Welcome!

Webinar #34:
PV Solar Fields in Thermoflow

15 September 2022

Agenda:

* Introduction
* PV Field model in THERMOFLEX / NOVO PRO
* PV Field design, configuration & options
* PV Panels Library & Irradiance specification and database
* PV Field annual yield calculation, Economics and available outputs
* Operation modes and combination with other technologies
* Q & A Session

Presenter: IGNACIO MARTIN (SPAIN)
Support: Meritt Elmasri (U.S. HQ)

Thermoflow Training and Support

- Standard Training
- On site training course
- User's Meetings / Advanced Workshops
- Webinars when new version is released
- Help, Tutorials, PPT, Videos
- Technical Support

→ **Feature Awareness Webinars**

Feature Awareness Webinars

1- Assemblies in TFX, June 2016
2- Scripts in Thermoflow programs, GTP-GTM-TFX
3- Multi Point Design in GTP-GTM
4- Reciprocating Engines in TFX
5- TIME in GTM
6- Matching ST Perfromance in STP
7- Modeling Solar Systems in TFX
8- Combining THERMOFLEX & Application-Specific Programs
9- Methods & Methodology in GT PRO & STEAM PRO
10- Supplementary Firing & Control Loops in GT PRO & GT MASTER
11- The Wind Turbine Feature in Thermoflex
12- Modelling GT's in Thermoflow programas-1
13- Thermoflex for on line and off line performance monitoring
14- Tflow 27, what's new
15- Modelling GT's in Thermoflow programas-2
16- Multi Point Design in GTP-GTM
17- Total Plant Cost in TFX
18- Steam Turbine Tunning
19- User Defined Components in TFX
20- Cooling System Optimization

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34- PV Field in Thermoflow

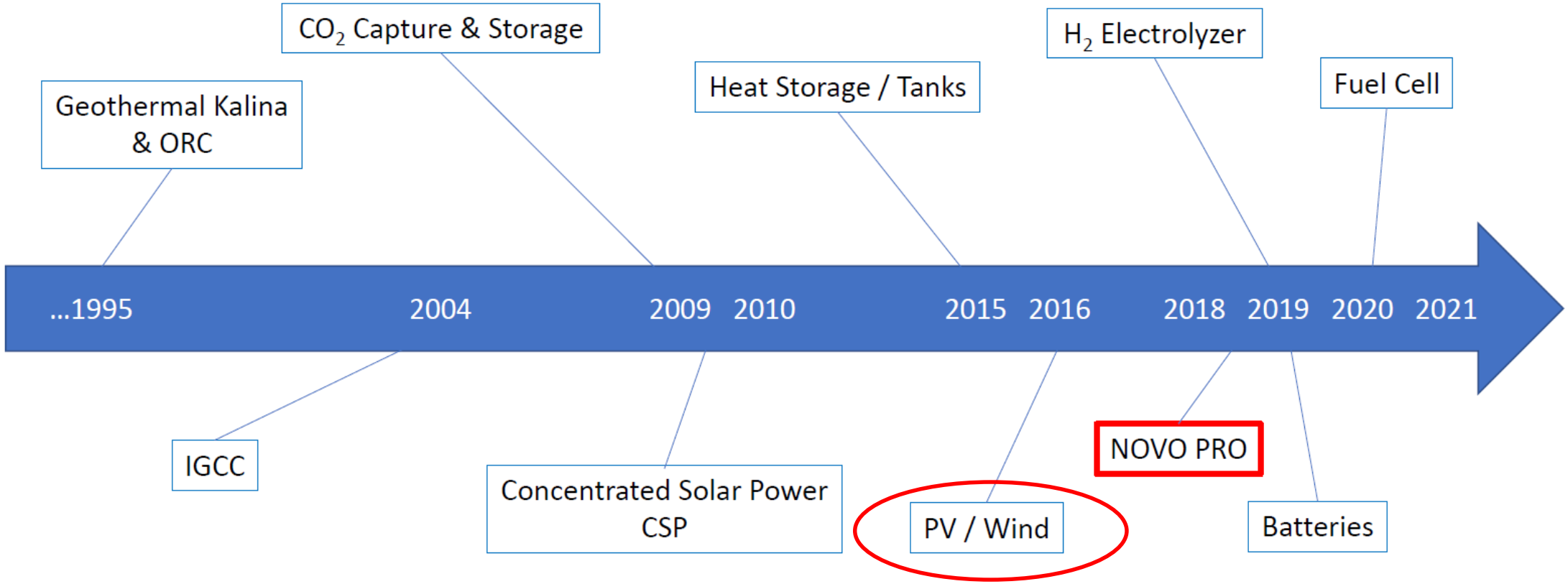
Previous Webinars on Solar

- FAW #7, July 2017, Modelling Solar Systems, focus on solar thermal, CSP
- FAW #26, April 2018, The Photovoltaic Field Feature in THERMOFLEX

Thermoflow

Thermoflow´s Products contribute to the "Green Transition"

Highlights / Milestones…



NOVO PRO Background & Evolution

- Thermoflow main programs released between 1987 (GT PRO) and 1998 (GT MASTER, PDE, STEAM PRO, STEAM MASTER, REMASTER, PEACE, THERMOFLEX)

- NOVO PRO version 1.1 was released with Thermoflow 28, in September 2018. Upgrades *1.2* in Mar-19, *1.3* in May-19, *1,4* in Jun-19, *1.5* in Sep-19, *1.6* in Feb-20
- Version 1.7 released with Tflow29 in Apr-20
- Version 1.9 released with Tflow30 in March-22. Current Revision (as of today) September 8, 2022

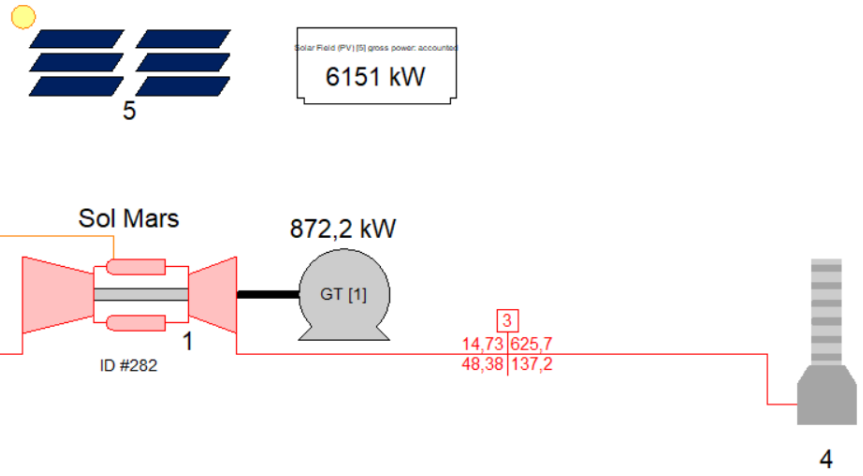
➡ Please check for new Revisions regularly, specially for NOVO PRO

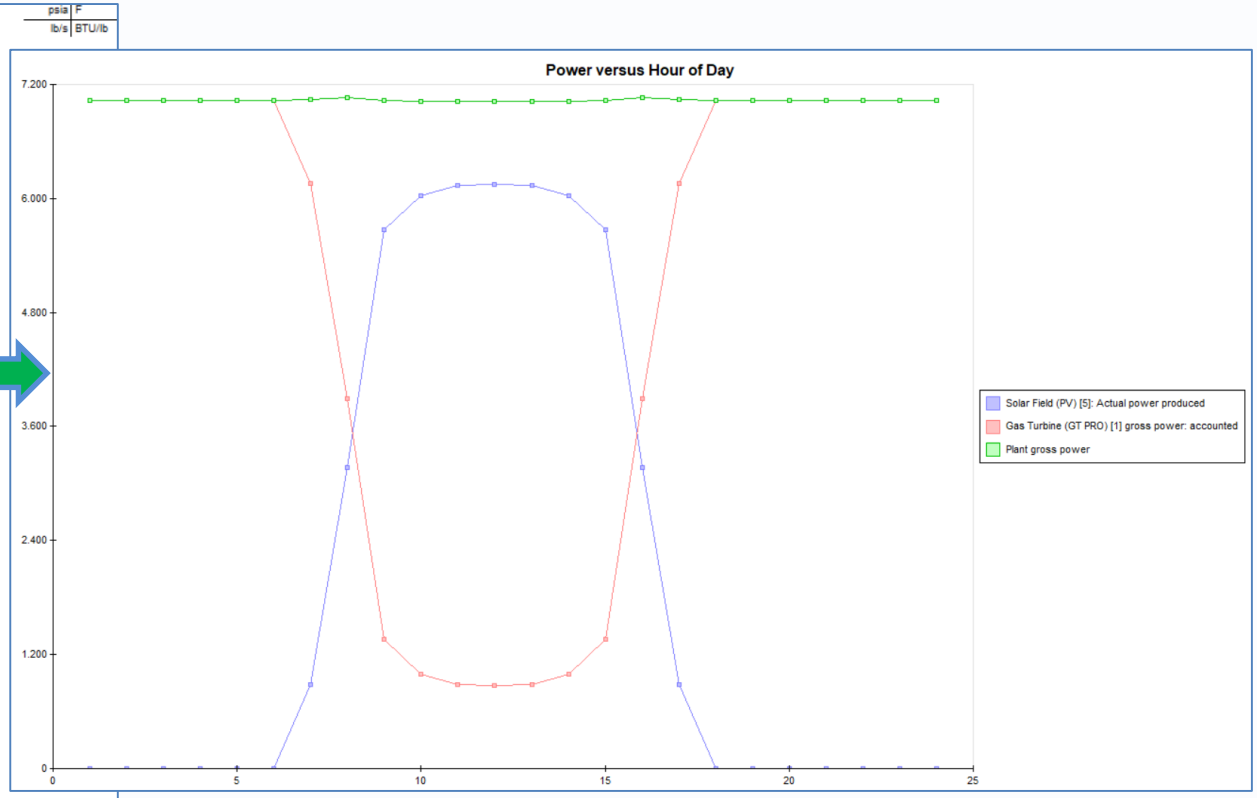
PV Field in THERMOFLEX – NOVO PRO

- THERMOFLEX:
  - More intended for **1 point calculation**, either the design point for sizing the components and system at the Design Mode, or one off design condition at Off Design mode.
  - Allows to combine with any other components within the TFX library in order to size a system and calculate performance at different conditions / operation modes
  - The user can make use of advanced TFX features like Scripts, Control Loops, Searcher, etc. to create the logic of how to operate the components and the system under different scenarios
  - Use ELINK / Macros to simulate 24 hours performance, or longer periods

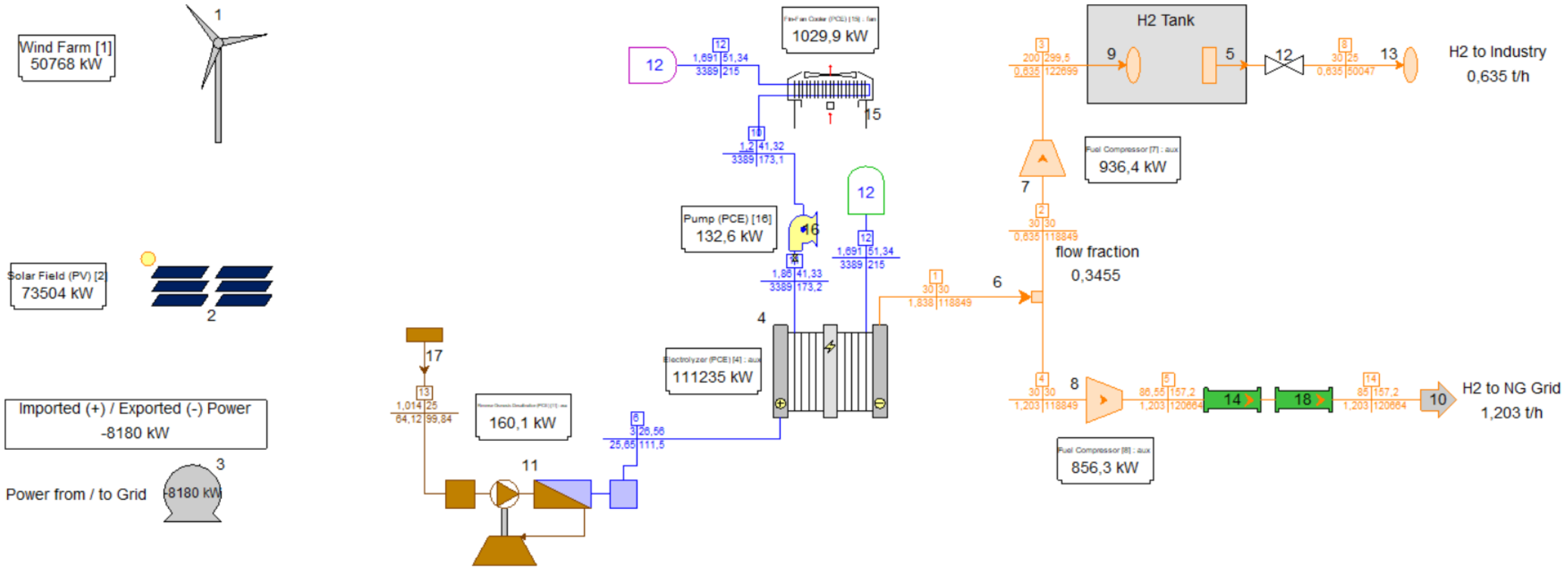
Example in TFX: Gas Turbine + PV, 24 hours operation, Scripts

Ambient temperature	59 F
Plant gross power	7023 kW
Solar Field (PV) [5]: Day in standard year	82
Solar Field (PV) [5]: Solar time	12 hours
Engine load scheduler: Solar power percentage	87,58 %
Engine load scheduler: Engine power percentage	12,42 %
Custom Inputs: Desired gross power	7 MW





Example in TFX: Wind+PV+Desalination+Electrolyzer+H2 Storage



PV Field in THERMOFLEX – NOVO PRO

- NOVOPRO:
  - Calculates **8,760 hours** of the year
  - Allows to define an hourly electric demand and various sources to supply it
  - Allows to combine power generation with Hydrogen production by Electrolysis
  - Allows to combine PV with storage systems
  - Allows to combine PV with thermal power for back up

PV Field in NOVO PRO

- Operating Mode:
  - Microgrid
  - Plants Only

- Plant Criteria:
  - Ambient Database → Select site
  - Electricity & Fuel prices
  - Grid Frecuency

- Economics:
  - Financial Assumptions

PV Field in NOVO PRO, Main Inputs

- Size of the Field (MW)
  - DC
  - AC
- Panel Model
  - User Defined
  - Library
- Row Tilt
  - Fixed Tilt
  - Variable Tilt
  - 1D Tracking

PV Field in NOVO PRO, Main Outputs

- Annual Performance, table
- Specification, table
- Site Plan / Elevation View
- Power Delivered (Map, Graphic, Data)
- Capacity Factor (monthy, weekly)
- Energy Output Graphs (monthly, weekly, daily), Histogram, Distribution
- Irradiance Data (GHI-DHI-DNI), Maps, Graphs, Data; hourly, daily, monthly
- Others
  - Performance Ratio (monthly)
  - Row Shading
  - Inverter Efficiency

Thermoflow PV Field in NOVO PRO, Outputs

Design Outputs - PV Solar Field [1]

- Performance
- Specification
- Site Plan
- Elevation View
- Power Delivered
- Capacity Factor (AC) (Monthly)
- Capacity Factor (AC) (Weekly)
- Energy Output (AC) (Monthly)
- Energy Output (AC) (Weekly)
- Energy Output (AC) (Daily)
- Energy Output Histogram (AC) (Daily)
- Energy Output Cumulative Distribution (AC) (Daily)
- Performance Ratio (Monthly)
- Row Shading
- Inverter Efficiency
- Hourly GHI
- Hourly DHI
- Hourly DNI
- Average Daily GHI
- Average Daily DHI
- Average Daily DNI
- Monthly Total GHI
- Monthly Total DHI
- Monthly Total DNI
- Messages

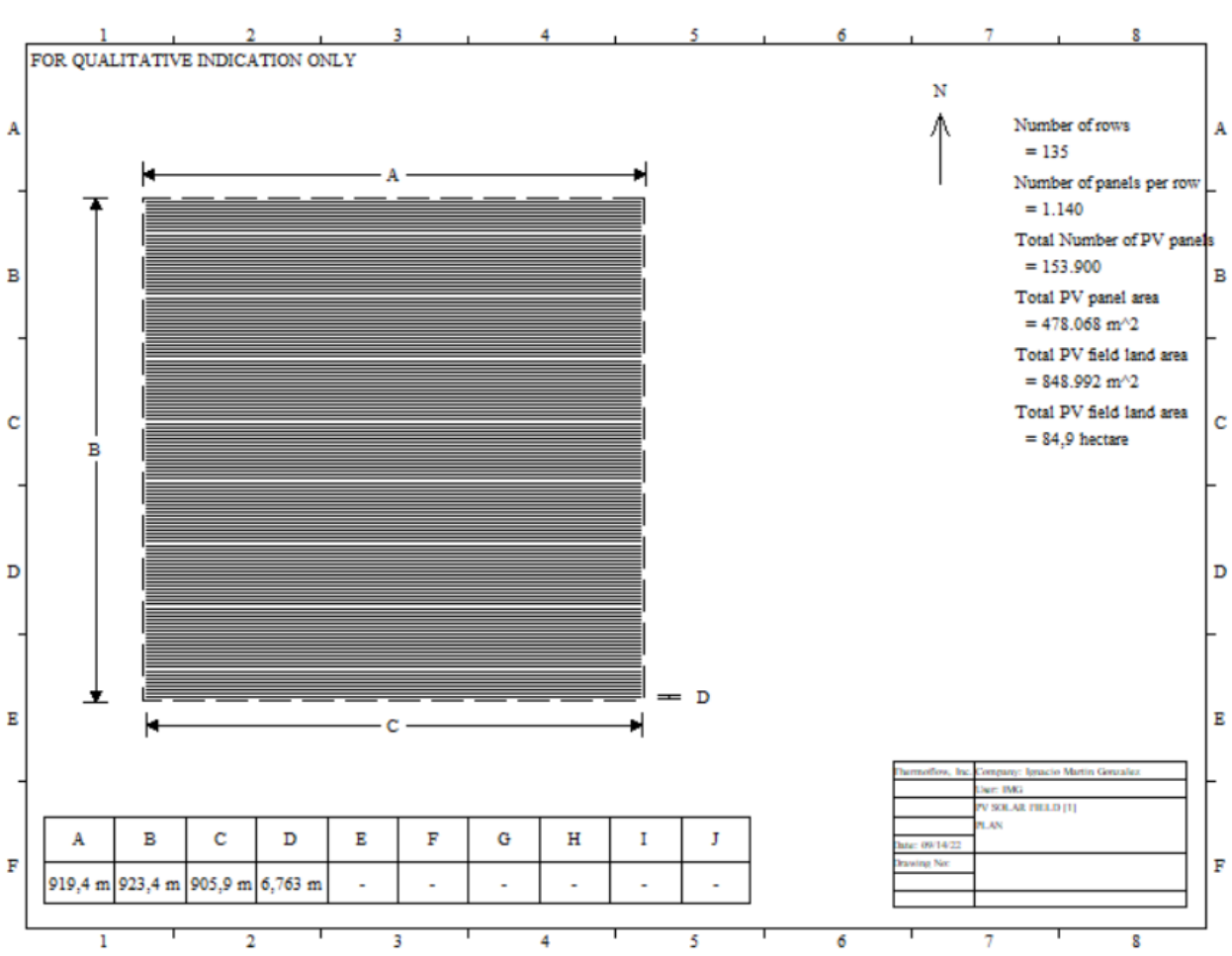
Performance		
PV Solar Field [1]		
1. Estimated Annual Performance		
Annual inverter output	163.214	MWh
Annual transformer output	162.398	MWh
Annual AC capacity factor (inverter AC output / inverter rated AC capacity)	20,7	%
Annual DC capacity factor (panel DC output / panel rated DC capacity)	20,21	%
Annual AC performance ratio (based on inverter output)	0,9033	-
Annual inverter clipping loss as percent of unclipped inverter output	0,2458	%
Annual inverter clipping loss	402,2	MWh
Number inverter-limited operating hours per year	122	hours
Irradiance method: User-defined GHI and DHI specified		
Site latitude	36,67	degrees
Elevation	7	m
Annual average user-defined global horizontal insolation (GHI)	4,5	kWh/m2-day
Annual average user-defined diffuse horizontal insolation (DHI)	1,5	kWh/m2-day
Maximum panel operating temperature	42,89	C
Maximum panel operating temperature above ambient	22,26	C
Maximum panel DC output as percent of nominal rating	108,1	%
Maximum plane of array irradiance	1.116	W/m2

Design Outputs - PV Solar Field [1]

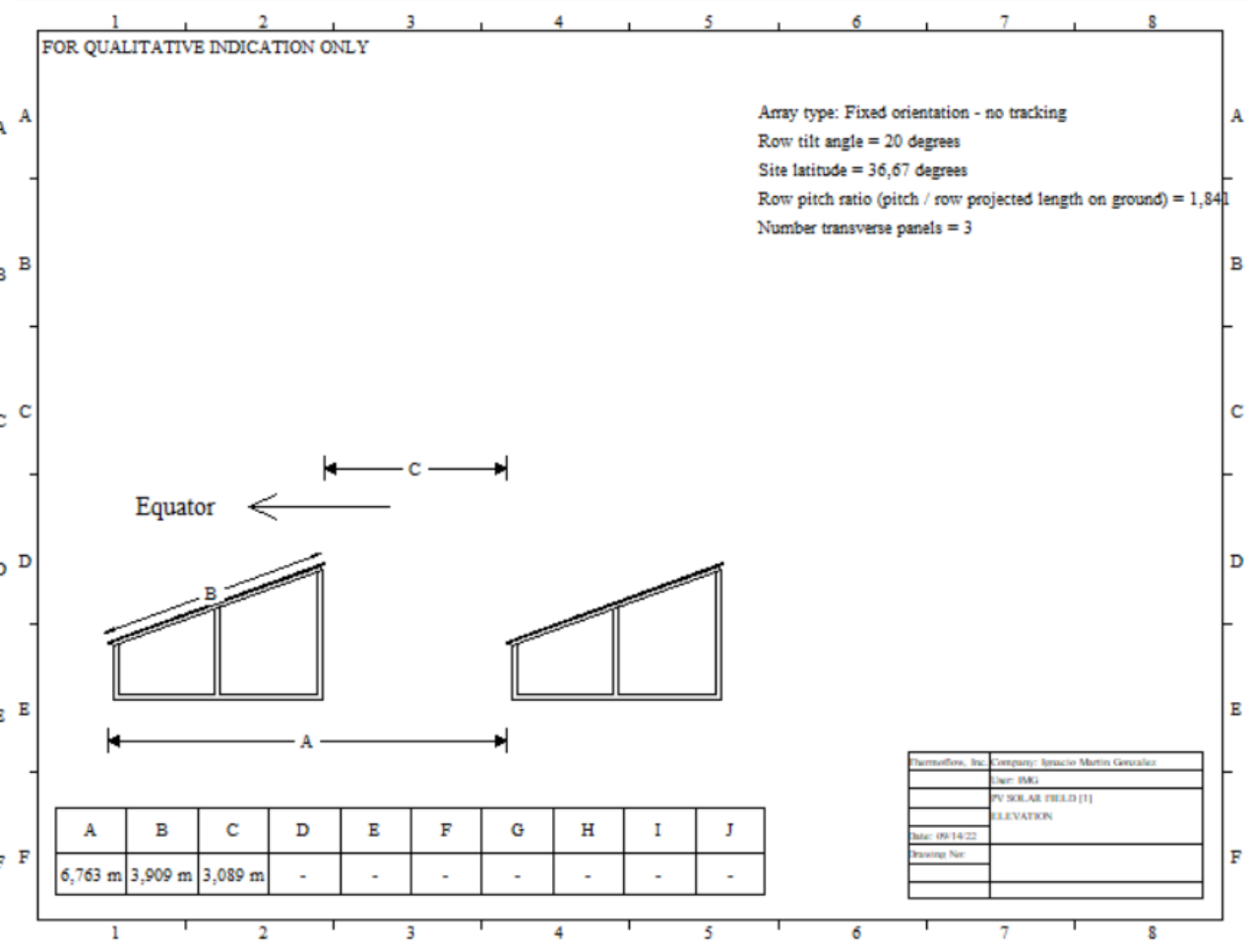
- Performance
- Specification
- Site Plan
- Elevation View
- Power Delivered
- Capacity Factor (AC) (Monthly)
- Capacity Factor (AC) (Weekly)
- Energy Output (AC) (Monthly)
- Energy Output (AC) (Weekly)
- Energy Output (AC) (Daily)
- Energy Output Histogram (AC) (Daily)
- Energy Output Cumulative Distribution (AC) (Daily)
- Performance Ratio (Monthly)
- Row Shading
- Inverter Efficiency
- Hourly GHI
- Hourly DHI
- Hourly DNI
- Average Daily GHI
- Average Daily DHI
- Average Daily DNI
- Monthly Total GHI
- Monthly Total DHI
- Monthly Total DNI
- Messages

Estimated Solar Field Data		
PV Solar Field [1]		
1. Summary		
Total number of PV panels	153.900	
Total PV panel area	478.068	m^2
Total nameplate panel DC rating	100.035	kW
Inverter AC rating	90.000	kW
Inverter AC rating / Panels DC rating	0,8997	
2. Field Details		
Field Configuration: Fixed orientation - no tracking		
Total land area occupied by the PV field	84,9	hectare
Total land area occupied by the PV field	848.992	m^2
Land aspect ratio	0,9957	
PV field length along east-west boundary	919,4	m
PV field length along north-south boundary	923,4	m
Number of rows	135	
Row length	905,9	m
Row pitch	6,763	m
Row tilt angle	20	degrees
Row azimuth angle	180	degrees
Number of panels per row	1140	
3. Panel Details		
Panel ID Number	1360	
Panel Manufacturer	CanadianSolar	
Panel Model	CS7N-650MS	
Nominal efficiency at rating condition	20,92	%
Nominal DC capacity at rating condition	650	W
Single panel area	3,106	m^2
Length (larger dimension)	2,384	m
Width (smaller dimension)	1,303	m
4. Inverter Details		
Inverter AC rating	90.000	kW
Inverter efficiency at rated AC output	95	%
Inverter weighted efficiency (CEC method)	95,44	%
Inverter weighted efficiency (EU method)	94,86	%
5. First Year Land and O&M costs		
First year land cost	0	USD
First year O&M costs	1.350.000	USD
6. Total Owner's Cost (computed using a simplified specific cost breakdown)		
Total nameplate panel DC rating	100.035	kW
Inverter AC rating	90.000	kW
Equipment cost (excluding inverters)	58.207.000	USD
Inverters cost	6.480.000	USD
Shipping cost for equipment and inverters	6.469.000	USD
Site preparation equipment, material, and construction cost	1.888.000	USD
Foundation equipment, material, and installation cost	1.500.000	USD
Mechanical erection equipment, material, and installation cost	9.270.000	USD
Electrical erection equipment, material, and installation cost	2.863.000	USD
Utility interconnection cost	3.686.000	USD
NOTE: Transmission line length set to zero, so interconnection cost EXCLUDES transmission line!	NOTE!	
Engineering, planning, project management cost	10.143.000	USD
User-defined overall estimated site-specific cost adjustment factor	**1**	
Total owner's specific cost $/kW DC	**1.000**	**USD/kW**
Total owner's specific cost $/kW AC	**1.120**	**USD/kW**
Total owner's cost	**100.505.000**	**USD**

PV Field in NOVO PRO, Outputs

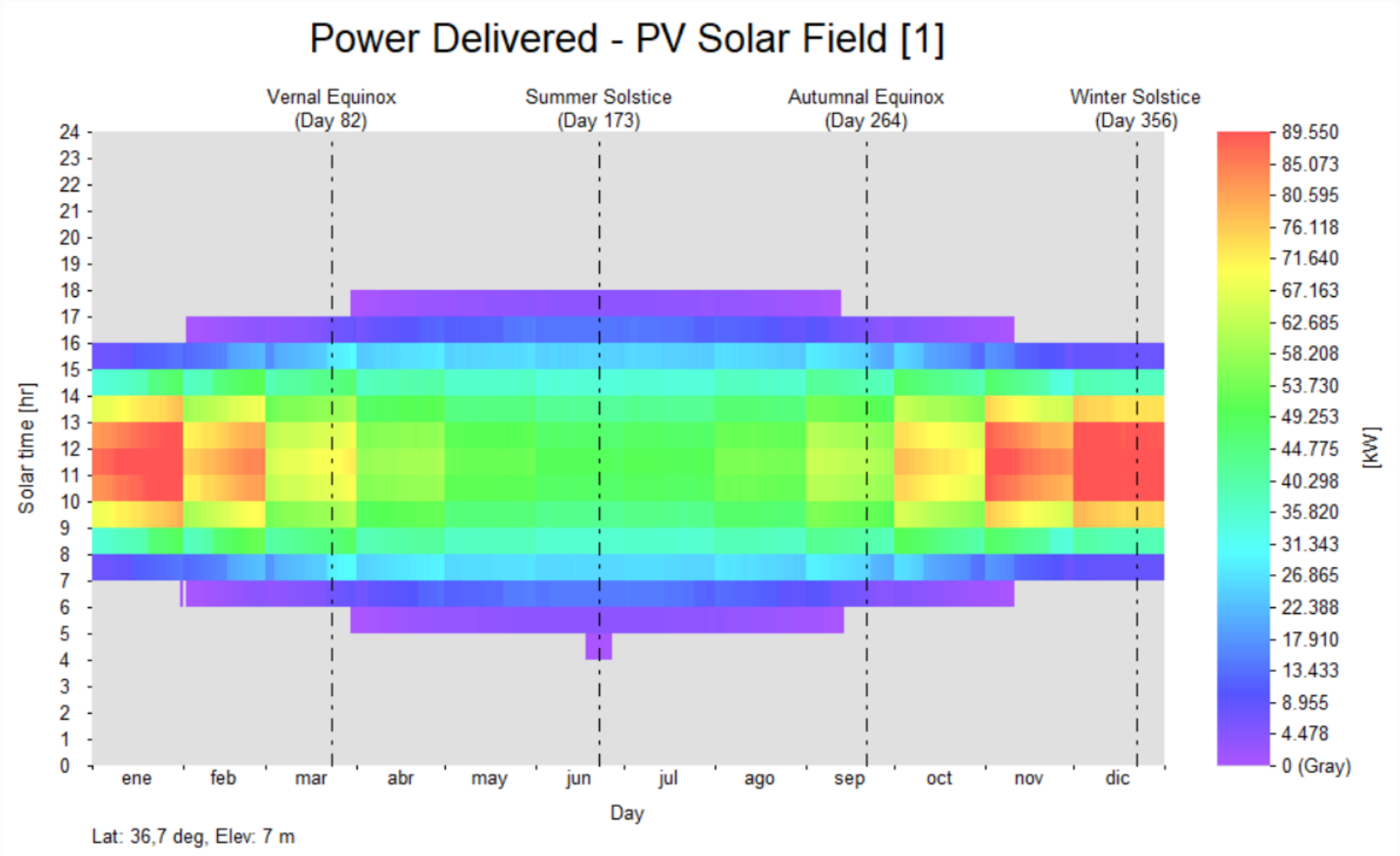


A	B	C	D	E	F	G	H	I	J
919,4 m	923,4 m	905,9 m	6,763 m	-	-	-	-	-	-

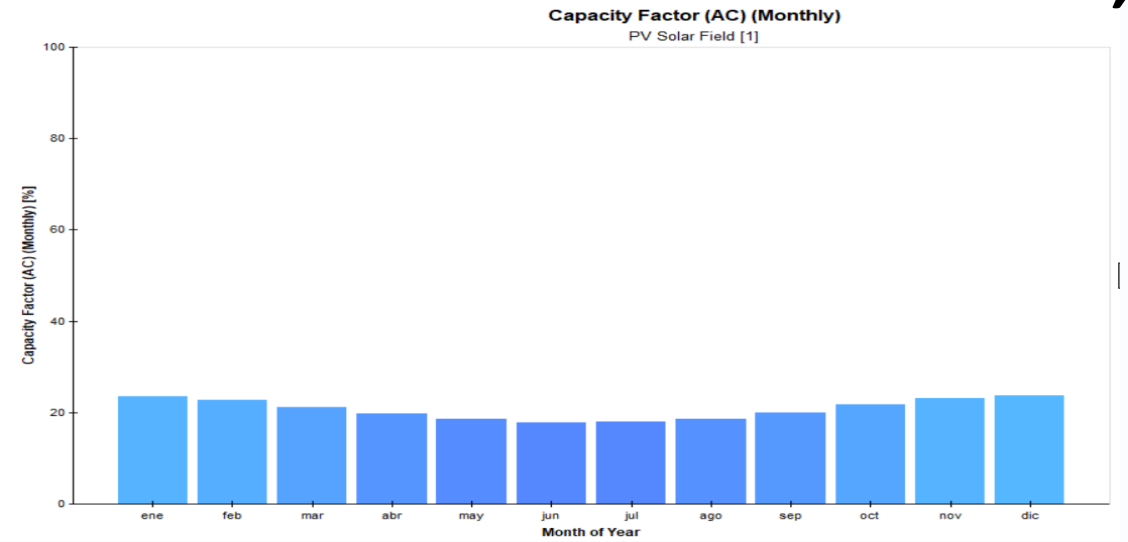


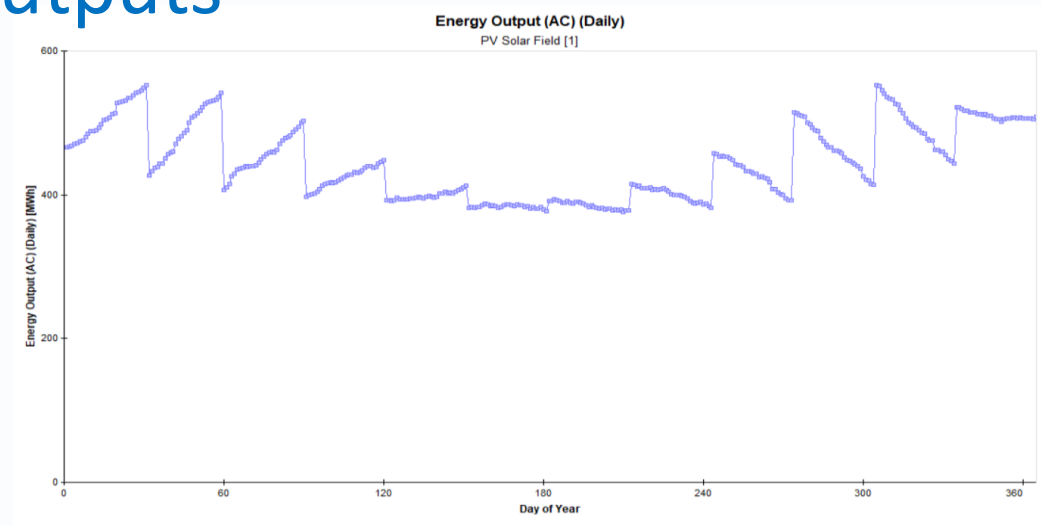
A	B	C	D	E	F	G	H	I	J
6,763 m	3,909 m	3,089 m	-	-	-	-	-	-	-

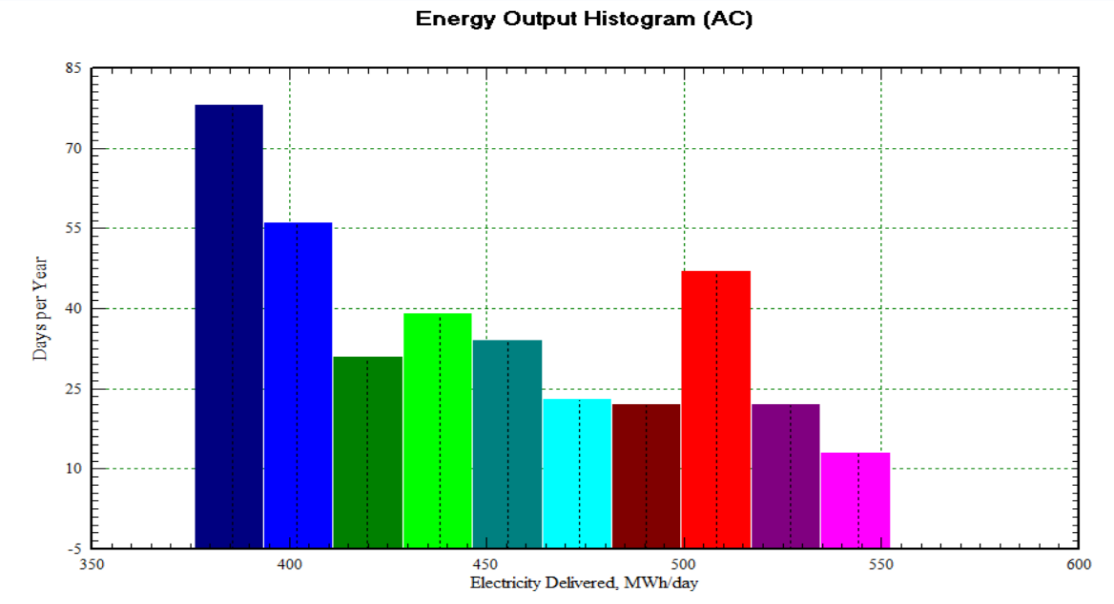
PV Field in NOVO PRO, Outputs

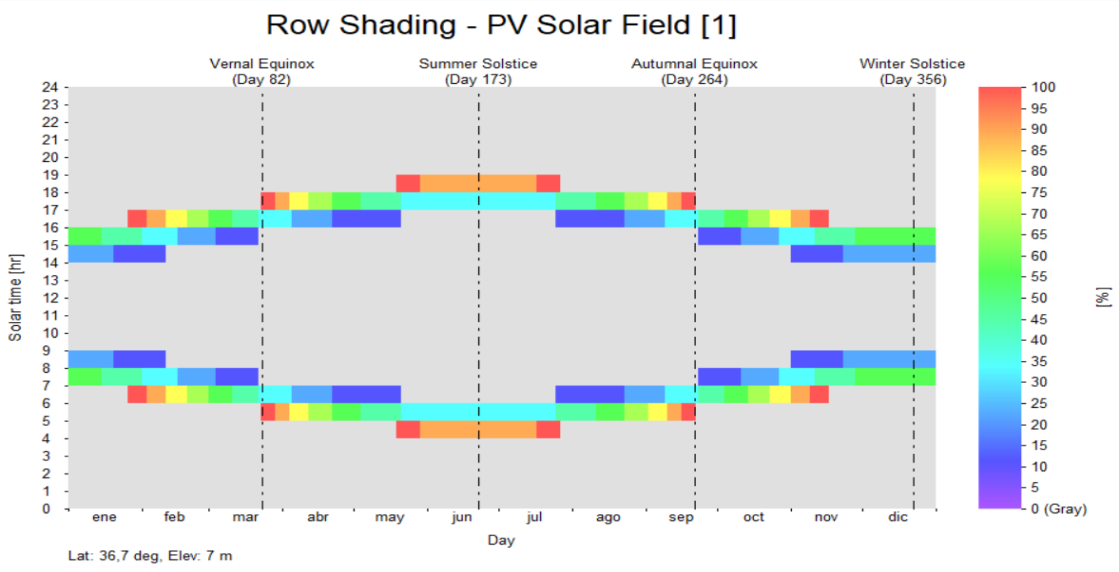


PV Field in NOVO PRO, Outputs

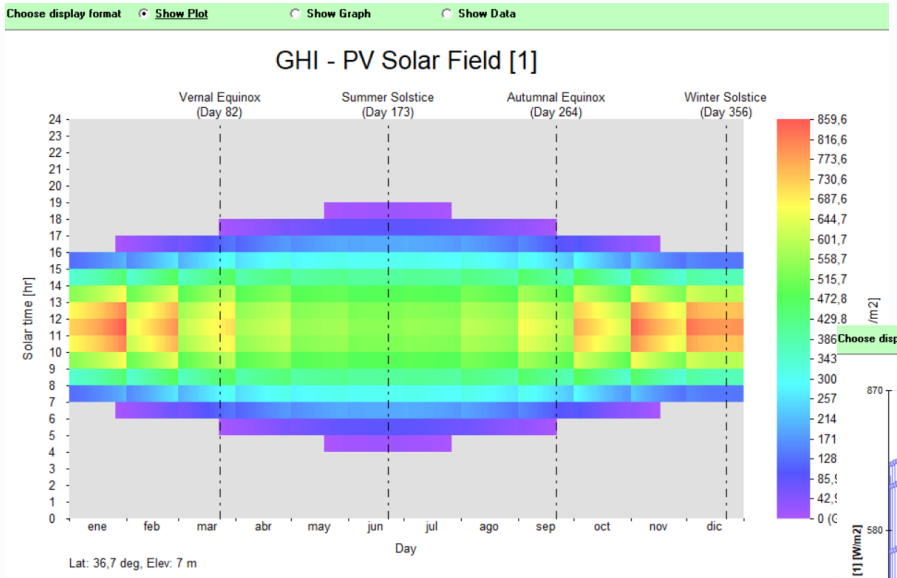


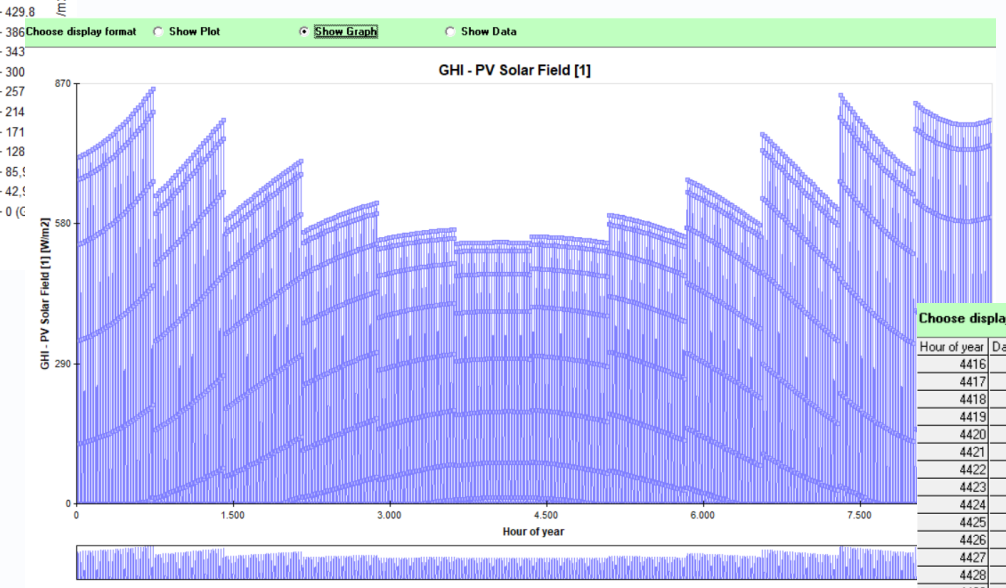






PV Field in NOVO PRO, Outputs



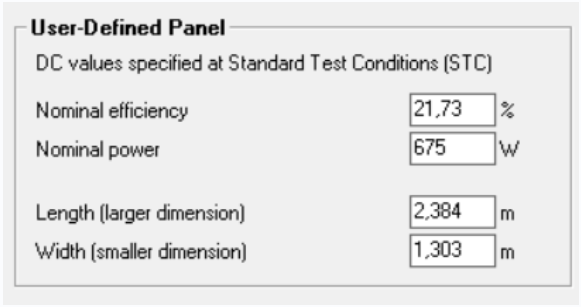


Choose display format ○ Show Plot ○ Show Graph ● Show Data

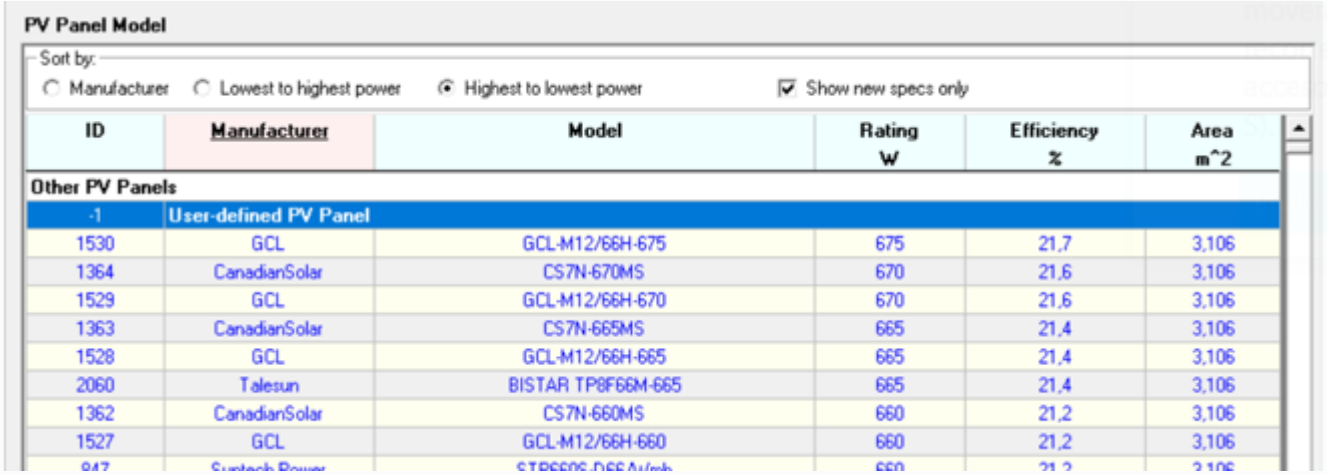
Hour of year	Day of year	Month	Day of month	Hour of day	GHI - PV Solar Field [1], W/m2
4416	184	7	3	24	0
4417	185	7	4	1	0
4418	185	7	4	2	0
4419	185	7	4	3	0
4420	185	7	4	4	0
4421	185	7	4	5	11,8433
4422	185	7	4	6	85,14411
4423	185	7	4	7	193,0191
4424	185	7	4	8	305,7824
4425	185	7	4	9	406,7934
4426	185	7	4	10	485,7854
4427	185	7	4	11	535,895
4428	185	7	4	12	553,051
4429	185	7	4	13	535,895
4430	185	7	4	14	485,7854
4431	185	7	4	15	406,7934
4432	185	7	4	16	305,7824
4433	185	7	4	17	193,0191
4434	185	7	4	18	85,14411
4435	185	7	4	19	11,8433
4436	185	7	4	20	0
4437	185	7	4	21	0
4438	185	7	4	22	0

PV Field in NOVO PRO, PV Panel Selection

User Defined



Library

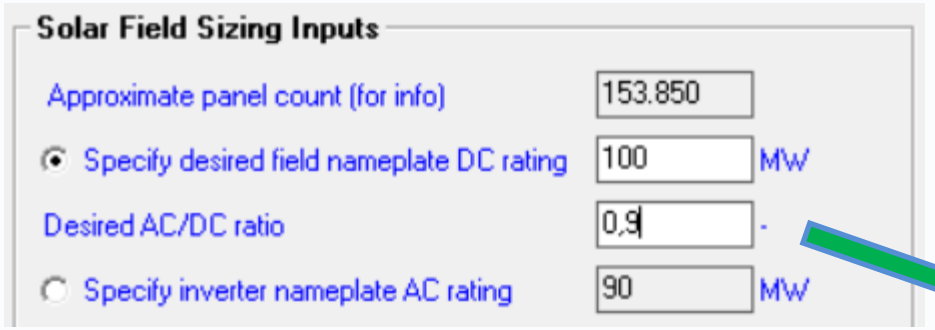


ID	Manufacturer	Model	Rating W	Efficiency %	Area m^2
Other PV Panels					
-1	User-defined PV Panel				
1530	GCL	GCL-M12/66H-675	675	21,7	3,106
1364	CanadianSolar	CS7N-670MS	670	21,6	3,106
1529	GCL	GCL-M12/66H-670	670	21,6	3,106
1363	CanadianSolar	CS7N-665MS	665	21,4	3,106
1528	GCL	GCL-M12/66H-665	665	21,4	3,106
2060	Talesun	BISTAR TP8F66M-665	665	21,4	3,106
1362	CanadianSolar	CS7N-660MS	660	21,2	3,106
1527	GCL	GCL-M12/66H-660	660	21,2	3,106

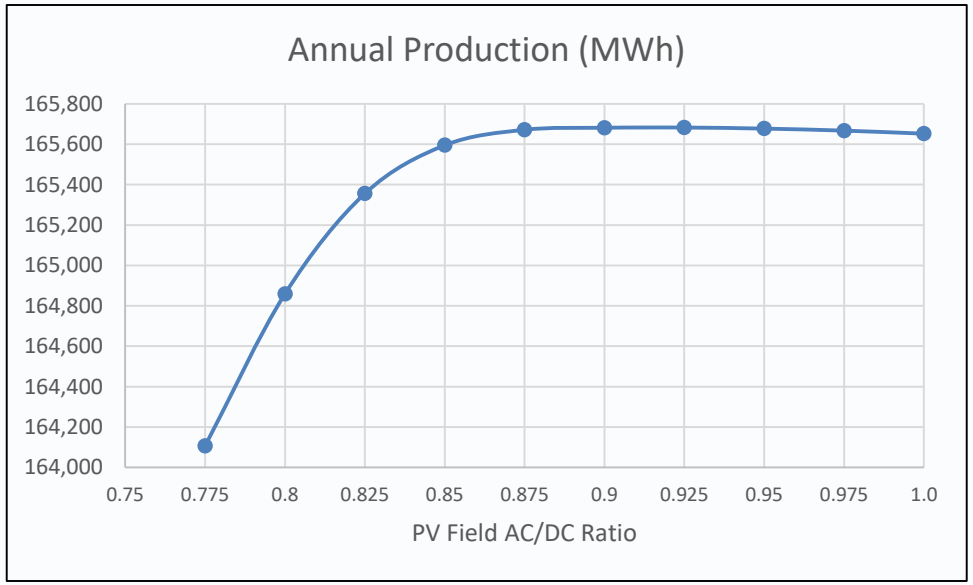
Data for each listed panel was gathered from publicly available spec sheets published by panel manufacturers

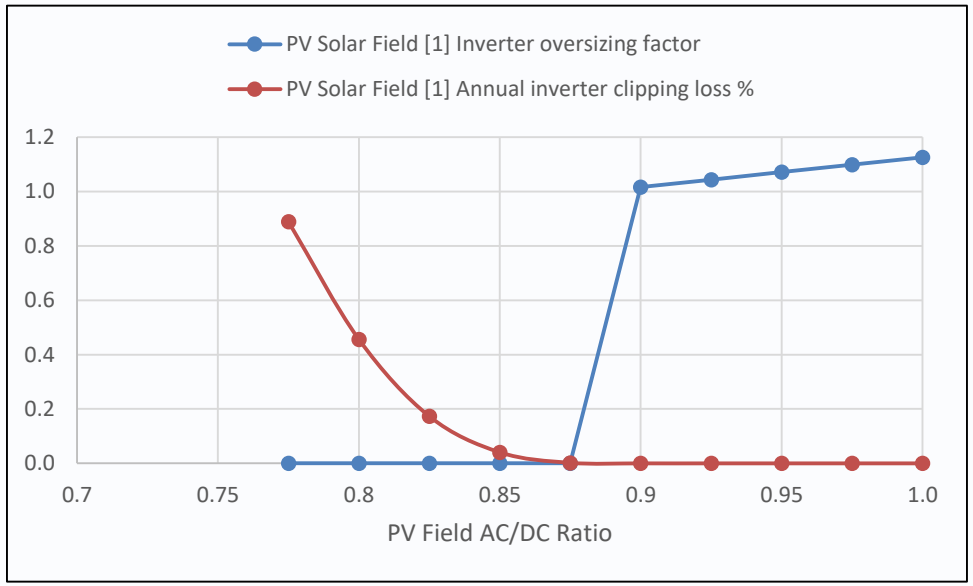
Note: Data for included panels is provided for information only! There is no guarantee that any panel listed here, with the associated specs, is still available at this or any performance level. It is solely the user's responsibility to verify the availability, suitability, and performance details for any panel used to build a performance and cost model. Data you receive from a vendor can be entered by selecting the 'User-defined PV Panel' entry atop this list and editing the characteristics on the Configuration tab.

PV Field in NOVO PRO, AC/DC Ratio



Performance		
PV Solar Field [1]		
1. Estimated Annual Performance		
Annual inverter output	165.682	MWh
Annual transformer output	164.853	MWh
Annual AC capacity factor (inverter AC output / inverter rated AC capacity)	21,01	%
Annual DC capacity factor (panel DC output / panel rated DC capacity)	20,5	%
Annual AC performance ratio (based on inverter output)	0,8915	-
Annual inverter clipping loss as percent of unclipped inverter output	0	%
Inverter oversizing factor	1,016	





PV Field in NOVO PRO, Effect of Variable Tilt / Tracking

Row Tilt
- (•) Fixed tilt
- ( ) Variable tilt
- ( ) 1D tracking

Row Configuration - Fixed Tilt Rows

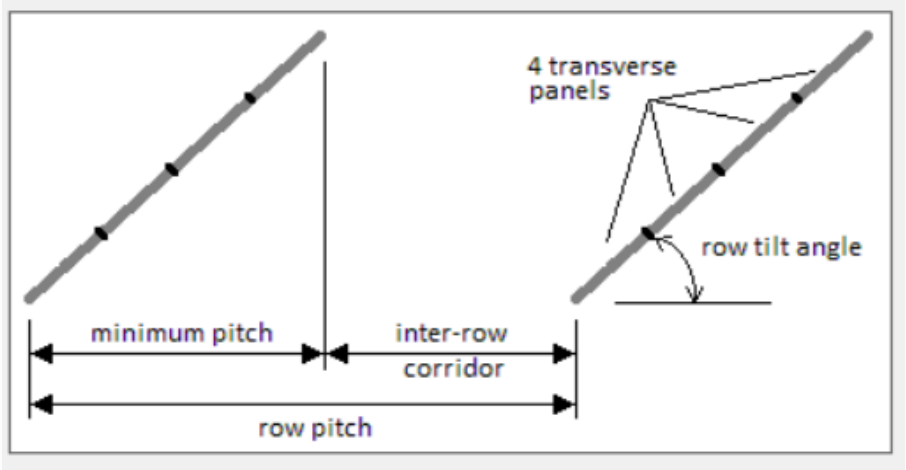
Transverse panel count: 3

Method to specify panel tilt angle and row spacing
- (•) Automatic
- ( ) User-defined

Minimum inter-row corridor: 0 m

Row tilt angle (from horizontal): 18 degrees

Row spacing factor (row pitch / min pitch): 1,819 -



Row Tilt
- ( ) Fixed tilt
- (•) Variable tilt
- ( ) 1D tracking

Variable Tilt Adjustment Frequency
- ( ) Biannual (centered on solstices)
- (•) Seasonal (centered on equinoxes and solstices)
- ( ) Monthly (calendar months)

Row Tilt
- ( ) Fixed tilt
- ( ) Variable tilt
- (•) 1D tracking

Row Configuration - 1D Tracking Rows

Transverse panel count: 3

Row spacing method
- (•) Automatic
- ( ) User-defined

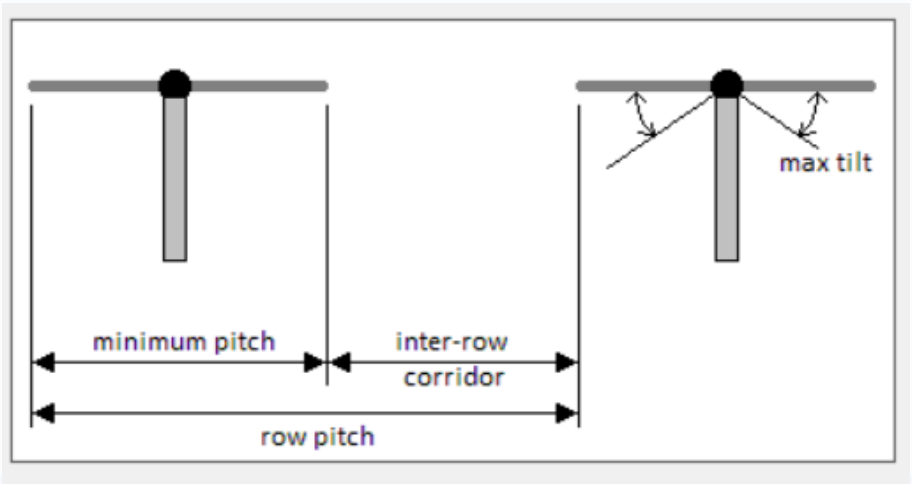
Minimum inter-row corridor: 0 m

Row spacing factor (row pitch / min pitch): 1,841 -

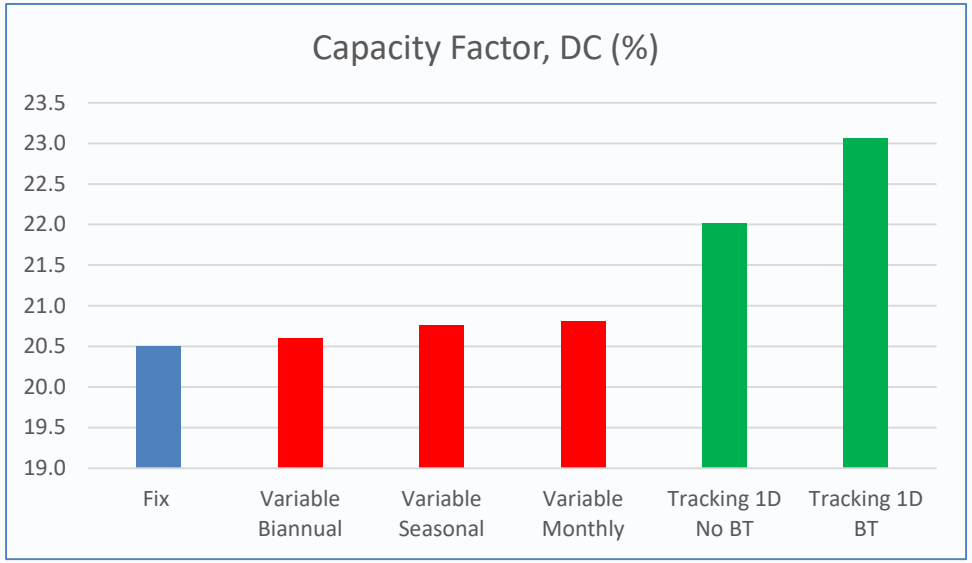
Tracking Details
- (•) North-South rows
- ( ) East-West rows

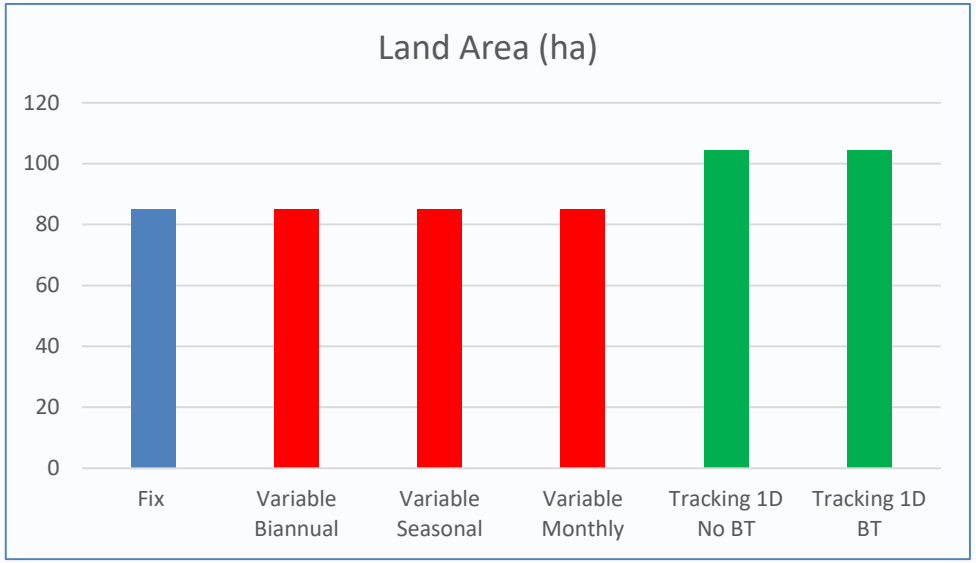
Maximum tilt from horizontal: 60 degrees

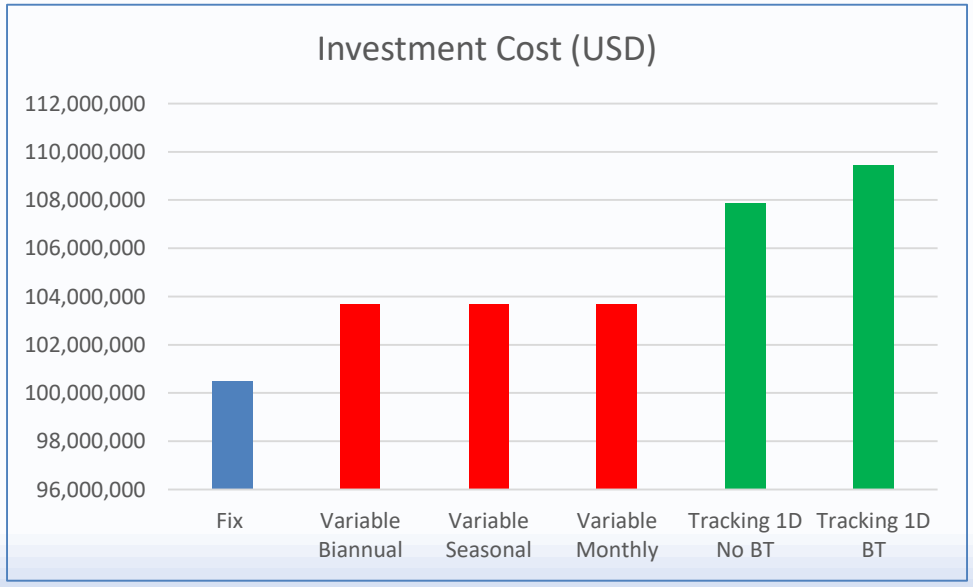
Use backtracking: ( ) No (•) Yes

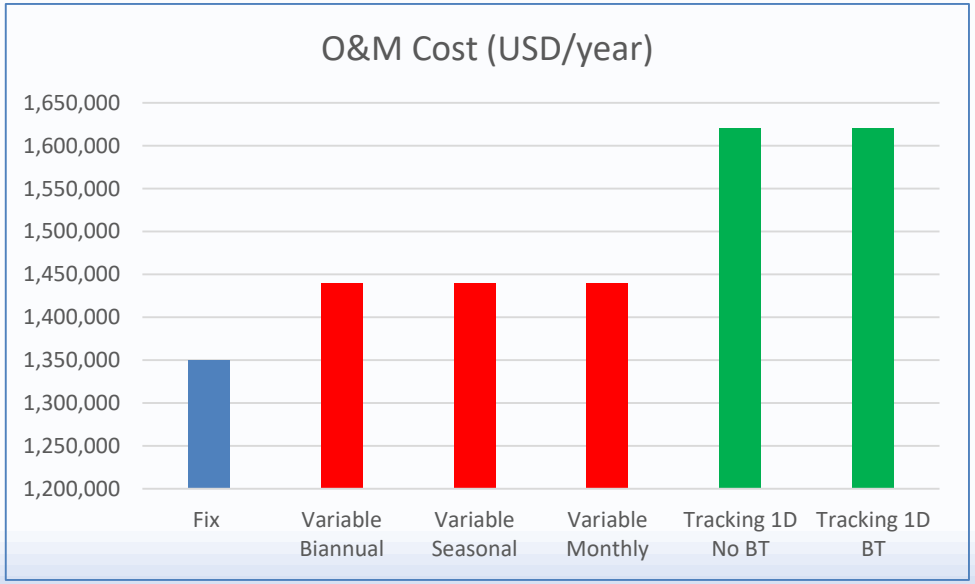


PV Field in NOVO PRO, Effect of Variable Tilt / Tracking









PV Field in NOVO PRO, Irradiance Specification

Irradiance Method

- (•) Estimated with specified cloud cover factor
- ( ) Use database
- ( ) User-defined monthly insolation data

Inputs for Estimated Irradiance

Site latitude	36,67	degrees
Site altitude	7	m
Annual average cloud cover factor	0	
Albedo of surroundings	0,2	-
Threshold solar altitude for beam irradiance	0	degrees

Irradiance Method

- ( ) Estimated with specified cloud cover factor
- (•) Use database
- ( ) User-defined monthly insolation data

Solar Irradiance Database

Change Location

Current Location:
Malaga,
Lat: 36,7 deg, Long: -4,5 deg, Elev: 7 m

Albedo of surroundings	0,2	-
Threshold solar altitude for beam irradiance	0	degrees
Irradiance adjustment factor for DNI & GHI	1	

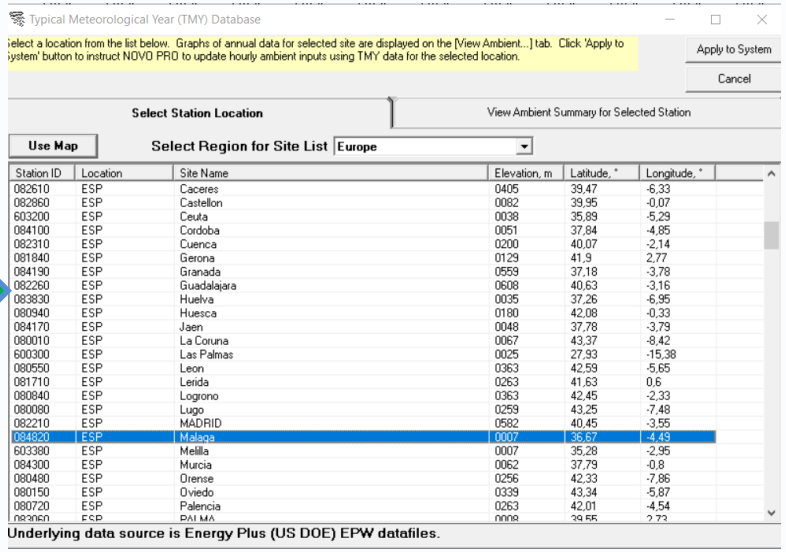
Irradiance Method

- ( ) Estimated with specified cloud cover factor
- ( ) Use database
- (•) User-defined monthly insolation data

User-defined Monthly Insolation

Site latitude	36,67	degrees
Site altitude	7	m
Albedo of surroundings	0,2	-
Threshold solar altitude for beam irradiance	0	degrees

	Daily Avg GHI	Daily Avg DHI
Month	kWh/m2-day	kWh/m2-day
enero	4,5	1,5
febrero	4,5	1,5
marzo	4,5	1,5
abril	4,5	1,5
mayo	4,5	1,5
junio	4,5	1,5
julio	4,5	1,5
agosto	4,5	1,5
septiembre	4,5	1,5
octubre	4,5	1,5
noviembre	4,5	1,5
diciembre	4,5	1,5



PV Field in NOVO PRO, Irradiance Specification

Irradiance Database (more details in NOVO PRO Help, Chapter 6.9.2)

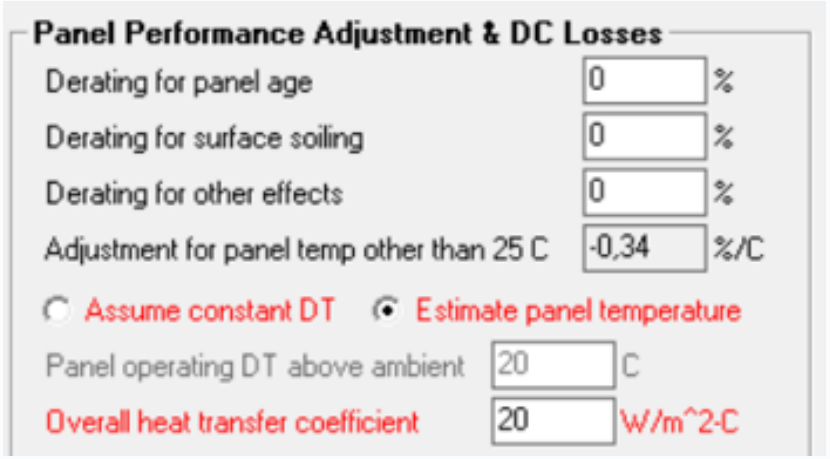
1.Data for **1020 locations in the United States** and selected territories comes from a database of Typical Meteorological Year (TMY) data compiled by **US NREL** and made publicly available on the NREL website (rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3).

2.Data for **80 Canadian** locations comes from **Meteorological Service of Canada**, Environment Canada, a part of the Government of Canada. The data are from Canadian Weather year for Energy Calculation (CWEC) database which is based on analysis to develop a Typical Meteorological Year (TMY). (www.climate.weather.gc.ca/prods_servs/engineering_e.html)

3.Data for locations in **Africa, Asia, Central America, Europe, South America, and Southwest Pacific** comes from weather data made available on the **EnergyPlus** website, https://energyplus.net/weather. EnergyPlus is funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO), and managed by the National Renewable Energy Laboratory (NREL). EnergyPlus is developed in collaboration with NREL, various DOE National Laboratories, academic institutions, and private firms.

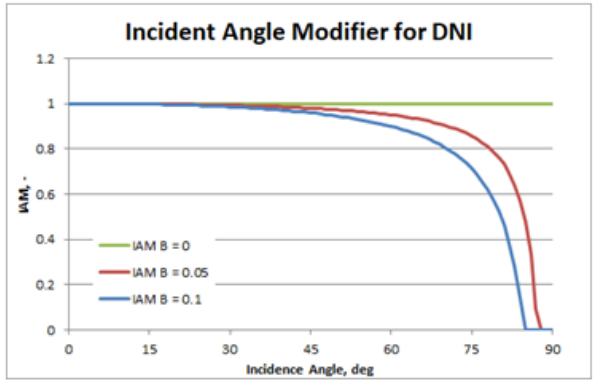
PV Field in NOVO PRO, Panel Performance adj. & DC Losses

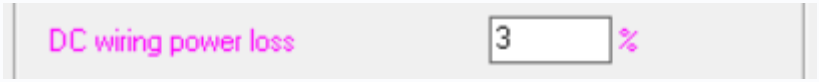
Current Panel Efficiency = Nominal Panel Efficiency * (1-D_1/100) * (1-D_2/100) * (1-D_3/100) * (1-(T_{panel}[C] - 25[C]) * D_4/100)



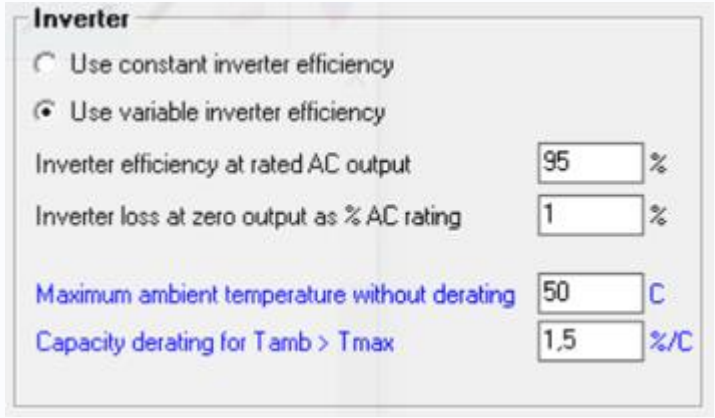
IAM = 1 - B *(1/COS(a) -1)

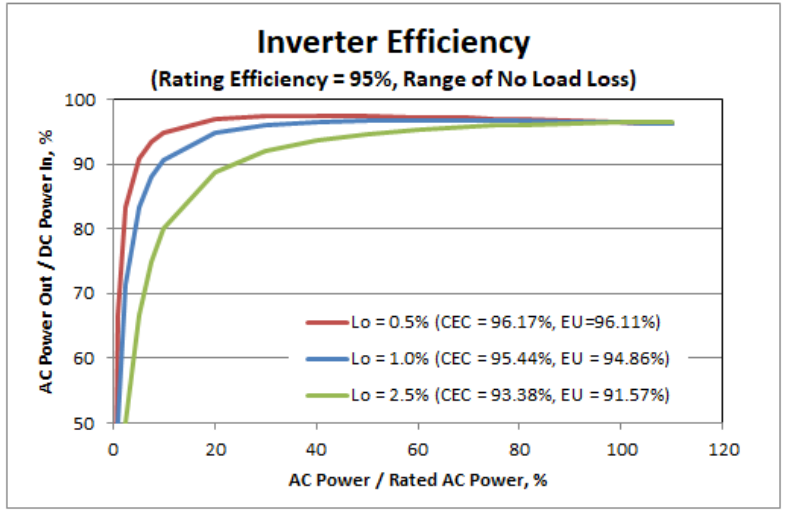
- "B" is the incident angle modifier coefficient, typical value is 0.05
- "a" is the incident angle measured from the normal

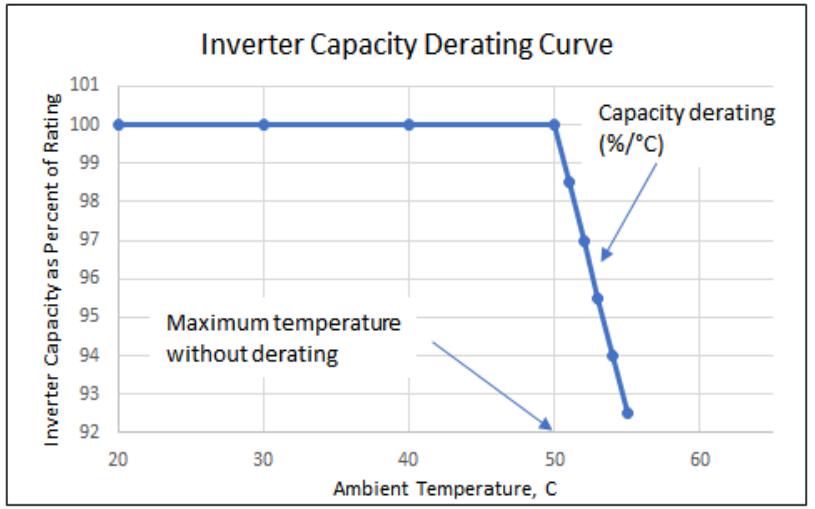




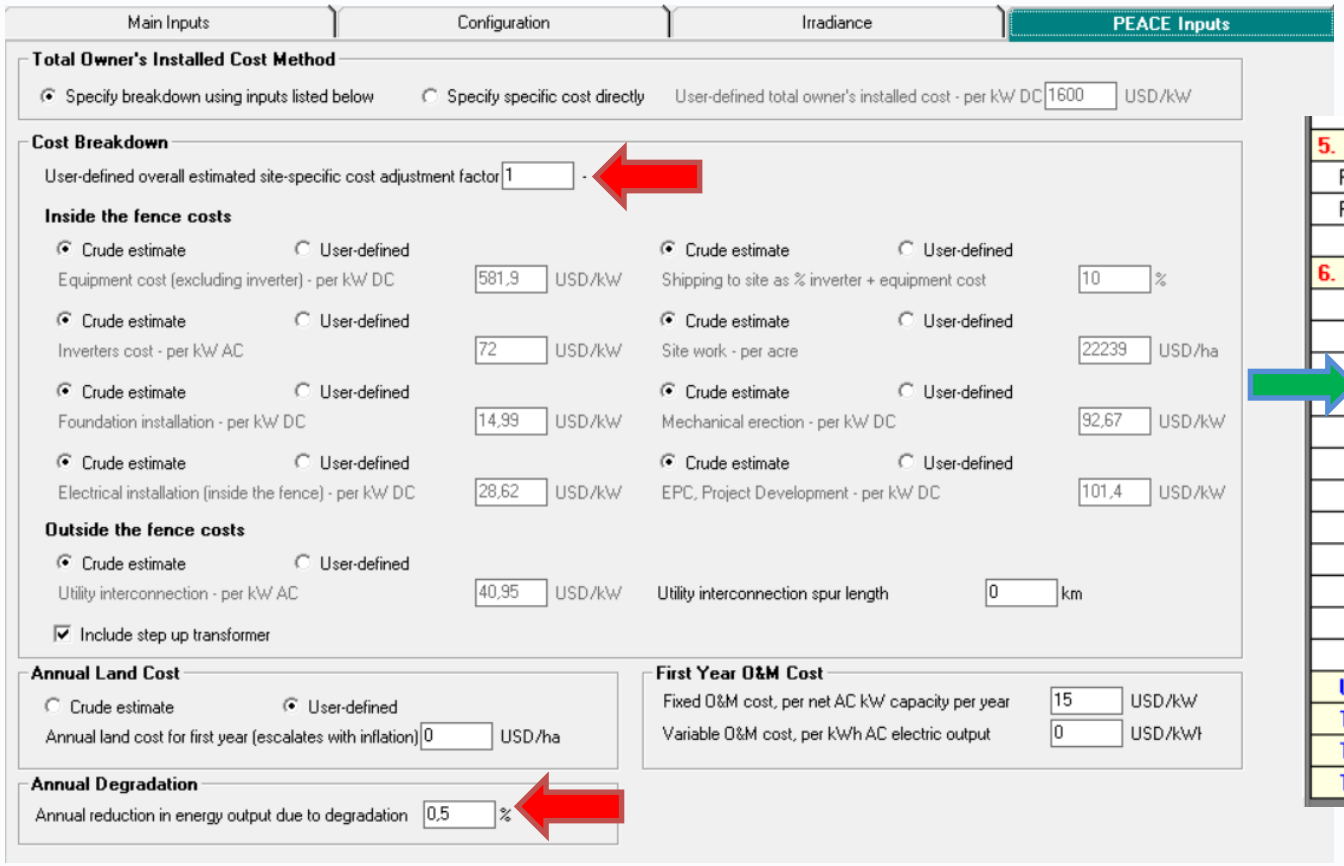
PV Field in NOVO PRO, Panel Performance adj. & DC Losses







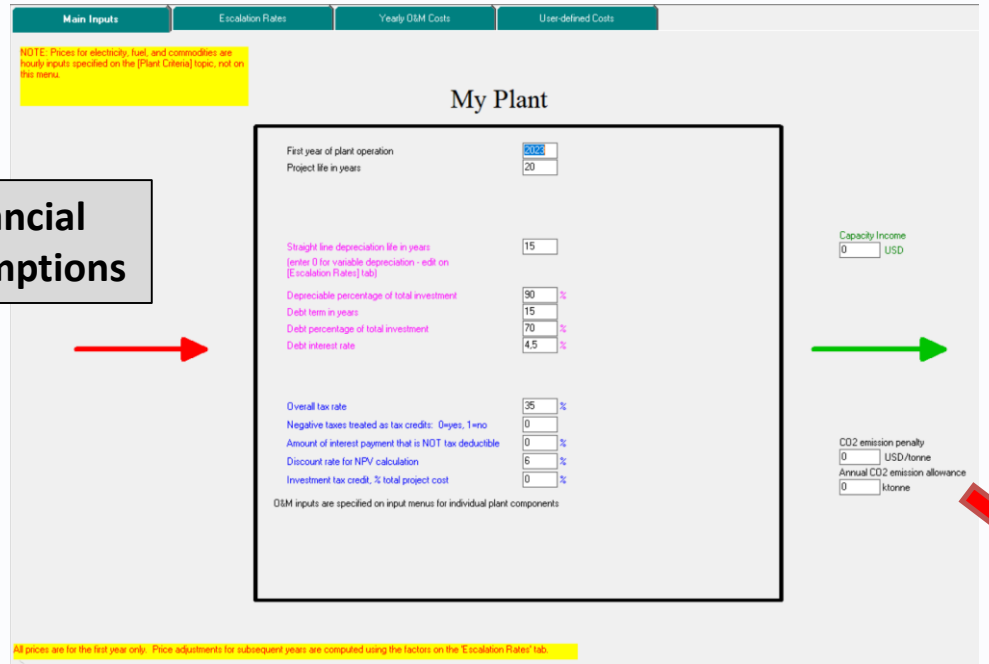
PV Field in NOVOPRO, PEACE Inputs & Cost Estimation



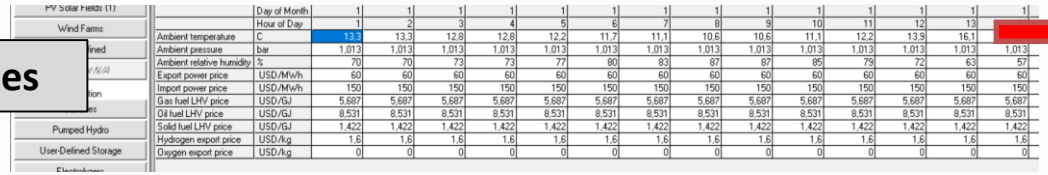
5. First Year Land and O&M costs		
First year land cost	0	USD
First year O&M costs	1.350.000	USD
6. Total Owner's Cost (computed using a simplified specific cost breakdown)		
Total nameplate panel DC rating	100.035	kW
Inverter AC rating	90.000	kW
Equipment cost (excluding inverters)	58.207.000	USD
Inverters cost	6.480.000	USD
Shipping cost for equipment and inverters	6.469.000	USD
Site preparation equipment, material, and construction cost	1.888.000	USD
Foundation equipment, material, and installation cost	1.500.000	USD
Mechanical erection equipment, material, and installation cost	9.270.000	USD
Electrical erection equipment, material, and installation cost	2.863.000	USD
Utility interconnection cost	3.686.000	USD
NOTE: Transmission line length set to zero, so interconnection cost EXCLUDES transmission line!	NOTE!	
Engineering, planning, project management cost	10.143.000	USD
User-defined overall estimated site-specific cost adjustment factor	**1**	
Total owner's specific cost $/kW DC	**1.000**	**USD/kW**
Total owner's specific cost $/kW AC	**1.120**	**USD/kW**
Total owner's cost	**100.505.000**	**USD**

PV Field in NOVO PRO, Investment Analysis

Financial Assumptions



Prices



PEACE Inputs

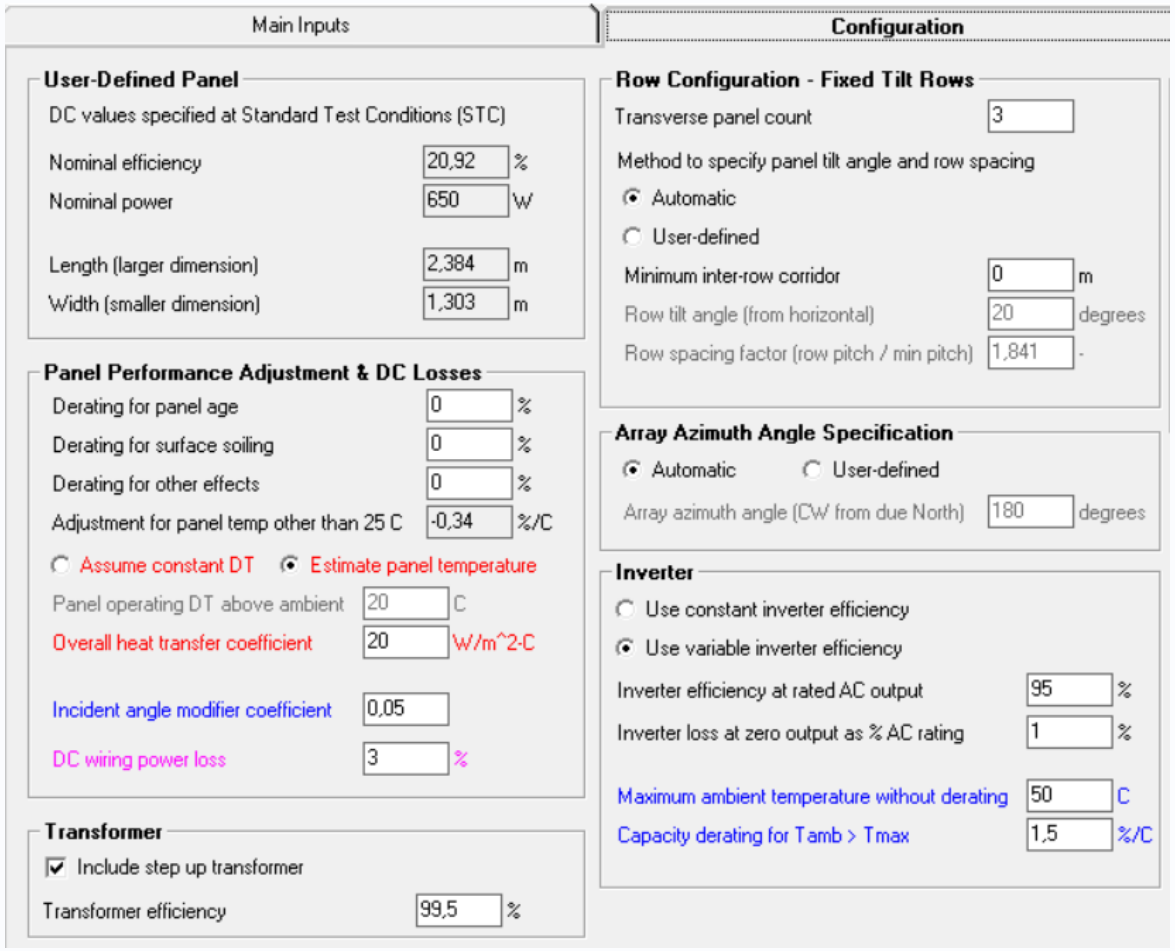
Summary Graphics	Summary Report	Messages (none)	Notes	Cost Report	Investment An...	Plots	Histograms	Input Data

Financial Summary | Cashflow

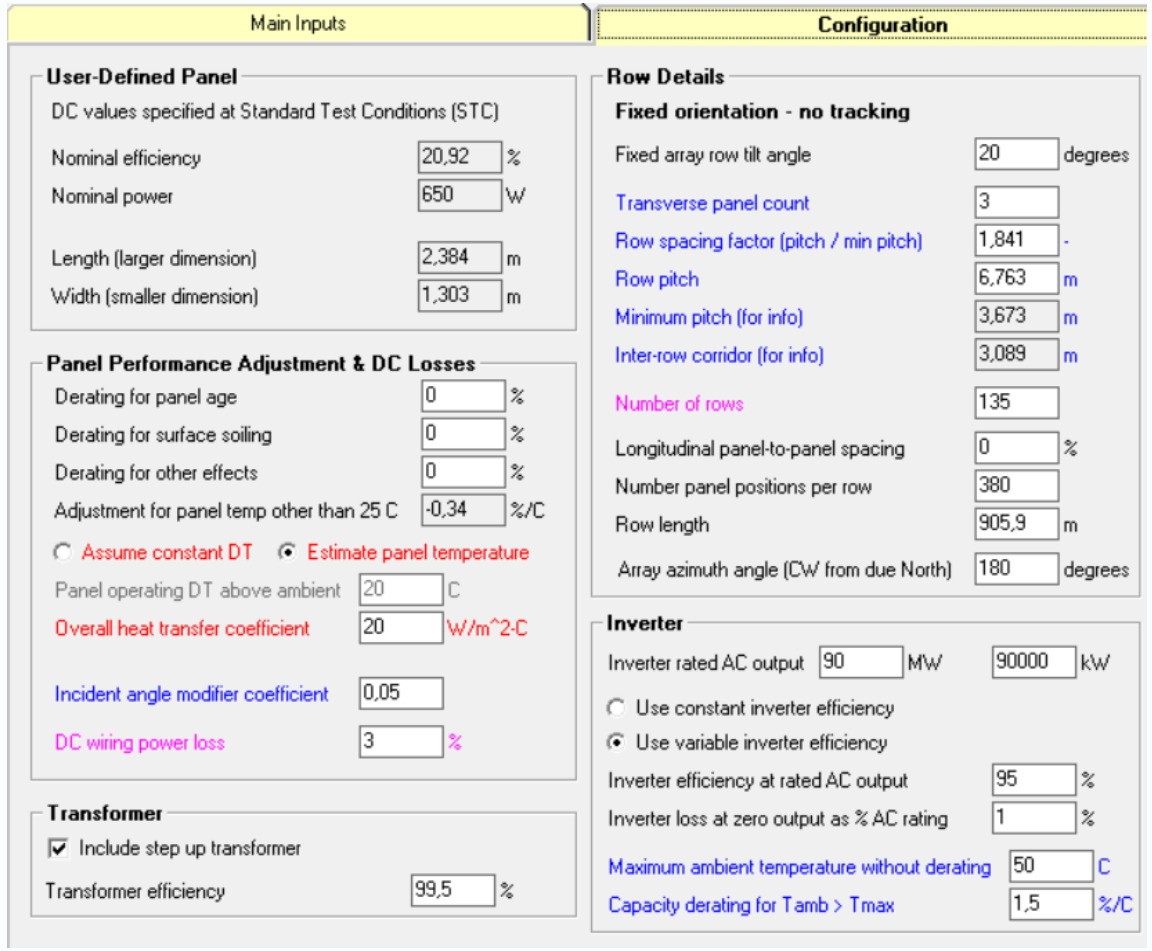
Financial Summary		
Annual Electricity Export	164,9	GWh
Annual Fuel Imported	0	TJ
Annual H2 Exported	0	tonne
Annual O2 Exported	0	tonne
Total Investment	100.505.000	USD
Initial Equity	30.151.000	USD
Cumulative Net Cash Flow	83.571.000	USD
Internal Rate of Return on Investment (ROI)	5,633	%
Internal Rate of Return on Equity (ROE)	9,071	%
Years for Payback of Equity	11,39	years
Net Present Value	10.741.000	USD
Break-even Export Power Price @ Input Fuel and Import Electricity Prices (i.e. Levelised Cost of Electricity)	0,0528	USD/kWh
Break-even Export Power Price @ Input Fuel and Import Electricity Prices (i.e. Levelised Cost of Electricity)	52,82	USD/MWh
Break-even Hydrogen Price @ Input Fuel and Import Electricity Prices (i.e. Levelised Cost of Hydrogen)	N/A	USD/kg
NOTE:		
Break-even prices (LCOE) shown above are comparable between NOVO PRO cases with the same [Economics] inputs.		
HOWEVER, myriad user-adjustable financial assumptions, without universally agreed defaults,		
are used to compute these outputs. Comparing them with values reported elsewhere IS NOT meaningful		
unless you ensure a comparable set of assumptions was used to produce those results. See help <F1> for details.		
Land cost is set to zero in this model.		
Including land cost can have a significant impact on these results.		
Land cost is editable on the [PEACE Inputs] tab for each renewable plant.		
Utility interconnection spur length is set to zero in this model.		
Including cost for a spur line can have a significant impact on these results.		
The spur length is editable on the [PEACE Inputs] tab for each renewable plant.		

PV Field in NOVO PRO, Create Design / Modify Design

Create Design, Inputs



Modify Design, Inputs



PV Field in NOVO PRO, Microgrid / Plants Only

Plants Only mode:

- PV Field makes as much power as it can, and just send it to the grid
- Can be combined with other renewable (Wind, UD) and thermal power sources. All of them add their energy to the grid, and behave independently
- Can be combined with Hydogen production and / or Storage, but they behave independently and need a *Schedule* specification

Microgrid mode:

- A electric demand is defined every hour
- PV can be one of the alternatives to supply the demand, subject to priorities
- PV production can be lower (deficit) or higher (surplus) than the demand. *Deficit* can be supplied by other source (wind, backup thermal, storage) or imported. Surplus can be stored or used to make H2. Otherwise it would be absorbed by the grid when possible or *curtailed*.
- PV can be combined with Hydrogen production, subject to H2 “Loading Strategy”

Q & A Session

- Please forward your questions on the WebEx Chat
- Further questions by email to: **info@thermoflow.com**

- PP Presentation will be available on the Website / Tutorials
- Video will be available on the Service Center

Thank you!

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