Journal of Circular Economy (2025) 3:3, 400-429
https://doi.org/10.55845/ZYFB4412

RESEARCH ARTICLE

# Exploration of solar energy as a means for sustainable management of non-renewable natural resources for present and future generations

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Received: 9. October 2024 / Accepted: 15. August 2025 / Published: 3. December 2025


## Abstract

Solar energy has the potential to help alleviate fears about depleting fossil fuel energy reserves, but it is not widely accepted. The concern about sustainability and resource depletion for non-renewable resources makes the evaluation of the acceptance rate of renewable energy resources an important endeavour to ensure adequate planning for energy sustainability for present and future generations. Using the amount of electricity generated from solar energy by selected provinces in Canada, this study evaluates the rate of acceptance of solar power as an alternative energy source. The study's results showed that there is considerable room for improvement in efforts to utilize solar power as a means of sustainably managing 'non-renewable' energy resources for present and future generations. This study recommends continuous improvement in the exploration of solar energy systems as an alternative source of energy to address concerns about the depletion of non-renewable fuels.

**Keywords** Solar Energy · Resource Depletion · Non-renewable Resources · Sustainability · Renewable Energy

## Research questions

- Are we doing enough in the application of solar energy systems as a strategy to sustainably manage non-renewable natural resources for present and future generations?
- How can we create win-win solutions for the concerns about renewable energy systems?

## Highlights

- Concern about fossil fuel depletion
- Application of solar energy systems for responsible energy resource management
- Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of increasing the micro-generation capacity of electricity from the rooftops of residential and commercial buildings.
- Strategies to address the concerns about large-scale renewable energy systems.
- Creating win-win solutions for concerns around sustainable energy production.

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# 1. Introduction

Energy development is important for the promotion of the economic and social well-being of the world's population. However, the rapid increase in the use of 'non-renewable' energy usage characteristics in the last 50 to 100 years cannot continue indefinitely in the face of depleting resources (Hseih, 1986). In addition to the concern about depleting non-renewable energy resources, the concern about climate change and global warming has generated increased interest in low-carbon economic development. Among other things, low-carbon economic development initiatives involve the use of renewable energy systems such as solar, wind, hydro power, etc. If adequately used, renewable energy such as solar energy will not only help to better manage 'non-renewable energy' reserves, but it will also help contribute to the goal of achieving a low-carbon economy through various means, such as providing a good supplement for energy supply to industries while reducing the embodied carbon in material production and recycling operations. In the effort to advance a sustainable future globally, low-carbon and circular economy work closely together to form the foundations of sustainable future development (Alliakbari et al., 2025). While it is the right of the present generations to develop and use natural resources, the present inhabitants of this planet do not have the right to use the resources in a wasteful manner. The rapid depletion of fossil fuel resources globally has made the search for alternative sources of energy for present and future generations a necessary endeavour (Hseih, 1986). Being an environmentally friendly source of energy, solar energy plays an important role in the future of sustainable energy (Abdallah et al., 2020). Large-scale adoption of solar energy systems is expected to create a pathway to design a sustainable energy supply for people in darkness in different parts of the globe. The cost of the grid for rural electrification is sometimes considered very high due to the low population in those areas. Renewable energy systems (Wind and Photovoltaic systems) may provide access for small and medium energy loads. These renewable energy systems are easy to install, their reliability is high, and they require low maintenance (Notton et al., 2011).

By tapping local resources, stand-alone hybrid power systems provide energy demands in remote areas that do not have access to electricity (Lujano-Rojas et al., 2014). Electrical energy can be used to provide power for various daily operations, including lighting, cooling and refrigerating, heating, transportation, etc. Hanjin et al. (2022) presented a method to estimate the power that was generated by solar trains with panels. The study performed experimental calculations on a railway line in Korea. It was reported that during the operation of the train, 122.15 MWh of power could be generated in a year, resulting in a reduction of 56 tons of $CO_2$. Note that the $CO_2$ emissions reduction that was mentioned for that study may vary with local conditions, especially as relating to the $CO_2$ emissions of the alternative energy that would have been used to power the train. In a feasibility study of the applications of microgrids for the reduction of GHG emissions and energy use for an industrial application, Li et al. (2016) reported that if there are no land limitations on the deployment of solar and wind power, GHG emission reduction of up to 66.3% and a significant reduction of fossil fuel energy up to 56.9% can be achieved. Given the concern about the long-term availability of non-renewable energy resources and carbon emissions, it is important to take proactive steps in evaluating the level of penetration of renewable energy resources in household and industrial energy use. This evaluation should be followed by good actions to improve the use of renewable energy to better manage the exploration and use of non-renewable energy resources. The ideal strategy would be to supplement renewable energy for purposes where available renewable energy is not sufficient to meet the needs of the operation under the present global technological state. Hence, continuous study on sustainability, resource depletion for 'non-renewable energy resources', and market penetration of all forms of renewable energy, including solar, wind, geothermal energy, etc., would be beneficial for the global community.

# 2. Literature Review

Electricity generation can be associated with different levels of GHG emissions (depending on the energy source for the generation of electricity). Various electricity power plants come with varying levels of GHG emissions (Mofolasayo, 2023). In 2020, 62% of global electricity generation came from fossil fuels, 10% from nuclear power, and 28% of the global electricity supply came from renewable energy. The share of renewable energy supply would need to be significantly increased to meet the global climate goals (International Renewable Energy Agency, 2023). Kannan et al. (2006) studied the Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) for a solar PV system in Singapore. The researchers noted that from the perspective of GHG emissions and fossil energy use, solar energy is a good choice that can be used to address the present environmental-energy issues. However, the cost of electricity for solar PV systems is not comparable with the fossil-fuel-based technology at the time. Although the study indicated that the cost of the solar PV system is higher than that of an oil or gas-fired power plant, the solar PV system was recommended as a good choice to address current energy-environmental issues. With the significant improvement in the technology behind solar panels and the decrease in cost, grid-connected photovoltaic systems are becoming an important alternative to reach the goal of low-carbon energy transition (Cristea et al., 2022). The payback and economic viability of solar will depend on the investment cost in different places. Ranganath & Sarkar (2021) indicated that the payback period for solar power plants depends on the initial investment and the rate of the power purchase agreement. The authors mentioned that the techno-economic feasibility of solar power plants in their study region is high. A high initial investment cost will impact the techno-economic feasibility of solar power plants. This calls for further research and effort to reduce the investment cost for solar PV systems in various municipalities. Photovoltaic technology has played an increasingly important role in the global energy outlook (Santos et al., 2021). As a clean technology, solar PV has seen dramatic growth around the world (Xu et al., 2018). Solar energy is widely distributed, and its utility has developed rapidly in recent years. In different places, some people have been making efforts to tap into various avenues to harness solar energy. The International Renewable Energy Agency estimates that the share of renewable energy would need to be increased from 28% in 2020 to 91% by 2050 under the scenario that targets limiting global warming to 1.5oC (International Renewable Energy Agency, 2023). The world is seeing an increase in the acceptance of solar energy. Global PV capacity additions grew from 17 GWDC to 139 GWDC. Global PV installations reached 760 GWDC by the end of 2020 (Feldman et al., 2021). Concentrated solar power CSP is a promising technology in renewable energy (Alami et al., 2023). CSP technology uses mirrors to concentrate solar rays onto a receiver (Mackenzie, 2022). Between 2010 and 2020, the cumulative CSP installed capacity grew just over fivefold globally, reaching 6.5 gigawatts by the end of that period (CSTA, 2022). Although the utilization of renewable energy is attracting considerable attention globally, the contribution of solar energy (including PV and CSP) is still low (Pourasi et al., 2023). In certain situations, the generation of energy from photovoltaics on rooftops is a viable way to produce sustainable energy for many residential units. Efforts to meet the target for penetration of renewable energy require exploration of all good avenues to harvest renewable energy.

## 2.1. The concern about fossil fuel depletion and the need to welcome alternative forms of energy as a supplement to the present energy system

The depletion of fossil fuels has been identified as a future challenge (Hook & Tang, 2013; Shafiee & Topal, 2009; Capellan-Perez et al., 2014; Holechek et al., 2022; Chia et al, 2022; & Azni et al, 2023). A lot of papers on the economics of global warming concentrate on the external effects of the combustion of fossil fuels without consideration for the exhaustibility of these resources (Hoel & Kverndokk, 1996). Various researchers have also echoed the concern about the depletion of non-renewable energy resources. Energy consumption is directly related to the depletion of non-renewable resources (Mendrela et al, 2024). In addition to high carbon emissions and environmental safety issues, non-renewable energy is subject to resource depletion, creating concerns for resource sustainability. Efforts to correct this necessitate an increase in the share of renewable energies while decreasing the share of non-renewable energies (Opeyemi, 2021). Global energy demand has significantly increased due to urbanization and the increase in the human population (Amin et al., 2022). Some other researchers have also mentioned that due to various factors, including industrialization, improper usage of natural resources, and population growth, the world's natural resources are depleting at a rapid pace over time. Over-exploitation of natural resources leads to critical environmental problems (Sadiq et al., 2023).

Excessive use of non-renewable energy not only creates pollution, but it will also lead to its depletion. On the other hand, green technologies help companies adopt sustainable development while reducing overall costs (Sridha et al., 2022). To support sustainable management of natural resources and the environment, regional development and economic growth require support for the use of renewable energy (Surya et al., 2021). The utilization of renewable energy resources (solar energy, hydropower, geothermal, biomass, and wind energy) offers benefits such as environmental friendliness, production of minimal secondary waste, cost-effectiveness, and ultimately leads to sustainable development (Agrawal & Soni, 2021). Discussion on world resource depletion (particularly the depletion of fossil fuel energy) has been diverted by the increased public and political focus on global warming (Leng, 2010). The issue of fossil fuel depletion is undeniable. Depleted oil reservoirs are now seen as avenues for the storage of $CO_2$ to reduce GHG emissions to the atmosphere (Luo et al., 2017b). Resources need not be extracted until depletion (Nyambuu & Semmler, 2023). Delaying the drastic decline in production while maintaining economic productivity is an urgent issue for the economic development and sustainability of Bakken tight oil reservoirs (Luo et al., 2017b). The concern about depletion of natural resources, especially depletion of fossil fuels, makes the need for the exploration of renewable energy an important endeavor. In the long run, the transition to renewable energy reduces the overall pollution (Hossain et al., 2023). Saskatchewan has numerous depleted oil pools for which enhanced oil recovery techniques may now be needed to recover the remaining oil. A list of oilfields in South East Saskatchewan with $CO_2$-enhanced oil recovery potential has been published (Gavin, 2022).

***2.1.1. Refracturing is not always economically viable*** The ability to get some oils from refracturing around existing wells is good news for the oil and gas industry. With modern diversion-based refracturing techniques, it is possible to create a 'pressure barrier' around the parent well that will help redirect the new fracturing treatment into some other virgin areas of the reservoir. When the parent well is refractured first, the original production of the parent well can be preserved, and the production of new infill wells, as well as the parent well, can also be increased (Miller et al., 2016). Mechanical isolation refracturing technology allows the refurbishment of regions that were not previously accessed by the initial refracturing. But it is costly and complex to construct. Cost reduction for mechanical isolation technology is an important research topic (Xu et al., 2024). Lindsay et al. (2016) searched over 20,000 laterals completed since the second half of 2013 in the US. The study noted that, based on public records, more than 100 horizontal wells were refractured by chemical diversion means. The economic success of the production results from the wells varies (i.e., not all the refractured wells were seen to be economically viable). The traditional belief is that petroleum is formed as a result of the action of high temperature and pressure on organic matter over a long period. The theory that petroleum is formed from sedimentary organic matter that was once living organisms is consistent with all-natural observations, theoretical considerations, laboratory analyses and experiments, and basin simulations (Walters, 2006). This raises questions about whether continuous action of high temperature and pressure on sedimentary organic matter and migration of petroleum from areas around initially depleted oil wells result in significant replenishment of these wells or their surrounding neighbourhood within a reasonable length of time. The accurate identification of potential target wells (with sufficient production potential to justify additional stimulation) is a crucial factor in refracturing success (Ren et al., 2025).

While considering the socio-economic benefits from the sale of fossil fuels, and the subsequent environmental impacts, (especially when adequate carbon capture technology is not employed), in the effort to sustainably manage non-renewable resources for present and future generations, it is important that adequate studies be done to know the rate by which petroleum is formed through natural processes. It is also important to adequately evaluate data on the rate of replenishment around oil wells that were once deemed as depleted to establish an adequate plan for resource management for present and future generations. This knowledge can be helpful in the development of optimization techniques that may be applied to set limits on the amount of natural resources that should be mined in various jurisdictions over a specific period. A previous study presented a framework for the application of optimization techniques in the achievement of global emission targets in the housing sector (Mofolasayo, 2022). A similar technique can be used to set targets for allowable oil exploration in different jurisdictions. Knowledge of the rate of depletion of oil reserves and the rate of oil formation can be used as constraints that may be applied to set targets for the maximum amount of allowable use of non-renewable energy while improving efforts to increase the use of renewable energy. Although many studies and relevant research have shown the advantages of refracturing concerning its significant technological and economic aspects, for various reasons, it has not yet convinced all operators to replace drilling a new well and fracturing it with refracturing (Kong et al., 2019). The study further noted that if not adequately regulated, hydraulic fracturing and refracturing have a significant effect on the environment. While exploration of 'non-renewable' energy resources helps in providing for various needs in society at the moment, it is important that adequate consideration be given to future generations. i.e., all the 'easy-to-explore' natural resources should not be mined now, while resources that are difficult to reach are left for future generations. Regardless of the success that has been reported in refracturing in some places (Lindsay et al., 2016), it is important to note that when the rate of exploration of oil is significantly more than the rate of its formation, the world may eventually get to a stage of a scarcity of oil while opportunities to significantly develop renewable energy resources have not been adequately explored.

## 2.2. Exploration of solar energy systems for the sustainable management of non-renewable natural resources

Solar energy (especially when supported by adequate energy storage systems) can support a considerable portion of the energy requirements of various industries and households. In the effort to reduce greenhouse gas emissions, electric cars are often promoted as a good option to help reduce emissions. Meanwhile, the level of indirect GHG emissions from electric vehicles depends on the amount of GHG emissions from the electricity grid where the electric vehicle is powered. A previous study (Mofolasayo, 2023) provided an illustration that indicated that in some situations, some electric vehicles can have more indirect GHG emissions than some fossil-powered vehicles (This is dependent on the extent of GHG emissions from the electricity grid that powers the electric vehicles). Meanwhile, solar energy can be used to generate sustainable energy for electric vehicles. When solar energy is used as the energy source for electric vehicles, the GHG emission from this transportation medium is significantly reduced. Increased use of solar energy for trains can significantly reduce $CO_2$ emissions in the transportation sector (Hanjin et al., 2022). Solar energy offers the opportunity to conserve non-renewable natural resources for present and future generations. The effort to increase the penetration of the use of solar energy is evident in the efforts of various governments to provide subsidies to attract people towards the installation of solar panels. The expansion of PV energy is due to the reduction in the price of solar panels, incentive policies and widespread application of the technology (Hanjin et al., 2022). However, even with the incentives (available subsidies for solar panels in different places), to many households and industries, solar energy does not yet seem very attractive. Among other things, the economic factors surrounding solar panels (as relating to the payback period on investment) will affect people's decisions on whether to explore solar panels as an alternative form of energy. Apart from the economic prospect that may be obtained, other factors that may affect the penetration of the use of solar energy include the effect of the panels on the aesthetics of the building, government policies, the political climate of a community, amount of distribution fees that those who have solar panels still have to pay the utility companies every month, the level of awareness about the expected environmental benefits in terms of indirect contributions to the reduction of air pollution, and the reduction of concern about GHG emissions. Given the benefits of solar energy, it is important that adequate attention be paid to how the attractive factors for the exploration of solar energy can be maximized while minimizing the factors that will discourage people from using solar energy for residential and commercial uses.

With the increase in population, there will be an increase in the number of buildings that are required to provide conducive accommodation for the increasing population. As the number of buildings increases, the dependence on natural resources that are considered non-renewable will increase. If adequate actions are not taken, the concern about the decrease in the reserves for these resources will increase. In addition, the concerns about GHG emissions and efforts to meet the emission targets may increase. With this in mind, it is important to explore opportunities to further utilize renewable energy resources such as wind and solar energy for the provision of energy to support various homes, transportation and industries. Note that the amount of electricity that is generated from solar power differs by the month of the year. Hence, if the new households will not add to the burden on the electricity grid for the community, it is better to have a design that will generate enough electricity (or the maximum amount of electricity that can be produced) for the household in the month where the least amount of energy is produced, given specific local conditions. This will mean that some households with large roof areas will produce more than the required energy in months with higher solar energy production potential. Meanwhile, in the effort to reduce GHG emissions from the electricity grid, it is important to note that when a household produces and contributes more energy than the household can use to the electricity grid, this means that the need to produce electricity from the grid will be reduced and those households that are contributing more energy to the grid through solar power are contributing to the reduction of GHG emissions for the global community. Hence, a study on factors that can affect the widespread acceptance of solar energy as a means for sustainable management of 'non-renewable energy resources' is worthwhile. This study reviews some benefits of solar energy as an alternative and sustainable form of energy. Some of the factors that can mitigate against the acceptance of solar energy on a wide scale were also discussed.

## 2.3. Are solar energy systems able to supply the energy needs of residential communities?

The US Energy Information Administration (EIA) reported that the average annual electricity consumption for a U.S. residential utility customer was 10,632 kWh in 2021. An average of 886 kWh per month. This varies from one community to another. While Hawaii had the lowest annual electricity consumption per residential customer at 6,369 kWh, Louisiana had the highest annual electricity consumption at 14,302 kWh per residential customer. Based on research in the last decade, the average Canadian household uses 11,135 kWh of electricity per year. While an average Ontario household uses about 9,500 kWh of electricity per annum, the average Alberta household uses 7,200 kWh per year. The lower number for Alberta is offset by higher usage of natural gas (Energy Rates, Canada). Table 1 shows the illustration of the annual electricity and natural gas usage of some households in Alberta. The data in Table 1 are from the electric bills of some residents (collected during this study). These are represented as customers A, B and C below

**Table 1.** Household annual electricity and natural gas usage in Alberta

| Customer | Annual Electricity Consumption (kWh) | Annual Natural Gas Usage (GJ) |
|---|---|---|
| Residential Customer A | 5771.0 | 80.60 |
| Residential Customer B | 13194.0 | 99.09 |
| Residential Customer C | 10664.5 | 50.53 |

Table 1 indicates that the annual electricity and natural gas usage varies with households. This may be affected by various building characteristics and differences in people's preferences for lighting, heating, cooling, etc. When adequately designed, solar energy (with adequate storage systems) has the potential to supply the sustainable energy required for daily living in many communities around the globe. In some situations, there may be a need to supplement household energy usage with electricity from the grid or other renewable power sources such as geothermal or wind power systems. Previous studies have looked into the feasibility of solar systems for residential energy supply. Some researchers (Awad et al., 2021) investigated the energy generation of 86 PV sites in northern latitudes to evaluate their long-term performance while considering various parameters. The transitivity of solar radiation in the atmosphere varies considerably with location, time of day, Earth-to-sun distance, and angle of incidence (Atthasongkhro et al., 2024). Awad (2018) cited a previous work that indicated that in Northern Germany, for south-facing PV systems at tilt angles 22 degrees to 50 degrees, the final yield varies between 750 and 850 kWh/kWp. Another study that was cited indicated that in Belgium, the average annual yield is 892 kWh/kWp. In Ireland, the annual yield is 885.1

kWh/kWp. Changing from 18 degrees to 60 degrees tilt angle resulted in a difference of 127 kWh/kWp (about 10% of the annual PV yield). The higher tilt angles (i.e., 60 degrees) that were reported are also associated with lesser accumulation of snow on the solar panels (since snow slides off the panels), yielding a tendency for more electricity yield during the winter (Awad et al., 2021). The study further noted that higher tilt angles, such as 50 degrees or 60 degrees, are recommended for Northern Altitudes not only because of location characteristics but also because of uniform energy distribution throughout the year and also less impact of snow on loss of energy generation. Another study (Abdallah et al., 2020) used PV Watts and PVGIS to calculate the solar radiation on a horizontal surface with tilt angles. The slope angle of solar panels is an important determinant of the solar radiation on the surface of photovoltaic panels (Abed & Al-Salami, 2021). The rotation of a PV system by 90 degrees away from the true south direction while maintaining the tilt angle at 30 degrees resulted in a loss of 20% of energy generation (Awad, 2018).

The annual energy generation of Edmonton, Sherwood Park, and Leduc is 1270.4 kWh/kWp, 1143.4 kWh/kWp and 1311.2 kWh/kWp, respectively (Awad et al., 2021). Urban (2021) reported on the average annual solar energy production for every province in Canada.

**Table 2.** The average annual solar production for various Canadian regions, kWh/KW/yr. (Urban, 2021)

| Province | Average solar production (kWh/KW/yr.) |
|---|---|
| Saskatchewan | 1330 |
| Alberta | 1276 |
| Manitoba | 1272 |
| Quebec | 1183 |
| Ontario | 1166 |
| New Brunswick | 1142 |
| Prince Edward Island | 1104 |
| Nunavut | 1092 |
| Nova Scotia | 1090 |
| Yukon | 965 |
| Newfoundland | 949 |

The yearly average varies with locations in various provinces. Solar production also varies by month. In the estimation of the monthly and yearly averages, Urban (2021) accounted for a 25% efficiency loss. The assumed orientation was also stated. In addition, the province or territory averages were calculated from the top 5 populated cities in each province. Sadler (1992) recorded the monthly data for ultraviolet radiation (Wh/m$^2$) for four consecutive years. The result indicated that the radiation, hours of sun, and cloud cover vary between months and between years. Recent studies also confirmed the potential for variability in sunshine duration (Aparicio et al., 2018) and cloud cover (Montero-Martin et al., 2023) over the years. In Alberta, the yearly average for solar production increases as you move south and east and decreases as you move north and west in the province. While Lethbridge has 1330 kWh/yr, Calgary has 1,292 kWh/yr, and the 1 kW solar system in Edmonton will produce 1,246 kWh/yr. (Urban, 2021b).

***2.3.1. Sizing Solar energy requirement for homes*** Solar energy maps give information on the amount of energy (kWh/kW/yr) that can be produced from solar photovoltaic systems based on the amount of light that reaches the Earth’s surface. These can be used to answer questions such as "How much energy can a solar power system produce in my region every year"? and "What size of panel will be needed to offset my electricity usage for the year"? (Urban, 2021). The 'photovoltaic potential and solar resource maps of Canada' by Natural

Resources Canada (Natural Resources Canada, 2020) indicated that photovoltaic panels in Edmonton, Alberta, have the potential to generate 1200 - 1300 kWh/kWp. This means that a 1 kW panel can generate between 1200 - 1300 kWh per year. A 5-kW panel has the potential to generate 6000 kWh to 6500 kWh for the year. Since solar power generation potential varies with the month, except with a carefully designed power storage system that can store excess power from one month to the other, a building that will be completely off-grid would need to have the solar system designed to be able to meet up with the power requirement for the month with the least amount of solar energy potential. It also means that such buildings may generate more than the required energy in months with higher solar power potential. Urban (2021) presented a simple procedure for sizing the solar power system. However, it is important to note that various factors, such as the angle of tilt of the roof, the amount of sunshine hours, temperature, the efficiency of the solar panels, etc., will affect the amount of solar power that is generated from the photovoltaic systems. The optimum tilt angle of solar panels is important when determining the factors that affect the performance of the panels (Abdallah et al., 2020). Hseih (1986) presented different formulas for the calculation of the amount of solar energy that reaches the earth's surface and can be collected by solar panels.

Given that various factors such as the tilt angle, dust on panels, temperature, amount of daylight hours, etc., may affect the amount of solar energy that is achieved from one community to the other, historical data from PV panels that have been previously installed in every community that includes different factors (that affect power generation) will be helpful in determining the performance ratio under the prevailing local conditions. Further study is recommended to use historical data on the performance of solar panels for both residential and commercial buildings in various communities to evaluate the expected versus the actual electricity production from solar panels and subsequently use those results to plan future designs of solar energy systems in the community. In addition to impacts from other factors, the amount of electricity that is generated (monthly) from photovoltaics on the rooftop is dependent on the capacity of the photovoltaic panels, the area of the rooftop that is used for the solar power systems and the monthly solar energy radiation for the location. The documented evidence as described above indicated that solar panels (when adequately adopted) have the potential to help reduce the demand on the electricity grid while reducing the concerns about GHG emissions from the electricity grid and helping to manage the reliance on non-renewable energy resources. The question is, "Why are solar energy systems not well applied to reap the expected potential"?

## 3. Research objectives

The objectives of this study are to answer the questions: "Are we doing enough in the application of solar energy systems as a strategy to sustainably manage non-renewable natural resources for present and future generations?" and "How can we create win-win solutions for the concerns about renewable energy systems"?

This research objective is evaluated by:

- The level of energy that is generated from solar power in different jurisdictions in Canada.
- The percentage of people installing solar panels in some communities.
- The analysis of the strengths, weaknesses, opportunities and threats (SWOT) of allowing for an increase in the micro-generation capacity of the roof area of residential and commercial buildings for harvesting of solar energy.
- A discussion on strategies to create win-win solutions around the concern about renewable energy systems.

## 4. Methodology

The records on the amount of solar energy that is generated in seven Canadian provinces were evaluated to know the level of penetration of solar energy systems in Canada (using data provided online from Canada's Renewable Power website). Field surveys are also done through a visual evaluation method. A car-mounted video recording system was used in conjunction with visual evaluation to check how many houses have solar panels.


**Figure 1.** Map of a community showing areas evaluated for solar penetration (online map).

The buildings that were checked during the field survey are some of the buildings around the rectangular shapes on the map in Figure 1. The video surveys are done in daylight hours and good weather conditions.

# 5. Results and Discussion

## 5.1. Penetration of solar energy systems in electricity

Figure 2 shows a comparison of the penetration of solar energy in electricity generation by selected provinces in Canada. From Figure 2, it is obvious that the market penetration of solar energy as an alternative source of electricity generation is very low.

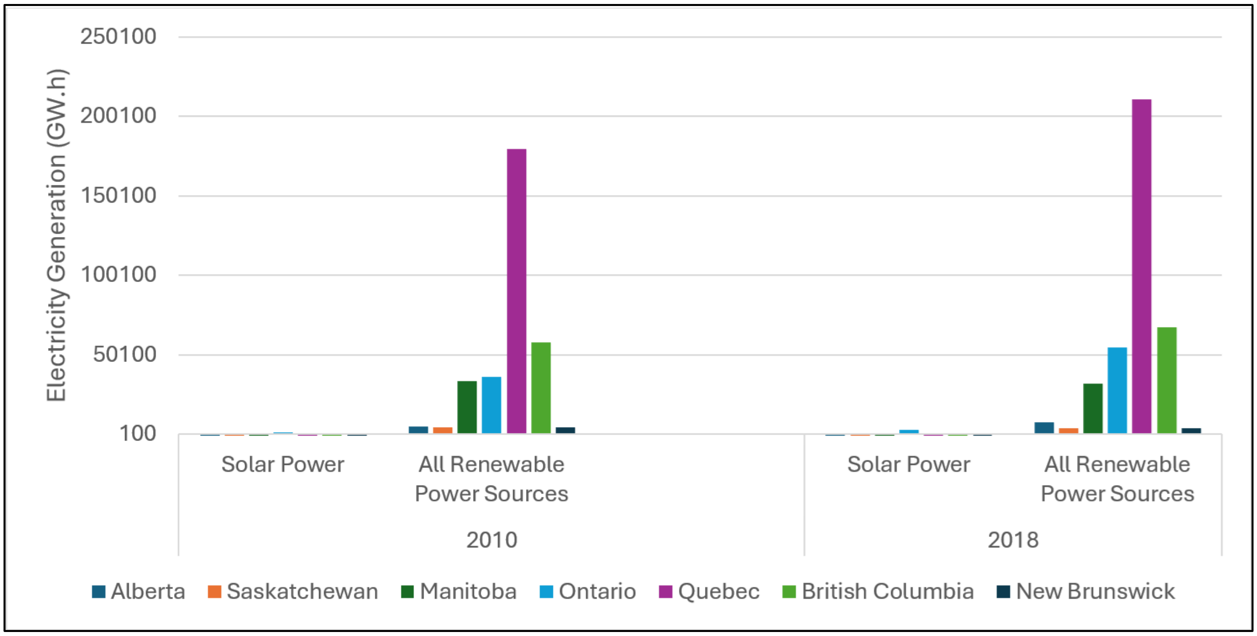


**Figure 2.** Comparison of the penetration of solar energy in electricity generation by selected provinces. Adapted from Online data by Canada's Renewable Power.

Figure 2 shows that in 2018, Ontario was leading the path in power generation from solar energy, while other provinces were lagging. Quebec, British Columbia, Ontario, and Manitoba are leading the pace in the use of other forms of renewable energy.

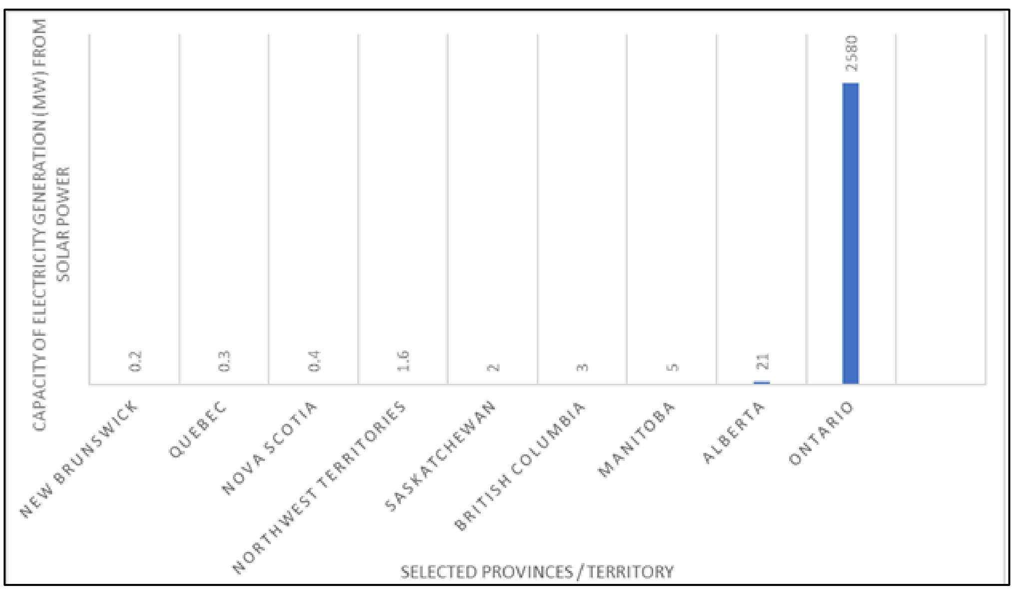


**Figure 3.** Capacity of electricity generated from solar power (MW) from selected provinces/territories (2017): Open data source: (Canada's Renewable Power)

The data for the year 2017 in Figure 3 also showed that Ontario is a leader in solar energy capacity. The open data from Canada's Renewable Power indicated that Quebec, Manitoba, and British Columbia use a huge supply of hydroelectricity. However, there is room for improvement in the uptake of solar energy in these areas, too. Further study on the feasibility of solar energy to supplement present energy sources in all communities around the globe is recommended.

For the year 2018, the percentages of renewable energy as a percentage of total electricity generation by the provinces are presented in Table 3 below.

**Table 3.** Percentages of renewable energy as a percentage of total electricity generation by selected provinces. (Canada's Renewable Power)

| Province | Percentage of renewable energy in electricity, % (Year 2018) |
|---|---|
| Alberta | 9.1 |
| Saskatchewan | 16.6 |
| Manitoba | 99.9 |
| Ontario | 34.8 |
| Quebec | 99.6 |
| British Columbia | 97.9 |
| New Brunswick | 30.6 |

For the year 2022, Alberta exceeded its goal of 15 percent renewable energy development when 17% of its power came from wind and solar (The Canadian Press, 2023). This shows an increase in the adoption of renewable energy when compared to the 2018 records. Provinces that are lagging in the use of renewable energy sources to significantly supplement non-renewable energy sources for present and future generations have the opportunity to improve on the use of renewable energy power sources (i.e., solar, wind, geothermal, etc.).

## 5.2. Results from the field evaluation of penetration of solar panels in a community

During the field survey to evaluate the extent of solar penetration on rooftops, four areas were randomly selected from four quadrants of a city. Table 4 shows the result of the count of the buildings with solar panels. The result indicated that the penetration of solar panels on rooftops is still very low at about 2.02%. Given that the survey was done with a vehicle-mounted camera, coupled with visual examinations of some of the buildings along the driving path. In situations where the rooftop is not seen at all, the building is not counted. For example, the areas that were visited in the North West quadrant are mostly industrial areas with flat roofs. The roofs of buildings with flat roofs were not counted. For an expanded study on the penetration of solar energy systems for residential and commercial buildings, further study is recommended with camera-equipped drones that can produce a bird's eye view record of rooftops while flying over the streets in different communities. This may be compared with the records from utility companies. If there are people who decide to use 100% renewable energy and are not on the records of utility companies, a field survey, as proposed (using recordings from video footage from camera-equipped drones), should be able to account for those. These surveys may also be supplemented with household surveys as people begin to transition to more aesthetic solar energy generation roofs that would be difficult to differentiate from other roofs in the community.

**Table 4.** Percentage of buildings with solar panels in some communities

| Location | Number of buildings counted | Number of buildings where solar panels were seen |
|---|---|---|
| North East Quadrant | 159 | 4 |
| North West Quadrant | 4 | 0 |
| South West Quadrant | 31 | 1 |
| South East Quadrant | 153 | 2 |
| Total | 347 | 7 |

In the effort to increase the penetration of photovoltaic energy systems for the management of non-renewable energy resources for present and future generations, it is important to carefully evaluate the factors that can affect the acceptance of solar energy systems.

***5.2.1. Under Utilization of roof spaces for solar energy generation*** In addition to the areas surveyed above, visual observations of some buildings in some other areas of the city indicated that the underutilization of roof areas for harvesting solar energy is prevalent in the community. While there are concerns about energy insecurity in many places, concerns about the depletion of non-renewable energy resources, and concerns about the impact of GHG emissions and pollution from power plants that have high GHG emissions, the underutilization of roof area for harvesting solar energy can be viewed as underutilization of natural resources that has the potential to produce renewable energy. Figure 4 shows some situations in which the roof areas of some buildings are underutilized. In some places, the roof areas are underutilized because of an existing policy that limits the amount of electricity that can be generated by households to the annual household electricity usage. Meanwhile, the annual household electricity usage is expected to increase with the increase in the adoption of electric vehicles by many households. If solar panels are only sized to cater to the present household electricity needs, when the annual electricity usage of the household increases in the future, the installed panels may not be sufficient to meet the annual electricity demand. This indicates that there will be an increased dependence on the electricity grid in the future until those households can install more solar panels or alternative renewable energy systems to meet their household electricity needs.

**Figure 4.** Underutilization of roof areas for solar energy harvesting

In line with the research question: "Are we doing enough in the application of solar energy systems as a strategy to sustainably manage non-renewable natural resources for present and future generations?" Can we say that limiting the amount of electricity that can be generated by each household in a year to the annual amount of electricity that the household can use helps the global community to better use renewable energy systems to manage non-renewable energy resources for present and future generations?

## 5.3. Important notes for deliberations during the decisions that are geared towards increasing the acceptance of solar panels for residential and commercial buildings

***5.3.1. Proper identification of goals*** In the effort to increase the acceptance of solar panels for residential and commercial uses, it is important that we properly identify the goals. In addition to proper identification of goals, it is important to ensure that policy decisions truly reflect the stated goals.

The goals for the increase in acceptance of photovoltaic panels can be stated as:

i. Use sustainable energy resources such as solar energy to sustainably manage 'non-renewable' energy resources for present and future generations.
ii. Reduce GHG emissions and the associated concerns for people in different parts of the globe.
iii. Improve air quality for a chance of better health for the immunocompromised, people with asthmatic conditions, and the entire population.
iv. Maximize the opportunity to harvest renewable energy resources in the community to reduce the load on the electricity grid (especially in communities with high GHG emissions from the electricity grid).
v. Reduce the cost of electricity so that people's purchasing power and standard of living can be increased.

In policy decisions to increase the acceptance of solar energy for residential and commercial applications, every nation needs to ask questions such as, "Do our present policies encourage the use of solar energy to sustainably manage non-renewable energy resources"? Do our present policies optimize the use of solar energy to reduce GHG emissions while improving air quality? Do our present policies help ensure a reduction in the cost of electricity in order to increase the purchasing power of people in our communities while improving their standard of living? Do our policies on distribution/transmission fees for people with solar energy systems reflect the above goals? When we set the limit of energy that can be generated to that which can be used by single households alone, does this reflect the goals that are mentioned above? Since the electricity needs of households will likely increase in the future, especially as electric cars become more affordable and more people continue to accept electric cars, allowing households to generate a considerable amount of electricity that is more than their annual usage can help reduce expected future burden on the electricity grid in various communities due to increase in the penetration of electric cars. Various communities have begun to embrace the concept of a community solar program.

The U.S. Department of Energy defines community solar as any solar project or purchasing program where the benefits flow to multiple customers in the area. Customers who own a portion of the energy generated by a solar array can receive an electric bill credit for the electricity that is generated by their share of the community solar system.

***5.3.2. Life Cycle Assessment (LCA) of solar panels*** Gerbinet et al. (2014) mentioned that there has been a rapid increase in the use of PV panels in recent years, although their environmental impacts are not yet fully determined. The researchers further reported that there are some shortcomings in the LCA of PVs. These include incomplete studies and a lack of published details about the system and the methods, leading to differences in many results and creating difficulty for comparisons. During the life cycle of the solar PV system, GHG emission potentially occurs from the energy that is used for the manufacturing of solar PV modules and the balance of the system (BOS), such as supporting structures, inverters and other accessories (Kannan et al., 2006). Energy payback time (EPBT) is the time required for a solar PV module to produce the equivalent amount of energy that is used during its manufacturing process. Without considering the impact of PV arrays on hosting ecosystems, the contribution of PV power generation to GHG reduction may be overestimated (Zhang et al., 2023). Lamnatou et al. (2023) conducted a Life Cycle Assessment (LCA) to evaluate the environmental profile of a Photovoltaic PV plant with hydraulic storage in Catalonia, Spain. It was reported that the life cycle emissions range from around 66 to 81 $gCO_2eq/kWh$. Some other researchers (Badza et al., 2024) reported that in a study to determine the energy payback time EPBT and evaluate the climate change environmental indicator that is caused by the generation of 1 kWh by a 1.1 MWp PV system in Burkina Faso, the EPBT varies between 1.86 to 2.71 years (depending on the end-of-life management) while the carbon emission varies between 24.6-58.3 $gCO_2$ eq/kWh. Zhang et al. (2023) reported that their evaluation models of GHG footprints of PV arrays during the operation period are 20.62 $gCO_2eq/kWh$. Wu et al. (2017) reviewed the life cycle assessment of energy payback of solar photovoltaic systems in China and reported that for a 1 Megawatt (MW) on-grid ground-mounted solar power station, the total energy input (including module manufacturing and balance of the system) is 19.5548 x $10^6$ MJ while the annual energy output is calculated to be 8.328 x $10^6$ MJ yielding an energy payback time of 2.3 years. With an assumed operation period of 30 years, it is expected that the installation will have 27 years of clean energy. The "GHG emissions intensity per unit of electricity generated in Canada (from the end-use electricity consumption viewpoint) is 43.20 tonnes $CO_2$eq./TJ (155.52 g $CO_2$eq./kWh) unlike natural gas emissions intensity, which is 49.68 tonnes $CO_2$eq./TJ (178.85 g $CO_2$-eq./kWh)" (Awad et al., 2021). Peng et al (2013) cited previous works that noted that the life-cycle GHG emissions rate for PV systems in the US was 22-49 $gCO_2eq/kWh$ for average irradiation of 1800 kWh/m2/yr. While in Switzerland, the GHG emissions for the average PV for the electricity mix were estimated to be around 73 $gCO_2eq/kWh$. In the consideration of life-cycle emissions of PV modules, it is also important to evaluate the emissions from the long-distance transportation of PV modules.

Given that the GHG emission from the production of photovoltaics is dependent on the GHG emissions from the electricity grid that the manufacturing plant is connected, the use of renewable energy sources such as wind and solar energy in the production of photovoltaic systems will go a long way to reduce the embodied carbon (GHG emissions) during the production phase for photovoltaic panels. Although the process of conversion of solar energy to electric energy by solar PV cells (solar cells) has practically zero emissions of pollutants during the operation phase (Muteri et al., 2020), GHG emissions can be encountered during the production processes. Mahmud et al. (2018) gave an illustration of step-by-step energy and material flows for solar PV and thermal systems. The processes are raw material extraction, raw material transportation, plant element production, plant element transportation, plant installation, plant operation and maintenance, and waste management.

## 6. SWOT Analysis of Limits on Electricity from Micro-Generators

When evaluating the use of solar energy as a means for sustainable management of non-renewable natural resources, it is important to evaluate the strengths, weaknesses, opportunities and threats of energy systems as they relate to sustainability principles (social, economic, and environmental impacts). Table 5 illustrates the Strengths, Weaknesses, Opportunities and Threats (SWOT) of removing limits in the maximum allowable micro-generation of electricity from rooftop photovoltaic systems.

**Table 5.** Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of limits on the amount of electricity by micro-generators.

| Parameters | Micro-generators (aspiring to increase the limit of electricity generation) | Big electricity companies that are in favor of limiting the amount of electricity that is generated by micro-generators |
|---|---|---|
| **Strengths** | Removal of limits on electricity generated by microgenerators (or increasing the allowable amount of electricity generated by micro-generators) will: | Limiting the amount of electricity that is generated by microgenerators will: Maintain the status quo of centralization of electricity generation while increasing the profit for the big electricity companies (if more people are using the electricity grid as the population increases and fewer people are in the micro generation business). |
| | Reduce the burden on the electricity grid | |
| | Reduce the GHG emissions that are associated with electricity from the grid | |
| | Reduce the time to break even while increasing the profitability of micro-electricity generation | |
| | Increase the profit attractiveness of micro-electricity generation | |
| | Create less reliance on electricity from the community grid when there is a need for maintenance works, either for transformers or other components of the electricity transmission system. | |
| | Keep the cost of electricity affordable for people on a long-term basis (especially if the service life of solar energy systems is greatly increased). | |
| **Weaknesses** | Lack of awareness of the expected benefit to the community and the upfront cost of solar panel installations makes exploration of solar energy not very attractive | Centralization of electricity generation can keep many people in darkness when there is a need for maintenance of the utility system. |
| **Opportunities** | Removal of limits on electricity generated by microgenerators (or increasing the allowable amount of electricity generated by micro-generators) will: | Maintaining the status quo maintains the level of jobs for people working in the electricity industry. However, other jobs can be created if established policies encourage the installation and maximization of solar panel potential while monitoring the amount of energy that is generated, efficiently stored, transmitted, and distributed, and researching ways to increase the amount of energy that is generated per square meter of photovoltaic systems that are installed. |
| | Reduce the concern about GHG emission reduction | |
| | Bring communities closer to the goal of achieving net zero on GHG emissions during the building's useful lifetime | |
| | Bring communities closer to the realization of energy independence ambitions. | |
| Threats | Removal of limits on electricity generated by microgenerators (or increasing the allowable amount of electricity generated by micro-generators) will: | Except carbon capture technology is employed on an efficient scale, centralization of electricity production while restricting the limits for micro electricity generation will maintain the status quo on the concern about GHG emissions from the electricity grid (for regions that have high rates of GHG emissions from the electricity grid). |
| | Reduce the amount of profit that would have been generated by big electricity companies. | |
| | Create the need for better planning for the transmission and storage of excess electricity that comes from micro-generators. | |
| | Create the need for better planning for additional energy when solar energy output is low. | |

The above evaluation of the strengths, weaknesses, opportunities and threats of micro-generation will allow policymakers to have more basis for discussion and decisions on how to minimize the threats and weaknesses while maximizing the strengths and opportunities. In addition to contributing to the stability of the energy supply, the GHG emission reduction opportunities of an increase in micro-electricity generation capacity make it worth exploring. Mofolasayo (2024a) illustrated how to estimate the GHG emission savings for an increase in micro-generation of electricity from rooftop solar panels on households. The study also presents how excess solar energy generated by households can be used. From table 5 above, it is obvious that the advantages of removing barriers towards maximizing the amount of solar energy that can be generated from the roof areas of people in residential communities are higher than the disadvantages.

## 6.1. How can we increase the penetration of solar panels?

The increase in the adoption of solar power systems can be achieved by the use of policies that make the use of solar power systems more attractive. In different communities, various policies are designed to attract people to accept renewable energy. For example, the Pace program allows people to put the solar cost on their mortgage https://www.paceab.ca/. Edmonton is offering $0.30 per watt for new homes with solar and 0.40/watt for older homes installing solar https://homes.changeforclimate.ca/solar-rebate-program/ (Change homes for climate program). https://homes.changeforclimate.ca/residential-solar-program-terms-and-conditions/. The EQUS program allows solar generators in Alberta to improve their return on their solar investment by selling their carbon offset credits. https://www.equs.ca/services/micro-generation/micro-generation/financing-and-incentives-for-solar/. Although there are some policies in place that are designed to encourage the use of solar energy systems, more strategies can still be employed to make the adoption of solar energy systems more attractive to people. Policies that allow private individuals to make money from the installation of solar panels for their homes are expected to go a step further to encourage more people to explore solar energy. Rather than having homes come with only gas systems for heating during the winter, the incorporation of electric-powered heating systems in many homes will help reduce reliance on non-renewable natural gas, and further exploration of renewable energy systems, such as solar, wind power, etc. Although the use of electricity for heating homes can increase the amount of electrical energy that would be used by households per annum, in regions that limit the capacity of solar panels to the amount that the household uses, replacing the use of other non-renewable energy sources for heating can help justify an increase to the capacity of solar panels that a household can install. Table 6 shows the annual cost of usage of natural gas by some households in Alberta (data collected during this project). This includes transmission fees, carbon tax and GST.

**Table 6.** Cost of natural gas usage for residential customers

| | **Residential customer A** | | **Residential customer B** | | **Residential customer C** | |
|---|---|---|---|---|---|---|
| **Statement Month** | **Natural Gas (GJ)** | **Total cost of natural gas** | **Natural Gas (GJ)** | **Total cost of natural gas** | **Natural Gas (GJ)** | **Total cost of natural gas** |
| June | 3.02 | $ 86.88 | 3.04 | $ 90.56 | 2.02 | $ 79.16 |
| July | 2.10 | $ 83.24 | 3.14 | $ 91.94 | 1.05 | $ 73.57 |
| August | 2.02 | $ 77.69 | 2.02 | $ 75.61 | 1.01 | $ 66.06 |
| September | 2.00 | $ 75.68 | 3.04 | $ 89.34 | 0.00 | $ 59.41 |
| October | 2.03 | $ 72.47 | 3.15 | $ 85.16 | 1.04 | $ 64.61 |
| November | 7.14 | $ 104.82 | 5.94 | $ 107.48 | 4.00 | $ 89.38 |
| December | 12.40 | $ 179.75 | 14.01 | $ 192.93 | 7.00 | $ 125.39 |
| January | 18.11 | $ 241.65 | 18.46 | $ 240.10 | 11.27 | $ 172.37 |
| February | 9.48 | $ 138.73 | 13.12 | $ 178.35 | 7.06 | $ 116.29 |
| March | 11.23 | $ 157.43 | 13.07 | $ 173.10 | 7.04 | $ 117.44 |
| April | 7.03 | $ 121.34 | 11.09 | $ 168.72 | 6.04 | $ 117.96 |
| May | 4.04 | $ 95.69 | 9.01 | $ 90.12 | 3.00 | $ 78.81 |
| **Total** | 80.60 | $ 1,435.37 | 99.09 | $ 1,583.41 | 50.53 | $ 1,160.45 |

During the review of the utility bills for natural gas, it was noted that the bill includes a carbon tax. As the carbon tax increases, the cost of natural gas will also increase. Hence, to ensure that citizens do not get trapped in carbon taxes without a way out, it is important to provide affordable alternatives for people to upgrade their home energy heating systems to electricity and energy systems that are not associated with the carbon tax. Those who rely on natural gas heating systems in areas that need a considerable amount of heat during the cold months will feel the impact of the carbon tax on home energy bills more than those who use an energy supply that is not charged for the carbon tax. Currently, the consumer carbon price has been cancelled in Canada. However, anyone considering this in the future must know its implications.

To achieve the high energy availability that is required for some applications, it is necessary to oversize the rating of the generating system (Notton et al., 2011). Furthermore, it is also possible to use a hybrid system. The provision of adequate energy storage facilities for various communities and allowing households to maximize the solar energy generation potential from their rooftops can help to ensure that there will be a considerable reduction in electricity from the grid in the winter months, when typically, lower solar energy is generated in cold regions. With adequate energy storage systems, a considerable portion of the excess energy that is generated in the months with higher sunlight hours may be stored for use in the winter months.

## 6.2. In the goal to use renewable energy resources as a means to ensure sustainable management of non-renewable energy resources, what strategies can be adopted in regions that limit the generation of solar energy to the annual usage of households?

i. Upgrade the policy to allow the household to generate enough energy that can completely cater to both the electrical energy needs and the equivalent energy that is used from natural gas.
ii. Grant permissions to households that are willing to maximize the capacity of their roof areas for solar energy systems.
iii. Allow households the opportunity to share excess energy that is generated from their solar panels with their friends or neighbors. In an excess energy-sharing program, households may be asked to name other electricity users whom they would like to share their excess energy with.
iv. When maximizing the amount of energy that can be generated from roof areas, allow households the opportunity to donate the proceeds of the excess energy that is generated from their solar systems to non-profit organizations, such as organizations that care for the homeless, organizations that care for the orphans, etc.
v. Allow households that want to keep the proceeds from excess energy that is generated by their households the opportunity to keep those proceeds to increase their standard of living. If desired, the excess energy that is generated may be treated as taxable income. The tax received from this may be used to maintain the energy transmission systems and energy storage systems for the entire community. The tax that is received from this may also be used to provide subsidies to low-income families that need assistance in installing solar energy systems and in upgrading their house heating systems from ‘non-renewable energy’ power sources to renewable energy systems.

In a study on sustainable development and solar energy using results from 35 countries, Guney (2022) reported that solar energy resulted in an increase in the level of sustainable development, while a decrease in sustainable development is associated with non-renewable energy. Another researcher recommended that electricity policies in all countries should seek a diversified and higher contribution from renewable and low-carbon energy technologies (Kabeyi & Olanrewaju, 2022). Sridhar et al. (2022) recommended that, although the initial investments are high, companies should consider adopting green technology in their businesses due to its long-term benefits and contribution to protecting the planet. The use of renewable energy, such as solar energy, and others can contribute significantly to mitigating greenhouse gas emissions and ultimately global warming (Agrawal & Soni, 2021). Maka et al. (2024) also echoed this saying, 'the use of renewable technology is a recommended measure to mitigate against the challenges of emissions in the goal towards achieving a net-zero emission'. It is forecasted that solar energy will have great installation capacity worldwide. The investment in solar energy and other clean technologies will significantly help to achieve sustainable development in the coming decades (Maka et al., 2024).

## 6.3. Addressing equity issues with solar panel subsidies?

In order to ensure that the installation of solar panels is not limited to the rich families, it is important to carefully design alternative programs that will better attract low-income households to install solar energy systems. This may include policies to increase the subsidies for solar panel installation to reduce the upfront cost and the total cost to low-income households. The upfront fees/down payment that a household has to pay to install solar energy systems may also be reduced for low-income families.

## 6.4. Challenges for solar energy penetration and what can be done to address the challenges

In addition to the economic challenges that solar panels face from the high cost of installation, various other factors need to be adequately addressed in the long term if photovoltaic energy systems are to see high penetration into the energy market.

***6.4.1. The need for storage*** It is known that at some point in every part of the world, even though we do enjoy many hours of bright sunshine, there are hours of darkness too. Hence, there is a need for reliable storage of solar energy. To ensure that excess solar energy that are generated by various homes can be safely stored for the winter months, long-term storage of solar energy is one of the topics that will benefit immensely from future study.

***6.4.2. High cost of batteries for the storage of solar energy*** Sometimes, there may be a need to supplement energy from renewable sources with energy from non-renewable sources. While solar energy cannot provide continuous energy as a result of low availability during the dark hours and in the wintertime, the energy from the wind system cannot provide a constant load due to changes in the magnitude of wind speed (Notton et al., 2011). Due to changes in weather and the alternation of night and day, there is instability in electric energy production when using wind power or PV alone. High battery cost doesn't let most owners go completely off the grid in Alberta. In addition, you cannot participate in the net billing program if you are disconnected from the grid (Urban, 2021b). The high cost of batteries for the storage of solar energy increases the investment cost for solar energy. With the high cost of batteries for solar energy systems, the payback period is also increased. This can be a discouraging factor for anyone who wants to install a solar power system and be assured of uninterrupted energy (especially in places that have longer hours of sunshine throughout the year). To address the issue of the high cost of batteries and energy storage systems for solar energy, there is a need to fund and encourage more research on topics on "development of low-cost energy storage systems for solar power". Hence, the establishment of research funds in different communities to support studies on affordable long-term storage of solar energy is recommended. In addition, there is a need for a review of the breakdown of the costs for the present energy storage.

***6.4.3. Transmission / Distribution fees*** Without adequate energy storage facilities to store excess energy that is generated during high sunshine hours, residential communities and industrial facilities would need to rely on energy from the electricity grid to supplement the energy that is generated from solar photovoltaic systems. The high cost of transmission/distribution fees will reduce the profitability of solar energy systems.

It will also increase the expected number of years to break even on the investment in solar energy systems. Governmental policies to reduce the distribution fees for households that install solar energy systems will make the installation of solar energy systems more economically attractive.

***6.4.4. Increasing the efficiency of photovoltaic systems*** The amount of solar energy that is produced is considerably reduced by various factors, as mentioned earlier. It is important to continuously research means to improve the efficiency of photovoltaic systems to increase the energy generated per unit area. Although concentrator technology can be used to significantly improve energy flux density, it can result in an increase in the solar cell surface temperature and lower conversion efficiency. The cooling working substance pump circulation may be used not only to reduce the surface temperature of the solar cell, but also to obtain heat energy. References to previous works that have used this technology to reduce the surface temperature of solar cells have been provided (Tan et al., 2014). Further study is recommended on how this technology can also be used to maintain an optimum temperature for photovoltaic panels during the winter months. A decrease in the operating temperature of the photovoltaic converter increases both the voltage and the efficiency (Karamov & Naumov, 2020). Souliotis et al. (2005) analyzed the energy, cost and LCA results of PV and Hybrid PV/T Solar systems. The hybrid photovoltaic/thermal solar system, PV/T Solar systems, are ones in which solar radiation is simultaneously converted into heat and electricity. A circulating fluid is used to cool the PV system down. The study noted that PV/T systems are more cost-effective and more environmentally friendly than standard PV modules. Lujanos-Rojas (2014) also showed a model that indicated that the efficiency of photovoltaic panels can be affected by the cell temperature and temperature coefficient.

The four main factors that contribute to normal degradation include thermal cycling (dramatic changes in extreme temperatures i.e., cold and heat impacting soldered connections of the panel), humidity freeze (sudden freezing in high humidity situation can affect the adhesion in junction box), ultraviolet exposure (discoloration and degradation of the cover of the side of panel that faces away from the sun due to exposure to the ultraviolent rays from the sun) and damp heat (long-term exposure to high humidity at high temperatures that can cause separation of materials that insulate the cells (Baldwin, 2019). To improve the efficiency and performance of solar panels, it is important to increase efforts in research and development to minimize the impacts of all the factors that result in the degradation of the panels. Potential induced degradation that could potentially lead to the failure of PV modules in the field has become a major issue for the PV industry (Luo et al., 2017a). The major reason for solar panel degradation over time can be broken down into three parts: Potential induced degradation (PID), light-induced degradation and aging-related degradation (Evergreen Electrical Services). Other factors that can affect the solar panel efficiency include solar panel orientation, the pitch of the roof, shade, temperature, and design (e.g., the size of cables and inverters, etc.). Hence, when exploring the use of solar panels on a large scale, it is important to continuously study the factors that reduce the efficiency of roof panels and how the negative impact of these factors may be significantly reduced. Most systems come with production warranties that step down over time as all solar panels gradually degrade. Generally, solar panel modules can be expected to degrade by 0.5 to 3% per year (Baldwin, 2019). Further research on how to ensure that solar panels maintain their efficiency through the lifecycle of the building and beyond is recommended.

***6.4.5. End-of-life use for photovoltaic systems*** There is concern about material handling after the useful lifetime of solar panels (Berg, 2018). Efforts to ensure that solar panels can be returned to the manufacturers to improve the efficiency of the products while reusing most of the existing materials will be commendable to ensure that solar panels can be continuously reused without contributing to the waste management burden for society at large. Further study is recommended on efficient reuse and recycling processes for photovoltaic systems at the end of their useful lifespan.

# 7. Other avenues for harvesting solar energy

Solar energy can be harvested through other means, including solar panels on cars to recharge the battery system. The photovoltaic systems may be incorporated into the material for the design of the body of the car (i.e., the roof, the hood of the car, the trunk lid, etc.). Previous works have mentioned the use of solar panels on trains (Hanjin et al., 2022) and Solar bike paths (Rooij, 2017). Major utility-scale ground solar panel installations (often called solar farms) are growing rapidly as solar energy becomes an increasingly cheap source of renewable energy (Yavari et al., 2022). Although the construction of these also comes with some environmental impacts, some researchers (Turney & Vasilis, 2011) reported that none of the impacts are negative relative to traditional power generation. Solar farms can be designed in a way to minimize the impact on the landscape's ecohydrological process, but there is a need for more research in this area (Yavari et al., 2022).

# 8. Addressing concerns about large-scale renewable energy systems

For large-scale renewable energy, various concerns have been raised. The concerns for some renewable energy projects include the effect on scenery, development on agricultural lands, reclamation security and system reliability (The Canadian Press, 2023). An important question is, 'Can these concerns be addressed in a way that creates a win-win solution for everyone?'.

## 8.1. Impact on farmlands

Solar farms can be designed to allow for the simultaneous planting and harvesting of crops that are beneficial for animals and for humans. Research that is focused on coupling solar farms with agriculture (agrivoltaics) demonstrates reduced water losses and the associated crop stress (Yavari et al., 2022). Organizations that submit permits for solar plants where there is concern about the impact on agricultural land may be asked to submit a plan on how the solar farm will be designed to contribute to agricultural produce (agrivoltaics). If approved on the condition of incorporating agrivoltaics, failure to meet the condition for approval may be a ground for the termination of the license for the owners of the solar farm. A strategy like this creates a win-win solution for those who are concerned that solar farms are taking agricultural space and those who want to explore renewable energy production on a commercial scale from solar farms. It is important to ensure continuous research on how to optimize agricultural output on farmlands where agrivoltaics systems are used. The European Union Joint Research Center reported that innovative multi-land-use applications of agrivoltaic systems (in which the panels are installed in a way that agricultural activities like crop production and livestock remain the primary use of the land area) could help surpass the EU's 2030 solar energy generation targets (European Commission, 2023).

Other land areas that may be used for renewable energy systems include:

- Abandoned mines that can be accessed by specialized personnel for the construction and maintenance of solar farms.
- Contaminated lands that are deemed not usable for agriculture and human living, but can still be accessed by specialized personnel for the construction and maintenance of solar farms.
- Old landfills that are no longer in use, but can be accessed by specialized personnel for the construction and maintenance of solar energy generation farms, etc.

If abandoned mines, sites that are considered as depleted oil wells, etc., are pre-approved as potential sites for renewable energy, this may create an incentive for mining companies, oil and gas investors to invest in renewable energy while creating further opportunity to sustainably manage 'non-renewable' natural resources for present and future generations.

## 8.2. Aesthetic impacts

In spite of the good social acceptance of solar energy systems, the transformation of the landscape causes an aesthetic impact (Sanchez-Pantoja et al., 2018). The interest in this has been growing in the literature. For rooftops, new designs are emerging in which an onlooker may hardly know if the roof has photovoltaics (https://www.tesla.com/solarroof). Some roads are classified as scenic routes. It may not be advisable to locate solar farms on such routes (except when it is intentionally approved for the advertisement of the social acceptance of renewable energy systems in various communities). Where aesthetics is of concern for solar panels from the road, solar panels that meet all other approval requirements may be cited further in the forest (away from the view of travellers who love to appreciate natural beauty when travelling). As an environmental impact assessment (EIA) should be done for projects of such magnitude, it is important to have an adequate review of the environmental impacts of large solar farms to ensure that strategies to meet various environmental concerns (including aesthetic concerns) are adequately addressed. Among other things, Uyan (2013) identified 'proximity to high transmission capacity lines' as one of the site selection issues for solar farms. The desire to locate solar farms close to high transmission capacity lines may not encourage those who want to establish solar farms to move deeper into the forest, where they may not be seen as causing aesthetic issues. In areas where there is interest in establishing huge solar farms, the investors may have to consider the cost to build additional transmission lines when the solar farms need to be moved further away from the roads. Alternatively, where there may be a concern that solar energy systems can cause a negative impact on the aesthetics near a roadway, a considerable number of trees (e.g., evergreen trees) may be planted between the solar farms and the roadway. This is expected to create a win-win solution for those who love to observe natural landscapes and forests from their vehicle while travelling, and those who want to develop large solar farms.

## 8.3. System reliability

System reliability is an important issue that needs to be given adequate attention, especially as it relates to the provision of a constant electricity supply during periods of low energy from solar power, such as nighttime and periods of the year when the hours of sunshine are low (such as winter periods). There is a need for some backup energy supplies during those periods. In some situations, solar energy from solar PV systems on rooftops alone may not be sufficient to meet household energy supply (Mofolasayo, 2024b). Hence, there is a need to supplement the household energy supply with other forms of energy. Although other renewable energy systems, such as wind power, geothermal, etc., may still be available when solar power is down, there is a need for adequate planning for efficient power storage systems for renewable energy. ‘Non-renewable’ energy systems can be used to supplement energy production in such a period. Where system reliability is a concern, as part of approval documents, large-scale renewable energy operators may be required to submit plans on how they will contribute to system reliability. This may include plans to contribute to the establishment of efficient energy storage systems for dark hours and periods with low solar hours in different communities. The plan to contribute to energy storage for system reliability can come in different formats. Large-scale energy storage systems would have financial implications. Some of this may be included in the user fees that would be collected from users in the long run. Governmental support may be necessary for funding systems to ensure system reliability (especially if the cost of a reliable energy storage system is high). Any associated environmental impact and applicable mitigation strategies for energy storage systems would need to be duly addressed during the planning stage. While further work is ongoing on efficient energy storage on a large scale, carbon capture technologies will help mitigate the impact of carbon emissions from fossil fuel energy systems. This study encourages further exploration and funding for research on affordable carbon capture technologies that reprocess carbon emissions into beneficial materials for humanity at large (in all areas where carbon emissions are of concern). Mofolasayo (2023) presented a concept for carbon capture technology. An increase in the adoption of renewable energy systems is expected to create less reliance on non-renewable energy while helping to achieve the goals of sustainability. i.e., the present generation should responsibly use natural resources with consideration for future generations.

# 9. Study Limitations

In some situations, the counting of buildings with solar panels was limited to the view of the roof that can be seen from the sections of the roofs that are visible from the direction of driving. It is not impossible that some buildings with solar panels may be missed if the solar panels are situated in the opposite direction to the driving direction or if the location of the solar panels is not within the line of view of the camera. The survey result is also subject to human error in counting. The goal of the study is not to present an exact number of houses that have solar panels in the community; rather, it is to show that there are more opportunities for improvement in the adoption of renewable energy systems in various communities. Canada's Renewable Power (referenced in the study) provides a record of renewable energy that is generated from different provinces. Physical field survey/counting of the number of houses that have rooftop solar panels should be done in good summer weather when the roofs are not covered in snow.

## 9.1. Recommendations for future research

Energy production capacity planning is very important not only for the efficient management of 'non-renewable' energy resources but also in ensuring that utility companies can produce and supply an adequate amount of energy for the community (especially as demand for electricity increases with an increase in population and an increase in the use of electric vehicles and equipment). The following further studies are recommended:

- Larger-scale field survey using camera-equipped drone technology for solar-power-penetration studies.
- Expanded studies in collaboration with utility companies and local governments to access more data on solar installations to help in planning the energy needs of the community.
- Elaborate studies on the integration of geographic information systems (GIS) to map solar potential across various communities around the globe.
- Expanded studies on the adoption of solar energy systems for residential and industrial applications for adequate planning of incentives and resource allocation to improve the use of renewable energy in the management of non-renewable energy resources in different communities globally.
- Expanded correlation tests or trend analysis to identify patterns (e.g., relationship between solar capacity and local policies such as public awareness programs, and financial incentives in various communities).
- Elaborate studies on international comparison of solar energy adoption rates between various nations to identify strategic policies and best practices that have helped to improve solar energy adoption for the management of 'non-renewable' energy resources in various countries.
- Qualitative and quantitative studies on how community attitudes, socioeconomic factors, aesthetic concerns, lack of awareness, and cultural barriers influence solar adoption. A study like this can be done using a survey and an interview approach.
- Quantitative analysis of how the adoption of solar energy reduces resource depletion (e.g., fossil fuel savings at the provincial, national, and global levels).
- Best practices on recycling of photovoltaic panels to reduce the potential for resource depletion.

# 10. Conclusion and Recommendations

The study reviews how solar energy can be applied as a means to sustainably manage non-renewable energy resources. Among other things, the study discussed:

- The concern about fossil fuel depletion
- The economics of solar energy systems
- Equity issues with solar panel subsidies
- Strengths, weaknesses, opportunities and threats (SWOT) analysis of increasing the micro-generation capacity of electricity from the rooftops of residential and commercial buildings
- The challenges for solar energy penetration and what can be done to address the challenges
- Strategies to address the concerns about large-scale renewable energy systems.
- How to create win-win solutions for concerns around sustainable energy production.
- Important notes to shape policy decisions for renewable energy systems using solar energy as an example.

This study illustrates a method for the evaluation of solar penetration and sets up important questions to guide policy decisions when deliberating about policies that should take priority in decisions that are geared towards increasing the acceptance of solar energy for residential and commercial uses. Important notes for deliberations during the decision geared towards increasing the acceptance of solar panels for residential and commercial buildings are presented. Strategies to increase the penetration of photovoltaic systems for the sustainable management of non-renewable resources are presented. The strengths, weaknesses, opportunities and threats SWOT analysis of allowing for a significant increase in the micro-generation potential by households for harvesting solar energy indicated that there is more benefit than harm if households are allowed to maximize the potential for solar generation from their rooftops. Households that decide to maximize their roof areas for the production and contribution of renewable electricity to the community grid become partners in the effort to reduce the GHG emissions from the electricity that is produced in communities with high GHG emissions from the electricity grid. The use of certified professionals is recommended to ensure appropriate wiring. To remove hurdles around the adoption of large-scale renewable energy systems, the study presents a discussion on the concerns about large-scale renewable energy systems. The concern about the impact of solar power on farmlands can be addressed through a combination of solar farms with agriculture (agrivoltaics). The concern about aesthetic impact can be addressed through careful selection of locations for renewable energy systems and planting of evergreen trees between the roads and the renewable energy farms (wherever the renewable energy farms can constitute an aesthetic issue). In order to prevent undesirable shading effects between the trees and the Solar PV systems, a considerable distance between the trees and the PV systems will be appropriate. Within this buffer, various crops that will not be as tall as the installed PV systems could be planted. System reliability issues can be addressed through adequate planning of energy storage systems for renewable power to ensure that renewable energy systems can contribute to a smooth supply of electricity throughout the year. In addition, efficient and affordable carbon capture systems are recommended whenever fossil fuel is used as a supplement to renewable energy systems. The evaluation of both online data on renewable energy generation and the field survey conducted indicated that there is a lot of room for improvement in the effort to use solar power as a means to sustainably manage non-renewable energy for present and future generations. Further research is recommended on how to better harness solar energy in a more economical way to improve access to sustainable energy while improving the standard of living for people globally.

**Acknowledgements** The journal thanks Desislava Bekyarova for their administrative assistance throughout the publication process.

**Funding** No funding was received for this work.

**Author Contributions** Adekunle Mofolasayo: Project conceptualization, design of study methodology, literature review, formal analysis, resource provision/funding, project management and oversight, writing of the manuscript, and response to review comments.

**Data Availability** A data summary is included in the manuscript. Any other data can be made available upon request to the author.

## Declarations

**Competing interests** The authors declare no competing interests.



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