UNIVERSITY OF CALGARY

Feasibility Study of Solar Photovoltaics System at Abandoned Mine Tailings Sites

by

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Abstract

The objective of my research study is to determine the feasibility of using solar photovoltaic (PV)-geomembrane technology to generate clean renewable energy at abandoned mine tailings sites. Commercial mining activities in the province of Nova Scotia have resulted in abandoned tailings sites over the years that contain significant concentrations of toxic substances that pose serious social and environmental problems. My research could provide a solution to remediation of abandoned mine tailings sites using solar PV-geomembrane technology to mitigate tailings contamination problems and generate renewable solar energy to reduce greenhouse gas emissions. The Victoria Junction Tailings Dam in Cape Breton, Nova Scotia was selected for this study. A techno-economic assessment of the mine tailings site was conducted using ArcGIS, RETScreen and SAM software. The study concluded that abandoned mine tailings sites can be utilized for installation of solar photovoltaic farms.

Preface

This Capstone project was sponsored by both SEEDA Inc. and Mitacs as part of the Business Strategy Internship (BSI) program. The internship program involved the research student , Jason Shim undertaking on site research with the sponsor organization, SEEDA Inc. to apply software tools, methodologies, and design concepts to conduct a feasibility study.

The project team members involved in this research were Mr. Jason Shim, Dr. David Wood and Mr. Max Chernetsov. Jason Shim is a registered Professional Engineer with the province of Alberta and a Master of Science (MSc) student in the Sustainable Energy Development (SEDV) program at the University of Calgary. Dr. David Wood is a professor at the Department of Mechanical and Manufacturing Engineering at the University of Calgary. Mr. Max Chernetsov is the President and CEO of SEEDA Incorporated. Mr. Jason was responsible for the design, technical analysis, and economic evaluation of the proposed solar photovoltaic power generation facility on an abandoned mine tailings site. David was Jason's academic supervisor for the project. Max was Jason's industry supervisor during his research development internship at SEEDA Inc. for the past six months.

SEEDA Inc., an engineering consulting services company based in Calgary, Alberta, authorized this research and provided the conceptual design and materials to Jason Shim for use as a foundation for this research project. The intellectual property including the copyrights to the project idea, conceptual design, data, methodology and research results are owned by SEEDA Inc. SEEDA's business strategy includes a design/construction concept integrated with renewable energy development to lower energy costs and carbon footprint throughout the project. The company is developing the Clean Energy in Problem Areas (CEPA) program to provide innovative solutions for remediation and reclamation of contaminated oil sands and coal mine tailings sites, as well as abandoned oil and gas well sites. CEPA's vision is to convert contaminated tailings impoundments from an environmental liability to an environmental asset by mitigating the environmental risks caused by contaminated tailings ponds at a considerably lower cost for all stakeholders. CEPA's innovative technology solutions would open up huge market opportunities for reclamation and remediation of contaminated tailings impoundments in Canada and around the world. SEEDA Inc. would benefit from results of this research study to be able to apply the combination of the solar-PV and geomembrane technology for remediation of contaminated mine tailings and abandoned oil and gas well sites.

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I also would like to thank Dr. Irene Herremans who had provided me assistance with my ethics application and successfully obtaining certification for the research survey study from the Conjoint Faculties Research Ethics Board (CFREB), University of Calgary.

To my wife, Jessie and my two kids, Jayden and Josie for their patience, understanding and support they had provided me during my studies in the Master of Science, Sustainable Energy Development Program.

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List of Abbreviations

AC	Alternating Current
AMD	Acid Mine Drainage
A-Si	Amorphous silicone
BC	Benefit-Cost
C	Initial cost of project
CAD	Canadian
CCA	Capital Cost Allowance
CCL	Geosynthetic Clay Liner
CdTe	Cadmium Telluride
CdS	Cadmium Sulphide
Cd_2SnO_4	Cadmium Stannate
CH_4	Methane
CIGS	Copper Indium Gallium Selenide
cm	Centimeter
C_n	Cash flow for year n
$\widetilde{C_n}$	After-tax cash flow for year n
$C_{in,n}$	Pre-tax cash inflow
$C_{out,n}$	Pre-tax cash outflow
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
C_{prod}	Cost of energy production

C_{capa}	Annual capacity savings or income
C_{RE}	Annual renewable energy
C_{fuel}	Annual cost of fuel or electricity
C_{GHG}	GHG reduction income
$C_{O\&M}$	Yearly operation and maintenance costs incurred by the clean energy project
C_{per}	Periodic costs or credits incurred by the system
C/20	Ampere-hours capacity of 20 hours
CRCE	Canadian Renewable and Conservation Expenses
D	Annual debt payment
DC	Direct Current
DEM	Digital Elevation Model
DEVCO	Cape Breton Municipality Region
dy/year	Days per year
$/kWh	Dollar per kilowatt hour
$/ha./$CO_2$/yr	Dollar per hectare per carbon dioxide per year
^{o}C	Degree Celsius
e_{cr}	GHG emission reduction credit transaction fee
e_{base}	Base case GHG emission factor
e_{prop}	Proposed case GHG emission factor
E_{prop}	Proposed case annual electricity produced
η	Fuel efficiency factor
EVA	Ethylene Vinyl Acetate
f_d	Debt ratio
g/m^2	Gram per meter square

GHG	Greenhouse Gas
GIS	Geographic Information System
GWh	Gigawatt hour
GWP	Global Warming Potential
ha	Hectares
h/dy	hour per day
HDPE	High Density Polyethylene
in.	inch
IGPM	Imperial Gallons Per Minute
IPP	Independent Power Producer
IRP	Integrated Resource Plan
IRR	Internal Rate of Return
JWA	Jacques, Whitford and Associates Ltd.
kg	Kilograms
kg/m^2	Kilogram per meter square
km	Kilometer
km^2	Square kilometer
KMA NIMR	Korea Meteorological Administration's National Institute of Meteorological Research
kPa	Kilopascals
kN/m^2	Kilonewton per meter square
KRW	South Korean Won
kV	Kilovolt
kWh	Kilowatt hour

kWp	Kilowatt peak
kW_{AC}	Kilowatt Alternating Current
kW_{DC}	Kilowatt Direct Current
kWh_{DC}	Kilowatt hour Direct Current
kWh_{E}	Kilowatt hour equivalent
kWh/m^2	Kilowatt hour per meter square
$kWh/m^2/d$	Kilowatt hour per meter square per day
kWh/kW/yr	Kilowatt hour per kilowatt per year
kWh/dy	Kilowatt hour per day
kWh/yr	Kilowatt hour per year
LCOE	Levelized Cost of Electricity
LIDAR	Light-imaging Detection and Ranging
LLDPE	Low Density Polyethylene
λ	Fraction of electricity lost in transmission and distribution
λ_{prop}	Fraction of electricity lost in transmission and distribution (T&D) for the proposed case
m	Meter
m^2	Meter square
m/s	Meters per second
m^2/s	Meter square per second
mm	Millimeter
mc-Si	Multi-crystalline Silicone
mono Si	Monocrystalline Silicone
M	Million

MDOD	Maximum Depth Of Discharge
MPPT	Maximum Power Point Tracker
MSW	Municipal Solid Waste
MT	Megatonne
MW	Megawatt
MWh	Megawatt hour
MWh/yr	Megawatt hour per year
N	Project life in years
N_2O	Nitrous oxide
NMC	Nickel-Manganese-Cobalt
NPV	Net Present Value
NRC	National Resources Canada
NREL	National Renewable Energy Laboratory
NS Power	Nova Scotia Power
OASIS	Open Access Same-Time Information System
O&M	Operations and Maintenance
PAH	Poly-aromatic hydrocarbons
PCB	Polychlorinated biphenyls
P_{DC}	Power Rating Direct Current
PP	Polypropylene
PPA	Power Purchase Agreement
PV	Photovoltaic
PVC	Polyvinyl Chloride
r	Discount rate

r_e	Energy cost escalation rate
r_i	Inflation rate
r_{RE}	Renewable Energy credit escalation rate
r_{GHG}	GHG credit escalation rate
SAM	System Advisor Model
sc-Si	Single-crystalline Silicone
SnO_2	Tin Oxide
T&D	Transmission and Distribution
TDR	Temperature and Discharge-Rate
TCO	Transparent Conducting Oxide
TOD	Time-Of-Day
T_n	Yearly taxes
tCO_2	Tonne of carbon dioxide
tCO_2/ha/yr	Tonne of carbon dioxide per hectare per year
TWh	Terrawatt hour
USD	US Dollar
V_{AC}	Volt Alternating Current
V_{DC}	Volt Direct Current
VJTB	Victoria Junction Tailings Basin
VJTD	Victoria Junction Tailings Dam
W	Watt
WRP	Waste Rock Pile

Chapter 1.0 Introduction

1.1 Background

Commercial coal mining in the province of Nova Scotia dates back to the early 1700's. Approximately 400 million tonnes of coal have been mined in Nova Scotia's surface and underground coal mines (Government of Nova Scotia, 2020). As mineral resources are depleted, mining activities in the province has resulted in a legacy of abandoned mine tailings sites over the years that contain significant concentrations of toxic chemicals and metals that pose serious social and environmental problems. Contaminated tailings ponds have resulted in the deaths of thousands of migratory birds due to the release of these toxic substances. Seepage losses from these tailings sites have caused elevated levels of toxic chemicals in nearby waterbodies leading to contamination of the water supply (Jacques, Whitford and Associates Ltd., 1993). Until these sites are fully remediated and reclaimed, they will continue to release harmful effluents into the environment. Remediation of these sites have cost the Government of Nova Scotia millions of dollars over the last twenty years. Nova Scotia still relies primarily on coal for electricity generation. The province generated 9.6 TWh of electricity in 2018, with coal accounting for approximately 63% of total electricity generation (Canada Energy Regulator, 2021). The burning of fossil fuels from coal-fired power generation plants has resulted in the emissions of greenhouse gases (GHGs) causing air pollution and adverse health impacts on residents in nearby communities. The total amount of GHG emissions from Nova Scotia's electricity sector was 7.0 MT of $C0_{2e}$ (Canada Energy Regulator, 2021). This is equivalent to a generation intensity of 720 grams of $C0_{2e}$ per kilowatt-hour.

The Victoria Junction Tailings Basin (VJTB) is located 3 km East of Sydney and 17 km West of New Waterford, Nova Scotia between Kehoe Lake and Kilkenny Lake. Figure 1 shows the location of New Waterford and Victoria Junction in the Cape Breton Municipality Region, Nova Scotia. The total catchment of the tailings basin is about 0.58 km^2 or 143 acres. Figure 2 shows the location of the VJTB. The VJTB was formerly owned by the Cape Breton Development Corporation (DEVCO). DEVCO built a coal preparation/mixing and wash plant at Victoria

Junction in the early 1980's. Coal from the Phalen and Lingan mine sites were trucked to the preparation plant for processing at Victoria Junction. The coal preparation plant was designed to process about 3 million tonnes of raw coal per year. This is equivalent to an average production of 145,000 tonnes of fine coal waste tailings over a period of 20 years. Approximately 120,000 to 150,000 tonnes of coal ended up as waste (Jacques, Whitford and Associates Ltd., 1993). Approximately 353,000 tonnes of fine tailings were produced as waste products during the processing of coal from the mines over the years (Jacques, Whitford and Associates Ltd., 1993). These waste material were disposed sub-aqueously at the tailings dam located 3 km North-West of the coal wash plant. Permanent subaqueous storage would prevent the chemical reaction of oxygen with the tailings thereby reducing the pyrite oxidation process and reduce acid generation. In 1990, surface water sampling results indicated elevated levels of sulphates and chlorides in Kilkenny Lake due to seepage losses from the tailings pond. The average seepage rate from the tailings pond into Kilkenny Lake was approximately 132 IGPM (Imperial Gallons Per Minute) (Jacques, Whitford and Associates Ltd., 1993). DEVCO subsequently ceased operations of the tailings dam to prevent further seepage losses causing contamination of the water supply in Kilkenny Lake. Since closure, the dam has been monitored for geotechnical stability and maintained with water cover over the tailings to prevent erosion, oxidation and creation of acid rock drainage. Figure 3 shows the location of the tailings basin and coal wash/preparation facility at Victoria Junction. An aerial view of the VJTB is shown in Figure 4.

1.2 Purpose of research

Solar energy generation infrastructures typically require extensive use of land. My proposed study will help investigate the feasibility of development of the VJTB for installation of a solar PV facility eliminating the need to lease or purchase new lands. The reuse of a decommissioned mine tailings site for installation of a solar PV facility could also reduce the substantial investment costs needed for the full remediation and reclamation of the land. Clean renewable energy generated from the solar PV facility can be integrated into the existing Nova Scotia Power Inc.'s transmission and distribution power grid infrastructure. The research study will provide a solution for the residential communities in the vicinity of the development area to reduce their dependency on the national power grid thereby lowering energy generation costs and reducing the environmental effects of burning fossil fuels. The solar PV modules installed on top of the tailings can also serve as protective shields against wind erosion, storm water and snow. Geomembrane cover on the surface with solar photovoltaic panels mounted on ballasted steel supports also prevent soil erosion and differential settlement due to tailings degradation or consolidation. Clean stormwater collected on top of the geomembranes can be used as a source of water supply for communities in the vicinity of the development area. Standing water can be pumped and filtered before being released for use. A membrane covering the surface of the mine pits could also prevent oxidation of the tailings from water runoff during the winter months. By diverting the flow of water and preventing wind erosion, the tailings could be stabilized. The installation of surface and sub-surface drainage and culverts for water runoff will allow the dam to be decommissioned.

The proposed solutions would offer six significant benefits over existing technologies. First, a geomembrane/liner system on top of the dry tailings ponds offer an advantage over the traditional method of soil cover in terms of area coverage and cost. Traditional landfill caps include a geomembrane layer placed over a compacted soil base, a drainage layer, a protective soil cover, topsoil then grass to prevent erosion and promote evapotranspiration (Devita et al., 2017). The use of an exposed geomembrane liner at the surface could replace the expensive traditional soil cover at a fraction of the cost by negating the requirement for vegetative support soil and top soil layers. Second, the geomembrane/liner system could replace the conventional method adopted by industry using the continuous flow of water to cover the top of the tailings. The newly proposed remediation technique could eliminate the use of water, thereby reducing treatment and maintenance costs. By eliminating the percolation of water into the tailings, the amount of acid water formed could also be reduced. Third, the combination of renewable energy generation and a water diversion/pumping system could be effectively used to: 1) collect fresh water; 2) pump and treat underground water; 3) irrigate farms; and 4) power greenhouse farms. This is not attainable with the current traditional method of soil cover remediation. Fourth, the geomembrane/liner cover would prevent storm water from infiltrating the stabilized dry tailings. This would significantly reduce the hydraulic gradient of the area thereby reducing the risk of dam failure. Fifth, the geomembrane and geosynthetic clay liner, and ballasted PV steel support mountings are flexible and lightweight. Therefore, the power generation system do not add significant loads to the surface of the settling waste tailings. This could provide a potential solution to overcome the current challenges of infrastructure development on tailings dams due to geotechnical stability issues. Sixth, a geomembrane-mounted PV system has several advantages over the floating PV technology: 1) Lower installation, operating and maintenance costs; 2) Ability to install a solar tracking system thereby enhancing power generating capacity; 3) Less prone to corrosion and wind problems as the PV modules are installed on land. Water surroundings can accelerate corrosion problems of solar PV modules (Sahu et al., 2016). Mists due to evaporation and subsequent condensation on the modules' surface can obstruct light arriving at the panels and reduce output (Choi, 2014). The performance of floating solar on water technology can also be negatively impacted by extreme winds during severe storms, hurricanes, typhoons and cyclones (Choi, 2014); 4) As the PV modules are installed on land, they are easier to access for monitoring and maintenance operations compared to floating PV modules.

Although the mining industry in Canada has used renewable energy systems for power generation at abandoned mine sites in recent years, very little research has been conducted to investigate the potential placement of PV systems operated on open-pit mines during the closure-planning process. It was assumed that open-pit mines are unsuitable as sites for installing large-scale PV systems because of their topographic limitations (Song & Choi, 2016). My research will attempt to address this misconception by analyzing the potential of installing PV systems on open-pit mines for renewable energy generation. My proposal could provide an alternative solution to the remediation and reclamation of unused tailings sites by developing a safe, cost-effective and reliable energy system.

New Waterford is an urban community located in the Cape Breton Regional Municipality of Nova Scotia. It is approximately 17 km West of the VJTB. According to a 2016 census, New Waterford has a population of 7,344 and 3,518 households (Statistics Canada, 2021). New

Waterford has an average temperature of -2.3 ^{o}C during the winter months and 14.0 ^{o}C during the summer months. For the winter and summer months, the town receives 271 hours and 819 hours of daylight respectively (Timebie, 2021). The total annual full sunlight hours is approximately 1,090 hours (Energyhub.org, 2021).

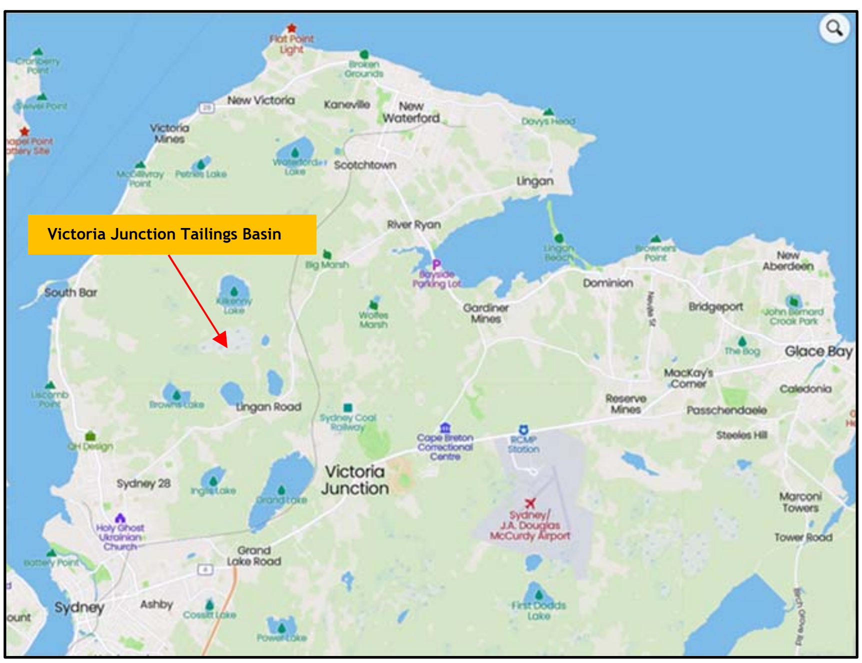
The town of New Waterford was selected for this research study to analyze the energy production output of the solar PV facility based on the annual electricity consumption requirement of the community. This community was also selected due to the small population and number of households for conducting the research study. It is also the author's interest to investigate the feasibility of installing a renewable energy power generation facility near New Waterford to reduce its dependency on coal generated fuel source for electricity supply.

New Waterford's household electrical power energy is currently supplied by the Lingan coal-fired plant operated by Nova Scotia Power. The Lingan Generating Station consists of four 150 MW units (Wikipedia, 2021). The power plant burns bituminous coal and petroleum coke at each of its units. The plant consumes 1.5 million tonnes of coal per year producing roughly fifty percent of the province's air pollution (MacDonald, 2003).

Figure 1. Location of New Waterford and Victoria Junction, Cape Breton, Nova Scotia

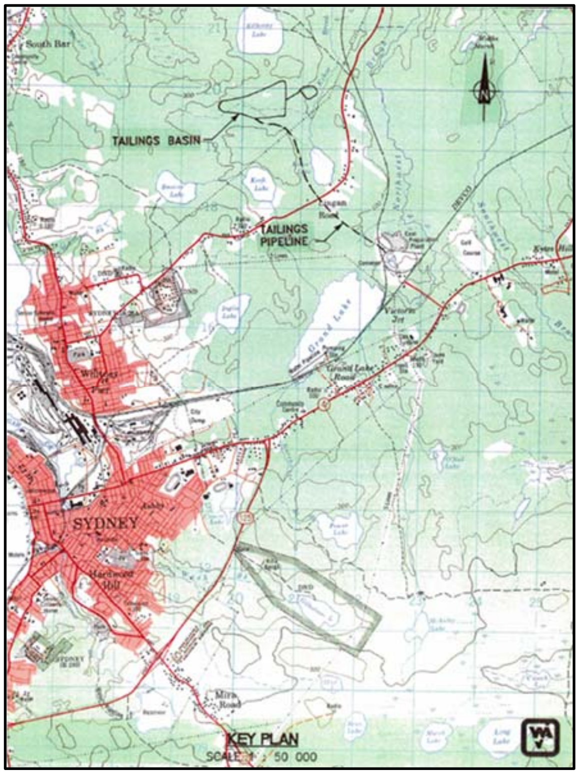
(Note: Google Map, 2021)

Figure 2. Location of Victoria Junction Tailings Basin



(Note: Mapbox, 2021)

Figure 3. Location of the Victoria Junction coal preparation facility



(Note: Jacques, Whitford and Associates Ltd., 1993)

Figure 4. Aerial view of the Victoria Junction Tailings Basin

(Note: ADI Limited, 2010)

1.3 Sustainable energy development goals

My research study encompasses three anchors of the United Nations Sustainable Development Goals (SDG) related to energy, the environment and, social and economic development.

1.3.1 Energy

Goal #7-Affordable and Clean Energy: The installation and operation of a solar PV system on an abandoned mine tailings site such as the Victoria Junction Tailings Dam will promote clean renewable energy technology and help remote communities in Nova Scotia to reduce the dependency on coal-generated fuels for electricity generation. The reduction on the dependency on the provincial power grid will also reduce greenhouse gas emissions thereby reducing air pollution to create a cleaner and healthier environment for residents in the vicinity of the development area. The use of renewable energy will also reduce the consumption demand of electricity from the power grid thereby lowering average energy production costs.

1.3.2 Environment

Goal#13-Climate Action: Utilizing abandoned mine pits for installation of solar PV modules with geomembrane cover on the surface of the remediated tailings site has the potential of reducing greater amounts of greenhouse gas emissions compared to the forest restoration of abandoned mines (Shim, 2021). The amount of greenhouse gas emissions reduced by replacing a coal-fired electricity power generation plant with a solar PV facility is substantially greater than the emissions reduced by trees and shrubs planted in the traditional methods of remediation.

1.3.3 Social and economic

Goal#11-Sustainable Cities and Communities: Installation and operation of solar energy systems on the surface of the tailings embankment could provide cost-effective long-term social and economic benefits for the sustainable development of abandoned mine lands in Nova Scotia. The proposed project will benefit the local economy by creating job opportunities during the construction and commissioning phases of the solar PV power generation facility.

1.4 Methodology

This feasibility study assessed the solar photovoltaic potential and the viability of three different remediation methods using geomembranes at the Victoria Junction Tailings Dam (VJTD). The solar PV facility was designed to meet 25 percent of the electricity consumption demand for the community of New Waterford. The solar radiation site assessment was conducted using ArcGIS. The energy production output of the facility was simulated by entering data on weather, hourly solar irradiance and PV system design using the System Advisor Model (SAM) software. The economic assessment and greenhouse gas emissions reduction analysis were conducted using the RETScreen software.

1.5 Results and findings

The solar radiation site assessment indicated that the total useable area for PV installation was 227,009 m^2. Taking into consideration of the land area available, the system was designed for a capacity of 15 MW. The average solar irradiance potential of the site was 1,056 kWh/m^2. It was determined that 15,842 MWh/year of electricity could be generated from the solar PV facility. The economic analysis indicated that a combination of solar PV-geomembrane and traditional remediation method would be the most cost effective and energy efficient option. The analysis showed that the net present value is -$27.4M CAD with an internal rate of return (IRR) of 1.9% and a payback period of 20 years considering a project economic life of 25 years. The amount of greenhouse gas emissions (GHG) reduced by installing the solar PV facility was determined to be 12,221 tCO_2. The results of the research study confirmed that energy generation from an abandoned mine tailings site using both solar photovoltaic and geomembrane technologies is feasible.

Chapter 2.0 Literature Review

2.1 Installation of solar PV systems on abandoned mine sites

The extraction, processing and transportation of mineral ores is energy-intensive. Specific energy consumption for waste removal, ore excavation, mine dewatering and mine support in Canada is between 12 and 13.6 kWh_E per tonne of waste and ore combined (Albanese & McGagh, 2011; NRCAN, 2005a). More and more mining operations are being moved or located to remote regions globally. The remoteness of these mine sites pose a serious challenge related to accessibility of power resources due to limited or no connection to existing electrical infrastructure. As such, a significant majority of remote mines heavily rely on diesel fuel and coal for electricity generation. Increasing energy demands not only involve significant costs of transporting diesel and coal to these sites, the burning of fossil fuels has created environmental and social issues resulting from greenhouse gas (GHG) emissions and adverse health impacts of air pollution on the surrounding communities. Mining companies worldwide have increasingly utilized renewable energy sources such as solar PV to reduce greenhouse gas (GHG) emissions and protect the environment. PV energy technology has been widely used by mining companies for power generation due to its ubiquity and sustainability (Kim et al., 2019). This renewable energy system has been deployed at both active and abandoned mine sites around the world. The 1.05 MW SunMine solar facility in Kimberley, BC, Canada was the first reclaimed lead-zinc underground mine site converted to a solar farm in Western Canada in 2014 (City of Kimberley, 2020). The Chevron Questa Mine solar facility, a reclaimed molybdenum mine site in New Mexico, USA completed in 2010 currently generates 1 MW of electricity at peak output. This solar power system is producing enough electricity to meet the demands of 500 to 600 households (US EPA, 2013). The largest solar power generation system installed in Germany is the 166 MW Solarpark Meuro photovoltaic power station. This solar power plant was built on 2 km^2 of an abandoned lignite mine site in the city of Shipkau (Cichom & Runyon, 2012). The Kidston Solar Project is currently under construction in Queensland, Australia. This 270 MW solar farm is being built on an abandoned gold mine site in the town of Kidston. Once completed, this solar facility will be capable of generating enough energy to power approximately 15,000 average Australian homes (Australia Renewable Energy Agency, 2020). Construction is currently underway for an 84 kWp floating solar PV pilot project for Anglo-American at the Los Bronces copper mine tailings pond located north of Santiago, Chile. The floating PV power plant is expected to generate 153 MWh per year for the company's energy needs once the project is completed (Power Magazine, 2019). The Hickory Ridge Landfill, a municipal solid waste landfill located in Atlanta, Georgia, USA was capped in 2011 with a dual-purpose landfill closure system referred to as an exposed geomembrane solar cover (EGSC). The solar energy generation system consisted of 7,000 laminated panels spanning an area of over 4 hectares capable of generating 1 MW of renewable electricity (Devita et al., 2017). The 348 MW capacity Chino solar PV system constructed on an abandoned mine site in Silver City, New Mexico (Kiatreungwattana et al., 2013) is capable of producing an annual electricity output of 595,776 MWh/yr.

Mardonova and Choi (2019) conducted a study to analyze the photovoltaic potential of eight operational mining sites in Uzbekistan. The eight mines sites were Sarmich, Ingichka, Kuytosh, Yakhton, Chauli, Sherobod, Chorkesar, and Tebinbuloq. The fixed-tilt 1 MW capacity PV system required a total project land area of 4,926 m^2. The iron mine site Tebinbuloq in Karakalpak showed the highest potential for energy production and greenhouse gas (GHG) reduction. The annual electricity production output that can be generated from this site is 1,685 MWh. A total of 930 tons of greenhouse gases is expected to be reduced from installation of the solar PV facility. The expected economic benefit of the PV system is $2.217 million USD net present value (NPV). The payback period for the project is approximately 13 years. The internal rate of return (IRR) for the Tebinbuloq mine site is expected to be 11.9%. Due to the current situation in Uzbekistan, only six sites have solar measurements available from meteorological stations. These sites are Solar Village Tashkent, Karmana, Dagbit, Pap, Sherobod, and Guzar (Bank, 2014). No solar measurement data exists for Bukhara, Jizzakh, and Karaklapak provinces. Therefore, solar irradiance data for the Tebinbuloq mine had to be taken from the Chauli mine site in the Tashkent district which has available ground-based measurement data.

Ground-based measurement data from the Tashkent-Yuzni meteorological station in Tashkent were compared to the satellite-based solar data obtained in previous analytical processes for the same site to assess precision and accuracy. Results show that the correlation between the two sets of data is highly accurate. Hence, the results of the research show that satellite-based measurements can be considered in solar project analysis studies where ground measurements from solar monitoring meteorological stations are not available.

Choi and Song (2016) conducted a feasibility study of the potential of installing a 3 MW solar photovoltaic (PV) system on an abandoned mine tailings dam of the Sangdong tungsten mine located in South Korea. A solar site assessment of the study area was conducted using a geographic information system (GIS), a digital elevation model (DEM) and a fish-eye lens camera. The 3 MW PV system was designed considering the area usable for PV installation analyzed in the site assessment together with the specifications of PV modules and array spacing. The total area estimated from the regional shading analysis of the surface of the tailings embankment indicated that 44,200 m^2 was usable for installing the PV system. Simulation results from the study concluded that the 3 MW PV system could produce 3,509 MWh of electric power annually. Economic feasibility analysis of the PV system indicated that the net present value would be $1,903,000 USD based on a project period of 20 years. The investment payback period of the PV system was determined to be 11.5 years with an IRR of 9.8%. The results of the study concluded that the installation of the 3 MW PV system was feasible and could be an economic option for clean energy power generation from development of the abandoned mine site.

Song and Choi (2016) conducted a study to analyze the potential of a 1-MW floating PV system to be installed on the pit lake surface of the abandoned Ssangyong open-pit limestone mine in Donghae City, South Korea. A shading analysis of the pit lake was conducted using geographic information system, a digital elevation model and a fish-eye lens camera to determine the suitably of the area for installing a floating PV system. The floating PV system was designed taking into consideration the voltage relationship between PV modules and inverters, optimal tilt angle and array spacing. The expected power generation, reduction of

GHG emissions, and economic effects of the installed floating PV system were calculated using the System Advisor Model (SAM) developed by the National Renewable Energy Laboratory (NREL), USA. The results from the study concluded that an estimated surface area of 87,650 m^2 was required to ensure at least 6 hours of sunshine in winter without any shadow effect. The SAM simulation revealed that 40^o is the optimal tilt angle of the PV array. The calculated annual electricity generation from the 1-MW floating PV facility was 971.57 MWh. The payback period calculated from the economic analysis of the system was 12.3 years over a 20-year lifespan. The net present value of the system was $897,000 USD. The annual reduction of greenhouse gas emissions was estimated at 471.21 tCO_2 per year. According to the study, installing a large-scale floating PV system in an abandoned open-pit mine is economically beneficial and could significantly reduce greenhouse gas emissions. The environmental and economic benefits from electricity production and greenhouse gas reduction render a floating PV system on an abandoned open-pit mine site an efficient reuse option for abandoned mines.

A study of photovoltaic potential at seven abandoned mine promotion districts in Korea was conducted by Song et al. (2015). The study was conducted to investigate the annual power production, net present value, internal rate of return, investment payback period, and amount of GHG reductions by installing PV systems at these seven abandoned mine districts. Solar radiation data for these mine districts were analyzed by collecting meteorological data using an insolation resource mapping tool created by Korea Meteorological Administration's National Institute of Meteorological Research (KMA NIMR). The annual power production estimated, GHG reductions and economic assessment of the PV system were analyzed using the RETScreen software developed by Natural Resources Canada (NRC). The PV system to be installed at each of the seven areas was designed to have a capacity of 99 kW. The results concluded that the area with the highest PV potential was Boryeong, with an estimated power production of 83 MWh per year. The net present value calculated for the PV system was 39 million KRW (South Korean Won). The estimated GHG reduction was 40 tCO_2.

Choi et al. (2013) conducted a study of photovoltaic power generation potential for abandoned mines in Buguk, Seongsan and Yeongwang in Jeollanam-do located in South Korea.

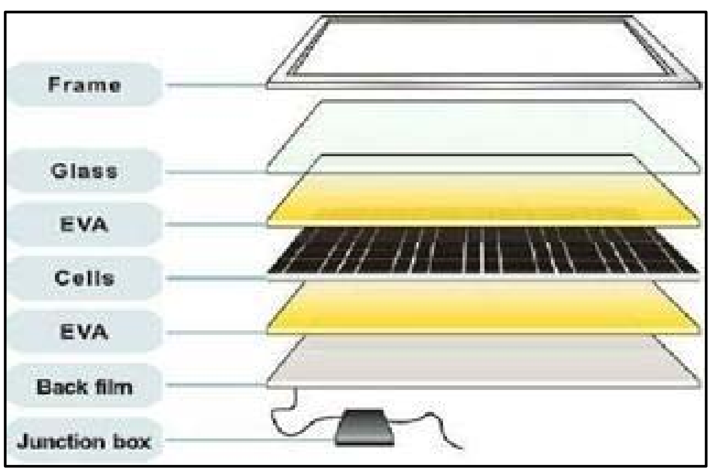
The research was conducted to determine the expected power production and the economic feasibility of the areas for installation of solar power generation systems. A site assessment study of the areas was conducted using topographical and shadow analysis methods to determine the suitability of the areas for installation of solar PV generation systems. The topographical analysis was performed using a Digital Elevation Model (DEM) while the shadow analysis was performed using the Hillshade tool of the ArcGIS software. The expected power production and economic impacts from the installation of the solar power generation system were analyzed using the RETScreen software. The results concluded that the Buguk, Seongsan abandoned mine has the highest annual solar radiation and has the largest area for PV installation. Therefore, this mine site has the highest photovoltaic potential. The estimated power production was about 436 MWh per year. The pre-tax internal rate of return (IRR) was 8.1% with an equity payback period of 9.1 years.

Momayez et al. (2009) conducted a study of utilizing abandoned tailings mine sites for installation of photovoltaic panels. The objectives of their research was to: 1) discuss the energy consumption demands of mining and processing of minerals; 2) discuss an opportunity for clean energy production such as solar energy generation on reclaimed mining sites to reduce the dependency on fossil fuels. The authors analyzed the long-term economic benefit of PV installation and energy production at mine sites. A tailings disposal area in Southern Arizona, USA was used as the study area for the research. The study concluded that the annual energy production of the PV system was 1,800 kWh per year per kW of electrical power. The estimated payback period was 28 years based on an estimated cost of electricity of 10-cents per kWh. The study suggested that advances in solar PV technology are likely to reduce the costs of PV modules and improve annual energy yield. A combination of these improvements could reduce the payback period to 8 years. The research also concluded that utilizing abandoned tailings mine sites for installation of photovoltaic panels has an added advantage besides reducing energy consumption. The soils or water in the tailings ponds may act as reflectors thereby increasing the efficiency of the panels by reflected radiation.

2.2 Solar photovoltaic applications

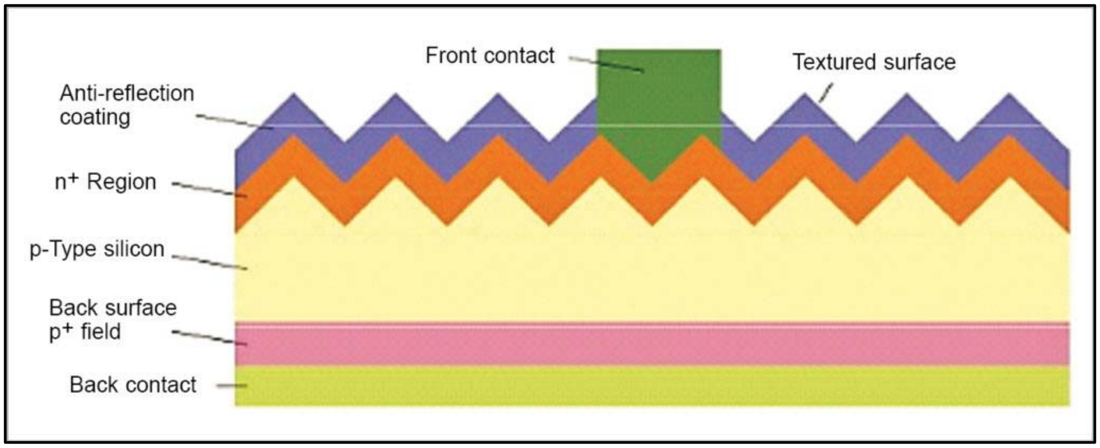
The use of renewable energy sources for electricity generation is growing rapidly and steadily worldwide. Solar energy has been widely used as a renewable energy source for power generation. It is free, sustainable and widely available throughout the world. The most common application of solar energy is through the use of solar photovoltaics. A photovoltaic (PV) cell is a material or device capable of converting solar radiation into direct electrical voltage and current using semiconductors. The most commonly used solar technology to generate electric energy is the photovoltaic solar module, typically comprising 60 or more cells. Semiconductor materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide (Shukla et al., 2014). A PV module consists of a number of pre-wired cells in series, all encased in durable, weather-resistant tempered glass, encapsulated in layers of ethylene vinyl acetate (EVA) and sheets of polymer. PV modules are typically wired in series to increase voltage, and strings of series-wired modules are then connected in parallel to increase current.

Figure 5. Monocrystalline solar cell structure



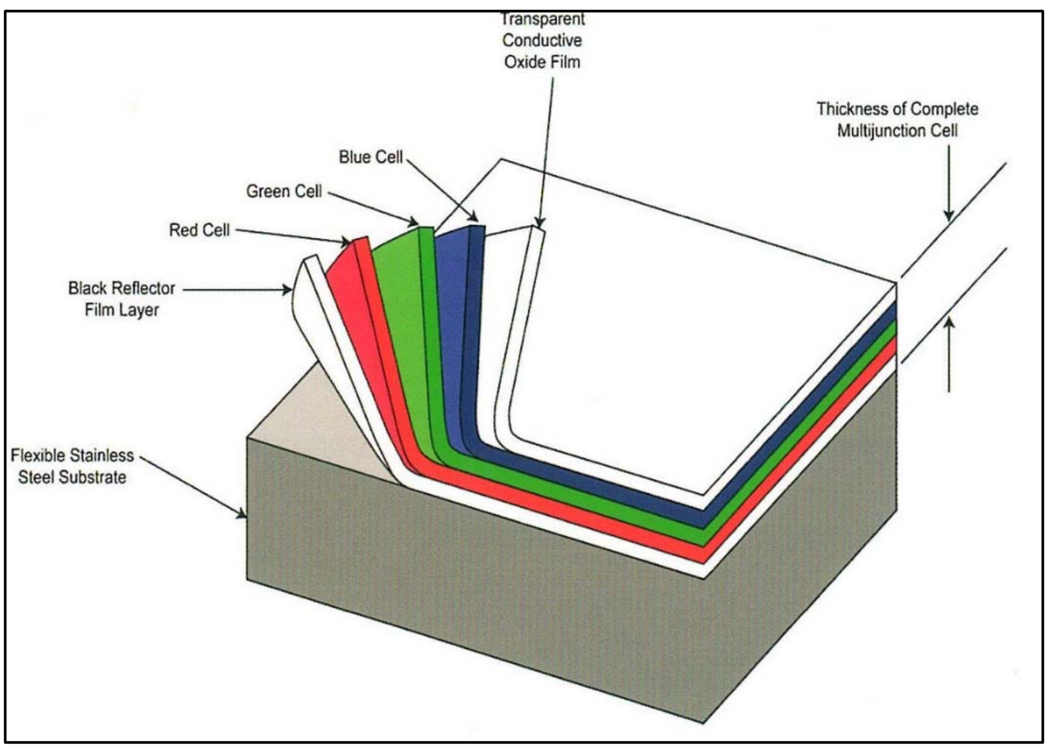
(Note: Bagher et al., 2015)

Figure 6. Polycrystalline solar cell structure



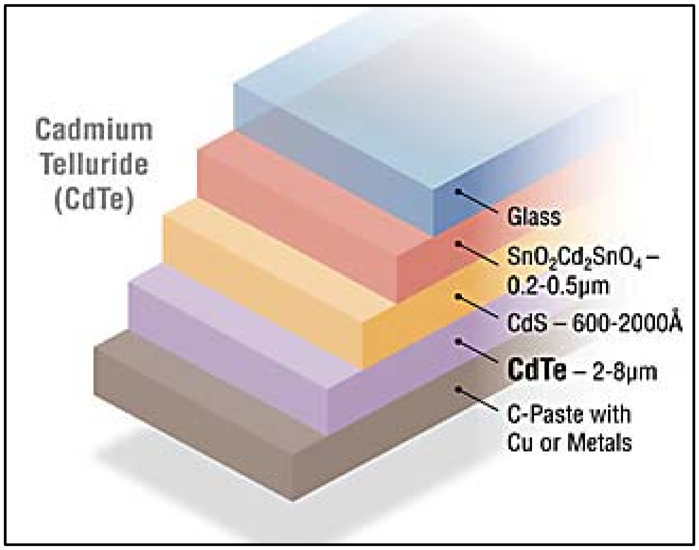
(Note: Electronicsforu.com, 2020)

Figure 7. Triple layer system of Amorphous silicon solar cell



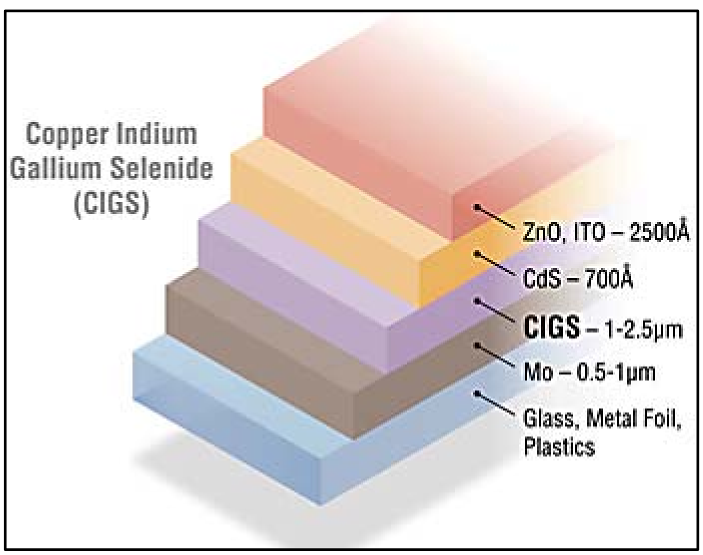
(Note: Bagher et al., 2015)

Figure 8. Five layers of Cadmium telluride (CdTe) solar cells



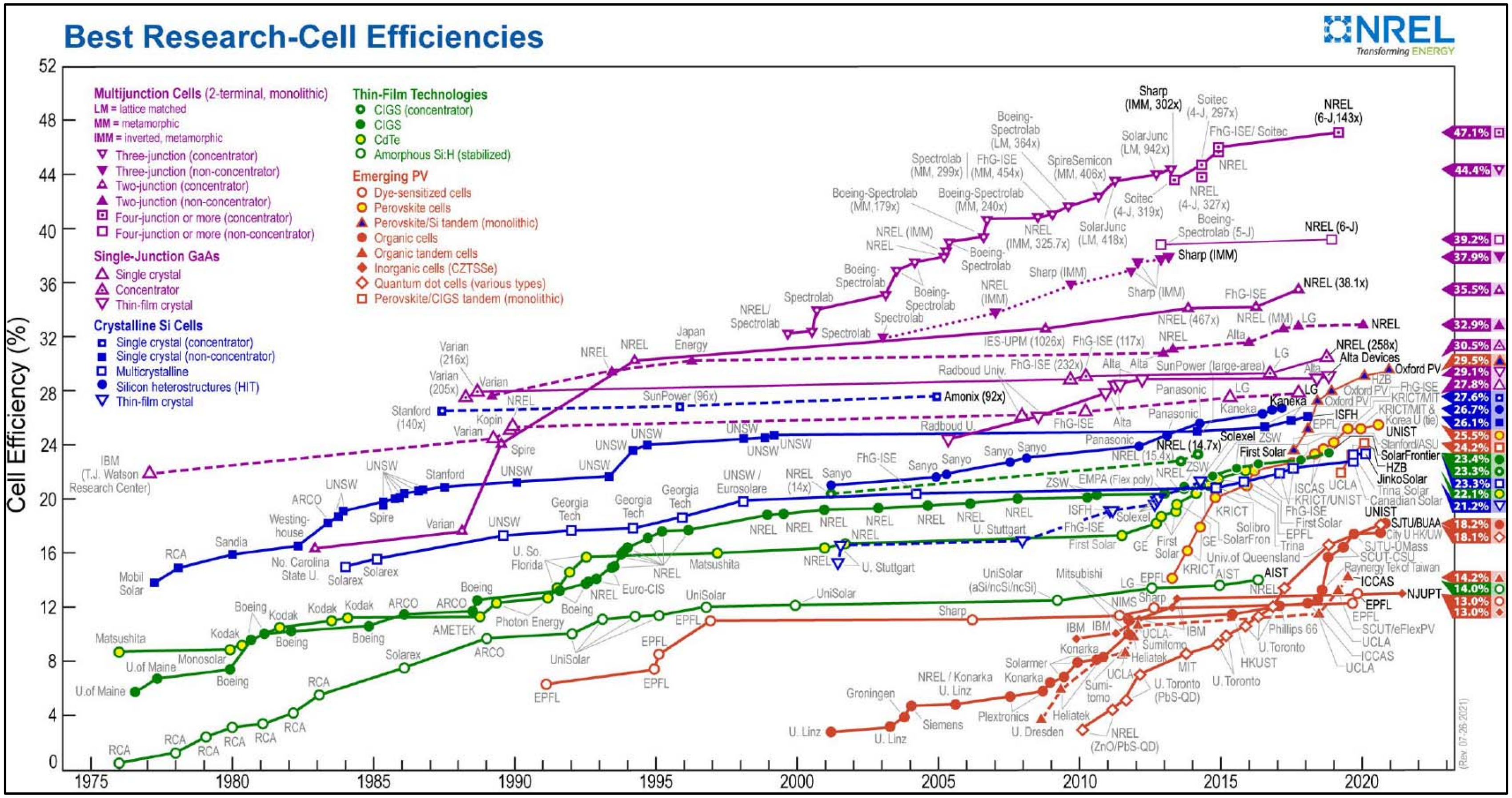
(Note: NREL, 2021a)

Figure 9. Five layers of Copper Indium Gallium Selenide (CIGS)



(Note: NREL, 2021b)

Figure 10. Cell efficiency chart for photovoltaic technologies



(Note: National Research Energy Lab, 2021c)

Crystalline silicon material is the most commonly used material in the PV industry today. About 80 percent to 90 percent of PV modules in the global market today are based on the wafer-based crystalline-Si (Shukla et al., 2014). Crystalline silicon modules are manufactured by growing ingots of silicon. The ingots are sliced into wafers to make solar cells. The cells are then electrically interconnected together and encapsulated into strings of cells to form a module. There are two main types of crystalline silicon modules: single- or mono-crystalline (sc-Si) and multi-crystalline (mc-Si). Single crystalline modules have higher energy conversion efficiency. They have a conversion efficiency of about 14 to 20 percent, and is expected to increase to 25 percent in the long term (Green Energy, 2011). Multi-crystalline modules have lower efficiencies due to their disordered atomic structure. They are typically less expensive and have a degradation rate of about 0.7 to 1.5 percent per year (Jordan & Kurtz, 2013). Their efficiency is expected to reach 21 percent in the long term (IEA, 2008). Monocrystalline silicone (mono-Si) has been widely used as a technological material in the development of electronic devices in the last few decades due to its availability at an affordable cost (Shukla et al., 2014). It consists of a crystal lattice of a single unbroken continuous piece of solid silicon to its edges without any grain boundaries. Silicon monocrystals are grown by the Czochralski process into ingots (Shukla et al., 2014). These cylinders are later sliced into thin wafers for further processing. The structure of the monocrystalline solar cell is shown in Figure 5. Polycrystalline silicon or poly-Si is manufactured by casting into multi-crystalline ingots. The cylinders are then sliced into thin silicon wafers used for the production of cells used in the solar photovoltaic and electronics industry. Polysilicon is made up of small crystals formed together to give the material its metal flake effect (Bagher et al., 2015). Figure 6 shows the structure of a polycrystalline silicon solar cell.

Amorphous silicon (A-Si) is a form of non-crystalline silicon material. It is one of the most widely used thin-film technologies in the solar energy market today (Bagher et al., 2015). The amorphous silicon panels are manufactured by a chemical vapour deposition method by placing a thin layer of silicon material roughly about 1 micrometer thick on a piece of glass or metal. The amorphous silicon solar cell has certain drawbacks in that it experiences significant degradation in the range of 15 to 35 percent in power output when exposed to the sun over a period of 14 months (Bagher et al., 2015; Radue & Van Dyk, 2010). This results in a decrease in energy yield from 10 percent to 7 percent (Bagher et al., 2015). Amorphous silicon panels have lower manufacturing costs as compared to the costs of other panels available in the market making them very cost effective. Figure 7 shows the triple layer system for the amorphous silicon solar cell.

The Cadmium Telluride (CdTe) photovoltaics is a PV technology that uses a thin layer of cadmium telluride as a semiconductor to convert sunlight into electricity (NREL, 2021a). The thin CdTe layer serves as the primary photoconversion layer absorbing sunlight. The SnO_2 and Cd_2SnO_4 act as transparent conducting oxide (TCO) layers. The combination of CdTe, CdS and TCO layers converts the sunlight absorbed in the CdTe layer into current and voltage. The costs of cadmium telluride is lower than conventional solar cells made of crystalline silicon. This is the only thin film PV technology with costs lower than conventional crystalline silicon cells in multi-kilowatt systems (Biello, 2008; Zweibel et al., 2008). Cadmium telluride PV has the shortest energy payback time and smallest carbon footprint among all solar technologies that enables faster carbon reductions (de Wild-Scholten, 2013). The disadvantage of using cadmium telluride is the issue of toxicity of cadmium which is an environmental concern. This problem is mitigated by recycling CdTe PV modules at the end of their economic life (Fthenakis, 2004). Figure 8 shows the five layers of the cadmium telluride solar cell.

The Copper Indium Gallium Selenide Solar Cells (CI (G) S) uses a thin film technology to convert sunlight into electric power. It is manufactured using a “three-stage process” to fabricate a CIGS absorbing layer that enables high absorption and energy conversion efficiency (NREL, 2021b). The panel consists of a thin layer of copper, indium, gallium and selenide deposited on glass or plastic with electrodes on the front and back to receive current (Bagher et al., 2015). The CIGS has the advantage of being able to be installed on flexible substrate materials. Therefore, the CIGS PV technology enables the production of highly flexible and lightweight solar panels. Figure 9 shows the five layers of the Copper Indium Gallium Selenide solar cell.

Figure 10 (NREL, 2021c) shows the highest confirmed solar cell conversion efficiencies for a range of photovoltaic technologies from 1976 to the present. The chart shows that crystalline silicon solar cells have efficiencies ranging from 21.2% to 27.6%. The efficiencies of multijunction solar cells range from 27.8% to 47.1% ranking them the highest among other solar cell technologies. Thin film and emerging PV technologies rank below crystalline silicon solar cells with efficiencies ranging from 14% to 23.4% and 13% to 25.5% respectively.

2.3 Geosynthetic material applications

Geosynthetic materials are widely used in the mining and construction industry for foundation stabilization, mine reclamation, surface water diversion, and soil erosion control. These construction materials are used as liners in landfill sites and mine tailings ponds for waterproofing, containment of leachates and leak detection purposes to mitigate seepage losses thereby preventing acid mine drainage (Lupo et al., 2007).

The most common types of geosynthetic materials used in the mining industry are geomembrane liners , geosynthetic clay liners, geonets and geotextiles. Geomembranes are made of high shear strength polymeric geosynthetic materials with thickness varying around 0.5mm to 3mm typically placed over a compacted liner bedding soil or clay liner (Solmax, 2021a). The most common geomembrane liners are the low density polyethylene (LLDPE), high density polyethylene (HDPE), polyvinyl chloride (PVC), and polypropylene (PP) (Lupo et al., 2007). The technical data specifications for a white- and black-textured HDPE geomembrane are shown in Appendix E and I. Geosynthetic clay liners are made of primarily of low permeability sodium bentonite clay “sandwiched” between two geotextiles or attached to a single polymer membrane (Solmax, 2021c). The materials are bonded together by needle-punching stitches and/or gluing with adhesives. The technical data specifications for a geosynthetic clay liner are shown in Appendix F. Geonets are geosynthetic drainage geo-composite liners with high load bearing and high transmittivity properties. This geo-composite acts as a drainage, water collection, leak detection and flow diversion layer. It is suitable for mining applications such as heap leach pads, tailing ponds and dams. The geonet consists of a lower and upper geotextile separator attached to it to act as a cushion to protect the HDPE geomembrane and installed beneath it from punctures. An over-liner drainage layer of crushed gravel with a thickness of 300 to 600mm are typically placed on top of the geonet (Solmax, 2021d). However, geonets such as Solmax's MineDrain geo-composite drainage liner can replace the gravel drainage layer partially or completely at a lower cost (Solmax, 2021d). The technical data specifications for a MineDrain geo-composite drainage liner are shown in Appendix G1 and G2. A geotextile liner are made of high quality polypropylene fibers held together by needle-punching stitches. The liner serve as a filter/separator between the bedding soil and tailings or landfill wastes. The woven and non-woven geotextiles are specifically designed for soil separation and serves as a protection layer against soil contamination (Solmax, 2021b). These liners can also serve as drainage layers and be used in mine tailings and landfill sites to prevent sub-surface erosion. The technical data specifications for a geotextile separator are shown in Appendix H.

The $400-million Sydney Tar Ponds and Coke Oven Sites Remediation project on Cape Breton Island, Nova Scotia was successfully completed in March, 2014 meeting site closure permitting and regulatory guidelines. The project included handling, stabilization, in-situ solidification, and capping of approximately 750,000 tonnes of PCB (polychlorinated biphenyls) and PAH (poly-aromatic hydrocarbons) contaminated sediments using a multi-layer engineered cap that consisted of geosynthetic materials such geomembranes, geo-composite drainage layers and geotextiles (AECOM, 2014). Seventy hectares (70 ha.) of the Cove Oven Site and thirty hectares (30 ha.) of the Tar Ponds site were remediated.

Lupo and Morrison (2007) conducted a study on design approaches used in the application of geosynthetic materials to mining projects. They focused on design, testing and performance of geomembrane liners and plastic pipes. Geosynthetic materials are often exposed to harsh environmental conditions and loads due to the location and nature of mining projects. It was concluded that proper material design, testing and construction methods must be developed to minimize and eliminate risks of failure of these geosynthetics.

Von Maubeuge et al. (2007) conducted a study on the design applications of geosynthetic clay liners (GCLs) used in landfill caps and mine closures that are exposed to shear stresses on slopes, differential settlement and temperature changes. The study concluded that GCLs must be properly designed according to site specific conditions such as soil material, slope angle and interface friction. Relevant characteristics should be specified to ensure a short- and long-term safe design of GCLs. GCLs have several advantages compared to a compacted clay liner such as easy installation, low hydraulic conductivity, self healing capabilities, capability of withstanding differential settlement, shear performance and cost effectiveness.

Geomembrane such as high-density polyethylene (HDPE) are commonly used as covers over waste rock piles (WRPs) to prevent water and oxygen ingress to inhibit acid mine drainage (AMD). High-density polyethylene geomembranes are expected to be very effective and durable. However, the installation of these cover systems over WRPs have been very limited. There are very few published studies monitoring the performance of these HDPE geomembranes at full-scale WRPs. Power et al. (2017) conducted an extensive five-year performance monitoring study of a HDPE geomembrane cover installed over the Scotchtown Summit WRP in Nova Scotia. A comprehensive hydrogeochemical conceptual model was developed to assess: 1) atmospheric ingress to the waste rock; 2) waste rock acidity and depletion; and 3) evolution of groundwater and surface water quality. The study concluded that the HDPE geomembrane cover system is effective and meet site closure objectives. Depletion in oxygen influx to the waste rock resulted in reduced sulphide oxidation and acid mine drainage. There was a significant reduction of water influx into the waste rock (approximately 90%) with decreasing annual precipitation from 512 to 50mm/year (Power et al., 2017). As a result, water seepage and AMD released from the WRP to groundwater reduced significantly. There was consistent improvement in groundwater quality with a decrease in sulphate and metals, and an increase in pH underneath and downgradient of the WRP. Significant improvements in surface water quality were observed in surrounding watercourses due to improved groundwater plume and elimination of contaminated runoff to perimeter ditches.

Meiers et al. (2011) conducted a research study of a cover system constructed over a waste rock pile at the Franklin coal mine located near Sydney, Nova Scotia in the fall of 2010. The Franklin WRP cover system consisted of a geotextile fabric, engineered 60 mil (1.5 mm) high density polyethylene (HDPE) geomembrane, a geo-composite drainage layer, and 600 mm of glacial till. For the study, a monitoring system was installed to assess the field performance of the cover system throughout all seasons of the year. The system was designed to monitor various climatic parameters, runoff and interflow, gaseous oxygen and carbon dioxide concentrations, pore-gas pressure, and moisture/temperature conditions within the cover and waste material. The system also measured the advective and diffusive oxygen fluxes to the underlying waste rock. Field performance monitoring data from the study concluded that moisture dynamics varies spatially across the WRP cover system profile and is influenced by barometric pumping. It is suggested that continuous monitoring of the Franklin WRP be carried out to provide a unique dataset to assess the performance of the cover system under site-specific climatic conditions.

2.4 Nova Scotia Power System

Nova Scotia's electricity generation consists of a mix of fossil fuels and renewable energy technology types that include coal, petroleum coke, light and heavy oil, natural gas, biomass, wind, tidal and hydro. Nova Scotia Power, a subsidiary of Emera generates a majority of Nova Scotia's electricity. Currently, NS Power has a total generating capacity of 2,357 MW (Nova Scotia Utility and Review Board, 2020). Table 1 shows the 2020 Firm Generating Capability for NS Power and Independent Power Producers (IPPs).

Figure 14 shows the electricity generation by fuel type. In 2018, Nova Scotia generated 9.6 TWh of electricity (Canada Energy Regulator, 2019). The province's primary source of electricity generation is coal. Coal accounted for 63% of the province's total generation of electricity in 2018. Coal, petroleum and natural gas contributed an additional 18%. Electricity generation from renewable sources grew from 16% in 2005 to 24% in 2018 (Canada Energy Regulator, 2019). Figure 11 shows the electricity capacity and electricity generation sources for Nova Scotia. The majority of renewable energy generation in the province is wind. In 2018, wind generated 1,153 GWh or 13% of Nova Scotia's total generation (Canada Energy Regulator, 2020). Total renewable energy generation in 2018 was 2,319 GWh or 26.1% of total generation (Canada Energy Regulator, 2020). Figure 12 shows the estimated energy generation by fossil fuels and renewables in Nova Scotia for 2020, 2030 and 2040. In 2015, it was estimated that 40% of the province's electricity will come from renewable sources of energy by 2020 (Government of Nova Scotia, 2015). It is estimated that total generation of electricity from renewables will further grow to 50% by 2040.

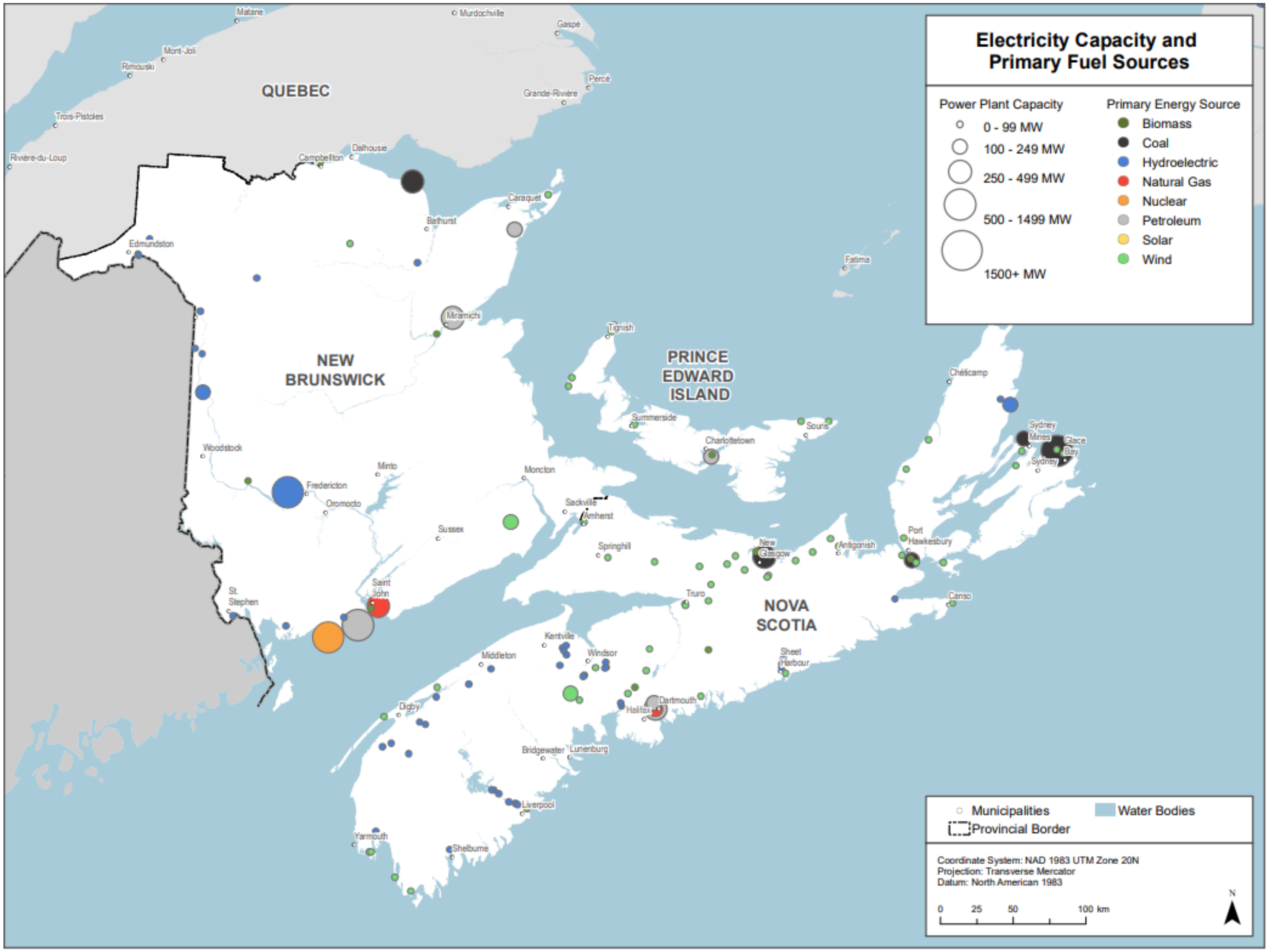
In 2015, residential demand accounted for approximately 44% of Nova Scotia's electricity consumption while the commercial sector and industrial sectors accounted for 34% and 24% respectively. Nova Scotia uses the Integrated Resource Plan (IRP) to forecast the province's electricity load. The Integrated Resource Plan (IRP) is a long term, flexible strategic plan for the electricity system that looks at supply-and-demand scenarios including input from stakeholders. In 2017, annual electricity consumption per capita in Nova Scotia was 11.1 MWh (Government of Canada, 2017). The residential sector comprised of the largest consuming sector for electricity in 2017 at 4.5 TWh (Government of Canada, 2017). It is projected that the province's electricity load will range between a low of 8 TWh and a high of 13 TWh by 2040 (Government of Nova Scotia, 2015). Figure 13 shows the Integrated Resource Plan (IRP) load growth projections to 2040.

In 2017, Nova Scotia's greenhouse gas emissions (GHGs) were 15.6 MT of CO_{2e} (Government of Canada, 2017). Nova Scotia's emissions per capita are 16.4 tonnes CO_{2e} which is 16% below the Canadian average of 19.6 tonnes per capita (Government of Canada, 2017). Electricity generation makes up the largest emitting sectors in Nova Scotia at 42% of emissions, transportation at 31% and buildings (residential and commercial) at 14% (Government of Canada, 2017). Figure 15 shows the GHG emissions by sector in Nova Scotia.

Nova Scotia's existing transmission system consists of approximately 5,220 km of transmission lines at the 69 kV, 138 kV, 230 kV and 345 kV levels (Nova Scotia Utility and Review Board, 2020). The province is interconnected with the New Brunswick electric system through one 345 kV and two 138 kV lines. These lines provide up 505MW of transfer capability to New Brunswick and between 0 and 300 MW of transfer capability from New Brunswick. Nova Scotia is interconnected with Newfoundland via a 500 MW, +/-200 kV DC Maritime Link tie. This interconnection was installed in January 2018 to receive energy from the Muskrat Falls

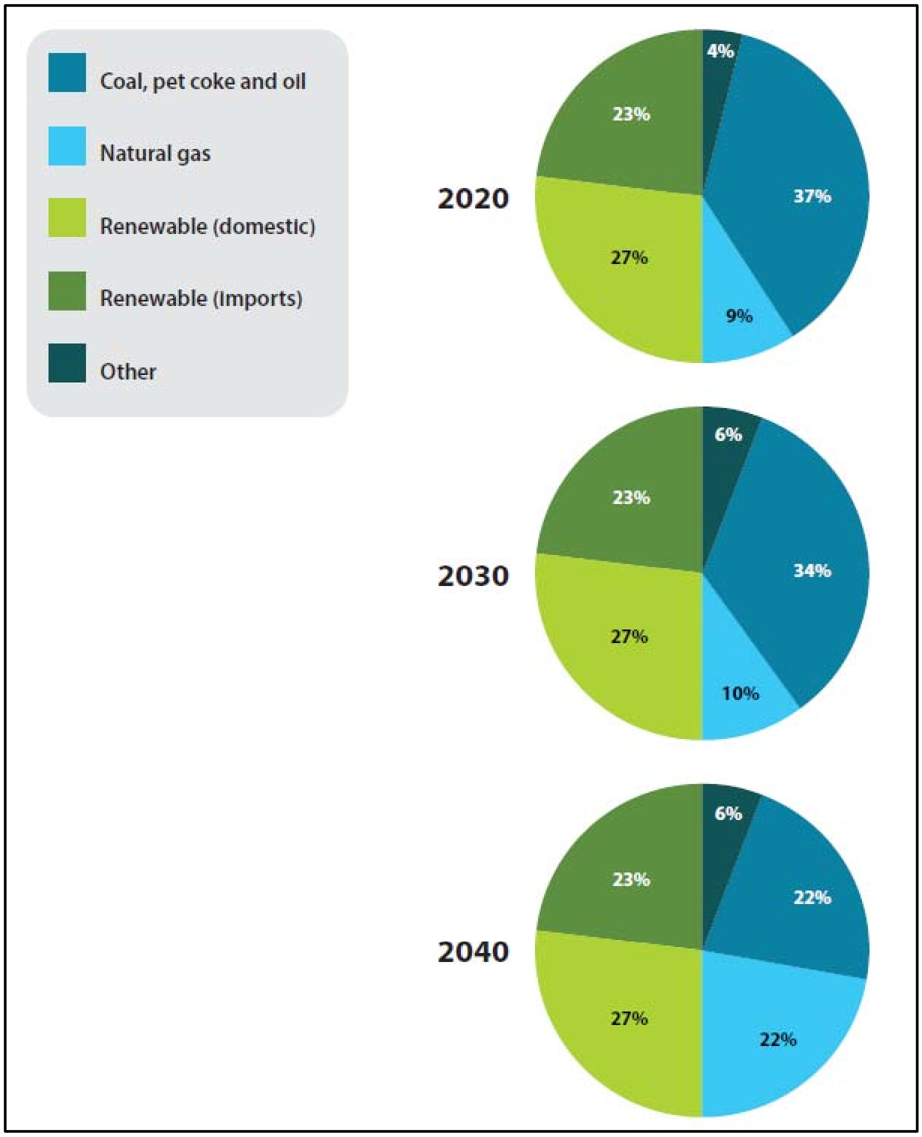
Hydro project and the Labrador Island Link DC tie between Labrador and Newfoundland. Figure 16 shows Nova Scotia Power Inc.'s major electricity generation facilities in 2020.

Figure 11. Electricity capacity and primary fuel sources



(Note: Canada Energy Regulator, 2017)

Figure 12. Estimated energy generation – 2020, 2030, 2040



(Note: Government of Nova Scotia,2013)

Table 1. 2020 Firm Generating Capability for NS Power and Independent Power Producers

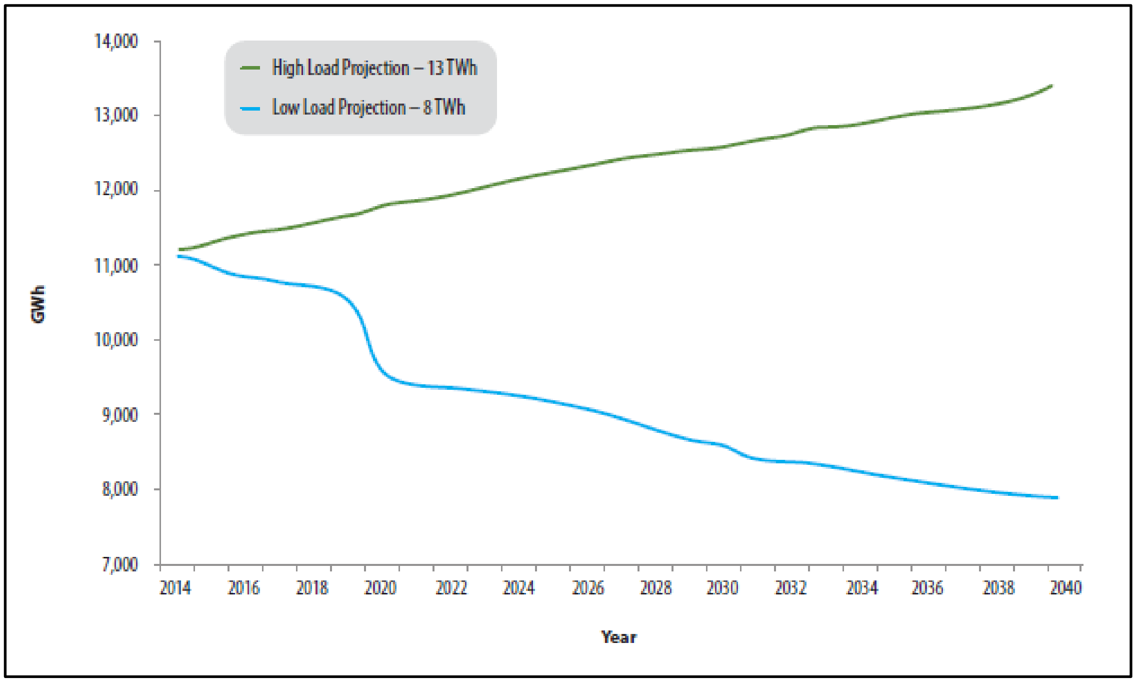
Plant/System	**Fuel Type**	**Winter Net Capacity[2] (MW)**
Avon	Hydro	6.4
Black River	Hydro	21.4
Lequille System	Hydro	23.0
Bear River System	Hydro	35.5
Tusket	Hydro	2.3
Mersey System	Hydro	40.4
St. Margaret's Bay	Hydro	10.3
Sheet Harbour	Hydro	10.2
Dickie Brook	Hydro	3.6
Wreck Cove	Hydro	201.4
Annapolis Tidal[3]	Hydro	0.0
Fall River	Hydro	0.5
Total Hydro		**355**
Tufts Cove	Heavy Fuel Oil/Natural Gas	318
Trenton	Coal/Pet Coke/Heavy Fuel Oil	304
Point Tupper	Coal/Pet Coke/Heavy Fuel Oil	150
Lingan	Coal/Pet Coke/Heavy Fuel Oil	607
Point Aconi	Coal/Pet Coke & Limestone Sorbent (CFB)	168
Total Steam		**1,547**
Tufts Cove Units 4,5 & 6	Natural Gas	144
Total Combined Cycle		**144**
Burnside	Light Fuel Oil	132
Tusket[4]	Light Fuel Oil	0
Victoria Junction[5]	Light Fuel Oil	33
Total Combustion Turbine		**165**
Pre-2001 Renewables	Independent Power Producers (IPPs)	25.8
Post-2001 Renewables (firm)	IPPs	70.6
NS Power wind (firm)	Wind	15.3
Community Feed-in Tariff (firm)	IPPs	34.7
Total IPPs[1] & Renewables		146.4
Total Capacity		**2,357**

Note: Table developed by (Shim, 2021); Data from Nova Scotia Utility and Review Board (Nova Scotia Utility and Review Board, 2020)

Notes:

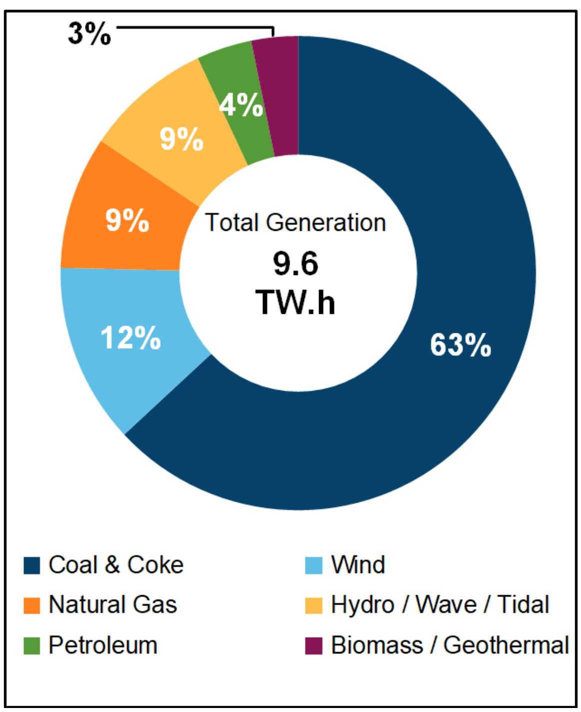
1. IPPs - Independent Power Producers
2. Wind and Hydro are Effective Load Carrying Capability (ELCC) values.
3. Annapolis assumed to be out of service.
4. Tusket CT assumed to be in service by winter 2020-2021.
5. This asset has been removed from the NS Power's listing of Firm Generating Capability.

Figure 13. Integrated Resource Plan (IRP) load growth projection



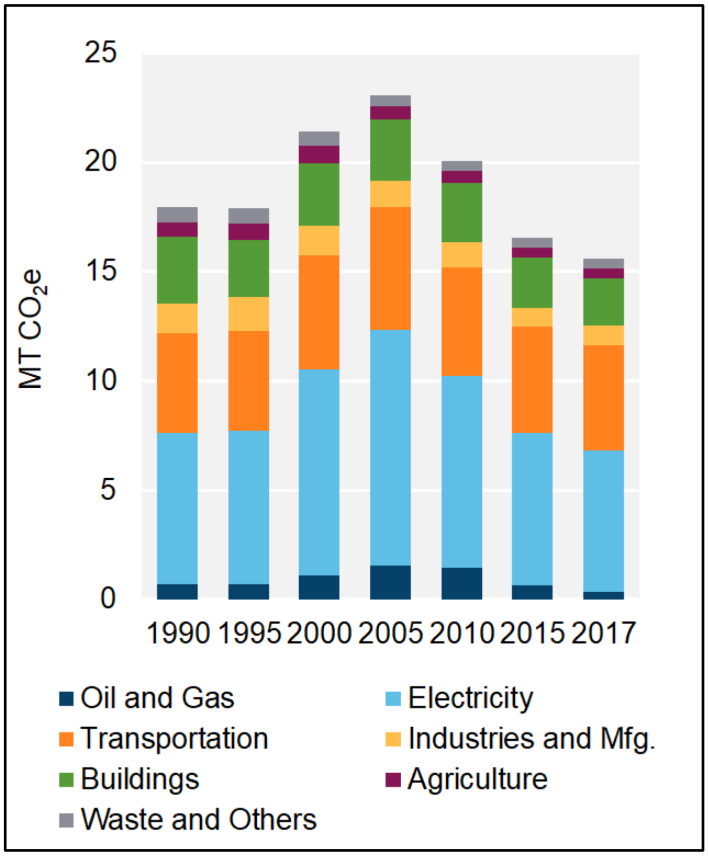
(Note: Government of Nova Scotia, 2015)

Figure 14. Electricity generation by fuel type (2018)



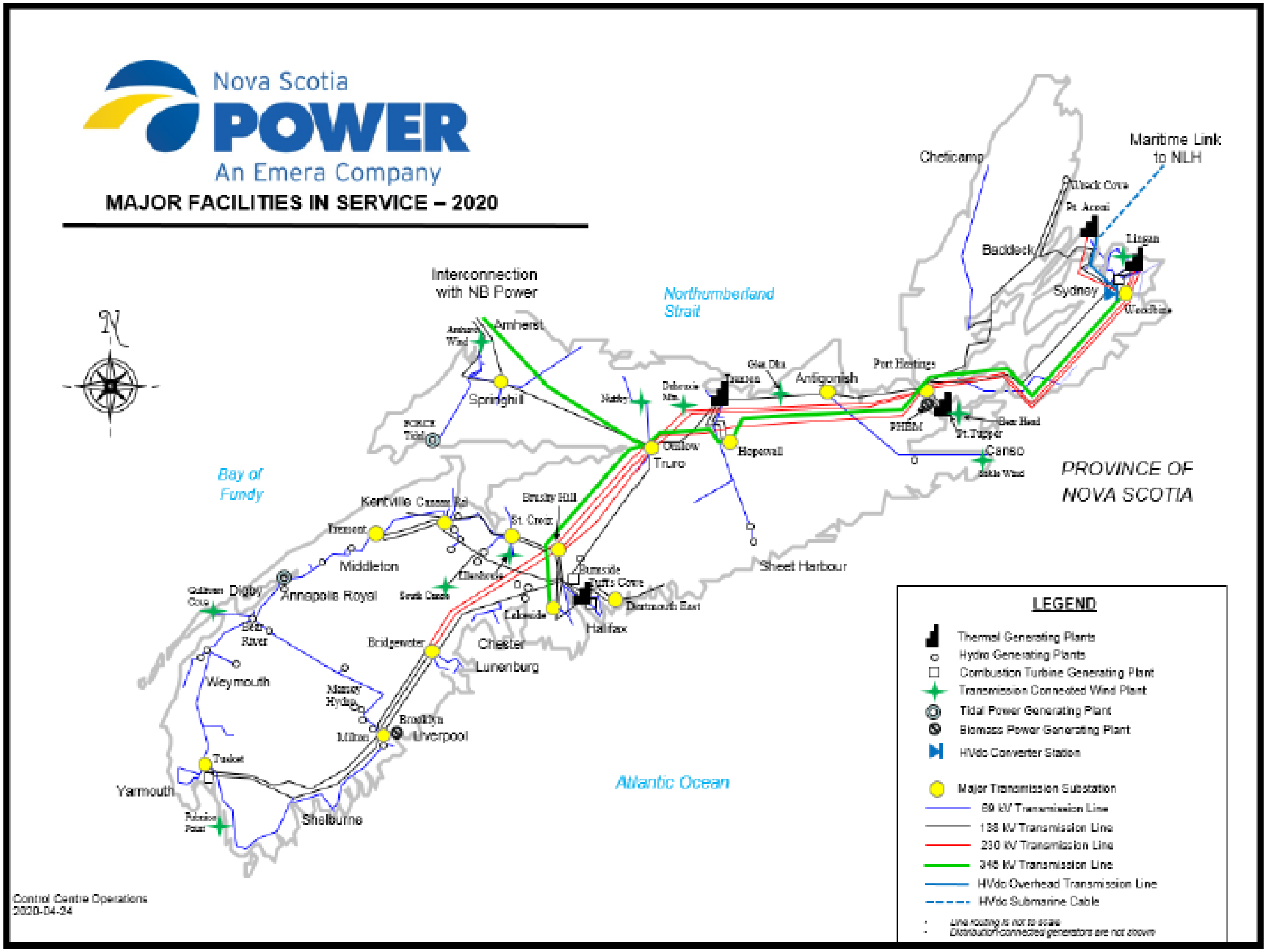
(Note: Canada Energy Regulator, 2019)

Figure 15. Greenhouse gas (GHG) emissions by sector



(Note: Government of Canada, 2017)

Figure 16. NS Power Major Facilities in Service 2020



(Note: Nova Scotia Utility and Review Board, 2020)

Chapter 3.0 Methodology

The methodology used for data collection and techno-economic assessment of the solar PV facility are described in the following sections. The methods involved in the data collection include retrieving information from websites, peer-reviewed literature, published journals, textbooks, Environment Canada, Government of Nova Scotia, Nova Scotia Power, product manufacturers and suppliers, and survey questionnaires. The processes for the technical and economic assessment of the solar PV facility system included: 1) Data gathering to assess the electricity demand consumption of New Waterford; 2) Assessment of the solar radiation potential of the VJTD; 3) Design of the photovoltaic system; 4) Analysis of the solar PV system production output; 5) Site remediation design; 6) Assessment of the geotechnical and structural integrity of the solar PV system and foundation; 7) Economic assessment of the solar PV system and remediation methods; and 6) Analysis of greenhouse gas emission reductions.

3.1 Data Collection

a) Aerial maps, construction drawings, monthly precipitation, storm, wind velocity, hydrogeochemical, geological and hydrological and dam safety analysis data for the Victoria Junction Tailings Basin (VJTB) were obtained from technical reports published by Jacques, Whitford and Associates Limited (1993) and ADI Limited (2010).

b) Digital topographical data for the tailings site were downloaded from DataLocator-Elevation Explorer on the Government of Nova Scotia website (Government of Nova Scotia, 2021a) to construct a digital elevation model of the VJTB in ArcGIS Pro, a geographic information system (GIS) software.

c) Climate data for Sydney, Nova Scotia were obtained from RETScreen software. The RETScreen database contains updated information acquired from ground climate data locations and NASA satellites. The closest ground data location to Victoria Junction is the JA Douglas McCurdy Sydney Airport.

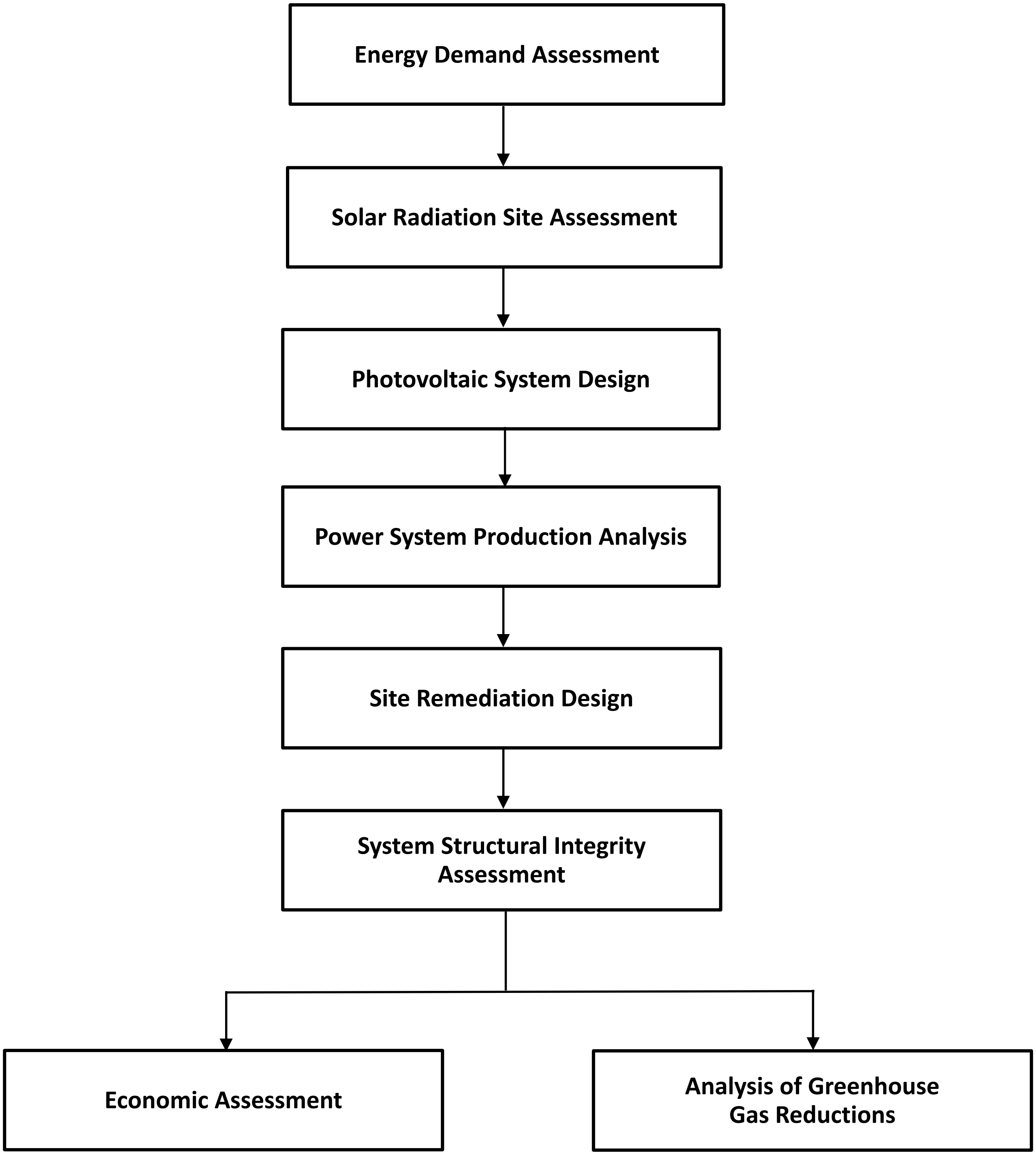
d) Technical data specifications for the solar PV modules were obtained from the PV manufacturer and supplier, SunPower (SunPower, 2021). Technical data specifications for the inverter were obtained from CanadianSolar, manufacturer and supplier for inverters (CanadianSolar, 2021). Technical specifications data for the battery storage unit were obtained from General Electric Energy (GE Energy, 2021). Technical data specifications for the SunPower, CanadianSolar and GE Energy products are shown in the Appendix.

e) Technical data specifications for the geomembrane, geosynthetic clay liner, geo-composite drainage layer and geotextile separator were obtained from the supplier, Solmax. Technical data specifications for the ballasted PV support mounting system were obtained from the supplier, Sunforson. Technical data specifications for both the Solmax and Sunforson products are shown in the Appendix.

f) Nova Scotia's hourly electricity consumption data were obtained from the Open Access Same-time Information System (OASIS) monthly reports downloaded from Nova Scotia Power's website (Nova Scotia Power, 2021b). Nova Scotia's 10-year system energy outlook and electricity load forecast information were obtained from the Nova Scotia Utility and Review Board (Nova Scotia Utility and Review Board, 2020) and Nova Scotia Power (Nova Scotia Power, 2019) respectively. Residential and industrial tariffs, power purchase agreement (PPA) information were obtained from Nova Scotia Power (Nova Scotia Power, 2020; Nova Scotia Power, 2021a). Transmission system interconnection requirements information were obtained from Nova Scotia Power (Nova Scotia Power, 2021c).

g) Feedback on the potential social and economic impacts of the proposed solar PV facility project will be obtained through an electronic survey questionnaire sent out to residents residing in the communities of Sydney and New Waterford. The electronic survey questionnaire was created in Qualtrics, an on-line survey tool (Qualtrics, 2021).

Figure 17. Overview of processes for techno-economic assessment of solar PV facility project



(Note: Shim, 2021)

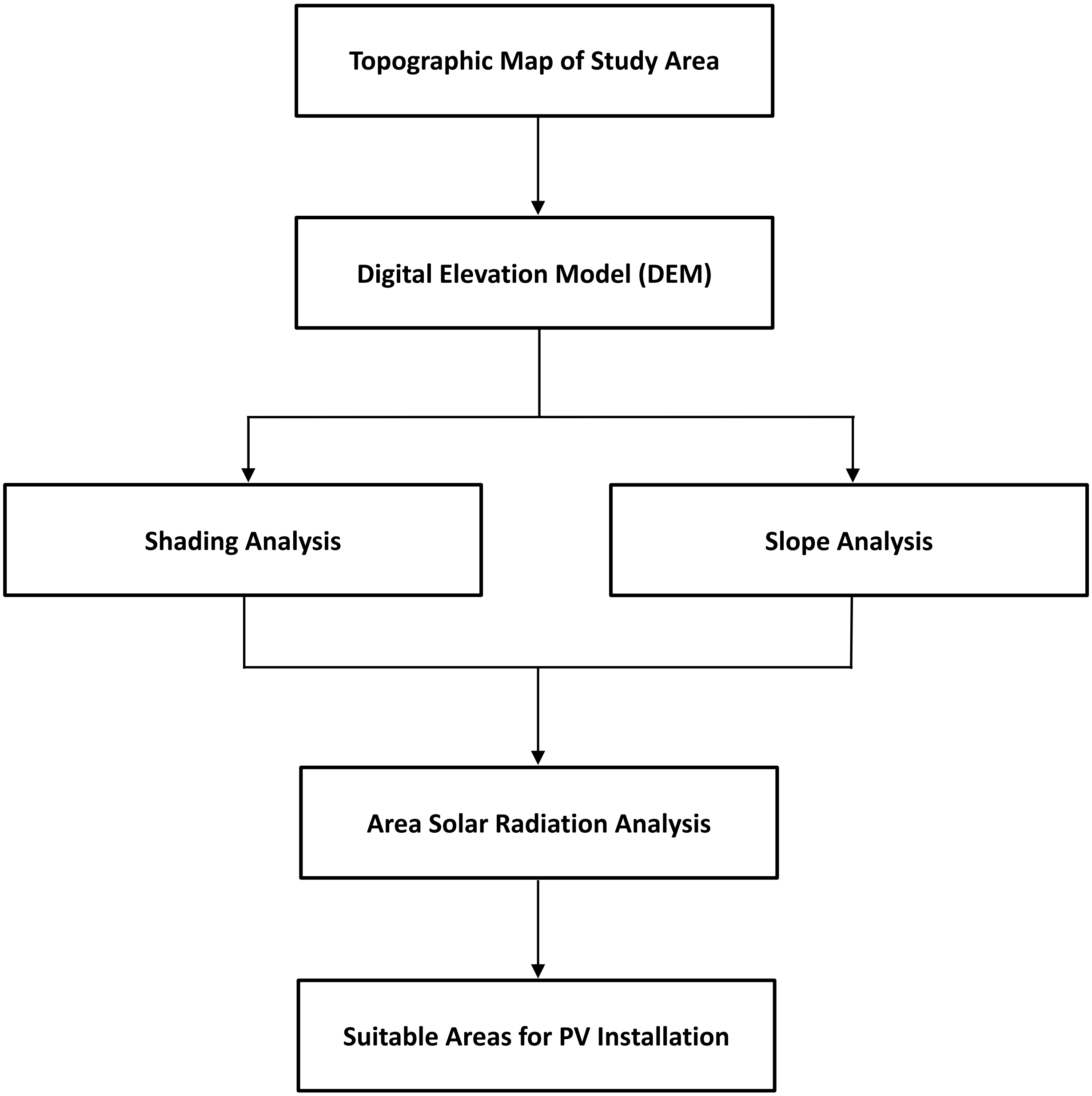
3.2 Techno-economic assessment of solar PV facility project

The energy production output of the solar PV facility will be assessed using the System Advisor Model (SAM) software by the National Renewable Energy Laboratory, USA (NREL, 2020a). The economic analysis of the solar PV facility will be conducted using the RETScreen software by Natural Resources Canada (NRCAN, 2021). The PV system performance analysis model selected in SAM is the Third Party Ownership-Host/Developer model. The client and property owner for this project will be the Provincial Government of Nova Scotia who currently owns and manages the VJTD. It is assumed that the renewable energy power generation system is installed on a commercial property. The project third party host/developer will be an independent renewable energy company/operator. The Provincial Government of Nova Scotia enters into an agreement with the third party host/developer who installs, operates, and owns the renewable energy power generation system. The Provincial Government of Nova Scotia makes payments to the third party host/developer for the power generated by the system at a fixed rate negotiated through a power purchase agreement (PPA). A portion of the excess electricity generated by the system will be sold to the provincial utility company, Nova Scotia Power Incorporated. The remaining portion will be stored in the PV system's back-up battery storage units.

The solar PV facility project is developed on the assumption that slurry water in the tailings pond has been drained and pumped into the nearby Kehoe Brook Lake located approximately 800 m south of the tailings pond. Slurry containing processed water and run-off from the tailings pond have been discharged into the Kehoe Brook Lake since the operations of the VJTD commenced. Therefore, the quality of the slurry water pumped from the tailings pond during the remediation process will be similar and compatible with the processed water already contained in the lake. It is also assumed that the coal tailings have been solidified and stabilized in a previous remediation project prior to VJTD site remediation project. The solar PV facility will be constructed on a nearly-flat dry tailings pond on top of solidified and stabilized tailings.

Figure 17 shows an eight-step analysis process that was performed to assess the expected performance of the solar PV system on a geomembrane cover installed on top of the mine tailings dam. The first step was the assessment of the monthly electricity demand for the town of New Waterford. The second step involved assessment of the mine tailings dam using the ArcGIS software to determine the average solar radiation of the site and suitable areas for installation of the solar PV power generation facility. The third step involved design of the photovoltaic system using the SAM software taking into consideration the average monthly consumption data, specifications of the PV modules, inverters, batteries, shading effects, array spacing, average solar radiation values and the area suitable for PV installation analyzed in the second step. The fourth step was the power production analysis of the PV system by conducting a sensitivity analysis of the solar PV system energy output to the different orientation and tilt angles of the PV modules. The expected total monthly energy production output of the solar PV system was calculated using SAM from the design parameters together with the optimum orientation and tilt angle of the PV module determined from the sensitivity analysis. The fifth step involved design of the site remediation layout for 3 different methods using geomembranes, geosynthetic liners and drainage layers, construction soil and vegetative cover. The sixth step involves assessing the structural integrity of the remediated site supporting the solar PV facility. After the design and analysis of the solar PV system and site remediation layout is completed, an economic assessment was conducted using the RETScreen software based on the design parameters from the third, fourth and fifth steps. The amount of greenhouse gas emission reductions from the three different remediation methods were analyzed using the RETScreen software.

Figure 18. Overview of processes for solar site assessment



(Note: Shim, 2021)

3.2.1 Energy demand assessment

Table 2. 5-year monthly electricity consumption data for New Waterford

Monthly Electricity Load Data for New Waterford														
2020			2019			2018			2017			2016		
Month	Monthly Total Load	Monthly Total Load	Month	Monthly Total Load	Monthly Total Load	Month	Monthly Total Load	Monthly Total Load	Month	Monthly Total Load	Monthly Total Load	Month	Monthly Total Load	Monthly Total Load
	MWh	kWh		MWh	kWh		MWh	kWh		MWh	kWh		MWh	kWh
Jan	4,755	4,755,447	Jan	5,243	5,242,989	Jan	4,867	4,866,529	Jan	4,200	4,200,415	Jan	3,784	3,784,071
Feb	4,935	4,934,710	Feb	4,392	4,392,084	Feb	4,082	4,082,003	Feb	4,396	4,396,425	Feb	4,877	4,876,721
Mar	4,250	4,249,739	Mar	4,290	4,289,971	Mar	4,280	4,280,276	Mar	4,340	4,340,370	Mar	4,444	4,443,608
Apr	3,269	3,269,051	Apr	3,748	3,747,880	Apr	3,984	3,984,116	Apr	3,224	3,224,408	Apr	4,101	4,101,303
May	3,170	3,170,108	May	3,878	3,878,217	May	3,212	3,211,550	May	3,591	3,591,051	May	3,225	3,225,004
Jun	2,823	2,823,407	Jun	2,618	2,618,079	Jun	3,196	3,195,653	Jun	3,043	3,042,969	Jun	3,182	3,182,060
Jul	3,265	3,264,780	Jul	3,212	3,212,058	Jul	3,132	3,132,003	Jul	2,625	2,624,568	Jul	3,388	3,387,845
Aug	3,211	3,211,385	Aug	3,415	3,415,183	Aug	3,560	3,559,753	Aug	3,376	3,376,277	Aug	3,199	3,199,227
Sep	3,034	3,034,066	Sep	2,823	2,822,874	Sep	3,063	3,062,683	Sep	3,133	3,133,141	Sep	3,077	3,076,920
Oct	3,288	3,288,340	Oct	2,967	2,966,697	Oct	3,542	3,541,758	Oct	3,222	3,221,987	Oct	3,371	3,371,373
Nov	3,802	3,801,621	Nov	3,991	3,991,191	Nov	4,663	4,662,937	Nov	3,908	3,908,060	Nov	3,548	3,547,859
Dec	4,763	4,763,346	Dec	3,881	3,880,972	Dec	4,474	4,474,285	Dec	4,828	4,828,390	Dec	4,738	4,737,602
Average	**3,714**	**3,713,833**	**Average**	**3,705**	**3,704,850**	**Average**	**3,838**	**3,837,795**	**Average**	**3,657**	**3,657,338**	**Average**	**3,744**	**3,744,466**
Total	**44,566**	**44,566,000**	**Total**	**44,458**	**44,458,195**	**Total**	**46,054**	**46,053,545**	**Total**	**43,888**	**43,888,060**	**Total**	**44,934**	**44,933,593**

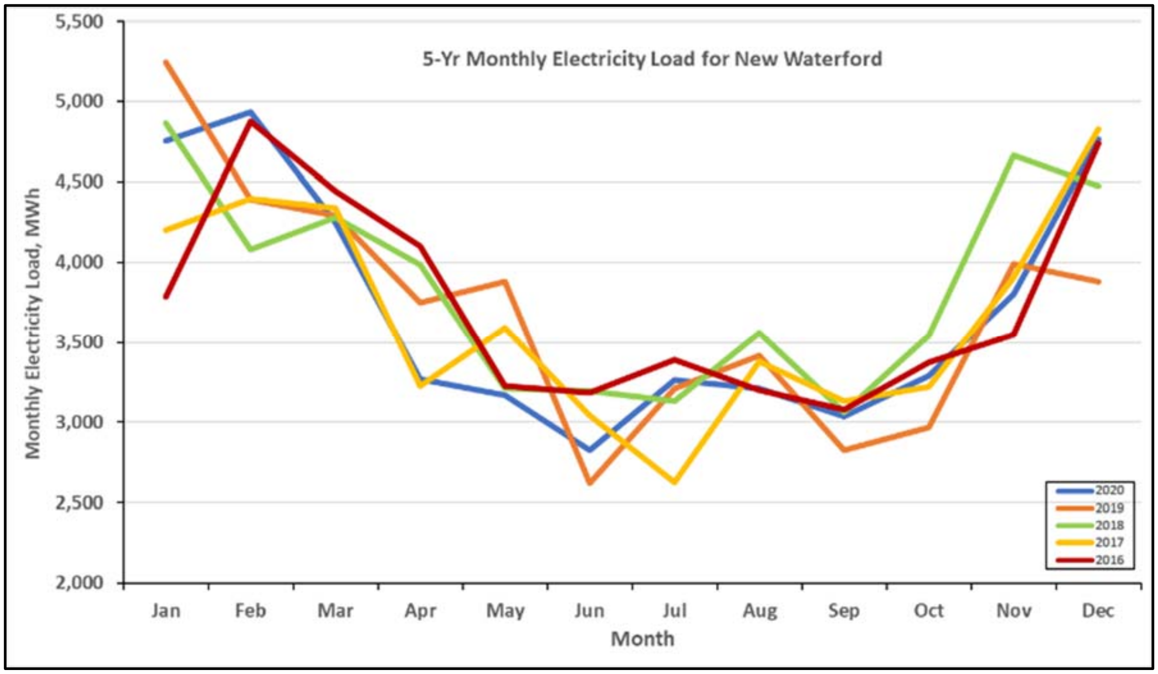
Note: Table developed by (Shim, 2021); Data from Nova Scotia Power (Nova Scotia Power, 2019)

Table 3. Average Monthly Total Load-New Waterford

Average Monthly Total Load New Waterford		
2020 to 2016		
Month	**Average Monthly Total Load**	**Average Monthly Total Load**
	MWh	**kWh**
Jan	4,570	4,569,890
Feb	4,536	4,536,388
Mar	4,321	4,320,793
Apr	3,665	3,665,352
May	3,415	3,415,186
Jun	2,972	2,972,434
Jul	3,124	3,124,251
Aug	3,352	3,352,365
Sep	3,026	3,025,937
Oct	3,278	3,278,031
Nov	3,982	3,982,334
Dec	4,537	4,536,919
5-Yr Average	**4,570**	**4,569,890**
5-Yr Total	**44,780**	**44,779,878**

Note: Table developed by (Shim, 2021); Data from Nova Scotia Power (Nova Scotia Power, 2019)

Figure 19. 5-year monthly electricity consumption graph for New Waterford



Note: Figure developed by (Shim, 2021); Data from Nova Scotia Power (Nova Scotia Power, 2019)

The Victoria Junction solar PV facility will be designed to supply electric power to the town of New Waterford. The community of New Waterford has a total of 3,520 households. The monthly reports on hourly net electricity load data for the province of Nova Scotia were obtained from Nova Scotia Power's Open Access Same-Time Information System (OASIS) website. The total number of households in the province of Nova Scotia is 390,280. The residential sector demand accounts for approximately 44% of Nova Scotia's electricity consumption (Government of Nova Scotia, 2015). The monthly electricity load data for the town of New Waterford was interpolated from the provincial load data by taking a ratio of the total number of households in New Waterford to the province of Nova Scotia and multiplying by the percentage of residential electricity consumption demand. Monthly electricity load data for the past five years, 2016 to 2020 were used to calculate the average monthly electricity consumption data for the town of New Waterford. The five-year average monthly electricity load for New Waterford is 4,569,890 kWh or 4,570 MWh. The five-year annual total electricity load is 44,779,878 kWh or 44,780 MWh. The Victoria Junction solar PV facility will be designed to meet twenty-five percent (25%) of New Waterford's annual total electricity load of 44,779,878 kWh which is 11,194,970 kWh or 11,195 MWh. The 25 percent annual electricity consumption demand of New Waterford was decided by taking into consideration several factors such as; 1) The land area available for PV installation; 2) The total number of households; and 3) Alternative sources of electrical power supply. New Waterford's household electricity comes primarily from the 607 MW Lingan coal-fired power generation plant which will make up approximately 75% of the total energy supply. The remaining 25% of the total energy supply will be generated from the proposed solar-PV farm. The solar-PV system design concept was also based on the $7.76M 3NE Solar Farm project located in Fort Chipewyan, Alberta (Government of Alberta, 2020). The 2.6MW solar farm consisting of 7,500 modules is located on 8 hectares of land and will meet 25% of Fort Chipewyan's community electricity need for 350 homes. Table 2 shows the 5-year monthly electricity consumption data for New Waterford. Figure 19 shows the 5-year monthly electricity consumption graph for New Waterford.

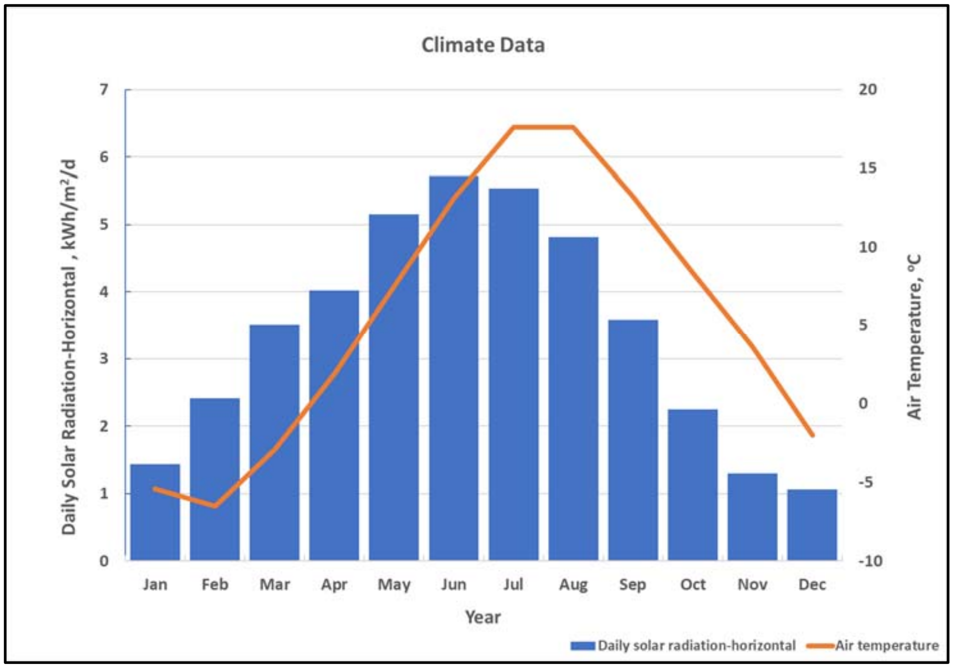
3.2.2 Solar radiation site assessment

Table 4. Climate data for Sydney, Nova Scotia

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation-horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	mm	$kWh/m^2/d$	kPa	m/s	°C	°C-d	°C-d
Jan	-5.4	76.4%	89.28	1.43	100.3	6.4	-2.9	725	0
Feb	-6.5	75.1%	78.96	2.41	100.3	6.1	-4.4	686	0
Mar	-2.9	76.4%	77.19	3.51	100.4	6.1	-2.3	648	0
Apr	1.9	78.2%	85.2	4.02	100.5	5.8	1.8	483	0
May	7.5	76.5%	72.85	5.15	100.7	5.6	6.5	326	0
Jun	13.1	77.0%	80.1	5.72	100.6	5.0	11.9	147	93
Jul	17.6	78.1%	73.47	5.53	100.7	4.7	17.3	12	236
Aug	17.6	78.7%	81.53	4.81	100.7	4.7	19.2	12	236
Sep	13.2	80.5%	89.4	3.58	100.8	4.7	15.8	144	96
Oct	8.3	80.3%	107.57	2.25	100.8	5.6	10.4	301	0
Nov	3.6	79.8%	102.9	1.3	100.6	5.8	5.2	432	0
Dec	-2.0	79.0%	108.81	1.06	100.4	6.1	0.5	620	0
Annual	**5.5**	**78.0%**	**1,047.26**	**3.40**	**100.6**	**5.6**	**6.6**	**4,536**	**661**

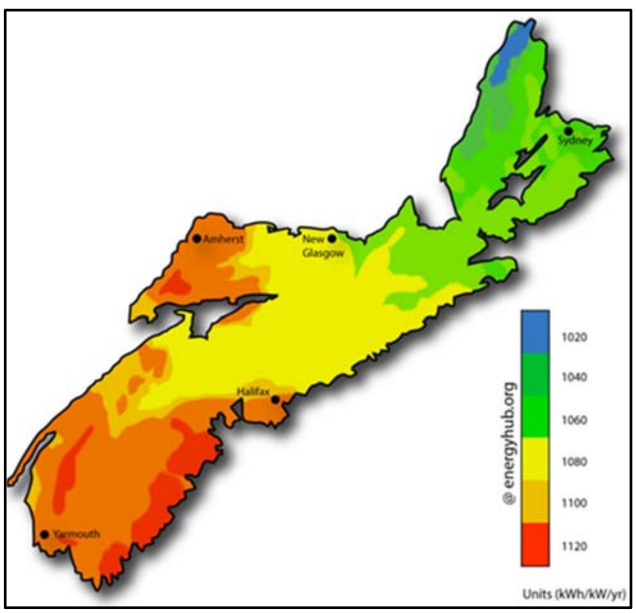
Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 20. Daily solar horizontal radiation and air temperature for Sydney, Nova Scotia



Note: Figure developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 21. Annual solar irradiance potential for Nova Scotia



(Note: www.energyhub.org)

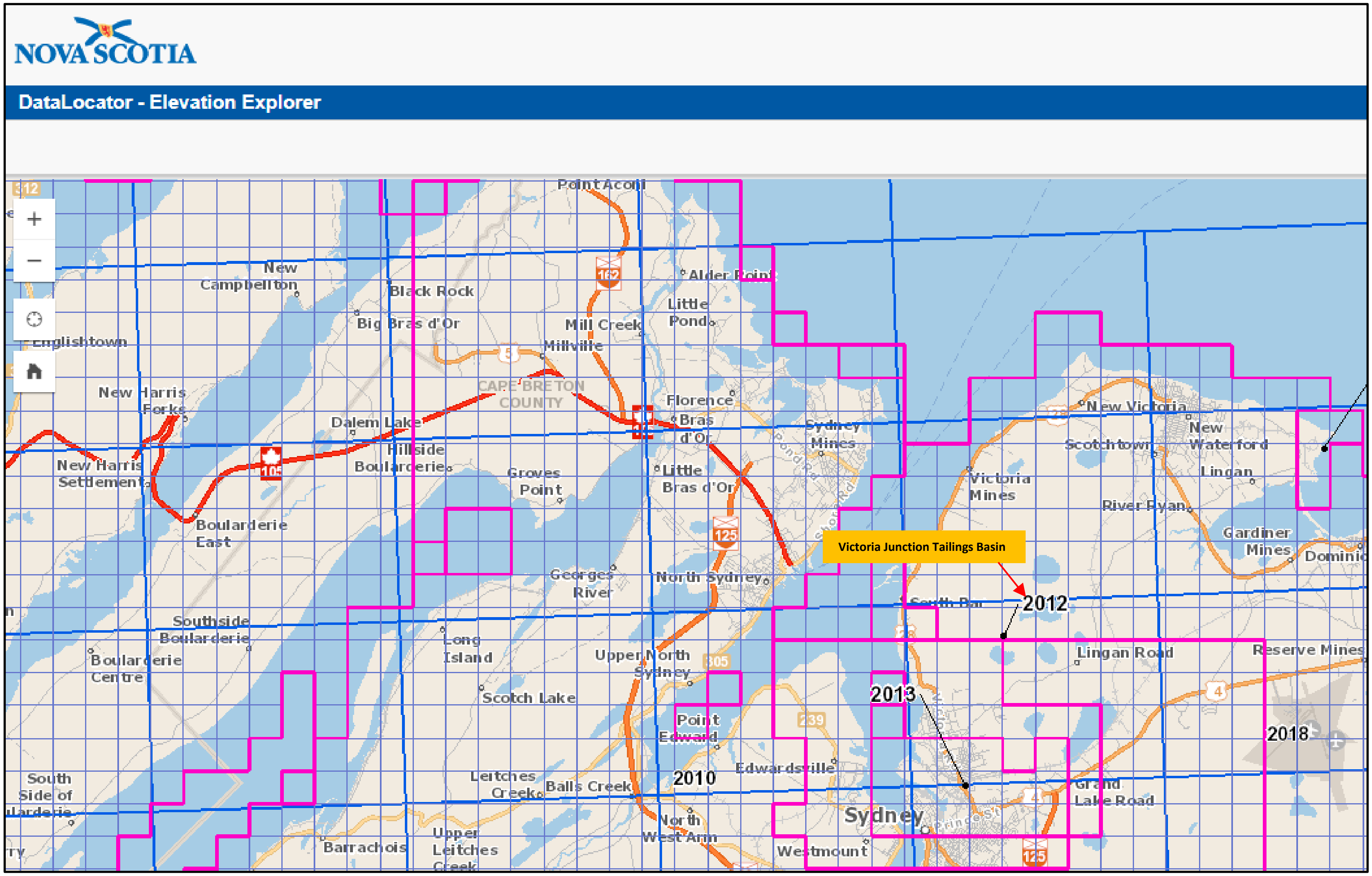
The climate data for Sydney, Nova Scotia obtained from the RETScreen software were used to determine the solar radiation potential of the Victoria Junction Tailings Basin. The meteorological data in the RETScreen software were obtained from ground data monitoring stations at the JA Douglas McCurdy Sydney Airport. As shown in Table 4 and Figure 21, the average annual daily solar horizontal radiation value for Sydney is 3.40 kWh/m^2/d. Figure 21 shows the annual solar irradiance for Nova Scotia. The annual solar irradiance for the town of New Waterford is between 1,040 to 1,060 kWh/kW/yr (Energyhub.org, 2021). These values were also used to design the capacity of the solar PV system and calculate the expected total AC and DC energy production from the facility.

Figure 18 shows the overview of processes for the solar radiation site assessment. The first step involved downloading digital LIDAR (Light-imaging Detection and Ranging) maps from the mapping tool, DataLocator-Elevation Explorer available on the Government of Nova Scotia website (Government of Nova Scotia, 2021a). The LIDAR maps are arranged in 1 km x 1 km tiles on the map with digital elevation data associated with each of these tiles as shown in Figure 22. The maps are indexed according to the project acquisition area and the year. Raw digital elevation map data were downloaded by selecting the tiles of interest on the map. The tiles of interest selected are shown in Figure 23. A digital elevation model (DEM) of the tailings pond was created using the ArcGIS software in the second step of the assessment. Two raw DEMs were clipped and merged to form a single DEM of the tailings pond. Figure 25 shows the DEM of the dry tailings pond created using the topo-to-raster spatial analysis tool in ArcGIS. Contour layers for the dry tailings pond were generated by georeferencing and digitizing a construction drawing overlaid on top of the DEM. The DEM was then projected to the NAD83 (2011) UTM Zone 20N coordinate system for Nova Scotia. Contours were also generated in ArcGIS to illustrate the topography of the area around the tailings pond. These contour lines are spaced at 1 m. Figure 24 shows the contour lines for the tailings pond and the surrounding topography. A shading analysis was conducted in the third step to analyze the shadow effects on the site terrain caused by the surrounding topography. For this analysis, a hillshade raster layer was generated from the DEM constructed in the second step. The hillshade model simulates the shading effects based on the azimuth and elevation of the terrain. In order to analyze the effects of shadows on the PV modules, a conservative evaluation method was used by calculating the total number of sunlight hours during the winter months. Figure 26 illustrates the shading analysis map showing the hillshade values of the terrain. The fourth step involved generating a slope raster layer to identify the inclination of the terrain. The slope map was also generated from the DEM. Figure 27 illustrates the slope map showing the inclination values of the terrain. Both the hillshade and inclination data were used as input parameters in the area solar radiation analysis tool in ArcGIS. The final step of the solar site assessment involved determining the suitable area for solar PV installation. The area solar radiation tool in ArcGIS was utilized for this analysis. The digital elevation model for the dry tailings dam was used as an input raster layer. This tool calculates the radiation based on following input parameters; 1) latitude of the site; 2) position of the sun throughout the year; and 3) topographic features of the tailings site such as azimuth and inclination. ArcGIS then generates the solar irradiation values for the entire dry tailings site. From the solar irradiance map generated by ArcGIS, the author was able to select suitable areas for PV installation by creating a polygon shapefile to digitize (trace) the boundaries of those areas selected. Once the areas have been digitized, the mean area size and average solar radiation values were calculated using the "zonal statistics as table" tool in ArcGIS. The following criteria were setup as filters in ArcGIS to eliminate areas with low solar irradiance, high slopes and areas facing North. Surfaces with solar radiation values with less than 800 kWh/m^2 were eliminated from the analysis. The value of 800 kWh/m^2 was selected as the cut-off value for this project based on the minimum amount of solar radiation value required to generate the required energy production output of the solar PV facility. Surfaces facing North with azimuth less than 22.5^o and greater than 337.5^o were eliminated from the analysis. In the Northern Hemisphere, surfaces facing North are likely to receive less solar radiation than surfaces facing South.

As shown in Figure 27, the slope inclination angle of the terrain calculated by the ArcGIS software ranges from less than 1.72^o to 90^o. In order to generate more accurate results, surfaces with inclination angles greater than 5.71^o were discounted from the analysis. Theoretically ,the SAM software calculates the energy output with an assumption that PV modules are placed on flat surfaces with a slope of 0^o. Surfaces with inclinations less than 5.71^o

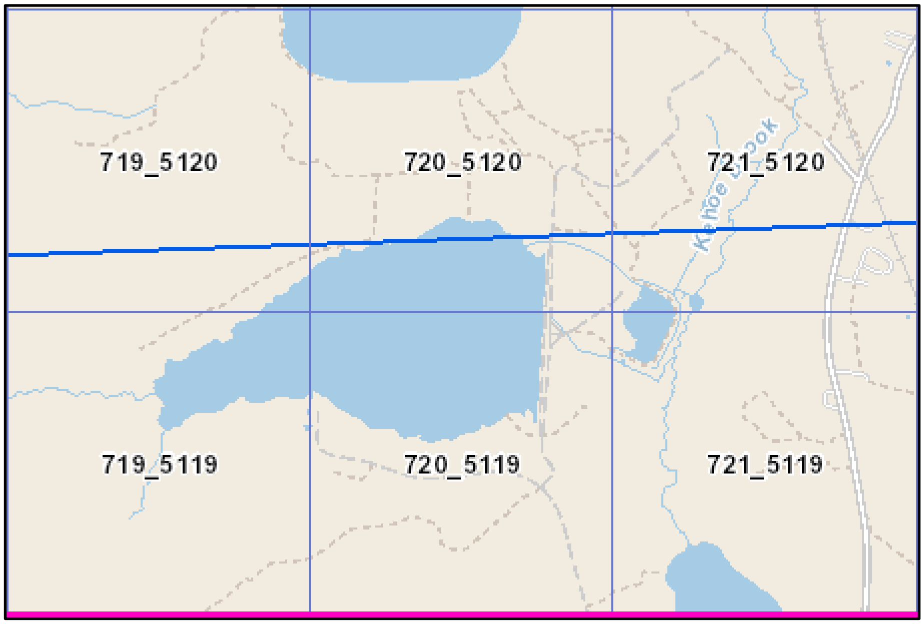
will be considered as a theoretically flat surface in SAM. An inclination of 5.71^{o} was also chosen as the maximum slope angle for installation of the PV modules because mounting support structures built on side slopes greater than 5 degrees will more likely increase the risks of soil erosion and stormwater control issues (Sampson, 2009).

Figure 22. DataLocator-Elevation Explorer



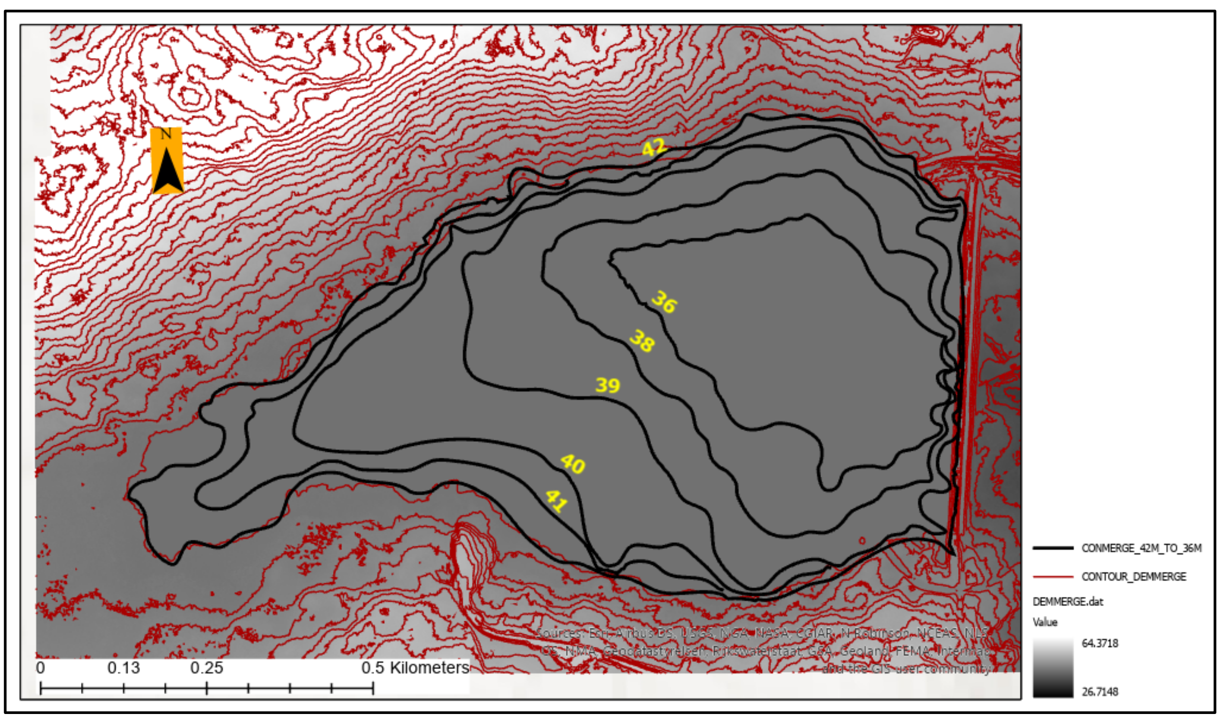
(Source: Government of Nova Scotia, 2021a)

Figure 23. LIDAR tiles for Victoria Junction Tailings Basin



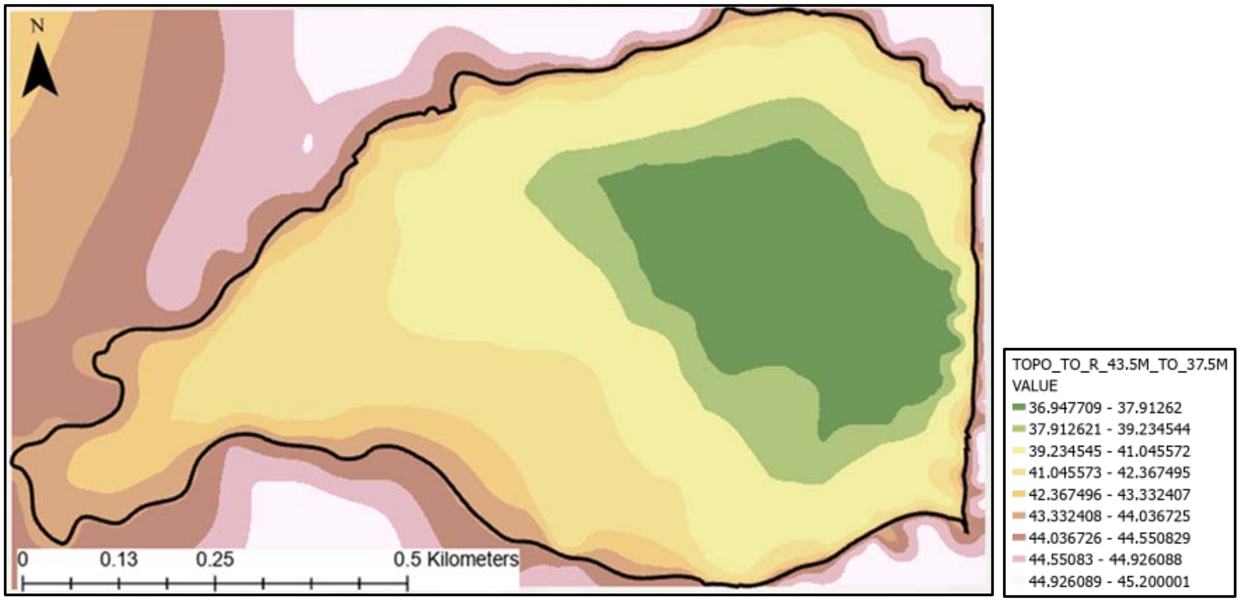
(Source: Government of Nova Scotia, 2021)

Figure 24. Digital elevation model of tailings pond



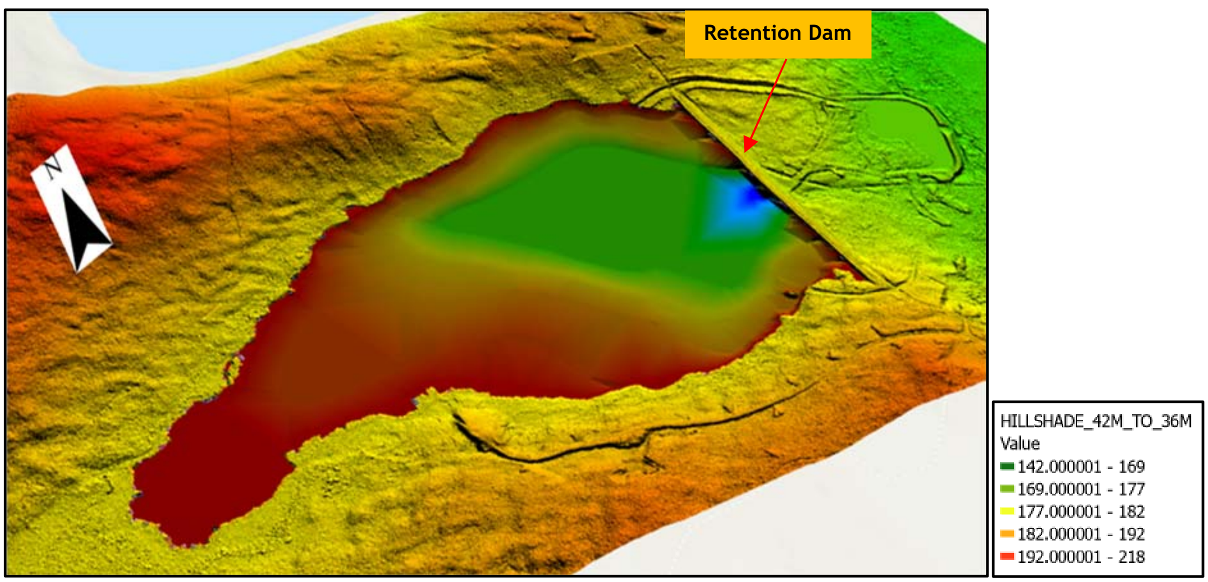
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 25. Topo-to-raster layer showing elevations of dry tailings *pond*



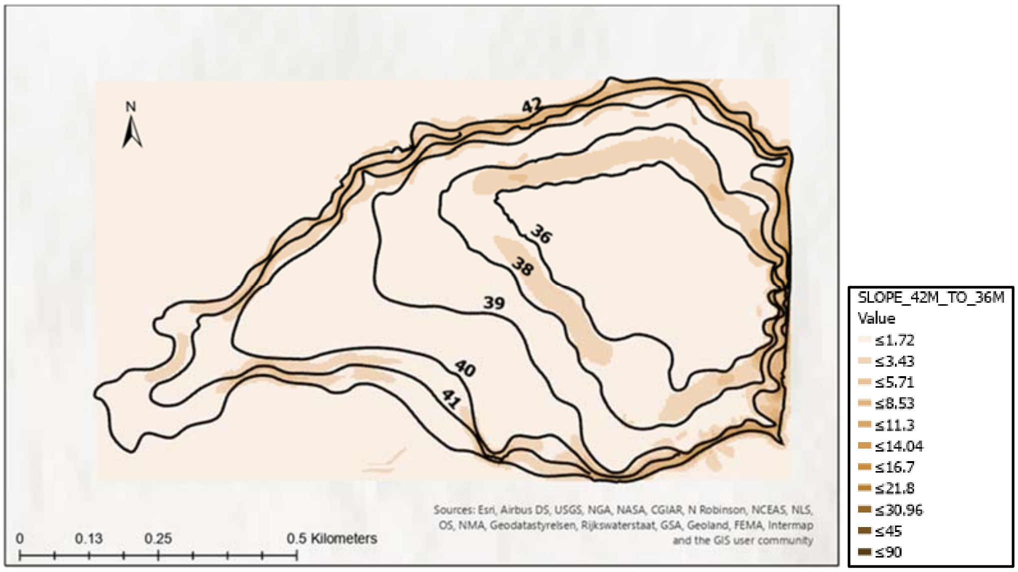
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 26. Shading (Hillshade) map of dry tailings pond



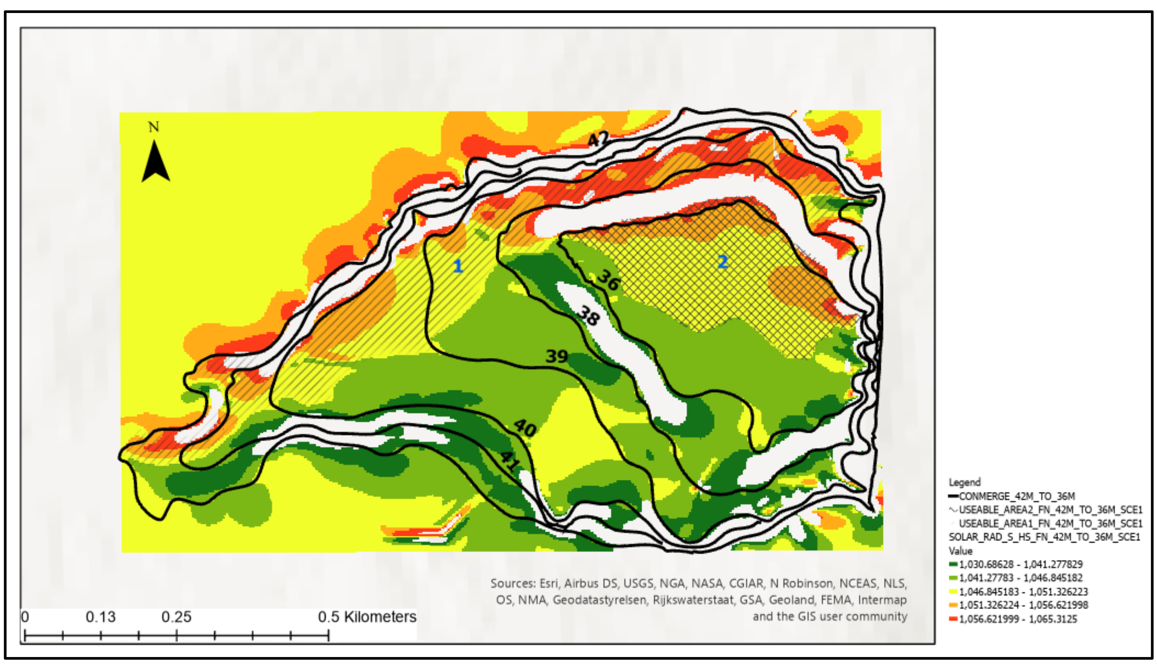
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 27. Slope map of dry tailings pond



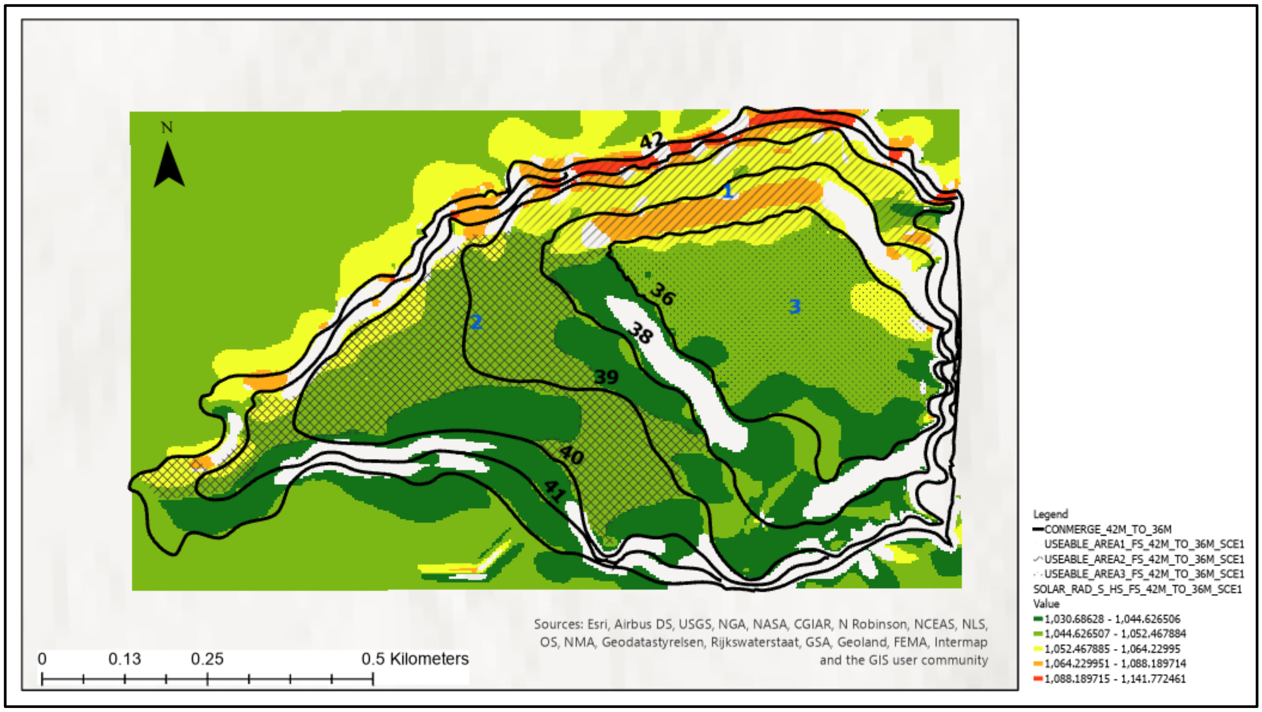
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 28. Solar radiation and useable areas for natural terrain-slope less than 1.72 degrees (North)



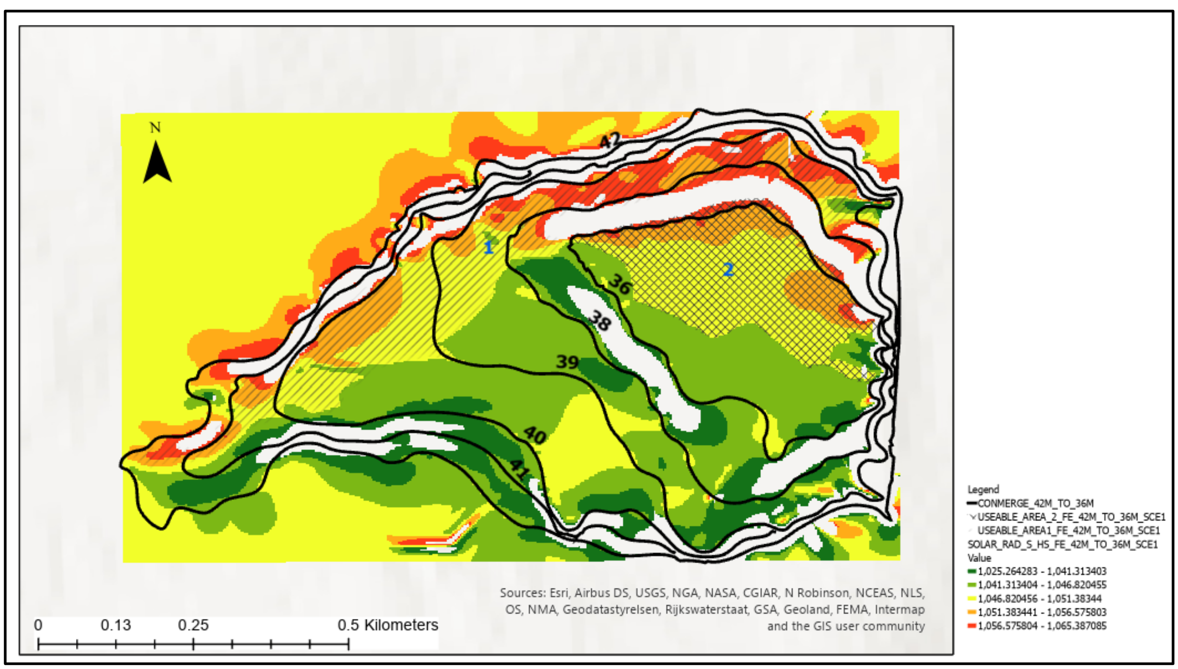
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 29. Solar radiation and useable areas for natural terrain-slope less than 1.72 degrees (South)



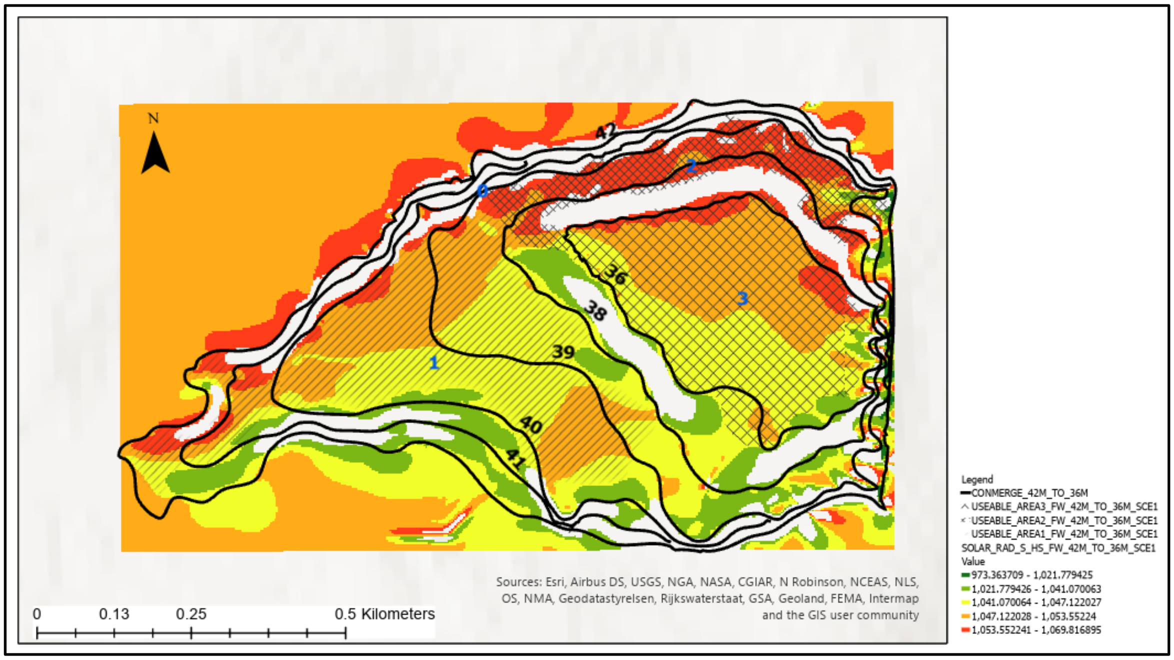
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 30. Solar radiation and useable areas for natural terrain-slope less than 1.72 degrees (East)



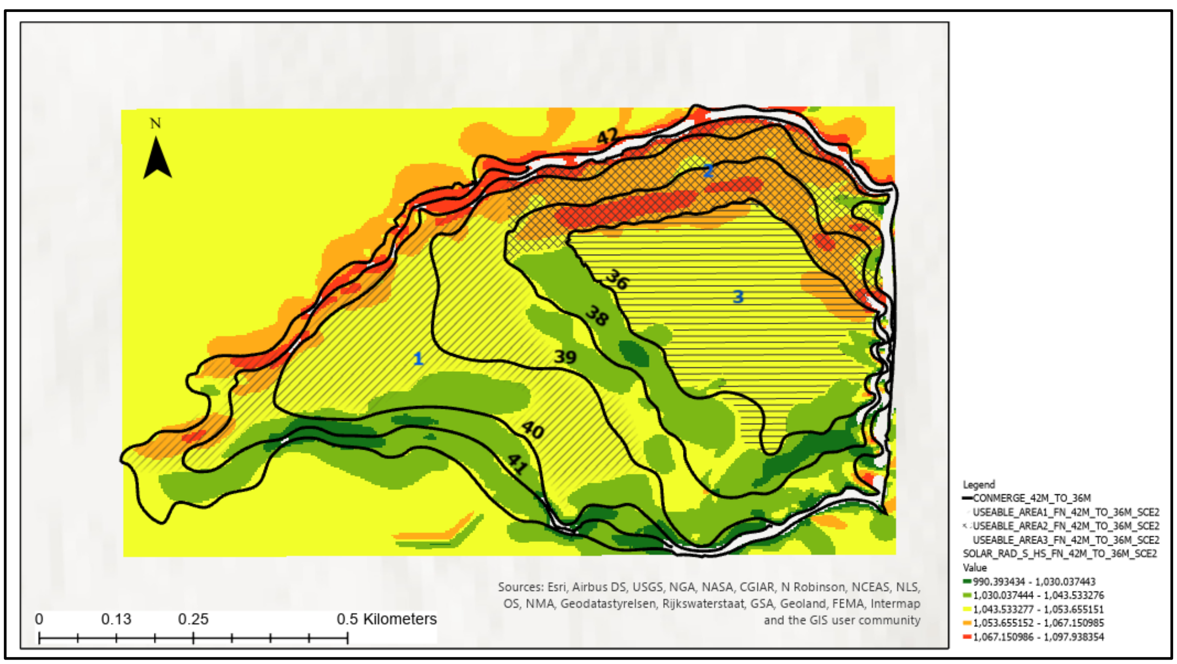
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 31. Solar radiation and useable areas for natural terrain-slope less than 1.72 degrees (West)



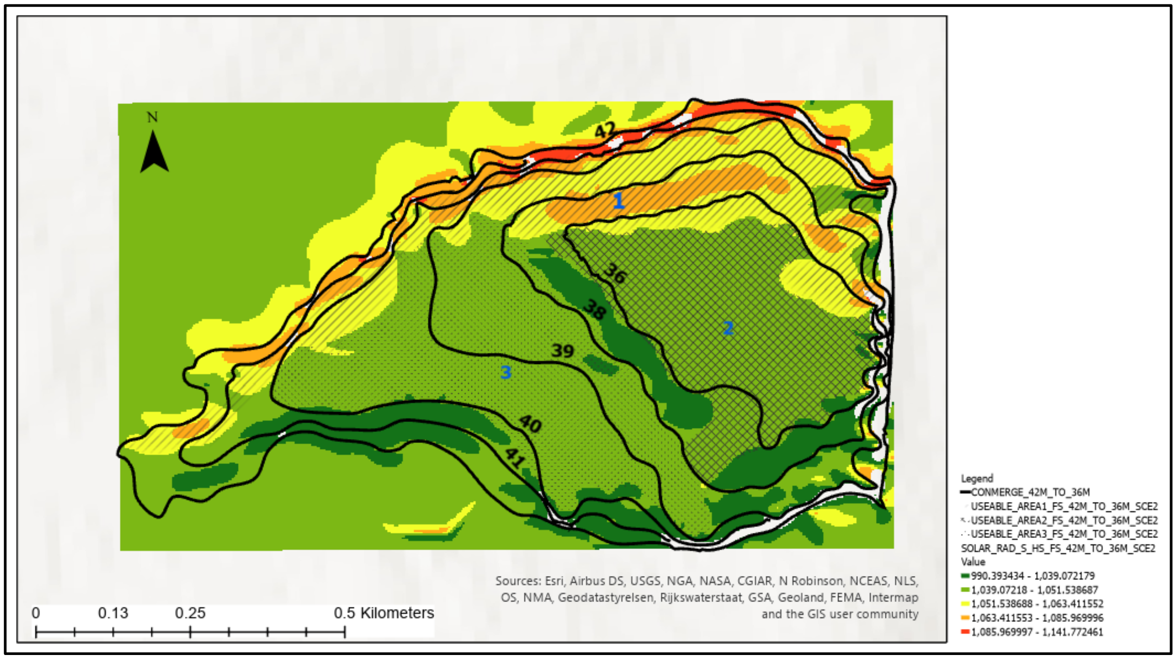
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 32. Solar radiation and useable areas for covered terrain-slope less than 5.72 degrees (North)



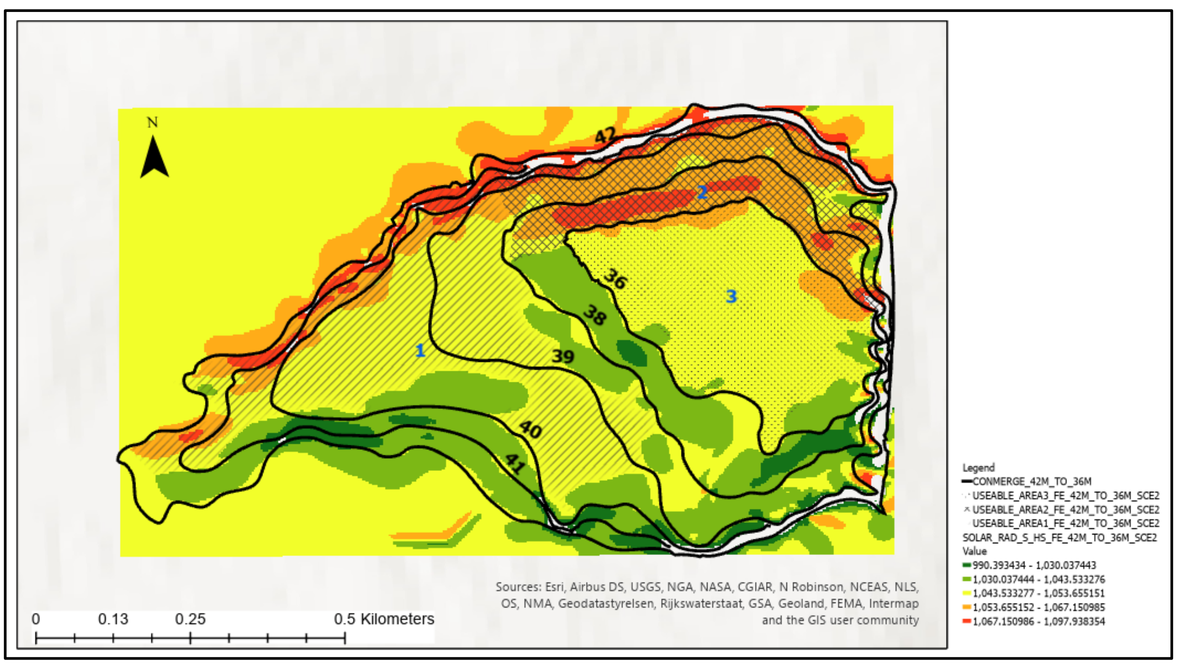
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 33. Solar radiation and useable areas for covered terrain-slope less than 5.72 degrees (South)



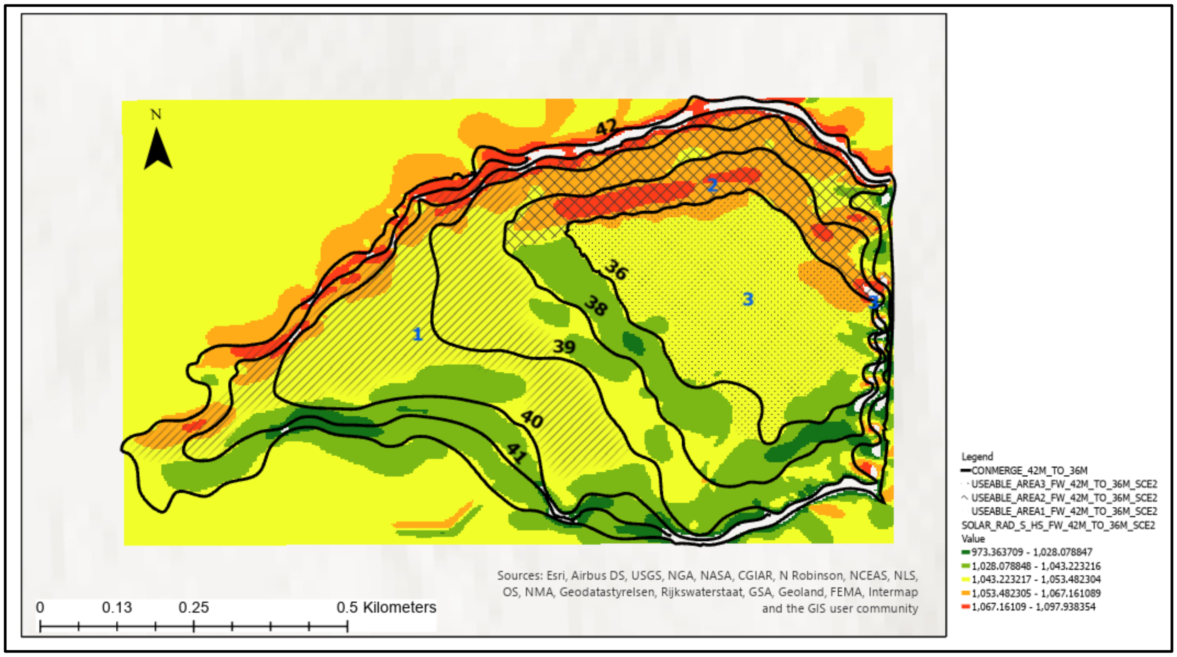
Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 34. Solar radiation and useable areas for covered terrain-slope less than 5.72 degrees (East)



Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 35. Solar radiation and useable areas for covered terrain-slope less than 5.72 degrees (West)



Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

A sensitivity analysis of varying PV module azimuth and PV tilt angles was conducted using ArcGIS and SAM to study the changes in the annual energy production output of the PV system, total solar radiation values and useable areas for PV installation.

The PV modules were orientated in 4 different directions-North, South, East and West. Modules facing North have an azimuth of greater than 22.5° and less than 337.5°. An average azimuth orientation angle of 0° was used in SAM to calculate the average energy production output. Modules facing South have an azimuth of greater than 157.5° and less than 202.5°. An average azimuth orientation angle of 180° was used in SAM to calculate the average energy output. East facing modules have an azimuth of greater than 67.5° and less than 112.5°. An average azimuth orientation angle of 90° was used in SAM to calculate the average energy output. Modules facing West have an azimuth of greater than 247.5° and less than 292.5°. An average azimuth orientation angle of 270° was used in SAM to calculate the average energy output. Average solar radiation values for the four different azimuth orientation angles for PV modules installed on the natural terrain topography with two different surface inclination angles of :1) Less than 1.72^o; and 2) Less than 5.71^o were calculated by ArcGIS. The natural terrain topography represents the surface of terrain of the dry tailings pond covered with sand and silt. Average solar radiation values were calculated in ArcGIS for the South facing azimuth orientation angle greater than 157.5^o and less than 202.5^o for PV modules installed on a covered terrain topography with two different surface inclination angles of: 1) Less than 1.72^o; and 2) Less than 5.71^o. The covered-terrain topography represents the surface of the dry tailings site installed with geomembranes. The objective in determining the area solar radiation values for two different slope inclination angles, 1.72^o and 5.71^o for both the natural-covered and geomembrane-covered terrains was to investigate whether there were any considerable differences in the solar irradiance values due to the differences in slope inclination angles.

Once the average solar radiation values have been determined for the PV modules orientated in 4 different directions-North, South, East and West, suitable areas for PV installation can be selected from the solar radiation map generated in ArcGIS. Areas with solar radiation values between 1,045 to 1,143 kWh/m^2 were determined to be suitable for PV installation. The boundaries for the selected areas were digitized in ArcGIS to create a shape file. A shapefile is an Esri vector data storage format for storing the location, shape, and attributes of geographic features (Esri, 2021). Once the boundary shape file has been created, it is used as an input raster layer in ArcGIS to calculate the mean area size. A “Zonal Statistics as Table” tool in ArcGIS was utilized to determine the average area size. The tool also shows the solar radiation value associated with the corresponding area. The solar radiation values and useable areas for PV installations for both the natural and covered terrain are shown in Figures 28 to 35.

3.2.3 Photovoltaic system design

From the energy demand assessment in Step #1, it was determined that the town of New Waterford has a total annual electricity consumption of 44,586,667 kWh/yr based on 3,520 households. The solar PV facility is to be designed to meet 25 percent of the total annual electricity consumption requirement which is 11,146,667 kWh/yr.

The solar radiation assessment of the Victoria Junction Tailings Dam (VJTD) mine tailings site determined in Step#2 was 1,056 kWh/m^2. The total land area required for installation of solar PV modules was determined to be 227,000 m^2 or 56 acres, the next step of the project scope, Step #3 is designing the capacity of the solar PV system to meet 25 percent of New Waterford's total annual electricity consumption requirement given the area and size of the mine tailings site suitable for PV installation. The preliminary design of the solar PV system involved determining the total power energy production capacities of the PV array, inverter and back-up battery storage system in using Excel based on the annual electricity consumption. The number of PV modules, inverters and batteries were determined based on the total power energy production capacities of the components. Table 5 shows the Victoria Junction Solar PV facility design and sizing calculations. These design parameters were entered into SAM to select the appropriate manufacturer and model for the PV module, inverter and battery units. Simulation runs were conducted in SAM using the selected component models to compare the total power energy production calculated in Excel.

Table 5. Victoria Junction Solar PV-Battery Storage facility design and sizing calculations

Solar PV Facility Design and Sizing Calculations		
Energy Demand Calculations		
Description	**Value**	**Units**
1. Total number of households in New Waterford	3,520	households
2. Annual energy demand per household	45.60	GJ/household
3. Convert to MWh	12.67	MWh/household
4. Annual energy demand for total number of households in New Waterford	44,587	MWh/yr
5. Convert to kWh	44,586,667	kWh/yr
6. 25% of annual energy demand for total number of households in New Waterford	**11,146,667**	kWh/yr
Solar Array Sizing Calculations		
Description	**Value**	**Units**
1. Derate factor	0.75	
2. Annual full sunlight hours for New Waterford	1,040.00	h
3. Daily full sunlight hours for New Waterford	2.71	h/dy
4. Power rating, P_{DC} (kW)	15,053.02	kW
5. Power rating, P_{DC} (W)	15,053,019.24	W
6. Nominal power rating of chosen module	448	W
7. Total number of modules needed	**33,601.00**	Modules
Battery Sizing Calculations		
Description	**Value**	**Units**
1. Total DC load	31,865.70	kWh/dy
2. Days of storage	3	dy
3. Usable storage capacity	95,597.10	kWh
4. Maximum depth of discharge, MDOD	80%	%
5. Temperature and discharge-rate factor, TDR	95%	%
6. Total storage capacity (kWh @ C/20, 25^{o}C)	125,785.66	kWh
7. Capacity of a single battery	4,184.00	kWh_{DC}
8. Total number of batteries required	**30**	Units
Inverter Requirement Calculations		
Description	**Value**	**Units**
1. Total inverter DC capacity (W_{DC})	25,565	W_{DC}
2. Total number of inverters required	**589**	Units

(Note: Shim, 2021)

The solar PV-battery storage grid-connected electricity power generation system was designed to meet 25% of the annual energy demand for 3,520 households in New Waterford which is 11,146,667 kWh per year. Based on this total energy consumption, it was determined that a solar array power output capacity of 15MW is required. The PV array and the battery were sized based on the assumption that the system includes a maximum power point tracker (MPPT) controller to allow the system to operate at its most efficient point during "peak" hours and during days of low sunlight hours. The MPPT controller was designed to handle a maximum voltage capacity of 1,000 V_{DC}. The annual AC energy production output of the 15MW system are shown in Table 9 and Figure 39.

For PV module design,

$$Power\ rating, P_{DC}\ (kW) = \frac{\%\ of\ Annual\ Energy\ Demand\ (kWh/yr)}{Derate * (h/dy\ full\ sun) * 365\ dy/yr} \quad (1)$$

$$Number\ of\ modules\ needed = \frac{Power\ rating,\ PDC\ \ (W)}{Nominal\ Power\ Rating\ of\ Chosen\ Module\ (W)} \quad (2)$$

For battery sizing design,

$$Total\ DC\ load = \frac{\%\ of\ Annual\ Energy\ Demand\ \left(\frac{kWh}{yr}\right)\ x\ \frac{1\ yr}{365\ dy}}{Inverter\ Efficiency\ x\ MPPT\ Controller\ Efficiency} \quad (3)$$

$$Useable\ storage\ Capacity\ (kWh) = Total\ DC\ load\ \left(\frac{kWh}{day}\right) x\ Days\ of\ storage\ (days) \quad (4)$$

$$Total\ storage\ capacity\ \left(kWh\ @\frac{C}{20}, 25^{O}C\right) = \frac{Usable\ storage\ capacity\ (kWh)}{(MDOD) x\ (T,DR)} \quad (5)$$

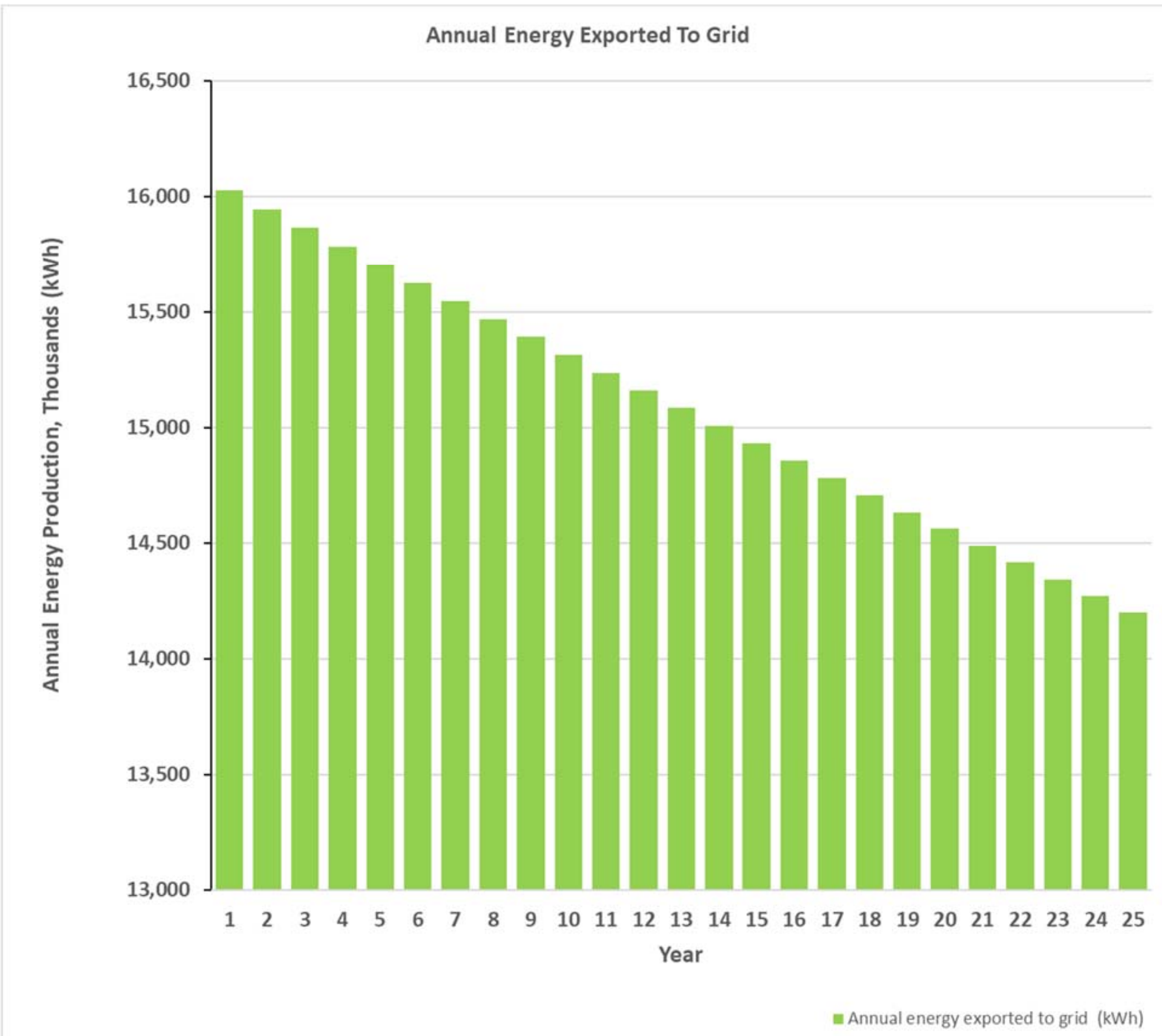
$$Number\ of\ batteries\ required = \frac{Total\ storage\ capacity\ (kWh)}{Capacity\ of\ a\ single\ battery\ (kWh)} \quad (6)$$

For inverter sizing design,

$$Number\ of\ inverters\ needed = \frac{Power\ rating,\ PDC\ \ (W)}{Total\ Inverter\ DC\ Capacity\ (W)} \quad (7)$$

The derate factor represents the amount of reduction in electricity generated after all losses in the solar PV system are taken into consideration. The maximum depth of discharge (MDOD) is the percentage of the battery that could be discharged relative to the overall capacity of the battery without freezing the electrolyte when exposed to potential freeze problems.

Figure 36. Annual energy production output for 15MW solar-PV system



Note: Figure developed by (Shim, 2021); Data from SAM (NREL, 2020a)

Table 6. Annual energy production output for 15MW solar-PV system

Annual energy exported to grid	
Year	Annual energy production
	(kWh)
1	16,024,600
2	15,944,100
3	15,864,000
4	15,784,300
5	15,704,900
6	15,626,000
7	15,547,400
8	15,469,300
9	15,391,500
10	15,314,100
11	15,237,100
12	15,160,400
13	15,084,200
14	15,008,300
15	14,932,800
16	14,857,600
17	14,782,900
18	14,708,500
19	14,634,500
20	14,560,800
21	14,487,600
22	14,414,700
23	14,342,100
24	14,269,900
25	14,198,100

Note: Table developed by (Shim, 2021); Data from SAM (NREL, 2020a)

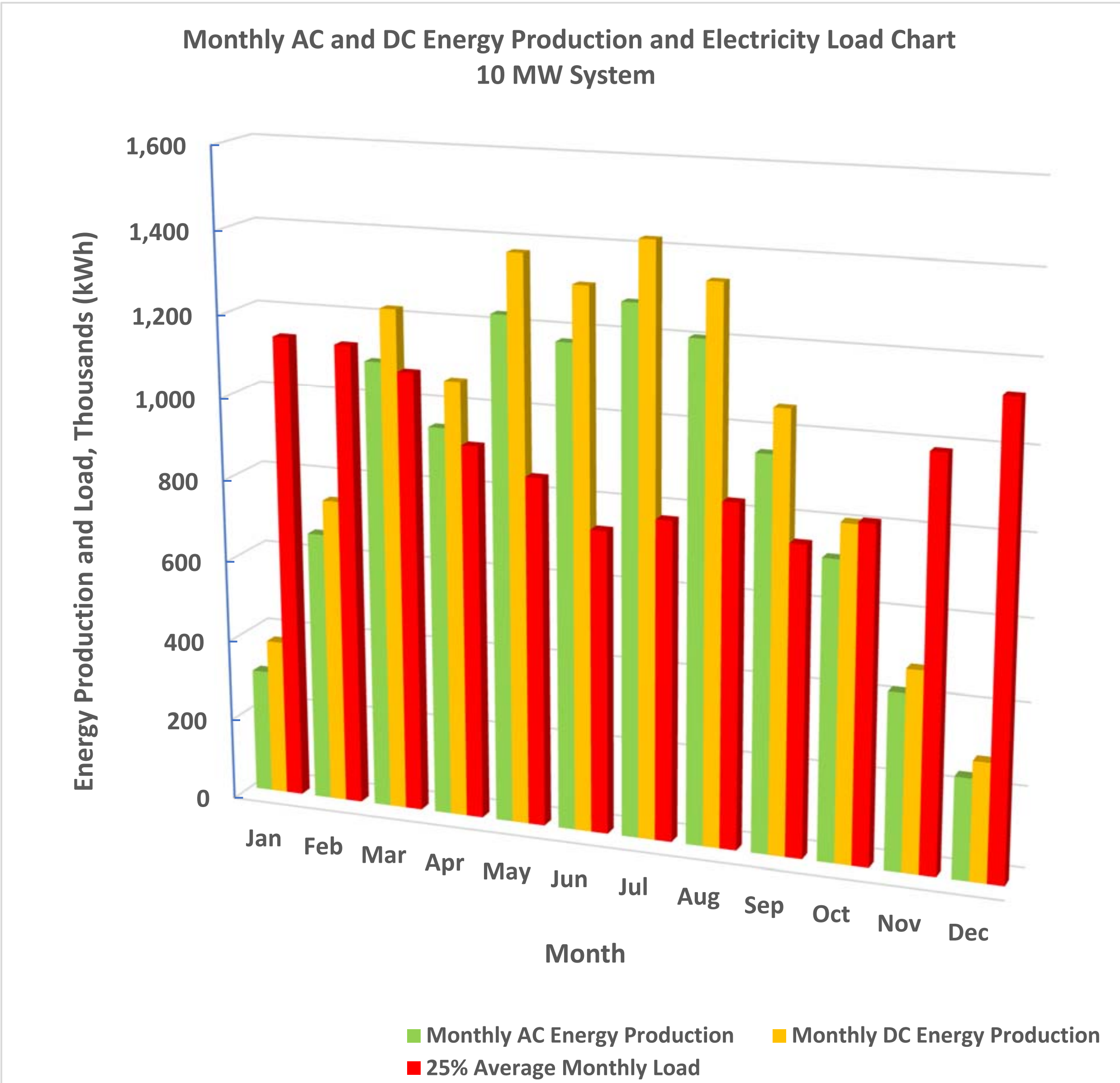
3.2.4 Power Production System Analysis

Table 7. Monthly energy production for 10MW solar-PV system and electricity load

Power Capacity			10MW					
Month	Average Monthly Total Load	25% Average Monthly Total Load	System Monthly Energy Production AC energy	System Monthly Energy Production DC energy	Shortfall AC Energy	Shortfall DC Energy	Percent of Monthly AC Electricity Covered	Percent of Monthly DC Electricity Covered
	kWh	kWh	kWh/mo	kWh/mo	kWh/mo	kWh/mo	%	%
Jan	4,569,890	1,142,473	302,287	383,484	-840,186	-758,989	26	34
Feb	4,536,388	1,134,097	666,289	750,334	-467,808	-383,763	59	66
Mar	4,320,793	1,080,198	1,099,680	1,228,520	19,482	148,322	100	100
Apr	3,665,352	916,338	953,307	1,067,380	36,969	151,042	100	100
May	3,415,186	853,796	1,233,970	1,378,860	380,174	525,064	100	100
Jun	2,972,434	743,108	1,180,510	1,315,200	437,402	572,092	100	100
Jul	3,124,251	781,063	1,283,670	1,428,580	502,607	647,517	100	100
Aug	3,352,365	838,091	1,212,080	1,344,080	373,989	505,989	100	100
Sep	3,025,937	756,484	957,917	1,066,370	201,433	309,886	100	100
Oct	3,278,031	819,508	729,447	815,092	-90,061	-4,416	89	99
Nov	3,982,334	995,583	429,810	488,296	-565,773	-507,287	43	49
Dec	4,536,919	1,134,230	246,203	288,681	-888,027	-845,549	22	25
Total	**44,779,878**	**11,194,970**	**10,295,170**	**11,554,877**	**-899,800**	**359,907**	**78**	**81**

(Note: Shim, 2021)

Figure 37. Monthly energy production for 10MW system and electricity load chart



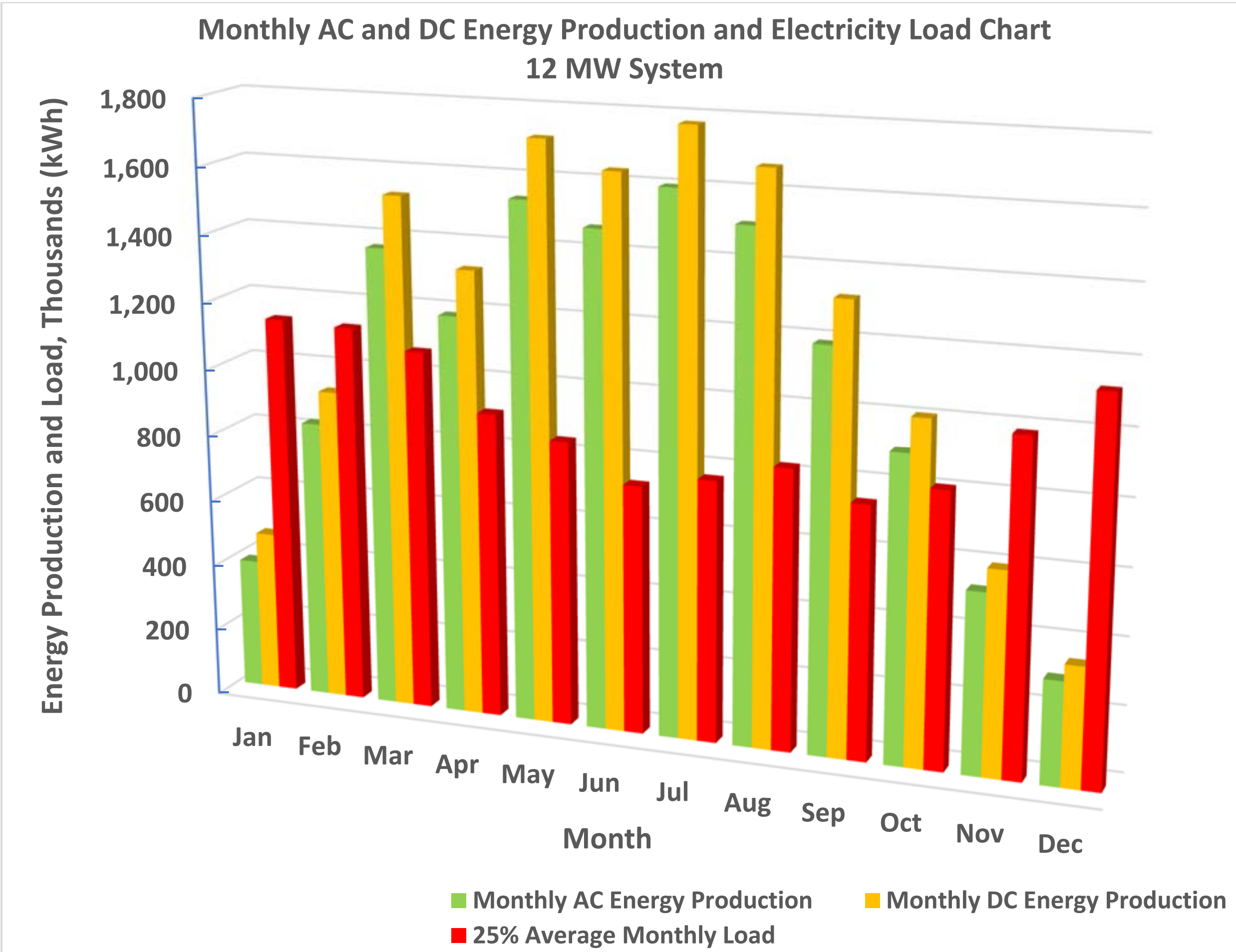
(Note: Shim, 2021)

Table 8. Monthly energy production for 12MW solar-PV system and electricity load

Power Capacity			12MW					
Month	**Average Monthly Total Load**	**25% Average Monthly Total Load**	**System Monthly Energy Production AC energy**	**System Monthly Energy Production DC energy**	**Shortfall AC Energy**	**Shortfall DC Energy**	**Percent of Monthly AC Electricity Covered**	**Percent of Monthly DC Electricity Covered**
	kWh	**kWh**	**kWh/mo**	**kWh/mo**	**kWh/mo**	**kWh/mo**	**%**	**%**
Jan	4,569,890	1,142,473	388,667	478,738	-753,806	-663,735	34	42
Feb	4,536,388	1,134,097	835,767	936,716	-298,330	-197,381	74	83
Mar	4,320,793	1,080,198	1,377,290	1,533,680	297,092	453,482	100	100
Apr	3,665,352	916,338	1,194,460	1,332,520	278,122	416,182	100	100
May	3,415,186	853,796	1,545,460	1,721,360	691,664	867,564	100	100
Jun	2,972,434	743,108	1,477,630	1,641,890	734,522	898,782	100	100
Jul	3,124,251	781,063	1,606,440	1,783,440	825,377	1,002,377	100	100
Aug	3,352,365	838,091	1,515,810	1,677,950	677,719	839,859	100	100
Sep	3,025,937	756,484	1,198,830	1,331,250	442,346	574,766	100	100
Oct	3,278,031	819,508	913,518	1,017,560	94,010	198,052	100	100
Nov	3,982,334	995,583	539,929	609,587	-455,654	-385,996	54	61
Dec	4,536,919	1,134,230	311,062	360,388	-823,168	-773,842	27	32
Total	**44,779,878**	**11,194,970**	**12,904,863**	**14,425,079**	**1,709,893**	**3,230,109**	**82**	**85**

(Note: Shim, 2021)

Figure 38. Monthly energy production for 12MW system and electricity load chart



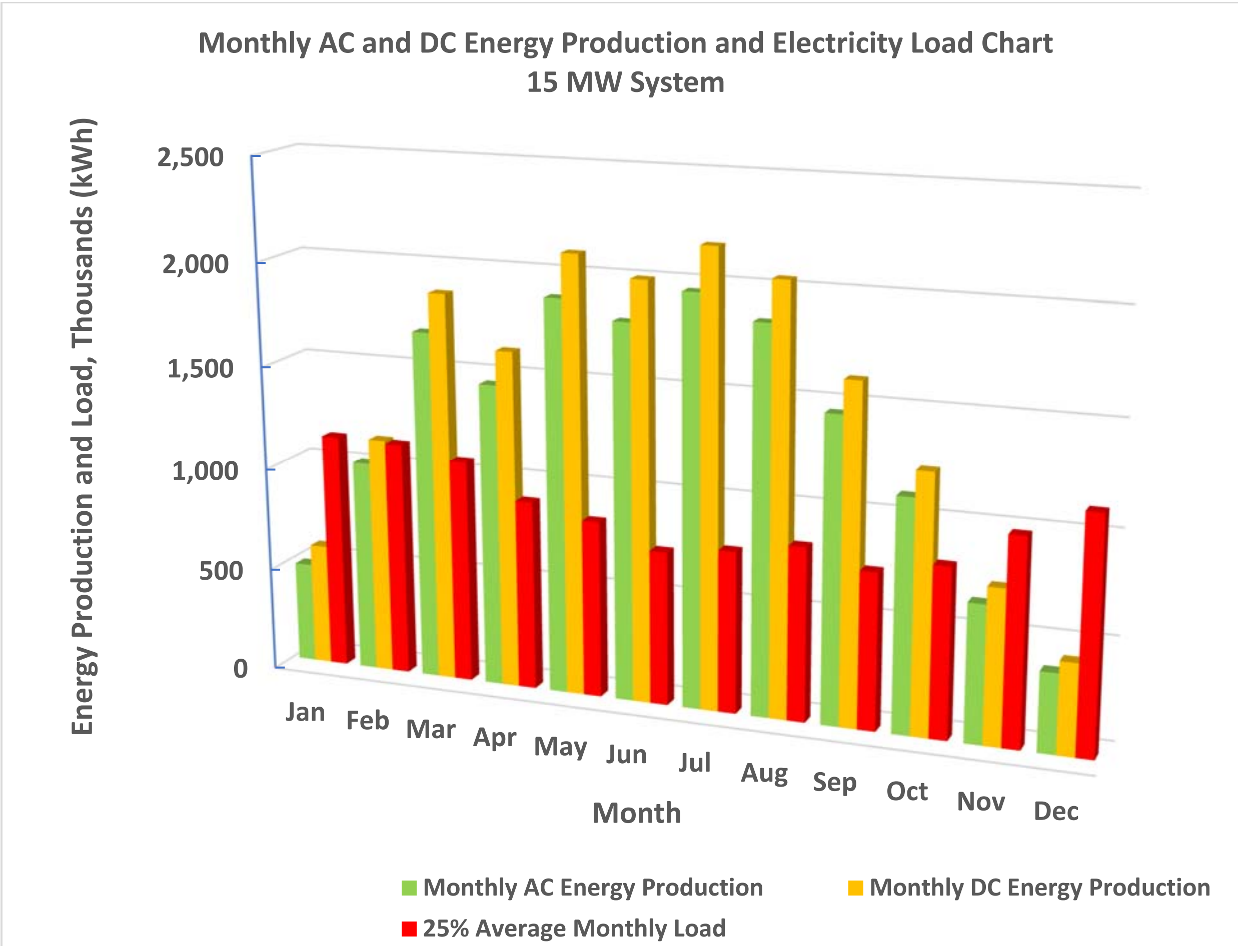
(Note: Shim, 2021)

Table 9. Monthly energy production for 15MW solar-PV system and electricity load

Power Capacity			15MW					
Month	**Average Monthly Total Load**	**25% Average Monthly Total Load**	**System Monthly Energy Production AC energy**	**System Monthly Energy Production DC energy**	**Shortfall AC Energy**	**Shortfall DC Energy**	**Percent of Monthly AC Electricity Covered**	**Percent of Monthly DC Electricity Covered**
	kWh	**kWh**	**kWh/mo**	**kWh/mo**	**kWh/mo**	**kWh/mo**	**%**	**%**
Jan	4,569,890	1,142,473	485,669	586,200	-656,804	-556,273	43	51
Feb	4,536,388	1,134,097	1,026,500	1,146,990	-107,597	12,893	91	100
Mar	4,320,793	1,080,198	1,690,070	1,877,960	609,872	797,762	100	100
Apr	3,665,352	916,338	1,465,950	1,631,640	549,612	715,302	100	100
May	3,415,186	853,796	1,896,280	2,107,770	1,042,484	1,253,974	100	100
Jun	2,972,434	743,108	1,812,190	2,010,460	1,069,082	1,267,352	100	100
Jul	3,124,251	781,063	1,969,950	2,183,780	1,188,887	1,402,717	100	100
Aug	3,352,365	838,091	1,857,890	2,054,610	1,019,799	1,216,519	100	100
Sep	3,025,937	756,484	1,470,060	1,630,090	713,576	873,606	100	100
Oct	3,278,031	819,508	1,120,610	1,245,980	301,102	426,472	100	100
Nov	3,982,334	995,583	663,578	746,424	-332,005	-249,159	67	75
Dec	4,536,919	1,134,230	383,668	441,285	-750,562	-692,945	34	39
Total	**44,779,878**	**11,194,970**	**15,842,415**	**17,663,189**	**4,647,445**	**6,468,219**	**86**	**89**

(Note: Shim, 2021)

Figure 39. Monthly energy production for 15MW system and electricity load chart

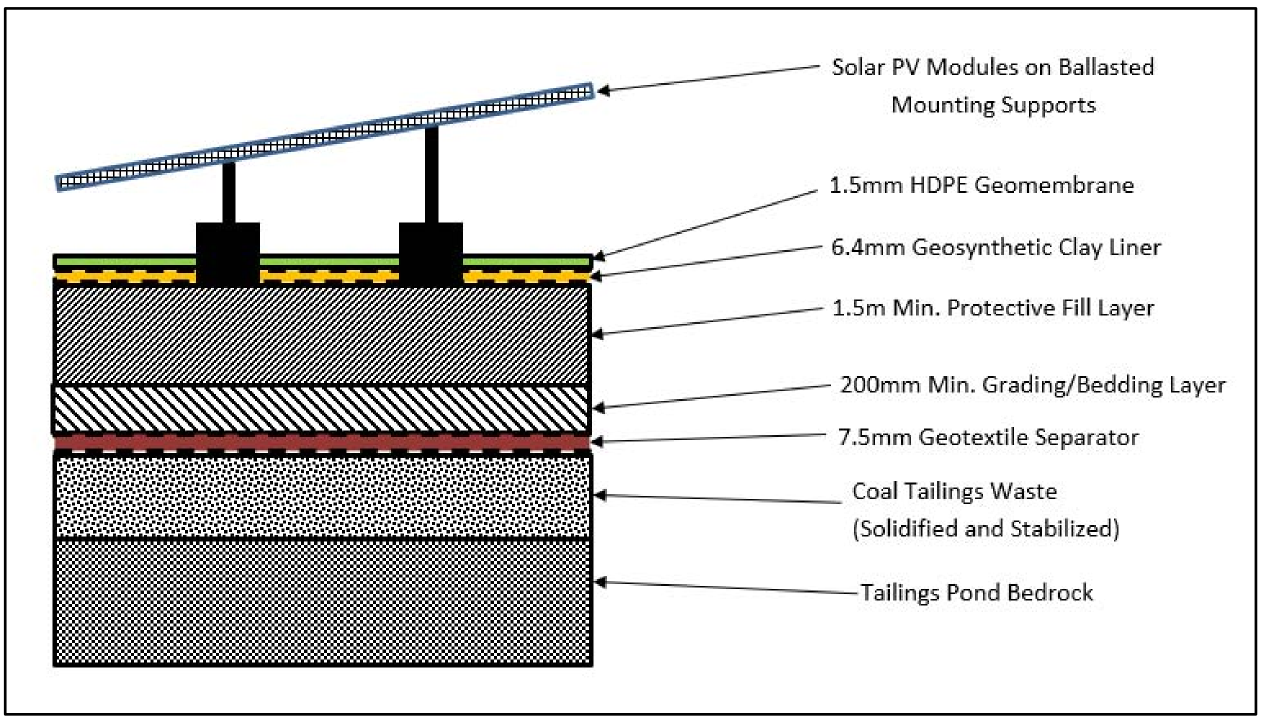


(Note: Shim, 2021)

In order to determine the appropriate sizing capacity of the solar-PV system, a sensitivity analysis was conducted to determine the annual energy production output for a 10MW, 12MW and 15MW solar-PV system. The annual AC and DC energy production output for the three different solar-PV system capacities were calculated using SAM. The monthly AC and DC energy production for a 10MW, 12MW and 15MW solar-PV system were compared to 25 percent of the average monthly electricity consumption for New Waterford. Table 7, Table 8 and Table 9 shows the monthly electricity load data, and energy production output (AC and DC) data for a 10MW, 12MW and 15MW solar-PV system respectively. Figure 37, Figure 38 and Figure 39 shows the monthly electricity load data, and energy production output (AC and DC) graphs for a 10MW, 12MW and 15MW solar-PV system respectively.

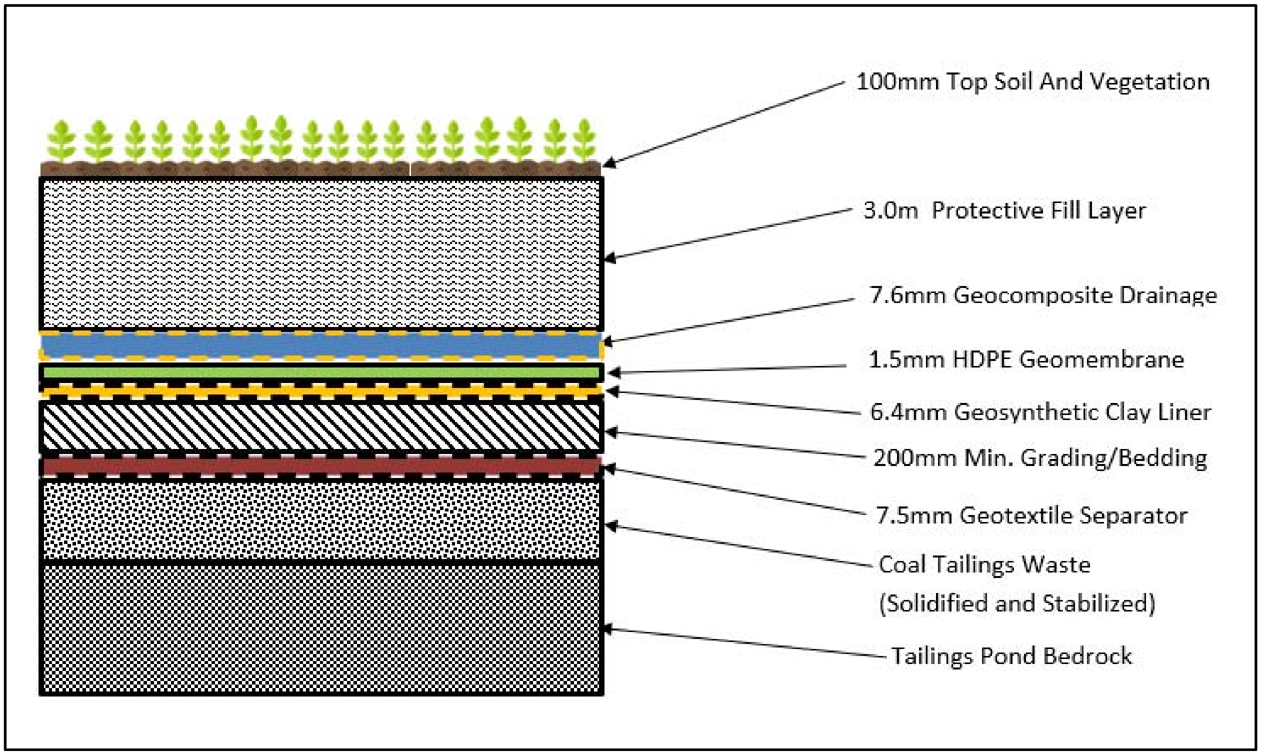
3.2.5 Site Remediation Design

Figure 40. Solar-PV geomembrane remediation method design cross sectional profile



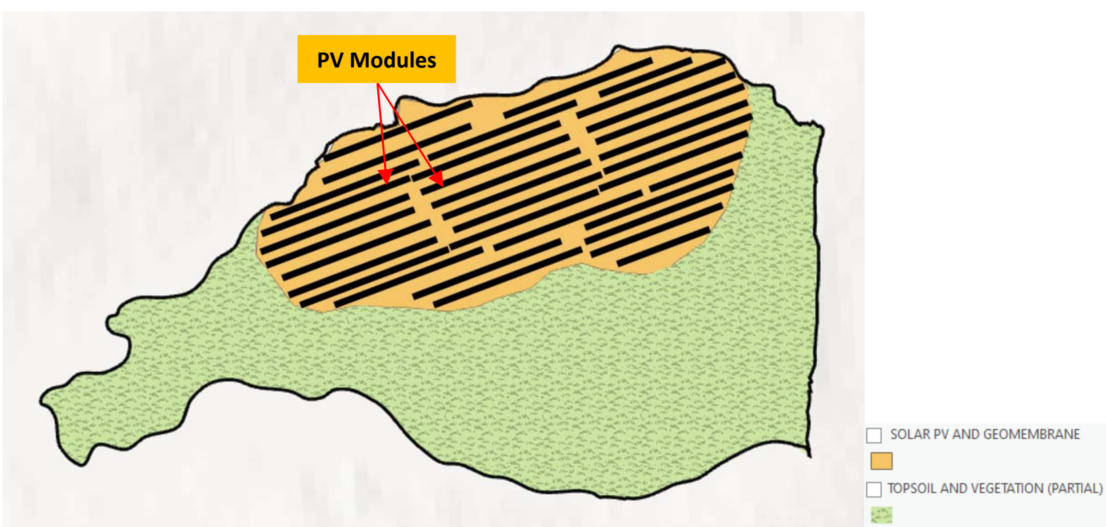
(Note: Shim, 2021)

Figure 41. Traditional remediation method design cross sectional profile



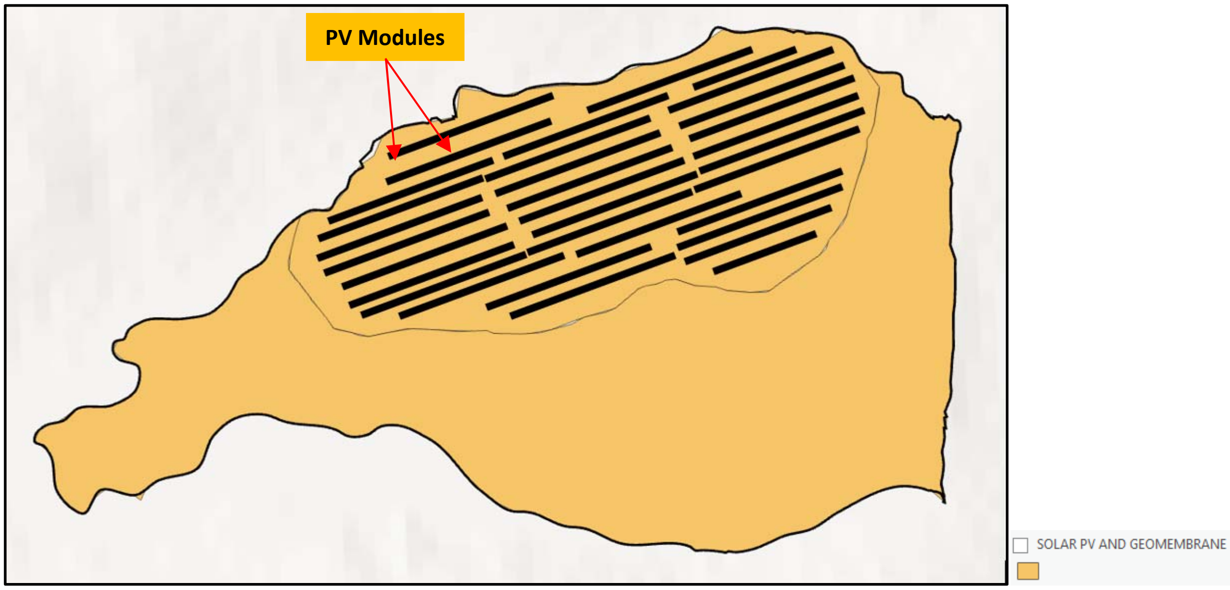
(Note: Shim, 2021)

Figure 42. Option#1 Solar-PV geomembrane and traditional remediation method layout



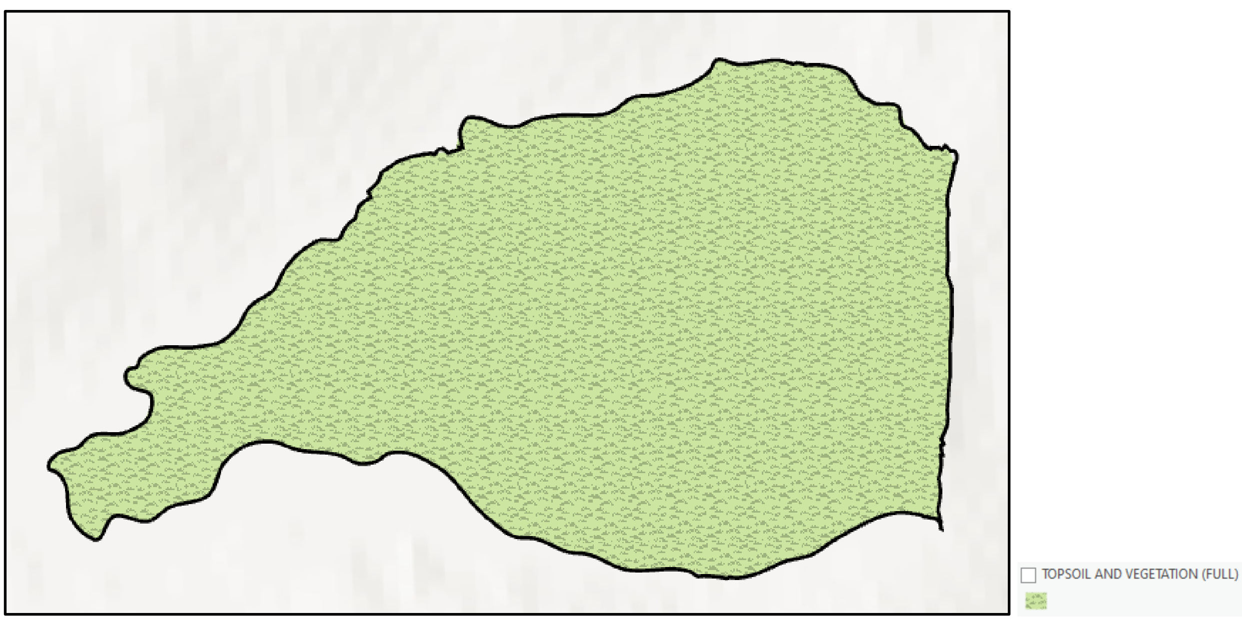
Note: (Shim, 2021); Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 43. Option#2 Solar-PV geomembrane remediation method layout



Note: (Shim, 2021); Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 44. Option#3 Traditional remediation method layout



Note: (Shim, 2021); Developed from ArcGIS (ArcGIS Pro, 2020)

There are two site remediation design proposed for this project. The two site remediation designs are:

3.2.5.1 Design#1 Solar-PV geomembrane remediation method

Figure 40 shows a cross sectional profile of a solar-PV geomembrane remediation design. This method consists of solar PV modules, geomembranes, geosynthetic clay liners, protective soil cover, bedding sand and geotextile separators placed on top of solidified and stabilized coal tailings waste. The design for the geosynthetic protective layers, soil cover and soil bedding layer was based on the Sydney Tar Ponds remediation project in Cape Breton, Nova Scotia (AECOM, 2014).

The solar PV modules installed on ballasted galvanized steel ground mounting structures with a layer of high density polyethylene (HDPE) geomembrane and geosynthetic clay liner placed underneath the geomembrane. It was recommended by the supplier that the solar PV ballasted mounting structures not be placed directly on top of the geomembrane to reduce mechanical load stresses on the polyethylene liner to prevent damage. Therefore, the HDPE geomembrane and geosynthetic clay liner are installed in between the concrete ballasted supports. The ballasted PV ground mounting support consists of light-weight galvanized steel railings on concrete blocks. The ground mounting support that will be used for the site will be the SunRack SFS-GM-03 model. The SunRack model can withstand a maximum wind speed of up to 60 m/s and snow load of 1.4 KN/m^2. Appendix D shows the technical specifications for the ballasted PV module ground mounting support. The geomembranes and the geosynthetic clay liners will be attached to the ballasted supports using concrete anchor screws and aluminum batten plates with neoprene gaskets and silicone caulking sealants. The size of each anchor bolt will be 3/8 in. X 3 in. spaced at 8 in. centre-to-centre. The size of each aluminum batten plate will be 3/8 in. X 1-3/4 in. The size of each neoprene gasket is 1-3/4 in. X ¼ in. The geomembranes and the geosynthetic clay liners will be secured to the ground by constructing anchor trenches with soil backfill. A 24 in. X 24 in. (610mm X 610mm) trench will be excavated around the perimeter of the solar PV installation boundary area. The geomembranes and the geosynthetic clay liners will be placed inside the trench and backfilled with protective soil.

Anchor trenches will also be constructed within the solar PV installation boundary area spaced at 100m apart to provide additional reinforcements to secure the geomembranes and the geosynthetic clay liners to the ground. A Solmax 1.50mm white reflective textured high-density polyethylene (HDPE) geomembrane will be installed on the surface as the topmost protective cover. A white HDPE is used to eliminate the thermal expansion and contraction that may occur due to temperature changes caused by seasonal weather, and to reducing stresses on the geomembrane. A white reflective surface has an added advantage of increasing the reflected solar irradiance onto the solar PV panels. The textured surface adds a factor of safety by increasing friction coefficients. Appendix E shows the technical specifications for the white-textured Solmax HDPE geomembrane. The geosynthetic clay liner (GCL) used is the 3.66 kg/m^2 Solmax Bentoliner Series. It is made of a uniform layer of sodium bentonite sandwiched between a woven and a nonwoven geotextile that is needle-punched together to create a composite structural waterproofing membrane. The GCL is placed underneath the geomembrane to act as leak protection and waterproofing layer. In the event that the HDPE geomembrane is punctured, the GCL also serves as a secondary leak protection layer by plugging the hole in the geomembrane. Appendix F shows the technical specifications for the Solmax Bentoliner GCL Series. Below the geomembrane and geosynthetic clay liner, is a layer of protective soil cover with a minimum of 1.50m depth followed by a layer of grading sand with a minimum thickness of 200mm. The bedding sand serves as a grading layer so that the HDPE geomembrane and the GCL is placed on a uniform levelled surface to reduce mechanical load stresses on the liners. A geotextile separator is placed on top of the solidified and stabilized coal tailings waste. The type of geotextile separator used is the 270.00 g/m^2 Environmental Geotextile Series. The non-woven needle-punched geotextile is made of high quality polypropylene staple fiber to act as a filter, drainage and a protective layer against soil contamination from the tailings waste. Appendix H shows the technical specifications for the Solmax Geotextile Series. The geomembrane panels are seamed together in the field using a heat fusion welding method with a minimum overlap length of 4.0 in. (10.16 cm). After the installation of the geomembranes are completed, the panels are pressure tested using an air pump to detect any leaks in the geomembranes and the seams between the panels.

3.2.5.2 Design#2 Traditional remediation method

Figure 41 shows a cross sectional profile of a traditional remediation design method. This method consists of topsoil and vegetation at the surface, protective soil cover, geocomposite drainage layers, geomembranes, geosynthetic clay liners, bedding sand, geotextile separators placed on top of solidified and stabilized coal tailings waste (Devita et al., 2017). The depth for the topsoil at the surface will be approximately 100mm. Vegetation includes grass and trees/shrubs. A layer of protective soil cover is placed under the topsoil and vegetation. A depth of 3m of protective soil cover is provided to allow room for the growth of roots from the trees/shrubs preventing damage to the geomembranes and geosynthetic clay liners installed underneath the vegetative topsoil layer from roots puncturing the liners. A Solmax MineDrain geocomposite drainage liner is installed below the protective soil layer for leak detection and water flow diversion purposes. The engineered geocomposite drainage liner has high strength and hydraulic transmittivity properties to serves as a drainage system. The MineDrain geocomposite drainage liner has a hydraulic transmittivity rate of 2.16 x 10^{-3} m^2/s (Solmax, 2021c). Transmissivity is the flow of water within the plane of a geosynthetic over a period of time measured in m^2/s. It is calculated by the flow rate, or volume of water per unit of time through the sample, divided by the hydraulic gradient and the width of the specimen (Dynamic CPD, 2017). The use of the MineDrain geocomposite drainage liner will imply that stone gravel is not required to be mixed in the protective soil layer as is commonly used in conventional mine tailings remediation sites. The drainage layer will replace the stone gravel completely at a lower cost. The MineDrain geocomposite drainage liner consists of a lower and upper geotextile separator attached to it and will act as a cushion to protect the HDPE geomembrane and geosynthetic clay liner installed beneath it from punctures potentially damaging the liners. The advantage of the geocomposite drainage liner is that it has the hydraulic transmittivity rate that exceeds a conventional stone gravel layer. Due to its high transmittivity properties, it has the ability to divert the flow of storm water away from the tailings effectively under high overburden stress loads. Appendix G1 and G2 shows the technical specifications for the Solmax Minedrain geocomposite drainage liner. A Solmax 1.50mm black textured high-density polyethylene (HDPE) geomembrane will be installed under the MineDrain geocomposite drainage liner. The textured surface adds a factor of safety by increasing friction coefficients. Appendix I shows the technical specifications for the black-textured Solmax HDPE geomembrane. The geosynthetic clay liner (GCL) used is the 3.66 kg/m^2 Solmax Bentoliner Series similar to Design#1-Solar PV geomembrane remediation method. The GCL is placed underneath the geomembrane to act as leak protection and waterproofing layer. In the event that the HDPE geomembrane is punctured, the GCL also serves as a secondary leak protection layer by plugging the hole in the geomembrane. Appendix F shows the technical specifications for the Solmax Bentoliner GCL Series. A layer of bedding sand with a minimum thickness of 200mm is placed below the geosynthetic clay liner so that the HDPE geomembrane and the GCL is placed on a uniform levelled surface to reduce mechanical load stresses on the liners. A geotextile separator is placed on top of the solidified and stabilized coal tailings waste. The type of geotextile separator used is the 270.00 g/m^2 Environmental Geotextile Series similar to Design#1-Solar PV geomembrane remediation method. Appendix H shows the technical specifications for the Solmax Geotextile Series. The geomembrane panels are seamed together in the field using a heat fusion welding method with a minimum overlap length of 4.0 in. (10.16 cm). After the installation of the geomembranes are completed, the panels are pressure tested using an air pump to detect any leaks in the geomembranes and the seams between the panels.

There are three different site remediation options proposed for this project. The remediation options are:

a) Option#1 Solar-PV geomembrane and traditional remediation method

Figure 42 shows a plan view layout of the combination of the solar-PV geomembrane and traditional remediation methods. This method involves the installation of solar PV modules on ballasted galvanized steel ground mounting structures with partial geomembrane cover and partial topsoil/vegetative cover on the surface of the remediated site.

b) Option#2 Solar-PV geomembrane method

Figure 43 shows a plan view layout of the solar-PV geomembrane remediation method. This method involves the installation of PV modules on ballasted galvanized steel support structures with geomembrane cover on the entire surface of the remediated site.

c) Option#3 Traditional remediation method

Figure 44 shows a plan view layout of the traditional remediation method. This method does not involve the installation of solar PV modules and therefore has no energy production output. The entire surface of the remediated site will be covered with topsoil and vegetation such as grass and trees/shrubs. The traditional remediation method alone will be considered as the baseline scenario to compare the economics, annual energy production output and greenhouse gas (GHG) emissions reductions of Option#1 and Option#2.

3.2.6 System Structural Integrity Assessment

The installation of 33,600 solar PV modules on the mine tailings site require a thorough understanding of the geotechnical properties of the mine tailings to assess the structural integrity of the bedrock. Geotechnical stability will need to be taken into consideration to design appropriate mounting systems to support the solar PV panels (Annavarapu et al., 2009).

The characteristics of the Victoria Junction mine tailings consist of mainly sand and silt of various grain sizes. Underlying the peat and tailings in the pond is a silty sand and gravel till which varies from approximately 2.4 m to 4.3 m minimum thickness (Jacques, Whitford and Associates Ltd., 1993). These deposits consist of Carboniferous clastic rocks of the Morien Group. The Morien Group consists of sandstones, mudstones, conglomerates and coal measures. The vane (undrained) shear strength of the tailings ranges from 2.15 kPa to 43.1 kPa (Jacques, Whitford and Associates Ltd., 1993). The shear strength of finer tailings ranges from 2.39 kPa to 7.18 kPa while that of the coarser tailings range from 4.79 kPa to 19.2 kPa (Jacques, Whitford and Associates Ltd., 1993). The total removal of tailings water from the tailings pond for the purpose of remediating the site would lower the hydraulic gradient around the retention dam and improve slope stability thereby decreasing the risks of a dam failure. Dam safety review reports by ADI Ltd., JWA (Jacques, Whitford and Associates Ltd.) and AMEC from 1998 to 2008 indicated no apparent cracks or differential settlement occurring at the retention dam.

The weight of the PV modules and the ballasted ground mounting support structure must be taken into consideration when determining the load bearing capacity of the underlying tailings and bedrock. The PV module selected for this project is the SunPower Maxeon SPR-A450W-COM model. The average weight of each module is 21.6 kg (SunPower, 2021). The technical data specifications for the SunPower Maxeon SPR-A450W-COM model are shown in Appendix A1 and A2. The PV mounting system will be fixed tilt orientated which is lighter weight than the single and double axis sun-tracking systems. The ballasted PV mounting support system was selected for this project because it is of lighter weight than the concrete slab option. The slab option consists of PV mounting supports placed on a slab of concrete that is typically 4 in. to 6 in thick in the center (Chowdhury, 2021). Reinforced steel bars are laid at equal spacing placed inside the slab to prevent the cement from cracking due to compressive stresses. The concrete is poured directly on top of the reinforced steel bars all at one time.

The PV mounting support system selected for this project is the Sunrack SFS-GM-03 model (Sunforson, 2021). The mounting support railings are made of light weight carbon steel. The average weight for each of the Sunrack support system is between 20 kg to 25 kg. The technical data specifications for the Sunrack SFS-GM-03 model are shown in Appendix D. The weight of the PV modules and the mounting supports are not expected to exert large stresses on the tailings and subsequently will not create any significant bearing capacity issues as the tailings are solidified and stabilized. Due to the light weight carbon steel railings and its lower weight advantage of the ballasted concrete footings over the concrete slab option, the Sunrack SFS-GM-03 model was selected to be the PV mounting support system.

The effects of wind loading and accumulation of snow can increase the stress exerted to the mounting supports and increase the weight placed on the solar PV modules (Sampson, 2009). The SunPower Maxeon SPR-A450W-COM PV modules are designed to resist wind loads of 3,500 Pa or 357 kg/m^2 and snow loads of 6,000 Pa or 612 kg/m^2 respectively (SunPower, 2021). The Sunrack SFS-GM-03 ballasted mounting support system are designed to resist maximum wind speeds of up to 60 m/s and snow loads of up to 1.4 kN/m^2 (Sunforson, 2021). The highest “1-in-50 year” wind speed recorded in Nova Scotia in recent years is 150 km/h (42 m/s) (Wikipedia, 2021b). Therefore, wind loading on the PV mounting support system is not expected to cause any potential issues. Snow loading on PV modules can increase the weight placed on the PV modules and mounting support system especially when the structure is installed on the mine tailings side slopes. Support structures built on side slopes greater than 5 degrees increase the risks of increased soil erosion and stormwater control issues (Sampson, 2009). The average inclination of the Victoria Junction tailings site is less than 5.71 degrees which is considered nearly flat. Therefore, snow accumulation on the PV modules will not create additional pressure on the ballasted mounting supports for the PV system. While installing PV modules on a nearly- flat terrain is an advantage due to decreased stability issues, snow accumulation on PV modules with low tilt angles may experience certain drawbacks such as losses in the system energy production output (NREL, 2020b). Snow losses have been taken into consideration and factored into the PV system design calculations in SAM.

Differential settlement is another factor that must be taken into consideration when designing solar PV systems for mine tailings site. Settlement is caused by mechanical consolidation, biochemical degradation and physiochemical changes that occur in the tailings over time (Christensen et al., 2020). Differential settlement within the mine tailings site is a risk to the PV mounting support structure, geosynthetics and electrical lines. It can also cause disruption to the PV modules due to shifting of the position of the panels in relation to the sun therefore affecting the energy production output of the system. Settlement can also be caused by the use of machinery, heavy equipment and vehicular traffic during the construction phases of the solar PV facility (Annavarapu et al., 2009). Numerous engineering measures were put in place in the design of the remediation of the Victoria mine tailings site to reduce the potential for settlement. These measures include : 1) Solidification and stabilization of the tailings using Type I or II Portland cement increases the compressive strength and decreases the permeability of the hazardous constituents.; 2) Geomembranes, geosynthetic clay liners and geotextile separators were placed on the surface and subsurface (in between soil layers) to prevent erosion minimizing the rates of differential settlement; 3) The dynamic compaction method will be adopted to consolidate the protective fill soil cover and bedding sand. Dynamic compaction has been shown to increase material density and decrease differential settlement in Municipal Solid Waste (MSW) landfill sites (Van Impe & Bouazza, 1997).

3.2.7 Economic Assessment

3.2.7.1 Costs for site remediation options

Initial capital and annual operations and maintenance (O&M) costs for the solar PV facility project are in Canadian dollars.

The initial capital and annual costs for Option#1-Solar PV geomembrane and traditional remediation method are shown in Table 10 and Table 11 respectively. The initial capital investment include costs for feasibility study, development, engineering, photovoltaic system including the inverter and battery, and construction costs for site remediation. The total initial capital costs for Option#1 is estimated at $112.2M. Annual O&M expenses for Option#1 include costs for servicing the photovoltaic system and maintaining the geomembrane and top soil cover plus vegetation. The annual O&M costs for Option#1 is estimated at $0.381M.

The initial capital and annual costs for Option#2-Solar PV geomembrane remediation method are shown in Table 12 and Table 13 respectively. The initial capital investment include costs for feasibility study, development, engineering, photovoltaic system including the inverter and battery, topsoil and vegetation, and construction costs for site remediation. The total initial capital costs for Option#2 is estimated at $123.6M. Annual operations and maintenance (O&M) expenses for Option#1 include costs for servicing the photovoltaic system and maintaining the geomembrane cover. The annual O&M costs for Option#2 is estimated at $0.248M (million).

The initial and annual costs for Option#3-Traditional remediation method are shown in Table 14. The initial capital investment include costs for feasibility study, development, engineering, topsoil and vegetation, and construction costs for site remediation. The total initial capital costs for Option#3 is estimated at $111.5M. Annual operations and maintenance (O&M) expenses for Option#3 include costs for maintaining the top soil cover and vegetation. The annual O&M costs for Option#3 is estimated at $0.217M.

Table 10. Initial costs for Option#1-Solar PV geomembrane and traditional remediation

Initial Costs

Feasibility Study

Description	Unit	Quantity	Unit Cost $	Amount $
Site investigation	person-dy	2	1,000	2,000
Resource assessment	project	2	800	1,600
Environmental assessment	person-dy	5	1,000	5,000
Preliminary design	person-dy	10	1,100	11,000
Detailed cost estimate	person-dy	3	1,000	3,000
GHG baseline study & Monitoring Plan	project	1	51,425	51,425
Report preparation	person-dy	7	1,000	7,000
Project management	person-dy	60	1,000	60,000
Travel & accommodation	p-trip	2	200	400
Subtotal				**141,425**

Development

Description	Unit	Quantity	Unit Cost $	Amount $
Contract negotiations	project	30	1,000	30,000
Permits & approvals	project	100	900	90,000
Site survey & land rights	project	300	1,800	540,000
GHG validation & registration	project	1	36,300	36,300
Project financing	project	1	0.015	1,686,712
Legal & accounting	project	200	1,000	200,000
Project management	project	140	1,200	168,000
Travel & accommodation	person-trip	2	200	400
Subtotal				**2,751,412**

Engineering

Description	Unit	Quantity	Unit Cost $	Amount $
Site & building design	project	7	1,100	7,700
Mechanical design	project	7	1,100	7,700
Electrical design	project	7	1,100	7,700
Civil design	project	7	1,100	7,700
Tenders & contracting	project	5	1,000	5,000
Construction supervision	project	300	1,800	540,000
Subtotal				**575,800**

Power System

Description	Unit	Quantity	Unit Cost $	Amount $
Photovoltaic	kW	15,000	1,450	21,750,000
Transmission line	km	1	100,000	100,000
Substation	project	1	2,000,000	2,000,000
Equipment mob & demob	dy	4	25,000	100,000
Site clearing and dirt removal	m^2	578,015	0.90	520,214
Earthwork (Structural fill and elevation)	m^2	578,015	5.23	3,023,018
Construction labour cost	person-dy	13,500	351	4,738,500
Grading bedding sand	m^3	115,603	38.10	4,404,474
Protective fill soil	m^3	867,023	40.55	35,157,762
Geomembrane anchor trench	m^3	870	38.10	33,141
Geosynthetic Clay Liner-Material	m^2	227,009	12	2,724,106
Geosynthetic Clay Liner-Installation	m^2	227,009	12	2,724,106
Geomembrane-Material	m^2	227,009	7	1,589,062
Geomembrane-Installation	m^2	227,009	6	1,362,053
Wedge Concrete Anchor Bolt	pc	832,000	0.85	707,200
Steel Batten Plate	pc	416,000	5.10	2,121,600
Geotextile Filter/Separator	m^2	578,015	0.24	138,724
Geocomposite Drainage Layer-Material	m^2	351,006	1.45	508,959
Geocomposite Drainage Layer-Installation	m^2	351,006	1.09	382,597
Topsoil for vegetation	m^3	53,493	52.32	2,798,770.21
Sod and Trees	m^2	351,006	5.24	1,839,271.44
Subtotal				**88,723,558**

Balance of System & Miscellaneous

Description	Unit	Quantity	Unit Cost $	Amount $
Training & commissioning	person-dy	8	1,000	8,000
Photovoltaic				
Inverter	kW	25	1,000	25,000
Collector support structure	m^2	227,009	15	3,405,133
Installation	project	15,000	1,000	15,000,000
Contingencies	%	1%	112,447,469	1,124,475
Interest during construction	months	10	112,447,469	468,531
Subtotal				**20,031,139**
Total Initial Costs				**112,223,333**

(Note: Shim, 2021)

Table 11. Annual O&M costs for Option#1-Solar PV geomembrane and traditional remediation

Annual Costs				
Operations & Maintenance (O&M)				
Description	**Unit**	**Quantity**	**Unit Cost $**	**Amount $**
Power System-Photovoltaic	$/kW	13	15,000	195,000
Parts & labour	project	12	1,000	12,000
GHG monitoring & verification	project	1	36,300	36,300
General & administrative	%	1%	243,300	2,433
Vegetation-Mowing	acres	87	36.3	3,158
Cover soil-Repair	acres	87	484	42,108
Damaged cover soil-Reseeding	acres	87	1,000	87,000
Contingencies	%	1%	378,000	3,780
Total O&M Costs				**381,779**

(Note: Shim, 2021)

Table 12. Initial costs for Option#2-Solar PV geomembrane remediation

Initial Costs

Feasibility Study

Description	Unit	Quantity	Unit Cost $	Amount $
Site investigation	person-dy	2	1,000	2,000
Resource assessment	project	2	800	1,600
Environmental assessment	person-dy	5	1,000	5,000
Preliminary design	person-dy	10	1,100	11,000
Detailed cost estimate	person-dy	3	1,000	3,000
GHG baseline study & Monitoring Plan	project	1	51,425	51,425
Report preparation	person-dy	7	1,000	7,000
Project management	person-dy	60	1,000	60,000
Travel & accommodation	person-trip	2	200	400
Subtotal				**141,425**

Development

Description	Unit	Quantity	Unit Cost $	Amount $
Contract negotiations	project	30	1,000	30,000
Permits & approvals	project	100	900	90,000
Site survey & land rights	project	400	1,800	720,000
GHG validation & registration	project	1	36,300	36,300
Project financing	project	1	0.015	1,850,462
Legal & accounting	project	200	1,000	200,000
Project management	project	140	1,200	168,000
Travel & accommodation	person-trip	2	200	400
Subtotal				**3,095,162**

Engineering

Description	Unit	Quantity	Unit Cost $	Amount $
Site & building design	project	7	1,100	7,700
Mechanical design	project	7	1,100	7,700
Electrical design	project	7	1,100	7,700
Civil design	project	7	1,100	7,700
Tenders & contracting	project	5	1,000	5,000
Construction supervision	project	400	1,800	720,000
Subtotal				**755,800**

Power System

Description	Unit	Quantity	Unit Cost $	Amount $
Photovoltaic	kW	15,000	1,450	21,750,000
Transmission line	km	1	100,000	100,000
Substation	project	1	2,000,000	2,000,000
Equipment mob & demob	dy	4	25,000	100,000
Site clearing and dirt removal	m^2	578,015	0.90	520,214
Earthwork (Structural fill and elevation)	m^2	578,015	5.23	3,023,018
Construction labour cost	person-dy	18,000	351	6,318,000
Grading bedding sand	m^3	115,603	38.10	4,404,474
Protective fill soil	m^3	867,023	40.55	35,157,762
Geomembrane anchor trench	m^3	1,520	38.10	57,922
Geosynthetic Clay Liner-Material	m^2	351,006	12	4,212,072
Geosynthetic Clay Liner-Installation	m^2	351,006	12	4,212,072
Geomembrane-Material	m^2	351,006	7	2,457,042
Geomembrane-Installation	m^2	351,006	6	2,106,036
Geosynthetic Clay Liner-Material	m^2	227,009	12	2,724,106
Geosynthetic Clay Liner-Installation	m^2	227,009	12	2,724,106
Geomembrane-Material	m^2	227,009	7	1,589,062
Geomembrane-Installation	m^2	227,009	6	1,362,053
Wedge Concrete Anchor Bolt	pc	832,000	0.85	707,200
Steel Batten Plate	pc	173,160	20.57	3,561,901
Geotextile Filter/Separator	m^2	578,015	0.24	138,724
Subtotal				**99,225,766**

Balance of System & Miscellaneous

Description	Unit	Quantity	Unit Cost $	Amount $
Training & commissioning	person-dy	8	1,000	8,000
Photovoltaic				
Inverter	kW	25	1,000	25,000
Collector support structure	m^2	227,009	15	3,405,133
Installation	project	15,000	1,000	15,000,000
Contingencies	%	1%	123,284,619	1,232,846
Interest during construction	months	13	123,284,619	667,792
Subtotal				**20,338,771**
Total Initial Costs				**123,556,924**

(Note: Shim, 2021)

Table 13. Annual O&M costs for Option#2- Solar PV geomembrane remediation

Annual Costs				
Operations & Maintenance (O&M)				
Description	**Unit**	**Quantity**	**Unit Cost $**	**Amount $**
Power System-Photovoltaic	$/kW	13	15,000	195,000
Parts & labour	project	12	1,000	12,000
GHG monitoring & verification	project	1	36,300	36,300
General & administrative	%	1%	243,300	2,433
Contingencies	%	1%	243,300	2,433
Total O&M Costs				**248,166**

(Note: Shim, 2021)

Table 14. Initial and O&M costs for Option#3-Traditional remediation method

Initial Costs				
Description	**Unit**	**Quantity**	**Unit Cost $**	**Amount $**
Construction surveying	m^2	578,015	0.93	538,537
Equipment mobilization & demobilization	dy	4	25,000	100,000
Site clearing and dirt removal	m^2	578,015	0.90	518,475
Earthwork (Structural fill and excavation)	m^2	578,015	5.23	3,024,438
Construction labour cost	dy	13,500	350.90	4,737,150
Project management cost	m^2	578,015	4.19	2,419,551
Grading/Bedding Sand	m^3	115,603	38.10	4,403,924
Geotextile Filter/Separator	m^2	578,015	0.24	138,724
Geosynthetic Clay Liner-Material	m^2	578,015	12.00	6,936,180
Geosynthetic Clay Liner-Installation	m^2	578,015	6.00	3,468,090
HDPE Geomembrane-Material	m^2	578,015	7.00	4,046,105
HDPE Geomembrane-Installation	m^2	578,015	3.00	1,734,045
Geocomposite Drainage Layer-Material	m^2	578,015	1.45	839,278
Geocomposite Drainage Layer-Installation	m^2	578,015	1.09	629,458
Protective soil layer	m^3	1,734,045	40.55	70,309,402
Topsoil and vegetation	m^3	88,089	52.32	4,608,668
Sod and Shrubs	m^2	578,015	5.24	3,030,972
Total Initial Costs				**111,482,996**
Annual Costs				
Operations & Maintenance (O&M)				
Description	**Unit**	**Quantity**	**Unit Cost $**	**Amount $**
Vegetation-Mowing	acres	143	36	5,185
Cover soil-Repair	acres	143	484	69,130
Damaged cover soil-Reseeding	acres	143	1,000	142,831
Total O&M Costs				**217,145**

(Note: Shim, 2021)

The economic assessment was conducted using the RetScreen Financial Analysis Model (NRCAN, 2005b). The financial model uses the following assumptions:

a. Year 0 is the initial investment year.
b. Incentives, grants and tax credits are applied in Year 0.
c. Inflation rate is applied from Year 1 onwards.
d. Yearly pre-tax and cumulative cash flows occur at the end of the year.

The Net Present Value (NPV) which is the value of all future cash flows of the project discounted to today's value was calculated using Equation (12) of (NRCAN, 2005b). N is the project life in years, $\widetilde{C_n}$ is the after-tax cash flow for year n and r is the discount rate.

$$NPV = \sum_{n=0}^{N} \frac{\widetilde{C_n}}{(1+r)^n} \tag{12}$$

The payback period which is the number of years it takes for the cash flow to equal the initial capital investment was estimated by calculating N when NPV is zero. The internal rate of return (IRR) is obtained using Equation (13) of (NRCAN, 2005b) by calculating the discount rate that makes NPV equals to zero. It is calculated by solving for IRR in Equation (13). N is the project life in years and C_n is the cash flow for year n

$$0 = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} \tag{13}$$

The benefit-cost ratio (BC) which is the ratio of present value of annual revenue of the project to the cost and investment of the project was calculated using Equation (14) of (NRCAN 2005b). NPV is the net present value. C is the total initial cost of the project and f_d is the debt ratio.

$$BC = \frac{NPV + (1 + f_d)C}{(1 + f_d)C} \tag{14}$$

The cost of energy production, C_{prod} is the avoided cost of energy that makes the NPV equals to zero. It is obtained by using Equation (15) of (NRCAN, 2005b) by solving for:

$$0 = \sum_{n=0}^{N} \frac{\widetilde{C_n}}{(1 + r)^n} \tag{15}$$

where,

$$\widetilde{C_n} = C_n - T_n \tag{16}$$

C_n is the cash flow for year n. T_n is the tax for year n.

$$C_n = C_{in,n} - C_{out,n} \tag{17}$$

$C_{in,n}$ in Equation (18) of (NRCAN, 2005b) is the pre-tax cash inflow for year n. $C_{out,n}$ in Equation (19) of (NRCAN, 2005b) is the pre-tax cash outflow for year n.

$$C_{in,n} = C_{prod}\,(1 + r_e)^n + C_{capa}\,(1 + r_i)^n + C_{RE}\,(1 + r_{RE})^n + C_{GHG}\,(1 + r_{GHG})^n \tag{18}$$

$$C_{out,n} = C_{O\&M}\,(1 + r_i)^n + C_{fuel}\,(1 + r_e)^n + D + C_{per}\,(1 + r_i)^n \tag{19}$$

C_{prod} is the cost of energy production, C_{capa} *is the annual capacity savings or income*, C_{RE} is the annual renewable energy and C_{GHG} is the greenhouse gas (GHG) reduction income.

r_e is the energy cost escalation rate, r_i is the inflation rate, r_{RE} is the Renewable Energy credit escalation rate and r_{GHG} is the greenhouse gas (GHG) credit escalation rate.

$C_{O\&M}$ is the yearly operation and maintenance costs incurred by the clean energy project, C_{fuel} is the annual cost of fuel or electricity, D is the annual debt payment and C_{per} is the periodic costs or credits incurred by the system.

Table 15. Financial viability for Option#1- Solar PV geomembrane and traditional remediation

Financial viability		
Financial parameters		
Inflation rate	%	2%
Discount rate	%	9%
Reinvestment rate	%	9%
Project life	yr	25
Incentives and grants	$	39,339,347
Debt ratio	%	50%
Debt	$	56,159,360
Equity	$	56,159,360
Debt interest rate	%	8%
Debt term	yr	10
Debt payments	$/yr	8,369,401
Annual revenue		
Electricity exported to grid	MWh	12,242
Electricity export rate	$/kWh	0.33
Electricity export revenue	$	4,039,800
Electricity export escalation rate	%	2%

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 16. Financial viability parameters for Option#1-Solar PV geomembrane and traditional

Financial viability		
Pre-tax IRR - equity	%	1.9%
Pre-tax MIRR - equity	%	4.9%
Pre-tax IRR - assets	%	-2.3%
Pre-tax MIRR - assets	%	1.6%
Simple payback	yr	20
Equity payback	yr	21.8
Net Present Value (NPV)	$	-$27,370,586
Annual life cycle savings	$/yr	-$2,786,497
Benefit-Cost (B-C) ratio		0.51
Debt service coverage		0.45
GHG reduction cost	$/C0$_2$	228
Energy production cost	$/kWh	0.624

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 17. Costs, savings and revenue for Option#1-Solar PV geomembrane and traditional

Costs|Savings|Revenue		
Initial Costs		
Feasibility study	0.13%	$141,425
Development	2.60%	$2,866,282
Engineering	0.51%	$575,800
Power system	79%	$88,723,573
Balance of system & miscellaneous	17.80%	$20,011,640
Total initial costs	100%	**$112,318,720**
Incentives and grants		$39,339,347
Yearly cash flows-Year 1		
Annual costs and debt payments		
O&M		$381,779
Debt payments - 10 yrs		$8,369,401
Total annual costs		**$8,751,180**
Annual savings and revenue		
Electricity export revenue		$4,039,800
GHG reduction revenue		$0
Other revenue (cost)		$0
CE production revenue		$0
Total annual savings and revenue		**$4,039,800**
Net yearly cash flow-Year1		**-$4,711,380**

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 18. Financial viability for Option#2-Solar PV/geomembrane remediation

Financial viability		
Financial parameters		
Inflation rate	%	2%
Discount rate	%	9%
Reinvestment rate	%	9%
Project life	yr	25
Incentives and grants	$	39,726,230
Debt ratio	%	50%
Debt	$	61,769,214
Equity	$	61,769,214
Debt interest rate	%	8%
Debt term	yr	10
Debt payments	$/yr	9,205,434
Annual revenue		
Electricity exported to grid	MWh	12,242
Electricity export rate	$/kWh	0.33
Electricity export revenue	$	4,039,800
Electricity export escalation rate	%	2%

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 19. Financial viability parameters for Option#2-Solar PV/geomembrane remediation

Financial viability		
Pre-tax IRR - equity	%	0.88%
Pre-tax MIRR - equity	%	4.3%
Pre-tax IRR - assets	%	-2.9%
Pre-tax MIRR - assets	%	1.2%
Simple payback	yr	22.1
Equity payback	yr	23.4
Net Present Value (NPV)	$	-$36,382,707
Annual life cycle savings	$/yr	-$3,703,987
Benefit-Cost (B-C) ratio		0.41
Debt service coverage		0.42
GHG reduction cost	$/C0$_2$	303
Energy production cost	$/kWh	0.699

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 20. Costs, savings and revenue for Option#2-Solar PV/geomembrane remediation

Costs|Savings|Revenue		
Initial Costs		
Feasibility study	0.11%	$141,425
Development	2.50%	$3,095,162
Engineering	0.61%	$755,800
Power system	80.30%	$99,225,781
Balance of system & miscellaneous	16.40%	$20,320,259
Total initial costs	100%	**$123,538,427**
Incentives and grants		$39,726,230
Yearly cash flows-Year 1		
Annual costs and debt payments		
O&M		$248,190
Debt payments - 10 yrs		$9,205,434
Total annual costs		**$9,453,624**
Annual savings and revenue		
Electricity export revenue		$4,039,800
GHG reduction revenue		$0
Other revenue (cost)		$0
CE production revenue		$0
Total annual savings and revenue		**$4,039,800**
Net yearly cash flow-Year1		**-$5,413,824**

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

3.2.7.2 Option#1 Solar PV geomembrane and traditional remediation method

The economic assessment was conducted for a project economic life of 25 years using RETScreen. A discount rate of 9% was used. The project is financed for a loan period of 10 years. The debt ratio assigned to this project is 50% with an interest rate of 8% per year. Debt payments over the loan period is expected to be $8.4M per year. The Canadian Renewable and Conservation Expenses (CRCE, 2013) green energy investment tax credit was applied for the initial year of capital costs incurred in the project. The CRCE represents the intangible expenses incurred by a business organization during the development of a renewable energy project where at least 50% of the capital cost of the depreciable property will be considered as deductible expenses under the Class 43.1 Asset or Class 43.2 Asset categories. This structure is similar to the Canadian taxation system for capital cost allowance (CCA) under Schedule II of the Income Tax Regulations (Government of Canada, 2021). The $0.60 per watt rebate from the Nova Scotia Renewable Energy Incentive Program (Efficiency Nova Scotia, 2021) was also deducted from the initial year of capital investment in the project. The total amount of incentives and grants applied to the project was $39.3M. The electricity export rate based on power purchase agreements for solar PV installations is $0.33/kWh (Government of Nova Scotia, 2021b). The electricity export escalation rate assigned to this project is 2%. The total initial capital costs for installing the solar-PV facility including costs for feasibility study, development, engineering, construction, and balance of system and miscellaneous was estimated to be $112.3M. The annual operations and maintenance (O&M) costs was estimated to be $0.382M. The total annual costs including debt payments is estimated to be $8.8M. The financial parameters and annual revenue are shown in Table 15. The financial viability parameters are shown in Table 16. The total costs, savings and revenue are shown in Table 17.

3.2.7.3 Option#2 Solar PV geomembrane remediation method

Similar to Option#1, the economic assessment was conducted for a project economic life of 25 years using RETScreen. A discount rate of 9% was used. The project is financed for a loan period of 10 years. The debt ratio assigned to this project is 50% with an interest rate of 8% per year. Debt payments over the loan period is expected to be $9.2M per year. The Canadian Renewable and Conservation Expenses (CRCE, 2013) green energy investment tax credit was applied for the initial year of capital costs incurred in the project. The CRCE represents the intangible expenses incurred by a business organization during the development of a renewable energy project where at least 50% of the capital cost of the depreciable property will be considered as deductible expenses under the Class 43.1 Asset or Class 43.2 Asset categories. This structure is similar to the Canadian taxation system for capital cost allowance (CCA) under Schedule II of the Income Tax Regulations (Government of Canada, 2021). The $0.60 per watt rebate from the Nova Scotia Renewable Energy Incentive Program (Efficiency Nova Scotia, 2021) was also deducted from the initial year of capital investment in the project. The total amount of incentives and grants applied to the project was $39.7M. The electricity export rate based on power purchase agreements for solar PV installations is $0.33/kWh (Government of Nova Scotia, 2021b).The electricity export escalation rate assigned to this project is 2%. The total initial capital costs for installing the solar-PV facility including costs for feasibility study, development, engineering, construction, and balance of system and miscellaneous was estimated to be $123.5M. The annual operations and maintenance (O&M) costs was estimated to be $0.248M. The total annual costs including debt payments is estimated to be $9.5M. The financial parameters and annual revenue are shown in Table 18. The financial viability parameters are shown in Table 19. The total costs, savings and revenue are shown in Table 20.

3.2.7.4 Option#3 Traditional remediation method

The initial capital investment for Option#3 include costs for feasibility study, development, engineering, topsoil and vegetation, and construction costs for site remediation. The total initial capital costs for Option#3 is estimated at $111.5M. Annual operations and maintenance (O&M) expenses for Option#3 include costs for maintaining the top soil cover and vegetation. The annual O&M costs for Option#3 is estimated at $0.217M. It is assumed that there will be no project finance loan for the traditional remediation method. Therefore, it is expected that there will be no yearly debt payments incurred by the provincial government of Nova Scotia. The only expenses incurred by the provincial government is the annual operations and maintenance costs required to maintain the topsoil and vegetation. Since this remediation method does not generate any electricity production from the site, it is expected that this remediation method does not generate any annual revenue. Therefore, the annual electricity export revenue will be zero.

3.2.8 Analysis of greenhouse gas (GHG) emissions

The greenhouse gas (GHG) emission reduction and costs for both Option#1 (Solar PV geomembrane and traditional remediation method) and Option#2 (Solar PV geomembrane remediation method) were analyzed using the RETScreen Greenhouse Gas (GHG) Emission Reduction Analysis model (NRCAN, 2005b). The greenhouse gas (GHG) emission reduction and costs for Option#3 (Traditional remediation method) were analyzed using Microsoft Excel. RETScreen calculates the GHG emission for the base case scenario which could be a natural gas, diesel or a coal fired power generation plant and for the proposed case scenario which is the renewable energy project. The GHG emission reduction potential is the difference between the base case and the proposed case scenarios. The combustion of fossil fuels such as coal, diesel and natural gas for electricity generation produces carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (US EPA, 2021). The RETScreen software converts methane and nitrous oxide emissions into the equivalent carbon dioxide emission according to their "global warming potential" (GWP). Carbon dioxide (CO_2) has a GWP of 1, methane (CH_4) has a GWP of 21 and nitrous oxide (N_2O) has a GWP of 310 (NRCAN, 2005b).

The base case electricity system GHG emission factor, $e_{\,base}$ for a single fuel source power generation facility is calculated using Equation (16) of (NRCAN, 2005b).

$$e_{\,base} = \left(e_{CO_2}\,GWP_{CO_2} + e_{CH_4}GWP_{CH_4} + e_{N_2O}GWP_{N_2O}\right)\frac{1}{\eta}\,\frac{1}{1-\lambda} \qquad (16)$$

where e_{CO_2}, e_{CH_4} and e_{N_2O} are respectively the CO_2, CH_4 and $N_2\,O$ emission factors for the fuel source considered. GWP_{CO_2}, GWP_{CH_4} and GWP_{N_2O} are the global warming potentials for CO_2, CH_4 and $N_2\,O$. η is the fuel conversion efficiency and λ is the fraction of electricity lost in transmission and distribution. The fuel conversion efficiency, η assigned for the GHG emission reduction analysis is 33% which is typical for a coal-fired power plant. The fraction of electricity lost in transmission and distribution, λ assigned for analysis is 7% or 0.07.

The proposed case electricity system GHG emission factor, $e_{\,prop}$ for a single fuel source power generation facility is calculated similar to that for the base case GHG emission factor by using Equation (16) of (NRCAN, 2005b).

The annual GHG emission reduction, Δ_{GHG} is calculated using Equation (17) of (NRCAN, 2005b).

$$\Delta_{GHG} = \left(e_{\,base} - e_{\,prop}\right)E_{prop}\left(1-\lambda_{prop}\right)\left(1-e_{cr}\right) \qquad (17)$$

where e_{base} is the base case GHG emission factor, e_{prop} is the proposed case GHG emission factor, E_{prop} is the proposed case annual electricity produced, λ_{prop} is the fraction of electricity lost in transmission and distribution (T&D) for the proposed case, and e_{cr} is the GHG emission reduction credit transaction fee. A GHG emission reduction credit transaction fee, e_{cr} was not used for the analysis. Therefore, e_{cr} is equal to zero.

Chapter 4.0 Analysis, findings, interpretation and discussion

4.1 Solar radiation site assessment

Table 21. Useable area sizes and solar radiation values for natural terrain

Natural Terrain (Slope Inclination < 1.72°)						
Module Orientation	**Azimuth**	**Area #**	**Useable Area Size**	**Useable Area Size**	**Average Solar Radiation**	**Total Solar Radiation**
	o		**m^2**	**acres**	**kWh/m^2**	**kWh**
Facing North	< 22.5° and > 337.5°	1	106,063.27	26.2	1,052.87	111,671,232
		2	66,891.59	16.5	1,050.98	70,302,035
		Total	**172,955**	**43**	**1,052**	**181,973,267**
Facing South	> 157.5° and < 202.5°	1	82,570.51	20.4	1,064.90	87,929,222
		2	122,741.33	30.3	1,048.67	128,715,283
		3	80,854.03	20.0	1,048.81	84,800,875
		Total	**286,166**	**71**	**1,054**	**301,445,381**
Facing East	> 67.5° and < 112.5°	1	105,456.95	26.1	1,052.78	111,023,163
		2	68,992.36	17.0	1,050.96	72,508,427
		Total	**174,449**	**43**	**1,052**	**183,531,590**
Facing West	> 247.5° and < 292.5°	1	154,235.81	38.1	1,047.67	161,587,633
		2	43,040.17	10.6	1,055.65	45,435,555
		3	115,644.83	28.6	1,048.26	121,226,268
		Total	**312,921**	**77**	**1,051**	**328,249,456**

Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Table 22. Useable area sizes and solar radiation values for natural terrain

Natural Terrain (Slope Inclination < 5.71°)						
Module Orientation	**Azimuth**	**Area #**	**Useable Area Size**	**Useable Area Size**	**Average Solar Radiation**	**Total Solar Radiation**
	o		**m^2**	**acres**	**kWh/m^2**	**kWh**
Facing North	< 22.5° and > 337.5°	1	145,679.01	36.0	1,050.16	152,985,846
		2	84,329.69	20.8	1,061.43	89,510,109
		3	106,071.81	26.2	1,048.65	111,231,906
		Total	**336,081**	**83**	**1,053**	**353,727,861**
Facing South	> 157.5° and < 202.5°	1	144,560.31	35.7	1,060.19	153,261,309
		2	113,509.90	28.0	1,046.47	118,784,178
		3	150,751.60	37.3	1,045.77	157,651,820
		Total	**408,822**	**101**	**1,051**	**429,697,306**
Facing East	> 67.5° and < 112.5°	1	105,456.95	26.1	1,052.78	111,023,163
		2	68,992.36	17.0	1,050.96	72,508,427
		3	115,644.83	28.6	1,048.62	121,267,032
		Total	**290,094**	**72**	**1,051**	**304,798,622**
Facing West	> 247.5° and < 292.5°	1	143,962.53	35.6	1,051.34	151,353,300
		2	82,297.24	20.3	1,061.26	87,338,617
		3	107,181.97	26.5	1,048.57	112,388,231
		Total	**333,442**	**82**	**1,054**	**351,080,147**

Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Table 23. Useable area sizes and solar radiation values for covered terrain

Covered Terrain (Slope Inclination < 1.72°)						
Module Orientation	**Azimuth**	**Area #**	**Useable Area Size**	**Useable Area Size**	**Average Solar Radiation**	**Total Solar Radiation**
	°		**m^2**	**acres**	**kWh/m^2**	**kWh**
Facing South	> 157.5° and < 202.5°	1	73,532.32	18.2	1,065.34	78,337,130
		2	112,225.46	27.7	1,049.93	117,829,305
		3	94,260.18	23.3	1,049.34	98,911,037
		Total	**280,018**	**69**	**1,055**	**295,077,472**

Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Table 24. Useable area sizes and solar radiation values for covered terrain

Covered Terrain (Slope Inclination < 5.71°)						
Module Orientation	**Azimuth**	**Area #**	**Useable Area Size**	**Useable Area Size**	**Average Solar Radiation**	**Total Solar Radiation**
	°		**m^2**	**acres**	**kWh/m^2**	**kWh**
Facing South	> 157.5° and < 202.5°	1	115,192.67	28.5	1,064.20	122,588,019
		2	122,099.12	30.2	1,051.23	128,354,629
		3	88,325.75	21.8	1,049.78	92,723,037
		Total	**325,618**	**80**	**1,055**	**343,665,684**

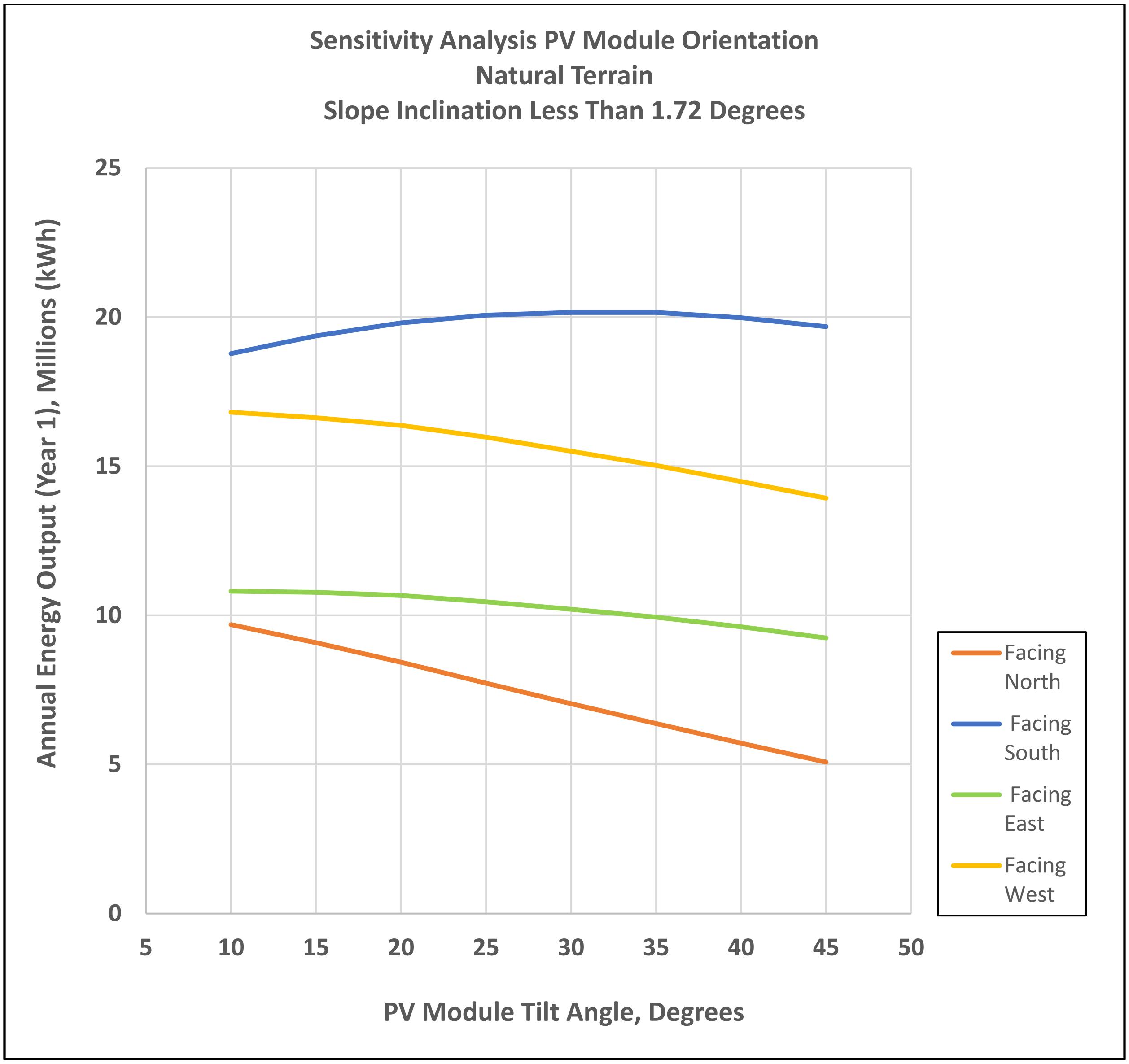
Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Table 25. Useable area size, PV tilt angle and annual energy output for natural terrain

Natural Terrain (Slope Inclination < 1.72°)					
Module Orientation	**Azimuth**	**Useable Area Size**	**Useable Area Size**	**PV Tilt Angle**	**Annual Energy Output (Year 1)**
	°	**m^2**	**acres**	**°**	**kWh**
Facing North	Less than 22.5° and Greater than 337.5°	172,955	43	10	9,688,391
				15	9,077,636
				20	8,426,113
				25	7,720,315
				30	7,034,451
				35	6,369,845
				40	5,710,576
				45	5,078,483
Facing South	Greater than 157.5° and Less than 202.5°	286,166	71	10	18,775,132
				15	19,370,120
				20	19,803,590
				25	20,064,472
				30	**20,155,370**
				35	20,152,772
				40	19,977,510
				45	19,677,246
Facing East	Greater than 67.5° and Less than 112.5°	174,449	43	10	10,811,220
				15	10,767,925
				20	10,663,342
				25	10,452,517
				30	10,198,430
				35	9,937,063
				40	9,613,193
				45	9,242,053
Facing West	Greater than 247.5° and Less than 292.5°	312,921	77	10	16,808,916
				15	16,621,774
				20	16,367,471
				25	15,969,711
				30	15,501,183
				35	15,021,489
				40	14,482,396
				45	13,926,557

Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Figure 45. Annual energy output versus PV module tilt angle for natural terrain



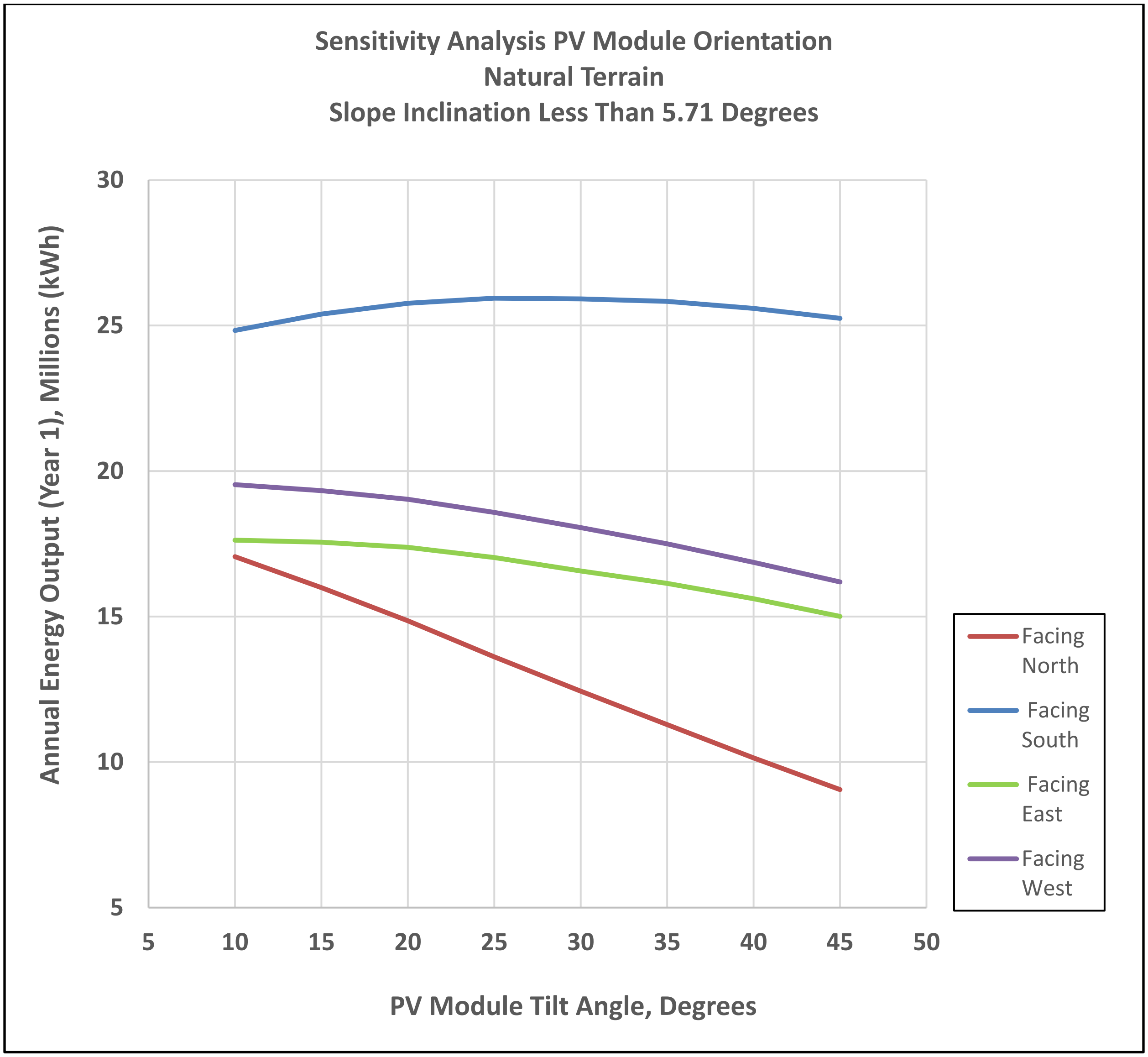
Note: Figure developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Table 26. Useable area size, PV tilt angle and annual energy output for natural terrain

Natural Terrain (Slope Inclination < 5.71^{o})					
Module Orientation	**Azimuth**	**Useable Area Size**	**Useable Area Size**	**PV Tilt Angle**	**Annual Energy Output (Year 1)**
	o	**m^2**	**acres**	**o**	**kWh**
Facing North	Less than 22.5^{o} and Greater than 337.5^{o}	336,081	83	10	17,061,640
				15	15,994,308
				20	14,853,742
				25	13,617,507
				30	12,434,792
				35	11,289,094
				40	10,141,160
				45	9,054,597
Facing South	Greater than 157.5^{o} and Less than 202.5^{o}	408,822	101	10	24,834,844
				15	25,391,534
				20	25,765,266
				25	**25,941,354**
				30	25,916,858
				35	25,829,840
				40	25,588,042
				45	25,250,120
Facing East	Greater than 67.5^{o} and Less than 112.5^{o}	290,094	72	10	17,626,046
				15	17,552,818
				20	17,377,562
				25	17,029,556
				30	16,568,702
				35	16,141,205
				40	15,612,761
				45	15,010,430
Facing West	Greater than 247.5^{o} and Less than 292.5^{o}	333,442	82	10	19,532,642
				15	19,326,598
				20	19,031,074
				25	18,580,196
				30	18,057,498
				35	17,501,378
				40	16,860,418
				45	16,192,027

Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Figure 46. Annual energy output versus PV module tilt angle for natural terrain



Note: Figure developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

For the natural terrain scenario with slope inclination less than 1.72°, it was found that PV modules orientated South (Azimuth greater than 157.5° and less than 202.5°) yielded the second largest area suitable for PV installation with a useable area size of 286,166 m^2 or 71 acres. PV modules orientated South also produced the highest annual energy output (Year 1) of 20,155,370 kWh at an optimum PV tilt angle of 30°. The average solar radiation for an area size of 286,166 m^2 is 1,054 kWh/m^2. The total solar radiation based on this size of area is 301,445,381 kWh. PV modules facing West (Azimuth greater than 247.5° and less than 292.5°) yielded the largest area suitable for PV installation with a useable area size of 312,921 m^2 or 77 acres. The optimum PV tilt angle that produced the highest energy output is 10°. The annual energy output (Year 1) is 16,808,916 kWh. The average solar radiation for an area size of 312,921 m^2 is 1,051 kWh/m^2. The total solar radiation based on this size of area is 328,249,456 kWh.

The useable area sizes and solar radiation values for the natural terrain scenario with slope inclination less than 1.72° for the PV modules orientated in four different directions are shown in Table 21. The useable area size, PV tilt angle and annual energy output (Year 1) for the natural terrain scenario with slope inclination less than 1.72° for the PV modules orientated in four different directions are shown in Table 25. The annual energy output versus PV module tilt angle for the natural terrain with slope inclination less than 1.72° are shown in Figure 45.

For the natural terrain scenario with slope inclination less than 5.71°, it was found that PV modules oriented South (Azimuth greater than 157.5° and less than 202.5°) yielded the largest area suitable for PV installation with a useable area size of 408,822 m^2 or 101 acres. PV modules oriented South also produced the highest annual energy output (Year 1) of 25,941,354 kWh at an optimum tilt angle of 25°. The average solar radiation for an area size of 408,822 m^2 is 1,051 kWh/m^2. The total solar radiation based on this size of area is 429,697,306 kWh. PV modules facing West (Azimuth greater than 247.5° and less than 292.5°) yielded the third largest area suitable for PV installation with a useable area size of 333,442 m^2 or 82 acres. The optimum PV tilt angle that produced the highest energy output is 10°. The annual energy output (Year 1) is 19,532,642 kWh. The average solar radiation for an area size of 333,442 m^2 is 1,054 kWh/m^2. The total solar radiation based on this size of area is 351,080,147 kWh.

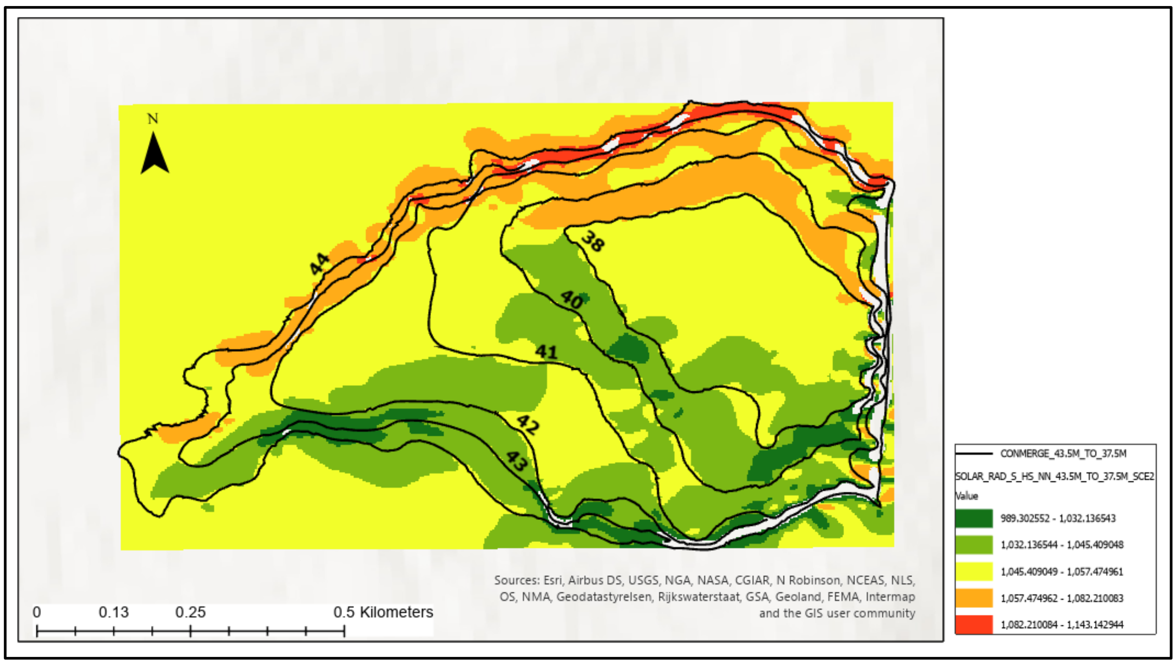
The useable area sizes and solar radiation values for the natural terrain scenario with slope inclination less than 5.71° for the PV modules orientated in four different directions are shown in Table 22. The useable area size, PV tilt angle and annual energy output (Year 1) for the natural terrain scenario with slope inclination less than 5.71° for the PV modules orientated in four different directions are shown in Table 26. The annual energy output versus PV module tilt angle for the natural terrain with slope inclination less than 5.71° are shown in Figure 46. The solar radiation site assessment results for the natural terrain shows that PV modules orientated South (Azimuth greater than 157.5° and less than 202.5°) at a tilt angle of 25° yielded the largest useable area for PV module installation and also produced the highest energy output compared to modules orientated in the North, East and West directions.

Based on the results of the solar radiation site assessment results for the natural terrain, a similar analysis was conducted for the covered terrain for PV modules orientated South (Azimuth greater than 157.5° and less than 202.5°) . For the covered terrain scenario with slope inclination less than 1.72°, the total useable area size suitable for PV installation was determined to be 280,018m^2 or 69 acres. The average solar radiation calculated was 1,055 kWh/m^2 with a total solar radiation of 295,077,472 kWh. For the covered terrain scenario with slope inclination less than 5.71°, the total useable area size suitable for PV installation was determined to be 325,618 m^2 or 80 acres. The average solar radiation calculated was 1,055 kWh/m^2 with a total solar radiation of 343,665,684 kWh. The useable area sizes and solar radiation values for the covered terrain scenario with slope inclination less than 1.72° are shown in Table 23. The useable area sizes and solar radiation values for the covered terrain scenario with slope inclination less than 5.71° are shown in Table 24. As it can be deduced from the solar radiation site assessment results for the natural terrain that South-facing PV modules yielded the highest energy production output, the analysis for PV modules orientated in the North, East and West directions were not necessary for the covered terrain scenario.

Based on the results of the solar radiation site assessment results for the covered terrain, it can be concluded that PV modules orientated South installed on a slope inclination of less than 5.71° yielded the largest area suitable for PV installation and the highest energy production output. The total useable area size suitable for PV installation was determined to be

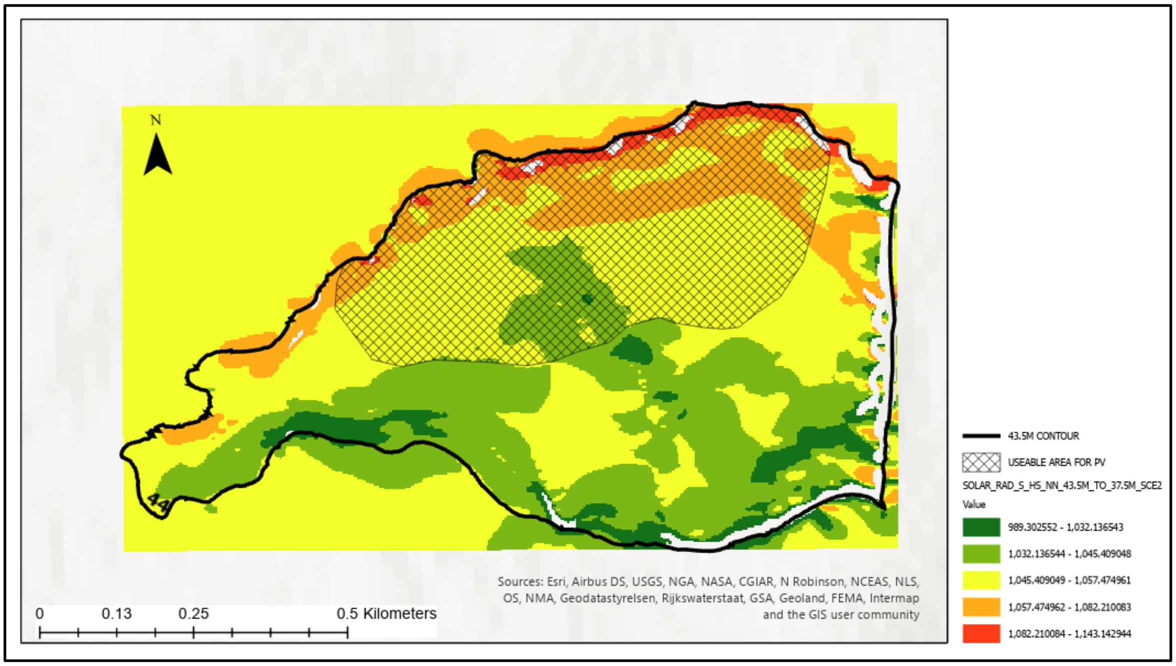
325,618 m^2 or 80 acres for the covered terrain scenario with slope inclination less than 5.71°. Based on the annual energy production output analysis in the System Advisor Model (SAM) software, a total land area of 227,009 m^2 or 56 acres is required to install a 15 MW capacity solar PV facility. Therefore, a land area of 227,009 m^2 or 56 acres was used for solar PV installation. Figure 47 shows the solar radiation values for PV modules facing South for the covered terrain scenario with slopes less than 5.72°. Figure 48 and Table 27 shows the area selected for PV installation based on solar radiation values for PV modules facing South for the covered terrain scenario with slopes less than 5.72°.

Figure 47. Solar radiation values for PV installation on covered terrain-slope less than 5.72 degrees (South)



Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Figure 48. Finalized area for PV installation on covered terrain-slope less than 5.72 degrees (South)



Note: (Shim, 2021) ;Developed from ArcGIS (ArcGIS Pro, 2020)

Table 27. Useable area size and average solar radiation for modules facing South

Useable Area Size	Useable Area Size	Average Solar Radiation
m^2	**acres**	**kWh/m^2**
227,009	56	1,056

Note: Table developed by (Shim, 2021); Data from ArcGIS (ArcGIS Pro, 2020)

Note: Values derived from Figure 48

4.2 Photovoltaic system design

4.2.1 PV module selection

The solar PV module selected from System Advisor Model (SAM) is the mono-Si SunPower Maxeon SPR-A450W-COM Commercial A-Series panel. Appendix A1 and A2 shows the technical specifications for the SunPower Maxeon 450W Commercial A-Series Panel (Sunpower, 2021) . This model was chosen for its high-efficiency rating with a capability of delivering up to 60% more energy than the conventional SunPower PV panels (Sunpower, 2021). The high power density of the SunPower Maxeon Gen 5 cell is suitable for delivering energy production requirements for a commercial utility-scale electricity power generation plant. SunPower's "interdigitated back contact" technology allows for the cells to absorb sunlight without any shading and the metal ribbons provide higher energy yield. The PV module power rating is calculated using Equation (1) of (Masters, 2013) taking into consideration the annual energy demand, derate factor and total number of full sunlight hours throughout the year. The derate factor represents the amount of reduction in electricity generated after all losses in the solar PV system are taken into consideration. It is expressed as a fraction of solar module nameplate DC capacity. The derate factor used for determining the power rating, P_{DC} of the solar PV module is 0.75 considering that the VJTB is located in a relatively cool climate region. The total number of modules required was determined by dividing the power rating, P_{DC} of the solar PV module by the nominal power rating of the SunPower Maxeon SPR-A450W-COM module which is 448 W as shown in Equation (2) of (Masters, 2013). It was determined that 33,600 PV modules are required. It was determined that 14 modules per string with 1,200 strings in parallel arranged in two sub-arrays will be the optimal configuration to produce the solar array power output capacity of 15 MW. The PV modules will be installed on ballasted ground-mount steel supports with fixed arrays at a tilt angle of 25 degrees. The solar radiation site assessment conducted in Section 4.1 determined that solar modules orientated at an azimuth of 180 degrees (South) yields the maximum solar irradiance output.

The tilt angle of 25 degrees and azimuth of 180 degrees were determined from the solar radiation site assessment in Chapter 4.1 to be the optimum PV tilt angle that would produce the largest area suitable for PV installation and highest annual energy production output. The PV module will be arranged in a portrait orientation. Each module has a length of 1.86 m and a width of 1.09 m. The area of each module is 2.03 m^2. The total modular area for 33,600 PV modules is 68,208 m^2. There will be two modules placed along the side of the row. The length of side is calculated using Equation (8) of (NREL, 2020b). The length of each side of the row is

3.71 m. There will be thirty number of modules placed along the bottom of the row. The row spacing is the distance between the bottom of any two rows in the subarray. It is calculated using Equation (10) of (NREL, 2020b). The estimated spacing between each row is 12.38 m. The ground coverage ratio (GCR) is calculated using Equation (9) of (NREL, 2020b). A ground coverage ratio of was calculated in SAM to be 0.3 for the PV system design. Ground coverage ratio is defined as the length of the side of one row divided by the distance between the bottom of one row and the bottom of its neighbouring row (NREL, 2020b).The number of rows is calculated using Equation (11) of (NREL, 2020b). The total number of rows will be 280 with 16,800 modules placed in each sub-array.

For the portrait module orientation,

$$Length\ of\ side = module\ length\ x\ number\ of\ modules\ along\ side\ of\ row \tag{8}$$

$$Ground\ coverage\ ratio\ (GCR) = Length\ of\ side\ of\ row \div Distance\ between\ bottom\ of\ one\ row\ and\ the\ bottom\ of\ its\ neighbouring\ row \tag{9}$$

$$Row\ spacing = Length\ of\ side \div Ground\ coverage\ ratio\ (GCR) \tag{10}$$

$$Number\ of\ Rows = Number\ of\ modules\ in\ subarray \div number\ of\ modules\ along\ side \div number\ of\ modules\ along\ bottom \tag{11}$$

Table 28. System efficiencies and losses

System Efficiencies & Losses	
Description	**Percentage**
Efficiencies	**%**
Inverter efficiency	98.8%
Battery efficiency	85.0%
MPPT efficiency	97.8%
Losses	**%**
Shading & array	1.7%
Snow	3.6%
Annual soiling	5.0%
Module mismatch	2.0%
Diodes & connections	0.5%
DC wiring	2.0%
AC wiring	2.0%
Transmission & Distribution	7.0%

Note: Table developed by (Shim, 2021); Data from SAM (NREL, 2020a)

The efficiency of the Canadian Solar CSI-25K-T400 inverter is 98.8% as given in Appendix C2 (CanadianSolar, 2021). The round-trip efficiency of lithium ion batteries typically range between 85% to 90% (Li & Tseng, 2015). To be conservative, an efficiency of 85% was used for the GE Energy RSU-4000 lithium-ion battery unit. The MPPT efficiency calculated in SAM for the Canadian Solar CSI-25K-T400 inverter is 97.8% (NREL, 2020a).

System Advisor Model (SAM) models reductions in solar irradiance caused by shadows and snow on the photovoltaic modules in the array. External shading of the photovoltaic subarrays caused by the topography of the terrain surfaces, surrounding objects such as shrubs, trees, the retention dam structure and decant tower of the VJTD was analyzed in the solar radiation site assessment, in Chapter 4.1. SAM also estimates losses in the PV array's energy production output due to self-shading caused by row-to-row shading of modules placed within the subarray.

Shadows from modules in neighbouring rows may block sunlight from reaching parts of other modules in the array during different times of the day.

Snow cover on photovoltaic modules causes reduction in incident solar irradiance resulting in the array energy production losses. The weather file in SAM contains snow depth data. Snow depth refers to the vertical height of frozen precipitation on the ground measured in centimeters (cm). SAM estimates losses by using the snow depth data from the weather file, taking into consideration specific days when the array is covered with snow. The percentage of the photovoltaic array that is covered with snow is estimated based on the PV module tilt angle, plane-of-array irradiance, and ambient temperature (NREL, 2020b). SAM assumes that the array is completely covered with snow when the snow depth data indicates a snowfall. When the ambient temperature rises, the model assumes that the snow slides off the array.

The presence of soil and dust on photovoltaic modules reduces the total solar irradiance incident on each subarray. The nominal incident irradiance value for each time step is calculated in SAM using solar irradiance values from the weather file, and sun and subarray angles (NREL, 2020b). The nominal irradiance value is adjusted in SAM by using the soiling loss percentage specified for each time step. The average monthly soiling loss for the PV modules is estimated to be at 5 percent. The module mismatch losses indicate differences in performance of individual modules in the array. The module mismatch loss is estimated to be at 2 percent. Losses in diodes and connections account for voltage drops across blocking diodes and electrical connections. Diodes and connections losses are estimated to be at 0.5 percent. DC and AC wiring losses account for resistive losses in electrical wiring on the DC and AC side of the system respectively. Both the DC and AC wiring losses are estimated to be at 2 percent. Transmission and distribution (T&D) losses represent electrical reductions in the output of the inverter from the distribution or substation transformer due to heat losses in the power transmission grid lines. The T&D loss in the power transmission grid lines is expected to be at 7 percent. The total land area required for installation of the solar PV modules was determined to be 227,009 m^2 or 56 acres in the solar site assessment analysis in Chapter 4.1. A summary of the system efficiencies and losses are summarized in Table 28.

4.2.2 Battery sizing

The battery storage units are provided as a back-up option for the solar-PV facility. Since the solar-PV system will be connected to the grid, battery storage units are not mandatory.

For the battery storage design and sizing, it was determined that the General Electric (GE) RSU-4000 model would be suitable for utility-scale power generation plants larger than 5 MW. Appendix B shows the technical specifications for the GE RSU-4000 battery storage unit. This battery cell is a lithium-ion/Nickel-Manganese-Cobalt (NMC) model. It comes with a battery management system with the capability of determining the timing of the charging and discharging limits. Lithium-ion batteries are known for their high efficiencies due to their size, weight, charge rates and energy density. The useable storage capacity of the battery is a function of the total DC load, kWh per day and the number of storage days required. The total DC load which is a function of 25 percent of the annual energy demand of New Waterford, inverter efficiency and MPPT controller efficiency is determined using Equation (3) of (Masters, 2013). The total DC load was calculated to be 31,865.70 kWh per day. It was determined that a total of 3 days of autonomy or storage days will be sufficient for the proposed solar PV-battery storage system given that the primary source of electricity supply for the town of New Waterford is the 607 MW Lingan coal generation plant. The Lingan coal generation plant will supply the remaining 75 percent of the total annual electricity demand. The useable storage capacity is a function of the total DC load and the number of days of autonomy. It was calculated using Equation (4) of (Masters, 2013). The useable storage capacity of the battery was calculated to be 95,597.10 kWh. The total storage capacity of the battery is a function of the useable storage capacity, maximum depth of discharge (MDOD) and temperature and discharge-rate factor (TDR). It was calculated using Equation (5) of (Masters, 2013). The maximum depth of discharge is the percentage of the battery that could be discharged relative to the overall capacity of the battery. Lithium-ion batteries have maximum discharge factors typically between 80% and 95%. An MDOD of 80% or 0.80 has been applied for the GE RSU-4000 battery model. The temperature and discharge-rate factor of 95% or 0.95 has been applied for the GE RSU-4000 battery model based on an ampere-hours capacity of 20 hours (C/20) and a temperature of 25 degrees Celsius. It was determined that the total storage capacity (desired bank capacity) required for the battery storage system is 125,785.66 kWh. The rated energy capacity of the GE RSU-4000 battery model is 4,184 kWh_{DC}. The rated nominal DC voltage of each battery is 1,300 V_{DC}. The nominal bank voltage calculated by SAM is 500.4 V_{DC}. The AC to DC conversion efficiency of the inverter is 96%. Similarly, the DC to AC conversion efficiency of the battery is also 96%. The total number of batteries required was calculated using Equation (6) of (Masters, 2013) by dividing the total storage capacity by the capacity of a single battery. It was determined that a total of 30 GE RSU-4000 battery units are required to provide back-up power storage for the 15MW solar PV system.

It is assumed that the battery will be replaced at the battery bank replacement threshold when its capacity has dropped to 50% of its original capacity. The battery replacement cost will be $400/kWh. The battery unit is connected to the DC side of the inverter. Since the solar-PV system is grid-connected, the battery is designed to be charged from the power grid. Electrical power stored in the battery will be discharged to the solar-PV system during days of low sunlight hours . In order to address intermittency issues due to low sunlight hours during the winter months or during days of inclement weather, it is recommended that a manual dispatch system be used to charge and discharge the battery. This requires the operator to specify the timing of the battery charges and discharges using up to six dispatch periods based on the time-of-day use with a set of weekday and weekend hourly profiles. The manual dispatch controller assumes that the system meets the electric load before charging the battery. When notification is received that a “charge from system” is allowed, the system will charge the battery with any power in excess of the load. The manual dispatch schedule based on time-of-day (TOD) usage is shown in Figure 49. The schedule is labelled 1 to 6 corresponding to the time period shown in the table.

Figure 49. Battery manual dispatch schedule based on time-of-day usage

Weekday

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	5	5	5	5	5	5	5	3	3	3	3	3	6	6	6	6	4	4	4	4	4	4	4	5
Feb	5	5	5	5	5	5	5	3	3	3	3	3	6	6	6	6	4	4	4	4	4	4	4	5
Mar	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Apr	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
May	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Jun	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Jul	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Aug	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Sep	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Oct	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Nov	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Dec	5	5	5	5	5	5	5	3	3	3	3	3	6	6	6	6	4	4	4	4	4	4	4	5

Weekend

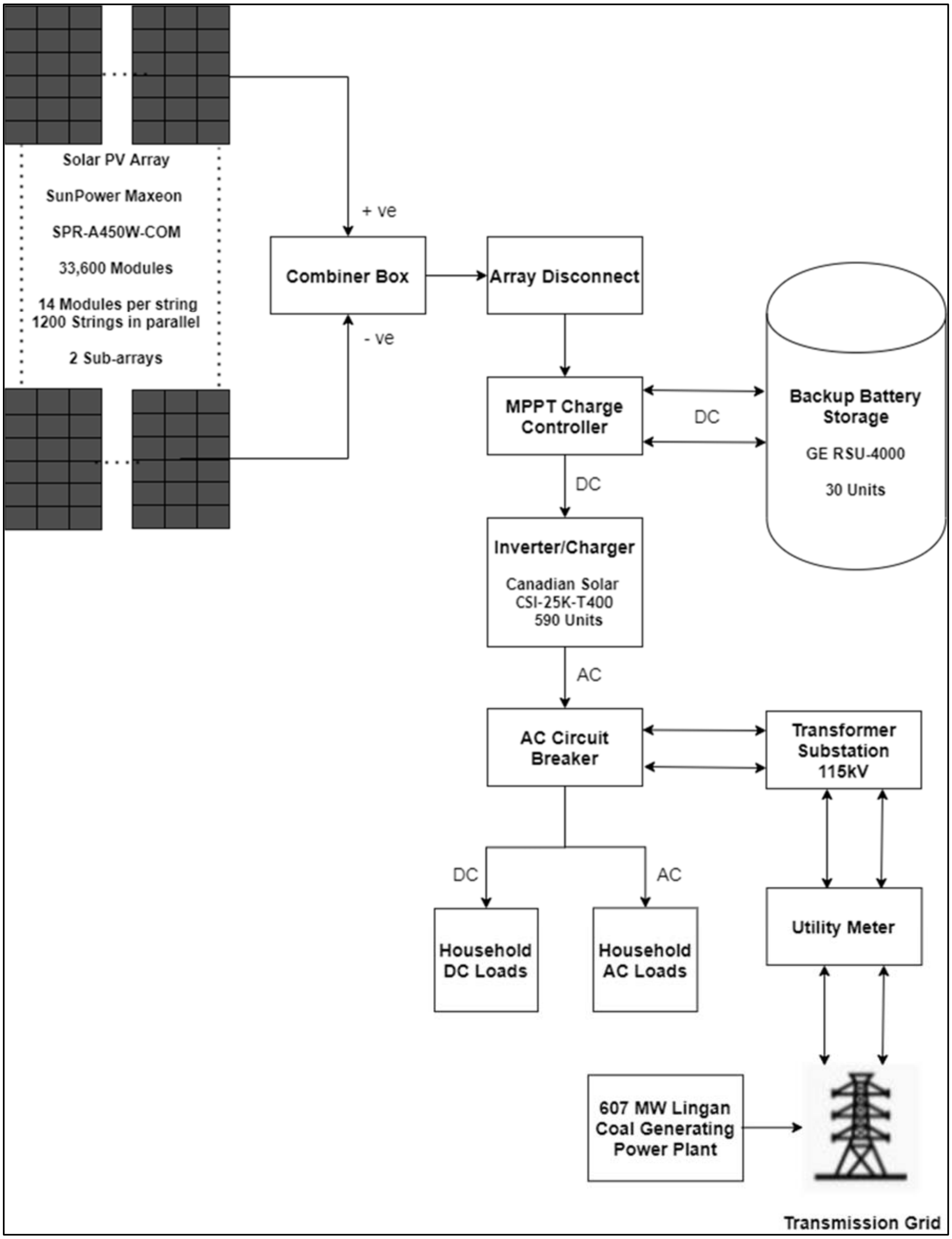
	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Feb	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mar	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Apr	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
May	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jun	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Jul	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Aug	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sep	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Oct	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Nov	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Dec	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

(Note: NREL, 2020a)

4.2.3 Inverter sizing

For the inverter design and sizing, it was determined that the Canadian Solar CSI-25K-T400 model would be the most suitable to support the 15MW DC energy load coming in from 33,600 solar PV modules. Appendix C1 and C2 shows the technical specifications for the Canadian Solar CSI-25K-T400 inverter model. The three-phase string inverter has four maximum power point trackers (MPPTs) to achieve high system energy efficiency. The CSI-25K-T400 inverter model is suitable for commercial utility-scale applications with built-in over-voltage and over-current protection. It also has an advanced thermal design and convection cooling feature. The inverter has a maximum efficiency of 98.8%. The CSI-25K-T400 model is rated for a maximum DC input voltage of 1,100 V_{DC} and a rated AC output voltage of 400 V_{AC}. The maximum PV power (DC input) for each unit is 33 kW or 33,000 W. The rated maximum AC output power for each unit is 25 kW_{AC} or 25,000 W. The rated maximum DC output power for each unit is 26 kW_{DC} or 25,568 kW_{DC}. The MPPT has a voltage range of 200 to 1,000 V_{DC}. The total number of inverters required was calculated using Equation (7) of (Masters, 2013). The total number of inverters required was calculated by dividing the power rating of the PV module, P_{DC} by the total DC capacity of the inverter. It was determined that a total of 590 units of the CSI-25K-T400 inverter units are required to support the 15MW solar-PV system. Figure 50 shows a layout of the Victoria Junction solar-PV battery facility design.

Figure 50. Victoria Junction Solar PV-Battery Facility Layout



(Note: Shim, 2021)

4.3 Power production system analysis

A sensitivity analysis was conducted in Section 3.2.4 to determine the appropriate capacity required for the solar-PV system based on 25% of New Waterford's annual electricity consumption requirements. From the results of the sensitivity analysis, it was determined that there was a shortfall of 900 MWh per month of AC energy production and a surplus of 360 MWh per month of DC energy production respectively for a 10-MW solar-PV system. The 10 MW system would cover 78% and 81% of New Waterford's monthly AC and DC electricity consumption requirements respectively.

For the 12 MW solar-PV system, there was a surplus of 1,710 MWh per month of AC energy production and 3,230 MWh per month of DC energy production. The 12 MW system would cover 82% and 85% of New Waterford's monthly AC and DC electricity consumption requirements respectively. Although, the 12 MW system would generate both excess AC and DC energy production output and meet current electricity consumption requirements, it was decided that the capacity of the PV system would be designed to be slightly higher by increasing it to 15MW to meet New Waterford's future electricity demand needs. Designing for a 15MW system would nearly double the energy reserves stored as compared to the 12MW system. This would reduce the dependency on the coal-fired electricity power grid during the winter months and days with low sunlight hours as the energy reserves stored could be utilized.

The 15 MW solar-PV system has an average AC energy production output of 15,842 MWh per month and an average DC energy production output of 17,663 MWh per month. There was no shortfall in both AC and DC energy production. Instead, there was a surplus in AC energy production of 4,647 MWh per month and DC energy production of 6,468 MWh per month. The excess electricity generated will be stored in the battery units as energy reserves to be used during the winter months and days with low sunlight hours. Excess electricity generated will be sold to the provincial utility company, Nova Scotia Power at an agreed pricing based on the power purchase agreement. The percentage of monthly AC and DC electricity consumption requirements covered by the 15 MW system is 86% and 89% respectively. Therefore, from the results of the energy production sensitivity analysis, it can be concluded that a 15 MW system would meet New Waterford's annual electricity consumption.

4.4 Economic Assessment

The economic assessment of the solar PV system was conducted to compare the economic indicators for three different remediation methods to determine the most viable option. The economics for both Option#1 (Solar-PV geomembrane and traditional remediation method) and Option#2 (Solar-PV geomembrane method) included the equipment and installation costs for the PV system and inverter, and construction costs for site remediation As the solar-PV system is grid-connected, the usage of battery units are optional and not mandatory. The battery units were merely provided as a back-up option. Therefore, the costs for the back-up battery storage units were excluded from the economic evaluations.

4.4.1 Option#1 Solar PV geomembrane and traditional remediation method

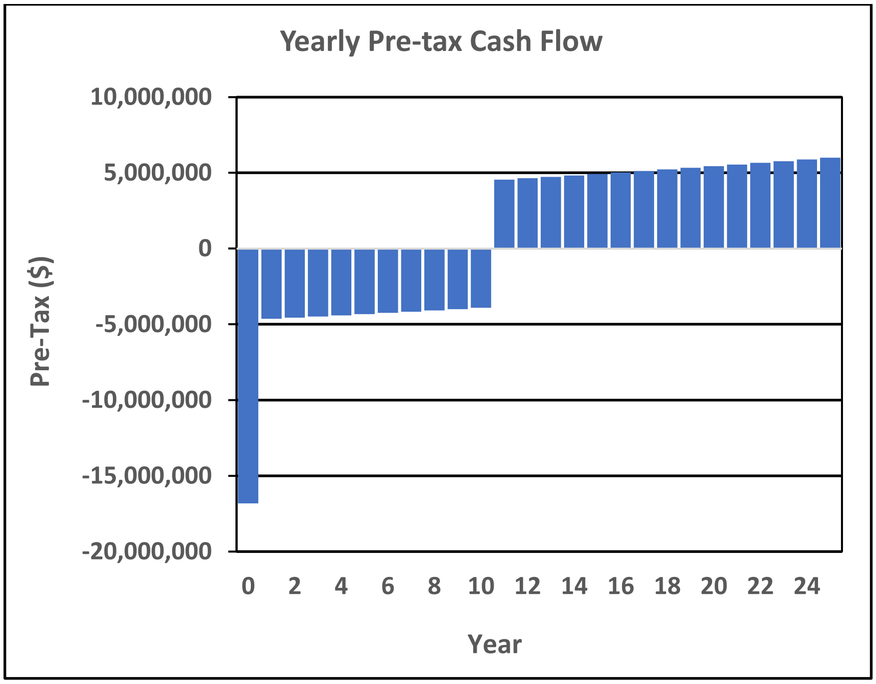
The results of the economic evaluation indicated that the pre-tax equity internal rate of return (IRR) is 1.9%. The expected payback period for the project is 20 years. The net present value (NPV) of the project is expected to be -$27.4M. The calculated benefit-cost (BC) ratio is 0.51. The energy production cost or levelized cost of electricity (LCOE) is expected to be 0.624 $/kWh. The electricity exported to the grid is estimated to be 12,242 MWh. The expected annual revenue from electricity exported to the grid is $4M. The cumulative cash flow at the end of the project economic life of 25 years is expected to be $19M. The yearly pre-tax and cumulative cash flows are shown in Table 29. Figure 51 shows the yearly pre-tax cash flow graph throughout the 25-year economic life of the project. Figure 52 shows the yearly cumulative cash flow graph throughout the 25-year economic life of the project.

Table 29.Yearly cash flows for Option#1-Solar PV geomembrane and traditional remediation

Year	Pre-tax	Cumulative
	$	$
0	-16,820,013	-16,820,013
1	-4,638,219	-21,458,232
2	-4,563,595	-26,021,827
3	-4,487,479	-30,509,307
4	-4,409,841	-34,919,148
5	-4,330,650	-39,249,797
6	-4,249,875	-43,499,672
7	-4,167,484	-47,667,156
8	-4,083,446	-51,750,602
9	-3,997,727	-55,748,328
10	-3,910,293	-59,658,622
11	4,548,290	-55,110,332
12	4,639,255	-50,471,077
13	4,732,041	-45,739,036
14	4,826,681	-40,912,355
15	4,923,215	-35,989,140
16	5,021,679	-30,967,461
17	5,122,113	-25,845,348
18	5,224,555	-20,620,793
19	5,329,046	-15,291,746
20	5,435,627	-9,856,119
21	5,544,340	-4,311,780
22	5,655,226	1,343,447
23	5,768,331	7,111,778
24	5,883,698	12,995,475
25	6,001,372	18,996,847

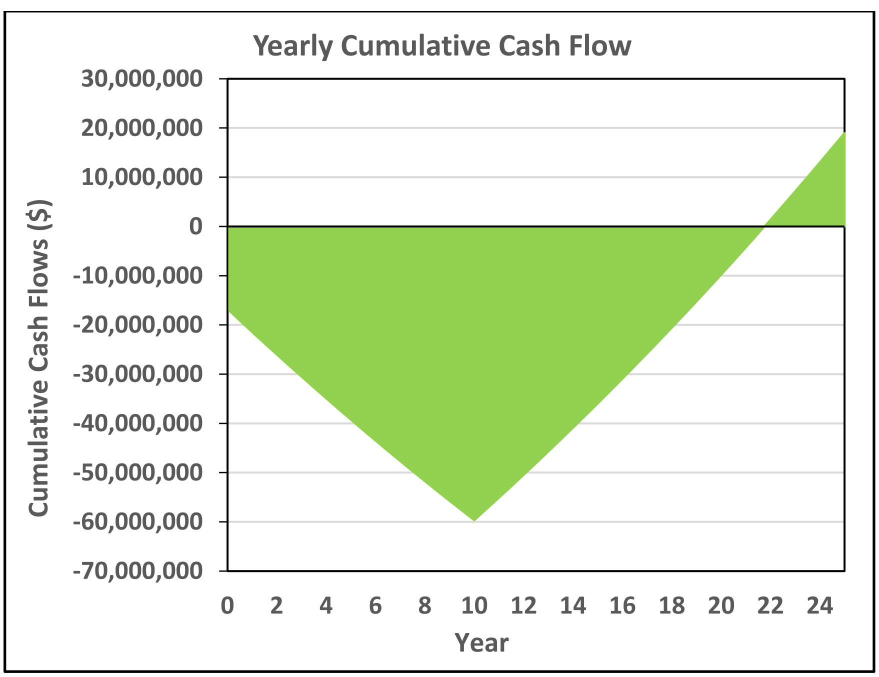
Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 51. Yearly pre-tax cash flow for Option#1-Solar PV geomembrane and traditional remediation



Note: Figure developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 52. Yearly cumulative cash flow for Option#1-Solar PV geomembrane and traditional remediation



Note: Figure developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

4.4.2 Option#2 Solar PV geomembrane remediation method

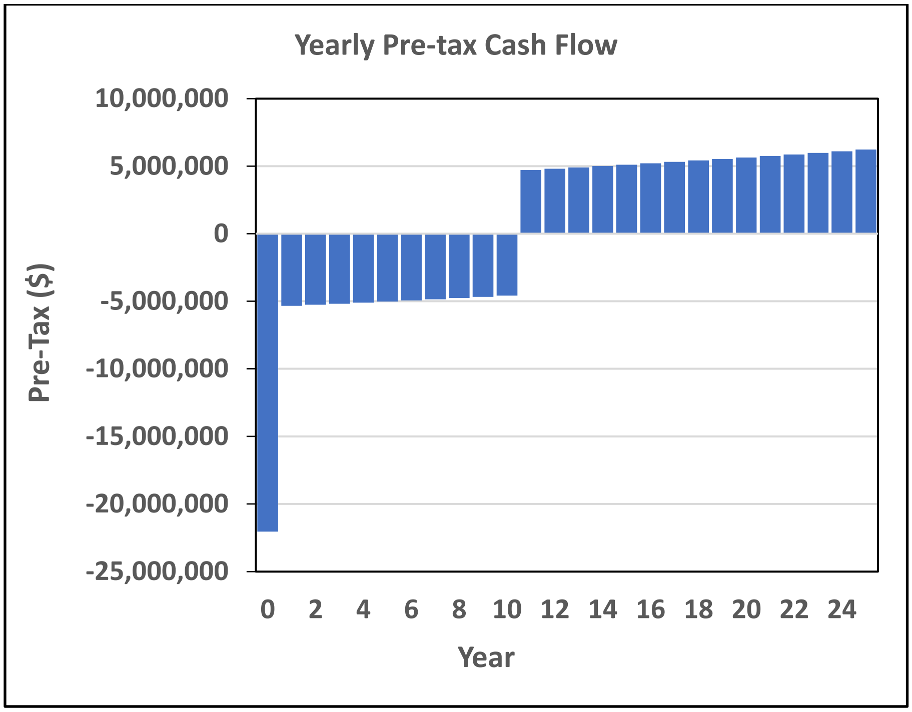
The results of the economic evaluation indicated that the pre-tax equity internal rate of return (IRR) is 0.9%. The expected payback period for the project is 22 years. The net present value (NPV) of the project is expected to be -$36.4M. The calculated benefit-cost (BC) ratio is 0.41. The energy production cost or levelized cost of electricity (LCOE) is expected to be 0.699 $/kWh. The electricity exported to the grid is estimated to be 12,242 MWh. The expected annual revenue from electricity exported to the grid is $4M. The cumulative cash flow at the end of the project economic life of 25 years is expected to be $9.8M. The yearly pre-tax and cumulative cash flows is shown in Table 30. Figure 53 shows the yearly pre-tax cash flow graph throughout the 25-year economic life of the project. Figure 54 shows the yearly cumulative cash flow graph throughout the 25-year economic life of the project.

Table 30. Yearly cash flows for Option#2-Solar PV/geomembrane remediation

Year	Pre-tax	Cumulative
	$	$
0	-22,042,984	-22,042,984
1	-5,337,992	-27,380,976
2	-5,260,643	-32,641,619
3	-5,181,747	-37,823,366
4	-5,101,274	-42,924,640
5	-5,019,190	-47,943,831
6	-4,935,466	-52,879,296
7	-4,850,066	-57,729,362
8	-4,762,959	-62,492,321
9	-4,674,109	-67,166,431
10	-4,583,483	-71,749,914
11	4,714,390	-67,035,523
12	4,808,678	-62,226,845
13	4,904,852	-57,321,993
14	5,002,949	-52,319,044
15	5,103,008	-47,216,036
16	5,205,068	-42,010,968
17	5,309,169	-36,701,799
18	5,415,353	-31,286,446
19	5,523,660	-25,762,786
20	5,634,133	-20,128,653
21	5,746,816	-14,381,838
22	5,861,752	-8,520,086
23	5,978,987	-2,541,099
24	6,098,567	3,557,468
25	6,220,538	9,778,006

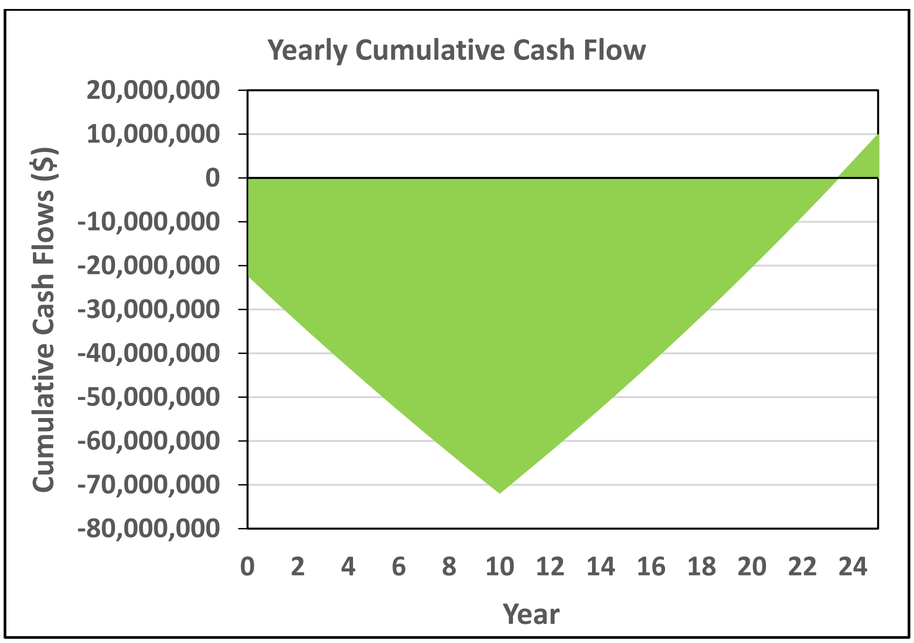
Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 53. Yearly pre-tax cash flow for Option#2-Solar PV geomembrane remediation



Note: Figure developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 54. Yearly cumulative cash flow for Option#2-Solar PV geomembrane remediation



Note: Figure developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

4.4.3 Comparison of economic indicators

Table 31. Comparison of economic indicators 1

Option #	Remediation Method	Initial Cost	O&M Cost	Pre-Tax IRR Equity	Simple Payback
		$M	$M/yr	%	Yrs.
1	Solar PV-Geomembrane & Traditional Remediation	112.2	0.38	1.9	20
2	Solar PV-Geomembrane	123.4	0.25	0.9	22.1
3	Traditional Remediation	111.5	0.22	0	0

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 32. Comparison of economic indicators 2

Option #	Remediation Method	Cumulative Cashflow at Year 25	Energy Production Cost	Total Annual Revenue
		$M	$/kWh	$M/yr
1	Solar PV-Geomembrane & Traditional Remediation	19	0.62	4.04
2	Solar PV-Geomembrane	10	0.70	4.04
3	Traditional Remediation	0	0	0

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

The comparison of economic indicators in Table 31 shows that Option#1, the combination of solar-PV geomembrane and traditional remediation method has the second highest initial capital cost of $112.2M and the highest annual operations and maintenance (O&M) cost of $0.38M/yr. The benefit-cost ratio shown in Table 16 is 0.51 which is less than 1.0. This indicates that the project costs exceeds the cash flow of the project. The net present value (NPV) of $-27.4M indicates that the expected rate of return earned for Option#1 is less than the project discount rate of 9%. The expected IRR for Option#1 is 1.9%. The negative present value also indicates that the project investment cost of $112.2M outweighs the total revenue generated at the end of the economic life of the project which is $101M. This number was derived by multiplying the total annual revenue of $4.04M per year by the economic life of the project which is 25 years. Option#1 has the highest cumulative cash flow at the end of 25 years of $19M. The expected energy production cost is $0.62/kWh. Table 32 shows the cumulative cash flow at end of 25 years, energy production cost and total annual revenue for Option#1.

The comparison of economic indicators in Table 31 shows that Option#2, the solar-PV geomembrane remediation method has the highest initial capital cost of $123.4M and the second highest annual operations and maintenance (O&M) cost of $0.25M/yr. The benefit-cost (B-C) ratio shown in Table 19 is 0.41 which is less than 1.0. This indicates that the project costs exceeds the cash flow of the project. The net present value (NPV) of $-36.4M that the expected rate of return earned for Option#2 is less than the project discount rate of 9%. The expected IRR for Option#2 is 0.9%. The negative present value also indicates that the project investment cost of $123.4M outweighs the total revenue generated at the end of the economic life of the project which is $101M. This number was derived by multiplying the total annual revenue of $4.04M per year by the economic life of the project which is 25 years. Option#2 has the second highest cumulative cash flow at the end of 25 years of $10M. The expected energy production cost is $0.70/kWh. Table 32 shows the cumulative cash flow at end of 25 years, energy production cost and total annual revenue for Option#2.

Table 31 and Table 32 shows that Option#3 does not generate any cumulative cash flow or annual revenue as there is no electricity production from the site. This method is not expected to generate any internal rate of return (IRR) but only incur annual operations and maintenance costs of $0.22M/yr.

4.5 Analysis of greenhouse gas (GHG) emissions

Table 33.Comparison of greenhouse gas (GHG) emission reductions

Description	Remediation Method	Facility Type	GHG Emission
			$tC0_2$
Base	None	Coal-fired Generation	13,140.70
Proposed	Option # 1 and 2	Solar PV Facility	919.90
Gross annual GHG emission reduction			**12,220.80**

Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Table 34. Comparison of greenhouse gas (GHG) emission reductions and costs

Option	Remediation Method	GHG Reduction	GHG Reduction Cost
		$tC0_2$/year	\$/$tC0_2$
1	PV-Geomembrane & Traditional Remediation	12,221	228
2	PV-Geomembrane	12,221	302
3	Traditional Remediation [1,2]	441	197

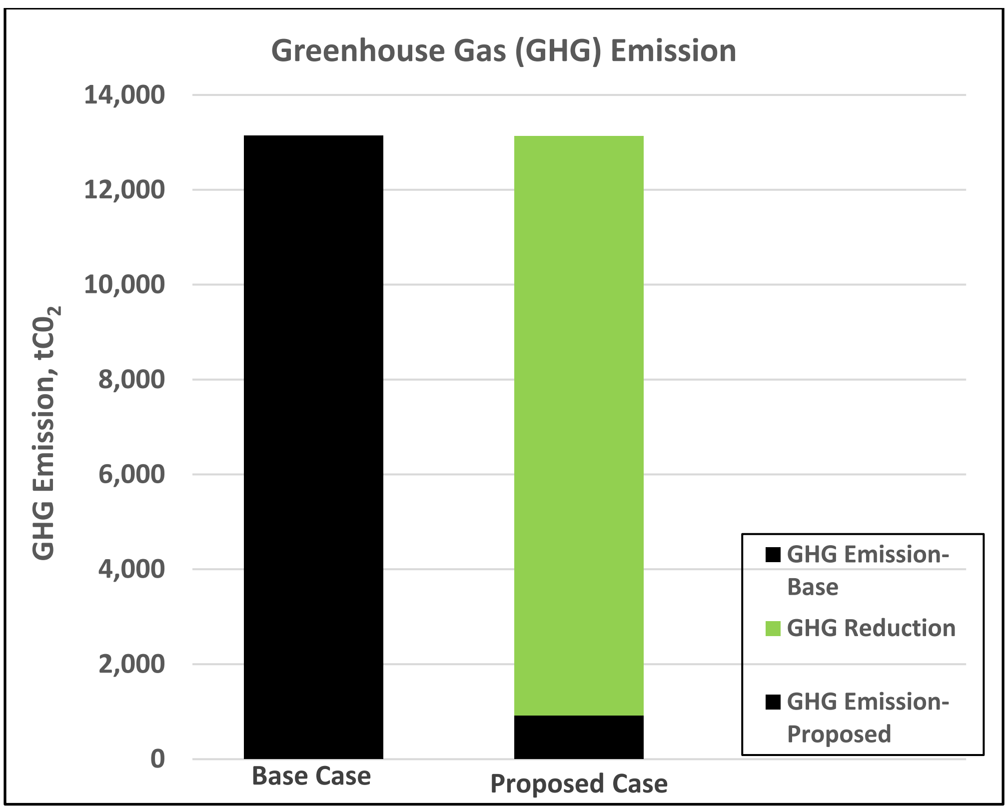
Note: Table developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Notes:

1. GHG emissions reduction for vegetation restoration: 7.6 tC02/ha./year

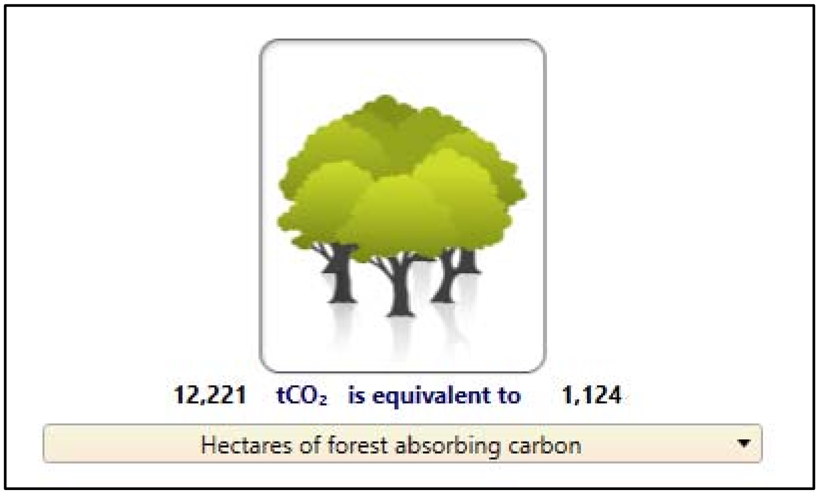
2. GHG reduction cost for vegetation restoration: $1,500/ha./year

Figure 55. Comparison of greenhouse gas (GHG) emission reduction



Note: Figure developed by (Shim, 2021); Data from RETScreen (NRCAN, 2021)

Figure 56. Greenhouse gas (GHG) emission reduction equivalence



(Note: NRCAN, 2021)

Table 33 shows a comparison between the greenhouse gas (GHG) emission reduction between the base case and the proposed case. The base case is the amount of GHG emissions produced by the coal-fired power generation plant. The proposed case is the amount of GHG emissions generated by the solar PV facility through transmission and distribution (T&D) losses in the power grid lines. The proposed case is Option#1 and Option#2 which consist of solar PV modules as part of the site remediation process. The annual amount of GHG emissions generated by the base case and the proposed case is 13,140.7 tCO_2/yr. and 919.9 tCO_2/yr. respectively. The gross annual GHG emission reduction is derived by deducting the amount of GHG emissions generated by the proposed case from the base case. The gross annual GHG emission reduction is 12,220.9 tCO_2/yr. Figure 55 shows a graph of the comparison of GHG emission reductions for the base case and proposed case. Figure 56 shows the GHG emission reduction of 12,220.9 tCO_2/yr. by installing the solar PV facility which is equivalent to 1,124 hectares of forest absorbing carbon.

Table 34 shows a comparison between the greenhouse gas (GHG) emission reductions and costs for the three different remediation methods. The amount of GHG reduction for both Option#1 and Option#2 calculated by RETScreen is 12,220.9 tCO_2 per year. The amount of GHG emission reduction calculated for Option#3 is 441 tCO_2 per year. Greenhouse gas (GHG) emission reduction for vegetative restoration in a dry temperate climatic region with pine tree/shrub species is estimated to be an average of 7.6 tCO_2/ha/yr. (Bernal et al., 2018). The site remediation area for Option#3 is 143 acres or 58 hectares. The amount of GHG emission reduction was determined by multiplying the average CO_2 removal rate for vegetation restoration and the total remediation area.

The total GHG reduction costs calculated for Option#1 and Option#2 are $228 per tCO_2 and $302 per tCO_2 respectively. The total GHG reduction cost calculated for Option#3 is $197 per tCO_2. This is based on a GHG reduction cost for vegetative restoration of $1,500/ha./$tCO_2$/yr. (Reij et al., 2017). The site remediation area for Option#3 is 143 acres or 58 hectares.

4.6 Survey study

A survey study was conducted to seek the public's opinion on how the proposed installation of a solar photovoltaic farm at the Victoria Junction Tailings Dam will impact the three pillars of sustainable development-social, economic and environmental.

The participants included in the research study are:

1) Individual homeowners and renters residing in the communities of Sydney and New Waterford.

2) Business owners for retail outlets, restaurants, cafeterias, bars, automotive service stations, health and fitness centres.

3) Management and staff of financial institutions, universities, schools, recreational facilities, hospitals, long-term care facilities, hotels, airport, shopping malls, museums, engineering, mining and environmental consulting companies.

The potential participants were initially contacted through a recruitment e-mail to obtain their consent to participate in the survey. If the individual agrees to participate in the survey, he or she will click on a link in the recruitment e-mail that contains an electronic survey questionnaire. The electronic questionnaire was created in an on-line survey tool called

Qualtrics (Qualtrics, 2021). There were a total of 23 questions. The set of questions are shown in Appendix J. The survey study commenced on July 19, 2021 and closed on August 19, 2021. A total of fifteen recruitment e-mails were sent out to potential participants. There were six respondents that were willing to participate in the survey study. Nine respondents replied that they were not interested in participating. The responses to the 23 questions are shown in Table 35. The responses received from the survey study showed that sixty percent (60%) of the respondents strongly agreed that renewable energy technologies will be a good fit for their communities. All (100%) of the respondents answered that they would like to see their utility service provider invest more in renewable energy technologies. Only half (50%) of the respondents agree that their current energy supply that powers their community meets their expectations. Eighty percent (80%) of the respondents supported the idea of installing a solar photovoltaic power generation facility in their community. Sixty percent (60%) of the respondents neither agree nor disagree that the installation of a solar farm in their community will lower the cost of their utility bill. Seventy five percent (75%) of the respondents agreed that the installation of a solar photovoltaic facility in their community will not reduce the cost of electricity. Eighty percent (80%) of the respondents strongly agreed that the installation of a solar farm in their community will reduce greenhouse gas emissions, mitigate air pollution problems, and improve the environment. Half (50%) of the respondents strongly agreed to the idea of decommissioning the Victoria Junction Tailings Basin and repurpose the land to build a solar power generation facility. Eighty percent (80%) of the respondents agreed that the proposed construction and commissioning of a photovoltaic power generation facility in their community will create job opportunities and boost the local economy. All (100%) of the respondents strongly agreed that replacing coal-fired power generation plants with renewable energy power generation plants will help improve the environment. There was mixed response when it comes to the question of whether relying solely on renewable energy as their main source of power will change the participants' daily household energy consumption usage. Forty percent (40%) of the respondents disagreed and forty percent (40%) agreed, while the other twenty percent (20%) neither agreed nor disagreed.

Table 35. Responses to survey questions

Participant	Survey Questions											
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
1	Strongly Agree	Agree	Strongly Disagree	Between \$100 to \$500	Invest more in renewable energy	Meets my expectation	Yes	Neither Agree or Disagree	Agree	Strongly Agree	Agree	Agree
2	Agree	Agree	Disagree	Between \$100 to \$500	Invest more in renewable energy	Meets my expectation	Yes	Agree	Strongly Agree	Strongly Disagree	Neither Agree or Disagree	Agree
3	Strongly Agree	Neither Agree or Disagree	Disagree	Less than \$100	Invest more in renewable energy	Meets my expectation	Yes	Disagree	Strongly Agree	Strongly Agree	Agree	Strongly Agree
4	Strongly Agree	Agree	Strongly Disagree	Between \$100 to \$500	Invest more in renewable energy	Does not meet my expectation	Yes	Neither Agree or Disagree	Strongly Agree	Strongly Agree	Agree	Neither Agree or Disagree
5	Neither Agree or Disagree	Strongly Agree	Disagree	Less than \$100	Invest more in renewable energy	Exceeds my expectation	Unsure	Neither Agree or Disagree	Strongly Agree	Agree	Agree	Disagree
6	Agree	Agree	Strongly Agree	Between \$100 to \$500	Invest more in renewable energy	Does not meet my expectation	Yes	Strongly Disagree	Strongly Agree	Agree	Strongly Agree	Strongly Disagree

Participant	Survey Questions										
	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23
1	Disagree	Strongly Agree	Agree	Strongly Agree	Disagree	Advanced	Rent	Greater than 4	Employed	Full time	Other
2	Neither Agree or Disagree	Agree	Agree	Agree	Agree	Basic	Own	Less than 4	Employed	Full time	Other
3	Neither Agree or Disagree	Strongly Agree	Neither Agree or Disagree	Agree	Neither Agree or Disagree	Advanced	Own	Greater than 4	Unemployed (Student)	Part time	Environment
4	Strongly Agree	Strongly Agree	Agree	Agree	Agree	Basic	Rent	Exactly 4	Unemployed (Student)	N/A	N/A
5	Strongly Agree	Strongly Agree	Agree	Strongly Agree	Neither Agree or Disagree	Basic	Rent	Exactly 4	Employed	Full time	Agriculture
6	Strongly Disagree	Strongly Agree	Agree	Disagree	Agree	Advanced	Own	Less than 4	Self-employed	Full time	Other

Note: Table developed by (Shim, 2021); Data from Qualtrics (Qualtrics, 2021)

Chapter 5.0 Conclusion, limitations, and recommendations

5.1 Conclusion

Based on the feasibility study of the project, it can be concluded that abandoned mine tailings sites can be utilized as solar PV farms. The research concluded that the Victoria Junction mine tailings site can be utilized for the installation of a solar PV facility based on the techno-economic assessment. The total land area of the mine tailings site that is suitable for solar PV installation is 227,009 m^2 or 56 acres. The solar irradiance potential of the useable area is 1,056 kWh/m^2. The total electrical energy production that can be generated from the solar PV facility installed on the mine tailings site is 15 MW or 15,842,415 kWh/yr.

Based on the comparison of the results of the economic assessment and greenhouse gas (GHG) emissions reduction analysis, it can be concluded that Option#1 which is a combination of solar PV geomembrane and traditional remediation method would be the recommended option. Although Option#3 which is the traditional remediation has the lowest initial capital cost of $111.5M and annual O&M cost of $0.22M per year among all the three options, there is no electrical energy produced from the site. Hence, this remediation method does not generate any internal rate of return (IRR) nor annual electricity revenue. The traditional remediation method does not generate any cash flow. Option#1 has an IRR of 1.9% and a simple payback period of 20 years. This remediation method generates the highest cumulative cashflow of $19M at the end of the economic life of the project at 25 years. The expected GHG emission reduction for both Option#1 and Option#2 is 12,221 tCO_2 per year. The GHG emission reduction for Option#3 is 441 tCO_2 per year. Therefore, the amount of GHG emission reduction for both Option#1 and Option#2 is 96% higher than that for Option#3. Option#1 has a GHG reduction cost of $228 t/CO2 which is lower than that for Option#2 with a GHG reduction cost of $303 t/CO_2. The energy production cost for Option#1 is $0.62/kWh compared to the energy production cost for Option#2 of $0.70/kWh. Option#3 does not incur any energy production cost as there is no electricity generated from this remediation method. Option#1 has a total annual revenue of $4.04M per year from electricity exported to the grid compared to Option#3 which does not generate any annual electricity revenue.

The economics for both Option#1 (Solar-PV geomembrane and traditional remediation method) and Option#2 (Solar-PV geomembrane method) included the equipment and installation costs for the PV system and inverter, and construction costs for site remediation. As the solar-PV system is grid-connected, the usage of battery units are optional and not mandatory. The battery units were provided as a back-up option. Therefore, the costs for the back-up battery storage units were excluded from the economic evaluations for Option#1 and Option#2. It was determined in Section 5.2.2 that the total useable storage capacity of the battery unit calculated by SAM is 95,597.10 kWh. The installed cost per unit capacity is $400/kWh (based on Lithium-ion batteries with a PV system capacity greater than 50,000 kWh). Therefore, the cost for a battery storage capacity of 95,597.10 kWh is estimated to be $38.2M. The results of the economic evaluation indicated that the IRR for Option#1 was 1.9% with a payback period of 20 years. The NPV of the project was estimated to be -$27.4M. Option#2 has an IRR of 0.9% with a payback period of 22 years. The NPV of the project was estimated to be -$36.4M. Therefore, it is expected that Option#1 and Option#2 will not yield any rates of return or annual revenue by adding the cost of the battery units. The cost of battery units is expected to further decrease the NPV of the project and generate negative cumulative cash flows. Hence, it can be justified that adding a battery option to the solar-PV system is not economical.

Based on the results of the survey study, it can be concluded that sixty percent (60%) of the respondents strongly agreed that renewable energy technologies will be a good fit for their communities. Eighty percent (80%) of the respondents supported the idea of installing a solar photovoltaic power generation facility in their community. Eighty percent (80%) of the respondents agreed that the proposed construction and commissioning of a photovoltaic power generation facility in their community will create job opportunities and boost the local economy. All (100%) of the respondents strongly agreed that replacing coal-fired power generation plants with renewable energy power generation plants will help improve the environment. However, sixty percent (60%) to seventy-five percent (75%) of the respondents neither agree nor disagree that the installation of a solar farm in their community will lower the cost of electricity.

5.2 Limitations

Hourly electrical consumption reports specifically for the town of New Waterford were not available for download from Nova Scotia Power Inc's website as installation of smart metering system are still in progress in the province. Therefore, monthly consumption data had to be interpolated from the provincial load data from monthly reports available on Nova Scotia Power's Open Access Same-Time Information System (OASIS) website. The monthly electricity load data for the town of New Waterford had to be interpolated from the provincial load data by taking a ratio of the total number of households in New Waterford to the province of Nova Scotia and multiplying by the percentage of residential electricity consumption demand.

Shading analysis of the dry mine tailings terrain was conducted using the ArcGIS software to account for the shadow effects on the PV modules caused by the surrounding topography. The Solmetric SunEye shade tool and software would normally be used generate shading data using an altitude-azimuth angle table was not used due to the cost and capital budget constraints for this project. Shading analysis was instead conducted using the "Area Solar Radiation" and "Hillshade" tool in ArcGIS to simulate shading effects. These solar radiation and shading data were then used as input parameters in SAM to calculate suitable areas for PV installation, annual energy production output and sizing of the PV system. There is a limitation in the SAM software that solar radiation and hillshade data from ArcGIS cannot be imported directly into the software. Beam and diffuse shading data can only be imported into SAM from the PVSyst, Solmetric Suneye and Solar Pathfinder software.

5.3 Recommendations

Recommendations for future work include:

1. The technical and economic feasibility of this project was limited to the solar radiation assessment of the dry mine tailings site using ArcGIS and SAM. It is recommended that

further studies be conducted to assess the structural integrity of the mine tailings foundation to support the solar PV system. A thorough research study of the characteristics and geotechnical properties of the mine tailings should be conducted.

2. A research study for a floating PV system for the Victoria Junction mine tailings site to investigate the solar photovoltaic potential of PV modules installed on water surface. It will be interesting to study the effects of reflected light from the water surface, fog and water flow on the performance efficiencies of the solar PV modules.

3. A research study for a laminated PV-geomembrane system for the Victoria Junction mine tailings site to compare the solar photovoltaic potential and economics of laminated PV's adhered on top of geomembranes compared to the three remediation options proposed for this project.

4. A storm water drainage and water pumping system to distribute water collected from the side of the solar PV panels to surrounding residential, businesses and industrial communities in Cape Breton.

5. Land permitting, zoning and provincial environmental regulations on post-closure mine tailings use for installation of solar PV facilities.

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Appendix A1. Technical specifications for SunPower SPR-A450W-COM PV module

A SERIES

SUNPOWER®

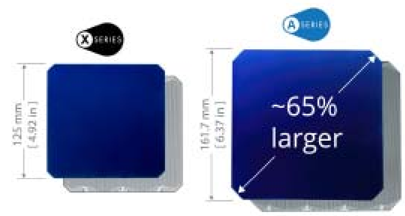
430–450 W Commercial A-Series Panels

SunPower® Maxeon® Technology

SunPower® Maxeon® cell-based panels maximize energy production and savings by combining industry-leading power, efficiency, and durability with the best power, product, and service warranty in the industry.[1,2]

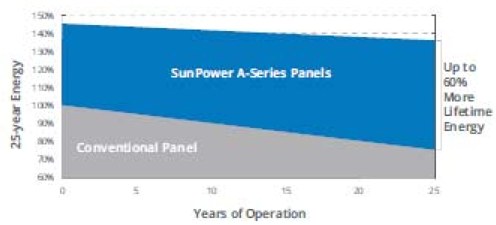
Highest Power Density Available

SunPower's new Maxeon® Gen 5 cell is 65% larger than prior generations, delivering the most powerful cell and highest efficiency panel in commercial solar. The result is more power per square meter than any commercially available solar.[1]



Maximum Lifetime Energy and Savings

Designed to deliver up to 60% more energy from the same space over the first 25 years in real-world conditions like partial shade and high temperatures.[1]



Best Reliability, Best Warranty

SunPower technology is proven to last and we stand behind our panels with the industry's best 25-year Combined Power, Product and Service Warranty.

BETTER PRODUCT · BETTER WARRANTY
25-yr SunPower Complete Confidence

SUNPOWER MAXEON SOLAR CELL TECHNOLOGY

Fundamentally Different.
And Better.

- Most efficient cell in commercial solar[2]
- Delivers unmatched reliability[3]
- Patented solid metal foundation prevents breakage and corrosion

As sustainable as the energy it produces.

- Achieved the #1 ranking on the Silicon Valley Toxics Coalition's Solar Scorecard for 3 years running
- SunPower modules can contribute to your business's LEED certification[4]

sunpower.com

(Note: SunPower,2021)

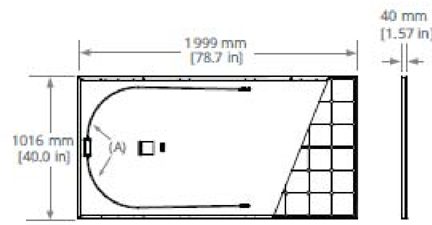
Appendix A2. Technical specifications for SunPower SPR-A450W-COM PV module

430–450 W Commercial A-Series Panels

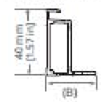
Electrical Data	SPR-A430-COM	SPR-A440-COM	SPR-A450-COM
Nominal Power (Pnom)[5]	430 W	440 W	450 W
Power Tolerance	+5/0%	+5/0%	+5/0%
Panel Efficiency	21.2%	21.7%	22.2%
Rated Voltage (Vmpp)	42.7 V	43.4 V	44.0 V
Rated Current (Impp)	10.1 A	10.2 A	10.2 A
Open-Circuit Voltage (Voc)	51.2 V	51.6 V	51.9 V
Short-Circuit Current (Isc)	10.9 A	10.9 A	11.0 A
Max. System Voltage		1500 V UL	
Maximum Series Fuse		20 A	
Power Temp Coef.		−0.29% / ° C	
Voltage Temp Coef.		−136 mV / ° C	
Current Temp Coef.		5.7 mA / ° C	

Operating Condition And Mechanical Data	
Temperature	−40° F to +185° F (−40° C to +85° C)
Impact Resistance	1 inch (25 mm) diameter hail at 52 mph (23 m/s)
Appearance	Class A
Solar Cells	72 Monocrystalline IBC cells
Tempered Glass	High-transmission tempered anti-reflective
Junction Box	IP-68, TE (PV4S)
Weight	47.7 lbs (21.6 kg)
Max. Load	Wind: 75 psf, 3500 Pa, 357 kg/m² front & back Snow: 125 psf, 6000 Pa, 612 kg/m² front
Frame	Class 2 silver anodized

Tests And Certifications	
Standard Tests	UL1703
Quality Management Certs	ISO 9001:2015, ISO 14001:2015
EHS Compliance	OHSAS 18001:2007, lead free, Recycle Scheme
Ammonia Test	IEC 62716 (Pending)
Desert Test	MIL-STD-810G (Pending)
Salt Spray Test	IEC 61701 (maximum severity) (Pending)
PID Test	1500 V: IEC 62804
Available Listings	UL, CEC



FRAME PROFILE



(A) Cable Length: 1320 mm +/-10 mm [52 in +/-0.4 in]
(B) Long Side: 32 mm [1.3 in]
Short Side: 24 mm [0.9 in]

Please read the safety and installation guide.

1 SunPower 450 W, 22.2% efficient, compared to a Conventional Panel on same-sized arrays (310 W, 16% efficient, approx. 2.0 m²), 4.9% more energy per watt (based on PVSyst pan files for avg US climate), 0.5%/yr slower degradation rate (Jordan, et. al. "Robust PV Degradation Methodology and Application." PVSC 2018).
2 Based on search of datasheet values from websites of top 20 manufacturers per IHS, as of January 2019.
3 #1 rank in "Fraunhofer PV Durability Initiative for Solar Modules: Part 3". PVTech Power Magazine, 2015. Campeau, Z. et al. "SunPower Module Degradation Rate," SunPower white paper, 2013.
4 A-Series panels additionally contribute to LEED Materials and Resources credit categories.
5 Standard Test Conditions (1000 W/m² irradiance, AM 1.5, 25° C). NREL calibration Standard: SOMS current, LACCS FF and Voltage.

See www.sunpower.com/company for more reference information.
For more details, see extended datasheet: www.sunpower.com/solar-resources.
Specifications included in this datasheet are subject to change without notice.

SUNPOWER®

1-800-SUNPOWER

532726 Rev C / LTR_US

sunpower.com

(Source: SunPower,2021)

Appendix B. Technical specifications for General Electric RSU-4000 battery storage unit

PRODUCT DATA	UNITS	ENERGY STORAGE UNIT RSU-4000
Nameplate Energy Capacity	kWh_{DC}	4184
Maximum Power	kW_{DC}	1300
Maximum DC Current	A	1760
DC PARAMETERS		
Battery Management System		GE Blade Protection Unit (BPU)
Compatible Inverters		GE RIU-2500
Inverter Connections		1
Augmentation Option for Lifecycle Management		Yes
Design Life	Years	20
BATTERY INFORMATION		
Battery Chemistry		Lithium-Ion / NMC
Continuous Discharge Rate; Pulse Discharge Rate	CP	<C/3; <C/3
Voltage Class	V	1500
Nominal DC Voltage	V	1300
Minimum DC Voltage	V	790
MECHANICAL INFORMATION		
Dimensions (L x W x H)	mm	6058 X 2438 X 2890
Package Format		20' High-Cube ISO (Exterior Access)
Fully Integrated HVAC		Dual Self-Contained High Efficiency Units
Fire Suppression		Stat-X (Aerosol)
Installation		Pad / Pier
Cable Entry		Bottom
NEMA Rating / IP Class		NEMA 3R / IP 54
DESIGN CONDITIONS		
Operating Temperature Range	°C	-20 (-40 w/ optional equipment package) to +50
Maximum Altitude	m	2000
Seismic		UBC Zone 4
Audible Noise (at 3m)	dBA	<70
CERTIFICATIONS & COMPLIANCE		
Certifications†		UL: 9540, 1973, 1741; UN38.3; CE; EMC
Compliance†		NFPA 70; IEEE C37.32; IEC: 62933, 62619, 60204; ASTM4169

†As of January 2020. Full list of certifications and compliance standards available upon request.

www.ge.com/energystorage

(Source: GE Energy, 2021)

Appendix C1. Technical specifications for Canadian Solar CSI-25K-T400 inverter

CanadianSolar

THREE PHASE STRING INVERTER 25-40 KW

CSI-25K-T400 | CSI-30K-T400
CSI-33K-T400 | CSI-36K-T400 | CSI-40K-T400

Canadian Solar's grid-tied, transformer-less string inverters help to accelerate the use of three-phase string architecture for commercial rooftop and small ground-mount applications. An NRTL approved, cost-effective alternative to MLPE, these inverters are modular design building blocks that provide high yield and enable significant BoS cost savings. They provide up to 98.8% conversion efficiency, a wide operating range of 180-1000 V_{DC}, and four MPPTs for maximum energy harvest.

5 years Standard warranty, extension up to 20 years

KEY FEATURES

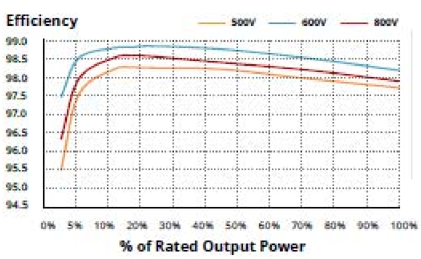
- Maximum efficiency of 98.8%, Maximum EU efficiency of 98.3%
- Four MPPTs to achieve higher system efficiency
- Strings intelligent monitoring, Smart I-V Curve Dignosis supported
- Up to 30% DC input oversize, 13A input for each PV sting

HIGH RELIABILITY

- Advanced thermal design and convection cooling
- Built in over-voltage and over-current protection
- DC reverse polarity and AC short circuit protection
- Fuse free design

EFFICIENCY CURVE

CSI-40K-T400GL02-E



*For detailed information, please refer to the Installation Manual.

BROAD ADAPTIBILITY

- IP65 rated for outdoor application
- Utility interactive controls: Active power derating, reactive power control and over frequency derating
- Integrated DC load rated disconnects
- Wide MPPT range for flexible string sizing
- High switching frequency and ultra fast MPPT for maximum efficiency over a wide load range

CANADIAN SOLAR INC. is committed to providing high quality solar products, solar system solutions and services to customers around the world. No. 1 module supplier for quality and performance/price ratio in IHS Module Customer Insight Survey. As a leading PV project developer and manufacturer of solar modules with over 40 GW deployed around the world since 2001.

CANADIAN SOLAR INC.
545 Speedvale Avenue West, Guelph, Ontario N1K 1E6, Canada, www.canadiansolar.com

(Source: CanadianSolar, 2021)

Appendix C2. Technical specifications for Canadian Solar CSI-25K-T400 inverter

SYSTEM/TECHNICAL DATA					
MODEL NAME	**CSI-25K-T400GL02-E**	**CSI-30K-T400GL02-E**	**CSI-33K-T400GL02-E**	**CSI-36K-T400GL02-E**	**CSI-40K-T400GL02-E**
DC INPUT					
Max. PV Power	33kW	39kW	43kW	47kW	52 kW
Max. DC Input Voltage	1100 V_{DC}				
Start-up DC Input Voltage/Power	180 V_{DC}				
Number of MPP Trackers	3			4	
MPPT Voltage Range	200 - 1000 V_{DC}				
Max. Input Current (Imp)	78A (26A per MPPT)			104A (26A per MPPT)	
Max. Short Circuit Current (Isc)	120A (40A per MPPT)			160A (40A per MPPT)	
Number of DC Inputs	6 (2 per MPPT)			8 (2 per MPPT)	
DC Disconnection Type	Load rated DC switch				
AC OUTPUT					
Rated AC Output Power	25 kW	30 kW	33 kW	36 kW	40 kW
Max. AC Output Power	27.5 kW	33 kW	36.3 kW	39.6 kW	44 kW
Rated Output Voltage	400 V_{AC}				
Grid Connection Type	3 W / N / PE				
Rated Grid Output Current	36 A	43.3 A	47.6 A	51.9 A	57.7 A
Max Output Current	41.8 A	50.2 A	55.1 A	60.2 A	66.9 A
Rated Output Frequency	50 / 60 Hz				
Output Frequency Range*	47 - 52 / 57 - 62 Hz				
Power Factor	>0.99 (0.8 leading ... 0.8 lagging)				
Current THD	< 3%				
DC Injection Current	< 0.5 % of Rated Grid Output Current				
SYSTEM					
Max. Efficiency	98.8 %				
EU Efficiency	98.3 %				
Night Consumption	< 1 W				
Anti-PID Module	Optional				
ENVIRONMENT					
Protection Degree	IP65				
Cooling	Natural Convection Cooling				
Operating Temperature Range	-25 ° C to +60 ° C				
Storage Temperature Range	-40 ° C to +70 ° C				
Operating Humidity	0 - 100 % Condensing				
Operating Altitude	4000 m				
Audible Noise	<30 dBA @ 1 m				
DISPLAY AND COMMUNICATION					
Display	LCD, 2×20 Z				
Communication	WIFI/RS485 Optional				
MECHANICAL DATA					
Dimensions (W / H / D)	647 x 629 x 252 mm				
Weight	45 kg				
Installation Angle	0~15 Degrees from Vertical				
DC Inputs	MC4				
SAFETY					
Safety and EMC Standard	IEC62109-1/2, IEC61000-6-1/2/3/4				
Grid Standard	IEC62116, IEC61727				

*The "Output Voltage Range" and "Output Frequency Range" may differ according to specific grid standard.

The specification and key features described in this datasheet may deviate slightly and are not guaranteed. Due to on-going innovation, research and product enhancement, Canadian Solar Inc. reserves the right to make any adjustment to the information described herein at any time without notice. Please always obtain the most recent version of the datasheet which shall be duly incorporated into the binding contract made by the parties governing all transactions related to the purchase and sale of the products described herein.

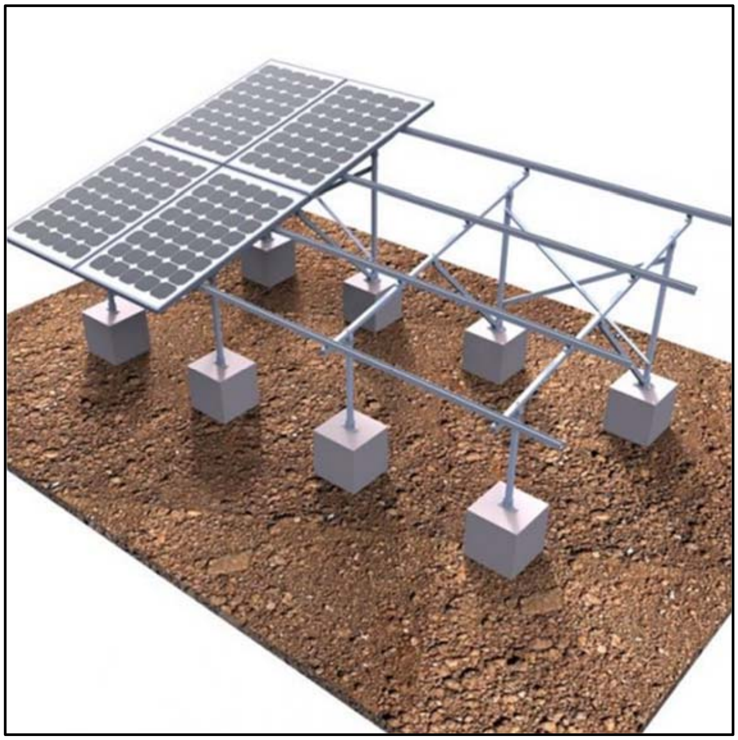
Caution: For professional use only. The installation and handling of PV equipment requires professional skills and should only be performed by qualified professionals. Please read the safety and installation instructions before using the product.

CANADIAN SOLAR INC.

545 Speedvale Avenue West, Guelph, Ontario N1K 1E6, Canada, www.canadiansolar.com

(Source: CanadianSolar, 2021)

Appendix D. Technical specifications for Sunrack SFS-GM-03 ground mounting support



(Source: Sunforson, 2021)

Technical Specifications	
Model	Sunrack SFS-GM-03
Mounting type	Carbon steel solar mounting system
Ground clearance	Customized
Tilt angle	Customized
Max wind speed	Up to 60m/s
Snow load	1.4KN/m2
System Weight	20-25 kg
Support rail	Extruded galvanized steel
Panel direction	Portrait or landscape
Standard	International Standard & AS/NZS1170

(Source: Sunforson, 2021)

Appendix E. Technical specifications for Solmax HDPE geomembrane-White

SOLMAX

Technical Data Sheet

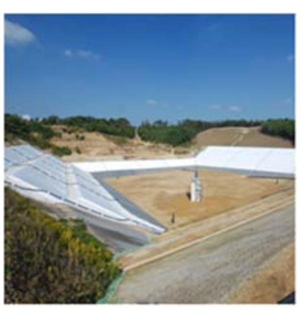
HDPE Series, 1.50 mm White Reflective, Textured

PROPERTY	TEST METHOD	FREQUENCY(1)	UNIT Metric	1101764
SPECIFICATIONS				
Nominal Thickness		-	mm	1.50
Thickness (min. avg.)	ASTM D5994	Every roll	mm	1.43
Lowest ind. for 8 out of 10 values			mm	1.35
Lowest ind. for 10 out of 10 values			mm	1.28
Asperity Height (min. avg.) (3)	ASTM D7466	Every roll	mm	0.40
Resin Density	ASTM D1505	1/Batch	g/cc	> 0.932
Melt Index - 190/2.16 (max.)	ASTM D1238	1/Batch	g/10 min	1.0
Sheet Density	ASTM D792	Every 10 rolls	g/cc	≥ 0.940
Carbon Black Content	ASTM D4218	Every 2 rolls	%	2.0 - 3.0
Carbon Black Dispersion	ASTM D5596	Every 10 rolls	Category	Cat. 1 / Cat. 2
OIT - standard (avg.)	ASTM D3895	1/Batch	min	100
Tensile Properties (min. avg) (2)	ASTM D6693	Every 2 rolls		
Strength at Yield			kN/m	23
Elongation at Yield			%	13
Strength at Break			kN/m	23
Elongation at Break			%	150
Tear Resistance (min. avg.)	ASTM D1004	Every 5 rolls	N	200
Puncture Resistance (min. avg.)	ASTM D4833	Every 5 rolls	N	535
Dimensional Stability	ASTM D1204	Certified	%	± 2
Stress Crack Resistance (SP-NCTL)	ASTM D5397	1/Batch	hr	500
Oven Aging - % retained after 90 days	ASTM D5721	Per formulation (5)		
HP OIT (min. avg.)	ASTM D5885		%	80
UV Resistance - % retained after 1600 hr	ASTM D7238	Per formulation (5)		
HP-OIT (min. avg.)	ASTM D5885		%	50
Low Temperature Brittleness	ASTM D746	Certified	°C	- 77
SUPPLY SPECIFICATIONS(Roll dimensions may vary ±1%)				
Roll Dimension - Width	-		m	6.86
Roll Dimension - Length	-		m	158.5
Area (Surface/Roll)	-		m²	1087.31
Color (one side) (4)	-			White

Page 1 of 2

SOLMAX.COM

Revision date: 31-May-2018



(Source: Solmax, 2021a)

Appendix F. Technical specifications for Solmax Bentoliner geosynthetic clay liner

SOLMAX

Technical Data Sheet

Bentoliner Series, 3.66 kg/m², NW

PROPERTY	TEST METHOD	FREQUENCY(1)	UNIT Metric	1101149
SPECIFICATIONS				
GEOTEXTILE PROPERTY		-		
Cap Description	-			Nonwoven
Cap Mass/Unit area	ASTM D5261	1/200,000 ft²	g/m²	200
Carrier Description	-			Scrim Nonwoven
Carrier Mass/Unit area	ASTM D5261	1/200,000 ft²	g/m²	200
BENTONITE PROPERTY		-		
Swell Index (min.)	ASTM D5890	1 / 100,000 lb	ml/2 g	24
Moisture Content (max.)	ASTM D4643	1 / 100,000 lb	%	12
Fluid Loss (max.)	ASTM D5891	1 / 100,000 lb	ml	18
FINISHED GCL PROPERTY		-		
Bentonite Mass (0% moisture)	ASTM D5993	1/40,000 ft²	kg/m²	3.66
Tensile Strength MD (min. avg.)	ASTM D6768	1/40,000 ft²	kN/m	7.8
Peel Strength (min.avg.)	ASTM D6496	1/40,000 ft²	N/m	610
Peel Strength (min.avg.)	ASTM D4632	1/40,000 ft²	N	93
Hydraulic Conductivity (max.)	ASTM D5887	1/week	cm/s	$5x10^{-9}$
Index Flux	ASTM D5887	1/week	m³/m²/sec	$1x10^{-8}$
Effective Confining Stress (max.)			kPa	34.5
Internal Shear Strength	ASTM D6243	Periodically	kPa	24
Normal Stress			kPa	9.6
SUPPLY SPECIFICATIONS(Roll dimensions may vary ±1%)				
Roll Dimension - Width	-		m	4.72
Roll Dimension - Length	-		m	45.7
Area (Surface/Roll)	-		m²	215.70

NOTES

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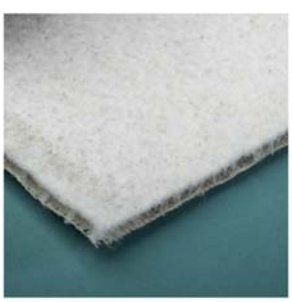
Revision date: 04-Mar-2019



(Source: Solmax, 2021b)

Appendix G1. Technical specifications for Solmax Minedrain geocomposite

PRODUCT SHEET

MINEDRAIN GEOCOMPOSITE

A HIGH STRENGTH HIGH FLOW SYSTEM

Heap leaching is a mineral processing technology whereby large piles of mineralized rock are irrigated with either a weak alkaline solution or a diluted acid to leach the target mineral.

Conventional pads are relatively flat and the ore is stacked in relatively thin lifts (5 to 15 m typically). Dumps are similar but the ore is generally uncrushed and of a very low grade. Valley fills are just the leach pads built in natural valleys using either a buttress dam at the bottom of the valley or a leveling fill within the valley.

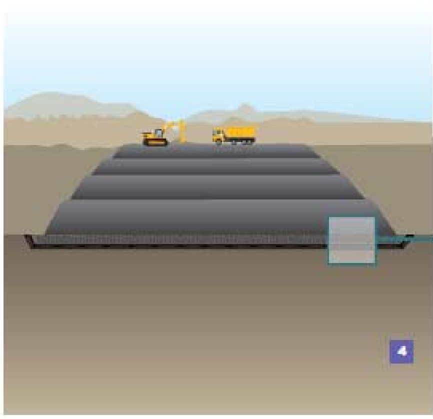
The overburden stress on the liner system is the depth of the ore times the density. Dynamic pads are universally graded to a near flat plane as the off-loading process requires precise knowledge of the evaluation of the liner relative to the depth of excavation. For dynamic pads, the maximum depth of ore is generally not important to the liner system design.

THE TYPICAL LINER-OVERLINER SYSTEM CONSISTS OF

From bottom up;

- Prepared subgrade of low to moderate permeability soil,
- 1.5 to 2.0 mm thick HDPE or LLDPE geomembrane,
- Drainage pipe network consisting of 65 to 100 mm diameter dual-wall corrugated perforated drainage pipes (laterals) feeding larger diameter collectors,
- Drainage layer (overliner) of crushed gravel, nominally -15 to -40 mm maximum particle size placed in a single layer of 300 mm to 600 mm thickness.

MINEDRAIN GEOCOMPOSITE



Mining Heap Leach Pad System

SOLMAX

(Source: Solmax, 2021c)

Appendix G2. Technical specifications for Solmax Minedrain geocomposite

INNOVATIVE GEOCOMPOSITE OVERLINER DRAINAGE SYSTEM

The crushed stone meeting the specific gradation is expensive and often time-consuming to procure. Sometimes, it takes several weeks for a gravel of the required gradation to be delivered to the jobsite. It is also not desirable to place a crushed stone directly against the geomembrane. An alternative is needed that will help alleviate the cost and time-constraints of the select gravel layer while meeting the drainage and geomembrane protection requirements. We have developed an innovative drainage geocomposite specifically for heap leach pad application. This drainage geocomposite consists of our patented **PermaNet®** geonet with a nonwoven needle-punched geotextile bonded to one or both sides.

The high density polyethylene core does not crush or collapse under very high normal loads of the overburden ore in heap leach pads. The geotextile performs the filter function and ensures the uninterrupted flow of pregnant solution. The installation of this material is significantly faster than aggregate drainage layer and the damage to the geomembrane liner is significantly less compared to the gravel layer alone.

PERFORMANCE OF MINEDRAIN

We have evaluated the performance of MineDrain under a rigorous and comprehensive test program. This test program simulates the response of the material under possible site application in actual heap leach pads. The test program included large-scale puncture, compression creep, transmissivity and shear strength tests.

COST COMPARISON

The average cost of an installed liner system (grading, subgrade preparation, and geomembrane) in 2010 was around $29 per square meter with a range of $16 to $59 per square meter. The estimated cost of the overliner gravel is $11 to $22 per square meter. The overliner drainage stone is about one-third of the total cost of the liner-overliner system and overliner costs have been escalating faster than general construction costs. This is because projects are increasingly remote, are increasingly large, and have less abundant borrow source options. The overliner gravel is also a common source of both cost overruns and project delays (due to unplanned borrow or screening problems). One goal of many construction managers is to reduce the reliance on select or engineered gravels to avoid these risks.

The use of **MineDrain** can be a key in realizing such a goal. MineDrain can replace the select gravel layer partially or completely at a lower cost. Often MineDrain can be used with a lower quality overliner with tremendous cost savings. The cushioning effect of the MineDrain protects the liner from damage and minimizes or even eliminates punctures of the geomembrane. The result is additional revenue and protection of the environment.

PERFORMANCE TRANSMISSIVITY

MineDrain can withstand extremely high compressive loads. This makes MineDrain especially suitable for use as a drainage and separation/protection layer under extremely high loads of large heap leach pads. The **MineDrain** drainage geocomposite provides sufficient in-plane flow capacity to transport leaching solutions effectively even under extremely high overburden stress.

The transmissivity of **MineDrain** exceeds that of a 50 cm thick gravel drainage layer. **MineDrain** separates the geomembrane from overlying rock or ore and significantly reduces the potential damages to the liner during both construction stage and long-term service life.

Materials	Load = 100 Meter Ores Temperature = 60°C Duration = 10 years
MineDrain	2.16×10^{-3} m^2/sec
Other conventional geonets	Not suitable due to roll-over failure
50-cm sandy gravel over liner	2.5×10^{-4} m^2/sec (typical)

Transmissivity Comparison Chart

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(Source: Solmax, 2021c)

Appendix H. Technical specifications for Solmax geotextile separator

SOLMAX

Technical Data Sheet

Geotextile Series, 270.00 g/m² Environmental, Calendered

PROPERTY	TEST METHOD	FREQUENCY(1)	UNIT Metric	1114240
SPECIFICATIONS				
AASHTO M288 Class		-		1
Mass per Unit Area	ASTM D5261	1/90,000 ft²	g/m²	270
Grab Tensile Properties (min. avg)	ASTM D4632	1/90,000 ft²		
Strength (MD)			N	975
Elongation (MD)			%	50
Trapezoidal Tear Strength	ASTM D4533	1/90,000 ft²	N	422
CBR Puncture Strength	ASTM D6241	1/540,000 ft²	N	3225
Apparent Opening Size (max.)	ASTM D4751	1/540,000 ft²	mm	0.180
Permittivity	ASTM D4491	1/540,000 ft²	sec^{-1}	1.3
Water Flow Rate	ASTM D4491	1/540,000 ft²	L/min/m²	3865
UV Resistance-% retained after 500 hrs	ASTM D4355	1/Formulation/Year	%	70
SUPPLY SPECIFICATIONS(Roll dimensions may vary ±1%)				
Roll Dimension - Width	-		m	4.57
Roll Dimension - Length	-		m	182.9
Area (Surface/Roll)	-		m²	835.85

NOTES

* The property values listed are in weaker principal direction. All values listed are Minimum Average Roll Values, except when specified as minimum or maximum.
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(Source: Solmax, 2021d)

Appendix I. Technical specifications for Solmax HDPE geomembrane-Black

SOLMAX

Technical Data Sheet

HDPE Series, 1.50 mm Black, Textured

PROPERTY	TEST METHOD	FREQUENCY(1)	UNIT Metric	1042792
SPECIFICATIONS				
Nominal Thickness		-	mm	1.50
Thickness (min. avg.)	ASTM D5994	Every roll	mm	1.43
Lowest ind. for 8 out of 10 values			mm	1.35
Lowest ind. for 10 out of 10 values			mm	1.28
Asperity Height (min. avg.) (3)	ASTM D7466	Every roll	mm	0.40
Resin Density	ASTM D1505	1/Batch	g/cc	> 0.932
Melt Index - 190/2.16 (max.)	ASTM D1238	1/Batch	g/10 min	1.0
Sheet Density	ASTM D792	Every 10 rolls	g/cc	≥ 0.940
Carbon Black Content	ASTM D4218	Every 2 rolls	%	2.0 - 3.0
Carbon Black Dispersion	ASTM D5596	Every 10 rolls	Category	Cat. 1 / Cat. 2
OIT - standard (avg.)	ASTM D3895	1/Batch	min	100
Tensile Properties (min. avg) (2)	ASTM D6693	Every 2 rolls		
Strength at Yield			kN/m	23
Elongation at Yield			%	13
Strength at Break			kN/m	23
Elongation at Break			%	150
Tear Resistance (min. avg.)	ASTM D1004	Every 5 rolls	N	200
Puncture Resistance (min. avg.)	ASTM D4833	Every 5 rolls	N	535
Dimensional Stability	ASTM D1204	Certified	%	± 2
Stress Crack Resistance (SP-NCTL)	ASTM D5397	1/Batch	hr	500
Oven Aging - % retained after 90 days	ASTM D5721	Per formulation		
HP OIT (min. avg.)	ASTM D5885		%	80
UV Res. - % retained after 1600 hr	ASTM D7238	Per formulation		
HP-OIT (min. avg.)	ASTM D5885		%	50
Low Temperature Brittleness	ASTM D746	Certified	°C	- 77
SUPPLY SPECIFICATIONS(Roll dimensions may vary ±1%)				
Roll Dimension - Width	-		m	6.80
Roll Dimension - Length	-		m	164.6
Area (Surface/Roll)	-		m^2	1119.28

NOTES

1. Testing frequency based on standard roll dimensions and one batch is approximately 180,000 lbs (or one railcar).
2. Machine Direction (MD) and Cross Machine Direction (XMD or TD) average values should be on the basis of 5 specimens each direction.
3. Lowest individual and 8 out of 10 readings as per GRI-GM13 / 17, latest version.

* All values are nominal test results, except when specified as minimum or maximum.
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(Source: Solmax, 2021e)

Appendix J. Survey Questionnaire

Thank you for participating in this survey. Your responses to the survey are anonymous and confidential. You may skip any question that you find intrusive or inappropriate, but it will help me if you respond to as many questions as you feel comfortable with. Please select your most appropriate response. There are no right or wrong answers.

(1) I believe renewable energy technologies such as solar, wind, hydro and biomass will be a good fit for my community.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Unsure

(2) I believe renewable energy will replace fossil fuels as a main source of energy in the next 30 years.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Unsure

(3) I anticipate major barriers in using renewable energy technology as the main source of power in my community.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree

(4) The electricity usage amount on my utility bill each month is approximately:

Answer choices: 1. Less than $100, 2. Between $100 to $500, 3. More than $500

(5) I would like to see the following actions taken by my utility service provider regarding renewable energy development:

Answer choices: 1. Do nothing, 2. Invest less in renewable energy, 3. Invest more in renewable energy

(6) The source of energy supply that currently powers my community:

Answer choices: 1. Does not meet my expectation, 2. Meets my expectation, 3. Exceeds my expectation

(7) I support the idea of installing a solar photovoltaic power generation facility in my community.

Answer choices: 1. Yes, 2. No, 3. Don’t know.

(8) The installation of a solar farm in my community will lower the cost of my utility bill.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure

(9) The installation of a solar farm in my community will reduce greenhouse gas emissions, mitigate air pollution problems and improve the environment.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure

(10) I support the idea of decommissioning the Victoria Junction Tailings Basin and repurpose the land to build a solar power generation facility.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure.

(11) The proposed construction and commissioning of a photovoltaic power generation facility in your community will create job opportunities and boost the local economy.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure

(12) The provincial government of Nova Scotia is doing enough to support renewable energy development in my community.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure.

(13) Relying solely on renewable energy as my main source of power will change my daily household energy consumption usage.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure.

(14) Replacing coal-fired power generation plants with renewable energy power generation plants will help improve the environment.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure.

(15) The installation of a solar photovoltaic facility in my community will not reduce the cost of electricity.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure

(16) Using renewable energy such as solar photovoltaic as the main source of power supply is unreliable.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure

(17) Relying solely on renewable energy as my main source of power will not change my daily household energy consumption usage.

Answer choices: 1. Strongly Disagree, 2. Disagree, 3. Agree, 4. Strongly Agree, 5. Not sure.

(18) How would you classify your knowledge of renewable energies such as solar, wind, hydro and biomass?

Answer choices: 1. Basic, 2. Intermediate, 3. Advanced

(19) Do you own or rent your home?

Answer choices: 1. Own, 2. Rent

(20) What is the size of your household?

Answer choices: 1. Less than 4, 2. Exactly 4, 3. Greater than 4

(21) What is your employment status?

Answer choices: 1.Unemployed, 2. Unemployed (Student), 3. Employed, 4. Self-employed

(22) If employed, do you work full time or part time?

Answer choices: 1. Full time 2. Part time

(23) Select the industry classification category that best corresponds to your employment:

Answer choices: 1. Agriculture 2.Finance, 3. Fisheries, 4. Education, 5. Environmental, 6. Medical, 7. IT, 8. Oil & Gas 9. Mining, 10. Manufacturing, 11. Military, 12. Retail, 13. Other