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Oct. 29th

System Design of PV utility scale

(9:30-10:00)

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

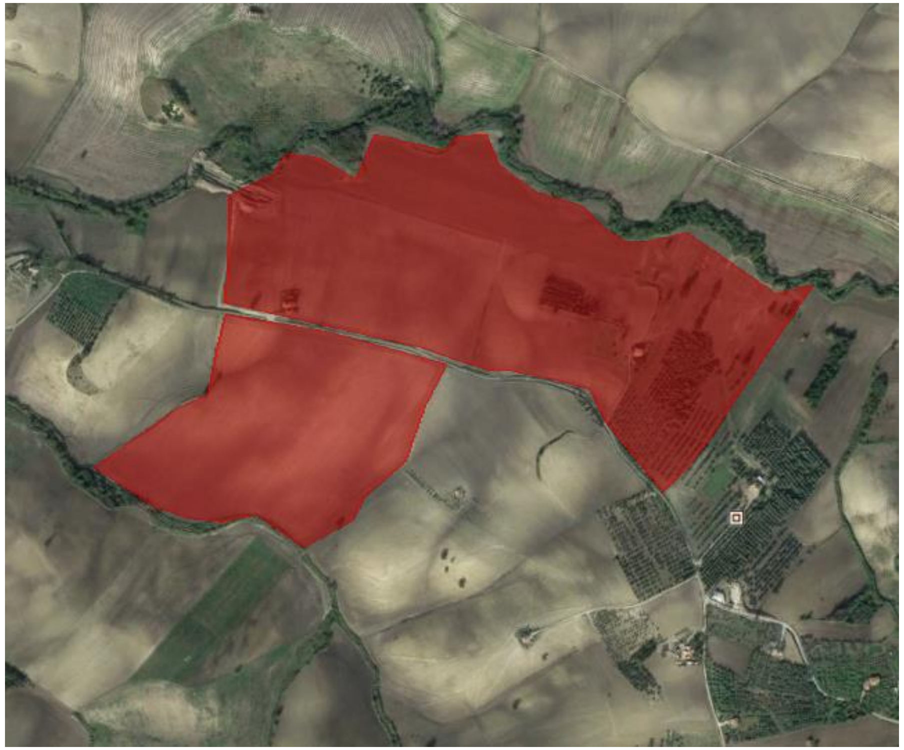
Agenda

1. Site Preliminary Analysis
2. Conceptual Design
3. Mitigation of Energy Losses

Site Preliminary Analysis

Land surface evaluation

Green Power

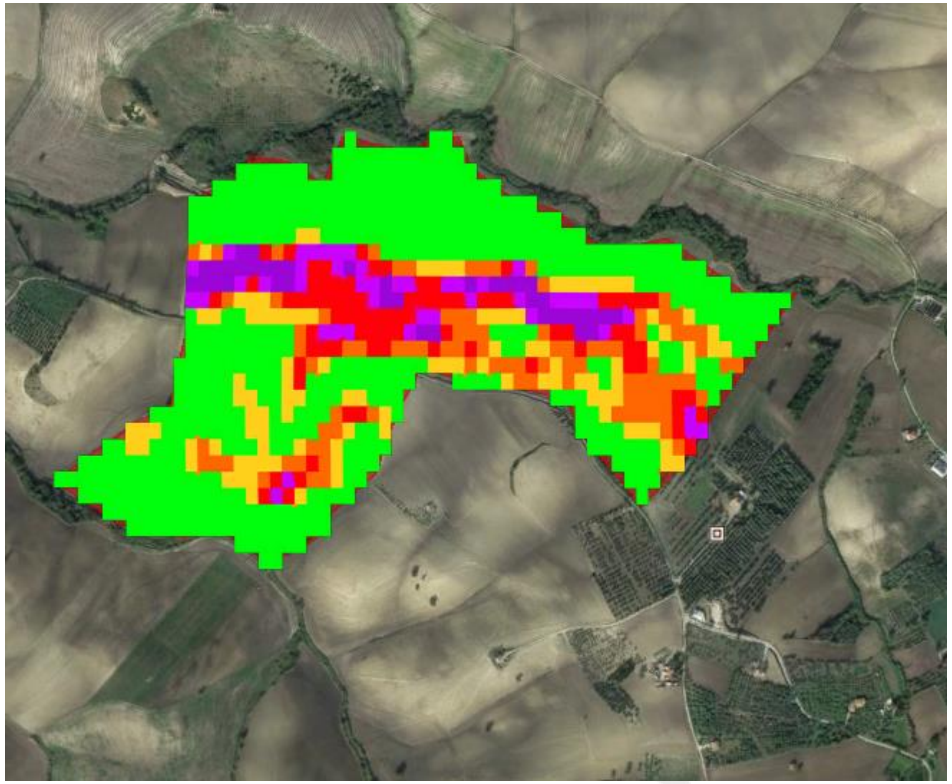


KMZ file of the site:

- *Land area;*
- *Exclusions;*
- *Interconnection point.*

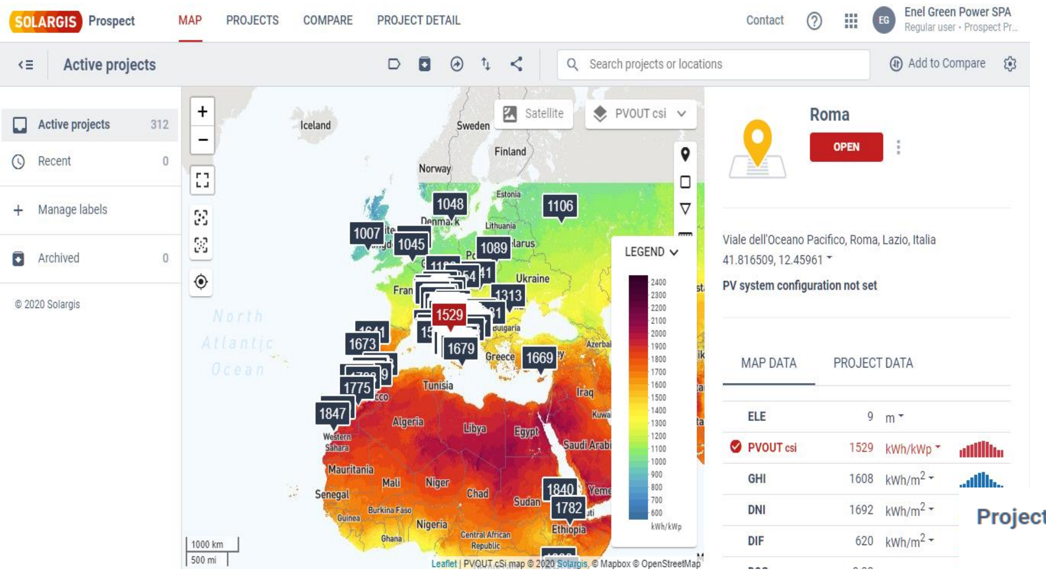
Slope analysis:

- <= -20
- -20 - -17.5
- -17.5 - -15
- -15 - -12.5
- -12.5 - -10
- -10 - 0
- 0 - 10
- 10 - 12.5
- 12.5 - 15
- 15 - 17.5
- 17.5 - 20
- > 20



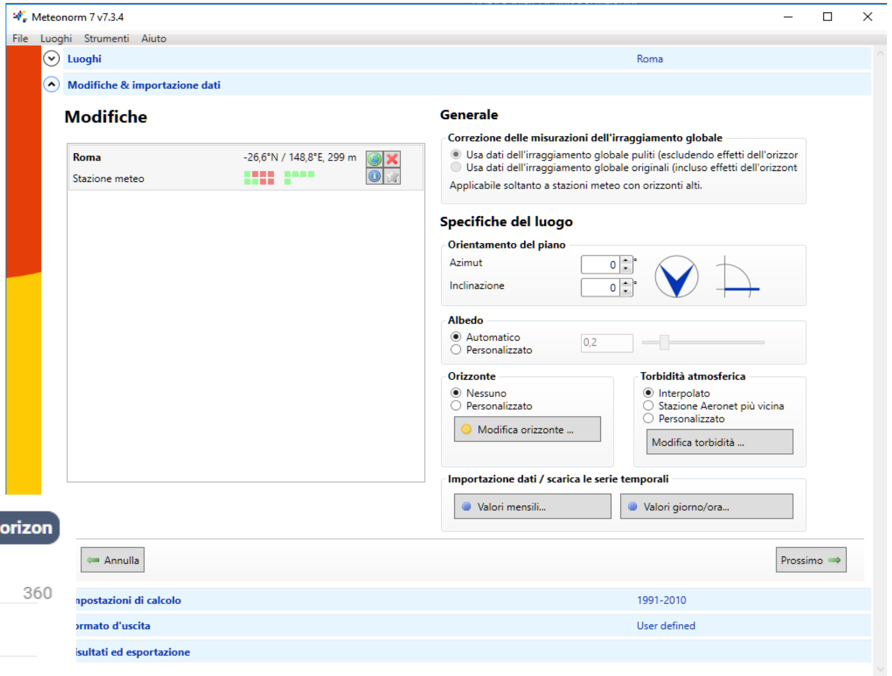
Site Preliminary Analysis

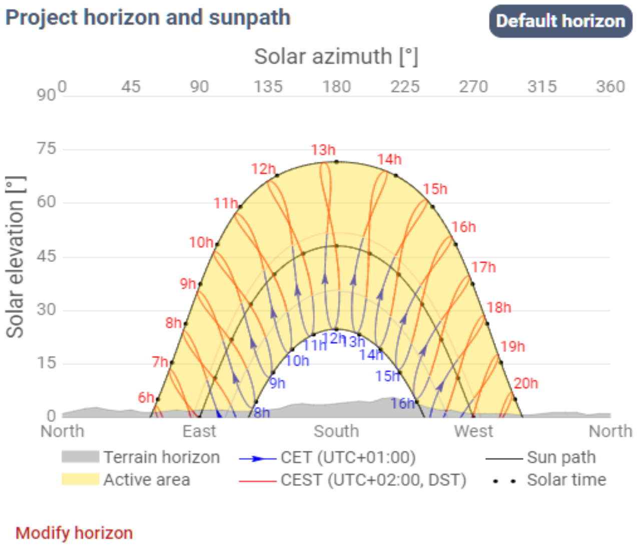
Local Meteo Parameters – Meteo Provider



Monthly/hourly meteo data:

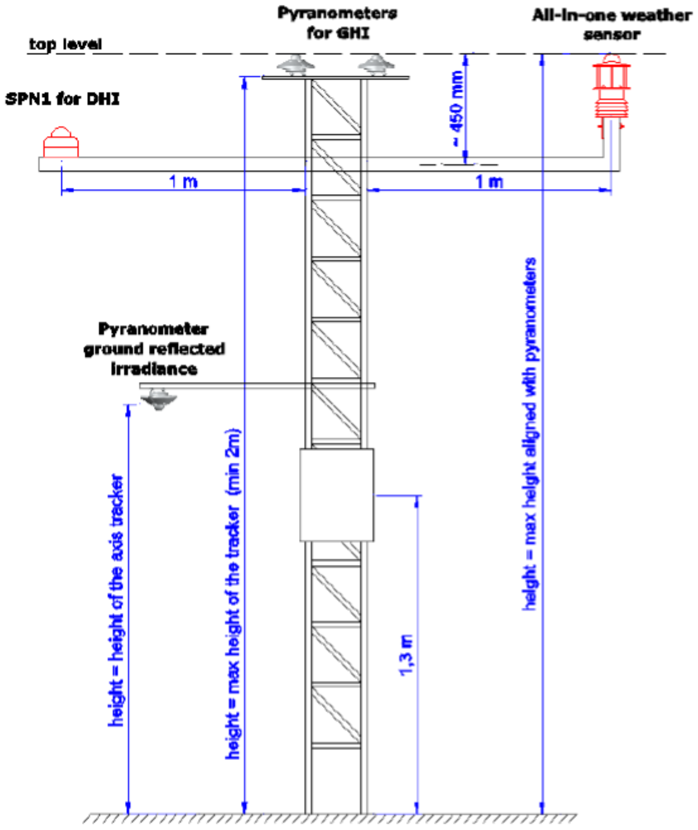
- *Global Irradiation;*
- *Diffuse Irradiation;*
- *Albedo;*
- *Air Temperature;*
- *Wind Speed;*
- *Rainfall rate;*
- *Horizon file.*





Site Preliminary Analysis

Local Meteo Parameters – Ground Measurements



Central meteorological tower

Pyranometer

SPN1

- Global (Total) and Diffuse irradiance in $W.m^{-2}$
- WMO sunshine threshold: 120 $W.m^{-2}$ direct beam
- DNI (Direct Normal Irradiance) calculations
- Sunshine status
- No moving parts, shade rings or motorized tracking

PROs

- High frequency measurements (sec. to min.)
- Higher accuracy, if properly managed

Cons

- Limited geographical representation
- Limited time availability
- Costs for acquisition and operation
- Regular maintenance and calibration
- Data quality control

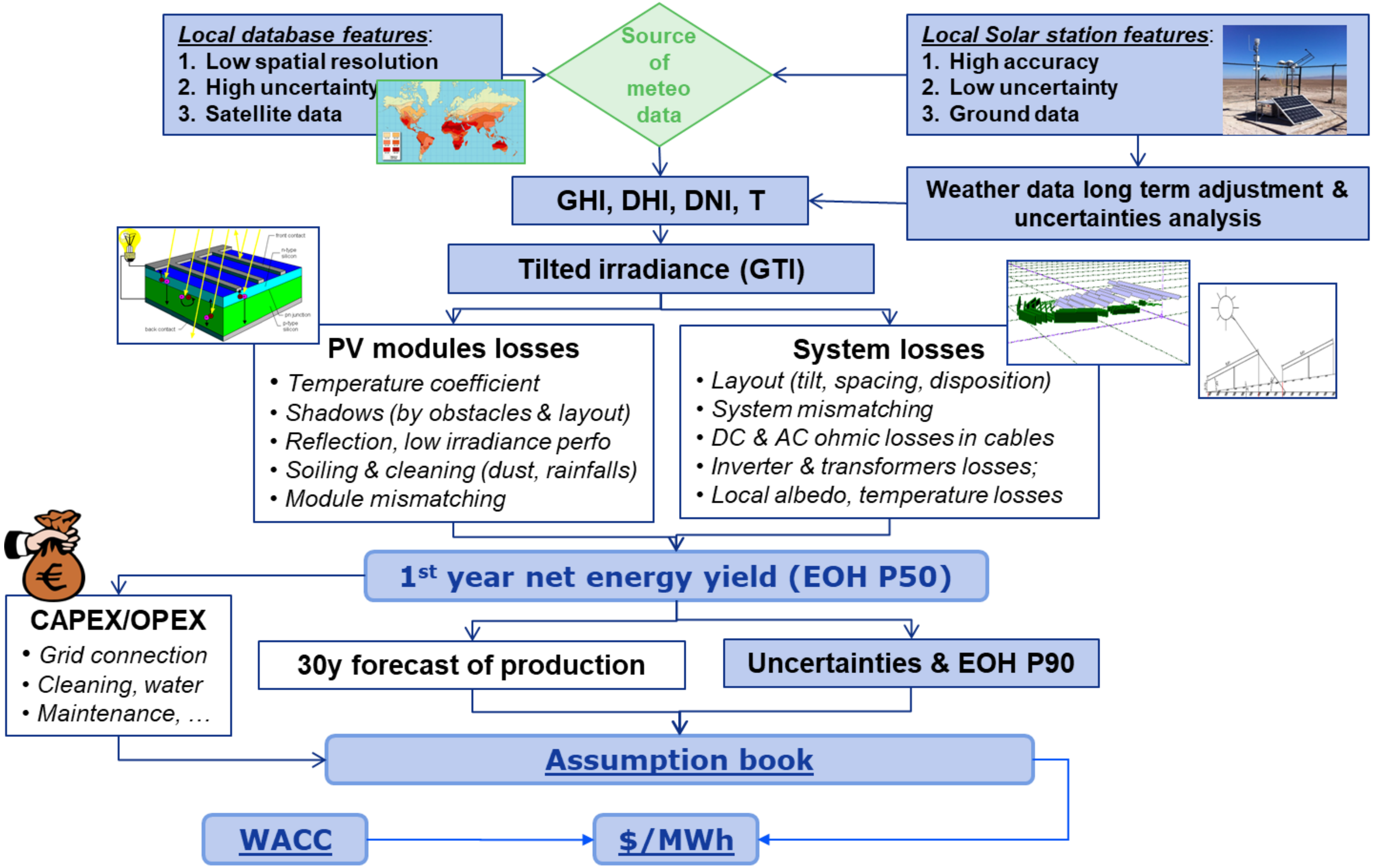
1 Site Preliminary Analysis

2 Conceptual Design

3 Mitigation of Energy Losses

Conceptual Design

Basic scheme of the conceptual design

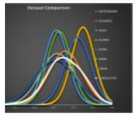


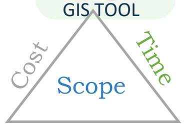
Conceptual Design

Input, design parameters and output

Green Power

INPUTS





Meteo data selection

Site constraints

Project constraints

DATABASE

Module
- Monofacial
- Bifacial

Inverter
- Centralized
- String

Structure
- Tracker
- Fixed

Design Parameters

OUTPUTS

Solar Resource Assesment Report

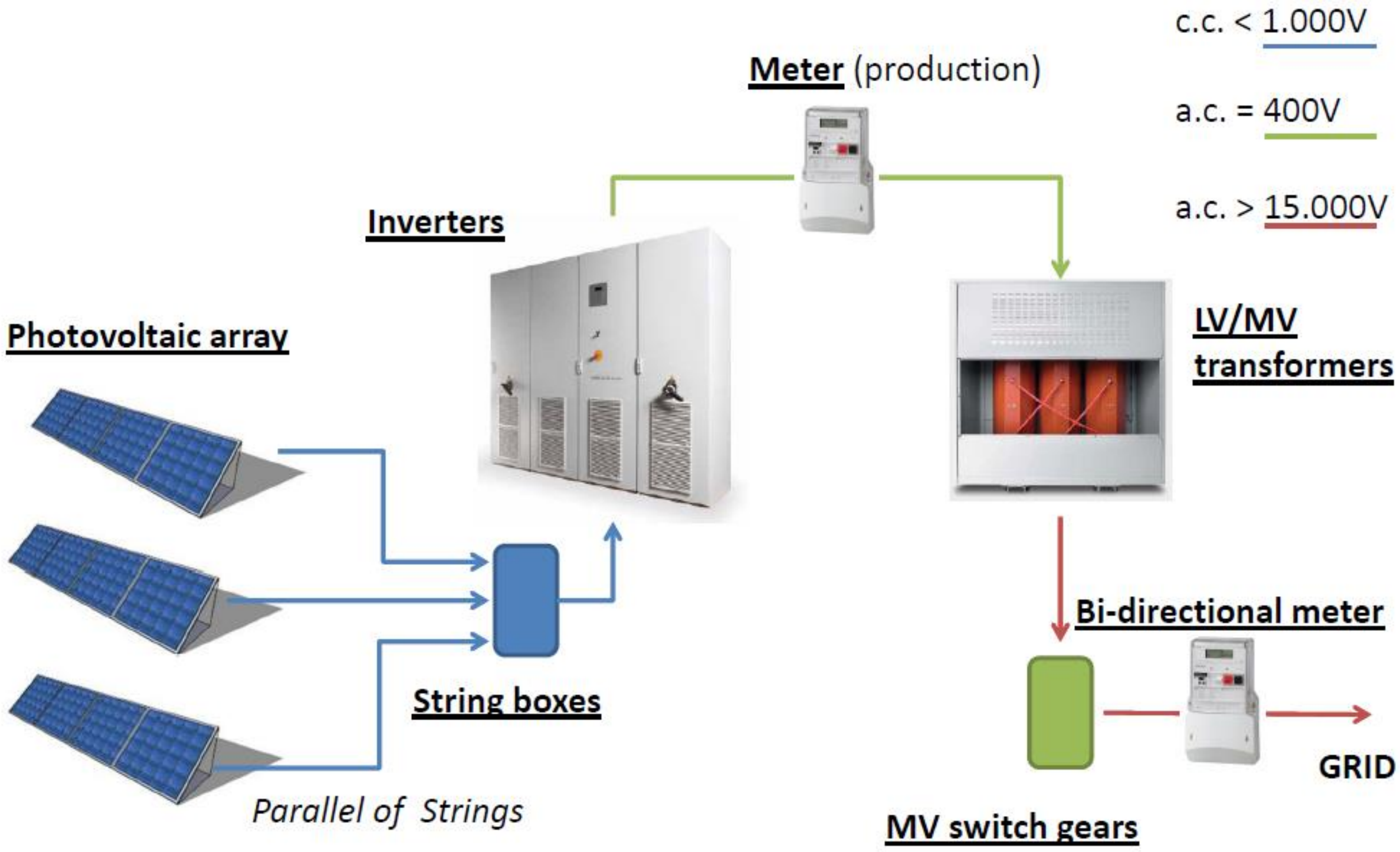
General Technical Specifications

Civil and Electro mechanical Bill of Quantity

Layout drawing

Conceptual Design

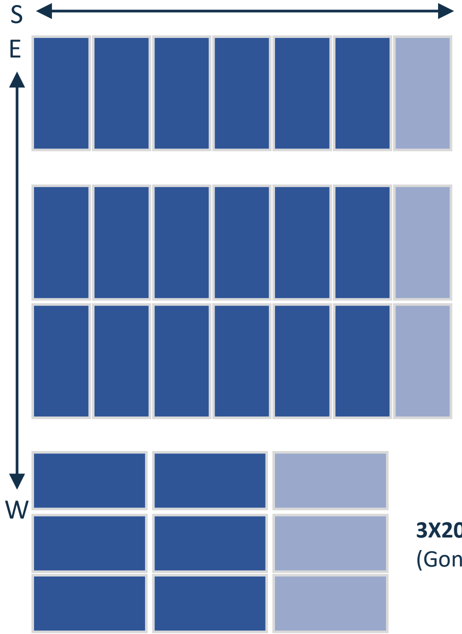
Grid connected PV plant - Equipments



Conceptual Design

PV modules disposition – Array Sizer

The PV module can be placed in several configurations:



1X30 Portrait (Convert)
1X90 Portrait (Nextracker)

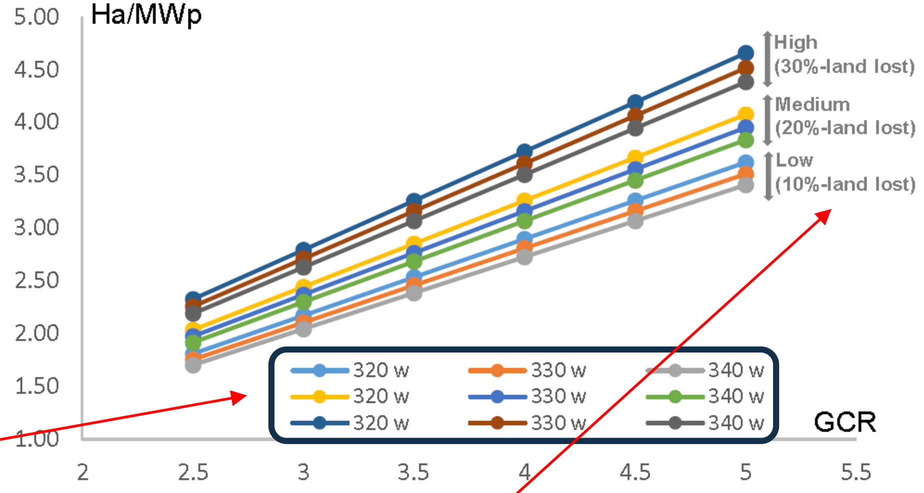
2X45 Portrait (Soltec)

3X20 Landscape (Gonvarri)

It is strongly dependent on the **Occupation ratio** = *the rate between the land area and the DC capacity [ha/MW]*

PV module technology (mono, poly, thin film, BiFi) – efficiency? *Module parameters?*

Ocupation ratio vs GCR



Perimeter of the area (w/o troubled area) fitting?

Maximum system voltage
1000/1500Vdc

How many # of modules per string → **Array Sizer tool**

Inputs

PV Module selection
Voc, Isc, α,β,γ

Maximum system voltage
1000/1500Vdc

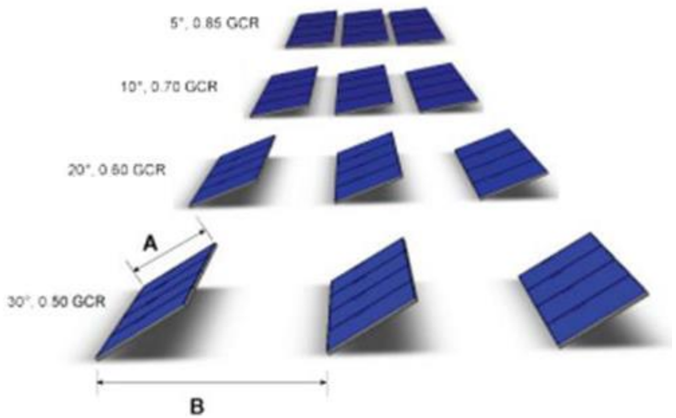
Maximum system current
2000A

Historical Time-series
GHI,T_{amb} over 20years

→ **# max. of module per string**

Conceptual Design

Layout – Spacing between rows and GCR



GCR^{-1} ↑ then EOH ↑ but also CapEX ↑

GCR^{-1} ↓ then CapEX ↓ but also EOH ↓

Most used GCR^{-1} are between 1,75/2 and 3,5. Below 1,75 is too short the distance between the trackers and from the O&M(you) is not accepted. Above 3,5 the gain in the energy production doesn't justify the capex increasing, because is too high.

GCR^{-1}

The inverse of the Ground Covered Ratio is the total area occupied by the PV system divided by the area of the PV Modules

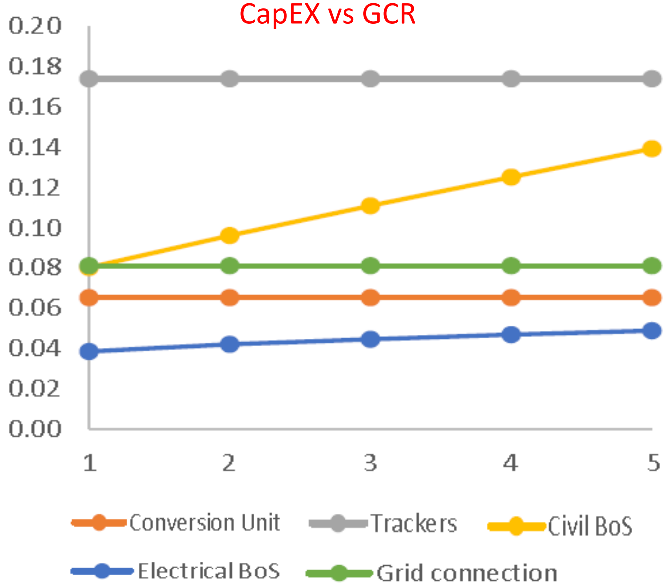
For NS tracking structures

$$GCR^{-1} = \frac{Pitch_{EW\ direction}\ (B)}{Width_{EW\ direction}(A)}$$

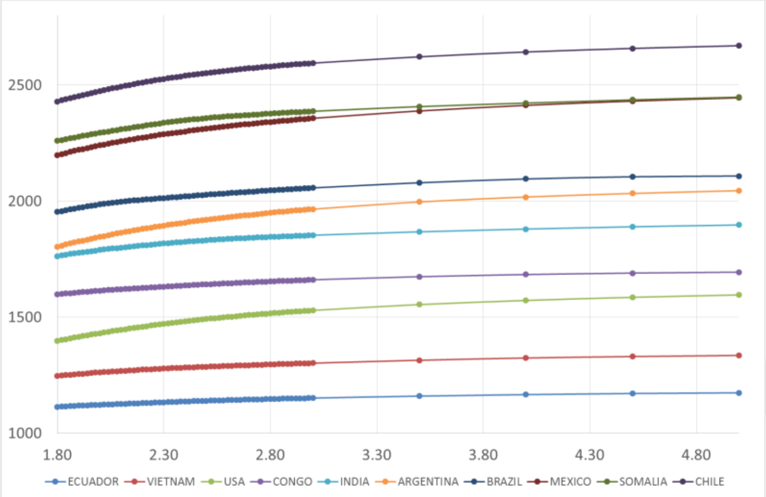
For fixed structures

$$GCR^{-1} = \frac{Pitch_{NS\ direction}(B)}{Width_{NS\ direction}(A)}$$

CapEX vs GCR



EOH vs GCR



Conceptual Design

Configuration – DC/AC Ratio

DC/AC ratio is the relationship between: **DC array's nameplate power at STC** to the **inverter AC output power**

When **DC**↑ and **AC** is constant:

- The generation profile increase (green curve);
- The peak power is clipped over the rated power of the inverters;
- The energy gained through the oversizing of DC is the green;
- The energy lost during the power limiting is the gray.

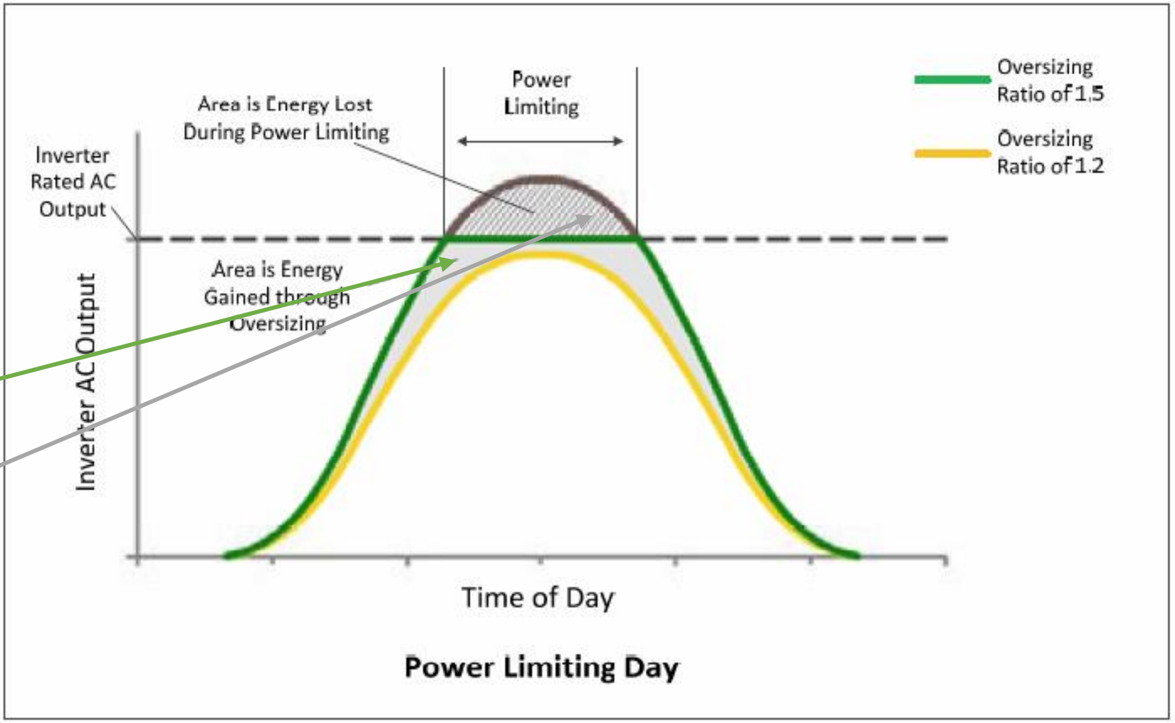
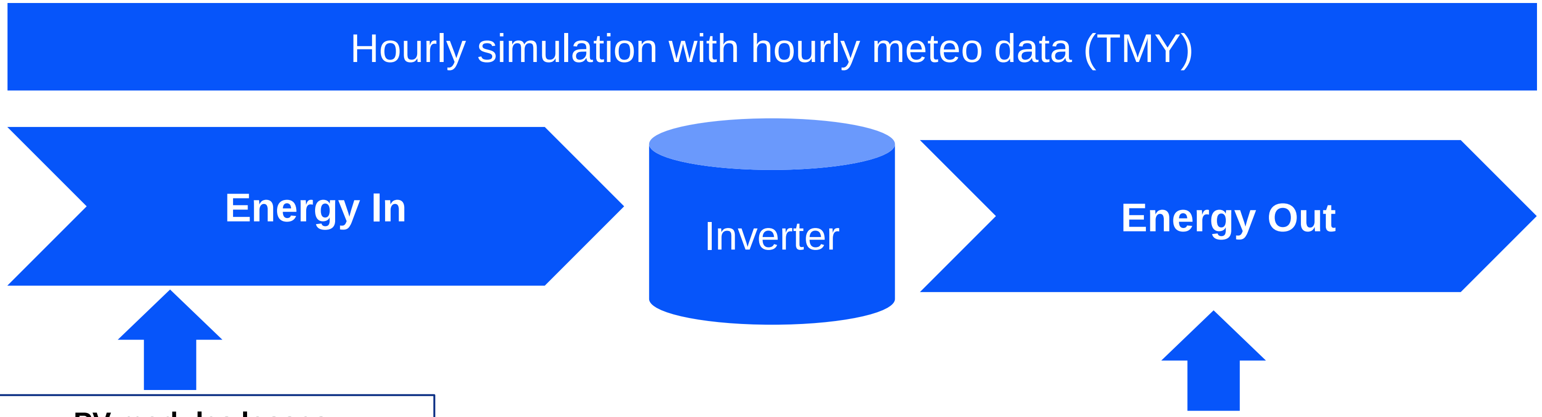


Figure 1a: Daily Production Profile Power Limiting Day

Conceptual Design

Configuration – DC/AC Ratio



PV modules losses

- *Temperature coefficient*
- *Shadows (by obstacles & layout)*
- *Reflection, low irradiance performance*
- *Soiling & cleaning (dust, rainfalls)*
- *Module mismatching*

System losses

- *Layout (tilt, spacing, disposition)*
- *System mismatching*
- *DC ohmic losses in cables*
- *Local albedo, temperature losses*

System losses

- *AC ohmic losses in cables*
- *Inverter & transformers losses;*

The correct evaluation of the losses is crucial.
Real losses > Estimated losses → Energy In ↓ clipping ↓ Energy out ↓
Real losses < Estimated losses → Energy In ↑ clipping ↑

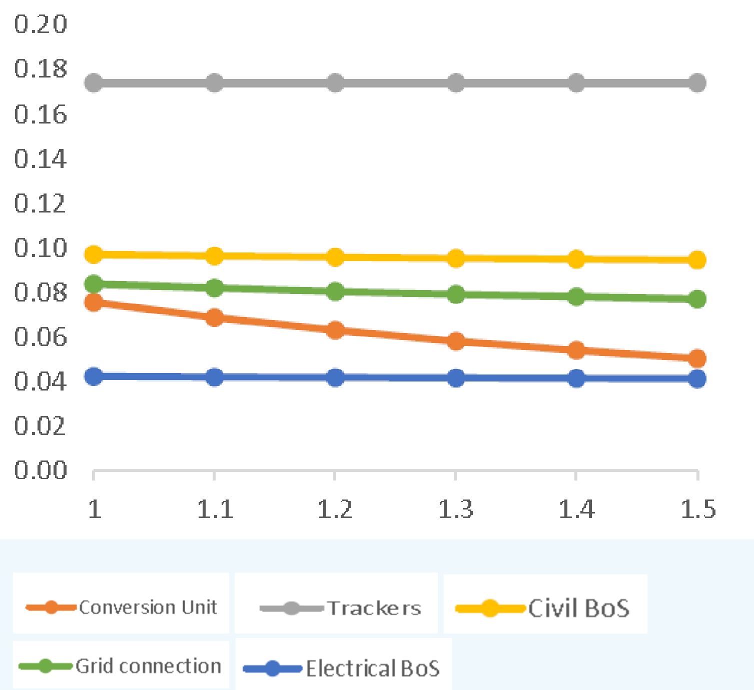
Conceptual Design

Configuration – DC/AC Ratio

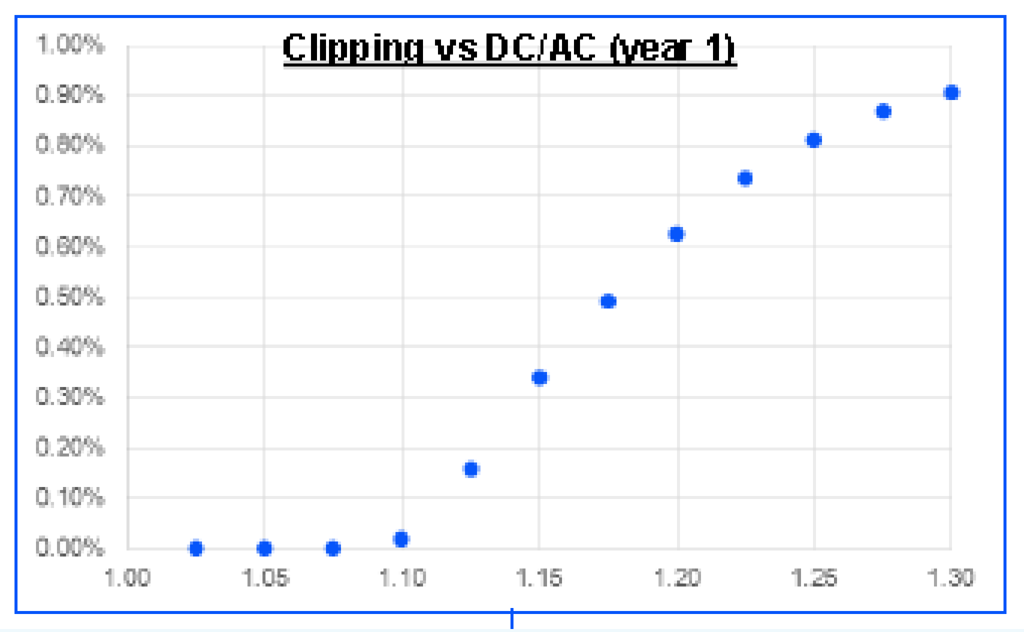
LCOE driver:

DC/AC ↑ then EOH ↓ but also CapEX ↓

CapEX vs DC/AC ratio



EOH vs DC/AC ratio



Conceptual Design

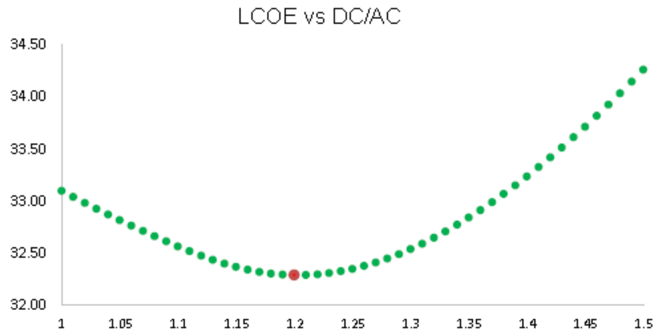
Best configuration and equipment selection – LCoE Minimization

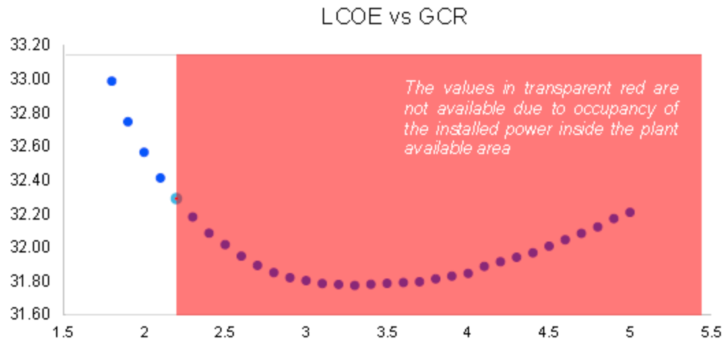
$$LCoE = \frac{CapEX + \sum_{i=1}^{N} \frac{OpEX}{(1+r)^i}}{\sum_{t=1}^{N} \frac{e_t}{(1+r)^t}}, \begin{cases} r = Discount\ rate \\ e_t = Specific\ energy\ yield\ [\frac{kWh}{kWp}] \\ N = Lifetime\ [years] \end{cases}$$

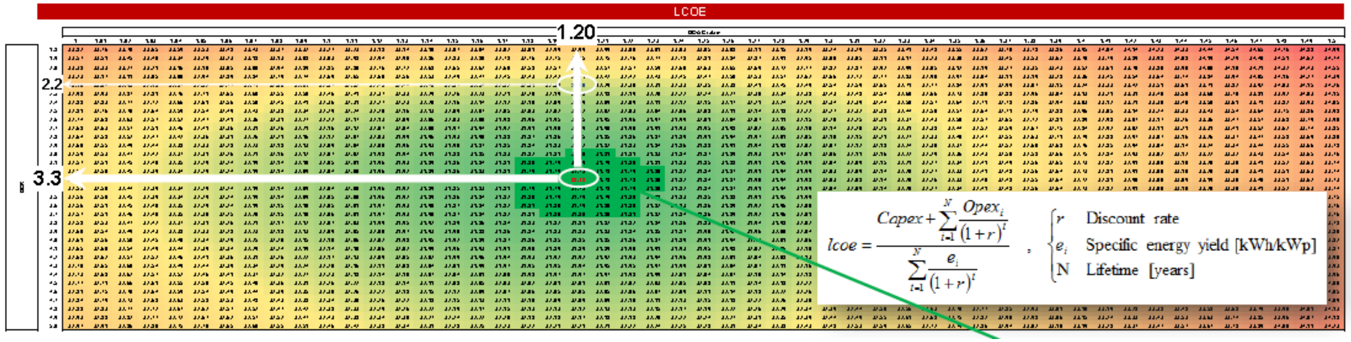
Which is the optimal engineering solution:

↑ or ↓ GCR ??
↑ or ↓ DC/AC??

Minimum LCOE





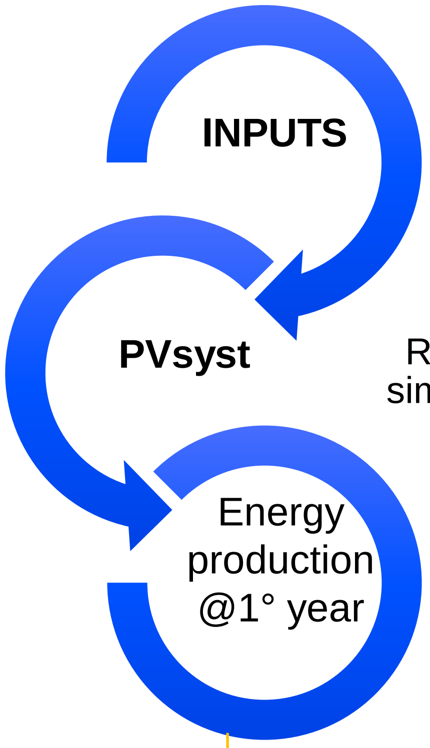


Conceptual Design

Conceptual Design Output – Energy production at 1st year (P50)

Green Power

TMY, layout information, PV module parameters, inverter characteristics, DC and AC capacity, soiling, mismatch, wiring,aux consumption,..ect



Run the simulation

+ HV losses

+ system availability

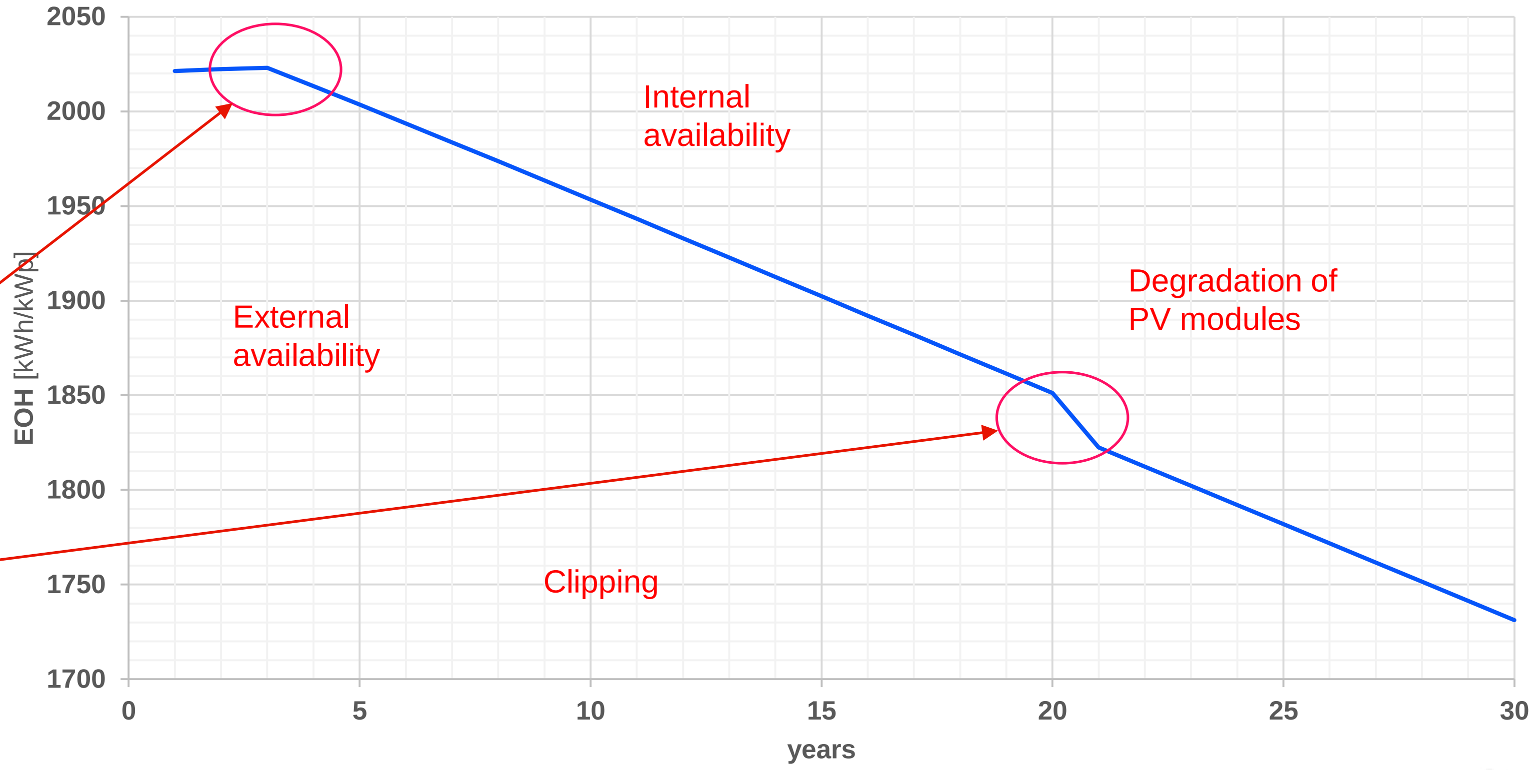
5 - Energy Production Assessment - Results	
DC - Plant Capacity [MW]	35.20
AC - Inverter Capacity at 50 °C[MW]	36.66
AC - Inverter Capacity at 25 °C[MW]	38.95
AC - Maximum achieved power at the delivery point	37.86
P50 for comparative purpose	
P50 - EOH downstream the inverter, 1st year	3495
P50 - EOH fed into the grid, 1st year	3434
P50 - Load factor fed into the grid = EOH/8760, 1st year	39.20%
P50 - Net Capacity Factor (NCF) fed into the grid = (EOH x DC/AC_ratio)/8760, 1st year	37.63%
Recommended values by Solar CoE according to the uncertainty level	
Pxx recommended	P50
=> Combined uncertainty, simulation + solar resource data (1 year)	8.10%
=> Combined uncertainty, simulation + solar resource data (1 years)	8.10%
Pxx - EOH downstream the inverter, 1st year	3495
Pxx - EOH fed into the grid, 1st year	3434
Pxx - Load factor fed into the grid = EOH/8760, 1st year	39.20%
Pxx - Net Capacity Factor (NCF) fed into the grid = (EOH x DC/AC_ratio)/8760, 1st year	37.63%
Pxx - Energy production fed into the grid, 1st year [GWh]	120.8504
Pxx - Average yearly performance ratio (PR) fed into the grid	82.18%
P90 for information purpose	
P90 - EOH downstream the inverter, 1st year	3132
P90 - EOH fed into the grid, 1st year	3077
P90 - Load factor fed into the grid = EOH/8760, 1st year	35.13%
P90 - Net Capacity Factor (NCF) fed into the grid = (EOH x DC/AC_ratio)/8760, 1st year	33.72%

Conceptual Design

Conceptual Design Output – Energy production over lifetime plant.

We start from the energy production at first year and we apply:

Year	Total Plant Availability (%)
1	98.00%
2	98.50%
3	99.00%
4	99.00%
> 5-20	99.00%
>20	98.00%



1 Site Preliminary Analysis

2 Conceptual Design

3 Mitigation of Energy Losses

Mitigation of Energy Losses

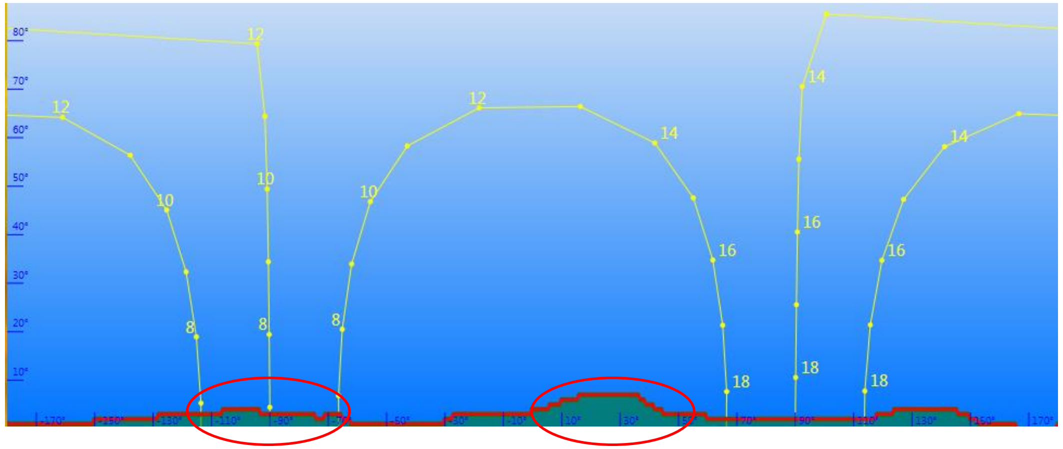
Energy Losses – Table

DC side losses	**Tracker**	Transposition Factor
		Shading (mutual)
	Far Shading	Far shading loss (horizon)
	PV Module	IAM factor on global
		LID
		Annual Degradation
		PV loss due to irradiance level
		PV loss due to temperature
	Soiling	Soiling
	Mismatching losses	Mismatching losses
	DC Cables	Yearly average DC side cable losses in operating conditions
AC side losses	**Inverter**	Yearly average inverter loss in operation (efficiency)
		Inverter loss over nominal power (clipping)
	AC Cables	Yearly average AC side cable losses in operating conditions
	Transformers	Yearly average transformer losses in operating conditions
	Transmission	Transmission line losses
	PPC	POC (Point of Connection) power limitation losses
Other and auxiliaries losses	**Auxiliaries**	Auxiliary consumption
	Internal Availability	Internal Availability
	External Availability	Grid Availability

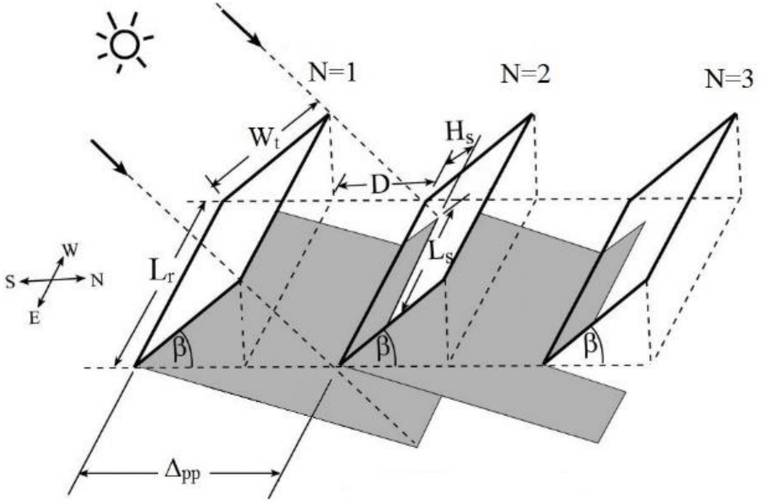
Mitigation of Energy Losses

Energy Losses – Shading losses

Far shading



Near shading



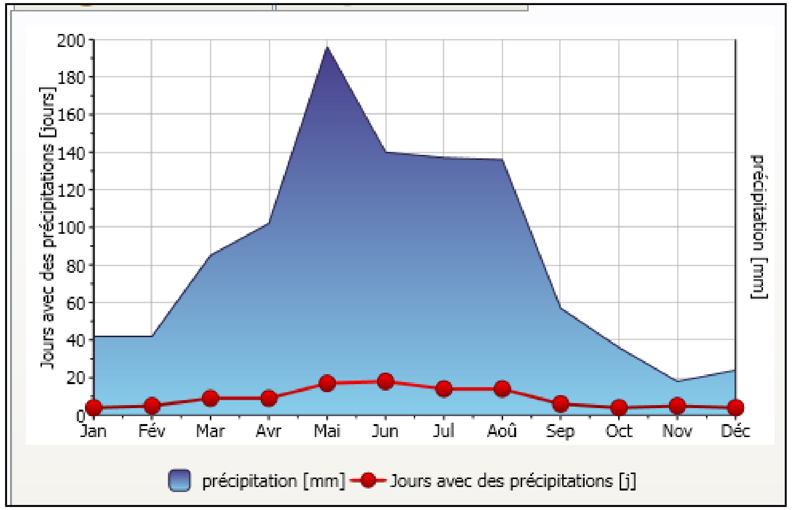
Avoid Beam shading:
Backtracking mode

Mitigation of Energy Losses

Energy Losses – Soiling Losses

Module technology (c-Si/Thin Film?)	c-Si
Environment (1~4, 1=Clean, 4=~Quarry)	3
Longest dry period (1~12, in months)	6
# of similar dry periods per year	1
# of manual cleaning/year (0~11)	2
% of losses in non dry period	25%
Annual soiling losses without cleaning	6.50%
Annual soiling losses with cleaning	4.18%

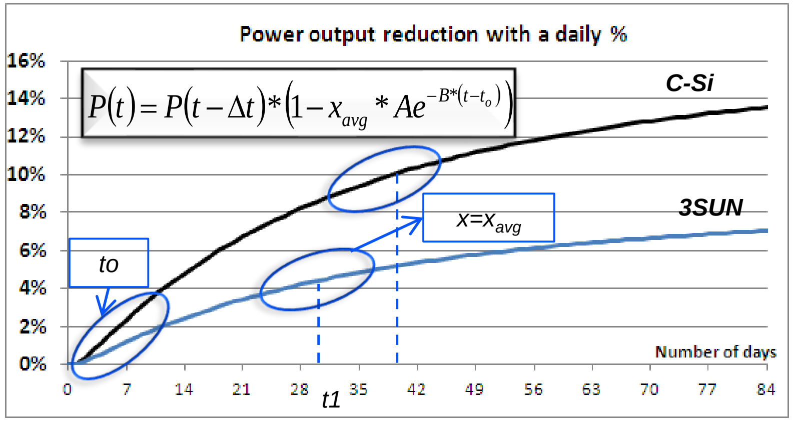
Frequency and intensity of the rainfall



Synthesis of data (average daily % of losses for dry day)

Conditions	Daily soiling losses rate
Clean environment & No activity	**~0.01%/dry day**
Clean environment & small road	**0.02-0.03%/dry day**
Metropolitan, Highway, pollution	**0.04-0.07%/dry day**
Desert	**0.1-0.2%/dry day**
Desert + Activity/Pollution	**0.2-0.3%/dry day**

The soiling losses impacts are not linear



Mitigation of Energy Losses

Energy Losses – Clipping Losses

When **DC↑** and **AC** is constant:

- The peak power is clipped over the rated power of the inverters;
- The energy lost during the power limiting is the gray.

Clipping normally less than 1-2%.

To reduce clipping → # CU (inverter) ↑

Algorythm evaluate the best DC/AC ratio to minimize losses.

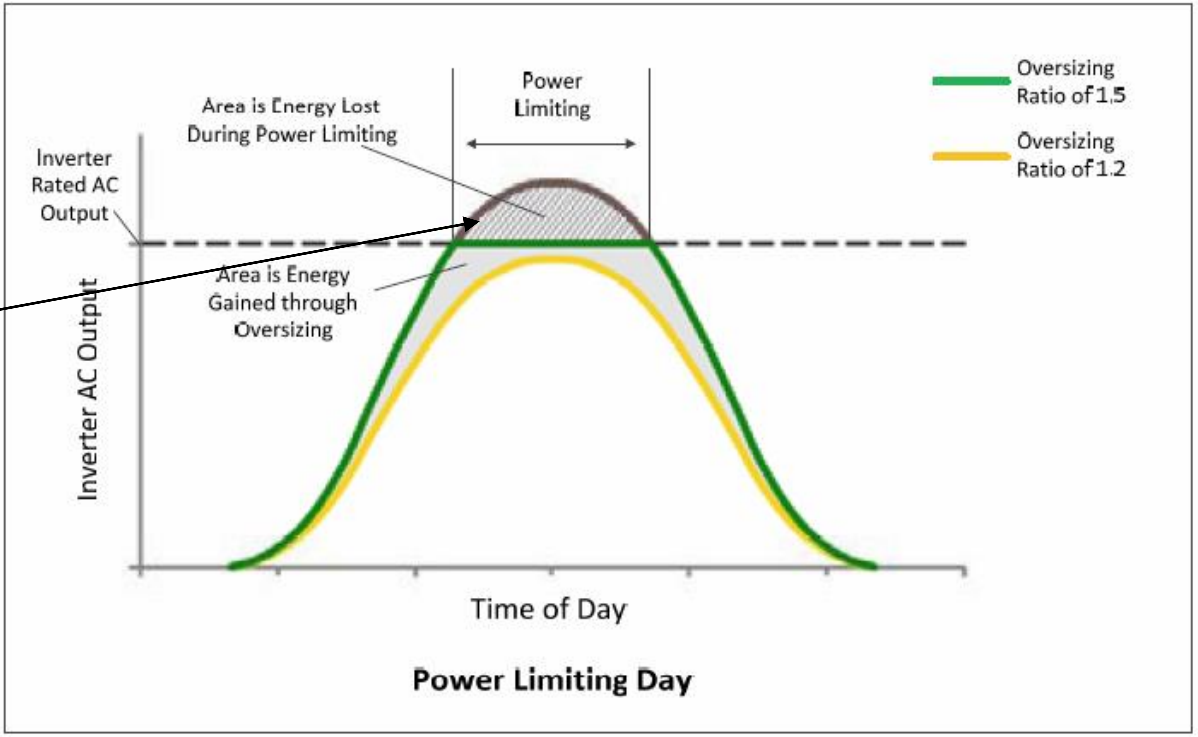
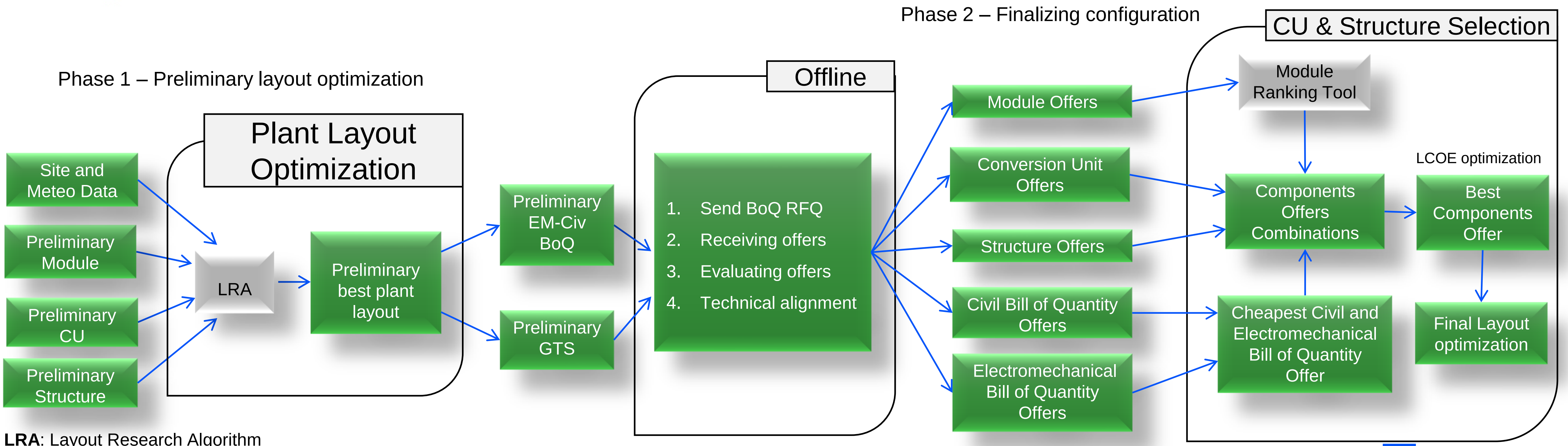


Figure 1a: Daily Production Profile
Power Limiting Day

Recap and Best Practice

System Design Software



LRA: Layout Research Algorithm

This module, given a set of main equipments, has the function of exploring many possible system configurations, in order to minimize LCOE. Each system configuration is described by an "admissible" combination of values of the three most important layout parameters:

- Ground Covering Ratio
- DC size
- DC/AC ratio

SREA – GTS – Civil and EM BoQ – Layout drawing

GLOBAL OPTIMIZATION OF INTEGRATED PHOTOVOLTAIC SYSTEM FOR LOW ELECTRICITY COST

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Thank you for your attention!

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