Fisuel Seminar – 15-16 of October 2025

Dakar – Senegal

Photovoltaic in Agriculture – Agri-PV

Jamal Haydar – OEA Lebanon

Outlines

- Introduction and Context
- Water consumption and Energy needs
- Solar Energy Availability
- Factors Affecting the Harvesting of Solar Energy
  - Tilt And Azimuth
  - STC and NOCT
- The Three Types of Solar System
- Some Useful Design Tools

Introduction and Context

Situation Challenges
Défis de situation

- Lebanon deep economic crisis affecting Agriculture and Essential Services
- Increasing fuel cost and power outages lead to :
  - Increased production cost
  - Reduce productivity for farmers and agrifood

Barriers *(Obstacles)*

- Limited technical and financial awareness on PV (at the start of the crisis)
- Lack of accurate tool to increase awareness and identify solutions
- Difficulty to reach reliable service providers
- Poor market linkage
- Lack of finance

The Thirsty Truth: Agriculture's Footprint

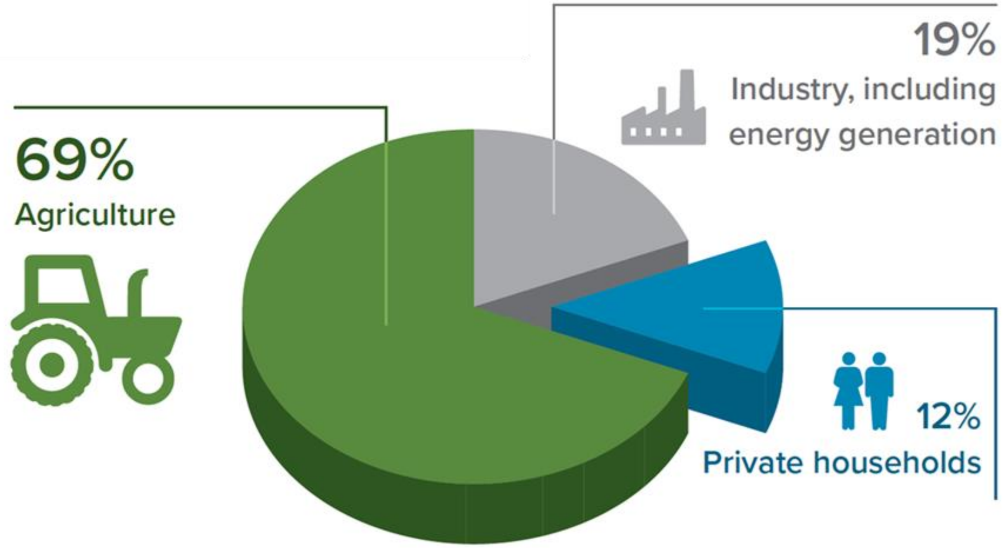
La vérité qui nous fait soif : L'empreinte de l'agriculture

Around 70% of the world's freshwater is used for agriculture!!!

Environ 70 % de l'eau douce mondiale est utilisée pour l'agriculture !

Water Consumption Worldwide

- Agriculture: ~70%
- Industry: ~20%
- Municipal: ~10%



Source: FAO, World Bank

The Water–Energy–Food Nexus

Le lien entre eau, énergie et alimentation

- Water use requires energy (pumping, treatment)

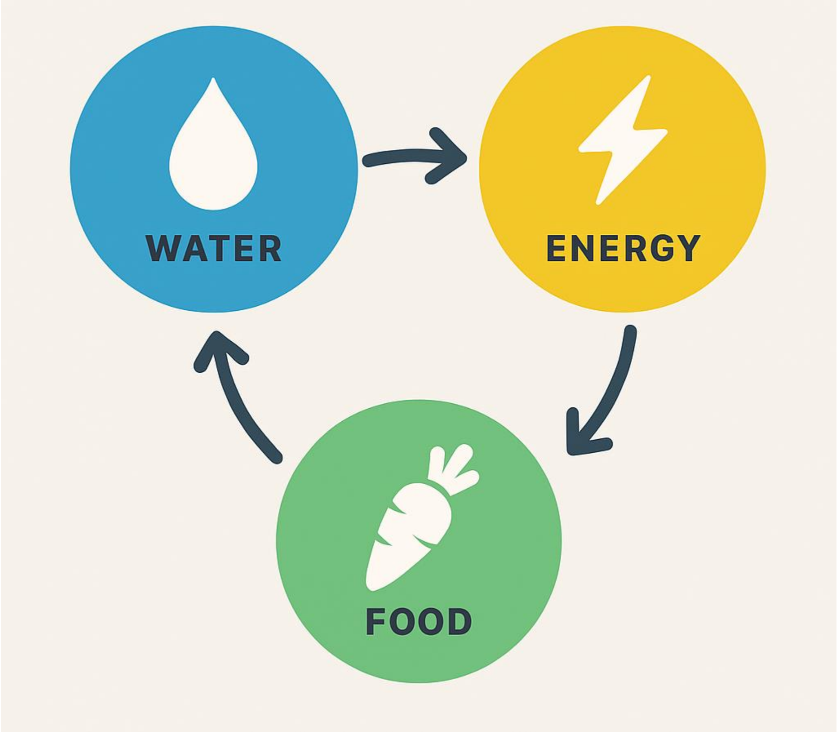
  L'utilisation de l'eau nécessite de l'énergie (pompage, traitement)

- Food production depends on both water & energy

  La production alimentaire dépend à la fois de l'eau et de l'énergie

- Stress in one area cascades to the others

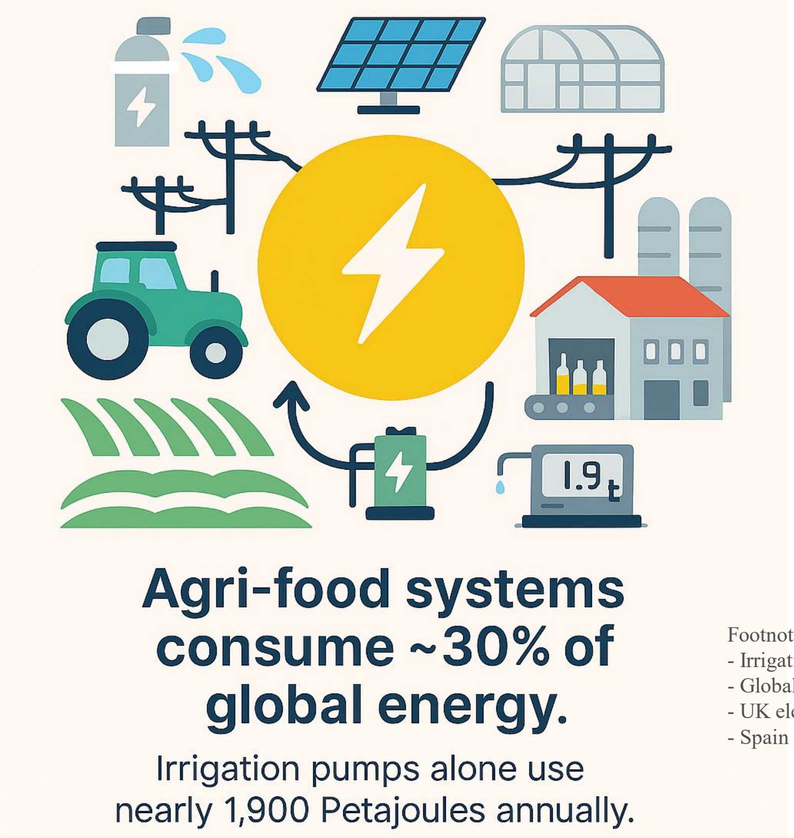
  Le stress dans un domaine se répercute sur les autres

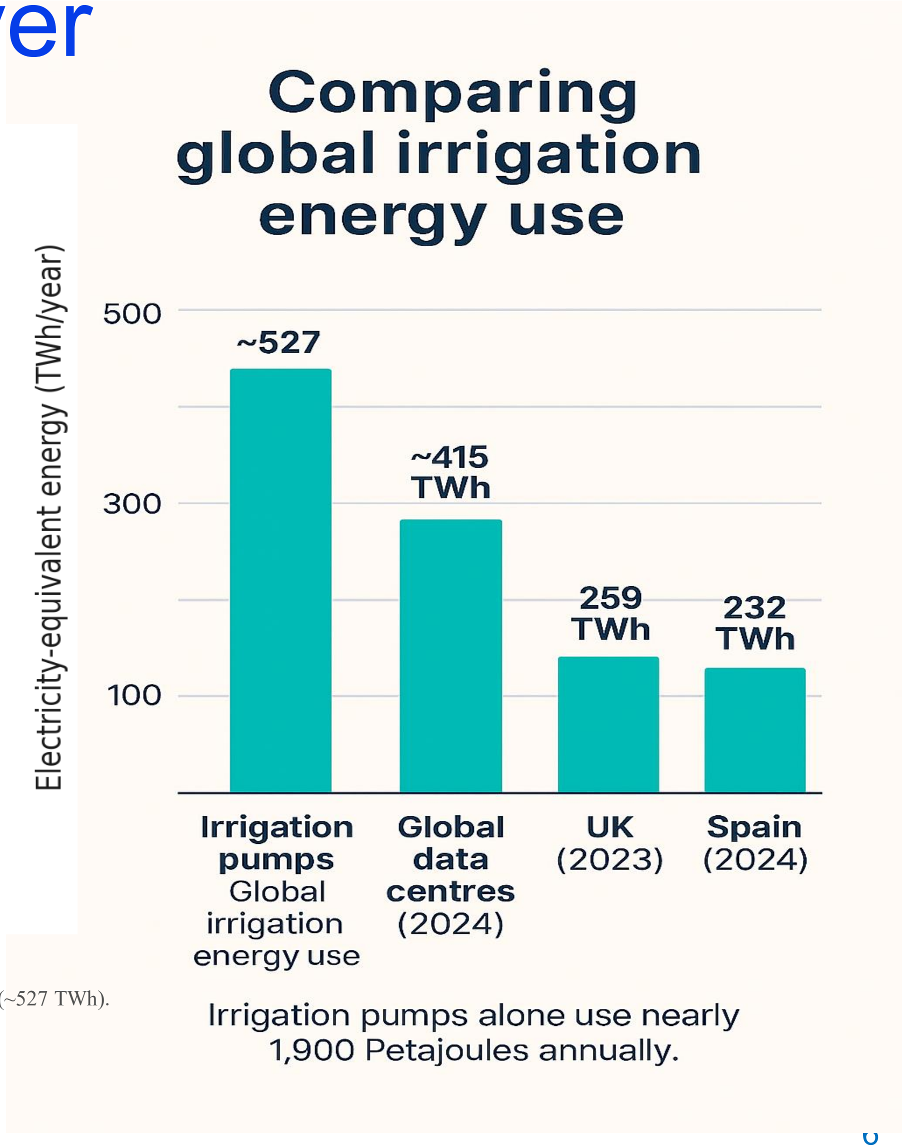


Energy: The Hidden Driver

Most powered by fossil fuels → high emissions

Principalement alimenté par les combustibles fossiles → émissions élevées





Footnotes:
- Irrigation pumps: Nature Communications (2024), global irrigation energy use ≈ 1,896 PJ/year (~527 TWh).
- Global data centres: IEA (2024), estimated ~415 TWh electricity demand.
- UK electricity consumption: 259 TWh in 2023 (UK Gov statistics).
- Spain electricity consumption: 232 TWh in 2024 (Enerdata).

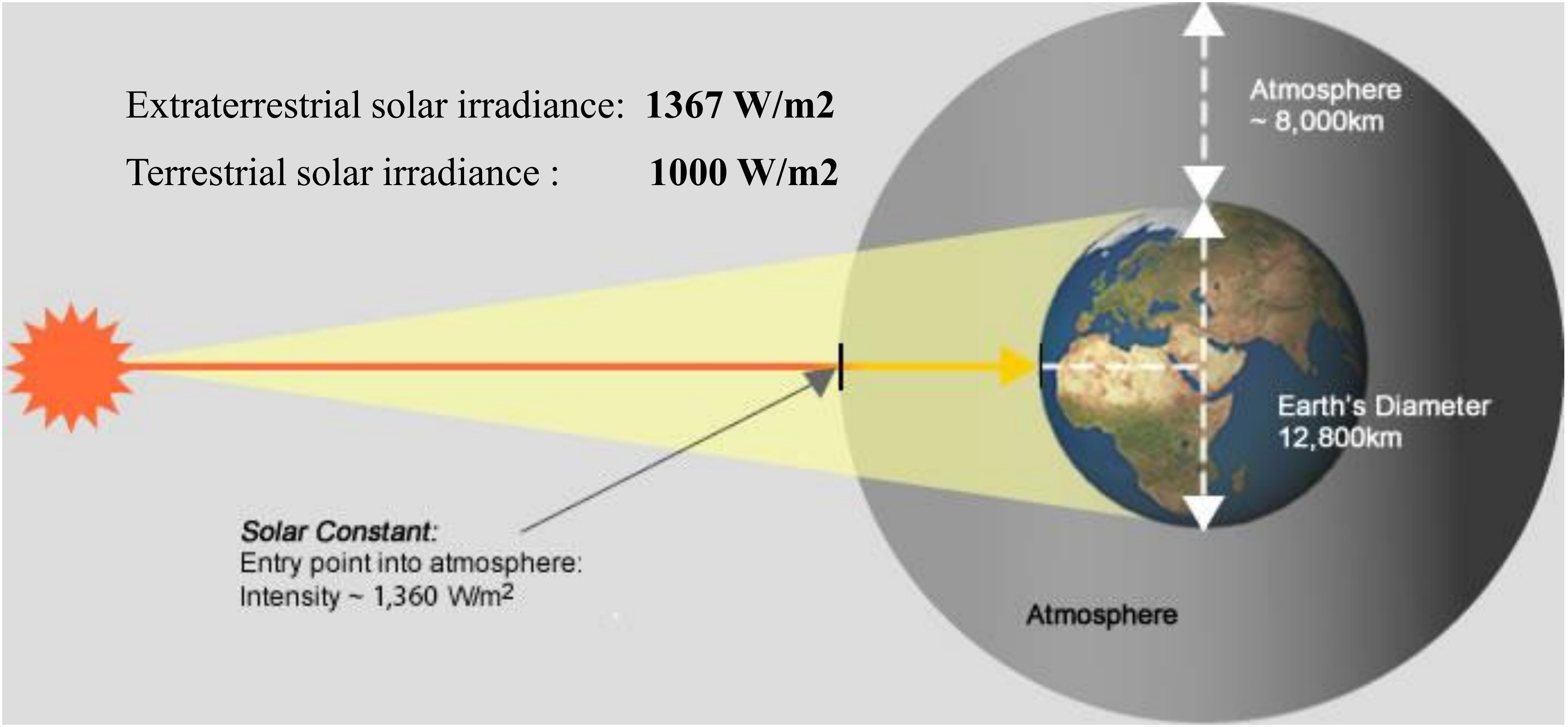
What if all this energy came from the Sun?

Et si toute cette énergie provenait du soleil ?

☀ Solar Energy: A clean, sustainable path to power irrigation and agriculture

Énergie solaire : Une voie propre et durable pour l'irrigation et l'agriculture

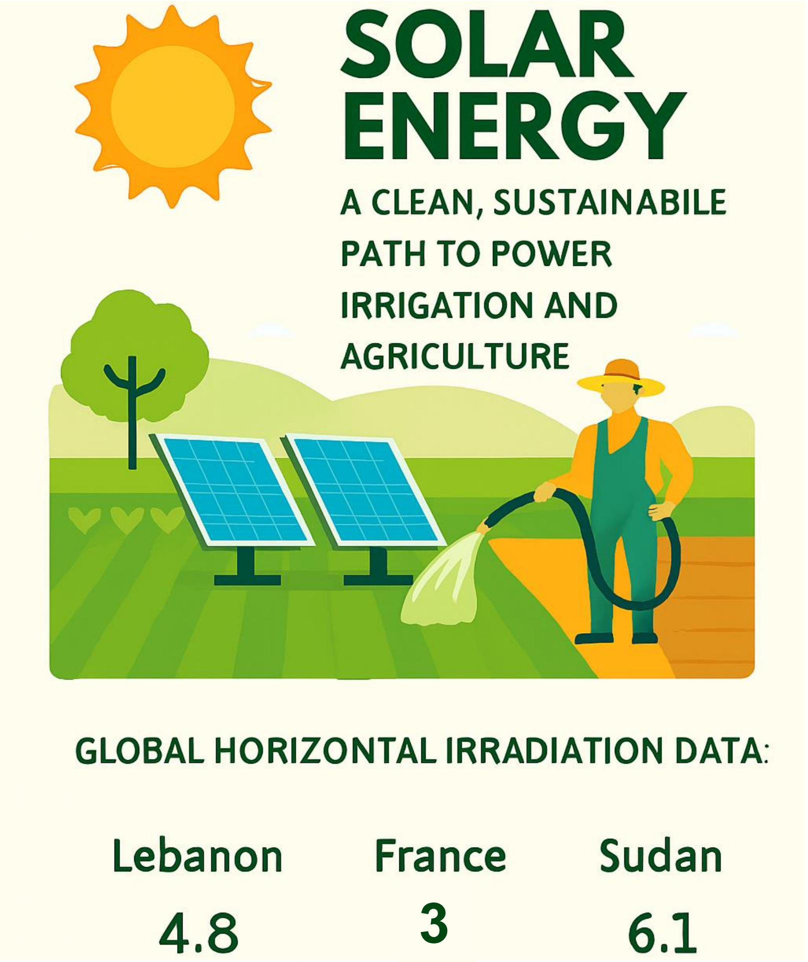
Solar Energy Availability



Moving from Solar Power to Solar Energy

Energy (KWh) = Power (W) x Time (h)

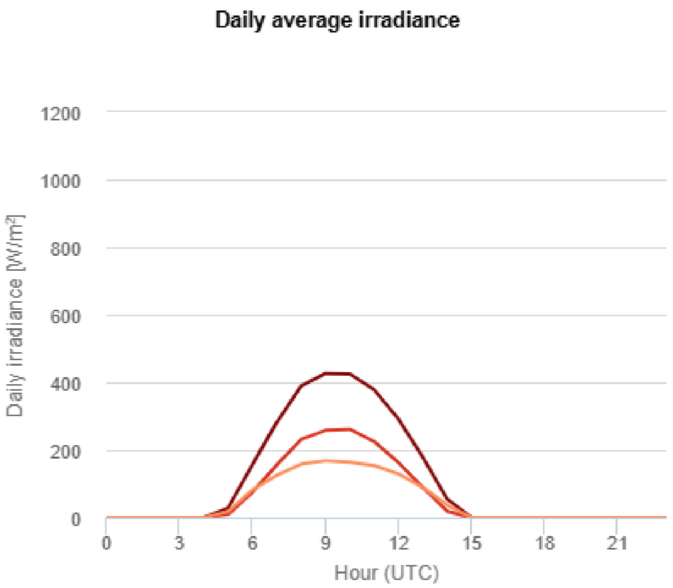
Energy in KWh/m2 is the main parameter that will be used to evaluate solar energy availability



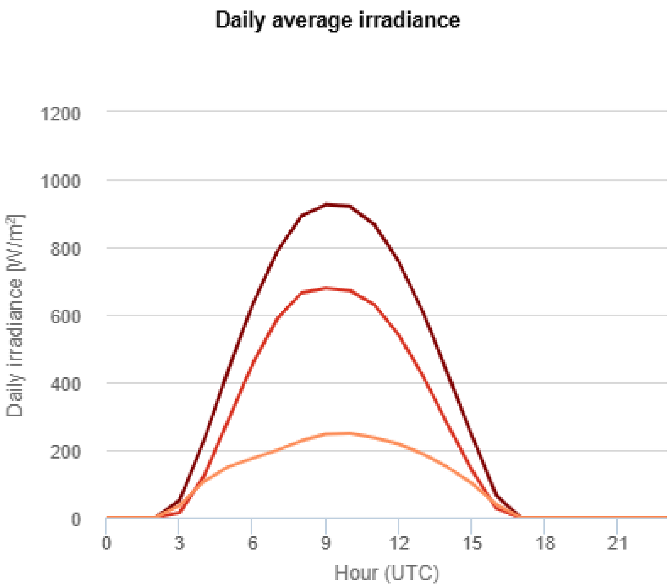
KWh/m2 . day

Solar Availability in different periods – Daily Curves in Beirut on Horizontal Plane

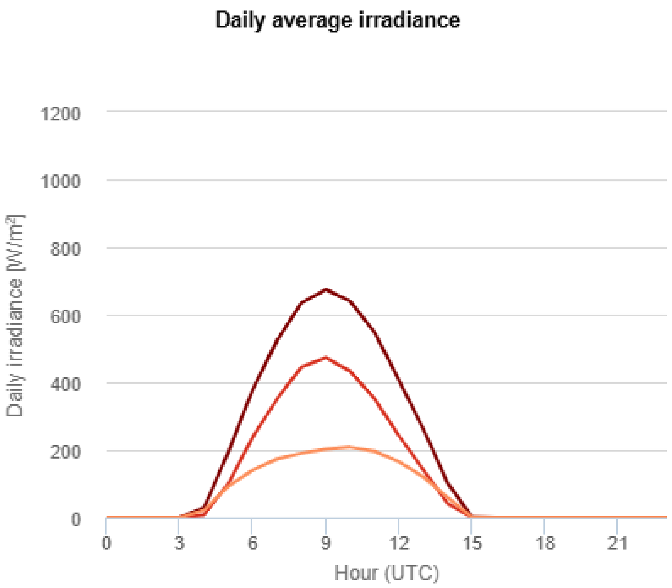
Global
Direct
Diffuse



January



June



October

Source: JRC PGIS

Solar Availability – Peak Sunshine Hours

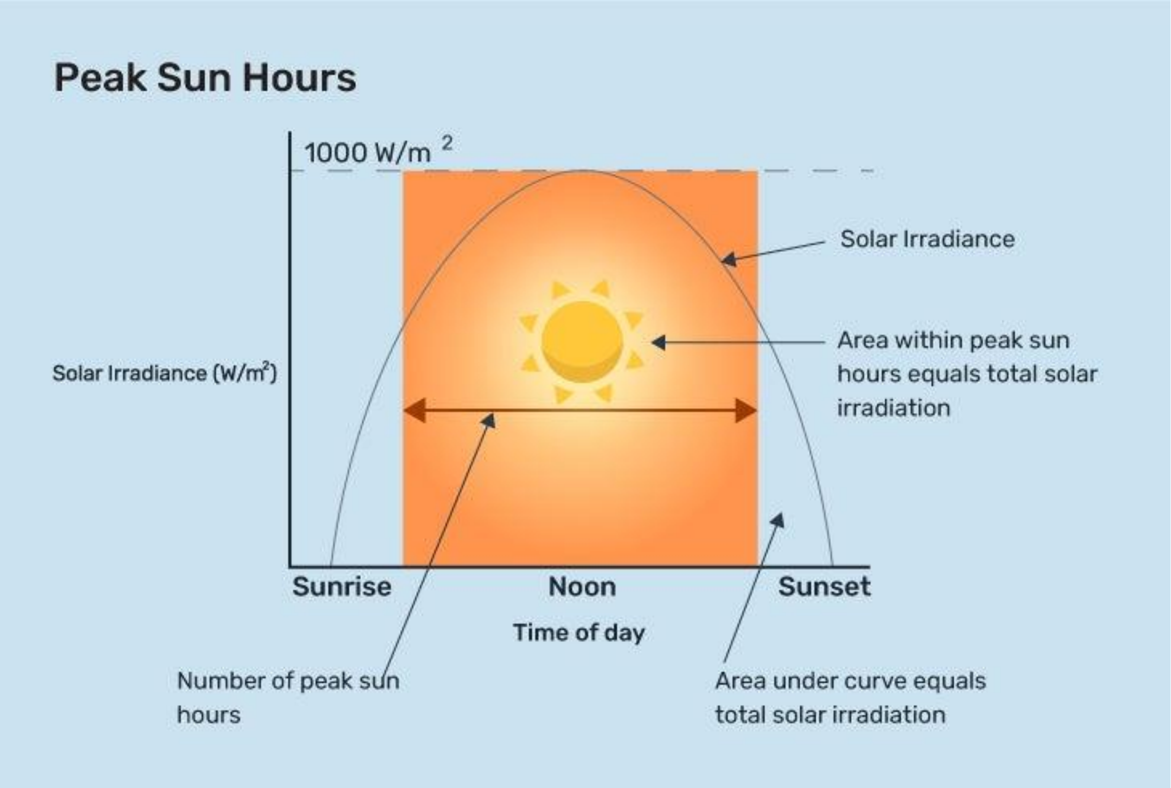
Peak sun hours are not the hours between sunrise and sunset.

Les heures de pointe d'ensoleillement ne se situent pas entre le lever et le coucher du soleil.

A peak sun hour (PSH) is defined as **an hour in the day when the intensity of the sunlight reaches an average of 1000 watts/meter²**.

It's the number of equivalent full sunlight hours per day under standard solar intensity.

$$PSH = \frac{\text{Daily Total Solar Energy (kWh/m}^2\text{)}}{1\ \text{kW/m}^2}$$



Solar Availability – GHI and PSH in Lebanon

Month	GHI	PSH
January	2.39 kWh/m²	2.39
February	3.20 kWh/m²	3.20
March	4.90 kWh/m²	4.90
April	6.01 kWh/m²	6.01
May	6.84 kWh/m²	6.84
June	7.19 kWh/m²	7.19
July	7.01 kWh/m²	7.01
August	6.34 kWh/m²	6.34
September	5.37 kWh/m²	5.37
October	3.87 kWh/m²	3.87
November	2.76 kWh/m²	2.76
December	2.27 kWh/m²	2.27

Example:

What is the average expected KWh can a 600Wp Panel Produce at tilt zero in a day in February? (excluding losses)

Answer:

600 Wp x 3.2Hr (PSH) = 1920 Wh = 1.92KWh

Factors Affecting the Harvesting of Solar Energy

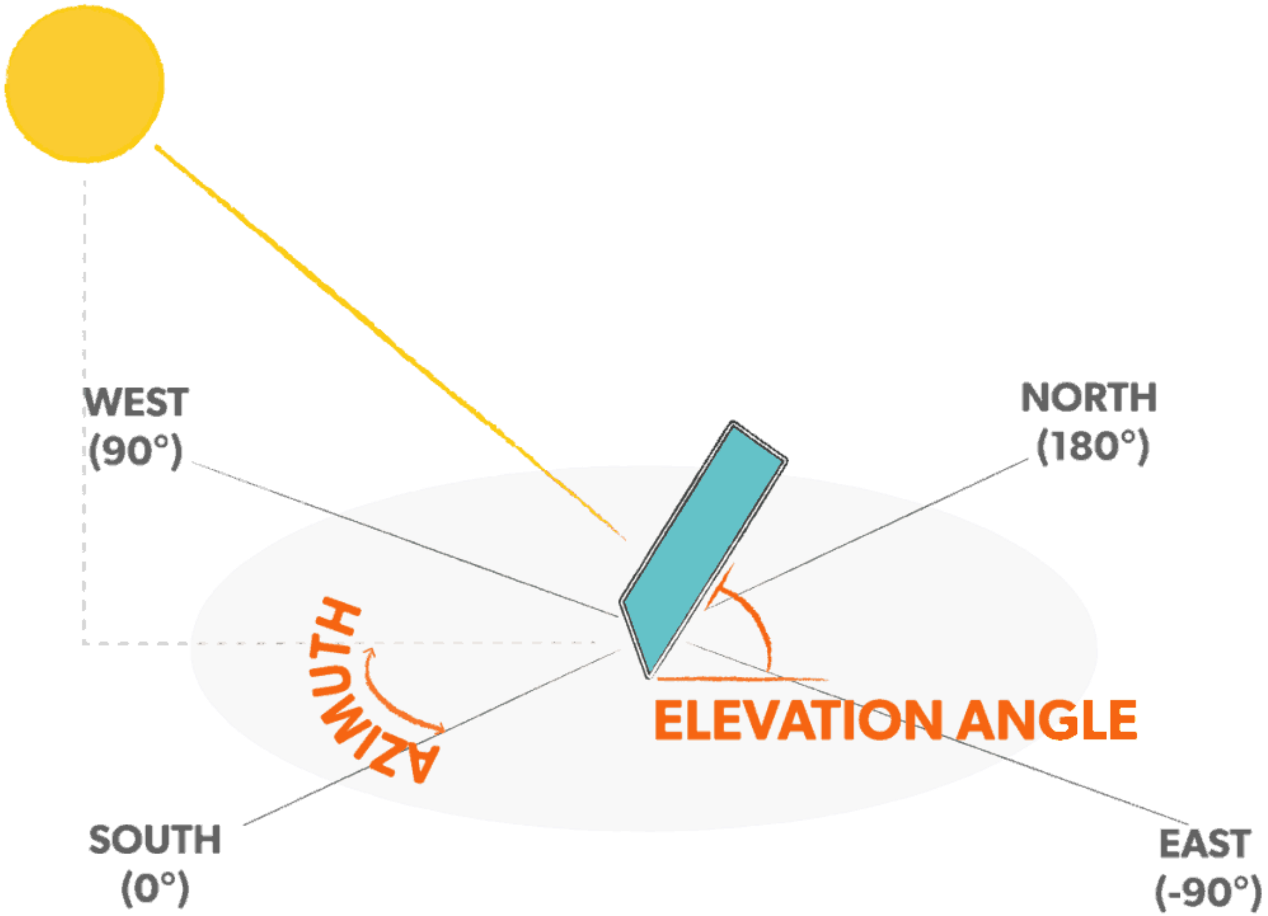
Facteurs affectant la récolte de l'énergie solaire

The Effect of Tilt and Azimuth

L'effet de l'Inclinaison et de l'Azimut

Azimuth and Tilt

- The orientation of PV panels is defined by two angles with respect to the earth surface: Azimuth and Tilt.
- The "tilt angle" or "elevation angle" describes the vertical angle of solar panels; it is the angle the array surface makes with the horizontal plane (earth).
- "Azimuth angle" represents the angle between true north and the direction the array faces.

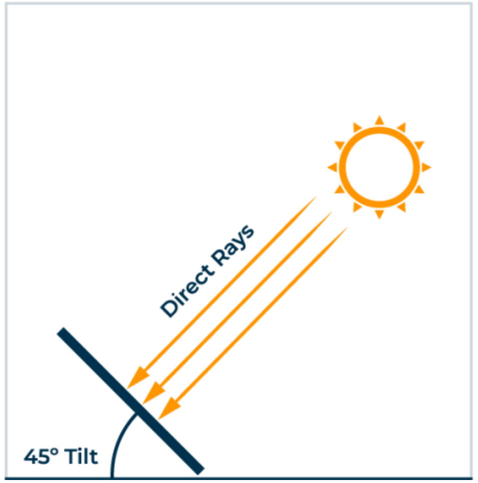


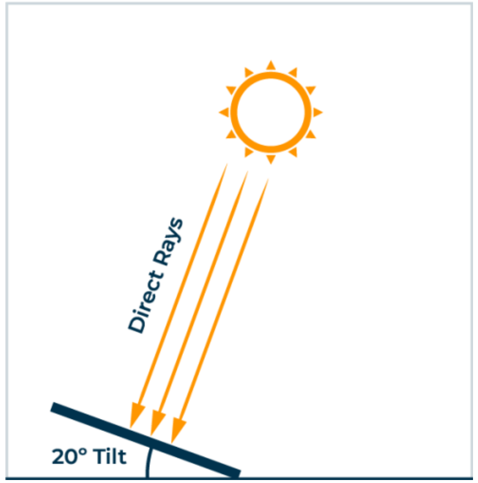
Optimal Tilt in Lebanon

Yearly Optimal: 28.7° from horizontal

Optimal tilt angles by season:

- Spring: 28.7°
- Summer: 13.7°
- Fall: 28.7°
- Winter: 43.7

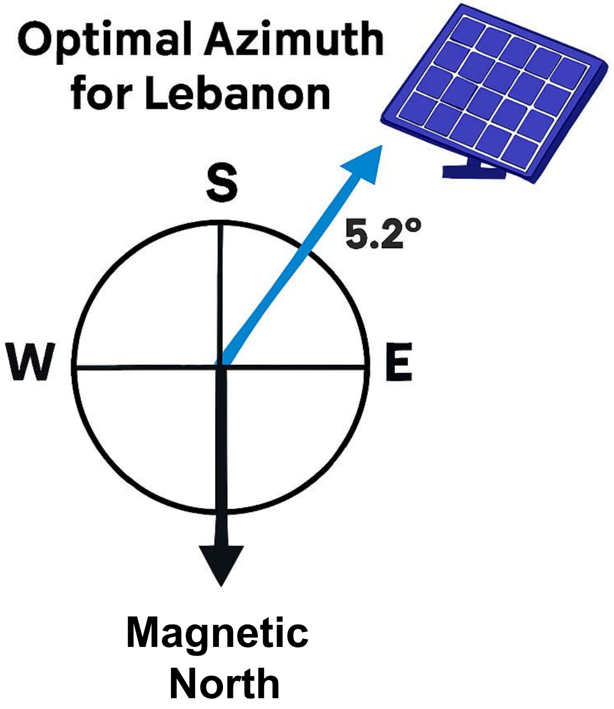




Optimal tilt angles by month:

- January: 38.7°
- February: 33.7°
- March: 28.7°
- April: 23.7°
- May: 18.7°
- June: 13.7°
- July: 18.7°
- August: 23.7°
- September: 28.7°
- October: 33.7°
- November: 38.7°
- December: 43.7°

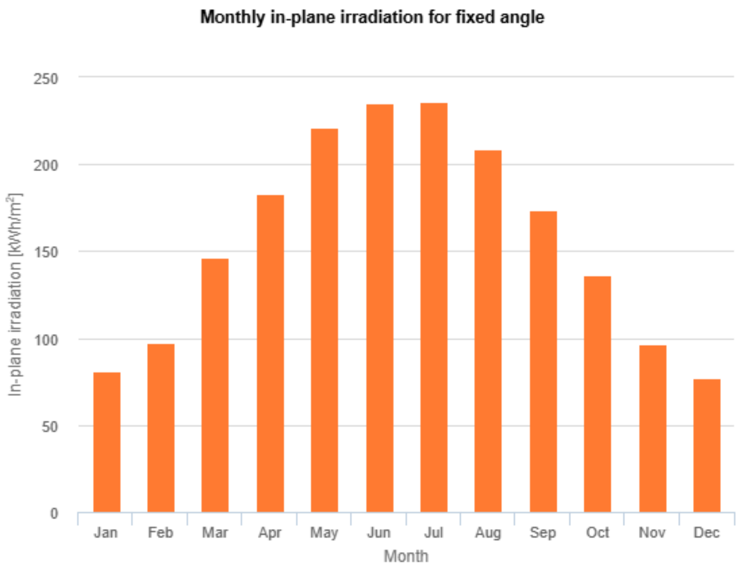
Optimal Azimuth in Lebanon



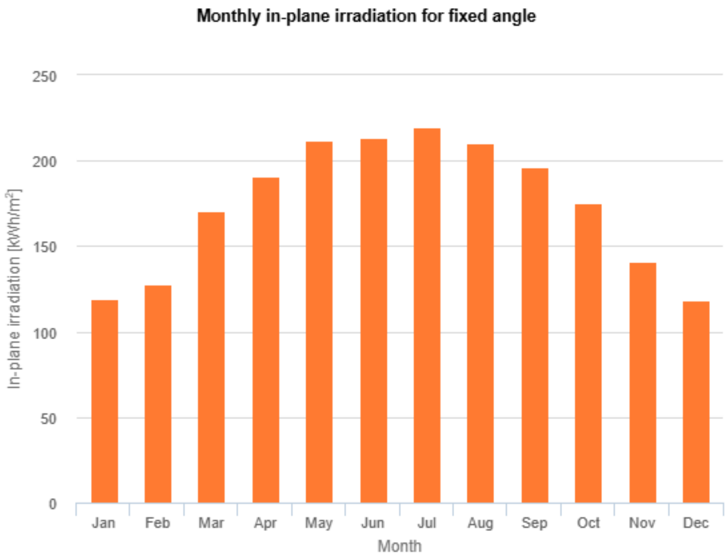
Source: GRC / Global Solar Atlas

Monthly in-plane irradiation for fixed angle

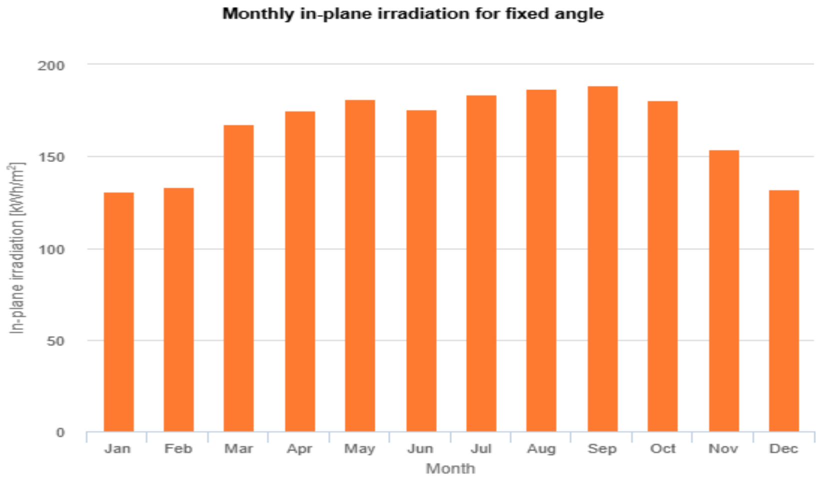
Irradiation mensuelle dans le plan pour angle fixe



Azimuth 0° and 0° Tilt



Azimuth 0° and 30° Tilt (Optimal)



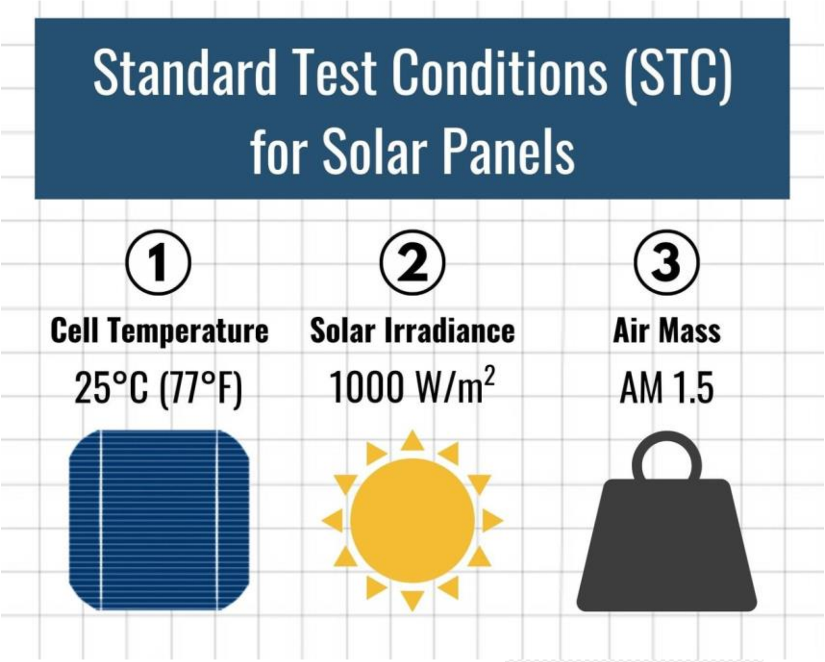
Azimuth 0° and 50° Tilt

STC & NOCT

Solar panel efficiency %*

$$\text{Efficiency of Solar Panels/Solar Cells} = \frac{\text{Power output}}{\text{Power input}} = \frac{\text{Power output}}{\text{Area x 1000W/ m}^2} \text{ x 100\%}$$

Note:
- Calculation is based on the standard test conditions (STC)
- Power output: the power converted by a solar panel or a solar cell (W)
- Area: the size of a solar panel or a solar cell (m²)



4 Zero wind speed

PV Panels Rating at NOCT *(Évaluation des PV)*

NOCT: Nominal Operating Cell Temperature

SPECIFICATIONS

Module Type	JKM535M-72HL4 JKM535M-72HL4-V		JKM540M-72HL4 JKM540M-72HL4-V		JKM545M-72HL4 JKM545M-72HL4-V		JKM550M-72HL4 JKM550M-72HL4-V		JKM555M-72HL4 JKM555M-72HL4-V	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	535Wp	398Wp	540Wp	402Wp	545Wp	405Wp	550Wp	409Wp	555Wp	413Wp
Maximum Power Voltage (Vmp)	40.63V	37.91V	40.70V	38.08V	40.80V	38.25V	40.90V	38.42V	40.99V	38.59V
Maximum Power Current (Imp)	13.17A	10.50A	13.27A	10.55A	13.36A	10.60A	13.45A	10.65A	13.54A	10.70A
Open-circuit Voltage (Voc)	49.34V	46.57V	49.42V	46.65V	49.52V	46.74V	49.62V	46.84V	49.72V	46.93V
Short-circuit Current (Isc)	13.79A	11.14A	13.85A	11.19A	13.94A	11.26A	14.03A	11.33A	14.12A	11.40A
Module Efficiency STC (%)	20.71%		20.90%		21.10%		21.29%		21.48%	
Operating Temperature(℃)	-40℃~+85℃									
Maximum system voltage	1000/1500VDC (IEC)									
Maximum series fuse rating	25A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.35%/℃									
Temperature coefficients of Voc	-0.28%/℃									
Temperature coefficients of Isc	0.048%/℃									
Nominal operating cell temperature (NOCT)	45±2℃									

*STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

JKM550M-72HL4
JKM550M-72HL4-V

STC	NOCT
550Wp	409Wp
40.90V	38.42V
13.45A	10.65A
49.62V	46.84V
14.03A	11.33A
21.29%	

Different Types of Solar Systems

for Agricultural value chain

Solar systems can be tailored to meet different energy needs across the agricultural value chain.

Below are the **three most relevant types**:

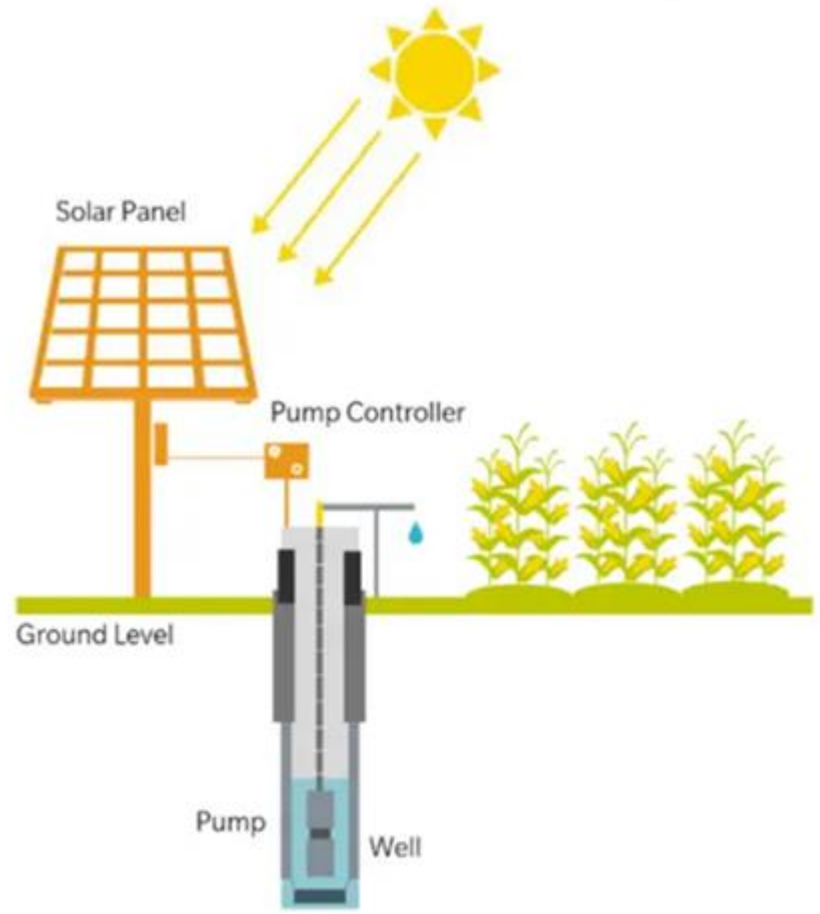
Les systèmes solaires peuvent être adaptés pour répondre aux différents besoins énergétiques de la chaîne de valeur agricole. Voici les trois types les plus pertinents :

- Solar Pumping Systems *(Systèmes de pompage solaire)*
- Solar Off-Grid Systems (with Battery) *(Systèmes solaires hors réseau)*
- Solar On-Grid Systems

1-Solar Pumping Systems

Systems that use solar power to operate **water pumps**, enabling **irrigation, livestock watering**, and **domestic water supply** without relying on grid or fuel.

Systèmes utilisant l'énergie solaire pour faire fonctionner les pompes à eau, permettant ainsi l'irrigation, l'abreuvement du bétail et l'approvisionnement en eau domestique sans dépendre du réseau électrique ni du carburant.



Main Components:

- PV Modules
- VFD or Solar Pump Controller
- AC/DC Pump (submersible or surface)
- Cabling & Combiner Boxes
- (Optional) Water Storage Tank

Solar Pumping Systems

Advantages:

- Fuel-free and low running cost *(Sans carburant et faible coût de fonctionnement)*
- Operates independently of grid *(Fonctionnement indépendant du réseau)*
- Ideal for remote, off-grid farms *(Idéal pour les exploitations agricoles isolées et hors réseau)*
- Can store water, not electricity *(Peut stocker de l'eau, mais pas de l'électricité)*

Challenges:

- Limited to daylight operation unless water storage is included *(Fonctionnement limité au jour)*
- Needs good site assessment (depth, head, water availability) *(Nécessite une bonne évaluation du site (profondeur, hauteur de chute)*
- Seasonal variations in solar energy impact output
- Borehole yield *(Rendement du forage)*

Relevance to Agriculture:

- Provides **reliable irrigation**, improves **crop yields**
- Supports **livestock farming**
- Reduces labor/time spent fetching water
- Ensures year-round water supply when properly sized

Solar Pumping Systems

Component	Sizing Basis
PV Modules	Based on daily water volume required and peak sunshine hours (PSH) in worst month (e.g., December)
VFD / Controller	Sized slightly above the motor capacity (typically 1.1× rated power)
Pump (Submersible or Surface)	Based on required flow rate (m^3/day) and total dynamic head (TDH in meters)
Mounting Structure	Based on panel tilt, site wind loads, and installation footprint
Cabling and Protection	Sized by voltage drop limits (max 3% DC / 5% AC) and trench distances

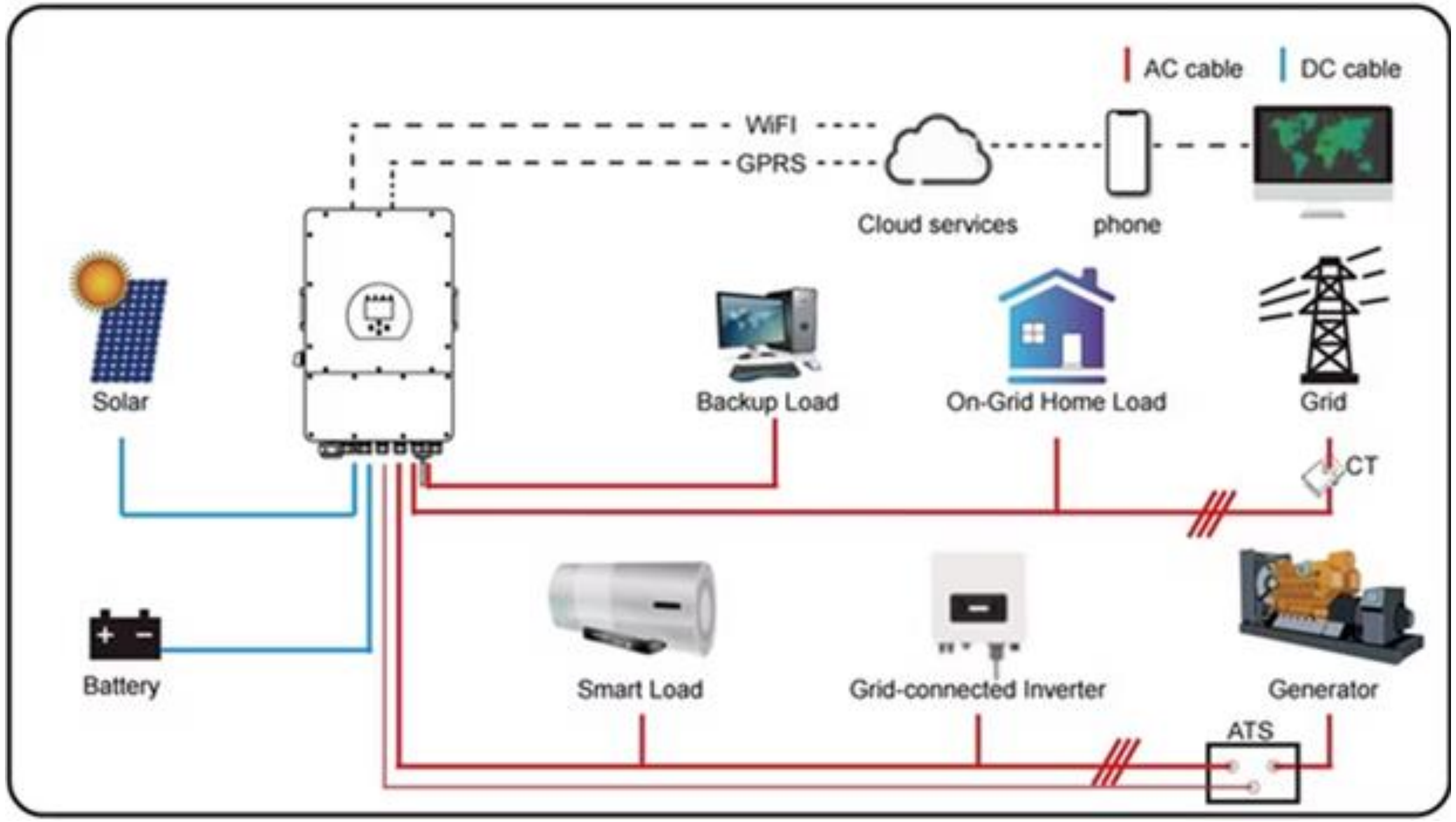
2- Solar Off-Grid Systems (with Battery)

A **standalone power system** that provides electricity to the facility independently of **the utility grid**.

Un système d'alimentation autonome fournit de l'électricité à l'installation indépendamment du réseau électrique.

Main Components:

- PV Panels
- Charge Controller / Inverter
- Battery Bank
- Protection and Cabling systems



Solar Off-Grid Systems (with Battery)

Advantages:

- Suitable for **remote areas** *(Adapté aux zones reculées)*
- Provides **24/7 power** when battery is sized well and consumption is well managed
  (Fournit une alimentation 24/7 lorsque la batterie est correctement dimensionnée et la consommation bien gérée)
- Enables **improved living conditions** in off-grid villages
  (Améliore les conditions de vie dans les villages hors réseau)

Challenges:

- High running cost of batteries *(Coût de fonctionnement élevé des batteries)*
- Lifespan of battery bank is limited *(Durée de vie limitée du parc de batteries)*
- Required monitoring and maintenance *(Surveillance et maintenance requises)*

Relevance to Agriculture:

- Operates **cold storage**, fans, lights, and **small machinery**
- Powers agro-processing (grinders, peelers, juice extractors)
- Ideal for **value-added agriculture** in rural settings

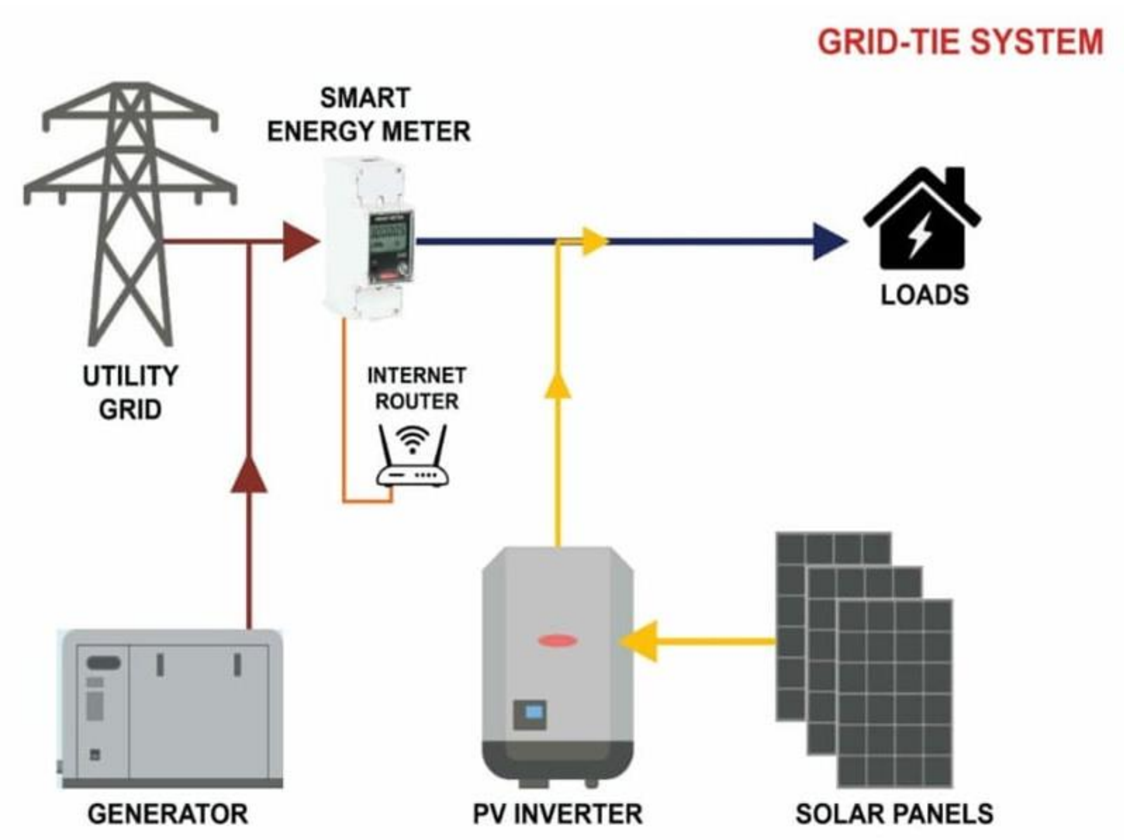
Solar Off-Grid Systems (with Battery)

Component	Sizing Basis
PV Modules	Based on daily energy use in kWh/day and worst month PSH
Battery Bank	Based on autonomy requirement, night loads and DoD (depth of discharge)
Charge Controller / Inverter	Rated to match solar array, battery voltage/current, peak load (W) and surge power needs (motors, fridges)
Wiring / Protection	Voltage drop + short-circuit ratings

3- Solar On-Grid Systems (Grid-Tie System)

Grid-tied systems that reduce energy bills by supplying solar electricity **in parallel with the utility grid and diesel generators**

Systèmes raccordés au réseau qui réduisent les factures d'énergie en fournissant de l'électricité solaire en parallèle avec le réseau électrique et les générateurs diesel



🔧 Main Components:

- PV Modules
- Grid-Tied Inverter
- DC Panel Board
- AC Distribution Board
- Monitoring Unit
- Fuel Save Controller
- Bidirectional Meter

Solar On-Grid Systems (Grid-Tie System)

Advantages:

- Reduces energy bills *(Réduit les factures d'énergie)*
- Simple design and **lower upfront cost** (no batteries) *(Conception simple et coût initial réduit)*
- Power reliability when grid or generator is present
  (Fiabilité de l'alimentation en présence du réseau ou d'un générateur)

Challenges:

- Not useful in **frequent blackout areas** *(Inutile dans les zones où les pannes de courant sont fréquentes)*
- Doesn't provide backup unless hybridized with batteries *(Ne fournit pas de secours, sauf en cas d'hybridation avec des batteries)*

Relevance to Agriculture:

- Ideal for **agro-industries**, **cooperatives**, and **agri-processing**
- Reduces operational costs for **cold rooms, mills, pack houses**
- Enables **sustainable agribusiness**

Solar On-Grid Systems (Grid-Tie System)

Component	Sizing Basis
PV Array	Sized to cover base load demand or to maximize available roof/land space
Grid-Tied Inverter	Sized equal to or slightly above total array size
Distribution Board	Should include SPD, MCCB, meter, and protections per local regulation
Monitoring Unit	Required for system performance tracking and reporting

Some useful tools

NREL NATIONAL RENEWABLE ENERGY LABORATORY

PVWatts® Calculator

estimates the energy production of grid-connected photovoltaic (PV) energy systems throughout the world

System Advisor Model

The System Advisor Model™ (SAM™) is a free desktop application for techno-economic analysis of energy technologies.

PVSYST PHOTOVOLTAIC SOFTWARE

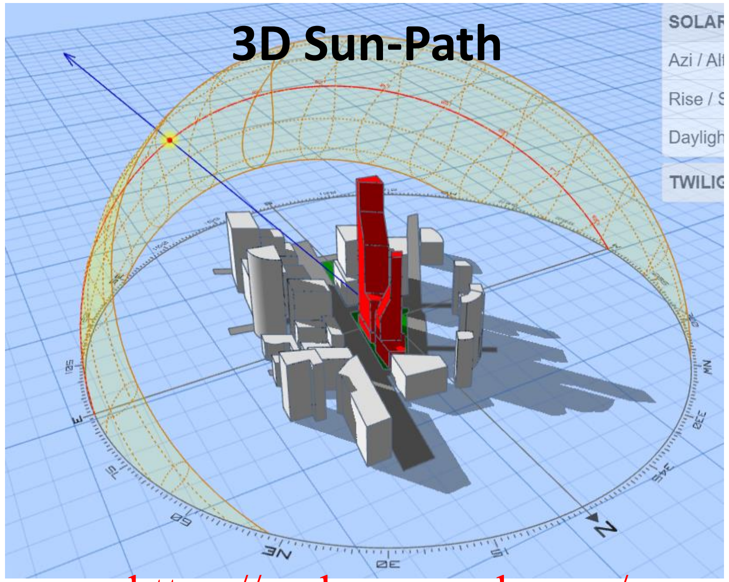
- Model your photovoltaic systems
- Make use of extensive databases
- Calculate the profitability of your projects

aurora

A **solar software** to design and sell advanced PV **systems**.

HelioScope by aurora

A cloud-based software platform for designing, simulating, and selling photovoltaic (PV) solar energy systems, particularly for commercial and industrial projects.



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