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Article

Sustainable integration of photovoltaic systems in different climatic conditions—A financial and environmental assessment

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Abstract: The current paper investigates a 6 MW grid-connected photovoltaic system model in two different countries: Canada and Egypt. The analysis was conducted in the frame of a sustainable development feasibility assessment. The two countries were chosen as they have significantly different irradiation levels. Two cities within each country were considered for comparison. The proposed system is simulated under realistic conditions in RETScreen. The weather conditions were imported from the NASA (National Aeronautics and Space Administration) website. The project viability has been assessed using different financial indicators. Amongst them is the payback. Payback of projects located in Egypt is considerably lower than in Canada. The payback in Kharga Oasis in Egypt is 7.3 years. It yields a reduction in greenhouse gas emissions of 62.7 tons of CO_2. The payback in a low-irradiation city like Victoria in Canada is 13.3 years. The project installed in Victoria mitigates greenhouse gas emissions by 53.2 tons of CO_2. The study also shows the detrimental effect of increasing the initial cost and debt term on the project's financial viability. The outcome of the study concludes that PV projects are very promising in moderate weather like Egypt. It can be viable in northern countries like Canada but under certain conditions of operation and financing.

Keywords: solar; photovoltaic; financial analysis; payback; economic feasibility

1. Introduction

Canada is one of the largest countries on earth. Its area is around 10 million square kilometers. **Figure 1** shows the average irradiation level in different Canadian locations. It can be seen that there is a vast variation between different provinces. Typically, most of the country receives a moderate level of irradiance (around 800 kWh/m^2). Those typically lie in Central Canada (Ontario and Quebec). There are some hotspots that have higher solar intensity (can reach up to 1400 kWh/m^2). They are concentrated in the Prairie Provinces (Saskatchewan, Alberta, and Manitoba). A below-average irradiance is experienced at the west coast of Canada (British Columbia).

Canada is committed to climate action and to the reduction in greenhouse gas emissions. Among the emerging clean technologies is the photovoltaic (PV) system. PV systems satisfy the electricity demand using renewable energy [1]. Throughout the recent decades, solar thermal energy has been used for water and space heating applications. Drake Landing solar community in Okotoks, Alberta, consists of 52 houses that have their heating demand provided by solar systems [2]. Seasonal storage has been a crucial part to utilize the excess heat in the summer months to be used in winter and cold months. The supply of heat to multi-residential buildings has been studied recently [3–6]. To accomplish this, different forms of storage—sensible, latent, or hybrid—can be used. The solar fraction of such systems can be more than 60%. This implies that more than three-fifths of the building heating demand is met through solar energy and the rest by auxiliary heating.

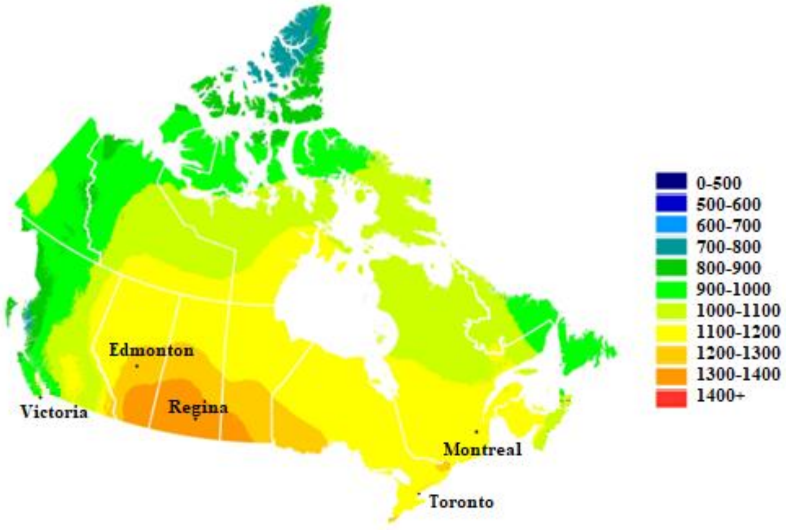

Figure 1. Solar irradiation map in Canada (units in KWh/m^2) [1] (yearly total).

In addition, solar energy has been used as a clean source for electricity generation. If it excites semiconductor material, an electric current is generated. The generated current is a strong function of semiconductor material and solar irradiance conditions [7–10]. The electricity can be used on a standalone basis for the small-scale applications. It can also be connected to the grid for large-scale plants. The exported electricity to the grid is a major source of revenue. In addition to the high potential of greenhouse gas emissions mitigation replacing traditional fossil fuel.

Although the solar technology is developing in Canada, the Canadian Solar Industry Association has high expectations for its future. It is setting an aggressive short-term goal to be accomplished by 2025 [11]. It targets a mitigation of 30 million tons of CO_2. Those targets are being supported by different incentives in the provinces and territories.

As photovoltaics is an emerging technology, the total installed capacity of PV plants worldwide is only a hundred gigawatts. Two-thirds of this capacity powers standalone small-scale projects. The rest is connected to the grid. The largest share of PV plants is in China, as it possesses two-fifths of the world’s capacity. Germany, Japan, and the United States of America come next after China. Although Canada has regions of high solar insolation, the total installed capacity is only three MW [12]. Until recent years, the PV plants were only located in the eastern provinces with minimal presence through the rest of the country. In the past two decades, the government has put in place its first program to support the renewable share in electricity generation [13]. It has provided 1.4 billion dollars of funding to expand the installed PV capacity by 50% in 2025. There are also indirect support programs that aim to expand the PV installations through different tax credits.

As Canada is a constitutional monarchy, the laws must be passed through both the federal and provincial levels. Unfortunately, the federal regulations are lacking.

However, the provinces have some incentives that vary widely from province to province. The provinces that have the highest support in place are Ontario (where half of PV plants are installed) and British Columbia.

In Ontario, there have been two major incentive programs: the Large Renewable Procurement program and microFIT [14]. British Columbia has three major incentive programs: BC Hydro net metering, FortisBC net metering, and the standing offer program. All of them offer extra cash incentives that range from 9 cents/kWh to 11 cents/kWh. This encourages residents to install their PV cells to be self-sufficient and to make more profit if applicable.

The rest of the provinces and territories offer comparable incentives. However, it still seems to be insufficient to encourage the widespread integration of PV technology in such a northern climate. In addition, there is still a huge misconception that Canada is not suitable for solar integration despite the moderate value of irradiance in the hotspots.

On the other hand, Egypt is a country with a much lower area (one-tenth the corresponding area of Canada). It is located in Africa, where the irradiation is a lot higher than in North America. The solar irradiation map for Egypt is shown in **Figure 2**. The country is dominated by above-average levels of solar irradiance compared to Canada (1500 KWh/m^2). Portions of the Delta and coastal cities on the Mediterranean Sea experience moderate levels of irradiance. The eastern region of the Nile River and the coasts of the Red Sea have significantly higher solar irradiance (more than 2500 KWh/m^2). The solar maps of the two different countries in two continents raise an interesting investigation for how solar integration will differ between them.

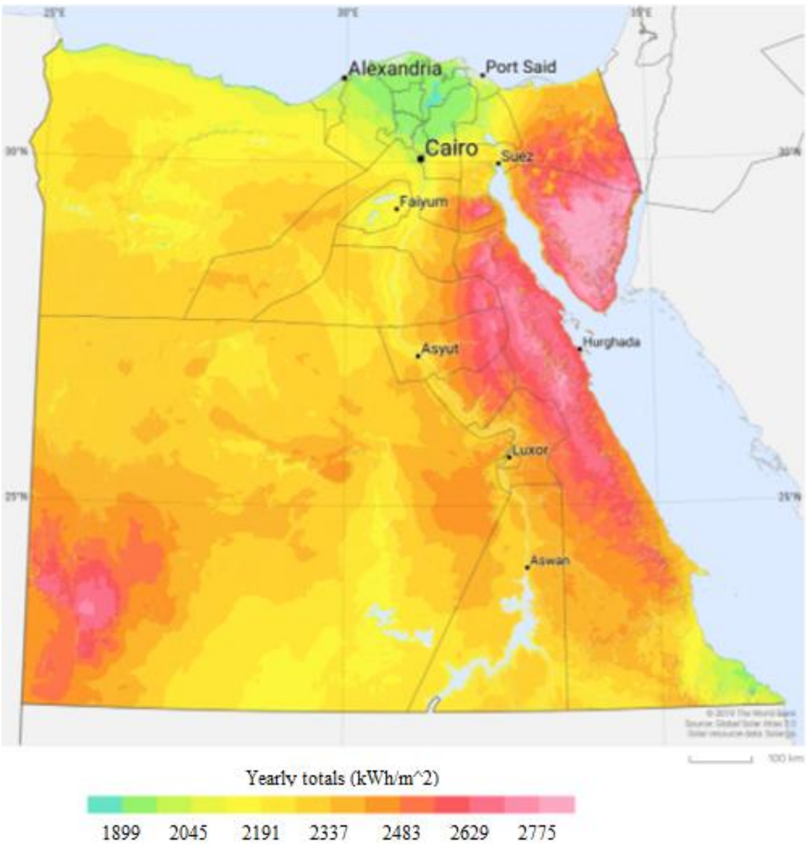

Figure 2. Solar irradiation map in Egypt (units in KWh/m^2) [15] (yearly total).

The higher solar irradiation in Egypt has motivated the authorities to increase the installed capacity in recent years. There has been an exponential increase in capacity from 2014 to 2018, where it increased from 20 MW to 750 MW [16]. In addition, Egypt is setting aggressive targets for renewable energy integration in the near future. The percent of renewables in the electricity supply mix will be 37% by 2035 [17].

One of the factors supporting the widespread integration of PV systems is the declining cost of PV modules in Egypt [18,19]. A decade ago, the cost of a residential system was about $10/watt. Recently, it dropped to $1/watt. This is attributed to the higher module efficiency with advanced technology and lower manufacturing cost for bulk production.

Residential photovoltaic systems prevailing in Egypt are two categories. The first one is a grid-connected configuration that does not include a battery or a generator. Although this configuration is less expensive, it is not reliable in case of a power outage. The second category includes the grid-connected system with a backup battery. This configuration is more reliable as the battery maintains the operation of some or all of the electrical equipment during power outages [20].

A recent research area has been directed towards including thermal storage in the PV system [21–27]. Those systems are sensitive to the operating parameters of the PV system and the storage. It is highly correlated to the availability of the solar resource and the demand needs. In such systems analysis, deterministic and probabilistic methods are used. The deterministic methods include an hourly representation for different variables that affect system operation. Probabilistic methods rely on creating hypothetical profiles for the variables under consideration that make them less accurate.

On the global level, different PV systems were studied either as standalone systems or integrated with other renewable technology. Jaszczur et al. [28] performed an optimization analysis for residential microgrid hybrid power. The optimization targets the lowest possible cost and the least environmental impact. They concluded that economic objective optimization has shown the lowest cost. Another work [29] has investigated the integration of a supercapacitor system to dampen the fluctuations experienced due to solar irradiation intermittency. It is an economical and efficient way compared to the battery system.

Ara et al. [30] presented a two-level framework for the economic feasibility of a renewable system. It investigates the integration of photovoltaic systems into wind systems. They proposed a particle swarm optimization technique for detailed analysis. A comprehensive review article by Mazzeo et al. [31] covered a wide matrix of operating conditions of such plants. Those include the location, component configurations, operating mode, and auxiliary components.

Both standalone PV systems and on-grid systems show promising potential. Hassan [32] studied both systems in the Iraqi climate. They concluded that the cost of an on-grid system is less than that of an off-grid system. In another study, Hassan [33] investigated the effect of different renewable energy integration fractions. They varied the annual renewable energy fraction for electricity supply from 32% to 96%. This has been accomplished by integrating an efficient fuel cell into the photovoltaic system.

Chen et al. [34] provided a review on the building-integrated photovoltaic systems. They reported the studies done since the 1990s on the topic. Their review found that PV panels were likely integrated into the walls and windows of buildings. Their performance was found to be sensitive to location and tilt angle. Belloni et al. [35] reported another review article on photovoltaic integrated building advancement. They focused more on the analysis and parameters influencing performance. They concluded that PV systems are crucial for smart buildings.

Hasan et al. [36] investigated the integration of a solar photovoltaic thermal system into a midsize office building. The buildings are supplied with heating through an air source heat pump. They considered the climatic conditions in 5 Canadian cities. They found that the 12 × 4 array on the building's north and the 12 × 5 array on the east and west facades could completely meet the power demand of the air source heat pump (ASHP) compressor.

Kathiravel et al. [37] reported a life cycle analysis of net-zero residential buildings in Canada. They drew their conclusions from 36 scenarios. They found that the building-integrated photovoltaic and geothermal systems yield a good performance. They show good economic feasibility when operating conditions are carefully considered.

Raihan et al. [38] investigated the renewable energy integration potential in Egypt. They found that there needs to be more incentives for businesses to consider renewable energy. They reported that an additional 1% incentivization for renewables can increase the gross domestic product (GDP) by 1.87%.

Megahed et al. [39] analyzed a roof-integrated photovoltaic system for a building in Egypt. They performed the sizing of different components. They reported that cooling of the PV system is crucial to ensure a steady, efficient performance. They pointed out that the cost of PV is the main hindrance to the widespread use of net-zero buildings in Egypt.

ElSayed et al. [40] studied the integration of photovoltaic and wind in water desalination in four ports in Egypt. They found that the technologies are very effective in reverse osmosis. The payback was also 1.1 years which is very reasonable for the application. Breuning et al. [41] studied both photovoltaic and wind energy in transporting green liquid nitrogen in Egypt. They have reported that the integration of both technologies yielded a desirable levelized cost of electricity. They also offered the advantage of flexibility of generation.

The previous review has shown the viability of PV integration worldwide. PV integration is being considered seriously in Canada and Egypt. However, it is still underdeveloped. There are still economic hurdles for widespread integration of such technology. However, incentives and global commitment to greenhouse gas emission reduction try to push it forward. This motivates the current paper to compare the integration of PV in the two countries. It includes a detailed financial model for comparison. It takes into account real weather data to simulate systems performance. This includes the variations on an hourly time step that increase the accuracy of the reported results. To the author's knowledge, such a comparison was not reported in the literature. The study aims to shed light on the conditions of viability of PV systems in different climates.

The main sub-objectives of the current research are as follows:

- Simulating PV systems under realistic climatic conditions for a detailed comparison between considered locations.
- Performing an economic analysis to investigate project financial feasibility in different climate zones.
- Comparing payback period and ensuring it is reasonable.
- Quantifying greenhouse gas emission reduction potential and hence environmental impact of PV system.
- Performing a parametric analysis and changing financial variables to ensure project feasibility.

According to the presented literature review, those sub-objectives have not been considered in both the Canadian and Egyptian contexts. The main goal of the proposed methodology is to provide researchers with creditable results. In addition to erasing the misconception of the inapplicability of solar systems in Canada.

2. Methodology and numerical model

The study aims to compare the feasibility of a PV project in different climates: Canada and Egypt. Two cities were selected in each country for the sake of comparison. In Egypt, Kharga Oasis and Safaga were chosen as they have high and low levels of radiation in the country. In Canada, Regina and Victoria were selected for comparison for the same reason. **Table 1** includes climatic data for the four locations. As the two countries lie within two different continents, they span a large range of latitude and longitude. Heating design temperatures are a lot higher in Egypt compared to Canada due to the warm weather in Egypt. Similarly, cooling design temperatures are higher in Egypt. Heating degree days and cooling degree days are used as an indicator for the times of the year when the system needs heating or cooling. They are defined as the number of days when heating/cooling is needed relative to a balance point temperature. The balance point temperature is the temperature at which the heat gain in the building is equivalent to the heat loss. Heating degree days are of the order of hundreds in Egypt, and it is thousands in Canada, as Canada has Northern inclement cold weather. Conversely, cooling degree days are a lot higher in Egypt compared to Canada, as the temperature there is a lot higher. The table shows the major difference in the climates in both countries. The present paper simulation considers the hourly variation of climate data. The degree days are listed to show the variation between regions climate conditions.

Table 1. Climatic data for the considered locations.

Location	Kharga Oasis, Egypt	Safaga, Egypt	Regina, Canada	Victoria, Canada
Latitude	25.5	26.7	50.4	48.4
Longitude	30.5	33.9	−140.7	−123.3
Heating design temperature (℃)	6.5	8.1	−30.9	−0.2
Cooling design temperature (℃)	42.6	38.9	29.4	22.3
Heating degree days	233	211	5613	2784
Cooling degree days	5513	5059	817	680

Average solar radiation on the horizontal is considered an important metric for photovoltaic system integration. **Figure 3** shows the average solar radiation in the four considered cities. As expected, cities in Egypt have much higher solar radiation. The highest is in Kharga Oasis, followed by Safaga. The Canadian cities possess lower radiation levels compared to Safaga. The radiation intensity in Regina is higher than in Victoria. The average annual values are given in **Table 2**. The irradiation level in Egyptian cities is 1.5 times higher compared to the corresponding level in the Canadian cities. **Figure 3** also shows the monthly trend of the irradiation. Levels in summer are much higher than in winter months for every location. It can reach as high as twice its value. The operation of the PV system on a continuous basis takes advantage of the shown variation.

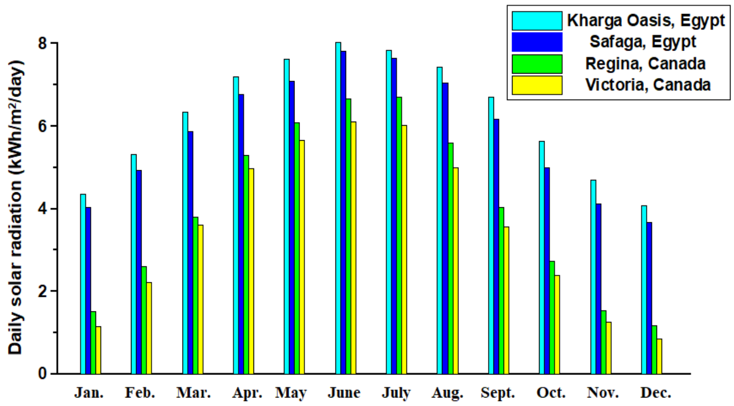

Figure 3. Monthly solar radiation on the horizontal in the considered locations.

Table 2. Average solar radiation per year for the considered locations.

Location	Kharga Oasis, Egypt	Safaga, Egypt	Regina, Canada	Victoria, Canada
Average annual solar radiation ($kWh/m^2/day$)	6.3	5.8	4	3.6

Table 3. Characteristics of the considered PV system.

Property	Value
Solar module type	Monocrystalline silicon
Total capacity	6 MW
Manufacturer	
Module number	20,000
Temperature coefficient	0.4%/℃
Nominal temperature of operation	45 ℃
Inverter type	Digital Luminous
Inverter rating	10 kVA/180 V
Inverter efficiency	95%

Table 3 includes the characteristics of the PV system components. It is composed of 20,000 modules, each of them with a 300 W output. The type of PV module is monocrystalline silicon material. They are more efficient than polycrystalline silicon

and more abundant. Their manufacturer is Greenpower, which is a common supplier for PV modules in both countries. The modules are positioned facing south with a tilt angle of 45° from the horizontal throughout the year. The chosen inverter for the system is a Digital Luminous one with a rating of 10 kVA/180 V. Its efficiency is 95%.

The simulations are done on RETScreen. It is a reliable simulation tool developed by Natural Resources Canada. It considers real climate data and system conditions. The RETScreen imports weather files from the NASA website. This takes into account the hourly climate variation and the day-night cycle. In addition to the energy model, there is detailed life cycle financial analysis. It uses the following economic parameters and equations to assess project economic feasibility:

- Project cash outflow: It takes into account the required operation and maintenance, annual cost of fuel or electricity, and debit-related parameters. It is given by:

$$C_{out,n} = C_{O\&M}(1 + r_i)^n + C_{fuel}(1 + r_e)^n + D + C_{per}(1 + r_i)^n \quad (1)$$

where n is the year, $C_{O\&M}$ is the yearly operation and maintenance costs, r_i is the inflation rate, C_{fuel} is the annual cost of fuel or electricity, r_e is the energy cost escalation rate, D is the annual debt payment and C_{per} is the periodic cost and credits.

- Project cash inflow: It takes into account annual energy savings, annual capital savings, and credits for renewable energy and GHG emission reduction. It is given by:

$$C_{in,n} = C_{ener}(1 + r_e)^n + C_{capa}(1 + r_i)^n + C_{RE}(1 + r_{RE})^n + C_{GHG}(1 + r_{GHG})^n \quad (2)$$

where n is the year, C_{ener} is the annual energy savings, C_{capa} is the annual capacity saving, C_{RE} is the annual renewable energy credit, r_{RE} is the renewable energy credit escalation rate, C_{GHG} is the greenhouse gas (GHG) reduction income, and r_{GHG} is the GHG credit escalation rate.

- After-tax cash flow: It is calculated by subtracting taxes from pre-tax cash flow according to the tax rules in different provinces and territories. It is given by:

$$\widetilde{C_n} = C_n - T_n \quad (3)$$

where C_n is the net cash flow and T_n is the yearly taxes.

- Simple payback is the period taken by the project to become profitable. It is calculated based on the following formula:

$$Payback = \frac{C_n}{\left(C_{ener} + C_{capa} + C_{RE} + C_{GHG}\right) - (C_{O\&M} + C_{fuel})} \quad (4)$$

- Internal rate of return (IRR) calculates the investment return of the project. It is given by:

$$0 = \sum_{n=0}^{N} \frac{C_n}{(1 + IRR)^n} \quad (5)$$

- Net present value (NPV) is the value of all future cash flows, discounted at the discount rate, in today’s currency:

$$NPV = \sum_{n=0}^{N} \frac{\tilde{C}_n}{(1+r)^n} \tag{6}$$

The considered PV system has been simulated in the four locations. RETScreen simulation software results were checked against the Natural Resources Canada database to ensure compliance with benchmarks. It has shown a very good agreement in the considered locations. **Table 4** shows a detailed performance comparison between them. It compares capacity factor, annual exported energy, and export revenue. The capacity factor is the ratio of annual electricity generated to the rated capacity. The capacity factor is higher in the high irradiation locations. It reaches more than 2% higher when comparing Kharga Oasis to Victoria. The higher the capacity factor, the better the performance of the modules. The higher capacity factor allows for more annual exported energy, as shown in the table. The 2% increase in the capacity factor reflects an additional 1.2 GWh of exported energy to the grid. This is translated to a higher revenue that can reach a magnitude of hundreds of thousands of dollars.

Table 4. Annual exported energy and revenue for considered configurations.

Location	Capacity factor	Annual exported energy	Annual revenue of exported energy
Kharga Oasis, Egypt	22.8	12,213 MWh	$1,415,028
Safaga, Egypt	22.3	11,945 MWh	$1,383,998
Regina, Canada	21.4	11,463 MWh	$1,328,141
Victoria, Canada	20.7	11,088 MWh	$1,284,697

Table 5. RETSreen model financial parameters.

Fuel escalation rate	2.5%
Inflation rate	2%
Discount rate	5%
Reinvestment rate	8%
Debt ratio	50%
Debt interest rate	7%
Debt term	10 years
Electricity export rate	0.1 $/kWhr
Initial cost	$9,000,000
Operation and maintenance cost	$246,000

To assess the project's financial feasibility, the model needs to take into account several financial parameters. The considered parameters are given in **Table 5**. Some parameters, like the fuel escalation rate and inflation, need to be assumed from the project start. They have an adverse effect on the project's profitability. A critical set of parameters for debt also determines the project's success. Those include the debt ratio, debt term, and debt interest rate. The lower debt ratio and interest rates are favorable. In addition, the initial cost of the project includes the installation of all system components that are in the magnitude of million dollars. The mechanical and electrical systems need regular maintenance. The cost of it can reach hundreds of thousands of dollars.

The RETScreen simulation was performed considering the financial parameters in **Table 5**. The first financial health indicator that was inspected is the yearly cash flow. In the beginning of the projects, all of the costs are directed towards covering initial costs. Once we progress in the project lifetime, positive cash flows arise, as revenues are greater than operation and maintenance costs. Yearly cash flows are shown for Regina and Kharga Oasis in **Figures 4** and **5**, respectively. The first yearly cash flow is negative, and it is equivalent to the initial cost of the project installation. Then, the yearly cash flow becomes positive for the 19 years until the end of the project lifetime. However, the yearly cash flows are almost double in Kharga Oasis compared to Regina. This is attributed to the higher solar irradiation in Egyptian cities relative to Canadian ones. This causes the PV project in Kharga Oasis to be more profitable compared to Regina.

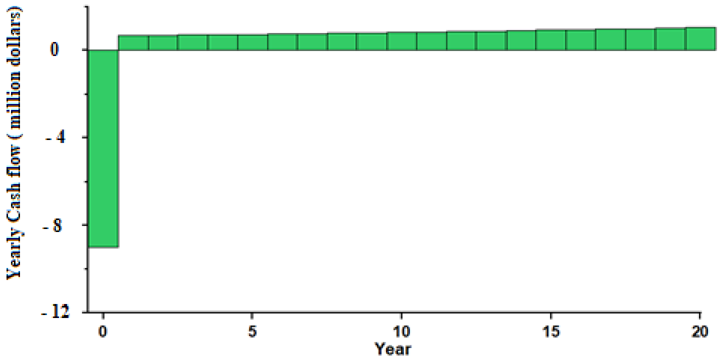

Figure 4. Yearly cash flow for the PV project in Regina.

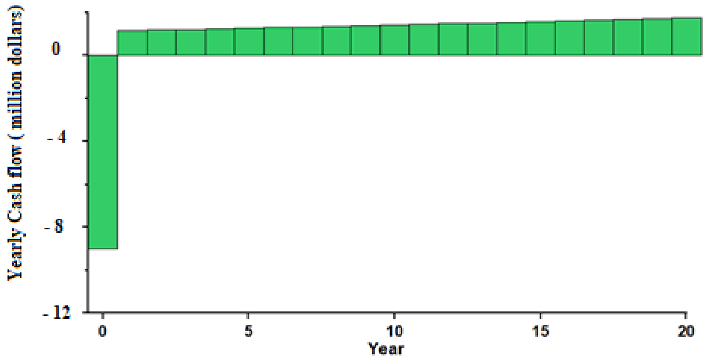

Figure 5. Yearly cash flow for the PV project in Kharga Oasis.

Another lens for financial viability is the cumulative cash flow. It is shown in **Figure 6** for Kharga Oasis and Regina. It accumulates the yearly cash flows together to give an indication of how long it needs for the project to pay back. As yearly cash flow is higher for Kharga Oasis (**Figure 5**), it shows higher cumulative cash flow compared to Regina. From the figure, it can be seen that the cumulative cash flow becomes positive in Kharga Oasis after 7.3 years. On the other hand, it turns positive in Regina after 11.2 years.

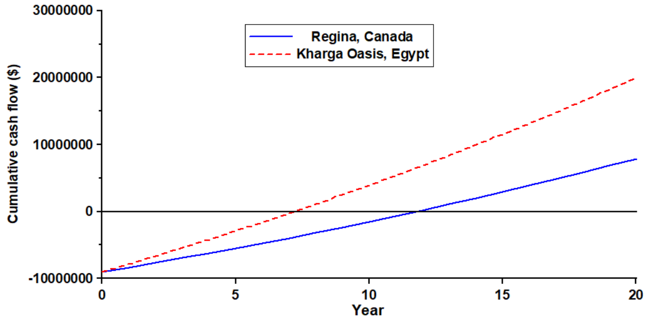

Figure 6. Cumulative cash flow for the PV project in Regina and Kharga Oasis.

The time at which the cumulative cash flow turns positive is the payback period. It is shown in **Figure 7** for the considered locations. The lowest payback is for Kharga Oasis (7.3 years) as it has the highest solar irradiation. It is a little bit higher for Safaga (7.9 years). For Canadian cities, it is found to be years higher. The highest payback is in Victoria (13.3 years) as it possesses the lowest solar irradiation. A payback of less than 10 years is favorable for PV projects. However, a payback that is less than 15 years is still considered feasible.

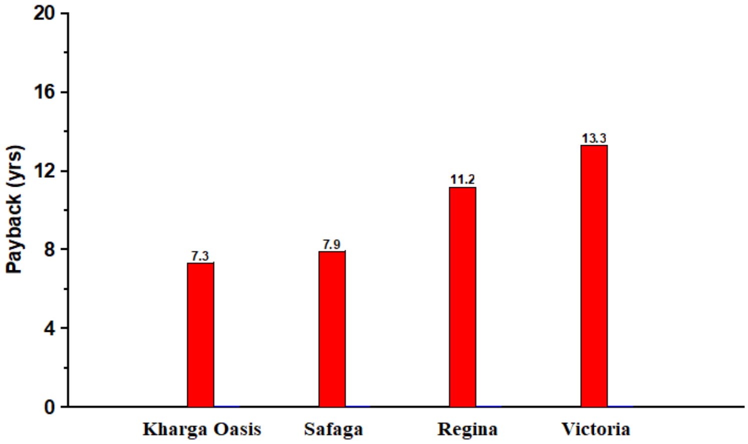

Figure 7. Payback period for the considered locations.

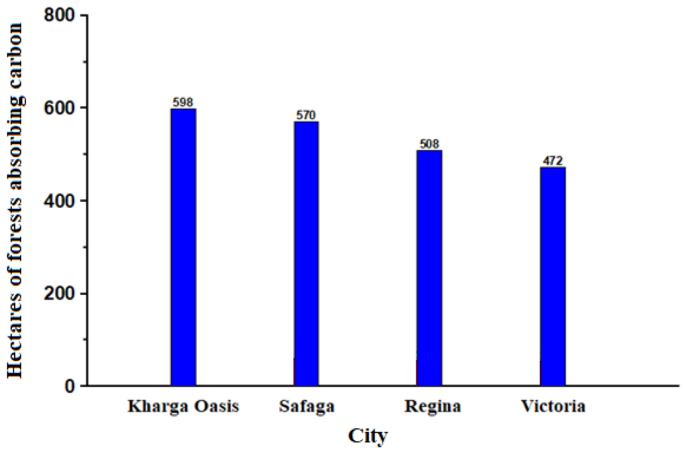

Figure 8. Equivalent hectares of forests absorbing carbon potential in the considered locations.

Photovoltaic as a clean technology is a part of the international effort to mitigate greenhouse gas emissions. It shows the potential mitigation of greenhouse gas emissions in the proposed case relative to the base case if no PV system is installed. Reduction of GHG emissions is the highest in Kharga Oasis, amounting to 62.7 tons of CO_2. The lowest is in Victoria (53.2 tons of CO_2). To visualize it better, the equivalent hectares of forests absorbing CO_2 are plotted in **Figure 8**. It is the highest for Kharga Oasis (598 hectares) and the lowest in Victoria (472 hectares).

To have a broader sensitivity analysis, several parameters are changed at a time. An example includes the combined effect of changing the initial cost and debt term on the payback period. It is shown in **Table 6** for Regina and in **Table 7** for Kharga Oasis. The payback of the base case is given in bold. Increasing the initial cost has the adverse effect of increasing the payback period. In addition, the longer debt term adversely affects the payback of the project. If the initial cost increases by 50% and the debt term increases by 50%, the payback period jumps from 11.2 years to 18.3 for Regina that might question the financial viability of the project. The effect will be more detrimental if Victoria is considered. The situation is less adverse when Kharga Oasis is considered. If the variations are kept the same, the payback period jumps from 7.3 years to 11.9 years. This still makes the project viable from the financial perspective. The results highlight the conditions of feasibility of the PV project. It is strongly correlated to financial parameters, especially in overcast regions.

Table 6. Effect of debt term and initial cost on payback of the project in Regina.

Debt term (yr)	**Initial cost ($)**				
	4,500,000	**6,750,000**	**9,000,000**	**11,250,000**	**13,500,000**
5	8.3	9.4	10.1	12.2	14.4
8	8.5	9.7	10.7	12.9	15.3
10	8.7	9.96	**11.2**	13.6	16.2
12	8.8	10.25	11.8	14.4	17.2
15	9	10.6	12.6	15.3	18.3

Table 7. Effect of debt term and initial cost on payback of the project in Kharga Oasis.

Debt term (yr)	**Initial cost ($)**				
	4,500,000	**6,750,000**	**9,000,000**	**11,250,000**	**13,500,000**
5	5.4	6.1	6.56	7.9	9.36
8	5.5	6.3	6.9	8.4	9.9
10	5.63	6.5	**7.3**	8.84	10.5
12	5.72	6.7	7.7	9.36	11.2
15	5.9	6.9	8.2	9.9	11.9

To assess the individual parameters, the change in the initial cost effect on payback is shown in **Figure 9**. The debt term is kept constant. The trend is shown for the four considered locations. The increase in initial cost has a detrimental effect on increasing payback, especially in low irradiation locations like Victoria. For the Kharga Oasis, the payback increases from 6.6 years to 8.2 years when the variation of the initial cost changes from −50% to +50%. A more pronounced effect is seen in Victoria. The payback period jumps from 10.3 years to 19.2 years when the variation of the initial cost changes from −50% to +50%. This causes the payback to be infeasible if the initial cost increases. It is also shown from the overlap of the trend line that the slope is not linear. There is a higher slope that is depicted for low solar irradiation regions for high debt terms.

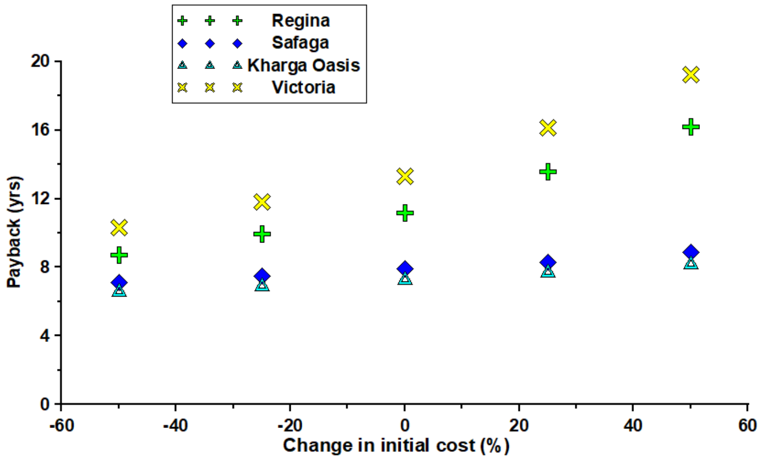

Figure 9. Change of initial cost effect on the payback in the considered locations.

3. Conclusion

The current study assesses the sustainable viability of a 6 MW grid-connected photovoltaic plant. Egypt and Canada were considered in the analysis as there is a vast variation in solar irradiation intensity between them. To analyze that, four cities were considered in the analysis: Kharga Oasis, Safaga, Regina, and Victoria. Kharga Oasis and Safaga represent different irradiation levels in Egypt. Regina and Victoria represent different irradiation levels in Canada. The simulations were performed on RETScreen software. The comparison was done under common financial parameters for a fair comparison between different regions. The simulation involves detailed financial modeling for the system, emission, and risk analysis. The main conclusions of the study can be summarized in the following points:

- The cities in Egypt were found to be more profitable for PV integration.
- The two considered locations in Canada have shown that PV systems can be profitable under certain financial parameters.
- The most viable integration was found to be in Kharga Oasis in Egypt, as it is one of the warmest climates relative to the other cities.
- A PV project in Kharga Oasis has a simple payback of 7.3 years. It can offer a mitigation of 62.7 tCO_2 of greenhouse gas emissions. This is equivalent to the reduction fulfilled by 598 forest hectares.
- The least viable integration was found for Victoria in Canada, as it has the lowest irradiation in the considered locations.
- A PV project in Victoria has a simple payback of 13.3 years. It can offer a mitigation of 53.2 tCO_2 of greenhouse gas emissions. This is equivalent to the reduction fulfilled by 472 forest hectares.

- PV project financial feasibility is adversely impacted by the initial cost, in particular for Canadian locations.
- If the initial cost increases by 50% and the debt term increases by 50%, the payback period jumps from 11.2 years to 18.3 for Regina that might question the financial viability of the project. The effect will be more detrimental if Victoria is considered.

The current paper has shed light on the conditions of feasibility of PV projects. It has shown the great potential of PV integration in Egyptian locations under a vast range of economic parameters. However, this integration needs careful consideration for colder climates like Canada. The project financial parameters, in particular initial costs and debt parameters, can make this integration infeasible from the financial perspective.

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Nomenclature

ASHP	Air source heat pump
C_{capa}	annual capacity saving
C_{ener}	Annual energy savings
C_{fuel}	Annual fuel cost
C_{GHG}	GHG reduction income
$C_{in,n}$	Project cash inflow
$\widetilde{C_n}$	After-tax cash flow
C_n	Pre-tax cash flow
$C_{out,n}$	Project cash outflow
$C_{O\&M}$	Yearly operation and maintenance costs
C_{per}	periodic cost
C_{RE}	annual renewable energy credit
D	annual debt payment
GDP	Gross domestic product
GHG	Greenhouse gas
IRR	Internal rate of return
NPV	Net present value
PV	Photovoltaic
r_e	energy cost escalation rate
r_{GHG}	GHG credit escalation rate
r_i	inflation rate
r_{RE}	renewable energy credit escalation rate

T_n Taxes

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