Webinar IV – Towards more sustainable and efficient SPWS

Increasing efficiency of solar water pumping schemes

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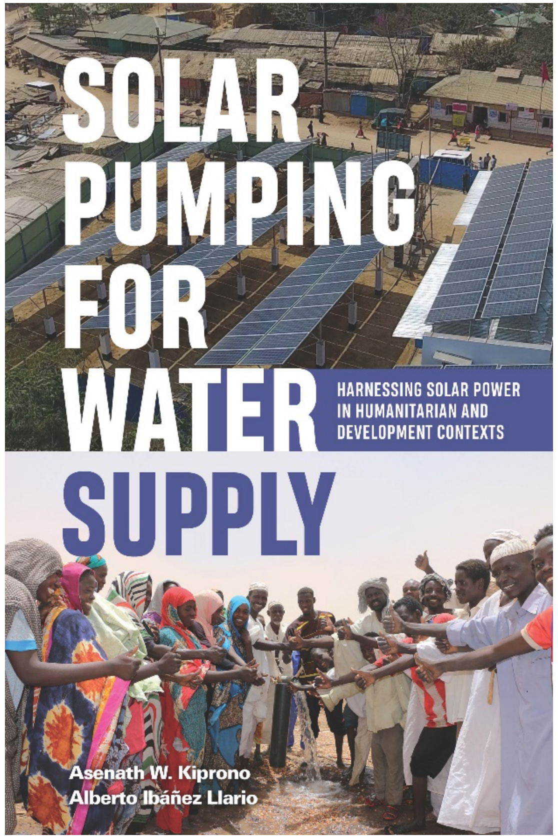
www.cursofotovoltaica.com https://thesolarhub.org/

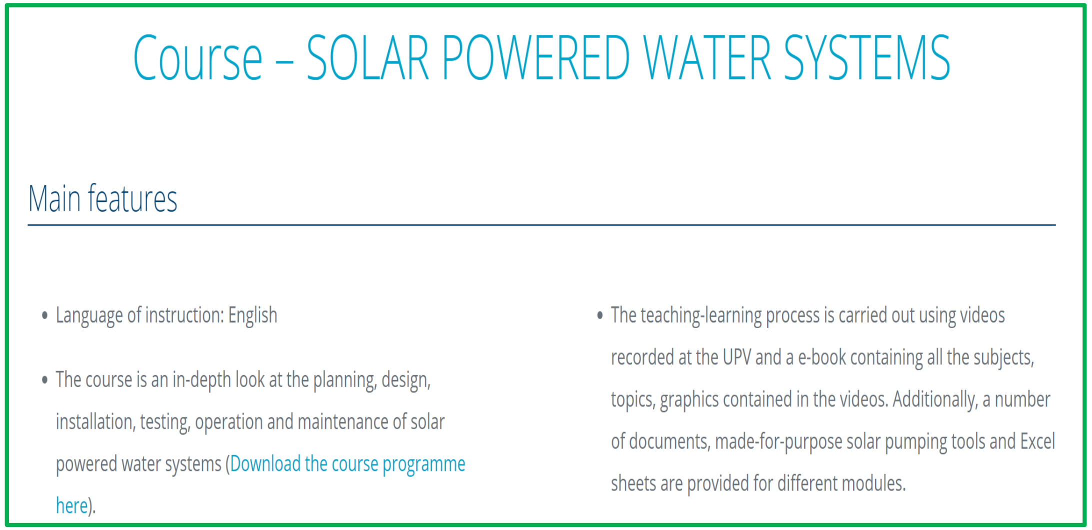
Our experience in PV systems:

- R&D.
- Training:
  - Face-to-face since 2000.
  - On-line since 2010.

Knowledge sharing and collaborations:

- online course on solar pumping: https://www.cursofotovoltaica.com/solar-powered-water-systems/
- online course on PV systems: https://www.cursofotovoltaica.com/introduction-to-photovoltaic/
- free e-version of the book Solar Pumping for Water Supply - Harnessing solar power in humanitarian and development contexts: https://thesolarhub.org/resources/solar-pumping-for-water-supply-harnessing-the-power-of-the-sun/

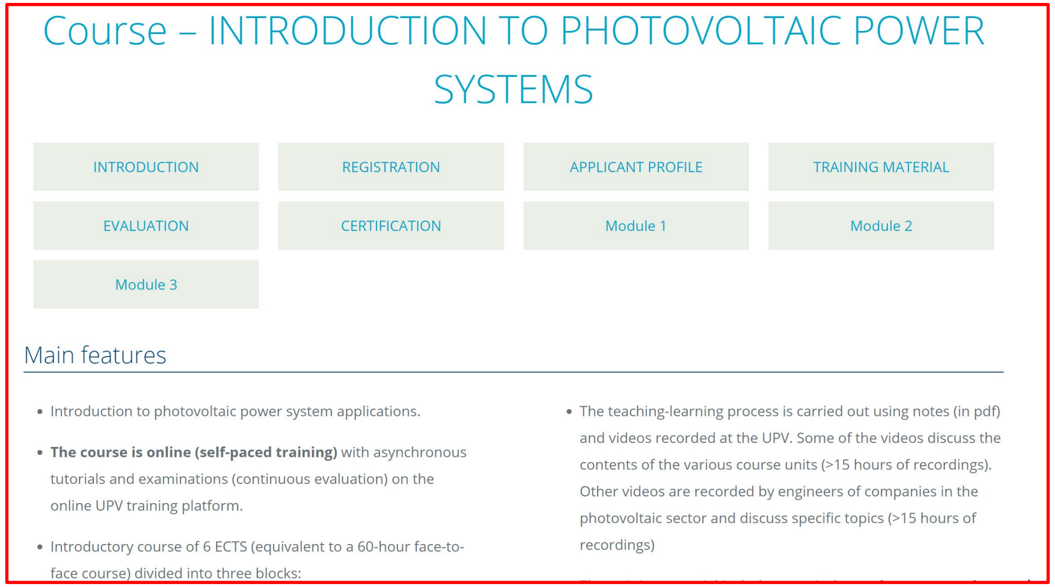




Course – SOLAR POWERED WATER SYSTEMS

Main features

- Language of instruction: English
- The course is an in-depth look at the planning, design, installation, testing, operation and maintenance of solar powered water systems (Download the course programme here).
- The teaching-learning process is carried out using videos recorded at the UPV and a e-book containing all the subjects, topics, graphics contained in the videos. Additionally, a number of documents, made-for-purpose solar pumping tools and Excel sheets are provided for different modules.



Course – INTRODUCTION TO PHOTOVOLTAIC POWER SYSTEMS

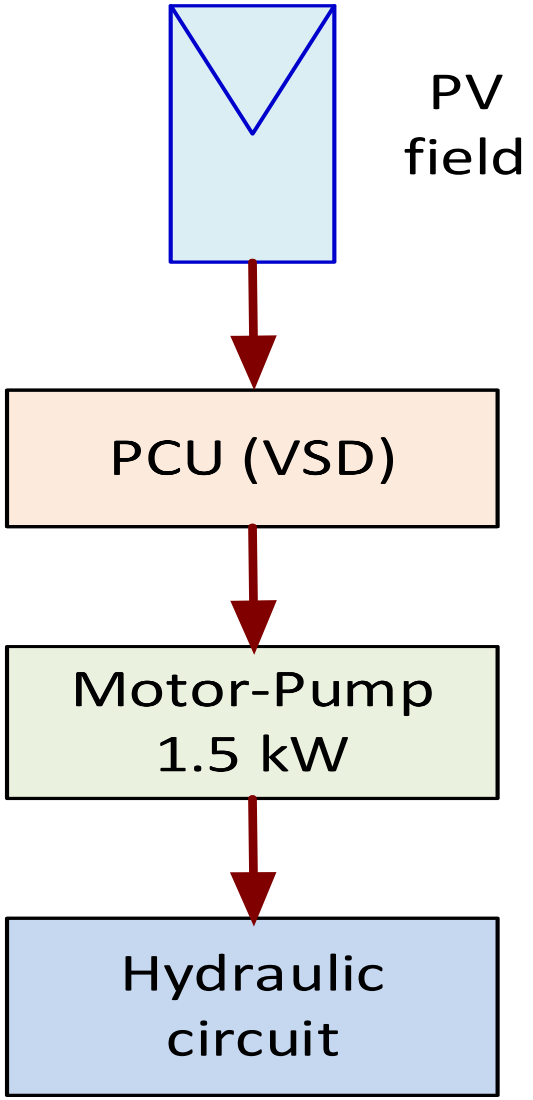
INTRODUCTION	REGISTRATION	APPLICANT PROFILE	TRAINING MATERIAL
EVALUATION	CERTIFICATION	Module 1	Module 2
Module 3			

Main features

- Introduction to photovoltaic power system applications.
- **The course is online (self-paced training)** with asynchronous tutorials and examinations (continuous evaluation) on the online UPV training platform.
- Introductory course of 6 ECTS (equivalent to a 60-hour face-to-face course) divided into three blocks:
- The teaching-learning process is carried out using notes (in pdf) and videos recorded at the UPV. Some of the videos discuss the contents of the various course units (>15 hours of recordings). Other videos are recorded by engineers of companies in the photovoltaic sector and discuss specific topics (>15 hours of recordings)

Index :

- Factors influencing solar energy production.
- Estimation of losses due to different factors.
  - Losses related with the PV module.
  - Losses related with the temperature.
  - Losses related to the balance of system (BOS).
- Energy losses and efficiencies in a solar water pumping schemes (PVWPS): facility in the UPV.



Calculation of the energy generated by a PVWPS system:

$$E_{PV} = P_{PV\_pk} \cdot PSH \cdot PR_{PV} \cdot n_{days} \quad \left(kWh/_{*}\right)$$

$$E_h = P_{PV\_pk} \cdot PSH \cdot PR_{PVWPS} \cdot n_{days} \quad \left(kWh/_{*}\right)$$

If E_h ↑, more water is produced

- P_{PK} is the peak power of the photovoltaic generator.
- PSH: equivalent number of hours per day when solar irradiance (*GI*) averages GI_{STC} (1000 W/m^2). Depend on tilt and orientation of the PV field.
- PR is the Performance Ratio of the PV installation, independent of the irradiation received or the installed power. It represents the power losses in a PV or in a PVWPS system.
- n_{days} is the number of days used to carry out the calculation.

$$PR = PR_{temp} \cdot PR_{tilt} \cdot PR_{ori} \cdot PR_{shadings} \cdot PR_{dirtyness} \cdot PR_{mismatch} \cdot \ldots$$

Losses in PV systems:

Page 50 in "Pumping for Water Supply - Harnessing solar power in humanitarian and development contexts"

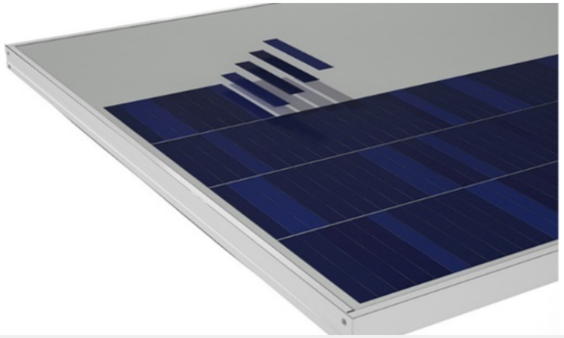
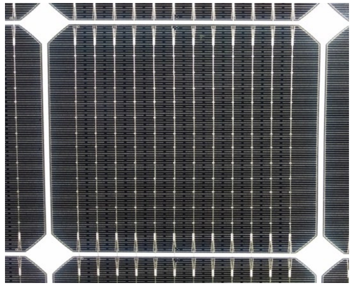
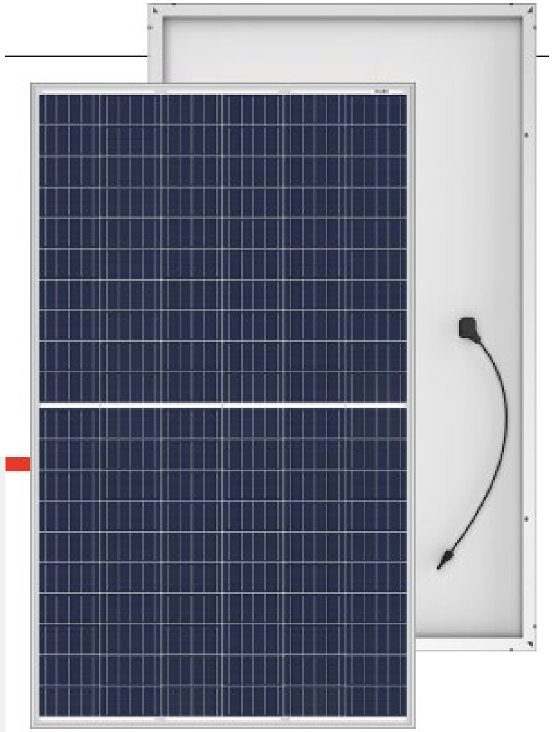
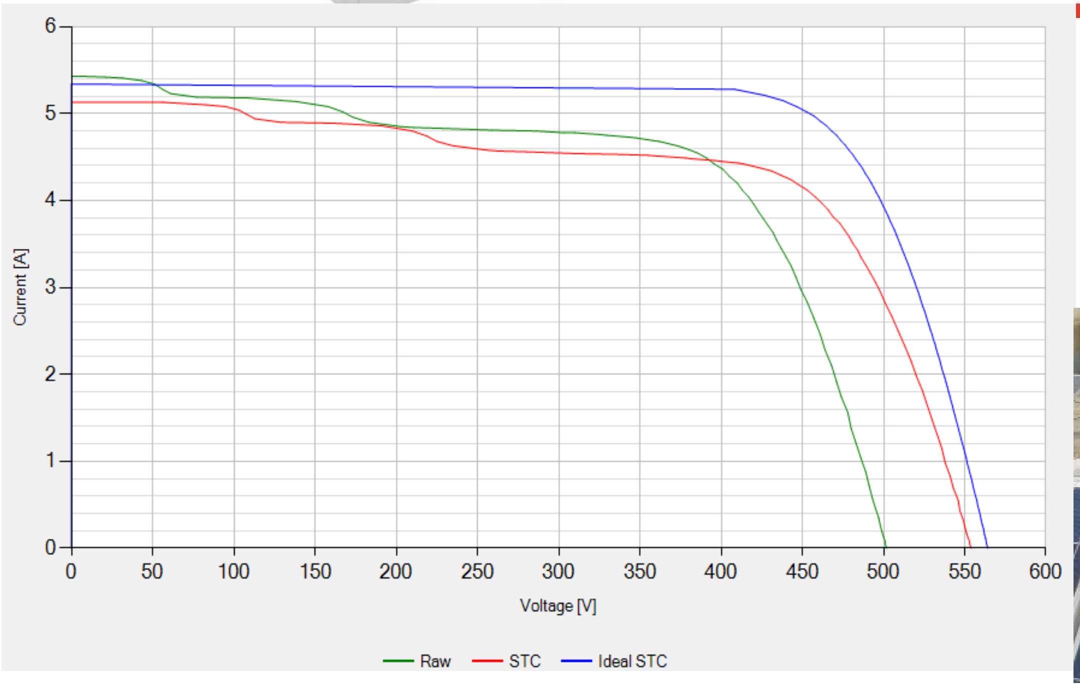
Table 4.1 Table of estimated losses as a percentage of total energy produced

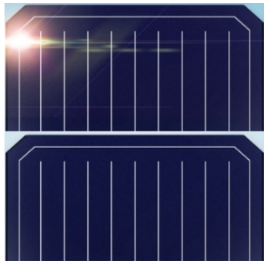
Losses due to	*Estimated losses (as % of total energy produced)*	*Losses due to*	*Estimated losses (as % of total energy produced)*
Module temperature	8–15%	Tolerance	0–5%
Wiring	1–3%	Mismatching[1]	1–2%
Soiling[2] (dust, dirt on modules)	2–15%	Low irradiance	1–4%
Shading[3]	0–2%	Light-induced degradation	3–20%
Reflectance	2–6%	Power converter	1–5%
Module orientation	0–2%	Availability	1–3%

[1] Can be much higher if PV modules of different power ratings are connected
[2] Can be much higher in dusty environments if modules are not cleaned regularly
[3] Can be higher if modules are regularly shadowed

Losses related with the PV module:

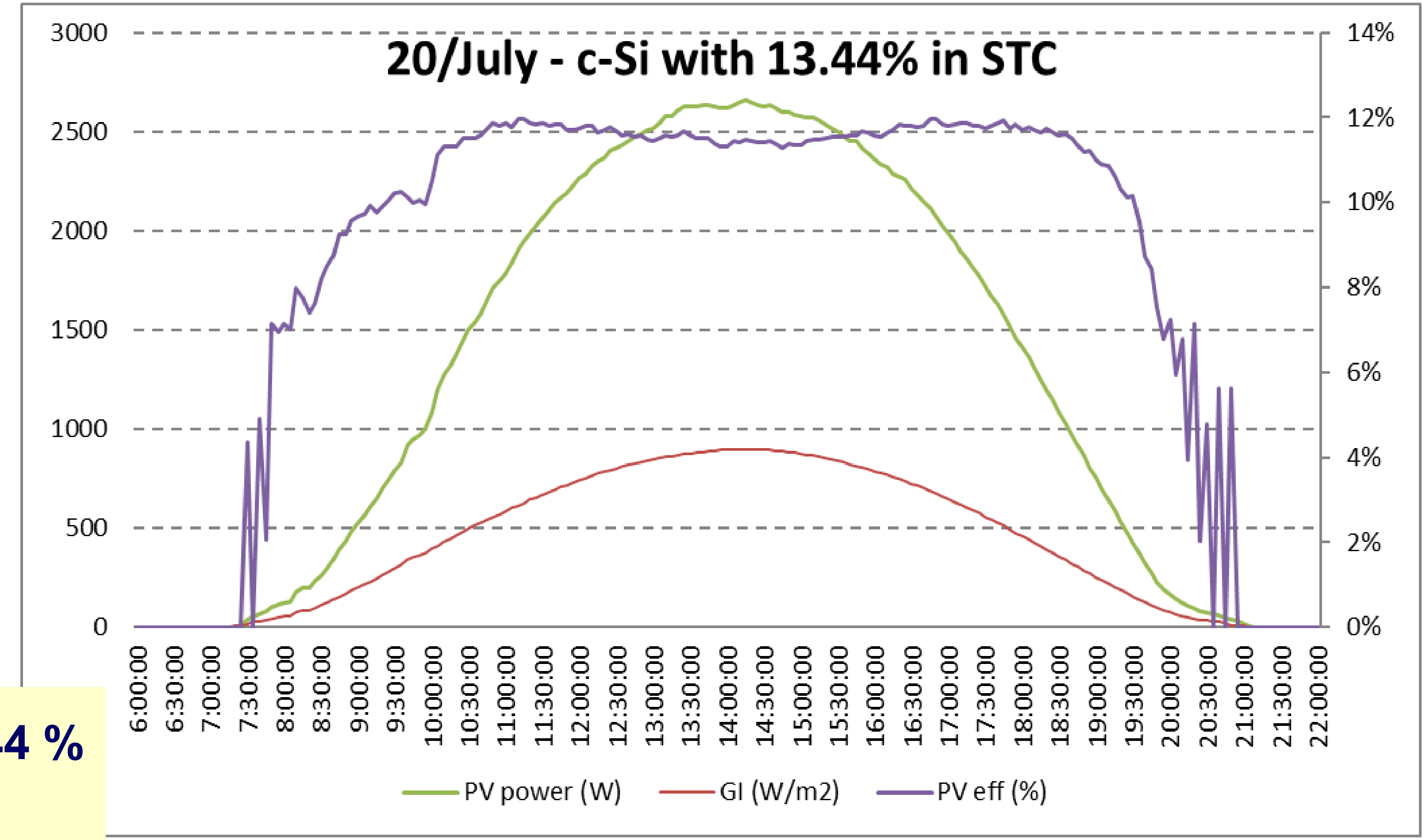
- Cell temperature.
- Power tolerance.
- Low irradiance efficiency.
- Mismatch.
- Module quality.
- Light induced degradation, ageing and other degradation factors.
- Module mounting conditions, etc.




Losses related with the PV module (in a PVWPS system):

- **Cell temperature.**
- **Power tolerance.**
- **Low irradiance efficiency.**
- **Mismatch.**
- **Module quality.**
- **Light induced degradation, ageing and other degradation factors.**
- **Module mounting conditions, etc.**



STC efficiency of the module: 13,44 %

Maximum efficiency: ≈ 12 %

Losses due to temperature (I):

1. **Determine the average temperature of the cell (T_{cell}) from the ambient temperature (T_{amb}) using the average daytime temperature of the period under study:**

$$T_{cell} = T_{amb} + (NOCT - 20) \cdot \frac{E}{800\, W/m^2}$$

2. **Calculate the losses due to temperature (L_{tem}) using the temperature coefficient of the power (g in K^{-1}):**

$$L_{tem} = |g(T_{PVcell} - 25)|$$

3. **Determine the performance by temperature (PR_{tem}) using the temperature coefficient of power (g):**

$$PR_{tem} = (1 - L_{tem}) = (1 - |g(T_{PVcell} - 25)|)$$

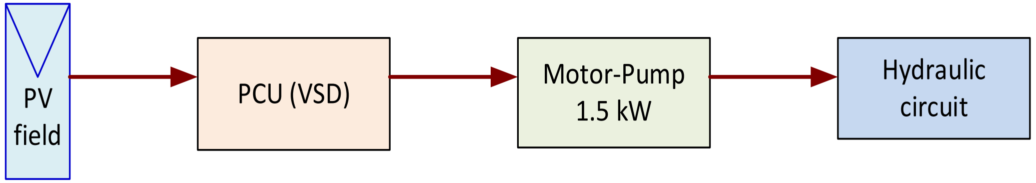
Table 4.2 NOCT, g, and efficiency factors for different PV module technologies

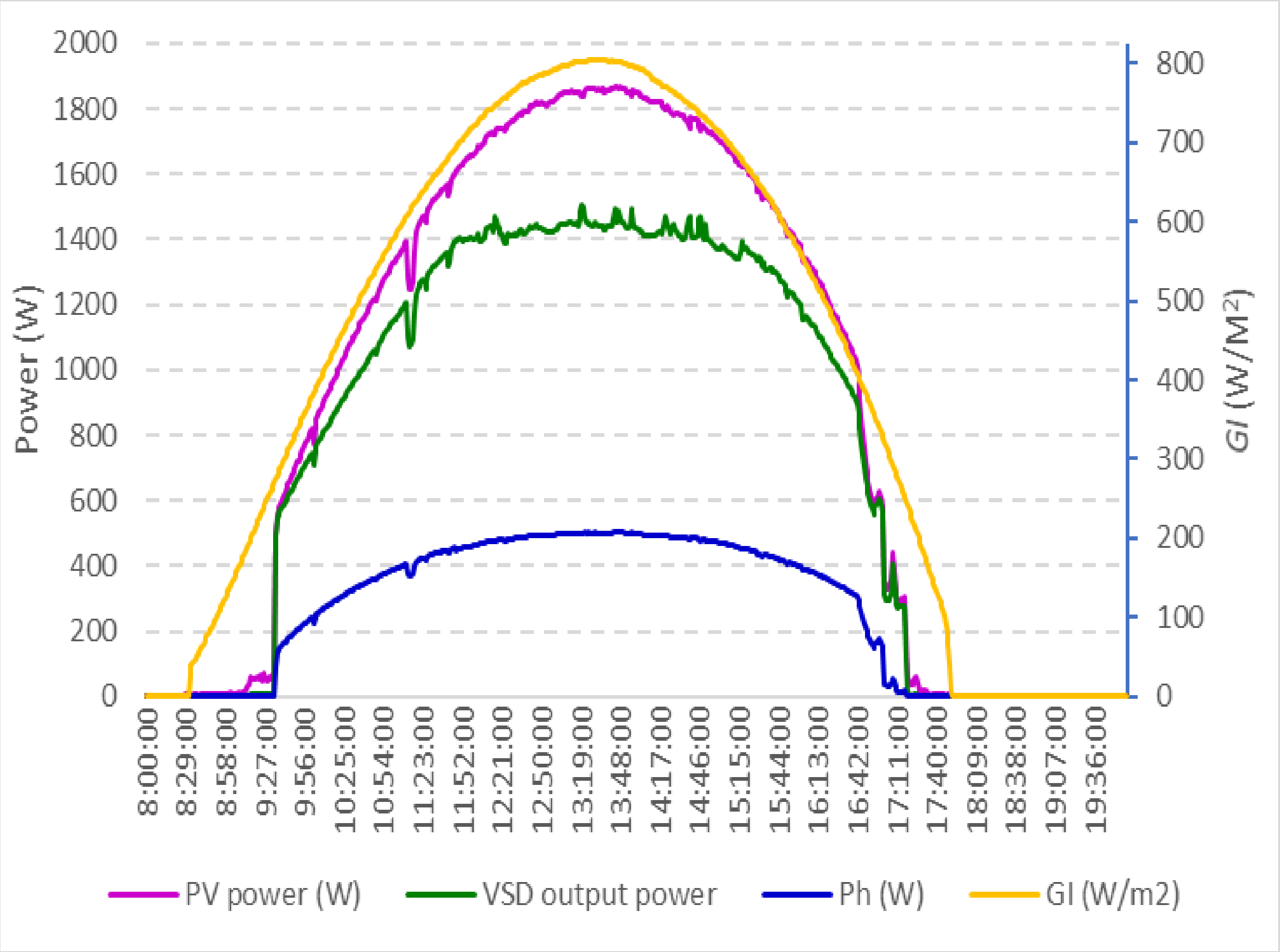
Technology	c-Si (silicon-based modules)		Thin-film technology			CISG	HIT
	s-Si (monocrystalline silicon)	p-Si (polycrystalline silicon)	a-Si/μc-Si (amorphus silicon)	CdTe (cadmium telluride)	CIS (copper indium selenide)		
NOTC (°C)	41 (±3)	41 (±3)	45	45	47	42	44
g (%/K)	−0.37	−0.38	−0.35	−0.32	−0.33	−0.3	−0.26
Module efficiency (%)	20.4	17.6	9.8	10.6	15.1	16	20.3

Page 54 in “Pumping for Water Supply ….”

Losses related to the balance of system (BOS) (I):

- **Voltage drops in the wiring.**
- **Power converter efficiency.**
- **Errors in tracking the maximum power point (MPP).**
- **Protections.**
- **Downtime periods for maintenance.**
- **Breakdowns or malfunctions.**
- **Power curtailment.**





Losses related to the balance of system (BOS) (II):

- Voltage drops in the wiring.
- Power converter efficiency.
- Errors in tracking the maximum power point (MPP).
- Protections;
- Downtime periods for maintenance.
- Breakdowns or malfunctions.
- **Power curtailment (clipping)**

if $P_{PV} >> P_{motor\text{-}pump}$

(excessive oversizing factor)

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DEPARTAMENTO DE INGENIERÍA ELECTRÓNICA

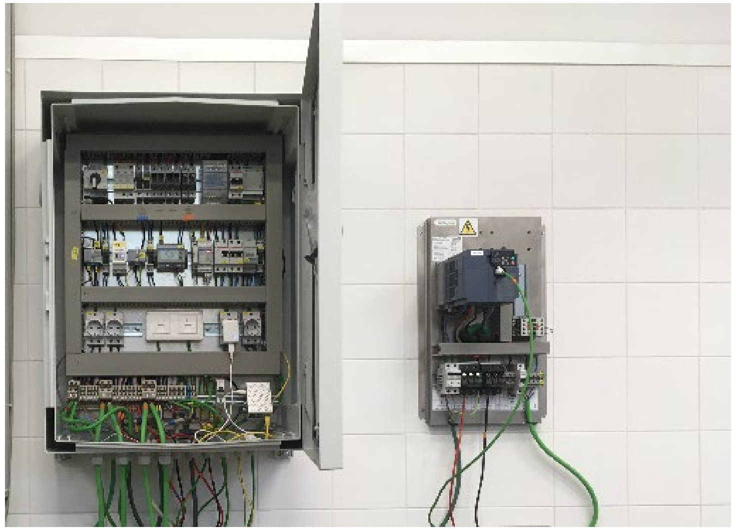
Wiring losses:

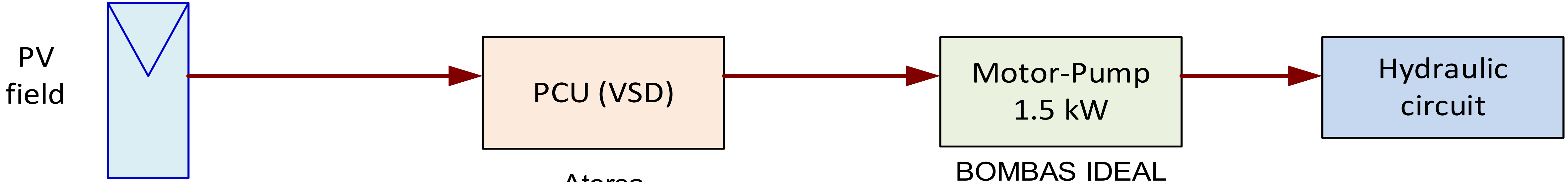
$$\Delta P_{wire} = \Delta V_{wire} \cdot I_{MPP} = R_{wire} \cdot I_{MPP}^2 = \rho \cdot \frac{l_{wire}}{S_{wire}} \cdot I_{MPP}^2 = \frac{1}{\gamma} \cdot \frac{l_{wire}}{S_{wire}} \cdot I^2$$

Temperature	20 °C	40 °C	50 °C	60 °C	70 °C	80 °C	90 °C
Resistivity (ρ) (Ω·mm²/m)	0,01786	0,01926	0,01996	0,02066	0,02136	0,02206	0,02276
Conductivity (γ) (m/Ω·mm²)	55,9910	51,9205	50,0994	48,4017	46,8153	45,3295	43,9352

Design wires to obtain: 1 %< L_{wires} < 3 % (and ΔV in the same range)

PVWPS in the UPV:



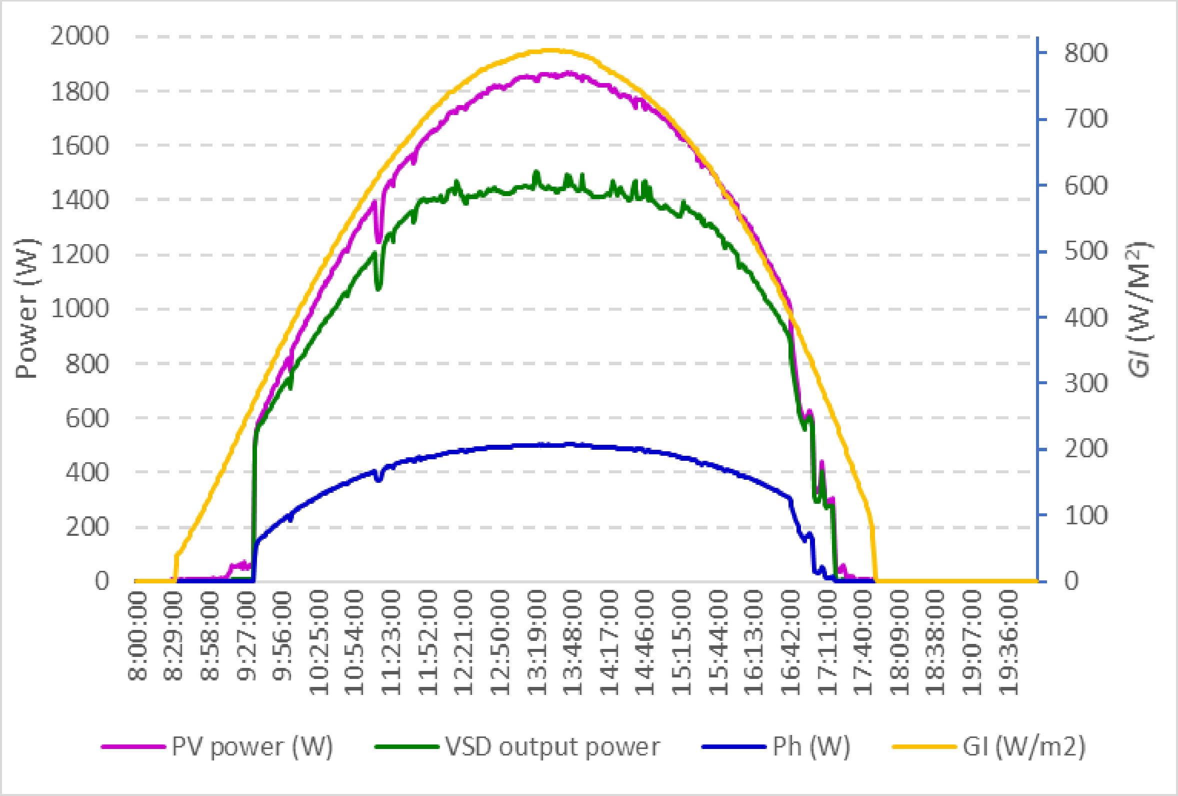


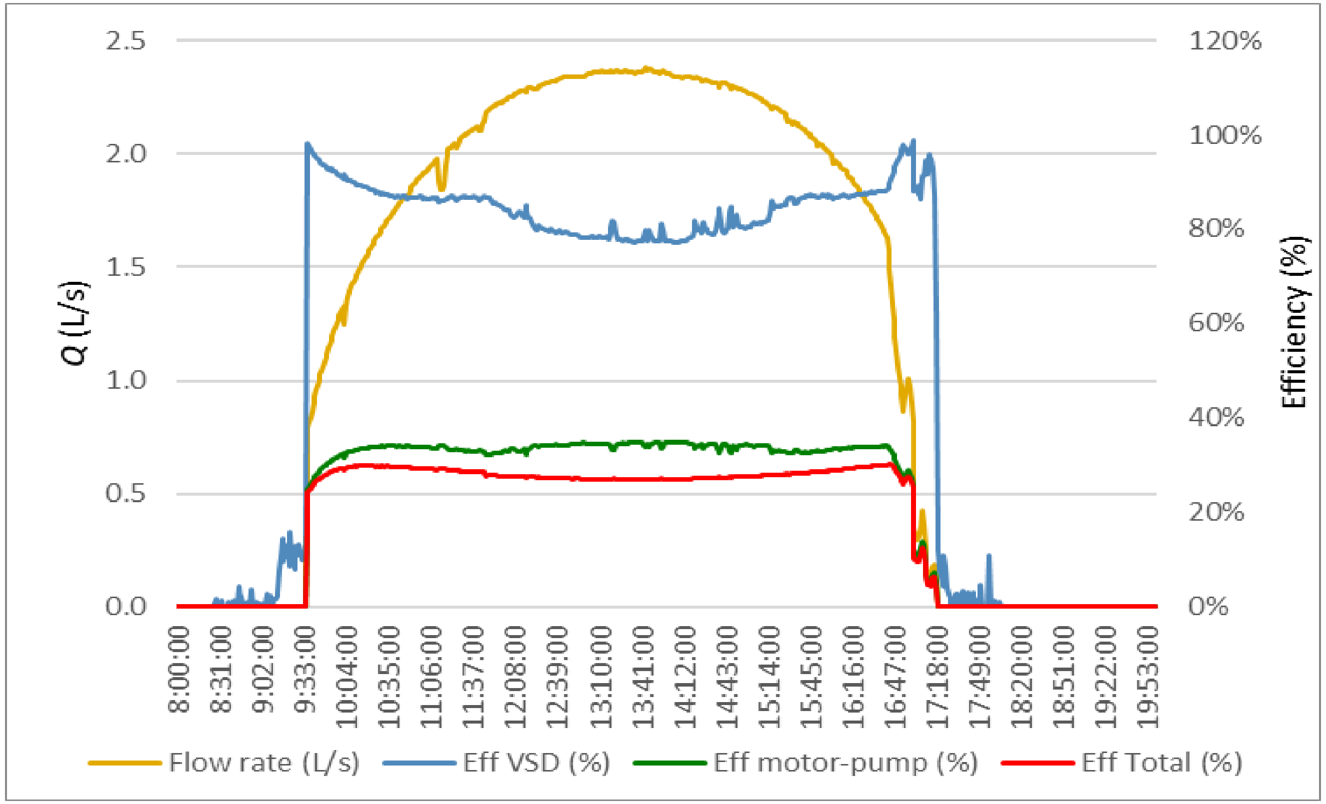
8 PV modules
in series
2.4 kW_{pk}

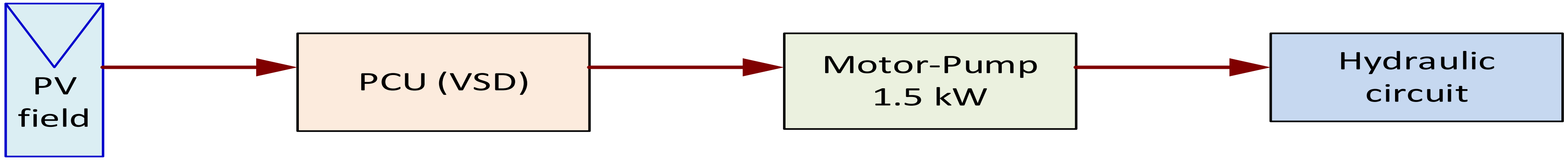
Atersa
EASY SUN PUMP
ESP-2,2/230-IP20-F200
Power converter unit
(variable speed drive)

BOMBAS IDEAL
4" SMI-8 1.5 kW
submersible pump

Efficiencies in the PVWPS facility (I):







Efficiencies in the PVWPS facility (II):

5.01 PSH

V_d= 53.96 m³/d

E_{PV}=10.99 kWh/d

E_{VSD_out}=9.14 kWh/d

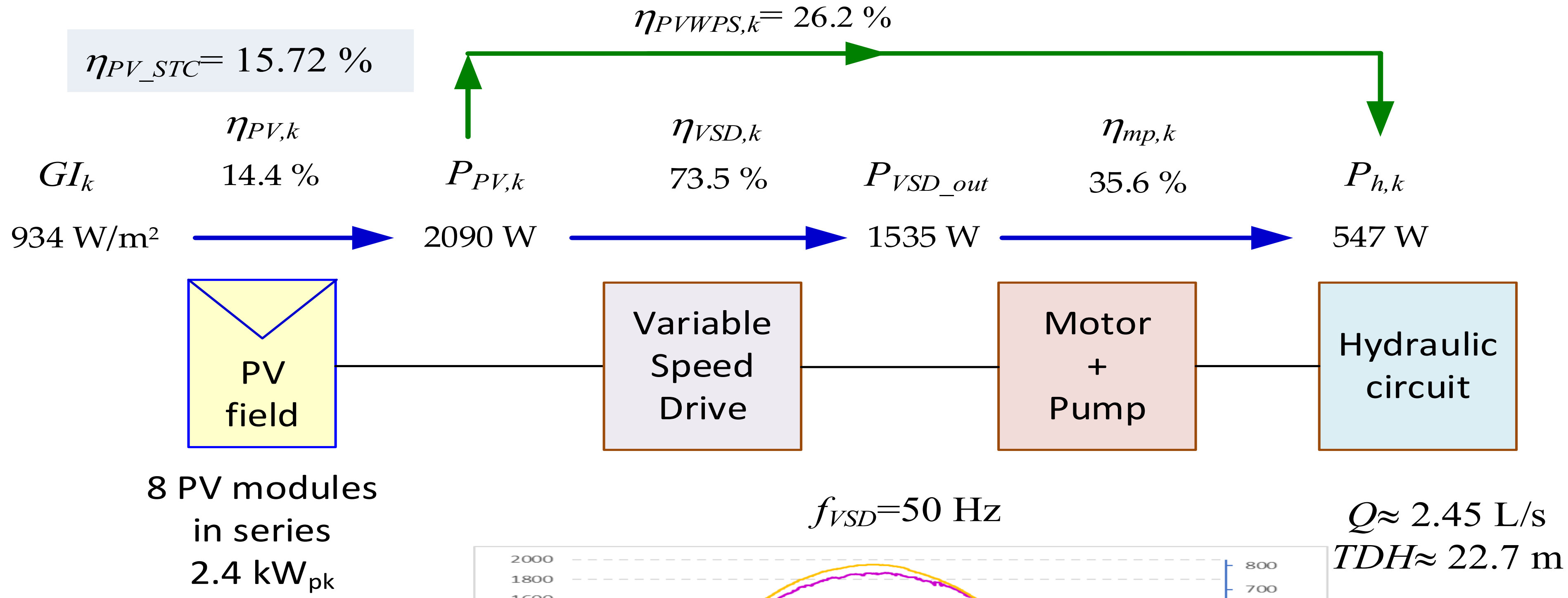
E_h= 3.05 kWh/d

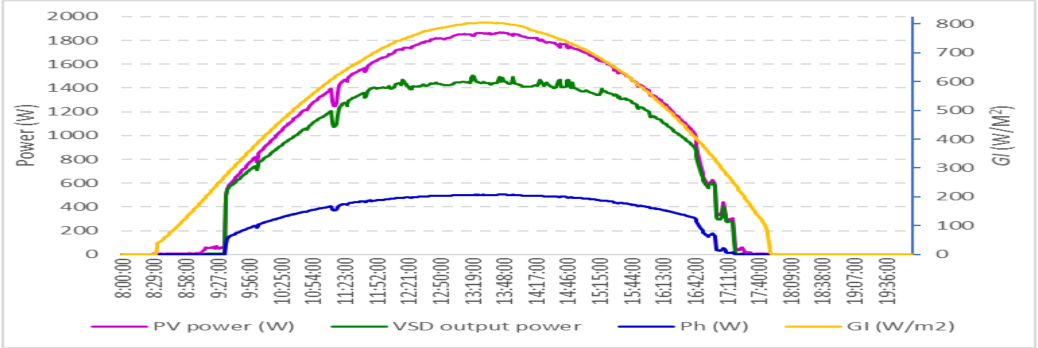
PR_{PV}= 90 %

PR_{VSD}=83.1 %

PR_{m-p}=33.4 %

PR_{PVWPS}≈25 %

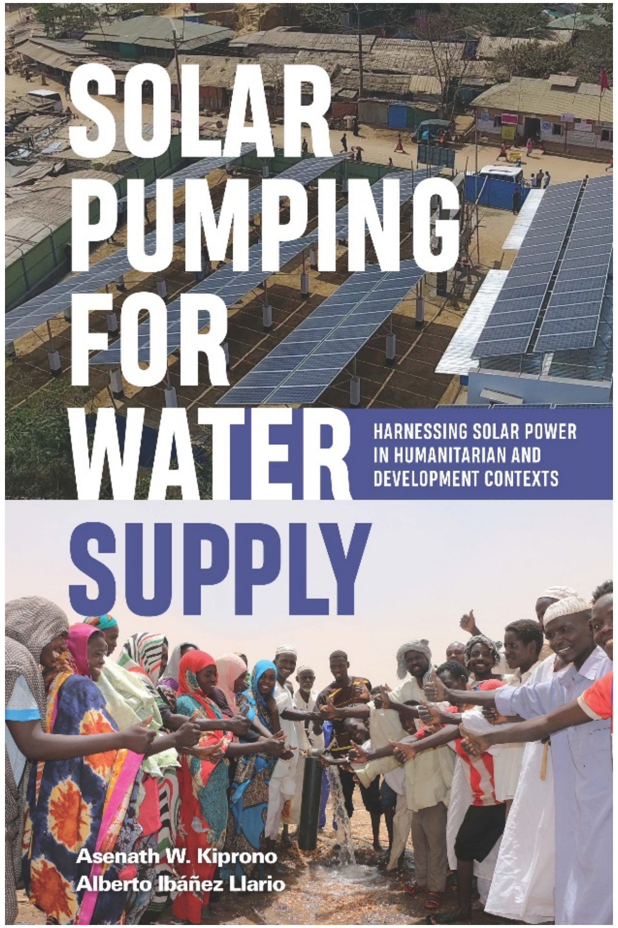




$$E_h = P_{PV\_pk} \cdot PSH \cdot PR_{PVWPS}$$

Conclusions:

- **More information in the book *Solar Pumping for Water Supply - Harnessing solar power in humanitarian and development contexts*: https://thesolarhub.org/resources/solar-pumping-for-water-supply-harnessing-the-power-of-the-sun/**
- **Loss factors that cannot be avoided: temperature, ageing, converter efficiency, etc.**
- **Loss factors that can be minimized: wiring, shadows, dirtiness, etc.**
- **Loss factors that sometimes are forgotten: ageing, tolerances, etc.**
- **Cost of improving PR vs initial budget: cross section of wires, selection of PV modules, etc.**
- **Cost of improving PR vs cost of the O&M: cleaning works.**



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The End

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