A RENEWABLE ENERGY OPTION

# PHOTOVOLTAIC SOLAR POWER

# THE ENERGY OF THE **SUN**

**PHOTOVOLTAIC SOLAR POWER:** ENERGY FROM SUNLIGHT, CONVERTED DIRECTLY INTO ELECTRICITY BY MEANS OF A PHOTOVOLTAIC COLLECTOR

## CURRENT STATE OF KNOWLEDGE

The photovoltaic industry has made considerable progress in the last decade. Its installed capacity shot from 1,790 MW to 137,000 MW between 2001 and 2013, an average increase of 40% per year. In 2013, photovoltaic solar power accounted for about 1% of the world's total electricity output and 4% of the available installed capacity.

Photovoltaic systems connected to a power grid represent 95% of the current market, with off-grid systems representing the remaining 5%.

In Québec, centralized photovoltaic solar power generation is in the experimental stage. While distributed generation does exist, it is still very rare.

## PHOTOVOLTAIC SOLAR POTENTIAL

The availability of solar energy varies: the amount of sunshine depends on the time of day, weather and season, and it can be difficult to predict. Daily sunshine levels in Canada also vary by region. In Québec, solar energy is unavailable during peak demand periods (mornings and evenings) in the winter. As a result, photovoltaic systems must be adapted to the wide swing in sunlight levels we experience between the summer and winter, especially in northern Québec.

This fluctuating availability of solar energy has a number of technical repercussions for photovoltaic systems connected to Québec's transmission system, especially if the total or local installed capacity becomes significant. Ultimately, these technical constraints will have an impact on the choice of power generation system, in light of the costs involved.

In southern Québec, where most of the population is concentrated, the average annual load factor for photovoltaic systems is close to 16% or 17%. That is higher than in Germany and Japan, even though they are the leaders in the global photovoltaic solar power industry.

Cover: Ground-mounted photovoltaic panels

Opposite: Photovoltaic panels on the roof of a house

## LEARN MORE

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## OUTPUT AND COSTS

In 2014, energy conversion efficiency for photovoltaic modules used in electrical microgrids averaged 15%. The efficiency rate for multijunction cells exceeded 40%, but their production cost is still too high for large-scale use. Photovoltaic technologies have varying levels of sensitivity to temperature, and as a result their efficiency and output for a given level of sunshine (insolation) can vary by up to 30% between summer and winter.

The main obstacle to the growth of photovoltaic solar power remains the upfront costs. Over the last decade, an entire industry has sprung up thanks to generous development incentives, especially for systems connected to power grids. In recent years, however, costs have come down considerably.

In Québec, the current upfront costs (2014) for small photovoltaic systems connected to a power grid are still higher than for wind power or hydroelectric projects (Hydro-Québec projects).

## ADVANTAGES AND DISADVANTAGES

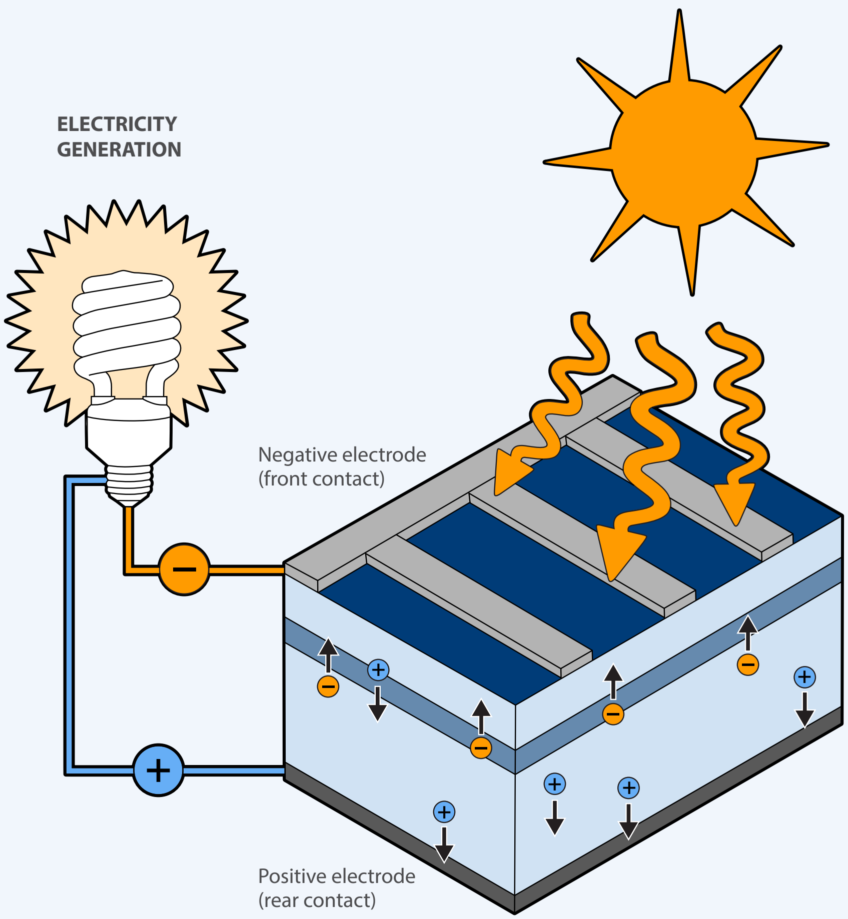
- Intermittent output that varies depending on the time of day, weather and season and can be difficult to predict
- Output optimized through the use of energy storage systems
- No moving parts
- Variable size and scalable or modular design (with modules added as required), making it possible to increase installed capacity
- Reliability and long service life (about 30 years)
- Little maintenance required and low operating costs
- High site potential (buildings, parking lot sun shades, open spaces, etc.)
- Ground-mounted systems requiring considerable space

## SUSTAINABLE DEVELOPMENT

The main issues for large-scale photovoltaic systems are the following:

- Visual impact: number of units, size, color and light reflection
- No noise
- Obstacle to rain runoff and partial soil sealing (depending on system foundation)
- Use of large quantities of water for cooling and cleaning purposes, production of wastewater
- Increased risks of soil degradation, including erosion
- Impact on natural habitats and disruption to wildlife
- Possible conflicts: farmland, access roads, woodlands and built environments (impact on property values)
- Use of toxins during manufacturing
- Zero greenhouse gas and atmospheric contaminant emissions during operation
- Small environmental impact over the facility's life cycle

# A SUSTAINABLE RESOURCE




## The photovoltaic effect

The photovoltaic effect is the direct conversion of photons (sunlight) into electric current by means of a semiconducting material. Most existing photovoltaic collectors, based on monocrystalline or polycrystalline silicon, come in the form of panels that are laid on the roofs of houses or other buildings.

Photovoltaic solar cells use the photovoltaic effect to convert sunlight directly into electricity. A photovoltaic system consists of an array of cells arranged in panels that are connected in series, in parallel or by both methods.

## Type of technologies

There are a range of photovoltaic technologies, and they have reached different levels of development.

### Photovoltaic panels

- **Crystalline silicon** – thin slices cut from a silicon crystal (in the case of monocrystalline silicon) or from a block of silicon crystals (polycrystalline silicon). The main types of crystalline cells in use are monocrystalline, polycrystalline and ribbon silicon. Their manufacture requires a significant amount of energy and raw materials.
- **Thin-film** – thin layers of a photosensitive material laid on a substrate (glass, stainless steel or plastic). The main types of materials used are amorphous silicon, cadmium

telluride, copper indium diselenide and copper-indium-gallium-selenium. Their manufacture requires less energy and raw material.

- **Flexible cells** – created by depositing an active material on a thin plastic substrate, making the entire assembly flexible. Their manufacture requires little energy and raw material.

### Concentrators

An optical concentrator uses a lens or mirrors to focus sunlight on photovoltaic cells placed inside a collector. This system generally uses a small number of multijunction solar cells, which provide record energy conversion rates exceeding 40%.

## Solar power generation methods

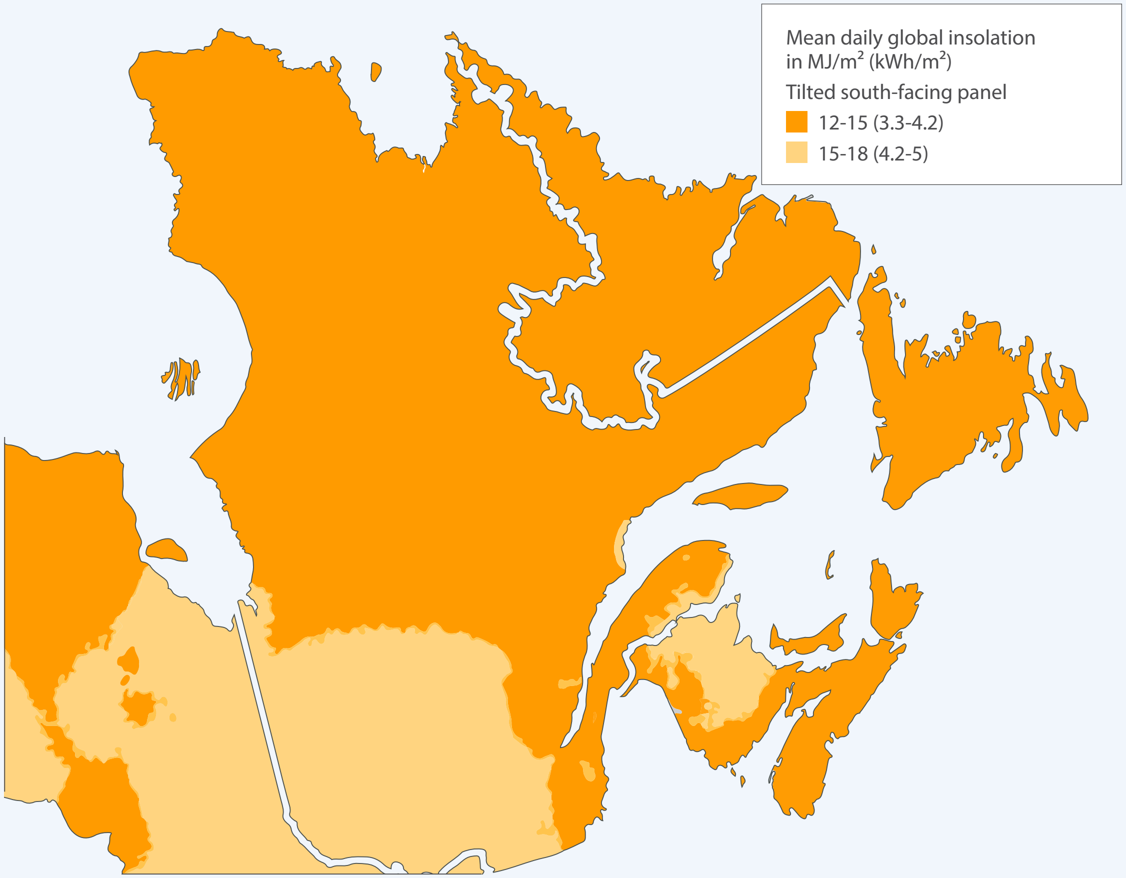
### Photovoltaic solar power generation

- **Autonomous photovoltaic device** – used to supply electricity to low-power systems for applications such as optical signaling, battery recharging and satellite powering
- **Building-integrated systems, whether connected to an electrical system or not** – used to provide power for buildings. Customer-generators can meet their own power needs and sell any surplus.
- **Photovoltaic power stations or farms connected to the electrical grid** – use the photovoltaic effect to generate electricity.

### Other solar power generation methods

- **Passive solar** – the building's orientation and its window placement and size, along with thermal walls and electrochromic windows, are designed to take maximum advantage of incoming solar energy to assist in heating and cooling.
- **Solar thermal** – these systems generate only heat and involve the use of a heat transfer fluid and glazed, unglazed or vacuum tube collectors or other collector materials. Frequent applications include water heaters and pool heaters.
- **Thermodynamic solar power plants** – the concentrator, or solar collector, uses reflecting metal sheets in a variety of shapes (flat plates, cylindrical or parabolic dishes) to focus direct radiation onto a collector surface at the focal point. Depending on the degree of concentration, focal point temperatures can reach 350°C to over 1,000°C. That heat is used to drive a steam turbine and produce electricity. This technology is most often used in desert regions.

### GEOGRAPHIC DISTRIBUTION OF MEAN DAILY INSOLATION* IN QUÉBEC




Source: Natural Resources Canada

* Insolation: the amount of incoming direct solar radiation on a unit horizontal surface at a specific level, measured in W/m²

## Intermittent sunshine

The amount of sunshine depends on the time of day, weather and season, a fact that has a direct effect on the production of photovoltaic solar power.

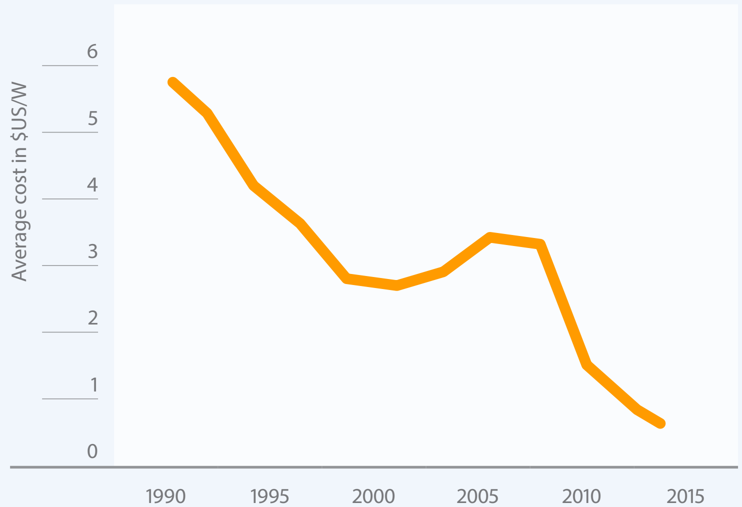
- **Day/night variation** – On a clear day, the intensity of sunlight drops from a maximum of roughly 1,000 W/m² around noon to nearly 0 W/m² when the sun has set. This variation is predictable.
- **Cloud cover** – Clouds reduce the amount of sunlight reaching the ground, decreasing the amount of power generated. The decrease can last anywhere from a few seconds (on partly cloudy days) to several days (during extended cloudy periods). This variation is more or less predictable.
- **Seasonal fluctuation** – Around the world, day-to-day sunlight varies by season. In southern Québec, average sunshine climbs 50% from December to June and rises even more as you move further north. This is a predictable variation.

## Daily insolation

In Québec, mean insolation for the most heavily populated regions (shown in light orange: 4.2 to 5 kWh/m²) is considerable. It is greater than in Germany and Japan, where insolation levels are comparable to those of central Québec (in dark orange: 3.3 to 4.2 kWh/m²). Nevertheless, these two countries are currently the world leaders in the photovoltaic solar power industry.

## Average costs

**AVERAGE COST OF A CRYSTALLINE SILICON PHOTOVOLTAIC MODULE – 1990-2013**




In recent years, the photovoltaic solar power market has undergone a significant transformation, resulting in steadily declining prices. In Canada, upfront costs for a photovoltaic system (> 100 kW) connected to an electrical system dropped from $1/kWh to less than $0.35/kWh between 2002 and 2014. The increase in photovoltaic module costs observed between 2004 and 2008 is the result of a global shortage of crystalline silicon, which has since been replaced by a type of silicon developed specifically for the industry. Over the 2009–2014 period, production of photovoltaic modules continued to increase, and upfront costs continued their steady fall. The decline is projected to level off at around $0.75/W.

## Systems and networks

Photovoltaic systems may or may not be connected to a power grid.

### Systems connected to a power grid

- Systems connected to a building that uses electricity
- Systems integrated into a structure that is connected to a power grid or another electrical system (e.g., a roof over a public walkway or a sound barrier)
- Systems composed of an array of cells arranged in ground-mounted panels connected in series, in parallel or by both methods. These systems can cover thousands or tens of thousands of square metres. Such centralized generating systems feed power to power grids.

### Off-grid systems

Artificial satellites, portable devices, small accessories like calculators and watches, road signs, highway emergency telephones, parking permit dispensers, telecommunications links, shipping and air traffic beacons and isolated sites (electrification).

## Climate change and air quality

In photovoltaic solar power, greenhouse gas and air contaminant emissions are produced solely during infrastructure manufacturing and installation. During the operations phase, photovoltaic systems do not produce any emissions. Emissions attributable to infrastructure manufacturing depend primarily on the types of energy used in the region where the components are made.

## Life cycle assessment

Generally speaking, the main environmental impacts of photovoltaic solar power, depending on the approach taken to the product or facility life cycle, are estimated to be slightly greater than for hydroelectricity and other renewable energy sources. System service life, sunlight conditions and the manufacture of panels are the most relevant factors in the life cycle analysis for this power option.

Comparing Power Generation Options and Electricity Mixes and Small-Scale Distributed Electric Power Generation: full reports available in French only.

## Ecosystems and biodiversity

The installation of a ground-mounted photovoltaic solar farm could have various impacts on the natural environment: erosion, small changes to vegetation cover, etc. The main risk is to local fauna, particularly any animals forced to move following the erection of a fence on sometimes extensive lands. Large projects should provide for fence openings and corridors to facilitate the safe passage of animals. The benefits provided by photovoltaic projects in arid regions include creating shade for small animals, limiting invasive species populations and reducing disturbances caused by off-road vehicles.

Disturbances to aerial fauna (birds and insects) caused by photovoltaic infrastructure would most likely be minor and much smaller than those caused by any other type of infrastructure. The idea that aquatic birds could confuse photovoltaic modules with bodies of water appears to be unfounded. A study carried out in Germany on a photovoltaic facility adjacent to an immense Main-Danube canal holding basin was inconclusive in this regard.

Cleaning panels requires a considerable volume of water, which may make less water available to fauna and flora in some areas. Overall, however, photovoltaic solar power would appear to require much less water than thermal generation (coal and nuclear energy, for example).

## Health and quality of life

Some material compounds used in manufacturing photovoltaic systems, such as cadmium telluride, are a concern due to their toxicity. However, only small quantities are used in the manufacturing process, and they are not released into the atmosphere during system operations. In the United States, cadmium emissions associated with solar power are 150 times smaller than those associated with coal-fired generation. Moreover, once the solar cells have reached the end of their useful life, the metals can be recycled. However, there are few recovery sites to date.

In non-electrified areas, the use of solar power improves quality of life. For instance, it can be used to provide lighting or access to information (radio, TV and cellular telephony), which can help improve literacy rates. Moreover, the use of electric lighting and electric or solar-powered stoves is beneficial for human health, unlike the use of wood or oil products inside the home, which produces atmospheric contaminants.

## Land use

Although a photovoltaic solar farm clearly occupies more surface area than a wind farm, its visual impact is smaller. Here's why:

- Its horizontal structure is only a few metres high, making it unobtrusive, even for observers at close proximity.
- Its colors are neutral, ranging from medium blue to dark gray.
- There are no moving parts to draw an observer's eye and attention.

Interestingly, a photovoltaic solar power plant does not occupy any more space than a U.S. coal-fired generation station. In fact, over the entire lifetime of a coal plant (25 years), generating and transportation activities take a great deal of space.

A building-integrated photovoltaic system may have a visual impact or obstruct the view, but less so than a ground-mounted system. Fixed to a roof, it does not require any ground of its own.

There may be land-use conflicts between agricultural operations and photovoltaic developments. However, photovoltaic systems can be located on a wide range of sites: vacant lots, brownfields, adjacent to highways, railways or airports, etc. They can even be compatible with certain agricultural practices, like raising sheep, beekeeping and vegetable farming.

## Regional economy

Photovoltaic solar power projects are expensive but can create jobs and local economic spinoffs during construction and dismantling. Leveraging this source of power, which can help secure energy supply, will also spur regional development and strengthen energy security. The extra power sold to customers or local distributors is a new source of revenue, and local benefits may be considerable if the owner and installer, as well as the material used, hail from the host community. In addition, the small amount of infrastructure maintenance required should be easy to carry out in the community using available local resources. The number of jobs created per megawatthour is higher for photovoltaic solar power than for thermal power.

## Social acceptability

Generally speaking, photovoltaic solar power is well accepted in the community. The environmental repercussions on the landscape and wildlife, when effectively managed, are limited. However, this source of energy still sees little use in Québec. Taking certain steps could contribute to its growth and development:

- Providing government support to municipalities to foster conditions conducive to photovoltaic solar power
- Ensuring a better understanding of the potential impacts of technologies currently in development

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