FICHTNER

GAF-RE Training Workshop
Yerevan, 11.05.2022

Promotion of Renewable Energies - GAF-RE Program Phase IV & V

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Revision status

Rev.	Date	Content/Amendments	Prepared	Checked
0	06.05.2022	Final draft	SM, MS, CM	Störring
1	10.05.2022	As presented	MS, CM	Störring

Agenda

GAF-RE Training Workshop Part I

1	Best practice design drawing package and design basis report
2	Installation challenges and lessons learnt (electrical, mechanical, civil)
3	Installation challenges and lessons learnt of small-scale and roof-top PV systems
4	Module mounting compliant with support structure and warranty conditions
5	Support structure foundation methods, best practice and lessons learnt
6	Structural verification of support structure foundation -- field test vs. calculation
7	Personal Protective Equipment (PPE)
8	Required ESHS documentation at Site

Agenda

GAF-RE Training Workshop Part II

9	Efficient ways of pre-commissioning PV module string testing
10	Weather station for on-site irradiation measurement and plant performance monitoring
11	Bankable solar resource and energy yield assessments
12	PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)
13	Plant fencing and anti-intrusion best practice
14	ESHS housekeeping
15	Waste Management on and off site
16	PV module disposal and recycling
17	Environmental Offset, Botanical Studies

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Best practice design drawing package and design basis report

Best Practice EPC Guidelines

Fichtner has marked up the Guide

- green highlighting = best practices, recommendations
- orange highlighting = important PV plant feature that was (initially) missing at most projects

Best practice design drawing package and design basis report

Overview of engineering design stages, milestones and deliverables

RfP/tender pre-qualification
- Technical concept design based on custom requirements
- Plan for feasibility study parametres

Investment decision/ financial closure
- Yield assessment based on solar resource
- (P50 - P90 values)
- Scaled plan of all requirements in RfP

Construction — PAC
- Provision acceptance certificate

BASIC DESIGN → **PRELIMINARY DESIGN** → **EXECUTION DESIGN** → **AS BUILT**

BASIC DESIGN
- Site identification
- PV technology definition
- Preliminary layout
- Energy yield prediction
- Initiate permitting
- Grid connection assessment
- Indicative BOM (bill of materials)

PRELIMINARY DESIGN
- Geothechnical survey and grid requirements
- Solar resource assessment
- General string layout
- System design: trenches, LV-MV layout, SCADA, surveillance, met station
- General civil design / drainage
- Preliminary BOM

EXECUTION DESIGN
- Final permitting and environmental considerations
- Execution layout
- IFC set of documents
- Commissioning and test plans
- Projects management plan
- Execution BOM

AS BUILT
- Set of as built documents
- Manuals and license
- O&M manual incl. MV switching plan (start-up / shutdown)
- Spare parts handover

IFC = issued for construction

Best practice design drawing package and design basis report

Design Basis Report – for what?

The point of Design Basis Report (DBR) is not a repetition of the data sheets and drawings that shall be provided separately anyway, but the **explanation** of the **design approach** and **assumptions** (such as design loads, site conditions, service life, etc.), as well as rationale for selection of specific structural components, mechanical and electrical systems, layout, etc.

A Design Basis Report can be structured as shown here →

1.0 GENERAL
1.1 INTRODUCTION
1.2 PROJECT SUMMARY
2.0 SYSTEM CONFIGURATION
2.1 DC SYSTEM
2.2 AC SYSTEM
2.3 CIVIL
2.4 MECHANICAL
3.0 ELECTRICAL EQUIPMENTS
- 3.1 SOLAR PV MODULE
- 3.2 DC CABLE
- 3.3 INVERTER/PCU
- 3.4 LV SWITCHGEAR
- 3.5 LV CABLE
- 3.6 CONVERTER TRANSFORMER
- 3.7 MV CABLE
- 3.8 MV SWITCHGEAR PANEL
- 3.9 LV AUX.POWER SUPLY
- 3.10 SWITCH YARD EQUIPMENTS:

4.0 FACILITY FOR METERING SYSTEM AT INTERFACE POINT
5.0 OPERATIONAL PHILOSOPHY OF PCU IN GRID CONNECT SYSTEM
6.0 PLANT EARTHING SYSTEM
7.0 LIGHTNING PROTECTION SYSTEM
8.0 SITE SECURITY
9.0 PLANT MONITORING / SCADA SYSTEM

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Installation challenges and lessons learnt

Civil

Failure to design a site drainage can cause **erosion problems** to the following areas:

- foundations
- roads
- embankments

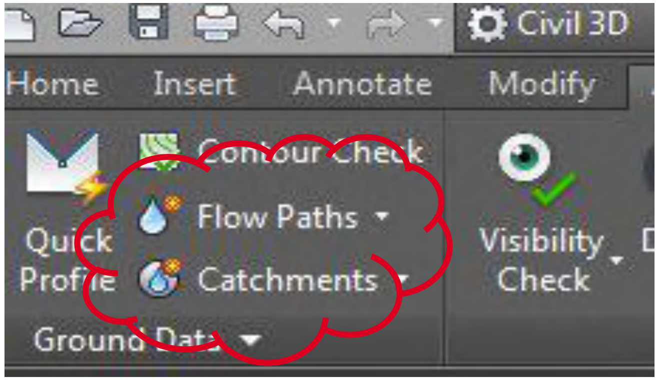
Due to the uncontrolled drainage, washed out concrete pile foundations can be observed at project site.

Installation challenges and lessons learnt

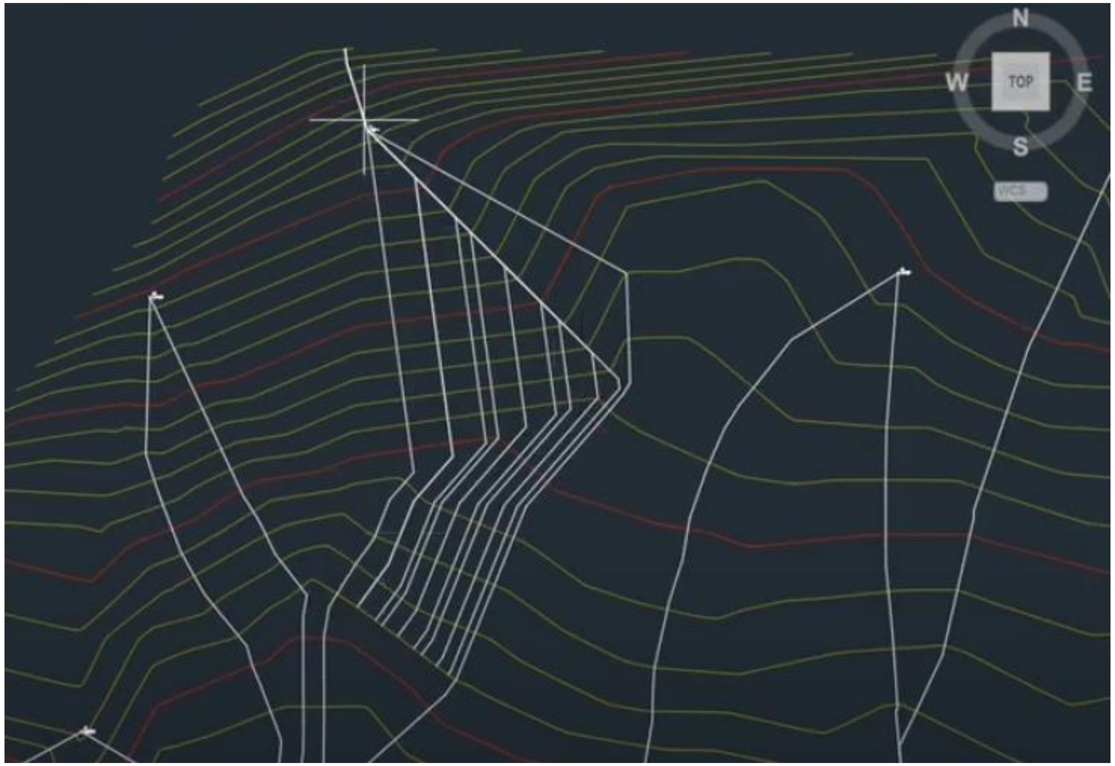
Civil

During Detailed Design, **water runoff vectors** (waterdrop paths) can be visualized by means of the Flow Paths tool in AutoCAD Civil 3D > [Analyze menu].

You can also define catchment areas through the tool "Catchments".



Runoff paths (white) perpendicular to contour lines (green/red), visualized by AutoCAD Civil 3D



Source:

https://www.infratechcivil.com/pages/civil-3d-water-drop-path-tutorial-guide

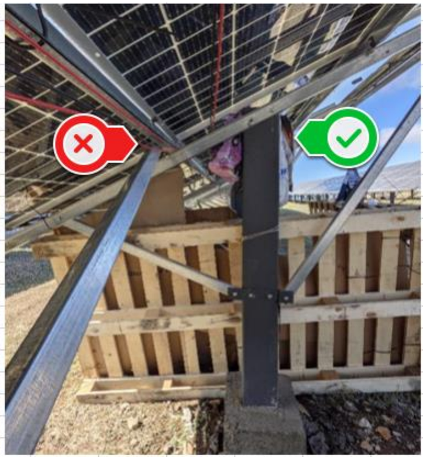
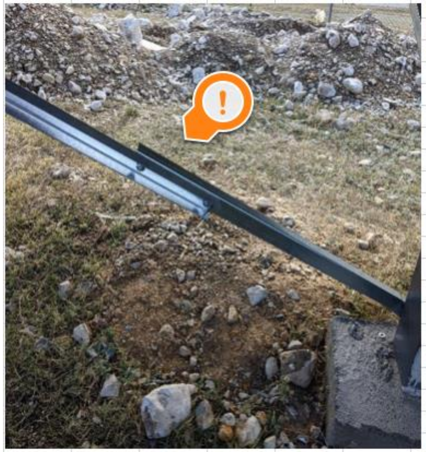
Installation challenges and lessons learnt

Mechanical

Issue	Impact	Example
The mounting structure delivered to site is inconsistent with the design drawing. The delivered mounting structure purlin is a **[** rail instead of a **C** rail	Provides **less mechanical strength** compared to the design structure.	 
The PV modules are not bearing properly onto the purlins as indicated in the design drawing	Modules would **fall through** if not held by additional steel plates under the clamps, which is not a state-of-the-art mounting method.	 

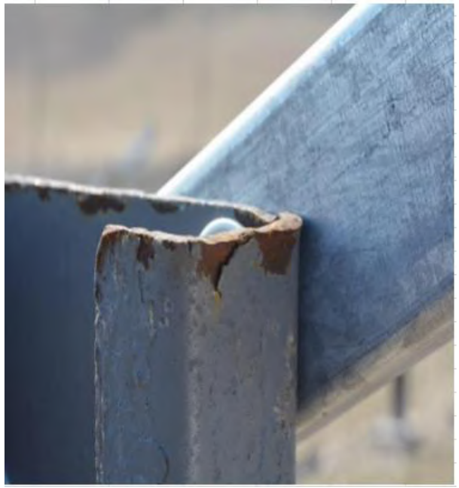
Installation challenges and lessons learnt

Mechanical

Issue	Impact	Example
Poorly installed or missing diagonal bracing: ▪ Bracing profiles must be installed **at the rear side of the posts**, not in the module plane. ▪ Diagonal bracing must be **continuous** and not patched together. ▪ Bracing profiles must be **rigid**, not buckling.	The bracing installed cannot serve the purpose of improving the structure stiffness. ▪ Forces introduced will **distort** and **stress** the modules.	   

Installation challenges and lessons learnt

Mechanical

Issue	Impact	Example
Corrosion ▪ PV structure posts should be **hot-dip galvanized** according to Industry Standard DIN EN ISO 1461 (75+ µm zinc coating) ▪ If not galvanized, posts must have an excellent anti corrosive paint ▪ For sheet metal that cannot be hot-dip galvanized, alternative coating systems like Magnelis® or PosMAC are available	▪ Reduced material strength and lifespan ▪ Risk of structure failure and collapse/sagging of PV array	  

Installation challenges and lessons learnt

Electrical

- Too **shallow cable laying** in trenches
- Trench depth not according to technical design (90 to 105 cm); actual cable depth observed at site 30-45 cm
- Cable trenches not cleared from **rock** and **debris**

Impacts

- Risk of cable scratch and **Isolation failure**
- Cable heat dissipation not according to design > affects the current carrying capacity

Installation challenges and lessons learnt

Electrical



Installation challenges and lessons learnt

Electrical

- Connection not according to industry practice – ohmic losses, **overheating**
- Substandard cable installation work – **risk of short circuit**
- Junction box should be installed with suitable height above ground – **risk of water ingress**

Installation challenges and lessons learnt

Electrical

For indoor installation:

- All exposed busbars require a **shield** or perspex cover
- **Warning signage** to be applied on shield

For outdoor installation:

- **Barrier** should be provided to protect cables against accidental touch or being caught by under passing workers.

Installation challenges and lessons learnt

Electrical

Issue

- DC string cable laying without **edge protection**
- Conduit end is open without proper **sealing**
- Fill factor!

Impact

- Cable isolation scratch – **isolation fault**
- Water or pest ingress
- Current carrying capacity

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Installation challenges and lessons learnt

Small-Scale and Rooftop PV – PV Module

Issue	Mitigation
PV module shading ▪ due to existing trees or infrastructure ▪ avoid as far as practicable ▪ potentially leads to module hotspots and early degradation	▪ To be <u>modelled into PVsyst</u> if can’t be relocated ➢ as near shading scene for close objects to the PV array ➢ as horizon/ far shading for sufficiently far objects • Possible mitigation by increasing the number of independent MPP trackers (sub-arrays connected to string inverters)

Installation challenges and lessons learnt

Small-Scale and Rooftop PV – Mounting structure

Issue	Mitigation	Example
▪ Improper mounting structure pile foundation	Soil investigation is essential - understand below ground underlying condition and dictates piling design	
▪ Use of unsuitable material as part of mounting structure connection members	Proper study and calculation of structure - suitable design, material, dimension, securement methodology, load bearing capacity etc	

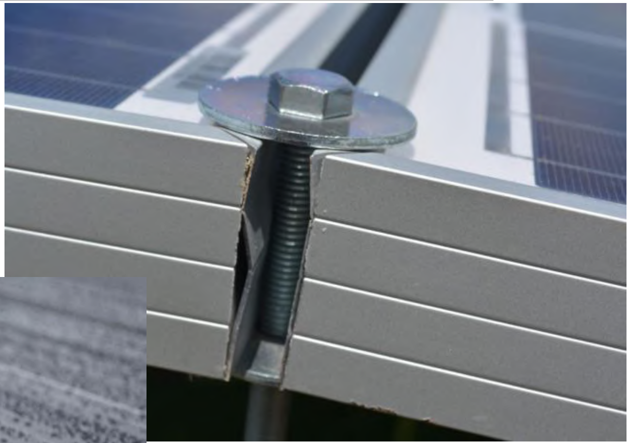
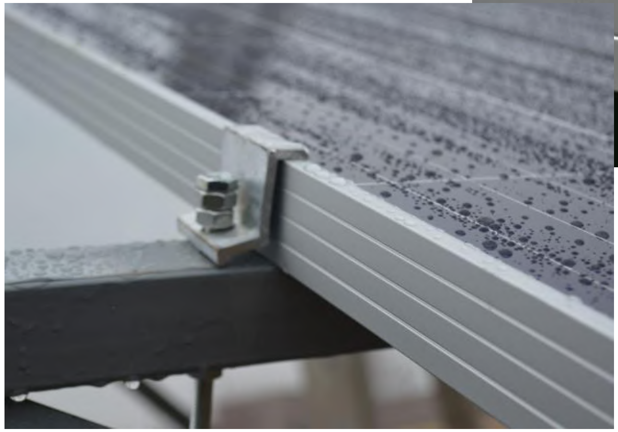
Installation challenges and lessons learnt

Small-Scale and Rooftop PV – Mounting structure

Issue	Mitigation	Example
▪ Use of improper method for piling securement	Proper study and calculation of structure - suitable design, material, dimension, securement methodology, load bearing capacity etc	
▪ Mounting structure material and dimension selection appears inadequate	Proper study and calculation of structure - suitable design, material, dimension, securement methodology, load bearing capacity etc	 

Installation challenges and lessons learnt

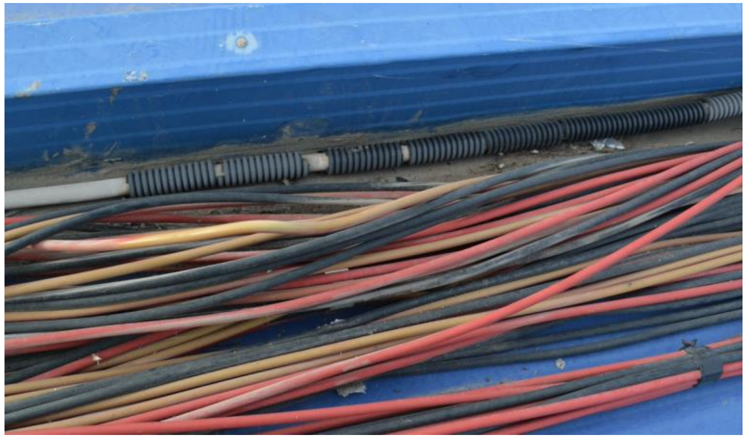
Small-Scale and Rooftop PV – Mounting structure

Issue	Mitigation	Example
▪ Use of non-designated module clamp - leads to damage module frame, deformation of clamp ▪ Module clamp securement not following OEM recommendation (bolt and nut with torque)	▪ Selection of clamps depending on PV module type - consult module supplier prior to procurement ▪ Always adhere to OEM installation manual	 
▪ Module clamp bolt and nut can't be properly secured due to difficult location/hole at the structure - leads to scratches and corrosion build up	Proper study and calculation of structure - suitable design, material, dimension, securement methodology, load bearing capacity etc	

Installation challenges and lessons learnt

Small-Scale and Rooftop PV – Cabling

Issue	Mitigation
DC string cables ➢ exposed to direct sunlight permanently (on the roof and on pole)- increase insulation degradation rate ➢ not provided with suitable cable tray - no mechanical protection ➢ laid in bundle - heat dissipation is questionable	▪ Cable tray to be provided for DC strings at rooftop PV installation going to the inverter ▪ Amount of cable per tray to follow IEC standard, affects cable current carrying capacity



Installation challenges and lessons learnt

Small-Scale and Rooftop PV – Cabling

Issue	Mitigation
DC string cables ➢ installed with big loop - not according to IEC standard - leads to increased risk of potential lightning strike Improper DC string cable fixation/securement/dressing at the back on module and at the mounting structure - difficulty to O&M team	▪ String cables behind PV module to be installed such that to reduce "big loop". ▪ String cables to be secured using UV resistant cable ties at mounting structure. Attention should be given to sharp edges.

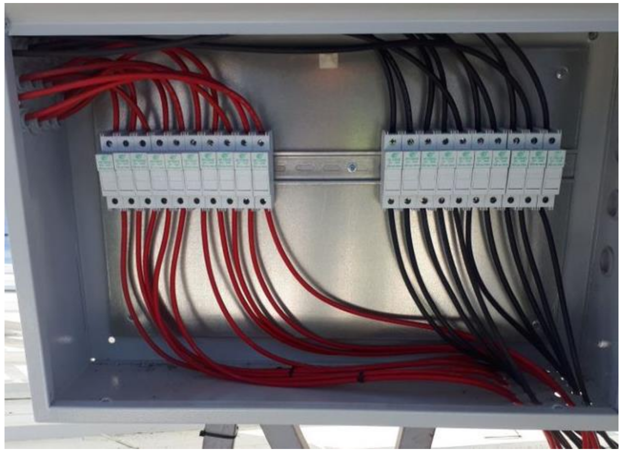
Installation challenges and lessons learnt

Small-Scale and Rooftop PV – AC and DC panel

Issue	Mitigation	Example
▪ Open holes and cable glands lead to ingress of small creatures, dust etc. ▪ Cables inside panel are not arranged properly.	✓ Spare cable glands to be sealed with suitable compound ✓ Panel cleaning as part of PM works by O&M staff	 
▪ Exposed busbar without Perspex cover/protection - Risk of electrocution. ▪ Holes are not properly sealed.	Panel to be manufactured according to relevant IEC.	

Installation challenges and lessons learnt

Small-Scale and Rooftop PV – AC and DC panel

Issue	Mitigation	Example
▪ Cables inside box are installed heavily on one side - leads to low heat dissipation, potential hotspot ▪ Cables are not provided with suitable labelling	Labelling for cables inside panel (positive, negative, earthing, communication (if any), SPD etc.)	 

Installation challenges and lessons learnt

Small-Scale and Rooftop PV – Safety

Issue	Mitigation
▪ PV array installation too close to roadside. No proper barrier provided - ➢ risk of property damage incident by vehicle, project delay, loss of generation. ➢ Increased soiling - loss of generation, reduce performance. ▪ Inverter installation close to gas piping - increased risk of fire, difficulty for monitoring, trouble shooting and maintenance ▪ Earthing cable is not properly installed – risk of tripping hazard and theft	✓ Provide barricade or fencing around PV array installation area ✓ Road layout engineering design to consider risk of soiling to the PV module in addition to maintenance access ✓ Consideration of existing infrastructure for inverter location during design stage

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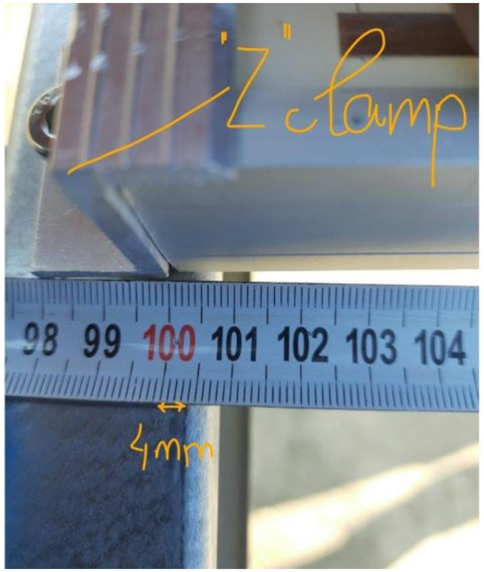
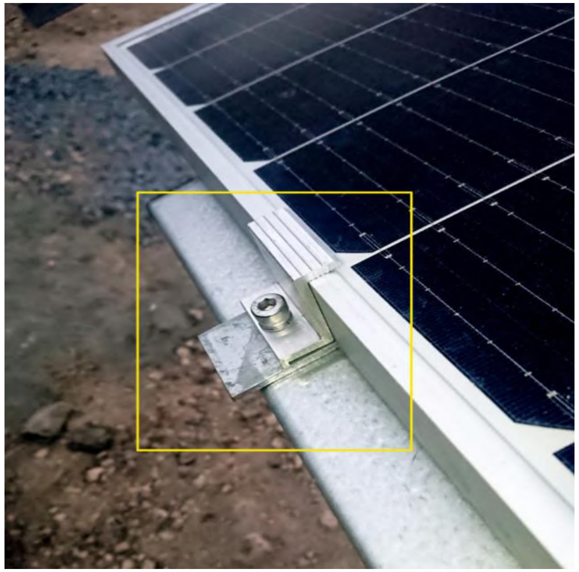
Installation with clamps

Improper module bearing

- The Solar First system clamps the module onto steel plates, not the **C profile** directly
- Steel plate (Q235B)
  - needs to introduce retaining force F_S into substructure
  - stressed for **bending**
- Structural calculation report shall include **proof** to this

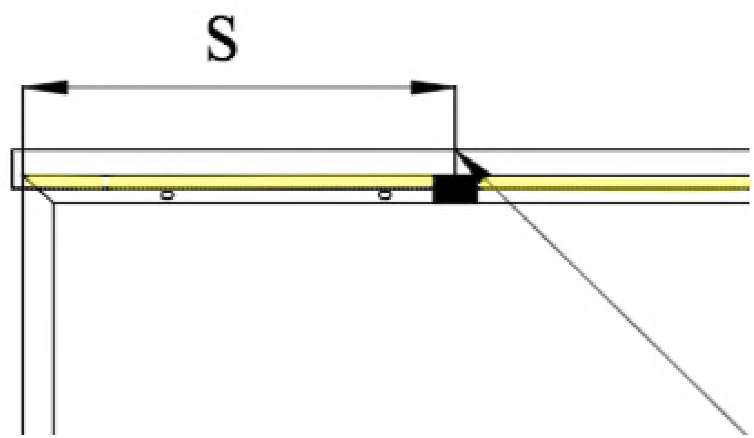


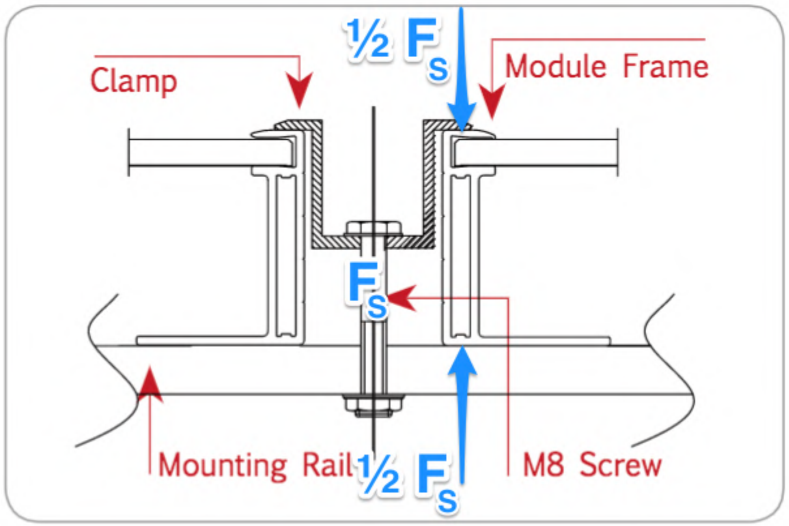


Installation with clamps

According to module mounting manual

- The module frame is supposed to be retained between the **module clamp** and a **rigid mounting rail**
- **Overlap** module frame – mounting rail (shaded yellow below)

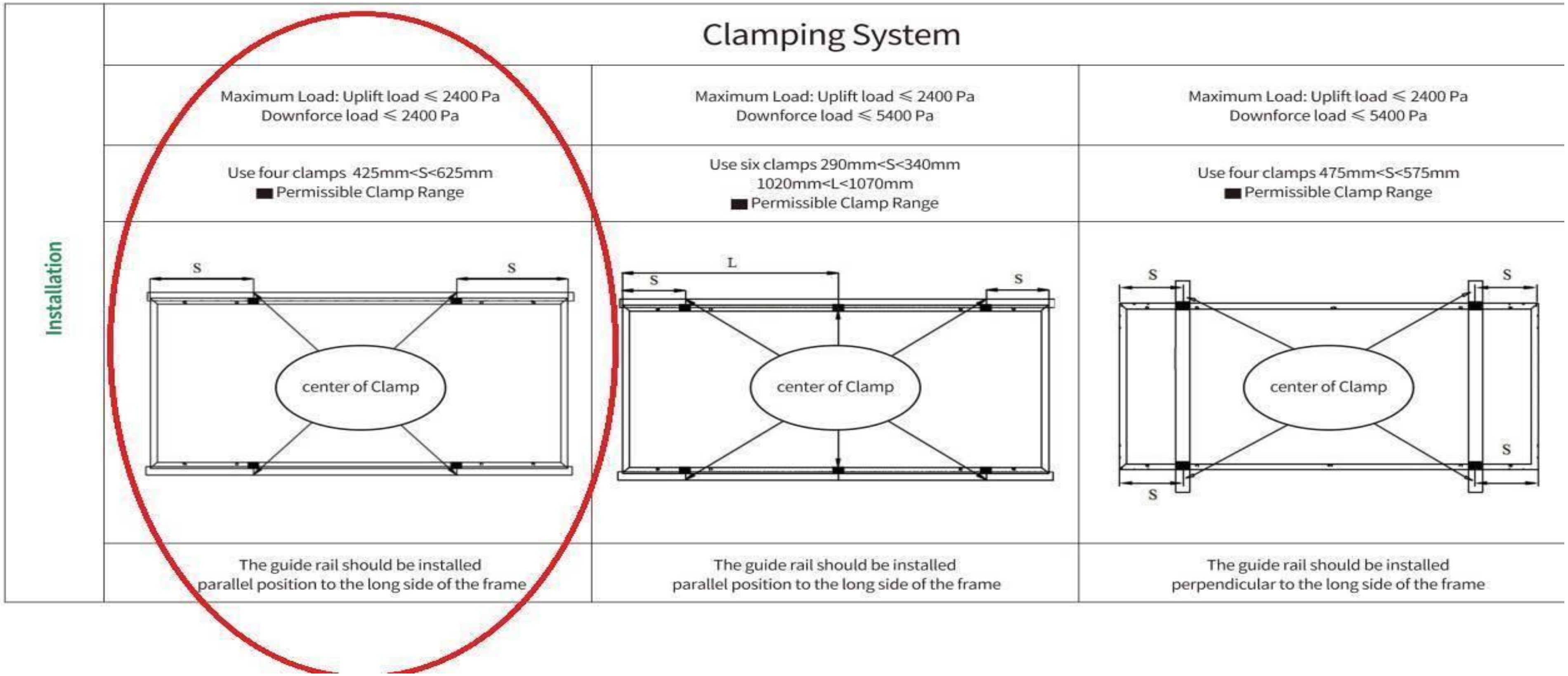




It is questionable that the module frame bearing on the steel plates is equivalent to the bearing on the mounting system rail as prescribed by the module manufacturer.

Installation with clamps

Module clamps must be installed at the **location** (range) specified by **module manufacturer**

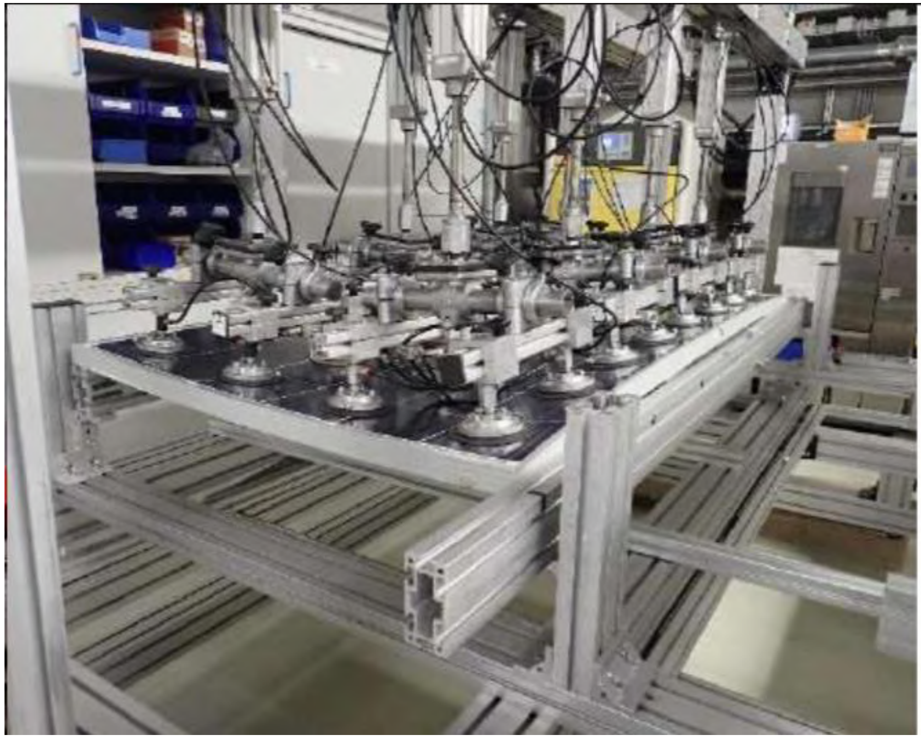


Installation	Clamping System		
	Maximum Load: Uplift load ≤ 2400 Pa Downforce load ≤ 2400 Pa	Maximum Load: Uplift load ≤ 2400 Pa Downforce load ≤ 5400 Pa	Maximum Load: Uplift load ≤ 2400 Pa Downforce load ≤ 5400 Pa
	Use four clamps 425mm<S<625mm ■ Permissible Clamp Range	Use six clamps 290mm<S<340mm 1020mm<L<1070mm ■ Permissible Clamp Range	Use four clamps 475mm<S<575mm ■ Permissible Clamp Range
	S, S, center of Clamp	L, S, S, center of Clamp	S, S, S, S, center of Clamp
	The guide rail should be installed parallel position to the long side of the frame	The guide rail should be installed parallel position to the long side of the frame	The guide rail should be installed perpendicular to the long side of the frame

- **Permissible** distance clamp to module edge: s = 425...625 mm
- **Actual** edge distance is 347 mm → outside of the range → **module warranty void**
- support structure **design issue**
- **Check** this prior to construction, **reject** non-compliant support structure

Installation with clamps

Lab test at TUV according to IEC 61215




- Test cycles with **2400 Pa** and **5600 Pa** (pressure)
- Module is tested / certified only with manufacturer-approved bearing / clamping

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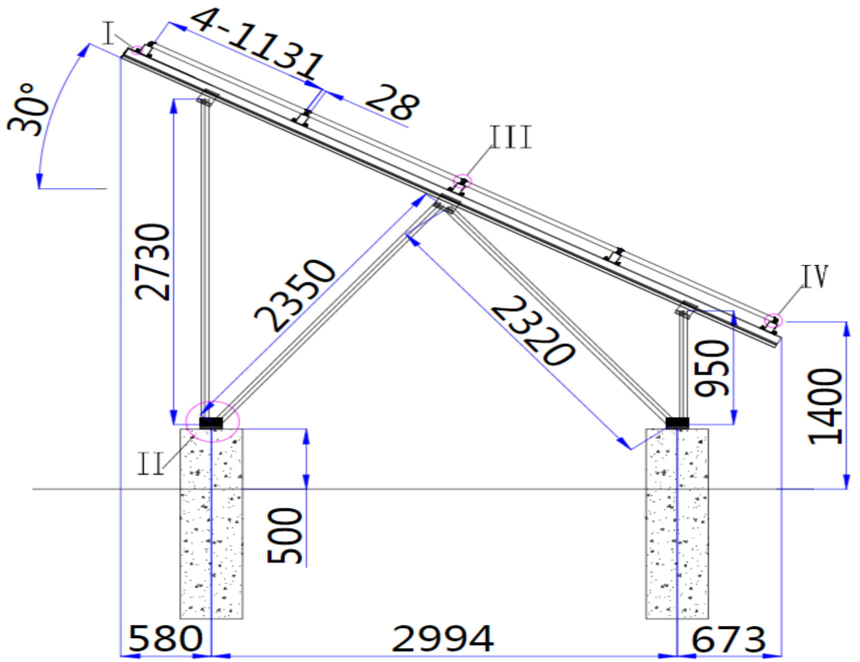
Support structure foundation methods, best practice and lessons learnt

Current trend in Armenia

Install the module support structure on top of **concrete pile foundations** (popular method in China)



Drawing of south-north span

Support structure foundation methods, best practice and lessons learnt

Quality issues observed with concrete pile foundations

- **Poor quality** of concrete work resulting in **reduced strength**
  - **Voids** in concrete due to lack of vibrating
  - Positioning tolerance, **mismatch** with structure → insufficient anchor bolt **edge distance**
- Reinforcement cage issues
  - Rebar cage eccentric, **misaligned**
  - insufficient concrete cover
  - reinforcement **not reaching top** of concrete foundation (→ anchor bolts)
- Regular **testing** of concrete is required (cube compression test, slump test etc.)
- Managing the **interface** foundation – structure is always a challenge
  - Rammed post method avoids this!

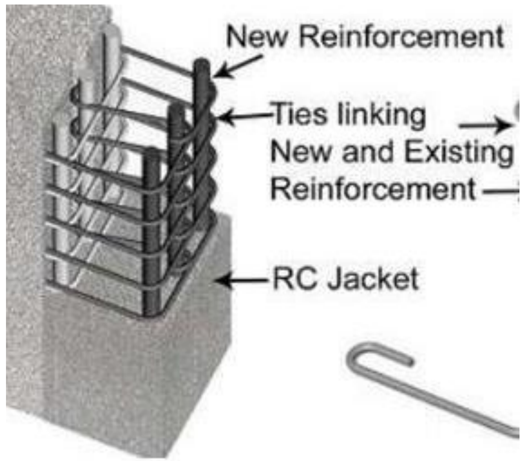
Support structure foundation methods, best practice and lessons learnt

Quality issues observed with concrete pile foundations

- Expansion type anchor bolts may burst the concrete if **no reinforcement cage** is present. Reinforcement cage needs to sufficiently **overlap and surround** the anchor bolts.
- Remediation of **damaged concrete foundations** is possible but often ineffective.

New rebar should tie in with existing rebar and be grouted into drilled holes. The mounting structure should be dismantled prior to remediation works.

New concrete should match full dimensions of existing foundation and sufficient cover to rebar achieved.



Example of good concrete foundation remediation works.

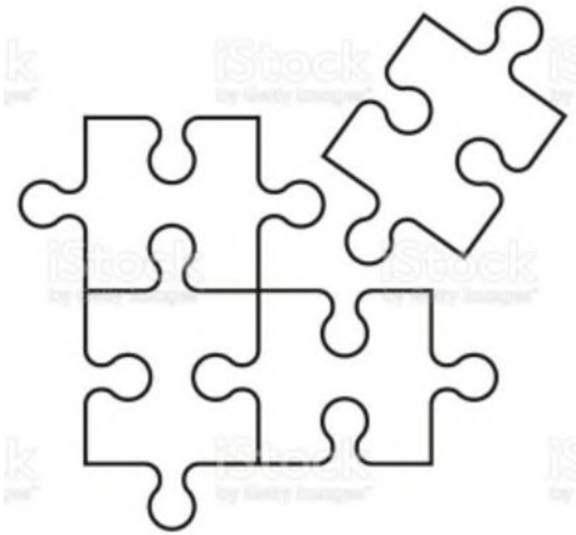
Support structure foundation methods, best practice and lessons learnt

Quality issues observed with concrete pile foundations

When mounting structure and foundation are constructed by different parties:

- Need to **manage the interface*** of two construction trades
- **QC and handover** of concrete foundation to structure installer (curing time for concrete needs to be considered)
- **Liability** issue, difficult recourse in case of damage due to high wind event or snow overload
- *who is in charge of the anchor bolts?
  Sometimes the structure supplier delivers no or uncertified anchor bolts

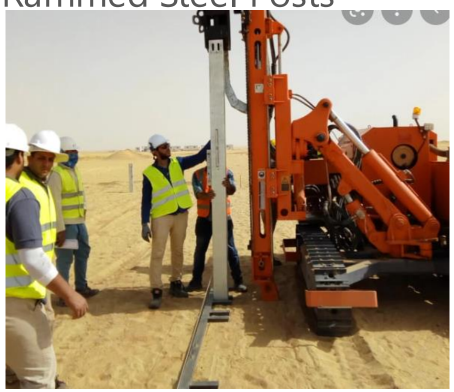
→ selecting a different foundation method/ technology may be a better option



Support structure foundation methods, best practice and lessons learnt

Various mounting structure technologies used in the market - 1

Selecting the most suitable mounting structure depends on several variables: Ground conditions, project size, type of mounting structure, loads applied, availability of machinery, time schedule, costs, liability risks etc.

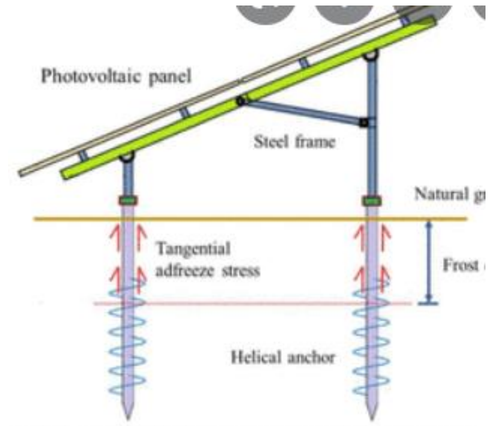
Type	Pro	Con
Concrete Foundation 	▪ No specialized machinery required ▪ **Common trade** that can be performed by local contractors ▪ Structurally very stable if constructed well	▪ Requires good **QC** and **interface** management ▪ **Liability** concerns ▪ Potential **access** issues for concrete trucks ▪ Less environmentally friendly (end of life **dismantling**) ▪ Potentially more expensive (especially for larger sites)
Rammed Steel Posts  	▪ **Fast** and **cost-effective** method ▪ **Prefabricated** posts → less on-site QC ▪ **No trade interface**	▪ Requires **specialized machinery** ▪ Not suitable to **rocky ground** conditions ▪ Pile refusals require **pre-drilling + concrete**

Support structure foundation methods, best practice and lessons learnt

Various mounting structure technologies used in the market - 2

Type | Pro | Con

Steel Screw Pile



Pro

- Relatively **fast** and cost effective
- **Prefabricated** ground screws → less on-site QC
- Suitable to more ground condition types than rammed piles
- Easy recycling and **dismantling**

Con

- Typically **trade interface**
- Requires **specialized machinery**
- Not suitable to **rocky ground** conditions
- More **expensive** than other options

Ballast

Pro

- Typically **prefabricated** → no on-site QC of concrete works required
- Anchoring design and **quality** better than on-site works
- Suitable for **most ground** types
- Fast installation
- Easy **dismantling**

Con

- **Expensive** (especially if large ballast is required due to high wind forces)
- Possibility for movement of ballast which may cause stress on PV modules
- Not suitable for tracking systems

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Support structure foundation -- field test vs. calculation

Simple pull test

Easiest setup with

- backhoe excavator
- sling
- Crane scale
- Displacement measurement by yardstick inaccurate
- PPE!??

Support structure foundation -- field test vs. calculation

Simple pull test

Alternative option

- build mechanism out of wooden beams and
- apply the force using a hydraulic jack
- use crane scale to measure force

Support structure foundation -- field test vs. calculation

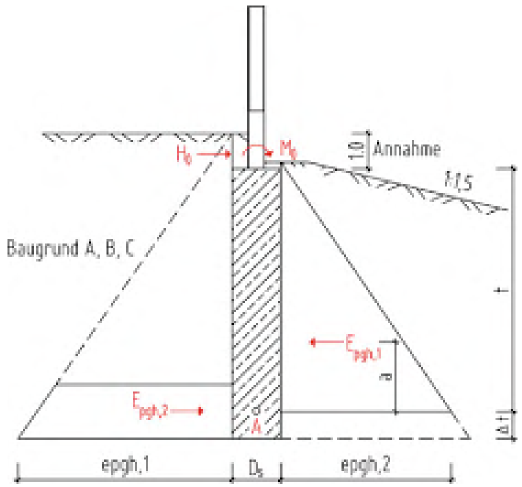
Proof by calculation

According to ZTV-LSW 88, ZTV-LSW 06

- Calculation of pile foundation
- Standard originally for noise barrier walls

Program: Gründung
Project: Helios_UC18_20220504
Short : Helios_UC18_L1_C1_Ext

Input data		
Angle of slope beta	1.00	degrees
Angle of friction	32.00	degrees
Cohesion c	0.50	kN/m²
reduced to	0.25	kN/m²
Specific gravity gamma	18.00	kN/m³
Skin friction angle delta	16.00	degrees
Breadth of pole b	0.35	m
Safety eta	1.40	(-)
Affecting H-load H	3.75	kN
Affecting moment M	21.43	kNm
Initial depth	0.00	m
Results of the calculations		
H * Eta	5.25	kN
M * Eta	30.00	kNm
Depth of the centre of motion t	1.517	m
Sliding surface angle theta	20.31	degrees
Guiding line a	3.913	m
Gap length L	4.172	m
Surface F	2.97	m²
Soil resistance Ephl	77.54	kN
Soil resistance stress eph	292.16	kN/m²
Equilibrium force Eph2	72.29	kN
delta t for SumH=0 dt	0.35	m
Necessary pole length l	**1.87**	**m**
Maximal pole moment Mpf	22.41	kNm
Mpf * eta	31.38	kNm
In a depth X0 =	0.39	m



Layer 1

GRAVEL GROUND with sand filling

from 0.0 m – 2.0 m below ground surface.

Specific gravity γ cal.	Angle of friction φ cal.	Cohesion c' cal	Skin friction (Breaking value)
kN/m³	°	kN/m²	MN/m²
18.0	32.0	0.5	0.030

Support structure foundation -- field test vs. calculation

PRO and CON

Advantages of pull tests	Disadvantages of pull tests
▪ A test is performed on site and demonstrates in this **experimental condition** that the profile can transmit the required forces. ▪ This implies quite a high level of safety.	▪ The **soil structure** and overall soil **mechanical properties** are not explored. The soil below the driven profiles, which is also affected by the force application, remains unknown. ▪ The **effort** for the tensile tests is relatively **high** (pile-driving crew with truck, pile driver on tracked vehicle, wheel loader, geotechnical engineer with test equipment and measuring instruments). ▪ measurements are taken in a **situation** that will not occur later in practice, distorting the test results: • **pile-driving channel** considerably reduces the skin friction between profile and soil • profile surface is still very **smooth**, sometimes even oily from production

Fortunately, the described **weaknesses** of the **pull test** method are on the ***safe side***. That means, the test results in a **lower** load capacity, compared to "settled" profiles in undisturbed soil after months → pull tests can be applied in many cases, even though they often result in unnecessarily large pile-driving depths (**oversizing**).

Either **pull tests** *or* **proof by calculation** must be done! It is **not** included in the structure supplier's calculation!

Agenda

	GAF-RE Training Workshop Part I
1	Best practice design drawing package and design basis report
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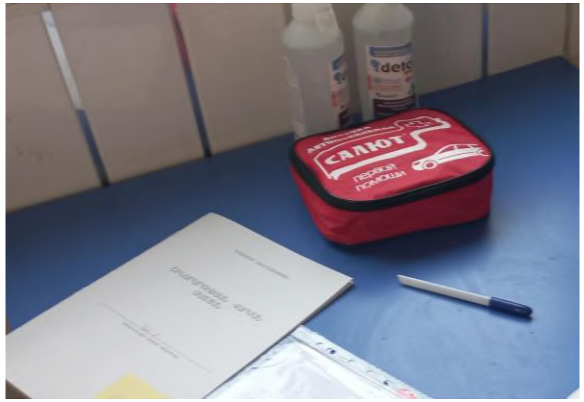
3	Installation challenges and lessons learnt of small-scale and roof-top PV systems
4	Module mounting compliant with support structure and warranty conditions
5	Support structure foundation methods, best practice and lessons learnt
6	Structural verification of support structure foundation -- field test vs. calculation
7	Personal Protective Equipment (PPE)
8	Required ESHS documentation at Site

Health and Safety

First Aid kit

- The First Aid kit shall be provided at project site.
- The kit should at least contain necessary medicines with valid expiration date.



Health and Safety

Personal Protective Equipment (PPE)

The minimum PPE set shall include:

- Safety helmet
- Gloves
- Hi-visibility vest
- Safety shoes (steel cap toe)

During operation:

- Hi-visibility vest
- Dielectric gloves
- Dielectric shoes

Other PPE depending on task:

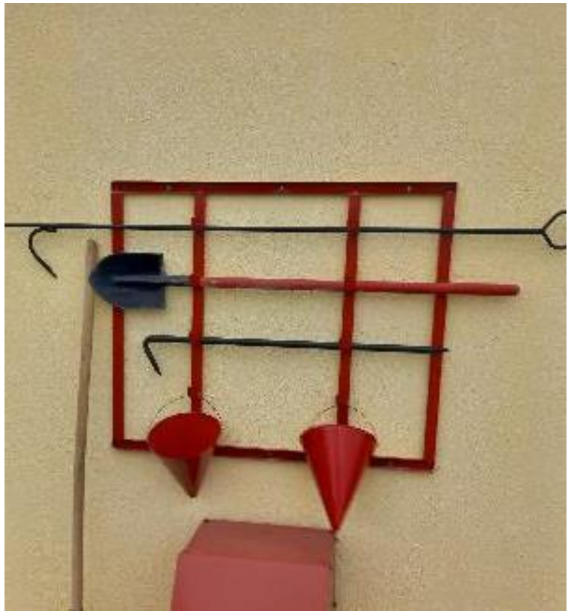
- Harness – working at height
- Mask/Respirator – excavation, dusty conditions
- Etc

Health and Safety

Fire extinguisher

Fire extinguishers should be available near the transformer, hazardous waste storage, and flammable materials storage.

Portable extinguishers should also have valid expiry date.



Health and Safety

Warning signage, tapes and posters

Warning signs and tapes shall be provided at the fences of the transformer, high voltage substation, electrical room as well as the plant area.

Signage must be bilingual.

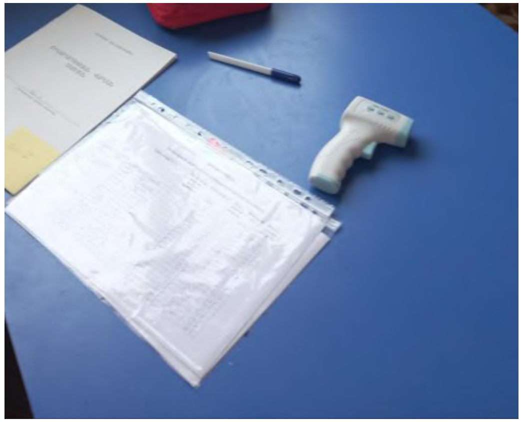
Signage must be fixed, sturdy

- [ГОСТ 12.4.026-76 Система стандартов безопасности труда (ССБТ). Цвета сигнальные и знаки безопасности (с Изменениями N 1, 2) от 24 мая 1976 - docs.cntd.ru]

Health and Safety

COVID-19

- Responsible person, should be appointed by head of organization
- Awareness sheet according to Form N3 of the Order of the Minister of HealthCare should be placed at a visible location
- Facility to wash hands at the project site should be provided
- Monitor situation in accordance with Governmental Regulations



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Required ESHS documentation at Site

The following documents shall be available at the project site during the Construction and Operation Phase

Construction

Permits and Licenses:

- Power Generation License;
- Construction Permit;
- Land Ownership Certificates;
- Servitude Right Certificate for the OHL;
- Construction License for the Contractor Company (Including Energy Sector Certificate);
- The Letter of the Ministry of Environment Regarding no need for EIA expertise (for 110 kV insertion, one span) or the EIA expertise positive conclusion (if EIA expertise is required);
- ESHMP (including the Emergency Response Plan).

Logs:

- Construction Log;
- Induction Register (available in any bookstore as well as on the internet GOST 12.0.004-2015)
- Accident Recording log (Form N2 of Decree of GoA N 458 dated 23.03.2006);
- COVID-19 Logs Form N 1 of the Decree of the Minister of Healthcare N17 dated 4.08.2020;
- COMPLAIN LOG/Grievance Register

Operation

Permits and Licenses:

- Power Generation License;
- Operation Permit;
- The Letter of the Ministry of Environment Regarding no need for EIA expertise (for 110 kV insertion, one span) or the EIA expertise positive conclusion (if EIA expertise is required);
- Land Ownership Certificate (updated to include the new structures);
- Servitude Right Certificate for the OHL;
- ESHMP (including the Emergency Response Plan).

Logs:

- Induction Register (available in any bookstore as well as on the internet GOST 12.0.004-2015)
- Accident Recording log (Form N2 of Decree of GoA N 458 dated 23.03.2006);
- COVID-19 Logs Form N 1 of the Decree of the Minister of Healthcare N17 dated 4.08.2020;
- COMPLAIN LOG/Grievance Register

ESHMP

Environmental Social, Safety Health Management Plan

- Plan must be developed to ensure compliance during Construction and finally Operation.
- Standardization across all Projects and GAF
- Bi-annual report based on ESHMP (only 2)
- All incidents, accidents and errors = captured according to ESHMP and corrected accordingly
- Site visits by any authorized person can flag ESHMP non-compliance (non-compliance results in investigation)
- Investor ensure that they accept all aspects in ESHMP, as this document is vital for compliance
- ESHMP standards and requirements based on project requirements (KfW)

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GAF-RE Training Workshop Part II

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14	ESHS housekeeping
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16	PV module disposal and recycling
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Efficient ways of pre-commissioning PV module string testing

Test procedure – According to IEC standard

[BS EN 62446-1:2016](#)

Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance. Part 1: Grid connected systems- Documentation, commissioning tests and inspection


IEC 62446-1

Edition 1.0 2016-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance –
Part 1: Grid connected systems – Documentation, commissioning tests and inspection

Efficient ways of pre-commissioning PV module string testing

Test procedure – According to IEC standard

Category 1 – PV string testing

The minimum requirement -
A standard set of tests that shall be applied to all systems.
Test regimes under Category 1 test regime include:

- **Continuity of protective earthing** and/or equipotential bonding conductors, where fitted
- **Polarity** test
- String **open circuit voltage** test
- String **short circuit current** test
- Functional tests
- **Isolation resistance** R_{ISO} of the DC circuits
- Combiner box test
    - A single string connected in reverse polarity within a PV string combiner box can sometimes be easy to miss. The consequence of a reversed string, particularly on larger systems with multiple often interconnected combiner boxes, can be significant. The purpose of the combiner box test is to ensure all strings interconnected at the combiner box are connected correctly.
- Tests of all AC circuits to the requirements of IEC 60364-6

Protocol
String measurement

customer:	inspected by:	approved by:	
plant:	signature:	signature:	
contractor:	date:	page:	total:
weather conditions:	measurement device:		DOCUMENT No.
responsible: Subcontractor	insulation proof voltage: 1000V		KTU-CH-String-2014-03-18-rev0

electric circuit / string	solar cable	actual irradiation	voltage/current/isolation > 1MOhm				remarks
no.	A(mm²)	W/m²	Voc	Isc / A	Impp / A	Riso / MOhm	

Efficient ways of pre-commissioning PV module string testing

Test procedure – According to IEC standard

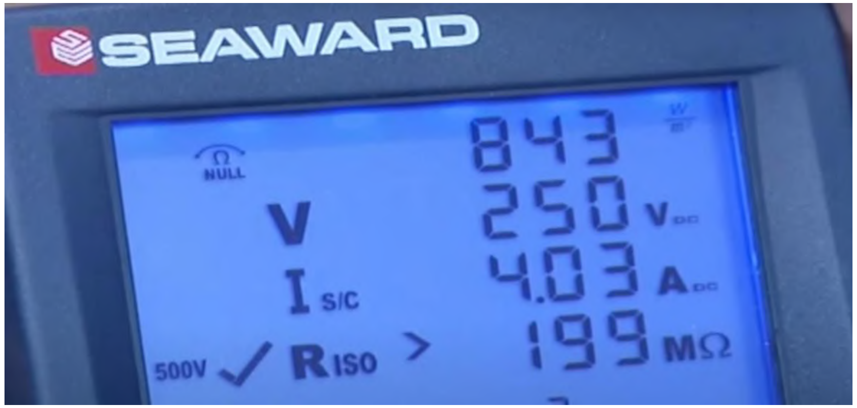
To be efficient, multipurpose and multifunctional test equipment is recommended
Equipment which can conduct multiple tests concurrently

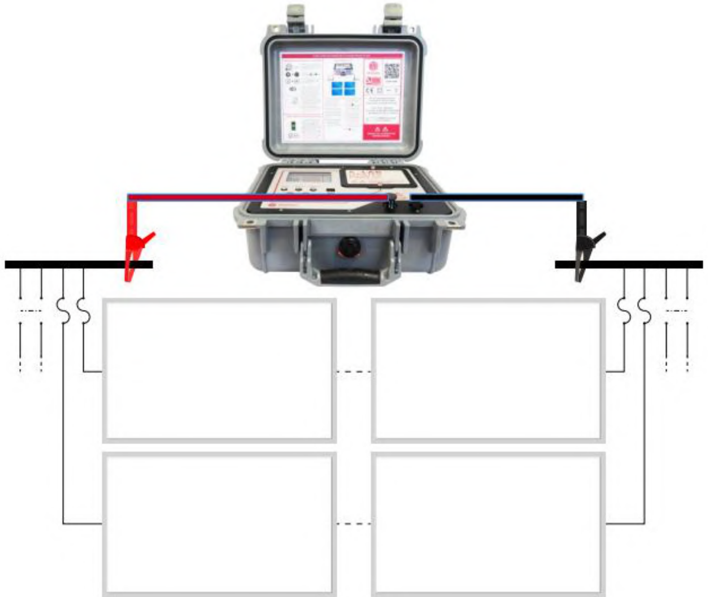
Brand	Model	Test capability
Seaward 795 (seaward.com)	Solar utility pro test kit	Open circuit voltage (V_{oc}) Short circuit current (I_{sc}) Polarity check Isolation resistance
Solmetric PV Analyser PVA-1500V4 PV Analyzer Kit (solmetric.com) PVA1500_ProductSheet_sm2.pdf (yimg.com) PVA User's Guide (yimg.com)	PV Analyser	I-V curve tracer, P-V curve tracer V_{oc} I_{sc} measurements
HT Italia PV-ISOTEST | Commissioning and Maintenance | HT Instruments (ht-instruments.com)	PV ISOTEST	Isolation resistance measurement Continuity of protective conductor
HT Italia 1500V I-V Curve Tracer I-V500w | HT Instruments (ht-instruments.com)	SOLAR I-V500w	I-V curve tracer V_{oc} I_{sc}

Efficient ways of pre-commissioning PV module string testing

Test procedure – According to IEC standard

To be efficient in string level testing, multipurpose and multifunctional test equipment is recommended





Quick testing string by string at combiner box or string inverter input

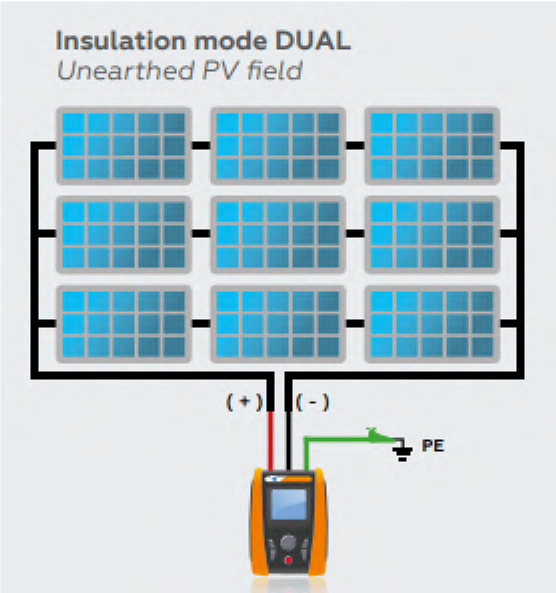
Sample of test result output using Seaward handheld equipment

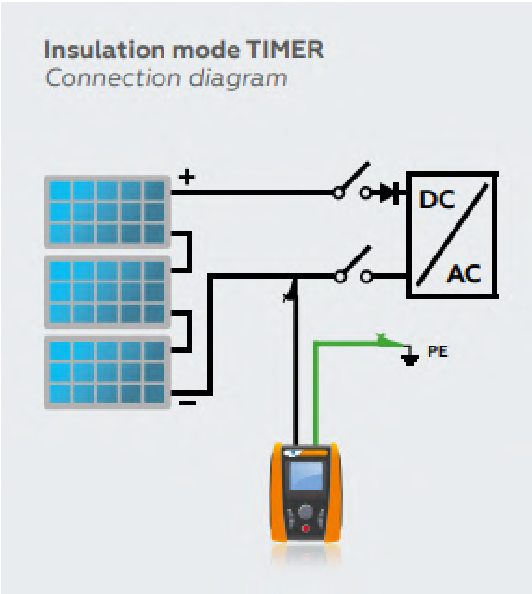
Source:
795 (seaward.com)

Efficient ways of pre-commissioning PV module string testing

Test procedure – According to IEC standard

To be efficient in string level testing, multipurpose and multifunctional test equipment is recommended





Example using HT Italia for Isolation resistance test of PV string using different modes

A worker using Solmetric PV Analyser for PV string testing

Sources:

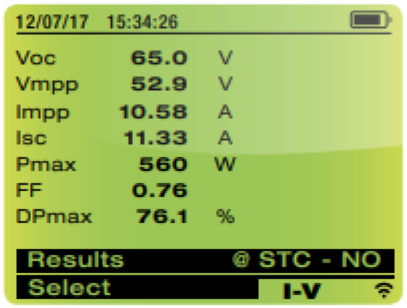
- https://www.ht-instruments.com/en/products/pv-isotest/download/brochure/
- PVA-1500V4 PV Analyzer Kit (solmetric.com)

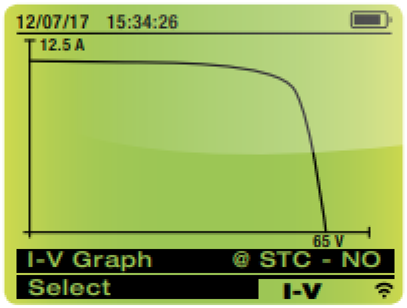
Efficient ways of pre-commissioning PV module string testing

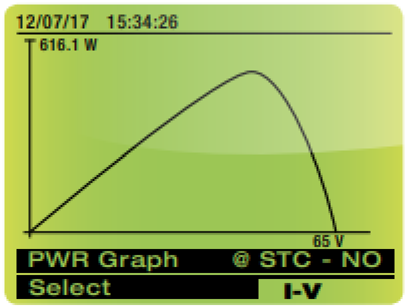
Test procedure – According to IEC standard

Category 2 – I-V curve tracing

An expanded sequence of tests for in-depth system performance analysis and trouble shooting







Source:
https://www.ht-instruments.com/en/products/solar-i-ve/download/brochure/

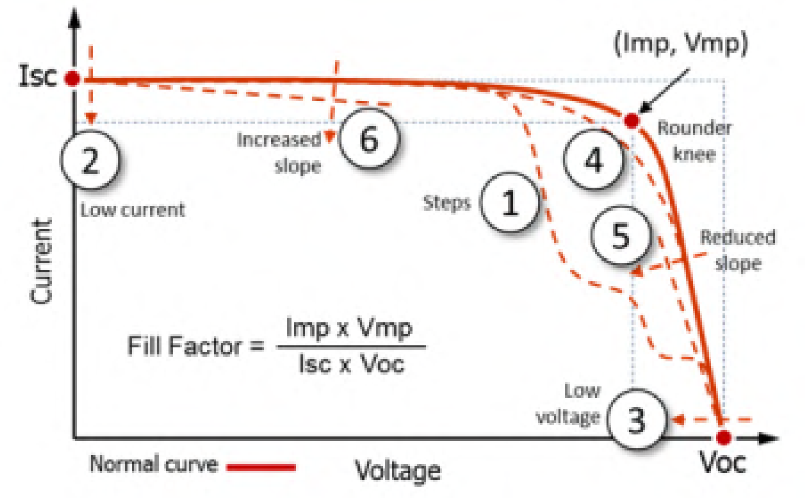
Efficient ways of pre-commissioning PV module string testing

Test procedure – According to IEC standard

String I-V curve test (I-V curve tracing)

More measurement parameters besides V_{oc}, I_{sc}:
e.g. V_{mpp} , I_{mpp} and P_{max} etc.

The shape of I-V curve (and the parameters) can be interpreted to identify potential issues/problems (and its causes) of the system including:



1. **Steps or notches** in curve are indications of **mismatch** between different areas of the array or module under test.
2. **Low current** – A number of factors can be responsible for a variation between the expected current and the measured current (array causes, modelling cases, or measurement causes)
3. **Low voltage** – Potential causes for a variation in voltage (Array causes, modelling causes, or measurement causes)
4. **Rounder knee** - Rounding of the knee of the I-V curve can be a manifestation of the **aging process**. Before concluding that this is the case, check the slopes of the horizontal and vertical legs of the I-V curve. If they have changed, it can produce a visually similar effect in the shape of the knee.
5. **Shallower slope** in vertical leg – The slope of this portion of the I-V curve between the maximum power point (V_{mpp}) and V_{oc} is influenced by the **series resistance** to the circuit under test. An increased resistance will reduce the steepness of the slope, due to PV wiring damage or faults (or cables insufficiently sized), faulty or poor connections, increased module series resistance.
6. **Steeper slope** in horizontal leg - A variation in slope in the upper portion of the I-V curve is likely due to: Shunt paths in PV cells, Module I_{SC} mismatch, tapered shade or soiling (e.g. dirt dams)

I-V curve interpretation and troubleshooting poster: SolarPro I-V feature article, Hernday.pdf (solmetric.com)

Efficient ways of pre-commissioning PV module string testing

String monitoring facility of PV array

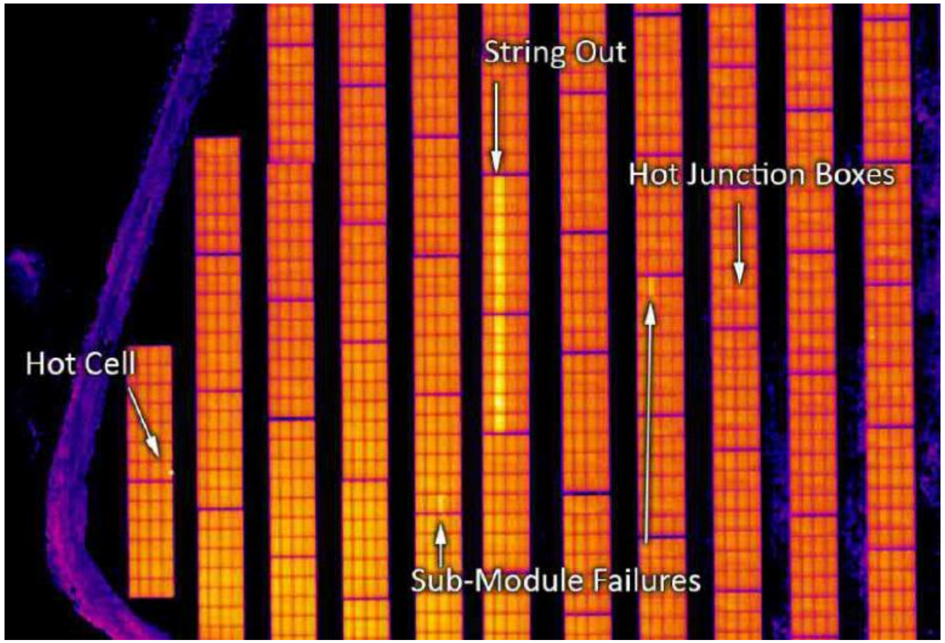
Overview	Importance	Example
▪ Additional equipment provided inside the combiner box or string inverter ▪ Measurement of **individual string current** in real time ▪ Combined application with Plant monitoring system (SCADA) ▪ String-level status available in SCADA	▪ Ability to monitor individual strings ▪ Improve troubleshooting time and enable **quick identification of defects** by the Operation and Maintenance (O&M) team ▪ Prevent accumulative malfunction of modules or strings ▪ Reduce downtime	

Efficient ways of pre-commissioning PV module string testing

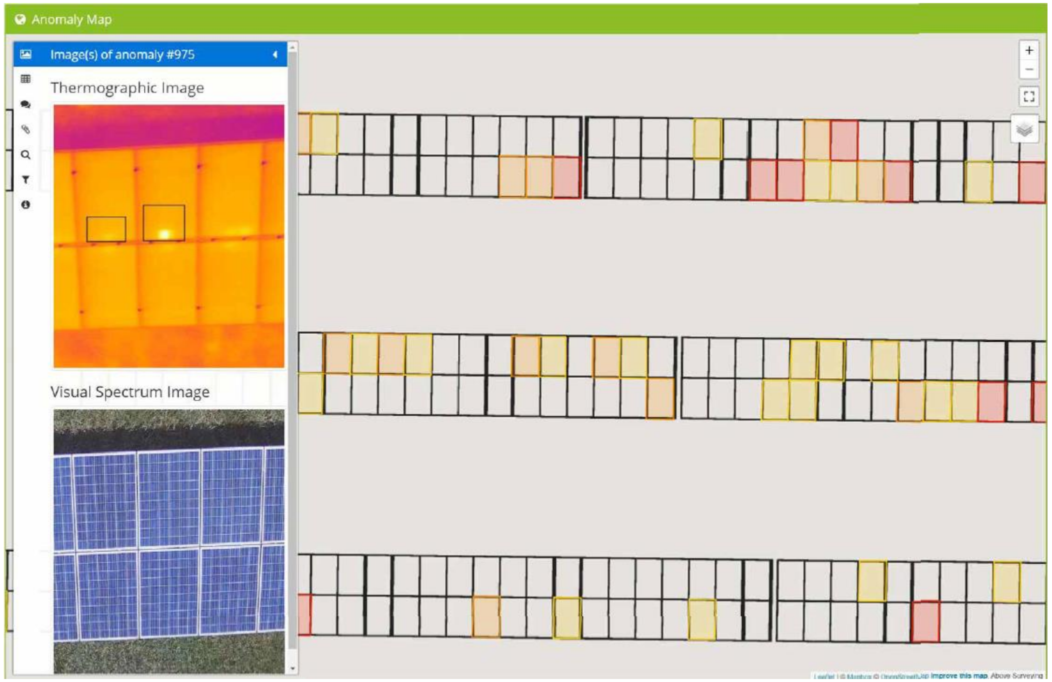
PV array infrared imaging – drone survey

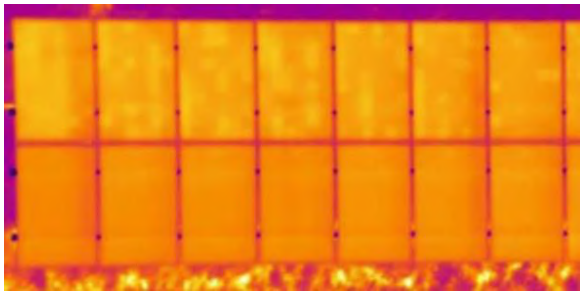
- **PV array infrared camera inspection**

The purpose of an infrared (IR) camera inspection is to detect **unusual temperature variations** in operating PV modules in the field. Such temperature variations may indicate problems within the modules and/or string, such as reverse-bias cells, bypass diode failure, solder bond failure, poor connections and other conditions that lead to localized high temperature operation (**hotspots**).



Source: NREL

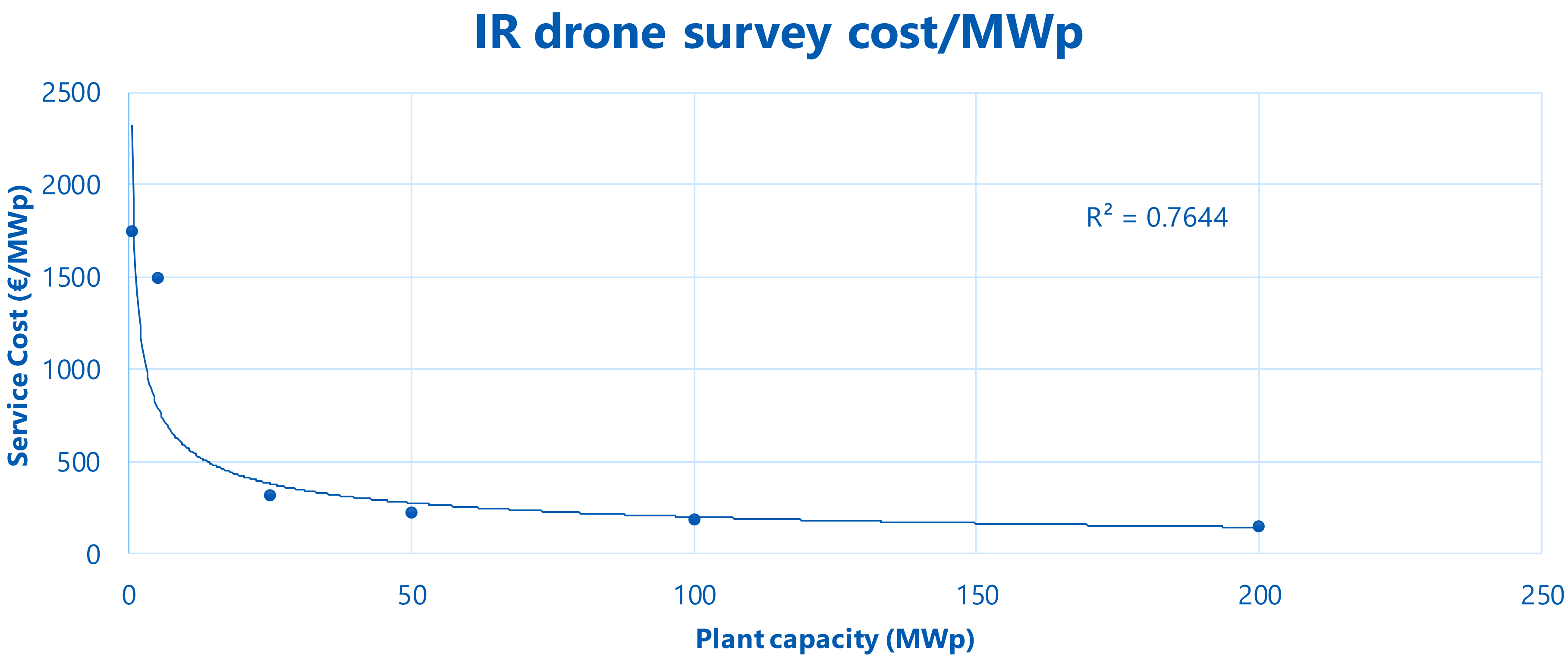




This so-called 'string-end heating pattern' (SEHP) is highly suggestive of PID

Efficient ways of pre-commissioning PV module string testing

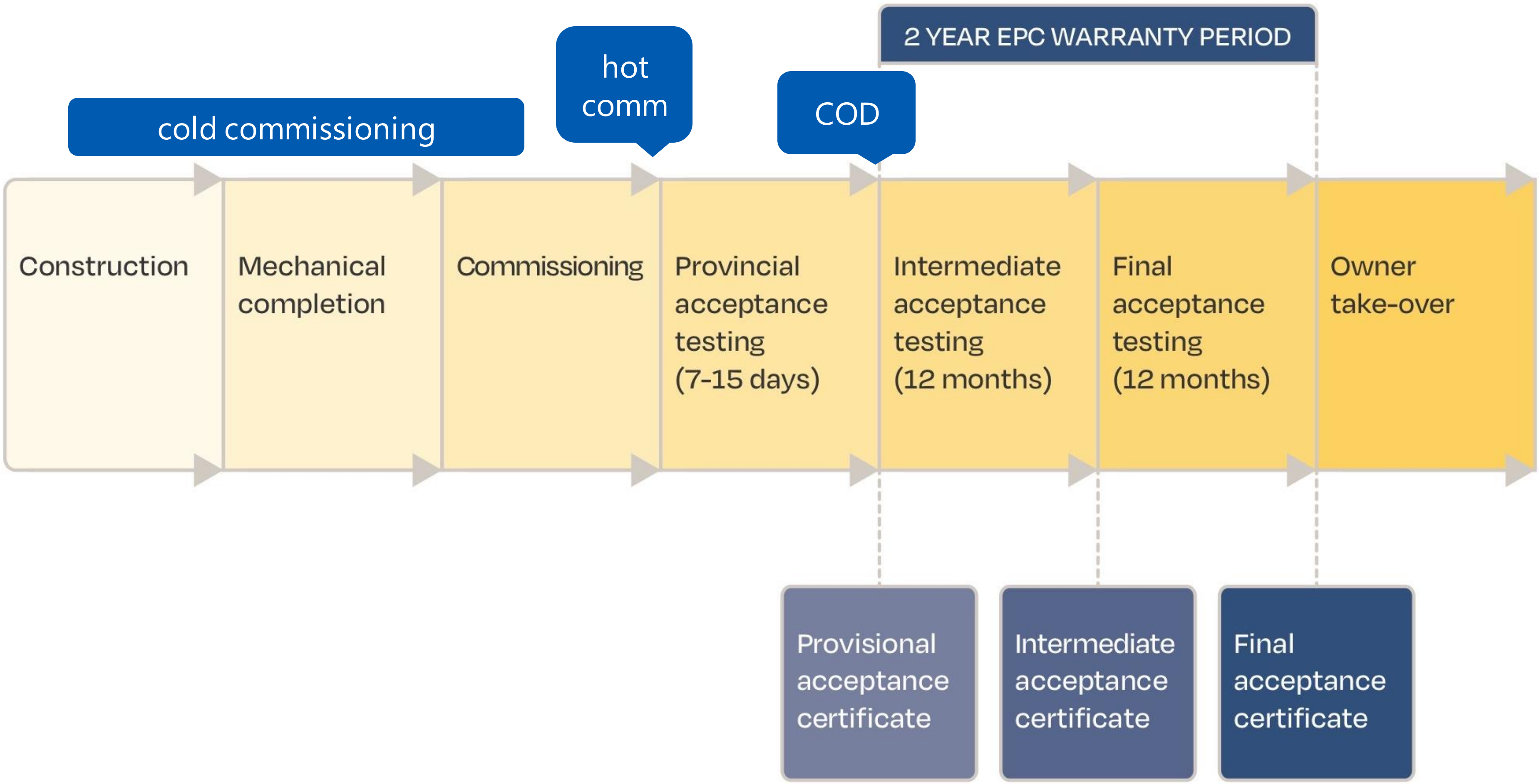
IR drone survey – indicative pricing



- The cost of IR drone survey decreases exponentially with MWp
- Duration to complete depending on location, plant capacity and availability of surveying team
- Reporting can be done with web-based portal for interactive information sharing

Efficient ways of pre-commissioning PV module string testing

Commissioning Milestones



SOURCE: World Bank Group.

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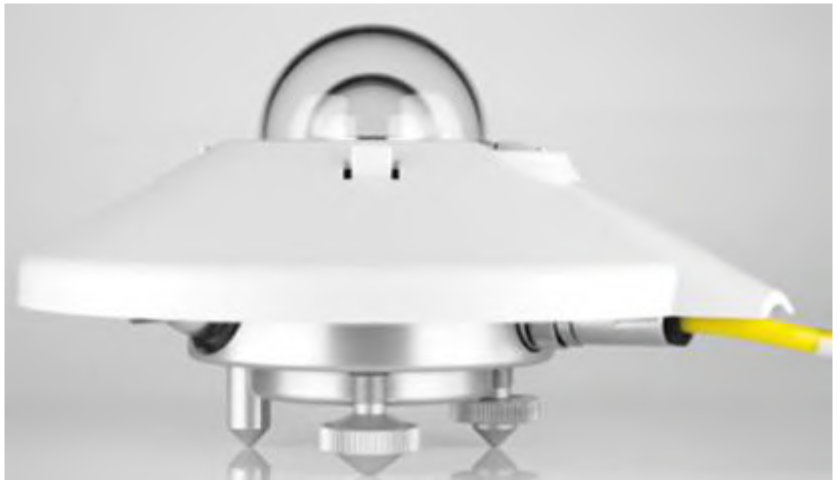
Requirements for solar irradiation measurement

Measurements of solar irradiation

- **On-site measurement** relevant for:
  - Verification during plant acceptance and operation phase (performance control / review of guarantees)
  - Optimization / validation of solar maps & satellite data

- Long-term measurement is **not** necessary for project development (compared to CSP or Wind energy)

- For bifacial modules, ground **albedo** can be measured locally for certain period of time



Pyranometer (Kipp & Zonen)

Albedometer (2 pyranometers)

Requirements for solar irradiation measurement

- **Pyranometers:** high measurement accuracy, measure the complete solar spectrum, good self-cleaning effect, reflects satellite irradiation data, expensive (about 2,000 €), usually required in project finance

- **Reference cells:** medium-low accuracy, measure the spectrum of the solar cell, prone to soiling, economic (starting at around 100 €)

Reference cell

Pyranometer & reference cells

Shadow ring

Solar Irradiation for PV Application

Pyranometers: high measurement accuracy, measure the complete solar spectrum, good self-cleaning effect, reflects satellite irradiation data, expensive (about 2,000 €), usually needed in project finance.

Reference cells: medium-low accuracy, measure the spectrum of the solar cell, prone to soiling, economic (starting with around 100 €).

Shadow ring: to measure diffuse irradiation.

Pyranometer

Reference cell

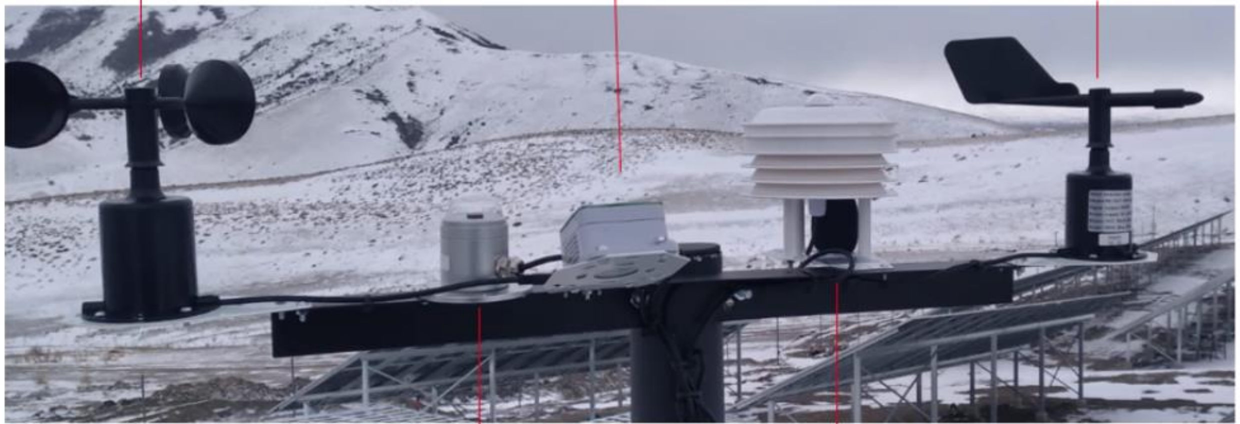
Shadow ring

Weather station for on-site irradiation measurement

Minimum Technical Requirements

Renke model RS-QXZN-M

- **Horizontal irradiation** (GHI)
- **Tilted irradiation**
- Ambient temperature
- Module temperature
  (to be installed at module)
- Wind speed and direction



Plant Performance Monitoring

Data from the **weather station**, **inverters**, **combiner boxes**, **meters** and **transformers** to be collected in data loggers and passed to a plant monitoring system. Monitoring system to include the **inverter / string monitoring** data, **production** data from the export meter, the data from the **meteo station** and module temperature sensor, to raise warnings on a daily basis in case of errors, defects or a performance shortfall

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Bankable solar resource and energy yield assessments (EYA)

EYA approach summary

Solar Resource Assessment

- Assess **different sources** with different quality
- National meteo station network
- Satellite data
- Ground measurement

Global Horizontal Irradiation (**GHI**) data in **TMY**

i.e., long-term high-quality satellite data

PVsyst set up

- **Layout**
- Plant design **configuration** (tilt, height, azimuth, shadings etc.)
- PAN file
- OND file

PVsyst model / simulation project

Simulation result

- PVsyst **loss diagram** (Sankey diagram)
- **Additional** losses

Performance ratio (**PR**)

Specific yield

Annual **generation**

Uncertainty and probability cases

- Simulation uncertainty (σ_{Sim})
- Irradiation data uncertainty ($\sigma_{Irr,acc}$).
- Long-term irradiation data uncertainty ($\sigma_{Irr,ltc}$).
- **P50**, P75, **P90**, P95, P99 energy yield

Energy production probability cases

Gaussian distribution of yield

Final result

- Annual **degradation**

Energy production, specific yield, PR **table for 20 years**

Requirements for solar irradiation data

Types of **solar resource data** — PROs and CONs

- **Data from national meteorological stations / institutes**
  - interpolation of data for project location, long-term data
  - programs available with worldwide data base like Meteonorm or PVGIS*
    - depending on the region high uncertainties
    - sometimes correlation with satellite data
  - simulations possible

- **satellite data**
  - exact project location (coordinates), 10 years and more available
  - different sources with different quality
  - suitable for simulation (yield study), bankability is given
  - industry leader: Solargis

- **on-site ground measurement**
  - High accuracy with high quality equipment possible if well maintained
  - Cost and time effort (min 1 year of data required)
  - Usually for performance control during operation (PR)

Long-term, high-quality **satellite data is "bankable"**. They are the basis to evaluate and develop utility scale PV projects. Costs for a data set is about 1,000 € or even less.

* https://ec.europa.eu/jrc/en/pvgis, https://meteonorm.com/

Solar Irradiation for PV Application

solargis

- Irradiation (**GHI**, DIF, DNI)
- Global irradiation on tilted surfaces (GTI or POA plane of array irradiation)
- ambient temperature (TEMP)

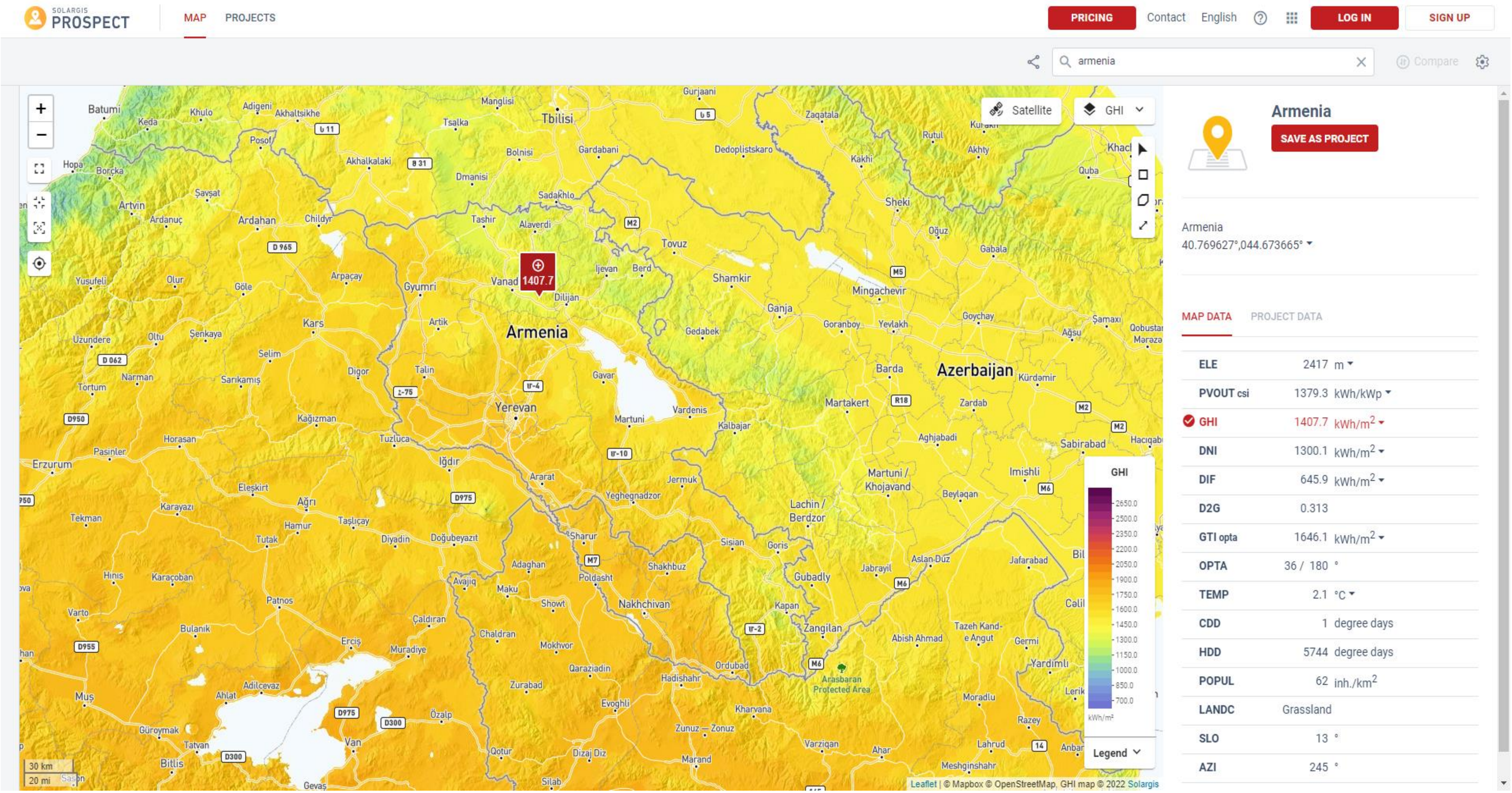
- Historical time-series
- Recent time-series - data for a continuous 12-month period
  - remember, PR is a **long-term KPI** across multiple seasons
- Typical Meteorological Year (**TMY**) = historical time series synthesized into one year
- Forecast data - Forecast horizon of up to 72 hours
- PVsyst input files

Long-term high-quality satellite data is "bankable". It is the basis to evaluate and develop utility-scale PV projects.
Costs for a data set are about 1,000 € or even less.

Pyranometers are used to measure the irradiation during the plant operation.

Bankable solar resource and energy yield assessments

Example of solar irradiation map



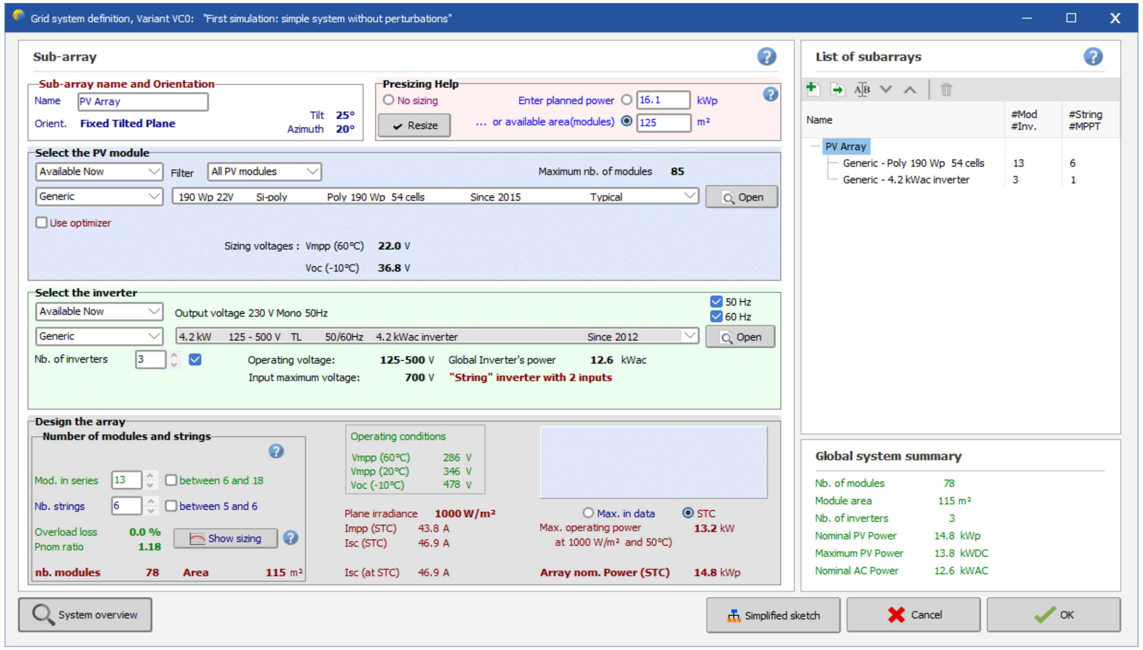
Bankable solar resource and energy yield assessments

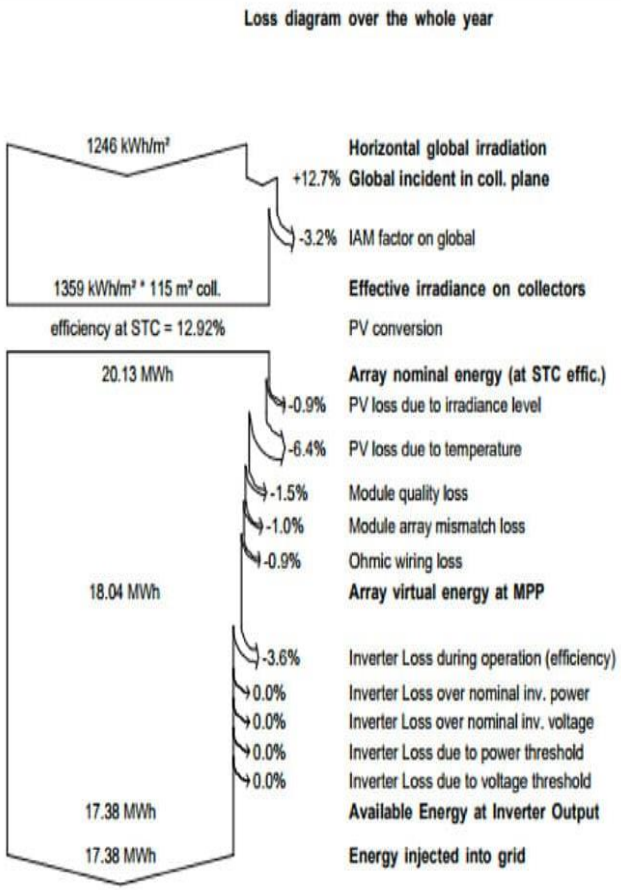
Energy Yield Assessment (EYA)

- Software to be utilized (industry standard)

PVSYST
PHOTOVOLTAIC SOFTWARE

- **System design set up** in PVsyst and **loss diagram** (Sankey diagram)





Source: Features – PVsyst

Bankable solar resource and energy yield assessments

Energy Yield Assessment (EYA) – Simulation approach

- Plant design
  - According to the information, document, data, drawing provided by **Designer** / EPC contractor
  - **.PAN** and **.OND files** for PV module and inverter respectively is important
  - Typical plant design and characteristics

PV_PLANT_NAME	Data
Installed capacity (DC peak power)	
Total power (AC) nom. inverter output	
Number of strings	
PV modules	
Manufacturer	
Module type	
Nominal power at STC	
Technology	
Bifaciality Factor	
Number of modules	
Number of modules per string	
Mounting system	
Manufacturer	
Inclination of modules / Orientation	
Installation type	
Limit shading angle	
Pitch distance	
Height above ground	
Inverters	
Inverter manufacturer	
Inverter type	
Rated input power	
Number of inverters	
Number of strings per inverter	
Cabling	
Max./Calculated DC ohmic losses	
Max./Calculated AC losses	
MV transformers	
Transformer type	
Number of transformers	
Iron and resistive losses	
HV transformers	
Transformer type	
Number of transformers	
Iron and resistive losses	
Soiling	
Soiling losses including cleaning	

Bankable solar resource and energy yield assessments

PR is simply the specific energy yield divided by the specific irradiation

- PVsyst simulation process
  - Performance Ratio (PR)
    - considered as the ratio (annual values) of total AC energy to the theoretically available energy
    - can be considered as the relationship between the effective and the theoretical (module operation at STC conditions) electricity production of a photovoltaic system measured at the relevant energy meter.
    - represents module performance that deviates from the standard conditions together with additional losses between module and relevant energy meter.
    - related to the peak capacity and can be determined for any period (usually annually).
    - The PR is defined as $PR = \frac{Y_{AC}}{G_{TILT} \times A_{1\,kW} \times \eta_{STC}}$

where

Y_{AC}	=	specific AC electricity yield
G_{TILT}	=	total global solar irradiation sum on the tilted module plane
A_{1kW}	=	area of a 1 kWp PV module array and
η_{STC}	=	PV module efficiency at standard test conditions.

$$\text{PR easy} = \frac{\text{specific yield}}{\text{specific irradiation}}$$

$$PR = \frac{Yield \; \frac{kWh}{kWp}}{Irradiation \; \frac{kWh}{m^2}} \times 1000 \, \frac{W}{m^2}$$

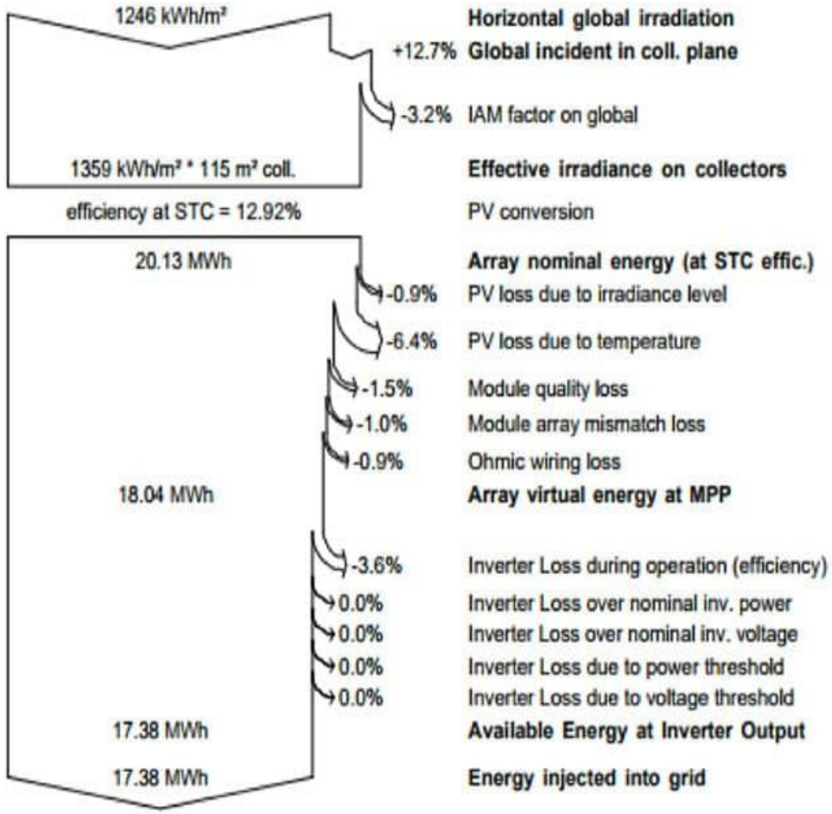
Bankable solar resource and energy yield assessments

Energy Yield Assessment (EYA) – Simulation approach

- Losses

Modeled in PVsyst	Additional losses
Mismatch	Initial degradation
Module quality factor	Annual degradation
DC losses	Own consumption
AC losses	Plant availability
Transformer losses	Grid availability
Soiling losses	

Reactive power generation



- Typical PVsyst simulation results table

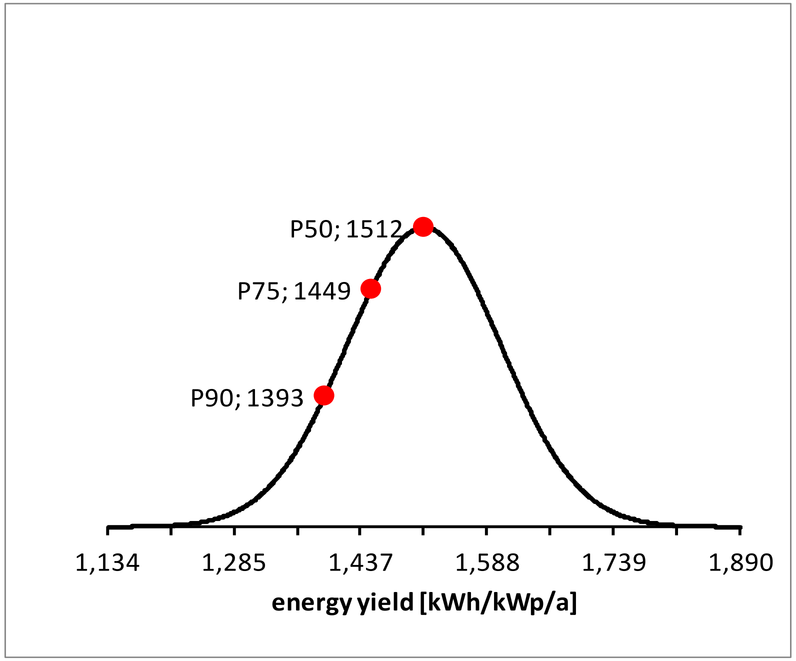
Site	Annual pwr generation (MWh)	Installed DC PV power (kWp)	Specific yield (kWh/kWp)	GHI (kWh/m²)	POA irradiation (kWh/m²)	Performance ratio (%)
Sharosolar-1	9476	5856	1618	1764	2021	80.05

Energy Yield Assessment (EYA) – Simulation approach

➢ Probability Analysis

- The **probability** of electricity production exceeding a certain percentage of the calculated output is determined by the total **uncertainty**
- Example of output table showing **uncertainty** and the **probabilities of energy generation** including additional losses and initial degradation:

Duration (years)	1	2	3	4	5	10	20
Total uncertainty (%)	7.4%	7.3%	7.3%	7.3%	7.2%	7.2%	7.2%
P50	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
P75	95.0%	95.1%	95.1%	95.1%	95.1%	95.1%	95.1%
P90	90.6%	90.7%	90.7%	90.7%	90.7%	90.7%	90.7%
P95	87.9%	88.0%	88.1%	88.1%	88.1%	88.1%	88.1%
P99	82.9%	83.0%	83.1%	83.1%	83.2%	83.2%	83.2%
P50 (kWh/kWp)	1,993	1,993	1,993	1,993	1,993	1,993	1,993
P75 (kWh/kWp)	1,894	1,895	1,896	1,896	1,896	1,896	1,896
P90 (kWh/kWp)	1,805	1,807	1,808	1,808	1,808	1,808	1,809
P95 (kWh/kWp)	1,752	1,754	1,755	1,756	1,756	1,756	1,757
P99 (kWh/kWp)	1,652	1,655	1,657	1,657	1,658	1,658	1,659



Bankable solar resource and energy yield assessments

Energy Yield Assessment (EYA) – Simulation approach

➢ Final output

- Example of specific yield figures including additional losses and total degradation over 20 years

Year	P50	P75	P90	P95	P99	Total degradation	Annual PR incl. degr.
1	1,993	1,896	1,809	1,757	1,659	0.75%	80.2%
2	1,983	1,887	1,800	1,748	1,650	1.25%	79.8%
3	1,973	1,877	1,791	1,739	1,642	1.75%	79.4%
4	1,964	1,868	1,782	1,730	1,634	2.25%	79.0%
5	1,954	1,859	1,773	1,722	1,626	2.75%	78.6%
6	1,944	1,849	1,764	1,713	1,618	3.25%	78.2%
7	1,934	1,840	1,755	1,705	1,610	3.75%	77.8%
8	1,925	1,831	1,747	1,696	1,602	4.25%	77.4%
9	1,915	1,822	1,738	1,688	1,594	4.75%	77.0%
10	1,905	1,813	1,729	1,679	1,586	5.25%	76.7%
11	1,896	1,804	1,721	1,671	1,578	5.75%	76.3%
12	1,886	1,795	1,712	1,662	1,570	6.25%	75.9%
13	1,877	1,786	1,703	1,654	1,562	6.75%	75.5%
14	1,868	1,777	1,695	1,646	1,554	7.25%	75.1%
15	1,858	1,768	1,686	1,638	1,546	7.75%	74.8%
16	1,849	1,759	1,678	1,629	1,539	8.25%	74.4%
17	1,840	1,750	1,670	1,621	1,531	8.75%	74.0%
18	1,831	1,741	1,661	1,613	1,523	9.25%	73.6%
19	1,821	1,733	1,653	1,605	1,516	9.75%	73.3%
20	1,812	1,724	1,645	1,597	1,508	10.25%	72.9%

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16	PV module disposal and recycling
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PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

O&M Contract Salient Point

Scope

- **Preventive Maintenance** (PM)
- **Corrective Maintenance** (CM)
- PV Module Cleaning

Guarantee

- **Availability** guarantee
- Other forms of guarantee (PR)

Spare part

- Adequacy of **spare parts**

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

O&M Contract Salient Point – Scope of Work

Preventive maintenance (PM)

Activity and **frequency** of preventive maintenance is set by the operations function and is influenced by a number of factors, such as equipment type, environmental conditions at the site (e.g., marine, snow, pollen, humidity, dust, wildlife), and **warranty terms**.

- Scheduled maintenance is often carried out at intervals to conform to the **manufacturers' recommendations**, as required by the equipment warranties. Check available **long-term service agreements** (LTSA) for inverters.
- Any **scheduled recurring** activity such as remote data acquisition and processing, e.g., to calculate performance KPIs is part of preventive maintenance
- **PV module cleaning** normally is considered part of preventive maintenance, and it is critical as it relates to the assumption in the yield study and **directly impacts the energy output** of the Project. Module cleaning can be due to soiling/dust or snow.

Corrective maintenance (CM)

Required to **repair** damage, malfunction or **replace** failed components. Critical **spare parts** to be kept on stock for a fast response.

- It is possible to perform some corrective maintenance such as inverter resets or communications resets remotely.
- Less urgent corrective maintenance tasks can be combined with scheduled, preventive maintenance tasks.

Source: NREL best practices for OnM PV ESS 73822.pdf

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

O&M Contract Salient Point – Scope of Works

Preventive Maintenance

- **PV module**
  - Visual inspection
  - Thermography
  - I-V curve
- **Combiner box**
  - Visual inspection, incl. SPD
  - Cleaning
  - Thermography
- **Mounting structure**
  - Visual inspection
  - Torque check
  - Corrosion protection thickness
- **Inverter**
  - According to OEM's recomm-endations including filter and ventilation maintenance
- **Meteorological equipment**
  - Cleaning
  - Calibration
- **MV** equipment, power evacuation facility
  - According to OEM's recommendations
- **Civil works**
  - Drainage
  - Fencing
  - Road
  - Vegetation
  - Building (if applicable)

Corrective Maintenance

- **PV module**
  - Cracks
  - Hot spots
  - Loose connector
- **Combiner box**
  - Blown fuse/fuse holder
  - Loose connection
- **Inverter**
  - Alarms and faults
- **MV equipment**
  - Alarm and faults
- **Meteorological equipment**
  - Invalid data
- **Spare part management**
  - replenish spare part stock after component replacements
  - keep the digital inventory up to date

Source: NREL best practices for OnM PV ESS 73822.pdf

PV Module Cleaning

- **Dust and soiling**
  - Manual cleaning by manpower
  - Robot assisted cleaning
- **Snow cleaning**
  - By powerful turbo-fan, not shovel or other mechanical means

Source: NREL best practices for OnM PV ESS 73822.pdf

Source: 210303 OM Manual EN.pdf

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

O&M Contract Salient Point – **Availability Guarantee**

Definition

- The percentage of **uptime** that a component or system is operating.
- Important to distinguish events that are **outside management control** such as grid availability, grid curtailment. Operators should not be penalized for such events.
- The energy availability may be reported for the complete system or for **building blocks** within systems.
- Availability can also be specific to the components or subsystems within a system e.g., tracking system, inverter.

Availability

Guaranteed Availability

Typically, 98 or 99% - derived from uptime of the system

$$\text{PV System Availability} = 1 - \frac{1}{H_{ttp} \times KW_{np}} \times \left(\sum_{Incident} (H_{un} KW_{dr}) \right)$$

Where:

Theoretical total production time (Http):
The hours in the period when sufficient sunlight exists to allow the inverters to reach the input voltage needed to operate.

Nameplate power (KWnp):
The nameplate power rating of the entire solar generating facility determined by the sum of each module's nameplate kWp rating.

Component unavailability hours (Hun):
The hours in the period when solar irradiance is sufficient to power the inverters, yet a component within the facility is not available to generate power due to an equipment fault.

Derated system power (KWdr):
The value for unavailability derated system power will be calculated by the amount of unavailable DC nameplate capacity for the period and is determined by sum of each module's

Incident:
Every outage incident during the measurement period.

Note 1: KWdr describes the fractional capacity reduction (not due to degradation).

Note 2: This calculation does not consider cumulative degradation, which should be calculated and tracked separately along with energy production.

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

O&M Contract Salient Point – Other forms of Guarantee

1 Energy availability

energy availability is a metric of energy throughput capability that quantifies the expected energy when the system is operating relative to the total expected energy

2 Energy performance index

comparison of the energy that was produced by the plant with the energy that was **expected** for the plant based on the measured weather and **irradiance**, and a **performance model** agreed to by the stakeholders.

3 Energy delivery

measured MWh/year energy delivery

$$PR = \frac{\frac{kWh}{kWp}}{\frac{kWh}{m^2}} \iff \frac{kWh}{kWp} = \frac{kWh}{m^2} \times PR_{[EYA]}$$

4 Specific performance

energy delivery divided by plant rated capacity, in units of kWh/kW/year

5 Performance Ratio (PR)

a measure of **PV plant capability**, of how effectively the plant converts sunlight collected by the PV panels into AC energy delivered to the off-taker; plant Design must include a final EYA → $\mathbf{PR_{EYA}}$ is the basis for minimum guaranteed performance

6 Power performance index

similar to the energy performance index except that it reflects the power output rather than the energy output

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

O&M Contract Salient Point – **Spare parts**

- Based on EPC and **manufacturer recommendations,** e.g., inverter "first aid kit"
- **Inventory management** – replacements of spare parts need to be ordered based on component failure history, balance on stock, lead time, reordering amount, storage requirements etc.
- Good practice for **inventory management**:
  - Strategically locate a **warehouse** to share stock and reduce travel time; **sharing spares** for long-lead-time items such as inverters and transformers across multiple projects in a portfolio
  - **Standardizing** certain supplier and models to reduce diversity in stock
  - Making arrangements with **suppliers** to guarantee availability or consignment stock with the manufacturer.
  - Storage of spare parts to be provided accordingly - indoor for electronics and sensitive equipment, outdoor under shed for outdoor equipment.

Spare Part List SC-XXX-CP

Production index: A

Category	Item designation	SMA order number	Description	Build-in quantity	Retail price / piece
Circuit Breaker	SC-Q5	60-9045	switch-disconnector 1SDA 4-pole-with accessories ABB	1	3.816,87 €
		60-90455	undervoltage tripping device ABB 1SDA062087R1	1	105,60 €
Fuses	SC-F5	61-117306	Circuit breaker 3pol 6A S203-B6 ABB	1	51,00 €
	SC-F20, -F21. -F22	10-6404	Strikesorb 40-G Raycap	3	288,00 €
	SC-F23, -F24	10-6405	Strikesorb 40-F Raycap	2	288,00 €
	SC-F29	62-951315	kombi-arrestor, modular (type 1) 3+1pol.-400VAC	1	996,21 €
		62-951001	protection modul Dehnventil, Dehn 951001	3	302,40 €
		62-951100	protection modul Dehnventil, Dehn 951100	1	375,30 €
	SC-F119	61-1263161	circuit breaker 3+NA pol K16A ABB S203-K16	1	58,50 €
Relays, power contactors	SC-Q1	60-000390	contactor ABB AF 1650T-30 w. FRT-option	1	4.816,80 €
	SC-K20	60-001000931202	power contactor 400V/AC 9A 3pol 24VDC	1	30,72 €
		60-0033011	varistor 24/50V RV5/50	1	4,11 €
	SC-K21	60-1504	relay monostable 3xW 24VDC 16A/400VAC	1	18,90 €
	SC-K22	60-154060	relay 24VDC 2xUM PLC-RSC-24DC/21-21	1	20,88 €
	SC-K25	60-154072	relay 230VAC 1x CO PLC-RSP-230UC/21AU	1	26,34 €
Switch cabinet heating	SC-E10	01-8319231	96R0x2 ±10% 2x150W compact resistor	1	97,23 €
	SC-B11	65-0507	SK Hygrostat Rittal SK 3118.000	1	106,65 €
Fan	SC-G11	46-5070	stack fan	1	1.509,66 €
	SC-E100, -E101	46-5185	Radial fan with engine and-Inlet nozzle	2	260,10 €
Power unit	SC-T11	64-114820	Power Stack 3x1470 A SKM400GB126D TRENCH UL	1	21.103,32 €
Electrical Components	SC-T10	30-94074	power supply MINI-PS-100-240AC/24DC-C2LPS	1	193,47 €
	SC-T20	30-90380	buffer module C-TEC 2410-1	1	615,78 €
	SC-T21	30-90111	power supply MINI-PS-100-240AC/24DC/2	1	162,00 €
	SC-R1	04-035505	107µHx3 1300A aluminium threephase choke	1	6.820,29 €
	SC-C1, -C2	02-911002	100µFx3 750VAC/80A three-phase capacitor	2	193,68 €
	SC-B2, -B3	09-6075	temperature controller 03EN	2	4,80 €
	SC-T12, -T13, -T14	04-0215004	current transducer through-hole 1500A	3	211,95 €
	SC-T6	60-80012	current transducer through-hole 2000A	1	224,25 €
	SC-B20, -B21, -B22	09-02050	NTC 2K00 1% 60mW Epcos	3	2,10 €
Control Components	SC-A1	SC20CONT.GR-S1	Sunny Central controller board - SEMIKUBE	1	N/A
	SC-A2	SC20CAIO.GR1	IO-extension for SC20CONT	1	N/A
	system cable	41-5186	M12 cable 8poel 3m shielded	1	58,80 €
	=11_0-X101 or =11_1-X100 or =11_2-X100	43-9389	ISDN terminator 2x 100ohm in RJ45, BK	1	2,16 €
	SC-X72. -X73	42-5101	M12 terminating plug 8-pole	2	10,80 €
	SC-W770, -W771, -W772, W773, -W774	41-5190	voltage measuring cable between AC/DC	1	275,94 €

O&M Contract Salient Point – **Spare parts**

TABLE 4 MINIMUM LIST OF SPARE PARTS (NON-EXHAUSTIVE)

No.	Spare part
1	Fuses for all equipment (e.g., inverters, combiner boxes etc) and fuse kits
2	Modules
3	Inverter spares (e.g., power stacks, circuit breakers, contactor, switches, controller board etc)
4	Uninterruptible Power Supply (UPS)
5	Voltage terminations (MV)
6	Power plant controller spares
7	SCADA and data communication spares
8	Transformer and switchgear spares
9	Weather station sensors
10	Motors and gearboxes for trackers
11	Harnesses and cables
12	Screws and other supplies and tools
13	Specified module connectors (male and female should be from the same manufacturer)
14	Structures components
15	Security equipment (e.g., cameras)

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

Operating Expenditure

Typical items/costs to be included in OPEX

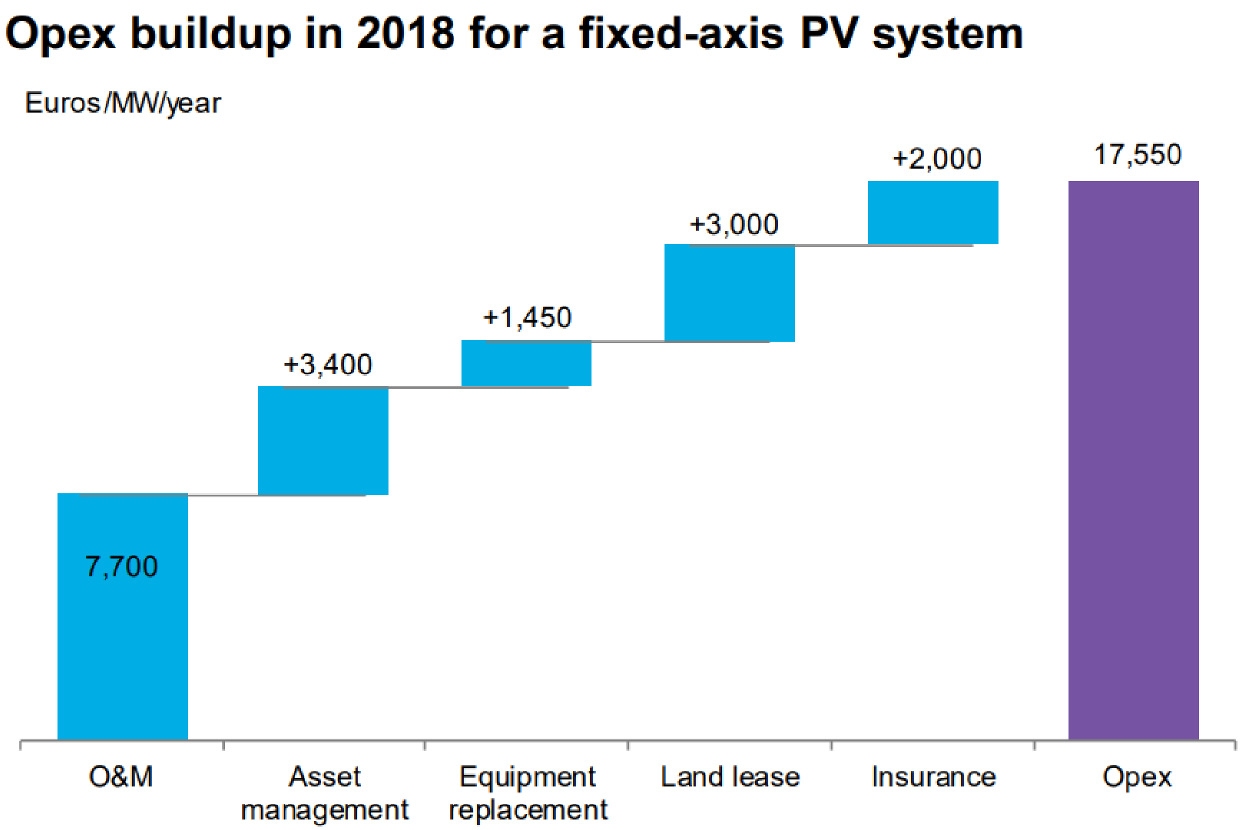
O&M cost incl. Maintenance reserve	Equipment replacement	Asset Management
Liability Insurance Property Insurance	Night consumption OPEX	Inverter Warranty extension
Land Lease cost	Land tax	Social Investment

OPEX typical range in the market : 7-12 EUR/kWp per year depending on the extent of the scope of works

PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)

Operating Expenditure

OPEX = O&M + Asset Management + Replacements + Land Lease + Insurance



Source: BloombergNEF. Note: Equipment replacement cost includes one inverter replacement during the lifetime of the plant. Insurance is assumed to be 0.25% of capex.

BloombergNEF

PV plant Operation and Maintenance (O&M)

O&M Reporting

Key elements of monthly O&M Report

- Preventive Maintenance
- Corrective Maintenance
- Facility Production and Consumption
  - monthly irradiance and production
  - monthly energy consumption
  - monthly inverter production
- Performance Ratio and Availability
- Spare Parts Management
- Security
- HSE

[sample O&M Report megawatt PV.pdf]

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Contents

Agenda

GAF-RE Training Workshop Part II

Plant fencing and anti-intrusion best practices

Overview of the essential purpose

Purpose	Best Practice
▪ For PV plant: security against external party **intrusion**, vandalism incident, public safety from **electrical hazard** (liability issue) ▪ For substation: public safety from electrical hazard, flashover incident, equipment tripping, unexpected plant shutdown ▪ For warehouse/laydown: prevention from theft incident, monetary loss, delay of project ▪ Unfenced site → consequences to **insurance** premium !??	▪ Suitable **height** and **material** of fencing (e.g., galvanized steel) ▪ Preferably anti-climb fence – slightly higher cost ▪ Fencing pole to be provided with adequate **foundation** for strength and reliability ▪ Substation fence exposed metallic structure to be provided with suitable **earthing** according to local regulation ▪ Suitable lock and danger **signage** to be provided ▪ **CCTV** cameras for critical areas e.g., office, gate entrance, warehouse/laydown, substation. Preferably with night vision and adequate Uninterruptible Power Supply (UPS). ▪ Perimeter fence could be provided with lighting as necessary.

Plant fencing and anti-intrusion best practices

Substation fencing following local regulation

Substation fencing following local regulation

Substation fencing should be lockable

Plant fencing and anti-intrusion best practices

Suitable height and material of perimeter fence

Fencing pole provided with concrete stump

Fencing and gate is provided for laydown area

Plant fencing and anti-intrusion best practices

CCTV and street lighting at gate entrance and fencing location

Agenda

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15	Waste Management on and off site
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Compliance of ESHS – housekeeping

Housekeeping refers to Environmental and Health and Safety aspects that:

- Reduce potential for accident and incidents
- Ensure long-term gains vs short-term.
- Reduce exposure to penalties and financial costs.

Good Housekeeping	Poor Housekeeping
Waste sorted and stored appropriately	Fly waste all over property and surrounds
Bunded hydro-carbons	Oil spills, wastage resulting in costs
Good storage = good stock keeping	Poor storage = excess purchases and wastage
Better moral	No care attitude

Housekeeping important for local and International Regulations and Standards.

ESHS housekeeping

Best practices for proper housekeeping

Proper housekeeping must be provided on the construction site not only after completion of construction works, but continuously during construction.

Actions	Objective
➢ Periodical removal of trash and debris shall be organized ➢ all types of waste shall be collected and disposed of off site ➢ solid waste shall be kept in a covered container, construction waste shall be collected at a separately allocated area ➢ construction and packaging materials must be collected and stored properly and not be spread on site ➢ construction waste shall be transported from the area (usually it is Contractor's responsibility) and disposed of at the community landfill (landfill, dumpsite) upon written consent of the community head.	**Best practices for proper housekeeping**

Compliance of ESHS – housekeeping issues that are common

- Agreements with local communities regarding Infrastructure
  - Domestic Waste
  - Hazardous / Industrial Waste
  - Construction Waste
  - Waste water discharge
  - Potable Water
  - Land use and access

- Drainage – to prevent erosion over time =prevent loss

- Types of Waste and management
  - Hazardous/Industrial – hydrocarbons of any nature, construction materials, - handling and disposal
  - Construction – excess soil, rocks – removal to approved location, prevent dumping ground
  - Domestic – disposal, vermin, fly-waste – removal to approved location

- Fires –not acceptable for waste handling nor heating

- Heating Equipment – health and safety


LONCIN
8000

ESHS housekeeping

Construction debris left uncleared

Construction debris left uncleared

Rubbish from water bottles and plastics

Agenda

GAF-RE Training Workshop Part II

Waste Management on and off site

Construction period – construction waste

- Written consent with nearby settlement or community administration on final disposal of construction waste, excavated soil and stones

- For projects, which are subject of Environmental Impact Assessment (EIA), the EIA usually contains information on remaining soil volume and preliminary place where it will be disposed. For all cases, written consent shall be obtained.

- Remaining soil and excavation materials can be stored in PV area, compacted and levelled. If the soil and stones are finally dumped at a private land, then a written consent of the landowner should be provided.

- Construction waste shall be transported from the area (usually it is responsibility of Contractor) and disposed at the community landfill (landfill, dumpsite, other) upon written consent of the community head.

- Separate place for construction waste temporary collection shall be allocated on construction site, preferably it shall be fenced with a tape.

Waste Management on and off site

Construction period – construction waste

Inverter boxes

Construction debris

Excavated soil

Waste boxes

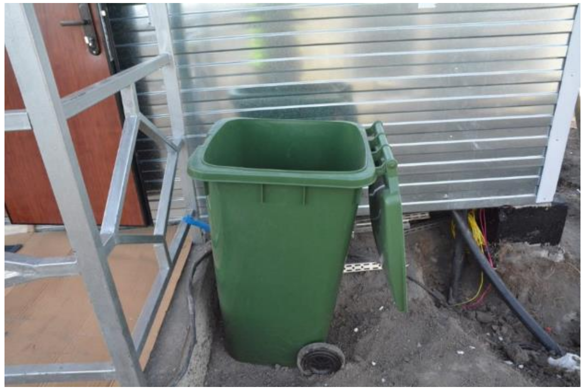
Waste boxes

Excavated soil

Waste Management on and off site

Construction period – solid domestic waste

For domestic waste plastic or metal big containers with lid shall be installed at the site

Acceptable bin	Closed lid better	Waste left uncleared
		
Acceptable bin with lid	**Waste left uncleared**	**Bin not used**
		

Waste Management on and off site

Construction period – hazardous waste

- Hazardous waste is classified in accordance with the Decree of the Minister of Environment N 430 dated 25.12.2006.
- Barrels with transformer oil or diesel should be stored on a waterproof surface and under the cover to avoid direct sunlight.
- Secondary containment with a volume of 110% of the volume of drums or oil container shall be provided. The oil barrels/containers shall be properly labelled. The fire extinguisher shall be placed not far from the storage location.





Waste Management on and off site

Operation period

Solid domestic waste

Transportation agreements shall be signed with local service provider for periodical transportation of generated waste during operation, construction and domestic waste from the area to designated landfill

Hazardous waste

Transformer oil or diesel containers

- ✓ Barrels with transformer oil or diesel should be stored on a waterproof surface and under the cover to avoid direct sunlight.
- ✓ Secondary containment with a volume of 110% of the volume of drums or oil container shall be provided.
- ✓ The oil barrels/containers shall be properly labelled. The fire extinguisher shall be placed not far from the storage location.

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PV module disposal and recycling

PV modules

Material classification

According to Republic of Armenia legislation, PV modules are not considered hazardous material.

As per international practice modules should be treated as hazardous waste.

Storage

On a waterproof surface and under the cover at the construction site or other location.

ESHMP*

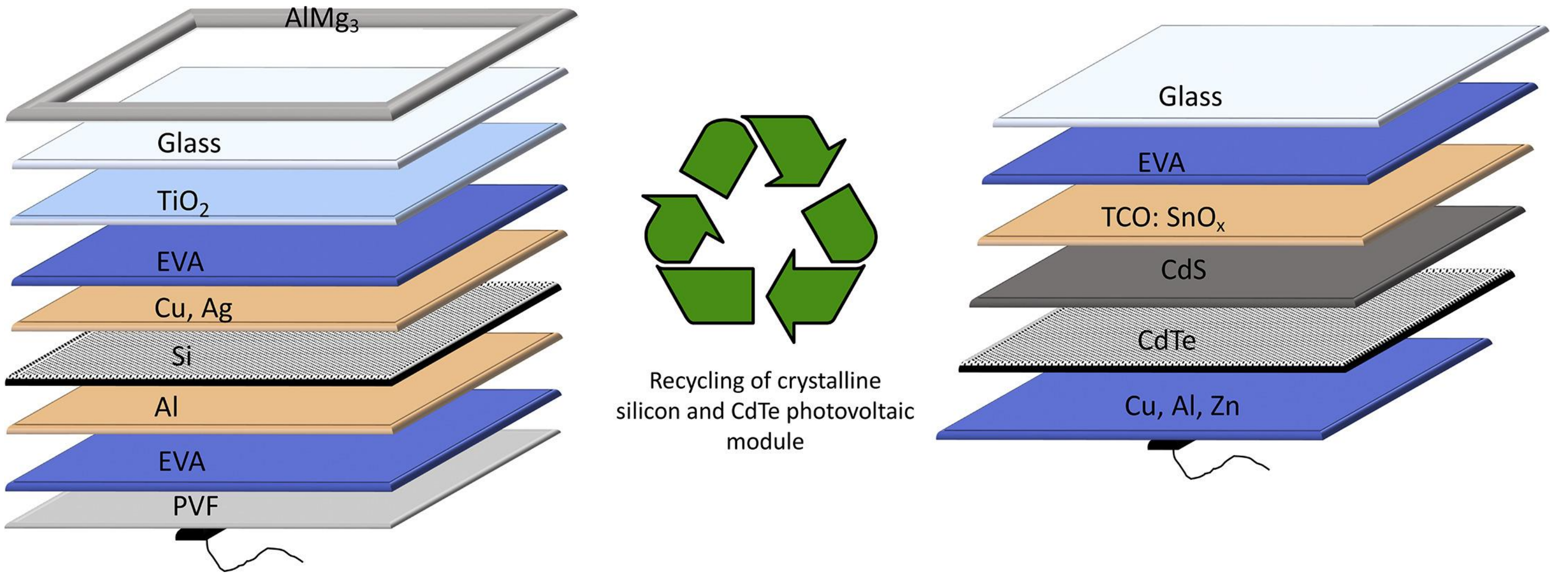
The exact location of the storage shall be provided in the ESHMP of the project.

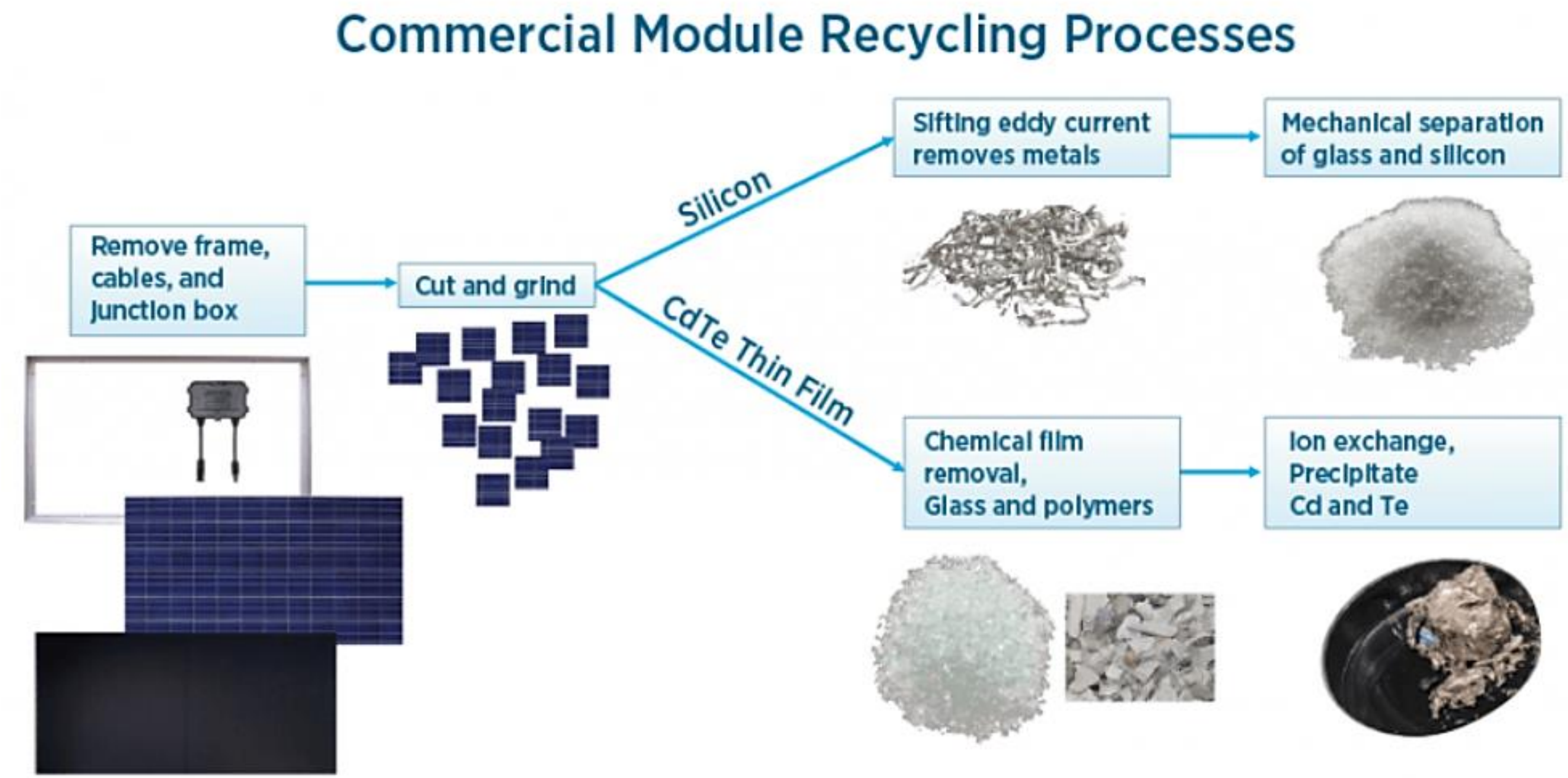
Related legislation

Hazardous waste is classified in accordance with the Decree of the Minister of Environment N 430 dated 25.12.2006.

*Environment Safety Health Management Plan

Studies have shown the heavy metals in solar panels — namely **lead** and **cadmium** — can leach out of the cells and get into groundwater, as well as affect plants. These metals also have a record for detrimental effects on human health. Lead is commonly known to impair brain development in children, and cadmium is a carcinogen.

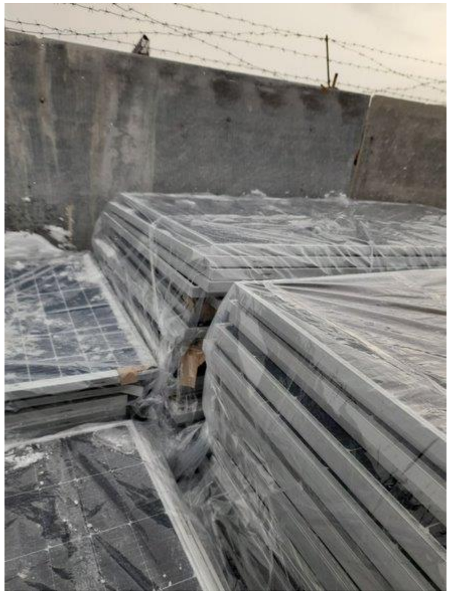



Commercial Module Recycling Processes
Remove frame, cables, and junction box
Cut and grind
Silicon
CdTe Thin Film
Sifting eddy current removes metals
Mechanical separation of glass and silicon
Chemical film removal, Glass and polymers
Ion exchange, Precipitate Cd and Te

PV module disposal and recycling

Sample of damaged PV modules

Broken glass	Broken glass	Delamination
		

Temporary storage of broken panels, wrapped		Kept of floor
		

Agenda

	GAF-RE Training Workshop Part II
9	Efficient ways of pre-commissioning PV module string testing
10	Weather station for on-site irradiation measurement and plant performance monitoring
11	Bankable solar resource and energy yield assessments
12	PV plant Operation and Maintenance (O&M), operation expenditures (OPEX)
13	Plant fencing and anti-intrusion best practice
14	ESHS housekeeping
15	Waste Management on and off site
16	PV module disposal and recycling
17	Environmental Offset, Botanical Studies

Environmental Offset, Botanical Studies

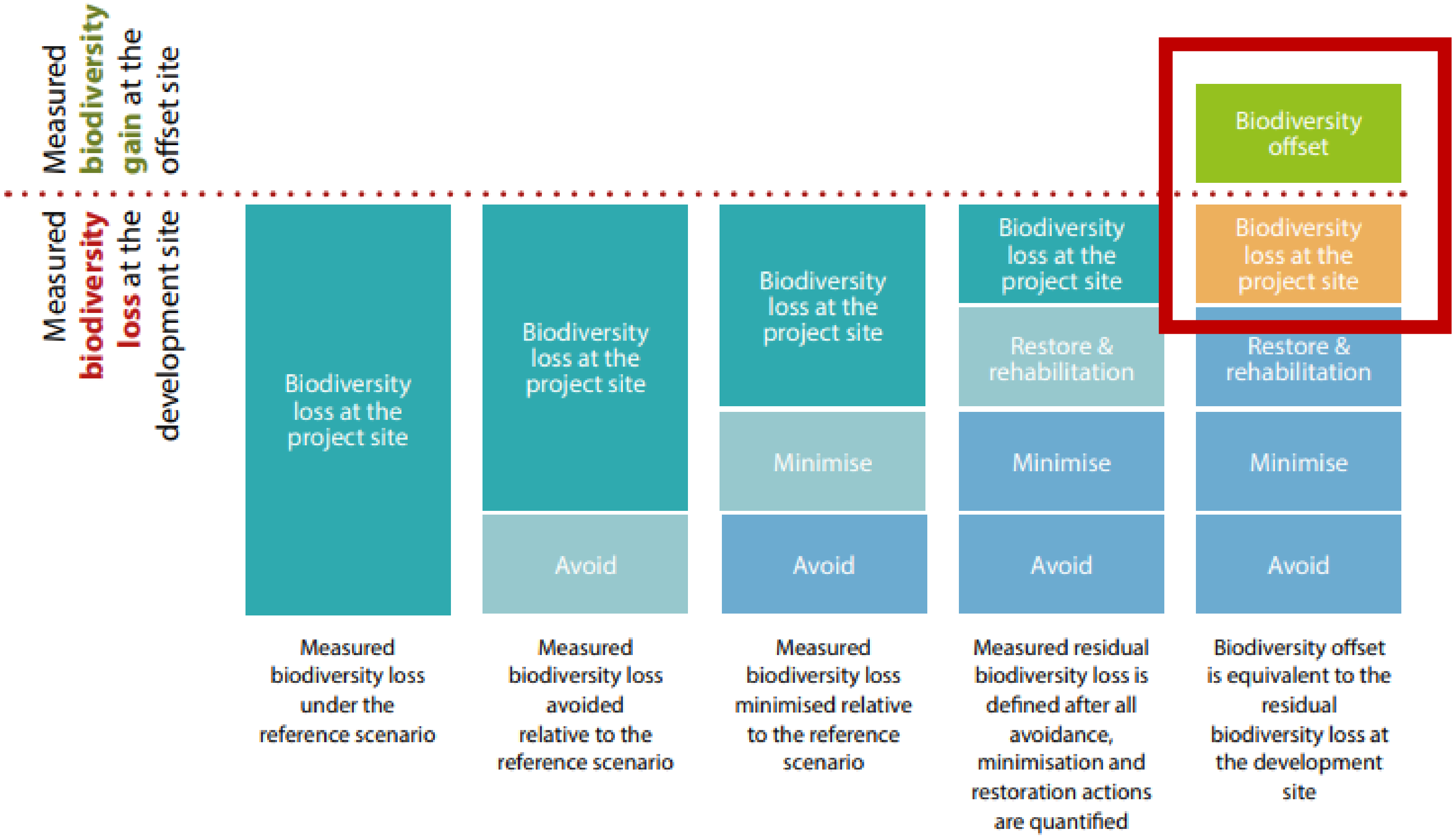
Biodiversity offsets are **measurable** conservation outcomes that result from actions designed to compensate for **significant, residual biodiversity loss** from development projects.

Biodiversity offsets are based on the premise that impacts from development can be compensated for if sufficient habitat can be protected, enhanced or established elsewhere.

Biodiversity offsets are **economic instruments** and are based on the polluter pays approach, and are measurable.

Environmental Offset, Botanical Studies

Figure 2. **The mitigation hierarchy**



Source: Adapted from Rio Tinto (2012). *Rio Tinto and Biodiversity: Working Towards Net Positive Impact*, Rio Tinto PLC, London, UK, Rio Tinto Limited, Melbourne, Australia. Available at: www.riotinto.com/ourcommitment/features-2932_8529.aspx.

Environmental Offset, Botanical Studies

Project Site = Area of Concern

Botanical Survey

Pre-Construction

Post-Construction

Identify occurrence & prevalence of species of concern

On –site

areas surrounding the site

Develop measurable offset amount

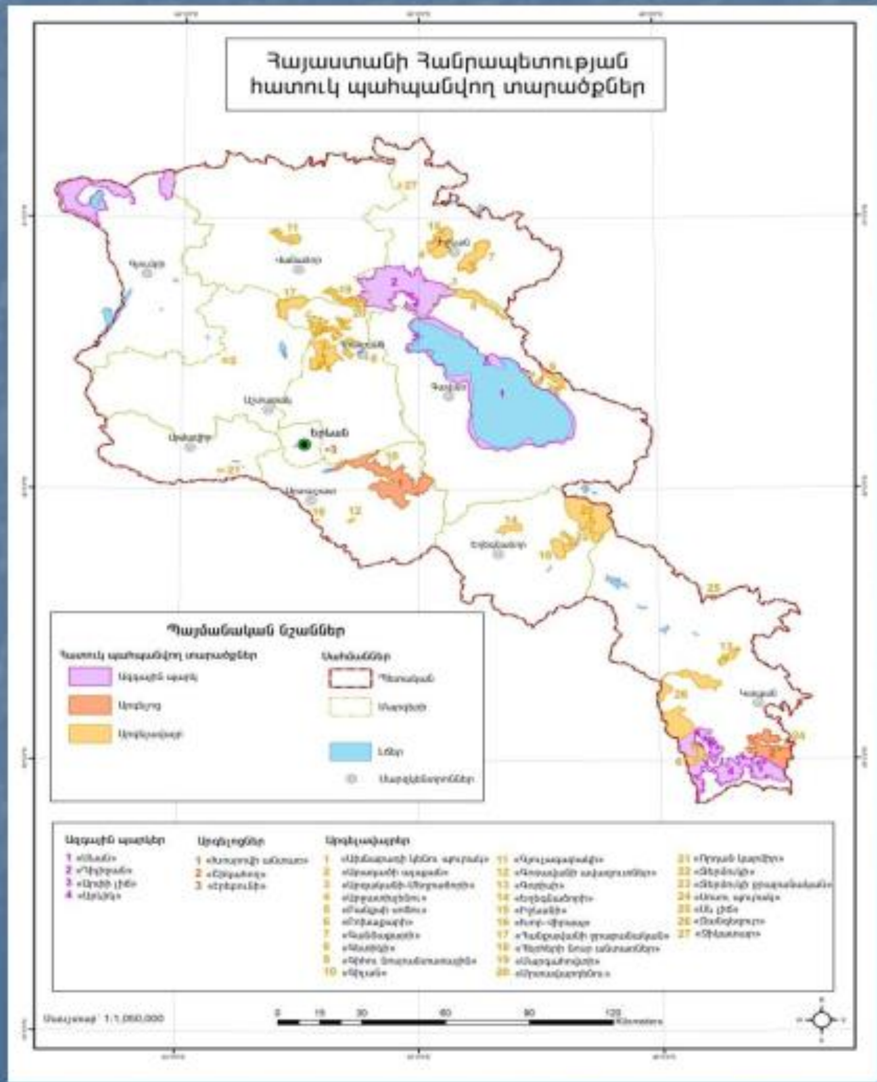
Identify location for offset

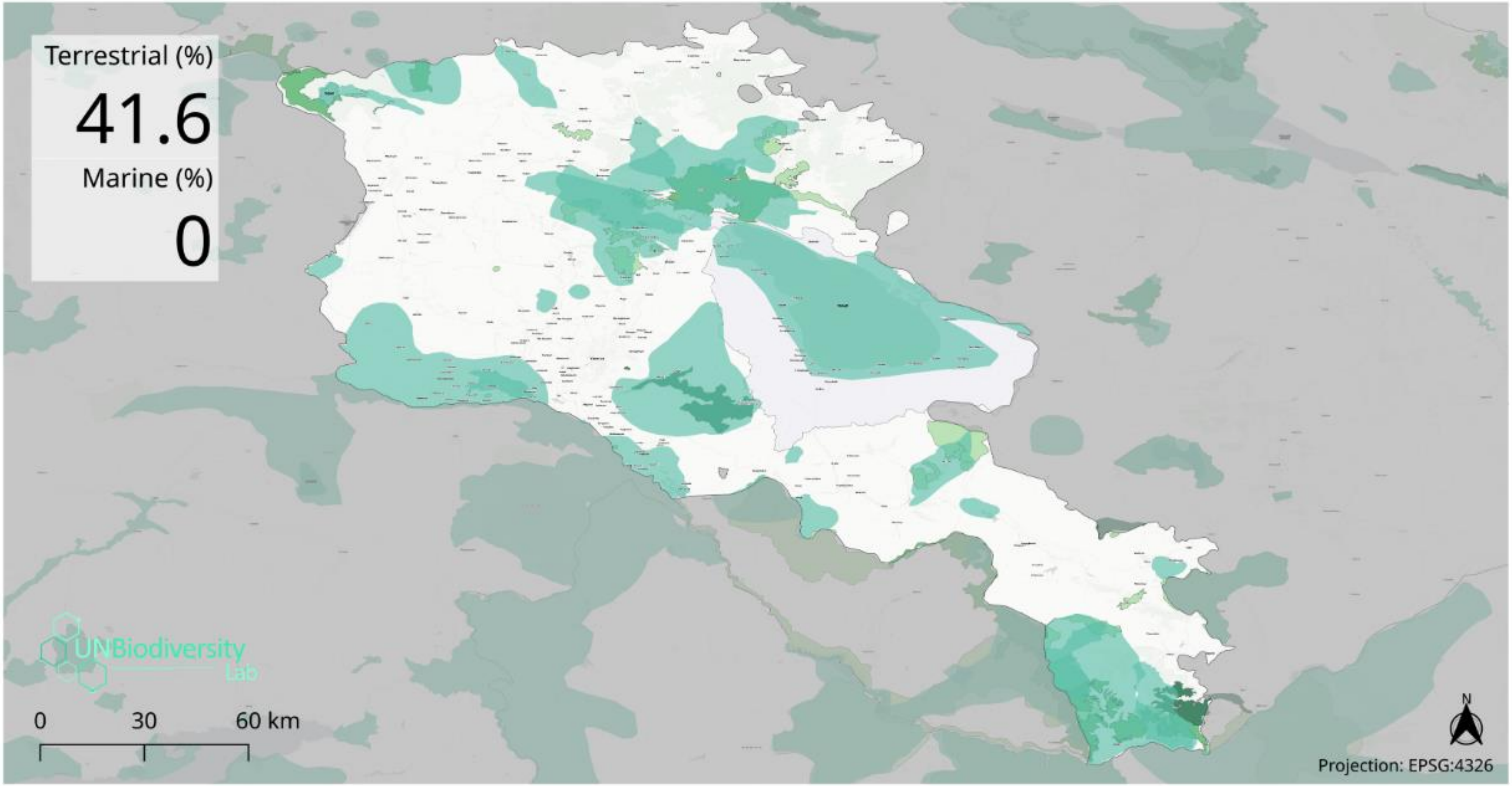
OFFSET NOT FINANCIAL PENALTY BUT MEANS TO ENSURE SUCCESS OF SPECIES.

SPECIALLY PROTECTED NATURE AREAS OF ARMENIA

- **State Reserves**
- **<<Khosrov Forest>>**
- **<<Shikahogh>>**
- **<<Erebuni>>**

- **National parks**
- **<<Dilijan>>**
- **<<Lake Sevan>>**
- **<<Lake Arpi>>**
- **<<Arevik**
- **26 State Reservations**
- **230 Nature Monuments**





Key Biodiversity Areas

WDPA IUCN Category

Land	Marine
Ia	Ia
Ib	Ib
II	II
III	III
IV	IV
Not Applicable	Not Applicable
Not Assigned	Not Assigned
Not Reported	Not Reported

Data: **Key Biodiversity Area Protection**

Country: **Armenia**

Data Sources:
World Database of Key Biodiversity Areas. Developed by the KBA Partnership (BirdLife International, International Union for the Conservation of Nature, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Global Wildlife Conservation, NatureServe, Rainforest Trust, Royal Society for the Conservation of Birds, Wildlife Conservation Society and World Wildlife Fund); UNEP-WCMC, IUCN, and NGS, 2018. Protected Planet: The World Database on Protected Areas (WDPA) [On-line], October 2018. Cambridge, UK: UNEP-WCMC and IUCN; Flanders Marine Institute (2018). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 10; Global Administrative Unit Layers (GAUL). 2015. UN Cartographic Unit

gef | Convention on Biological Diversity | UN environment United Nations Environment Programme | UNDP Empowered lives. Resilient nations.

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