UNIVERSITY OF CALGARY

Solar Panels in Alberta and Greenhouse Gas (GHG) Emissions

by

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ABSTRACT

The project quantifies Greenhouse Gas (GHG) emissions reduction in Alberta if it is considered that 25% of total energy generated from natural gas and coal is soon replaced with solar panels. A typical solar panel lifecycle is 25 years. When 25% of electricity is generated from solar panels in Alberta, calculating environmental payback time shows that solar panels will be carbon neutral after 2 years of operation. Whereas over 25 years of operation, 29.6 Mt CO_2eq is avoided compared to consuming electricity from the grid. The project also aims to assess the GHG footprint during the upstream manufacturing of solar panels deployed in Alberta, and how to improve sustainability for the upstream value chain of major Alberta solar projects. The primary reason for identifying GHG emissions during the upstream side of solar panels will help potential customers of Alberta to know how sustainable solar technology is across its entire lifecycle.

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LIST OF TERMS AND ABBREVIATIONS

ABC – Anti Bribery and Corruption

CEO - Chief Executive Officer

CO_2 – Carbon Dioxide

CO_2eq – Carbon Dioxide Equivalent

CSA - Canadian Standards Association

EPC - Engineering, Procurement and Construction

ERA – Emissions Reduction Alberta

ESG - Environmental, Social, and Governance

GHG – Greenhouse gas

KWH - Kilowatt Hour

LCA – Life Cycle Assessment

LCOE – Levelized Cost of Electricity

Mt CO_2eq – Megatonne of Carbon Dioxide Equivalent

MW – Megawatt

MWH – Megawatt Hour

NASA - National Aeronautics and Space Administration

NREL - National Renewable Energy Laboratory

PV - Photovoltaic

SAM – System Advisor Model

SDG – Sustainable Development Goal

TWH – Terawatt Hour

CHAPTER 1: INTRODUCTION

1.1 Introduction

Canada consumed 625.95 TWh of energy in 2021, out of which 29.92%, 30.78%, and 3.44% of energy was produced by burning fossil fuels, oil, gas, and coal respectively. Whereas only 0.35% of electricity was generated by converting solar energy into electricity (Ritchie et al., 2022a). See Table 1 below.

Table 1: Canada Energy Mix for 2021

Total Energy (TWh)	Sources of Energy	Share from total energy (%)
625.95	Gas	30.78
	Oil	29.92
	Hydropower	25.74
	Nuclear	5.96
	Coal	3.44
	Wind	2.37
	Other renewable	0.8
	Solar	0.35

Note: Recreated on Microsoft Excel from World in Data, 2022.

Overall, the generation of electricity in Canada is still heavily dependent on oil and gas. Coal is phasing out and renewables particularly wind and solar are gaining popularity. To reach net zero, meaning our economy either emits no greenhouse gas emissions or offsets its emissions

(Government of Canada, 2023), the wind and solar industry will play a vital role in Canada's future electricity mix.

Alberta is the third largest producer of electricity in Canada, and in 2019 it generated 76.1 TWh of electricity, out of which 36% and 54% came from burning coal and natural gas (Government of Canada, 2022). At that time solar energy's share in Alberta was less than 0.1% (Government of Canada, 2022).

In terms of GHG emissions, most emissions are coming from the oil and gas sector and electricity generation as Alberta is still heavily dependent on burning coal and natural gas to cover its energy needs. However, with The Canadian Net-Zero Emissions Accountability Act, which became law on June 29, 2021, Canada is committed to reaching net-zero emissions by 2050 (Government of Canada, 2023). To achieve this goal, in the coming years burning of fossil fuels will be phased out and renewable energy will take over for clean energy generation.

In Alberta, since solar radiation is high and temperature is low compared to other provinces, investing in solar energy makes sense, as under these conditions operating efficiency of solar panels is increased, meaning that it produces more energy under high sun and low temperature. An example of this is a typical solar panel in winter in Alberta, from January to April will have an efficiency of approximately 20% compared to summers, from May to August, where its efficiency will be 15% (less than in winters). Hence, there are many large-scale solar panel projects which have been developed in Alberta, an example is the nation's largest solar facility located in Vulcan County, the Travers Solar Project, with 465 MW capacity and over 1.3 million solar panels, and the public is also interested in installing solar panels on rooftops to support sustainability and get provincial or federal incentives by accessing electricity from solar energy.

The initiative for using solar energy in Alberta is gaining popularity and according to U.S. Energy Information Administration (2022), solar energy technologies do not produce GHGs during the usage phase of solar panels. However, during the upstream processes like the extraction of raw materials and manufacturing of solar panels, there will be emissions. In this research project, I will estimate the GHG footprint during the upstream manufacturing of solar panels potentially to be deployed in Alberta. This estimate will be based on a combination of interviews with major Alberta solar projects as well as market research. Additionally, in this project, I will make recommendations around how we can improve sustainability for the upstream value chain of major Alberta solar projects. This research is significant in Alberta as currently solar panels are not manufactured locally, therefore, from this research, we will help potential future consumers of solar energy make informed choices based on the entire GHG footprint of solar energy.

Other than this, based on our research, I will estimate how much emission reduction can be done by transitioning from fossil fuel sources to solar energy in Alberta. For example, if 25% of electricity is generated from solar energy in the future, how much emissions will be saved in comparison to fossil fuel burning to generate electricity?

1.2 The Project Goal and Importance

The project quantifies GHG emissions reduction in Alberta, with the current energy production switch to 25% of total energy from coal and natural gas replaced with solar panels. The research addresses the following question: *What are the GHG emissions during the upstream manufacturing of solar panels?*

The project outcomes can be useful for Albertans to make informed choices based on the upstream GHG footprint of solar energy as according to U.S. Energy Information Administration

(2022) solar energy technologies do not produce GHGs during the usage phase of solar panels. This project helps in clearing the public misconception that manufacturing solar panels emits a large amount of GHG emissions. The project also addresses the social aspect of sustainability related to solar panel manufacturing.

The study can be helpful for private and public companies who will be looking into transitioning from the fossil fuels industry to renewable energy projects, especially solar projects. This will serve as a pioneer that solar energy projects in Alberta have a bright future and is one of the best options if the province plans to meet net zero target.

1.3 Multidisciplinary Aspect of the Project

In sustainable development, often social aspect is ignored. Whereas environmental and economic dimensions of sustainable development are given more importance. This project takes multidisciplinary approach anchored in energy, environmental and social aspect of sustainability. The project not only promotes solar energy for generation of electricity and reducing dependency on fossil fuels which pollutes environment, it also promotes ethically manufactured solar panels to be used in Alberta for sustainable development.

1.4 Addressing United Nations Sustainable Development Goals

Out of the 17 United Nations Sustainable Development Goals (SDGs), the project is in line with achieving the following SDGs:

- SDG13 - Climate Action, by proposing how much emissions can be reduced if solar energy is added to current Alberta’s energy mix.
- SDG9 - Industry, Innovation, and Infrastructure, by proposing more solar infrastructure needs to be developed to get a sustainable grid in Alberta.

- SDG11 - Sustainable Cities and Communities, by recommending sustainable practices, especially focusing on the social aspect of sustainability during the manufacturing of solar panels.

CHAPTER 2: LITERATURE REVIEW

2.1 Solar Energy

Solar energy is a free, abundant, and never-ending source of energy. According to NASA (n.d) annually approximately 342 watts of solar energy fall upon every square meter of Earth. This is equivalent to 4.4×10^{16} watts or 44 quadrillion watts of power to be exact (NASA, n.d). Photovoltaic (PV) panels or simply solar panels are the technology used to convert radiation from the sun to electricity.

2.2 Working of Solar Panels

Solar panels work on the principle of the PV effect that converts light into electricity. Each solar cell consists of two slices of silicon. Each slice of silicon is doped with other materials to give it a net positive or a net negative charge. Usually, the top slice is N-type as it is doped with phosphorous to add electrons and produce a negative charge. Whereas the bottom slice is P-type as it is doped with boron to produce a positive charge and fewer electrons (TWI, n.d.). This creates an electric field at the junction between the layers and each layer has metal conducting plates on one side (Aggarwal, 2023).

Light particles are called photons, and when a photon of sunlight strikes the solar cell, it dislocates an electron from the cell. This dislocated electron is free to move between the conductors and through the circuit to generate electricity TWI. (n.d.). Note, solar panels produce electricity in direct current (DC) as the flow of current is in one direction, i.e., from the negative to the positive side (TWI, n.d.). However, this DC is converted into alternating current (AC) using an inverter which is then connected to the power AC load.

2.3 Types of Solar Panels

The three main types of solar panels are as follows:

- **Monocrystalline**

Solar panels with monocrystalline solar cells are made from a single source of silicon (Unbound Solar, 2020). The "mono" in monocrystalline refers to the process of using a single silicon crystal during production (Jude, 2023). Hence, they used the purest form of silicon. Also, visually, and aesthetically they are perfect due to the same size and shape used from a single source of silicon. These panels have a black hue and are most efficient and more expensive than others (Marsh, 2023a). This type is good for residential and commercial use.

- **Polycrystalline**

Solar panels with monocrystalline solar cells are made from multiple sources of silicon (Unbound Solar, 2020). This type sometimes also includes the wasted silicon from monocrystalline solar cells (Jude, 2023). Hence, they are not using the purest silicon. Visually they differ in color and texture due to the multiple sources of silicon used. These panels have a blueish hue and are less efficient and less expensive than monocrystalline (Marsh, 2023a). This type is good for residential and commercial use.

- **Thin film**

This type is the least popular which is created by depositing a thin layer of conductive material onto a backing plate made of glass or plastic (Unbound Solar, 2020). These are far less efficient than the two popular types, however, they are the cheapest to produce. This type is only good for commercial use, not residential use due to less efficiency.

Note, the function of these three different types of solar panels is the same, i.e., converting solar energy into electrical energy. However, the difference between them lies in their efficiency, appearance, and long-term benefits.

2.4 Raw Materials

Below are the raw materials used in the manufacturing of a typical crystalline silicon solar panels.

Table 2: Raw Materials of a typical crystalline silicon solar panels

No.	Raw Materials	Approximate %
1	Silicon	5
2	Glass	76
3	Plastic polymer	10
4	Aluminium	8
5	Copper	1
6	Silver	<0.1
7	Other metals	<0.1

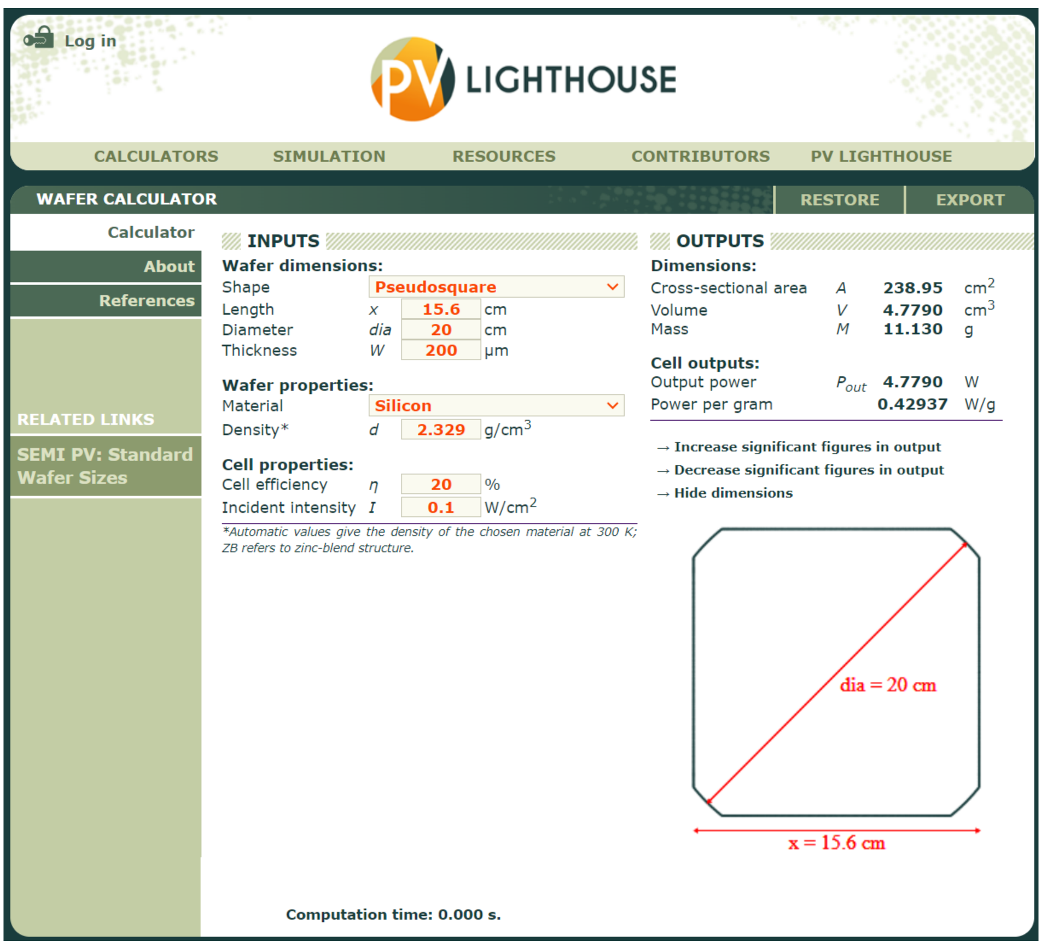
Note: Recreated on Microsoft Excel from Dominish et al., 2019.

2.5 Silicon and Emissions Associated with its Extraction and Production

Solar panels main component is PV cells which are made of silicon. Silicon is abundant in nature, and it is found in beach sand. After oxygen, it is the second most abundant material on Earth (Energy, n.d.). Hence extraction of silicon in the future will not be a problem due to its high quantity available. However, converting sand into high-grade silicon comes at a high cost and is an energy-intensive process (GreenMatch, 2023). As most of the silicon manufacturing happens in China and there the primary source of electricity generation is coal, there are emissions involved in extracting silicon from sand which is done by using an arc furnace at very high temperatures (GreenMatch, 2023). According to Hoffs (2022) producing 1 kilogram of metallurgical grade silicon requires 14-16 kWh of power.

To find out how much quantity of silicon is used in a solar panel, a PV lighthouse wafer calculator is used (Wafer calculator, n.d.). For the inputs in the calculator, I selected silicon as a material for a pseudo square shape for a single cell. Length 15.6 cm, diameter 20 cm, and thickness 200 µm are selected, output result shows with this input approximately 11 grams of silicon is used for 1 cell as shown in Figure 1.

Figure 1: PV lighthouse wafer calculator for estimating quantity of silicon in a single cell.



Note: Wafer calculator, n.d.

For a standard-size solar panel consisting of 60 cells, the quantity of silicon used will be 11 grams x 60 = 660 grams. According to Solaris Renewables (n.d.), silicon manufacturing accounts for around 6.0 kg CO_2eq/kg per silicon metal made.

2.6 Other Materials and Emissions

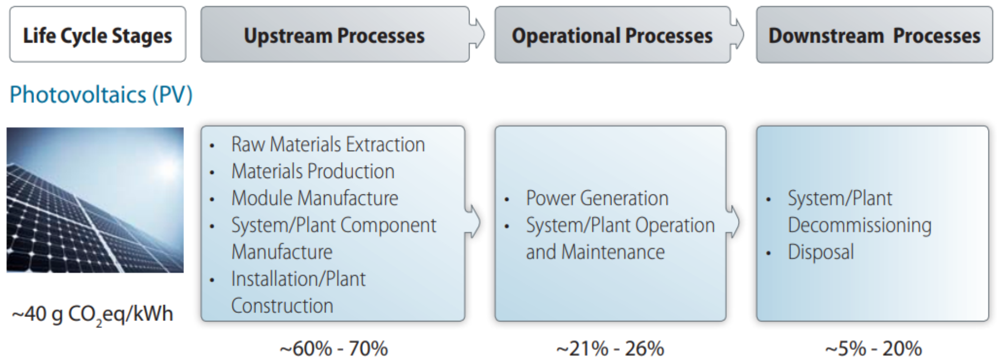
Once the silicon cells are prepared then they are interconnected with copper wires which work as a conductor to pass the flow of electrons. Mining of copper is also energy intensive procedure. Finally, glass is used to cover the solar cells which are also being prepared from sand and the structure on which solar panels sit is made of either steel or aluminium. One of the advantages of solar panels is that all the materials used in manufacturing of solar panels are abundant in nature and can be recycled.

Furthermore, to exactly measure the quantities of a solar panel, it is difficult to find out this information as solar panels differ in size and type. However, silicon is the main component for which the data has been analyzed.

2.7 Publicly Available Life Cycle Assessment (LCA) Analysis

The scope of this research project only focuses on the emissions produced during the upstream processes. To get an estimate of how much emissions are produced during the manufacturing phase, publicly available LCA was studied. There are a variety of LCAs available on residential and utility-scale solar panels, however, due to the different technology of solar panels used, and assumptions made in LCA methods, each LCA result for emissions is different from another. The National Renewable Energy Laboratory (NREL) led the LCA Harmonization Project, a study that helps to clarify inconsistent and conflicting life cycle GHG emission estimates in the published literature and provide more precise estimates of life cycle GHG emissions from PV systems (NREL, 2012). The results are shown in Figure 2.

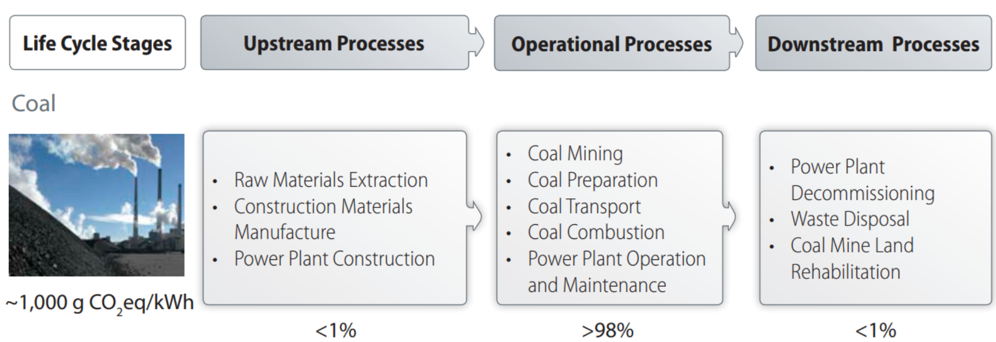
Figure 2: Life cycle GHG emissions of a solar panel



Note: NREL, 2012.

During a lifecycle of 30 years, a solar panel emits approximately 40 grams of CO_2eq/kWh. Whereas approximately 60-70% of emissions are coming from the manufacturing phase. Furthermore, it was also noted in the results that no matter what type of solar panel is used, the emissions are roundabout the same. NREL LCA also does a comparison of PV panels GHG emissions with coal-fired power plants, showing coal generates 1000 grams CO_2eq/kWh as shown in Figure 3 below.

Figure 3: Lifecycle GHG emissions of a coal fire plant



Note: NREL, 2012.

Another LCA was studied, which states that a solar panel emits approximately 45 grams of CO_2eq/kWh (Hsu et al., 2012).

Similar research compared to this project has been done in Brazil by Schultz and Carvalho (2022), which used the methodology of LCA to quantify the GHG emissions and concluded that solar panels have some emissions but when compared to other sources in Brazil's energy mix, they present significantly lower emissions. Their study aimed to design a 16.4 MW monocrystalline photovoltaic panel system with a lifetime of 25 years (Schultz & Carvalho, 2022). Using the LCA approach, they found that a 16.4 MW solar project will emit 22,817,275 kg CO_2eq emitted over 25 years (Schultz & Carvalho, 2022). Whereas the total energy supplied throughout 25 years is 521,443 MWh (Schultz & Carvalho, 2022). Therefore, the emission factor of the electricity generated by the photovoltaic plant is given below:

$$Emission\ Factor = \frac{Emissions\ over\ 25\ years}{Energy\ supplied\ over\ 25\ years} \quad (1)$$

= 22,817,275 kg CO_2eq / 521,443 MWh

= 22,817,275 kg CO_2eq / 521,443 x 1000 kWh

= 0.04375 kg CO_2eq / kWh

= 43.7 g CO_2eq / kWh

≈ 44 g CO_2eq / kWh

They estimated that the 16.4 MW solar project will take approximately 5 years to completely offset the emissions produced during its life cycle. This was found using the environmental payback time equation which is as below:

$$Tpayback1 = EmissionsPV25 - Eannual1 \cdot 1000 \cdot (EF\text{Mix} - EFPV)$$

$$Tpayback\,(n) = Tpayback\,(n-1) - Eannual\,(n-1) \cdot 1000 \cdot (EF\text{Mix} - EFPV) \quad (2)$$

Where,

$EmissionsPV25$ = Emissions produced over 25 years

$Eannual1$ = Annual generation of PV panels in year 1

$EF\text{Mix}$ = Emission factor of the grid

$EFPV$ = Emission factor of PV panels

n ranges from 2 to 25.

They concluded till the end of 25 years; the 16.4 MW solar project has avoided 72,733,030 kg of CO_2 emissions compared to consuming electricity from the Brazilian grid.

CHAPTER 3: METHODOLOGY

The following methodology was employed to meet the research goal and answer the research question.

- Based on the literature review and after examining different publicly available LCAs, I can say that solar panels, regardless of what type of panels are used, emit 40-50 grams of CO_2 emissions per kWh of generation. For the analysis and comparison with other fossil fuels, I will be using 50 grams of CO_2 emissions per kWh of generation from solar panels. However, depending on the capacity of annual generation, a typical solar panel within operations of 2-3 years starts offsetting its manufacturing emissions.
- NREL System Advisor Model (SAM), an open-source simulation desktop software was used to calculate the performance metrics of different capacity solar panels using different types of modules. This was done to find an annual energy output from a proposed solar project. According to Blair et al. (2018), "Project developers, policymakers, equipment manufacturers, and researchers use graphs and tables of SAM results in the process of evaluating financial, technology, and incentive options for renewable energy projects". In this research report, SAM results are used to find the environmental payback time for the proposed solar project and compare the Levelized Cost of Electricity (LCOE) of three solar modules with different efficiencies.
- One-on-one interviews were conducted with some of the major solar providers/projects in Alberta on which Emissions Reduction Alberta (ERA) has directly worked in the past. This was done to find out if they consider the emissions produced during the manufacturing phase from different branded solar panels when deciding which brand to

be used in the project. Also, how to improve the overall sustainability for the upstream value chain of Alberta's current and future solar projects.

- Resulting from interviews, market research has been performed to provide suggestions on how the sustainability and overall manufacturing emissions can be reduced for solar panels.

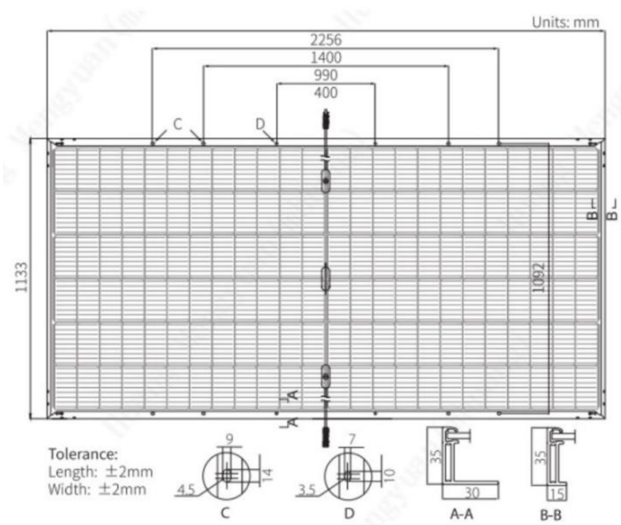
CHAPTER 4: ANALYSIS AND FINDINGS

4.1 Carbon Footprint for Manufacturing Solar Panels?

There is a general misconception that solar panels should not be used to generate clean energy as during the manufacturing phase they have a large carbon footprint. However, this is not true when considering the complete life cycle for panels and compared with other fossil fuels. This is primarily true due to the raw materials used in solar panel production which can be recycled. Yes, mining/extraction of silicon, glass, and copper is energy intensive but solar panels due to their long-life bring benefits which will be discussed below.

Consider a proposed 100 MW solar farm project. For this project, the brand Longi HI-MO 5 series modules are selected to install on-site. The power output of 1 PV module of HI-MO 5 is 550 watts with respectable efficiency of 21% (Longi, n.d.). The quantity required to generate 100 MW from HI-MO 5 module is $100x10^6/550$ = 181818 No. Each solar panel consists of 144 cells (6x24) as shown in the Figure 4.

Figure 4: Longi HI-MO 5 schematic

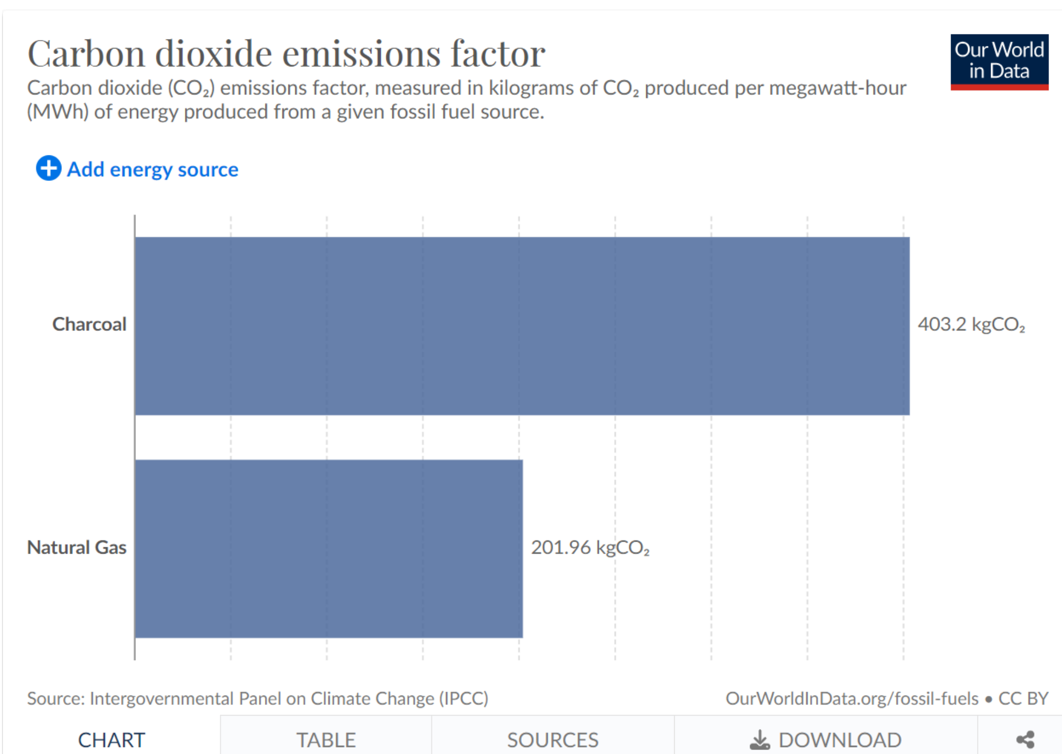


Note: Longi, n.d

We know approximately 11 grams of silicon is used for 1 cell. Since the No. off cells are 144 in HI-MO 5, 11 x 144 = 1584 grams or 1.58 kg of silicon is used in 1 panel. As No. of panels is 181818, 1.58 x 181818 = 287272 kg of silicon is used. According to Solaris Renewables (n.d.), silicon manufacturing accounts for around 6.0 kg CO_2eq/kg per silicon metal made. Hence the CO_2 emissions in producing 287272 kg of silicon is 6 x 287272 = 1723632 kg CO_2eq.

Also, we know that according to Hoffs (2022) producing 1 kilogram of metallurgical grade silicon requires 14-16 kWh of power. For calculation, I took 16 kWh as a baseline. The quantity of silicon produced is 287272 kg. So, the total power required is 287272x 16 = 4596352 kWh = 4596.352 MWh. According to Our World in Data (n.d.) CO_2eq factor measured in kg of CO_2 per MWh for charcoal and natural gas is shown in the Figure 5 below.

Figure 5: CO_2 emission factor for charcoal and natural gas



Note: Our World Data, n.d.

If the fossil fuel source used is charcoal for producing 4596.352 MWh, the CO_2 emissions are 403.2 x 4596.352 MWh = 1853249.12 kg CO_2eq. Note, this calculation approximately matches when considering 6.0 kg CO_2eq/kg per silicon as shown above.

However, if natural gas is used then emissions will be less. 201.96 x 4596.352 MWh = 928279.25 kg CO_2eq

Since the information is not transparent and difficult to find what source of fossil fuel is used during manufacturing, it is hard to find the actual emissions data. Similarly, actual emission data from different raw materials couldn't be found due to confidentiality and not being transparent However, the bottom line is there are emissions involved.

Based on public data, below is the comparison of lifecycle greenhouse gas emissions between Solar panels, natural gas, and coal (Solaris Renewables, n.d.).

Table 3: Lifecycle greenhouse gas emissions between solar panels, natural gas, and coal

No.	**Source**	**CO_2 emissions per kWh**
1	Solar Panels	50 g
2	Natural Gas	0.41 kg
3	Coal	1 kg

Note: Recreated on Microsoft Excel from Solaris Renewables, n.d.

The above CO_2 emissions per kWh from coal and natural gas are from life to death. However, solar panels emissions are coming only from manufacturing, transporting and constructing them. During the usage phase, it emits zero emissions. Overall, solar panels' carbon footprint is roughly 20 times less than that of coal-generated electricity (Cool Effect, 2021). Emissions produced during manufacturing take around 3 years of operation to completely offset carbon emissions (Cool Effect, 2021), thus becoming carbon neutral for the rest of life. A typical solar panel life is 25-30 years. So, if it offsets the emissions during 3 years of operations, after that till the end of life it is 100% contributing to sustainability with zero emissions involved in producing clean energy. Whereas the average life span of a coal plant is 50 years and natural gas is 25-30 years. Depending on the kWh produced, they emit way more emissions compared to solar panels.

According to Alberta.ca. (n.d.) the province will have fully transitioned from coal-powered electricity by the end of 2023. According to Jeyakumar & Noel (2023), there are only 2 coal power plants left in Alberta which are Genesee unit 1: 400 megawatts (MW) and unit 2: 420 MW) which are in plans to shut/transfer to natural gas before the end of 2023.

Considering Genesee unit 1 coal plant to estimate the emissions. It produced 400 MW of power. In a year there are 8760 hours, so energy generated by it annually is 400 MW x 8760 h = 3,504,000 MWh = 3504000000 kWh. Therefore, annual CO_2 emissions are 3,504,000,000 kg CO_2eq. When this unit will be changed to a natural gas plant of the same capacity, the emissions produced by it will be reduced to 60% as per the table above. However, if this is replaced by solar panels, emissions emitted during manufacturing will cover its carbon dept within a few years of operation, and then the project will be net zero carbon.

4.2 Alberta Energy Mix

Alberta is the hub of oil and gas. A decade ago, the generation of electricity from coal was the most dominant source, however, fast forward to today, it is generating less than the renewables in Alberta. According to Alberta Electric System Operator. (2023), "For the first time, renewable generation, at 12.6 percent of total generation, provided more electricity than coal" (pg. 2). This is primarily because renewables are gaining popularity while coal plants are either closing or getting replaced with natural gas plants.

As of December 1, 2022, the total energy generated in terms of sources and percentage is shown in the table below (Fletcher, 2023).

Table 4: Alberta energy mix as of December 1, 2022

No.	Source	Electricity Generation (MW)	Percentage (%)
1	Natural Gas	6921.83	73
2	Coal	1108.75	12
3	Renewables	1189.5	12.6
4	Others	236.83	2.4
5	Total	9456.91	100

Note: Recreated on Microsoft Excel from Fletcher, 2023.

Concerning renewable generation, wind generation provided 8.8% (104.67 MW), whereas solar provided 1.4% (16.65 MW) of electricity generated in Alberta in 2022 (Alberta Electric System Operator, 2023).

If it is assumed that 25% of total energy generated from natural gas and coal is generated from solar energy, then how much emissions could be reduced. To answer this some assumptions are taken into consideration. Coal generation is set to zero as its capacity is replaced by natural gas and then overall natural gas capacity is reduced which is replaced by solar generation.

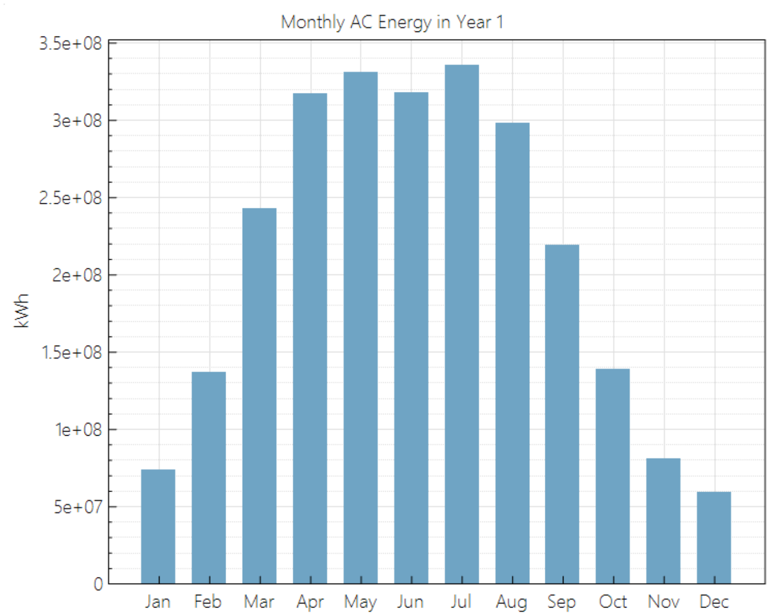
Table 5: Reduction in MW from natural gas and coal and increase in MW of solar energy, if 25% of total energy generated from natural gas and coal is replaced with solar panels

No.	Source	Electricity Generation (MW)	Assumed Electricity Generation (MW)
1	Natural Gas	6921.83	6022.94
2	Coal	1108.75	0.00
3	Solar		2007.65

Note: Author, 2023 generated from Microsoft Excel.

Assuming total electricity generation remains same, when 25% of solar energy is used, then natural gas generation used is (6921.83+1108.75-2007.65) 6022.94 MW. So, natural gas usage is reduced by 898.90MW. Whereas coal is reduced to zero. For finding how much generation of electricity is produced from 2007.65 MW solar panels, SAM software is used where Alberta coordinates are set as a location for generation which are 53.9333° N, 116.5765° W. This location is towards the west of Edmonton. The results from the simulation software are shown in the Figure 6 and table below.

Figure 6: Annual electricity generation from proposed 2007.65 MW solar panels



Note: Author, 2023 generated from NREL SAM software.

Table 6: Annual electricity generation from proposed 2007.65 MW solar panels

Months	AC output | (kWh)
Jan	73862300
Feb	136613000
Mar	242498000
Apr	317297000
May	331232000
Jun	318094000
Jul	335244000
Aug	297869000
Sep	218973000

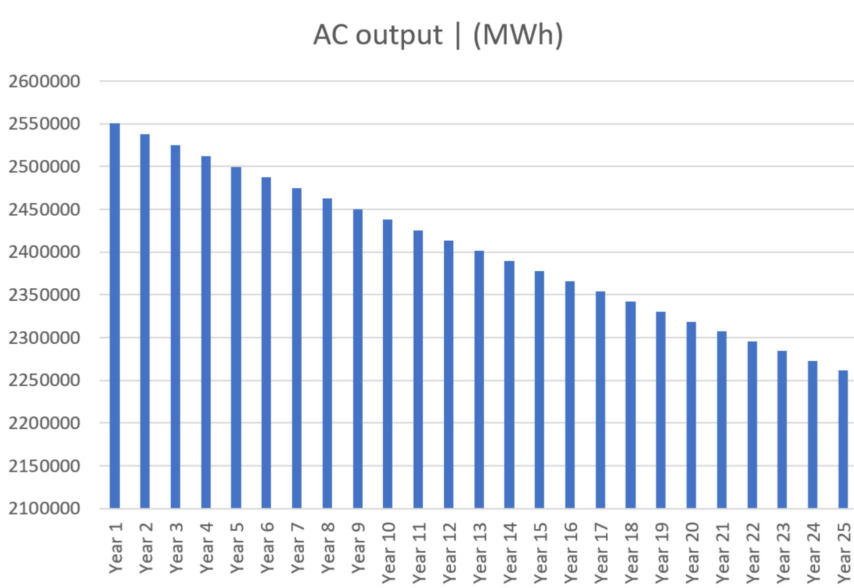
Oct	138502000
Nov	80942000
Dec	59261200
Total	**2550387500**

Note: Author, 2023 generated from Microsoft Excel.

Therefore, year-1 electricity generation from 2007.65 MW solar panels is 2.55E+09 kWh.

Considering a lifecycle of 25 years, these panels' output degrades over time. According to Jordan & Kurtz (2015), the research done by NREL shows that solar panel's annual output degrades by 0.5% per year. Therefore, in the 25^{th} year, the panels will approximately produce 88% of the electricity produced in year 1 (Mow, 2018). The estimated 25-year production of electricity is shown in the Figure 7 below.

Figure 7: Estimated 25-year production of electricity from proposed 2007.65 MW solar panels



Note: Author, 2023 generated from Microsoft Excel

Hence the total generation in 25 years from solar panels is 60,076,804,027 kWh. From the literature review, we know,

$$Emission\ Factor = \frac{Emissions\ over\ 25\ years}{Energy\ supplied\ over\ 25\ years} \ (1)$$

Also, from the literature review, considering 50 grams of CO_2 emissions per kWh of generation from solar panels. So, from the above equation, Emissions over 25 years can be calculated as below.

Emissions over 25 years	**=**	**Emission Factor x Energy supplied over 25 years**
	=	50 g CO_2eq / kWh x 60,076,804,027 kWh
	=	3,003,840,201,350.00 g CO_2eq
	=	3,003,840,201.350 kg CO_2eq = 3 Mt CO_2eq

Considering Alberta's electricity mix in 2020, according to Canada Energy Regulator (2023) Alberta's grid emission factor is 590 g CO_2eq per kWh of electricity generated. This is approximately 12 times higher than 50 g CO_2eq / kWh obtained from a literature review of solar panels.

The equation to calculate the environmental payback time of 2007.65 MW solar panels is used from the literature review study of Schultz and Carvalho (2022), which is as follows:

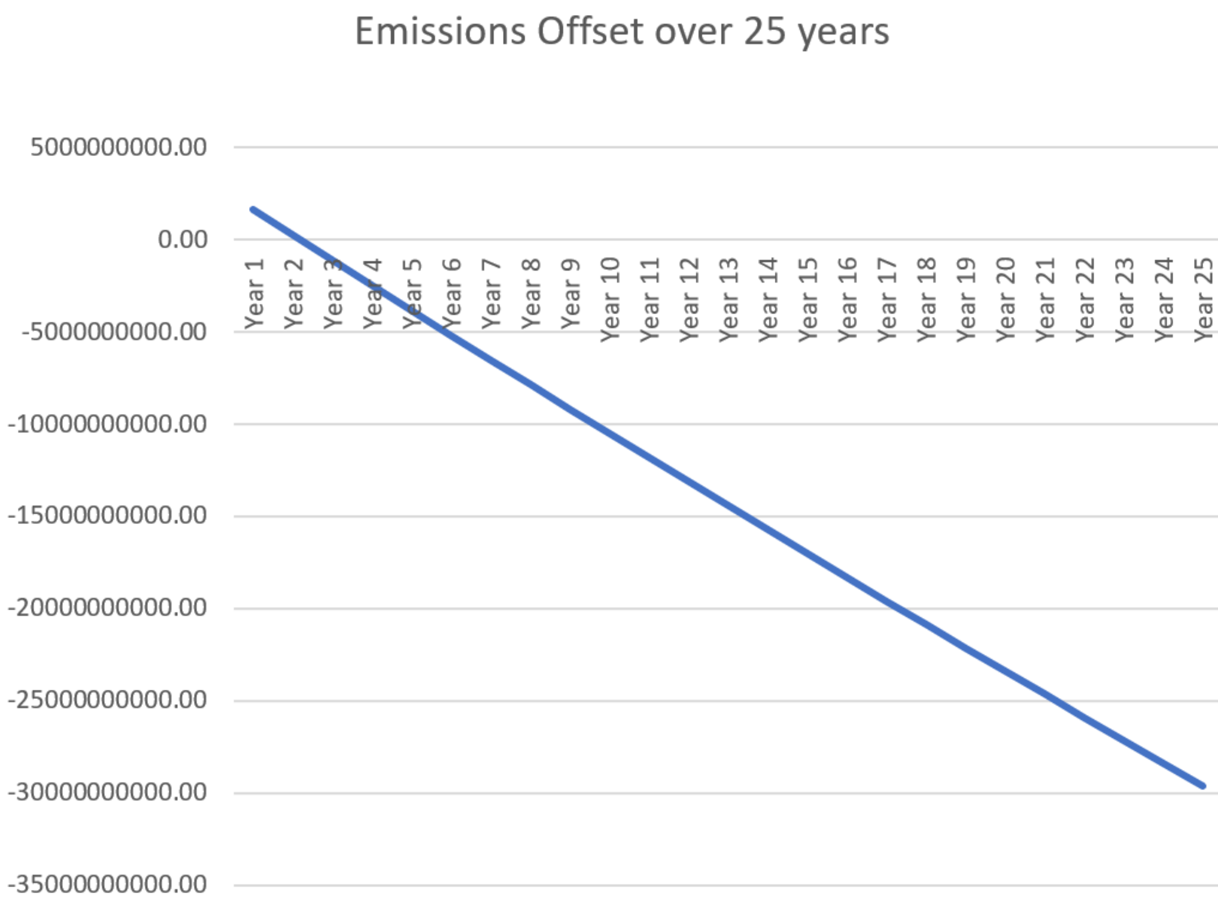
$$Tpayback1 = EmissionsPV25 - Eannual1 \cdot 1000 \cdot (EF\text{Mix} - EFPV)$$

$$Tpayback\ (n) = Tpayback\ (n-1) - Eannual\ (n-1) \cdot 1000 \cdot (EF\text{Mix} - EFPV)\ (2)$$

Where n ranges from 2-25 and the 1000 factor is used to convert MWh to kWh.

Applying this equation shows that solar panels will be carbon neutral after 2 years of operation. Whereas over 25 years of operation, 29,593,735,807.18 kg CO2-eq or 29.59 Mt CO_2eq is avoided compared to consuming electricity from the grid.

Figure 8: Environmental payback time equation result for proposed 2007.65 MW solar panels



Note: Author, 2023 generated from Microsoft Excel

The calculations are shown in Appendix A.

4.3 Interviews

This research project utilized the methodology of conducting interviews with solar providers/projects in Alberta. The purpose of conducting interviews is to help find an answer to how sustainable solar technology is and how we can improve sustainability for the upstream value chain of major Alberta solar projects. Furthermore, it is conducted to find an answer if these companies in Alberta consider sustainability when procuring solar panels. Do they check about emissions before deciding which solar panel brand is to be selected?

In total 5 interviews were held, 1 company is a North American manufacturer of solar panels, 1 is an electric utility company in Alberta and the other 3 companies are solar contractors/developers in Alberta. Names of participants are not disclosed in this report and each company is given an identification label as below.

Table 7: List of interview participants

No.	Interview Participants
1	Contractor A
2	Developer A
3	Manufacturer A
4	Electric Utility Company A
5	Developer B

The questions asked to the participants are given in Appendix B.

4.3.1 Summary of Interview with Contractor A

Contractor A is a Certified B Corporation that intends to become Net-Zero by 2030. Installation of solar panels is their core business since 2001. They have installed solar panels close to 100 MW from residential to commercial to utility-scale.

The CEO of this company was interviewed to check on how sustainable the PV technology is during its life cycle. As per him, the solar industry will play a key role in Alberta's energy mix as the PV technology is getting cheaper, and it is easiest to install as it requires less labor compared to other renewable sources. Furthermore, he said the solar industry is the future in Alberta but the only barrier to its success is the provincial government when it comes to the economy, Alberta is the oil and gas hub so the solar industry ideally will not disrupt the oil and gas market at once. It will take time.

When asked about the manufacturing/procurement practices if sustainability is accounted for during the brand selection for solar panels, the answer was their selection is based on economics, availability, mainly levelized cost of energy (LCOE), and if the specific brand is complying to the specifications provided by the proponent. However, internally they have looked back through the supply chain and have estimated how much emissions will be produced per kilowatt of energy generation from solar panels. Based on this no. they identify how much offset they need to buy to become net zero. This is their main strategy in terms of sustainability. No matter how much emissions are produced during the manufacturing and transportation of these panels. The carbon footprint will be calculated internally, and they will buy offset credits to compensate for carbon emissions to make their company net zero.

Furthermore, in their selection of panels, it was noted that the highest efficiency module is often not the best purchase, their selection is based on LCOE calculations. Regardless of efficiency, if the module LCOE is less that module will be given more priority in the selection process.

Note, when asked what the emissions are calculated for offsetting purposes, this data was not disclosed.

In the interview, it was also asked if the social practices of manufacturers are accounted for in the selection of solar panels, as most of the silicon manufacturing is done in Asia where forced labor is an issue. In reply to this, till now, no, they are not much concerned, however, Canada has enacted legislation to combat modern slavery in supply chains (Pollock, 2023). Bill S-211, an Act to enact the Fighting Against Forced Labour and Child Labour in Supply Chains Act and to amend the Customs Tariff (the Act) will be in force on January 1, 2024 (Pollock, 2023). As per this Act, a manufacturer of any product imported to Canada must report it has no forced labor content. Thus, this act may have the potential to solve the issue of the social aspect of sustainability for solar panels in Canada.

No project of this company has reached the end of life yet; however, they plan to recycle waste silicon with the help of SUNSET Renewable Asset Management Inc. which will start operations in Q2 of 2024. As of right now, there is no recycling facility in Alberta.

4.3.1.1 LCOE Analysis using SAM.

According to Contractor A, in the selection of solar panels, it was noted that the highest efficiency module is often not the best purchase, their selection is based on LCOE calculations. This can be explained using the SAM simulation software for different PV modules.

A proposed 100 MW solar project located in Calgary is used in the simulation software as an example. The three modules selected are from SunPower of different efficiencies which are as follows:

- SunPower SPR-E19-310-COM with a nominal efficiency of 19.02%.
- SunPower SPR-E20-327 with nominal efficiency of 20.07%.
- SunPower SPR-343J-WHT-D with nominal efficiency of 21.04%.

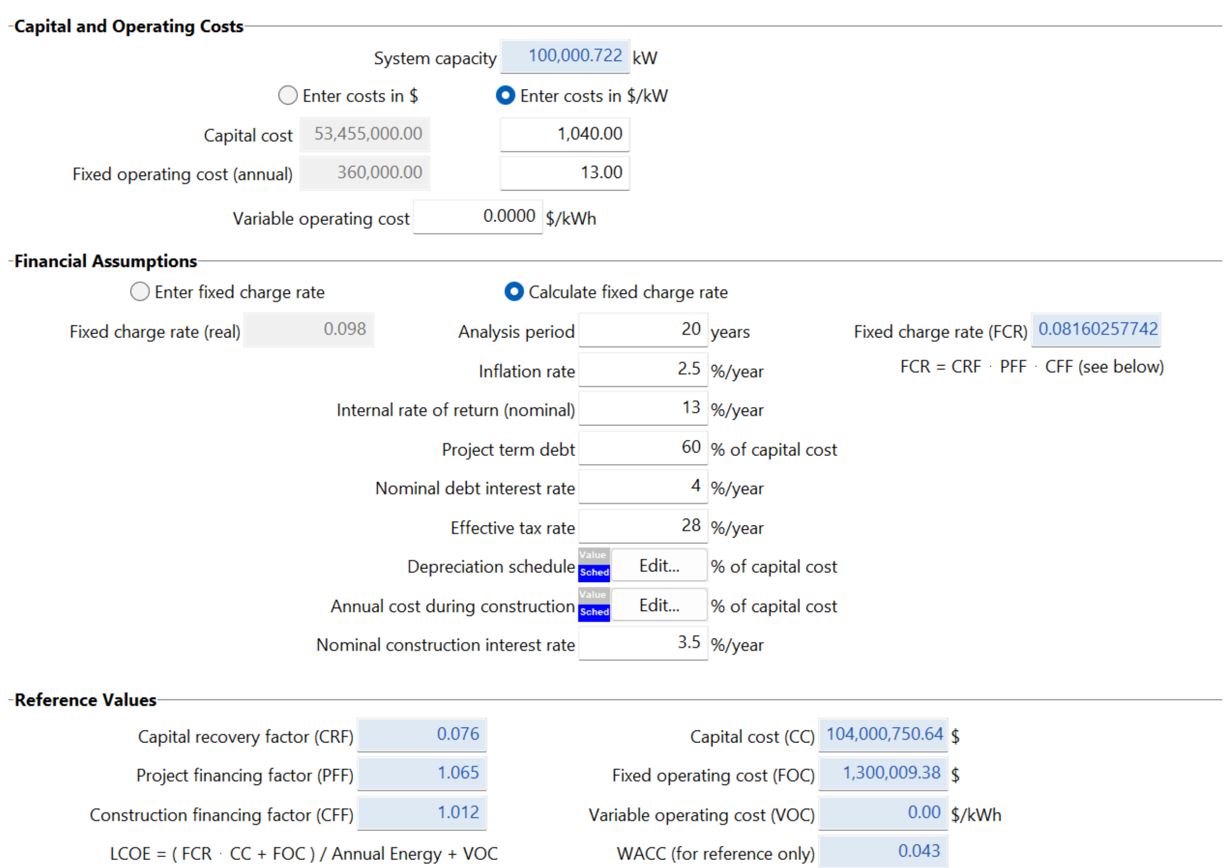
Whereas the inverter used for the three modules is the same, i.e., Yaskawa Solectria Solar: SGI 750XTM [380V].

In the system design settings in SAM, modules per string in subarray are taken as 12, and strings in parallel in subarray are taken as 26,869, so the total number of modules considered for baseline calculation is 322,428. No. of inverters are 99.

For tracking and orientation, 1-Axis is used with tilt and azimuth angle selected as default. Furthermore, losses are kept as default.

In the financial parameters, capital cost, operating cost, and financial assumptions are kept as default as shown in the Figure 9 below.

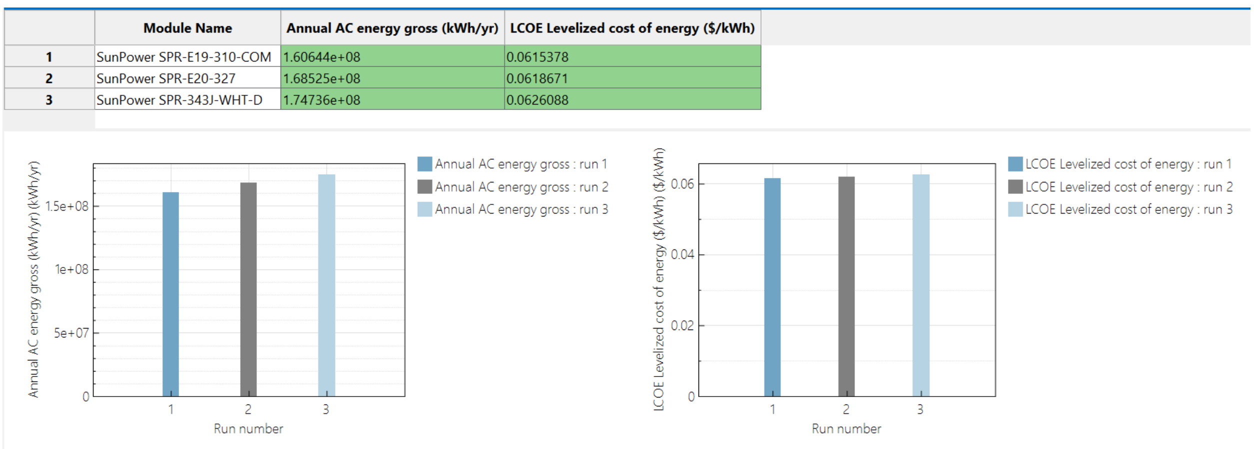
Figure 9: Capital cost, operating cost, and financial assumptions in SAM for three PV modules



Note: Author, 2023 generated from NREL SAM software.

For the above setup, running the simulations in the SAM from the Parametrics section for the three modules selected as an input, results in the following for annual energy and LCOE.

Figure 10: Results of annual electricity output and LCOE for the three PV modules.



	Module Name	Annual AC energy gross (kWh/yr)	LCOE Levelized cost of energy ($/kWh)
1	SunPower SPR-E19-310-COM	1.60644e+08	0.0615378
2	SunPower SPR-E20-327	1.68525e+08	0.0618671
3	SunPower SPR-343J-WHT-D	1.74736e+08	0.0626088

Note: Author, 2023 generated from NREL SAM software.

Based on the analysis of LCOE calculation between SunPower SPR-E19-310-COM (nominal efficiency: 19.02%), SunPower SPR-E20-327 (nominal efficiency:20.07%), and SunPower SPR-343J-WHT-D (nominal efficiency: 21.04%), during the procurement process, if the three modules are available and are priced same, Contractor A will select the module with lower LCOE which in this case is SPR-E19-310-COM. Note, the selected module is less efficient and produces less annual energy. Still, it will be selected due to lower LCOE.

4.3.2 Summary of Interview with Developer A

Developer A has installed 84 MW of solar projects in Alberta and is currently working on 183 MW of solar projects which are in the planning/construction phase in Alberta. It is also a Certified B Corporation. The principal of the company was interviewed and according to him in

Alberta in the next 5 to 10 years there will be a huge push for solar projects. When asked what factors are considered when selecting the origin of the panel or a brand of solar panel to be installed in the project, price, availability, and delivery schedule of all components are most important to them. They don't consider the manufacturing emissions of different solar panel brands; however, Developer A does check the ESG reports. Being a Certified B Corporation, they always select highly reputed TIER 1 manufacturers for solar panels.

Regarding forced/child labor, Developer A acknowledged that they have already notified their suppliers about Bill S-211. Whereas they do consider the emissions coming from the transportation of panels from Asia to Canada, however, they don't buy offset as solar panels during the operational phase automatically offset the emissions produced during its lifecycle.

4.3.3 Summary of Interview with Manufacturer A

Manufacturer A is a top-ranked PV module producer in North America with significant operations on both sides of the border (America and Canada). They are in the solar business since 2012 and in Alberta, this manufacturer's solar modules have been used in one utility-scale project. The Regional Sales Manager was interviewed to ask how sustainable solar technology is. With regards to social issues in solar panel manufacturing like forced/child labor, manufacturer A is free from this as the assembly of technology is prepared itself in North America and wages are also provided to the workers on time. Though in terms of pricing, they are more expensive than Asian models, however, they are fully complying with sustainability regarding social aspects. According to the participant, this is their biggest selling point in North America when compared with Asian competitors. However, in Alberta or Canada, some companies are ignoring the domestic manufacturer for a cheaper solar module as till now there is no rigid regulation that prevents products from using forced labor. According to the participant, silicon is the most important component of a solar panel. Manufacturer A till now has no manufacturing plant for silicon but they have plans to open one. Currently, they are sourcing silicon wafers from Asia, but they confirm through internal documentation that there was no forced/child labor involved in manufacturing silicon wafers. 80% of the silicon they are importing from China and 20% is coming from India and Korea. In the next 5 years, manufacturer A has plans to extract silicon in the USA and have a glass manufacturing plant too. Whereas in Canada, they do wish to have a complete supply chain domestically. The participant says that the government needs to support and provide incentives to develop the solar industry locally just like how the USA is doing. As the USA is providing tax incentives, this is the reason why there is more solar panel industry in the USA compared to Canada. Furthermore, Canada is more focused on achieving environmental goals rather than investing in an industry. When asked about emissions data, they don't investigate that.

4.3.4 Summary of Electric Utility Company A

Headquartered in Edmonton, Electric Utility Company A distributes electricity to two-thirds of Alberta. An engineer in the renewables and microgrid engineering team was interviewed to find answers for this research report. The electricity sector in Alberta is divided into the regulated and nonregulated side of projects, the participant interviewed works primarily on nonregulated projects, especially solar panels. During the interview, the participant mentioned that during the procurement they not only look at top-of-the-line solar panel brands, but they do consider the ethical side of things. The preferred brands mentioned were Longi, Canadian Solar, and Hanwha. Why these panel brands are used because of their high industry rating which means these brands are tried and tested in different solar projects and have got positive reviews. Furthermore, the decision of which brand is selected is not primarily based on economics, sustainability is also factored. They do consider the social issues associated with panel manufacturing in Asia as 2 out of 3 brands mentioned are made in China. According to the participant ethical practices during manufacturing are considered while deciding as they need to justify their decision to the customer/client. However, when asked if emissions during manufacturing are considered between these three brands, participant informed they don't check that. The only thing they check is the CSA sticker on the final product which ensures that it follows the Canadian Standards Association. So, if the brand is listed in the vendor list and it is complying with the specification, and there is no problem in availability and delivery, and it comes with a certificate then they have no problem in selecting a specific brand. Another keyword the participant mentioned is class A TIER 1 suppliers for solar modules are always used. This classification means that the supplier is financially stable and produces a high-quality module.

Longi is a Chinese brand and on checking different solar model data sheets, they have a CSA certificate. Similarly, Canadian Solar and Hanwha panels are also CSA complied. However, going in-depth into the CSA certificate revealed that it just indicates that the product, in our case solar panel, is tested for performance and safety. This certification doesn't mention anything about emissions.

4.3.5 Summary of Developer B

Contractor B, one of the leading energy infrastructure companies in North America is planning to achieve net zero from operations by 2050. The director of the supply chain and the manager of a renewable energy team together were interviewed for this research. According to the participants soon solar energy is going to lead the next transition for utility-scale production of electricity. When compared with wind, solar is a lot easier to install, requires a straight landscape and it is less expensive. When asked if sustainability is factored in when selecting a specific brand, Contractor B replied since Alberta is an emerging market, till now the decisions are solely made on economics. If a certain brand is complying with specifications, it's high-quality and is well-reputed in the solar industry, we will select that brand. Similarly, availability and delivery on time are the other two most important factors in the selection process. They explained they are the owners of the solar facility. Based on project to project, sometimes procurement is done by themselves, or other times they hire an EPC under contract to build the facility. Regardless, they procure top-quality TIER 1 manufacturers which serve their claim of producing electricity as mentioned on the nameplate.

When asked about social issues associated with the solar industry? Contactor B informed they have a strict ABC policy. ABC stands for anti-bribery and corruption. They follow this policy, and they make sure that their subcontractors also follow it. To date, they haven't been subject to any sanctions for violating this policy. According to Contractor B, this policy supersedes all the processes and procedures. They check the bill of materials and history from where the panels are coming from.

According to Contractor B, once the Canadian government starts providing more federal and provincial incentives like tax credits to developers like them, then it will allow them to surpass the economics of solar panels and will motivate them to identify the greenhouse gas emissions across the value chain.

4.4 Major Findings from Interviewing Participants and Recommendations

4.4.1 Supply chain issue

While it is true that solar panels have a bright future in Alberta's market and it is a viable solution to reach net zero by 2050, this type of renewable comes with not so hidden ethical issues

(Marsh, 2023b). During the interview sessions, the biggest supply chain issue put forward by all the participants is forced/child labor. Most of the manufacturing is taking place in China. From the mining of raw materials to manufacturing the assembly of solar panels. It is the mining and melting of silicon for solar panels where force/child labor is used (Marsh, 2023b). Furthermore, as discussed above, China's electricity grid is still heavily dependent on coal, so the emission impact on manufacturing solar panels is large. Due to the reasons mentioned above, manufacturing taking place in China adversely impact both environmental and social aspects of sustainability.

Though all the participants agreed that they are against forced/child labor, and they check with the manufacturer that they are complying with their sustainability standards. An official answer from Canada to this supply chain issue is Bill S-211, which is an Act to enact the Fighting Against Forced Labour and Child Labour in Supply Chains Act and to amend the Customs Tariff (the Act) and will be in force on January 1, 2024 (Pollock, 2023). As per this Act, a manufacturer of any product importing to Canada must submit a report to the Canadian government that it has no forced and no child labor activities involved during the manufacturing phase. Thus, any solar panel manufacturer in China needs to comply with Bill S-211 to export their product. Implementing this might bring some challenges, but this act has the potential to solve the issue of social in the sustainable manufacturing of solar panels.

4.4.2 Battery storage integrated solar panels

All the participants mentioned about battery storage during the interview sessions stating that in the future solar panels will be integrated with batteries. As solar energy is contributing less to Alberta's energy mix, as of right now battery storage is not much important, but once the capacity produced from solar projects is high then batteries will play an important role. Solar panels are not active 24 hours a day. They are only generating energy only during the sunshine. When solar panels are generating more energy than the load's demand during the day, the excess energy generated will be stored in connected batteries and sent back to the grid to use at times when there is no sunshine.

However, batteries come with their own sustainability issues, and they are expensive. Once the technology is matured and is less expensive, then there will be a boom in battery-integrated solar panels. Note, understanding the lifecycle sustainability of batteries is beyond the scope of this project, but could be a topic of future work.

4.4.3 Recommendations for supply chain

North America should invest in the manufacturing of solar panels. Manufacturing companies should start exploring what supply chain advantages they can take, e.g., if silicon mining and manufacturing plants can be developed in North America. Not only this new market will create job opportunities, but the production of panels in North America will also decrease the emissions produced by the transport sector for importing panels from China. Furthermore, as China's grid is heavily dependent on coal if manufacturing starts in North America, it will automatically reduce the emissions produced during the manufacturing phase of solar panels. Participant Manufacturer A, who has operations in both America and Canada, urged that the Canadian solar market should learn from the American solar market. In America to start a solar business government is giving good incentives, however, in Canada there are not many incentives for companies to develop the industry in Canada. America is providing tax credits for developers to do manufacturing there. Furthermore, due to political tensions between America and China, America wants to decrease its dependence on China imports. So, they are more interested in heavily investing in developing solar technology in America than in Canada.

4.5 Solar Panels for Albertans

Provincial and federal incentives motivate the public to install solar energy. People who can afford to install panels on rooftops should invest in this, as the initial cost might be more but over time it brings the capital cost to zero by reducing the electricity bill every month. Net metering is being offered in Alberta, which ensures if solar panels are generating more energy than consumed then customers will be given kWh credits, thus reducing the bill further.

CHAPTER 5: CONCLUSION, LIMITATIONS, AND FUTURE WORK

5.1 Conclusion

Following are the conclusions made from conducting a literature review, interviews, and market research:

- Solar panels produce approximately 50 grams of CO_2eq/kWh during their lifecycle.
- Solar panels become carbon neutral after a few years of operation, anywhere from 2-5 years based on the emission factor of panels, emission factor of grid, annual output of panels and supply chain.
- In Alberta if 25% of total energy generated from natural gas and coal is replaced with solar panels then over the course of 25 years, 29.6 Mt CO_2eq can be avoided compared to consuming electricity from the grid. Note, this only includes the lifecycle emissions from the solar panels but does not include the emissions avoided from upstream production of coal and gas that would no longer be needed.
- Biggest issue in the supply chain for solar panels is forced/child labor. The Act, Bill S-211 may have the potential to solve this problem, however, its credibility can only be checked once it is in force on January 1, 2024.
- Solar panels not only bring economic advantages to consumers but also environmental advantages for the province/country. As Canada is committed to reaching net-zero emissions by 2050 (Government of Canada, 2023), market research and interview participants all agreed that generation of electricity via solar energy will play a vital role in achieving this target.

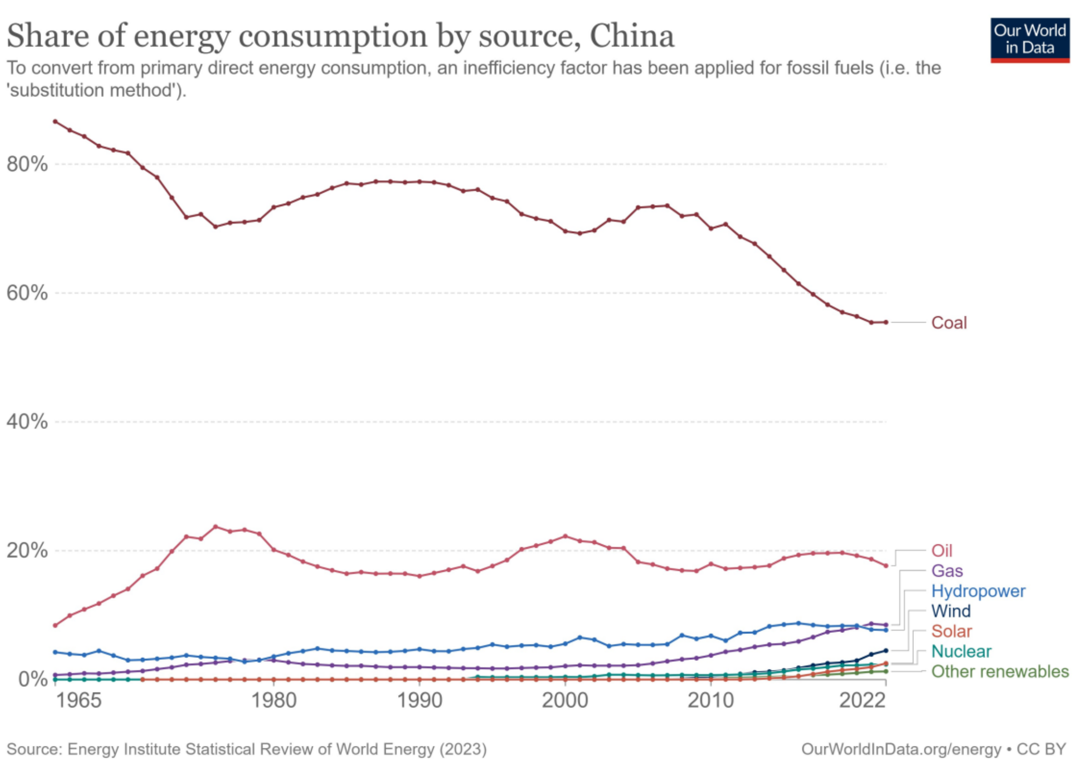
- To reduce manufacturing and transporting emissions, North America should start manufacturing and assembling solar panels and reduce their dependency on Chinese/Asian brand modules.
- Manufacturing solar panels in North America will create jobs and will be free from forced/child labor.
- In Alberta the decision of selecting a solar module is heavily dependent on economics and availability. Manufacturing emissions are not factored into deciding which solar module will be installed in Alberta.
- Currently in Alberta, manufacturing emissions are not as important to the solar developers as they know during the operation phase, solar panels offset their emissions within a few years and become carbon neutral.
- Battery storage will be integrated into current and future solar projects in Alberta.

5.2 Limitations of the research project

In the research project despite interviewing key players of the solar industry in Alberta, actual manufacturing emissions data reports were not collected from participants. This was hard to get as panels in Alberta are mostly imported from China, so Chinese manufacturers need to be contacted for the right emissions data. Furthermore, most of the extraction of different raw materials is done in different Asian countries and by different companies. For example, one company is responsible for silicon another for glass, then there is another company with collects these raw materials and does the assembly for solar panels. So, if in-depth and accurate emissions data needs to be checked, the complete supply chain needs to be studied and examined in China/Asia. Once emissions data is collected then recommendations can be made on how to improve it. In absence of this, the NREL studies still provide high quality generic estimates of the lifecycle emissions impact of solar panels.

In China, till 2022, 55% of total energy consumption is still dependent on coal (Ritchie, et al., 2022b). Coal produces maximum emissions per kilowatt, this is the reason why Canada/Alberta is phasing out coal. So, if China reduces its dependency on coal and increases the generation capacity of electricity from renewables, then emissions produced during the extraction of raw materials and manufacturing of solar panels will automatically reduce. In 2023, according to Murtaugh (2023) China has approved construction of six nuclear reactors. This is a $17 Billion investment (Murtaugh, 2023). China showing interest and investing in nuclear reactors means in future they plan on increasing the share of energy consumption from nuclear, which will result in lowering their dependency on coal.

Figure 11: Electricity energy mix in China



Note: Our World in Data, 2022.

5.3 Future work

This research report's scope is emissions produced only during the upstream processes for the manufacturing of solar panels. In the future, research on downstream processes can be done. For example, after the end of life of solar panels, what quantity of materials can be recycled, and how emissions can be reduced in recycling processes.

Solar panels do not operate 24 hours a day, as they are dependent on sun radiation. In the future to efficiently utilize solar energy, solar panels need to be integrated with battery storage. Research on battery storage can also be done to see how sustainable batteries are during their lifecycle.

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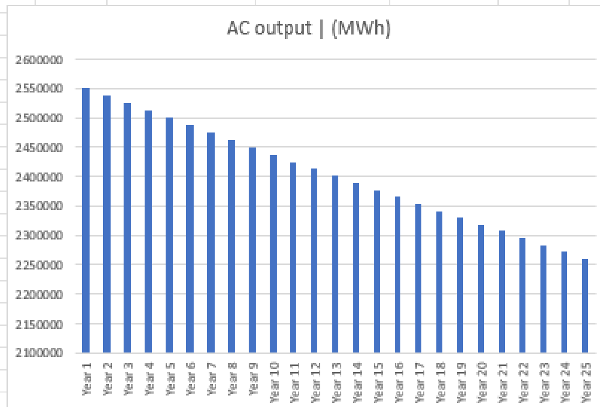
Appendix A: Environmental Payback Time Calculation and Graphs

Description	Quantiy	Unit
EPLANT,TOT25	60076804.03	MWh
EmissionsPV25	3003840201.35	kg CO2-eq
EFMix	0.59	kg CO2-eq/kWh
EFPV	0.05	kg CO2-eq/kWh

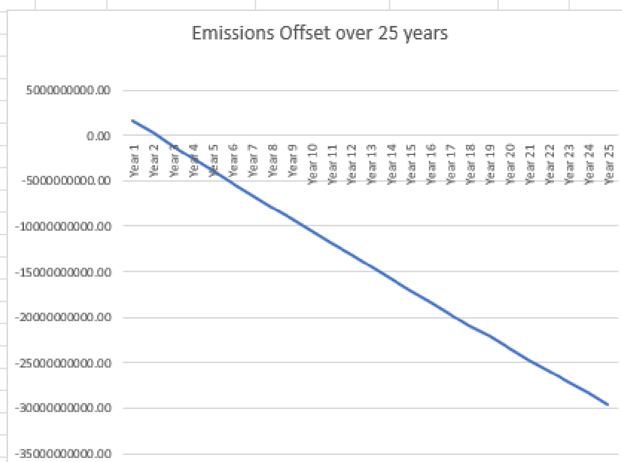
Year	AC output | (MWh)
Year 1	2550387.5
Year 2	2537635.563
Year 3	2524947.385
Year 4	2512322.648
Year 5	2499761.035
Year 6	2487262.229
Year 7	2474825.918
Year 8	2462451.789
Year 9	2450139.53
Year 10	2437888.832
Year 11	2425699.388
Year 12	2413570.891
Year 13	2401503.036
Year 14	2389495.521
Year 15	2377548.044
Year 16	2365660.303
Year 17	2353832.002
Year 18	2342062.842
Year 19	2330352.528
Year 20	2318700.765
Year 21	2307107.261
Year 22	2295571.725
Year 23	2284093.866
Year 24	2272673.397
Year 25	2261310.03



$Tpayback1 = EmissionsPV25 - Eannual1 \cdot 1000 \cdot (EFMix - EFPV)$

$Tpayback\,(n) = Tpayback\,(n-1) - Eannual\,(n-1) \cdot 1000 \cdot (EFMix - EFPV)$

Tpayback (n)	Emissions
Year 1	1626630951.35
Year 2	249421701.35
Year 3	-1120901502.40
Year 4	-2484373090.13
Year 5	-3841027319.92
Year 6	-5190898278.57
Year 7	-6534019882.42
Year 8	-7870425878.25
Year 9	-9200149844.10
Year 10	-10523225190.12
Year 11	-11839685159.42
Year 12	-13149562828.86
Year 13	-14452891109.96
Year 14	-15749702749.66
Year 15	-17040030331.15
Year 16	-18323906274.74
Year 17	-19601362838.61
Year 18	-20872432119.66
Year 19	-22137146054.30
Year 20	-23395536419.27
Year 21	-24647634832.42
Year 22	-25893472753.50
Year 23	-27133081484.98
Year 24	-28366492172.80
Year 25	-29593735807.18



Note: Author, 2023 generated from Microsoft Excel

Appendix B: Interview Questions

1) Can you give us a brief overview of your company and your company's major solar projects in Alberta?

2) Do you think solar energy as a source of generating electricity will be used more in the future in Alberta?

3) At a high level, are you able to give us an idea of where are most of the components for solar power systems you procure sourced from? Do you have any challenges procuring critical solar system components?

4) During the procurement process, what are the considerations you take when deciding which solar panel brand to be used in the project? Also, is sustainability an important factor during decisions or is it mostly dependent on economics?

5) Is the country of origin of solar panels important? If then usually what country of origin do you select and why?

6) Do you consider how sustainable the manufacturing process is in that country and what are their sustainability practices?

7) Do you consider GHG emissions associated with the transportation of solar panels to the deployment site?

8) During the procurement process, one gets more than 2-3 quotations for solar panels. Considering the specifications of two different brands are matching the requirements of the proponent, which brand solar panel will you select? Is the decision based on country of origin or

better rate or how sustainable one brand is compared to others during the manufacturing stage or overall life cycle?

9) Once the brand is selected, do you check how much this specific brand solar panel emitted GHG emissions during its manufacturing phase?

10) During installation, do you check if panels are installed sustainably?

11) At the end of life, what consideration do you take to make sure it emits a minimum amount of GHG emissions?

12) In your view, how sustainable is solar technology during its life cycle compared to other renewable sources and fossil fuels, and what improvements could be made?

13) As our research is based on the manufacturing phase of solar panels, how do you think we can improve overall sustainability for the upstream value chain of current and future solar projects in Alberta?