University of Science and Technology of Hanoi
ENERGY DEPARTMENT

INTRODUCTION TO RENEWABLE ENERGY TECHNOLOGIES

Bachelor in Energy – 2nd year, 2019/2020

Lecturer
Dr. Nguyen Xuan Truong & Dr. Nguyen Hong Nam

UNIT - N°.0
Course Information

Credit points	2	
Level	Undergraduate – B2	
Time Commitment	Lecture	18 hrs
	Exercise	00 hrs
	Practical	4 hrs
	Total	22 hrs
Prerequisites	Physics, Chemistry, Electric Circuits I	
Subject description:	This subject is about Renewable Energies (sources, technologies) We will see the basic concepts: energy security concerns and energy efficiency concepts We will deal with the conversion of solar, wind, biomass, hydro and geothermal energies into electricity energy We will consider the environmental and social effects of renewable technologies and examine how people's energy decisions impact policies	
Assessment/ Evaluation	Attendance and Attitude	15%
	Practical	25%
	Final exam	60%

Reference: https://www.irena.org
https://www.iea.org/fuels-and-technologies/renewables
https://gwec.net/global-wind-report-2019/

UNIT - N°.0
Course Information

THEORY

Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
Introduction to Renewable technologies	Energy security Concerns and energy efficiency Concepts	Solar Energy	Wind energy	Biomass & Biofuel energy	Hydroelectric Energy	Geothermal energy

Core

ASSIGNMENT

- ✓ How to evaluate the potential of renewable energies ?
- ✓ What is the definition for energy security in your country?
- ✓ What are important factors for your country energy security?

PRACTICAL WORK

LAB – USTH and on-site visit (more information on the course syllabus)

What is energy?

Sources

- **Fossil fuels:** Fuels formed by natural processes such as anaerobic decomposition of buried dead organisms.
- **Fissile material:** In nuclear engineering, fissile material is material capable of sustaining a nuclear fission chain reaction.
- **Renewable resource:** It is a resource which is replaced naturally and can be used again. Examples are: oxygen, fresh water, solar energy, timber, and biomass.

Fossil fuels

- **Natural Gas:** A combustible mixture of gaseous hydrocarbons that accumulates in porous sedimentary rocks, especially those yielding petroleum.
- **Liquefied Petroleum Gas** : A gas liquefied by compression, consisting of flammable hydrocarbons, as propane and butane, obtained as a by-product from the refining of petroleum or from natural gas : used chiefly as a domestic fuel in rural areas, as an industrial and motor fuel, and in organic synthesis, especially of synthetic rubber.

What is energy?

Fossil fuels

- **Fuel :** Fuels are any materials that store potential energy in forms that can be practicably released and used for work or as heat energy.
- **Coal :** A black or dark-brown combustible mineral substance consisting of carbonized vegetable matter, used as a fuel.

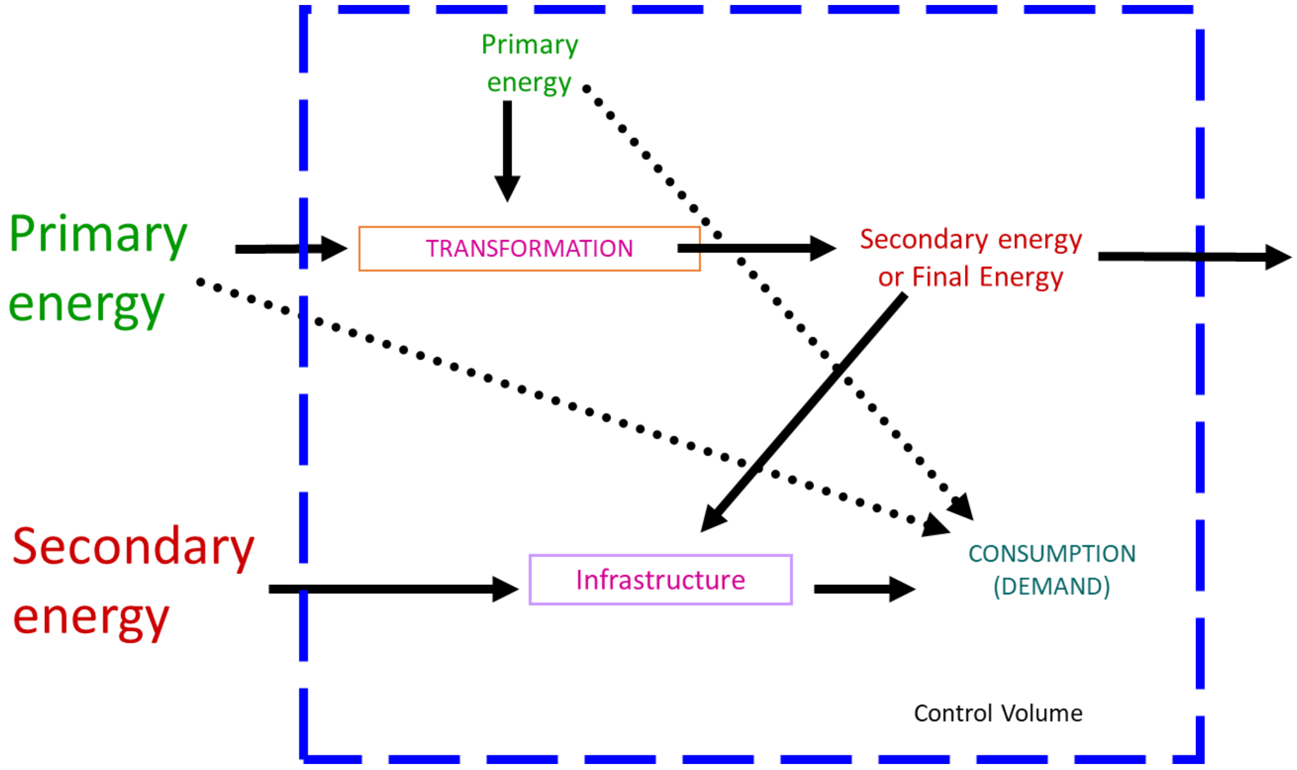
Fissile material

- **Uranium :** A radioactive metallic element having compounds that are used in photography and in coloring glass. The 235 isotope is used in atomic and hydrogen bombs and as a fuel in nuclear reactors.
- **Plutonium**

Energy Terms?

- **Primary energy** is energy contained in raw fuels and any other forms of energy received by a system as input to the system. The concept is used especially in energy statistics in the course of compilation of energy balances.
- **Secondary energy or Final energy** is a more usable and convenient forms of energy such as electricity and fuel oils. In another word, primary energies are transformed to secondary energies.

Energy pathway



What is green energy?

Vocabulary

- **Difference between renewable energy, proper, sustainable ?**
  - **Renewable:** that does not deplete over time.
  - **Proper:** which does not reject or very little harmful emissions to the environment and has a neutral impact on nature.
  - **Sustainable:** which is managed in a sustainable, responsible to ensure the renewal of the species (plant or animal) in its exploitation.

Challenges

- **Why ?**
  - Dealing with the shortage of fossil fuels to more or less short term.
  - Limit the effects of global warming.
  - Reduce the emission of greenhouse gases (GHG) in the energy sector (electricity generation)

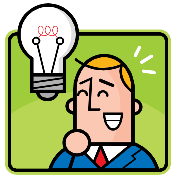
UNIT - N°.1
INTRODUCTION TO RENEWABLE TECHNOLOGIES

What is green energy?

Challenges

- **What is the interest to exploit renewable energy?**

  - Fight against the greenhouse effect, particularly in reducing carbon dioxide emissions into the atmosphere.



  - Intelligently manage local resources.
  - Create jobs.

Concept of sustainable development

- **Sustainable Development:**
  - Sustainable development is the organizing principle for sustaining finite resources necessary to provide for the needs of future generations of life on the planet (Brundtland Commission, 1987)

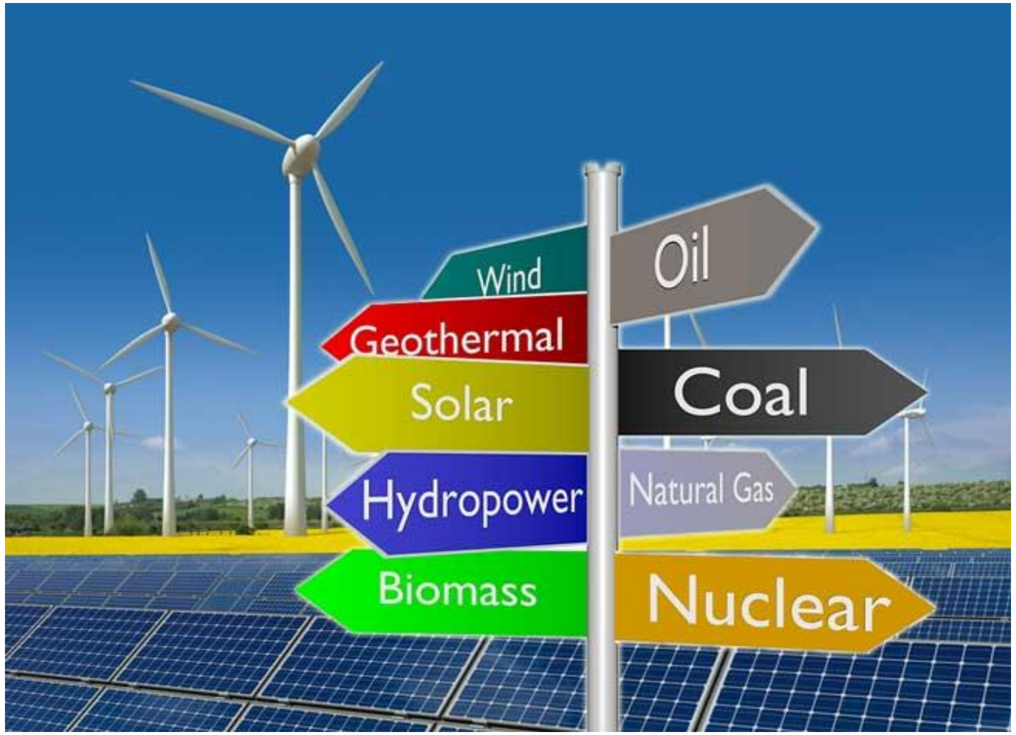
What is green energy?

Concept of sustainable development

- **Sustainable Development:**
  - Sustainable development is the organizing principle for sustaining finite resources necessary to provide for the needs of future generations of life on the planet (Brundtland Commission, 1987)
- **This concept involves :**
  - Developing new energy sources
  - Minimize discharges affecting the environment
- **But also:**
  - To manage the balance between economic development, social equity and environmental protection
  - Everywhere in the world

Renewable energy ?

- **What is it ?**
  - They are inexhaustible energy provided by the sun, wind, heat from the earth, waterfalls, tides or plant growth. Their use does not create or little wastes and emissions.



Why develop renewable energy ?

- To reduce the emission of greenhouse gases.
- To manage the inevitable depletion of fossil fuels by limiting the expected increase in production cost, and control a difficult international geopolitical context.
- To improve the energy independence of countries, diversifying the modes of energy production.
- To decentralize power generation throughout the territory of a country, increasing the use of regional natural resources, generate local jobs and reduce energy loss by limiting transport.
- To renew and modernize the entire electricity production.

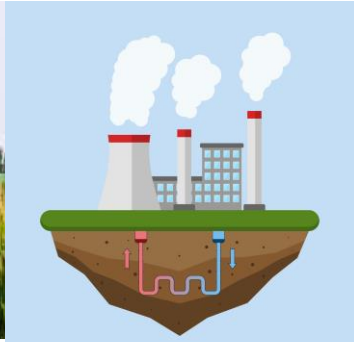
The five renewable energy sources (convert to electricity)

Solar power

Wind turbine

Hydropower plant

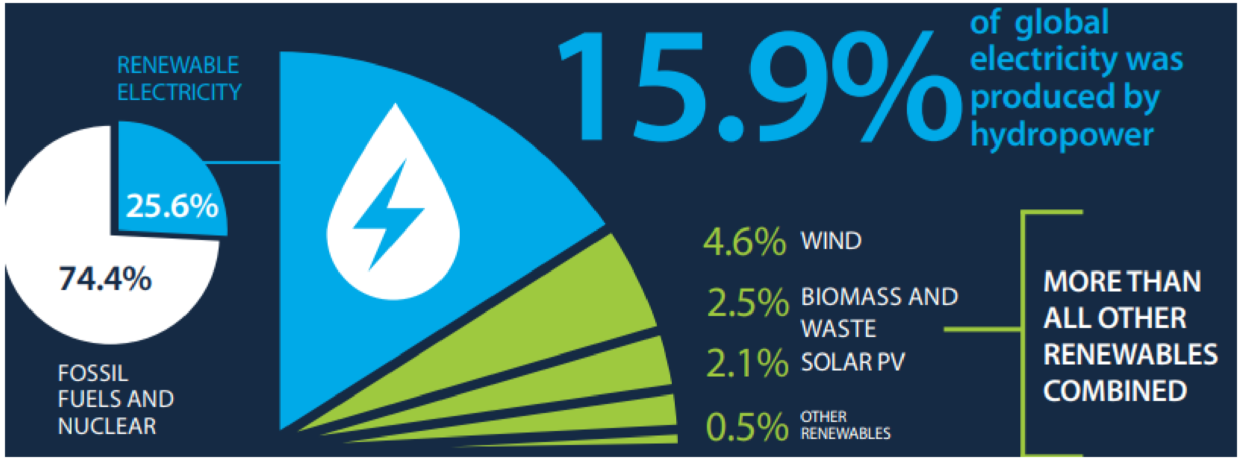
Biomass plant



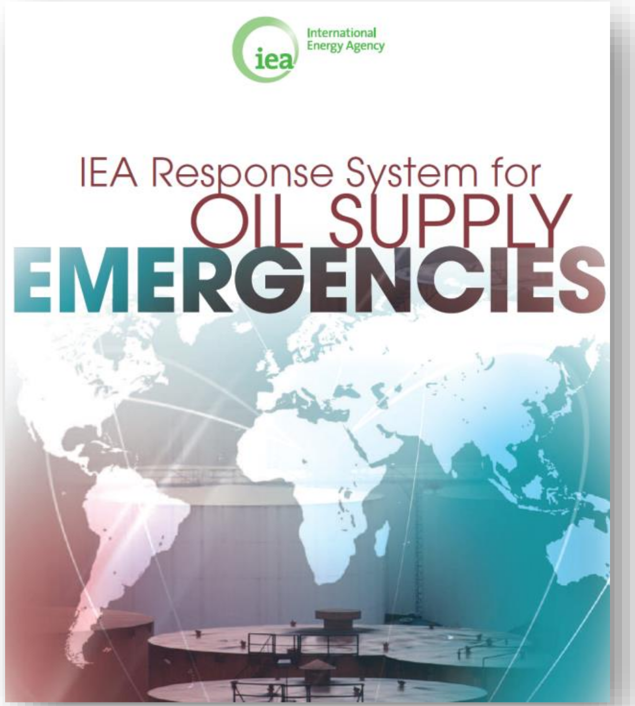
Geothermal

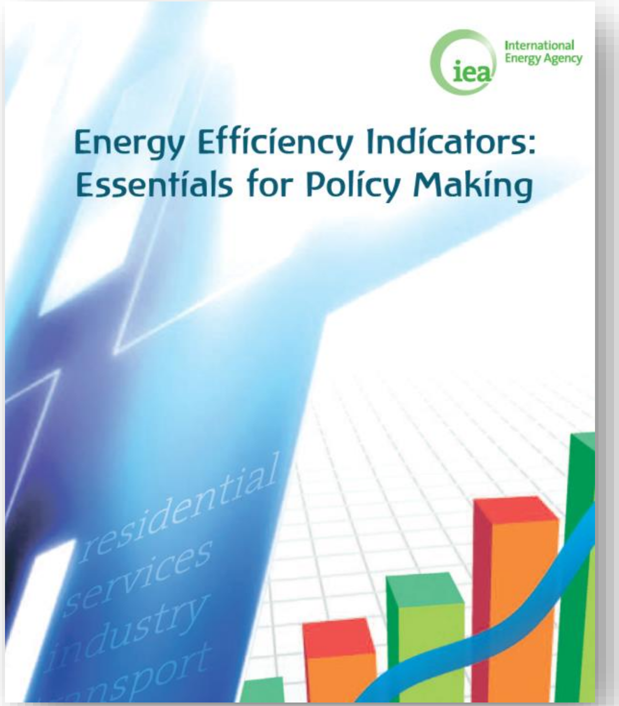
Lecture Question: unit 3 to 7

- What are the renewable energy sources? Make a list, as comprehensive as possible.
- What are the environmental impacts of these energy sources?
- **Renewable Energy Sources:**
  - ✓ **Radiant solar energy**
    - Solar heating (passive and active) & Solar power plants (PV system), CSP
  - ✓ **Biomass energy**
    - Direct: combustion of biomass
    - Indirect: chemical conversion to biofuel
  - ✓ **Wind energy**: onshore and offshore
  - ✓ **Hydro energy**: large and small-scale
  - ✓ **Geothermal energy**
    - Power plants, direct use, heat pumps



References





Activity

- Please define
  - What is the definition for energy security in your country?
  - What are important factors for your country energy security?

UNIT - N°.2

ENERGY SECURITY CONCERNS AND ENERGY EFFICIENCY CONCEPTS

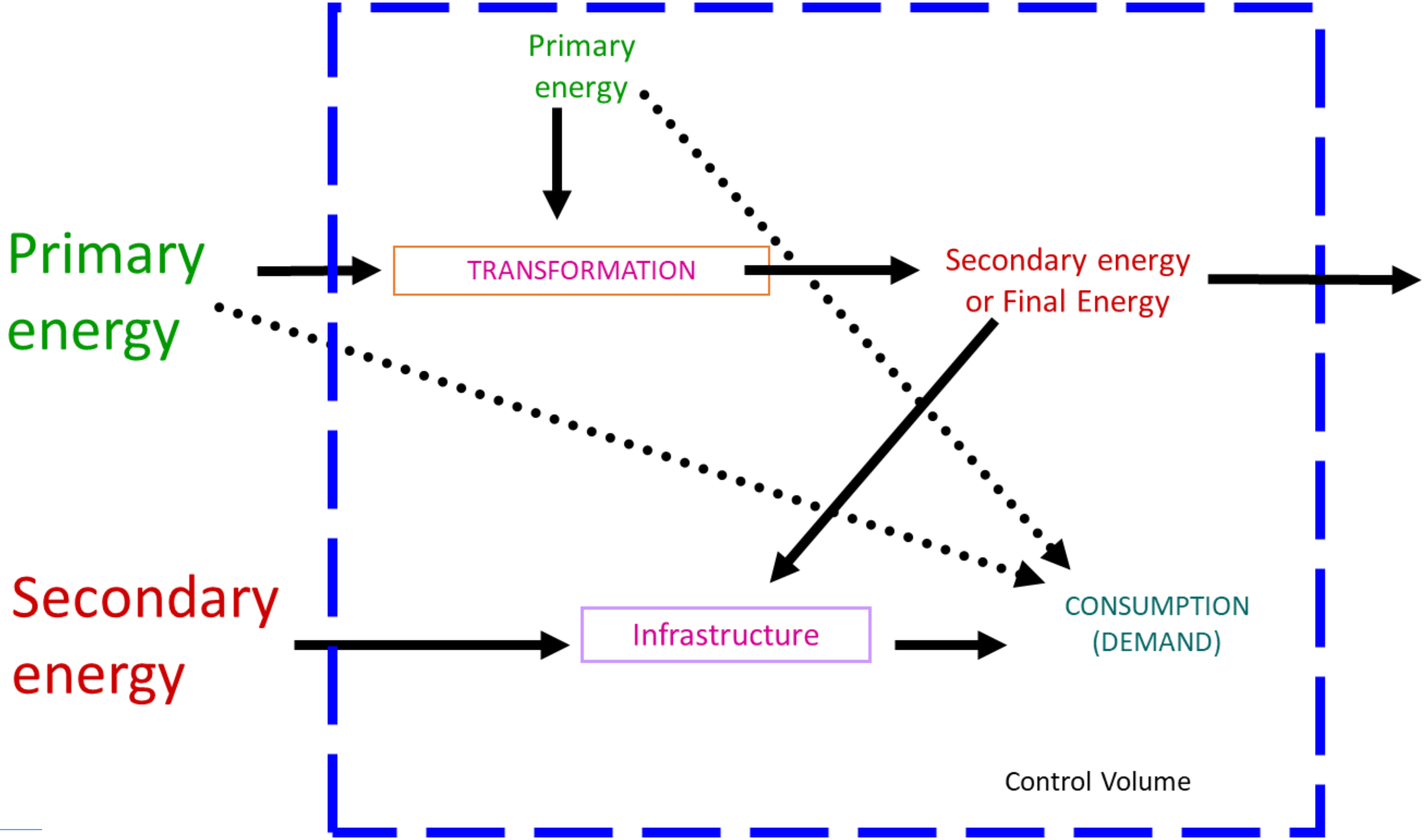
What is energy security?

- The IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price".
- Energy security has many dimensions:
  - Short-term energy security focuses on the ability of the energy system to react promptly to sudden changes within the supply-demand balance.
  - Long-term energy security mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs.
- Lack of energy security is thus linked to the negative economic and social impacts of either physical unavailability of energy, or prices that are not competitive or are overly volatile.

IEA: International Energy Agency

What is energy security?

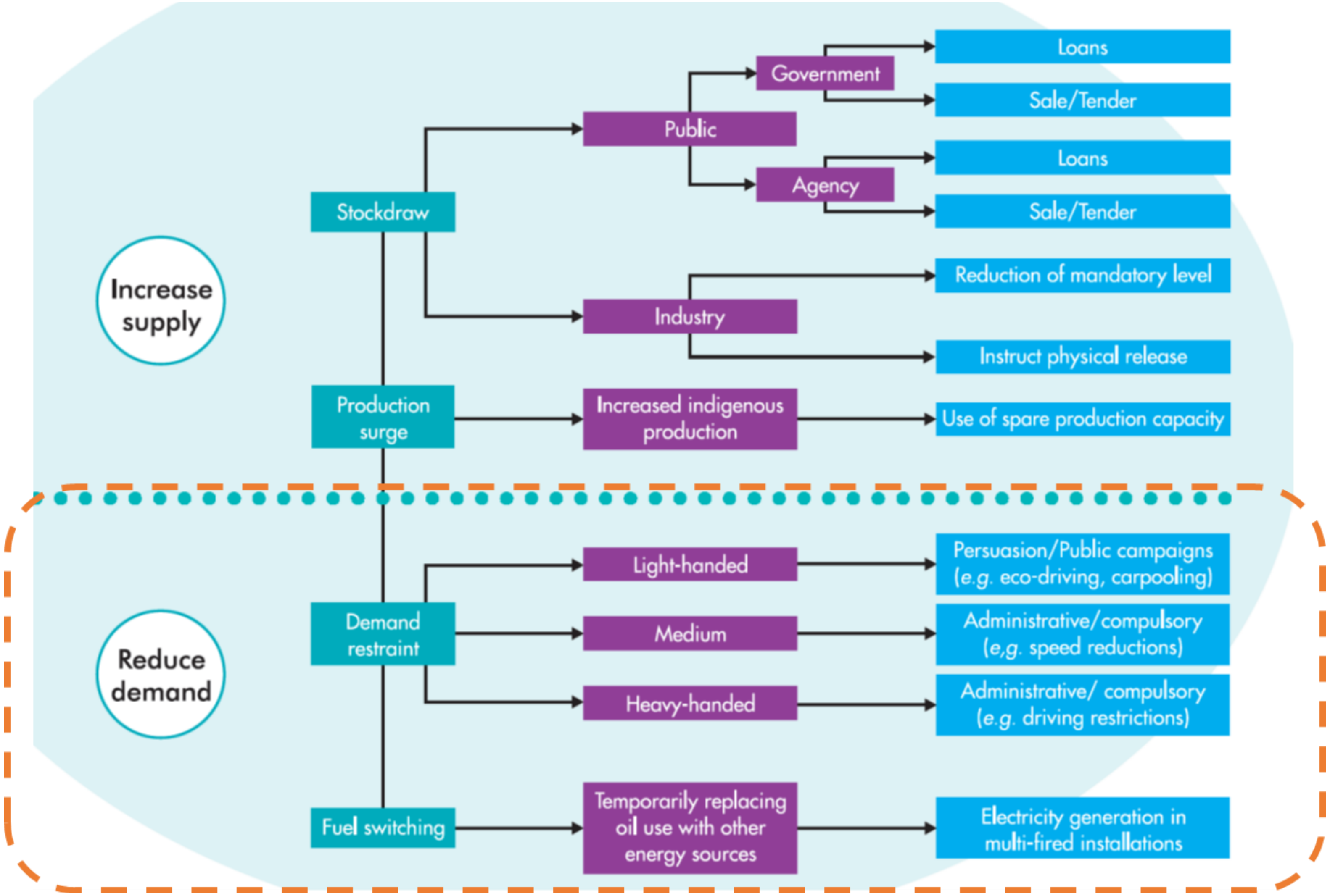
Point of supply interruption



What is energy security?

IEA respond to energy security : oil

Short term measures

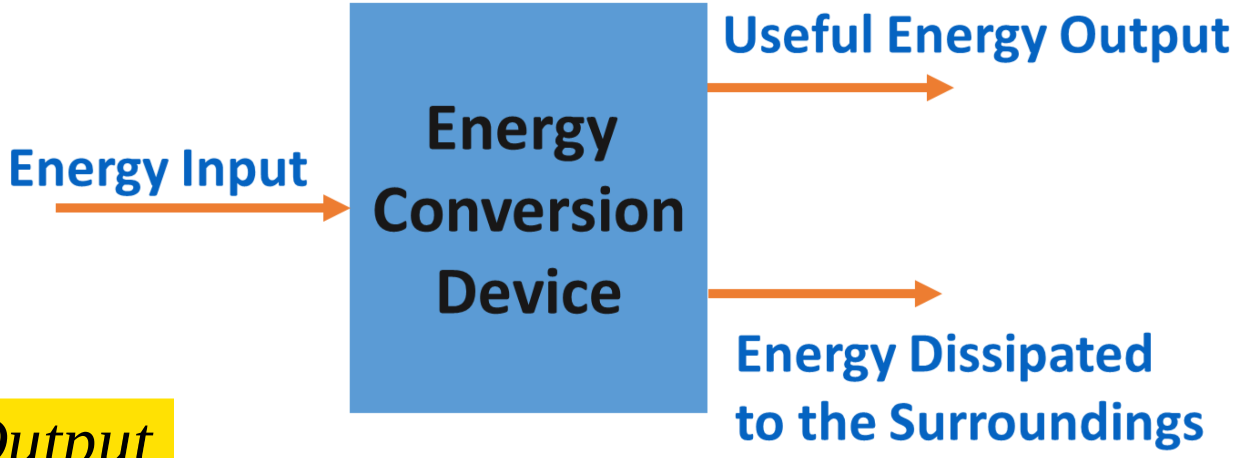


What is energy efficiency?

Efficiency of Energy Conversion

If we are more efficient with the energy we already have there will be less pollution, less reliance on foreign oil and increased domestic security.

Energy Efficiency



$$Efficiency = \frac{Useful\ Energy\ Output}{Total\ Energy\ Input}$$

What is energy efficiency?

Energy efficiency refers to the efficient conversion and use of energy and is a measure of the productivity provided per unit of energy consumed. It employs devices and practices, which result in less energy being used for the same task and function. An example would be a fluorescent bulb as opposed to an incandescent bulb. Other ways in which energy efficiency can be enhanced are through retrofits and capital improvements.Technological advances have allowed for increases in energy efficiency, reducing energy demand while increasing economic activity. Studies have indicated that energy savings of 20 –30% could be obtained globally over the next 3 decades through improvements in energy using technologies and energy supply systems. Furthermore, technological advances will allow companies to enhance profits as a result of the reduction in energy use and materials. Direct costs will be minimized through less resource inputs and lower disposal costs. Resource efficiency can enhance productivity, streamline production and improve workplace conditions

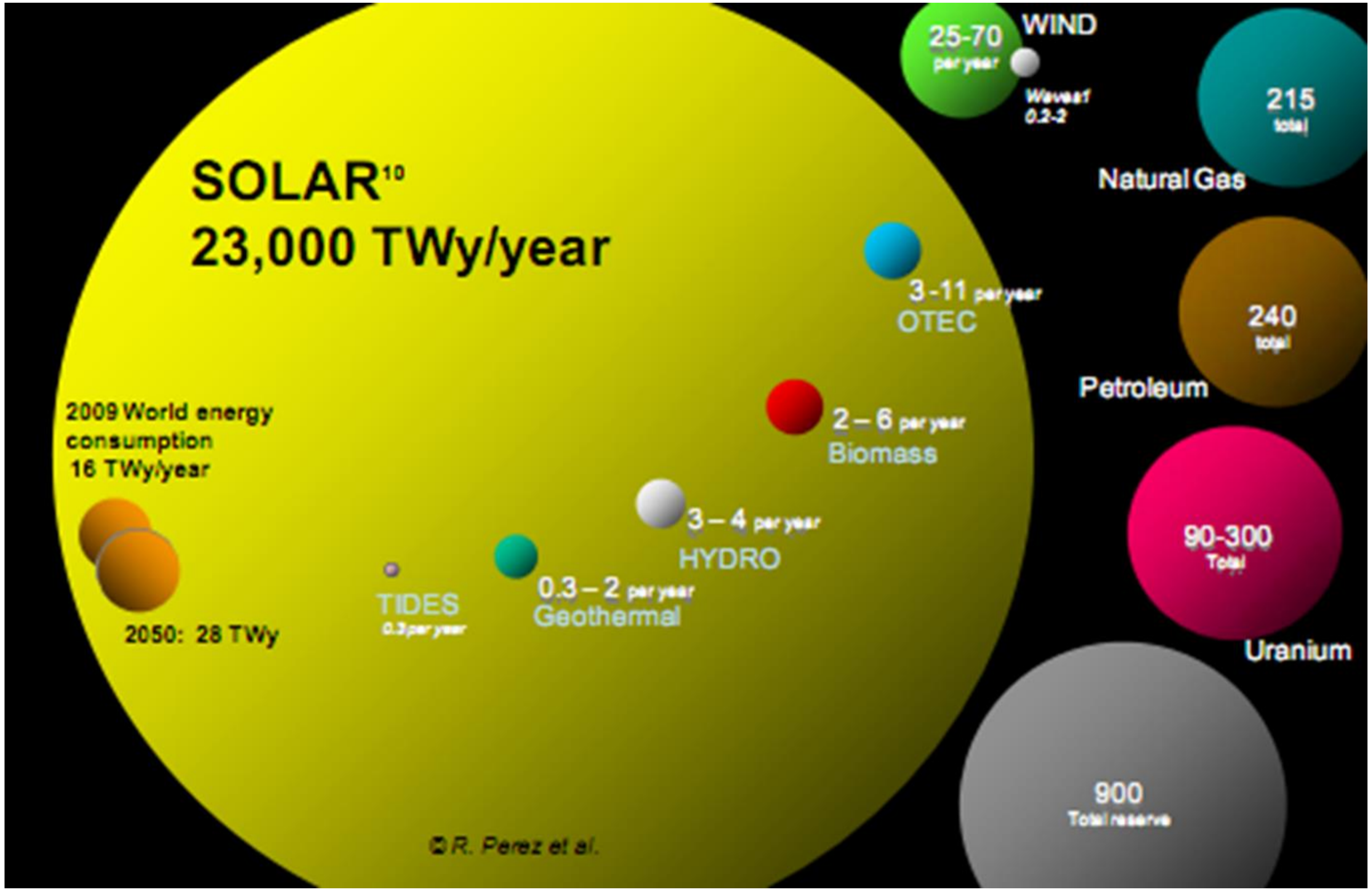
Question ?

How Energy Efficiency can contribute to Energy Security?

What really is Energy Efficiency?

How we rate Energy Efficiency?

Comparing finite and renewable planetary energy reserves



Source : http://cleantechnica.com/solar-power/

Comparing finite and renewable planetary energy reserves (Terawatt-years per year). Total recoverable reserves are shown for the finite resources. Yearly potential is shown for the renewables (source: Perez & Perez, 2009a).

OTEC: Ocean thermal energy conversion

Well, according to "science," the sun produces 23,000 TWy/year and humans use 16 TWy/year. We should be fair. 16 TWy/year was 2009 and it's been 5 years… so let's round it up to 28 TWy/year which is what the Mole People told us we'd use in 2050. So… we use a thousandth of the energy produced by the sun each year.

SOLAR : ENERGY FROM THE SUN

The sun has produced energy for billions of years. Solar energy is the sun's rays (solar radiation) that reach the earth. Solar energy can be converted into other forms of energy, such as **heat and electricity**.

In the 1830s, the British astronomer John Herschel used a solar thermal collector box (a device that absorbs sunlight to collect heat) to cook food during an expedition to Africa. Today, people use the sun's energy for lots of things.

Solar energy can be converted to thermal (or heat) energy and used to:

- **Heat water** – for use in homes, buildings, or swimming pools.
- **Heat spaces** – inside greenhouses, homes, and other buildings.

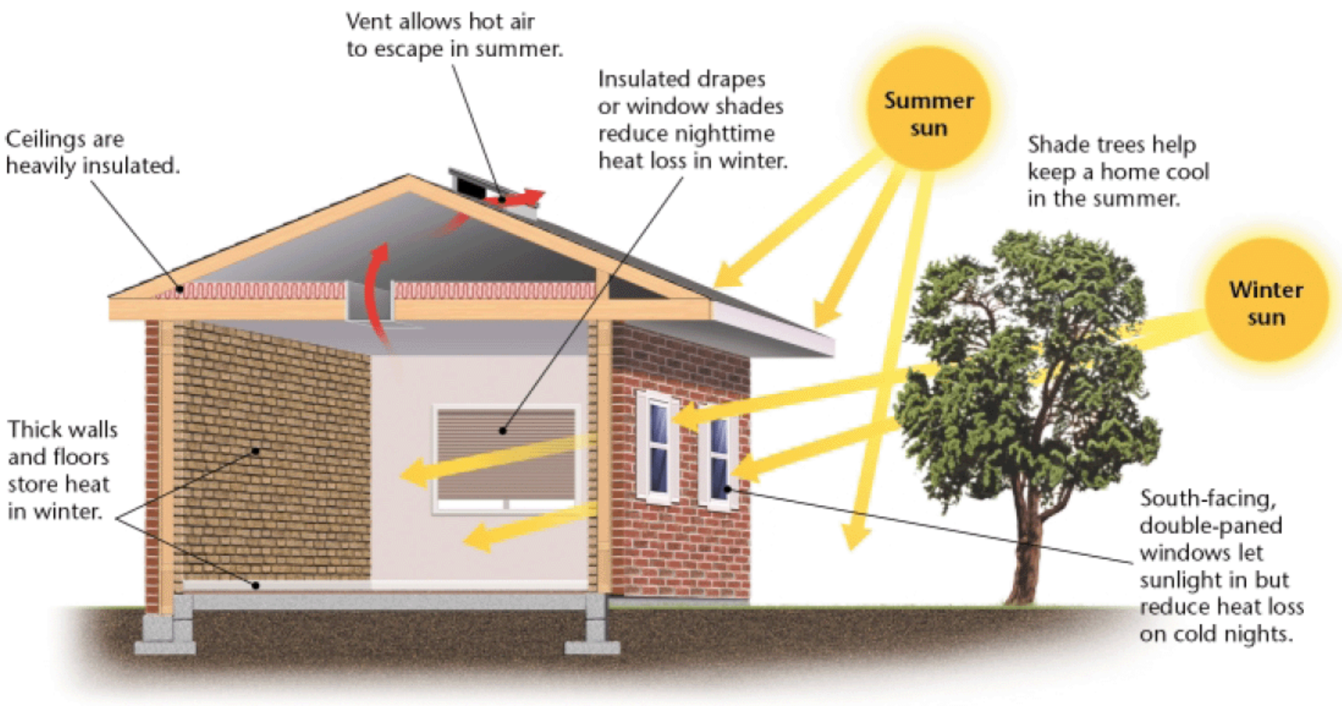
Solar energy can be converted to electricity in two ways:

- **Photovoltaic (PV devices) or "solar cells"** – change sunlight directly into electricity. PV systems are often used in remote locations that are not connected to the electric grid. They are also used to power watches, calculators, and lighted road signs.
- **Concentrated Solar Power Plants** - indirectly generate electricity when the heat from solar thermal collectors is used to heat a fluid which produces steam that is used to power generator. Out of the 15 known solar electric generating units operating in the United States at the end of 2006, 10 of these are in California, and 5 in Arizona. No statistics are being collected on solar plants that produce less than 1 megawatt of electricity, so there may be smaller solar plants in a number of other states.

SOLAR : Solar Thermal Energy

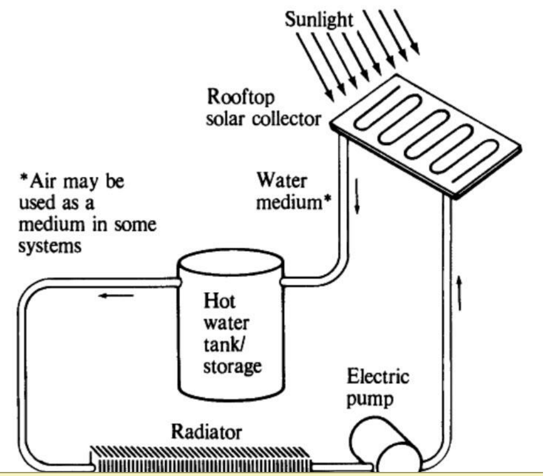
- **Passive solar heating/cooling**

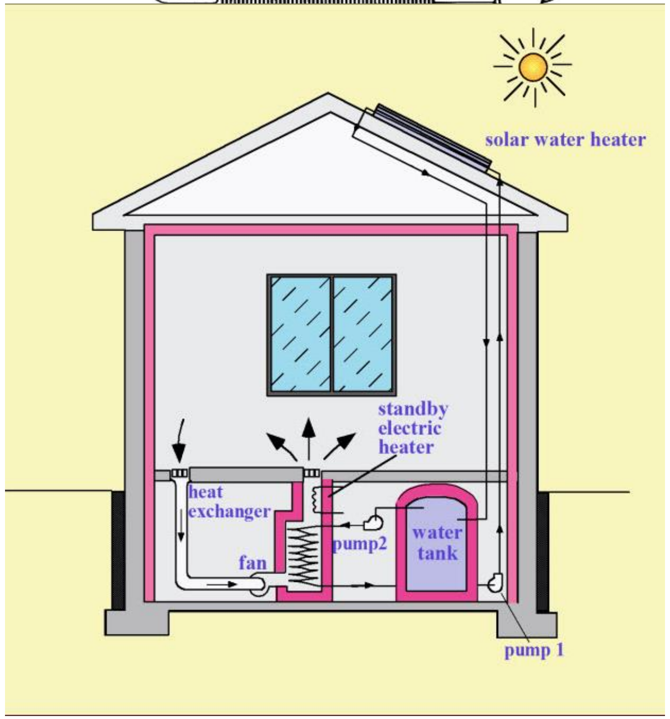
- Passive solar heating is the use of sunlight to heat buildings directly.
- In the Northern Hemisphere, south facing windows receive the most solar energy.
- Therefore, passive solar buildings have large windows that face south.
- Trees – A house shaded by trees is a much cooler house during the summer. Also, keep in mind that during the winter, the leaves are gone off the deciduous trees, so the winter sun can still shine into the home.

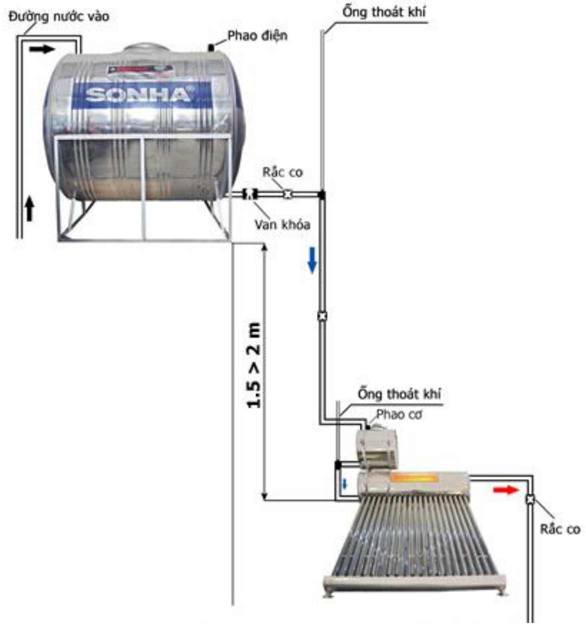


SOLAR : Solar Thermal Energy

- **Active solar heating**
- Active solar heating is the gathering of solar energy by collectors that are used to heat water or heat a building.
- Solar collectors, usually mounted on a roof, capture the sun’s energy.
- A liquid is heated by the sun as it flows through solar collectors.
- The hot liquid is then pumped through heat exchangers, which heats water for the building.





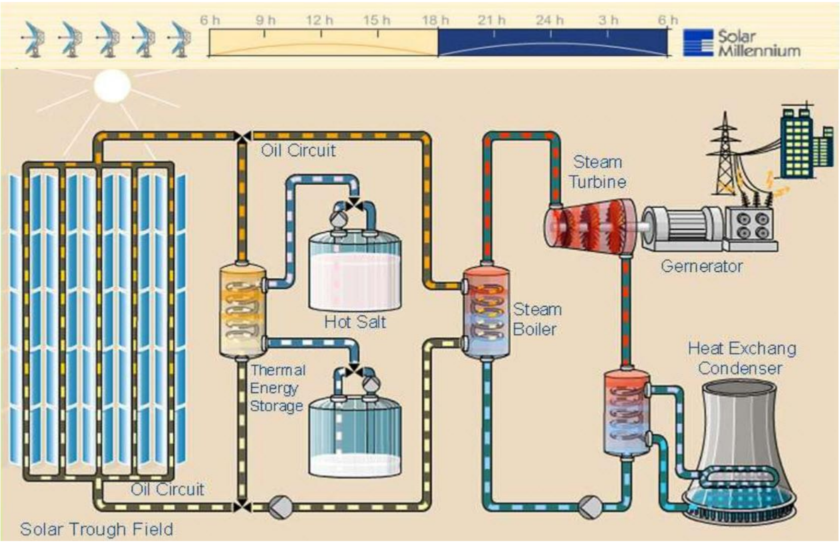


SOLAR : Solar Power Energy

▪ Concentrated solar power

- CSP systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area.
- Electricity is generated when the concentrated light is converted to heat, which drives a heat engine (usually a steam turbine) connected to an electrical power generator or powers a thermomechanical reaction.

Many power plants (including most CSP) use a Rankine steam power cycle to make electricity.

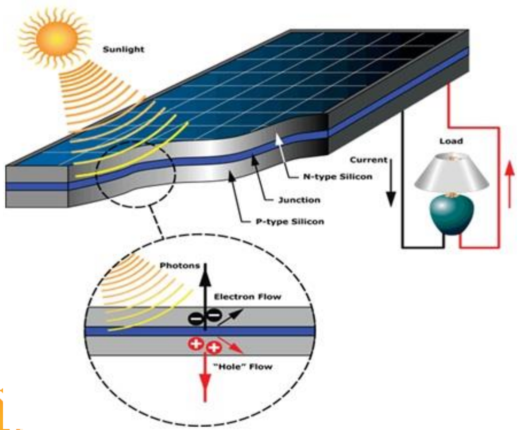


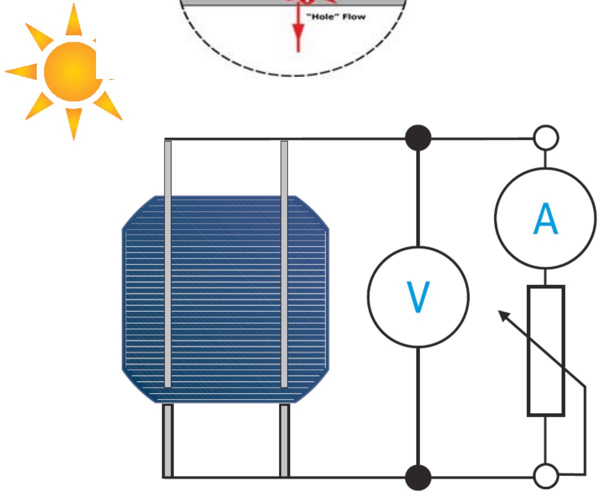
700 MW concentrated solar power plant in Dubai hits a new record bid with $7.3 cents per KWh

Solar : Photovoltaic Cells

What is photovoltaic solar energy ?

- **Photovoltaic (PV) cells** are solar cells that convert the sun's energy into electricity.





PV-cell and resistor as a load

- This conversion occurs in "semiconductor" materials, which have the property of releasing their electrons under the influence of external energy.
- In the case of photovoltaic, this energy is provided by the photons, light components, which collide with electrons and release them, inducing electric current.
- However, they produce a ***very small electrical current***. *Meeting the electricity needs of a small city would require covering hundreds of hectares with solar panels.*

Question:

How many square miles of solar panels would it take to power the U.S.? Vietnam, Hanoi city ???

ADVANTAGES OF SOLAR POWER

- Solar energy is an immaculate and renewable energy source.
- Once a solar panel is installed, solarenergy can be produced free of charge.
- Solar energy will last forever while it is estimated that the world's oil supply will run out in 30 or 40 years.
- Solar energy causes no pollution.
- Solar cells create no negative impact at all. On the other hand, the giant machines that pump oil are noisy polluters, and therefore very unfeasible.
- Almost no maintenance is required to keep solar cells running. There are no moving parts in solar cells, making it difficult to harm them.
- In the long term, there can be a high return on an initial investment because of the amount of free energy a solar panel can produce; it is estimated that the normal family can generate half of its energy from solar panels.

DISADVANTAGES OF SOLAR ENERGY

- ✓ As with all renewable energy sources, solar energy has regularity issues; the sun does not shine at night, and during the day there may be clouds or rain.
- ✓ Therefore, the intermittency and idiosyncrasies of solar energy make solar panels a less reliable a solution.
- ✓ Solar panels require additional equipment, like inverters, to convert direct power (DC) to alternating current (AC) for use on the power network.
- ✓ For a constant supply of electric power, particularly for on-grid connections, photovoltaic panels require inverters as well as storage batteries, increasing the initial investment for solar power accordingly.
- ✓ In the case of land-mounted PV panels, moderately large areas are needed; more often than not, land is available for this use for only 15-20 years.
- ✓ Solar panel efficiency is generally low (between 14%-25%),in contrast to the higher effectiveness of other renewable energy systems.
- ✓ In spite of the fact that PV panels require no excessive maintenance or operating costs, they are fragile and can be damaged easily; extra insurance costs are therefore essential to protect a PV investment.

Dictionary

- **Irradiance**
  - *Instantaneous illumination power*
  - ***G** in W/m²*
- **Radiation or incident energy**
  - *Received energy*
  - ***H** in Wh/m²*

- **Global radiation = Direct solar radiation + Diffuse radiation + Albedo**

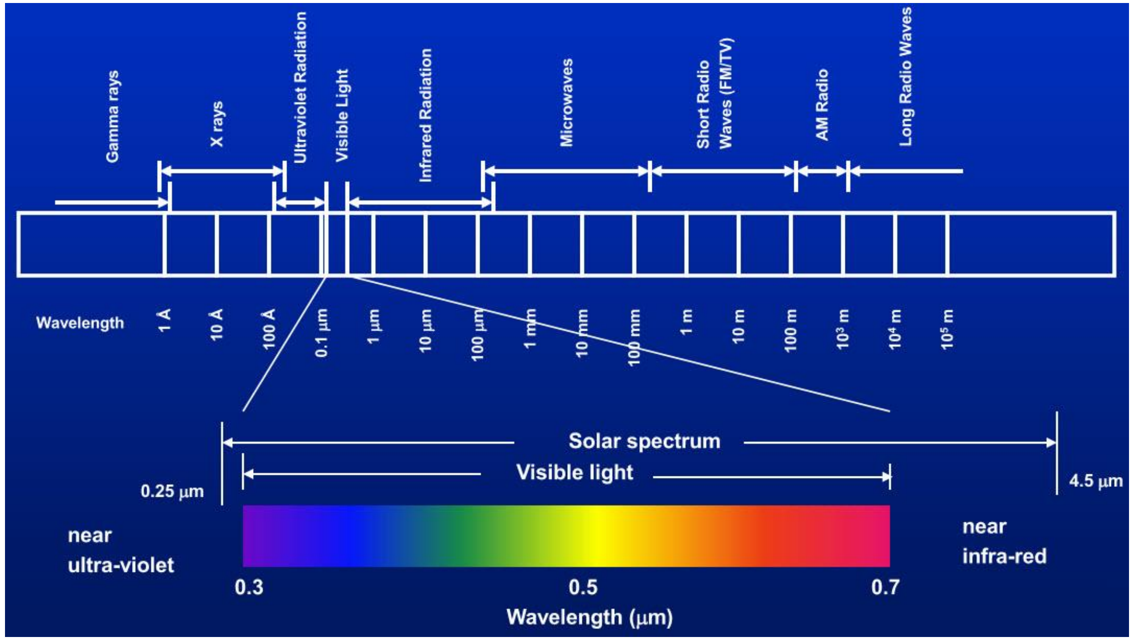
Potential of solar energy

- **Peak power or rate power or capacity**
  - Maximum instantaneous power delivered by a module expressed in Wp.
  - Standard test conditions:
    - *Radiation/Irradiance/Illuminance: 1000 W/m²*
    - *Air-mass: 1,5 (AM1,5)*
    - *Temperature: 25°C*

PV Power Installation Capacity

- **Solar Irradiance**
  - *Instantaneous illumination power*
  - *G in W/m²*

Solar radiation is electromagnetic radiation ranging from about **0.25 to 4.5 µm** in wavelength, including the near ultraviolet (UV), visible light, and near infrared radiation

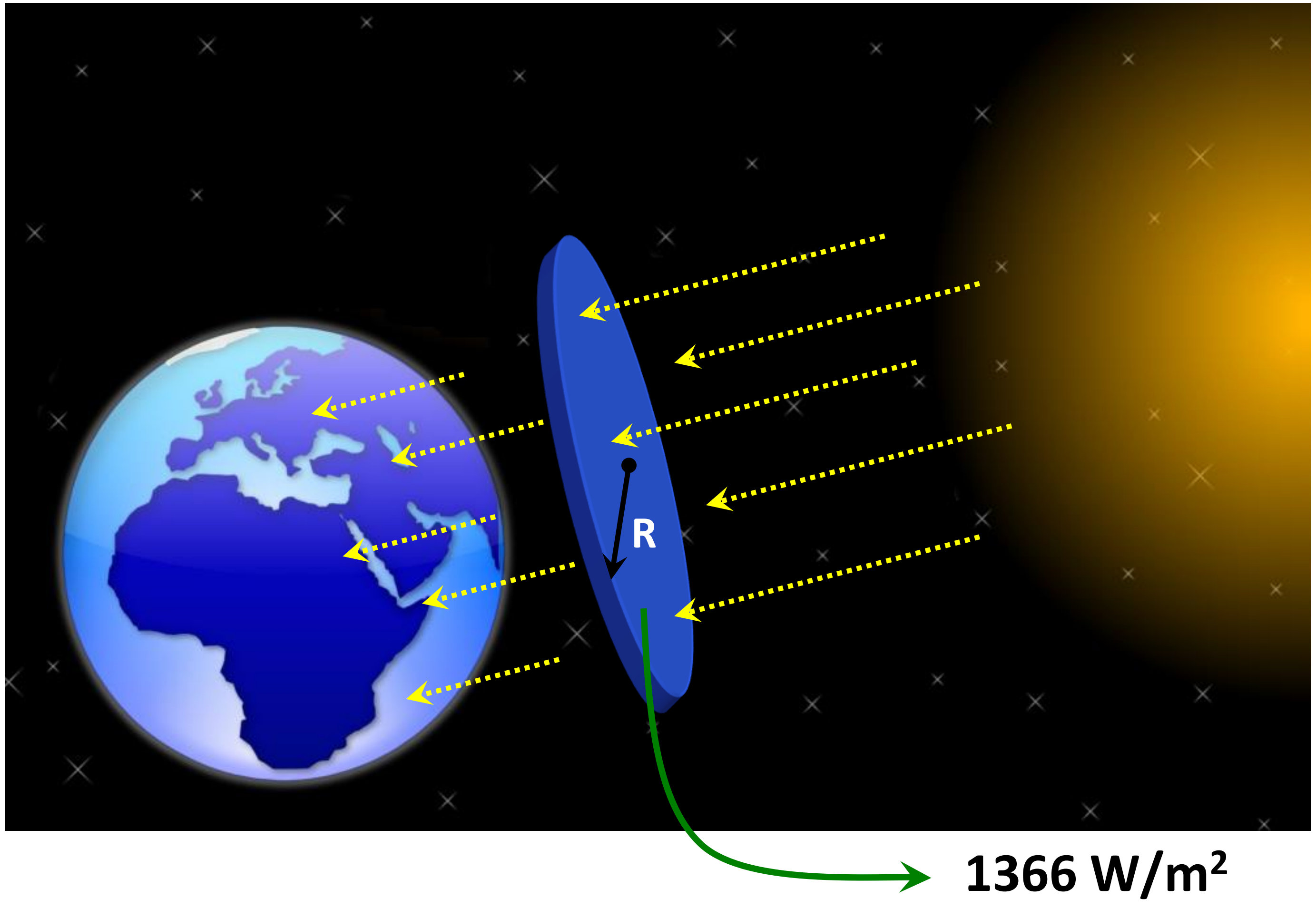


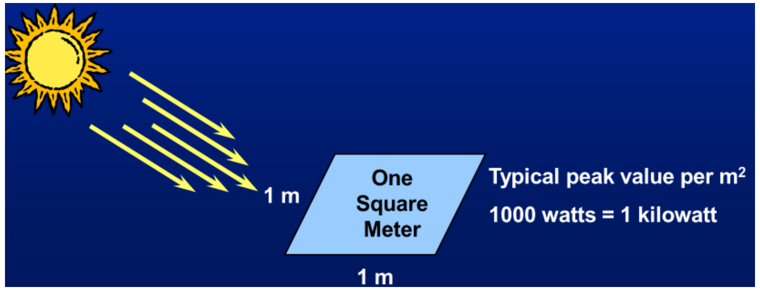
Solar irradiance is the sun's radiant power, represented in units of W/m^2 or kW/m^2

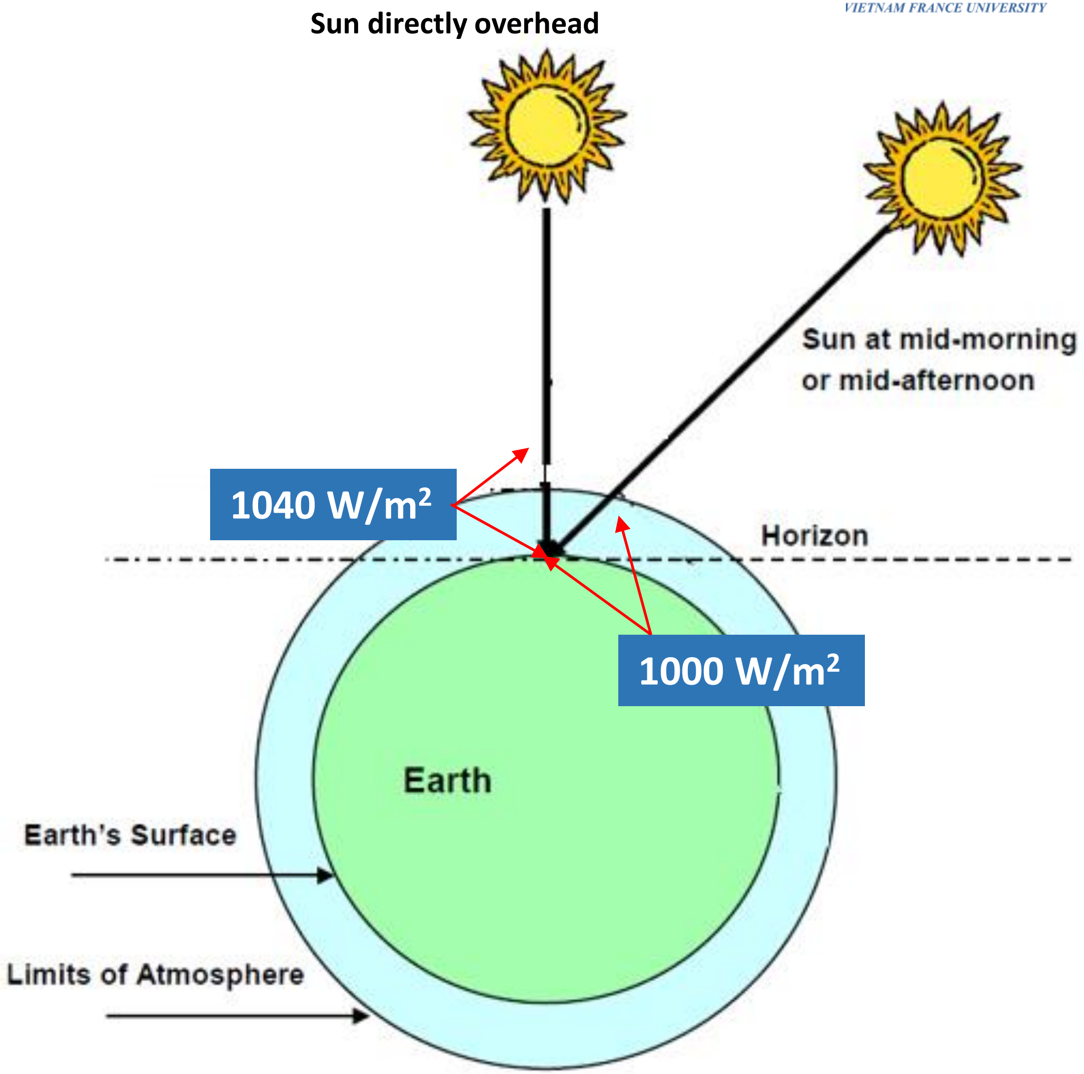
The **Solar Constant** is the average value of **solar irradiance** outside the earth's atmosphere, about **1366** W/m^2

Typical **peak value** is 1000 W/m^2 on a terrestrial surface facing the sun on a **clear day** around **solar noon at sea level**, and used as a rating condition for PV modules and arrays.

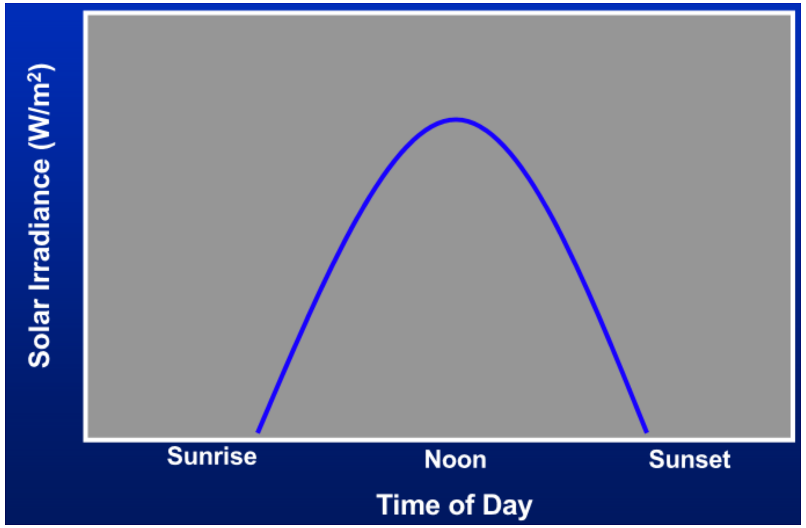
- Solar constant





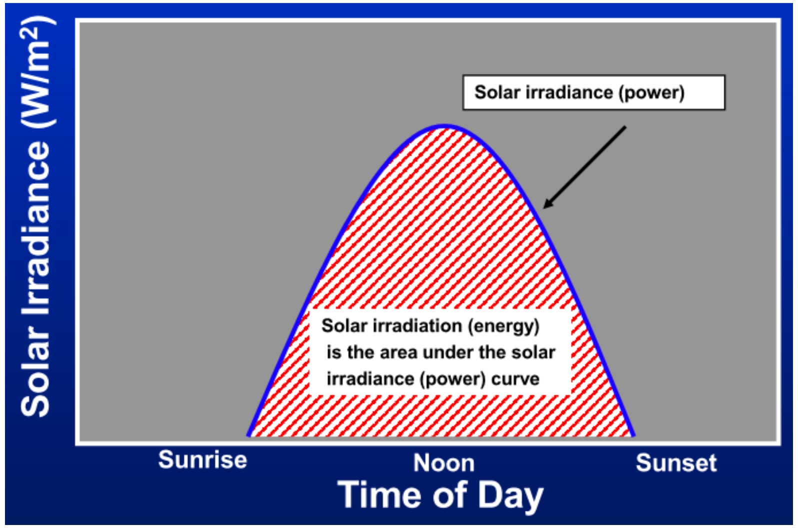


- **Solar Irradiance**
  - *Instantaneous illumination power*
  - *G in W/m^2*



For south-facing fixed surfaces, solar power varies over the day, peaking at solar noon, ***kW/m^2***

- **Radiation or incident energy**
  - *Received energy*
  - *H in Wh/m^2*

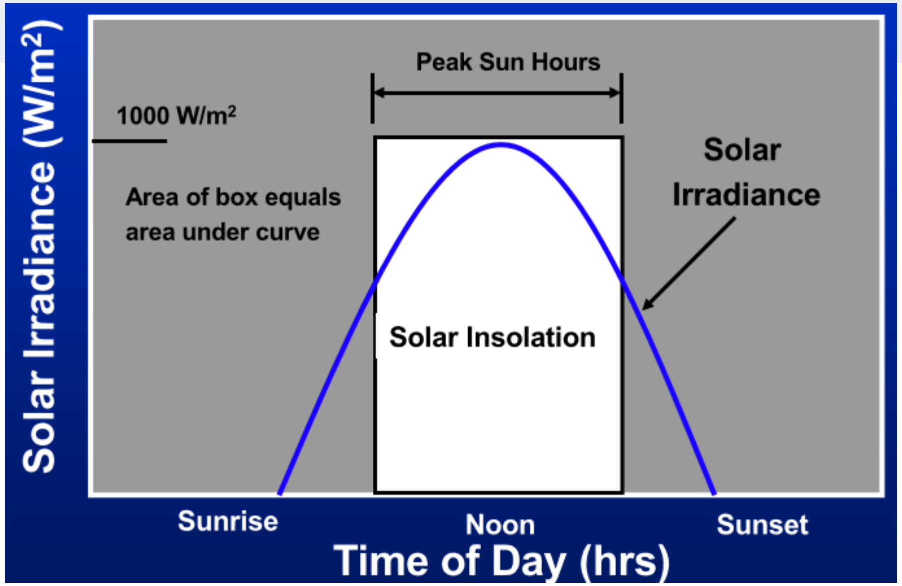


Solar irradiation is the sun's radiant energy incident on a surface of unit area, expressed in units of ***kWh/m^2***

- Typically expressed on an average daily basis for a given month.
- Also referred to as solar insolation or peak sun hours.

Peak sun hours (PSH) is the average daily amount of solar energy received on a surface. PSH are equivalent to :

- The number of hours that the solar irradiance would be at a peak level of 1000 W/m^2.
- Also the equivalent number of hours per day that a PV array will operate at peak rated output levels at rated temperature.



- The solar power incident on a surface averages 400W/m^2 for 12hours. How much solar energy is received?

  $400W/m^2 * 12hours = 4800Wh/m^2 = 4.8kW/m^2$; **PSH = 4.8hours**

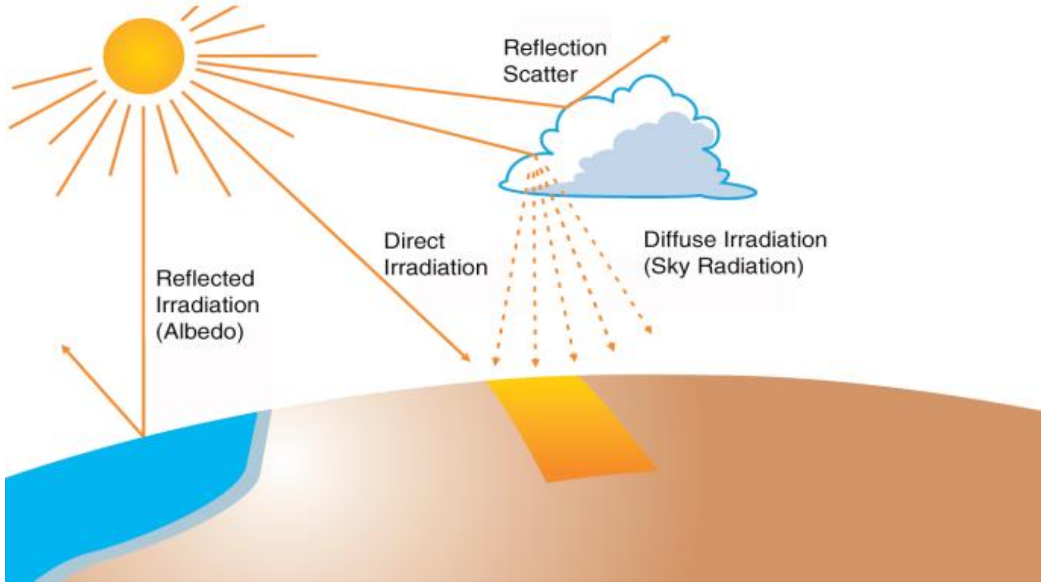
- The amount of solar energy collected on a surface over 8 hours is 4 kWh/m^2. What is the average solar power received over this period?

  $4\ kW/m^2 / 8hours = 0.5\ kW/m^2 = 500\ W/m^2$

- **Atmospheric Effects**

• **Outside the Earth's atmosphere solar energy has an almost constant value of 1366 W/m². While passing through the atmosphere, the energy and the spectral behaviour of the sunlight changes. Due to reflections on particles in the air, clouds, as well as ground reflection, the direct irradiation is reduced and a diffuse irradiation is added. The sum of both irradiation types is usually below the value found outside the atmosphere.**

• **For a sunny day and optimised orientation towards the sun, the global irradiation is about 1000 W/m². On cloudy days there is almost no direct irradiation left, the diffuse irradiation depends on the cloud type, and can be less than 100 W/m².**

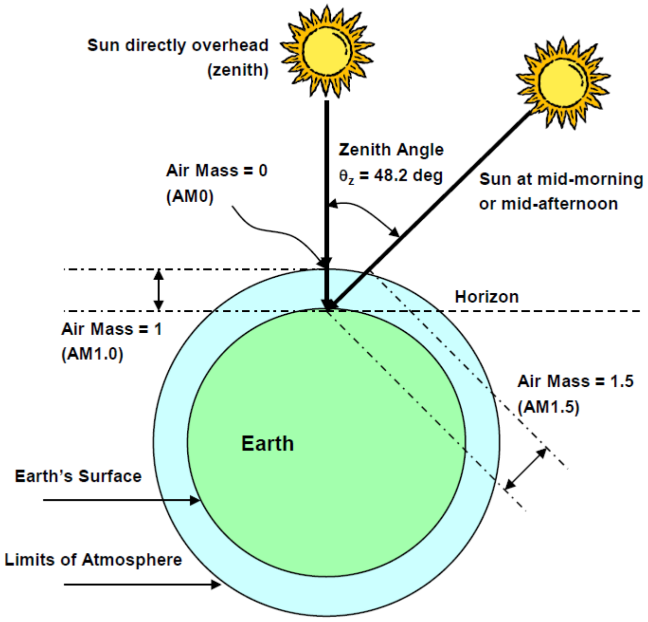


- Passing through the atmosphere, solar radiation is partially absorbed and distributed. On the ground, there are several components:
  - **Direct radiation**: the Sun received straight.
  - **Diffuse radiation**: light scattered by the atmosphere (air, cloudiness, aerosols, ...)
  - **Albedo**: partly reflected by the ground. Depends on the site environment (snow, asphalt, ...)
- **Global radiation = Direct + Diffuse + Albedo**

Air Mass

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass quantifies the **reduction in the power of light as it passes through the atmosphere** and is absorbed by air and dust.

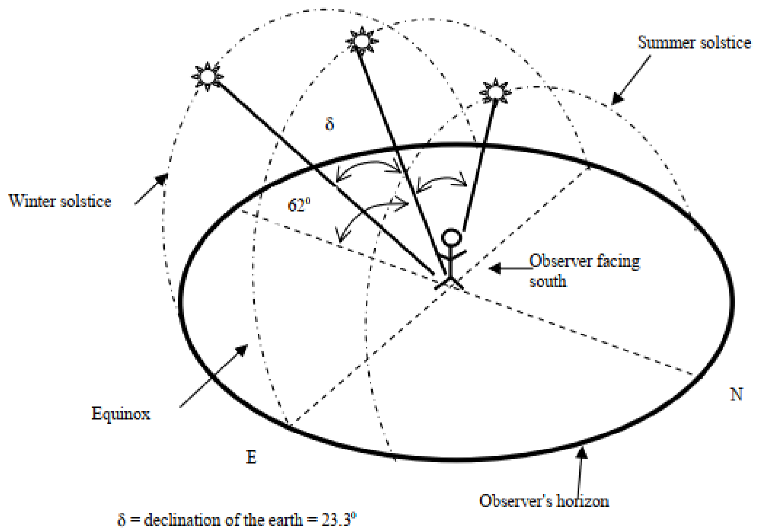
The Air Mass describes the attenuation of the irradiation and also spectral changes.



Examples	
AM0	Spectrum outside the atmosphere (1366 W/m²)
AM1	Sun at zenith (1040 W/m²)
AM1,5	Sun at 48,2° (1000 W/m²) (**PV standardization**)
AM2	Sun at 30°

Sun-path Effects

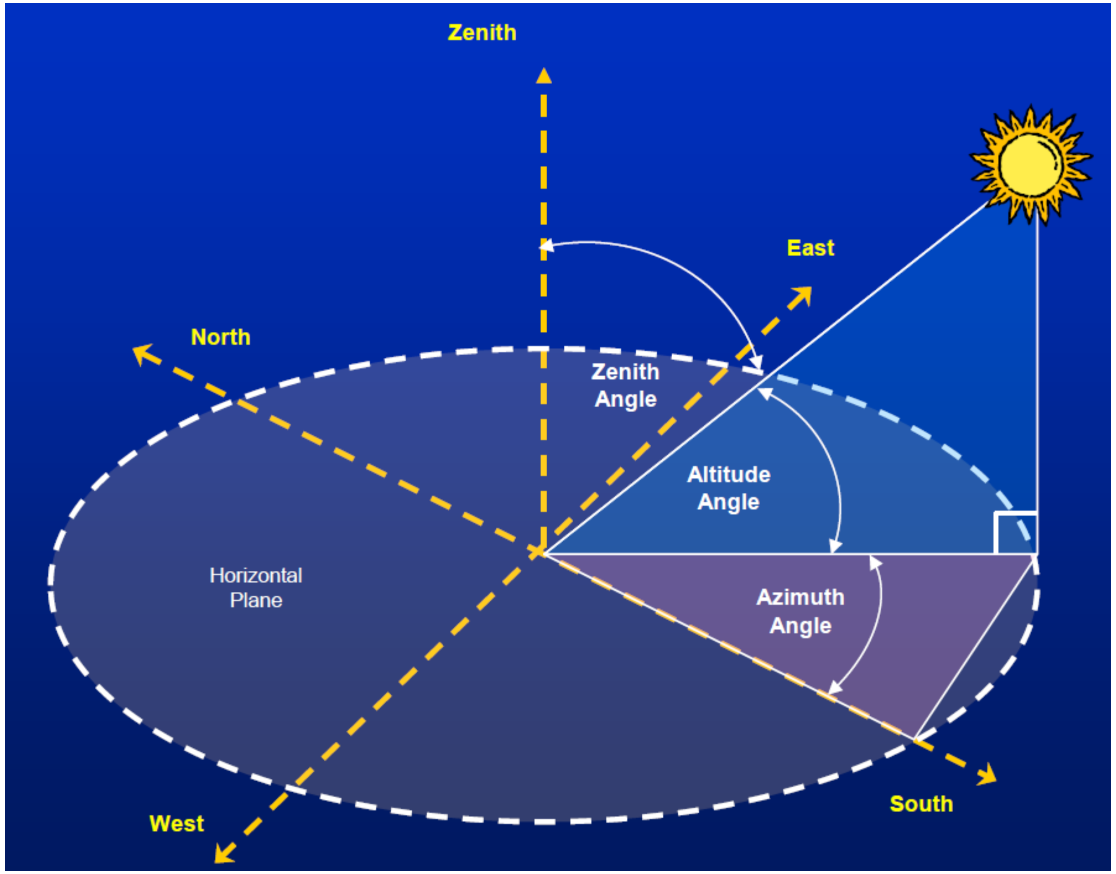
The irradiation on a tilted surface also depends on the position of the Sun. This position depends on the way the Earth moves around the Sun, and also the tilt of the Earth's axis in relation to this orbit. In winter the sun-path is lower than in summer. Also, the sunshine duration in winter is shorter than in summer.



• Sun Position

The sun's position in the sky at any moment relative to an observer on earth is defined by two angles:

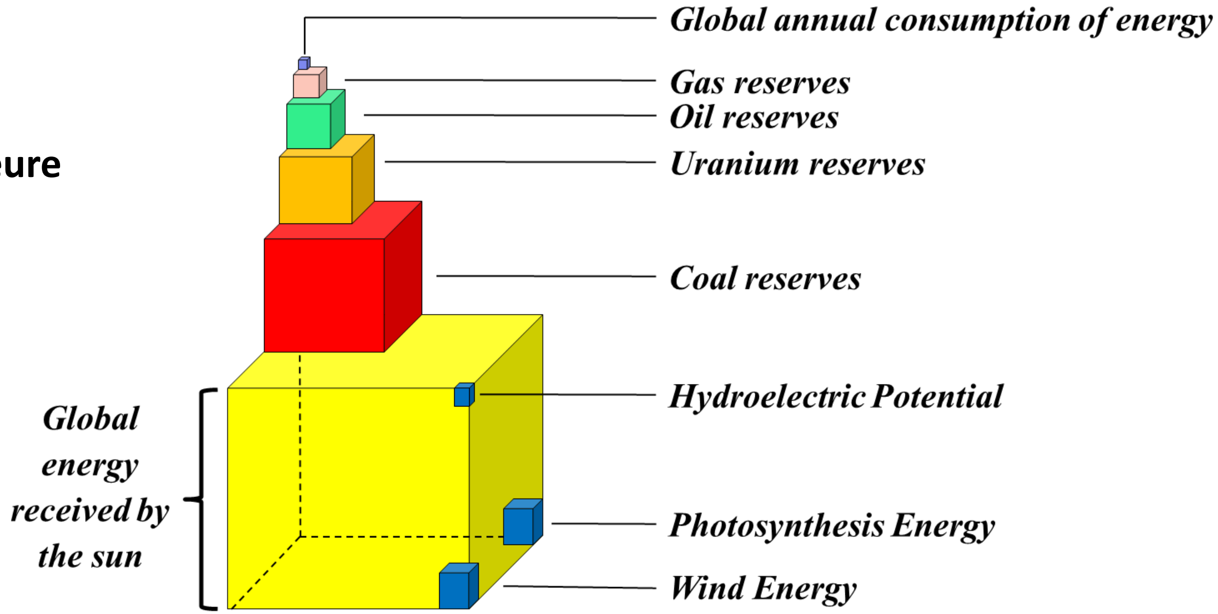
- **The *solar altitude angle* (*a*) is the angle between the sun's rays and the horizon.**
- **The *solar azimuth angle* (q_z) is the angle between the horizontal projection of a the sun's rays and geographic due south.**
- **The *zenith angle* is the angle between the line to the sun and directly overhead.**
- **The *zenith and altitude angles* are complementary: a + q_z = 90°**



Since the earth makes a complete 360° rotation in 24 hours, the hour angle changes 15° every hour. The hour angle is measured from the local meridian, or the sun's highest point in the sky at solar noon (not necessarily 12:00 hours), with angles between sunrise and solar noon being positive and angles after noon being negative. The sun's declination angle is the angular position of the sun at its highest point in the sky with respect to the plane of equator it depends on the momentary position of the earth in its revolution around the sun. Changes in the declination angle are caused by a simple fact: the earth's axial tilt of 23.34° remains constant and in the same direction during the earth's entire orbit around the sun. In the northern hemisphere, the declination angle reaches its most northern and positive peak of +23.45° on June 21st (the summer solstice) and drops to its most southerly and negative peak of –23.45° on December 21st (the winter solstice)

What is the potential of solar energy ?

10^{15} watts = 1PW = 1 pétawatts
10^{18} joules = 1EJ = 1 exajoules
Un watt-heure vaut 3 600 joules, et un kilowatt-heure vaut 3 600 kilojoules donc 1W vaut 1000 joules
174 PW : Instantaneous Power, 174 x 24h x 365j = 1524240 PWh = 1524 EWh.
1524 EWh x 3600 = 5 486 400 EJ



- 174 petawatts (PW) of energy comes in form of solar radiation (or insolation) hits our atmosphere.
- Almost one third of this is reflected back into space. The rest, 3 657 000 exajoules (EJ) every year, is absorbed by the atmosphere, clouds, oceans and land – one hour of insolation is the equivalent to more than the world's energy consumption for an entire year.
- Solar energy is by far the largest energy resource on the Earth.

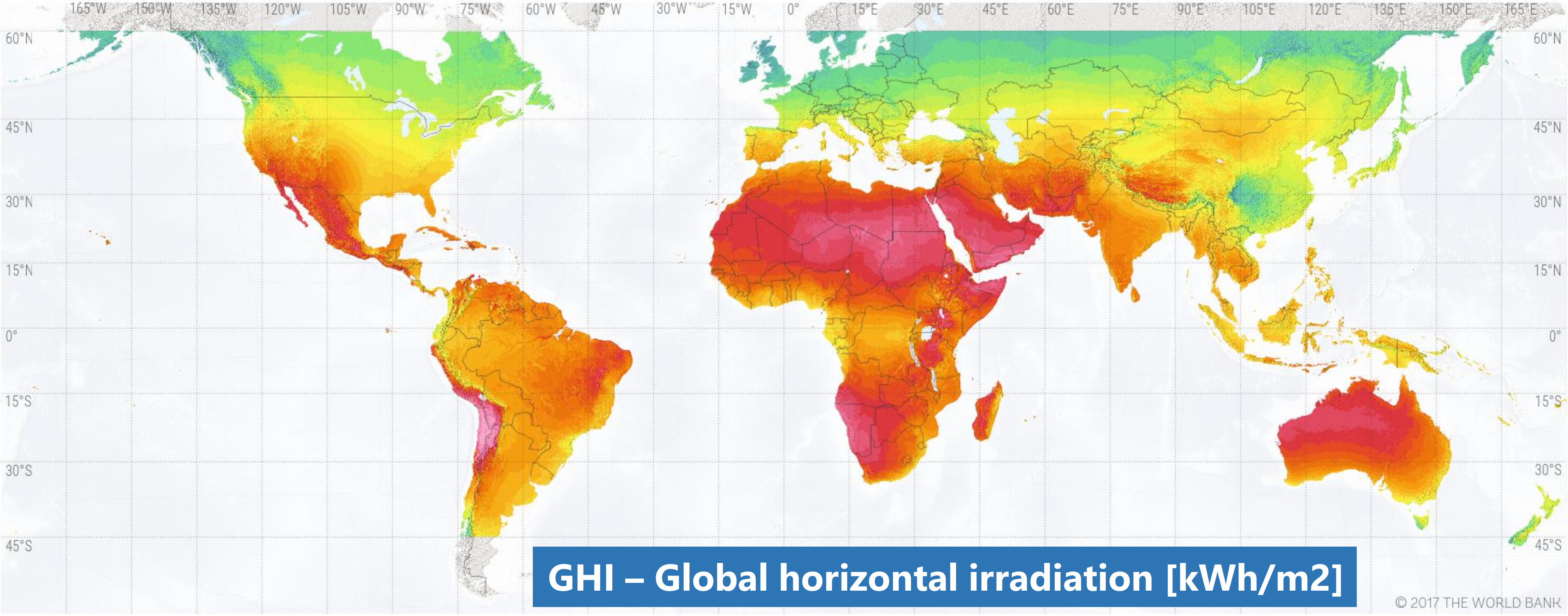
What is the potential of solar energy ?

https://solargis.com/maps-and-gis-data

Global solar potential

SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION

WORLD BANK GROUP · THE WORLD BANK · IFC · ESMAP · SOLARGIS



GHI – Global horizontal irradiation [kWh/m2]

Long-term average of daily/yearly sum

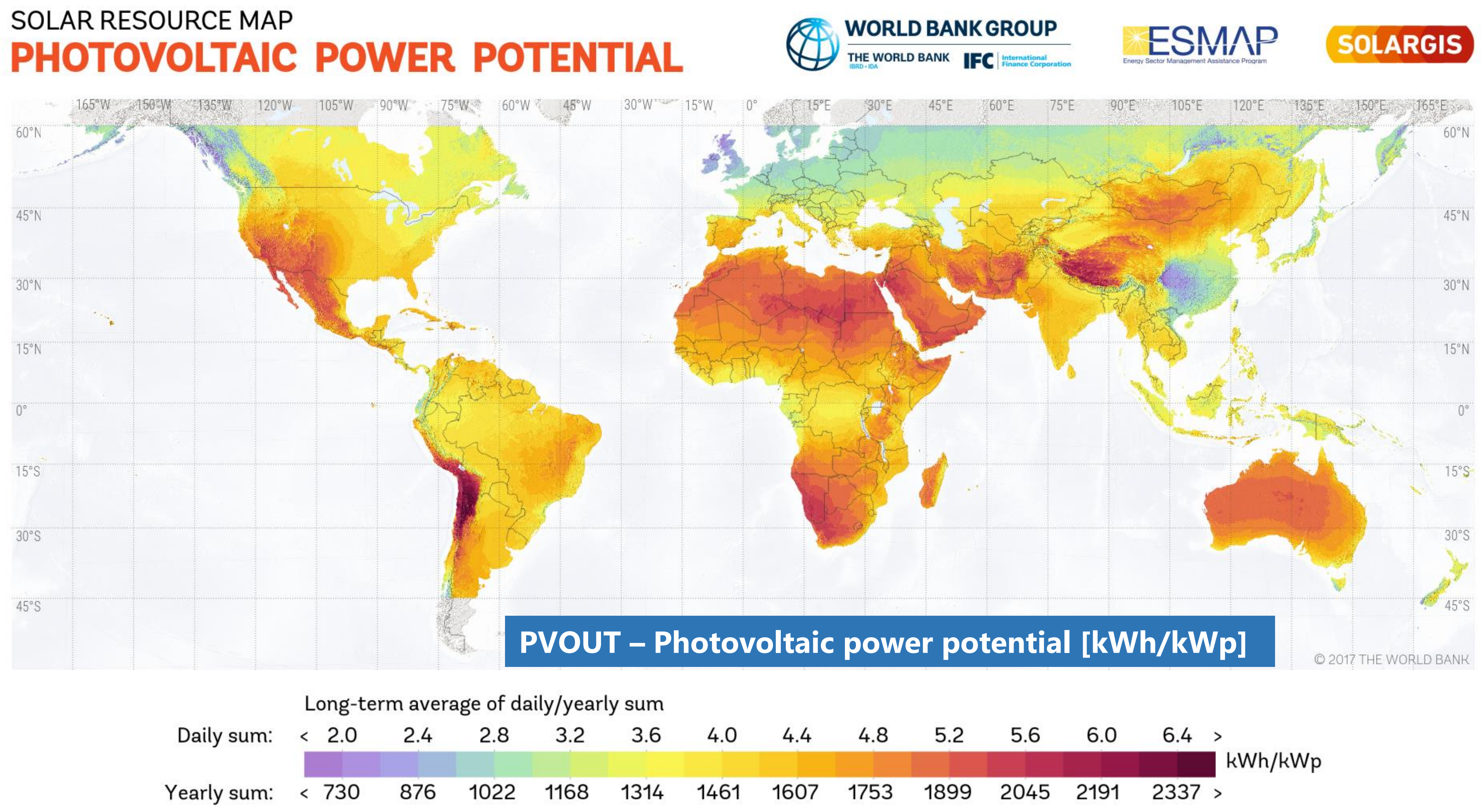
Daily sum:	<	2.2	2.6	3.0	3.4	3.8	4.2	4.6	5.0	5.4	5.8	6.2	6.6	7.0	7.4	>
Yearly sum:	<	803	949	1095	1241	1387	1534	1680	1826	1972	2118	2264	2410	2556	2702	>

kWh/m²

What is the potential of solar energy ?

https://solargis.com/maps-and-gis-data

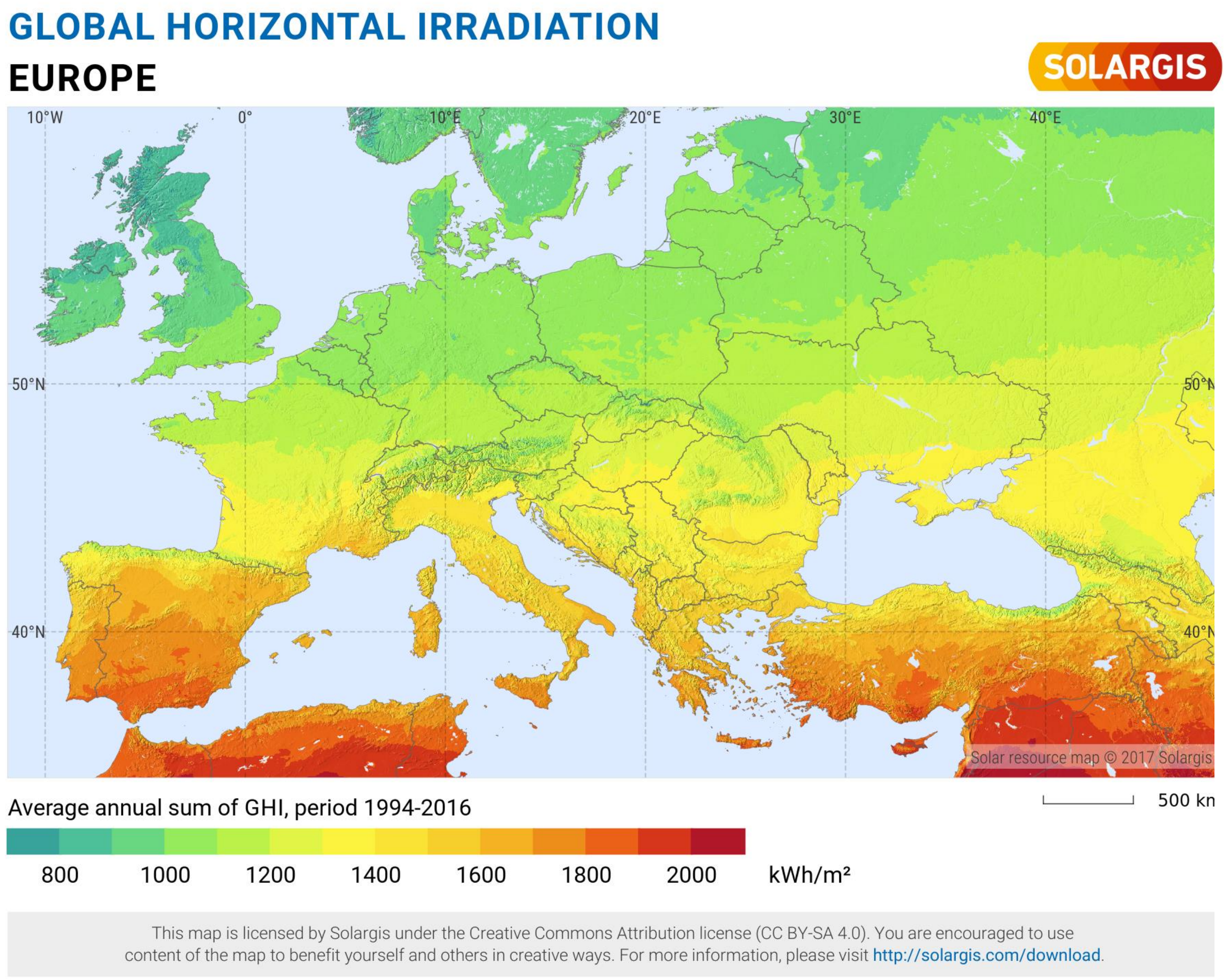
Global solar potential

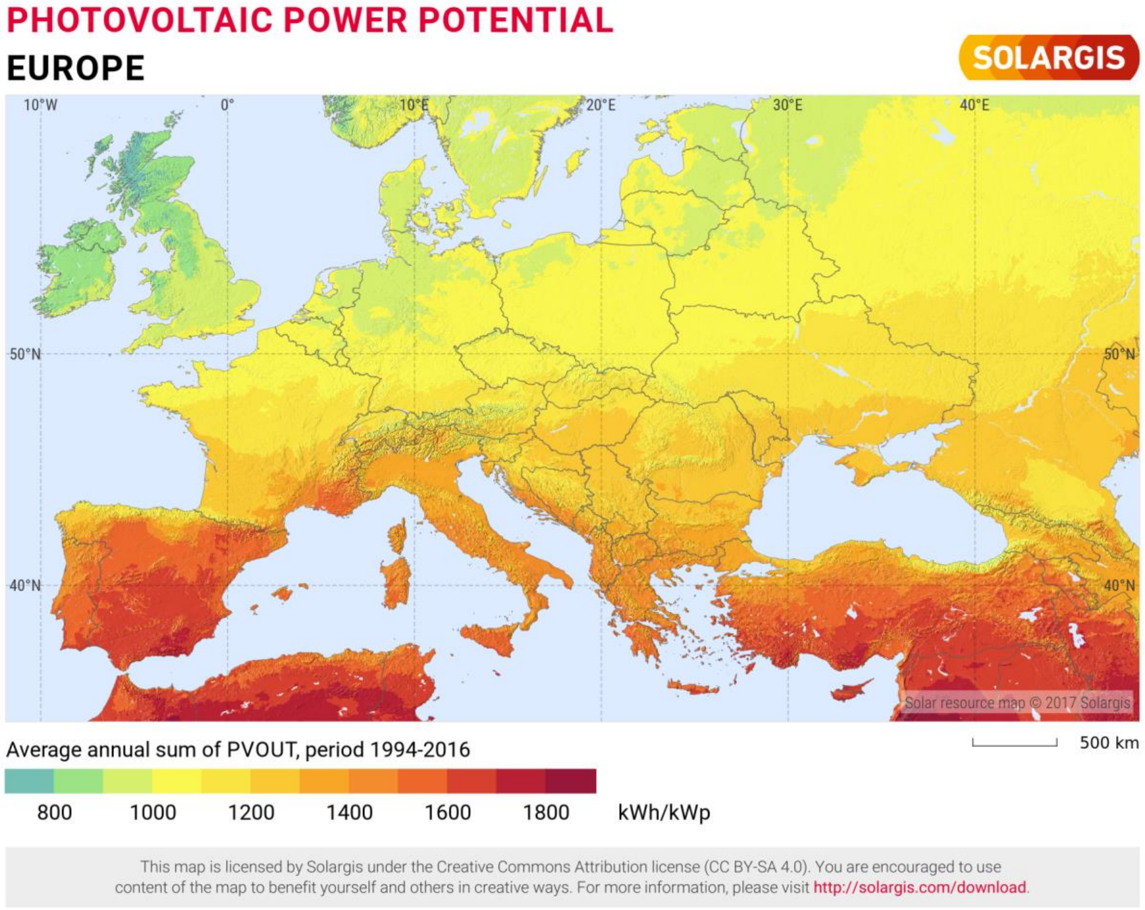


PVOUT – Photovoltaic power potential [kWh/kWp]

What is the potential of solar energy ?

European solar potential





GHI – Global horizontal irradiation [kWh/m2]

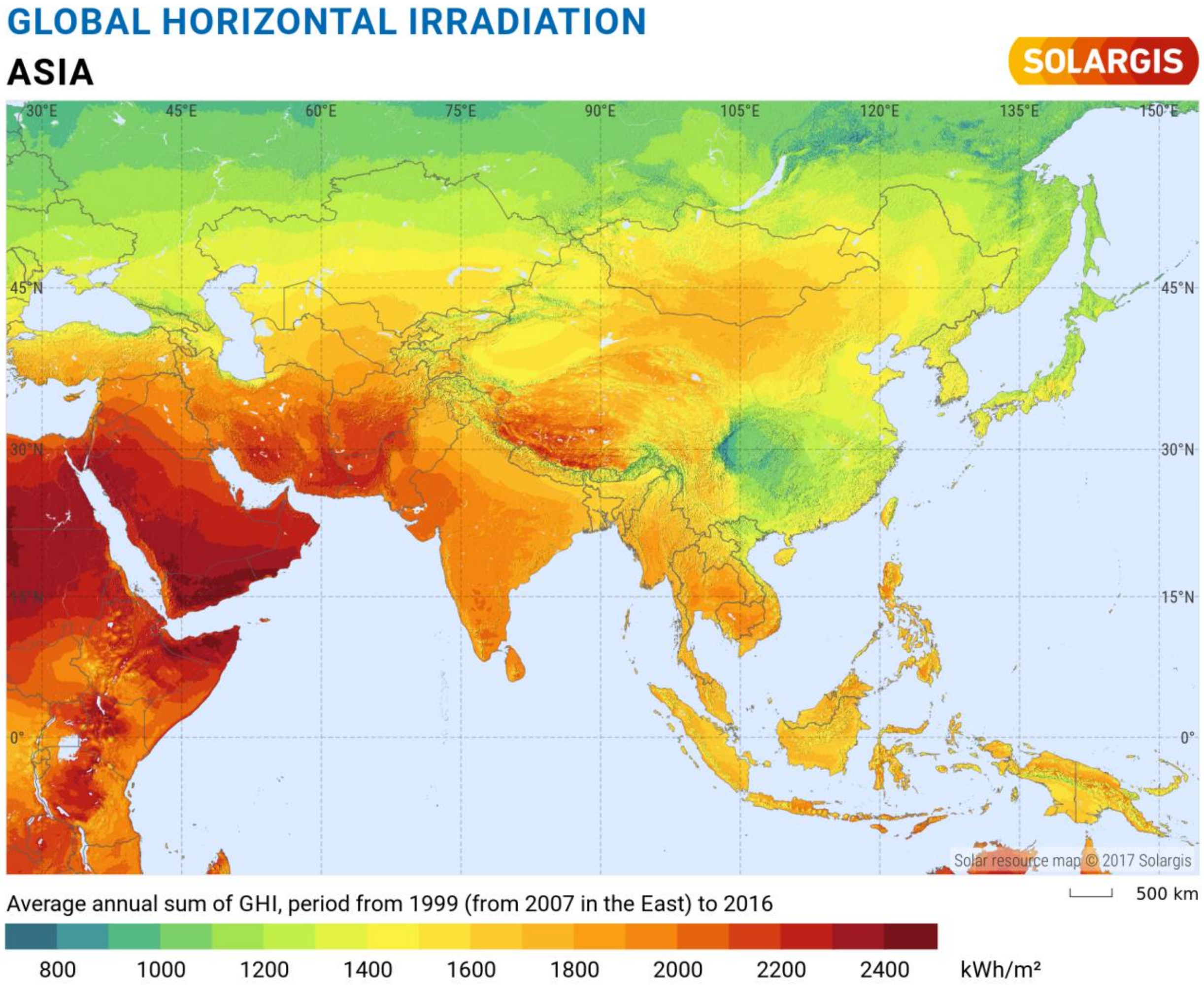
PVOUT – Photovoltaic power potential [kWh/kWp]

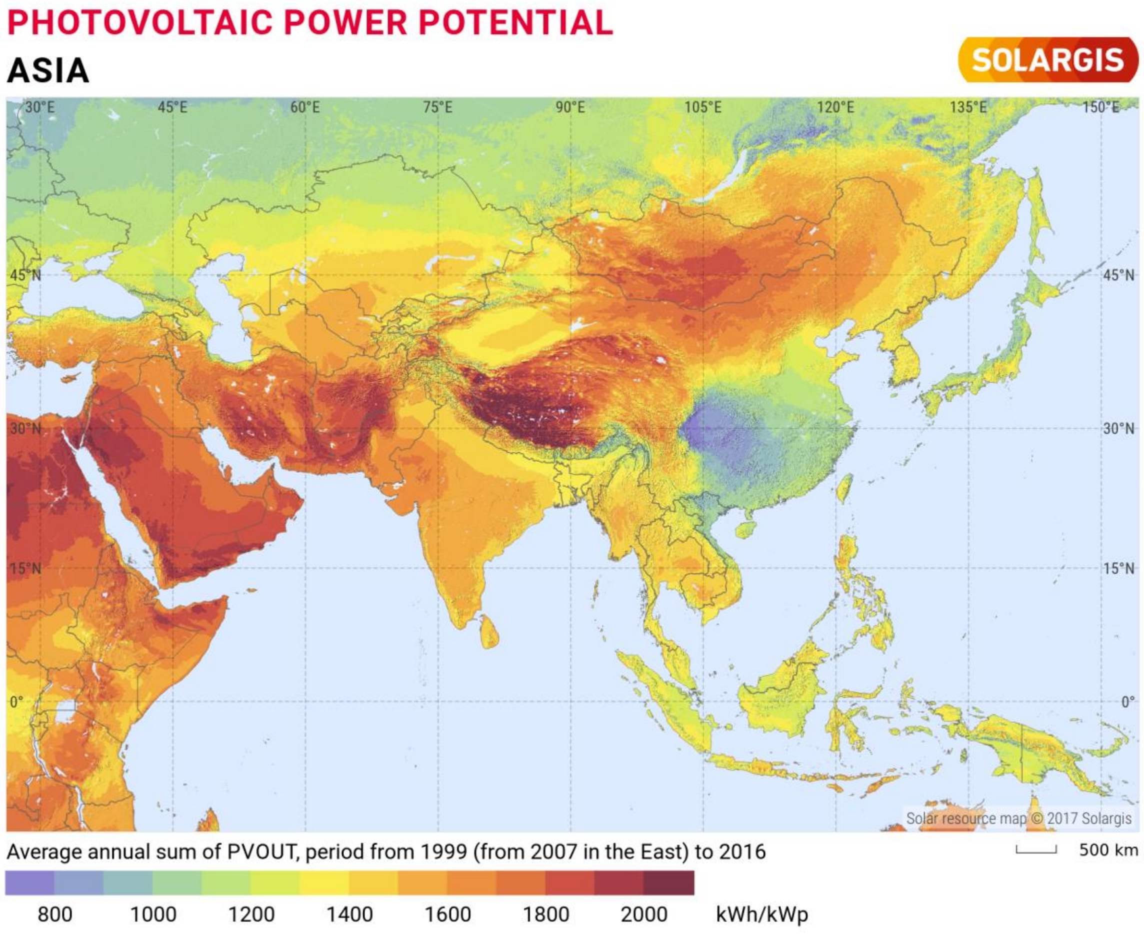
https://solargis.com/maps-and-gis-data

What is the potential of solar energy ?

https://solargis.com/maps-and-gis-data

Asia solar potential



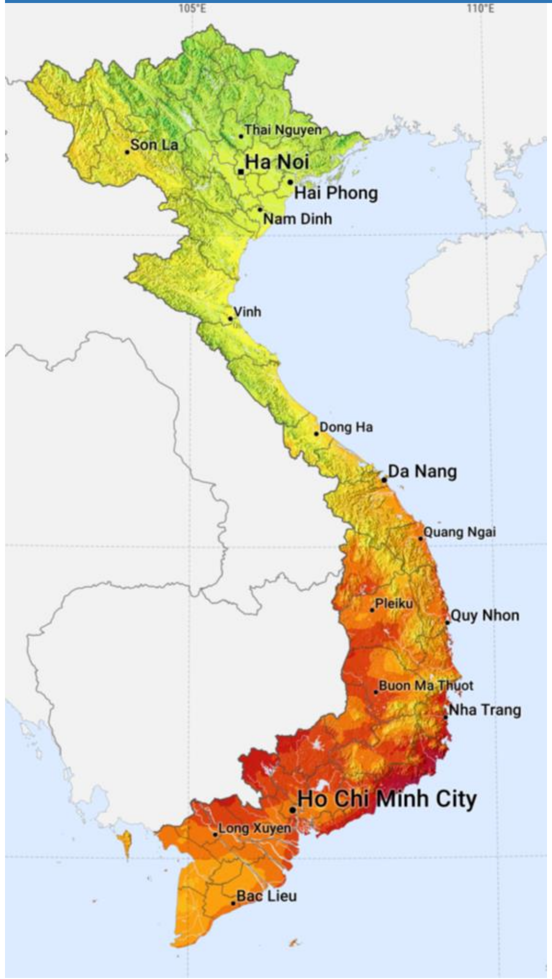


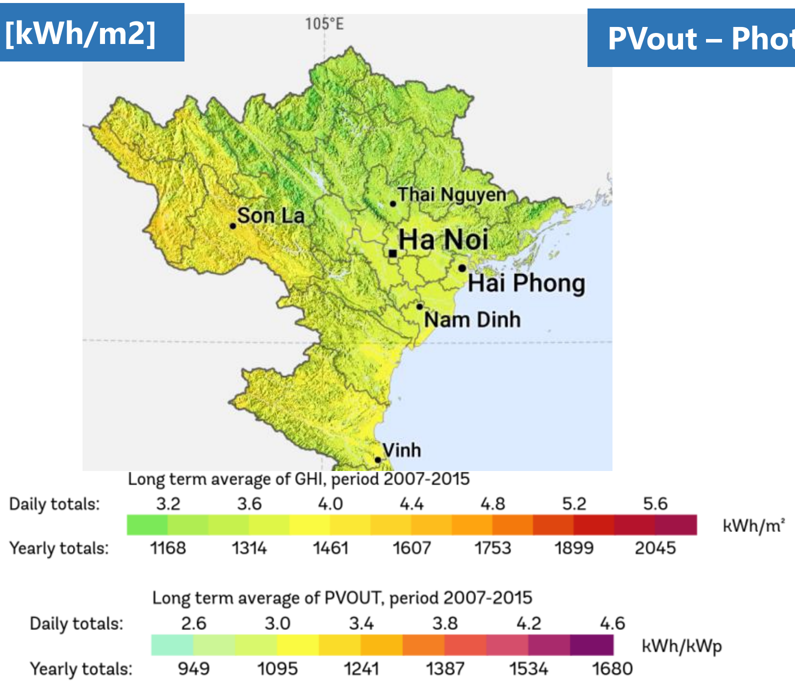
GHI – Global horizontal irradiation [kWh/m2]

PVOUT – Photovoltaic power potential [kWh/kWp]

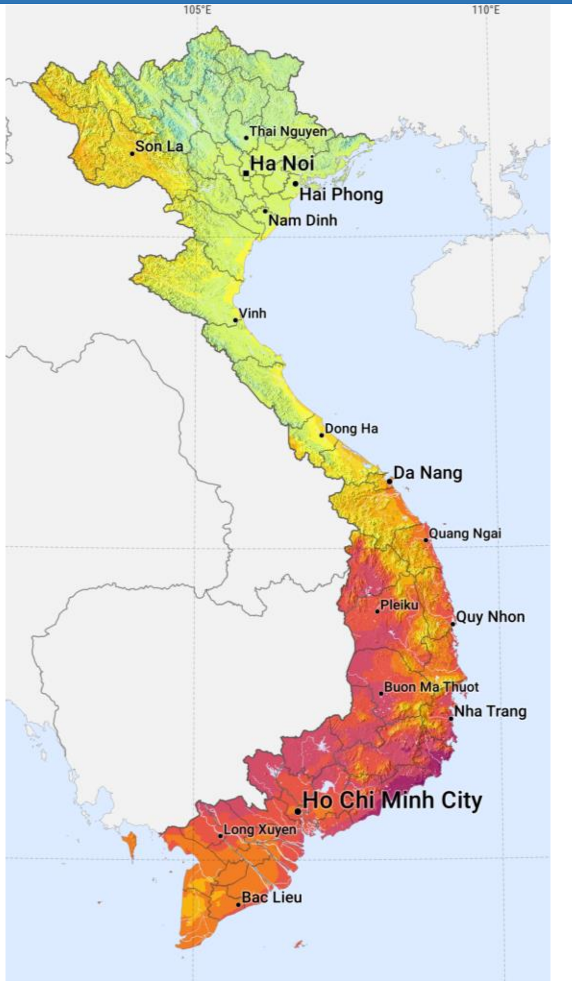
What is the potential of solar energy in Vietnam ?

GHI – Global horizontal irradiation [kWh/m2]





PVout – Photovoltaic power potential [kWh/kWp]



Areas	Sunshine Hours	Solar Radiation Intensity (kWh/m2/day)	Remark
North East	1600 – 1750	3,3 – 4,1	Fair
North West	1750 – 1800	4,1 – 4,9	Fair
Middle North	1700 – 2000	4,6 – 5,2	Good
Central Highlands and South Central Region	2000 – 2600	4,9 – 5,7	Very good
South	2200 – 2500	4,3 – 4,9	Very good
Country on average	1700 – 2500	4,6	Good

In the best scenario, might be 2-5 GW for residential and commercial rooftops, and 20 GW for solar PV plants

→ Ref " GIZ, report - Framework Assessment for the Promotion of Solar Energy in Viet Nam, 2015'

What is the potential of solar energy ?

- The change in the atmosphere of solar radiation obeys fairly complex phenomena and especially in largely random. The state of our sky and therefore the luminous flux received at ground level at a given instant depends on a number of parameters:
  - Gases in the atmosphere;
  - Clouds;
  - Albedo;
  - Ambient temperature ;
  - Wind speed;
  - Relative humidity, …
- **However, these parameters depend on:**
  - Geographical location;
  - Season;
  - The time of day;
  - Current weather conditions, ...

Geographical Location

Weather Database

Weather Database

- Weather stations develop solar radiation statistics from billions of data collected. Databases are so constituted, with other information such as minimum and maximum temperatures, atmospheric pressure, humidity, ... Unfortunately, access to this information is not always obvious and almost always surcharge.

- However, these data are essential for sizing a photovoltaic system.

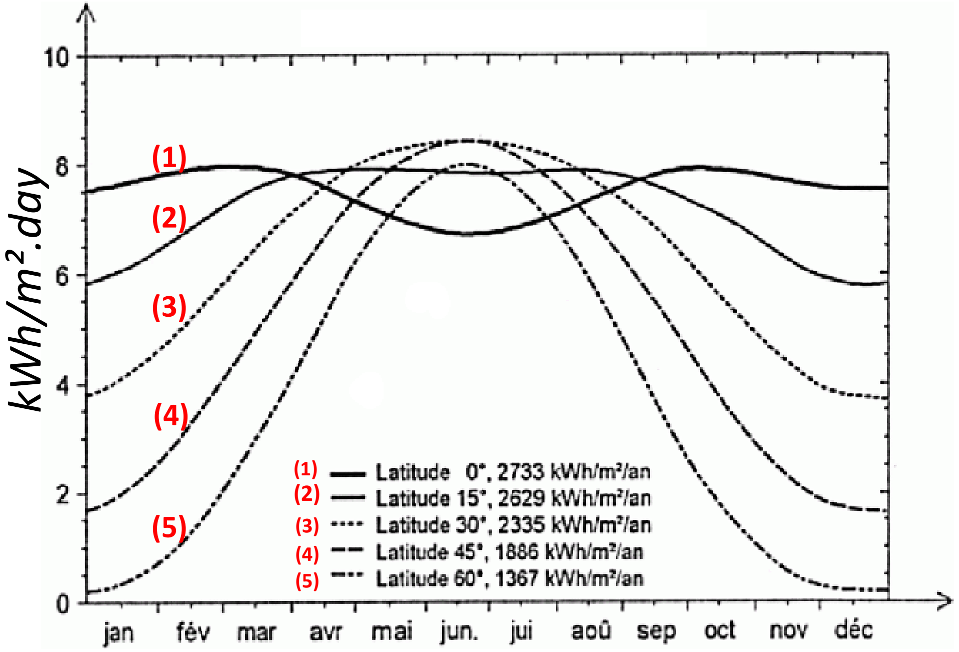
- Examples :
  - PVGIS : http://re.jrc.ec.europa.eu/pvgis
  - Meteonorm : www.meteotest.ch
  - NASA : http://eosweb.larc.nasa.gov/sse/
  - RETscreen : www.retscreen.net
  - Pvsyst : www.pvsyst.com

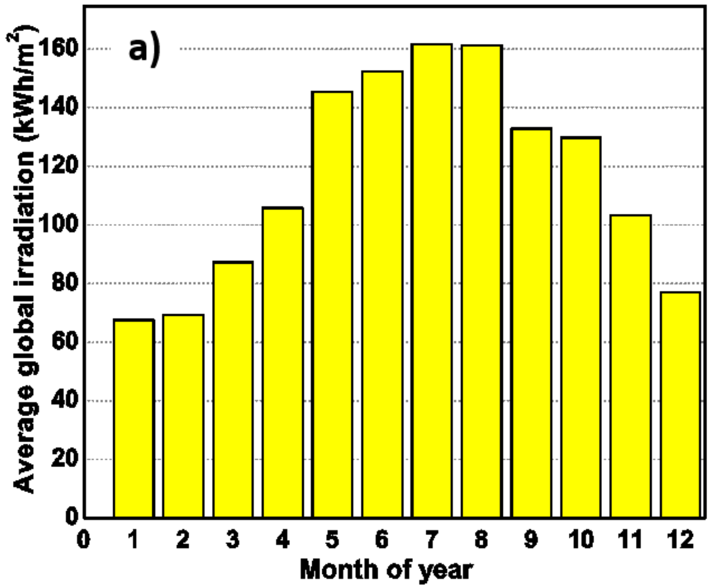
https://energydata.info/dataset/esmap-solar-measurements-in-vietnam

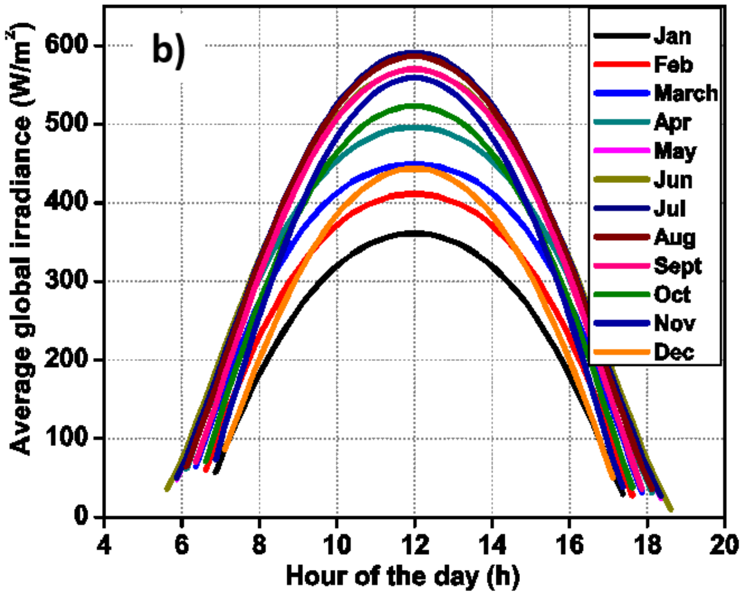
Latitude

- **Ideal daily global radiation (model of a clear cloudless day*) depending on the season and latitude.**

*Hanoi - 21°01'42"N 105°51'15"E (a: Meteonorm and b: Climate-SAF PVGIS) ***







In countries with low latitudes (15 ° S and 15 ° N), the daily radiation is relatively constant and the electrical output of the photovoltaic generator varies little during the year. By cons, when the contrast summer / winter is accentuated with higher latitude, designer must be based on the lowest of the year sunshine and manage the excess energy during the sunny season.

** Source : Energie Solaire Photovoltaïque - Anne Labouret, Michel Villoz)*

*** Source: Performance comparison between tracking and fixed photovoltaic system: A case study of Hoa Lac Hi-tech Park, Hanoi – Xuan Truong Nguyen and al*

Measurement

- **Scientists, especially climatologists, developing models to describe and predict the atmospheric phenomena, but the safest way to have reliable data is still resorting to statistics accumulated over previous years, with measurement instruments.**

Pyranometer for measuring solar irradiance)

Sunshine recorder (records the amount of sunshine at a given location)

Pyrheliometer (measures of direct beam solar irradiance)

- In practice, these devices are expensive and unwieldy. For current measurements, but precise, professional use solar cells reference calibrated by laboratories (LCIE, Ispra, Fraunhofer Institute, ...). This allows manufacturers to calibrate the electrical measuring devices of PV modules.

- Even more economical for the installer, a simple solarimeter equipped with a small crystalline silicon cell can be sufficient for an evaluation if one does not seek a measure within **5% accuracy**.

Solarimeter (Solar Power Meter)

PV conversion

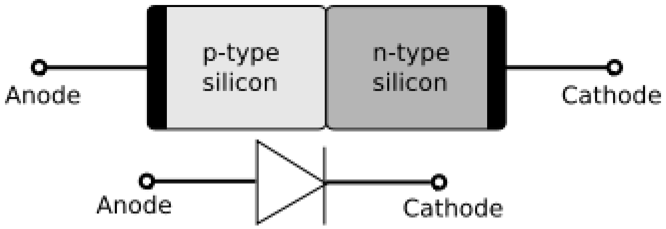
a) **explains the basic principles of photo-electric conversion, basic parameters of a solar cell, generations of solar cells, basics of solar photovoltaic technology**

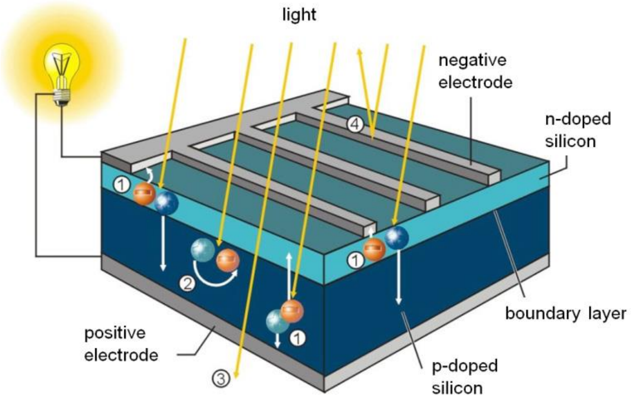
b) **explains the construction and parameters of solar modules and solar arrays.**

- ***PV conversion = conversion of light into electricity***.
- 3 physical phenomena :
  - Absorption of light in the material
  - The transfer of energy from photons to electrical charge
  - Electrical charges collection
- Therefore, it’s clear that the material must have specific optical and electrical properties to allow the photovoltaic conversion.

✓ **The solar cell:** A diode that generates a current

Solar cell





Electrodes solar cell

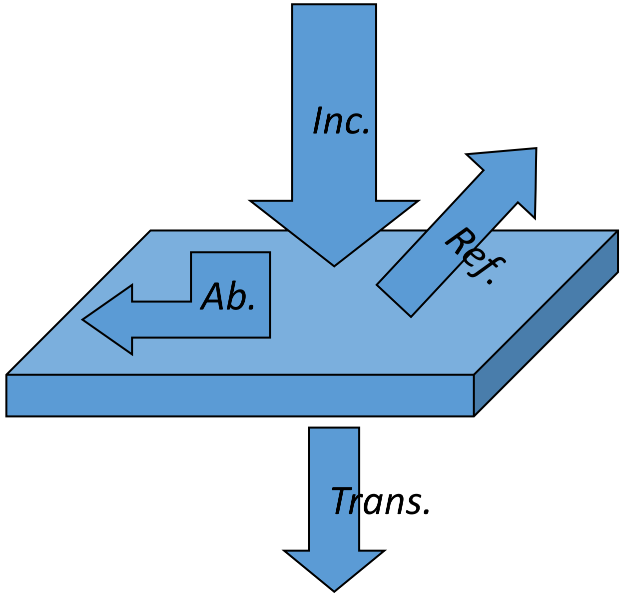
PV conversion

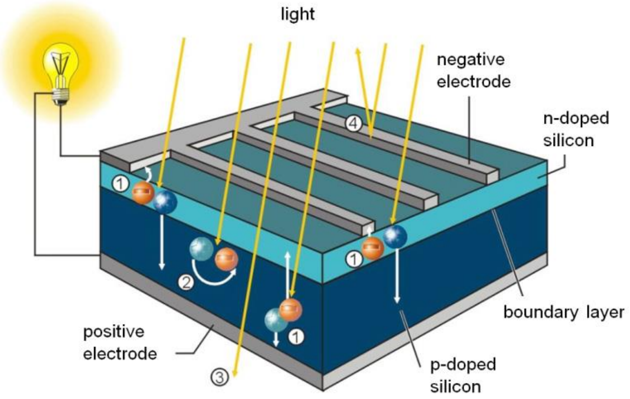
The solar cell: A diode that generates a current

Converting light into electricity (1/8)

- 3 optical events:
  - Reflection
  - Transmission
  - Absorption

Inc. = Ab. + Ref. + Trans.





Electrodes solar cell

- Light absorbed:
  - Often converted into heat (infrared radiation).
  - In a PV material, a portion will be converted into electrical energy.

PV conversion

The solar cell: A diode that generates a current

Converting light into electricity (2/8)

What about a piece of colored glass in red **?**

- **It transmits the red light because the eye receives it. About the reflected portion, it will amount to 8% of the luminous flux from all colors, because of the glass refractive index. And the rest of the light (blue, yellow, ...) will be absorbed in the material.**

Converting light into electricity (3/8)

- **In a photovoltaic material, a portion of the absorbed light output will be returned in the form of electrical energy.**
- **It should, initially, the material has the ability to absorb visible light, since that's what we try to convert (sunlight or other artificial sources)**

Converting light into electricity (4/8)

What happens when a material absorbs light?

- Energy follows a decreasing exponential law, because the part that remains to absorb, it decreases gradually as we enter into the material.
- The remaining energy, at depth z, in a material follows the law:

$$\boxed{E(z) = E_{inc} e^{-\alpha . z}}$$

- The energy absorbed, at depth d, of material is:

$$\boxed{E_{abs} = E_{inc} - E_{inc} e^{-\alpha . d} = E_{inc} \left(1 - e^{-\alpha . d}\right)}$$

- The absorption coefficient α depends on:
  - material
  - of the wavelength of the incident energy

The solar cell: A diode that generates a current

Converting light into electricity (5/8)

- Examples :
  - *Silicon:*
  - on a 100 µm thick slice, all of the incident energy is absorbed
  - *Amorphous silicon:*
  - a layer of 1 mm is sufficient to capture all of the radiation.

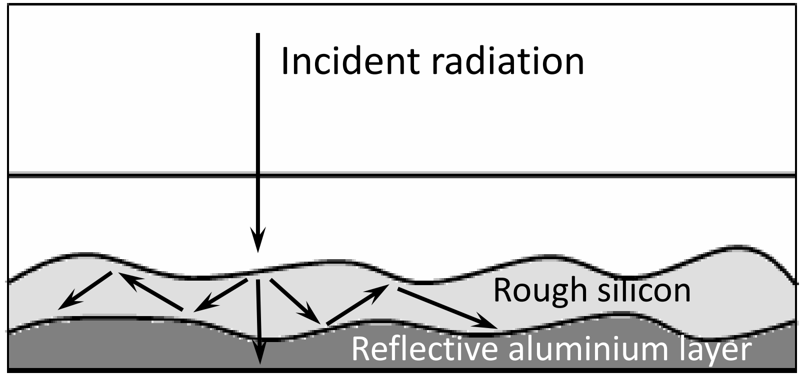
Data for λ=0,59μm :

Material	α (cm^{-1})
Crystalline silicon	$4{,}5.10^3$
Amorphous silicon	$2{,}4.10^4$
Gallium arsenide	$5{,}4.10^4$

Additional techniques can improve the process:

- Using an aluminum reflective layer at the back of the active layers (reducing transmission losses).
- Increase diffusion by increasing the roughness of the active layers.

Trapped light



PV conversion

The solar cell: A diode that generates a current

Converting light into electricity (7/8)

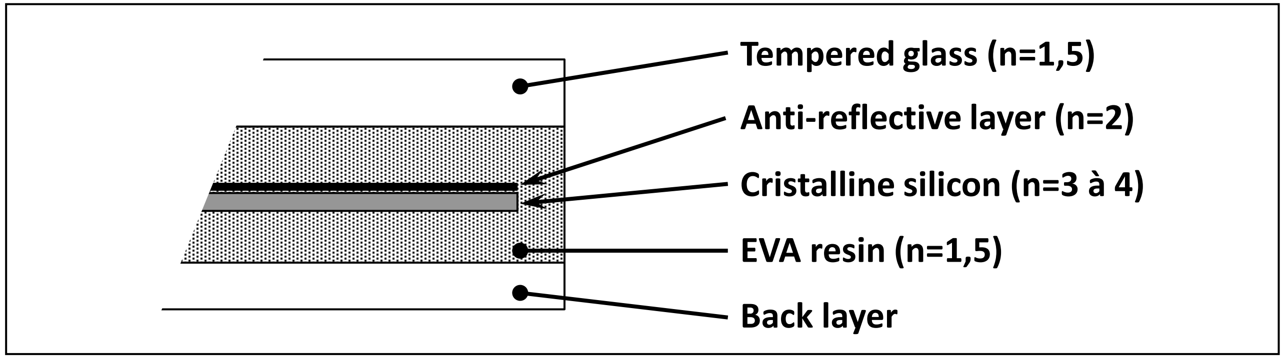
- Reflection rate: $$R = \left(\frac{n_2 - n_1}{n_2 + n_1} \right)^2$$

What about raw silicon ?

- Raw Silicon (n = 3.75 for **l** = 0.6 mm)
- **R = 33% !!**

In practice,

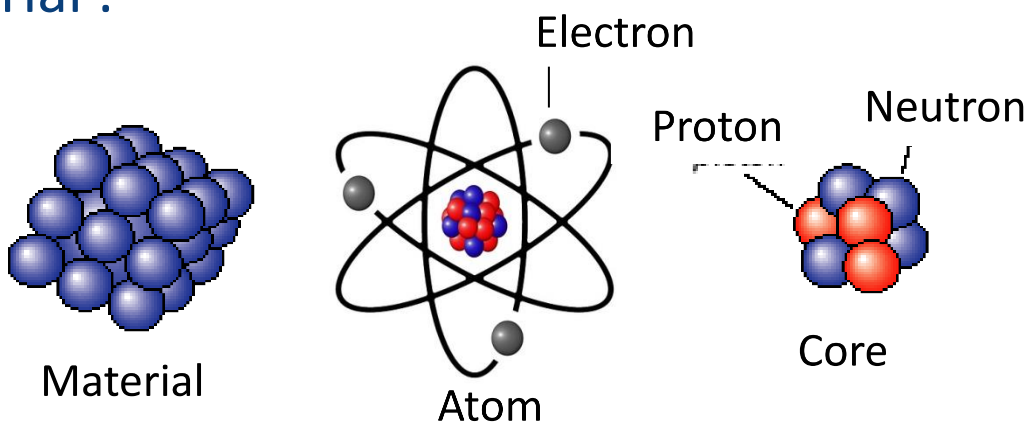
- **EVA (ethylene-vinyl-acetate) anti-reflective and safety glass: the example of crystalline silicon.**



PV conversion

Transfer of photon energy to electrical charges

- Solid material :



How it works ?

Photons absorbed → Photon energy to electron → Release of electron → Hole

→ Electron from a neighboring atom replaces the hole → New hole created

→ New Electron from a neighboring atom replaces the hole →

→ Electric charges flow → **Electric current**

PV conversion

Electrical charges

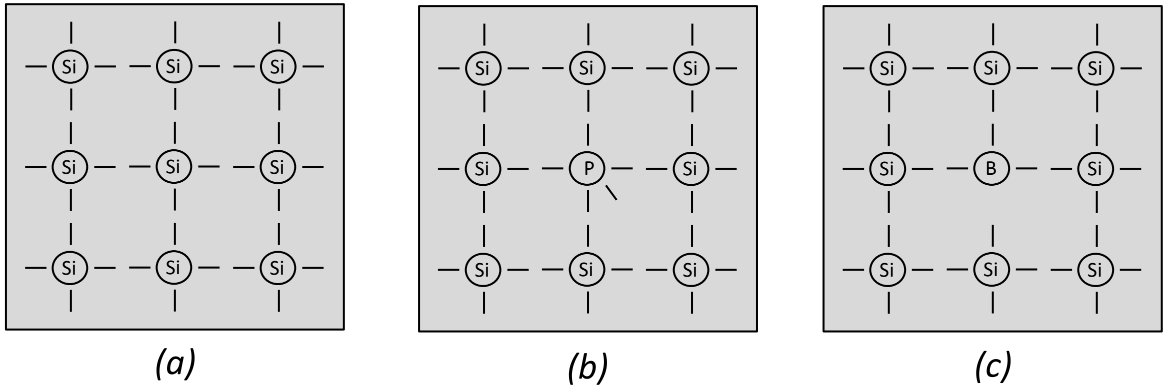
How to generate electrical energy?

- For the charges released by the illumination become energy generators, they must circulate.
- PN junction created in the semiconductor.
- Goal : Generate an electrical field
- This is possible by doping the semiconductor

PV conversion

Doping (Semiconductor)

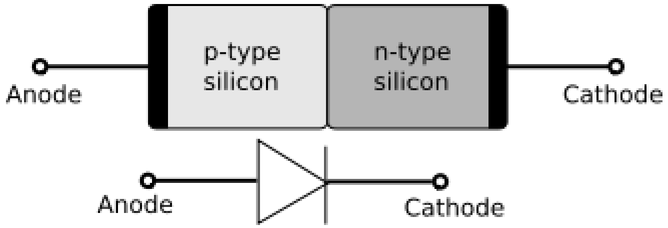
- **Doping a pure semiconductor will allow to bring excess charges that will improve the conductivity of the material.**



Schematic view of pure silicon atoms (a), n-type silicon (b) and p-type silicon

- **n-type silicon => "donor" of electrons => Phosphorous**
- **p-type silicon => "acceptor" of electrons => Boron**

- **A PN junction is a boundary or interface between two types of semiconductor material, p-type and n-type, inside a single crystal of semiconductor.**



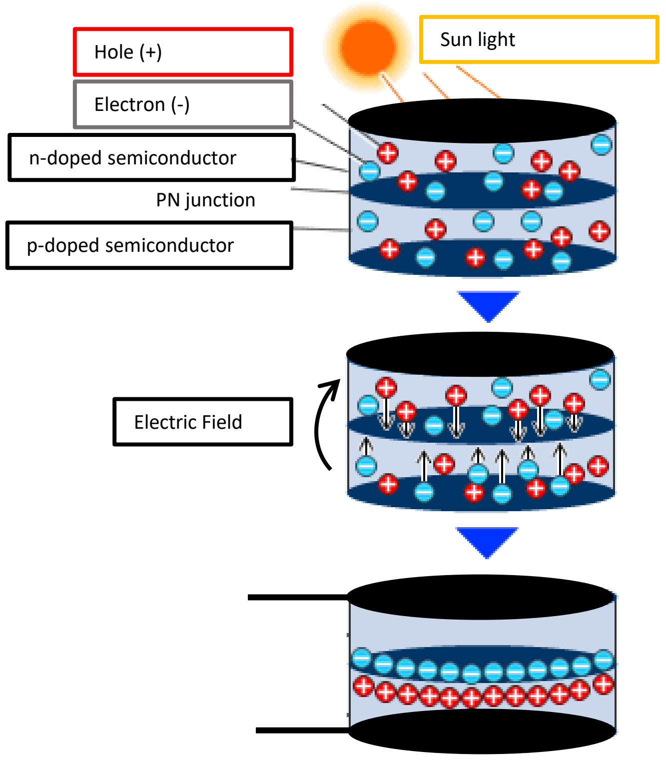
PV conversion

Process

Generation and transmission in a semiconductor material of positive and negative electrical charges in response to light:

- 1) This material has two layers, one with an excess of electrons (n-doped) and the other an electron deficit (p-doped).
- 2) When the first layer is in contact with the second, the excess electrons in the n material diffuse into the p material.
- 3) The initially n-doped region becomes positively charged, and the initially p-doped region negatively charged.
- 4) It is therefore created between them an electric field which tends to push electrons in the n region and the holes toward the p region.

- 5) A junction (p-n) has been formed. By adding metal contacts on the n and p, a diode is obtained.
- 6) When the junction is illuminated, the photons of energy equal to or greater than the width of the band gap communicate their energy to the atoms.
- 7) Each passing electron from the valence band into the conduction band, leaves a hole capable of moving, thus generating an electron-hole pair.

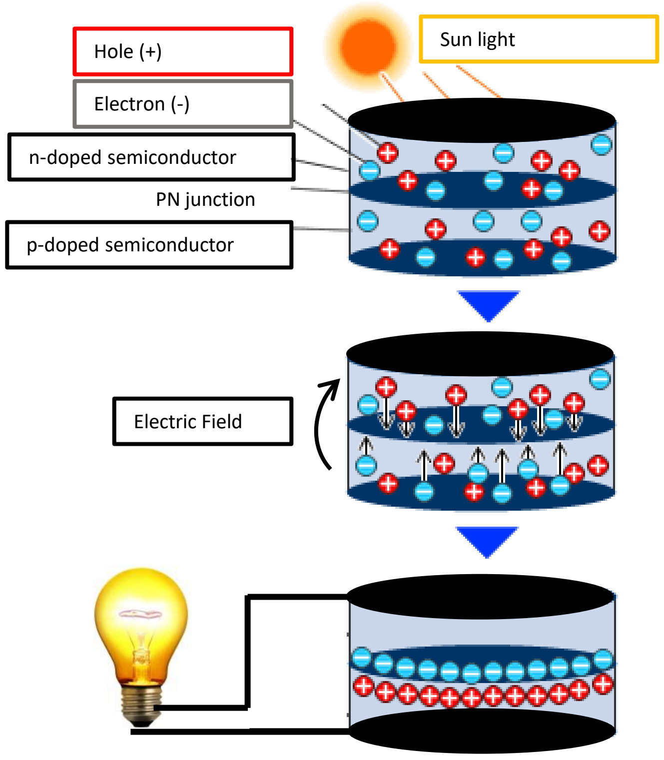


PV conversion

Process

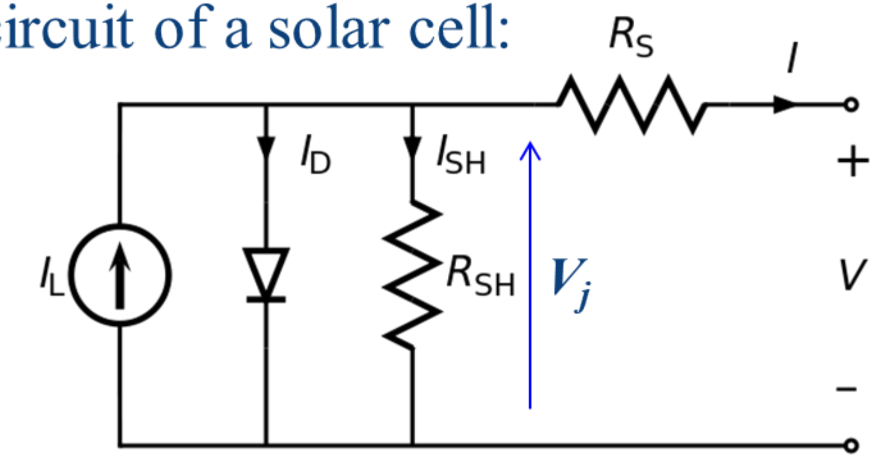
Generation and transmission in a semiconductor material of positive and negative electrical charges in response to light:

- 8) If a load is plugged across the cell, the area of the n electrons meet the holes of the p-zone via the external connection, giving rise to a potential difference: the electric current flows.



PV junction

- Equivalent circuit of a solar cell:



Determine the characteristic equation of a solar cell?

$$\boxed{I = I_L - I_D - I_{SH}}$$

- I: output current
- I_L: photogenerated current
- I_D: diode current
- I_{SH}: shunt current

$$\boxed{V_j = V + I.R_S}$$

PV junction

What about I_D?

$$I_D = I_0\left(e^{V_j/Vt} - 1\right)$$

$$I_D = I_0 e^{V_j/Vt}$$

- V: voltage imposed on the diode
- Vt: kT/q=26mV à 300K
- k: 1,38x10^{-23} Boltzmann constant
- q: 1,602x10^{-19} electron charge
- T: absolute temperature in kelvin
- I_0: reverse saturation current of the diode

- Under illumination :

$$I_D = I = I_L - I_0\left(e^{V_j/Vt} - 1\right)$$

- I_L: photogenerated current

Dr. Nguyen Xuan Truong, EN department

PV conversion

PV junction

What about I_{SH}?

$$I_{SH} = \frac{V_j}{R_{SH}}$$

What about I?

$$I = I_L - I_0\left\{e^{\frac{q(V+I.R_S)}{kT}} - 1\right\} - \frac{V+I.R_S}{R_{SH}}$$

What about Isc?

- $Isc = I_L$

What about $Vc0$?

$$V_{0C} = \frac{kT}{q}\ln\left(1+\frac{I_L}{I_0}\right)$$

- $I_L >> I_0$

$$V_{0C} = \frac{kT}{q}\ln\left(\frac{I_L}{I_0}\right)$$

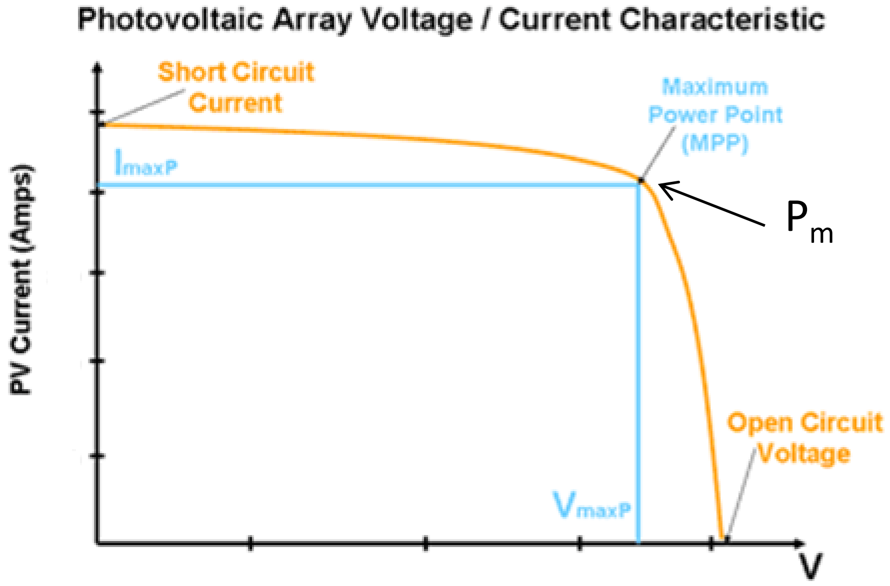
PV conversion

Power and efficiency

- At point P_m of the characteristic, the power of the cell is maximum. This point is called **maximum power point**.
- It is clear that the more the curve is square, the higher the maximum power. This property is measured by the fill factor:

$$\boxed{FF = \frac{P_m}{V_{0C} \cdot I_{SH}}}$$

- It reports the quality of the cell, incorporating the serial and parallel internal resistance.



Cell technologies

Photovoltaic solar energy

- **Photovoltaics** (**PV**) is the name of a method of converting solar energy into direct current electricity using semiconducting materials that exhibit the **photovoltaic effect**.

- A photovoltaic system employs **solar panels** composed of a number of **solar cells** to supply usable solar power. The process is both physical and chemical in nature, as the first step involves the photoelectric effect from which a second electrochemical process takes place involving crystallized atoms being ionized in a series, generating an electric current.

Solar cell

produce a *very small electrical current & voltage*

Solar panel/ PV module

produce *more voltage → more power*

Cell technologies

Different technologies

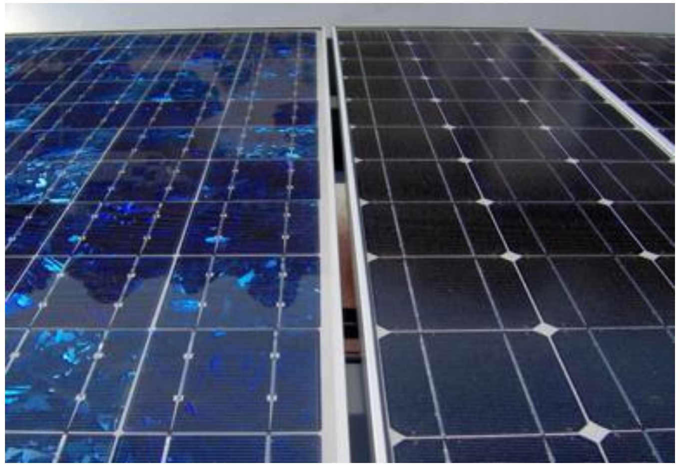
- Two main types of technologies exist:
- The first, based on crystalline silicon, covers about 85% of world production, and includes:
  - Monocrystalline silicon,
  - Poly-crystalline silicon (or multi-crystalline),
  - Amorphous silicon.
- The second, the thin film, includes:
  - Amorphous silicon cells,
  - Cadmium telluride,
  - Copper indium selenium,
  - Gallium arsenide.

- In addition, other technologies are being tested as **organic cells**, **polymers** or based on **fullerenes**.

Cell technologies

Monocrystalline silicon (mc-Si)

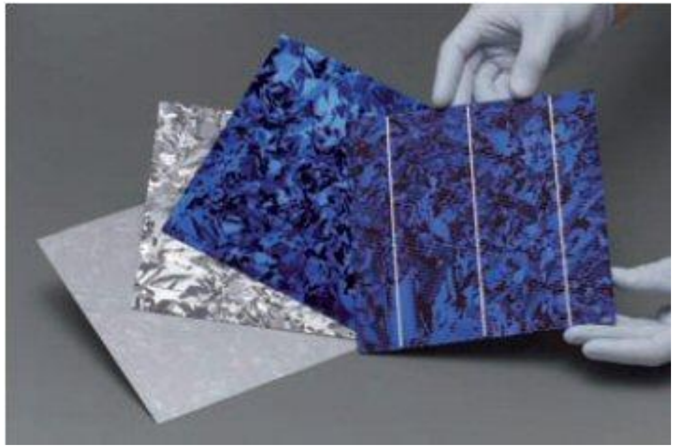
- **The technology is expensive since it requires pure silicon wafers.**
- **Its efficiency is highest (14 to 21%). This has the advantage of reducing the size of the modules for the same power, useful thing when space saving is required.**



(a) (b)
Polycrystalline silicon (a), Monocrystalline silicon(b)

Polycrystalline silicon (pc-Si)

- **The multi-crystalline technology is determined by the re-melting of scraps of silicon crystals in the electronics industry and requires 2 to 3 times less energy than the previous technology.**
- **Its efficiency is lower (12 to 14%), but its cost is more advantageous, which allows this technology to dominate the market.**

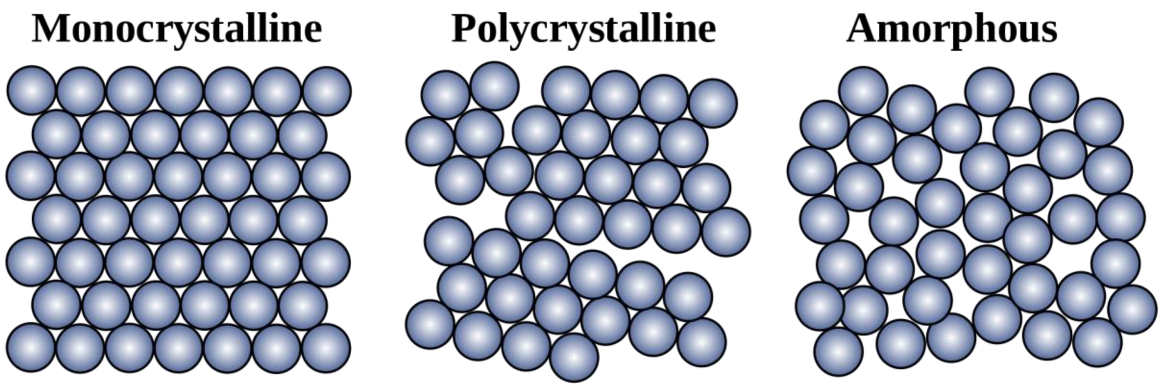


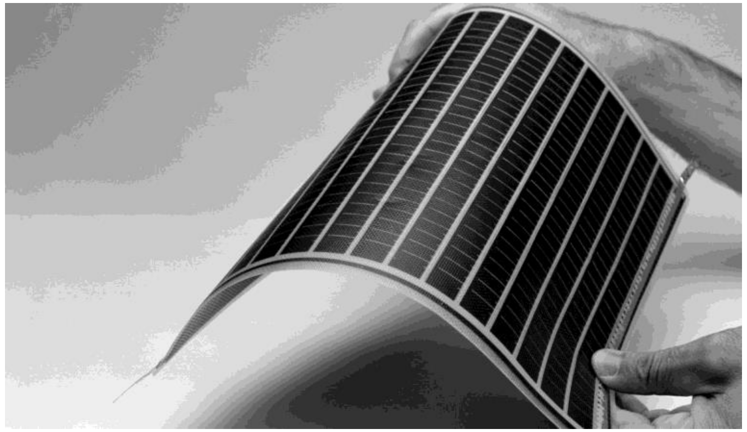
Polycrystalline silicon

Cell technologies

Amorphous silicon

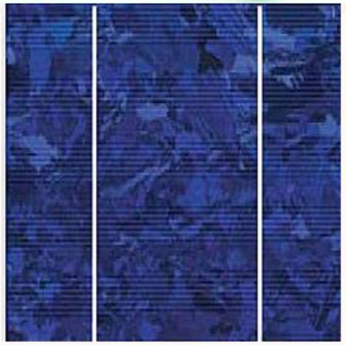
- Material composed of hydrogenated silicon (non-crystalline state) deposited on a glass substrate.
- From an efficiency worse than the crystalline silicon (5-7%), amorphous silicon is often applied to low power devices (calculators, lamps or timestamps), but firms like Solarex, Phototronix, Canon or Fortum offer modules of the same size as crystalline modules.
- Sanyo has developed an amorphous silicon technology on a monocrystalline silicon layer (HIT technology), the efficiencies are higher than that of single-crystal silicon (around 19%).





Cell technologies

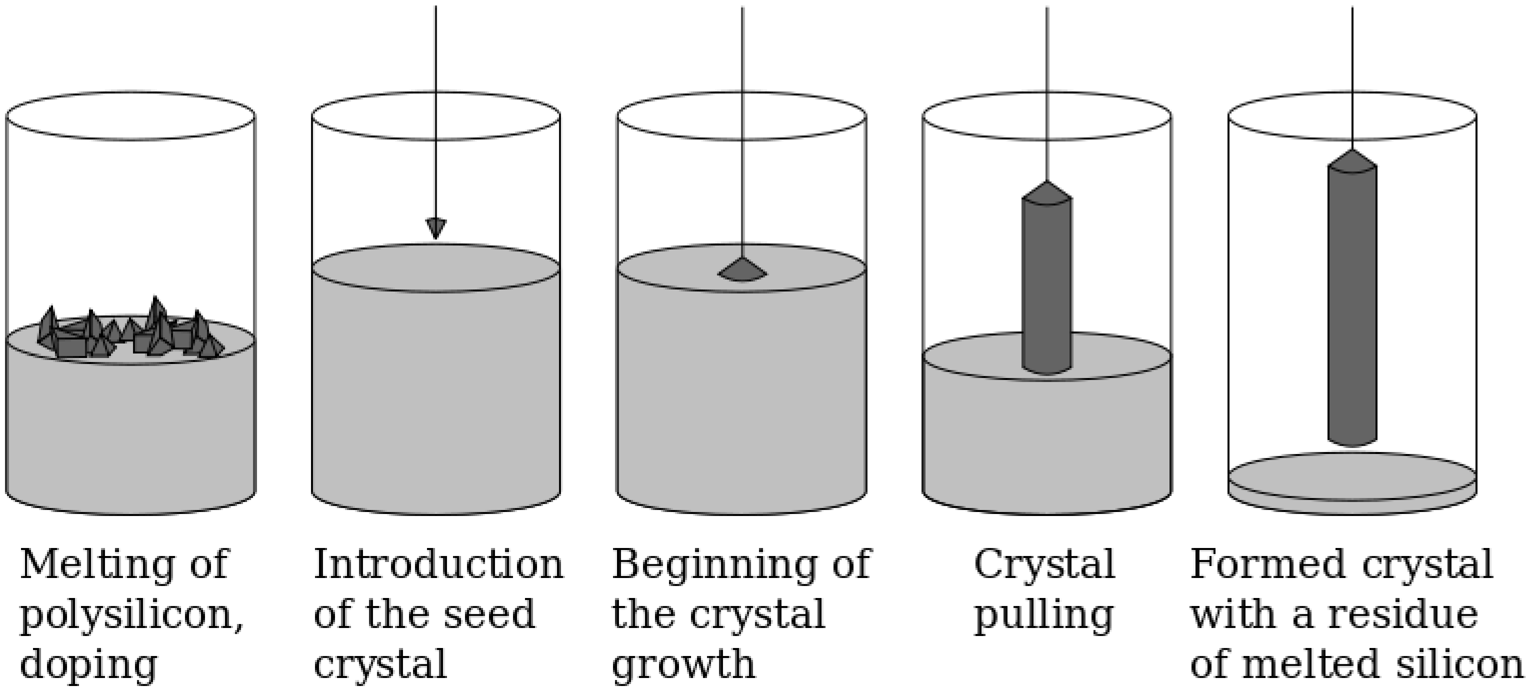
Silicon comparison

		Benefits	Disadvantages
mc-Si		✓Very good efficiency ✓Performance in terms of Production	✓very expensive ✓Low efficiency if the irradiance power is low
pc-Si		✓Proper efficiency ✓Correct performance ✓Cheaper than monocrystalline	✓Low efficiency if the irradiance power is low
amorphous		✓Productive even in low illumination ✓Less expensive than other technologies ✓Withstands high T ° C unlike the mc and pc Flexible	✓Very low efficiency ✓Performance decreases rapidly with time.

Cell technologies

Silicon wafers (1/3)

- Wafers are formed of highly pure (99.9999999% purity), nearly defect-free single crystalline material. One process for forming crystalline wafers is known as **Czochralski growth** invented by the Polish chemist Jan Czochralski.



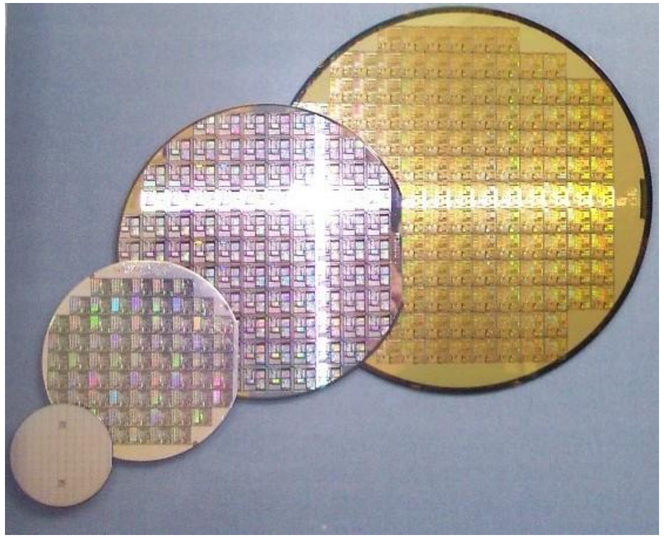
Cell technologies

Silicon wafers (2/3)

- In this process, a **cylindrical ingot** of high purity mono crystalline semiconductor, such as silicon or germanium (called “a boule”) is formed by pulling a seed crystal from a “melt”. Donor impurity atoms, such as boron or phosphorus in the case of silicon, can be added to the molten intrinsic material in precise amounts in order to dope the crystal, thus changing it into n-type or p-type extrinsic semiconductor.
- The boule is then sliced with a wafer saw and polished to form wafers. The size of wafers for photovoltaics is 100–200 mm square and the thickness is 200–300 μm.

Silicon wafers (3/3)

Monocrystalline silicon boule



2-inch (51 mm), 4-inch (100 mm), 6-inch (150 mm), and 8-inch (200 mm) wafers

Cell technologies

From the wafer to the cell

Monocrystalline silicon boule

Solar cell

Solar panel/ PV module

PV rooftop system

PV farm

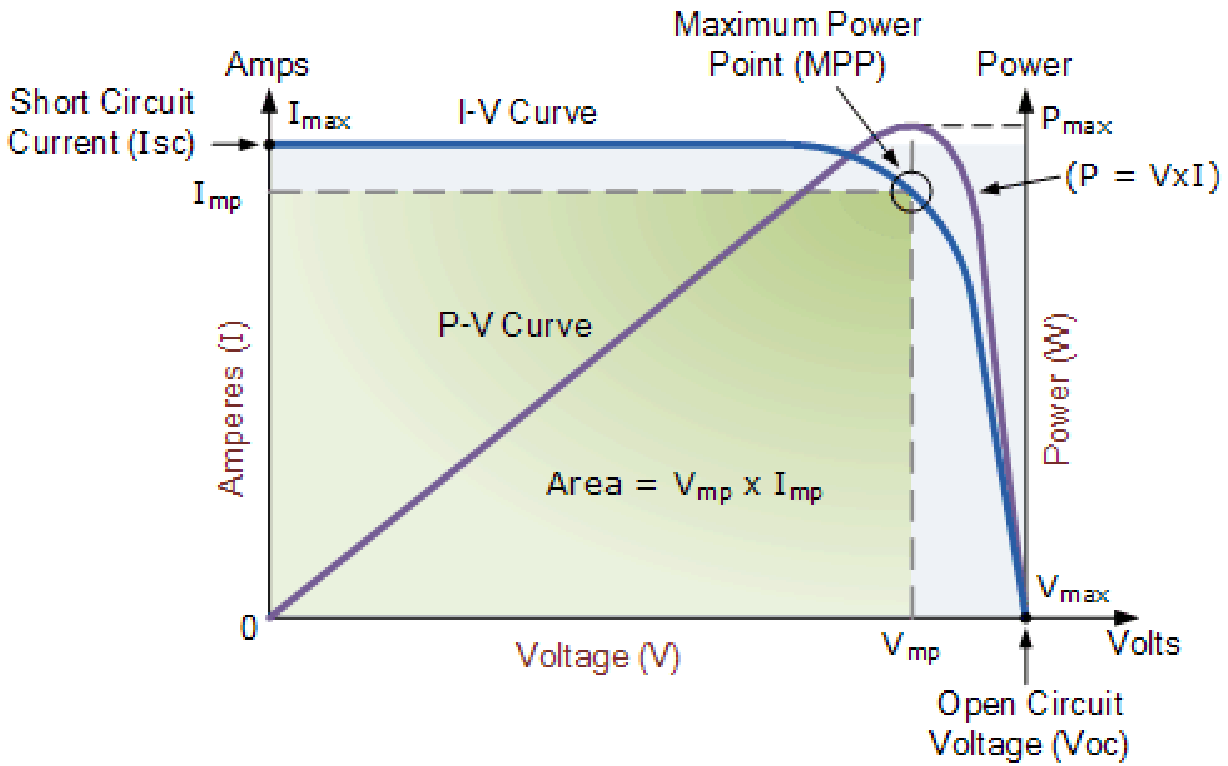
PV floating

What are the steps to manufacture the cells ?

- Pickling the surface (Eliminating sawing defects, Selective etching)
- The phosphorus diffusion (to realize the photovoltaic junction)
- Doping of the back layer with aluminum
- Depositing of an anti-reflective layer on the front
- Depositing of a gate metallization on the front (electrode (-))
- Depositing of a weldable metal on the back (electrode (+))
- Testing and sorting all cells

Electrical characteristics – PV Cell

Solar cell performances • Maximum power performance of a photovoltaic cell



A crystalline silicon cell $V_{0C} \approx 0.6V$ and a voltage at the maximum power $V_{maxP} \approx 0.45 \div 0.5V$, and will produce around 3.05 A of Imp and 3.36 A of Isc at STC

Short Circuit Current (Isc) – It is the maximum current (in A or mA) produced by the cell under given conditions of irradiance and surrounding temperature. Isc is the current when the load is short-circuited, i.e. the output voltage is zero. The output power at this point is essentially zero.

Open Circuit Voltage (Voc) – It is the maximum voltage generated by the cell under given conditions of light and temperature. Voc is the voltage when the load is open-circuited, i.e. the output current is zero. The output power at this point is again essentially zero.

Maximum Power (Pmax) – It is the maximum power that can be delivered from the cell under specific environmental conditions. The point at I-V curve at which the maximum power is attainable is called Maximum Power Point (MPP).

Current at Maximum Power (Imp) – It is the current that results in maximum power. Imp is also called the “Rated” current of the cell.

Voltage at Maximum Power (Vmp) – The voltage that results in maximum power output is called Voltage at maximum power. Vmp is also called “Rated” voltage of the cell.

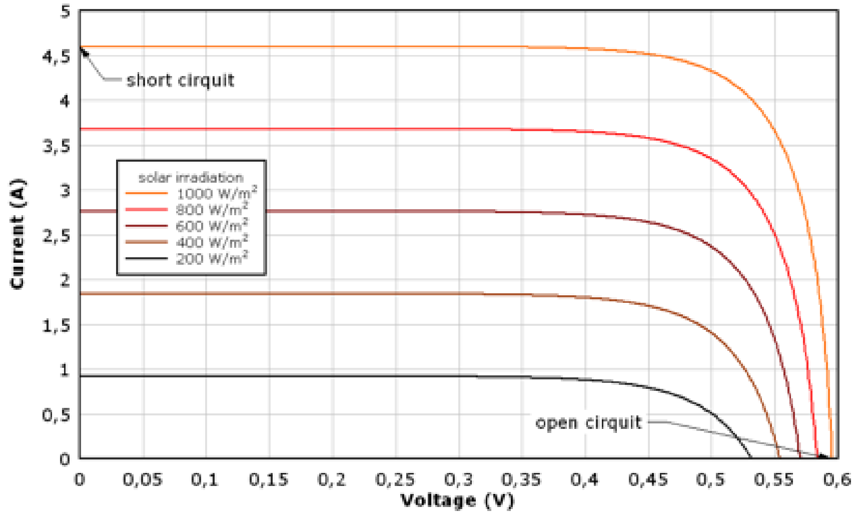
Electrical characteristics

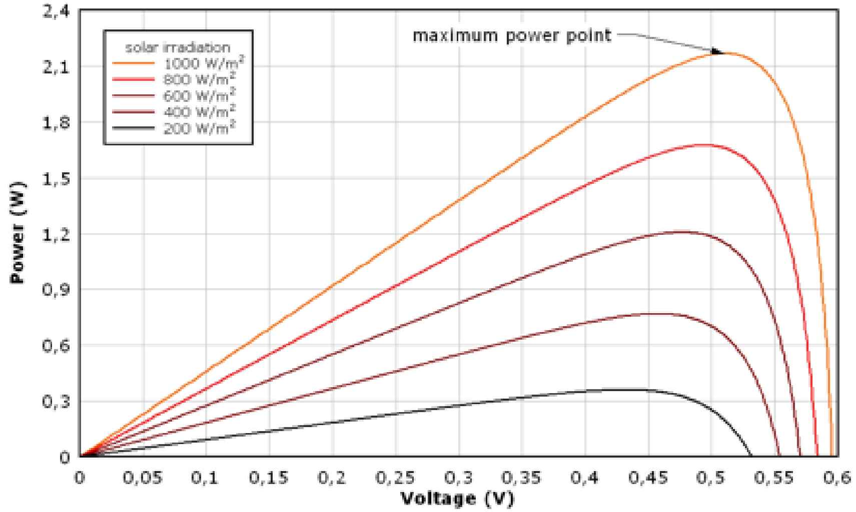
Solar cell performances • Maximum power performance of a photovoltaic cell

Solar cell I-V and power characteristics for different solar irradiation values

Influence of irradiation ?

- The production of a photovoltaic panel directly dependent on the received light flux.
- Current proportional to the solar radiation.
- Voltage is less degraded when the light varies (The voltage varies as the Logarithm of the radiation.





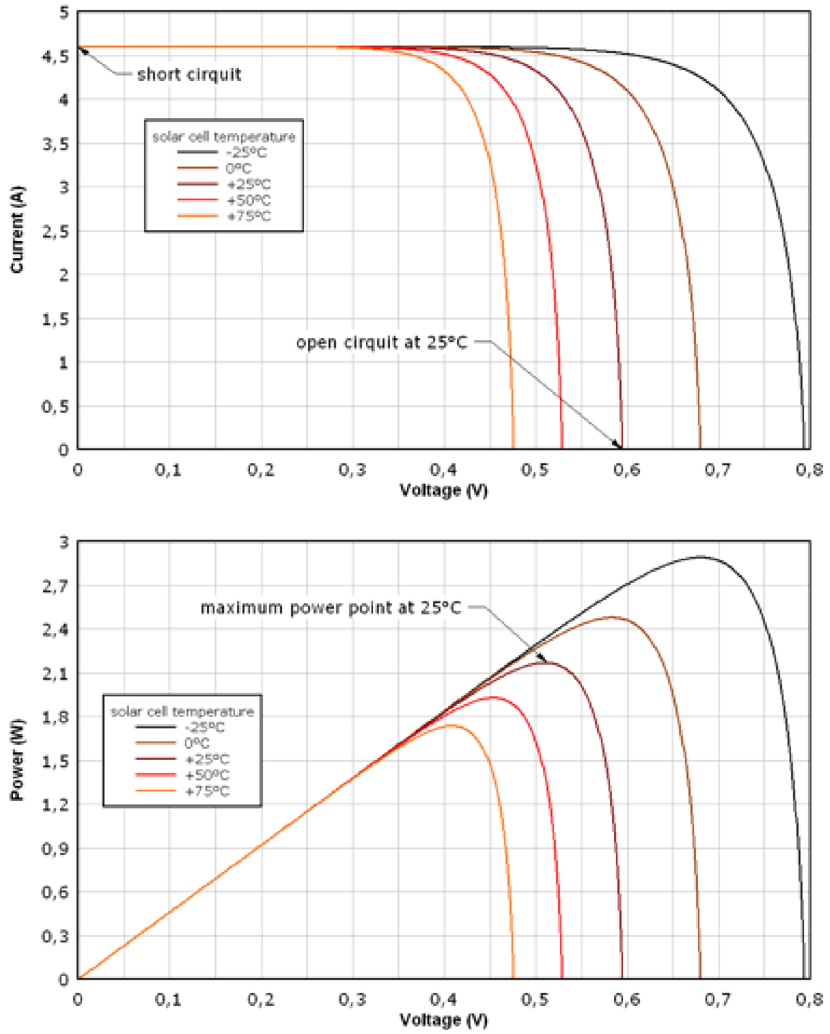
Electrical characteristics

Solar cell performances • Maximum power performance of a photovoltaic cell

Solar cell I-V and power characteristics temperature dependency

Influence of temperature ?

- The temperature has a significant impact on the performance of crystalline cells.
- Indeed, the voltage of a crystalline cell decrease with temperature.
- **The voltage of a cell typically loses 2 mV/°C.**
- It is possible to reach 70°C.
- The actual operating temperature of a cell is still above ambient temperature.



From cell to photovoltaic panel

- A single solar cell of size 4 sq. inch (105 sq.cm) will produce around 3.05 A of Imp and 3.36 A of Isc at STC. Assuming Vmp to be 0.5 V, the maximum power generated by the cell would not exceed 1.52 Wp (Watt peak). This is too low power for any practical applications. In fact, increasing the size of the cell can increase the power, but there are practical limitations of cell size.
- Therefore, numbers of cells are connected in series and/or parallel to increase the current, operating voltage as well as the output power.

✓ When two cells are connected in series the voltage doubles (or the total output voltage is the product of voltage produced by individual cell and the numbers of cells connected in series). But the current through the series connected cells will be equal to the current produced by a single cell.

✓ if we connect number of cells in parallel, the total output voltage will not change but the total current will be equal to the product of current produced by one cell and number of cells connected in parallel.

If 60 cells with Vmp = 0.5 V and Imp = 3 A are connected in series:
The Vmp for 36 series connected cells = 0.5 V* 60 = 30 V, and Imp 60 series connected cells = current produced by the single cell =3A
The total power (at MPP) in this case would be:
Pm = Vmp x Imp = 30 x 3 = 90 Wp

The I-V curve with series connected cells will now have the voltage axis shifted 36 times

If 60 cells with Vmp and Imp are connected in parallel:
The Vmp for 60 parallel connected cells = Vmp of single cell = 0.5 V, and Imp for 60 parallel connected cells = Imp (of a single cell) * 60 = 3 * 60 = 180 A.
The total maximum power in this case will be Pm = 0.5 V x 180 A = 90 Wp.

The I-V curve with parallel-connected cells will now have the current axis shifted 36 times.

The power will be multiplied by number of cells no matter how these cells are connected (in series or in parallel)

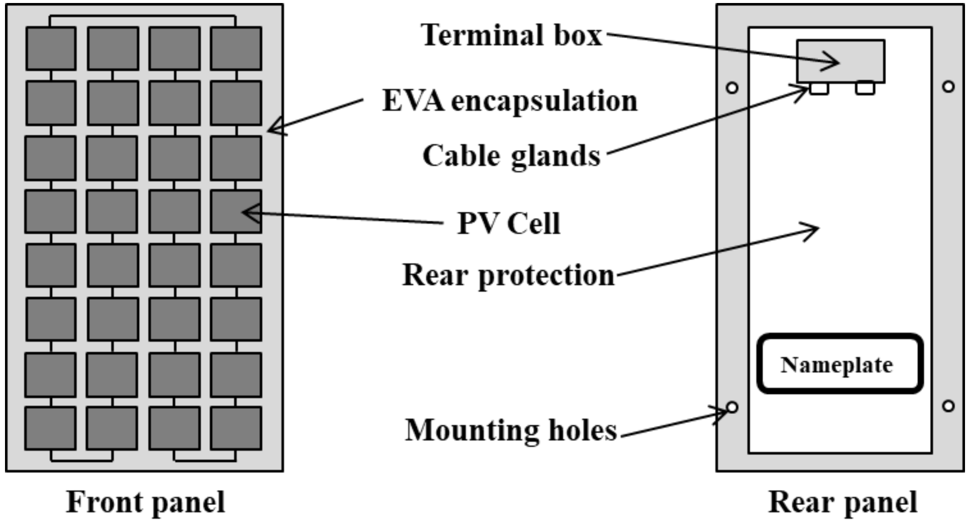
From cell to photovoltaic panel

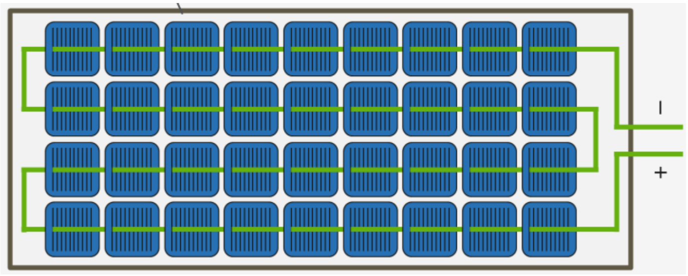
A solar module is nothing but number of cells connected either in series (in most of the cases it is the series connection that makes a module) or in parallel and encapsulated in a single frame.

- Panels of various powers are formed depending on the surface implementation (1 to 400 Wp per panel), capable of generating direct current.
- Cells connected in series.
- Standard cell size:156mm x 156mm.

Solar cell

Solar panel or Solar module





What's going on when the cells are in series?

- Tensions are added
- The current is the same as that of a single cell
- => So, always add cells with the same current in series.

3 cells in series

From cell to photovoltaic panel

How to define the number of cells per panel?

- A crystalline silicon cell $V_{0C} \approx 0.6V$ and a voltage at the maximum power $V_{maxP} \approx 0.45\text{-}0.5V$.

- In most common load for a solar PV application is a 12V storage battery. To charge a 12 V battery fully, the charging voltage needs to be not less than 14-15 V. So most modules are made of enough cells in series to produce at least 14.5 V at MPP, to be able to efficiently charge the batteries.

- To achieve this voltage, 30-36 Silicon cells or 24-28 thin film silicon cells are connected in series. The I-V curve for a single cell is added along the voltage axes 36 times.

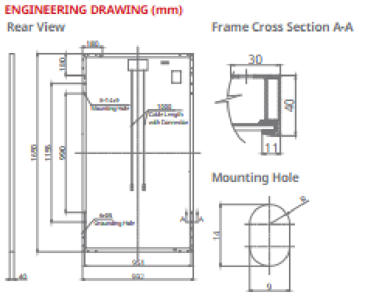
❑ Panels for battery charging (autonomous system):

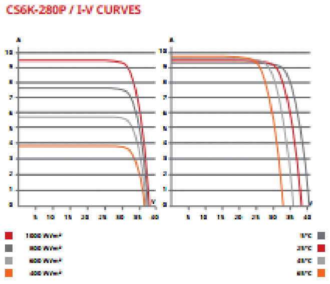
They must be calculated to satisfy the requirements of the batteries usually in 6, 12 or 24 V.

For a 12V panel, 36 cells in series (36 x 0,45V = 16,2V).

❑ Panels for grid connection:

It is interesting to have panels with a higher voltage, > 30V.





ELECTRICAL DATA | STC*

CS6K	270P	275P	280P
Nominal Max. Power (Pmax)	270 W	275 W	280 W
Opt. Operating Voltage (Vmp)	30.8 V	31.0 V	31.3 V
Opt. Operating Current (Imp)	8.75 A	8.88 A	8.95 A
Open Circuit Voltage (Voc)	37.9 V	38.0 V	38.2 V
Short Circuit Current (Isc)	9.32 A	9.45 A	9.52 A
Module Efficiency	16.50%	16.80%	17.11%
Operating Temperature	-40°C ~ +85°C		
Max. System Voltage	1000 V (IEC) or 1000 V (UL)		
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)		
Max. Series Fuse Rating	15 A		
Application Classification	Class A		
Power Tolerance	0 ~ + 5 W		

* Under Standard Test Conditions (STC) of irradiance of 1000 W/m², spectrum AM 1.5 and cell temperature of 25°C.

MECHANICAL DATA

Specification	Data
Cell Type	Poly-crystalline, 6 inch
Cell Arrangement	60 (6×10)
Dimensions	1650×992×40 mm (65.0×39.1×1.57 in)
Weight	18.2 kg (40.1 lbs)
Front Cover	3.2 mm tempered glass
Frame Material	Anodized aluminium alloy
J-Box	IP68, 3 diodes
Cable	4.0 mm² (IEC), 12 AWG (UL), 1000 mm (39.4 in)
Connector	T4 series
Per Pallet	27 pieces, 538 kg (1186.1 lbs)
Per Container (40' HQ)	756 pieces

ELECTRICAL DATA | NMOT*

CS6K	270P	275P	280P
Nominal Max. Power (Pmax)	199 W	202 W	206 W
Opt. Operating Voltage (Vmp)	28.3 V	28.5 V	28.8 V
Opt. Operating Current (Imp)	7.01 A	7.10 A	7.16 A
Open Circuit Voltage (Voc)	35.3 V	35.4 V	35.6 V
Short Circuit Current (Isc)	7.52 A	7.63 A	7.68 A

* Under Nominal Module Operating Temperature (NMOT), irradiance of 800 W/m², spectrum AM 1.5, ambient temperature 20°C, wind speed 1 m/s.

TEMPERATURE CHARACTERISTICS

Specification	Data
Temperature Coefficient (Pmax)	-0.40 % /°C
Temperature Coefficient (Voc)	-0.31 % /°C
Temperature Coefficient (Isc)	0.05 % /°C
Nominal Module Operating Temperature (NMOT)	43 ± 2 °C

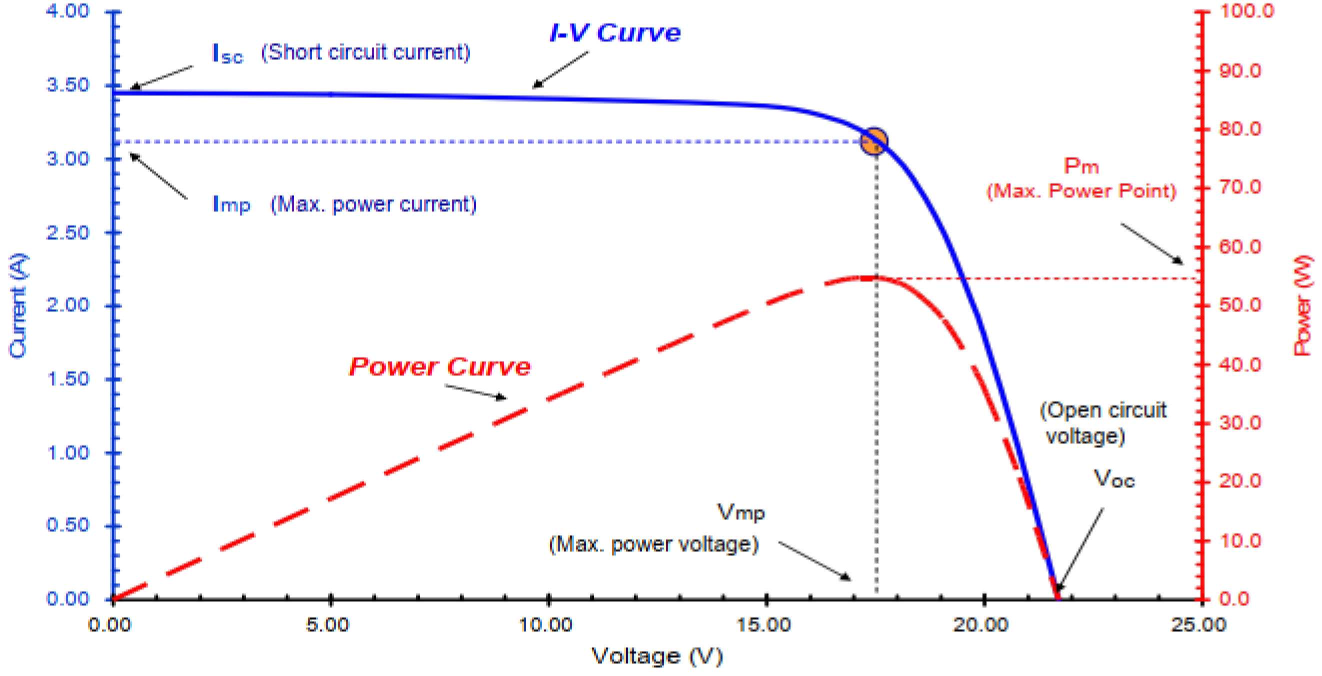
Why?

- They are made to supply inverters with input voltages increasingly high (150-200V at least).
- The higher the voltage, the lower the current (thinner cables and less powerful circuit breaker).

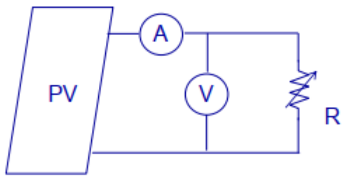
From cell to photovoltaic panel

Output of PV Module

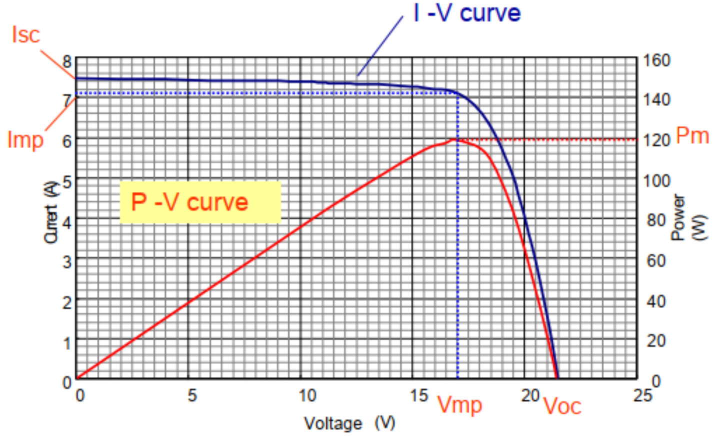
- ✶ Unlike the other power generation devices, output voltage varies
- ✶ Output current depends on what output voltage is used
- ✶ Output power depends on what output voltage is used
- ✶ Max. output power (rated Wp) is available only at Vmp point under STC



– I-V curve is the most important data for PV module



	Short				Open
R	0	→	R1	→	∞
V	0	→	Vmp	→	Voc
I	Isc	→	Imp	→	0



STC: Standard Test Conditions => AM = 1.5, t = 25° C, Irradiance = 1.0 [kW/m²]

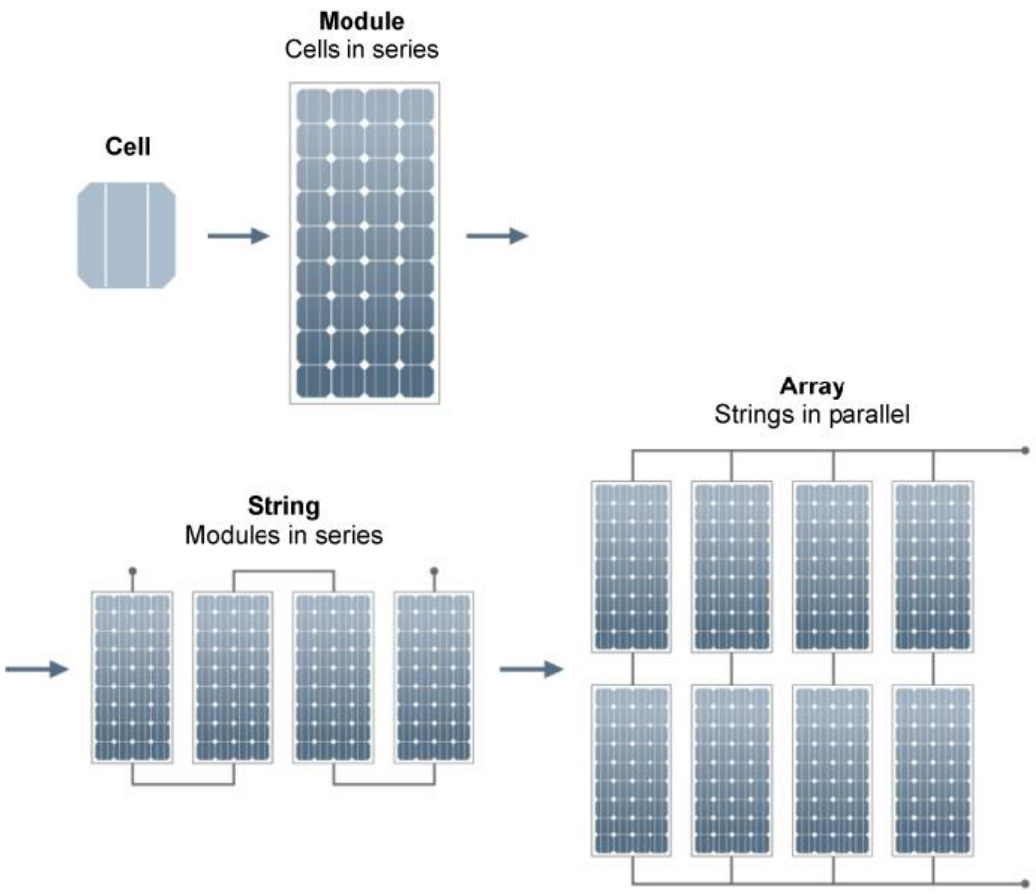
Like PV Cell, PV Module has same characteristics

- ✶ Higher temperature reduces output voltage
  approx. – 2.2 mV / ºC per Cell
  approx. – 80 mV / ºC per 36-cell PV module
- ✶ Higher irradiance increases output current
- ✶ Rated output (Wp) does not mean actual output power at the site
  - – Maximum power (P = I x V) depends on Irradiance (I) and Temperature (V)
  - – Maximum power changes approx. – 0.5 % / ºC,
    100Wmp at 25 ºC → 85Wmp at 55 ºC

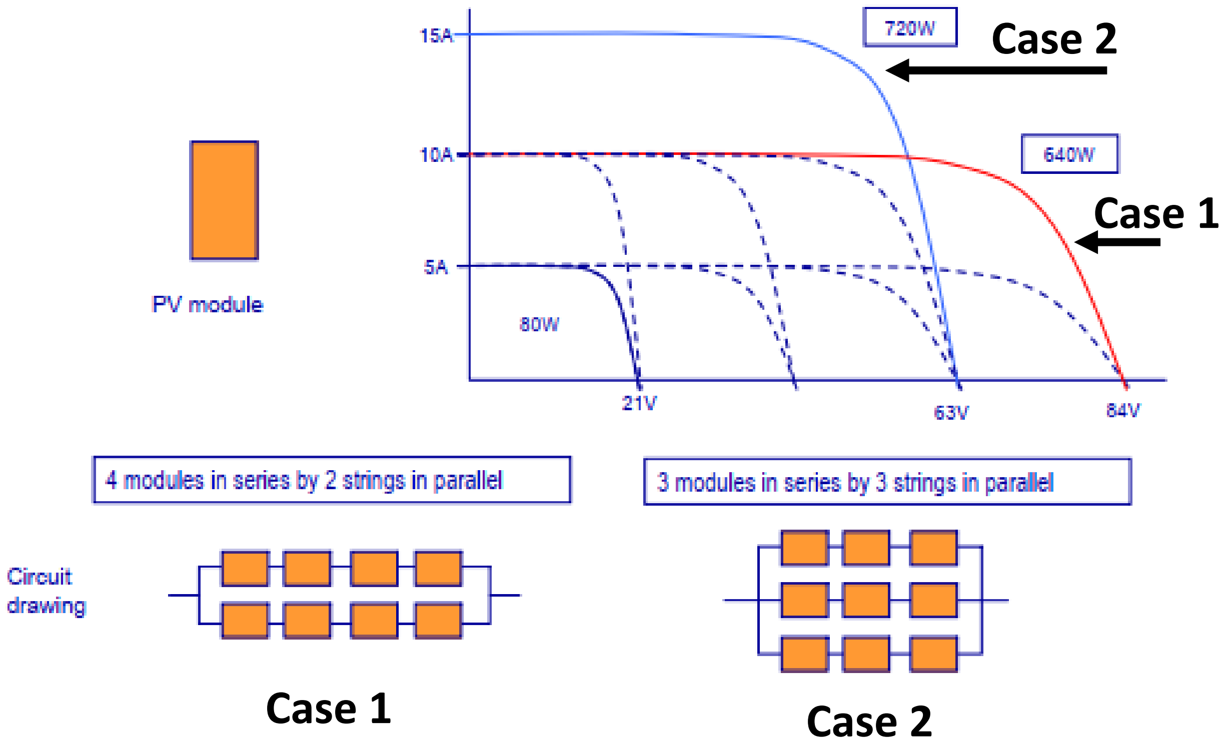
From cell to photovoltaic panel

PV Array assembly

- To have an installed capacity of several hundred watts, kilowatts, or even megawatts, it is necessary to assemble photovoltaic panels => Photovoltaic field or photovoltaic power station.



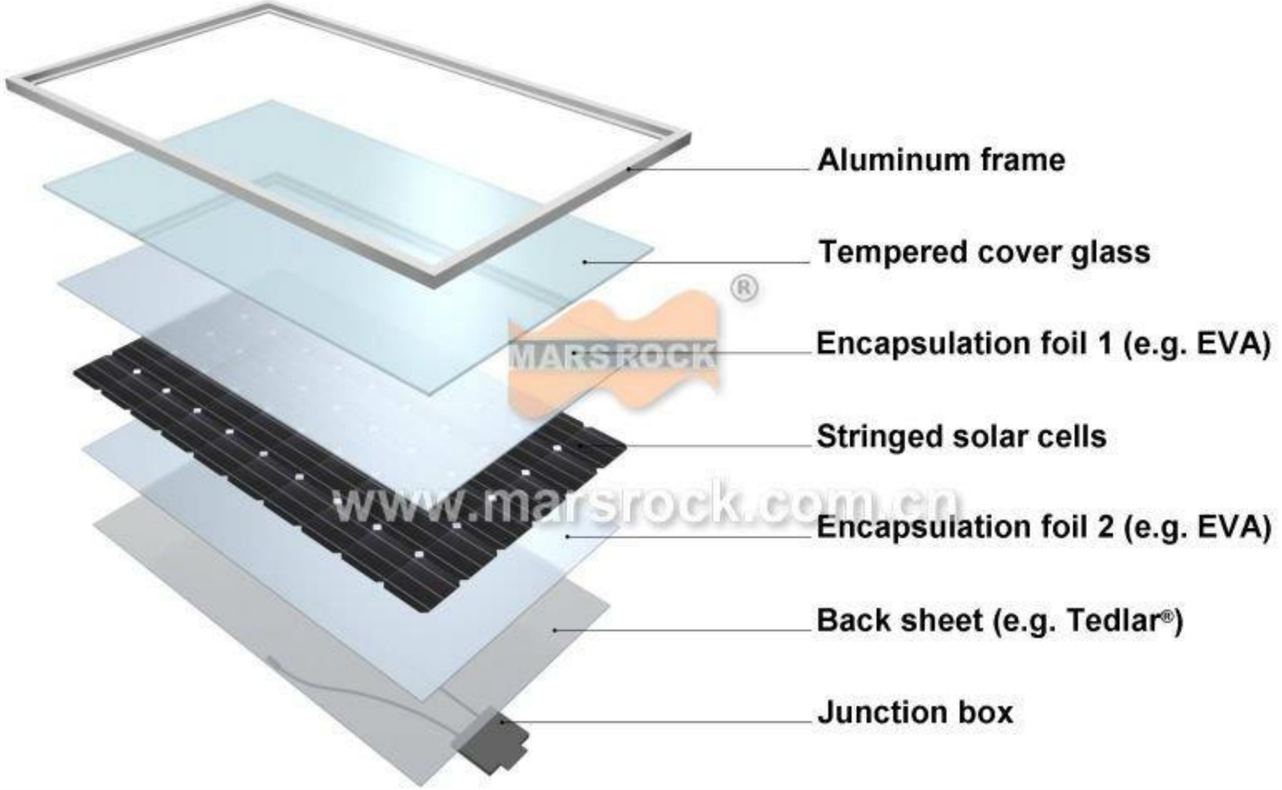
Series & Parallel Connection



From cell to photovoltaic panel

Encapsulation of photovoltaic module:

- A polymer widely used as an encapsulant between the glass cover of a solar module and the glass cover of the solar cells within the module is Ethylene Vinyl Acetate (EVA). EVA is chosen for its hard-wearing, transparency, corrosion resistance and flame retardant properties.



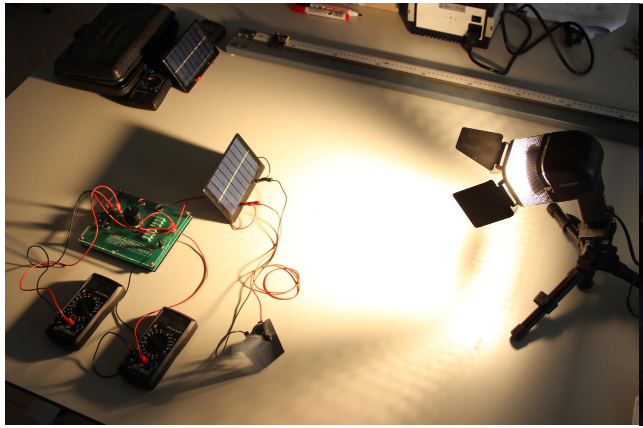
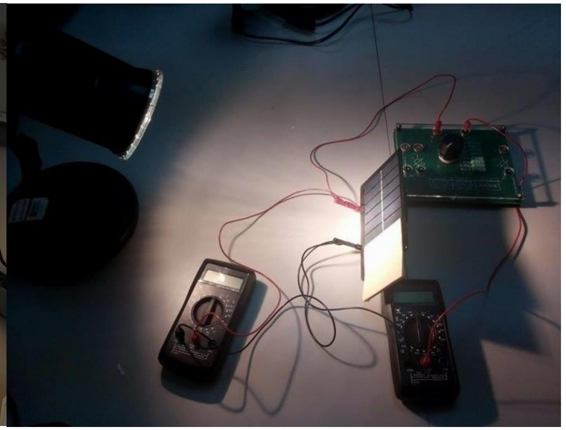
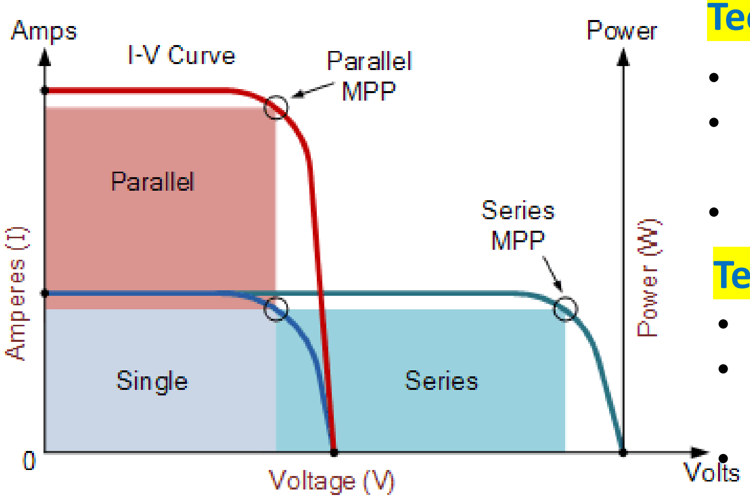
- The passage from the cell to the panel is not without consequence ?
- Glass and EVA generates an optical loss (≈ 4%).
- The dispersion between cells.
- Losses due to the geometrical arrangement.
- Electric series losses (welding, cables)

PRACTICAL WORK N°1

Electrical Characteristics – PV Modules

Laboratory 1: Electrical characteristics of PV module (Normal and Perturbed conditions)

→ I-V curves depending on Temperature, Solar Irradiance)

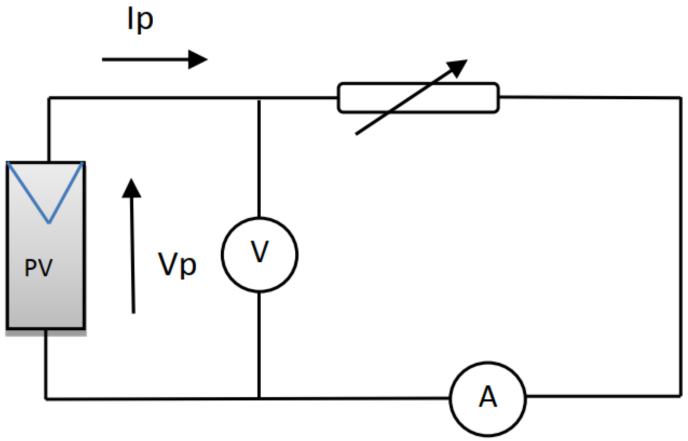




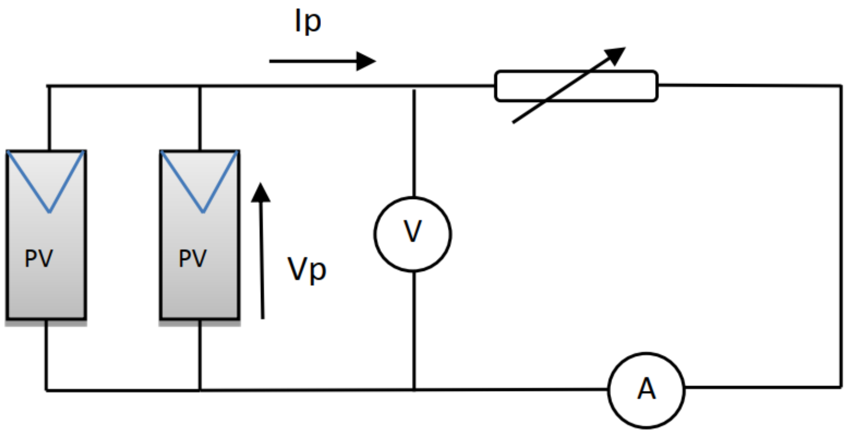
Technical Specifications A118

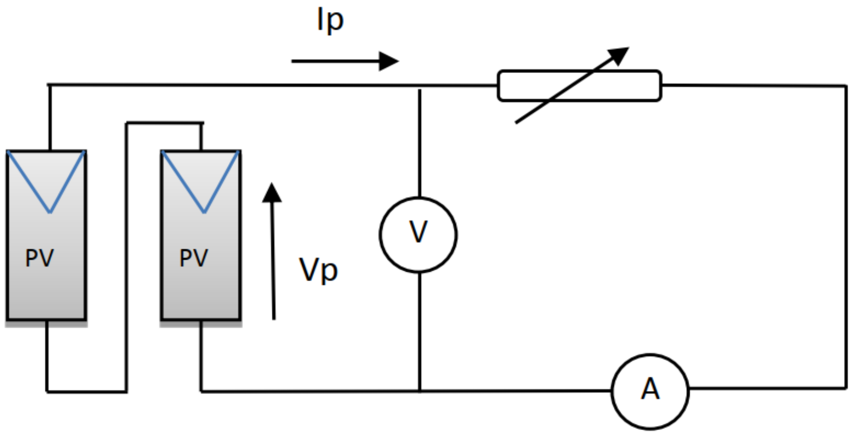
- Power: 4.0 V / 350 mA
- Dimensions (H x W x D): 115 x 155 x 100 mm)
- Connections: 2 mm banana sockets

Technical Specifications A113

- Power: 2.0 V / 600 mA
- Dimensions (H x W x D): 115 x 155 x 100 mm)
- Connections: 2 mm banana sockets





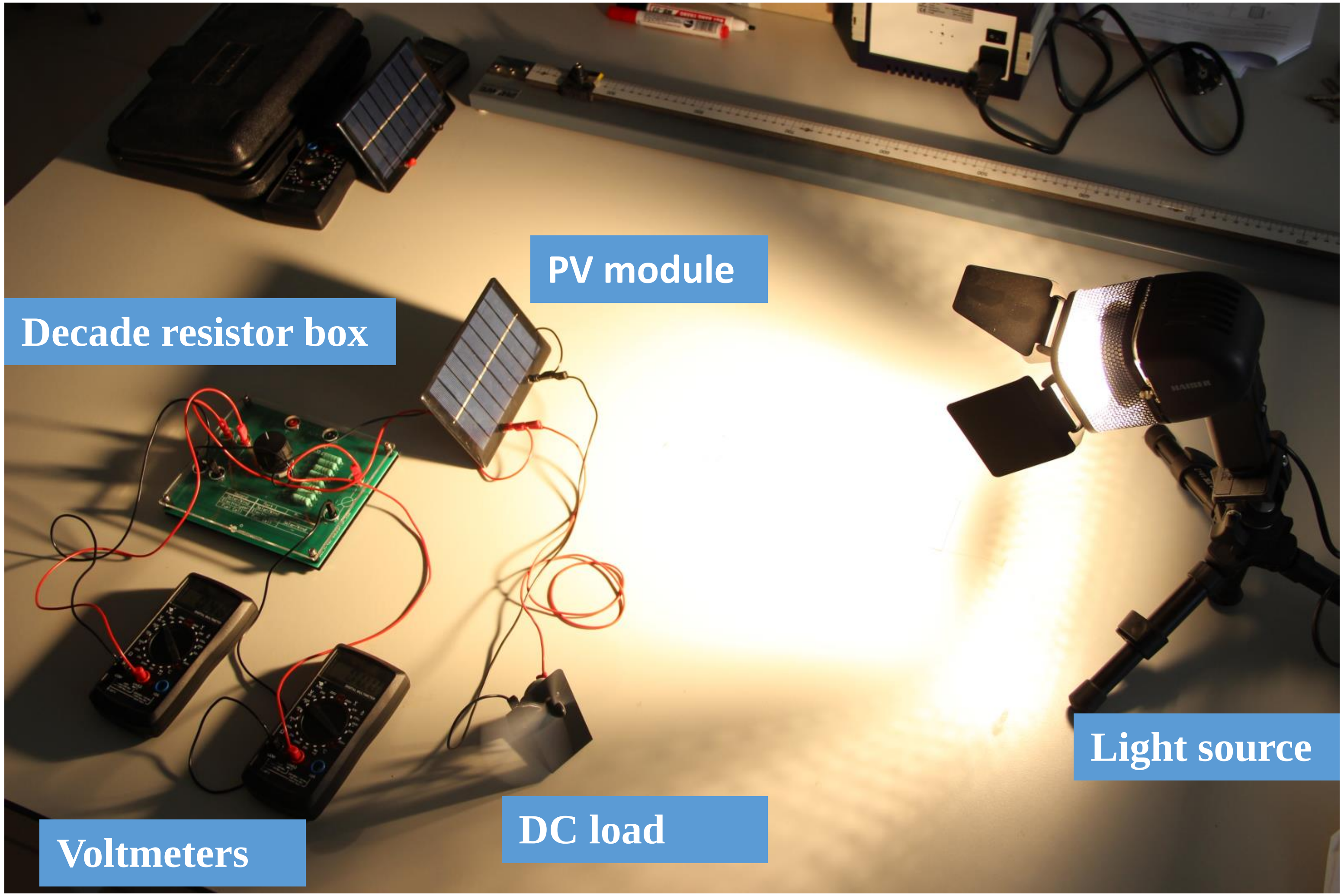


Material: https://www.fuelcellstore.com/solar-power/solar-panels/solar-panel-4v-350ma

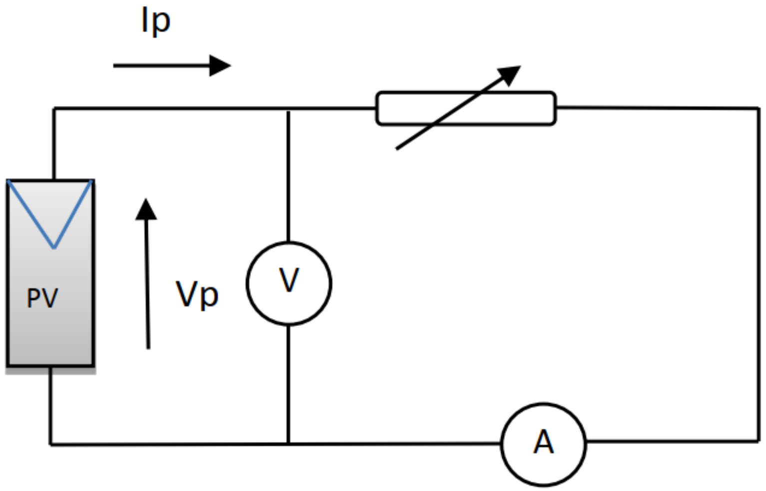
Dr. Nguyen Xuan Truong, EN department

PRACTICAL WORK N°1

Electrical Characteristics – PV Modules



N°1. A simple



Solarimeter

Material: https://www.fuelcellstore.com/solar-power/solar-panels/solar-panel-4v-350ma

Wind Turbine Generators (WTG) & Wind Farm

Netherlands = coastal development

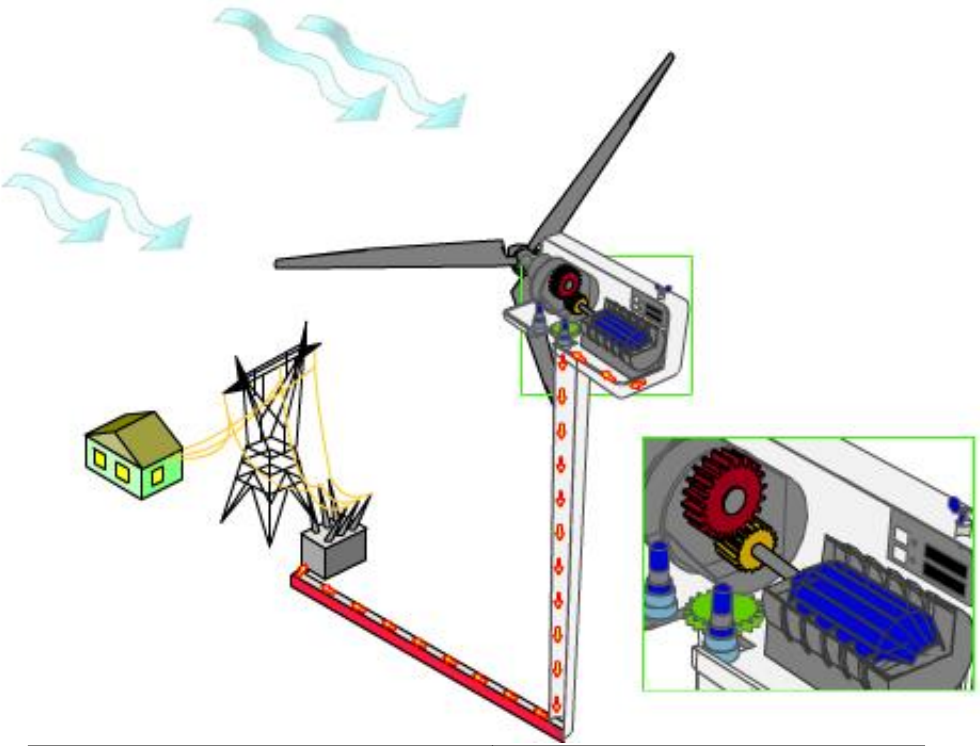
England = off shore

Wind energy problems

- Location – near population center !!!
- Bird migration
- Visual
- Must be coupled with other sources of electricity (intermittent supply)

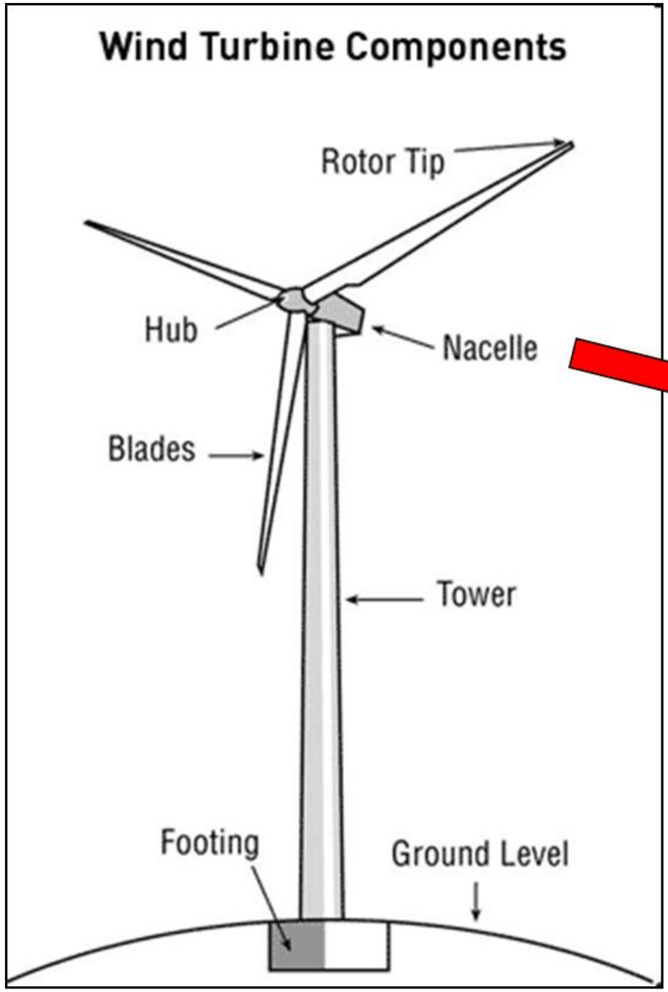
Wind Energy - Technology

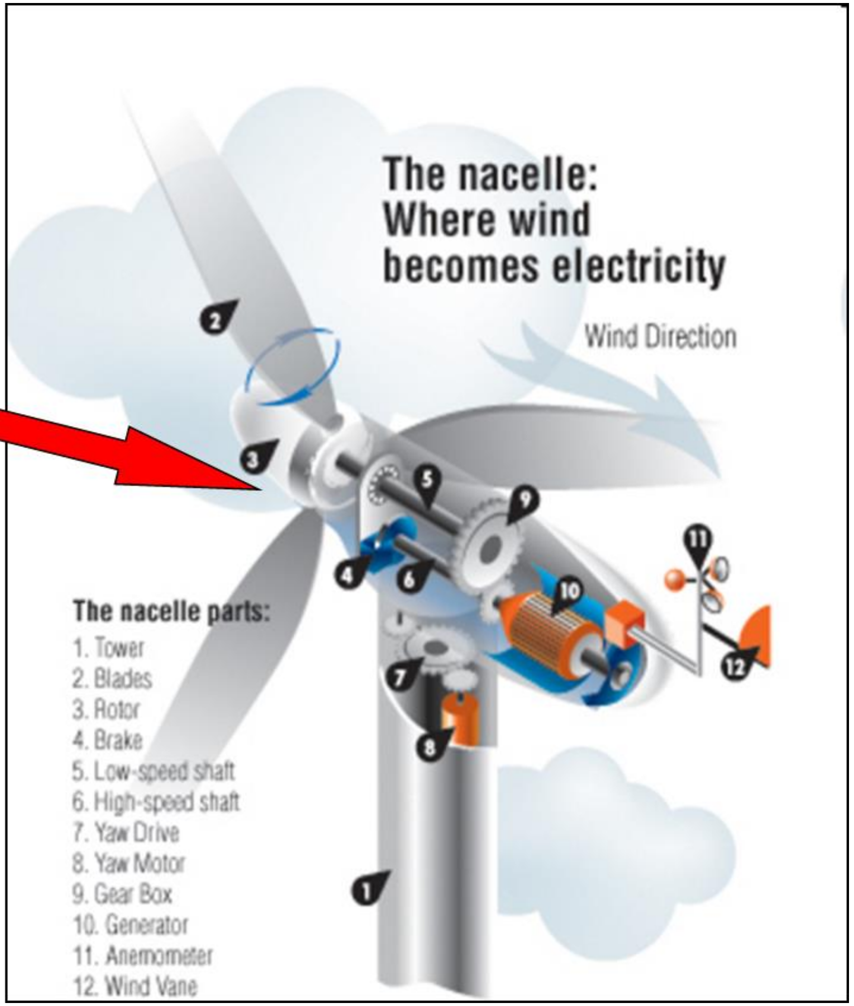
- Differential heating of the earth's surface and atmosphere induces vertical and horizontal air currents that are affected by the earth's rotation and contours of the land and generates **WIND**.
- A wind turbine obtains its power input by converting the force of the wind into a **torque (turning force)** acting on the rotor blades.
- The amount of energy which the wind transfers to the rotor depends on the **density of the air, the rotor area, and the wind speed.**
- PLF (*plant load factor*) of Wind Farm is normally in the range of **20 % to 30%** depending upon the site conditions and WTG rating.



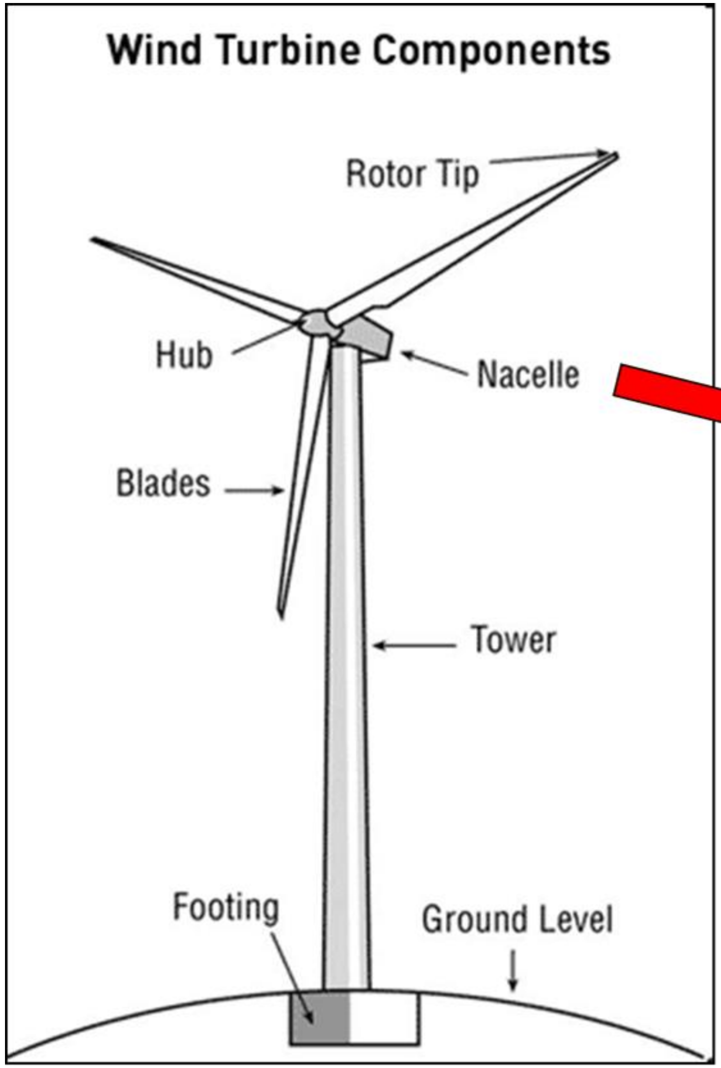
$P = 0.5 * \rho * A * V^3$	P → Power ρ → Air Density (kg/m^3) A → Blade Area -turbine (m^2) V → Wind velocity (m/s)

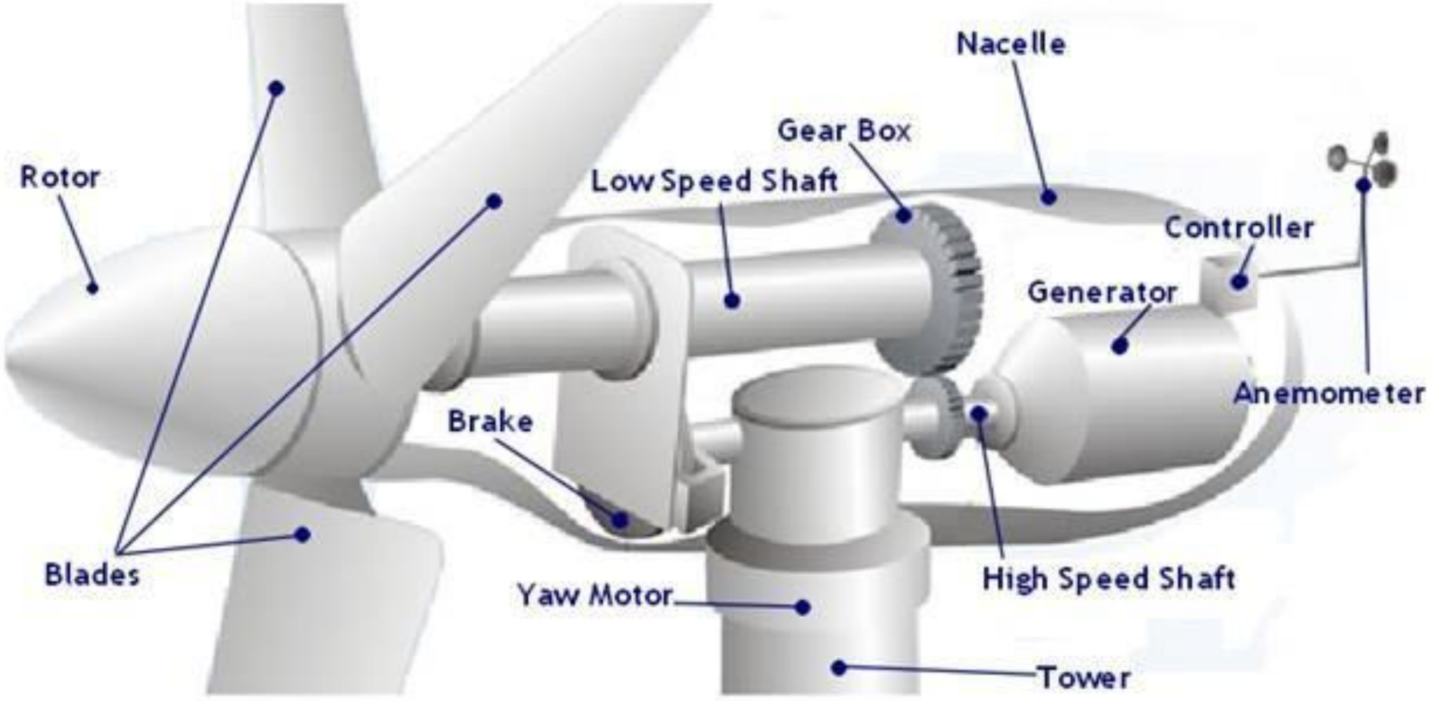
Major Components of Wind Turbine





Major Components of Wind Turbine



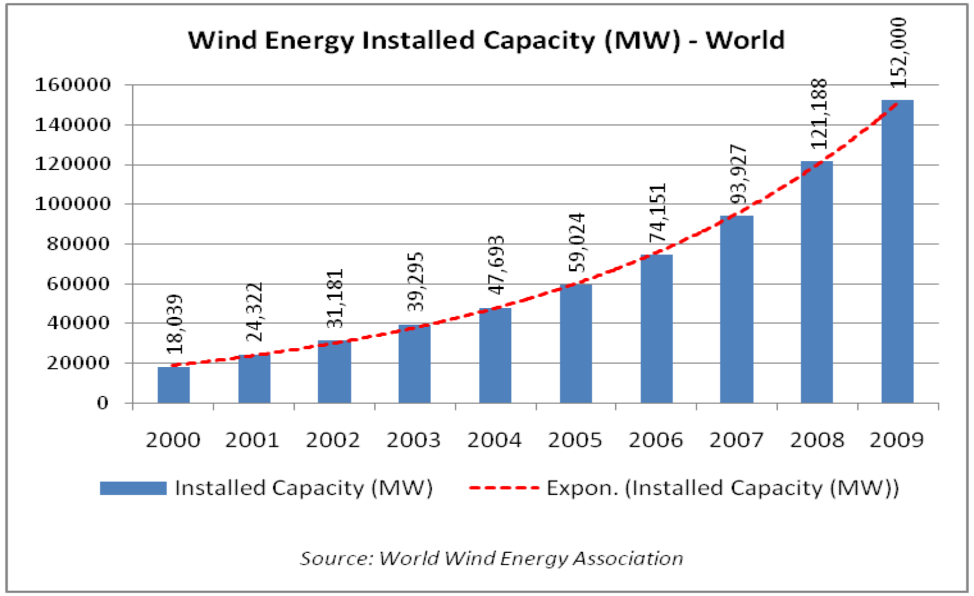


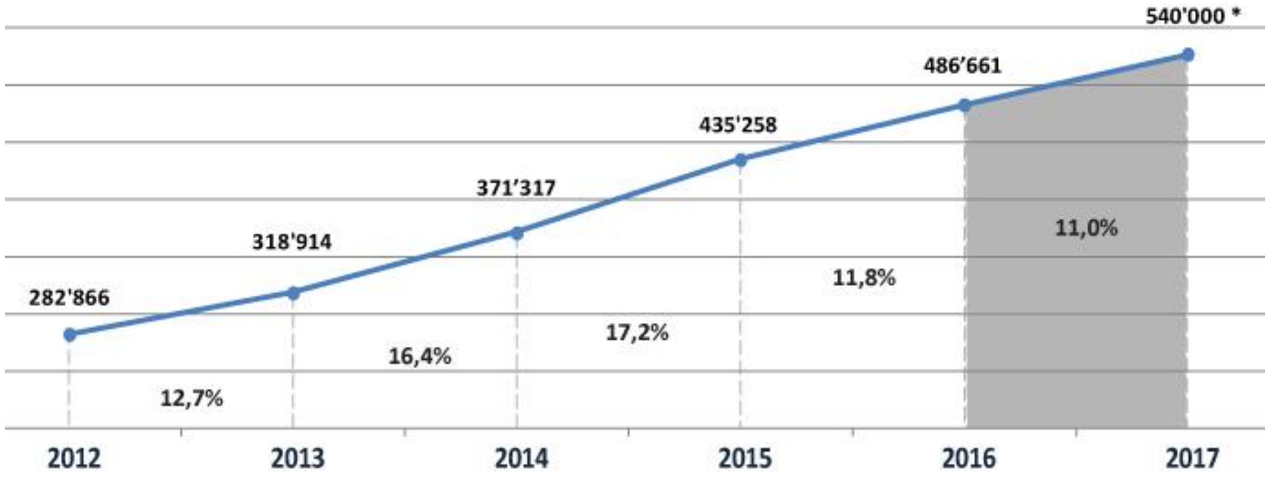
Nacelle - Siemens

UNIT - N°.4 WIND ENERY

Wind Energy – Present Scenario

- Wind Power – **Fastest growing** renewable energy source
- Globally, it grew at the average rate of **27 %** pa over the past 10 years.
- While in India it grew at the average rate of **33%** over the past 9 years.
- Presently, India is ranked **4th in the world** in terms of Wind Energy Installed Capacity
- **Drivers of growth**
  - Environmental Awareness and Sustainable Development
  - Growing Global Energy Demand
  - Improving Competitiveness of renewable energy
  - Security of Supply Concerns
  - New Markets (e.g. India, China etc)
  - Carbon Trading
  - Fiscal Benefits by Govt. (PTC, feed in tariffs, etc)





Wind Energy – Present Scenario

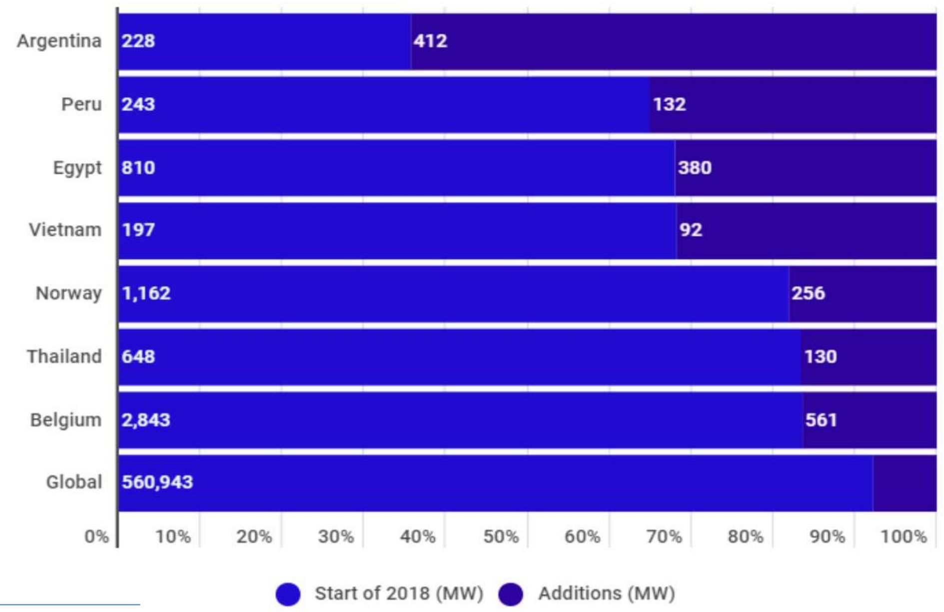
World Region	End 2017	New 2018	End 2018	Change
Asia-Pacific	234,417	26,737	261,152	11.4%
Europe	178,136	11,677	189,606	6.4%
Americas	123,121	11,940	135,071	9.7%
Africa & Middle East	4,758	962	5,720	20.2%
World Total MW	**540,432**	**51,316**	**591,549**	**9.5%**

Source: Global Wind Energy Council (GWEC) and WindEurope

Country	End 2017	New 2018	End 2018	Change
China	188,392	23,000	211,392	12.2%
USA	89,077	7,588	96,665	8.5%
Germany	56,189	3,122	59,311	5.6%
India	32,938	2,191	35,129	6.7%
Spain	23,097	397	23,494	1.7%
United Kingdom	19,069	1,901	20,970	10.0%
France	13,757	1,552	15,309	11.3%
Brazil	12,769	1,939	14,707	15.2%
Canada	12,240	566	12,816	4.6%
Italy	9,506	452	9,958	4.8%
Sweden	6,700	707	7,407	10.6%
Turkey	6,872	497	7,369	7.2%
Poland	5,848	16	5,864	0.3%
Denmark	5,490	268	5,758	4.9%
Portugal	5,313	67	5,380	1.3%
Australia	4,813	549	5,362	11.4%
Mexico	4,006	929	4,935	23.2%
Netherlands	4,377	94	4,471	2.1%
Japan	3,399	262	3,661	7.7%
Ireland	3,371	193	3,564	5.7%
World Total MW	**540,435**	**51,316**	**591,549**	**9.5%**

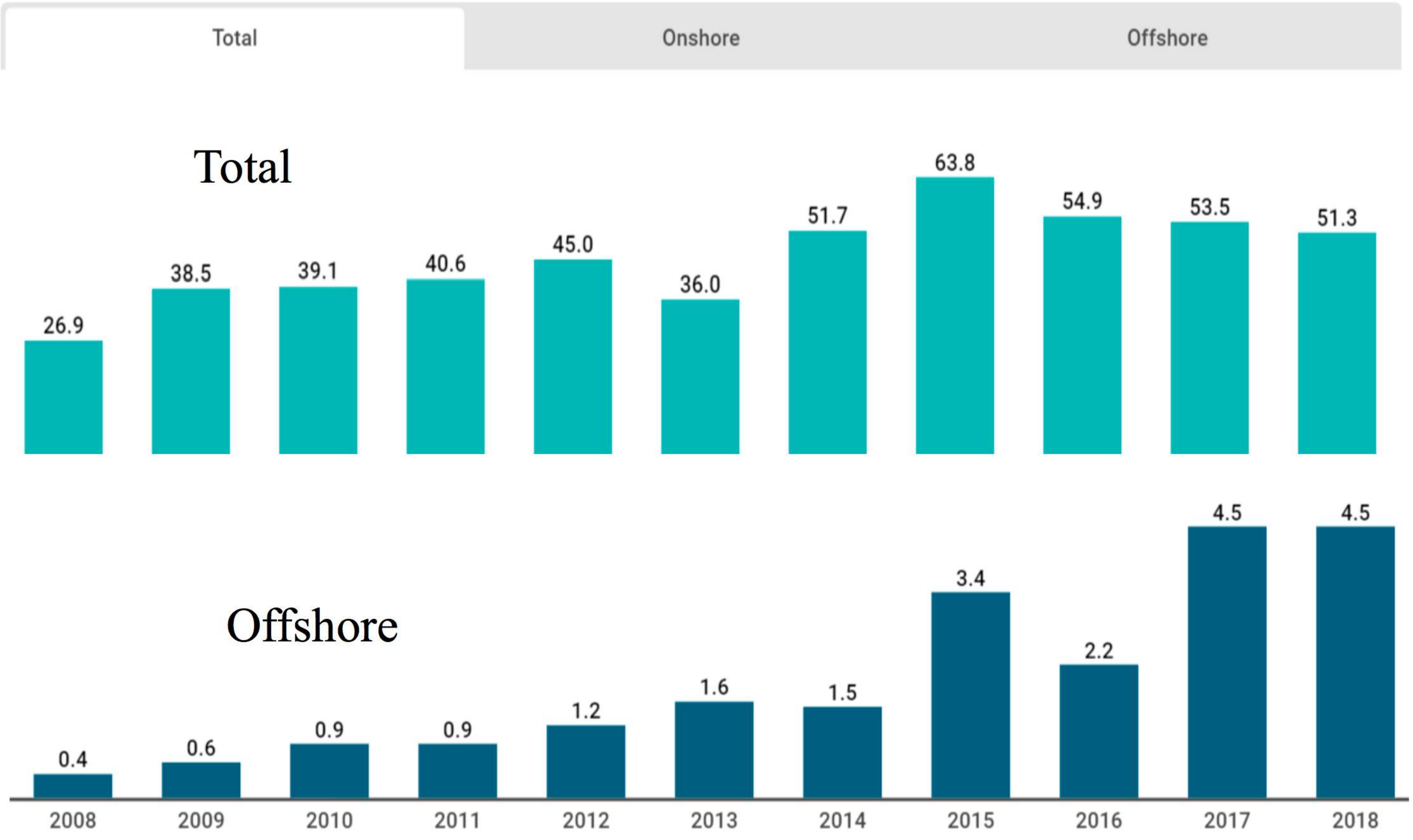
Source: Global Wind Energy Council (GWEC) and WindEurope

Countries grew the most by the percentage of its installed base last year



Wind power installed in the world (2018)

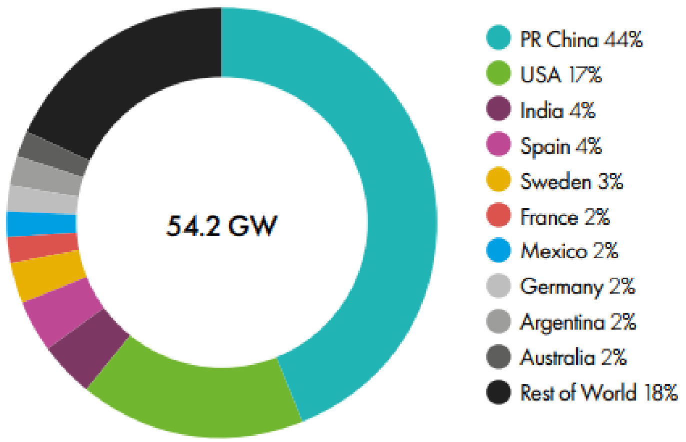
Wind Energy – Present Scenario



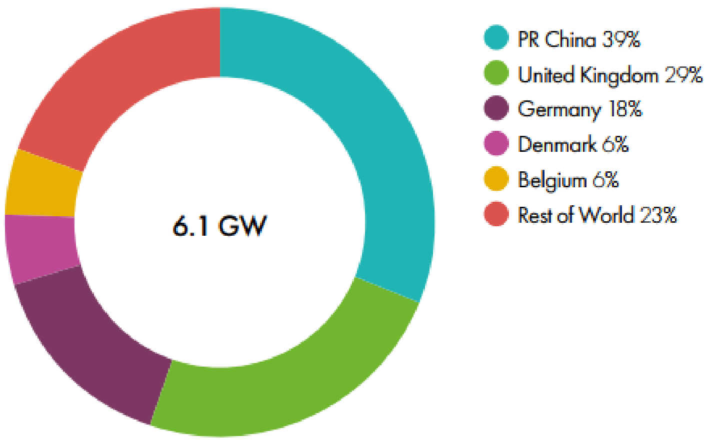
Wind power installed in the world (2018)

Wind Energy – Present Scenario

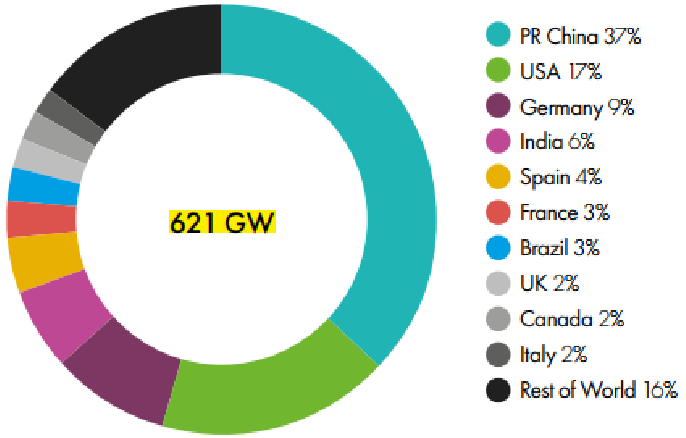
New installations onshore (%)



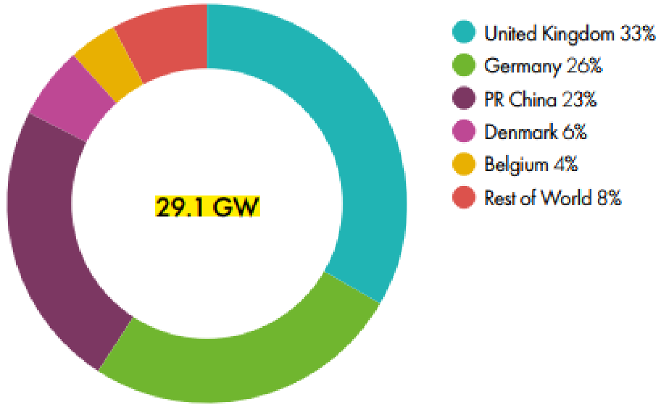
New installations offshore (%)



Total installations onshore (%)



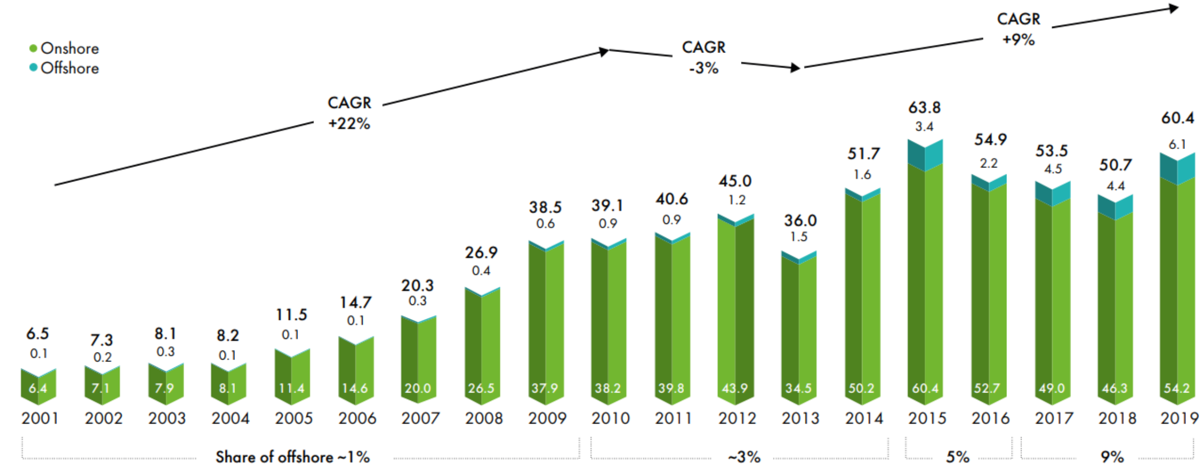
Total installations offshore (%)

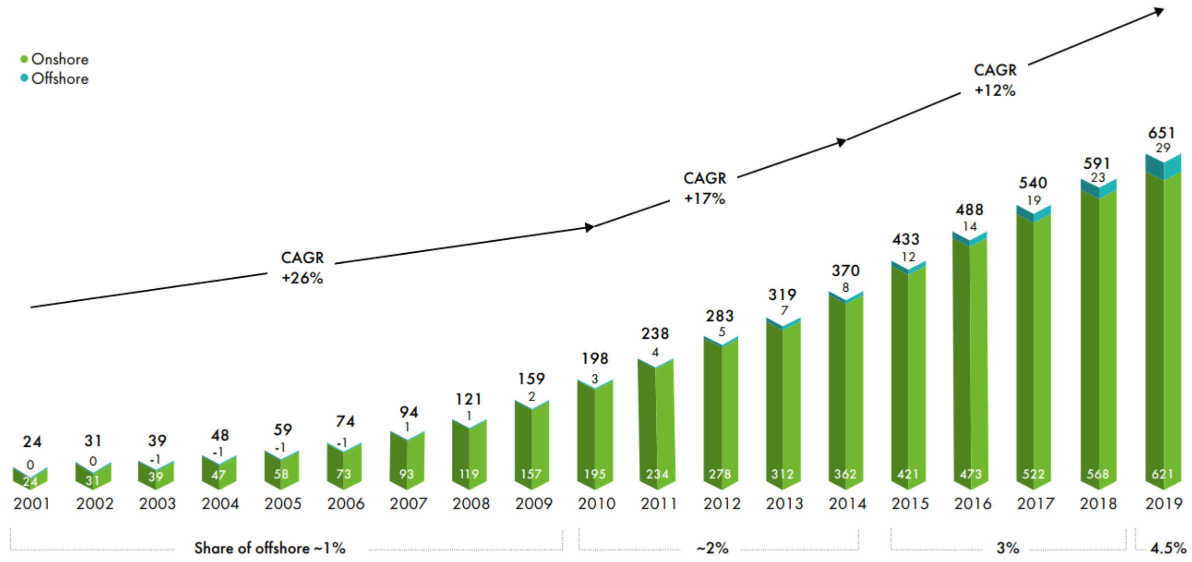


Wind power installed in the world (2019)

Wind Energy – Present Scenario

CAGR: compound annual growth rate





- **Wind Power Capacity Worldwide Reaches 597 GW, 50,1 GW added in 2018**
- **China with more than 200 GW, USA close to 100 GW, Europe in decline**
- **Over 60 GW of wind energy capacity installed in 2019, the second-biggest year in history**
- **Total capacity for wind energy globally is now – March 2020 - over 651 GW, an increase of 10 per cent compared to 2018.**

- ## Wind Power in Vietnam
  - **Legal Rules:** Decision 37/2011/QD-TTg, dated 20/6/2011 issued by Prime Minister and Circular 32/2014/BCT issued by MOIT.
  - ✓ Electricity Tariff (FIT):

7.8 USCents/kWh	Decision 37/2011/QD-TTg
8.5 USCents/kWh	Onshore projects (Decision. 39/2018/QD-TTg dated 10 Sept 2018)
9.8 USCents/kWh	Offshore projects (Decision. 39/2018/QD-TTg)

  - ✓ PPA : based on sample PPA
  - So far, there have been 9 projects signed PPA with EVN with total installed capacity of 403.9 MWp and around 189.2 MW in commercial operation

UNIT - N°.4 WIND ENERY

Wind Power in Vietnam

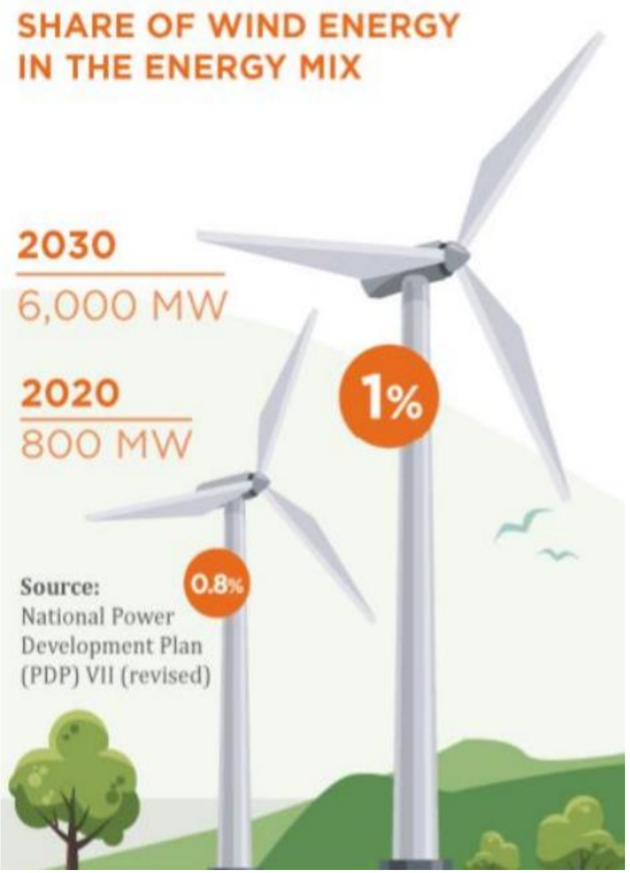
Current Status

End 2019: total cumulative installed wind power capacity of 487.4 MW

- Vietnam has an estimated total wind capacity of 513,360 MW, the largest in Southeast Asia - Ref: Vietnam Energy Association (VEA)
- 24 GW of onshore and 475 GW of offshore wind technical capacity – ref https://gwec.net/global-wind-report-2019/

Target

- Vietnam has a good potential to develop wind energy for both onshore and offshore
- Promising wind speeds in the southwest and central highlands regions



Wind Power in Vietnam: Potential

Wind Resource Atlas in 2011

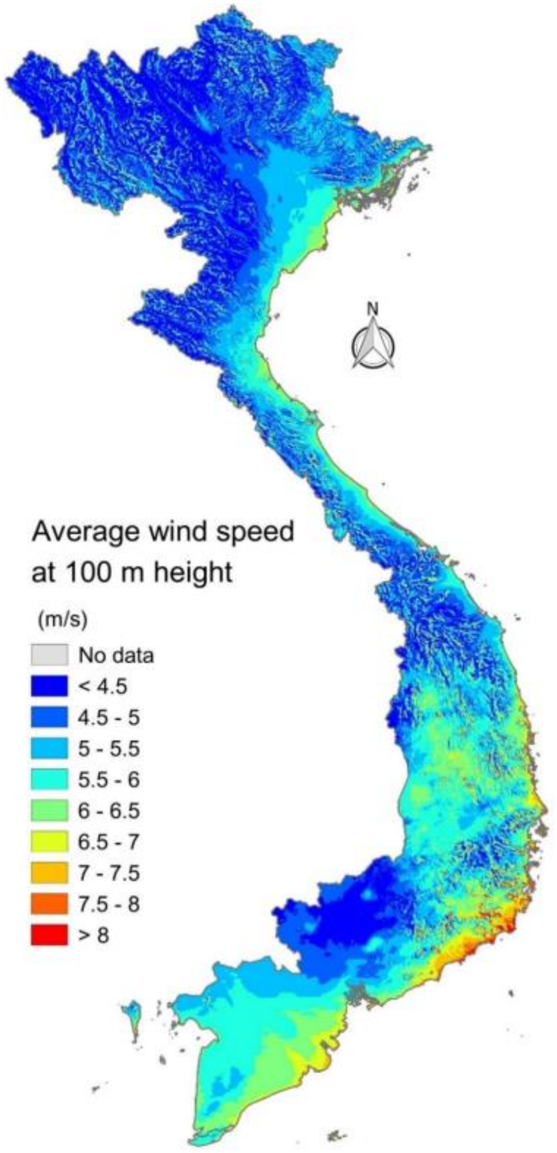
- Onshore : 24 ± 27 GW of potential installation capacity (ref)

✓ *Wind energy theoretical potential based on the Wind Resource Atlas (ref-1)*

✓ *Estimation of Technical Wind Power Potential (ref-2)*

Wind potential in Vietnam concentrates mostly in the southern central coastal region (Binh Thuan Province) and the southern coastal region (Tra Vinh, Bac Lieu and Soc Trang provinces) with average windspeeds of 7 m/s or higher

Average wind speed on height of 80m [m/s]	Area for wind power development/deployment [km²]	Share on total Viet Nam size (310,070 km²) [%]	Technical power rate potential for wind turbines [MW] [50]
<4	95,920	30.9	959,200
4-5	70,870	22.9	708,700
5-6	40,470	13.1	404,700
6-7	2,440	0.8	24,400
7-8	220	.07	2,200
8-9	20	.006	200
>9	1	0	10
Total	209,941	67.8	2,099,410
Best suited	2,681	0.88	26,810



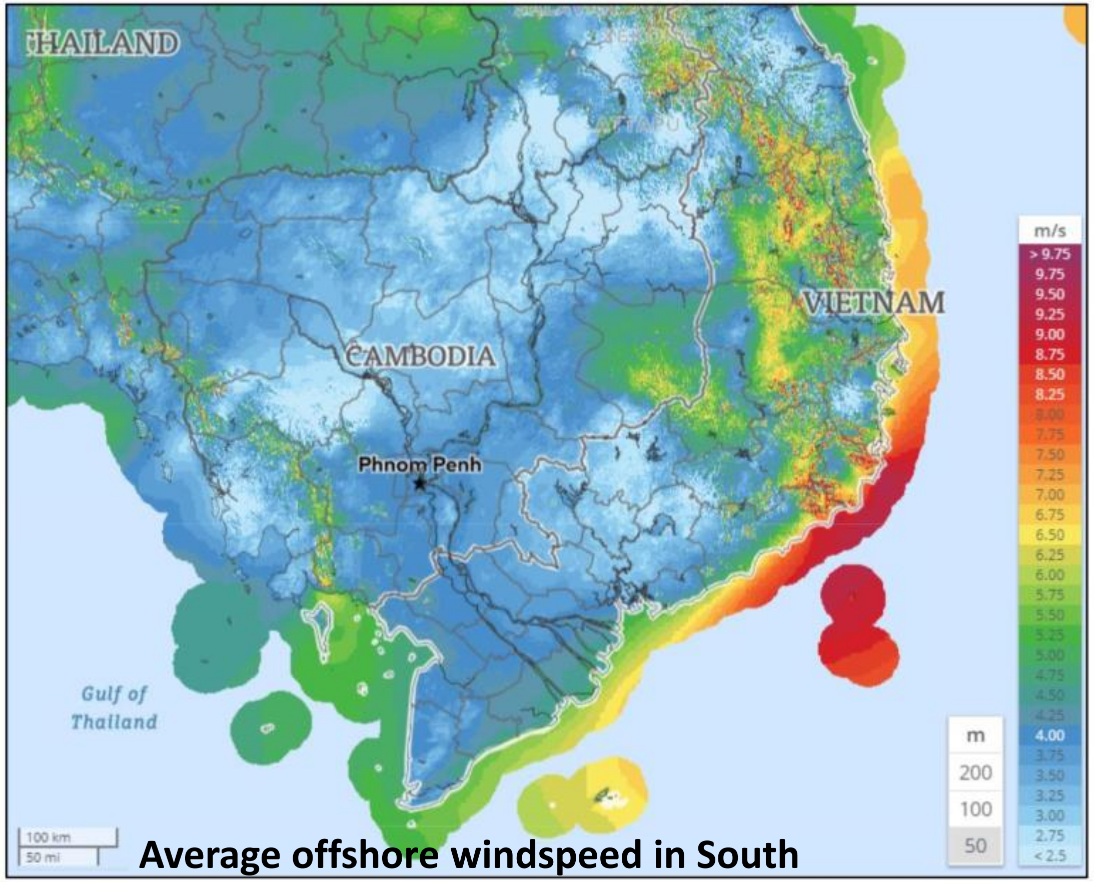
Wind Resource Atlas of Vietnam, 2011

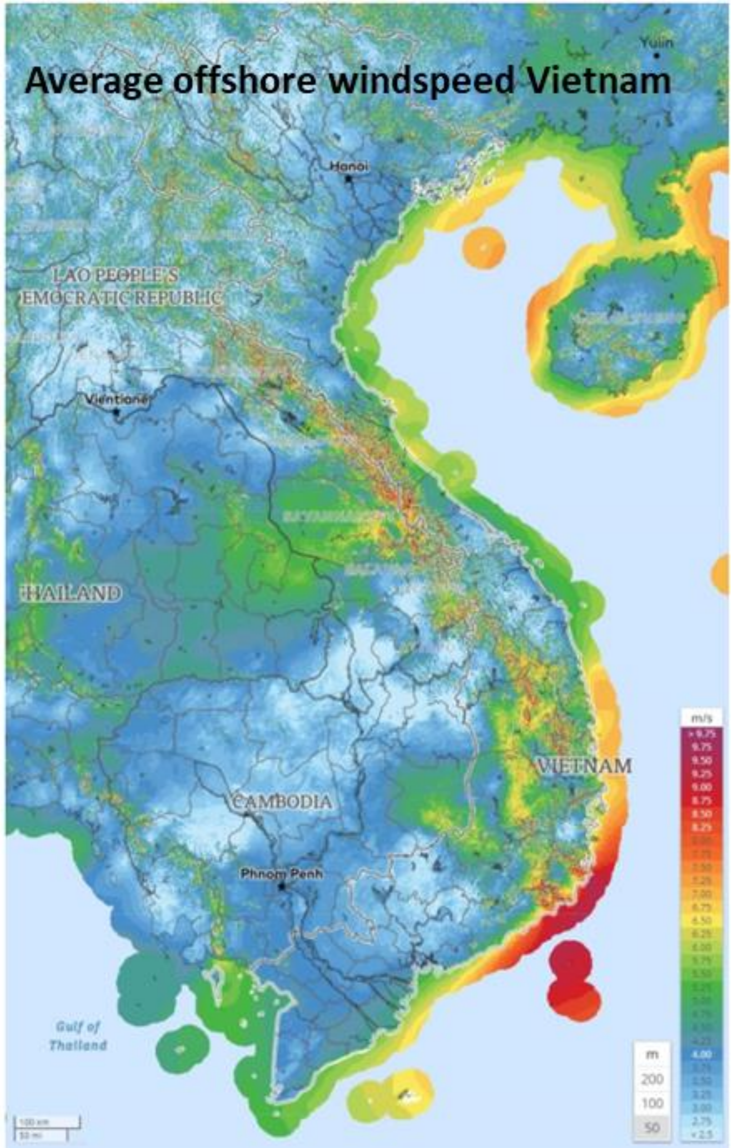
Ref-1: Wind Energy Potential Vietnam, Joost Sissingh, Eric Arends (Wind Minds) Baseline Study Wind Energy Vietnam, July 2018
Ref-2: GIZ Energy Support Programme (2015): Overview of the Vietnamese Power Market – A Renewable Energy Perspective, 2015

Wind Power in Vietnam: Potential

https://www.evwind.es/2017/07/13/vietnam-has-large-wind-power-potential/60444

- **Offshore :**





Offshore wind energy is a relatively new and emerging market in Vietnam, with huge potentia

Possible disadvantages:

- Limited available wind resources, higher than 6.5m/s is economical
- Costly: transmission line, wind energy conversion system.
- More costly with small wind projects (<100 kW)
- Environmental impact: visual pollution, bird killer, land usage

UNIT - N°.5
BIOMASS & BIOFUEL ENERY

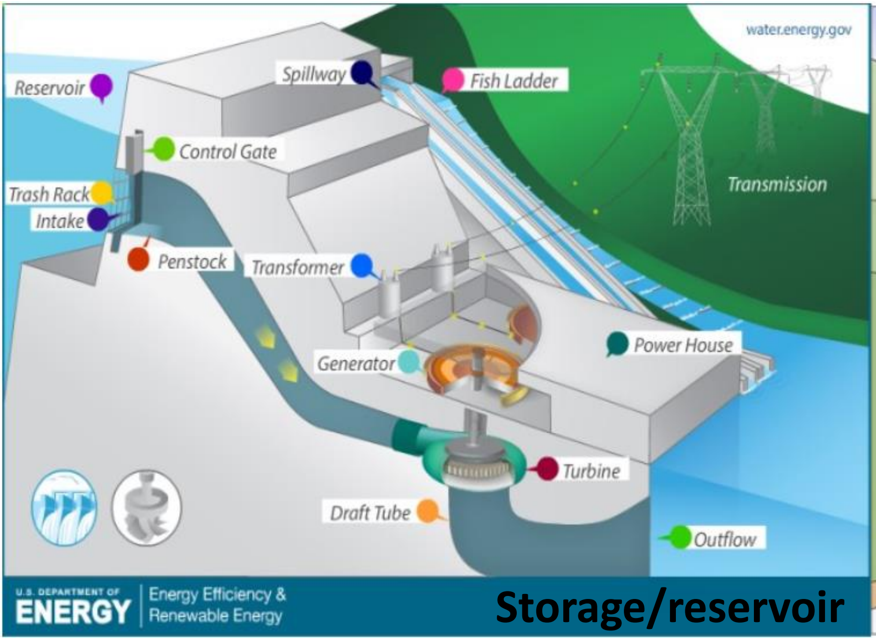
Dr. Nguyen Hong Nam

UNIT - N°.6 HYDRO ENERGY

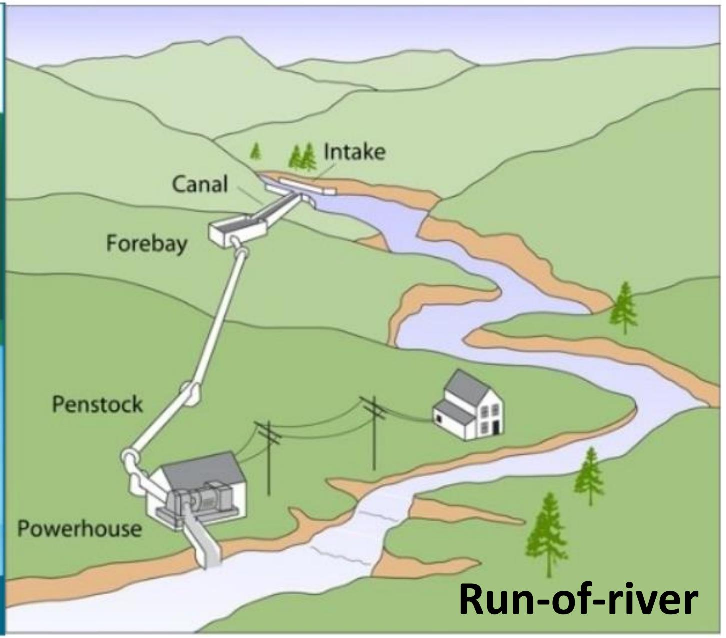
Hydropower Plant

There are three types of hydropower facilities: *(IEA-ETSAP and IRENA, 2015, "Hydropower: Technology Brief")*

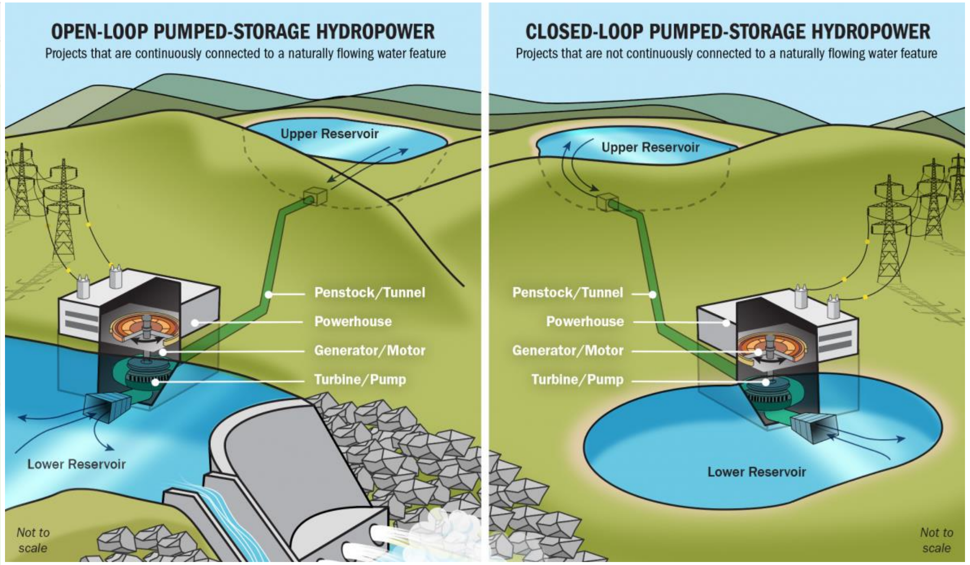
- **Run-of-river.** A facility that channels flowing water from a river through a canal or penstock to spin a turbine. Typically, a run-of-river project will have little or no storage facility. Typical small capacity.
- **Storage/reservoir**. Uses a dam to store water in a reservoir. Electricity is produced by releasing water from the reservoir through a turbine, which activates a generator. Typical large capacity.
- **Pumped storage**. Provides peak load supply, harnesses water which is cycled between a lower and upper reservoir by pumps which use surplus energy from the system at times of low demand



Storage/reservoir



Run-of-river



Pumped-storage hydropower: type of hydroelectric energy storage

Hydropower Plant

Classification: *(IEA-ETSAP and IRENA, 2015, "Hydropower: Technology Brief")*

Type	Capacity
Large- Hydropower	**> 30 MW**
Small-Hydropower	**1 MW – 30 MW**
Pico and Micro hydropower	**< 1 MW**

What are the biggest hydroelectric power plants in the world?

Three Gorges (Đập Tam Hiệp), China – 22.5GW

32 turbine / generator units rated 700MW each, and two 50MW power generators

Itaipu, Brazil & Paraguay – 14GW

20 generating units with a capacity of 700MW each

Xiluodu, China – 13.86GW

18 Francis turbine-generator units of 770MW each

Guri, Venezuela – 10.2GW

20 generating units of different capacities ranging between 130MW and 770MW

Input

The falling water from either reservoir or run-of-river having certain head (height) and flow rate

Output

Power capacity (kW) and energy (kWh)

Typical capacities (tổ máy)

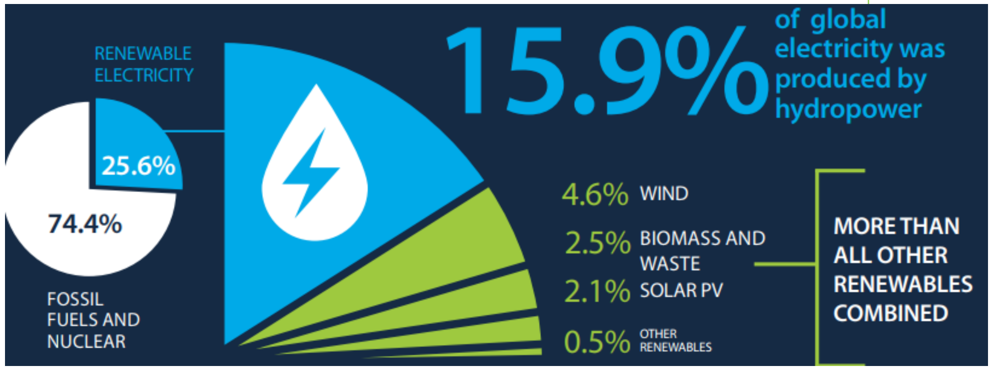
Hydropower systems can range from tens of Watts to hundreds of Megawatts. Currently up to 900 MW per unit

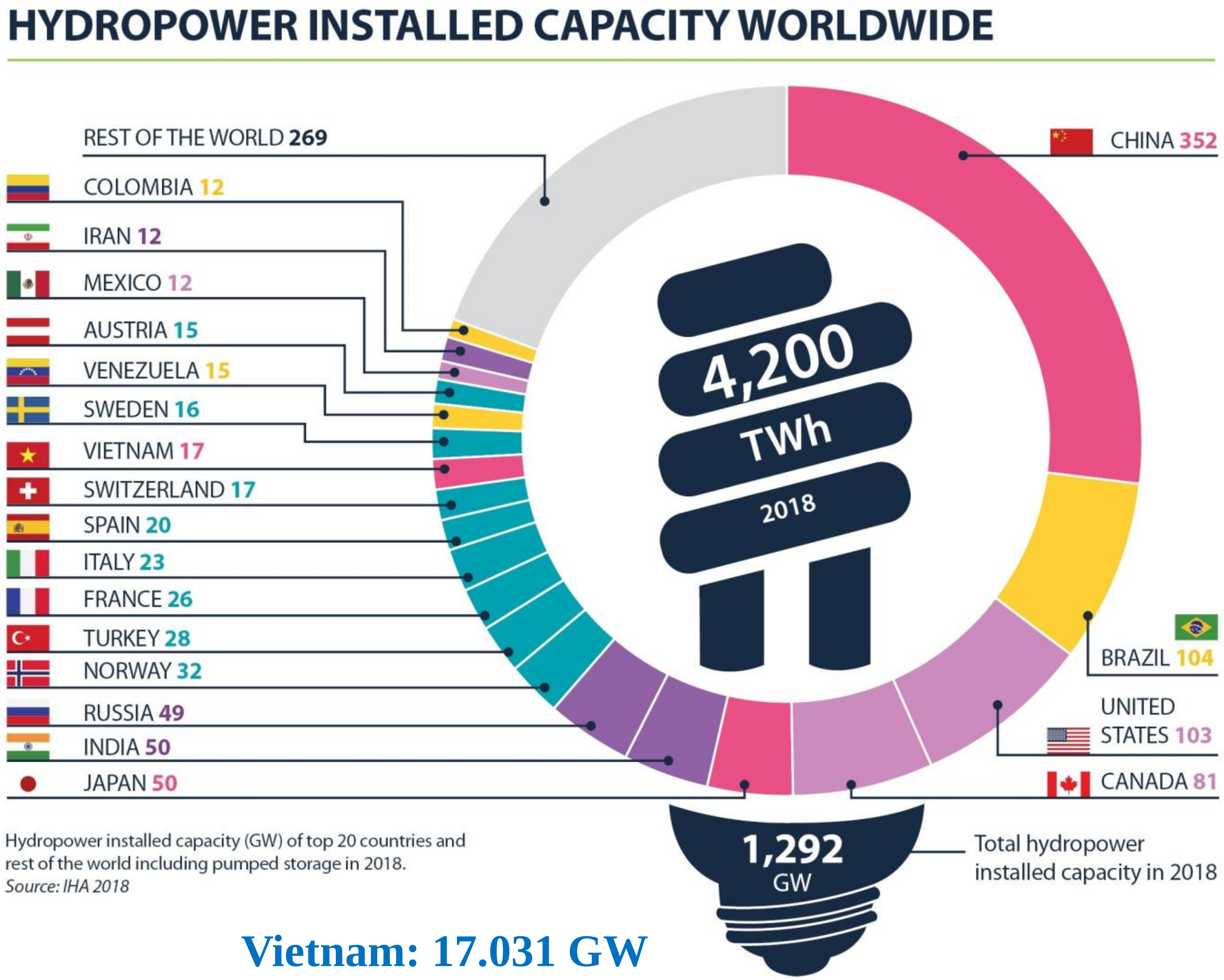
Ramping configurations

Hydropower helps to maintain the power frequency by continuous modulation of active power, and to meet moment-to-moment fluctuations in power requirements. It offers rapid ramp rates and usually very large ramp ranges, making it very efficient to follow steep load variations or intermittent power supply of renewable energy such as wind and solar power plants.

UNIT - N°.6 HYDRO ENERGY

- In 2018, electricity generation from hydropower reached an estimated 4,200 terawatt hours (TWh), setting the highest ever contribution from a renewable energy source.
- An estimated 21.8 gigawatts (GW) of hydropower capacity was put into operation in 2018, including nearly 2 GW of pumped storage, bringing the world's total installed capacity to 1,292 gigawatts (GW).



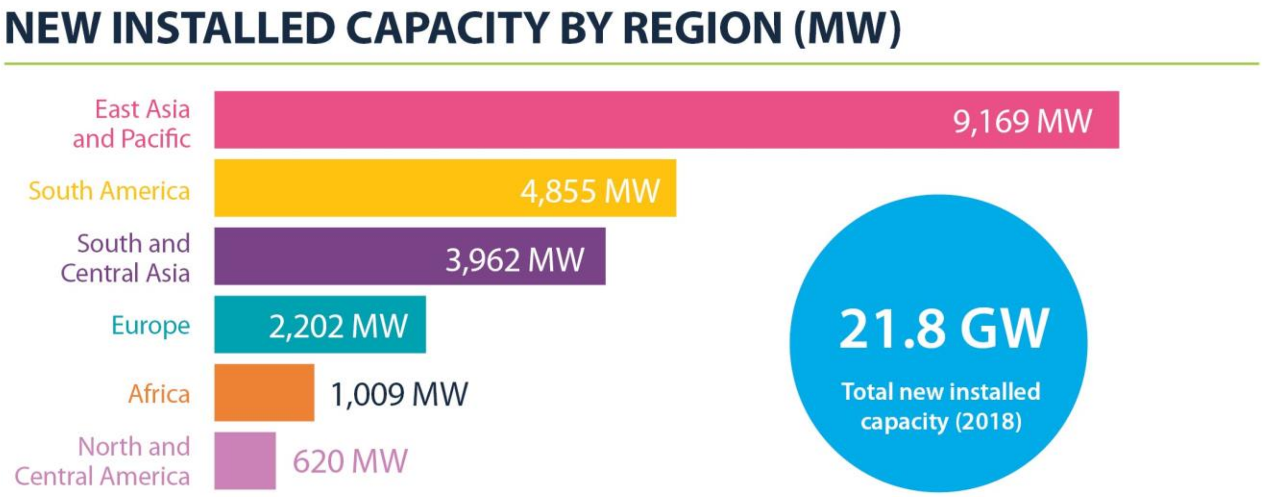


Vietnam: 17.031 GW

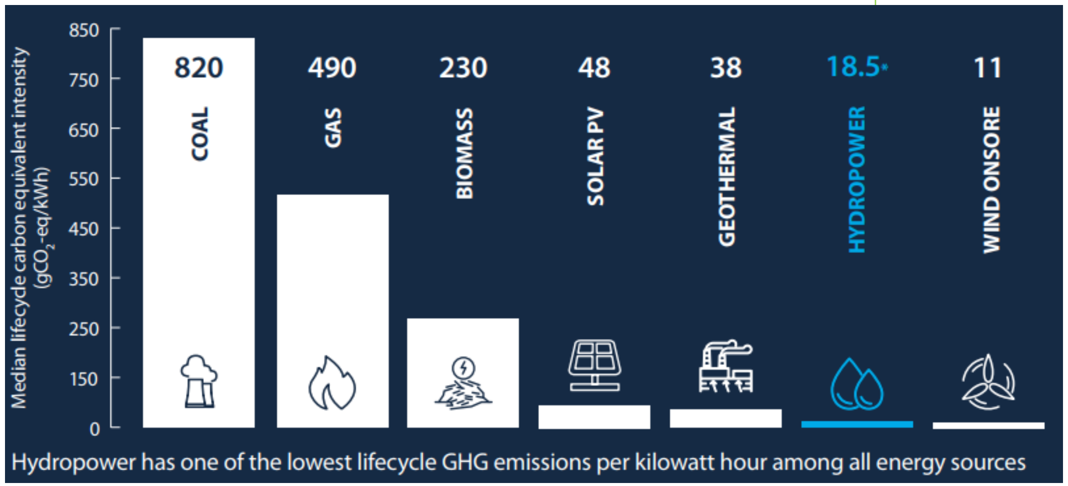
Hydropower is the world's largest source of renewable electricity generation

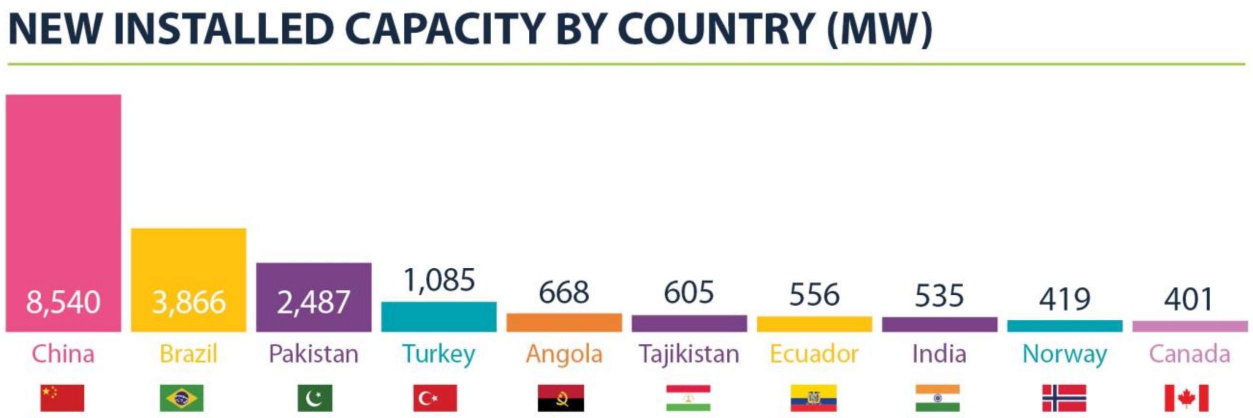
UNIT - N°.6 HYDRO ENERGY

- 2018, the East Asia and Pacific region once again added the most capacity, with 9.2 GW installed.
- It was followed by South America (4.9 GW), South and Central Asia (4.0 GW), Europe (2.2 GW), Africa (1.0 GW) and North and Central America (0.6 GW).



REDUCING EMISSIONS





UNIT - N°.6 HYDRO ENERGY

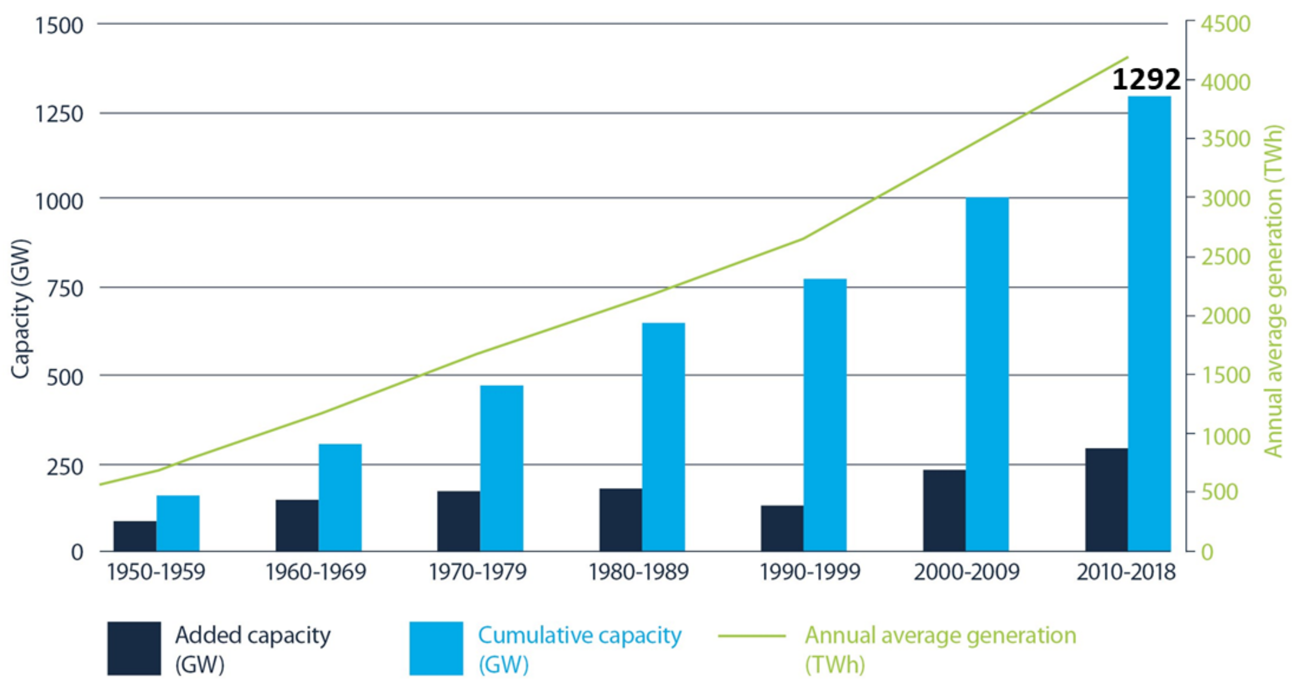
Hydropower has come a long way since first emerging as a new and innovative form of power generation, with worldwide installed capacity nearly 1,300 gigawatts.

EAST ASIA AND PACIFIC CAPACITY*

Rank	Country	Total installed capacity
1	China	352,260
2	Japan	49,905
3	Vietnam	17.031
4	Australia	8,790
5	South Korea	6,490
6	Malaysia	6,094
7	Indonesia	5,511
8	New Zealand	5,346
9	Laos	5,308
10	North Korea	5,010

* including pumped storage

HYDROPOWER GROWTH THROUGH THE DECADES



COUNTRIES BY ADDED CAPACITY IN 2018 (MW*)

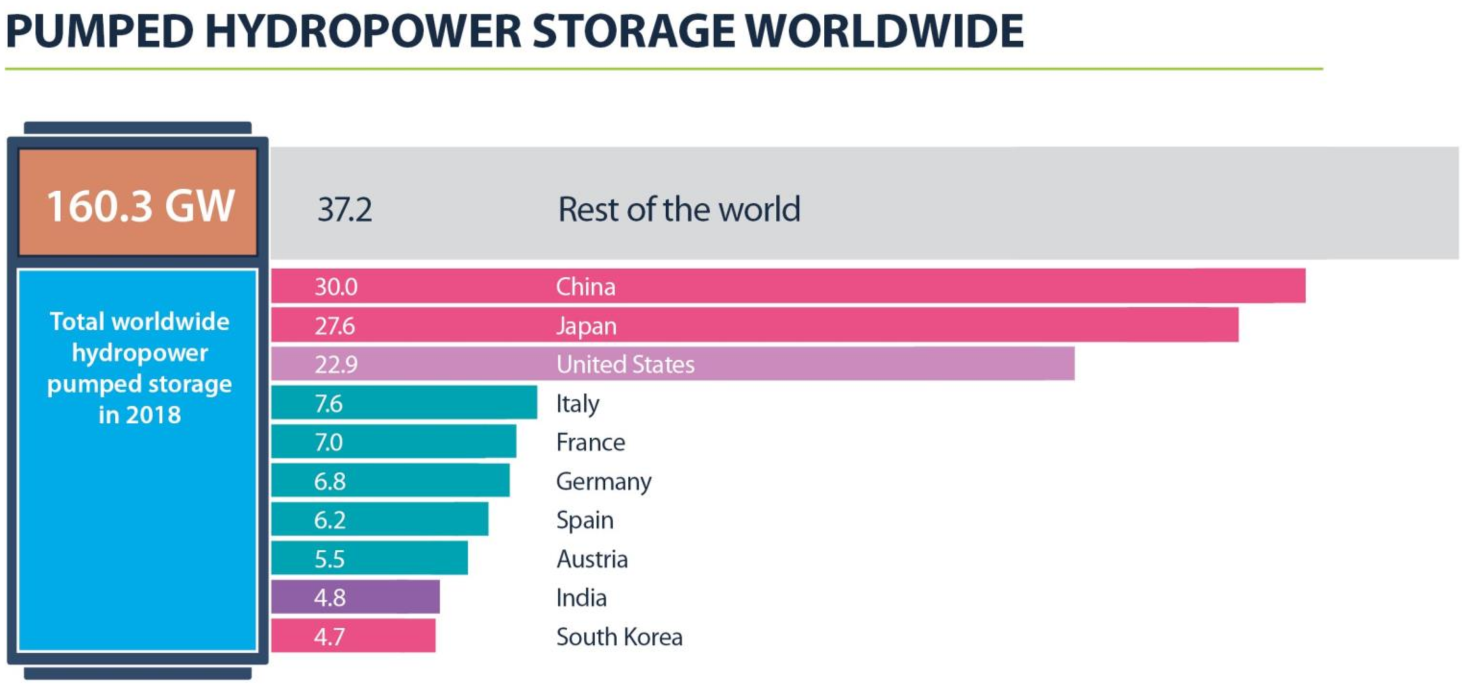
1st	2nd	3rd	4th	5th
China	Cambodia	Laos	Indonesia	North Korea
8,540	300	254	61	10

East Asia and Pacific installed capacity (2018)

Dr. Nguyen Xuan Truong, EN department

UNIT - N°.6 HYDRO ENERGY

Pumped hydropower storage has proven to be an essential component for modern and future clean energy systems. The significant increase in variable renewable electricity sources like wind and solar coupled with their displacement of conventional generators has put increasing pressure on power grids and underlined the need for pumped hydropower 'water batteries'.



Pumped hydropower storage capacity (GW) of top 10 countries and rest of the world in 2018.
Source: IHA 2018.

USTH
VIETNAM FRANCE UNIVERSITY

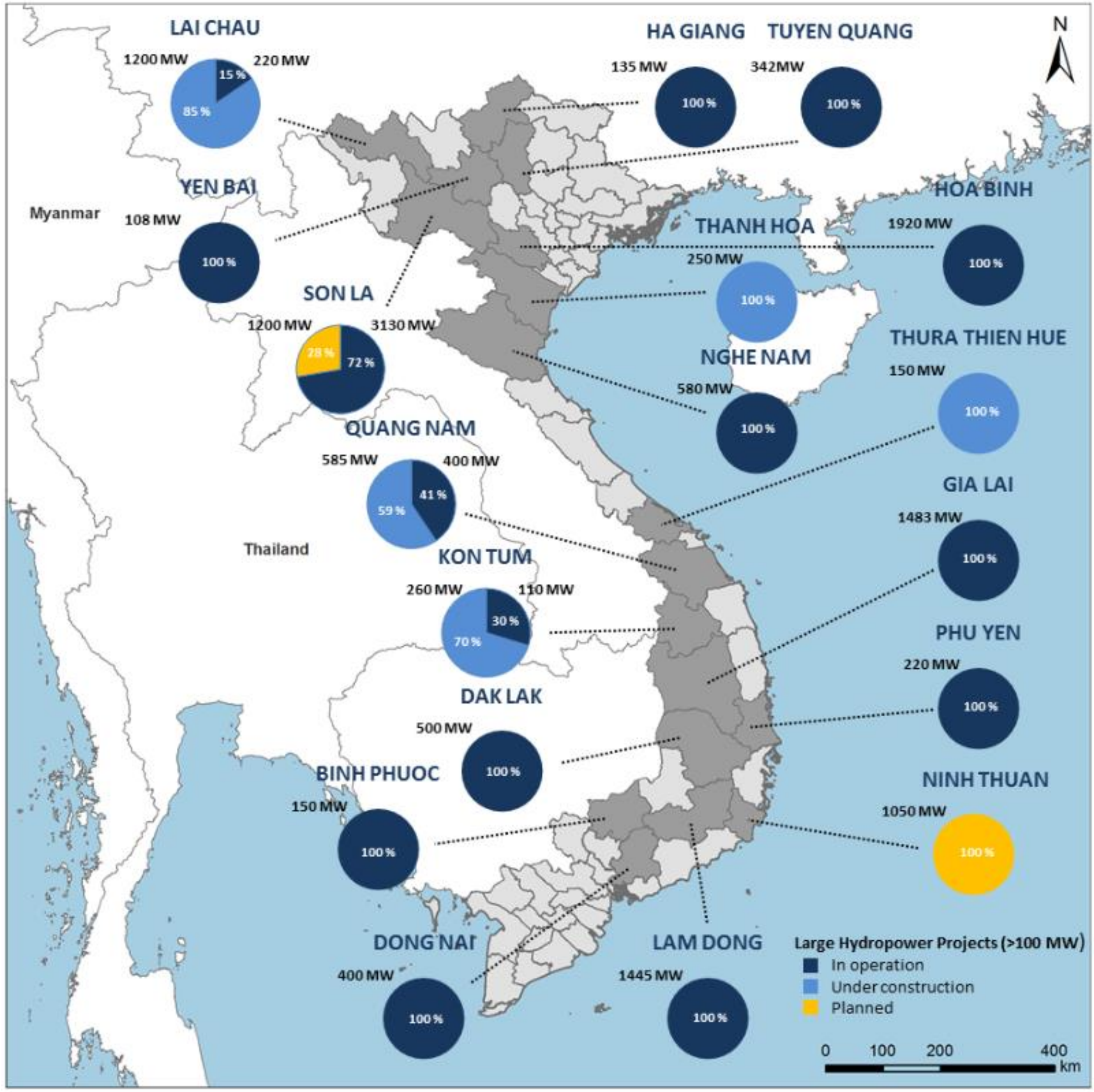
Hydropower plant in Vietnam

Vietnam has great potential for hydroelectric power

- ✓ Vietnam has 2360 rivers of ≥ 10km long, including 9 systems with a basin area of ≥ 10,000 sq km
- ✓ **Theoretical capacity of about 35 GW, the technical potential is about 26 GW, annually it can produce more than 100 GWh**;
- ✓ Small hydropower (the installed machine capacity <30 MW), annually 15-20 GWh of electricity.

- ✓ **60% in the North (Da, Lo, Thao, Ma, Ca.. river)**
- ✓ **27% in the Central Region (Se san, Srepok, Ba, Vu gia– Thu Bon, Huong river..)**
- ✓ **13% in the South (Dong Nai river)**

Some big hydro-power plants: Son La (2400 MW), Hoa Binh (1920 MW), Lai Chau (1200 MW), Ialy (720 MW) play as strategic and multipurpose hydro power plants: They act at supplying the water and reducing floods, as river transportation means, and for the power grid ensure frequency regulation and voltage stabilization of the entire system and contribute to a largeamount of electricity production



WB 2016

Small hydro power in Vietnam

- **Legal Rules:** Decision 18/2008/QĐ- BCT dated 18/7/2008 and replaced by Circular 32/2014/TT-BCT dated 9/10/2014 issued by MOIT.
  - ✓ Electricity Tariff (Avoided cost)
    - ❖ By year, by season
    - ❖ Avoided cost issued by ERAV, 2016 tariff is around 5 Uscent/kWh
  - ✓ PPA : based on sample PPA

✓ **The theoretical potential of SHP production: 300 billion kWh/ year**

✓ **The technical potential of SHP production: 123 million kWh/ year.**

✓ **The total technical potential capacity of SHP: 1,600-2,000 MW**

- ➢ **100-10,000kW per station: 500 small hydropower stations with total capacity of 1,400-1,800MW, accounting for 80–97% of total small hydropower stations**
- ➢ **5-100kW per station: 2,500 sites of small hydropower stations with total capacity of 100-150MW, accounting for 5-7.5 % of total small hydropower); and**
- ➢ **0.1 to 5 kW per station (also called as Micro-Hydro Power Stations): total capacity of 50–100 MW, accounting for 2.5–5% of total small hydropower capacity**

The potential and current use of RE in Vietnam 2018 (NLDC)

Small hydro power
Potential: > 7.000 MW
Current use: 3300 MW

Solar power
Potential: 4-5 kWh/m²
Current use: ~ 5000 MWp

Wind power
Potential: 27 GW
Current use: 300 MW

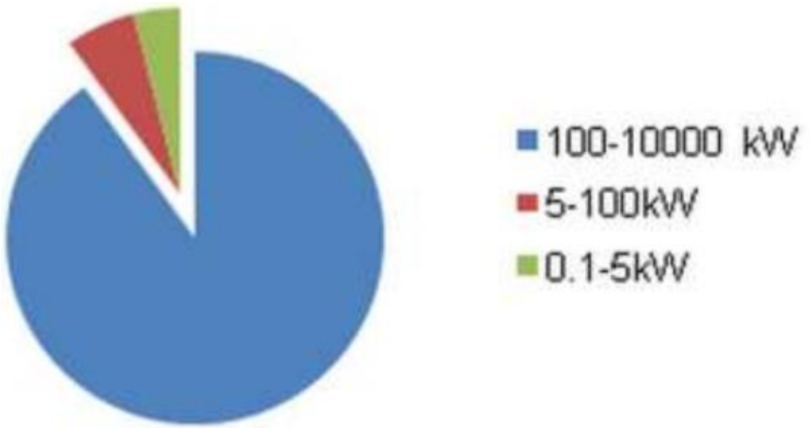
Biomass
Potential: >3000 MW
Current use: 400 MW

Biogas
Potential: 58 MW
Current use: 0.5 MW

Municipal wastes
Potential: 220 MW
Current use: 2.4 MW

Geothermal
Potential: 340 MW
Current use: 0 MW

Tidal
Potential: 100-200 MW
Current use: 0 MW



UNIT - N°.6 HYDRO ENERGY

- **Advantages**
  - Cheap to operate
  - Long life and lower operating costs than all other power plants
  - Renewable
  - High yield
  - Lower energy cost than any other method
  - Pretty plentiful
  - Some countries depend almost entirely on it
  - Not intermittent (if reservoir is large enough)
  - Reservoirs have multiple uses
  - Flood control, drinking water, aquaculture, recreation
  - Less air pollution than fossil fuel combustion

- **Disadvantages:**
  - Human population displacement
  - More significant breeding ground for disease
  - Reduces availability of water downstream
  - Ecosystem impacts
    - ✓ Barriers to migrating fish
    - ✓ Loss of biodiversity both upstream and downstream
    - ✓ Coastal erosion
    - ✓ Reduces nutrient flow (dissolved and particulate)
  - Water pollution problems
    - ✓ Low dissolved oxygen (DO)
    - ✓ Increased H_2S toxicity; other DO-related problems
    - ✓ Siltation a big problem (also shortens dam life)
  - Air pollution
    - ✓ Actually may be a significant source of GHGs (CH_4, N_2O, CO_2)
  - Decommissioning is a big problem
  - The Size Issue
    - ✓ Many (most) of the above problems are significantly worse for larger dams
    - ✓ However, small dams have shorter lifetimes, less capacity, and are more intermittent

UNIT - N°.7 GEOTHERMAL ENERGY

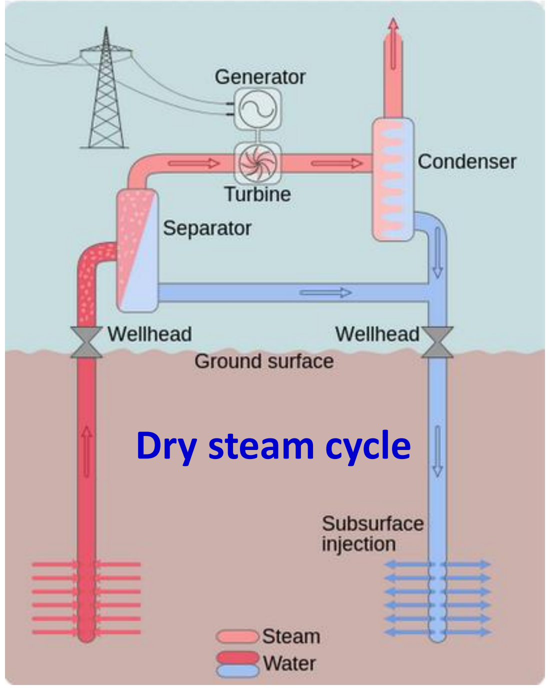
- How it works ?
  - ✓ **Geothermal power plants**
    - Use earth's heat to power steam turbines
  - ✓ **Geothermal direct use**
    - Use hot springs (etc) as heat source
  - ✓ **Geothermal heat pumps**

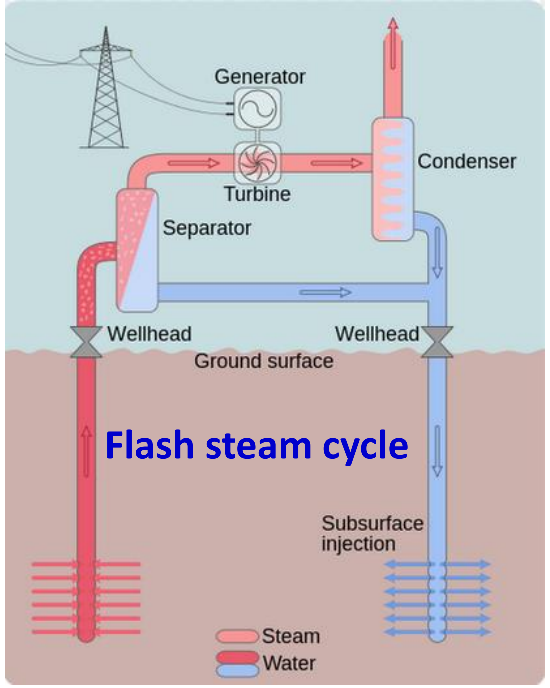
Geothermal power plants

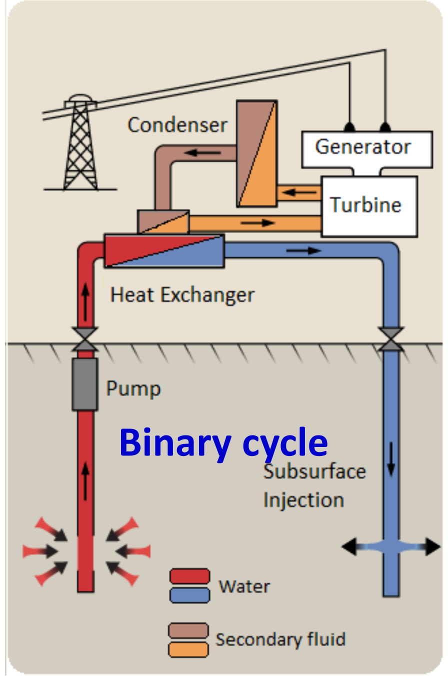
Geothermal power plants are used in order to generate electricity by the use of geothermal energy (the Earth's internal thermal energy). They essentially work the same as a coal or nuclear power plant, the main difference being the heat source. With geothermal, the Earth's heat replaces the boiler of a coal plant or the reactor of a nuclear plant

Types of geothermal power plants

- ✓ **Dry steam plants** use steam directly from a geothermal reservoir to turn generator turbines.
- ✓ **Flash steam plants** take high-pressure hot water from deep inside the earth and convert it to steam to drive generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used again. Most geothermal power plants are flash steam plants.
- ✓ **Binary cycle power plants** transfer the heat from geothermal hot water to another liquid. The heat causes the second liquid to turn to steam, which is used to drive a generator turbine

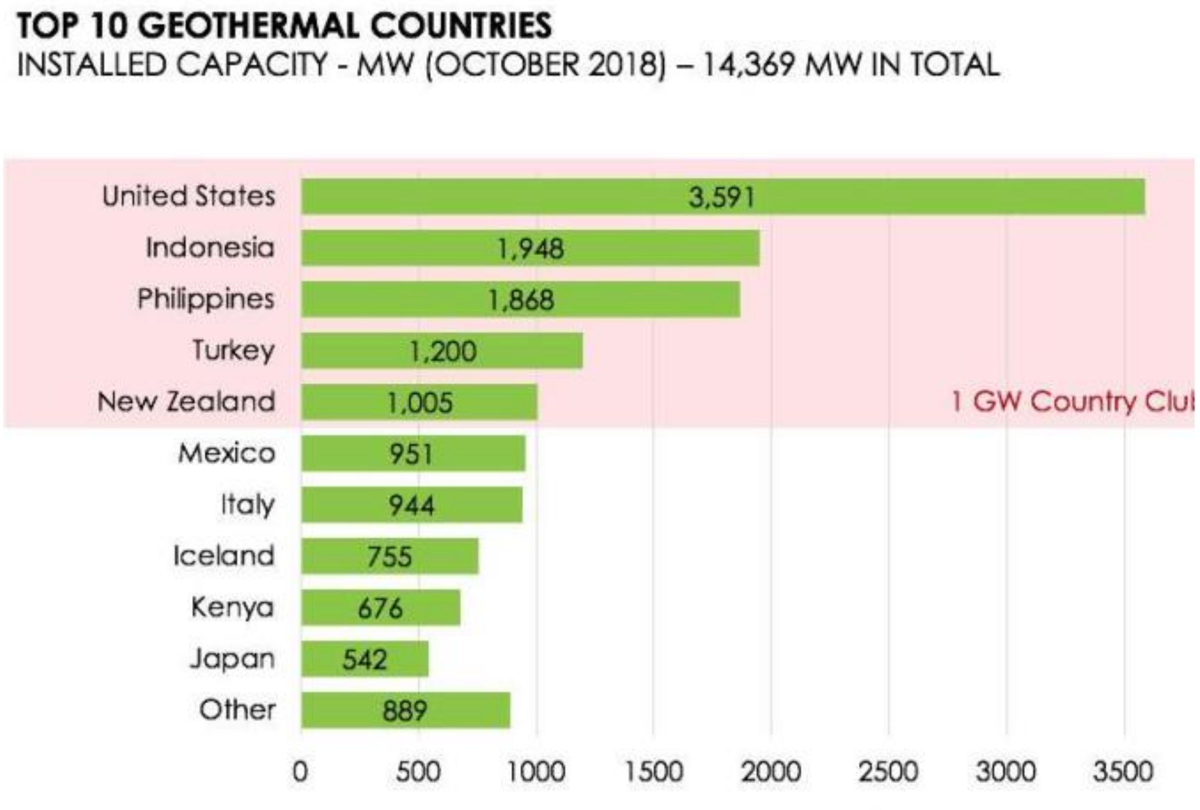


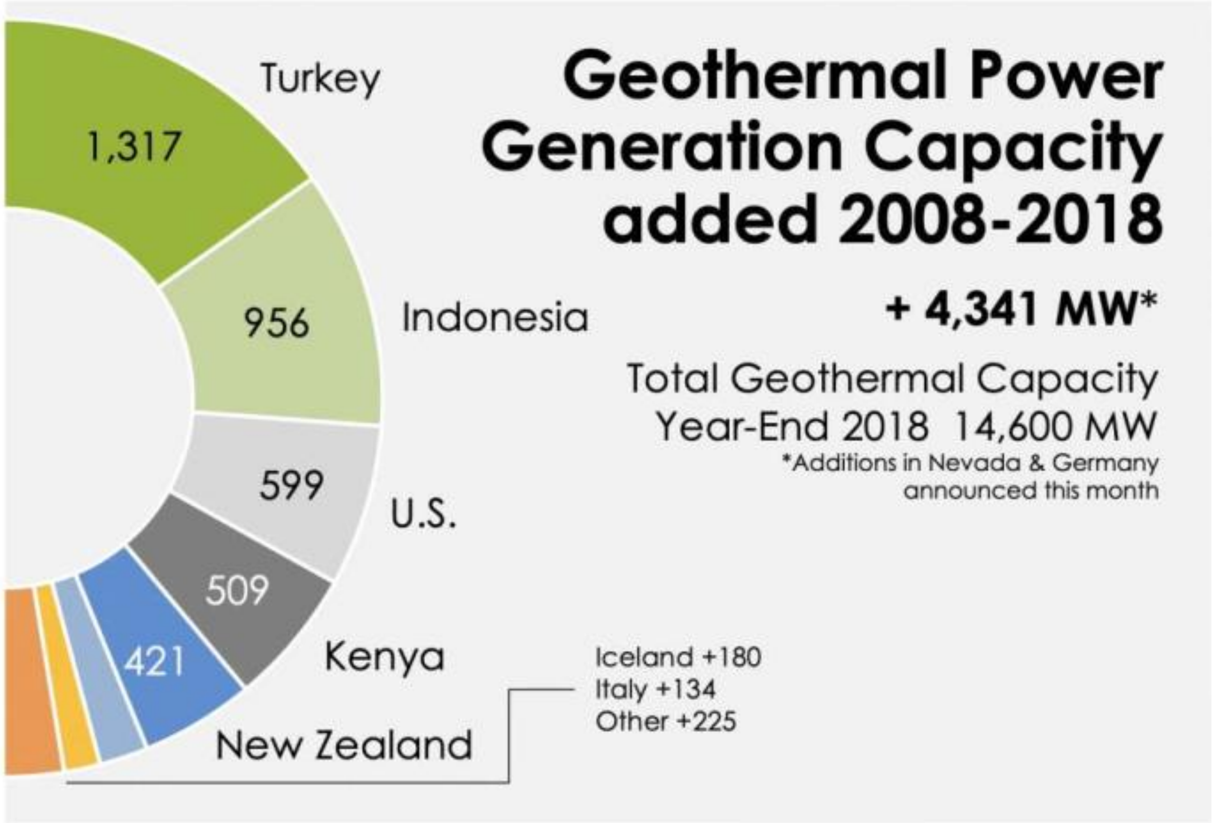




Dr. Nguyen Xuan Truong, EN department

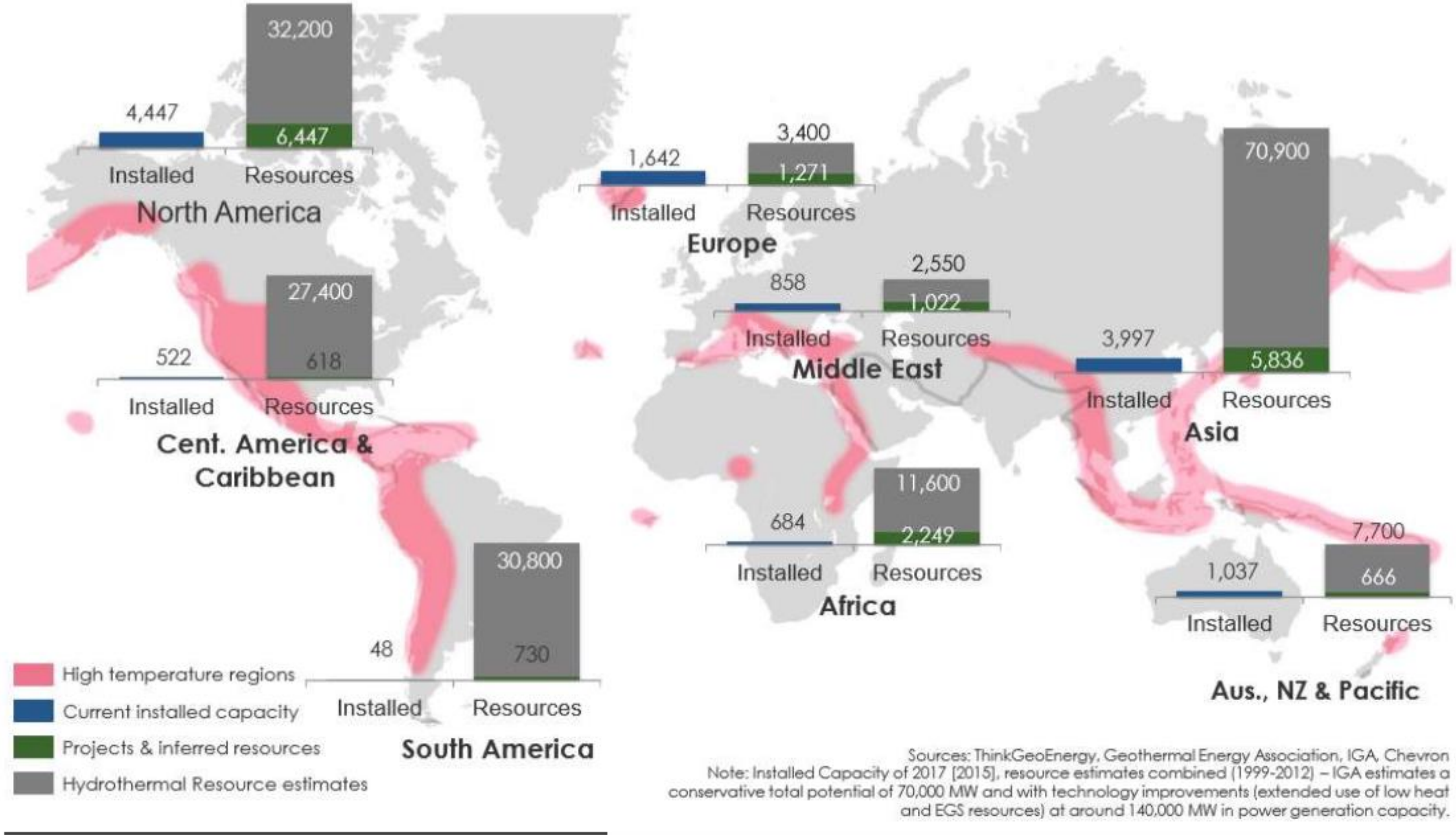
INTERNATIONAL MARKET GROWTH





UNIT - N°.7 GEOTHERMAL ENERGY

GLOBAL GEOTHERMAL POWER GENERATION POTENTIAL

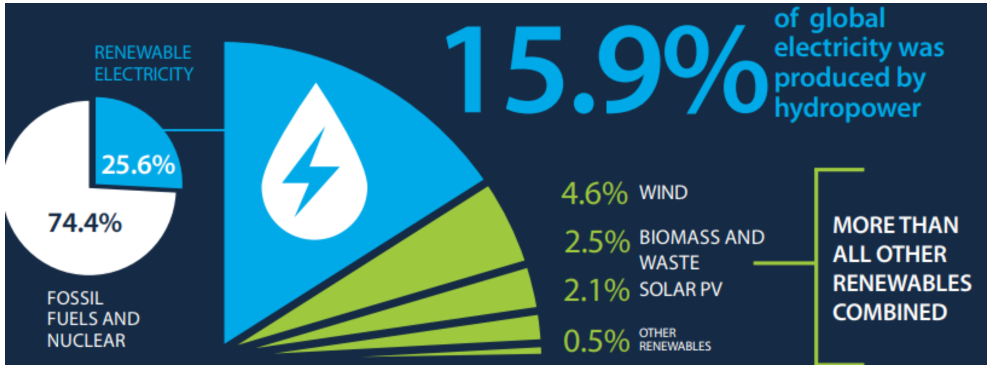


UNIT - N°.7 GEOTHERMAL ENERGY

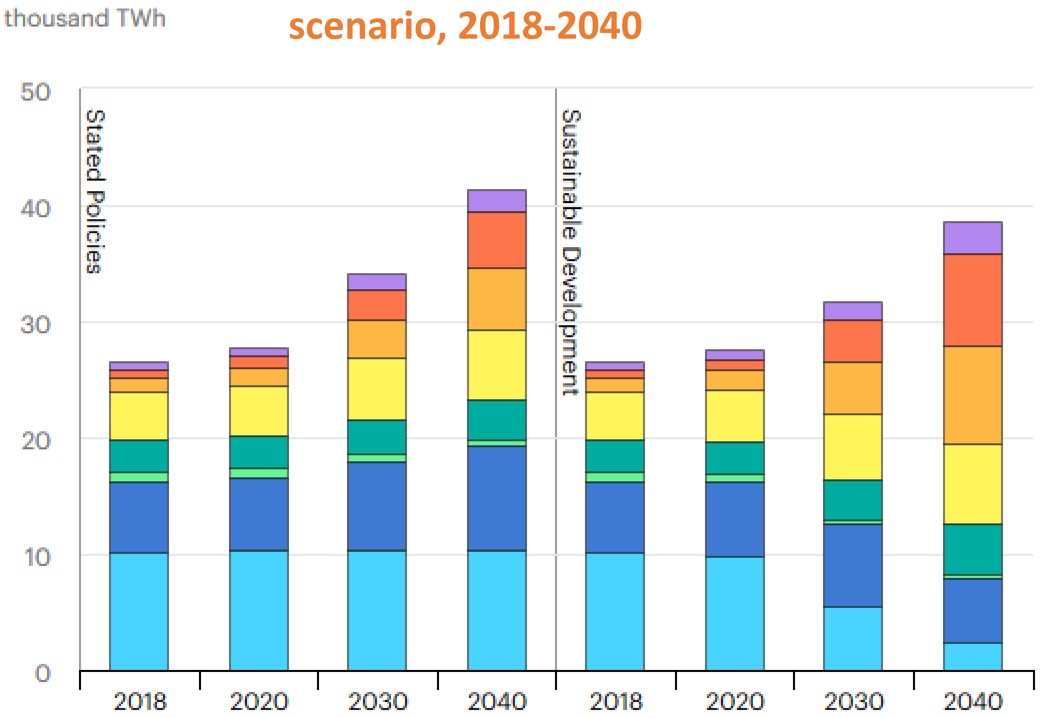
- Advantages
  - Renewable
  - Easy to exploit in some cases
  - CO_2 production less than with fossil fuels
  - High net energy yield
- Disadvantages
  - Not available everywhere
  - H_2S pollution
  - Produces some water pollution (somewhat similar to mining)

RENEWABLE ENERGY BRIEFING

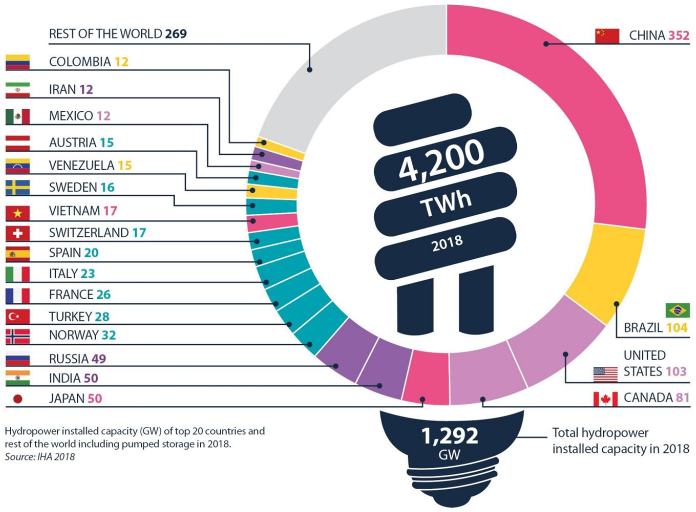
RE – PRODUCED ELECTRICITY 2018



Electricity generation by fuel and scenario, 2018-2040

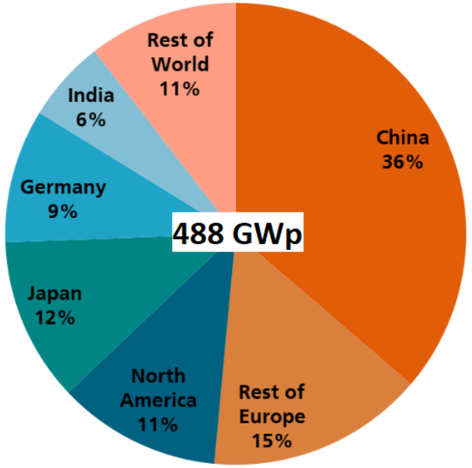


HYDROPOWER INSTALLED CAPACITY WORLDWIDE



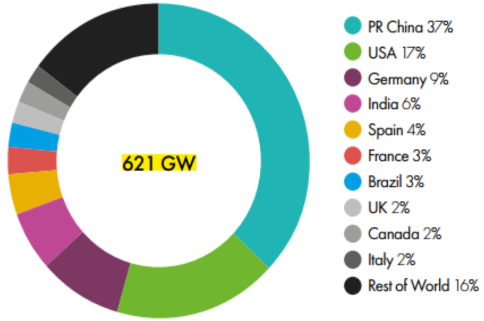
Hydropower installed capacity (GW) of top 20 countries and rest of the world including pumped storage in 2018.
Source: IHA 2018

CUM PV INSTALLATION 2018

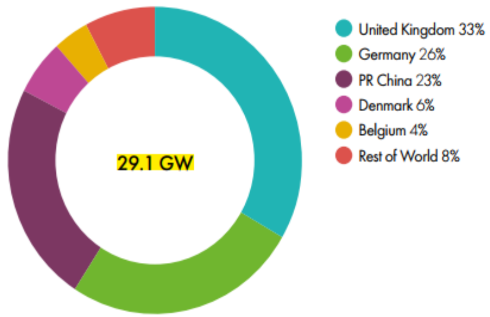


CUM WIND TURBINE INSTALLATION 2019

Total installations onshore (%)



Total installations offshore (%)



Dr. Nguyen Xuan Truong, EN department