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ON THE MAP

Solar power in Quebec: a unique potential soon to be fulfilled

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Abstract

Quebec's large solar power potential markedly contrasts with its poor achievements in using solar energy in this large and wealthy region of the world. Reviewing recent developments and putting discussion in the socioeconomic context, we provide arguments that justify our viewpoint that solar energy will soon be a relevant source of power in this Province of Canada. The rapid fall in price of both main solar power technologies, photovoltaics, and solar thermal, along with significant levels of insolation and the pronounced environmental awareness of Quebec's population support the conclusions of this study.

The Case for Solar Power in Quebec

Quebec is a huge Province of Canada seven times larger than Italy, with only 8 million inhabitants [1]. The Province is unique with regard to electricity production amongst industrialized countries. With the most abundant fresh water resources in the world, the country's entire electricity needs are met by the government-owned utility (Hydro-Québec) installed capacity of 35,829 MW that is 98% hydroelectricity [2]. Large quantities of electricity, mainly produced in the northern dams in a hydrological network of more than a million lakes and rivers of the Canadian Shield Forest Lands, are transmitted over long distances using high-voltage transmission lines. Hydro-Québec, for instance, was the first electric power company in the world to build a first 735 kV line already in the 1960s [3].

Given the abundance of renewable electricity with no fuel cost to be met, as it happens with any thermoelectric powerhouse, it does not come as a surprise that the price of the kWh in Quebec is only 7–9 ¢ for families and 10–13 ¢ for enterprises, namely the lowest in Northern America [4]. For example, as of April 2010 the price of a domestic kWh in Montréal was two times lower than in Halifax (Nova Scotia) and three times lower than in New York (Fig. 1). Why, therefore, should other renewable energy sources such as wind and solar power be adopted in Quebec to produce electricity, and even heat?

One reason is that even in Quebec clean, safe, and inexhaustible solar power is now profitable in both its main technological applications (photovoltaics [PV] and solar thermal), that is, it is capable of rapidly affording a relevant return on investment, providing electricity (and heat) at a cost that is at, or below, the current retail price of grid power or of natural gas. As we detail below, PV panels have dropped in price by 90% in the past 5 years; whereas solar thermal systems today are an economic and highly efficient alternative to traditional heating systems in many countries, including Quebec.

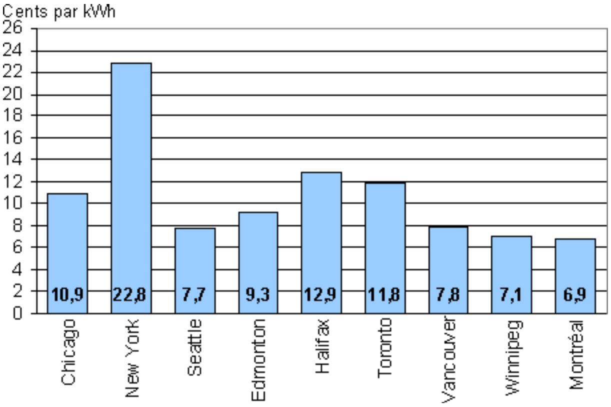

Figure 1. Comparison of the domestic electric tariff in different North America cities as of 1 April 2010. (Reproduced from www.mrn.gouv.qc.ca/energie/statistiques/statistiques-energie-prix-electricite.jsp, with kind permission).

Another reason is to protect the environment. In 2010, the award-winning documentary *Chercher le Courant* ("Seeking the Current") used the Romaine river dam project to demonstrate to the French-speaking community of Quebec the serious damage to the ecosystems imparted by dams, which continues to affect wildlife for decades. Once dammed, rivers that once supported a variety of wildlife become artificial lakes that are foreign and useless to local species [5]. Moreover, mercury deposited over centuries, when lowlands are flooded by a dam, is released into the water, poisoning fish not only for man's consumption but also for endemic fauna.

Finally, energy transition from large centralized stations (even hydropower stations) to decentralized energy production is a common shift throughout developed countries [6]. In Germany, the Feed-In-Tariff (FiT) incentives enabled the installation of over 32,000 MW of grid-connected PV power. On 25 May and 26 May 2012, over two-thirds of the Germany's daily electricity power needs were provided by the PV modules [7]. On February 2012, a winter month, Germany was able to export electricity to France, even though at the same time eight of German 17 nuclear reactors had been shut down following the Fukushima's catastrophe. In the following article, we expand upon this topic and provide arguments that support our viewpoint that solar power technologies will soon become a widespread means to locally producing energy in this large region of the world.

The Potential of Solar Power in Quebec

The potential for both solar and wind power in Quebec is impressive. According to a 2005 study commissioned by the Province's Government, Quebec's wind power potential exceeds 4000 GW (gigawatt) [8], enough to power the whole Northern America three times with clean electricity. In practice, the development of wind power in the Province has been rather limited. For example, Sicily, a windy Mediterranean island, with its 2.1 GW windmill farms installed at the end of 2012 had almost twice the installed capacity of wind power of Quebec (1057 MW), even though many wind farms are still under construction and the estimated installed capacity in Quebec for 2015 is 4000 MW [9].

In 2006, new insolation maps were made available online by Natural Resources Canada providing citizens and companies with reliable estimates of yearly PV system electricity production at any chosen location [10]. From these maps, one can learn that, contrary to mainstream thinking, Quebec is a sunny region whose solar power potential (900–1200 kWh/kW PV potential, depending on the region) is comparable with Spain's Barcelona. For instance, the insolation level of Quebec City, the Province's capital, is only 27% lower than that of the capital of Sicily:

Québec: 1.134 kWh/kW
Palermo: 1.438 kWh/kW

Furthermore, in Quebec customers of Hydro-Québec with power demand lesser than 50 kW who are able to meet their own electricity needs from a renewable energy source can already choose the Net-Metering option [11]. In other words, residential or agricultural customers and small-power business self-generators of electricity can feed their surplus power into the Hydro-Québec grid in exchange for credits in kilowatt hours that are applied to the self-generator's electricity bill. Inversely, if customers do not generate enough power for their needs, they can draw electricity from the grid.

Yet, solar PV plants in Quebec are almost absent. In general, the prolonged high cost of PV modules as well as of batteries made off-grid solar power a costly but unavoidable solution to power remote homes, telecommunications equipment, oil and pipeline monitoring stations, and navigational devices. Again, for comparison, in March 2013 the PV power installed in Sicily exceeded 1100 MW when the overall power installed in Quebec did not reach 10 MW [12].

What are thus the main obstacles to the widespread adoption of PV electricity in Quebec? According to a survey commissioned by a Canadian bank in 2010, 67% of Canadians aged more than 25 years who owned a home wanted to install a solar plant, but they were deterred by high cost [13].

One recent case is somewhat revealing. The administration of Quebec City on January 2012 commissioned a 15 kW PV plant to be installed on the rooftop of a public building (Fig. 2). The city agreed to pay the plant over

Figure 2. Since early 2012, the "Drolet" building of Quebec's municipality hosts 60 PV monocrystalline silicon modules each of 250 W nominal power. (Reproduced from Ref. [14], with kind permission).

150,000 CAD (134.100 CAD plus taxes; and 12.500 CAD plus taxes for the monitoring system) [14].

In other words, taking into account the average January 2012 rate exchange between United States and Canada's dollar (1 CAD = 1.01 USD) [15], while the price of the solar modules had dropped to 0.80 $/W(dollar-per-watt; see below), the city paid the PV plant 10 dollar-per-watt. Given that the above system is expected to produce 19.000 kWh per year, affording about 1900 $ savings in the electricity bill, its payback time will be 79 years.

Nor are such exceptionally high prices typical only of PV systems. For example, according to a public relations website [16] established by the monopolistic utility of the Province, the price of a water solar heater for a family of four would be in the range of "$6000 to $ 9000" leading to payback period "in the order of 50 years". Yet, in most EU countries, where the cost of labor and taxation are generally higher than in Quebec, the market price of a state-of-the-art solar water heater for a family of four is currently less than 1.000 €, installation included.

We are not aware of any trade barriers imposed by Canada's and Quebec's Governments to imported solar systems, and therefore, the price above seems to indicate a local market of solar systems apparently unrelated to the global market of solar energy technologies.

On the other hand, the solar thermal market in Quebec is rather developed with two leading manufacturers of thermal solar systems producing efficient air heating systems increasingly installed in the Province's buildings where they provide a rapid (2–3 years) payback time. Solar thermal collector plants, furthermore, are ideally suited for buildings of Quebec, as they will contribute to saving electricity largely used for heating purposes during the long and dry (and thus sunny) winters typical of the Province.

Both passive wall solar systems facing south and solar thermal rooftop collectors are a very valuable way of producing heat in Quebec with no CO_2 footprint, with much lower return on investment timeframes due to the low cost of materials (Fig. 3) [17].

For example, the large building of Quebec City RTC public transportation company was previously using 650,000 m^3 of natural gas in conventional gas-fired equipment and 11.5 million kWh of electric power annually (of which 8 million were attributed to heating costs) costing nearly $1 million in energy annually [18]. Now, wall-mounted and roof-mounted (Fig. 4) solar hot air collectors, entirely manufactured in Quebec, allow 35% energy savings.

Solar Energy Markets in Quebec

The current PV market in Quebec is economically not significant. As of 21 January 2013, out of 3.7 million customers of Hydro-Québec, only 41 were self-producers of

Figure 3. Part of the 144 solar collectors on the flat roof of Quebec City public transportation company bus headquarter. Each collector rapidly heats air and generates a 2.5-kW capacity on optimum solar days. (Reproduced from Ref. [18], with kind permission).

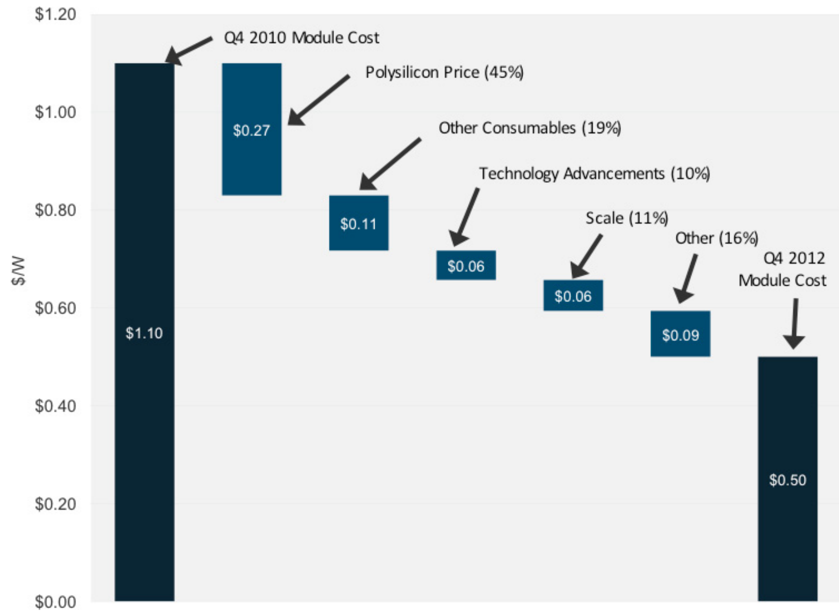

Figure 4. Contribution of key drivers toward module cost reduction (2010–2012). (GTM Research [29]).

electricity under the Net-Metering scheme (and 69 more customers were in the process of being admitted to the program). Annual insolation levels in Quebec are higher than Germany's. In Germany, however, 10 million buildings are equipped with solar modules that locally generate electricity where it is needed, when it is mostly needed; namely during the solar day.

The biggest obstacles to the diffusion of PV electricity in Quebec are not technical nor economical, but rather dependent on the lack of an adequate commercial offer for Quebec's population. Since 1983, the not-for-profit organization *Énergie Solaire Québec* (ÉSQ) associates the few solar companies of the Province, and carries out admirable public outreach work on the use of solar energy.

In Quebec, public subsidies to solar investment have been made available for decades, until the recent *Programme d'aide à l'installation d'équipements solaires opérationnels* (PAIESO) that, between March 2012 and March 2013, covered up to 50% of the installed cost of solar thermal systems, or up to 75% of solar PV installations. The program specifically targeted commercial, industrial, institutional, municipal, and agricultural installations burning fossil fuels for power generation in off-grid and minigrid applications. It ended on December 2012, and was recently replaced by a new action Plan (*ÉcoPerformance*) supporting clean energy development [19].

This policy differs from the FiT program for grid-connected solar systems adopted in 2006 by the confining Province of Ontario where in a few years, more than 750 MW were installed [20]. Ontario's authorities indeed promised to phase out coal power, and to retire 1/3 of its nuclear power capacity in the Province by the end of the decade. With limited ability to further develop hydro resources, renewable solar energy is providing a way to meet a perceived capacity shortfall over the coming decade. Quebec faces none of these issues, and did not offer the same level of incentives.

First conceived by German sociologist and politician Hermann Scheer [21], under the FiT scheme the Government pays only the clean electricity actually produced (the kWh) by the PV system, but does not finance the purchase of the solar plant (the kW) like many States and Provinces (including Quebec) did between the 1970s and the 1990s. The FiT incentives therefore pushes investors to look for PV systems of lowest cost and highest efficiency, thereby promoting price reduction and technical innovation, along with economy growth and job creation.

Manufacturers of solar PV modules mainly concentrated on other regions of the world where the market was booming, have chosen not to advertise nor make strong commercialization efforts in Quebec. However, the current fall in cost of solar electricity to unprecedented lows makes solar electricity economically viable also in Quebec. For example, in 2012, Marquis Lemieux, a resident of the Chaudière-Appalaches region, self-installed a 7.5 kW PV system on his roof paying 15,000 $ the whole system (including cables, mounting system and inverter) [22]. This price (2 $/W) translates into a cost of solar electricity of 7,3 ¢/kWh for a system scheduled to last 25 years. The resident was paying a tariff of 8 ¢/kWh for the electricity retrieved from the Hydro-Quebec's grid.

The same family recently saw its electricity needs to increase, following purchase of an electric car that consumes between 5 and 7 kWh per day. The resident of Quebec was, therefore, planning to add 10 more solar panels (each of 240 W nominal power) on the roof, thereby bringing the installed power to 10 kW, for an overall cost of 20,000 $ including taxes.

The PV system will produce 11,500 kWh per year, covering the whole original electricity needs of the house (11,000 kWh per annum) where a geothermal heating pump system is used for heating.

Why do other inhabitants of Quebec not emulate their fellow citizen of the Chaudière-Appalaches region?

Few entrepreneurs and building owners are aware that $2/W is a realistic installed capital cost estimate for PV in Quebec. The most recent year for which data are available is 2011 when, according to Natural Resources Canada, the average installed cost for small (<10 kW) grid-connected systems in Canada was $6.79/W [23]. Since then, however, the price of solar modules has reached the $0.5/W threshold. Even including labor installation and BoS (Balance of Systems) costs, the apparently low $2/W installed capital cost comprehensively includes the profit margins expected by the PV installation companies.

Quebec's typical flat large roofs of low-rise government and commercial buildings, as well as the steepy domestic rooftops, are ideally suited for integrating new-generation BIPV (building-integrated PVs) solar modules [24], providing buildings with several new functions while producing a portion of the building's electricity need. Roofs will thus be conveniently covered with PV modules converting buildings from energy users to energy producers, whereas façades oriented toward the south will be integrated with thermal solar collectors providing heat at no fuel cost for buildings currently consuming huge amounts of electricity for heating; a high entropy generation use of valued electricity that should be avoided. Indeed, a high exergy source such as electrical power should be used to power appliances that require a high exergy content, such as artificial lighting, electronic devices, and electric motors [25]. If high exergy sources are to be used anyway, efficient processes are needed, like heating with heat pumps, but not with direct heaters degrading high exergy electricity into low value heat at low temperature.

Trends in the Global PV Market

In the last decade, the global PV industry has turned from a stagnant industrial sector with a few traditional players serving niche markets, into a global large industry with over 2000 modules manufacturers across the world assembling solar cells.

Solar cells today are mainly manufactured in Asia, and especially in China. Contrary to many segments of the electronics market, there is no dominant player in the PV industry. In 2012, when the global PV industry manufactured 31.6 GW of solar cells, even the two largest PV module manufacturers of 2012 (Table 1) accounted for about 6% of the global market [26].

With booming production and overcapacity, the price of solar modules fell from 7 $/W in early 2008 to 0.80 $/W (dollar par watt) on March 2012. Such a rapid fall in price of PV modules inevitably caused bankruptcy of numerous manufacturers of PV modules, not only in Europe and in the United States, but also in China. Yet, it has eventually made solar electricity cost-competitive with fossil electricity, initiating a boom that is eventually extending to North America where PV energy had remained stagnant for over 30 years. For example, despite the large dumping and countervailing duties on solar cells and modules imported from China enforced by the U.S. Government in 2012 [27], 100% of new U.S. electricity generation installed in March 2013 was solar power (Table 2).

As remarked by Barnes [28], a decade ago overflowing broadband capacity bankrupted some major telecoms

Table 1. The top 10 photovoltaic module suppliers by production in 2012[1].

Rank	Company	Production (MW)
1	Yingli Green Energy Holdings Co. Ltd (China)	1950
2	First Solar Inc. (U.S.)	1900
3	Trina Solar Limited (China)	1700
4	Suntech Power Holdings Co. Ltd (China)	1500
5	Canadian Solar Inc. (China and Canada)	1500
6	JA Solar Holdings Co. Ltd (China)	950
7	Flextronics International Ltd (Singapore)	900
8	JinkoSolar Holding Co. Ltd (China)	900
9	SunPower Corp. (U.S.)	850
10	Hanwha SolarOne Co. Ltd (South Korea)	850

[1]Source: IHS Solar Integrated PV Market Tracker – Q1 13 April 2013.

Table 2. New electricity generation (new build and expansion) in the United States on March 2013[1].

Primary energy source	March 2013 installed capacity (MW)	January–March 2013 (cumulative)
Coal	0	0
Natural gas	0	340
Nuclear	0	0
Oil	0	0
Water	0	5.4
Wind	0	958
Biomass	0	46
Solar	44	537

[1]Adapted from Ventyx Global LLC, Veolicty Suite, 2013.

players, but laid the foundation for the explosive growth of the Internet that today binds us all. Something similar is happening to the PV industry. In other words, today's PV manufacturing companies mainly compete on price and quality as many computer manufacturers did during the 1990s, with many companies failing along the way (over 150 only in the United States).

The target of 0.5 $/Watt panels was reached in late 2012 (Fig. 4) [29], opening the route to retail grid parity in large parts of the world, including developing countries. For example, in Bangladesh (where 60% of the 150 million population has no access to electricity) around 1.4 million solar home systems are already installed to supply electricity to some 5 million people. In 2002, the number of PV systems installed in this large country was about 7000 [30].

One might, therefore, ask if the industry overcapacity (production capacity of PV cells at 55 GW vs. 36 GW demand in 2012) will lead Chinese manufacturers to take off line the manufacturing capacity installed at high cost in the last 5 years [31]. We argue that this will not be the case. Clean solar electricity is a strategic energy option for a huge country such as China where electricity demand grows at a double-digit rate [32], and where heavy atmospheric pollution requires the Government to act to protect the environment and public health.

China has no economic and environmental interest to dismantle an advanced technology infrastructure thanks to which the country gained predominance in a market once dominated by Japanese and German manufacturers. To the contrary, the country's PV companies will increasingly supply low-cost solar modules to families and businesses in large developing countries such as China, Brazil, India where electricity demand is growing at fast rate; and also to North American customers, including those based in Quebec, where the solar power potential has remained largely untapped due to prolonged high cost of solar modules, and to burdensome permit rules. For example, it can take as little as 8 days to license and install a solar system on a house in Germany. In the United States, depending on the State, the average ranges from 120 to 180 days [33].

Indeed, the first signals that this shift in the PV market was already underway are evidenced from recent estimates that forecasted 250% growth of the installed PV capacity in 2013 in the Middle-East and Africa regions; 50% in the Americas; and 65% in Asia [34].

Outlook and Conclusions

One might reasonably ask if Quebec does really need solar PV. The Province, after all, currently has a significant overcapacity in its electricity system and exports power to neighboring jurisdictions making substantial profits. The reason to bring in significant solar PV into the grid, we argue herein, lies in the low cost of today's and tomorrow's solar electricity, as well as in the need to increase the resilience of the region's power system whose weakness was clearly shown by a dry summer in 2013 and the subsequent winter storms.

The main objection to solar electricity is that PV systems in Quebec operate the equivalent of about 1100 h/year at full capacity. Hence, what will the homeowner do for the other 7600 h/year when she/he wants heat or light or refrigeration or the Internet?

Like in Germany and Italy, where huge 32 and 18 GW amounts of solar power are installed, the homeowner in Quebec will continue to use the existing grid-scale power generation conveniently providing building owners with power during the 85% of time the PV system is not generating. Yet, as mentioned above, Quebec is unique as its electricity originates from an eminent renewable source, hydropower. Said huge dam reservoirs are ideally suited to store the reserve power necessary for development of intermittent renewable energy sources, especially wind and solar power [35].

Hence, the clean electricity generated by new solar roofs and solar fields scattered across Quebec, covering a very small fraction of the huge Province surface, will be directly fed into the existing grid, or stored through the dams and made available for use when most needed. This will avoid power outage such as the one that hit many cities of Quebec, including Montreal, during the 2013 dry summer when three major transmission lines were shut down by heat and smoke from forest fires in northern Quebec [36]. Indeed, this is what happens today in Sicily, where summer power outages were all too common until 2011 and since the summer of 2012 have practically disappeared thanks to the new 1000 GW solar power installed that is fed into the grid from several large (>1 MW) PV plants scattered across the island.

Considering adoption of PV energy on large scale, the economic criterion limits action to what is economically viable [37]. Hence, an evaluation of the feasibility of proposed policies and the economic potential should be taken into account first. It is the low (<0.50 $/W) and continuously diminishing price of solar modules of prolonged stable efficiency (25 years linear performance guarantee on production is now the industry's standard for reputable manufacturers) that makes the case for a rapid adoption of solar electricity also in Quebec.

In brief, today's low-cost PV electricity provides the community in Quebec with the potential to transform the roofs of hundreds of thousands of homes, government, and commercial buildings into energy generators creating wealth and thousands of domestic jobs.

The rooftop solar industry in Quebec will grow at a fast rate. The entry level is low, and companies that traditionally built houses and large buildings in Quebec have the basic knowledge that will allow them to develop new skills quickly. Snow accumulation during winter provides PV cells with extra light coming from the albedo effect. Facing South and mounted at a steep angle for optimal light collection during winter, solar modules easily shed snow requiring no clearing from homeowners, unlike driveways and sidewalks in Quebec.

Finally, one should acknowledge that no technology will be adapted by the market without broad social recognition. Everywhere in affluent countries people convincingly appreciate solar energy [38]. In 2004, due to environmental concern, Quebec's citizens had declared their preference for wind over hydroelectric power [39]. In the early 1990s, 83% of Canadians agreed that environmental protection would stimulate rather than hinder economic development [40]. Canada's citizens were, and are, convinced that each person can take positive actions and solve the environmental crisis.

Few other actions provide more personal gratification than installing solar modules over one's property roof and monitoring their production (money savings and the amount of carbon dioxide and particulate emissions offest) [41]. Citizens using solar systems to self-generate energy benefit from positive emotions due to pollution mitigation, and develop a sense of responsibility and awareness thanks, for example, to the easy monitoring via a mobile phone of the energy that is being produced by their plant during the day.

Finally, distributed solar power made available through tens of thousands of PV plants distributed across Quebec's roofs and solar fields will be ideally suited to provide recharge of batteries for the new battery-powered electric vehicles in line with what Bolduc, an eminent practitioner of the electricity industry in Quebec, has called "electricity's second coming-of-age" [42], that will see rapid penetration of clean electricity into markets traditionally dominated by the petroleum industry: personal and public transportation.

In conclusion, what Quebec now mostly needs, to make this shift a reality, is entrepreneurial initiative. After all, Quebec has been using hydroelectricity for over 40 years to entirely produce its electricity from renewable resources, showing the commitment of its government and population towards green energy. Massive adoption of low-cost solar energy technologies and the electrification of the transport system will be natural further steps.

Conflict of Interest

None declared.

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