaluate the behavior of financial savings in Ontario and Quebec, when the Photovoltaic maximum power is raised from 3% (150 kW) to 10% (500 kW) of total power required to supply ÉTS (5MW).

An economic feasibility study will be held at RETScreen Clean Energy Management Software, which was developed by the Government of Canada.

A study indicated that there is enough surface area on the roof of ÉTS' buildings in blocks B and A to fit 500 kW of Photovoltaic Arrays. The PV Arrays dimensioning study is included in the item 6.1.2 – Dimensioning of Photovoltaic Panels.

5.4 Basis of Calculs - GDP (Gestion de la Demande de Puissance) by MATLAB

MATLAB considered the following GDP events to calculate the total credit from their demand response program, where a minimum of 200 kW per hour of event is required to participate of it. The calculus is based on the average of saved power (kW) in all GDP events during winter season and multiplied by 70$/kW, as HQ rate [86].

Table 5-3 Basis of GDP calculus by MATLAB
Adapted from MATLAB SimScape Power System Model: Smart Micro-Grid, 2017a (2018)

	Day	Month	Start Time	Finish Time	Saving hours	Minimum Required Power (kW) by HQ	Maximum Discharge Power of BESS (kWh)	Total kW saved
GDP Event 01	8	1	6	9	3	200	800,0	266,7
GDP Event 02	8	1	16	20	4	200	800,0	200,0
GDP Event 03	31	1	16	20	4	200	800,0	200,0
GDP Event 04	2	2	6	9	3	200	800,0	266,7
GDP Event 05	2	2	16	20	4	200	800,0	200,0
GDP Event 06	13	2	6	9	3	200	800,0	266,7
GDP Event 07	16	2	6	9	3	200	800,0	266,7
GDP Event 08	16	2	16	20	4	200	800,0	200,0
Average kW saved during winter season								**233,33**
Unit Credit rate to be provided by HQ ($/kW)								**70,00**
Total Credit amount to be provided by HQ ($/kW)								**16 333,33**

CHAPTER 6

TECHNICAL - ECONOMIC FEASIBILITY STUDY

6.1 Technical Feasibility Study

A technical study intends to evaluate the feasibility of a project in regard to its basic design, constraints, premises, dimensioning, place, time and general conditions to get it established from technical point of view.

This master's thesis will focus on dimensioning a 150 kW Maximum Power Point Photovoltaic Solar Panels Arrays (Scenarios 02, 03 and 05B) as well as a 500 kW MPP (Scenario 06). The energy produced from Photovoltaic Solar Arrays will be injected directly in the grid, in order to reduce the energy consumption and peak power over 5 MW.

In addition to it, a 250 kW battery energy storage system is dimensioned (scenarios 03, 04, 05 and 06), in order to reduce the peak power over 5 MW from Quebec and Ontario and to participate of Program Demand response from Hydro Quebec, Gestion de la Demande de Puissance, during winter season.

6.1.1 Origin, Main Concepts, Solar Capacity and Price of PV Cell and System

In 1876, the British philosopher William Grylls Adams together with his student Richard Evans Days demonstrated for the first time, the photovoltaic effect in a junction based on platinum and the semiconductor selenium with a very poor performance [35]. The Photovoltaic (PV) effect is the process of converting light (photons) to electricity (voltage) [87]. The real development of Solar cells or photovoltaic cells, started at Bell Laboratories in 1954. A silicon-based solar cell was developed and it converted sunlight directly into electricity, with an efficiency of about 6 %. Thus, the scientists Daryl M. Chapin, Calvin S. Fuller and Gerald L. Pearson demonstrated the PV effect, as we know today. It was discovered that the silicon created an electric charge when exposed to sunlight [35]. Soon, solar cells were used to power from power space satellites to smaller items like watches and calculators [87].

A PV Array consists of several solar panels, which is a set of PV modules and which is compounded by a set of solar cells, as shown on the figure 6-1 [35] .

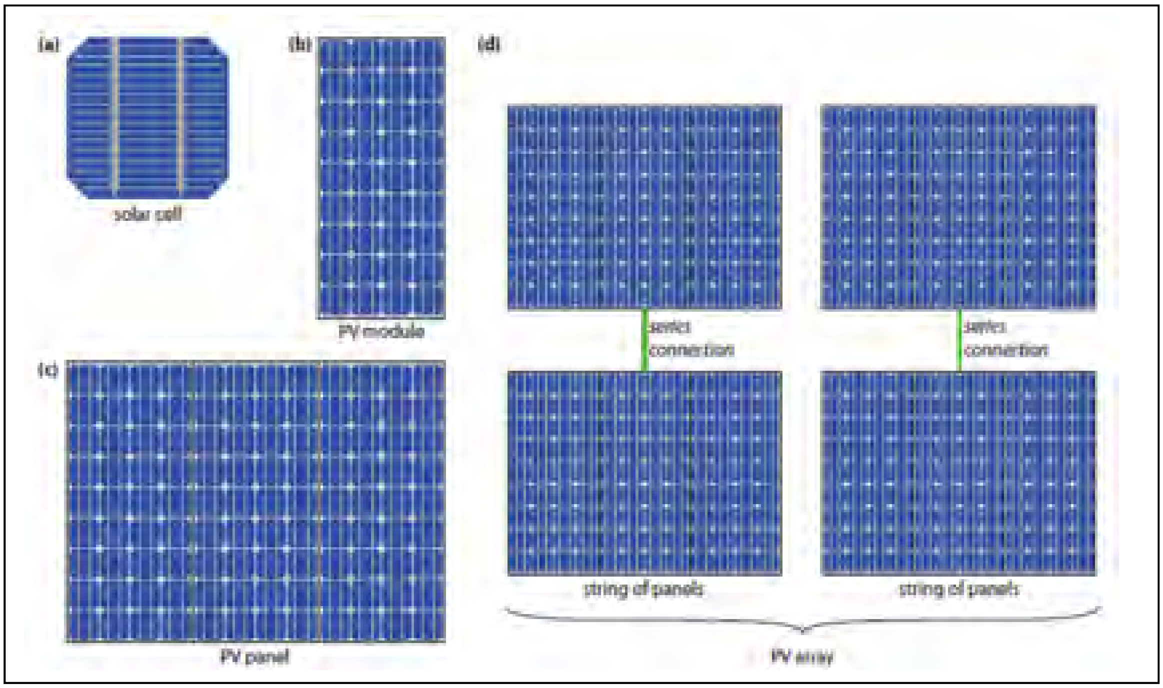


Figure 6-1 (a) a solar cell, (b) a PV module (c) a solar panel and (d) a PV array
Taken from book - Solar Energy: Fundamentals, Technology and Systems (2016)

A grid-connected PV system is connected to the grid via a DC - AC power inverter, which converts the DC power into AC electricity [35].

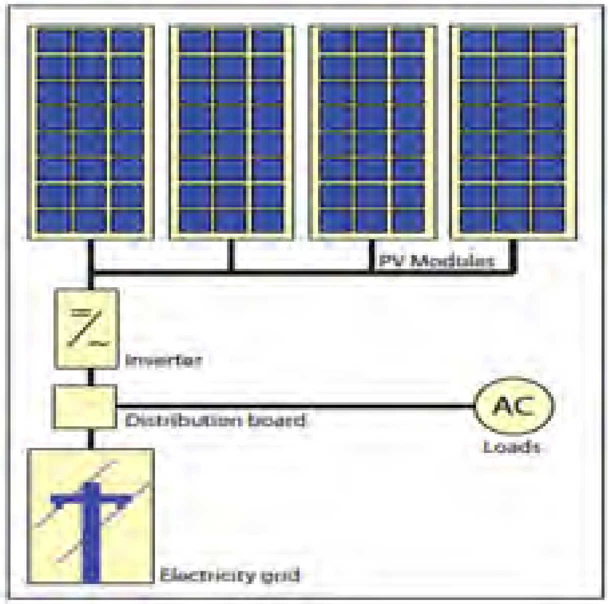


Figure 6-2 Schematic Representation of a Grid-connected PV System
Taken from book - Solar Energy: Fundamentals, Technology and Systems (2016)

The main parameters used to characterize the performance of a solar cell are: the Peak Power or nominal maximum power, short-circuit current, open-circuit voltage and fill factor. All of them come from the illuminated I-V Curve, whose parameters determine the conversion efficiency [35].

The short-circuit current ($I_{sc.}$) is the current that flows through the external circuit when the electrodes of the solar cell are short-circuited. It depends on the photon flux density incident on a solar cell, which is determined by the spectrum of the incident light (Air Mass 1.5 spectrum under STC or an angle of 48.2^o that the Sun makes to the Earth). The maximum current that the solar cell can deliver, strongly depends on the optical properties of the solar cell, such as absorption in the absorber layer and reflection.

The open-circuit voltage (V_{oc}) at which no current flows thought the external circuit. It is the maximum voltage that a solar cell can deliver.

The fill factor (FF) is the ratio between the maximum power generated by a solar cell and the product between V_{oc} and I_{sc}..

$$FF = \frac{I_{mp} * V_{mp}}{I_{sc} * V_{oc}}$$

The conversion efficiency (η) is calculated as the ratio between the maximal generated power and the incident power. The irradiance value P_{in} of 1000 W/m^2 for the AM1.5 spectrum has become a standard for measuring the conversion efficiency of solar cells,

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{mp} * V_{mp}}{P_{in}} = \frac{I_{sc} * V_{oc} * FF}{P_{in}}$$

A typical external parameters of a crystalline silicon solar cell: I_{sc} = 35 mA/cm2, V_{oc} up to 0.65 V, FF from 0.75 to 0.80 and η around 17 to 18% [35].

PV Solar capacity: it has nearly quadrupled over the last five years and contributing to nearly 20 % of global power growth in 2017 [88]. According to REN 21, the Renewables 2018 Global Status Report shows the Solar PV Global Capacity and Annual Additions, 2007-2017 [41]:

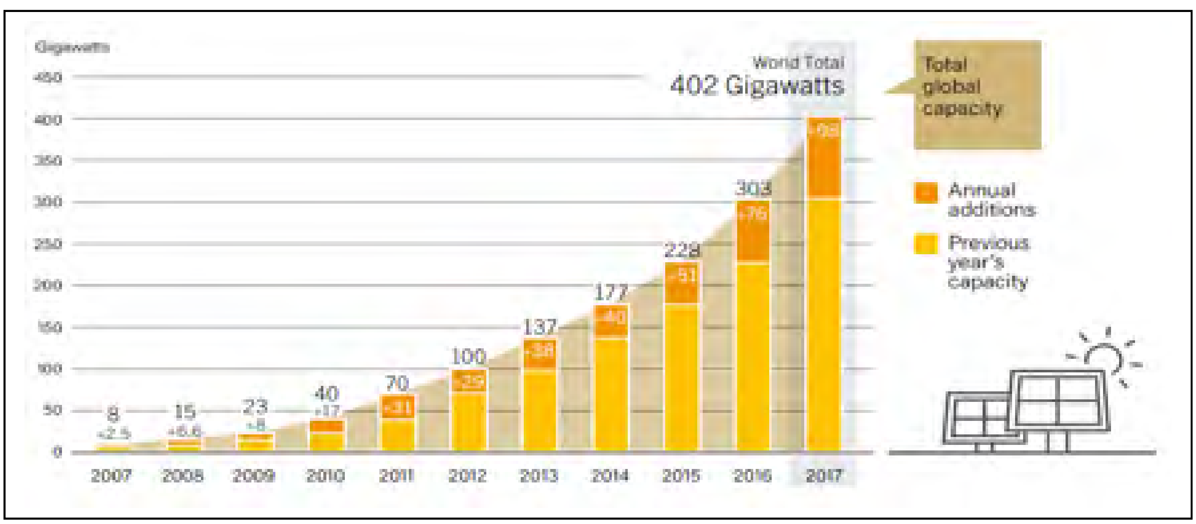


Figure 6-3 Solar PV Global Capacity and Annual Additions, 2007-2017
Taken from REN21 - Renewables 2018 Global Status Report (2018)

PV System Cost Benchmark: According to NREL PV System cost benchmark, a huge fall on the price per Wdc (Watt direct current) to install a PV System from 2010 to 2017 has been occurred, as shown below [34]:

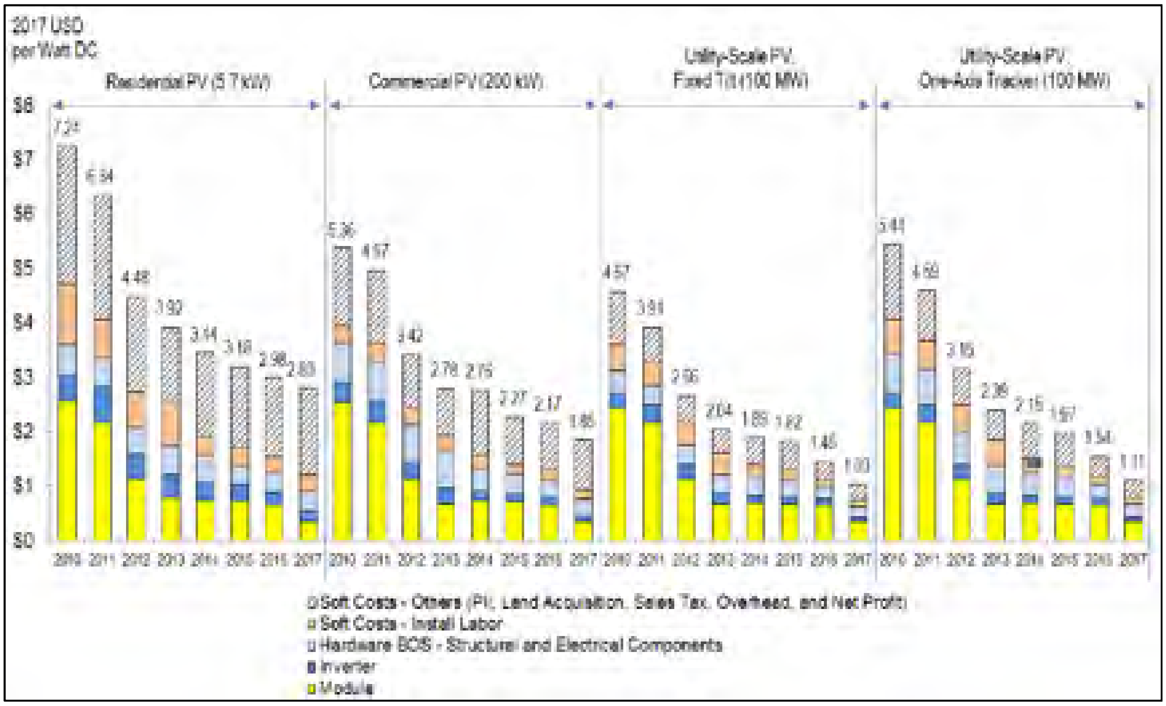


Figure 6-4 NREL PV System cost benchmark summary
Taken from National Renewable Energy Laboratory (NREL) – U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017 Report (2017)

NREL classifies the "commercial rooftop systems client" from 10 kW to 2 MW PV system size range, which is the one that ÉTS is placed. The chart above shows a fall on the price per Wdc on a 200 kW PV System basis from US$5.36 in 2010 to US$1.85 in 2017, a total fall of 65 % (sixty-five percent) in just 7 (seven) years. Thus, the Photovoltaic Solar Technology of converting light to electricity is considered as one of the most prosperous source of renewable energy for the near future: besides having a mature technology, a huge size range (from 280 W to more than 2,000 MW, public awareness about environmental problems, its price has been falling down drastically in the last years.

6.1.2 Dimensioning of Photovoltaic Panels

The objective of a medium-sized PV system, such as 150 or 500 kW, as the one to be proposed, is to reduce the energy consumption and peak power of ÉTS over 5 MW. Firstly, a 150 kW PV system, which represents 3 % (three per cent) out of 5 MW ÉTS' necessity will be analyzed. After observing some potential gains in one of the provinces, a 500 kW PV system, which represents 10 % (ten per cent) out of 5 MW ÉTS' necessity, will also be analyzed and results compared.

The PV panels dimensioning was divided into 03 (three) main parts: Solar Module type, Layout design (Size, Solar Modules in series and parallels, General Arrangement) and DC – AC power Inverter for both 150 kW and 500 kW Maximum Power Point.

The Solar Module chosen was the Canadian Solar CS6X-280M, which presents a good benefit-cost ratio: reasonable efficiency, features and price. The appendix II brings the datasheet from manufacturer while the Mechanical data, Electrical Data under Standard Test Conditions (Solar Irradiance: 1000 W/m^2, Temperature=25 ^{o}C, Spectrum AM 1.5), I-V Curves and its picture are shown below.

Table 6-1 Mechanical Data of Solar Module CS6X-280M
Taken from Canadian Solar Datasheet of Photovoltaic Module CS6X-280M (2012)

Cell Type	Mono-crystalline 156 x 156mm, 2 or 3 Busbars
Cell Arrangement	72 (6 x 12)
Dimensions	1954 x 982 x 40mm (76.93 x 38.7 x 1.57in)
Weight	23kg (50.7 lbs)
Front Cover	3.2mm Tempered glass
Frame Material	Anodized aluminium alloy
J-BOX	IP65, 3 diodes
Cable	4mm (IEC)/12AWG(UL), 1150mm
Connectors	MC4 or MC4 Comparable
Standard Packaging (Modules per Pallet)	24pcs
Module Pieces per container (40 ft . Container)	528pcs (40'HQ)

Table 6-2 Electrical Data under STC of Solar Module CS6X-280M
Taken from Canadian Solar Datasheet of Photovoltaic Module CS6X-280M (2012)

Standard Test Condition	CS6X-280M
Nominal Maximum Power (P_{max})	280W
Optimum Operating Voltage (V_{mp})	36.0V
Optimum Operating Current (I_{mp})	7.78A
Open Circuit Voltage (V_{oc})	44.6V
Short Circuit (I_{sc})	8.30A
Module Efficiency	14.59%
Operating Temperature	-40 °C - 85 °C
Maximum System Voltage	1000V (IEC) /600V (UL)
Maximum Series Fuse Rating	15A
Application Classification	Class A
Power Tolerance	0 -+5W

The Solar PV Module presents the following I-V Curves from a similar module, CS6X-290M.

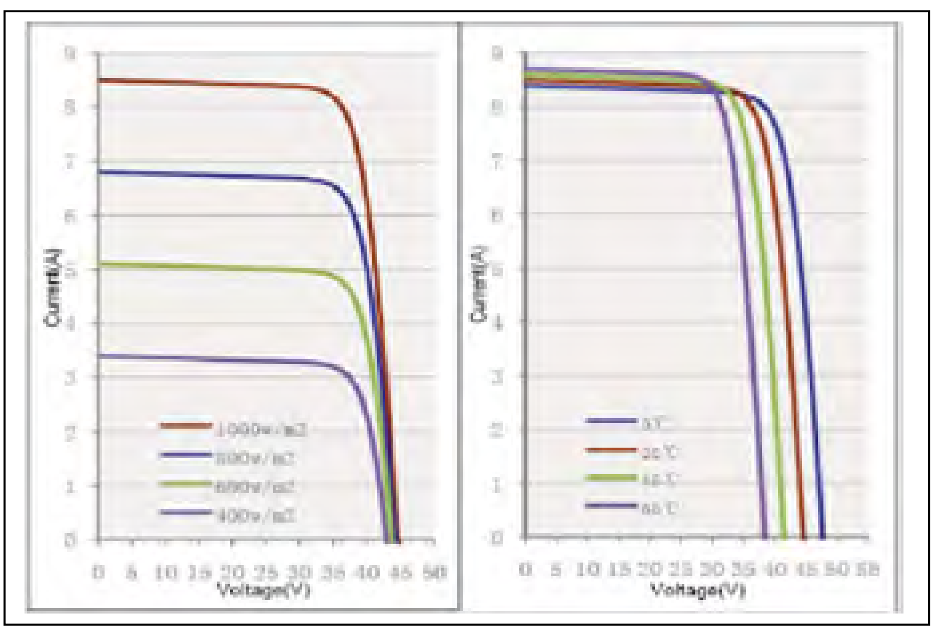


Figure 6-5 I-V Curves CS6X-290M (similar Solar Module)
Taken from Canadian Solar Datasheet of Photovoltaic Module CS6X-280M (2012)

Figure 6-6 Solar Module with 72 Mono-crystalline solar cells
Taken from Canadian Solar Datasheet of Photovoltaic Module CS6X-280M (2012)

The chosen of Silicon Monocrystalline solar cells is due to its mature technology, proven efficiency, Short-circuit Current, Open Circuit Voltage by a reasonable price. Monocrystalline silicon, also known as single-crystalline silicon, is a crystalline solid, in which the crystal lattice is continuous and unbroken without any grain boundaries over the entire bulk, up to the edges. In contrast, polycrystalline silicon, also known as polysilicon, is a material that consists of many small crystalline grains, with random orientations [35].

The scenario 02 will simulate 150 kW MPP Photovoltaic System. Thus, the following number to Solar Modules will be required.

Table 6-3 Number of PV Modules and Minimum Surface area - 150 kW MPP

PV Modules Calculus - 150 kW: Photovoltaic Module type: Canadian Solar CS6X-280M		
Power	150,00	kW
Power	150000,00	W
Each PV module	280,08	W
Number of modules	535,6	units
Module dimension: 1954 x 982 x 40 mm	1,92	m^2
Total surface area required [not included space between modules, space for inverter and other parts of the system]:	1027,65	m^2

The scenario 06 will simulate 500 kW MPP Photovoltaic System. Thus, the following number of Solar Modules will be required.

Table 6-4 Number of PV Modules and Minimum Surface area - 500 kW MPP

PV Modules Calculus - 500 kW: Photovoltaic Module type: Canadian Solar CS6X-280M		
Power	500,00	kW
Power	500000,00	W
Each PV module	280,08	W
Number of modules	1785,2	units
Module dimension: 1954 x 982 x 40 mm	1,92	m^2
Total surface area required [not included space between modules, space for inverter and other parts of the system]:	3425,50	m^2

The Layout design will compose the following characteristics: total surface with the space between solar modules, number of PV Modules in series and parallels and general arrangement for scenario 02 with 150 kW PV Arrays and scenario 06 with 500 kW PV Arrays.

In order to calculate the space between two solar modules, it will be considered the same methodology as the master project of Arthaud Beraud-Sudreau from ÉTS [44]. Firstly, it shall be regarded the angle from the Sun to the Earth at noon of each day of the year. The site

National Research Council Canada [89] provided this Solar Altitude for the 21st day of each month in 2017, as shown below.

Table 6-5 Solar Altitude at noon of each month in 2017
Adapted from National Research Council Canada – Sunrise and sunset calculator (2018)

Month	Time	Hour Angle	Solar Altitude	Solar Azimuth	Shadow Length Factor
January-2017	12:00	-0.10	24,5	178.5	2.20
February-2017	12:00	-0.14	33,6	177.6	1.50
March-2017	12:00	-0.03	44,5	179.3	1.02
April-2017	12:00	0.11	56	182.9	0.67
May-2017	12:00	0.15	64,4	184.8	0.48
June-2017	12:00	0.06	67,9	182.3	0.41
July-2017	12:00	-0.01	65,1	179.5	0.46
August-2017	12:00	0.04	56,8	181.0	0.65
September-2017	12:00	0.20	45,3	184.3	0.99
October-2017	12:00	0.35	33,8	186.1	1.49
November-2017	12:00	0.33	24,5	185.1	2.19
December-2017	12:00	0.12	21	181.8	2.60
Yearly Average at noon			44,78	degree	

Through Excel MS office, it was calculated the shadow that can be made in every month and the distance between two Solar Modules at noon, as detailed below:

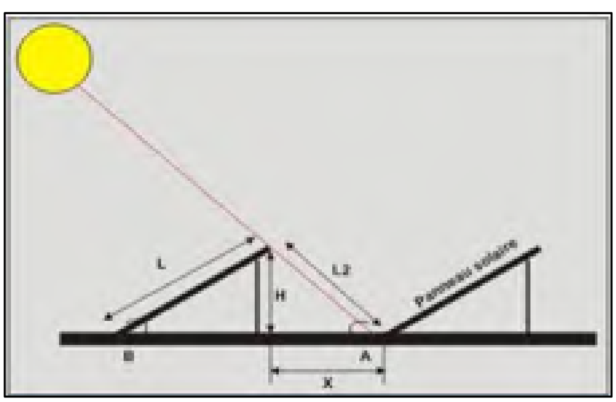


Figure 6-7 Schematic to represent the distance between 2 Solar Modules
Taken from Master of Engineering Report – A. B. Sudreau (2016)

Table 6-6 Average Space between 2 Solar Modules

Angle of latitude - Montreal	45 degrees		
Length of PV Module	195,4 cm		
Widtht of PV Module	98,2 cm		
Sin B = H / L			
SIN 45o	L	H	
0,707106781	195,4	138,17	cm
	SPACE BETWEEN TWO SOLAR PANELS		
	January-2017	303,18	cm
	February-2017	207,96	cm
	March-2017	140,60	cm
	April-2017	93,20	cm
	May-2017	66,20	cm
	June-2017	56,10	cm
	July-2017	64,14	cm
	August-2017	90,42	cm
	September-2017	136,73	cm
	October-2017	206,39	cm
	November-2017	303,18	cm
Tan A = H / X	December-2017	359,94	cm
X=			
Space between 2 Modules:	Average =	169,00	cm

Based on the table above, it will be considered the average space between 2 (two) Solar Modules as 169 cm. Thus, the total surface area [44] to allocate all Solar Modules will be calculated for both Scenario 02 (150 kW MPP) and Scenario 06 (500 kW MPP):

$$Surface\ area = (P_{serie} * W_{panel}) * \left((P_{parallel} * L_{panel}) + (P_{parallel} - 1) * Space\right) * N_{blocks} =$$

Legend:

P_{serie} = Number of Panels in serie

W_{panel} = Width of Panel

$P_{parallel}$ = Number of Panels in parallel

L_{panel} = Length of Panel

N_{blocks} = Number of blocks

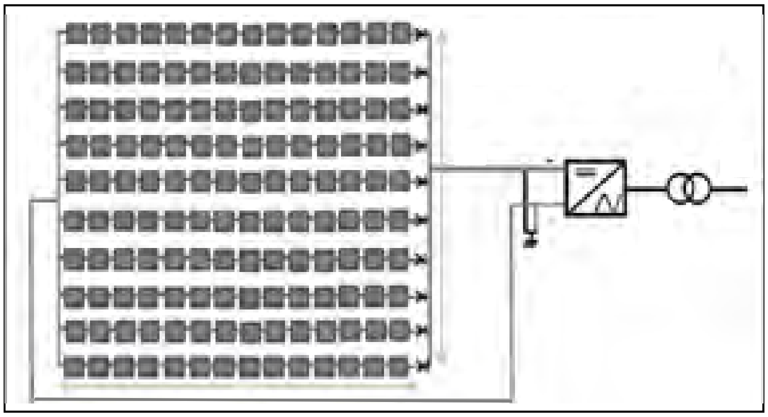


Figure 6-8 Electrical Schematic of a PV Array
Taken from Master of Engineering Report – N. Mary and
A. B. Sudreau (2016 and 2016)

Scenario 02 – 150 kW MPP:

Table 6-7 150 kW Total Surface area for and General Arrangement Solar Modules

Arrang. # 1	Number of modules in serie:	22	
	Number of modules in parallel:	10	
	Number of blocks:	1	
Arrang. # 2	Number of modules in serie:	21	
	Number of modules in parallel:	15	
	Number of blocks:	1	
	Total of of PV Panels	535	
	Surface area required (Arrangement # 1):	750,75	m2
	Surface area required (Arrangement # 2):	1 092,36	m2
	All Surface area required (Arrangement # 1 + 2)	1 843,10	m2
	Total Area available in block B	3 771	m2

A total area of 1,843.10 m^2 shall be regarded to allocate all 535 Solar Modules on the roof of Block B at ÉTS.

In addition to it, 2 (two) arrangements are proposed to accommodate them:

- Arrangement 01: 22 modules in series and 10 in parallel in just one block, total surface area required: 750.75 m2.
- Arrangement 02: 21 modules in series and 15 in parallel in just one block, total surface area required: 1,092.36 m2.
- Total surface area required to allocate 535 Solar Modules on the roof of Block B at ETS: 1,843.10 m2.
- Total estimated surface area available on the roof of Block B: 3,771 m2.

Scenario 06 – 500 kW MPP:

Table 6-8 500 kW Total Surface area for and General Arrangement Solar Modules

Arrang. # 1	Number of modules in serie:	17	
	Number of modules in parallel:	7	
	Number of blocks:	15	
	Total of of PV Panels	1785	
	All Surface area required:	5 964,32	m2
	Total Area available in block B (by Google earth)	3 771	m2
	Surface area of each block:	397,62	m2
	Surface area required at Block B (08 blocks):	3 180,97	m2
	Number of PV Modules at Block B:	952	units
	Number of PV Modules at Block B:	53%	%
	Surface area required at Block A (07 blocks):	2 783,35	m2
	Number of PV Modules at Block A:	833	units
	Number of PV Modules at Block A:	47%	%
	Total of PV Modules at both Blocks A and B:	1785	units

A total area of 5,964.32 m^2 shall be regarded to allocate all 1785 Solar Modules on the roof of Block B and A at ÉTS.

In addition to it, 1 (one) arrangement is proposed to accommodate them:

- Arrangement 01: 17 modules in series and 7 in parallel in 15 blocks, total surface area required: 5,964.32 m2.
- Total surface area required to allocate 952 Solar Modules in 08 blocks (17 modules in series and 7 in parallel) on the roof of Block B at ÉTS: 3,180.97 m2.
- Total surface area available in Block B: 3,771 m2.
- Total surface area required to allocate 833 Solar Modules in 07 blocks (17 modules in series and 7 in parallel) on the roof of Block A at ETS: 2,783.35 m2.
- Total surface area available in Block A: 19,257 m2.

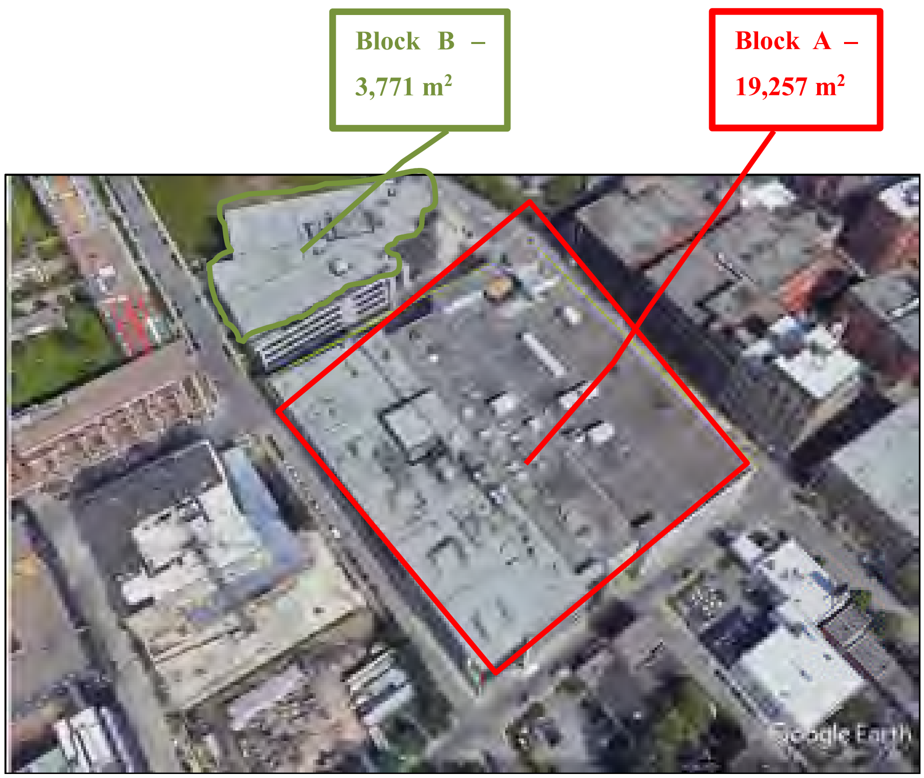


Figure 6-9 ÉTS`Block B and A Roof's Estimated Surface Area
Taken from Google Earth Pro – View of ÉTS' Blocks B and A (2018)

The DC – AC Power Inverters for Scenario 02 (MPP 150 kW) and Scenario 06 (MPP 500 kW) were dimensioned as followed. Also, their Datasheet are attached in Appendix IV and VI.

Scenario 02 – 150 kW MPP:

The DC Output power required for the Project is 150 kW, where it must be considered a 95 % Inverter efficiency. Thus, the minimum AC Output power required for the Project is 158 kW.

Regarding their arrangement, in serie or parallel, the DC AC Inverter specification must consider:

Table 6-9 Maximum Voltage, Current and Power Point for 150 kW PV

		V_{oc}	I_{sc}	N. in serie	N. in parallel	PV System V_{mp} or I_{mp}	Unit
Arrang. # 1	V_{mp}	44,6		22		981,2	V
	I_{mp}		8,3		10	83	A
			Minimum Power Inverter = V_{mp}*I_{mp} =			81 440	W
		V_{oc}	I_{sc}	N. in serie	N. in parallel	PV System V_{mp} or I_{mp}	Unit
Arrang. # 2	V_{mp}	44,6		21		936,6	V
	I_{mp}		8,3		15	124,5	A
			Minimum Power Inverter = V_{mp}*I_{mp} =			116 607	W

It was chosen 2 (two) units of 125 kW of the DC AC Power Inverter Sungrow SG 125 HV, where 1 (one) unit will be allocated for each arrangement.

The recommended surface area to accommodate 2 units of 125 kW DC – AC Power Inverter is:

Table 6-10 Surface area for 2 units of 125 kW DC AC Power Inverters

Number of Inverters with a 125 kW AC output power	2	unit
Surface area for each 125 kW DC/AC Inverter	0,20	m^2
Minimum Surface area required for 2 X DC/AC Inverters:	0,39	m^2
Recommended Surface area required for DC / AC Inverter	1,00	m^2

A Summary of Datasheet of the 125 kW DC – AC Power Inverter is shown below.

Table 6-11 125 kW DC AC Power Inverter Datasheet Summary
Adapted from Sungrow SG 125 HV Technical Datasheet (2017)

125 kW DC AC Inverter - Brand and Model: Sungrow SG 125 HV	
Brand and Model	**Specification**
Brand	Sungrow
Model	SG 125 HV
General Data	**Specification**
Dimension (W x H x D)	670 x 810 x 294 mm
Weight	68 Kg (150 Lbs)
Operating temperature range	-25°C to 60°C
Input (DC)	**Specification**
MPP voltage range for nominal power	860 - 1250 V
Maximum DC short circuit current	240 A
Output (AC)	**Specification**
Nominal AC Power (at 50°C)	125 000 W
Maximum AC output current	120 A
Nominal AC voltage	3 / PE, 600V
Feed-in phases / Connection phases	3 / 3
Efficiency	**Specification**
Efficiency	Around 98%

Figure 6-10 125 kW DC - AC Power Inverter for PV Arrays
Taken from Sungrow SG 125 HV Technical Datasheet (2017)

Scenario 06 – 500 kW MPP:

The DC Output power required for the Project is 500 kW, where it must be considered a 95 % Inverter efficiency. Thus, the minimum AC Output power required for the Project is 526 kW.

Regarding their arrangement, in serie or parallel, the DC AC Inverter specification must consider:

Table 6-12 Maximum Voltage, Current and Power Point for 500 kW

		V_{oc}	I_{sc}	N. in serie	N. in parallel	PV System V_{mp} or I_{mp}	Unit
Arrang. # 1	V_{mp}	44,6	xxx	17	xxx	758,2	V
	I_{mp}	xxx	8,3	xxx	7	58,1	A
			Minimum Power Inverter = V_{mp}*I_{mp} =			44 051	W

It was chosen 15 (fifteen) units of 36 kW of the DC AC Power Inverter Yaskawa Solectria Solar PVI 36 TL, where 1 (one) unit will be allocated for each block.

The recommended surface area to accommodate 15 units of 36 kW DC – AC Power Inverter:

Table 6-13 Surface area for 15 units of 36 kW DC AC Power Inverters

Number of Inverters with a 40 kW AC output power	15	units
Surface area required for each 36 kW DC/AC Inverter	0,14	m^2
Minimum Surface area required for all DC/AC inverters:	2,09	m^2
Recommended Surface area required for DC / AC Inverter	5,00	m^2

A Summary of Datasheet of the 36 kW DC – AC Power Inverter is shown below:

Table 6-14 36 kW DC AC Power Inverter Datasheet Summary
Adapted from Yaskawa Solectria Solar PVI 36TL Technical Datasheet (2017)

36 kW DC AC Inverter - Brand and Model: Yaskawa Solectria Solar and PVI 36 TL	
Brand and Model	Specification
Brand	Yaskawa Solectria Solar
Model	PVI 36 TL
General Data	Specification
Dimension (W x H x D)	600 x 1001 x 232 mm
Weight	55 Kg (121Lbs)
Operating temperature range	-25°C to 60°C
Input (DC)	Specification
MPP voltage range for nominal power	540 - 800 V
Maximum DC short circuit current	70 A
Output (AC)	Specification
Nominal AC Power (at 50°C)	125 000 W
Maximum AC output current	43.5 A
Nominal AC voltage	3 / PE, 480V
Feed-in phases / Connection phases	3 / 3
Efficiency	Specification
Efficiency	Around 98%

Figure 6-11 36 kW DC - AC Power Inverter - PV Arrays
Taken from Yaskawa Solectria Solar PVI 36TL Technical
Datasheet (2017)

6.1.3 Inclination and Orientation and of Photovoltaic Panels in Montreal

The inclination of the Solar Modules shall be kept in 45º, as the latitude angle of Montreal, QC, in order to avoid loss of reflectiveness and to get a higher conversion efficiency. In addition to it, it should be also regarded their orientation during the installation, which will be considered the same methodology as the master project of Arthaud Beraud-Sudreau from ÉTS [44]. The PV Modules should be oriented directly in the South zone, in order to have a more linear production during the day. It is possible to orient to the East (or the West), if the load is greater at the beginning (or end) of the day [44].

6.1.4 Some Concepts of Battery Energy Storage System

The function of a battery is to store electricity in the form of chemical energy and to convert to electrical energy when required [81]. This process occurs by an electrochemical oxidationreduction reaction between the active materials packed in its cell chamber and separated by an ion-conducting electrolyte. After a discharge, it can be electrically recharged by supplying current in an opposite direction and restoring the battery to its original status, in a limited number of cycles.

One of most used batteries is the lithium-ion, which has a high energy density and long cycle life in comparison to others, however it is one of the most expensive too. It is well used in portable electronics and it is being stimulated for Electrical Vehicles energy storage system as complimentary of renewable energy resources.

A relatively low-cost energy storage is the Lead-acid battery, which presents a mature rechargeable storage technology and is very well-established in the vehicles energy storage system and also, in some small-scale power storage, such as UPS to provide power backup for electronics, lighting, etc. On the other hand, there are disadvantages in this kind of battery: limited number of cycles, environmental impacts of improper disposal of these batteries, caused by the Pb (lead) and H_2SO_4 (Sulphuric acid) or the necessity of a battery room ventilation, which it will be detailed below. A very positive fact, is that over 98% of the lead used in these batteries is recycled, as revealed from 2007 to 2011 [90].

A VLA cells battery technology, Vented Lead-Acid batteries or flooded batteries consist of plates flooded with an acid electrolyte. Also, an energy storage unit consists of two or more connected cells, where a conversion of chemical to electrical energy takes place [23]. Hydrogen is emmited from electrolyte while charging, mainly, during heavy recharge periods. Thus, a battery room ventilation is necessary to exhaust this hydrogen out of the building or operational area. Otherwise, explosion may occur in contact with oxygen in the battery room. Also, it is hazardous to human health, causing skin burns and eye issues. So, mechanical ventilation using exhaust fans is recommended, if the level of hydrogen in a battery room exceeds 1% after 1 hour of charging [81].

A VRLA GEL (sealed) battery, known as a valve-regulated lead acid battery or sealed acid battery, gel cell, contains a phosphoric acid rather than a sulfuric acid which allows it to have a long life (over 15 years) and a great capacity of cycling (over 2,100 cycles at 80% operating state of charge). These batteries does not require a hydrogen evacuation system, since the cells are sealed. The Appendix VII provide more details about the VRLA battery cells.

6.1.5 Dimensioning of Battery Energy Storage System

The objective of the Battery Energy Storage System at ÉTS is to reduce the Peak Power over 5 MW and to participate of the Demand Response Program from Hydro Québec, called "Gestion de la Demande de Puissance" or GDP. In order to do it, the large consumer must guarantee that will achieve the following Energy Saving per day, according to previous planned calls from HQ:

$$200\ kW * 4\ h = 800\ kWh$$

Regarding that the lower Battery's state of charge limit is 20%, this range should be considered in the calculus, so:

$$= \frac{800\ kWh}{0.8} = 1{,}000\ kWh$$

Thus, the battery capacity in Ampere hours (Ah) must work with 1,000 kWh of full energy, in order to participate of the GDP program and to save a 70 $/ kW based on the average of power reductions of all GDP Events during winter season, as previous notices by HQ.

A company donated two used battery banks of VLA (Vented Lead-acids) with a total of 512 cells to ÉTS, whose datasheet is attached in appendix III. Due to the inconvenience of having a special ventilation battery room, in order to exhaust the hydrogen emitted during recharge periods and a high investment to get it implemented (around $300,000.00), this master's thesis will use a VRLA GEL (sealed) battery for technical-economic feasibility study. As mentioned on sub-chapter 6.1.4 “Some Concepts of BESS”, this battery bank does not require a special ventilation system, because it is sealed, maintenance-free and leak-proof. In addition, the price is around 15% higher than a VLA battery, with a double number of cycles and no exhausting system requirement, as mentioned on Appendix VII. So, it is an excellent option for a new acquisition.

The appendix III brings the VLA battery Technical Datasheet, that was donated to ÉTS. Its model, picture and a summary of specification are described below.

Table 6-15 Battery Bank model and capacity donated to ÉTS
Adapted from BAE Secura OGI – Stationary VLA Cells Technical Datasheet (2015)

Battery Bank Model BAE Secura OGI - Stationary VLA Cells						
Item Number from Datasheet	Model and Capacity	Number of cells	Length (m)	Width (m)	Mass (kg)	Mass (Lb)
8	OGI 640 Ah	256	0,145	0,206	47	103,59
17	OGI 1360 Ah	256	0,21	0,275	98	215,99

Figure 6-12 One Battery Cell of BAE Secura OGi - Stationary VLA Cells
Taken from BAE Secura OGI – Technical Datasheet (2015)

Table 6-16 Summary of Specification Battery BAE Secura OGI
Adapted from BAE Secura OGI – Stationary VLA Cells Technical Datasheet (2015)

Brand and Model	Specification
Brand	BAE
Model	Secura OGi 640 Ah and Secura OGi 1360 Ah
Design	**Specification**
positive electrode	round-grid plate with low antimony alloy (1,6%), circular bars high lead weight
negative electrode	flat plate with long life expander and low antimony alloy
electrolyte	sulphuric acid of 1.24 kg/l
Charging	**Specification**
I - characteristic	I_{max} without limitation
U - characteristic	U = 2.23 V/cell ±1 %
Discharge	**Specification**
reference temperature	20°C
initial capacity	100%
depth of discharge	normally up to 80% (Avoid discharge more than 80%)
Maintenance	**Specification**
every 6 months	check battery voltage, pilot block voltage, temperature
every 12 months	record battery voltage, block voltage, temperature
Operational data	**Specification**
operational life	16 years at 20°C, stand-by operation, float
water refilling interval	> 3 years at 20°C
IEC 896-1 cycles	> 1200
self-discharge	approx. 3% per month at 20°C
operational temperature	-20°C to 55°C

The VLA battery operational lifetime is 16 (sixteen) years in stand-by operation and 1,200 cycles. ÉTS expects to utilize from 70 to 100 charge / discharge cycles per year of the battery bank. In this case, the expected battery lifetime for ÉTS's real case is:

$$Battery\ Expected\ lifetime\ at\ \text{ÉTS (real)} = \frac{1{,}200\ battery\ total\ cycles}{100\ \text{ÉTS}'\ \text{yearly cycles}} = 12\ years$$

This master thesis will consider a number of cycles of 2,100 cycles of a VRLA battery, for its technical-economic feasibility study. In this case, the expected battery lifetime is:

$$Battery\ Expected\ lifetime\ at\ \text{ÉTS (thesis)} = \frac{2{,}100\ battery\ total\ cycles}{100\ \text{ÉTS' yearly cycles}} = 21\ years$$

These batteries will be allocated in a refrigerated room kept in around 20 ºC. The total surface area and weight dimensioning to accommodate them are calculated below:

Table 6-17 Surface area and weight for Battery Cells Room
Adapted from BAE Secura OGI – Stationary VLA Cells Technical Datasheet (2015)

Item Number from Datasheet	Model and Capacity	Number of cells	Length (m)	Height (m)	Width (m)	area per cell (m^2)	Surface area (m^2)	Unit Mass (kg)	Total Mass (Kg)
8	OGI 640 Ah	256	0,145	0,7	0,206	0,02987	7,64672	47	12 032,00
17	OGI 1360 Ah	256	0,21	0,7	0,275	0,05775	14,784	98	25 088,00
Total							**22,4**		**37 120,00**
Recommended Surface area for Battery cells room (m^2)							**35,0**		
Recommended Weight dimensioning for Battery cells room (Kg)									**44 544,00**

The layout of the battery cells' room will have a 2 or 3-tier Rack, as shown below.

Figure 6-13 Layout of Battery Cells Room
Taken from IEEE – Lead Acid Battery Fundamentals Presentation

The battery cells should be stacked in a 2 or 3-tier Rack as shown above, with a minimum of 35m^2 room size and weight dimensioning of 45 tons. Thus, this 20 ºC refrigerated room shall be allocated on the ground level of block B, in order to support around 1,285 kg/m^2. This ÉTS building was built in 2003 and follows the 1995 Building's National Code legislation in Quebec, which imposed a minimum of 1 kPa or 101.97 kg/m^2 [91] on the roof of buildings [31].

These battery banks' AC output power were limited by two DC AC tri-phases Inverters of 125 kW each, total of 250 kW output power AC, which will also be part of this study. These Inverters come also with Battery Charger and Controller. A picture, a schematic to AC Load or Grid and a summary of specification are shown below.

Figure 6-14 125 kW DC AC Inverter and Battery Charger Taken from Princeton Power System GTIB-480-125 (2017)

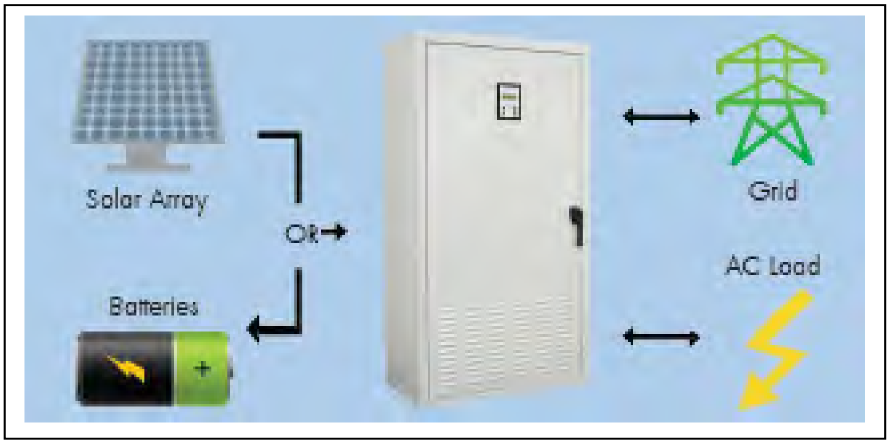


Figure 6-15 Schematic of Battery Inverter to AC Load or Grid [6]
Taken from Princeton Power System GTIB-480-125 (2017)

Table 6-18 Summary of Specification - Inverter for Battery
Adapted from Princeton Power System GTIB-480-125 (2017)

125 kW DC AC Inverter - Brand and Model: Princeton GTIB-480-125	
Brand and Model	Specification
Brand	Princeton Power Systems
Model	GTIB-480-125
General Data	Specification
Dimension (W x H x D)	914.4 x 1905 x 457.2 mm
Weight	463 Kg (1020 Lbs)
Operating temperature range	0°C to 50°C
Input (DC)	Specification
MPP voltage range for nominal power	350 - 830 V
Maximum DC short circuit current	380 A
Output (AC)	Specification
Nominal AC Power (at 50°C)	125 000 W
Maximum AC output current	160 A
Nominal AC voltage	3 / 480V
Feed-in phases / Connection phases	3 / 3
Efficiency	Specification
Efficiency	Around 97%

The above 125 kW DC-AC Power Inverter was chosen because it has a built-in MPPT for solar arrays and high round-trip efficiency for battery charging. Also, the inverter can be used for peak shaving, demand response, frequency regulation and other advanced grid support functions [6].

The recommended surface area for 2 (two) DC AC 125 kW Inverters is indicated below:

Table 6-19 Recommended Surface area for 125 kW DC AC Inverter

Number of Inverters with a 125 AC output power	2	units
Surface area for each 125 kW DC/AC Inverter	0,20	m^2
Surface area required for all DC/AC Inverters:	0,39	m^2
Minimum Surface area required for 2 X DC/AC Inverters:	1,00	m^2

As mentioned above, the battery bank total AC output power is 250 kW, so the following Battery Capacity is enough for ÉTS, in order to participate of GDP Program from HQ:

$$Battery\ Capacity = \frac{1{,}000{,}000\ Wh}{512\ V} = 1{,}953\ Ah$$

For a 250 kW battery bank, we should have:

$$250\ kW * 4\ h = 1{,}000\ kWh$$

Thus, 4 hours of full battery charge is enough to achieve 1,953 Ah at 512 V, in order to reach around Ca$16,330 of yearly savings during winter season in GDP Program in Quebec, as it will be indicated in the simulation results.

6.1.6 Recycling of Lead (Acid) Battery materials

After the battery banks lifetime, around 98% of lead (acid)'s material can be sold for recycling. Thus, around 40 tons of lead materials can be economically saved based on weight of 512 battery cells, where the recycling price per pound was informed by Métaux Dépot [92] in October 2018.

Table 6-20 Recycling of Lead (Acid) Battery Cells materials
Adapted from BAE Secura OGI – Stationary VLA Cells Technical Datasheet (2015)

Model and Capacity	Number of cells	Mass (kg)	Mass (Lb)	Total Mass (Lb)
OGI 640 Ah	256	47	103,59	26518,53
OGI 1360 Ah	256	98	215,99	55293,95
Total				**81 812,48**

6.2 Economic Feasibility Study

The economic feasibility of a project includes the evaluation of all available economic results and indicators, so that the decision-maker can make the best decision in making the investment and having the project executed or not doing it and keeping the money in the bank.

There are some economic indicators available, but the most reliable and used for companies and specialized advisors are listed below:

6.2.1 Net Present Value (NPV)

Net Present Value (NPV) or Present Value (NPV) is the main indicator for comparing the profitability of energy investments. This value is defined as the sum of all discounted financial flows of the project in full operation minus the initial investment, where the analysis takes into account the equivalent present value according to their chronology. Therefore, for an investment to be profitable the NPV must be greater than zero at the end of the life cycle, this is a basic criterion of acceptability of the project.

The methodology can be summarized as [93]:

- Estimate the life of the project;
- Determine the net cash flow by subtracting for each period disbursements (or initial investment) of revenues;
- Calculate the present value of each component of net cash flow using an interest rate equal to MARR (Minimum Attractive Rate of Return);
- Add these present values to obtain the net present value of the project.

The formula is presented below [94] :

$$NPV\ (i) = \frac{A_0}{(1+i)^0} + \frac{A_1}{(1+i)^1} + \frac{A_2}{(1+i)^2} + \cdots + \frac{A_N}{(1+i)^N} = \sum_{n=0}^{N} \frac{A_n}{(1+i)^n}$$

i : Interest rate or MARR;

N : Lifetime of the project (number of periods);

A_n : Net Cash flow (Difference between Annual Revenues (R) and Disbursement (D)) or Initial Investment (I);

n : End of (annual) period in reference;

NPV : Net Present Value [93].

If NPV $(i) > 0$, accept the investment;

If NPV $(i) = 0$, remain indifferent;

If NPV $(i) < 0$, reject the investment [94].

6.2.2 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is a primary financial indicator used to estimate the profitability of potential investments. The internal rate of return is a discount rate, where the net present value (NPV) of all cash flows for a particular project is zero (the rate of return at which the net present value of a project is zero).

The IRR calculations are based on the same formula of P.V, but it equals zero. The higher the rate, the more attractive the investment.

$$NPV\ (i^*) = \frac{A_0}{(1+i^*)^0} + \frac{A_1}{(1+i^*)^1} + \cdots + \frac{A_N}{(1+i^*)^N} = 0$$

i^* : internal rate of return when the present value is zero [94].

If IRR $> MARR$, accept the investment;
If IRR $= MARR$, remain indifferent;
If IRR $< MARR$, reject the investment [94].

Companies and Specialized Consultants prefer this method because it allows them to qualify the degree of acceptability of a project for example acceptable of accuracy, interesting or very interesting percentage per year.

If the project's internal rate of return is equal to or greater than the company's required rate of return, the project may be deemed financially acceptable, at equivalent risk. If it is lower, the project is usually rejected.

6.2.3 Simple Payback and Discounted Payback Period (PP)

It is a secondary economic indicator, in time, periods or years that it takes to recover the amounts invested in the project by an investor. The decision maker accepts the project if it has a recovery period lower than that required by the company. It consists of dividing the investment for the project's annual net revenue (Simple Payback Period), where all net revenues (annual revenues - annual disbursements) are constant.

In addition to it, there is the Discounted Payback Period, which uses the same formula, but the net revenue values are discounted by the same interest rate of the project. Therefore, the accuracy is greater than the simple recovery period.

$$Payback\ Period\ = \frac{Investment}{(Annual)\ Revenues\ - (Annual)\ Disbursements}$$

[93]

If PP $<\ PP^0$, accept the investment;
If PP = PP^0, remain indifferent;
If PP $>\ PP^0$, reject the investment [94].

PP^0 : Minimum Acceptable Payback Period set by Company Management (benchmark) [94].

In another words, a project is accepted if the initial investment is recovered quickly enough.

6.2.4 Economic Feasibility Scenarios' Premises and Results

In this Master's thesis, the comparison of three different scenarios will be analyzed:
1) 150 kW Solar Photovoltaic Arrays in Ontario and Quebec – Scenario 02;
2) 500 kW Solar Photovoltaic Arrays in Ontario and Quebec – Scenario 06;
3) 250 kW Battery Energy Storage System in Ontario and Quebec – Scenario 04.

The purpose of this economic analysis is to find out if the investment to install PV Arrays and BESS, separately, in Ontario and Quebec is economically feasible.

For the Solar Photovoltaic Modules analysis, the RETScreen (Clean Energy Management Software developed by Natural Resources Canada) was utilized [12] , where one simulation was executed in Ontario and another to Quebec, both with 150 and 500 kW of MPP (Maximum Power Point) and solar irradiance data from Montreal, QC. Thus, following economic indicators were presented: NPV, IRR and Payback Period.

For the Battery Energy Storage System analysis, the excel software calculated the same economic indicators: NPV, IRR and Payback Period, which was developed by the author of this master's thesis.

The economic premises and results will be presented on this order:

1) 150 kW Solar Photovoltaic Arrays in Ontario and Quebec – Scenario 02
   - Common Inputs;
   - 150 kW Solar Photovoltaic Arrays in Ontario;
   - 150 kW Solar Photovoltaic Arrays in Quebec.

2) 500 kW Solar Photovoltaic Arrays in Ontario and Quebec – Scenario 06
   - Common Inputs;
   - 500 kW Solar Photovoltaic Arrays in Ontario;
   - 500 kW Solar Photovoltaic Arrays in Quebec.

3) 250 kW Battery Energy Storage System in Ontario and Quebec – Scenario 04
   - Common Inputs;
   - 250 kW Battery Energy Storage System in Ontario;
   - 250 kW Battery Energy Storage System in Quebec.

6.2.4.1 150 kW Solar Photovoltaic Arrays in Ontario and Quebec – Scenario 02

Firstly, the main common inputs to be utilized in both Ontario and Quebec for a 150 kW Photovoltaic System economic feasibility study were considered, as followed:

Table 6-21 Scenario 02 Inputs - 150 kW PV Arrays Economic Study at RETScreen

Description	Value
Scenario 02 – Investment for a 150 kW PV Arrays in Ontario (Ca$)	873,050.22
Scenario 02 – Investment for a 150 kW PV Arrays in Quebec (Ca$)	873,050.22
Interest Rate (%)	5
Project Lifetime (years)	25
Scenario 06 - Ontario's Average Unit Price of Electricity (₵/kWh)	30.572
Scenario 06 - Quebec's Average Unit Price of Electricity (₵/kWh)	5.732

In order to make a more accurate cost analysis, this master's thesis will utilize a parametric estimate from the Design and Cost Estimate Report prepared by an advisory company in October 2016 to ÉTS. Their scope of work was to evaluate the Construction and Electrical design and cost to implement a mini-electrical network on the roof of block B at ÉTS.

In addition, a Superstructure is mandatory to be installed on the roof of Block B, in order to support the weight of the 535 Solar modules units and its components, as followed.

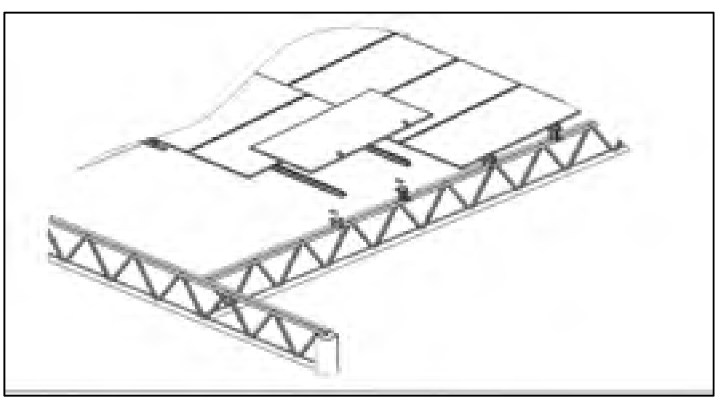


Figure 6-16 Superstructure to support PV Arrays + Components on roof of block B
Taken from Advisory Company Design and Cost

Table 6-22 Cost Breakdown for a 150 kW Photovoltaic System
Adapted from Advisory Company Design and Cost Estimate Report

Description	Quantity	Unit	Material		Service - Workforce			Total
			Unit Price	Total	Hours	Rate	Total	
1. Photovoltaic Module								**162 983,42**
1.1 - Photovoltaic Module	535	unit	202,05	108 096,75	544,9	72	39 233,33	147 330,08
1.2 - Connection between Solar Modules	535	unit	0,00	0,00	128,8	72	9 273,33	9 273,33
1.3 - Grounding	1	lot	3500,00	3 500,00	40,0	72	2 880,00	6 380,00
2. Junction Box								**24 558,65**
2.1 - Junction Box (JB) with fusibles, NEMA 4 X	6	unit	1340,00	7 965,56	17,8	72	1 284,00	9 249,56
2.2 - Support for JB	6	unit	275,00	1 634,72	9,9	72	713,33	2 348,06
2.3 - Connectors between PV Modules and JB (2c.# 10)	842	m	6,75	5 684,38	79,1	72	5 706,67	11 391,04
2.4 - Grounding	1	lot	850,00	850,00	10,0	72	720,00	1 570,00
3. DC AC Power Inverter								**44 483,67**
3.1 - DC AC Power Inverter	2	unit	16550,00	33 100,00	24,0	72	1 728,00	34 828,00
3.2 - Support for Power Inverter	2	unit	225,00	450,00	15,3	72	1 104,00	1 554,00
3.3 - Connectors between Power Inverter and JB	233	lot	14,75	3 441,67	50,0	72	3 600,00	7 041,67
3.4 - Grounding	1	lot	340,00	340,00	10,0	72	720,00	1 060,00
4. AC Side (Level 04)								**33 110,00**
4.1 - Panel 800 A, 480 V	1	unit	7500,00	7 500,00	30,0	72	2 160,00	9 660,00
4.2 - Breaker 1 X 500 A, 7 X 80 A	1	lot	15500,00	15 500,00	16,0	72	1 152,00	16 652,00
4.3 - Cables connection (Output of Inverter)	100	lot	6,50	650,00	16,0	72	1 152,00	1 802,00
4.4 - Measurement	1	lot	3500,00	3 500,00	12,0	72	864,00	4 364,00
4.5 - Grounding	1	lot	200,00	200,00	6,0	72	432,00	632,00
5. Connections / Transformer - 480 / 600 V								**20 079,50**
5.1 - Electric Transformer 350 kVA	1	unit	12477,50	12 477,50	36,0	72	2 592,00	15 069,50
5.2 -Cables Connection (entrance and exit)	1	lot	2300,00	2 300,00	20,0	72	1 440,00	3 740,00
5.3 - Grounding	1	lot	550,00	550,00	10,0	72	720,00	1 270,00
6. Connections to HQ network								**36 968,00**
6.1 - Distribution Panel 800 A, 600 V, 3 phases	1	unit	3800,00	3 800,00	28,0	72	2 016,00	5 816,00
6.2 - Breaker 400 A, 600 V, 3 poles	1	unit	3500,00	3 500,00	4,0	72	288,00	3 788,00
6.3 - Connection to the SS 2 level and fusibles 400 A	1	lot	15800,00	15 800,00	140,0	72	10 080,00	25 880,00
6.4 - Grounding	1	lot	620,00	620,00	12,0	72	864,00	1 484,00
7. Contingency (15%)								**48 327,49**
7.1 - Contigency (15%)								48 327,49
8. Administration Fees (10%)								**37 051,07**
8.1 - Administration fees (10%)								37 051,07
TOTAL AMOUNT FOR PHOTOVOLTAIC SYSTEM								**487 561,79**
	Cost per kW ($/kW)							
	2 717,08 $/kW							

The cost per kW, in Canadian dollars, for a 150 kW PV System is 2,717.08 $ / kW, which is in accordance to the U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017 report, published by NREL in September 2017, which informs that the PV cost benchmark is around US$1.85 per Wdc (Watts direct current) installed for commercial rooftop systems (200 kW PV System) in 2017. This project achieved US$2.07/Wdc for a 150 kW PV System [34].

Table 6-23 Superstructure Cost Breakdown for a 150 kW PV Array Adapted from Advisory Company Design and Cost Estimate Report

Description	Quantity	Unit	Material and Service	
			Unit Price	Total
1. Roof's Superstructure				**338 537,04**
1.1 - Galvanized steel superstructure	49 537	kg	4,50	222 916,67
1.2 - Extension of steel columns	43	unit	600,00	25 561,11
1.3 - Mobilization / Demobilization	79	h	80,00	6 340,74
1.4 - Crane Rental	40	h	220,00	8 718,52
1.5 - Fixation structure of solar modules	150 000	W	0,50	75 000,00
2. Contingency (25%)				**84 634,26**
2.1 - Contigency (25%)				84 634,26
3. Administration Fees (10%)				**42 317,13**
3.1 - Administration fees (10%)				42 317,13
TOTAL AMOUNT FOR ROOF'S SUPERSTRUCTURE				**465 488,43**
	Cost per kW ($/kW)			
	3 103,26 $/kW			

Thus, the Total Investment Cost to implement the Photovoltaic system on a super-structure in Canadian dollars is:

Table 6-24 150 kW PV System + Superstructure Total Cost/kW & Total Investment

Total Cost per kW ($/kW)	Total Investment
5 820,33 $/kW	**873 050,22 $**

Based on the above cost, where a contingency of 10% and 25% were utilized for Photovoltaic System and Roof's Superstructure, respectively, RETScreen detailed the costs, as followed.

Table 6-25 RETScreen Investment for 150 kW PV System + Superstructure Taken from RETScreen (2018)

Power system						
Photovoltaic	kW	150.00	$ 2 717	$	407 562	
Road construction	km			$	-	
Transmission line	km			$	-	
Substation	project			$	-	
Energy efficiency measures	project			$	-	
User-defined	cost			$	-	
Roof's Superstructure (with 25% Contingency)		150	$ 3 103	$	465 488	
Subtotal				$	873 050	100.0%

6.2.4.1.1 150 kW Solar Photovoltaic Arrays in Ontario – Scenario 02

In Ontario, the following Inputs were also added: Electricity rate, Slope, type of PV Module, Solar Irradiation (in this case used the same as Montreal), solar tracking mode, inverter capacity and efficiency were considered at RETScreen:

Table 6-26 ON's 150 kW PV Arrays Inputs for Economic Study at RETScreen
Taken from RETScreen (2018)

Solar tracking mode		One-axis
Slope	°	45.0
Azimuth	°	0.0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	1,52	3,38	257,6	15,82
February	2,43	4,93	258,7	20,57
March	3,57	5,92	164,3	26,61
April	4,41	5,99	209,1	25,38
May	5,34	6,48	296,9	27,59
June	5,77	7,01	362,1	28,29
July	5,85	7,41	381,2	30,42
August	4,84	6,30	472,8	26,04
September	3,74	5,39	300,0	21,98
October	2,31	3,78	292,9	16,45
November	1,29	2,35	296,3	10,26
December	1,11	2,39	339,9	11,11
Annual	**3,52**	**5,11**	**305,72**	**260,53**

Annual solar radiation - horizontal	MWh/m²	1,29	
Annual solar radiation - tilted	MWh/m²	1,87	
Photovoltaic			
Type		mono-Si	
Power capacity	kW	150,00	
Manufacturer		Canadian Solar	
Model		mono-Si - CS6X-280M - MaxPower	1 unit(s)
Efficiency	%	14,6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0,40%	
Solar collector area	m²	1 028	
Miscellaneous losses	%	1,0%	
Inverter			
Efficiency	%	96,0%	
Capacity	kW	250,0	

Table 6-27 Ontario's 150 kW PV Arrays Economic Analysis by RETScreen
Taken from RETScreen (2018)

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	2.0%
Inflation rate	%	2.0%
Discount rate	%	5.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	0.0%
Income tax analysis		☐

Annual income

Electricity export income		
Electricity exported to grid	MWh	261
Electricity export rate	$/MWh	305.72
Electricity export income	$	79 647
Electricity export escalation rate	%	2.0%
GHG reduction income		☐
Net GHG reduction	tCO2/yr	60
Net GHG reduction - 25 yrs	tCO2	1 252
Customer premium income (rebate)		☐

Project costs and savings/income summary

Initial costs			
Power system	100.0%	$	873 050
Balance of system & misc.	0.0%	$	0
Total initial costs	100.0%	$	873 050
Annual costs and debt payments			
O&M		$	0
Fuel cost - proposed case		$	0
Total annual costs		$	0
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	79 647
Total annual savings and income		$	79 647

Financial viability

Pre-tax IRR - equity	%	9.8%
Pre-tax IRR - assets	%	9.8%
After-tax IRR - equity	%	9.8%
After-tax IRR - assets	%	9.8%
Simple payback	yr	11.0
Equity payback	yr	9.8
Net Present Value (NPV)	$	522 988
Annual life cycle savings	$/yr	37 107
Benefit-Cost (B-C) ratio		1.60
Energy production cost	$/MWh	191.15
GHG reduction cost	$/tCO2	(741)

Yearly cash flows

Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	-873 050	-873 050	-873 050
1	81 240	81 240	-791 810
2	82 865	82 865	-708 946
3	84 522	84 522	-624 424
4	86 212	86 212	-538 211
5	87 937	87 937	-450 275
6	89 696	89 696	-360 579
7	91 489	91 489	-269 090
8	93 319	93 319	-175 771
9	95 185	95 185	-80 586
10	97 089	97 089	16 503
11	99 031	99 031	115 534
12	101 012	101 012	216 546
13	103 032	103 032	319 578
14	105 092	105 092	424 670
15	107 194	107 194	531 864
16	109 338	109 338	641 202
17	111 525	111 525	752 727
18	113 755	113 755	866 483
19	116 031	116 031	982 513
20	118 351	118 351	1 100 864
21	120 718	120 718	1 221 583
22	123 133	123 133	1 344 715
23	125 595	125 595	1 470 310
24	128 107	128 107	1 598 417
25	130 669	130 669	1 729 086

Based on the above costs and input data, the RETScreen made the economic study, whose results were shown below:

The Primary indicator, the IRR, Internal rate of return, indicated a 9.8 % gain per year, while the NPV, Net Present Value, was positive in Ca$522,988. Thus, both primary indicators indicate the investment is economically feasible in Ontario. In addition to it, the Payback period indicates that it will take 9.8 years to recover the money invested in the project, which is also a short period for a project in the renewable energy area. In addition, if we consider that a superstructure was added to the photovoltaic system, with a cost per kW of 3,103.36 Ca/kW and 2,717.08 Ca/kW, respectively, the payback is still competitive.

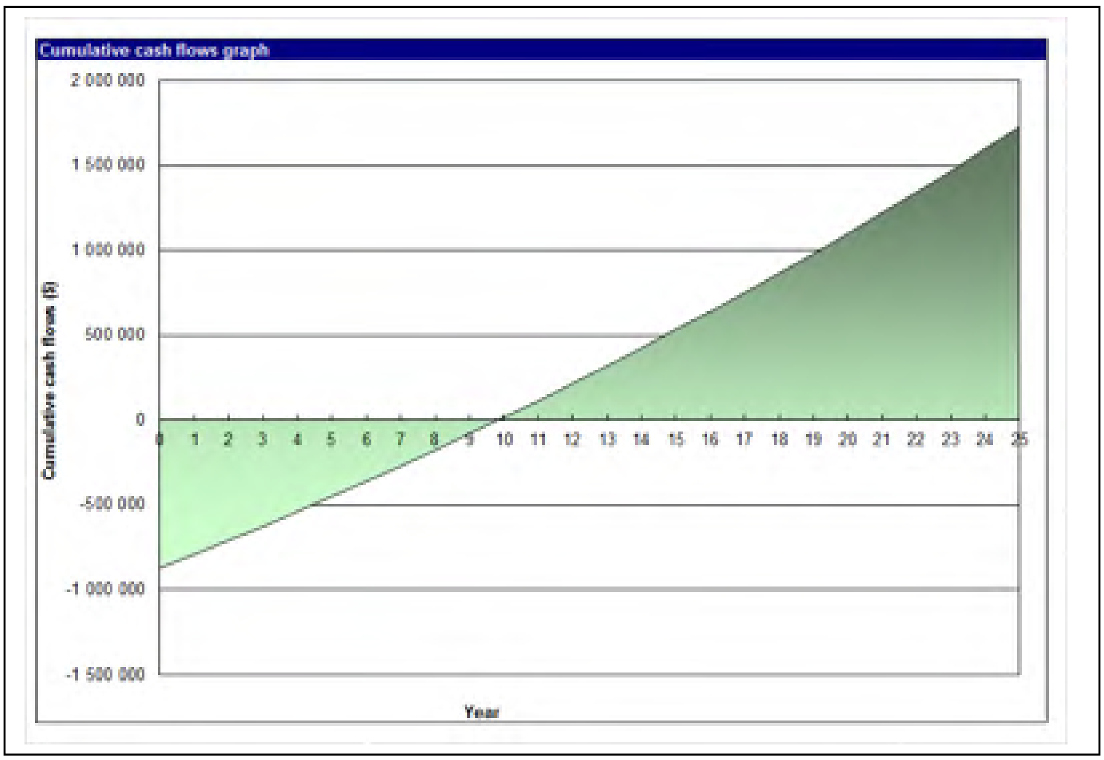


Figure 6-17 Ontario's 500 kW PV Arrays Payback Period by RETScreen
Taken from RETScreen (2018)

6.2.4.1.2 150 kW Solar Photovoltaic Arrays in Quebec – Scenario 02

In Quebec, the following Inputs were also added to the 150 kW PV System: Electricity rate, Slope, type of PV Module, Solar Irradiation from Montreal, solar tracking mode, inverter capacity and efficiency were considered at RETScreen:

Table 6-28 QC's 150 kW PV Arrays Inputs for Economic Study at RETScreen
Taken from RETScreen (2018)

Solar tracking mode		One-axis
Slope	°	45,0
Azimuth	°	0,0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	1,52	3,38	56,4	15,82
February	2,43	4,93	59,0	20,57
March	3,57	5,92	55,6	26,61
April	4,41	5,99	56,9	25,38
May	5,34	6,48	58,3	27,59
June	5,77	7,01	59,3	28,29
July	5,85	7,41	56,2	30,42
August	4,84	6,30	55,8	26,04
September	3,74	5,39	60,4	21,98
October	2,31	3,78	57,0	16,45
November	1,29	2,35	55,6	10,26
December	1,11	2,39	55,3	11,11
Annual	**3,52**	**5,11**	**57,32**	**260,53**

Annual solar radiation - horizontal	MWh/m²	1,29	
Annual solar radiation - tilted	MWh/m²	1,87	
Photovoltaic			
Type		mono-Si	
Power capacity	kW	150,00	
Manufacturer		Canadian Solar	
Model		mono-Si - CS6X-280M - MaxPower	1 unit(s)
Efficiency	%	14,6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0,40%	
Solar collector area	m²	1 028	
Miscellaneous losses	%	1,0%	
Inverter			
Efficiency	%	95,0%	
Capacity	kW	250,0	

Based on the above costs and input data, the RETScreen made the economic study, whose results were shown below:

Table 6-29 Quebec's 150 kW PV Arrays Economic Analysis by RETScreen
Taken from RETScreen (2018)

RETScreen Financial Analysis - Power project

Financial parameters		
General		
Fuel cost escalation rate	%	2.0%
Inflation rate	%	2.0%
Discount rate	%	5.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	0.0%
Income tax analysis		

Annual income		
Electricity export income		
Electricity exported to grid	MWh	261
Electricity export rate	$/MWh	57.32
Electricity export income	$	14 932
Electricity export escalation rate	%	2.0%
GHG reduction income		
Net GHG reduction	tCO2/yr	50
Net GHG reduction - 25 yrs	tCO2	1 252
Customer premium income (rebate)		

Project costs and savings/income summary			
Initial costs			
Power system	100.0%	$	873 050
Balance of system & misc.	0.0%	$	0
Total initial costs	100.0%	$	873 050
Annual costs and debt payments			
O&M		$	0
Fuel cost - proposed case		$	0
Total annual costs		$	0
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	14 932
Total annual savings and income		$	14 932

Financial viability		
Pre-tax IRR - equity	%	-3.8%
Pre-tax IRR - assets	%	-3.8%
After-tax IRR - equity	%	-3.8%
After-tax IRR - assets	%	-3.8%
Simple payback	yr	58.5
Equity payback	yr	> project
Net Present Value (NPV)	$	-611 324
Annual life cycle savings	$/yr	-43 376
Benefit-Cost (B-C) ratio		0.30
Energy production cost	$/MWh	191.19
GHG reduction cost	$/tCO2	###

Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	-873 050	-873 050	-873 050
1	15 231	15 231	-857 820
2	15 535	15 535	-842 284
3	15 846	15 846	-826 438
4	16 163	16 163	-810 275
5	16 486	16 486	-793 789
6	16 816	16 816	-776 973
7	17 152	17 152	-759 821
8	17 495	17 495	-742 326
9	17 845	17 845	-724 480
10	18 202	18 202	-706 278
11	18 566	18 566	-687 712
12	18 937	18 937	-668 775
13	19 316	19 316	-649 458
14	19 703	19 703	-629 756
15	20 097	20 097	-609 659
16	20 499	20 499	-589 161
17	20 908	20 908	-568 252
18	21 327	21 327	-546 926
19	21 753	21 753	-525 172
20	22 188	22 188	-502 984
21	22 632	22 632	-480 352
22	23 085	23 085	-457 267
23	23 546	23 546	-433 721
24	24 017	24 017	-409 704
25	24 498	24 498	-385 206

All economic indicators confirm that a 150 kW of PV Arrays are NOT economically feasible in Quebec. The Primary indicator, the IRR, indicated a - 3.8 % loss per year and the NPV, was negative in - Ca$611,324. Thus, both primary indicators show that the investment is not economically feasible in Quebec. In addition to it, the Payback period indicates that it would take more than 50 years to recover the money invested in the project, whose project lifetime is

25 years. In fact, two factors are responsible for that: If we consider just the investment for a Photovoltaic system (without a superstructure) at ÉTS in Quebec, whose cost per kW is 2,717.08 Ca$/kW, the payback period is around 25 years; However, after adding the roof's superstructure with a cost per kW of 3,103.26 Ca$/kW, the payback period is around twice longer. The second factor is the low price of electricity in Quebec, which is around 0.0571 $/kWh, which makes the majority of the projects in renewable energy unfeasible in this province.

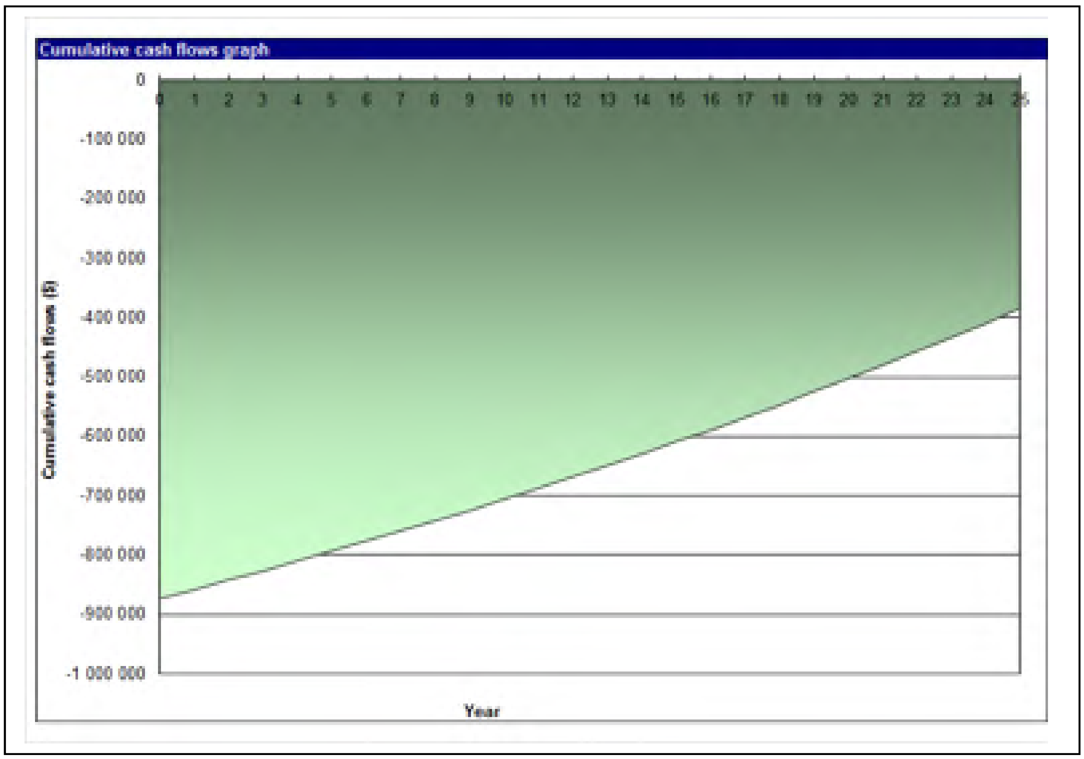


Figure 6-18 Quebec's 150 kW PV Arrays Payback Period by RETScreen
Taken from RETScreen (2018)

6.2.4.2 500 kW Solar Photovoltaic Arrays in Ontario and Quebec – Scenario 06

Firstly, the main common inputs to be utilized in both Ontario and Quebec for a 500 kW Photovoltaic System economic feasibility study were considered, as followed:

Table 6-30 Scenario 06 Inputs - 500 kW PV Arrays Economic Study at RETScreen

Description	Value
Scenario 06 – Investment for a 500 kW PV Arrays in Ontario (Ca$)	2,773,434.53
Scenario 06 – Investment for a 500 kW PV Arrays in Quebec (Ca$)	2,773,434.53
Interest Rate (%)	5
Project Lifetime (years)	25
Scenario 06 - Ontario's Average Unit Price of Electricity (¢/kWh)	30.572
Scenario 06 - Quebec's Average Unit Price of Electricity (¢/kWh)	5.732

The same parametric estimate taken from the Design and Cost Estimate Report, which was utilized for the 150 kW Photovoltaic System, will be used for the 500 kW PV System. Also, the same kind of reinforced structure to support the PV Arrays, proportional to its number of solar modules: 1785 units.

Table 6-31 Cost Breakdown for a 500 kW PV System
Adapted from Advisory Company Design and Cost Estimate Report

Description	Quantity	Unit	Material		Service - Workforce			Total
			Unit Price	Total	Hours	Rate	Total	
1. Photovoltaic Module								**535 259,25**
1.1 - Photovoltaic Module	1785	unit	202,05	360 659,25	1818,1	72	130 900,00	491 559,25
1.2 - Connection between Solar Modules	1785	unit	0,00	0,00	429,7	72	30 940,00	30 940,00
1.3 - Grounding	2	lot	3500,00	7 000,00	80,0	72	5 760,00	12 760,00
2. Junction Box								**79 840,46**
2.1 - Junction Box (JB) with fusibles, NEMA 4 X	20	unit	1340,00	26 576,67	59,5	72	4 284,00	30 860,67
2.2 - Support for JB	20	unit	275,00	5 454,17	33,1	72	2 380,00	7 834,17
2.3 - Connectors between PV Modules and JB (2c # 10)	2810	m	6,75	18 965,63	264,4	72	19 040,00	38 005,63
2.4 - Grounding	2	lot	850,00	1 700,00	20,0	72	1 440,00	3 140,00
3. DC AC Power Inverter								**159 636,81**
3.1 - DC AC Power Inverter	15	unit	5335,29	80 029,31	180,0	72	12 960,00	93 049,31
3.2 - Support for Power Inverter	15	unit	225,00	3 375,00	115,0	72	8 280,00	11 655,00
3.3 - Connectors between Power Inverter and JB	1750	lot	14,75	25 812,50	375,0	72	27 000,00	52 812,50
3.4 - Grounding	2	lot	340,00	680,00	20,0	72	1 440,00	2 120,00
4. AC Side (Level 04)								**76 131,00**
4.1 - Panel 800 A, 480 V	2	unit	7500,00	15 000,00	60,0	72	4 320,00	19 320,00
4.2 - Breaker 1 X 500 A, 7 X 80 A	2	lot	15500,00	31 000,00	32,0	72	2 304,00	33 304,00
4.3 - Cables connection (Output of Inverter)	750	lot	6,50	4 875,00	120,0	72	8 640,00	13 515,00
4.4 - Measurement	2	lot	3500,00	7 000,00	24,0	72	1 728,00	8 728,00
4.5 - Grounding	2	lot	200,00	400,00	12,0	72	864,00	1 264,00
5. Connections / Transformer - 480 / 600 V								**40 159,00**
5.1 - Electric Transformer 350 KVA	2	unit	12477,50	24 955,00	72,0	72	5 184,00	30 139,00
5.2 - Cables Connection (input and output)	2	lot	2300,00	4 600,00	40,0	72	2 880,00	7 480,00
5.3 - Grounding	2	lot	550,00	1 100,00	20,0	72	1 440,00	2 540,00
6. Connections to HQ network								**73 936,00**
6.1 - Distribution Panel 800 A, 600 V, 3 phases	2	unit	3800,00	7 600,00	56,0	72	4 032,00	11 632,00
6.2 - Breaker 400 A, 600 V, 3 poles	2	unit	3500,00	7 000,00	8,0	72	576,00	7 576,00
6.3 - Connection to the SS 2 level and fusibles 400 A	2	lot	15800,00	31 600,00	280,0	72	20 160,00	51 760,00
6.4 - Grounding	2	lot	620,00	1 240,00	24,0	72	1 728,00	2 968,00
7. Contingency (15%)								**144 744,38**
7.1 - Contingency (15%)								144 744,38
8. Administration Fees (10%)								**110 970,69**
8.1 - Administration fees (10%)								110 970,69
TOTAL AMOUNT FOR PHOTOVOLTAIC SYSTEM								**1 220 677,59**

Cost per kW ($/kW)
2 441,36 $/kW

The cost per kW, in Canadian dollars, for a 500 kW PV System is 2,441.36 $ / kW, which is in accordance to the U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017 report, published by NREL in September 2017, which informs that the PV cost benchmark is around US$1.85 per Wdc (Watts direct current) installed for commercial rooftop systems (200 kW PV System) in 2017.This project achieved US$1.86/Wdc for a 500 kW PV System [34].

Table 6-32 Superstructure Cost Breakdown for 500 kW PV Array Adapted from Advisory Company Design and Cost Estimate Report

Description	Quantity	Unit	Material and Service	
			Unit Price	Total
1. Roof's Superstructure				**1 129 277,78**
1.1 - Galvanized steel superstructure	165 278	kg	4,50	743 750,00
1.2 - Extension of steel columns	142	unit	600,00	85 283,33
1.3 - Mobilization / Demobilization	264	h	80,00	21 155,56
1.4 - Crane Rental	132	h	220,00	29 088,89
1.5 - Fixation structure of solar modules	500 000	W	0,50	250 000,00
2. Contingency (25%)				**282 319,44**
2.1 - Contigency (25%)				282 319,44
3. Administration Fees (10%)				**141 159,72**
3.1 - Administration fees (10%)				141 159,72
TOTAL AMOUNT FOR ROOF'S SUPERSTRUCTURE				**1 552 756,94**
	Cost per kW ($/kW)			
	3 105,51 $/kW			

Thus, the Total Investment Cost to implement the Photovoltaic system on a super-structure in Canadian dollars is:

Table 6-33 500 kW PV System + Superstructure Total Cost/kW & Total Investment

Total Cost per kW ($/kW)	Total Cost ($)
5 546,87 $/kW	**2 773 434,53 $**

Based on the above cost, where a contingency of 10 and 25 % were utilized for Photovoltaic System and Roof's Superstructure, respectively, RETScreen detailed the costs, as followed:

Table 6-34 RETScreen Investment for 500 kW PV System + Superstructure Taken from RETScreen (2018)

Power system					
Photovoltaic	kW	500,00	$ 2 441	$ 1 220 678	
Road construction	km			$ -	
Transmission line	km			$ -	
Substation	project			$ -	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
Roof's Superstructure (with 25% Contingency)	cost	500	$ 3 106	$ 1 552 757	
Subtotal:				$ 2 773 435	100,0%

6.2.4.2.1 500 kW Solar Photovoltaic Arrays in Ontario – Scenario 06

In Ontario, the following Inputs were also added: Electricity rate, Slope, type of PV Module, Solar Irradiation (in this case used the same as Montreal), solar tracking mode, inverter capacity and efficiency were considered at RETScreen:

Table 6-35 Ontario's 500 kW PV Arrays Inputs for Economic Study at RETScreen
Taken from RETScreen (2018)

Solar tracking mode		One-axis
Slope	°	45,0
Azimuth	°	0,0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	1,52	3,38	257,6	52,74
February	2,43	4,93	258,7	68,56
March	3,57	5,92	164,3	88,70
April	4,41	5,99	209,1	84,62
May	5,34	6,48	296,9	91,98
June	5,77	7,01	362,1	94,29
July	5,85	7,41	381,2	101,40
August	4,84	6,30	472,8	86,81
September	3,74	5,39	300,0	73,28
October	2,31	3,78	292,9	54,82
November	1,29	2,35	296,3	34,18
December	1,11	2,39	339,9	37,05
Annual	**3,52**	**5,11**	**305,72**	**868,42**

Annual solar radiation - horizontal	MWh/m²	1,29	
Annual solar radiation - tilted	MWh/m²	1,87	
Photovoltaic			
Type		mono-Si	
Power capacity	kW	500,00	
Manufacturer		Canadian Solar	
Model		mono-Si - CS6X-280M - MaxPower	1 unit(s)
Efficiency	%	14,6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0,40%	
Solar collector area	m²	3 427	
Miscellaneous losses	%	1,0%	
Inverter			
Efficiency	%	95,0%	
Capacity	kW	540,0	

Based on the above costs and inputs data, the RETScreen made the economic study, whose results were shown below:

Table 6-36 Ontario's 500 kW PV RETScreen Economic Analysis
Taken from RETScreen (2018)

RETScreen Financial Analysis - Power project

Financial parameters		
General		
Fuel cost escalation rate	%	2.0%
Inflation rate	%	2.0%
Discount rate	%	5.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	0.0%
Income tax analysis		
Annual income		
Electricity export income		
Electricity exported to grid	MWh	868
Electricity export rate	$/MWh	305.72
Electricity export income	$	265 490
Electricity export escalation rate	%	2.0%
GHG reduction income		
Net GHG reduction	tCO2/yr	167
Net GHG reduction - 25 yrs	tCO2	4 175
Customer premium income (rebate)		
Other income (cost)		

Project costs and savings/income summary			
Initial costs			
Power system	100.0%	$	2 773 435
Balance of system & misc.	0.0%	$	0
Total initial costs	100.0%	$	2 773 435
Annual costs and debt payments			
O&M		$	0
Fuel cost - proposed case		$	0
Total annual costs		$	0
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	265 490
Total annual savings and income		$	265 490

Financial viability		
Pre-tax IRR - equity	%	10.4%
Pre-tax IRR - assets	%	10.4%
After-tax IRR - equity	%	10.4%
After-tax IRR - assets	%	10.4%
Simple payback	yr	10.4
Equity payback	yr	9.4
Net Present Value (NPV)	$	1 880 025
Annual life cycle savings	$/yr	133 392
Benefit-Cost (B-C) ratio		1.68
Energy production cost	$/MWh	182.20
GHG reduction cost	$/tCO2	(796)

Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	-2 773 435	-2 773 435	-2 773 435
1	270 799	270 799	-2 502 635
2	276 215	276 215	-2 226 420
3	281 740	281 740	-1 944 680
4	287 375	287 375	-1 657 305
5	293 122	293 122	-1 364 183
6	298 985	298 985	-1 065 199
7	304 964	304 964	-760 234
8	311 063	311 063	-449 171
9	317 285	317 285	-131 886
10	323 630	323 630	191 744
11	330 103	330 103	521 847
12	336 705	336 705	858 553
13	343 439	343 439	1 201 992
14	350 308	350 308	1 552 300
15	357 314	357 314	1 909 614
16	364 460	364 460	2 274 074
17	371 750	371 750	2 645 824
18	379 185	379 185	3 025 009
19	386 768	386 768	3 411 777
20	394 504	394 504	3 806 281
21	402 394	402 394	4 208 675
22	410 442	410 442	4 619 116
23	418 651	418 651	5 037 767
24	427 024	427 024	5 464 790
25	435 564	435 564	5 900 354

The Primary indicator, IRR indicated a 10.4 % gain per year, while the NPV, Net Present Value, was positive in Ca$1,880,025. Thus, both primary indicators indicate the investment is very economically feasible in Ontario, even better than 150 kW PV System, due to economies of scale (a proportionate saving in investment costs gained by assembling a bigger PV system).

In addition to it, the Payback period indicates that it will take 9.4 years to recover the money invested in the project, which is also a short period for a project in the renewable energy area. In addition, if we consider that a superstructure was added to the photovoltaic system, with a cost per kW of 3,105.51 Ca/kW and 5,546.87 Ca/kW, respectively, the payback is still very competitive.

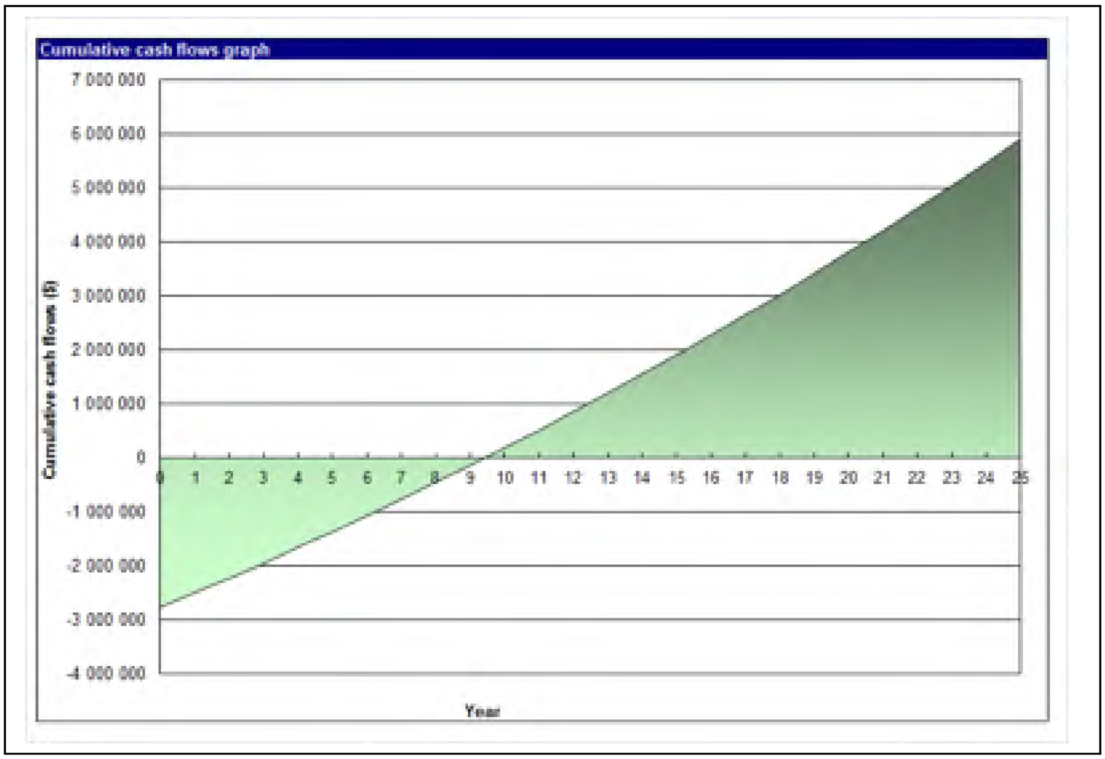


Figure 6-19 Ontario's 500 kW PV Arrays Payback Period by RETScreen
Taken from RETScreen (2018)

6.2.4.2.2 500 kW Solar Photovoltaic Arrays in Quebec – Scenario 06

In Quebec, the following Inputs were also added to the 500 kW PV System: Electricity rate, Slope, type of PV Module, Solar Irradiation from Montreal, solar tracking mode, inverter capacity and efficiency were considered at RETScreen:

Table 6-37 QC's 500 kW PV Arrays Inputs for Economic Study at RETScreen
Taken from RETScreen (2018)

Solar tracking mode		One-axis
Slope	°	45,0
Azimuth	°	0,0

☑ Show data

Month	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Electricity export rate $/MWh	Electricity exported to grid MWh
January	1,52	3,38	56,4	52,74
February	2,43	4,93	59,0	68,56
March	3,57	5,92	55,6	88,70
April	4,41	5,99	56,9	84,62
May	5,34	6,48	58,3	91,98
June	5,77	7,01	59,3	94,29
July	5,85	7,41	56,2	101,40
August	4,84	6,30	55,8	86,81
September	3,74	5,39	60,4	73,28
October	2,31	3,78	57,0	54,82
November	1,29	2,35	55,6	34,18
December	1,11	2,39	55,3	37,05
Annual	3,52	5,11	57,32	868,42

Annual solar radiation - horizontal	MWh/m²	1,29	
Annual solar radiation - tilted	MWh/m²	1,87	
Photovoltaic			
Type		mono-Si	
Power capacity	kW	500,00	
Manufacturer		Canadian Solar	
Model		mono-Si - CS6X-280M - MaxPower	1 unit(s)
Efficiency	%	14,6%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0,40%	
Solar collector area	m²	3 427	
Miscellaneous losses	%	1,0%	
Inverter			
Efficiency	%	95,0%	
Capacity	kW	540,0	

Based on the above costs and input data, the RETScreen made the economic study, whose results were shown below.

Table 6-38 Quebec's 500 kW PV RETScreen Economic Analysis
Taken from RETScreen (2018)

RETScreen Financial Analysis - Power project

Financial parameters		
General		
Fuel cost escalation rate	%	2.0%
Inflation rate	%	2.0%
Discount rate	%	5.0%
Project life	yr	25
Finance		
Incentives and grants	$	
Debt ratio	%	0.0%
Income tax analysis		
Annual income		
Electricity export income		
Electricity exported to grid	MWh	868
Electricity export rate	$/MWh	57.32
Electricity export income	$	49 774
Electricity export escalation rate	%	2.0%
GHG reduction income		
Net GHG reduction	tCO2/yr	167
Net GHG reduction - 25 yrs	tCO2	4 175
Customer premium income (rebate)		
Other income (cost)		

Project costs and savings/income summary			
Initial costs			
Power system	100.0%	$	2 773 435
Balance of system & misc.	0.0%	$	0
Total initial costs	100.0%	$	2 773 435
Annual costs and debt payments			
O&M		$	0
Fuel cost - proposed case		$	0
Total annual costs		$	0
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	49 774
Total annual savings and income		$	49 774

Financial viability		
Pre-tax IRR - equity	%	-3.5%
Pre-tax IRR - assets	%	-3.5%
After-tax IRR - equity	%	-3.5%
After-tax IRR - assets	%	-3.5%
Simple payback	yr	55.7
Equity payback	yr	> project
Net Present Value (NPV)	$	-1 901 012
Annual life cycle savings	$/yr	-134 881
Benefit-Cost (B-C) ratio		0.31
Energy production cost	$/MWh	182.20
GHG reduction cost	$/tCO2	808

Yearly cash flows			
Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	-2 773 435	-2 773 435	-2 773 435
1	50 769	50 769	-2 722 666
2	51 784	51 784	-2 670 881
3	52 820	52 820	-2 618 061
4	53 876	53 876	-2 564 185
5	54 954	54 954	-2 509 231
6	56 053	56 053	-2 453 177
7	57 174	57 174	-2 396 003
8	58 318	58 318	-2 337 686
9	59 484	59 484	-2 278 202
10	60 674	60 674	-2 217 528
11	61 887	61 887	-2 155 641
12	63 125	63 125	-2 092 516
13	64 387	64 387	-2 028 129
14	65 675	65 675	-1 962 453
15	66 989	66 989	-1 895 465
16	68 328	68 328	-1 827 136
17	69 695	69 695	-1 757 441
18	71 089	71 089	-1 686 353
19	72 511	72 511	-1 613 842
20	73 961	73 961	-1 539 881
21	75 440	75 440	-1 464 441
22	76 949	76 949	-1 387 492
23	78 488	78 488	-1 309 004
24	80 058	80 058	-1 228 947
25	81 659	81 659	-1 147 288

All economic indicators confirm that a 500 kW of PV Arrays are NOT economically feasible either in Quebec. The Primary indicator, the IRR, indicated a - 3.5 % loss per year and the NPV, was negative in - Ca$1,901,012. Both primary indicators show that the investment is not economically feasible in Quebec. Due to economies of scale, the unit cost per kW to install a 500 kW PV system is reduced from 2,717.08 $/kW to 2,441.36 $/kW. Thus, economic figures is a little bit better than 150 kW PV System. In addition to it, the Payback period indicates that it would take more than 50 years to recover the money invested in the project, whose project lifetime is 25 years. In fact, two factors are responsible for that: If we consider just the investment for a Photovoltaic system (without a superstructure) at ÉTS in Quebec, whose cost per kW is 2,441.36 Ca$/kW, the payback period is around 20 years; However, after adding the roof's superstructure with a cost per kW of 3,105.51 Ca$/kW, the payback period is around twice longer. The second factor is the low price of electricity in Quebec, which is around 0.0571 $/kWh, which makes the majority of the projects in renewable energy unfeasible in this province.

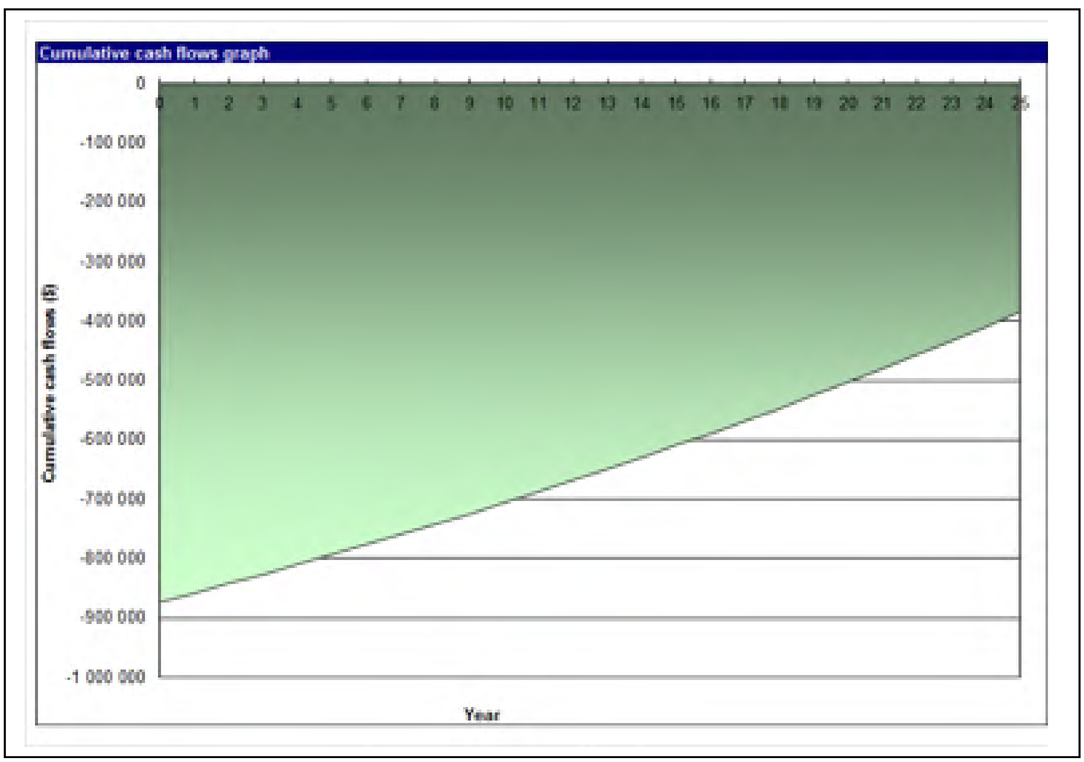


Figure 6-20 Quebec's 500 kW PV Arrays Payback Period by RETScreen
Taken from RETScreen (2018)

6.2.4.3 250 kW Battery Energy Storage System in Ontario and Quebec – Scenario 04

Firstly, the main common inputs to be utilized in both Ontario and Quebec for a 250 kW Battery Energy Storage System economic feasibility study were considered, as followed.

Table 6-39 Inputs of Scenario 04 - 250 kW BESS for Economic Study

Description	Value
Scenario 04 – Investment for a 250 kW BESS in Ontario (Ca$)	869,062.05
Scenario 04 – Investment for a 250 kW BESS in Quebec (Ca$)	869,062.05
Interest Rate (%)	5
Project Lifetime (years)	21
Scenario 04 - Ontario's Yearly Bill Savings from MATLAB (Ca$)	50,547.60
Scenario 04 - Quebec's Yearly Bill Savings from MATLAB (Ca$)	47,872.88

Table 6-40 250 kW BESS Investment in Ontario and Quebec

Item	Description	Investment (Ca$)	Breakdown (%)	Breakdown ($)
		869,062.05		
1.1	Battery Bank - VRLA Cells technology		64.06%	556,706.00
1.2	2 or 3-Tier Rack		5.75%	50,000.00
1.3	250 kW DC/AC Inverter with Battery Charger		5.91%	51,333.97
1.4	Electrical Cables, Materials and others		4.90%	42,562.80
1.5	Installation		10.29%	89,453.65
1.6	Contingency		9.09%	79,005.64
Total			100.00%	869,062.05

The high investment comes mainly, from the price of VRLA battery cells, which was estimated by a specialized professional in batteries system from ÉTS, as 556.71 $/kWh for a 1 (one) MWh battery capacity, as shown in appendix VII. In addition, a 2-tier or 3-tier rack to accommodate all 512 battery cells was estimated by the same professional in Ca$50,000.00. Finally, 2 X 125 kW DC-AC Power Inverters with battery charging, whose unit cost is US$19,600 and was converted to Ca$ with a 1.30954 Ca$/US$ exchange rate from October

23rd 2018 [95]. Electrical cables, materials, installation and contingency compound the rest. In addition, a Ca$500.00 annual maintenance contract for the batteries was added.

6.2.4.3.1 250 kW Battery Energy Storage System in Ontario– Scenario 04

The Ontario's economic figures are displayed below.

Table 6-41 Ontario's 250 kW BESS Yearly Gross Revenue and Maintenance Contract

	Power (kW)	Yearly Electricity Saving (from Matlab Economic Study)
2.1	250	50 547,60
Maintenance Contract of Scenario 04 - ETS in Ontario with 250 kW Batteries		
	Type	Estimated Amount
3.1	Annual Maintenance Contract	500,00

Table 6-42 Ontario's 250 kW Project Cash-Flow

Interest rate (%)	5,00%
Project Lifetime (years)	21

Year	Simple Cash-flow	Simple-Payback	Yearly Discounted Cash-flow	Accummulated Discounted Cash-flow
0	-869 062,05	-869 062,05	-869 062,05	-869 062,05
1	50 047,60	-819 014,46	47 664,38	-821 397,68
2	50 047,60	-768 966,86	45 394,64	-776 003,03
3	50 047,60	-718 919,27	43 232,99	-732 770,04
4	50 047,60	-668 871,67	41 174,28	-691 595,76
5	50 047,60	-618 824,08	39 213,60	-652 382,16
6	50 047,60	-568 776,48	37 346,29	-615 035,87
7	50 047,60	-518 728,88	35 567,89	-579 467,98
8	50 047,60	-468 681,29	33 874,18	-545 593,80
9	50 047,60	-418 633,69	32 261,13	-513 332,67
10	50 047,60	-368 586,10	30 724,88	-482 607,79
11	50 047,60	-318 538,50	29 261,79	-453 345,99
12	50 047,60	-268 490,91	27 868,37	-425 477,62
13	50 047,60	-218 443,31	26 541,31	-398 936,31
14	50 047,60	-168 395,72	25 277,44	-373 658,88
15	50 047,60	-118 348,12	24 073,75	-349 585,13
16	50 047,60	-68 300,53	22 927,38	-326 657,75
17	50 047,60	-18 252,93	21 835,60	-304 822,15
18	50 047,60	31 794,67	20 795,81	-284 026,34
19	50 047,60	81 842,26	19 805,53	-264 220,80
20	50 047,60	131 889,86	18 862,41	-245 358,39
21	50 047,60	181 937,45	17 964,20	-227 394,19

Table 6-43 Ontario's 250 kW Economic Indicators

Economic Indicators of Scenario 04 - ETS in Ontario with 250 kW Batteries		
Net Present Value	$	-227 394,19
Internal rate of return	%	1,80%
Simple Payback	year	17,4
Discounted Payback	year	41,5

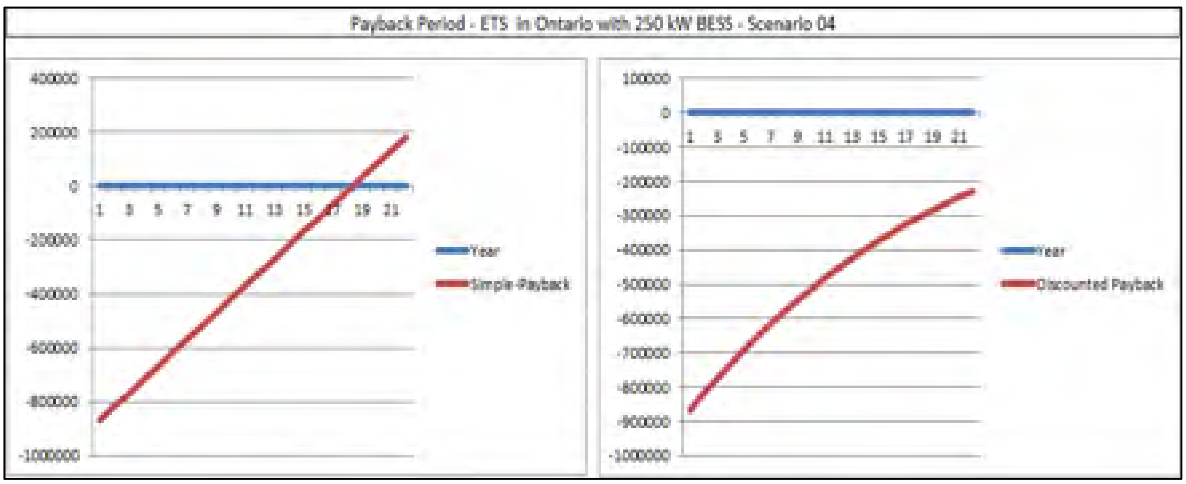


Figure 6-21 Ontario's 250 kW BESS Payback Period

6.2.4.3.2 250 kW Battery Energy Storage System in Quebec – Scenario 04

The Quebec's economic figures are displayed below:

Table 6-44 Quebec's 250 kW BESS Yearly Gross Revenue and Maintenance Contract

	Power (kW)	**Yearly Electricity Saving (from Matlab Economic Study)**
2.1	250	**47 872,88**
Maintenance Contract of Scenario 04 - ETS in Quebec with 250 kW Batteries		
	Type	**Estimated Amount**
3.1	Annual Maintenance Contract	**500,00**

Table 6-45 Quebec's 250 kW Project Cash-Flow

Project Cash-Flow and Economic Indicators - ETS inQuebec with 250 kW BESS - Scenario 04

Interest rate (%)	5,00%
Project Lifetime (years)	21

Year	Simple Cash-flow	Simple-Payback	Yearly Discounted Cash-flow	Accummulated Discounted Cash-flow
0	-869 062,05	-869 062,05	-869 062,05	-869 062,05
1	47 372,88	-821 689,17	45 117,03	-823 945,02
2	47 372,88	-774 316,29	42 968,60	-780 976,43
3	47 372,88	-726 943,41	40 922,48	-740 053,95
4	47 372,88	-679 570,53	38 973,79	-701 080,16
5	47 372,88	-632 197,65	37 117,89	-663 962,27
6	47 372,88	-584 824,77	35 350,37	-628 611,90
7	47 372,88	-537 451,89	33 667,02	-594 944,88
8	47 372,88	-490 079,01	32 063,83	-562 881,05
9	47 372,88	-442 706,13	30 536,98	-532 344,07
10	47 372,88	-395 333,25	29 082,84	-503 261,23
11	47 372,88	-347 960,37	27 697,94	-475 563,29
12	47 372,88	-300 587,49	26 378,99	-449 184,30
13	47 372,88	-253 214,61	25 122,85	-424 061,45
14	47 372,88	-205 841,73	23 926,52	-400 134,92
15	47 372,88	-158 468,85	22 787,17	-377 347,76
16	47 372,88	-111 095,97	21 702,06	-355 645,69
17	47 372,88	-63 723,09	20 668,63	-334 977,06
18	47 372,88	-16 350,21	19 684,41	-315 292,65
19	47 372,88	31 022,67	18 747,06	-296 545,60
20	47 372,88	78 395,55	17 854,34	-278 691,26
21	47 372,88	125 768,43	17 004,13	-261 687,12

Table 6-46 Quebec's 250 kW Economic Indicators

Economic Indicators of Scenario 04 - ETS in Quebec with 250 kW Batteries		
Net Present Value	$	-261 687,12
Internal rate of return	%	1,26%
Simple Payback	year	18,3
Discounted Payback	year	51,1

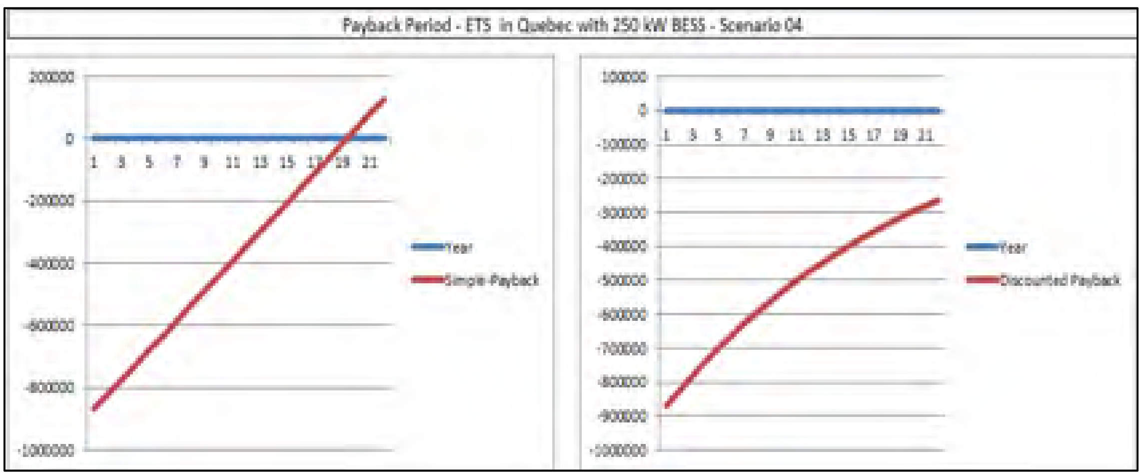


Figure 6-22 Quebec's 250 kW BESS Payback Period

The Economic indicators pointed out that the installation of battery energy storage system is NOT economically feasible neither in Ontario nor in Quebec, due to its high investment, a total of Ca$869,062.05 for a 21-year lifetime, according to ÉTS usage (from 70 to 100 cycles per year). The Valve Regulated Lead Acid is estimated in 2,100 cycles, as informed in Appendix VII, thus, 21 years of expected lifetime, with an expected yearly electricity saving of just $50,547.60 and $47,872.88 in ON and QC, respectively. In addition, the IRR was lower than MARR (around 1% p.a.), while NPV was negative in around two hundred thousand. In addition, the discounted payback period was around twice longer than the project lifetime and the simple payback was less than the project lifetime, but close to it. Thus, this kind of investment shall be rejected, except if there is a financial incentive to acquire the battery cells from a supplier or the government, as the way ÉTS is going to acquire its batteries banks. In this specific case, there are 3 (three) potential savings, for instance:

1) Participation of DR Program from HQ, called GDP, where a potential saving of Ca$16,336 during winter time is achievable;

2) The reduction of the Peak Demand over 5 MW, where a potential saving of Ca$31,537 is also achievable;

3) Recycling the lead materials after its 21 year lifetime period, which will be moneyed on the next topic.

6.2.4.4 Recycling of Lead (Acid) Battery materials

Around 40 tons of Lead materials can be recycled, where it will generate around Ca$24,543.74 saving, after the battery's lifetime of 21 years. According to the website of Métaux Dépot in Montreal, QC, it is paid Ca$0.30 per pound of Lead material in October 2018, as displayed in appendix IX [92].

Table 6-47 Recycling Total Price of 40 tons of Lead Materials
Adapted from BAE Secura OGI – Stationary VLA Cells Technical Datasheet (2015)

Model and Capacity	Number of cells	Mass (kg)	Mass (Lb)	Total Mass (Lb)	Recycling price per pound	Total Recycling amount in Ca$ (Oct 2018)
OGI 640 Ah	256	47	103,59	26518,53	0,3	7955,5584
OGI 1360 Ah	256	98	215,99	55293,95	0,3	16588,1856
Total				**81 812,48**		**24 543,74**

CHAPTER 7

SIMULATION RESULTS

7.1 Scenario 00: ÉTS in ON and QC with electricity standard rates (baseline);

Table 7-1 Scenario 00: ÉTS in ON with electricity standard rates (baseline)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and Std. Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)
January	449 834,56	277 948,97	19 250,41	22 558,07	60 457,54	85,25	0,00	830 134,80	0,2576	3 222 581,83
February	383 781,34	259 041,98	17 088,57	20 025,85	59 993,04	85,25	0,00	740 017,93	0,2587	2 860 850,21
March	185 870,16	238 903,01	19 034,67	22 293,34	57 618,81	85,25	0,00	523 247,44	0,1643	3 184 791,25
April	171 925,17	303 983,95	16 073,77	18 835,13	51 708,24	85,25	0,00	562 611,14	0,2091	2 690 731,41
May	368 986,57	353 903,20	16 887,07	19 202,74	55 925,14	85,25	0,00	814 473,97	0,2969	2 748 248,56
June	570 874,35	348 156,90	16 746,68	19 624,30	59 572,23	85,25	0,00	1 015 061,09	0,3621	2 803 482,64
July	701 314,29	358 145,85	18 107,80	21 213,13	56 324,78	85,25	0,00	1 155 195,10	0,3812	3 031 364,57
August	991 641,63	313 030,95	17 647,50	20 679,75	53 846,00	85,25	0,00	1 396 911,02	0,4728	2 954 249,38
September	497 841,09	268 799,08	17 292,75	20 264,04	64 066,60	85,25	0,00	868 447,81	0,3000	2 894 862,38
October	357 591,45	365 071,41	16 567,73	19 414,44	53 502,57	85,25	0,00	812 232,75	0,2929	2 773 491,12
November	463 383,04	288 058,32	16 928,64	19 835,26	51 237,58	85,25	0,00	839 527,03	0,2963	2 833 608,65
December	672 706,88	305 508,82	18 907,59	22 156,44	56 342,41	85,25	0,00	1 075 905,23	0,3399	3 165 191,52
Yearly Total	5 815 744,46	3 680 128,43	210 022,19	246 108,77	680 938,53	1 023,00	0,00	10 633 966,37	0,3023	35 158 395,50

Table 7-2 Scenario 00: ÉTS in QC with electricity standard rates (baseline)

2017	Billed Power (kW)	Energy Cost (monthly kWh * 0,03420 $/kWh)	Power Cost (kW * 11,95 $/kW)	Fixed Cost	GDP (Gestion de la Demande de Puissance)	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)
January	5 985,89	110 212,30	71 531,44	0,00	0,00	181 743,74	0,0564	3 222 581,83
February	5 939,98	97 841,08	70 982,81	0,00	0,00	168 823,88	0,0590	2 860 850,21
March	5 708,79	108 919,86	68 220,08	0,00	0,00	177 139,94	0,0556	3 184 791,25
April	5 119,63	92 023,08	61 179,55	0,00	0,00	153 202,63	0,0569	2 690 731,41
May	5 537,54	93 819,10	66 173,59	0,00	0,00	159 992,69	0,0583	2 745 248,56
June	5 898,24	95 879,11	70 483,97	0,00	0,00	166 363,08	0,0593	2 803 482,64
July	5 576,71	103 670,62	66 641,69	0,00	0,00	170 312,31	0,0562	3 031 364,57
August	5 331,29	101 035,33	63 708,88	0,00	0,00	164 744,21	0,0558	2 954 246,96
September	6 353,13	99 004,29	75 919,89	0,00	0,00	174 924,18	0,0604	2 894 862,38
October	5 297,28	94 853,40	63 302,55	0,00	0,00	158 155,94	0,0570	2 773 491,12
November	5 075,01	96 909,42	60 622,44	0,00	0,00	157 531,86	0,0556	2 833 608,65
December	5 598,26	108 249,55	66 899,19	0,00	0,00	175 148,74	0,0553	3 165 191,52
Yearly Total	5 618,31	1 202 417,13	805 666,07	0,00	0,00	2 008 083,20	0,0571	35 158 395,50

7.2 Scenario 01: ÉTS in ON with financial incentives and in QC with demand response;

Table 7-3 Scenario 01: ÉTS in ON with financial incentives – GA by PDF

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and Std. Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline and Real Monthly Consumption (kWh)
January	449 834,36	220 595,00	19 230,41	22 568,07	60 457,54	85,25	0,00	772 780,83	0,2398	3 222 581,88
February	383 781,34	202 142,72	17 088,57	20 025,95	39 993,84	85,25	0,00	663 118,67	0,2318	2 860 850,21
March	185 876,16	183 095,99	19 024,67	22 293,54	37 658,81	85,25	0,00	468 034,41	0,1470	3 184 791,25
April	171 925,17	229 630,90	16 073,37	18 835,18	51 706,24	85,25	0,00	488 258,05	0,1815	2 690 733,41
May	368 986,57	272 147,22	16 387,07	19 202,74	55 929,38	85,25	0,00	732 717,98	0,2671	2 743 248,56
June	570 874,35	267 436,92	16 746,88	19 624,38	59 572,23	85,25	0,00	934 340,01	0,3454	2 803 482,64
July	701 314,29	249 970,83	18 107,80	21 219,13	56 324,78	85,25	0,00	1 047 022,08	0,3454	3 031 304,57
August	991 641,63	224 759,58	17 647,50	20 679,75	53 846,00	85,25	0,00	1 318 959,71	0,4464	2 954 249,36
September	497 843,09	187 255,77	17 293,73	20 264,04	64 168,60	85,25	0,00	786 907,50	0,2718	2 894 862,38
October	357 591,45	250 677,80	16 567,73	19 414,44	53 502,57	85,25	0,00	697 839,24	0,2516	2 773 491,12
November	463 389,04	208 647,31	16 926,84	19 835,26	51 337,08	85,25	0,00	760 121,08	0,2683	2 833 608,65
December	672 706,83	233 368,45	18 907,59	22 156,34	56 542,41	85,25	0,00	1 003 766,86	0,3171	3 165 191,52
Yearly Total	5 615 744,46	2 759 728,49	210 022,15	246 108,77	680 939,53	1 023,00	0,00	9 713 566,44	0,2763	35 158 395,50

Table 7-4 Scenario 01: ÉTS in QC with demand response – GDP

2017	Billed Power (kW)	Energy Cost (monthly kWh * 0,03420 $/kWh)	Power Cost (kW * 11,95 $/kW)	Fixed Cost	GDP (Gestion de la Demande de Puissance)	Total	Price per kWh ($/kWh)	Baseline and Real Monthly Consumption (kWh)
January	5 985,89	110 203,72	71 531,44	0,00	0,00	181 735,16	0,0564	3 222 581,88
February	5 939,58	97 841,36	70 982,61	0,00	-16 335,95	152 496,82	0,0533	2 860 850,21
March	5 708,79	108 919,86	68 220,08	0,00	0,00	177 139,94	0,0556	3 184 791,25
April	5 119,63	92 023,08	61 179,55	0,00	0,00	153 202,63	0,0569	2 690 733,41
May	5 537,54	93 819,10	66 173,59	0,00	0,00	159 992,69	0,0583	2 743 248,56
June	5 898,24	95 879,11	70 483,99	0,00	0,00	166 363,10	0,0593	2 803 482,64
July	5 576,71	103 670,62	66 641,69	0,00	0,00	170 312,11	0,0562	3 031 304,57
August	5 331,29	101 035,33	63 708,88	0,00	0,00	164 744,21	0,0558	2 954 249,36
September	6 353,13	99 004,29	75 919,89	0,00	0,00	174 924,18	0,0604	2 894 862,38
October	5 297,29	94 853,40	63 302,60	0,00	0,00	158 155,99	0,0570	2 773 491,12
November	5 075,01	96 909,42	60 622,44	0,00	0,00	157 531,86	0,0556	2 833 608,65
December	5 598,26	108 249,35	66 899,39	0,00	0,00	175 148,74	0,0553	3 165 191,52
Yearly Total	5 618,31	1 202 417,44	805 666,14	0,00	-16 335,95	1 991 747,63	0,0567	35 158 395,50

7.3 Scenario 02: ÉTS in ON with FI and Photovoltaic Arrays (150 kW) as well as in QC with standards rates and PV Arrays;

Table 7-5 Scenario 02: ÉTS in ON with FI and Photovoltaic Arrays (150 kW)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and Std. Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess	Energy Saving (kWh) after adding PV and / or Bess
January	446 887,51	233 042,49	19 525,85	22 412,11	39 919,50	85,25	0,00	764 172,71	0,2371	3 222 561,83	3 201 729,36	20 852,48
February	380 646,60	197 604,49	16 926,33	19 834,69	58 690,62	85,25	0,00	673 788,03	0,2359	2 860 850,21	2 833 525,98	27 324,23
March	283 514,31	278 980,36	18 606,51	22 040,23	57 414,78	85,25	0,00	460 641,46	0,1447	3 184 791,25	3 148 604,90	36 186,35
April	169 569,20	234 475,54	15 085,42	18 575,74	50 500,00	85,25	0,00	479 095,14	0,1780	2 690 713,41	2 654 248,41	36 465,00
May	382 411,78	299 037,33	16 121,48	18 891,52	54 481,40	85,25	0,00	718 933,57	0,2617	2 743 248,56	2 698 788,90	44 459,66
June	580 566,42	280 883,77	16 449,32	19 299,33	58 134,69	85,25	0,00	935 948,09	0,3338	2 803 482,64	2 757 018,30	46 464,34
July	887 558,39	245 900,33	17 828,56	20 887,73	54 887,84	85,25	0,00	1 026 643,48	0,3387	3 031 304,57	2 983 959,03	47 345,54
August	972 275,78	230 580,93	17 366,75	20 350,75	52 808,28	85,25	0,00	1 299 047,69	0,4377	2 954 249,16	2 907 249,94	46 999,42
September	480 487,82	183 906,71	17 060,09	19 990,46	62 728,88	85,25	0,00	774 260,13	0,2675	2 894 862,38	2 855 914,70	38 947,68
October	353 607,67	246 294,48	16 395,13	19 212,19	52 343,88	85,25	0,00	687 928,54	0,2482	2 773 491,12	2 744 598,55	28 892,57
November	460 943,64	204 515,96	16 013,76	15 702,75	50 564,37	85,25	0,00	753 030,40	0,2657	2 833 608,65	2 814 678,53	18 930,12
December	668 303,17	229 194,88	18 758,81	22 017,18	56 839,11	85,25	0,00	995 030,15	0,3144	3 165 191,52	3 145 308,43	19 883,09
Yearly Total	5 737 409,13	2 704 001,44	207 566,47	243 214,18	688 302,11	1 023,00	0,00	9 561 991,71	0,2726	35 158 395,50	34 745 625,02	412 770,48

Table 7-6 Scenario 02: ÉTS in QC with standards rates and PV Arrays

2017	Billed Power (kW)	Energy Cost (monthly kWh * 0.03420 $/kWh)	Power Cost (kW * 11,95 $/kW)	Fixed Cost	GDP (Gestion de la Demande de Puissance)	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess	Energy Saving (kWh) after adding PV and / or Bess
January	5 932,62	109 499,14	70 894,85	0,00	0,00	180 394,00	0,0560	3 222 581,83	3 201 729,36	20 852,48
February	5 810,96	98 906,59	69 440,92	0,00	0,00	168 347,51	0,0581	2 860 850,21	2 833 525,98	27 324,23
March	5 684,63	107 682,29	67 931,35	0,00	0,00	175 613,64	0,0551	3 184 791,25	3 148 604,90	36 186,35
April	5 000,00	90 775,30	59 750,00	0,00	0,00	150 525,30	0,0559	2 690 713,41	2 654 248,41	36 465,00
May	5 393,19	92 298,58	64 472,50	0,00	0,00	156 771,08	0,0571	2 743 248,56	2 698 788,90	44 459,66
June	5 755,09	94 290,03	68 782,88	0,00	0,00	163 072,91	0,0582	2 803 482,64	2 757 018,30	46 464,34
July	5 434,38	102 651,48	64 940,60	0,00	0,00	166 992,90	0,0551	3 031 304,57	2 983 959,03	47 345,54
August	5 185,94	99 427,95	62 007,79	0,00	0,00	161 435,74	0,0566	2 954 249,16	2 907 249,94	46 999,42
September	6 216,78	97 672,28	74 218,80	0,00	0,00	171 891,08	0,0594	2 894 862,38	2 855 914,70	38 947,68
October	5 162,56	93 865,27	61 931,59	0,00	0,00	155 796,86	0,0562	2 773 491,12	2 744 598,55	28 892,57
November	5 006,37	96 283,01	59 826,16	0,00	0,00	156 088,16	0,0551	2 833 608,65	2 814 678,53	18 930,12
December	5 564,27	107 549,55	66 491,00	0,00	0,00	174 062,35	0,0550	3 165 191,52	3 145 308,43	19 883,09
Yearly Total	5 513,88	1 188 300,38	790 690,45	0,00	0,00	1 978 990,83	0,0563	35 158 395,50	34 745 625,02	412 770,48

7.4 Scenario 03: ÉTS in ON with FI, PV Arrays (150 kW) and Batteries (250 kW) as well as in QC with DR , PV Arrays and Batteries;

Table 7-7 Scenario 03: ÉTS in ON with FI, PV Arrays (150 kW) and BESS (250 kW)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and SSS Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess
January	446 570,62	212 694,81	19 134,67	22 416,72	57 394,99	85,25	0,00	758 280,06	0,2353	3 222 581,83	3 201 581,30
February	380 225,59	194 901,19	16 928,57	19 837,28	56 160,65	85,25	0,00	668 145,92	0,2333	2 860 830,21	2 833 896,72
March	183 484,01	176 536,59	18 608,60	22 010,40	54 039,70	85,25	0,00	485 846,89	0,1443	3 184 791,25	3 148 629,24
April	169 565,18	221 426,90	15 655,42	18 579,74	50 900,00	85,25	0,00	475 996,49	0,1765	2 690 733,41	2 634 248,35
May	362 449,38	202 400,34	16 121,55	18 891,60	51 948,40	85,25	0,00	711 914,72	0,2593	2 743 248,56	2 698 806,28
June	561 189,88	277 142,66	16 469,39	15 299,21	55 264,87	85,25	0,00	925 951,27	0,3017	2 808 452,64	2 757 030,08
July	687 601,84	243 939,06	17 625,33	20 888,13	52 578,50	85,25	0,00	1 022 910,91	0,3374	3 031 304,57	2 984 017,99
August	972 226,82	229 095,61	17 166,77	20 330,77	50 500,00	85,25	0,00	1 289 625,23	0,4363	2 954 246,36	2 907 253,43
September	490 591,85	182 737,51	17 080,47	19 991,03	60 203,08	85,25	0,00	770 971,26	0,2662	2 894 862,38	2 855 978,59
October	353 697,28	244 629,78	16 195,21	19 212,28	50 505,00	85,25	0,00	684 519,80	0,2466	2 773 491,12	2 744 611,38
November	460 946,68	203 611,34	16 813,77	19 702,75	50 500,00	85,25	0,00	751 663,79	0,2653	2 833 608,65	2 814 679,07
December	668 755,09	227 738,04	18 789,16	22 017,56	53 708,43	85,25	0,00	991 093,54	0,3131	3 165 191,52	3 145 396,25
Yearly Total	5 737 110,67	2 676 841,03	207 358,96	245 212,38	644 664,00	1 023,00	0,00	9 510 519,91	0,2705	35 158 395,50	34 748 843,67

Table 7-8 Scenario 03: ÉTS in QC with DR, PV Arrays and Batteries

2017	Billed Power (kW)	Energy Cost (monthly kWh * 0,03420 $/kWh)	Power Cost (kW * 11,93 $/kW)	Fixed Cost	GDP (Gestion de la Demande de Puissance)	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess
January	5 882,62	109 492,83	67 907,35	0,00	0,00	177 400,19	0,0550	3 222 581,83	3 201 531,30
February	5 560,56	96 915,83	65 453,42	0,00	-16 335,95	147 037,30	0,0514	2 860 850,21	2 813 896,72
March	5 434,63	107 683,12	64 943,85	0,00	0,00	172 626,97	0,0542	3 184 791,25	3 148 629,24
April	5 000,00	90 775,29	59 750,00	0,00	0,00	150 525,29	0,0559	2 690 733,41	2 634 248,35
May	5 145,19	92 298,97	61 485,00	0,00	0,00	153 783,97	0,0561	2 743 248,56	2 698 806,28
June	5 521,27	94 290,43	65 979,23	0,00	0,00	160 269,66	0,0572	2 808 452,64	2 757 030,08
July	5 205,00	102 053,42	62 199,75	0,00	0,00	164 253,17	0,0542	3 031 304,57	2 984 017,99
August	5 000,00	99 428,07	59 750,00	0,00	0,00	159 178,07	0,0539	2 954 249,36	2 907 253,43
September	5 960,78	97 674,47	71 231,30	0,00	0,00	168 905,77	0,0583	2 894 862,38	2 855 978,59
October	5 000,00	93 865,71	59 750,00	0,00	0,00	153 615,71	0,0554	2 773 491,12	2 744 611,38
November	5 000,00	96 262,02	59 750,00	0,00	0,00	156 012,02	0,0551	2 833 608,65	2 814 679,07
December	5 117,67	107 571,53	62 546,12	0,00	0,00	171 117,64	0,0541	3 165 191,52	3 145 396,25
Yearly Total	5 319,01	1 188 315,68	762 746,02	0,00	-16 335,95	1 934 725,76	0,0550	35 158 395,50	34 746 842,67

7.5 Scenario 04: ÉTS in ON with financial incentives and Batteries (250 kW) as well as in QC with DR and Batteries;

Table 7-9 Scenario 04: ÉTS in ON with FI and Batteries (250 kW)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and Std. Supply Services	TBM	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess
January	449 528,42	217 634,47	19 245,39	22 538,87	57 932,54	85,23	0,00	766 996,94	0,2380	3 222 581,88	3 222 410,42
February	383 541,20	159 429,84	17 851,69	20 028,43	57 460,84	85,25	0,00	678 545,34	0,2370	2 860 850,21	2 861 203,81
March	185 841,49	180 638,72	19 674,72	22 293,68	53 133,81	85,25	0,00	463 017,60	0,1454	3 184 791,25	3 184 800,25
April	171 925,21	226 549,11	16 073,38	18 835,15	50 509,06	85,25	0,00	483 968,16	0,1799	2 690 733,41	2 690 735,98
May	389 022,58	268 494,83	16 387,18	19 202,87	53 404,14	85,23	0,00	726 596,81	0,2649	2 743 248,56	2 743 267,06
June	571 080,30	283 579,33	16 747,08	19 624,63	57 280,26	85,23	0,00	948 316,94	0,3383	2 803 482,64	2 803 515,97
July	701 110,61	249 025,64	18 308,13	21 219,32	54 004,70	85,23	0,00	1 043 753,83	0,3443	3 031 304,57	3 031 359,77
August	991 348,59	233 671,90	17 847,62	20 873,68	51 489,80	85,23	0,00	1 315 123,06	0,4452	2 954 249,36	2 954 268,24
September	497 518,91	186 547,72	17 291,85	20 264,57	61 643,60	85,25	0,00	783 751,25	0,2707	2 894 862,38	2 894 938,30
October	357 876,43	249 729,94	16 567,84	19 414,58	50 977,61	85,25	0,00	694 152,64	0,2504	2 773 491,12	2 773 510,85
November	463 389,00	207 858,37	16 526,81	19 823,22	50 509,00	85,25	0,00	758 594,65	0,2677	2 833 608,65	2 833 602,96
December	672 849,51	232 488,03	18 987,89	22 158,70	54 037,41	85,23	0,00	1 000 502,79	0,3181	3 165 191,52	3 165 243,67
Yearly Total	5 815 742,30	2 735 845,90	210 024,94	246 131,36	654 270,70	1 023,00	0,00	9 693 032,84	0,2749	35 158 395,50	35 158 856,26

Table 7-10 Scenario 04: ÉTS in QC with DR and Batteries

2017	Billed Power (kW)	Energy Cost (monthly kWh * 0,03420 $/kWh)	Power Cost (kW * 11,95 $/kW)	Fixed Cost	GDP (Gestion de la Demande de Puissance)	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess
January	5 735,88	110 206,53	68 543,94	0,00	0,00	178 750,47	0,0555	3 222 581,88	3 222 410,42
February	5 689,58	97 854,69	67 995,31	0,00	-16 335,55	149 513,45	0,0523	2 860 850,21	2 861 203,81
March	5 458,79	108 920,17	65 232,58	0,00	0,00	174 152,75	0,0547	3 184 791,25	3 184 800,25
April	5 000,00	92 023,17	59 750,00	0,00	0,00	151 773,17	0,0564	2 690 733,41	2 690 735,98
May	5 287,54	93 819,73	63 186,09	0,00	0,00	157 005,82	0,0572	2 743 248,56	2 743 267,06
June	5 663,39	95 880,25	67 677,53	0,00	0,00	163 557,78	0,0583	2 803 482,64	2 803 515,97
July	5 347,00	103 672,50	63 896,65	0,00	0,00	167 569,15	0,0553	3 031 304,57	3 031 359,77
August	5 095,00	101 035,97	60 921,10	0,00	0,00	161 957,07	0,0548	2 954 249,36	2 954 268,24
September	6 103,13	99 006,89	72 932,39	0,00	0,00	171 939,28	0,0594	2 894 862,38	2 894 938,30
October	5 047,29	94 854,07	60 315,10	0,00	0,00	155 169,17	0,0559	2 773 491,12	2 773 510,85
November	5 000,00	96 909,22	59 750,00	0,00	0,00	156 659,22	0,0553	2 833 608,65	2 833 602,96
December	5 345,26	108 251,30	63 911,69	0,00	0,00	172 162,99	0,0544	3 165 191,52	3 165 243,67
Yearly Total	5 396,27	1 202 433,90	774 112,36	0,00	-16 335,55	1 960 210,32	0,0558	35 158 395,50	35 158 856,26

7.6 Scenario 05A / 5B: ÉTS in ON with FI, Batteries with Time of Use Pricing (250 kW) and with and / or without PV Arrays (150 kW);

Table 7-11 Scenario 5A: ÉTS in ON with FI and Batteries with ToU Pricing (250 kW)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and Std. Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess
January	446 693,41	217 534,47	19 343,83	22 552,70	57 932,54	85,25	0,00	766 134,20	0,2177	3 222 881,83	3 221 814,36
February	383 301,47	199 429,84	17 095,19	20 032,54	57 468,84	85,25	0,00	677 413,13	0,2368	2 860 880,13	2 861 790,93
March	135 584,23	190 618,72	19 024,91	22 291,82	55 133,81	85,25	0,00	462 760,72	0,1453	3 184 791,25	3 184 831,26
April	171 933,19	228 549,11	16 073,40	18 538,17	50 500,00	85,25	0,00	481 996,11	0,1789	2 690 713,41	2 690 758,37
May	358 946,10	268 896,23	18 187,15	19 202,83	53 464,16	85,25	0,00	738 526,29	0,2648	2 788 248,34	2 788 281,33
June	570 686,58	283 578,33	16 747,04	19 624,56	57 200,26	85,25	0,00	947 922,99	0,3381	2 803 482,64	2 803 508,31
July	700 054,26	249 025,84	18 507,23	21 233,44	54 004,70	85,25	0,00	1 042 455,50	0,3439	3 032 804,57	3 031 206,08
August	990 333,15	239 871,90	17 646,67	20 663,13	51 489,60	85,25	0,00	1 314 389,88	0,4448	2 954 249,36	2 954 444,08
September	498 960,13	186 547,72	17 290,22	20 204,59	61 941,60	85,25	0,00	782 801,15	0,2703	2 896 862,36	2 896 941,42
October	357 930,38	249 729,94	16 567,79	19 434,51	50 977,61	85,25	0,00	694 295,37	0,2503	2 773 491,13	2 773 503,08
November	463 389,84	207 838,37	16 928,78	19 835,17	50 500,00	85,25	0,00	758 584,29	0,2677	2 833 608,83	2 833 595,14
December	671 535,20	232 486,04	18 996,00	22 156,83	54 017,41	85,25	0,00	999 566,72	0,3157	3 166 191,57	3 166 260,95
Yearly Total	5 608 485,67	2 733 945,51	210 025,17	248 112,26	654 270,70	1 023,00	0,00	9 455 362,71	0,2746	35 158 395,30	35 158 809,59

Table 7-12 Scenario 5B: ÉTS in ON w/ FI, BESS ToU Price (250 kW) & PV(150 kW)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and Std. Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Monthly Consumption (kWh) after adding PV and / or Bess
January	445 888,68	212 894,83	19 121,24	22 408,70	57 194,50	85,25	0,00	757 590,59	0,2351	3 222 583,83	3 203 956,90
February	380 278,54	194 961,19	16 932,01	19 881,31	56 165,85	85,25	0,00	668 305,95	0,2336	2 860 890,13	2 834 472,32
March	133 353,34	178 538,59	18 608,73	22 060,47	54 889,78	85,25	0,00	455 716,15	0,1411	3 184 791,25	3 140 608,11
April	159 583,18	221 406,90	15 855,42	13 579,74	50 500,00	85,25	0,00	473 996,49	0,1769	2 690 713,43	2 654 246,35
May	392 412,03	262 400,34	16 121,56	18 831,60	51 966,40	85,25	0,00	711 877,36	0,2595	2 748 248,34	2 698 808,09
June	560 925,85	277 142,66	16 469,37	19 299,19	55 764,87	85,25	0,00	929 687,10	0,3346	2 803 482,64	2 757 026,57
July	686 536,23	243 924,97	17 825,26	20 898,06	52 570,50	85,25	0,00	1 021 850,26	0,3571	3 031 384,57	2 984 698,98
August	971 726,05	229 083,82	17 396,72	20 350,72	50 500,00	85,25	0,00	1 289 120,36	0,4304	2 954 249,36	2 907 345,72
September	489 523,80	180 736,75	17 060,63	19 992,02	60 203,86	85,25	0,00	769 592,29	0,2658	2 894 862,38	2 856 002,31
October	353 660,53	244 614,84	16 395,27	19 212,35	50 500,00	85,25	0,00	684 468,24	0,2468	2 773 491,12	2 744 621,05
November	460 948,23	203 600,91	16 811,73	19 702,71	50 500,00	85,25	0,00	751 650,88	0,2653	2 833 608,83	2 834 672,72
December	667 645,93	207 734,13	18 796,77	22 017,69	53 708,43	85,25	0,00	899 970,68	0,3128	3 168 191,53	3 145 088,83
Yearly Total	5 732 496,47	2 678 759,70	207 359,18	243 222,55	644 664,00	1 023,00	0,00	9 503 726,91	0,2704	35 158 395,36	34 746 079,13

7.7 Scenario 06: ÉTS in ON with FI, 500 kW PV Arrays and Batteries (250 kW) as well as in QC with DR, 500 kW PV Arrays and Batteries;

Table 7-13 Scenario 06: ÉTS in ON with FI, 500 kW PV Arrays and BESS (250 kW)

2017	HOEP	Global Adjustment	Whole Sale Market Service	Debt Retirement	Delivery (Distribution and Transmission)	Monthly Service Charge and MS Supply Services	GDP	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess	Energy Saving (kWh) after adding PV and / or Bess
January	449 655,69	201 162,84	18 854,89	22 035,68	56 127,51	83,25	0,00	748 916,47	0,2293	3 222 581,83	3 152 954,84	69 626,99
February	373 116,41	184 519,79	16 585,88	19 588,32	54 632,56	83,25	0,00	648 209,12	0,2260	2 860 850,21	2 769 830,17	91 020,04
March	177 946,56	167 113,11	18 503,56	21 448,55	54 129,61	83,25	0,00	489 237,06	0,1579	3 184 791,25	3 064 078,65	120 712,60
April	164 064,53	209 610,97	15 346,20	17 903,02	50 580,00	83,25	0,00	457 589,38	0,1701	2 690 731,41	2 569 002,93	121 730,48
May	347 098,45	248 430,58	15 580,80	18 144,86	50 580,00	83,25	0,00	679 767,59	0,3478	2 743 344,56	2 594 908,52	148 340,04
June	317 932,04	282 377,28	15 822,94	18 170,34	52 995,04	83,25	0,00	687 149,88	0,2164	2 803 482,84	2 648 476,61	155 006,03
July	655 760,12	232 680,67	17 164,10	20 118,88	50 580,00	83,25	0,00	976 303,41	0,3221	3 031 304,37	2 873 325,26	157 979,11
August	907 938,43	218 511,39	16 730,78	19 903,07	50 580,00	83,25	0,00	1 232 428,09	0,4172	2 954 249,36	2 797 438,16	156 811,20
September	473 221,10	174 303,53	16 517,00	19 105,00	56 844,60	83,25	0,00	740 526,51	0,2557	2 894 882,38	2 764 999,68	129 882,70
October	364 600,15	231 338,74	15 991,09	18 729,68	50 580,00	83,25	0,00	668 256,88	0,2391	2 773 491,12	2 677 093,73	96 397,39
November	455 346,78	194 215,44	16 549,59	19 550,14	50 580,00	83,25	0,00	735 990,13	0,2597	2 833 608,65	2 770 449,28	63 159,37
December	659 311,08	217 236,03	16 511,51	21 450,21	53 484,01	83,25	0,00	970 310,70	0,3086	3 165 191,52	3 098 887,49	66 304,03
Yearly Total	5 508 099,71	2 563 710,87	201 798,84	236 470,13	631 450,36	1 011,00	0,00	9 149 503,49	0,2608	35 158 395,50	33 781 445,33	1 376 950,17

Table 7-14 Scenario 06: ÉTS in QC with DR, 500 kW PV Arrays and Batteries

2017	Billed Power (kW)	Energy Cost (monthly kWh * 0,03420 $/kWh)	Power Cost (kW * 11,95 $/kW)	Fixed Cost	GDP (Gestion de la Demande de Puissance)	Total	Price per kWh ($/kWh)	Baseline Monthly Consumption (kWh)	Real Monthly Consumption (kWh) after adding PV and / or Bess	Energy Saving (kWh) after adding PV and / or Bess
January	5 616,59	107 824,35	67 118,22	0,00	0,00	174 942,57	0,0543	3 222 581,83	3 152 954,84	69 626,99
February	5 409,16	94 738,96	64 635,44	0,00	-16 335,95	143 040,45	0,0500	2 860 850,21	2 769 830,17	91 020,04
March	5 378,18	104 791,49	64 269,26	0,00	0,00	169 060,75	0,0531	3 184 791,25	3 064 078,65	120 712,60
April	5 000,00	87 859,30	59 750,00	0,00	0,00	147 609,30	0,0549	2 690 731,41	2 569 002,93	121 730,48
May	5 000,00	88 745,87	59 750,00	0,00	0,00	148 495,87	0,0541	2 743 344,56	2 594 908,52	148 340,04
June	5 187,61	90 577,90	61 992,13	0,00	0,00	152 570,05	0,0544	2 803 482,84	2 648 476,61	155 006,03
July	5 000,00	98 267,72	59 750,00	0,00	0,00	158 017,72	0,0521	3 031 304,37	2 873 325,26	157 979,11
August	5 000,00	95 672,39	59 750,00	0,00	0,00	155 422,39	0,0526	2 954 249,36	2 797 438,16	156 811,20
September	5 628,18	94 562,99	67 256,79	0,00	0,00	161 819,78	0,0559	2 894 882,38	2 764 999,68	129 882,70
October	5 000,00	91 556,61	59 750,00	0,00	0,00	151 306,61	0,0546	2 773 491,12	2 677 093,73	96 397,39
November	5 000,00	94 749,37	59 750,00	0,00	0,00	154 499,37	0,0548	2 833 608,65	2 770 449,28	63 159,37
December	5 295,45	105 981,96	63 280,59	0,00	0,00	169 262,54	0,0535	3 165 191,52	3 098 887,49	66 304,03
Yearly Total	5 209,60	1 155 327,45	747 056,45	0,00	-16 335,95	1 886 047,95	0,0536	35 158 395,50	33 781 445,33	1 376 950,17

CHAPTER 8

DISCUSSION OF SIMULATION RESULTS

A 5 (five) minute interval simulation was run over the entire year 2017 in Quebec, with a 5 minute data of ÉTS apparent power, power factor, active power and solar irradiance and temperature data from Montreal, in order to achieve an accurate simulation. The Energy Cost charge (Monthly Consumption of ÉTS in kWh) and Power Cost charge (maximum monthly peak power calculated on a 15 minute average from a 5-minute interval of ÉTS peak demand in kW) will be analyzed separately, along with the monthly and yearly bill and price/kWh. After running the Economic Study Simulation from MATLAB SimScape Power System Model with or without GDP, Photovoltaic Arrays and/or batteries in the 6 (six) proposed scenarios and the baseline, a 10 minute time simulation results were saved, along with Quebec's yearly and monthly electricity bills. New algorithms were developed to calculate the same yearly and monthly electricity bills in Ontario with their specific energy, power and fixed charges. The Power data were downloaded directly from IESO website [96]. The following Energy, Power and Fixed Cost charges were considered in Ontario: energy cost - HOEP in an hourly basis and modified to a 5-minute interval, GA per consumption (mandatory for all customers up to 499.99 kW) or Global Adjustment per percentage contribution/Peak demand factor (available for customers from 500kW on, according to applied condition from IESO). In addition, two other energy cost were added: WMSC and Debt retirement (which was cancelled on April 1, 2018). To finalize, three power costs were considered as well as two fixed costs: Power costs: Delivery – Distribution charge, Transmission Network and Transmission Connection charge and Fixed costs: Standard Supply Services (SSS) and Delivery – Monthly Service charge.

Finally, the goal was to evaluate the total yearly and monthly bill expenses, savings, energy and power costs and price/kWh of ÉTS in Ontario and Quebec. Thus, the monthly and yearly expenses, savings, price per kWh and general comments for each scenario are displayed below.

8.1 Scenario 00: ÉTS in ON and QC with electricity standard rates (baseline);

Table 8-1 Scenario 00: ÉTS in ON and QC with electricity standard rates (baseline)

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate: Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ETS in Ontario with standard rates (Baseline) - Scenario 00	10,633,966.37	9,952,003.85	93.59%	680,939.53	6.40%	0.3025	5.30	Baseline	Baseline
ETS in Quebec with standard rates (Baseline) - Scenario 00	2,008,083.20	1,202,417.13	59.88%	805,666.07	40.12%	0.0571		Baseline	Baseline

Scenario baseline of ÉTS in ON and QC, based on their standard rates only. In ON, it was used Global Adjustment by Consumption.

	ÉTS in Ontario	ÉTS in Quebec
• Yearly Bill (Baseline):	$10,633,966.37	$2,008,083.20
• Price/kWh	0.3025 $/kWh	0.0571 $/kWh
• Energy Cost	93.59%	59.88%
• Power Cost	6.40%	40.12%
• Comparison Rate (ON/QC)	5.3 X higher	1

8.2 Scenario 01: ÉTS in ON with financial incentives and in QC with demand response;

Table 8-2 Scenario 01: ÉTS in ON with FI and in QC with DR

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate: Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ÉTS in Ontario with financial incentive (GA by PDF) - Scenario 01	9,713,566.44	9,031,603.91	92.98%	680,939.53	7.01%	0.2763	4.88	-8.66%	-8.66%
ÉTS in Quebec with demand response (GDP) - Scenario 01	1,991,747.63	1,202,417.44	60.37%	789,330.20	39.63%	0.0567		-0.81%	-0.81%

Scenario with financial incentives or Global Adjustment by Percentage Contribution / Peak Demand Factor in ON and with Demand Response Program, GDP ("Gestion de la Demande de Puissance") in QC.

	ÉTS in Ontario	ÉTS in Quebec
• Yearly Bill (Baseline):	$10,633,966.37	$2,008,083.20
• Yearly Bill (Scenario 01):	$9,713,566.44	$1,991,747.63
• Price/kWh	0.2763 $/kWh	0.0567 $/kWh
• Energy Cost	92.98%	60.37%
• Power Cost	7.01%	39.63%
• Comparison Rate (ON/QC)	4.88 X higher	1

In ON, a reduction of 8.66% or $920,399.93 in the Yearly Bill, in relation to the Baseline.

In QC, a reduction of 0.81% or $16,335.57 in the Yearly Bill, in relation to the Baseline.

8.3 Scenario 02: ÉTS in ON with FI and Photovoltaic Arrays (150 kW) as well as in QC with standards rates and PV Arrays;

Table 8-3 Scenario 02: ÉTS in ON w/ FI, PV(150 kW) and in QC w/ std rates & PV

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate: Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ÉTS in Ontario with GA by PDF and Photovoltaic Arrays (150kW) - Scenario 02	9,561,991.71	8,892,686.41	93.00%	668,282.31	6.99%	0.2720	4.83	-10.08%	-10.08%
ÉTS in Quebec with standard rates and PV arrays (150kW) - Scenario 02	1,978,990.83	1,188,300.38	60.05%	790,690.45	39.95%	0.0563		-1.45%	-1.45%

Scenario with financial incentives (GA by PDF) and Photovoltaic System (150 kW) in ON and with standard rates and Photovoltaic System (150 kW) in QC.

	ÉTS in Ontario	ÉTS in Quebec
• Yearly Bill (Baseline):	$10,633,966.37	$2,008,083.20
• Yearly Bill (Scenario 02):	$9,561,991.71	$1,978,990.83
• Price/kWh	0.2720 $/kWh	0.0563 $/kWh
• Energy Cost	93.00%	60.05%
• Power Cost	6.99%	39.95%
• Comparison Rate (ON/QC)	4.83 X higher	1

In ON, a reduction of 10.08% or $1,071,974.66 in the Yearly Bill, in relation to the Baseline.
In ON, a yearly saving of <u>$151,574.73</u> just by <u>Photovoltaic System</u> installation.

In QC, a reduction of 1.45% or $29,092.37 in the Yearly Bill, in relation to the Baseline.
In QC, a yearly saving of <u>$29,092.37</u> just by <u>Photovoltaic System</u> installation.

8.4 Scenario 03: ÉTS in ON with FI, PV Arrays (150 kW) and Batteries (250 kW) as well as in QC with GDP, PV Arrays and Batteries;

Table 8-4 Scenario 03: ÉTS in ON w/ FI, PV (150 kW) & BESS (250 kW) and in QC

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ETS in Ontario with GA by PDF, Photovoltaics Arrays (150kW) and Batteries (250kW) - Scenario 03	9,510,619.91	8,864,932.91	93.21%	644,664.00	6.78%	0.2705	4.92	-10.56%	-10.56%
ETS in Quebec with GDP, PV Arrays (150kW) and Batteries (250kW) - Scenario 03	1,934,725.76	1,188,315.68	61.42%	746,410.08	38.58%	0.0550		-3.65%	-3.65%

Scenario with financial incentives (GA by PDF), Photovoltaic System (150 kW) and BESS (250kW) in ON and with GDP, Photovoltaic System (150 kW) and BESS (250kW) in QC.

	ÉTS in Ontario	ÉTS in Quebec
• Yearly Bill (Baseline):	$10,633,966.37	$2,008,083.20
• Yearly Bill (Scenario 03):	$9,510,619.91	$1,934,725.76
• Price/kWh	0.2705 $/kWh	0.0550 $/kWh
• Energy Cost	93.21%	61.42%
• Power Cost	6.78%	38.58%
• Comparison Rate (ON/QC)	4.92 X higher	1

In ON, a reduction of 10.56% or $1,123,346.47 in the Yearly Bill, in relation to the Baseline.
In ON, a yearly saving of $51,371.80 just by BESS, when a PV System is installed.

In QC, a reduction of 3.65% or $73,357.44 in the Yearly Bill, in relation to the Baseline.
In QC, a yearly saving of $44,265.07 just by BESS, when a PV System is installed.

8.5 Scenario 04: ÉTS in ON with financial incentives and Batteries (250 kW) as well as in QC with DR and Batteries;

Table 8-5 Scenario 04: ÉTS in ON w/ FI and BESS (250 kW) as well as in QC

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate: Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ETS in Ontario with GA by PDF and Batteries (250kW) - Scenario 04	9,663,018.84	9,007,725.14	93.22%	654,270.70	6.77%	0.2748	4.93	-9.13%	-9.13%
ETS in Quebec with GDP and Batteries (250kW) - Scenario 04	1,960,210.32	1,202,433.90	61.34%	757,776.42	38.66%	0.0558		-2.38%	-2.38%

Scenario with financial incentives (GA by PDF) and BESS (250kW) in ON and with GDP, and BESS (250kW) in QC.

	ÉTS in Ontario	ÉTS in Quebec
• Yearly Bill (Baseline):	$10,633,966.37	$2,008,083.20
• Yearly Bill (Scenario 04):	$9,663,018.84	$1,960,210.32
• Price/kWh	0.2748 $/kWh	0.0558 $/kWh
• Energy Cost	93.22%	61.34%
• Power Cost	6.77%	38.66%
• Comparison Rate (ON/QC)	4.93 X higher	1

In ON, a reduction of 9.13% or $970,947.53 in the Yearly Bill, in relation to the Baseline.
In ON, a yearly saving of $50,547.60 just by BESS, individually (without PV System).

In QC, a reduction of 2.38% or $47,872.88 in the Yearly Bill, in relation to the Baseline.
In QC, a yearly saving of $47,872.88 just by BESS, individually (without PV System).

8.6 Scenario 05A/05B: ÉTS in ON with FI, Batteries with Time of Use Pricing (250 kW) and with and / or without PV Arrays (150 kW);

Table 8-6 Scenario 05: ÉTS in ON w/ FI, BESS w/ ToU Price (250 kW) w/wo PV

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate: Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ETS in Ontario GA by PDF and Batteries with TOU pricing (250kW) - Scenario 05_A	9 655 762,71	9 000 469,01	93,21%	654 270,70	6,78%	0,2746	NOT APPLICABLE	-9,20%	-9,20%
ETS in Ontario GA by PDF, Batteries with TOU pricing (250kW) and with Photovoltaics Arrays (150kW) - Scenario 05_B	9 505 726,91	8 860 039,91	93,21%	644 664,00	6,78%	0,2704		-10,61%	-10,61%

Scenario with financial incentives and BESS (250kW) with Time of Use price (5A) and with financial incentives, BESS (250kW) with Time of Use price and Photovoltaic System (150 kW) (5B), both in ON. There is a variable price/kWh according to the hour of the day, to encourage consumer to delay energy consumption to off-peak period. Scenario not run in QC.

	ÉTS in Ontario (5A)	ÉTS in Ontario (5B)
• Yearly Bill (Baseline):	$10,633,966.37	$10,633,966.37
• Yearly Bill (Scenario 05):	$9,655,762.71	$9,505,726.91
• Price/kWh	0.2746 $/kWh	0.2704 $/kWh
• Energy Cost	93.21%	93.21%
• Power Cost	6.78%	6.78%

Scenario 5A: a reduction of 9.20% or $978,203.66 in the Yearly Bill, in relation to the Baseline.
Scenario 5A: a yearly saving of $7,256.14 just by BESS with ToU Pricing, charging at night.

Scenario 5B: a reduction of 10.61% or $1,128,507.19 in the Yearly Bill, in relation to Baseline.
Scenario 5B: a yearly saving of $150,035.80 just by PV System with ToU Pricing BESS.

8.7 Scenario 06: ÉTS in ON with FI, 500 kW PV Arrays and Batteries (250 kW) as well as in QC with DR, 500 kW PV Arrays and Batteries;

Table 8-7 Scenario 06: ÉTS in ON w/ FI, 500 kW PV and BESS (250 kW) and in QC

	Yearly Bill ($)	Energy Cost ($)	Energy Cost Weight (%)	Power Cost ($)	Power Cost Weight (%)	Yearly Price/kWh ($/kWh)	Comparison Rate: Ontario/Quebec	Price/kWh percentage (%) reduction from baseline	Yearly Bill percentage (%) reduction from baseline
ÉTS in Ontario GA by PDF, 500 kW Photovoltaics Arrays and Batteries (250kW) - Scenario 06	9,169,503.69	8,537,077.34	93.10%	631,403.56	6.89%	0.2608	4.86	-13.77%	-13.77%
ÉTS in Quebec with GDP, PV Arrays (500 kW) and Batteries (250kW) - Scenario 06	1,886,047.99	1,155,327.49	61.26%	730,720.50	38.74%	0.0536		-6.08%	-6.08%

Scenario with financial incentives (GA by PDF), Photovoltaic System (500 kW) and BESS (250kW) in ON and with GDP, Photovoltaic System (500 kW) and BESS (250kW) in QC.

	ÉTS in Ontario	ÉTS in Quebec
• Yearly Bill (Baseline):	$10,633,966.37	$2,008,083.20
• Yearly Bill (Scenario 06):	$9,169,503.69	$1,886,047.99
• Price/kWh	0.2608 $/kWh	0.0536 $/kWh
• Energy Cost	93.10%	61.26%
• Power Cost	6.89%	38.74%
• Comparison Rate (ON/QC)	4.86 X higher	1

In ON, a reduction of 13.77% or $1,464,462.68 in the Yearly Bill, in relation to the Baseline.
In ON, a yearly saving of $493,515.15 just by Photovoltaic System installation.

In QC, a reduction of 6.08% or $122,035.21 in the Yearly Bill, in relation to the Baseline.
In QC, a yearly saving of $74,162.33 just by Photovoltaic System installation.

8.8 Comparison of Total yearly bill and price per kWh between ON and QC – 1

Table 8-8 Comparison of Total yearly bill and price per kWh between ON and QC - 1

	Yearly Total Monthly Bill ($)	Yearly Bill percentage reduction from	Yearly Average Price/kWh ($/kWh)	Price/kWh percentage reduction from baseline
ETS in Ontario with Standard Rates (GA by Consumption) - Scenario 00	10,633,966.37	baseline	0.3025	baseline
ETS in Ontario with financial incentives (GA by PDF) - Scenario 01	9,713,566.44	-8.66%	0.2763	-8.66%
ETS in Ontario with financial incentives (GA by PDF) and PV Arrays - Scenario 02	9,561,991.71	-10.08%	0.2720	-10.08%
ETS in Ontario with financial incentives (GA by PDF), PV and BESS - Scenario 03	9,510,619.91	-10.56%	0.2705	-10.56%
ETS in Ontario with financial incentives (GA by PDF) and BESS - Scenario 04	9,663,018.84	-9.13%	0.2748	-9.13%
ETS in Ontario GA by PDF and Batteries with TOU pricing (250kW) - Scenario 05_A	9,655,762.71	-9.20%	0.2746	-9.20%
ETS in Ontario GA by PDF, Batteries with TOU pricing (250kW) and with Photovoltaics Arrays (150kW) - 05_B	9,505,726.91	-10.61%	0.2704	-10.61%
ETS in Ontario with financial incentives (GA by PDF), 500 kW PV, BESS and TOU - Scenario 06	9,169,503.69	-13.77%	0.2608	-13.77%

	Yearly Total Monthly Bill ($)	Yearly Bill percentage reduction from	Yearly Average Price/kWh ($/kWh)	Price/kWh percentage reduction from baseline
ETS in Quebec with Standard Rates - Scenario 00	2,008,083.20	baseline	0.0571	baseline
ETS in Quebec with Standard Rates and demande reponse (GDP) - Scenario 01	1,991,747.63	-0.81%	0.0567	-0.81%
ETS in Quebec with standard rates and PV - Scenario 02	1,978,990.83	-1.45%	0.0563	-1.45%
ETS in Quebec with GDP, PV and BESS - Scenario 03	1,934,725.76	-3.65%	0.0550	-3.65%
ETS in Quebec with GDP and Bess - Scenario 04	1,960,210.32	-2.38%	0.0558	-2.38%
ETS in Quebec with Batteries with TOU pricing - Scenario 05	NOT APPLICABLE			
ETS in Quebec with GDP, 500 kW PV and BESS - Scenario 06	1,886,047.99	-6.08%	0.0536	-6.08%

	Yearly Total Monthly Bill	Yearly Average Price/kWh
Comparison of Ontario to Quebec yearly electricity rate - Scenario 00	5.30	5.30
Comparison of Ontario to Quebec yearly electricity rate - Scenario 01	4.88	4.88
Comparison of Ontario to Quebec yearly electricity rate - Scenario 02	4.83	4.83
Comparison of Ontario to Quebec yearly electricity rate - Scenario 03	4.92	4.92
Comparison of Ontario to Quebec yearly electricity rate - Scenario 04	4.93	4.93
Comparison of Ontario to Quebec yearly electricity rate - Scenario 05	NOT APPLICABLE	
Comparison of Ontario to Quebec yearly electricity rate - Scenario 06	4.86	4.86

8.9 Comparison of Total yearly bill and price per kWh between ON and QC – 2

Table 8-9 Comparison of Total yearly bill and price per kWh between ON and QC – 2

	Price/kWh ($/kWh)	Percentage Reduction	Yearly Amount ($)	Percentage Reduction	Yearly Savings just by PV Arrays	Yearly Savings just by Bess (when PV are installed)	Yearly Savings just by PV Bess individually	Yearly Savings just by Demand Response (QC) or financial incentive (ON)
ETS in Quebec with standard rates (Baseline) - Scenario 00	0,0571		2 008 083,20					
ETS in Quebec with demand response (GDP) - Scenario 01	0,0567	-0,81%	1 991 747,63	-0,81%				16 335,57
ETS in Quebec with standard rates and PV arrays (150kW) - Scenario 02	0,0563	-1,45%	1 978 990,83	-1,45%	29 092,37			
ETS in Quebec with GDP, PV Arrays (150kW) and Batteries (250kW) - Scenario 03	0,0550	-3,65%	1 934 725,76	-3,65%		44 265,07		
ETS in Quebec with GDP and Batteries (250kW) - Scenario 04	0,0556	-2,38%	1 960 210,32	-2,38%			47 872,88	
ETS in Quebec with GDP, PV Arrays (500 kW) and Batteries (250kW) - Scenario 06	0,0536	-6,08%	1 886 047,99	-6,08%	74 162,33			

	Price/kWh ($/kWh)	Percentage Reduction	Yearly Amount ($)	Percentage Reduction	Yearly Savings just by PV Arrays	Savings just by Bess (when PV are installed)	Yearly Savings just by PV Bess individually	Yearly Savings just by Demand Response (QC) or financial incentive (ON)
ETS in Ontario with standard rates (Baseline) - Scenario 00	0,3025		10 633 966,37					
ETS in Ontario with financial incentive (GA by PDF) - Scenario 01	0,2763	-8,66%	9 713 566,44	-8,66%				920 399,93
ETS in Ontario with GA by PDF and Photovoltaic Arrays (150kW) - Scenario 02	0,2720	-10,08%	9 561 991,71	-10,08%	151 574,73			
ETS in Ontario with GA by PDF, Photovoltaics Arrays (150kW) and Batteries (250kW) - Scenario 03	0,2705	-10,56%	9 510 619,91	-10,56%		51 371,80		
ETS in Ontario with GA by PDF and Batteries (250kW) - Scenario 04	0,2748	-9,13%	9 663 018,84	-9,13%			50 547,60	
ETS in Ontario GA by PDF and Batteries with TOU pricing (250kW) - Scenario 05_A	0,2746	-9,20%	9 655 762,71	-9,20%				
ETS in Ontario GA by PDF, Batteries with TOU pricing (250kW) and with Photovoltaics Arrays (150kW) - Scenario 05_B	0,2704	-10,61%	9 505 726,91	-10,61%				
ETS in Ontario GA by PDF, 500 kW Photovoltaics Arrays and Batteries (250kW) - Scenario 06	0,2608	-13,77%	9 169 503,69	-13,77%	493 515,15			

CONCLUSION

Firstly, the simulation results showed there is an enormous electrical power pricing difference between Ontario and Quebec, in spite of the fact they are neighboring provinces in Canada. In fact, there are three main reasons for this huge difference:

1) Power generation characteristics and infrastructure are completely different: 99.8% of electrical power generation in Quebec comes from Renewable sources, mainly from Hydropower (94.5%), while 58.5%, 23.3% and 9.5% come from Nuclear power plants, Hydropower and Renewable energy sources, respectively, in Ontario;

2) Electrical Power administration extremely different between QC, with HQ and in ON with OEB, IESO, public/private power generators, transmitters and utilities operating together. IESO manages the power system in real-time, plans the province's future energy needs, makes the balance of energy supply and demand and manages the Wholesale Market, while OEB sets rules, licenses companies, monitors the electrical system and sets energy rates.

3) Ontario had a huge financial deficit in electrical power in the past due to:
   Over budgeted projects in nuclear power plant construction during 1980s and 90s;
   High investment in Infra-structure to feed private gas power plants (from 2000 on);
   High Investment to close Coal Power Plants and to implement Biomass Plants;
   Lucrative long term contracts with companies for wind & solar power plants;
   Surplus Capacity – 30% & 85% higher than peak and baseload demand, respectively.

Consequently, the largest part of electricity bill comes from the Global Adjustment (to cover the cost of building new infrastructure and providing conservation programs) and HOEP (to cover the cost of producing electricity).

After running a 5 (five) minute interval simulation on the MATLAB SimScape Power System, the following results were obtained: Firstly, a PV System reduced the 5 MW peak power and energy consumption in both provinces, while battery energy storage system reduced the peak power and allowed the participation in the demand response program, GDP, in Quebec. Secondly, Energy and Power cost represented around 93% and 7% of the yearly bill in ON, and 61% and 39% in QC, respectively. Thirdly, the results showed that the electricity rate variance between both provinces is huge. It is around four times more expensive in ON than in QC. Fourthly, it showed that the price per kWh was reduced up to 13.77% in ON and up to 6.08% in QC, after adding FI in ON or DR Program in QC, BESS and / or PV System.

In Ontario, where the price of electricity is very high, a very considerable yearly bill reduction from the baseline may be achieved, if ÉTS utilizes the Global Adjustment by PDF. Also, the installation of 150kW MPP Photovoltaic Arrays showed a reduction in the yearly bill of 10.08% from the baseline and it is economically feasible with a low payback period, high IRR and NPV. The 250 kW power of BESS is not economically feasible even with ToU pricing. Due to a potential saving from a 150 kW PV System in ON, a random higher MPP was simulated. Thus, a 500 kW PV achieved a great yearly saving and is economically feasible.

In Quebec, where the electricity price is already low, a reasonable yearly bill reduction may be achieved by utilizing a 250kW maximum discharge batteries energy storage system. A yearly savings of -2.38% from baseline by reducing the peak power over 5MW and participating of GDP from HQ. However, neither the PV System nor the BESS are economically feasible.

In addition, the simulation showed a yearly energy saving of 412.77 MWh on MATLAB and 260.53 MWh on RETScreen for energy exported to grid with a 150 kW PV System, as well as, 1,376.95 & 868.42 MWh with a 500 kW PV. The 50% lower value on RETScreen shows a more accurate method for energy saving, with different temperature, irradiance & loss factor.

Finally, the technical-economic study indicated that a 150 or 500 kW PV System is greatly recommended in ON and not recommended in QC. Also, a BESS is neither recommended in ON nor in QC, because its price is still high for a low yearly saving. However, it is great in QC, if a FI or donation is provided to acquire it, for peak shaving and GDP Program.

RECOMMENDATIONS

In Ontario, firstly, a large-power consumer connected to the Transmission network, should participate in the wholesale market held by IESO, in order to achieve a lower price per kWh in comparison to HOEP. The electricity wholesale market occurs through bids between dispatchable generators and large load consumers, with IESO between them to manage the province's power demand & supply and, consequently, the applicable price in each 5 minutes.

Secondly, paying the Global Adjustment by Peak Demand Factor or percentage contribution (instead of GA by consumption) is greatly recommended, where a drop of around 9 (nine) % in the total yearly and monthly bill may be achieved.

Thirdly, participating in the Yearly Demand Response Auction on IESO website, where some considerable savings may be reached in electrical energy. If a large consumer wins the bid in its specific region and saves the electrical power promised and agreed in the contract with IESO, will save a reasonable amount of money. Otherwise, some penalties may be applicable.

Finally, the ÉTS in Ontario should utilize a system of 500 kW or even higher MPP of PV System, without any batteries, in order to save at least 868.42 MWh of energy annually and achieve a considerable reduction in the price per kWh and in the yearly bill, with a low payback period, high IRR and NPV. According to simulation, a yearly saving of $ 493,515.15 is reached with a 500 kW PV System for a $2,773,434.53 investment and 9.4 years of payback.

In Quebec, the ÉTS should utilize a 250 kW BESS without any Photovoltaic Arrays to reduce the peak power over 5 MW and participate in the GDP demand response program from Hydro Québec, but only if there is a financial incentive or donation to acquire the equipment from a supplier or the government, as it is going to occur to ÉTS. Otherwise, this is not economically feasible. Also, the investment required for a BESS is very high, $869,062.05 for a yearly saving of only $47,872.88. Thus, if no financial incentive or donation is provided, neither a Photovoltaic system nor batteries banks are recommended in Quebec.

APPENDIX I

2017 HQ ELECTRICITY RATES FOR RESIDENCE AND BUSINESS

Electricity rates

Average increase of 0.7% on April 1, 2017, except for Rate L, for which the increase is 0.2%

Article April 1, 2016	Article April 1, 2017	Rate	Description	Prices at April 1, 2016	Prices at April 1, 2017
2.7	2.7	D	Fixed charge per day	40.64¢	40.64¢
			First kWh per day : 30 kWh in 2016 and 33 kWh in 2017	5.71¢	5.82¢
			Remaining consumption	8.68¢	8.92¢
			Demand charge, summer period (> 50 kW)	$3.79	n/a
			Demand charge, winter period (> 50 kW)	$6.21	n/a
n/a	2.18	DP	Fixed charge per month	n/a	$6.09
			First 3 200 kWh per month	n/a	5.77¢
			Remaining consumption	n/a	8.77¢
			Demand charge, summer period (> 50 kW)	n/a	$4.59
			Demand charge, winter period (> 50 kW)	n/a	$6.21
			Minimum monthly bill, single-phase	n/a	$12.18
			Minimum monthly bill, three-phase	n/a	$18.27
2.19	2.27	DM	Fixed charge per day, times the multiplier	40.64¢	40.64¢
			First kWh per day, times the multiplier : 30 kWh in 2016 and 33 kWh in 2017	5.71¢	5.82¢
			Remaining consumption	8.68¢	8.92¢
			Demand charge, summer period (> 50 kW or 4 kW x multiplier)	$3.79	$4.59
			Demand charge, winter period (> 50 kW or 4 kW x multiplier)	$6.21	$6.22
2.29	2.30	DT	Fixed charge per day, times the multiplier	40.64¢	40.64¢
			Energy, temperature ≥ -12°C or -15°C	4.40¢	4.46¢
			Energy, temperature < -12°C or -15°C	26.71¢	26.21¢
			Demand charge, summer period (> 50 kW or 4 kW x multiplier)	$3.79	$4.59
			Demand charge, winter period (> 50 kW or 4 kW x multiplier)	$6.21	$6.22
2.32	2.40	Additional Electricity Option - *Photosynthesis*	Floor price (¢/kWh) - Average price at Rate M (2nd block) for 25 kV and 100% load factor	3.56¢	3.58¢
3.2	3.2	G	Fixed charge per month	$12.33	$12.33
			Demand charge (> 50 kW)	$17.31	$17.43
			First 15,090 kWh per month	9.71¢	9.78¢
			Remaining consumption	8.60¢	8.69¢
			Minimum monthly bill, three-phase	$36.99	$36.99
3.5	3.5	*G Short-term contract*	Increase in monthly fixed charge and minimum monthly bill	$12.33	$12.33
			Increase in monthly demand charge (winter period)	$5.94	$5.97
3.7	3.7	Winter activities	Reference index as at March 31, 2006	1.00	1.00
			Adjustment on April 1 of each year, starting on April 1, 2006	2%	2%
			Index adjustment as at April 1, 2017 = 1.3604		
4.2	4.2	M	Demand charge	$14.37	$14.43
			First 210,000 kWh per month	4.95¢	4.97¢
			Remaining consumption	3.66¢	3.69¢
			Minimum monthly bill, single-phase	$12.33	$12.33
			Minimum monthly bill, three-phase	$36.99	$36.99
4.7	4.7	*M Short-term contract*	Increase in monthly demand charge (winter period)	$5.94	$5.97
4.10	4.10	G-9	Demand charge	$4.20	$4.20
			Energy price	9.90¢	9.97¢
			Minimum monthly bill, single-phase	$12.33	$12.33
			Minimum monthly bill, three-phase	$36.99	$36.99
			Increase for low power factor	$10.17	$10.23
4.13	4.13	G-9 Short-term contract	Increase in monthly fixed charge	$12.33	$12.33
			Increase in monthly demand charge (winter period)	$5.94	$5.97
4.17	4.17	GD	Demand charge	$5.22	$5.25
			Energy, summer period	6.34¢	6.35¢
			Energy, winter period	15.22¢	15.30¢
			Minimum monthly bill, single-phase	$12.33	$12.33
			Minimum monthly bill, three-phase	$36.99	$36.99
4.22	4.22	*Transitional Rate - Photosynthesis*	Monthly fixed charge	$34.77	$34.77
			Monthly charge per kilowatt of contract power	3.48¢	6.48¢
			Energy price	3.51¢	3.51¢
4.27	4.27	*Transitional Rate - Photosynthesis*	Price for each kilowatt exceeding 10% of contract power	$15.50	$15.50
4.28	4.28	*Transitional Rate - Photosynthesis*	Reference index on April 1, 2005	1.0	1.0
			Adjustment on April 1 of 2005, 2006 and 2007 (also subject to the average rate increase)	5%	5%
			Adjustment on April 1 of each year, starting April 1, 2008 (also subject to the average rate increase)	6%	8%
			Index adjustment as at April 1, 2017 = 5.0969		
4.34 & 4.35	4.33 & 4.34	*Running-in for New Equipment*	Adjustment of the average price	4%	4%
4.38	4.38	*Equipment Testing - Medium Power*	Multiplier (per kWh)	33.00¢	30.00¢
4.43	4.43	Interruptible Electricity Option - Medium Power	Option I :		
			Fixed nominal credit, winter period (per kW)	$13.00	$13.00

Electricity rates

Average increase of 0.7% on April 1, 2017, except for Rate L, for which the increase is 0.2%

Article April 1, 2016	Article April 1, 2017	Rate	Description	Prices at April 1, 2016	Prices at April 1, 2017
4.47	4.47	*Interruptible Electricity Option - Medium Power*	Option I : Penalty (per kW) Option II : Penalty (per kW)	 $1.25 $0.50	 $1.25 $0.50
4.50	4.50	*Additional Electricity Option - Medium Power*	Floor price (¢/kWh) - Average price at Rate M (2nd block) for 25-kV and 100% load factor	5.50¢	5.53¢
n/a	4.55	Rate BR	Consumption associated with the first 50 kW of maximum power demand (per kWh) Consumption associated with maximum power demand in excess of 50 kW (per kWh) Remaining consumption (per kWh) Minimum monthly bill, single-phase Minimum monthly bill, three-phase	n/a n/a n/a n/a n/a	10.90¢ 20.47¢ 16.15¢ $12.33 $36.99
5.2	5.2	L	Demand charge Energy price	$12.87 3.26¢	$12.87 3.27¢
5.6	5.6	*L*	Daily optimization charge Monthly optimization charge	$7.33 $22.34	$7.35 $22.38
5.14	5.14	LG	Demand charge Energy price	$13.05 3.39¢	$13.11 3.42¢
5.25	5.25	*LG*	Daily optimization charge Monthly optimization charge	$7.62 $22.86	$7.65 $22.95
5.33	5.33	*H*	Demand charge Energy consumed outside winter weekdays Energy consumed on winter weekdays	$5.22 5.26¢ 18.08¢	$5.25 5.29¢ 18.08¢
5.38 a)	5.38 a)	*LD (Firm option)*	Demand charge Energy consumed outside winter weekdays Energy consumed on winter weekdays	$5.22 5.26¢ 18.08¢	$5.25 5.29¢ 18.08¢
5.38 b)	5.38 b)	*LD (Non-firm option)*	Demand charge per day for planned interruptions Demand charge per day for unplanned interruptions Energy price Monthly maximum - Demand charge	$0.52 $1.06 5.26¢ $5.22	$0.53 $1.06 5.29¢ $5.25
5.41	5.41	*LD (Non-firm option)*	Price for consumption during unauthorized period (per kWh)	50¢	50¢
5.47	5.47	*Running-in for New Equipment (12 or more consumption periods)*	Maximum increase of the average price Minimum increase of the average price	4% 1%	4% 1%
5.48	5.48	*Running-in for New Equipment (fewer than 12 consumption periods)*	Increase of the average price	4%	4%
5.51	5.51	*Running-in for New Equipment*	Price for consumption during unauthorized period (per kWh)	50¢	50¢
5.55 b)	5.55 b)	*Equipment Testing - Large Power*	Multiplier (per kWh)	10.00¢	10.00¢
5.57	5.57	LP	Annual fixed charge	$1,000	$1,000
5.64	5.64	LP	Price for unauthorized consumption of energy (per kWh)	50¢	50¢
6.20	6.20	*Interruptible Electricity Option - Large Power*	Option I : Fixed nominal credit, winter period (per kW) Variable nominal credit for each of the first 20 interruption hours (per kWh) Variable nominal credit for each of the next 20 interruption hours (per kWh) Variable nominal credit for each of the 60 subsequent interruption hours (per kWh) Option II : Fixed nominal credit, winter period (per kW) Variable nominal credit for each interruption hour (per kWh)	 $13.00 20.00¢ 25.00¢ 45.00¢ $6.50 20.00¢	 $13.00 20.00¢ 25.00¢ 45.00¢ $6.50 20.00¢
6.24	6.24	*Interruptible Electricity Option - Large Power*	Option I : Penalty (per kW) Amount for the determination of the maximum penalty (per kW) Option II : Penalty (per kW) Amount for the determination of the maximum penalty (per kW)	 $1.25 $5.00 $0.60 $2.50	 $1.25 $5.00 $0.60 $2.50
6.32	6.32	*Additional Electricity Option - Large Power*	Floor price (¢/kWh) - Average price at Rate L for 120-kV and 100% load factor	4.45¢	4.46¢
6.36	6.36	*Additional Electricity Option - Large Power*	Consumption beyond reference power during unauthorized period (per kWh)	50¢	50¢
6.45	6.45	*Economic Development Rate*	Initial rate reduction	20%	20%
7.1	n/a	*D Off-Grid Systems*	Energy in excess of 30 kWh per day	37.62¢	n/a
7.2	n/a	*DM Off-Grid Systems*	Energy in excess of 30 kWh per day times the multiplier	37.62¢	n/a
n/a	7.2	*DN*	Fixed charge per day, times the multiplier First 30 kWh per day, times the multiplier Remaining consumption Demand charge, summer period (> 50 kW or 4 kW x multiplier) Demand charge, winter period (> 50 kW or 4 kW x multiplier)	n/a n/a n/a n/a n/a	40.64¢ 5.92¢ 40.99¢ $4.59 $6.21
7.4	7.8	*G, G-9, M, MA Off-Grid Systems*	Penalty on energy	76.90¢	77.45¢
7.6	7.10	*Rate MA - Structure*	Heavy diesel power plant (per kW exceeding 900 kW) Heavy diesel power plant (per kWh exceeding 390,000 kWh) All other cases (per kW exceeding 900 kW)	$90.75 13.22¢ $40.51	$91.02 13.44¢ $40.86

Electricity rates
Average increase of 0.7% on April 1, 2017, except for Rate L, for which the increase is 0.2%

Article April 1, 2016	Article April 1, 2017	Rate	Description	Prices at April 1, 2016	Prices at April 1, 2017
7.7	7.11	*Rate MA - Energy price revision*	A - Heavy diesel power plant: operating and maintenance cost (per kWh)	2.73¢	2.75¢
			B - Heavy diesel power plant: energy cost set for 2006 (per kWh)	11.87¢	11.87¢
			C - Average price of No. 6 diesel (2% S) for the Montréal area (Price at October 2016: 53.75 $/barrel)	n/a	n/a
			D - Average reference price of No. 6 diesel (2% S) (per barrel)	$58.20	$58.20
			E - All other cases: operating and maintenance costs (per kWh)	2.73¢	2.75¢
			F - All other cases: energy cost for 2006 (per kWh)	26.44¢	26.44¢
			G - Average price of No. 1 diesel for the Montréal area (Price at October 2016: 68.84 ¢/litre)	n/a	n/a
			H - Average reference price of No. 1 diesel (per litre)	61.51¢	61.51¢
7.15	7.19	*Interruptible Electricity Option With Advance Notice - Off-Grid Systems*	Fixed credit (per kW)	$6.00	$6.00
7.16	7.20	*Interruptible Electricity Option With Advance Notice - Off-Grid Systems*	Variable credit components:		
			A - Operating and maintenance costs (per kWh)	2.70¢	2.72¢
			B - Energy cost for the reference year 2012 (per kWh):		
			- north of the 53rd parallel	54.50¢	54.50¢
			- south of the 53rd parallel	35.50¢	35.50¢
			C - Average price of No. 1 diesel for the Montréal area (Price at October 2016: 68.84 ¢/litre)	n/a	n/a
			D - Average reference price of No. 1 diesel (per litre)	57.66¢	57.66¢
7.25	7.29	*Interruptible Electricity Option Without Advance Notice - Off-Grid Systems*	Credit (per kW)	$1.20	$1.20
			Maximum credit (per kW)	$33.33	$33.33
8.2	8.2	*a) T1 (daily)*	Demand charge per day	$4.88	$4.91
			Maximum per week	$14.65	$14.77
		b) T2 (weekly)	Demand charge per week	$14.65	$14.77
			Maximum per month	$43.89	$44.22
		c) T3 (30 days or more)	Demand charge per month	$43.89	$44.22
8.3	n/a	*T (Minimum monthly bill)*	Minimum per month, single-phase	$8.79	n/a
			Minimum per month, three-phase	$25.37	n/a
9.4	9.4	*Public Lighting (general service)*	Energy price	10.16¢	10.24¢
9.10 a)	9.10 a)	*Public Lighting (complete service)*	Sodium-vapor: 5,000 lumens (or 70 W) - per luminaire	$22.08	$22.23
			Sodium-vapor: 8,500 lumens (or 100 W) - per luminaire	$24.08	$24.24
			Sodium-vapor: 14,400 lumens (or 150 W) - per luminaire	$25.95	$26.13
			Sodium-vapor: 22,000 lumens (or 250 W) - per luminaire	$30.45	$30.69
9.10 b)	9.10 b)	*Public Lighting (complete service)*	Light-emitting diode: 6,100 lumens (or 45 W) - per luminaire	$22.74	$22.92
9.14	9.14	*Sentinel (with poles)*	7,000 lumens (or 175 W) - per luminaire	$40.93	$41.10
			20,000 lumens (or 400 W) - per luminaire	$53.79	$54.18
9.15	9.15	*Sentinel Lighting (without poles)*	7,000 lumens (or 175 W) - per luminaire	$32.17	$32.31
			20,000 lumens (or 400 W) - per luminaire	$46.23	$46.56
10.2	10.2	*Credit for supply at medium or high voltage*	Voltage equal to or greater than 5 kV, but less than 15 kV	$0.612	$0.612
			Voltage equal to or greater than 15 kV, but less than 50 kV	$0.981	$0.981
			Voltage equal to or greater than 50 kV, but less than 80 kV	$2.190	$2.190
			Voltage equal to or greater than 80 kV, but less than 170 kV	$2.679	$2.679
			Voltage equal to or greater than 170 kV	$3.540	$3.540
10.3	10.3	*Credit for supply for domestic rates*	Voltage equal to or greater than 5 kV	0.241¢	0.243¢
10.4	10.4	*Adjustment for transformation losses*	Monthly discount on the demand charge	17.67¢	17.79¢
11.8	11.8	VISILEC Service	Monthly charge	$89	$89
11.20	11.20	VIGIELIGNE Service	Annual charge	$2,400	$2,400
			Additional charge for second or third licence	$600	$600
			Charge for each additional licence	$120	$120
11.27	11.27	SIGNATURE Service (basic service)	Annual charge per delivery point	$5,250	$5,250
11.28	11.28	SIGNATURE Service (complementary options)	Annual charge for harmonics tracking	$5,000	$5,000
			Annual charge for dashboard	$500	$500
			Annual charge for review of indicators and load behavior analysis	$5,000	$5,000
12.3	12.3	*Administrative charges*	File administration charge	$20	$20
			New file charge	$50	$50
			Charge for insufficient funds	$50	$50
12.4	12.4	*Charges related to the supply of electricity*	Prospective cost of capital	5.560%	5.057%
			Charge for establishing service	$361	$361
			Charge for travel without establishing service	$177	$172
			Special connection charge for off-grid systems		
			First 20 kW (total)	$5,000	$5,000
			Each kilowatt in excess (per kW)	$250	$250
			Charge for interrupting service		
			At the delivery point	$50	$50
			Other	$361	$361

Electricity rates

Average increase of 0.7% on April 1, 2017, except for Rate L, for which the increase is 0.2%

Article April 1, 2016	Article April 1, 2017	Rate	Description	Prices at April 1, 2016	Prices at April 1, 2017
12.5	12.5	*Allocated amounts*	Amount allocated for domestic use (per dwelling unit)	$2,600	**$2,600**
			Amount allocated for non-domestic use (per kW)	$335	**$335**
			Non-domestic use allocation adjustment charge (per kW)	$67	**$67**
12.6	12.6	*Components of the table for calculating the cost of work in Schedule VI of the Conditions of Electricity Service*	Acquisition fee	2.0%	**2.0%**
			Contract management fee, overhead work	2.4%	**2.4%**
			Contract management fee, underground work	10.4%	**10.4%**
			Materials management fee, overhead work	17.0%	**17.0%**
			Materials management fee, underground work	12.0%	**12.0%**
			Minor materials fee, overhead work	11.0%	**11.0%**
			Minor materials fee, underground work	7.0%	**7.0%**
			Engineering and applications management fee, overhead work	24.3%	**24.3%**
			Engineering and applications management fee, underground work	29.6%	**29.6%**
			Provision for future operation and maintenance, overhead work, overall	22.5%	**22.5%**
			Provision for future operation and maintenance, overhead work, front lot	19.2%	**19.2%**
			Provision for future operation and maintenance, overhead work, back lot	24.8%	**24.8%**
			Provision for future operation and maintenance, underground work	10.7%	**10.7%**
			Provision for reinvestment at end of useful life	22.4%	**22.4%**
12.7	12.7	*Unit prices*	Price per metre - overhead single-phase line, nonjoint-use pole, front lot	$61	**$61**
			Price per metre - overhead single-phase line, nonjoint-use pole, back lot	$74	**$74**
			Price per metre - overhead three-phase line, nonjoint-use pole, front lot	$74	**$74**
			Price per metre - overhead three-phase line, nonjoint-use pole, back lot	$87	**$87**
			Joint-use credit (per metre), front lot	$13	**$13**
			Joint-use credit (per metre), back lot	$13	**$13**
			Price per building – underground - If the option for a local underground power line and main overhead power line is selected:		
			Individual house with a 600-A service box	$9,490	**$9,490**
			Individual house with a 320-A or a 400-A service box	$2,950	**$2,950**
			Individual house with a 200-A service box	$1,980	**$1,980**
			Semi-detached house	$1,780	**$1,780**
			Townhouse	$1,030	**$1,030**
			Duplex	$3,950	**$3,950**
			Triplex	$3,630	**$3,630**
			Fourplex	$4,400	**$4,400**
			Fiveplex	$7,600	**$7,600**
			Sixplex	$7,680	**$7,680**
			Sevenplex	$10,160	**$10,160**
			Eightplex	$10,240	**$10,240**
			Price per building – underground - If the option for local and main underground power line is selected:		
			Individual house with a 600-A service box	$17,170	**$17,170**
			Individual house with a 320-A or a 400-A service box	$8,480	**$8,480**
			Individual house with a 200-A service box	$6,590	**$6,590**
			Semi-detached house	$5,440	**$5,440**
			Townhouse	$4,100	**$4,100**
			Duplex	$6,820	**$6,820**
			Triplex	$10,060	**$10,060**
			Fourplex	$11,770	**$11,770**
			Fiveplex	$16,810	**$16,810**
			Sixplex	$16,890	**$16,890**
			Sevenplex	$20,900	**$20,900**
			Eightplex	$22,520	**$22,520**
			Price per additional metre - underground	$87	**$87**
			Price for overhead work - Low- and medium-voltage line:		
			Per nonjoint-use pole, low voltage	$1,303	**$1,303**
			Per joint-use pole, low voltage	$794	**$794**
			Per nonjoint-use pole, medium voltage	$1,568	**$1,568**
			Per joint-use pole, medium voltage	$957	**$957**
			Per nonjoint-use anchor pole and brace	$1,303	**$1,303**
			Per joint-use anchor pole and brace	$794	**$794**
			Per nonjoint-use anchor	$484	**$484**
			Per joint-use anchor	$295	**$295**
			Per guy	$584	**$584**
			Per line protection, medium voltage, single-phase	$704	**$704**
			Per line protection, medium voltage, three-phase	$1,988	**$1,988**
			Price for overhead work - Additional service cable, low voltage:		
			Per metre for a 200-A service box, 120/240 V	$15	**$15**
			Per metre for a 320-A or a 400-A service box, 120/240 V	$31	**$31**
			Per metre for a 600-A service box, 120/240 V	$91	**$91**

Electricity rates

Average increase of 0.7% on April 1, 2017, except for Rate L, for which the increase is 0.2%

Article April 1, 2016	Article April 1, 2017	Rate	Description	Prices at April 1, 2016	Prices at April 1, 2017
			Price for underground work – Additional service cable, medium voltage:		
			For metre for the 1st section, 2 X 3/0 Al, single-phase	$45	$45
			For metre for the 1st section, 2 X 3/0 Al, three-phase	$104	$104
			For metre for the 1st section, 4 X 3/0 Al, single-phase	$90	$90
			For metre for each additional section, 2 X 3/0 Al, single-phase	$211	$211
			For metre for each additional section, 2 X 3/0 Al, three-phase	$270	$270
			For metre for each additional section, 4 X 3/0 Al, single-phase	$223	$223
			For splice assembly 2 X 3/0 Al, single-phase in a cable vault	$3,744	$3,744
			For splice assembly 2 X 3/0 Al, three-phase in a cable vault	$9,236	$9,236
			For splice assembly 4 X 3/0 Al, single-phase in a cable vault	$6,495	$6,495
			Price for underground work – Low-voltage line:		
			For metre of triplex cable, 3/0 Al (120/240 V)	$15	$15
			For metre of triplex cable, 350 kcmil (120/240 V)	$28	$28
			For metre of triplex cable, 500 kcmil (120/240 V)	$38	$38
			For metre of triplex cable, 750 kcmil (120/240 V)	$48	$48
			For metre of quadruplex cable, 3/0 Al (347/600 V)	$18	$18
			For metre of quadruplex cable, 350 kcmil (347/600 V)	$35	$35
			For metre of quadruplex cable, 500 kcmil (347/600 V)	$47	$47
			For metre of quadruplex cable, 750 kcmil (347/600 V)	$62	$62
			For single-phase connection (120/240 V)	$407	$407
			For three-phase connection (347/600 V)	$634	$634
			For installation of a section of cable of 30 metres or less, 500 kcmil or less	$1,663	$1,663
			For installation of a section of cable of over 30 metres, 500 kcmil or less	$2,662	$2,662
			For installation of a section of cable over 500 kcmil	$2,662	$2,662
			Price for underground work – Medium-voltage line:		
			For metre of cable, 3/0 Al, single-phase	$23	$23
			For metre of cable, 3/0 Al, three-phase	$52	$52
			For metre of cable, 750 kcmil, three-phase	$123	$123
			For connection with single premoulded splice, 3/0-3/0 Al single-phase	$936	$936
			For connection with single premoulded splice, 3/0-3/0 Al three-phase	$2,310	$2,310
			For connection with single premoulded splice, 750-750 kcmil, three-phase	$2,354	$2,354
			For connection with separable straight splice, (2-way), 750 kcmil, three-phase	$3,246	$3,246
			For connection with separable Wye splice (3-way), 750 kcmil, three-phase	$2,971	$2,971
			For connection with separable H splice (4-way), 750 kcmil, three-phase	$2,888	$2,888
			For installation of a section of cable	$3,329	$3,329
			For voltage generator test	$1,331	$1,331
12.8	12.8	*Flat for work*	*Temporary underground supply, single-phase, 200 A (120/240 V):*		
			Without extra cable	$600	$600
			With extra cable	$1,450	$1,450
			Temporary overhead supply with temporary modification, single-phase, 200 A (120/240 V):		
			With transformer replacement	$2,450	$2,450
			With extra cable	$1,835	$1,835
			With extra cable and transformer replacement	$3,365	$3,365
			With extra cable and new poles and transformer replacement	$5,890	$5,890
			Modification of an overhead underground service entrance, single-phase, 200 A maximum		
			Connection to pole supplied by customer	$675	$675
			Connection to Hydro-Québec pole	$815	$815
			Service box modification, low-voltage, overhead:		
			400-A, single-phase (120/240 V) or three-phase (347/600 V)	$895	$895
			400-A or 800-A, single-phase (120/240 V) or three-phase (347/600 V)	$1,700	$1,700
			Service box relocation, low-voltage, overhead:		
			200-A, single-phase (120/240 V) with or without cable replacement	$361	$361
			400-A, single-phase (120/240 V) with cable replacement	$895	$895
			Preventive maintenance, medium-voltage, overhead or underground		
			Per job, for interrupting and re-establishing service	$900	$900
			Per additional job requested by the customer	$2,800	$2,800
12.9	12.9	*Flat for metering*	*Temporary metering:*		
			Low voltage, single-phase (120/240V), self-contained metering	$290	$290
			Low voltage, polyphase (347/600V), self-contained metering	$450	$450
			Low voltage, single-phase (120/240V), instrument transformer metering	$720	$720
			Low voltage, polyphase (347/600V), instrument transformer metering	$1,230	$1,230
			Medium voltage	$3,200	$3,200
			Medium-voltage metering related to an option:		
			Single-phase, instrument transformer metering, structure	$12,910	$12,910
			Polyphase, instrument transformer metering, structure	$28,080	$28,080

APPENDIX II

DATASHEET OF SOLAR PHOTOVOLTAIC MODULE CS6X-280M

CanadianSolar

MaxPower CS6X

280/285/290/295/300M

MaxPower CS6X is a robust solar module with 72 solar cells. These modules can be used for on-grid solar applications. Our meticulous design and production techniques ensure a high-yield, long-term performance for every module produced. Our rigorous quality control and in-house testing facilities guarantee Canadian Solar's modules meet the highest quality standards possible.

Key Features

- High module efficiency up to 15.63%
- Positive power tolerance: 0~ +5W
- Robust frame to up to 5400 Pa load
- Anti-reflective and self-cleaning surface
- Outstanding performance at low irradiance
- High energy yield at Low NOCT
- **Backed By Our New 10/25 Linear Power Warranty Plus our added 25 year insurance coverage**

- 10 year product warranty on materials and workmanship
- 25 year linear power output warranty

Best Quality

- 235 quality control points in module production
- EL screening to eliminate product defects
- Current binning to improve system performance
- Accredited Salt mist resistant

Best Warranty Insurance

- 25 years worldwide coverage
- 100% warranty term coverage
- Providing third party bankruptcy rights
- Non-cancellable
- Immediate coverage
- Insured by 3 world top insurance companies

Comprehensive Certificates

- IEC 61215 /IEC 61730, UL1703, IEC61701 ED2, CEC Listed, CE, MCS
- ISO9001: 2008: Quality Management System
- ISO/TS16949:2009: The automotive quality management system
- ISO14001:2004: Standards for Environmental management system
- QC080000 HSPM: The Certification for Hazardous Substances Regulations
- OHSAS 18001:2007 International standards for occupational health and safety
- Reach Compliance

www.canadiansolar.com

CS6X-280/285/290/295/300M
MaxPower

Electrical Data

STC	CS6X-280M	CS6X-285M	CS6X-290M	CS6X-295M	CS6X-300M
Nominal Maximum Power (Pmax)	280W	285W	290W	295W	300W
Optimum Operating Voltage (Vmp)	36.0V	36.1V	36.3V	36.4V	36.5V
Optimum Operating Current (Imp)	7.78A	7.89A	8.00A	8.11A	8.22A
Open Circuit Voltage (Voc)	44.6V	44.7V	44.7V	44.9V	45.0V
Short Circuit Current (Isc)	8.30A	8.40A	8.51A	8.63A	8.74A
Module Efficiency	14.59%	14.85%	15.11%	15.37%	15.63%
Operating Temperature	-40°C~+85°C				
Maximum System Voltage	1000V (IEC) / 600V (UL)				
Maximum Series Fuse Rating	15A				
Application Classification	Class A				
Power Tolerance	0 ~ +5W				

Under Standard Test Conditions (STC) of irradiance of 1000W/m², spectrum AM 1.5 and cell temperature of 25°C

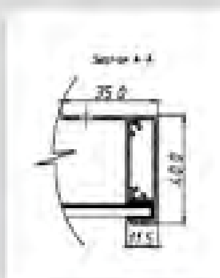
NOCT	CS6X-280M	CS6X-285M	CS6X-290M	CS6X-295M	CS6X-300M
Nominal Maximum Power (Pmax)	202W	206W	209W	213W	217W
Optimum Operating Voltage (Vmp)	32.8V	32.9V	33.1V	33.2V	33.3V
Optimum Operating Current (Imp)	6.16A	6.25A	6.32A	6.41A	6.51A
Open Circuit Voltage (Voc)	40.9V	41.0V	41.0V	41.2V	41.3V
Short Circuit Current (Isc)	6.72A	6.80A	6.89A	6.98A	7.08A

Under Normal Operating Cell Temperature, Irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s

Mechanical Data

Cell Type	Mono-crystalline 156 x 156mm, 2 or 3 Busbars
Cell Arrangement	72 (6 x 12)
Dimensions	1954 x 982 x 40mm (76.93 x 38.7 x 1.57in)
Weight	23kg (50.7 lbs)
Front Cover	3.2mm Tempered glass
Frame Material	Anodized aluminium alloy
J-BOX	IP65, 3 diodes
Cable	4mm² (IEC)/12AWG(UL), 1150mm
Connectors	MC4 or MC4 Comparable
Standard Packaging (Modules per Pallet)	24pcs
Module Pieces per container (40 ft. Container)	528pcs (40'HQ)

I-V Curves (CS6X-290M)



*Specifications included in this datasheet are subject to change without prior notice.

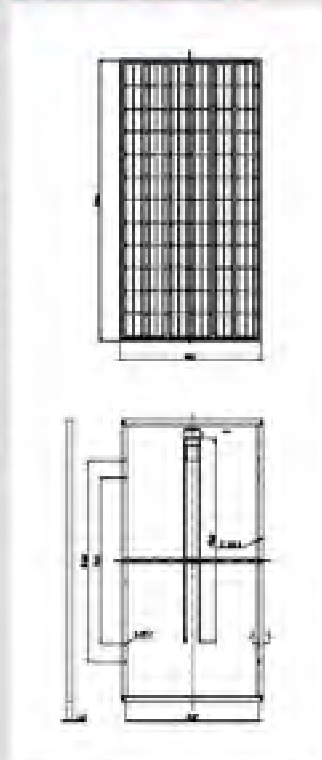
Temperature Characteristics

Temperature Coefficient	Pmax	-0.45%/°C
	Voc	-0.35%/°C
	Isc	0.060%/°C
Normal Operating Cell Temperature		45±2°C

Performance at Low Irradiance

Industry leading performance at low irradiation environment, +95.5% module efficiency from an irradiance of 1000w/m² to 200w/m² (AM 1.5, 25°C)

Engineering Drawings



About Canadian Solar

Canadian Solar Inc. is one of the world's largest solar companies. As a leading vertically-integrated manufacturer of ingots, wafers, cells, solar modules and solar systems, Canadian Solar delivers solar power products of uncompromising quality to worldwide customers. Canadian Solar's world class team of professionals works closely with our customers to provide them with solutions for all their solar needs.

Canadian Solar was founded in Canada in 2001 and was successfully listed on NASDAQ Exchange (symbol: CSIQ) in November 2006. Canadian Solar has module manufacturing capacity of 2.05GW and cell manufacturing capacity of 1.3GW.

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APPENDIX III

DATASHEET OF BAE SECURA OGi BATTERY CELLS

BAE *Secura OGi*

Technical Specification for Stationary VLA - Cells

1. Application

BAE OGi - cells are suitable for safety batteries where operational safety and long operational life has top priority and high discharge currents during short discharge times and capacitive loads over longer discharge times are required.

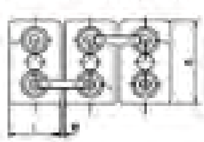
They are used as standby source in power supply stations, transforming stations, UPS - stations, emergency light equipment acc. VDE 0108 and VDE 0107.

The round-grid plate used by BAE grants due to the high lead weight and the circular bars a long operational life and a very good high - current - performance. The straight - walled containers and the supported plates offer a high power - density related to the small foot-print. The transparent containers allows an all-round - control and they make service and maintenance easier.

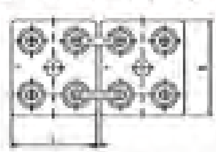
2. Types, capacities, dimensions, mass

Type Un V/Cells	C10 20°C Ah 1.80	C5 20°C Ah 1.80	C3 20°C Ah 1.75	C1 20°C Ah 1.70	C1/2 20°C Ah 1.65	C1/6 20°C Ah 1.50	C8 25°C Ah 1.75	Ri 1) mΩ	Ik 2) kA	length mm	width mm	height (max.) mm	mass 3) kg	mass 4) kg
5 OGi 400	410	340	297	233	186	117	396	0.450	4.5	145	206	700	26.5	40
6 OGi 480	490	406	351	270	233	138	481	0.375	5.4	145	206	700	30.5	43
7 OGi 560	550	455	390	314	262	157	537	0.321	6.3	145	206	700	34.5	47
8 OGi 640	610	510	447	352	295	177	583	0.281	7.2	145	206	700	38.0	51
9 OGi 720	690	568	495	383	328	196	658	0.250	8.1	145	206	700	42.0	54
10 OGi 800	810	675	594	466	391	224	791	0.225	9.0	210	191	700	49.5	62
11 OGi 880	880	741	646	508	430	250	857	0.205	9.9	210	191	700	53.0	68
12 OGi 960	960	800	699	549	465	275	923	0.188	10.8	210	191	700	57.5	73.5
13 OGi 1040	1030	856	750	589	494	296	991	0.173	11.7	210	233	700	62.0	78
14 OGi 1120	1090	915	805	628	526	315	1063	0.161	12.6	210	233	700	66.0	84
15 OGi 1200	1160	975	849	667	560	334	1129	0.150	13.5	210	233	700	70.0	88
16 OGi 1280	1230	1025	897	709	590	353	1197	0.141	14.4	210	275	700	74.5	94
17 OGi 1360	1290	1070	945	741	621	371	1262	0.133	15.3	210	275	700	78.5	98
18 OGi 1440	1350	1130	990	777	651	389	1319	0.125	16.2	210	275	700	82.0	102
19 OGi 1520	1540	1285	1128	886	740	444	1491	0.118	17.1	210	360	675	87.5	125
20 OGi 1600	1610	1345	1179	925	775	464	1565	0.113	18.0	210	360	675	91.5	126
21 OGi 1680	1680	1405	1230	966	809	484	1633	0.107	18.9	210	360	675	94.0	128
22 OGi 1760	1750	1460	1279	1005	842	503	1697	0.102	19.8	210	360	675	99.0	130
23 OGi 1840	1820	1516	1329	1043	874	523	1762	0.098	20.7	210	360	675	103.0	133
24 OGi 1920	1880	1570	1377	1081	906	542	1821	0.094	21.6	210	360	675	107.0	135
25 OGi 2000	1950	1625	1425	1119	937	560	1887	0.090	22.5	210	440	675	112.0	148
26 OGi 2080	2010	1680	1470	1155	967	579	1953	0.087	23.4	210	440	675	115.5	150
27 OGi 2160	2070	1730	1515	1191	997	597	2011	0.083	24.3	210	440	675	119.5	153
28 OGi 2240	2130	1780	1560	1226	1027	614	2068	0.080	25.2	210	440	675	123.5	155.5
29 OGi 2320	2190	1830	1605	1261	1056	632	2126	0.078	26.1	210	440	675	127.5	158
30 OGi 2400	2250	1880	1650	1296	1086	649	2184	0.075	27.0	210	440	675	131.5	160

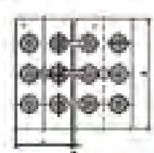
1, 2) internal resistance and short - circuit - current according to IEC 60896-11 3) dry charged 4) filled and charged



5 OGi 400 to 9 OGi 720



10 OGi 800 to 18 OGi 1440



19 OGi 1520 to 30 OGi 2400

ENERGY FROM BATTERIES BAE

Technical Specification for BAE *Secura OGi*

3. Design

positive electrode	round-grid plate with low antimony alloy (1,6%), circular bars high lead weight
negative electrode	flat plate with long life expander and low antimony alloy
separation	microporous separator
electrolyte	sulphuric acid of 1.24 kg/l,
lid	halogene-free SAN in dark grey colour
container	high stability by transparent halogene-free SAN, straight-walled containers
plugs	labyrinth plugs for arresting aerosol, optional ceramic plugs or ceramic funnel plugs acc. DIN 40 740
pole bushing	100% gas- and electrolyte-tight, sliding, injection-moulded Panzer pole
kind of pole	M10 copper insertion
connector	insulated solid copper connectors with cross-section of 90, 150 or 300 mm² or flexible insulated copper cables with cross-section of 50, 70, 95 or 120 mm²
pole screw	M10, steel, insulated
kind of protection	IP 25 regarding DIN 40 050, touch protected according VBG 4

4. Charging

IU - characteristic	I_{max} without limitation U = 2.23 V/cell ±1 %
float current	15 mA/100 Ah, increasing to 45 mA/100 Ah at the end of life
boost charge	U = 2.40 V/cell, time limited
charging time up to 90%	6 h with 1.5 x I_{10} initial current, 2.23 V/cell, 80% C3 discharged

5. Discharge characteristics

reference temperature	20°C
initial capacity	100%
depth of discharge	normally up to 80%
depth of discharges	more than 80% DOD or discharges beyond final discharge voltages (dependent on discharge current) have to be avoided

6. Maintenance

every 6 months	check battery voltage, pilot block voltage, temperature
every 12 months	record battery voltage, block voltage, temperature

7. Operational data

operational life	15 years at 20°C, stand-by operation, float
water refilling interval	> 3 years at 20°C
IEC 896-1 cycles	> 1200
self-discharge	approx. 3% per month at 20°C
operational temperature	-20°C to 55°C recommend 10°C to 30°C
dimensions according	DIN 40 736 part 1
tests according	IEC 60 896-11
safety standard, ventilation	EN 50 272-2
transport	Batteries are not subject to ADR (road transport), if the conditions of the special rule 598 (chapter 3.3) are observed.

BAE

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APPENDIX IV

DATASHEET OF 125 kW DC AC INVERTER FOR BATTERY

Grid-Tied Inverter (GTIB-480-125)

PRINCETON POWER SYSTEMS
Clean Power Made Simple™

Grid-tied Inverter and Battery Controller (GTIB-480-125)

The GTIB-480-125 is a 125kW hybrid inverter that offers high efficiency, proven reliability, and unprecedented flexibility. The highly-configurable GTIB can condition power from alternative energy sources as well as Energy Storage and AC Microgrids.

What's New in GL3
- Higher DC Voltage Range (280 - 820 VDC)
- Higher DC Input Current (380A)
- Quiet Operation (<75 dB)
- Transformerless
- 25% Higher Power - 125 kW

Efficient
With 97% peak efficiency, the GTIB has builtin MPPT for solar arrays and high roundtrip efficiency for battery charging

Advanced Functions
Independent real and reactive power controls allow the inverter to be used for frequency regulation, VAR compensation, demand response, peak shaving, and other advanced grid support functions. Microgrid capabilities allow the inverter to form or join a microgrid.

Features
- Microgrid "offgrid" and backup power capable
- TUV Certified to UL1741
- Web-based remote performance monitoring, control, fault clearing, firmware upgrade
- Automatic transfer to offgrid with builtin transfer switch
- Over 100 MW Deployed

ABOUT PRINCETON POWER SYSTEMS

Princeton Power Systems, based in New Jersey and founded in 2001, designs and manufactures state-of-the-art technology solutions for energy management, microgrid operations and electric vehicle charging. The company is a global leader working with customers and partners across North America, Europe, Africa and the Caribbean. It manufactures UL and CE-certified power electronics that are used in advanced battery operations and alternative energy, with builtin smart functions for ancillary services. The company solves power issues to allow continued growth of distributed renewable energy by providing energy storage solutions that are proven to work, even in harsh environments. Princeton Power Systems builds integrated systems and designs, commissions and operates microgrids for leading organizations, including Fortune 500 automakers and industrials, and non-profit organizations. The company proudly manufactures its products in the USA. More information about Princeton Power Systems is available at www.princetonpower.com.

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Grid-Tied Inverter (GTIB-125)

GTIB-125	
Power Terminals	1 DC | 2 AC
Powerstage Technology	High Frequency PWM
Size (inches)	36 W x 18 D x 73 H
Weight (Lbs)	1020
Mounting	Floor-standing

DC PORT SPECIFICATIONS - BATTERY	
DC Voltage (Full Power)	330-820 VDC (125 kW)
DC Voltage (Dark Start) (optional)	256-780 VDC or 430-820 VDC (with extended Dark Start Option)
DC Voltage (Full Range)	50-800 VDC
Max Power	125kW
DC Current Max	380 A
Battery Charge Controller	Integrated configurable 3-stage charge controller for lead-acid batteries
Battery Management System	External control from BMS interface via Site Controller
DC Voltage Ripple	<1%

AC GRID SPECIFICATIONS	
AC Line Voltage	480 VAC +10%, -12%, 3-phase 3/4 wire with transformer option)
AC Line Frequency	60Hz nominal, 57-60.5 Hz range
Continuous AC Current	160 A RMS
Continuous AC Power	125kW
Power Factor	Greater than 0.95
Current Harmonics	IEEE 1547 compliant, <5% THD
Precharge DC from AC	Optional (External)

AC LOAD PORT SPECIFICATIONS	
AC Line Voltage	480 VAC +10%, -12%, 3-phase 3/4 wire with transformer option)
Continuous AC Current	160 A RMS
Continuous AC Power	125kW
Power Factor	0 to 1.00 (leading-lagging)
Automatic Transfer Switch	Yes (internal)
Ongrid/Offgrid Autotransfer time	160 ms to Backup/300 ms to Grid

ENVIRONMENTAL SPECIFICATIONS	
Temperature Operating	0 to 50°C
Storage	-20°C to 60°C
Humidity	5-95% (noncondensing)
Cooling	Forced Air
Rated Max Elevation	3,300 feet
Enclosure	NEMA 1 (indoor)

USER INTERFACES	
Front-Panel Interface	Industrial LCD Keypad
Accessibility	Web-based Ethernet Interface
Remote Accessibility	via Web interface
Communication	MODBUS Over RS485 and/or RS232 Native
Performance Monitoring	Realtime & Historic, web-based performance data

EFFICIENCY	
Peak Efficiency	97%
CEC Efficiency	96% (transformerless)

APPENDIX V

DATASHEET OF 125 kW DC AC INVERTER - 150 kW PV ARRAYS

SUNGROW

SG125HV NEW

String Inverter for 1500 Vdc Systems

High Yield

- Patented five-level topology, 98.8% CEC efficiency, 98.5% Euro efficiency
- Full power operation without derating up to 50 ℃

Higher ROI

- World's highest output string inverter at 125kW (1500Vdc/600Vac)
- 2 to 5 MW power block design for lower total installed costs
- DC/AC ratio up to 1.5

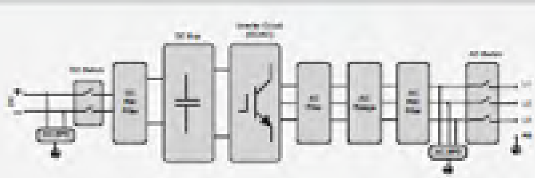
Easy O&M

- Virtual central inverter design concept enables easy O&M
- Compact design and light weight (65kg) for easy installation

Grid Support

- Certifications: UL 1741/1741 SA, IEEE 1547/1547.1, CSA C22.2 107.1-01-2001, FCC Part 15 Sub-part B Class A Limits, California Rule 21
- Low/High voltage ride through (L/HVRT)
- Active & reactive power control, power ramp rate control

Circuit Diagram

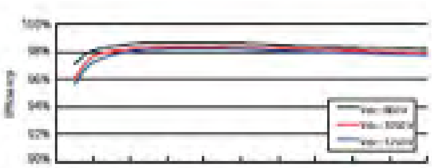


SUNGROW
www.sungrowpower.com

SG125HV

Input (DC)	SG125HV
Max. PV input voltage	1500 V
Min. PV input voltage / Startup input voltage	860 V / 860 V
Nominal input voltage	1050 V
MPP voltage range	860 - 1450 V
MPP voltage range for nominal power	860 - 1250 V
No. of independent MPP inputs	1
Max. number of PV strings per MPPT	1
Max. DC short circuit current	240 A
Output (AC)	
Nominal AC power (at 50 °C)	125000 W
Max. AC output at PF=1 (at 50 °C)	125000 W
Max. AC apparent power (at 50 °C)	125000 VA
Max. AC output current	120 A
Nominal AC voltage	3 / PE, 600 V
AC voltage range	480 - 690 V
Nominal grid frequency / Grid frequency range	50 Hz / 45 - 55 Hz, 60 Hz / 55 - 65 Hz
THD	< 3 % (at nominal power)
DC current injection	< 0.5 % In
Power factor at nominal powe / Adjustable power factor	> 0.99 / 0.8 leading - 0.8 lagging
Feed-in phases / Connection phases	3 / 3
Efficiency	
CEC efficiency / Euro efficiency	98.8 % / 98.5 %
Protection	
DC reverse connection protection	Yes
AC short-circuit protection	Yes
Leakage current protection	Yes
Grid monitoring	Yes
DC switch / AC switch	Yes / Yes
DC fuse	No
PV string current monitoring	No
Anti-PID function	Optional
Overvoltage protection	DC Type II / AC Type II
General Data	
Dimensions (W*H*D)	670*810*294 mm
Weight	68 kg (150 lbs)
Isolation method	Transformerless
Degree of protection	IP65
Night power consumption	< 2 W
Operating ambient temperature range	-25 to 60 ℃ (> 50 ℃ derating)
Allowable relative humidity range (non-condensing)	0 - 100 %
Cooling method	Smart forced air cooling
Max. operating altitude	4000 m (> 3000 m derating)
Communication	RS485, PLC Optional
DC connection type	Screw Clamp terminal (Max. 120 mm²)
AC connection type	Screw Clamp terminal (Max. 120 mm²)
Certifications/Compliance	UL 1741/1741 SA, IEEE 1547/1547.1, CSA C22.2 107.1-01-2001, FCC Part 15 Sub-part B Class A Limits, California Rule 21
Grid Support	LVRT, HVRT, active & reactive power control and power ramp rate control

Efficiency Curve



APPENDIX VI

DATASHEET OF 36 kW DC AC INVERTER - 500 kW PV ARRAYS

YASKAWA
SOLECTRIA SOLAR

PVI 14TL
PVI 20TL
PVI 23TL
PVI 28TL
PVI 36TL

FEATURES
- 600 or 1000 VDC
- Best in class efficiency
- Touch-safe fuses
- Dual & wide MPP tracking zones
- Modbus communications
- Integrated DC fused string combiner
- DC arc-fault protection
- PVI 36TL - HECO and Rule 21 compliant

OPTIONS
- Web-based monitoring
- Shade cover
- DC/AC disconnect covers
- Roof mount array brackets
- DC combiners bypass

3-PH TRANSFORMERLESS STRING INVERTERS

Yaskawa - Solectria Solar's PVI 14TL, PVI 20TL, PVI 23TL, PVI 28TL, and PVI 36TL are compact, transformerless three-phase inverters with a dual MPP tracker. These inverters come standard with AC and DC disconnects, user-interactive LCD, and an 8-position string combiner. Its small, lightweight design makes for quick and easy installation and maintenance. These inverters include an enhanced DSP control, comprehensive protection functions, and advanced thermal design enabling highest reliability and uptime. They also come with a standard 10 year warranty with options for 15 and 20 years. Options include web-based monitoring, shade cover, DC/AC disconnect covers, DC combiners bypass, and roof mount array bracket.

SOLECTRIA.COM

SPECIFICATIONS	PVI 14TL	PVI 20TL	PVI 23TL	PVI 28TL	PVI 36TL
DC Input					
Absolute Maximum Open Circuit Voltage	600 VDC			1000 VDC	
Operating Voltage Range	180-500 VDC	260-500 VDC	300-900 VDC		200-950 VDC
Max Power Input Voltage Range (MPPT)	300-510 VDC	300-550 VDC	480-850 VDC	500-850 VDC	540-850 VDC
MPP Trackers			2 with 4-fused inputs per tracker		
Maximum Operating Input Current	25 A per MPPT (50 A)	35 A per MPPT (70 A)	25 A per MPPT (50 A)	29 A per MPPT (58 A)	35 A per MPPT (70 A)
Maximum Available PV Current (Isc x 1.25)	45 A per MPPT (90 A)	45.5 A per MPPT (91 A)	41 A per MPPT (82 A)	48 A per MPPT (96 A)	53.5 A per MPPT (107 A)
Maximum PV Power (per MPPT)	9.5 kW	13.5 kW	15.5 kW	19 kW	27 kW
Strike Voltage	300V			330V	
AC Output					
Nominal Output Voltage	208 VAC, 3-Ph		480 VAC, 3-Ph		
AC Voltage Range (Standard)			-12%/+10%		
Continuous Output Power (VAC)	14 kW	20 kW	23 kW	28 kW	36 kW
Maximum Output Current (VAC)	39 A	25.5 A	27.7 A	33.7 A	43.5 A
Maximum Backfeed Current			0 A		
Nominal Output Frequency			60 Hz		
Output Frequency Range		59.3-60.5 Hz (adjustable 55-65 Hz)			57-63 Hz
Power Factor	Unity, >0.99 (±0.8 adjustable)	Unity, >0.99 (±0.9 adjustable)		Unity, >0.99 (±0.8 adjustable)	
Total Harmonic Distortion (THD) @ Rated Load			< 3%		
Grid Connection Type			3Ø + N/GND (4-wire)		
Efficiency					
Peak Efficiency	96.3%	97.6%	98.6%	98.4%	
CEC Efficiency	96.0%	97.0%		98.0%	
Tare Loss	4 W		2 W		
Integrated String Combiner					
8 Fused Positions (4 positions per MPPT)		15 A (Fuse by-pass available)			15 or 30 A (30 A only for combined inputs)
Temperature					
Ambient Temperature Range	-13°F to +140°F (-25°C to +60°C) Derating occurs over +50°C			-13°F to +140°F (-25°C to +60°C) Derating occurs over +45°C	
Storage Temperature Range		-22°F to +158°F (-30°C to +70°C)			-40°F to +158°F (-40°C to +70°C)
Relative Humidity (non-condensing)			0-95%		
Operating Altitude			13,123 ft/4,000 m (derating from 6,562 ft/2000 m)		
Data Monitoring					
Optional SolrenView Web-based Monitoring			Integrated		
Optional Revenue Grade Monitoring			External		
External Communication Interface			RS-485 Modbus RTU		
Testing & Certifications					
Safety Listings & Certifications			UL 1741/IEEE 1547, CSA C22.2#107.1, FCC part 15 B		
Testing Agency	ETL			CSA	
Warranty					
Standard			10 year		
Optional			15, 20 year; extended service agreement		
Enclosure					
dBA (Decibel) Rating			< 50 dBA @ 3 m		
AC/DC Disconnect			Standard, fully-integrated		
Dimensions (H x W x D)	41.4 in. x 21.3 in. x 8.5 in. (1052 mm x 544 mm x 216 mm)			39.4 in. x 23.6 in. x 9.1 in. (1001 mm x 600 mm x 232 mm)	
Weight	141 lbs (64 kg)	132 lbs (60 kg)	148 lbs (67.2 kg)		121 lbs (55kg)
Enclosure Rating		Type 4			Type 4X
Enclosure Finish			Polyester powder coated aluminum		

YASKAWA SOLECTRIA SOLAR www.solectria.com | inverters@solectria.com | 978.683.9700

APPENDIX VII

PRICE OF A BATTERY ENERGY STORAGE SYSTEM

Prix batteries

Belhumeur, Vincent

Sent: Friday, October 05, 2018 11:49 AM

To: Dias da Cruz, Fernando

Bonjour M. Dessaint,

Afin d'obtenir 1MWh de batteries (80%DOD pour 800kWh), voici les deux options que je vous propose pour une application demandant ~100 cycles/année :

1. Batteries VLA (vented) : Rolls Surrette 4KS27P (cellules de 4 volts)

   2 x 146 cellules (200kW par système)
   485,974$CAD

   Cette batterie (typiquement d'application de chariot élévateur) offre un meilleur cyclage puisque les plaques sont à haute concentration d'antimoine contrairement aux batteries typiquement retrouvées dans les applications d'UPS. Par contre, la durée de vie que nous voyons pour cette batterie est de 8 à 10 ans.

2. Batteries VRLA GEL (sealed) : GNB Sonnenschein A602/1415 (cellules de 2 volts)

   2 x 280 cellules (200kW par système)
   556,708$CAD

   Cette batterie contient un acide phosphorique plutôt qu'un acide sulfurique ce qui lui permet d'avoir une longue durée de vie (>15 ans) et une grande capacité de cyclage (2100 cycles à 80%DOD, voir pièce jointe). Les batteries peuvent être installées horizontalement pour sauver de l'espace et l'installation ne requiert pas de système d'évacuation de l'hydrogène puisque les cellules sont scellées.

Pour toutes questions, n'hésitez pas à me contacter,

Cordialement,

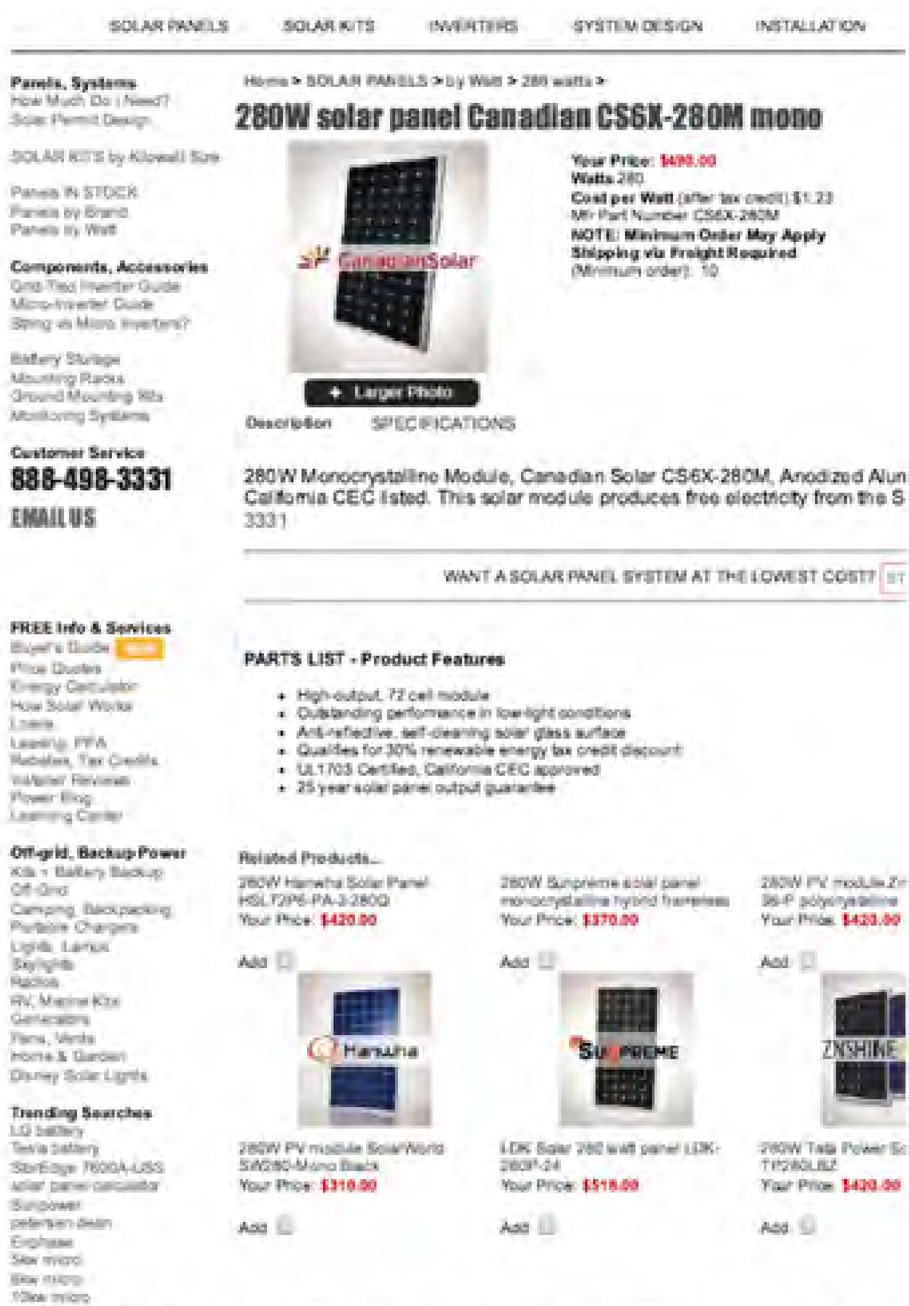
Vincent Belhumeur

Étudiant à la maîtrise en génie électrique,

École de technologie supérieure, Montréal, Qc

APPENDIX VIII

PRICE OF A 280 W SOLAR PANEL CANADIAN CS6X-280M



SOLAR PANELS SOLAR KITS INVERTERS SYSTEM DESIGN INSTALLATION

Home > SOLAR PANELS > by Watt > 280 watts >

280W solar panel Canadian CS6X-280M mono

Your Price: $490.00
Watts 280
Cost per Watt (after tax credit) $1.23
Mfr Part Number CS6X-280M
NOTE: Minimum Order May Apply
Shipping via Freight Required
(Minimum order): 10

Description SPECIFICATIONS

280W Monocrystalline Module, Canadian Solar CS6X-280M, Anodized Alun
California CEC listed. This solar module produces free electricity from the S
3331

WANT A SOLAR PANEL SYSTEM AT THE LOWEST COST?

PARTS LIST - Product Features

- High-output, 72 cell module
- Outstanding performance in low-light conditions
- Anti-reflective, self-cleaning solar glass surface
- Qualifies for 30% renewable energy tax credit discount
- UL1703 Certified, California CEC approved
- 25 year solar panel output guarantee

Panels, Systems
How Much Do I Need?
Solar Permit Design

Components, Accessories

Customer Service
888-498-3331
EMAIL US

FREE Info & Services

Off-grid, Backup Power

Trending Searches

Related Products...

280W Hanwha Solar Panel HSL72P6-PA-3-280Q
Your Price: $420.00

280W Supreme solar panel monocrystalline hybrid frameless
Your Price: $370.00

280W PV module SolarWorld SW280-Mono Black
Your Price: $310.00

LDK Solar 280 watt panel LDK-280P-24
Your Price: $518.00

280W Tata Power Sc TP280LBZ
Your Price: $420.00

APPENDIX IX

RECYCLING PRICE OF LEAD-ACID BATTERY PER POUND

Non Ferrous * All our prices are per pound except car batteries*

Product	Specifications	Price	Units	Last Update
alum tin	Specifications	$0.75	lbs	2-10-2018
Aluminium radiator clean	Specifications	$0.35	lbs	2-10-2018
aluminium copper rads with steel attached	Specifications	$0.55	lbs	2-10-2018
Aluminium siding	Specifications	$0.60	lbs	2-10-2018
Aluminum turnings	Specifications	$0.20	lbs	2-10-2018
Aluminum car wheels	Specifications	$0.60	lbs	2-10-2018
Aluminum Copper Radiator-clean	Specifications	$1.15	lbs	2-10-2018
Aluminium mixed	Specifications	$0.40	lbs	2-10-2018
Aluminium-casting	Specifications	$0.45	lbs	2-10-2018
[illegible]	Specifications	[illegible]	lbs	2-10-2018
Battery from , motorcycle, UPS, alarm system, truck , buy per lbs	Specifications	$0.19	lbs	2-10-2018
big electric motors copper inside [illegible]	Specifications	[illegible]	lbs	2-10-2018
Brass [illegible]	Specifications	$0.65	lbs	2-10-2018
Brass radiators from cars or truck	Specifications	$1.75	lbs	2-10-2018
Car Battery ,based on (38lbs)	Specifications	$11.00	ea	2-10-2018
Copper #1- unsoldered wires pipes/ big gauge rods / no hair wire or small gauge [NO BURNT WIRES]	Specifications	$3.03	lbs	2-10-2018
Copper #2	Specifications	$2.81	lbs	2-10-2018
Copper Wire insulated #2	Specifications	$0.65	lbs	2-10-2018
Industrial battery steel cased		$0.27	lbs	2-10-2018
Lead	Specifications	[illegible]		2-10-2018
Lead Tire Weights	Specifications	$0.18	lbs	2-10-2018
New Copper Pipe, 12 inches and more	Specifications	$2.91	lbs	2-10-2018
small electrique motors (copper inside)	Specifications	$0.20	lbs	2-10-2018
Stainless Steel	Specifications	$0.40	lbs	2-10-2018
stainless turnings	Specifications	$0.20	lbs	2-10-2018
Yellow brass	Specifications	$1.90	lbs	2-10-2018

E-scrap* for large quantities call Eric 514-648-8602 ext5807

Product	Specifications	Price	Units	Last Update
Incomplete Laptop	Specifications	$0.20	lbs	2-10-2018
Laptop Lithium Battery		$0.70	lbs	2-10-2018
Cable box from Videotron or Bell		$0.13	lbs	2-10-2018
Cd drive and Floppy disc		$0.04	lbs	2-10-2018
Cell Phones		$1.25	lbs	2-10-2018
cellular lithium battery		$0.40	lbs	2-10-2018
Complete Laptop	Specifications	$0.40	lbs	2-10-2018

APPENDIX X

PRICE OF A 125 kW DC AC INVERTER FOR BATTERY

APPENDIX XI

PRICE OF A 36 kW DC AC INVERT FOR PV SOLAR PANEL

CIVICSOLAR.

Home › Inverters › Yaskawa-Solectria Solar 36kW 480VAC 3-Phase TL Inverter, PVI-36TL-480

Yaskawa-Solectria Solar 36kW 480VAC 3-Phase TL Inverter, PVI-36TL-480

YASKAWA SOLECTRIA SOLAR

Manufacturer:	Yaskawa-Solectria Solar
Category:	Inverters
Min Qty:	1
Bundle Size:	1
Unit Price:	$4,271.43
Ext Price:	$4,271.43
$/W:	$0.119

APPENDIX XII

PRICE OF A 125 kW DC AC INVERTER FOR PV SOLAR PANEL

CIVICSOLAR.

Home › Inverters › Sungrow 125kW 600VAC 1500VDC TL String Inverter w/ 1 MPPT SG125HV

Sungrow 125kW 600VAC 1500VDC TL String Inverter w/ 1 MPPT SG125HV

SUNGROW

Manufacturer:	Sungrow
Category:	Inverters
Min Qty:	1
Bundle Size:	1
Unit Price:	$13,240.00
Ext Price:	$13,240.00
$/W:	$0.106

APPENDIX XIII

MATLAB ALGORITHMS

Scenario 00 - Algo_Economic_Study_Ontario2017_GA_by_Consumpt_Scenario_00.m

```
load('ontario.mat')
 load('ontario.mat')

load('Simulation_Results_Ontario2017_NoBess_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000

    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power + TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;% $/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

      %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power, Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;

    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;
```

Scenario 00 - Algo_Economic_Study_Ontario2017_GA_by_Consumpt_Scenario_00.m

```
%----Calculation of Energy Monthly_bill and Power Monthly_bill-----
for month=1:length(Months_length)
    if month > 1
        plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
    end
    plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

    %Billed_Power Calculation and Power Costs
    if DataStep == 5 %Mean Value over 15 minutes
        for i=plage_month_start:(plage_month_end-2)
            Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
            if Temp > Billed_Power(month)
                Billed_Power(month)  = Temp;
            end
        end
    else %Max value as datastep >= 15 min
        Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
    end
    if Billed_Power(month) < Contract_Power
        Billed_Power(month)=Contract_Power;
    end

    Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

    %--Calculating Energy costs---

    % The first column of Monthly_Bill is the ENERGY PART of the bill

    for i=plage_month_start:plage_month_end
        Price_HOEP=HOEP2016(i)/100;
        Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

        Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
    end

    price_GA= GlobalAdjustmentbyConsumption2017inkWh_Energy(month)/100;
    Monthly_Bill(month,2) = Monthly_Energy_Consumption(month,1) *
(1+Loss_Adjustment_Factor) * price_GA;


    Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

    Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;
end
```

Scenario 00 - Algo_Economic_Study_Ontario2017_GA_by_Consumpt_Scenario_00.m

```
Calculation of GDP Credits-------------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-----------------Calculting Total Bill-----------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption

else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');

end
```

Scenario 04 - Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_wBess_noGDP_S_04

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_noPV_wBess_noGDP_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000
```

Scenario 04 - Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_wBess_noGDP_S_04.m

```
   %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)


    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
      Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
      TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;

    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %------Calculation of Energy Monthly_bill and Power Monthly_bill------
    for month=1:length(Months_length)
        if month > 1
```

Scenario 04 - Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_wBess_noGDP_S_04.m

```
plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end


        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs---

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month, 1) = Monthly_Energy_Consumption(month, 1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015_noPV_wBess *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000
        else

            Monthly_Bill(month,2) = PDF2016_noPV_wBess *
PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-6)*1000000

        end

  Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;
```

Scenario 04 - Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_wBess_noGDP_S_04.m

```
        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;


    end

    %-----------------Calculation of GDP Credits--------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-----------------Calculting Total Bill----------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption


else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');

end
```

Scenario 01 - Algo_Economic_Study_Ontario2017_GA_by_PDF_Scenario_01.m

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_NoBess_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000


    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;

    Monthly_Energy_Consumption=zeros(12,1);
```

Scenario 01 - Algo_Economic_Study_Ontario2017_GA_by_PDF_Scenario_01.m

```
    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %-----Calculation of Energy Monthly_bill and Power Monthly_bill------
    for month=1:length(Months_length)
        if month > 1
            plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end
        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs---

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015 *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000

        else
```

Scenario 01 - Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_noBess_Scenari_01.m

```
Monthly_Bill(month,2) = PDF2016 * PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-
6)*1000000

        end


        Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;


    end

    %-------------------Calculation of GDP Credits-----------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %------------------Calculting Total Bill-----------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption

else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');
end
```

Scenario 02 - Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_noBess_Scenari_02.m

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_wPV_NoBess_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000


    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;
```

Scenario 02 - Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_noBess_Scenari_02.m

```
    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %-----Calculation of Energy Monthly_bill and Power Monthly_bill------
    for month=1:length(Months_length)
        if month > 1
            plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end
        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs---

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015_wPV_noBess *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000
```

Scenario 02 - Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_noBess_Scenari_02.m

```
        else
            Monthly_Bill(month,2) = PDF2016_wPV_noBess *
PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-6)*1000000

        end


        Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;

    end

    %------------------Calculation of GDP Credits-----------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-----------------Calculting Total Bill---------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption
else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
    can''t be achieved.');

end
```

Scenario 03 – Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_wBess_Scenario_03.m

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_wPV_wBess_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000


    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;
```

Scenario 03 – Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_wBess_Scenario_03.m

```
    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %-----Calculation of Energy Monthly_bill and Power Monthly_bill-----
    for month=1:length(Months_length)
        if month > 1
            plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end
        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs--

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015_wPV_wBess *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000
```

Scenario 03 – Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_wBess_Scenario_03.m

```
        else

            Monthly_Bill(month,2) = PDF2016_wPV_wBess *
PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-6)*1000000

        end

        Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;
      end

    %-------------------Calculation of GDP Credits----------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-----------------Calculting Total Bill-----------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill Filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption
else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');
end
```

Scenario 05A: Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_woptmBess_S_05A.m

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_noPV_woptmBess_WTOU_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000


    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;
```

Scenario 05A: Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_woptmBess_S_05A.m

```
    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %-----Calculation of Energy Monthly_bill and Power Monthly_bill-----
    for month=1:length(Months_length)
        if month > 1
            plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end
        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs---

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015_noPV_woptmBess *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000
```

Scenario 05A: Algo_Economic_Study_Ontario2017_GA_by_PDF_noPV_woptmBess_S_05A.m

```
        else

            Monthly_Bill(month,2) = PDF2016_noPV_woptmBess *
PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-6)*1000000

        end

        Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;


    end

    %-----------------Calculation of GDP Credits--------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-----------------Calculting Total Bill-----------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption
 else
%Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');
 end
```

Scenario 05B: Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_woptmBess_S_05B.m

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_wPV_woptmBess_wTOU_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000


    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;
```

Scenario 05B: Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_woptmBess_S_05B.m

```
    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %-----Calculation of Energy Monthly_bill and Power Monthly_bill------
    for month=1:length(Months_length)
        if month > 1
            plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end
        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs---

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015_wPV_woptmBess *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000
```

Scenario 05B: Algo_Economic_Study_Ontario2017_GA_by_PDF_wPV_woptmBess_S_05B.m

```
        else

            Monthly_Bill(month,2) = PDF2016_wPV_woptmBess *
PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-6)*1000000

        end

        Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;

      end

    %-------------------Calculation of GDP Credits----------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-----------------Calculting Total Bill----------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption
else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');
end
```

Scenario 06: Algo_Economic_Study_Ontario2017_GA_by_PDF_w1MWPV_wBess_S_06.m

```
load('ontario.mat')

load('Simulation_Results_Ontario2017_w1MWPV_wBess_noGDP_22-08-2018.mat')

% Time = get_param(bdroot, 'SimulationTime');
Time = 31536000;

if Time == 31536000


    %Constant Initialisation
    DataStep=Vec_Const(1);%Step between every data. (min)
    Contract_Power=Vec_Const(2); %Contract Power (kW)
    Months_length=Vec_Const(3:14); %Length of months (days)

    DeltaT=1/(60/DataStep);%Step between every value (1/12 for 5min 1/4 for 15mn)
    NbrValue=(60/DataStep)*24;%Nbr of value for the predictions (96 for 1 day & 15min
precision)
    NbrValuePerH=NbrValue/24; %Nbr of value per hours

    Usable_Capa=Batt_Data(1)/1000*(Batt_Data(6)-Batt_Data(5))/100; %Battery usable
capacity

    %Prices initialisation
    Price_kWh=ToU_Data(1); %c/kWh
    Price_kW= DistributionCharge_Power + TransmissionNetwork_Power +
TransmissionConnection_Power; %$/kW
    Price_kW_GDP=ToU_Data(3); %$/kW
    Price_Subscription=StandardSupplyServices_Fixed + MonthlyServiceCharge_Fixed;%
$/month
    Price_WhosaleMarketService= WholesaleMarketService_Energy;
    Price_DebtRetirement= DebtRetirement_Energy;

    %Loss Adjustment Factor

    Loss_Adjustment_Factor=LossAdjustmentFactor;

        %Power demand data initialization
    k=2:2:(length(Finale_Demand.time)-1);
    LoadRealPowerDataTmp = Finale_Demand.signals.values(k);
    Demand=LoadRealPowerDataTmp;

    %Variables initializations
    Monthly_Bill=zeros(12,8); %Column : EnergyHOEP, EnergyGA, WSMS, Debt, Power,
Subscription, GDP, Total
    Monthly_Bill(:,6)=Price_Subscription;
```

Scenario 06: Algo_Economic_Study_Ontario2017_GA_by_PDF_w1MWPV_wBess_S_06.m

```
    Monthly_Energy_Consumption=zeros(12,1);

    plage_month_start=1;%Start of the month
    Billed_Power=ones(12,1)*Contract_Power;

    %-----Calculation of Energy Monthly_bill and Power Monthly_bill------
    for month=1:length(Months_length)
        if month > 1
            plage_month_start=(sum(Months_length(1:(month-1)))*NbrValue) +1;
        end
        plage_month_end=sum(Months_length(1:month))*NbrValue;%End of the Month

        %Billed_Power Calculation and Power Costs
        if DataStep == 5 %Mean Value over 15 minutes
            for i=plage_month_start:(plage_month_end-2)
                Temp = (Demand(i,1)+Demand((i+1),1)+Demand((i+2),1))/3;
                if Temp > Billed_Power(month)
                    Billed_Power(month)  = Temp;
                end
            end
        else %Max value as datastep >= 15 min
            Billed_Power(month)=max(Demand(plage_month_start:plage_month_end));
        end
        if Billed_Power(month) < Contract_Power
            Billed_Power(month)=Contract_Power;
        end

        Monthly_Bill(month,5)=Billed_Power(month)*Price_kW;

        %--Calculating Energy costs---

        % The first column of Monthly_Bill is the ENERGY PART of the bill

        for i=plage_month_start:plage_month_end
            Price_HOEP=HOEP2016(i)/100;
            Monthly_Bill(month,1)= Monthly_Bill(month,1) +
((Demand(i)*DeltaT*(1+Loss_Adjustment_Factor))*Price_HOEP);

            Monthly_Energy_Consumption(month,1) = Monthly_Energy_Consumption(month,1) +
(Demand(i)*DeltaT);
        end

        if month < 7

            Monthly_Bill(month,2) = PDF2015_w1MWPV_wBess *
PDF_totalmonthlyvalue_JantoJun_2017_Energy(1,month)*1000000
```

Scenario 06: Algo_Economic_Study_Ontario2017_GA_by_PDF_w1MWPV_wBess_S_06.m

```
        else

            Monthly_Bill(month,2) = PDF2016_w1MWPV_wBess *
PDF_totalmonthlyvalue_JulytoDec_2017_Energy(1,month-6)*1000000

        end

        Monthly_Bill(month,3) = Monthly_Energy_Consumption(month,1)
*(1+Loss_Adjustment_Factor) * Price_WhosaleMarketService;

        Monthly_Bill(month,4) = Monthly_Energy_Consumption(month,1) *
Price_DebtRetirement;

    end

    %-------------------Calculation of GDP Credits-----------------------
    Power_GDP=0;
    if sum(GDPData) ~= 0
        for i=1:size(GDPData,1)

            month=GDPData(i,2);

            Power_GDP=Power_GDP+(Usable_Capa/(GDPData(i,4)-GDPData(i,3)));

        end
        Monthly_Bill(month,7)=-(Power_GDP/size(GDPData,1))*Price_kW_GDP;
    end

    %-------------------Calculting Total Bill-------------------
    for month=1:length(Months_length)
        Monthly_Bill(month,8)=sum(Monthly_Bill(month,1:7));
    end
    Monthly_Bill(13,:)=sum(Monthly_Bill);%Monthly_Bill Complete
    Billed_Power(13,:)=mean(Billed_Power);%Monthly Billed_Power

    %Clearing Workspace before saving keeping only needed variables.
    %Remember to add your variables if you modify above code.
    clearvars -except ToU_Data Finale_Demand Vec_Const Batt_Data GDPData
Simulation_Results_* Billed_Power  Monthly_Bill filename Scope_* Price_* Contract_Power
Usable_Capa Temp Table_Parameters_* Demand Monthly_Energy_Consumption
else
    %Display warning when simulation wasn't run a full year.
    fprintf('Simulation wasn''t run for a whole year (365*24*3600 sec), economic study
can''t be achieved.');
end
```

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