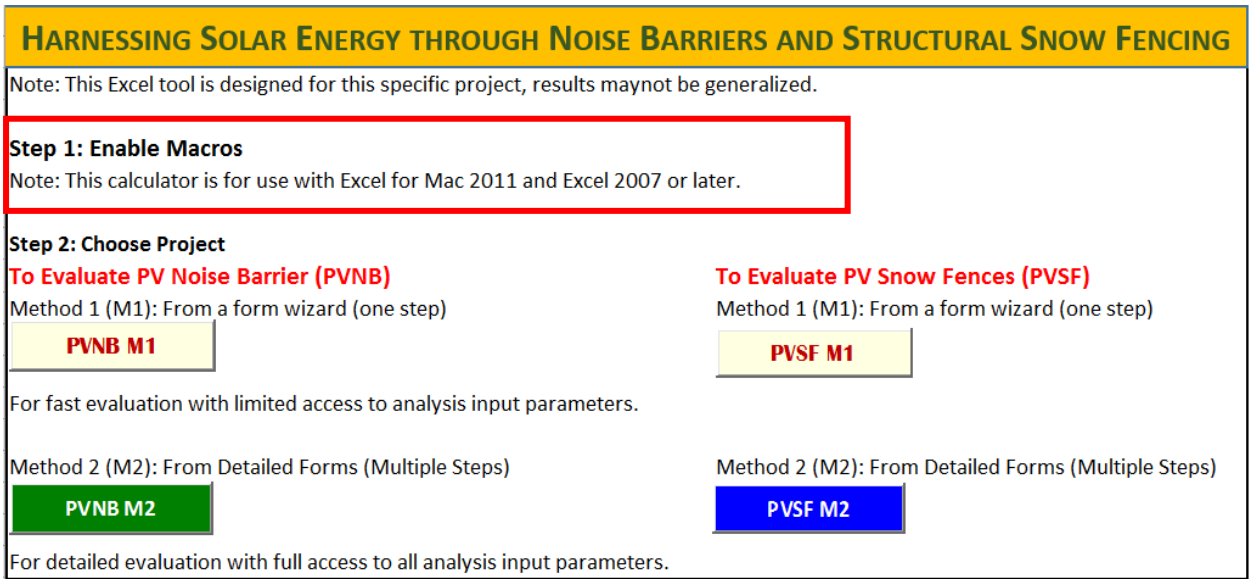
COST-BENEFIT ANALYSIS CALCULATOR USER GUIDE

The user guide is to facilitate the Cost-Benefit Analysis (CBA) of the Photovoltaic Noise Barriers (PVNB) and Photovoltaic Snow Fences (PVSF), as part of the project funded by the Minnesota Department of Transportation (MnDOT) – "Harnessing Solar Energy Through Noise Barriers and Structural Snow Fencing." The CBA calculator was developed using MS Excel for ease of use and access. A user-friendly interface was developed with the basic worksheet types and navigation tabs. To use the calculator, there are several steps to follow as described in detail below.

Intro Page

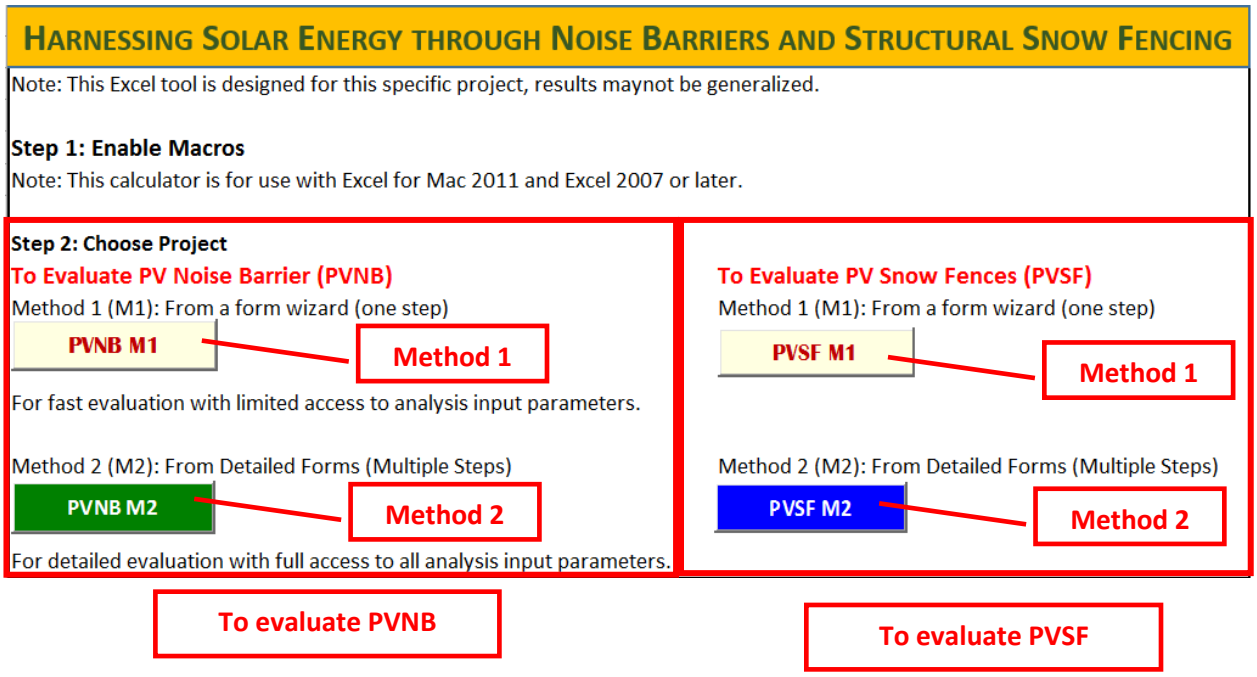
Step 1 is to enable Macros, and more information about how to enable Macros can be found here https//support.microsoft.com/en-us/topic/enable-or-disable-macros-in-office-files-12b036fd-d140-4e74-b45e-16fed1a7e5c6.



Step 2 is to choose a project, where the user may choose to evaluate a PVNB project or a PVSF project. Under each project, the user may choose one of the two alternative ways, i.e., Method 1 (M1) and Method 2 (M2) to conduct the CBA.

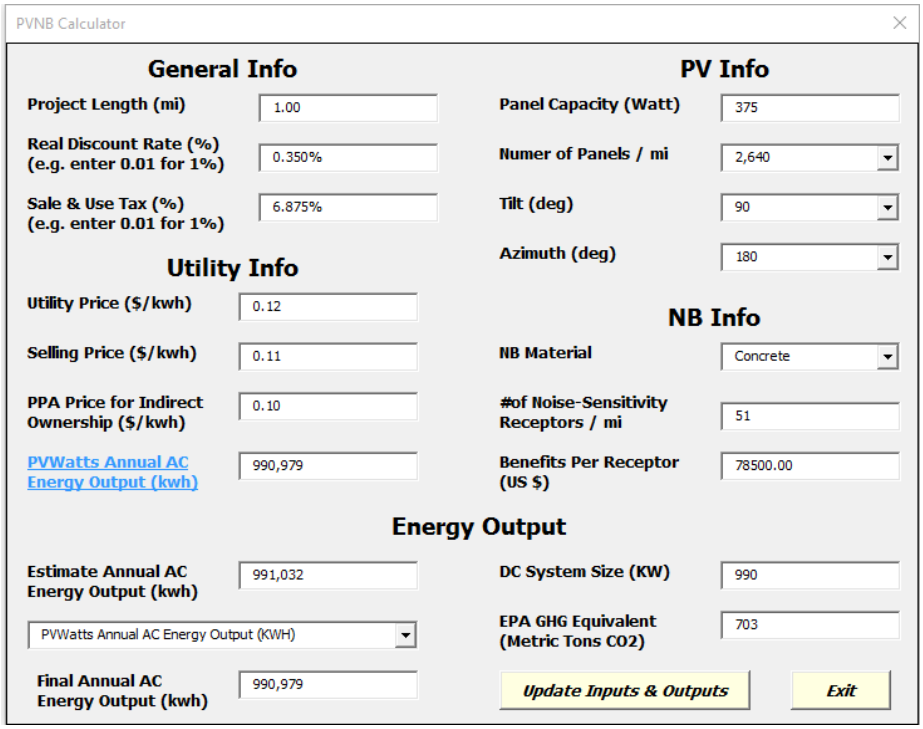
- **Method 1 (M1)** uses a form wizard for **fast** evaluations with **limited** access to analysis input parameters. **The user can use M1 when limited input parameters are known.**
- **Method 2 (M2)** uses detailed forms for **detailed** evaluation with **full** access to all analysis input parameters. **The user can use M2 when detailed input parameters are known.**

The two methods are described in detail in the following sections. All the parameters used in the CBA calculator are defined in Appendix A.



Method 1 (PVNB M1 or PVSF M1)

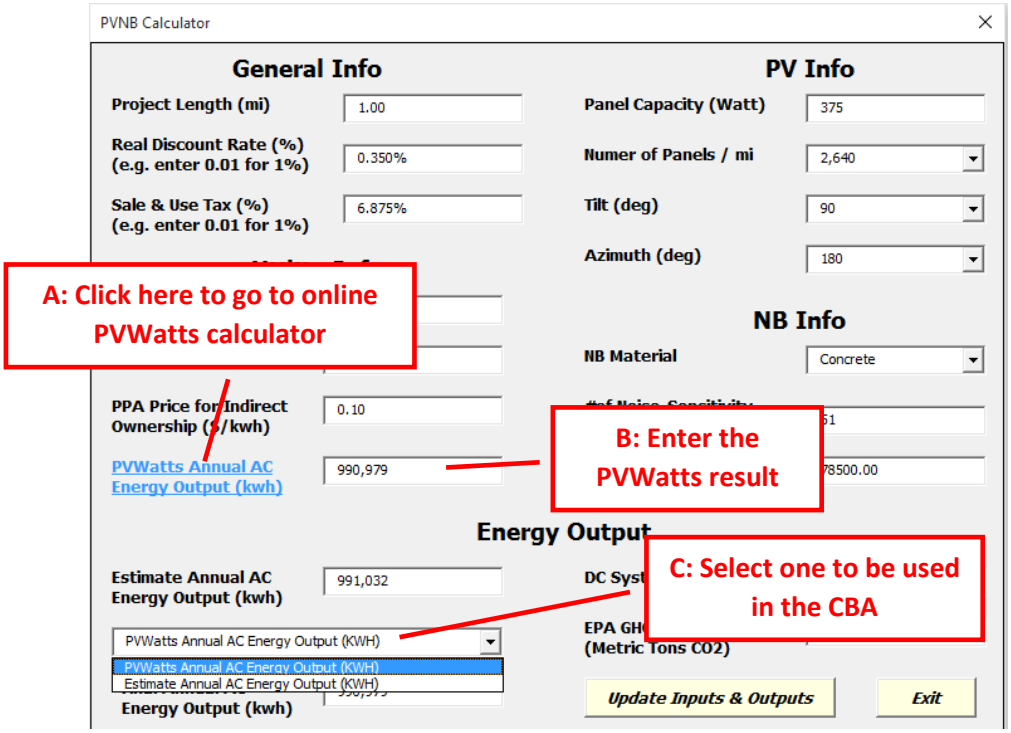
By clicking the button of "PVNB M1" or "PVSF M1", a window will pop up, as shown below, which includes the critical (but limited) parameters of a PVNB/PVSF project, which allows the user to define the project by altering these parameters.



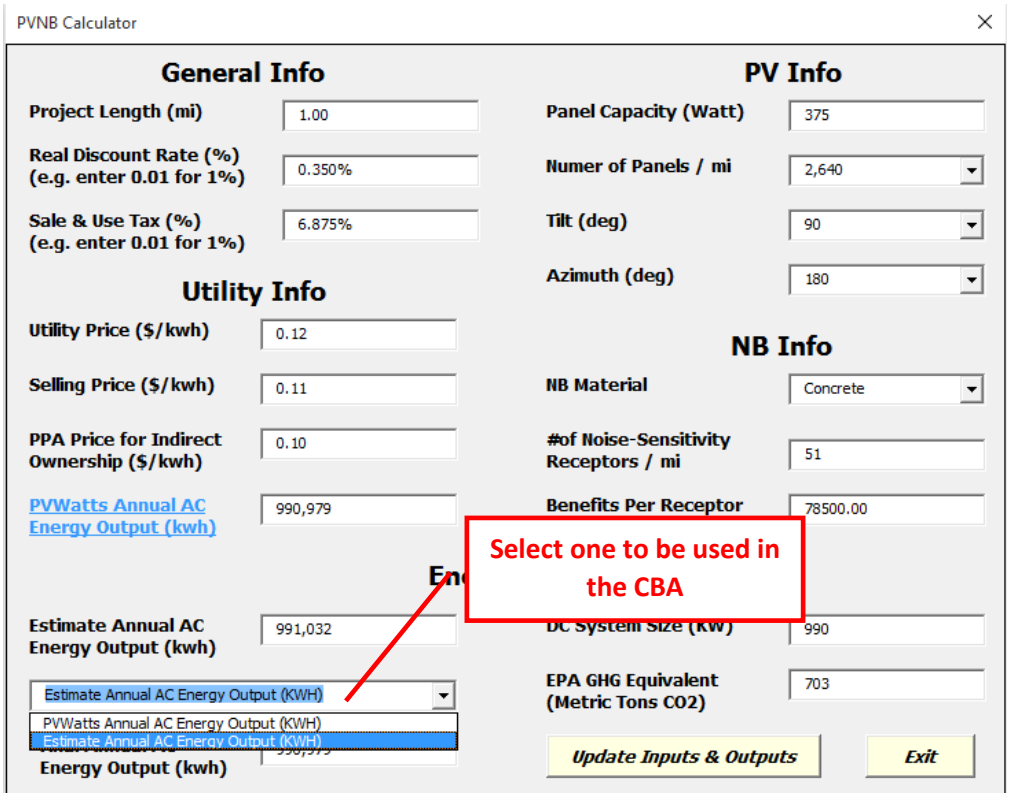
One thing to note is that the CBA calculator provides two ways to estimate the electrical power generated by the PV system specified. The user can select and use either of them in the analysis.

- Online PVWatts calculator. The user needs to click the hyperlink that will lead to the online PV Watts calculator, where the user can enter the information about the PV project, and the calculator will estimate the annual electrical power (Step A). The user then needs to enter the calculation result into the blank space (Step B). The last step is to specify that the PVWatts result will be used in the CBA by selecting "PVWatts Annual AC Energy Output (KWH)" from the dropdown list (Step C).

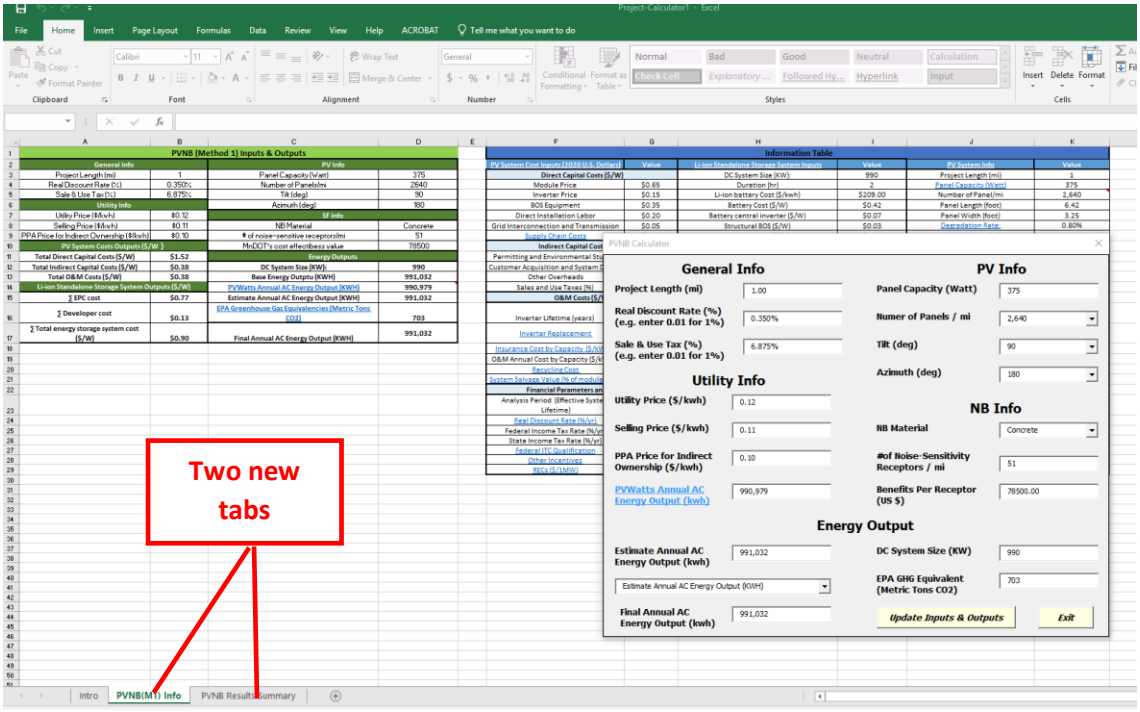
  By using the online PVWatts calculator, the user may specify the PV project location not only in Minnesota but also in other states across the US, and it would give a more accurate result in terms of annual electrical power generation.



- Estimation by the developed CBA calculator. The developed CBA calculator has the function to estimate the amount of annual electrical power generation by a PV system but only at a specified location in Minnesota, i.e., a location along the US-10 in Moorhead, MN. Therefore, the Online PVWatts calculator (see above) is recommended if the PV project is not deployed at this specified location. To activate this function, the user just needs to select "Estimate Annual AC Energy Output (KWH)" from the dropdown list, as shown below. Then the CBA calculator will estimate the output energy power and use it in the analysis.

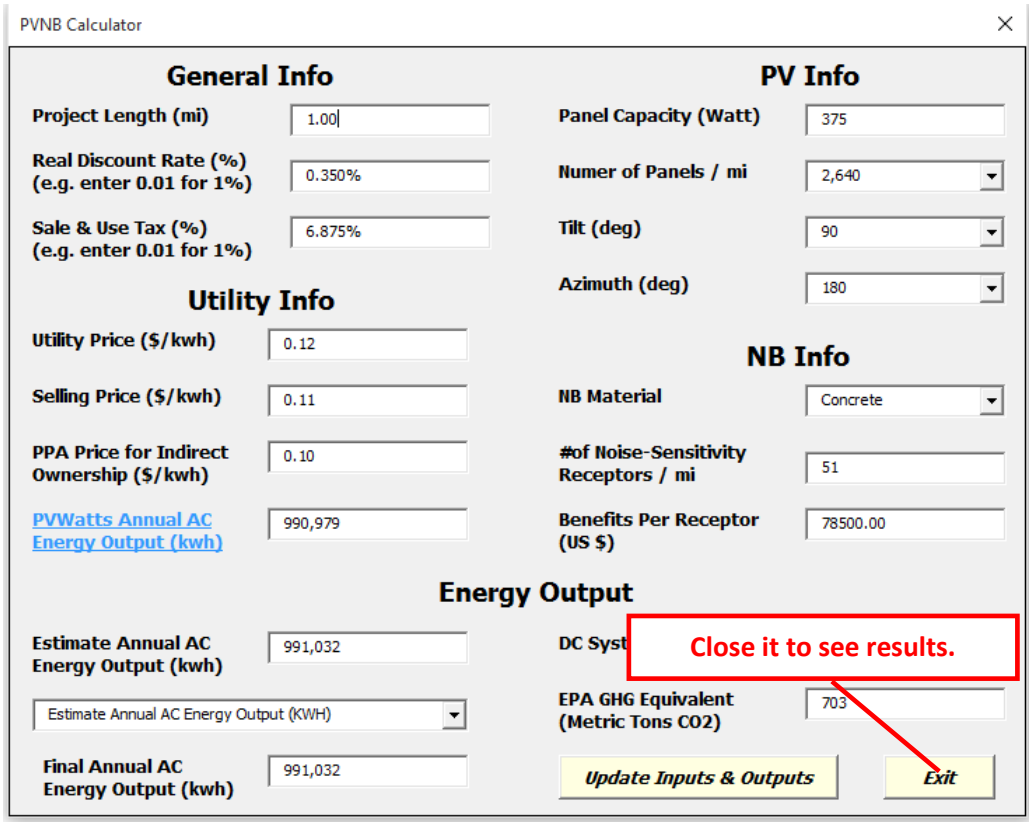


Once the parameters are specified, click the button “Update Inputs & Outputs”, and then two new spreadsheet tabs will be created, as shown below.



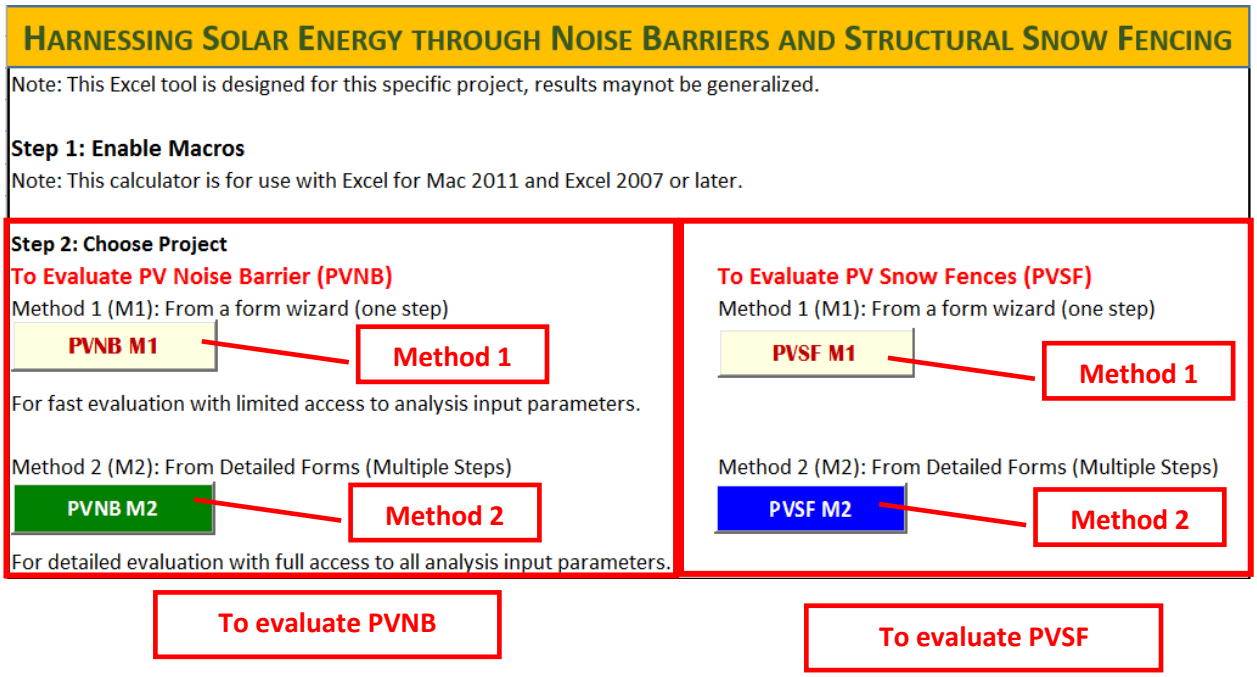
One of them is called “PVNB(M1) Info” or “PVSF(M1) Info” and the other “PVNB Results Summary” or “PVSF Results Summary”. The tab “PVNB(M1) Info” or “PVSF(M1) Info” shows all the input and output parameters used in the CBA, and the CBA results are summarized in the tab “PVNB Results Summary” or “PVSF Results Summary”, respectively.

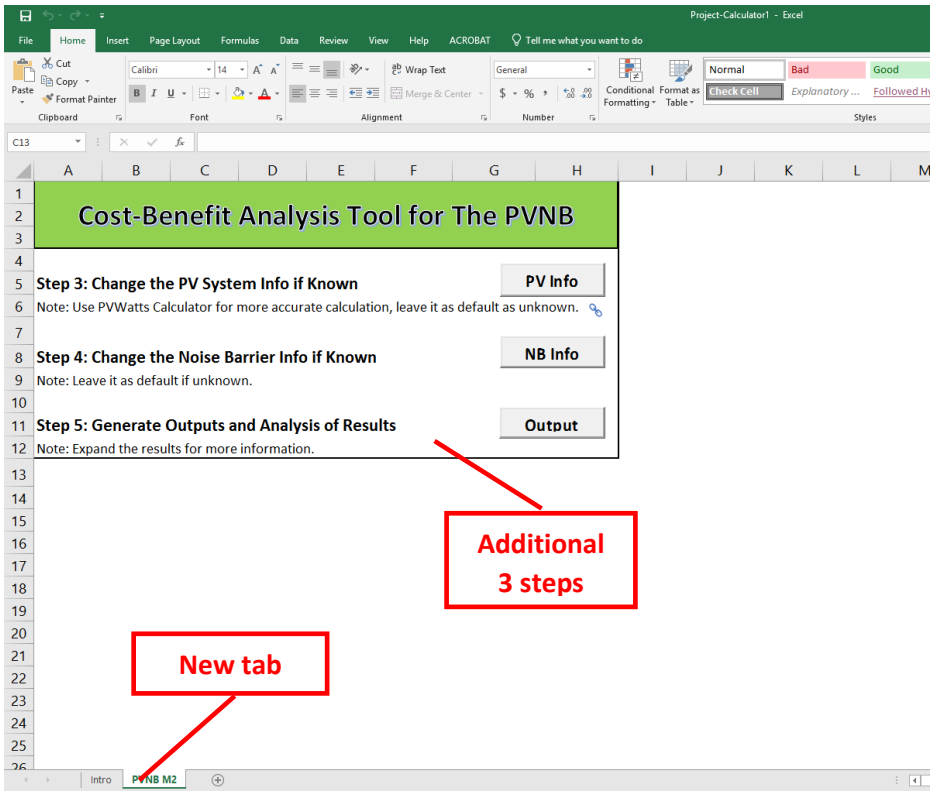
Please note: to access these two spreadsheets, the user needs to close (or exit) the pop-up window. The information shown in the “PVNB(M1) Info” or “PVSF(M1) Info” cannot be modified (view only). To modify parameters, the user needs to go back to the “Intro Page” and click the “PVNB M1” or “PVSF M1” button again to repeat the above-mentioned process.



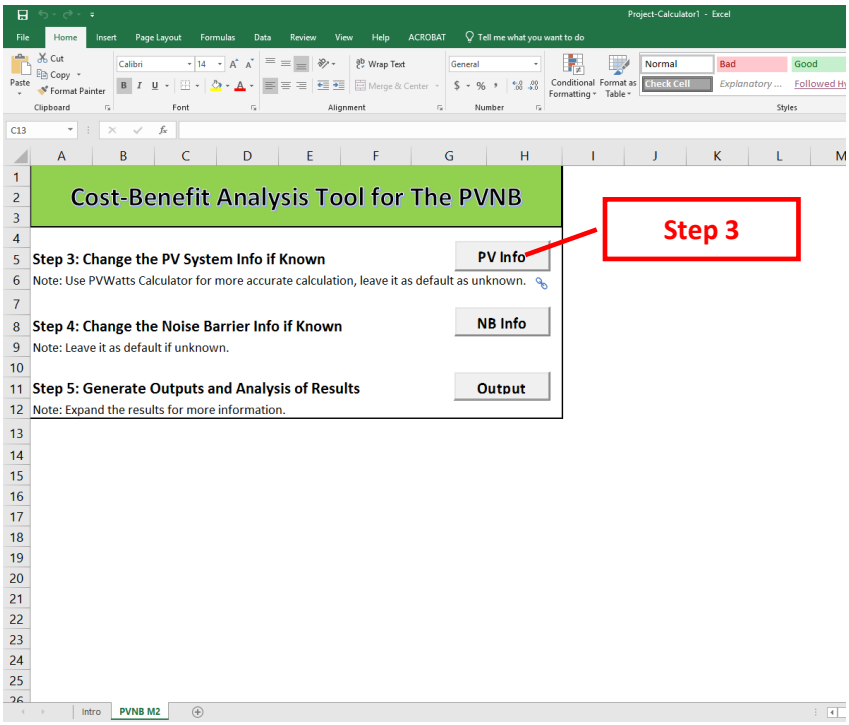
Method 2 (PVNB M2 or PVSF M2)

By clicking the button of "PVNB M2" or "PVSF M2", a new spreadsheet tab will pop up, as shown below, which includes additional 3 steps (Step 3, 4, and 5) to allow the user to define the PVNB or PVSF project in more detail.

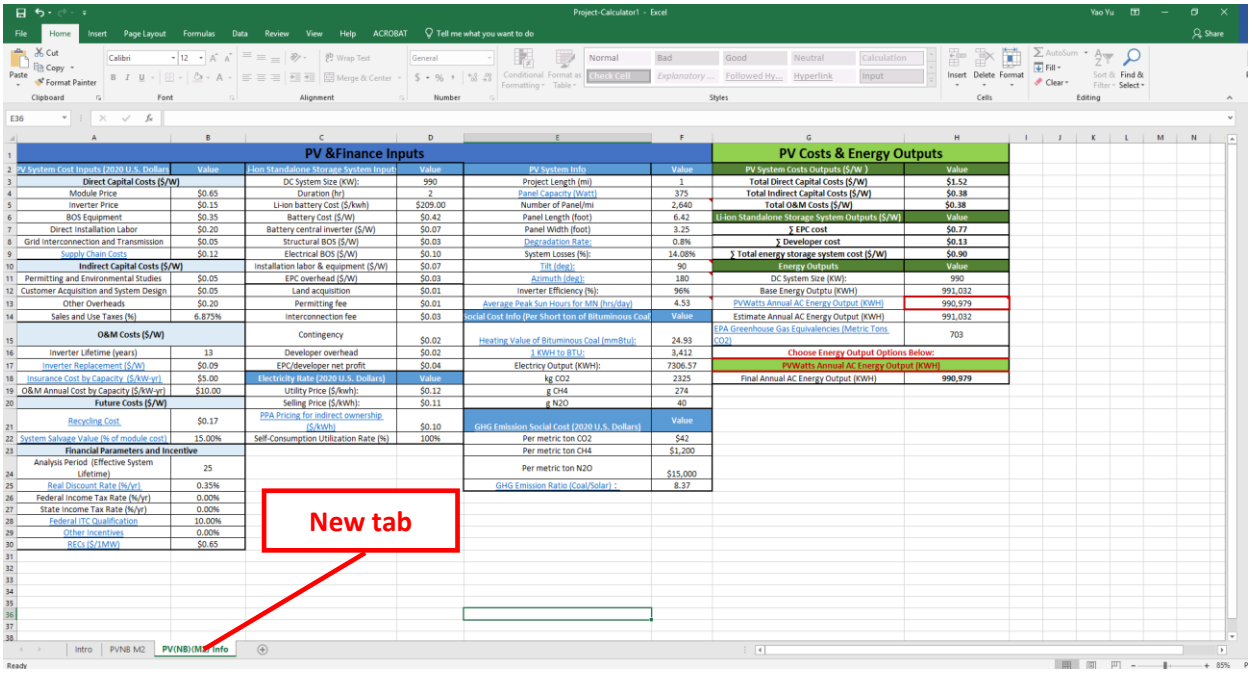




Step 3 is to enter the PV system information, where all the parameters (full access) related to the PV system (blue tables as shown below) can be specified or modified.



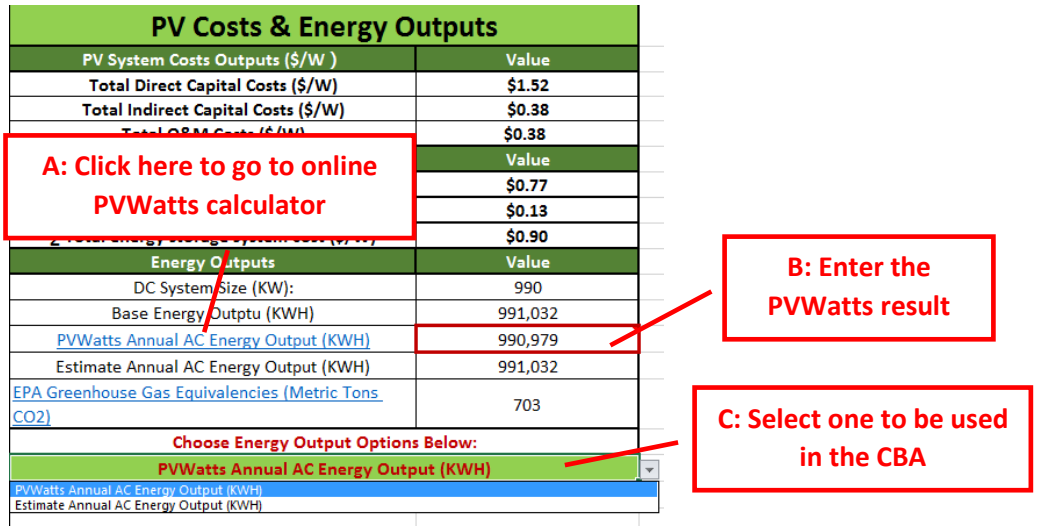
By clicking the button "PV Info", a new spreadsheet ("PV(NB(M2) Info)" or ("PV(SF(M2) Info)") will show up. The hyperlinks (blue texts with underline) allow the user to visit additional external resources related to a specified parameter.



The green table shows the outputs with given input parameters entered in the blue tables, and again two alternative ways are provided to estimate the electrical power generated by the PV system specified.

- Online PVWatts calculator. The user needs to click the hyperlink that will lead to the online PV Watts calculator, where the user can enter the information about the PV project, and the calculator will estimate the annual electrical power (Step A). The user then needs to enter the calculation result into the blank space (Step B). The last step is to specify that the PVWatts result will be used in the CBA by selecting "PVWatts Annual AC Energy Output (KWH)" from the dropdown list (Step C).

  By using the online PVWatts calculator, the user may specify the PV project location not only in Minnesota but also in other states across the US, and it would give a more accurate result in terms of annual electrical power generation.



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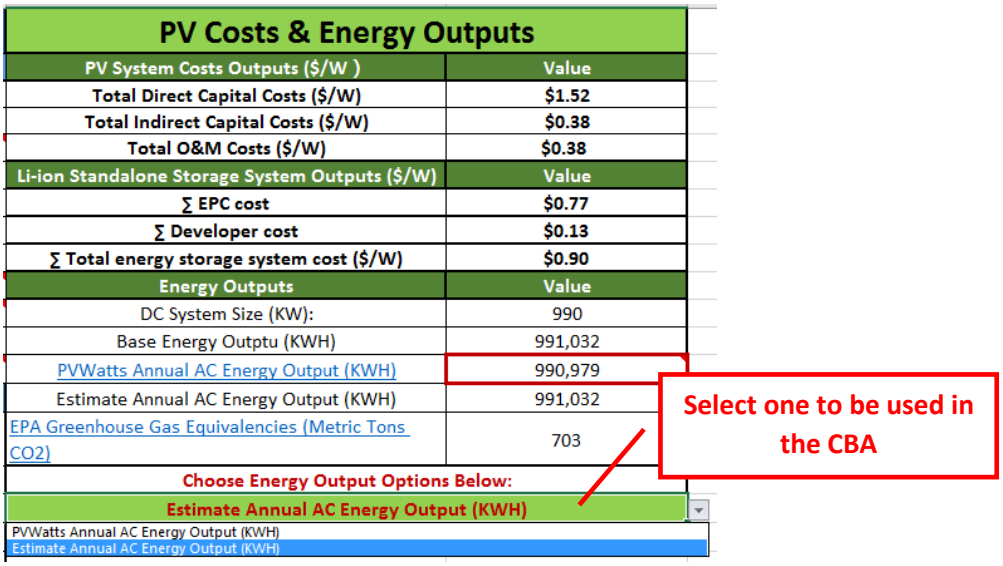
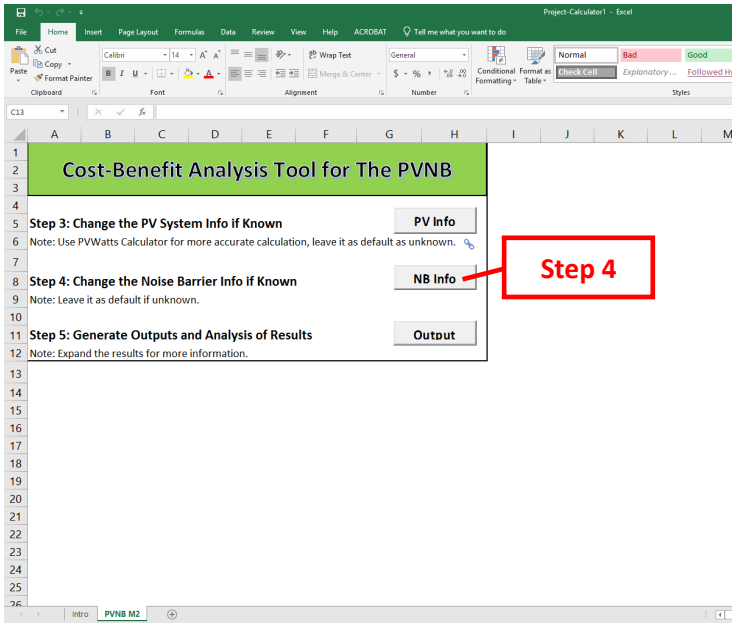
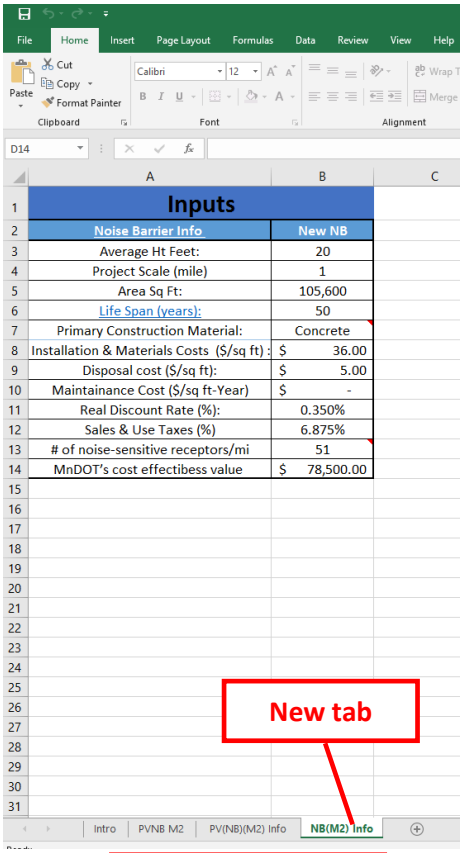
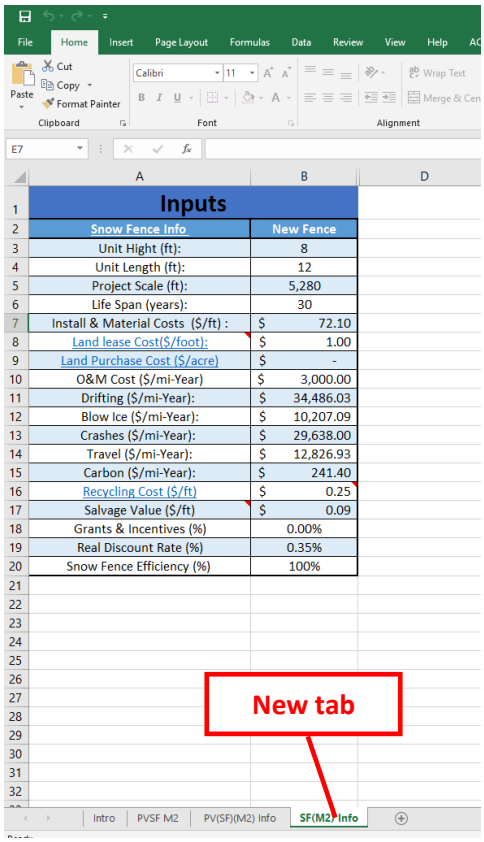


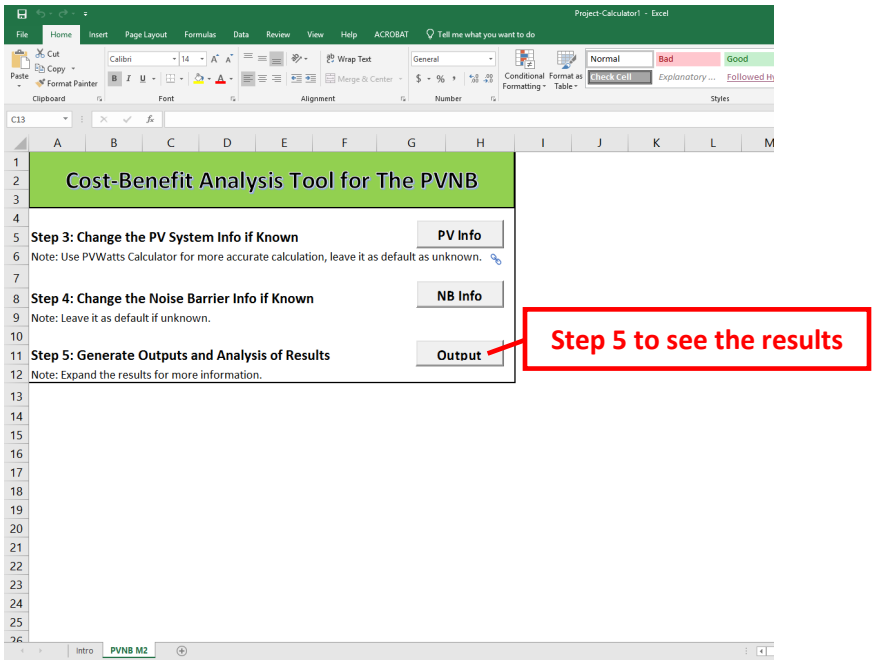
Once the parameters for the PV system are specified, go back to the "PVNB M2" or "PVSF M2" tab and click the button "NB Info" or "SF Info" to define the noise barriers or snow fences (**Step 4**). Then a new spreadsheet tab will show up named "NB(M2) Info" or "SF(M2) Info". This allows the user to enter or modify the noise barrier or snow fence information.





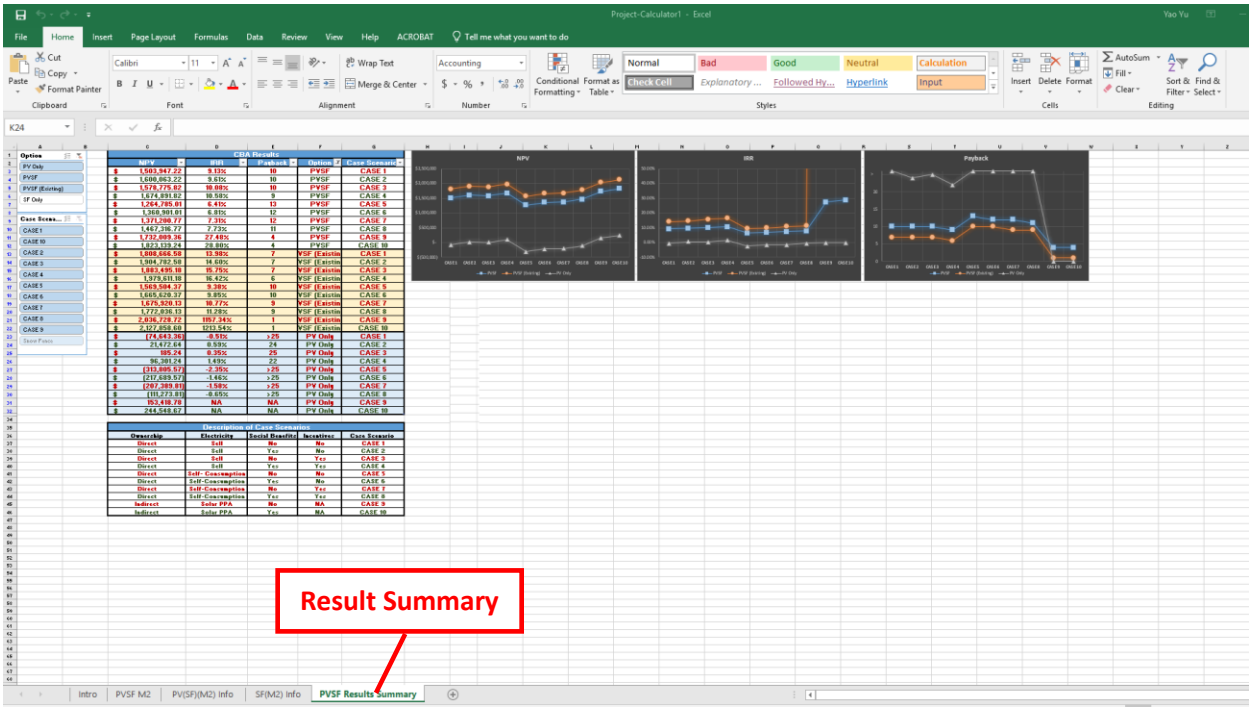


Once the parameters for the noise barriers or snow fences are specified, go back to the "PVNB M2" or "PVSF M2" tab and click the button "Output" to see the CBA results (**Step 5**). Then a new spreadsheet tab will show up named "PVSF Results Summary" or "PVNB Results Summary".



CBA Result Summary

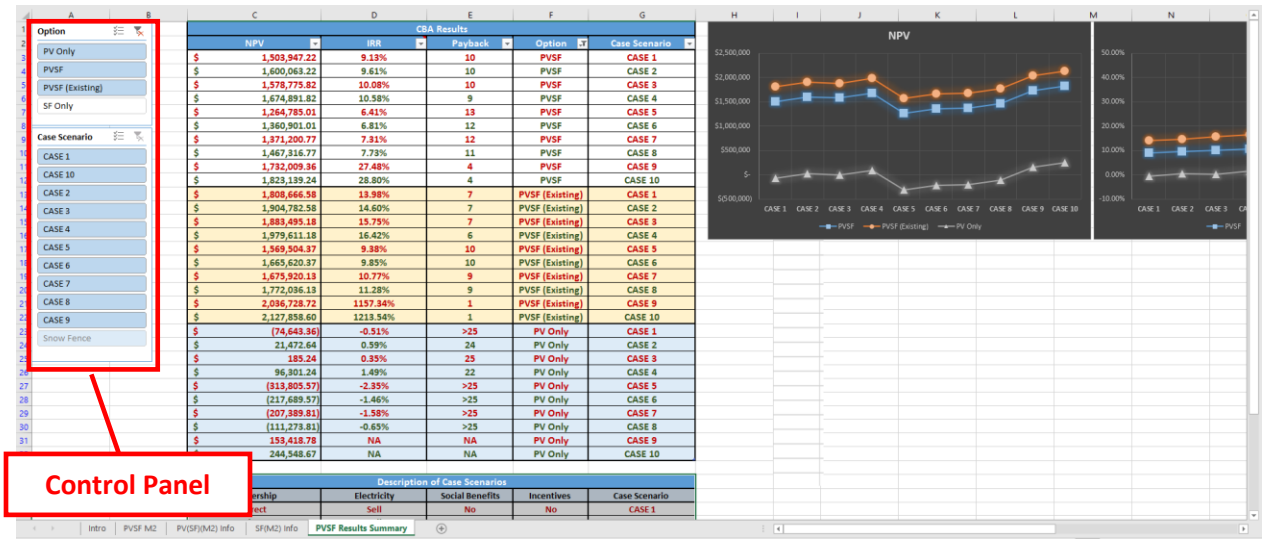
Either Method 1 or Method 2 will lead to the same spreadsheet tab called “PVNB Results Summary” or “PVSF Results Summary”.



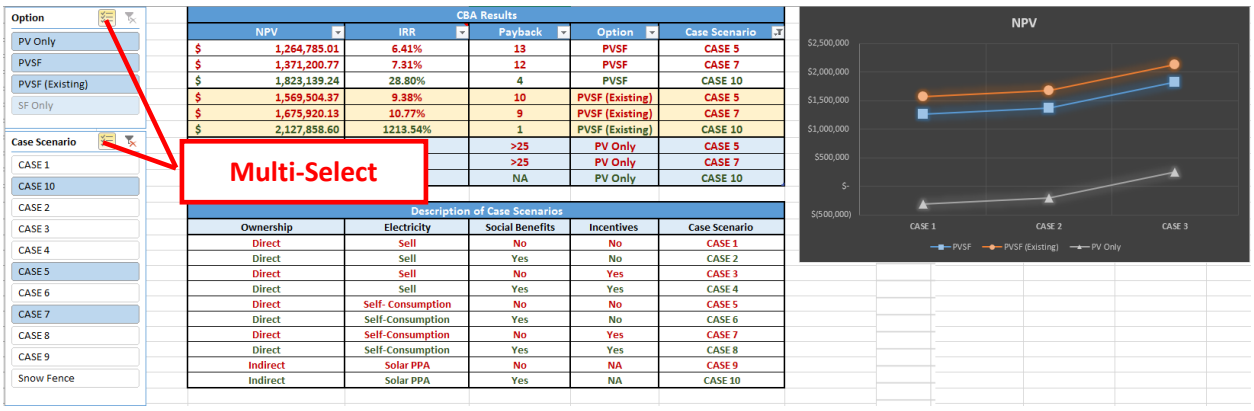
The CBA results, including Payback Period (PP), Net Present Value (NPV), and Internal Rate of Return (IRR), are shown in tables and figures. The 10 case scenarios listed below are consistent with those in the final project report.

Description of Case Scenarios				
Ownership	Electricity	Social Benefits	Incentives	Case Scenario
Direct	Sell	No	No	CASE 1
Direct	Sell	Yes	No	CASE 2
Direct	Sell	No	Yes	CASE 3
Direct	Sell	Yes	Yes	CASE 4
Direct	Self- Consumption	No	No	CASE 5
Direct	Self-Consumption	Yes	No	CASE 6
Direct	Self-Consumption	No	Yes	CASE 7
Direct	Self-Consumption	Yes	Yes	CASE 8
Indirect	Solar PPA	No	NA	CASE 9
Indirect	Solar PPA	Yes	NA	CASE 10

The control panel on the left allows the user to select different results to view, and the data shown in the tables and figures will be changed accordingly.



The "Multi-Select" button in the control panel allows selecting multiple cases/options simultaneously.



Appendix A – Parameter Definition

For PV System

Project Length (mi)	The length of a PVNB/PVSF project in mile.
Panel Capacity (Watt)	The electricity output (in Watts) a PV panel can provide at full rated power.
Panel Length (feet)	The length of a PV panel.
Panel Width (feet)	The width of a PV panel.
Number of Panels/Mile	The number of panels installed per mile.
Degradation Rate (%)	The percentage of power production loss due to PV system degradation.
System Losses (%)	The performance losses of the PV system.
Tilt (deg)	The vertical angle of a PV panel.
Azimuth (deg)	The horizontal facing of a PV panel in relation to the Equator.
Inverter Efficiency (%)	The inverter's nominal rated DC-to-AC conversion efficiency, defined as the inverter's rated AC power output divided by its rated DC power output.
Average Peak Sun Hours (hrs/day)	The solar insolation that a particular location would receive if the sun were shining at its maximum value for a certain number of hours.
Module Price ($/W)	Solar PV modules' price in US dollars per Watt.
Inverter Price ($/W)	Solar inverter price in US dollars per Watt.
BOS Equipment ($/W)	Balance-Of-System (which compasses all components of a photovoltaic system other than the photovoltaic panels) costs in US dollars per Watt.
Direct Installation Labor ($/W)	Direct installation labor cost for a PV system in US dollars per Watt.
Grid Interconnection and Transmission ($/W)	The cost of integrating the PV system into the electricity grid in US dollars per Watt.
Supply Chain Costs ($/W)	The costs and fees associated with shipping and handling of equipment in US dollars per Watt.
Permitting and Environmental Studies ($/W)	Includes all permitting fees and the costs for the environmental study, as well as the labor costs for corresponding documents preparation and submission in US dollars per Watt.
Customer Acquisition and System Design ($/W)	The total cost of system design and marketing activities (such as site visits, bid preparation, and contract negotiation) in US dollars per Watt.
Other Overheads ($/W)	General and administrative expenses—including fixed overhead expenses covering payroll (excluding permitting payroll), facilities, administrative, finance, legal, information technology, and other corporate functions as well as office expenses in US dollars per Watt.
Inverter Lifetime (years)	The average lifespan of a solar inverter in years.
Inverter Replacement ($/W)	The costs to replace all inverters for a PV system in US dollars per Watt.
Insurance Cost by Capacity ($/kW-yr)	The annual insurance costs for a PV system in US dollars per Kilowatt.
O&M Annual Cost by Capacity ($/kW-yr)	The annual costs of operations and maintenance for a PV system in US dollars per Kilowatt.
Recycling Cost ($/W)	The unit expense (per Watt) associated with the PV panel's disposal and recycling at the end of its useful life.
System Salvage Value (% of module cost)	The amount that a PV panel is estimated to be worth at the end of its useful life.
Analysis Period (Effective System Lifetime)	The lifetime (years) for a PV system to properly function in a cost-effective way.
Real Discount Rate (%/yr)	The interest rate that the Federal Reserve Banks charges when they make collateralized loans to depository institutions.
Sales & Use Taxes (%)	The percentage tax on the price of a sale that collected by a merchant or consumer and remitted to a state government.
Federal Income Tax Rate (%/yr)	The rate of the tax levied by the Internal Revenue Service (IRS) on the annual earnings of the PV system.

State Income Tax Rate (%/yr)	The rate of the tax levied by a state on the annual earnings of the PV system.
Federal ITC Qualification (%)	The solar Investment Tax Credit (ITC), which is one important federal policy mechanism to support the growth of solar energy in the United States. It allows the developer to deduct a certain percent of the cost of installing a solar energy system from the federal taxes.
Other Incentives (%)	Other incentives and grants can be applied to the solar PV project.
RECs ($/1MW)	A Renewable Energy Certificates (REC) is produced when a renewable energy source generates one megawatt-hour (MWh) of electricity and delivers it to the grid, which can be sold in the market as a means of limiting rate impacts to their ratepayers.
Utility Price ($/kWh)	The average electricity rate per kilowatt-hour (kWh) MnDOT needs to pay.
Selling Price ($/kWh)	The average electricity rate per kilowatt-hour (kWh) when selling the generated power to utility companies.
PPA Pricing for indirect ownership ($/kWh)	The average electricity rate per kilowatt-hour (kWh) if MnDOT buys power from a project developer via a Power Purchase Agreement (PPA).
Self-Consumption Utilization Rate (%)	The percent of the energy generated from the PV system for self-usage by MnDOT. Considering the limited battery capacity when the generated power is self-used by MnDOT, 75% means that 25% of the generated electrical power would either be discarded or sold to utility companies. 100% implies that all the generated electrical power would be used by MnDOT facilities, such as for street lights and/or rest areas.
DC System Size (KW)	The size of the solar PV system in Direct Current (DC), which is equal to the number of panels multiplied by the panel capacity.
Base Energy Output (kWh)	The annual energy output generated by the PV system.
PVWatts Annual AC Energy Output (kWh)	The annual energy output calculated by using the online PVWatts calculator.
Estimate Annual AC Energy Output (kWh)	The annual energy output calculated by using the developed CBA calculator.
Final Annual AC Energy Output (kWh)	The annual energy output eventually used in the CBA calculation.
Total Direct Capital Costs ($/Watt)	The total direct catpical costs in US dollars per Watt.
Total Indirect Capital Costs ($/Watt)	The total indirect catpical costs in US dollars per Watt.
Total O&M Costs ($/W)	The total operation and maintenance costs in US dollars per Watt.

For Li-ion Standalone Storage System

Storage Duration (hr)	The number of hours of continuous output allowed by the lithium-ion batteries.
Li-ion battery Cost ($/kWh)	The average cost in US dollars of a lithium-ion (Li-ion) battery cell per kilowatt-hour (kWh).
Battery Cost ($/W)	The average cost in US dollars of a lithium-ion (Li-ion) battery per Watt of its capacity.
Battery central inverter ($/W)	Battery inverter price in US dollars per Watt.
Structural BOS ($/W)	The structural balance of system costs of the storage system in US dollars per Watt.
Electrical BOS ($/W)	The electrical balance of system costs of the storage system in US dollars per Watt.
Installation labor & equipment ($/W)	The labor and equipment costs of the direct installation of the storage system in US dollars per Watt.
EPC overhead ($/W)	General and administrative expenses of Engineering, Procurement, and Construction (EPC) in US dollars per Watt.

Land acquisition ($/W)	The cost of all land to be acquired for building the storage system in US dollars per Watt.
Permitting fee ($/W)	Includes all permitting and labor costs for corresponding documents preparation and submission in US dollars per Watt.
Interconnection fee ($/W)	The cost of integrating the storage system into the electricity grid in US dollars per Watt.
Contingency ($/W)	The amount of money that is included to cover potential events that are not specifically accounted for in a cost estimate, in US dollars per Watt.
Developer overhead ($/W)	General and administrative expenses of the developer in US dollars per Watt.
EPC/developer net profit ($/W)	The costs that are set forth on the budget for the EPC/developer's profit in US dollars per Watt.
∑ EPC cost ($/W)	The total direct costs of the storage system in US dollars per Watt.
∑ Developer cost ($/W)	The total indirect costs of the storage system in US dollars per Watt.
∑ Total energy storage system cost ($/W)	The total costs of the storage system in US dollars per Watt.

For Social/Environmental Costs/Benefits

Heating Value Per Short Ton (mmBtu)	The annual average heat content per short ton of bituminous coal produced in the United States in million British thermal units (Btu).
1 kWh to BTU	The amount of heat (in Btu) generated from one kilowatt-hour of electricity.
Electricity Output Per Short Ton (kWh)	The amount of electricity (in kWh) that can be generated per short ton of bituminous coal consumed.
kg CO_2	The amount of CO_2 produced in kilogram (kg) per short ton of bituminous coal consumed.
g CH_4	The amount of CH_4 produced in grams (g) per short ton of bituminous coal consumed.
g N_2O	The amount of N_2O produced in grams (g) per short ton of bituminous coal consumed.
Per metric ton CO_2	The social cost (3% Average) of CO_2 in 2007 dollars per metric ton by 2020.
Per metric ton CH_4	The social cost (3% Average) of CH_4 in 2007 dollars per metric ton by 2020.
Per metric ton N_2O	The social cost (3% Average) of N_2O in 2007 dollars per metric ton by 2020.
GHG Emission Ratio (Coal/Solar)	The ratio between the estimated greenhouse gas emission of a coal-fired power generation and the estimate emitted from a solar energy system to generate the same amount of energy.
EPA Greenhouse Gas Equivalencies (Metric Tons CO2)	The equivalent GHG emissions in metric tons that translated from "kWh" generated by the PV system (calculated by using the EPA Greenhouse Gas Equivalencies Calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator)

For Noise Barrier

Average Height (ft)	The average height in feet of the noise barriers above ground.
Project Scale (ft)	The length of the PVNB project in feet.
Area (sq ft)	The total area of the noise barrier walls installed in square feet.
Year of Original Construction	The year when the PVNB system is expected to be installed.
Life Span (years)	The average length of time for a noise barrier wall to properly function.
Primary Construction Material or NB Material	The materials of noise barriers.

Installation & Materials Costs ($/sq ft)	The total cost of materials, installation, and labor for one square foot of noise barriers.
Disposal cost ($/sq ft)	The unit expense (per square foot) associated with the noise barrier's disposal at the end of its useful life.
Maintenance Cost ($/sq ft-Year)	The unit cost (per square foot) incurred every year to keep the noise barrier working in good condition.
# of noise-sensitive receptors/mi	The number of receptors (like hospitals and schools) per mile that are potentially sensitive to noise and vibration.
MnDOT's cost-effectiveness value or Benefits Per Receptor ($)	The value of the MnDOT's cost-effectiveness criteria for each benefited receptor.

For Snow Fence

Unit Height (ft)	The height in feet of the snow fences above ground.
Unit Length (ft)	The length of snow fence rails between poles.
Project Scale (ft)	The length of the PVSF project in feet.
Life Span (years)	The average length of time for a snow fence to properly function.
Install & Material Costs ($/ft)	The total cost of materials, installation, and labor for one foot of snow fence.
Land lease Cost ($/ft-Year)	The annual rent cost per foot of the land along the highway for the use of snow fences.
Land Purchase Cost ($/acre)	The one-time purchase cost of an acre of the land for the use of snow fences.
O&M Cost ($/mi-Year)	The unit cost (per mile) incurred every year to operate and maintain the snow fence.
Drifting ($/mi-Year)	The annual cost savings of drifting snow events.
Blow Ice ($/mi-Year)	The annual cost savings of blowing snow and ice events.
Crashes ($/mi-Year)	The annual cost savings from fatal, injury, and property damage crashes avoided due to the use of snow fences.
Travel ($/mi-Year)	The annual cost savings caused by travel time reductions due to improved road conditions resulted from the use of snow fences.
Carbon ($/mi-Year)	The annual cost savings from reduced carbon emissions by agency equipment.
Recycling Cost ($/ft)	The unit expense (per foot) associated with the snow fence's disposal at the end of its useful life.
Salvage Value ($/ft)	The salvage value of the materials at the end of the life of snow fences.
Grants & Incentives (%)	The percentage of the overall cost for building the snow fence that is covered by grants and incentives.
Snow Fence (SF) Efficiency (%)	The effective percentage of the overall benefits generated by snow fences (cost savings from drifting, blow ice, crashes, travel, and carbon).