Photovoltaic on the rise

From the sun, to the future of energy

Amareleja, Portugal - Part of the 62 MW Moura Photovoltaic Power Station built with more than 376.000 solar panels [2]

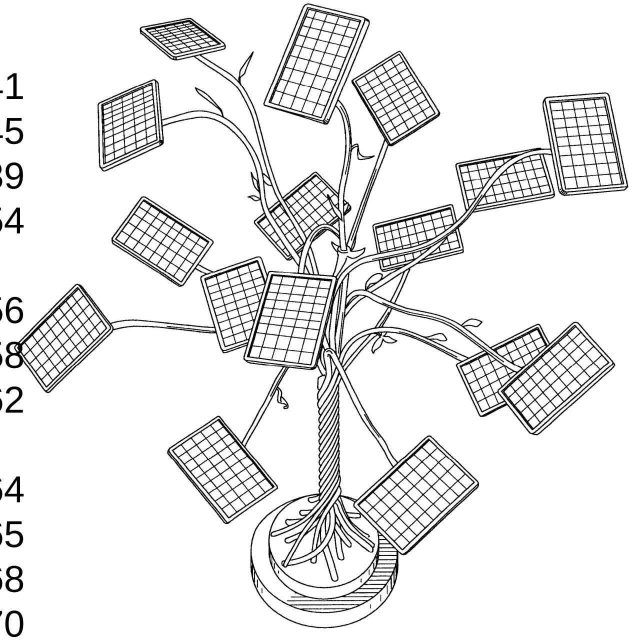
– Bologna, October 19, 2015. info@energyhunters.it; www.energyhunters.it; www.you-net.eu

“The use of solar energy has not been opened up because the oil industry does not own the sun.”

— Ralph Nader

Washington DC, 1979 - President Jimmy Carter explain the motivation of insatllation of thermal solar panels on the withe house, wishing for a future with no dependance on oil sources, after the 1979 energy crisis

Contents:



AIM of the presentation

The aim of this presentation is to give you a complete overview of the world of photovoltaic. The overview is driven by the following topics:

- To understand **the roole of photovoltaic** in the global scenario

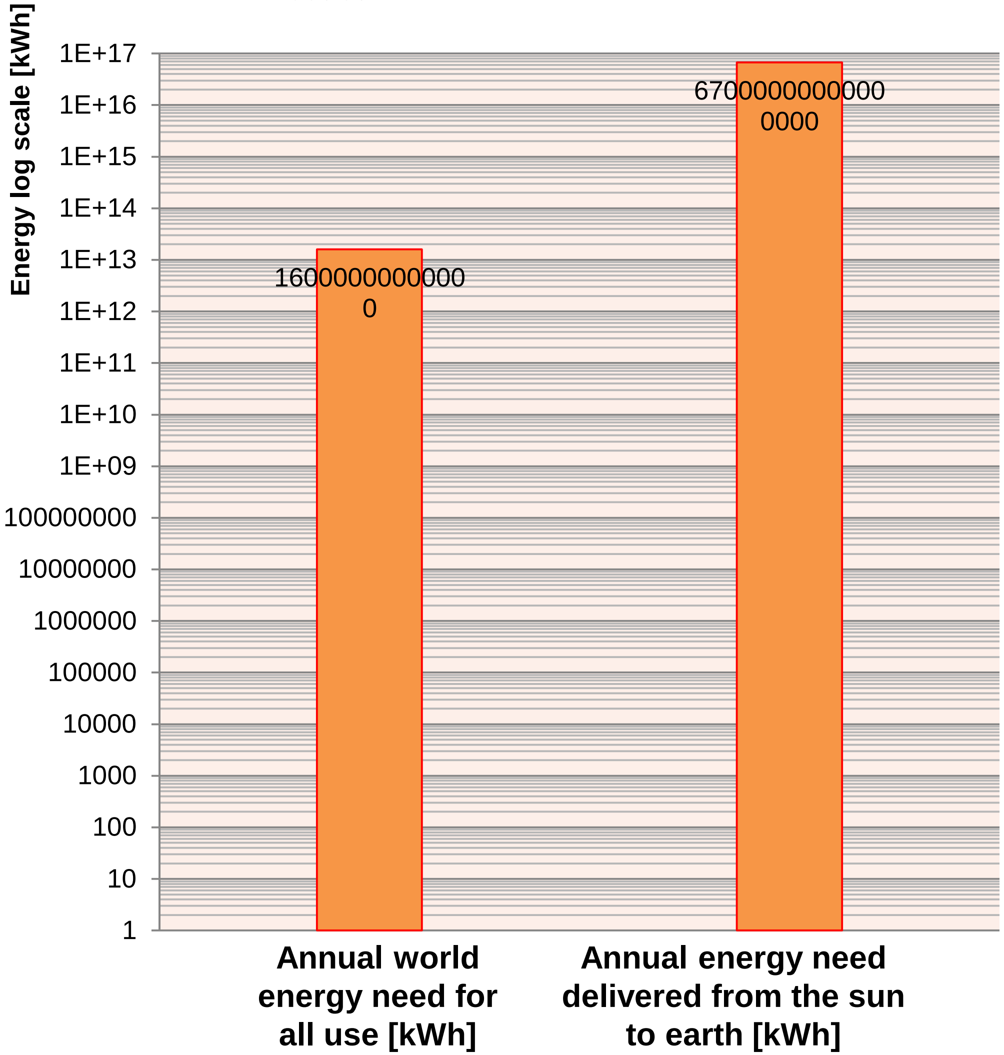
- To understand **WHY photovoltaic** can lead the future scenario and the market of energy in the future

- To understand **HOW it will do**

- To understand **WHEN** it will happen

WHY A PRESENTATION ON PHOTOVOLTAIC?

$$\frac{E_{sun}}{E_{needed}} \cong 4200$$



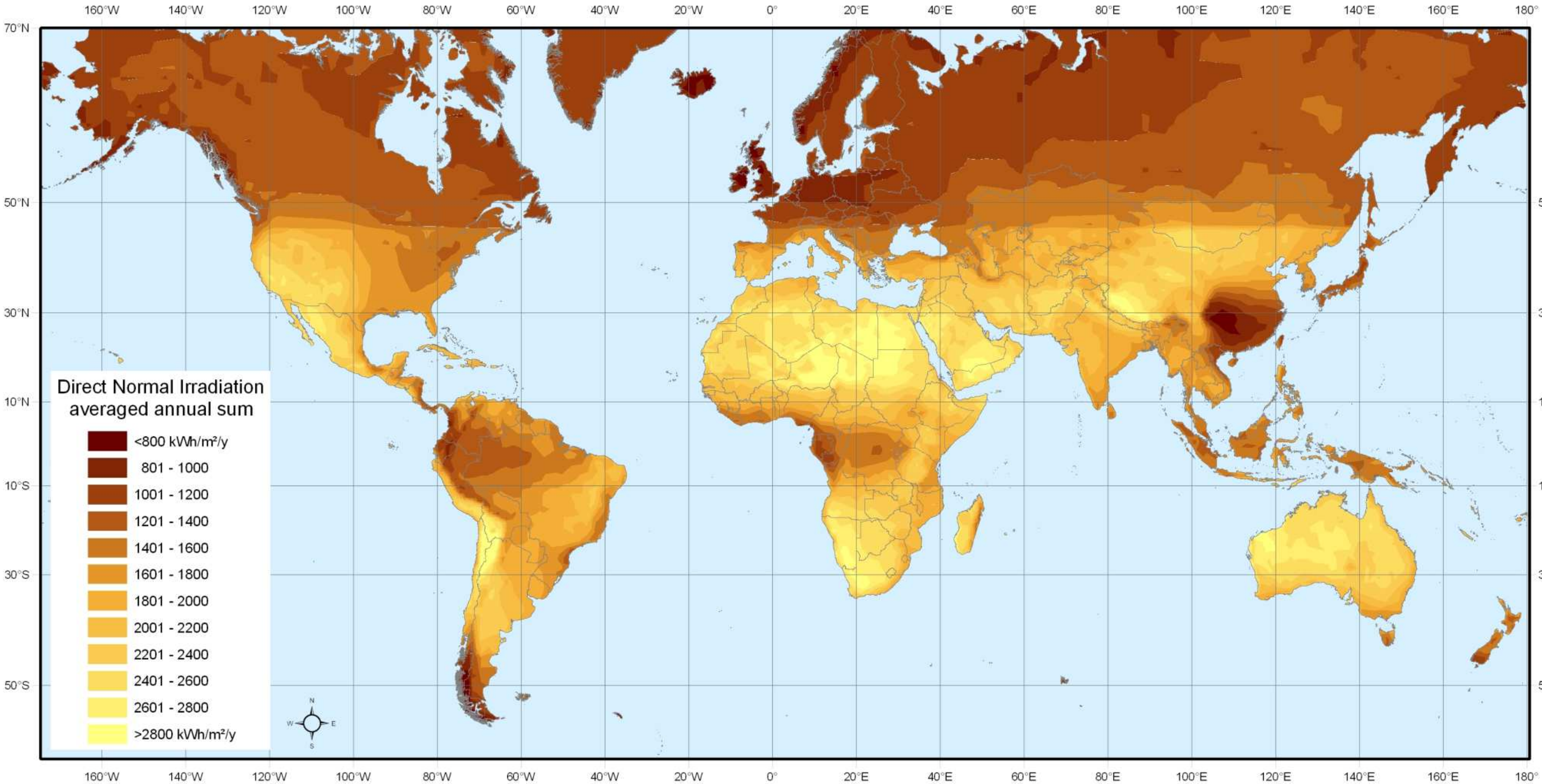
- Because is totally free of pollution source of energy
- Because solar energy is the form of energy that need less sel power to be operated (around 1%) and this is **due to a simple reason: photovoltaic panels doesn't moove.**
- Because the price of energy produced by fossil fuel is by now competitive in most of the developed countries **and it will be always lower time by time.**
- **Because is reliable**
- **Because the sun provide much more energy that human need and the availability of this source is simply everywhere.**

*Part 1 - Photovoltaic in numbers – **Where we are***

- **0% Growth of China total energy consumption; 1st time in 17 years; Gross domestic product +7,3% same period**
- **1$**, are the subsides that in 2011, according to IEE (*International Energy Agecy*) were give to renewable energy sources every **4$** give to conventional sources of energy
- **1%** is even the share of the global electricity demand that now photovoltaic power provide in the world
- **3%** is the share of global electricity demand that could be probably covered by photovoltaic in the world by 2019
- **1 to 3,5** is the energy footprint of a solar panel depending on the technology used
- **8%** is the share of energy covered by photovoltaic in Italy in 2014 and it is probably underestimated
- **19 GWp** is the photovoltaic power that will be installed worldwide in 2016 in the balanced scenario
- **21%** is the share of global electricity demand that could be probably covered by photovoltaic in the world by 2050
- **21,5%** is the highest solar panel efficiency reached for a commercial solar panel – Sunpower X series 345 Wp [5]
- **40 GWp** is the global installed power capacity reached in the only 2014, more than 2 times the all installed in Italy now.
- **46%** is the highest solar cell efficiency reached by Soitec corporation and Fraunhofer laboratories in December 1st 2014 with a multi junction concentrated solar cell
- **75%** is the mean photovoltaic price decline in the last 10 years
- **178 GWp** is the global photovoltaic capacity actually installed in the world according to SPE [4]
- **540 GWp** is the global photovoltaic capacity expected to be reach in 2019 according to SPE [4]
- **560 W** is the rated power of the most powerful solar panel actually on the market [3]
- **579 MWp** is the power of the world largest solar farm named Solar Star and placed in Rosamond, California built with more thant 1.700.000 solar panel
- **1290 kWh/kWp** is the world average productivity of photovoltaic plants in the world and this is not a good news
- **20301 TWh** is the yearly global electricity consumption at the end of 2014 according to enerdata [6]
- **2.273.000** are the employers of the photovoltaic sector worldwide, according to IRENA [7]
- **174.000.000.000.000.000 Wh every hour** is the the amount of energy delivered from the sun to the earth, this correspond to more than **75.000 time the energy requested for the all human activity**

Part 1 - Photovoltaic in numbers – ***Where we are***

World solar irradiation – 22 years observation mean values.
Credit: NASA
Values are expressed in kWh/(m²· year)

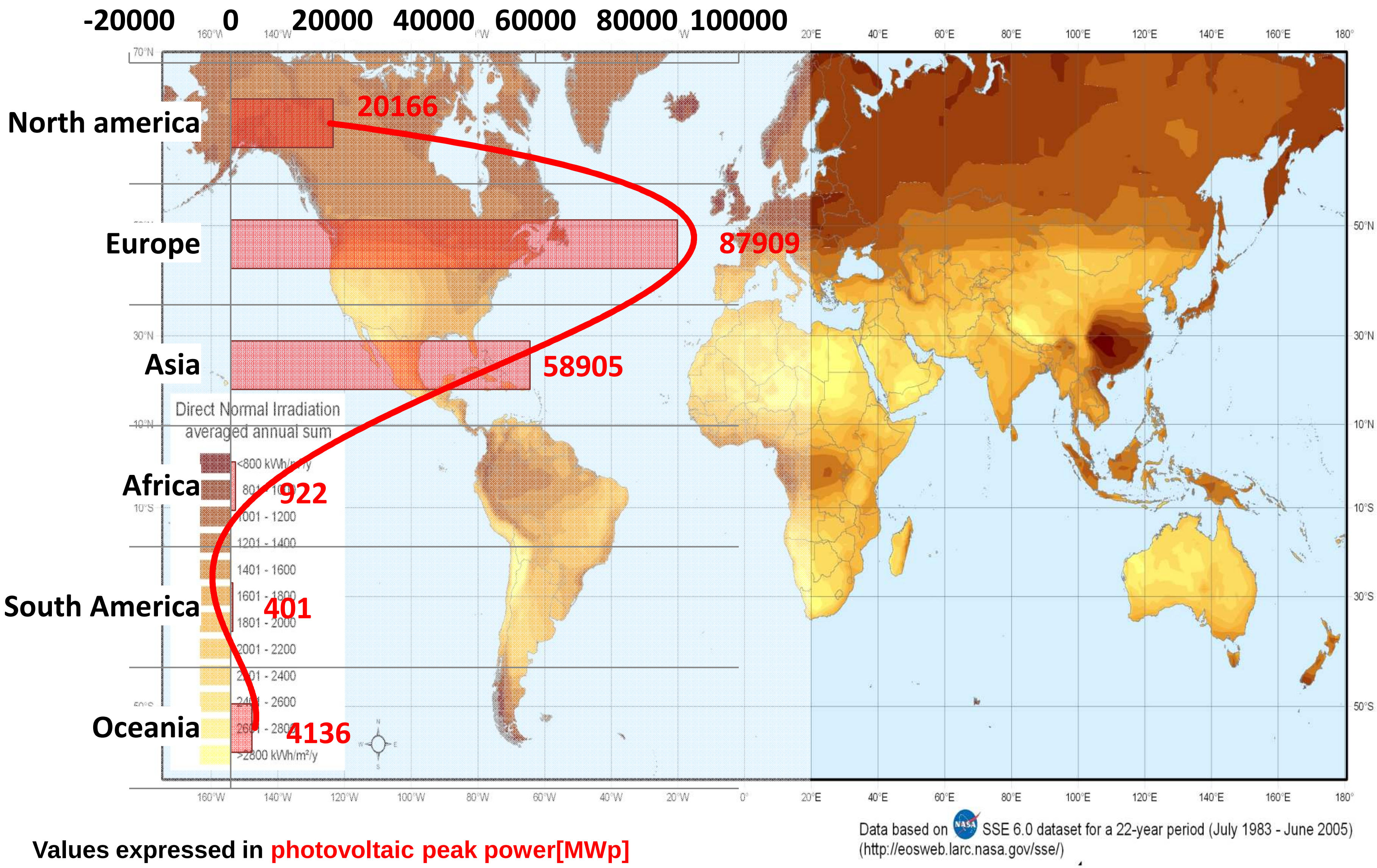


Data based on NASA SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(http://eosweb.larc.nasa.gov/sse/)

$$I = f(l, h, exposition, \rho)[\frac{kWh}{m^2}]$$

Part 1 - Photovoltaic in numbers – ***Where we are***

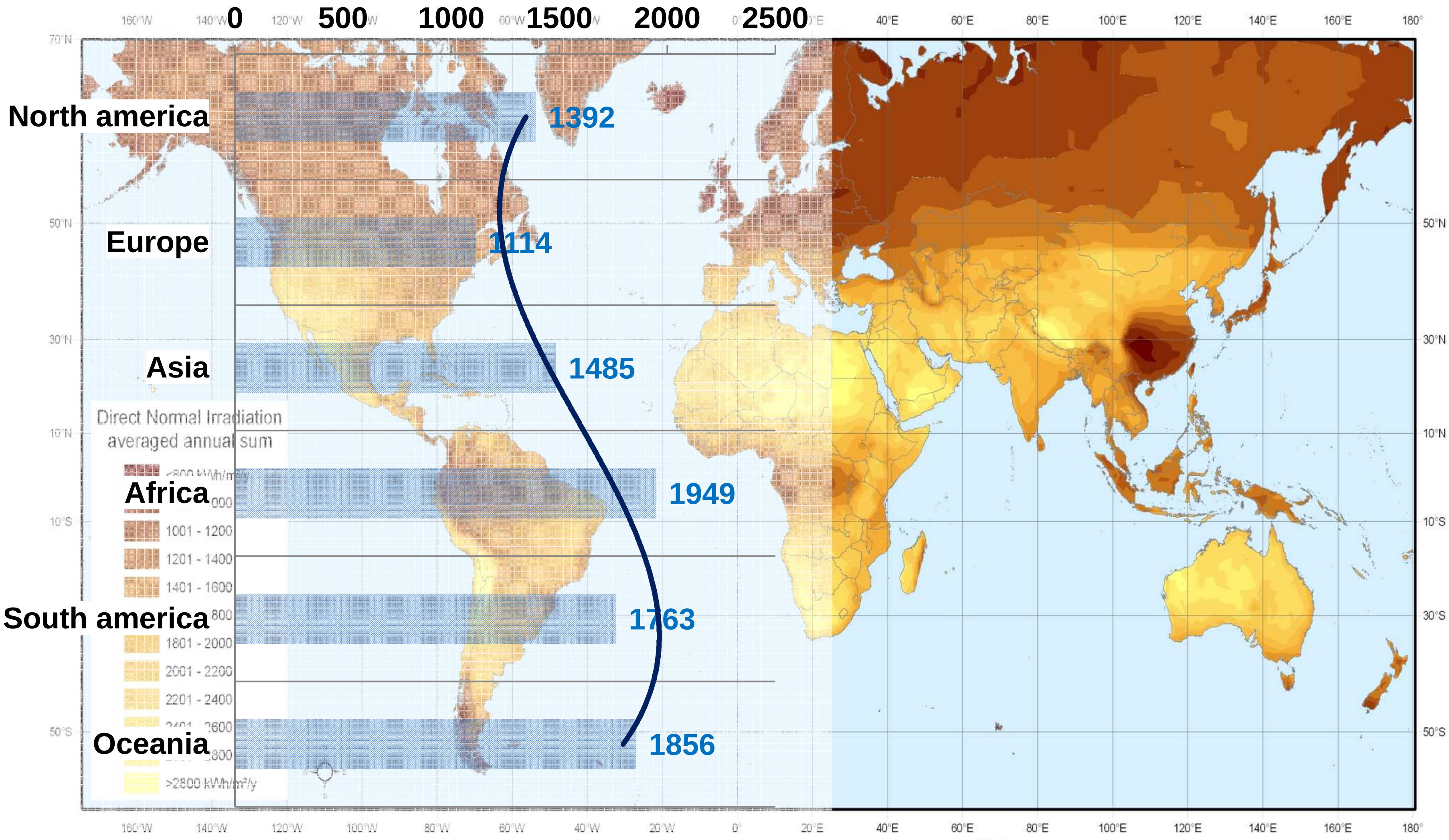
Where are the installations? Where are the world areas with more power installed?



Values expressed in photovoltaic peak power[MWp]

Part 1 - Photovoltaic in numbers – ***Where we are***

Where is the higher potential? Mean values of photovoltaic plant productivity expressed in kWh/kWp



Data based on SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
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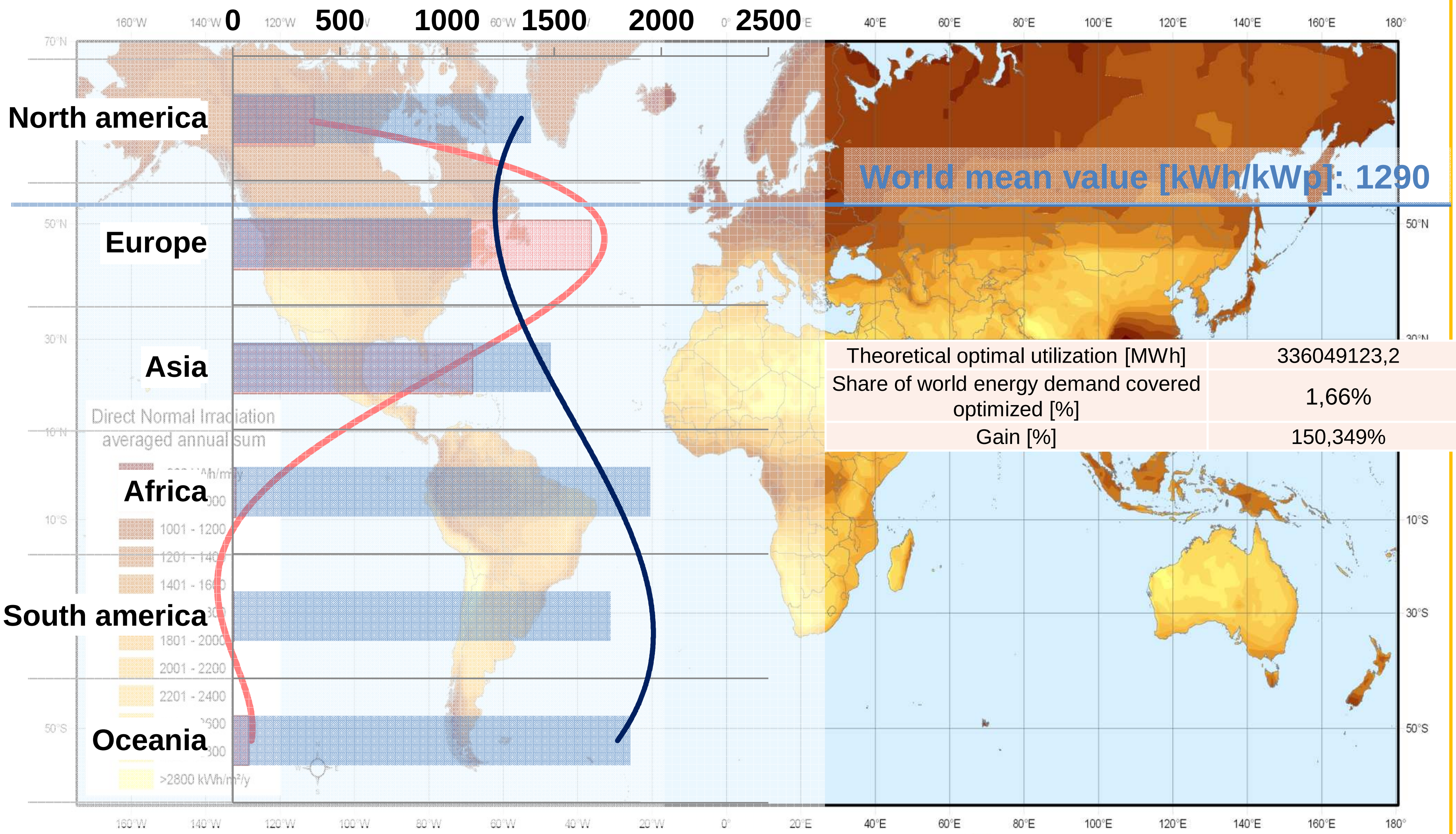
*Part 1 - Photovoltaic in numbers – **Where we are***

Where is the higher potential?



Theoretical optimal utilization [MWh]	336049123,2
Share of world energy demand covered optimized [%]	1,66%
Gain [%]	150,349%

Data based on NASA SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(http://eosweb.larc.nasa.gov/sse/)

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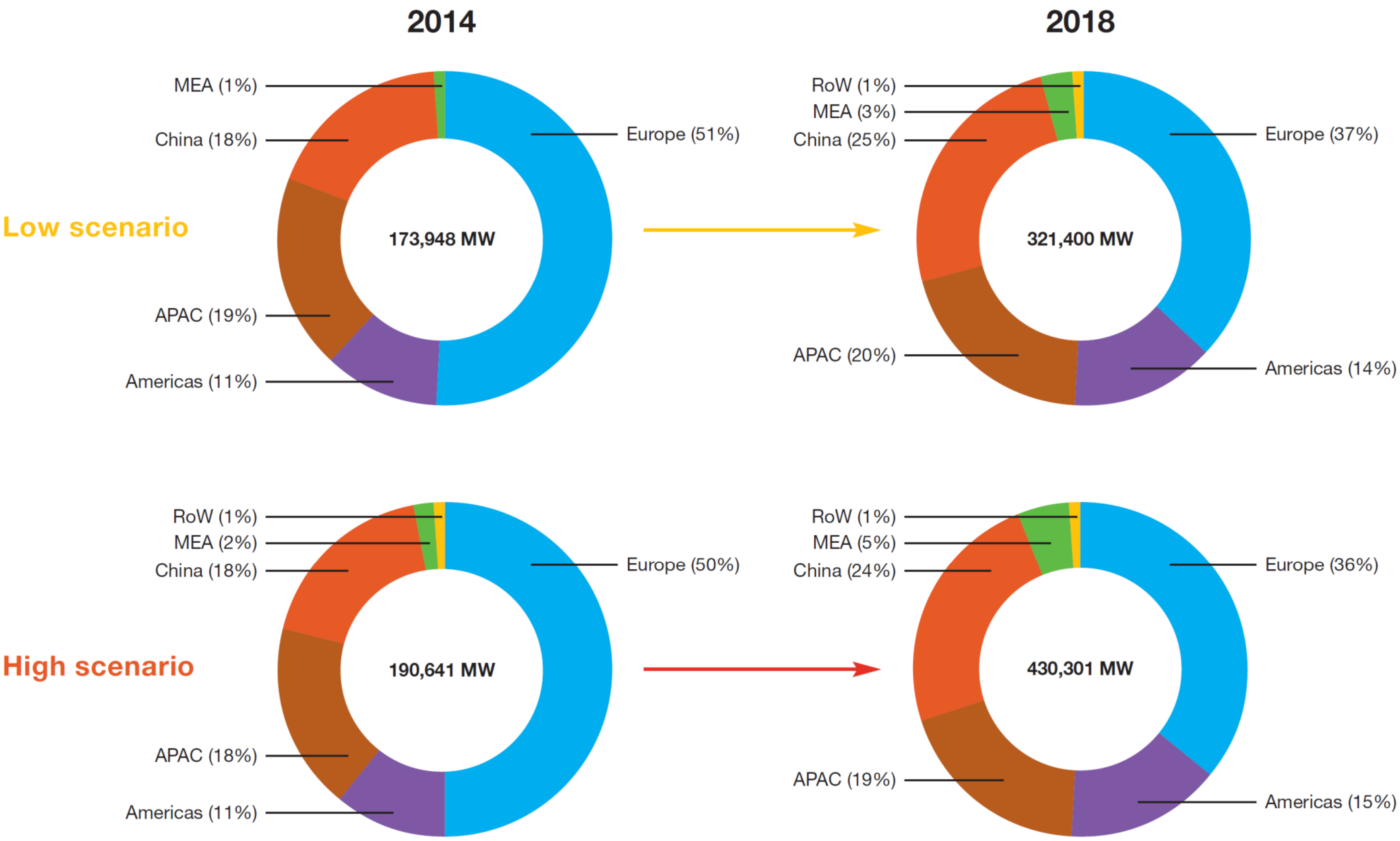
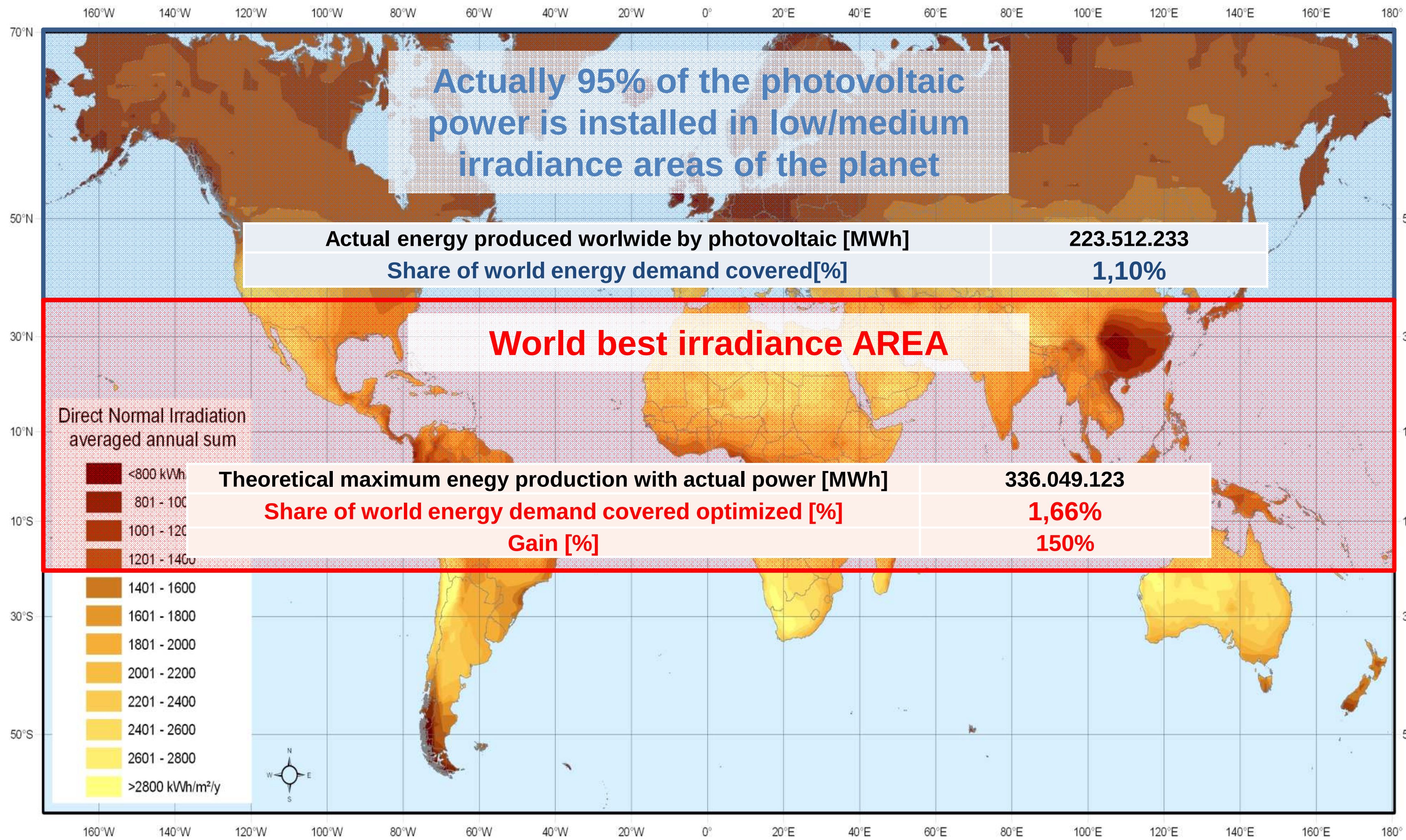
*Part 1 - Photovoltaic in numbers – **Where we are***



RoW: Rest of the World. MEA: Middle East and Africa. APAC: Asia Pacific.
Methodology used for RoW data collection has changed in 2012.

Part 1 - Photovoltaic in numbers – ***Where we are***

Where is the higher potential?



Actually 95% of the photovoltaic power is installed in low/medium irradiance areas of the planet

Actual energy produced worlwide by photovoltaic [MWh]	**223.512.233**
Share of world energy demand covered[%]	**1,10%**

World best irradiance AREA

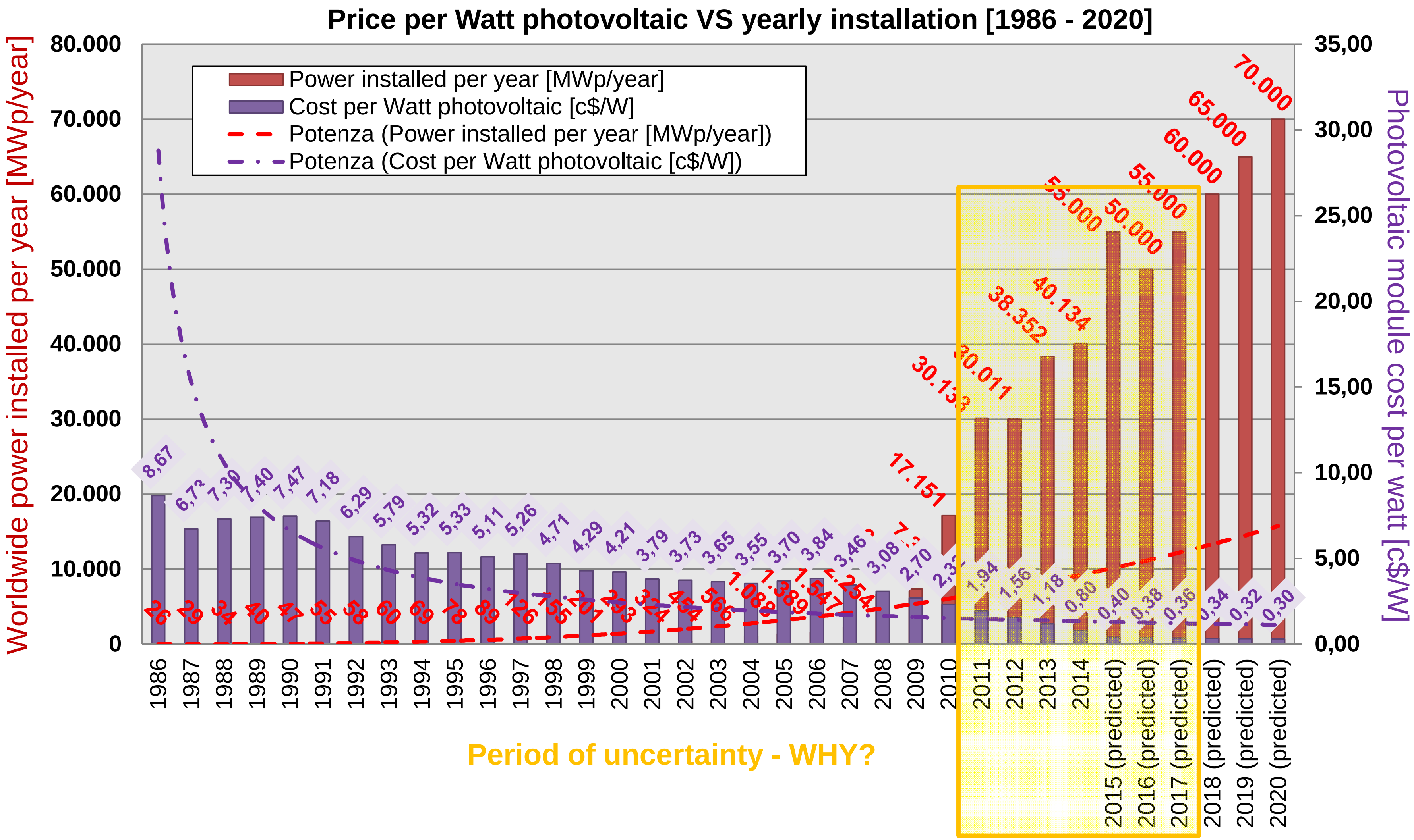
Theoretical maximum enegy production with actual power [MWh]	**336.049.123**
Share of world energy demand covered optimized [%]	**1,66%**
Gain [%]	**150%**

Data based on NASA SSE 6.0 dataset for a 22-year period (July 1983 - June 2005) (http://eosweb.larc.nasa.gov/sse/)

Where is the real BIG future of photovoltaic?

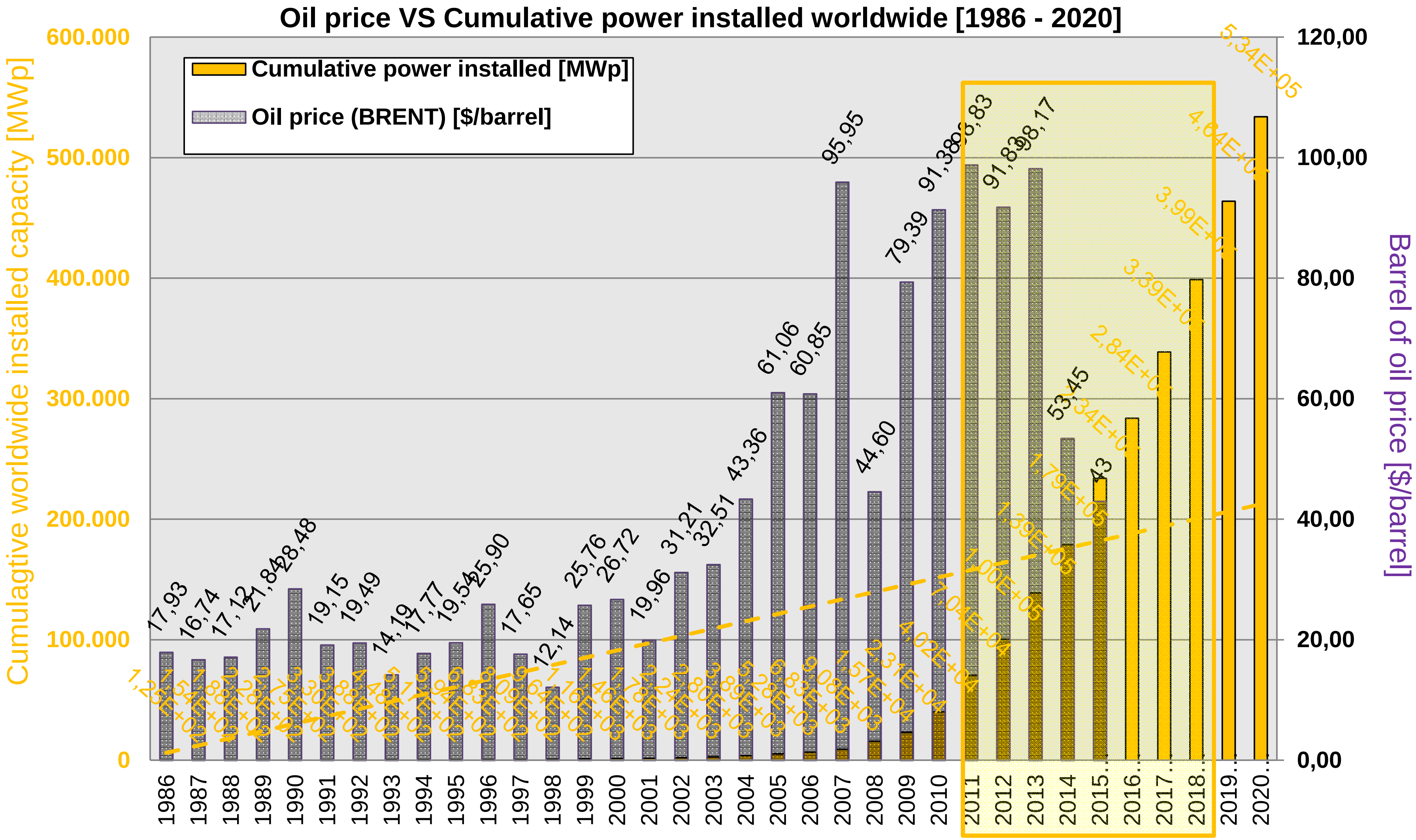
*Part 1 - Photovoltaic in numbers – **Why we are here***

Let’s consider price of PV modules VS yearly power installation worldwide to understand the economic trend of photovoltaic now and in the future



*Part 1 - Photovoltaic in numbers – **Why we are here***

The answer, is *also (non only)* in the oil price



Let's take a clooser look

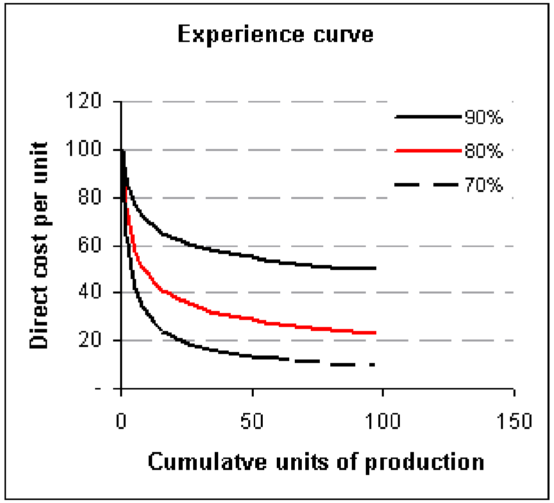
*Part 1 - Photovoltaic in numbers – **Why we are here***

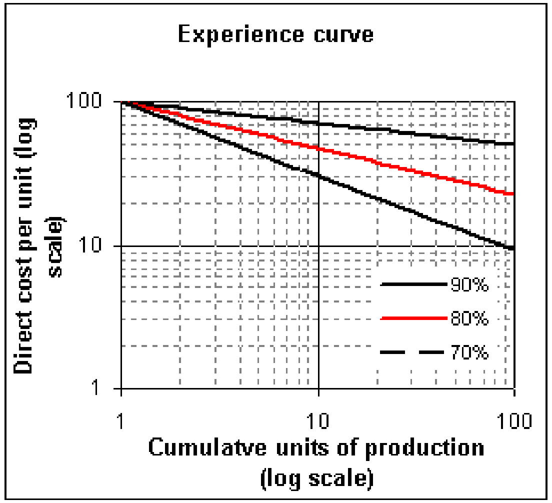
What is the GRID PARITY?

The photovoltaic market, since from the beginning, was characterized by the classical experience curve of price **or expertise curve**. For every product scale made and introduced on the market the unit price is function of the number of item that are produced. Same things was happening for the photovoltaic panels.
You can figure an simplified model of the experience curve with:

$$C_n = C_1 n^{-a}$$

- C_1 is the cost of the first unit of production
- C_n is the cost of the n-th unit of production
- *n* is the cumulative volume of production
- *a* is the elasticity of cost with regard to output





Because of declining of prices due to the expertizing progress of producers:

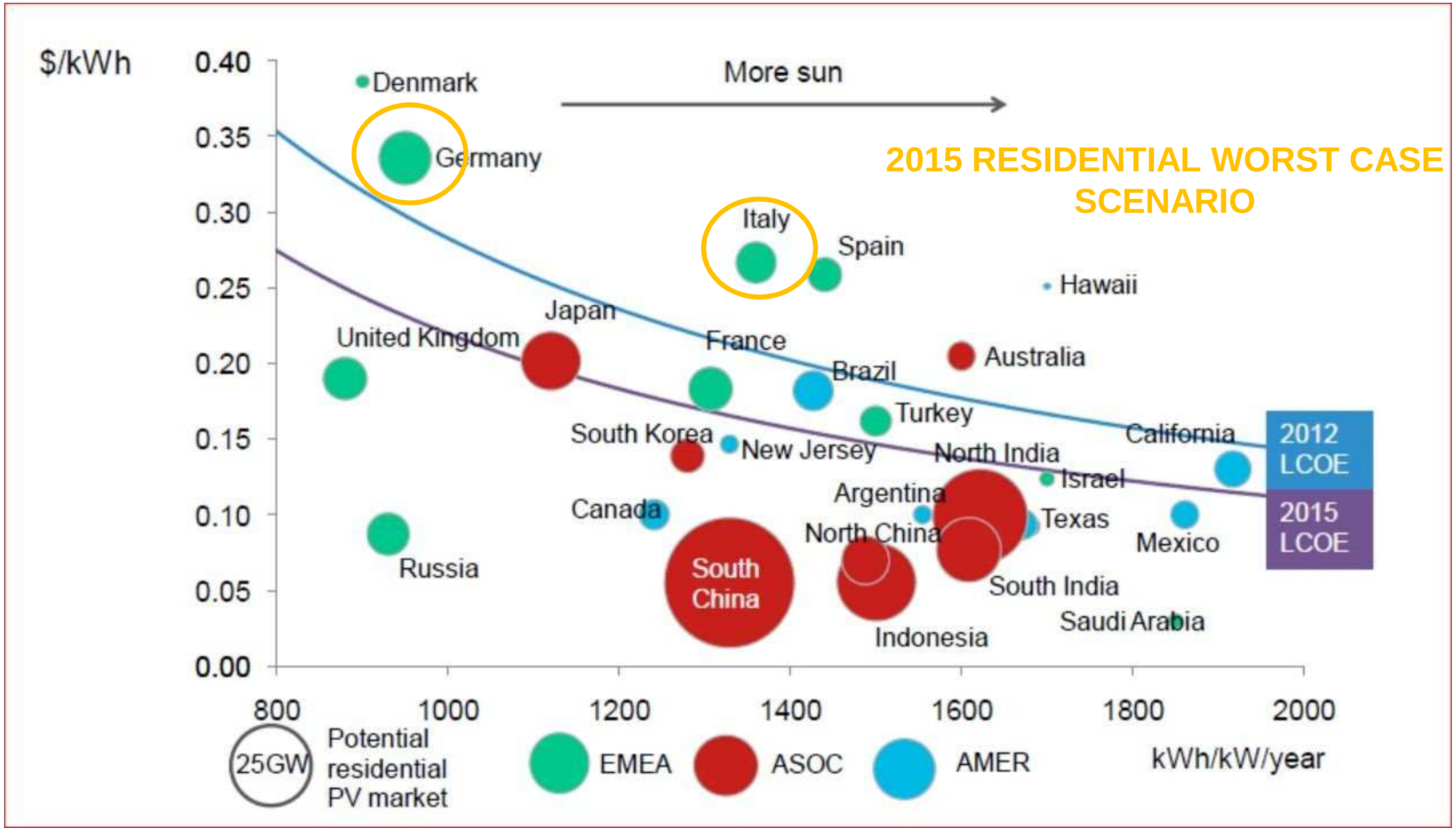
- **Firstly with financial subsides in EU countries**
- **Secondary, with the progress of prices, in many countries**

We started and we continue to face in this years the phenomena of grid parity

*Part 1 - Photovoltaic in numbers – **Why we are here***

What is the GRID PARITY?

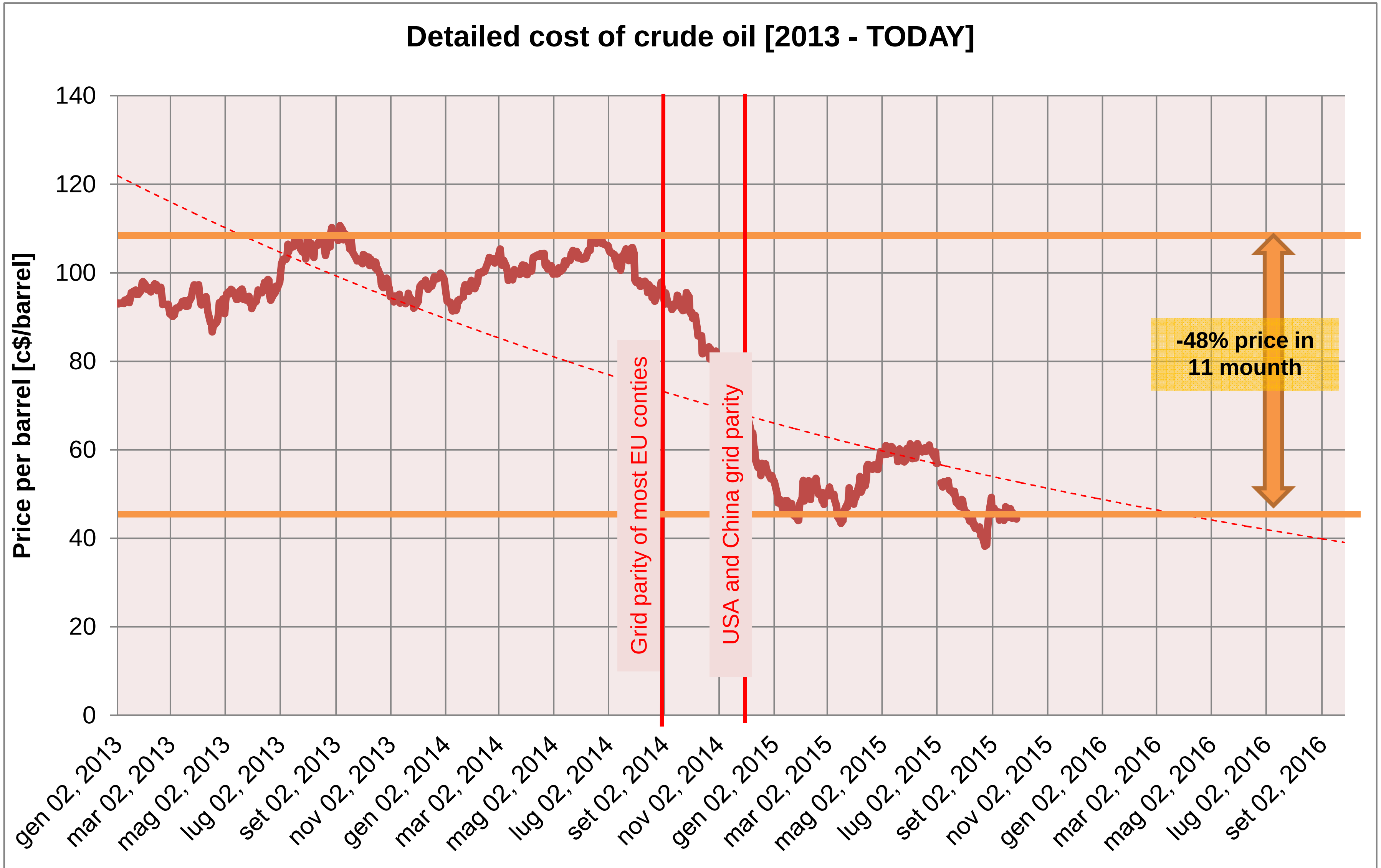
Grid parity (or socket parity) occurs when an alternative energy source can generate power at a levelized cost of electricity (LCOE) that is less than or equal to the price of purchasing power from the electricity grid. The term is most commonly used when discussing renewable energy sources, notably solar power and wind power. Grid parity depends upon whether you are calculating from the point of view of a utility or of a retail consumer.



Example of grid parity comparions per country – Renewableinternational.net

Part 1 - Photovoltaic in numbers – ***Why we are here***

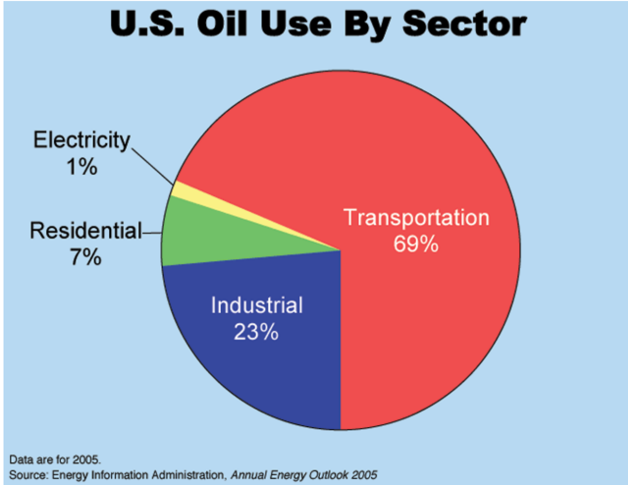
WHAT WAS THE REACTION OR THE PURE CASE OF THE MARKET?



*Part 1 - Photovoltaic in numbers – **Why we are here***

CONSIDERATION:

- We definatly NOT can correlate the oil price decline with photovoltaic and renewable energy sources penetration in global scenario, the renewable market and the electric market only rapresent a few amount of the World oil demand (More or less 1%)
- BY THE CONTRARY, we can FOR SURE adfirm that the big fall in oil qutation cause a fall in conventional electrity cost and, by consequences, put further the grid parity in some state/areas of the World
- So far, by this phenomena, and by the end, in most countries, of subsidies policies, we can explain the declining in the world installation rate
- All agency, in this moment, adfirm that, at most in 2017, this trouble moment of uncertainty will end, due to the declining of PV module price
- **FROM THE ECONOMY POINT OF VIEW, THE MARKET HAS SHOWN 3 DIFFERENT MOMENTS:**
  - **Experimental phase – no industrial diffusion, decline of price due to laboratory work and big margins from prime tecnology**
  - **Subsides phase till first grid parity – massive installation, price decline due to much power installed**
  - **Recent days – the oil reaction and the grid parity moment – no subsides, price down due to market constraints to remain in grid parity and avoid bankrupts**



"Lower Oil Price Will Not Stop the Dazzling Rise of Solar Photovoltaic"

Frost & Sullivan consulting

*Part 1 - Photovoltaic potential – **What we can do***

TO POWER THE ENTIRE WORLD IN 2030, WE WHOULD NEED 450.000 Km^2 OF LAND COVERED BY PHOTOVOLTAIC AND THAT IS THE EQUIVALENT AREA OF:

1 TIME X MOROCCO **4 TIME X BULGARIA** **4% OF SAHARA DESERT**

Do you think is a lot of space?

BUT DID YOU KNOW THAT IN THE WORLD WE HAVE, AT LEAST, MORE THAN 7,2 BILION OF HINABITANTS MOST OF THEM LIVING IN HOUSES WITH ROOFS?
AND DO YOU KNOW THAT PANELS ARE IDEAL FOR ROOF INSTALLATION?

Let's take into account only:

- 80% of the roof surface with 80% of the maximum local annual solar input
- And let's consider to cover the roof with this type of photovoltaic characteristics

Photovoltaic system characteristics	
Photovoltaic system efficiency [%]	17%
Mean module power[W]	270
Mean module surface[m^2]	1,6
World mean irradiance [kWh/m^2]	1717
Mean world productivity 2014 [kWh/kWp]	1593

*Part 1 - Photovoltaic potential – **What we can do***

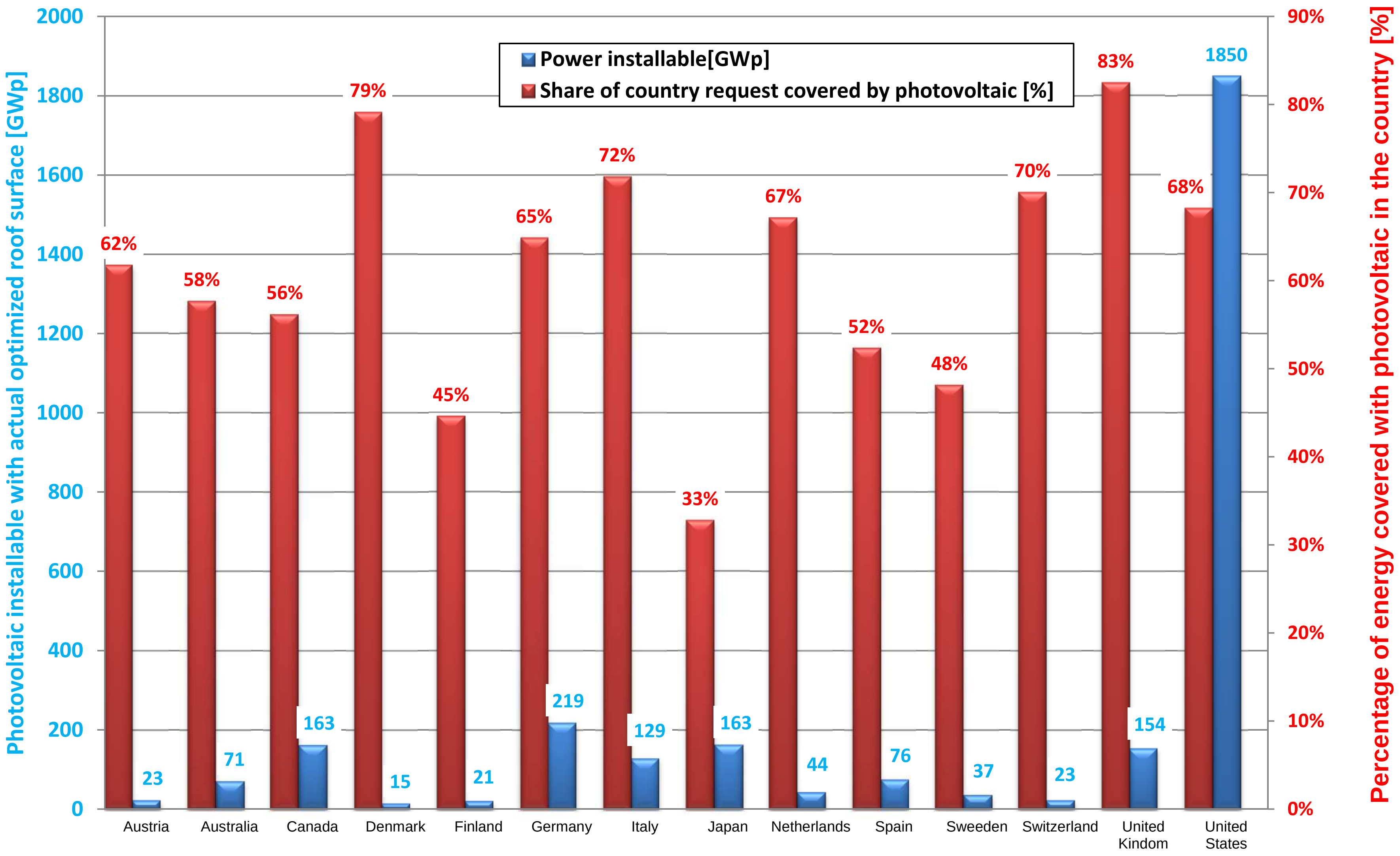
THOSE ARE THE RESULTS OF 14 OF THE MOST INDUSTRIALIZED COUNTRIES IN THE WORLD:

Country	All buildings good surface area [km^2] [9]	Power installable [GWp]	Energy produced by all the surface covered with photovoltaic [TWh]	Electricity consumption per country [TWh/year]	Share of country request covered by photovoltaic [%]	Share of world request covered by photovoltaic [%]
Austria	139	23	41	66	62%	0,20%
Australia	422	71	123	214	58%	0,61%
Canada	963	163	281	500	56%	1,38%
Denmark	87	15	25	32	79%	0,13%
Finland	127	21	37	83	45%	0,18%
Germany	1295	219	378	583	65%	1,86%
Italy	763	129	223	310	72%	1,10%
Japan	966	163	282	860	33%	1,39%
Netherlands	259	44	76	113	67%	0,37%
Spain	448	76	131	250	52%	0,64%
Sweeden	218	37	64	132	48%	0,31%
Switzerland	138	23	40	58	70%	0,20%
United Kindom	914	154	267	323	83%	1,31%
United States	10960	1850	3198	4686	68%	15,76%
TOTAL	**17699**	**2987**	**5165**	**8208**	**63%**	**25,44%**

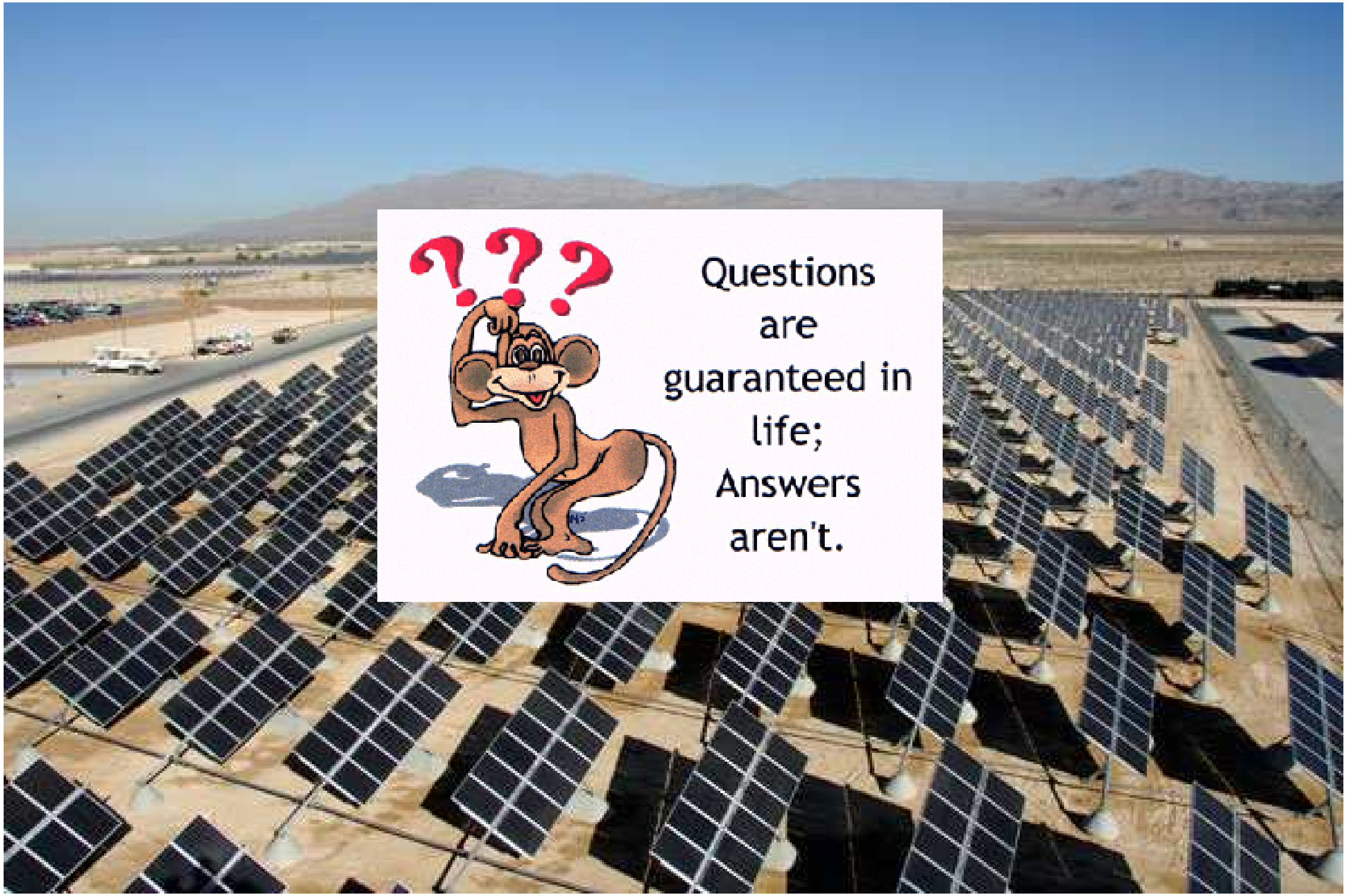
Photovoltaic potential in 14 industrialized country – data are evalueted starting form good surface availability [9] and photovoltaic hypotesis as in the previous slide

*Part 1 - Photovoltaic potential – **What we can do***

In graphic terms….



END OF PART 1 – QUESTION?

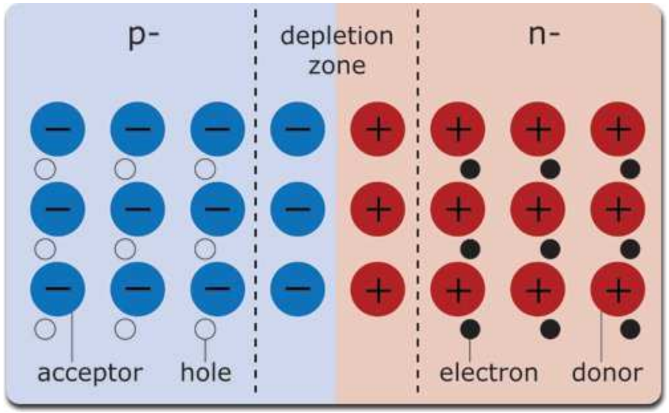


Photovoltaic basics – a brief overview

Part 2 – PV basics

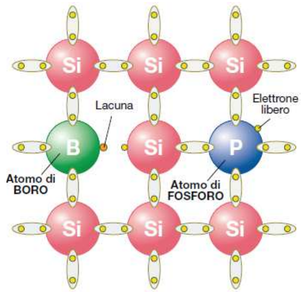
What do I need to generate photovoltaic effect?

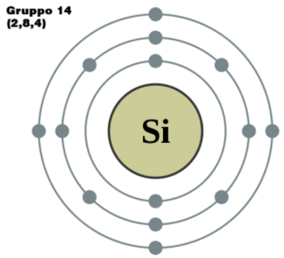
- **1** To have a material that has, in the external layer, has the most participative configuration as possible, and, together, that is present in good quantity and availability in the nature → **Silicon**

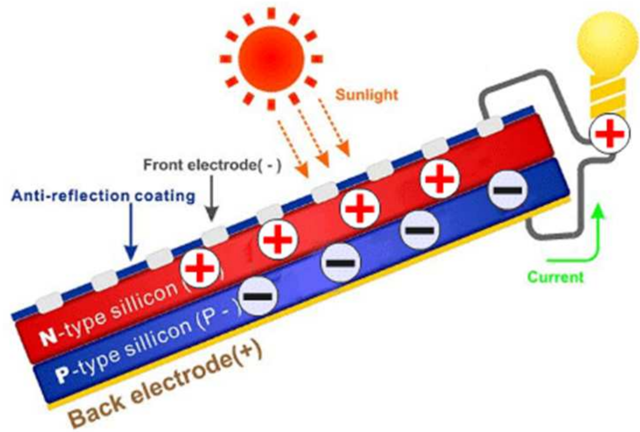


- **2 To dope** with different materials the silicon (for example with phosphorus and boron) in order to obtain different areas of doping dose. The negative dopen area is named N side, the positive area is called P side. The sandwich obtained is called a PN junction and can react with light in order to make the system fall in a state of unbalance

- **The mean doping ratio for modern technology is quantified in 1 atom of dope every 10 million of substrate (silicon) atoms**







Part 2 – PV basics

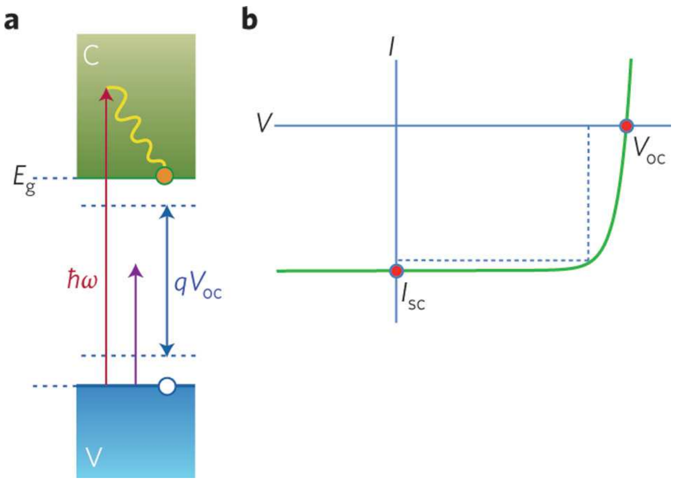
How to arrive to a photovoltaic current.

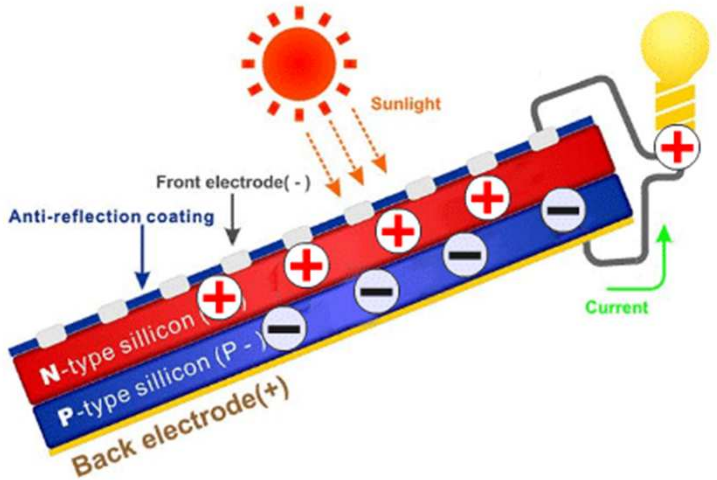
3 - The two surfaces are sandwich together. On both side a conductor material is faced in order to prepare the way for the electrons. A → **A PN junction is born**

4 - Because of the electric charge unbalance the two regions try to recombine, but the moving charges generate an electric field that prevent a complete recombination. This area is named deletion zone and NOT participate to energy production

5 - The depleting zone is only created when the sun hits the semi conductor and let some electrons to go on conduction (conduction band) → **We just created the open circuit voltage**

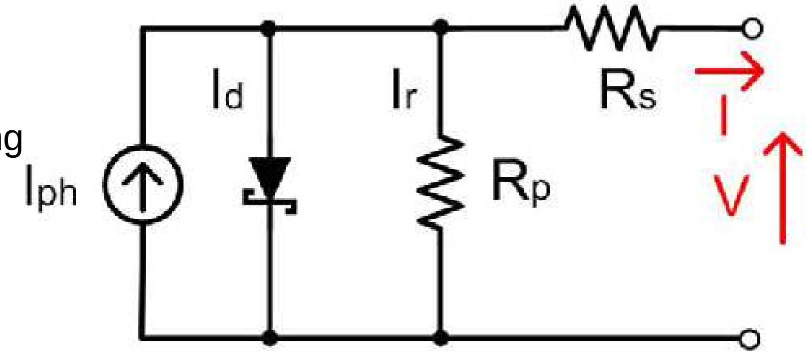
6 - To balance the other are out of the depleting zone I must connect P side to the N side with a conductor → **I have just created the electric photovoltaic current**





Part 2 – PV basics

Currents



- I_{ph} [A]: Ideal current produced by photovoltaic effect
- I_d [A]: Polarizing current due to the creation of depliting zone
- I_{sc} [A]: Short circuit current generated by the juction
- I_{mp} [A]: Maximum power current generated by the juction

Voltage

- V_{oc} [V]: Open voltage applied on the junction in presence of solar light, is the maximum voltage to be find on this side
- V_{mp} [V]: Voltage to be applied to the junction in order to have the best extraction of power

Other parmeters

- P_{max} [W]: Maximum power to be generated by the panel, that is formed by the series of more cells
- $\eta = P_{max}/P_{IN}$[-]: Is the ration between the maximum power generable by one panel and the quantity of power delivered by the sunlight
- FF(Fill Factor) = $(V_{max}\ I_{mpp})/(I_{sc}\ V_{oc})$: is the capacity to obtain the maximum power from a PN junction with precise characteristics

Current equation for PV cell. Remember, PV is a **current generator**

$$I = I_{ph} - I_0\left[\left(\exp\frac{qV}{nkT}\right) - 1\right] - I_r$$

Part 2 – PV basics

In the equivalent circuit **2 resistance model are inserted** in order to model the losses present in every photovoltaic cell. Those losses are not neglect able, they represent the past, the present and the future of photovoltaic. By reducing those losses, in fact, the photovoltaic conversion ratio (the efficiency) have rised until present time and will continue by optimizing those characteristics.

Photovoltaic cell losses

Series losses Rs

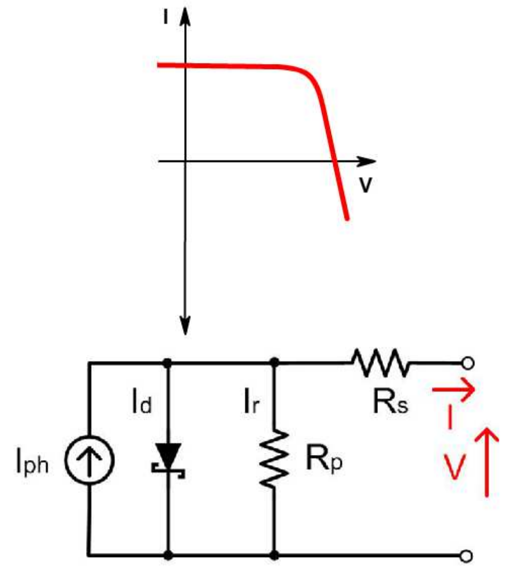
They represent a loss of voltage at the poles of the solar cell and can be caused by:

- **Contacts losses**
- **Mismatching losses**
- **Wire losses**
- **Conducting material quality**
- **Temperature losses (up to 50% of losses in PV plants)**

Shunt losses Rp:

They represent the main factor of losses (up to 90%) and model problems internal problems of semiconductor, for example:

- **Dope problems**
- **Pollution**
- **Recombination problems**
- **Irradiance problems**



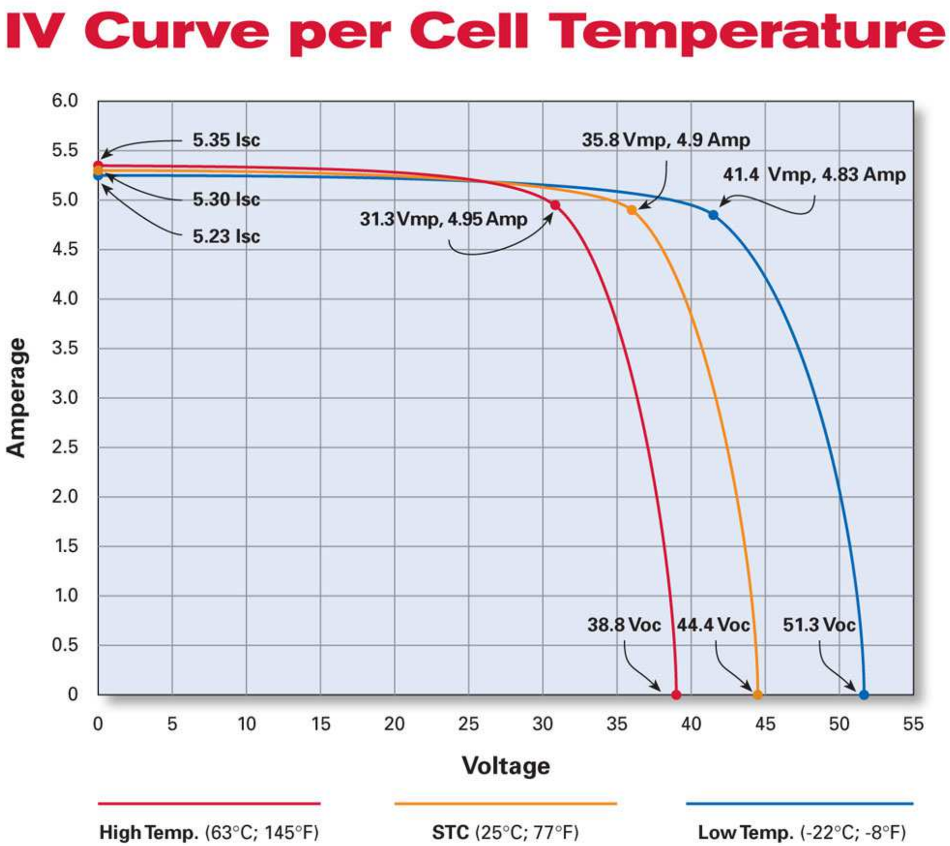
$$I_{sc} - I_{mp} ; V_{oc} - V_{mp}$$

$$\alpha_P = -0{,}30 \div -0{,}45 \left[\frac{\%}{°C} \right]$$

Part 2 – PV basics – A focus on temperature losses [10]

Tmperature losses are both the problem and the solution for PV system efficiency.

- **The problem** because the represent the main factor of losses in PV systems
- **The solution** because the industry today is focusing on decreasing those losses in order to prepare photovoltaic to higher irradiance area installation (higher irradiance → higher temperature → higher losses)



$$\eta = \eta_{standard}\left[1 - \alpha_p\left(T_c - T_{c,standard}\right)\right]$$

$$\alpha_P = -0{,}27 \div -0{,}45\left[\frac{\%}{°C}\right]$$

α_P Is measured at NTC condition, usually:

- Air mass AM 1.5
- Irradiance I = 800 W/m^2
- Air temperature 20°C

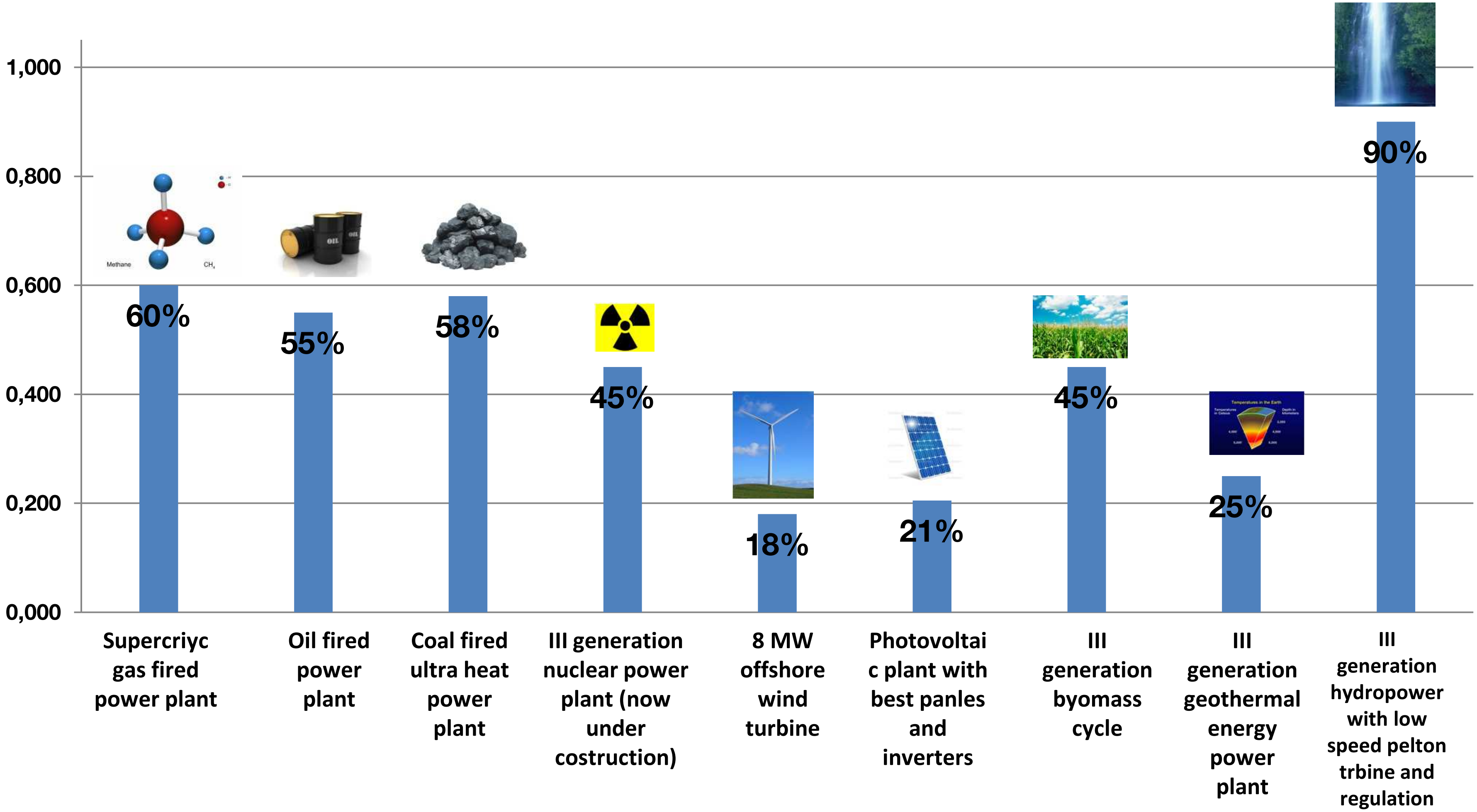
But genrally temperature losses are half of the all losses, so far, depending on α_p the total losses can vary of:

$$Losses = \pm 20\%$$

Part 2 – PV footprint

Let's talk about efficiency

In physics efficiency is defined as the ratio between the power enetering in a system vs the power going out to this system. Thermodynamic ensure us that this ratio can NEVER be higher than 1 by definition.
Let's consider the best efficiency on the market by technology.



Part 2 – PV footprint

But for a moment let's consider other concept of consumption and add the primary need of every form of energy.

If we consider those other efficiency coefficients:

- **Soil consumption:** every power plant need soil to be constructed, to get the materials needed to built it and to dismelt it. Everything comes from soil, so far everything can be traduced in soil consumption terms. [11]

$$\overline{U}_{soil} = \frac{S_{used}}{E_{produced}} = \left[\frac{Km^2}{TWh \cdot year}\right]$$

- **Water consumption** every power plant need water to be built (in the concrete, to produce steam or for other uses), it's called the water footprint and is essential. [12]

$$\overline{U}_{H_2 0} = \frac{liters}{E_{produced}} = \left[\frac{l}{MWh \cdot year}\right]$$

- **Carbon emission** – every power plant produces carbon dioxide, at least in the built process. The carbon footprint is essential to evaluate the goodness of a form of energy

$$\overline{E}_{CO_2} = \frac{Q.ty_{CO_2}}{E_{produced}} = \left[\frac{g_{CO_2}}{kWh_{el.} \cdot year}\right]$$

Part 2 – PV footprint

Here is the table of results

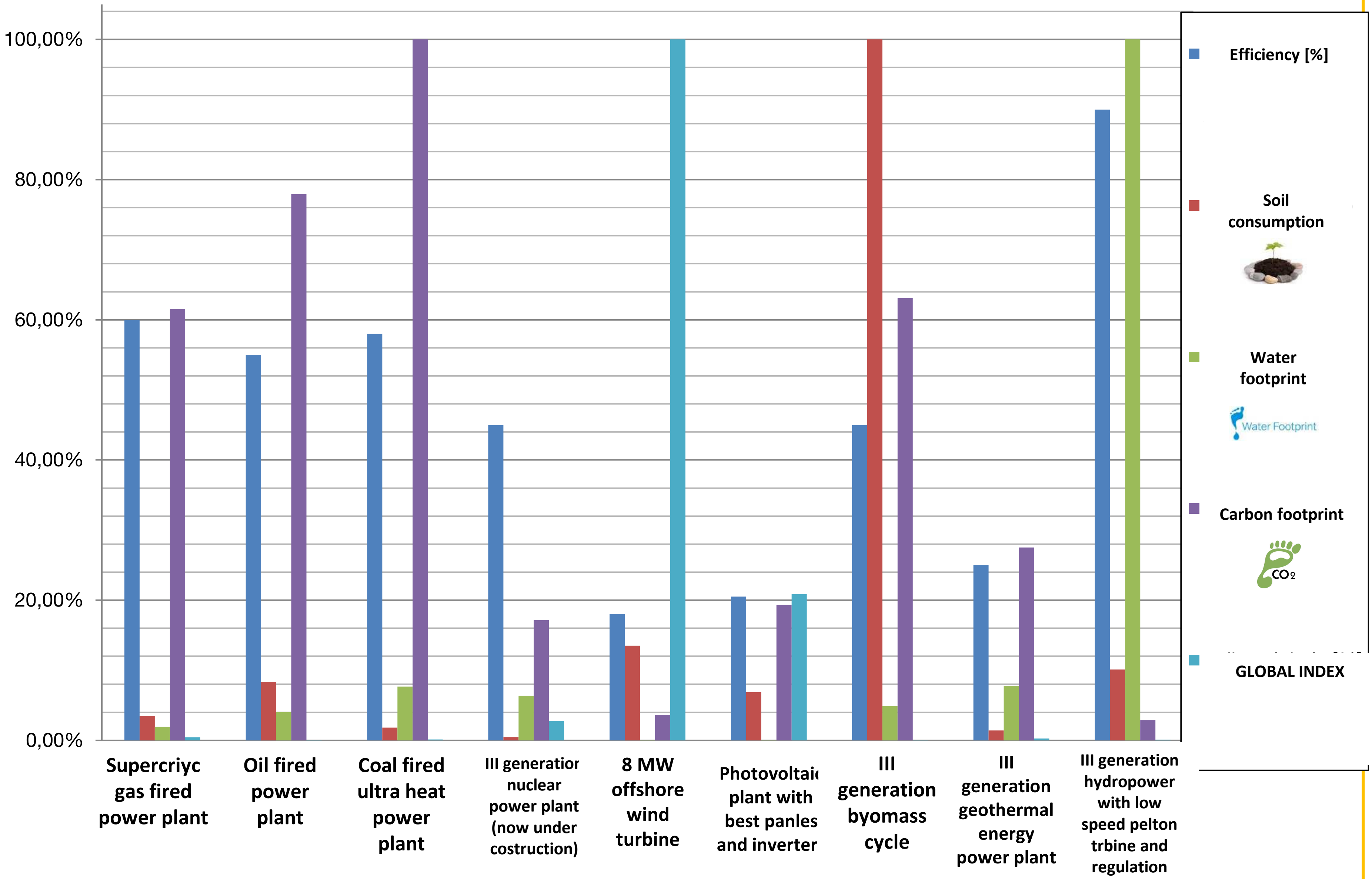
Type of power plant	Maximum efficiency[-]	Soli consumption [km^2/TWh·year]	Water footprint [l/MWh]	Carbon footprint CO_2 [gCO_2/kWh_{el}]
Supercriyc gas fired power plant	60%	18,6	782	237
Oil fired power plant	55%	44,7	1640	300
Coal fired ultra heat power plant	58%	9,7	3146	385
III generation nuclear power plant (now under costruction)	45%	2,4	2600	66
8 MW offshore wind turbine	18%	72,1	4,5	14,1
Photovoltaic plant with best panles and inverters	21%	36,9	9,1	74,4
III generation byomass cycle	45%	534,4	2000	243
III generation geothermal energy power plant	25%	7,5	3182	106
III generation hydropower with low speed pelton trbine and regulation	90%	54	40914	11

And let's now consider a global parmeter

$$I_s = \left[\frac{1}{\overline{\overline{U}}_{soil}} \cdot \frac{1}{\overline{\overline{U}}_{H_2O}} \cdot \frac{1}{\overline{\overline{E}}_{CO_2}} \cdot \eta_{el} \right] \cdot 100 = [\%]$$

Part 2 – PV footprint

The results in graph

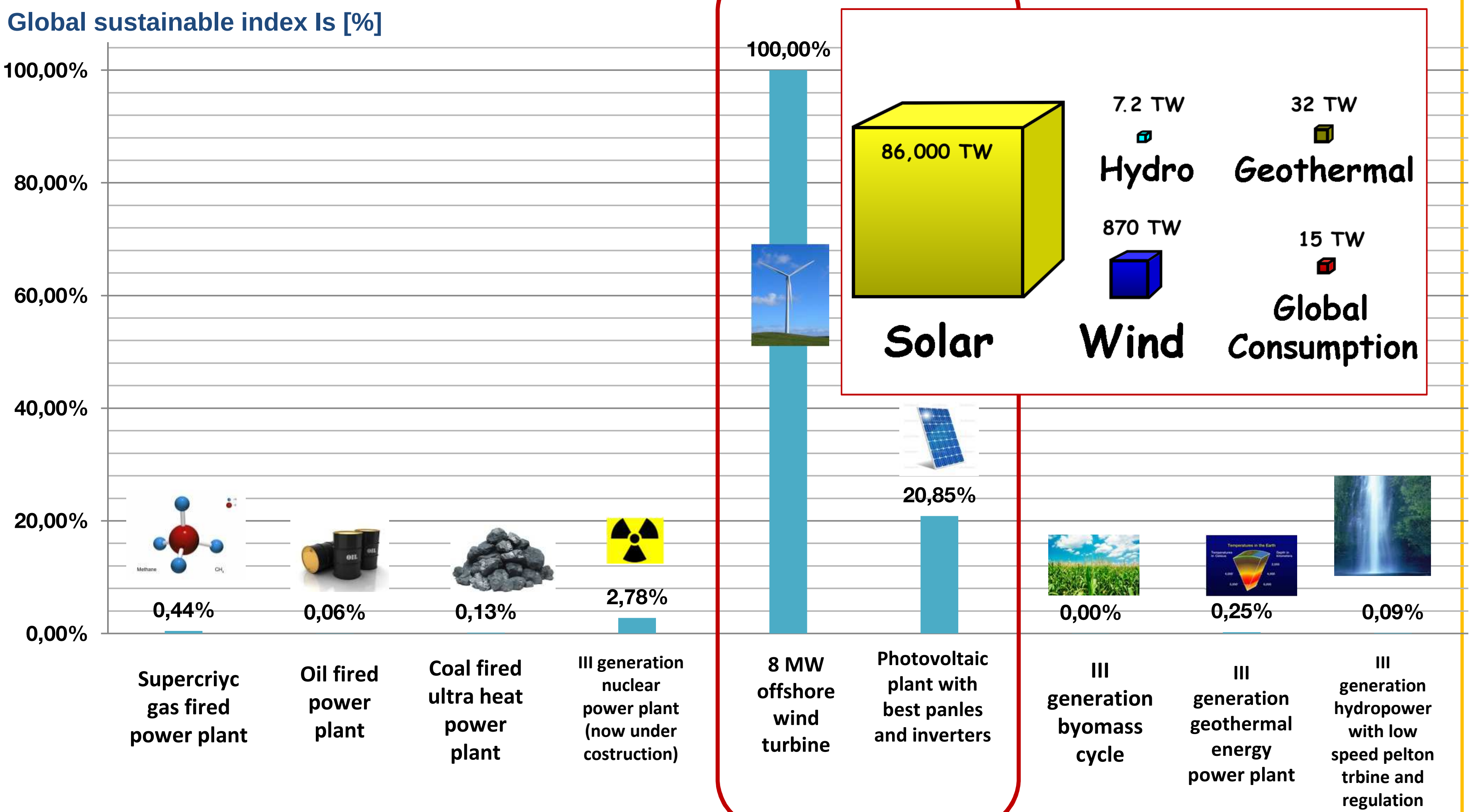


Part 2 – PV footprint

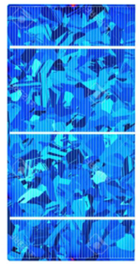
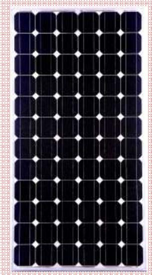
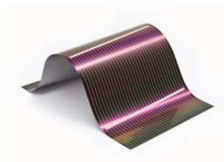
The global index of sustainability – <u>IMPORTANT CONCEPT!!!</u>

$$I_s = \left[\frac{1}{U_{soil}} \cdot \frac{1}{U_{H_2O}} \cdot \frac{1}{E_{CO_2}} \cdot \eta_{el} \right] \cdot 100 = [\%]$$

WHY PV WINS? BECAUSE OF THE AVAILABILITY OF THE PRIMARY SOURCE, THE SUN!!!



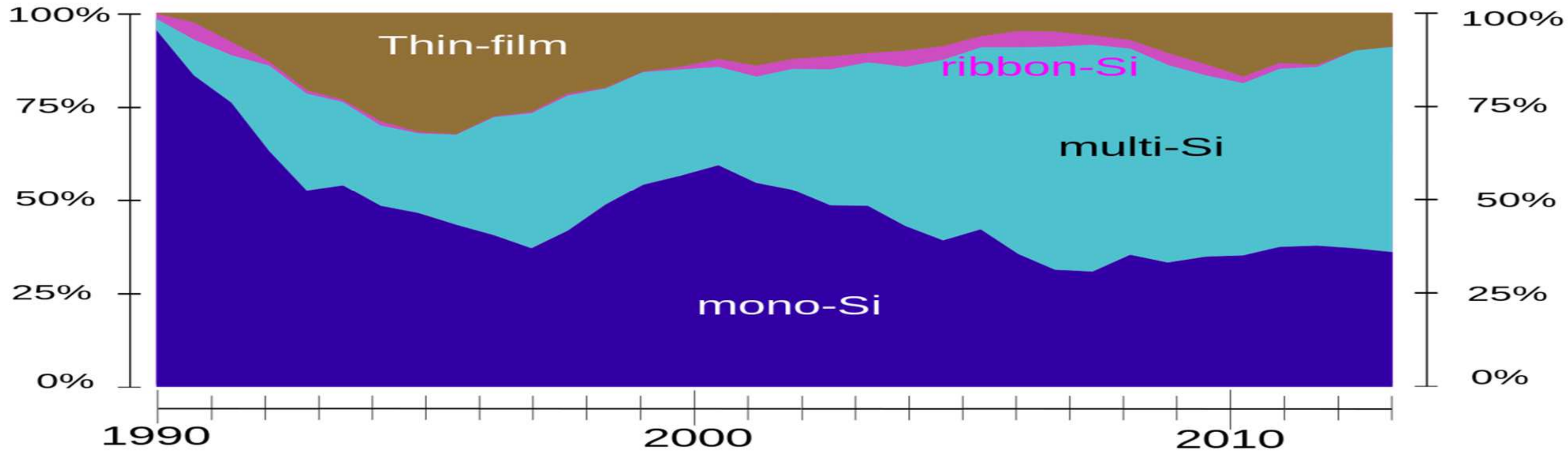
MAIN PHOTOVOLTAIC CELL TYPES

Type	Characteristics	Maximum commercial effciency [%]	Picture	Main Producers
Poly or multi christalline	• Most diffused in the market • Not good answer to temperature • Cheap	Around 19%		Trina solar Bosh solar BP solar Sanyo Panasonic
Mono christaline	• Rising market share • Less temperaure losses • Bit more expensive • Better answer for more wavelenght (optimal cloud condition functionality)	Around 22%		Trina Solar Sunpower Sanyo Panasonic
Thin film tecnologies	• Architecture flexibility • Lower Efficiency • Good price • Optimal for large scale and strange architecture roof or facade	Around 14%		First solar

Part 2 – PV basic – Type of PV cells [

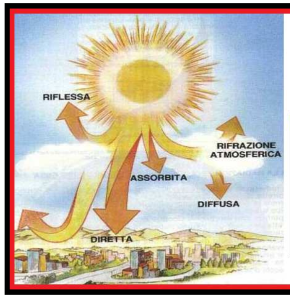
Ranking	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	Sharp Solar	Sharp Solar	Sharp Solar	Sharp Solar	Sharp Solar	Sharp Solar	Sharp Solar	Q-Cells	First Solar	Suntech	Suntech	Yingli	Yingli	Trina
2	BP Solar	BP Solar	BP Solar	Kyocera	Kyocera	Q-Cells	Q-Cells	Suntech	Suntech	JA Solar	First Solar	First Solar	Trina	Hanwha SolarOne / Q-Cells
3	Kyocera	Kyocera	Kyocera	BP Solar	Q-Cells	Kyocera	Suntech	Sharp	Sharp Solar	First Solar	JA Solar	JA Solar	JA Solar	Yingli
4	Shell Solar	Shell Solar	Shell Solar	Shell Solar	Schott Solar	Suntech	Kyocera	First Solar	Yingli	Yingli	Yingli	Trina	CSI	NeoSolar
5	AstroPower	RWE/Schott	RWE/Schott	Q-Cells	BP Solar	Sanyo	First Solar	Kyocera	Q-Cells	Q-Cells	Gintech	Canadian Solar	First Solar	Jinko Solar
6	RWE/Schott	AstroPower	Mitsubishi Electric	Schott Solar	Mitsubishi Electric	Mitsubishi Electric	Motech	Motech	JA Solar	Sharp	Trina	Suntech	Hareon	First Solar
7	Isofoton	Isofoton	Sanyo	Sanyo	Sanyo	Schott Solar	Sanyo	Sanyo	Trina	Trina	Motech	Motech	Motech	Motech
8	Photowatt	Mitsubishi Electric	Isofoton	Mitsubishi Electric	Shell Solar	Motech	Deutsche Cell/SolarWorld	SunPower	SunPower	Motech	Canadian Solar	Gintech	NeoSolar	Hareon
9	Sanyo	Sanyo	Q-Cells	Isofoton	Motech	BP Solar	Mitsubishi Electric	JA Solar	Kyocera	Gintech	Sharp Solar	Sharp Solar	Jinko Solar	CSI
10	Kaneka	Photowatt	Photowatt	Motech	Isofoton	SunPower	SunPower	BP Solar	Motech	Kyocera	Jinko Solar	NeoSolar	Gintech	Gintech
% Above	94%	81%	93%	85%	83%	80%	69%	63%	62%	61%	58%	56%	53%	51%
% All Others	6%	19%	7%	15%	17%	20%	31%	37%	38%	39%	42%	44%	47%	49%
Total Shipments	339.9	540.1	643.2	1016.1	1372.5	1954.1	3037.6	5470.7	7910.3	17387.3	23529.3	26358.2	34011.3	39244.6

Global Market Share by PV Technology
from 1990 to 2013

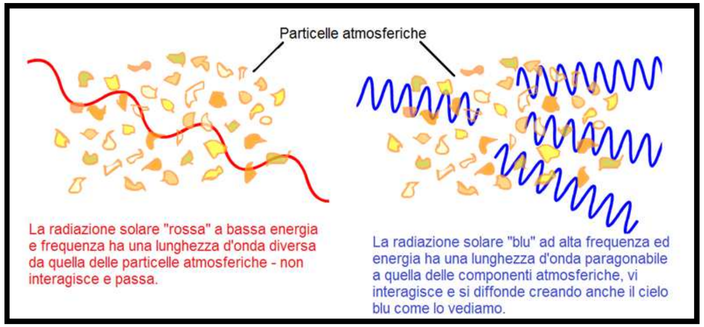


Part 2 – PV basic – Type of PV cells

Different solar cell → different absorptption of light, but same mechanism of energy conversion



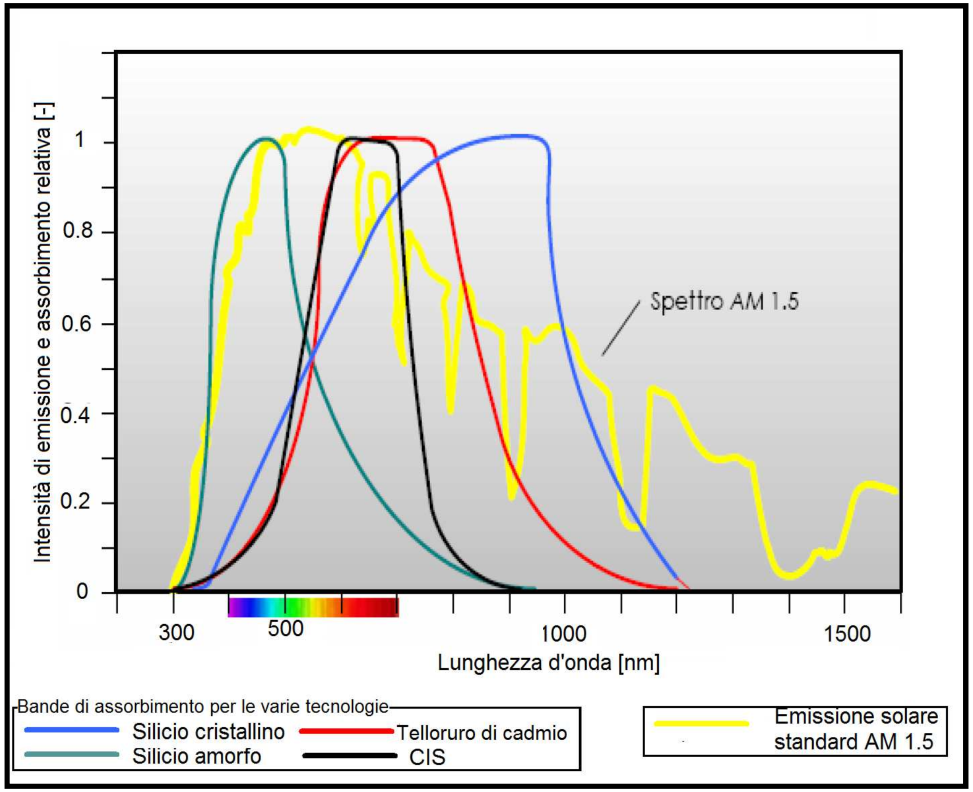
Descrizione cielo	Radiazione Globale [W/m2]	di cui diretta [%]	di cui diffusa [%]
Sereno	1000	90,00%	10,00%
Nebbia	600	50,00%	50,00%
Nuvoloso	500	70,00%	30,00%
Disco solare giallo	400	50,00%	50,00%
Disco solare bianco	300	40,00%	60,00%
Sole appena percettibile	200	0,00%	100,00%
Nebbia fitta	100	0,00%	100,00%
Cielo coperto	50	0,00%	100,00%



Efficiency in a solar cell:

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

$$P_{max} = V_{OC} I_{SC} FF$$



$$\frac{\eta}{df} = \left(I_{AM1,5} - I_{ass.tecnol.}\right) df$$

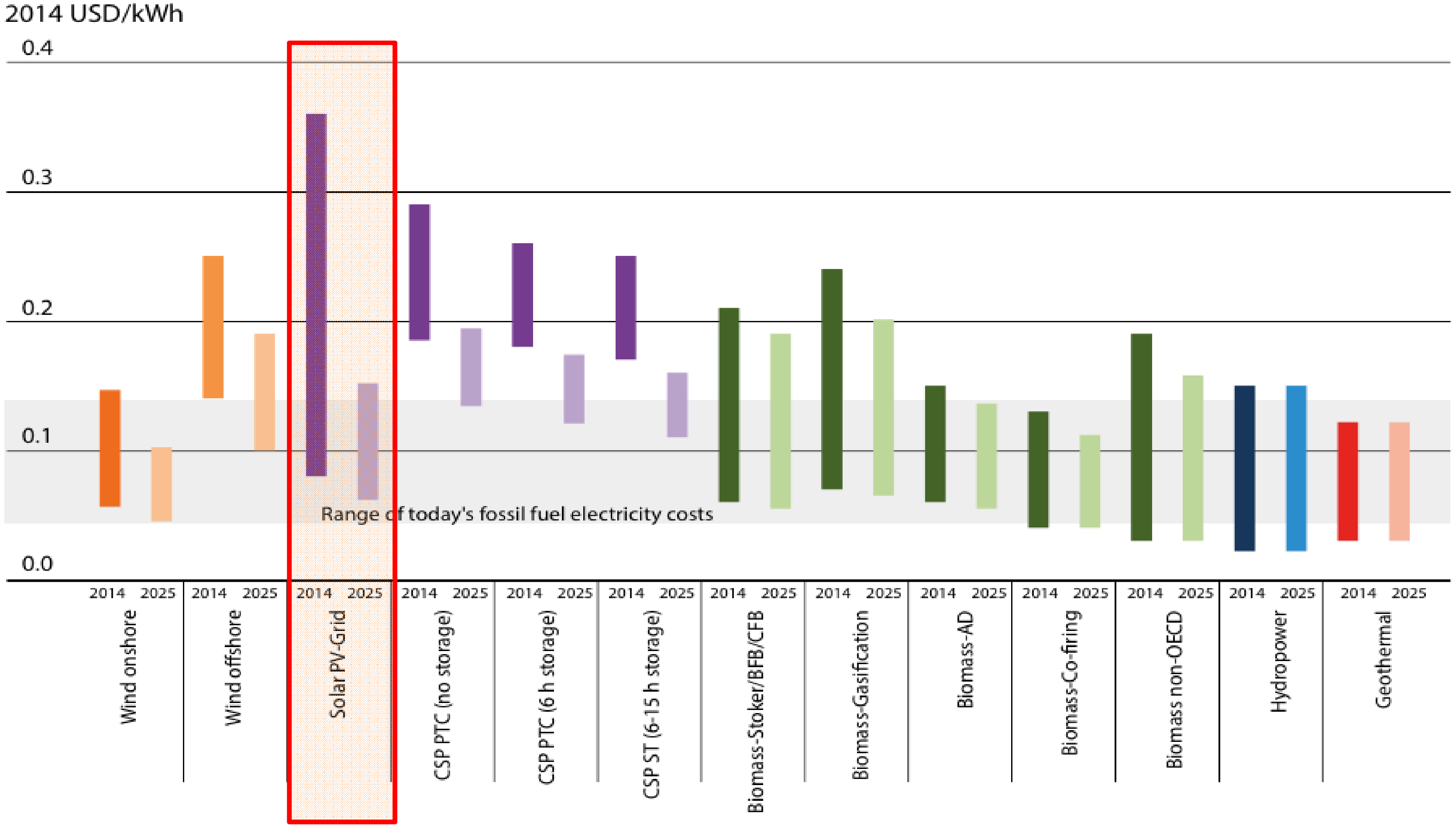
$$\eta = \frac{\int I_{ass} df}{\int I_{AM1,5} df}$$

<u>A better definition of efficiency in solar cell would take into account the absorption of energy at different wavelength</u>

Part 2 – PV basic – LCOE Levelized Cost Of Energy

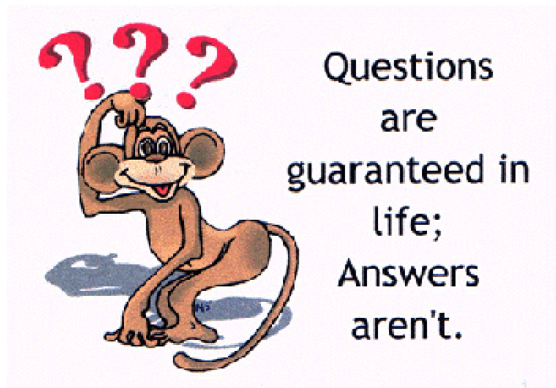
$$LCOE = \frac{Capex \cdot cfr + Opex}{E_{net}} \quad (2)$$

- **Capex** - *(Capital Expenditure)*
- **Opex** - *(Opertation Expenditure)*
- **Cfr** *(Capital Financial Rate)*
- **E_{net}**: *net energy produced*



In the figure – LCOE of reneable energy per source 2015 and projection to 2025 – source: IRENA [14]

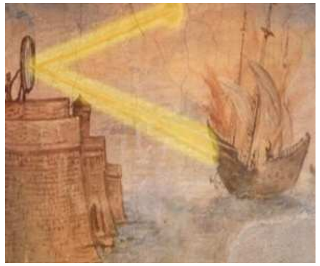
END OF PART 2 – QUESTION?



*Part 3 – History of photovoltaics – **Experimental phase and the beginning 7th cent. BC – 1200 AD***

- **7th Century B.C. :** Magnifying glass used to concentrate sun's rays to make fire and to burn ants.

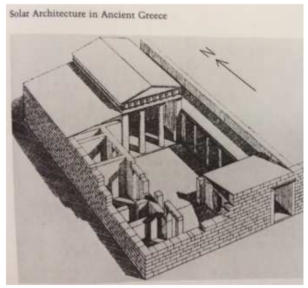
- **3rd Century B.C. :** Greeks and Romans use burning mirrors to light torches for religious purposes.



- **2nd Century B.C.:** As early as 212 BC, the Greek scientist, Archimedes, used the reflective properties of bronze shields to focus sunlight and to set fire to wooden ships from the Roman Empire which were besieging Syracuse. (Although no proof of such a feat exists, the Greek navy recreated the experiment in 1973 and successfully set fire to a wooden boat at a distance of 50 meters.). This is considered the first proper use of humankind of sun power.

- **20 A.D.:** Chinese document use of burning mirrors to light torches for religious purposes.

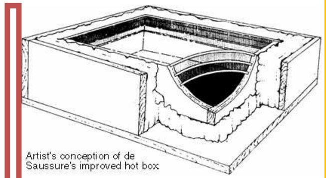
- **1st to 4th Century A.D.** The famous Roman bathhouses in the first to fourth centuries A.D. had large south facing windows to let in the sun's warmth.



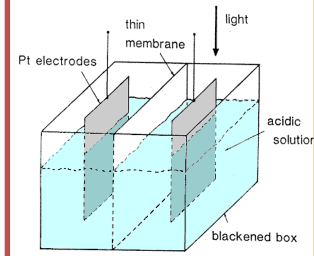
- **6th Century A.D.:** Sunrooms on houses and public buildings were so common that the Justinian Code initiated "sun rights" to ensure individual access to the sun.
- **1200s A.D.** Ancestors of Pueblo people called Anasazi in North America live in south-facing cliff dwellings that capture the winter sun. In other word After the 6th century humanity understood the importance of solar power for house heating.

*Part 3 – History of photovoltaics – **Experimental phase and the beginning – 1767 - 1891***

- **1767** Swiss scientist Horace de Saussure was credited with building the world's first solar collector, later used by Sir John Herschel to cook food during his South Africa expedition in the 1830s. See the Solar Cooking Archive. First use of a panel concept for grave sun power

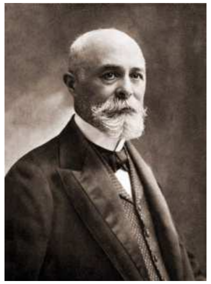


- **1816**: On September 27, 1816, Robert Stirling applied for a patent for his economiser at the Chancery in Edinburgh, Scotland. He built heat engines in his home workshop.This engine was later used in the dish/Stirling system, a solar thermal electric technology that concentrates the sun's thermal energy **in order to produce power.**



- **1839:** French scientist Edmond Becquerel **discovers the photovoltaic effect while experimenting with an electrolytic cell** made up of two metal electrodes placed in an electricity-conducting solution—electricity-generation increased when exposed to light.

- **1860:** French mathematician August Mouchet proposed an idea for solar-powered steam engines. In the following two decades, he and his assistant, Abel Pifre, constructed the first solar powered engines and used them for a variety of applications. These engines became the predecessors of modern parabolic dish collectors.

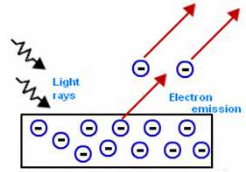

Edmond Becquerel

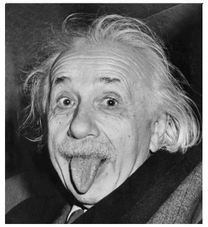
- **1873:** Willoughby Smith **discovered the photoconductivity of selenium.** *Photoconductivity is an optical and electrical phenomenon in which a material becomes more electrically conductive due to the absorption of electromagnetic radiation such as visible light, ultraviolet light, infrared light, or gamma radiation.*

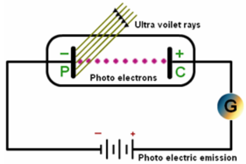
- **1876:** William Grylls Adams and Richard Evans Day discover that selenium produces electricity when exposed to light. **Although selenium solar cells failed to convert enough sunlight to power electrical equipment,** they proved that a solid material could change light into electricity without heat or moving parts. **The substrate was born**

- ***1887:*** Charles fitter, an American inventor, **described the first solar cell made from selenium wafers**

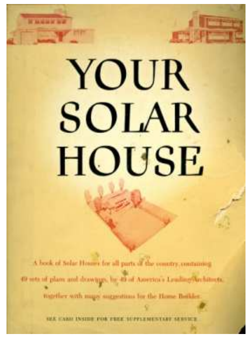
- **1904:** Wilhelm Hallwachs discovered that a combination of copper and cuprous oxide is photosensitive.
- **1905: Albert Einstein published his paper on the photoelectric effect (along with a paper on his theory of relativity). The second and last father of photovoltaic technology.**
- **1908:** 1908 William J. Bailley of the Carnegie Steel Company invents a solar collector with copper coils and an insulated box—roughly, it's present design. The concept of panel was born.
- **1914:** The existence of a barrier layer in photovoltaic devices was noted.
- **1916:** Robert Millikan provided experimental proof of the photoelectric effect.
- **1918:** Polish scientist Jan Czochralski developed a way to grow single-crystal
- **1921:** Albert Einstein wins the Nobel Prize for his theories (1904 research and technical paper) explaining the photoelectric effect.
- **1932:** Audobert and Stora discover the photovoltaic effect in cadmium sulfide (CdS). **The first thin film technology was born**
- **1947:** Passive solar buildings in the United States were in such demand, as a result of scarce energy during the prolonged W.W.II, that Libbey-Owens-Ford Glass Company published a book entitled Your Solar House, which profiled forty-nine of the nation's greatest solar architects.




Albert Einstein




Robert Andrews Millikan



- **1953:** Dr. Dan Trivich, Wayne State University, makes the first theoretical **calculations of the efficiencies** of various materials of different band gap widths based on the spectrum of the sun.

- **1954:** 1954 Photovoltaic technology is born in the United States when Daryl Chapin, Calvin Fuller, and Gerald Pearson develop the silicon photovoltaic (PV) cell at Bell Labs — the first solar cell capable of converting enough of the sun's energy into power to run everyday electrical equipment. Bell Telephone Laboratories produced a silicon solar cell with 4% efficiency and later achieved 11% efficiency. **The first PV panel was born**

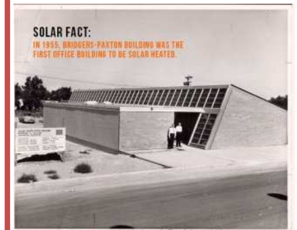
- **1955:** Western Electric began to sell commercial licenses for silicon photovoltaic (PV) technologies. Early successful products included PV-powered dollar bill changers and devices that decoded computer punch cards and tape.

- **Mid. 1950s:** using solar water heating and passive design. This solar system has been continuously operating since that time and the Bridgers-Paxton Building, is now in the National Historic Register as the world's first solar heated office building.

- **1957:** Hoffman Electronics achieved 8% efficient photovoltaic cells.

Bell Laboratories

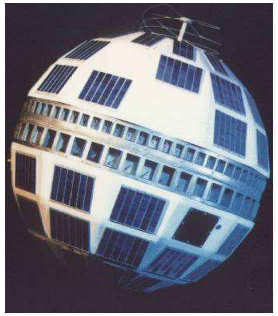
Gerald Pearson, Daryl Chapin, and Calvin Fuller (left-to-right), inventors of the Bell Solar Battery. Photo credit: NREL, *The Silicon Cell; Turns 50*, with permission from AT&T Bell Labs



Part 3 – History of photovoltaics – ***The space invasion and propulsion***

- **1956:** William Cherry, U.S. Signal Corps Laboratories, approaches RCA Labs' Paul Rappaport and Joseph Loferski about developing photovoltaic cells for proposed orbiting Earth satellites.
- **1958:** Hoffman Electronics achieved 9% efficient photovoltaic cells.
- **1958:** The Vanguard I space satellite used a small (less than one watt) array to power its radios. Later that year, Explorer III, Vanguard II, and Sputnik-3 were launched with PV-powered systems on board. Despite faltering attempts to commercialize the silicon solar cell in the 1950s and 60s, it was used successfully in powering satellites. It became the accepted energy source for space applications and remains so today. **The space era was begun**
- **1959:** Hoffman Electronics achieves 10% efficient, commercially available photovoltaic cells. Hoffman also learns to use a grid contact, reducing the series resistance significantly.
- **1960:** Hoffman Electronics achieves 14% efficient photovoltaic cells. Today this is normally lower efficiency for the low quality PV arrays.
- **1960:** Silicon Sensors, Inc., of Dodgeville, Wisconsin, is founded. It starts producing selenium and silicon photovoltaic cells.
- **1962:** Bell Telephone Laboratories launches the first telecommunications satellite, the Telstar (initial power 14 watts).
- **1963:** Sharp Corporation succeeds in producing practical silicon photovoltaic modules.

Vanguard 1 – The first Solar power satellite



The Telstar, PV power onboard was 14W

*Part 3 – History of photovoltaics – **The space invasion and propulsion***

- **1964:** NASA launches the first Nimbus spacecraft—a satellite powered by a 470-watt photovoltaic array
- **1969:** The Odeillo solar furnace, located in Odeillo, France was constructed. This featured an 8-story parabolic mirror. **First concentrated solar power plant.**
- **1970s:** Dr. Elliot Berman, with help from Exxon Corporation, designs a significantly less costly solar cell, bringing price down from $100 a watt to $20 a watt. Solar cells begin to power navigation warning lights and horns on many offshore gas and oil rigs, lighthouses, railroad crossings and domestic solar applications began to be viewed as sensible applications in remote locations where grid connected utilities could not exist affordably.
- **1972:** The Institute of Energy Conversion is established at the University of Delaware to perform research and development on thin-film photovoltaic (PV) and solar thermal systems, becoming the world's first laboratory dedicated to PV research and development.
- **1973:** The University of Delaware builds **"Solar One," one of the world's first photovoltaic (PV) powered residences.** The system is a PV/thermal hybrid. The roof-integrated arrays fed surplus power through a special meter to the utility during the day and purchased power from the utility at night. In addition to electricity, the arrays acted as flat-plate thermal collectors, with fans blowing the warm air from over the array to phase-change heat-storage bins.
- **1976:** David Carlson and Christopher Wronski, RCA Laboratories, fabricate first amorphous silicon photovoltaic cells.

The Nimbus spacecraft

The Odiello solar furnace

The "solar one" house In 1973

<u>*Part 3 – History of photovoltaics – **The space invasion and propulsion***</u>

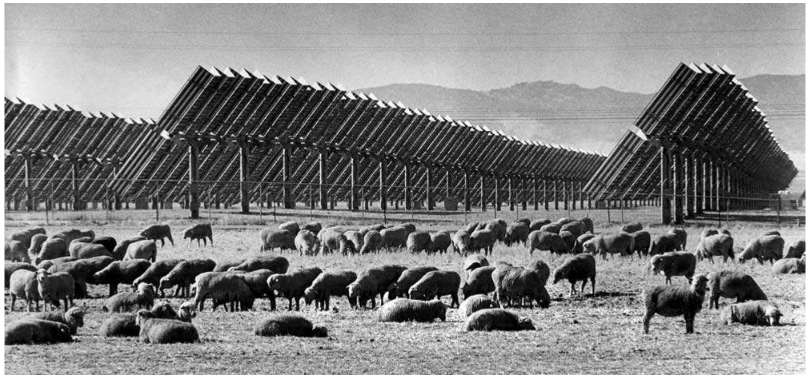
- **1977:** The U.S. Department of Energy launches the Solar Energy Research Institute http://www.nrel.gov/ “National Renewable Energy Laboratory”, a federal facility dedicated to harnessing power from the sun.

- **1977:** Total photovoltaic manufacturing production exceeds 500 kilowatts.

- **1980:** ARCO Solar becomes the first company to produce more than 1 megawatt of photovoltaic modules in one year.

- **1981:** Paul Mac Cready builds the first solar-powered aircraft—the Solar Challenger—and flies it from France to England across the English Channel. The aircraft had over 16,000 solar cells mounted on its wings, which produced 3,000 watts of power.

- **1982:** The first, photovoltaic megawatt-scale power station goes on-line in Hisperia, California. It has a 1-megawatt capacity system, developed by ARCO Solar, with modules on 108 dual-axis trackers.



The firs photovoltaic plant in Hisperia, California - 1982

A modern car racing in World Solar challenge

- **1982:** Australian Hans Tholstrup drives the first solar-powered car—the Quiet Achiever—almost 2,800 miles between Sydney and Perth in 20 days—10 days faster than the first gasoline-powered car to do so. Tholstrup is the founder of the “World Solar Challenge” in Australia, considered the world championship of solar car racing.

NATIONAL RENEWABLE ENERGY LABORATORY

The solar challanger

The quiet achiver in 1982

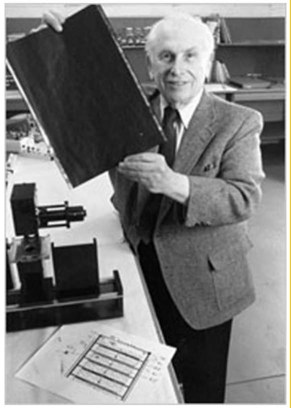
WORLD SOLAR CHALLENGE

The world solar challenge logo

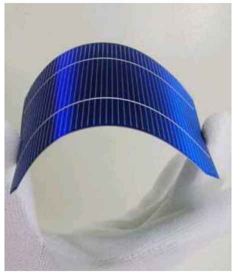
*Part 3 – History of photovoltaics – **The space invasion and propulsion***

- **1982:** The U.S. Department of Energy, along with an industry consortium, begins operating Solar One, a 10-megawatt central-receiver demonstration project. The project established the feasibility of power-tower systems, a solar-thermal electric or concentrating solar power technology. In 1988, the final year of operation, the system could be dispatched 96% of the time. **The firs CSP plant h24 was born**
- **1982:** Volkswagen of Germany begins testing photovoltaic arrays mounted on the roofs of Dasher station wagons, generating 160 watts for the ignition system.
- **1982:** Worldwide photovoltaic production exceeds 9.3 megawatts.
- **1982:** Worldwide photovoltaic production exceeds 21.3 megawatts, with sales of more than $250 million.
- **1986:** ARCO Solar releases the G-4000—the world's first commercial thin-film power module.
- **1988:** Dr. Alvin Marks receives patents for two solar power technologies he developed: Lepcon and Lumeloid. Lepcon consists of glass panels covered with a vast array of millions of aluminum or copper strips, each less than a micron or thousandth of a millimeter wide. As sunlight hits the metal strips, the energy in the light is transferred to electrons in the metal, which escape at one end in the form of electricity. Lumeloid uses a similar approach but substitutes cheaper, film-like sheets of plastic for the glass panels and covers the plastic with conductive polymers, long chains of molecular plastic units.
- **1992:** University of South Florida develops a 15.9% efficient thin-film photovoltaic cell made of cadmium telluride, breaking the 15% barrier for the first time for this technology.
- **1994:** The National Renewable Energy Laboratory develops a solar cell—made from gallium indium phosphide and gallium arsenide—that becomes the first one to exceed 30% conversion efficiency.
- **1999: The National Renewable Energy Laboratory achieves a new efficiency record for thin-film photovoltaic solar cells. The measurement of 18.8 percent efficiency for the prototype solar cell topped the previous record by more than 1 percent. World capacity rised to 1 GWp**

Solar one power plant



Dr. Alvin Marks



Starting form the year 2000 two different phenomena drive the photovoltaic development:

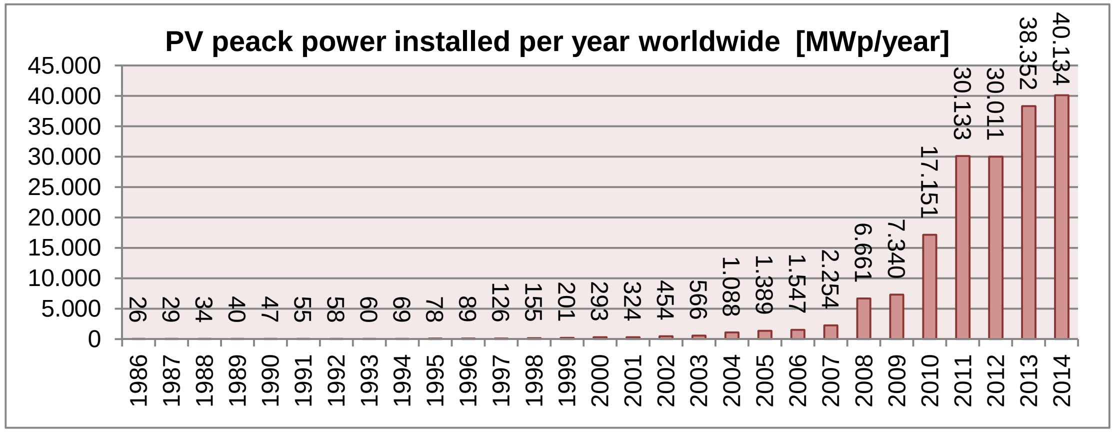
- The **climate change warning exposed** to the world firstly with the Kyoto protocol
- The **rise on oil price and the contemporany starting of state subsides** in Europe

- **1997:** in Kyoto, Japan, 180 different worlwide nations ratify the kyoto protocol, an international agreement under the United Nation . The Kyoto Protocol implemented the objective of the UNFCCC to fight global warming by reducing greenhouse gas concentrations in the atmosphere to "a level that would prevent dangerous anthropogenic interference with the climate system"

- **2005:** The Kyoto protocol enter into force

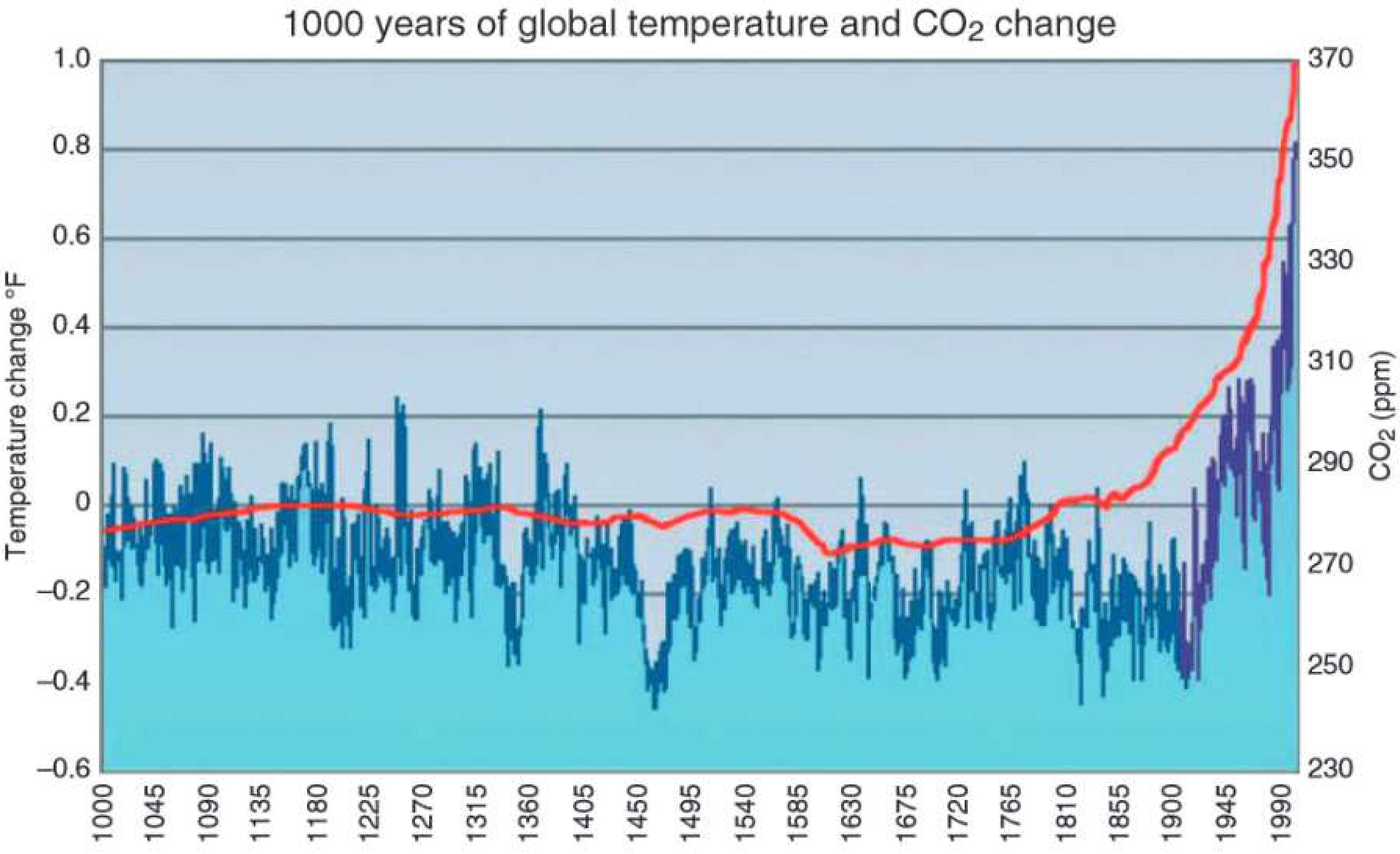
- **2007:** subsides start in europe for photovoltai installation

- Starting from 2007 the cumulative worlwide installed capacity follows this trend [MWp]:
  - **2006:** 6.826
  - **2007:** 9.080
  - **2008:** 15.741
  - **2009:** 23.081
  - **2010:** 40.232



Kyoto conference Japan, 1997

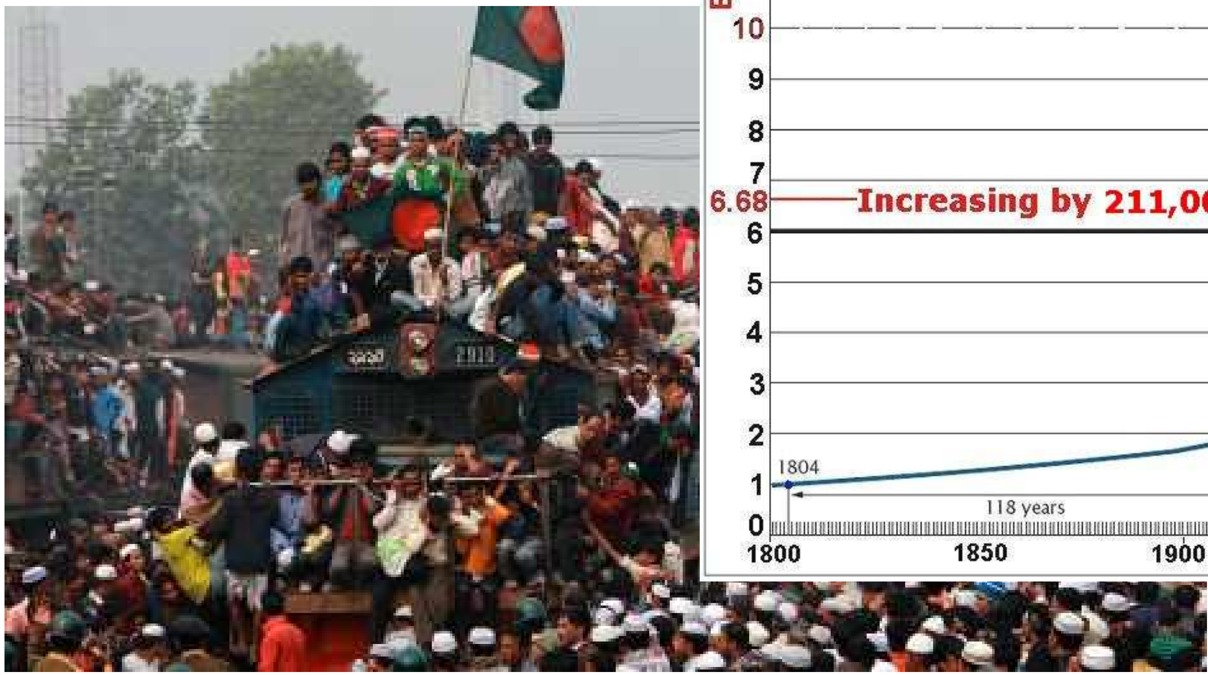
United Nations Framework Convention on Climate Change

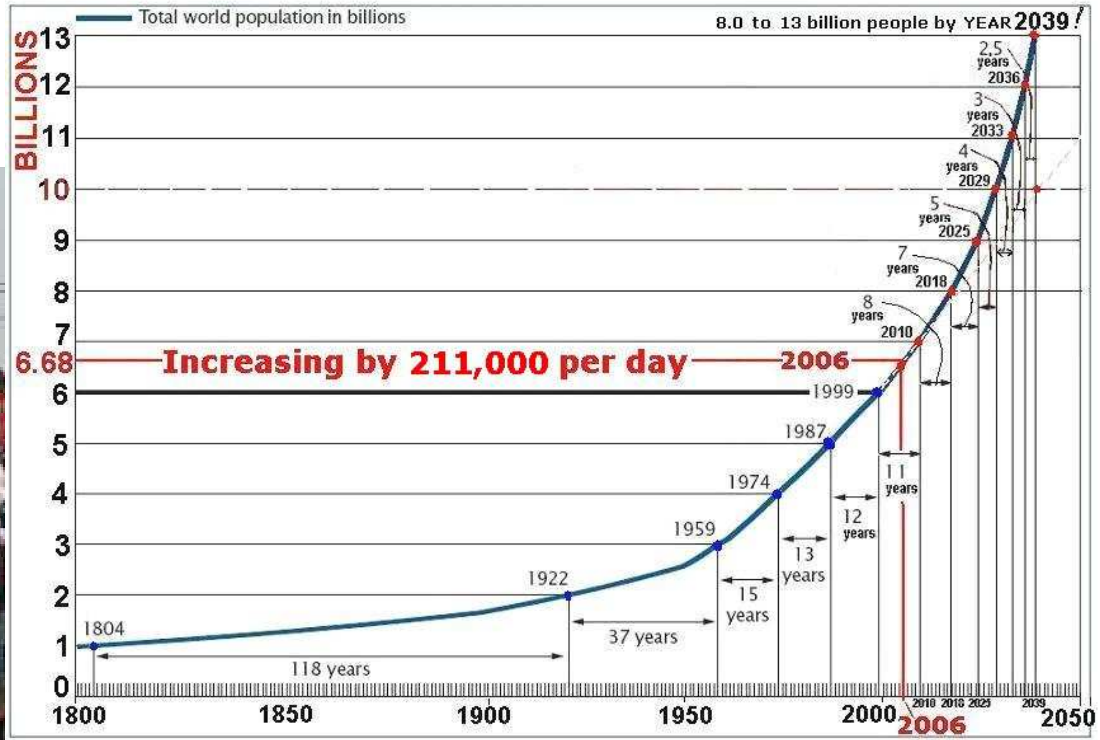


The main dangerous and pollution gas emission quantity in the air measured by NOA from 1975 ttill today [17]

Why isn't working:

- **1 - World popultaion growing:** sustainability and renewable energies are entered in the main immagination but even if people consume less resources we are much more and the effect is the same.



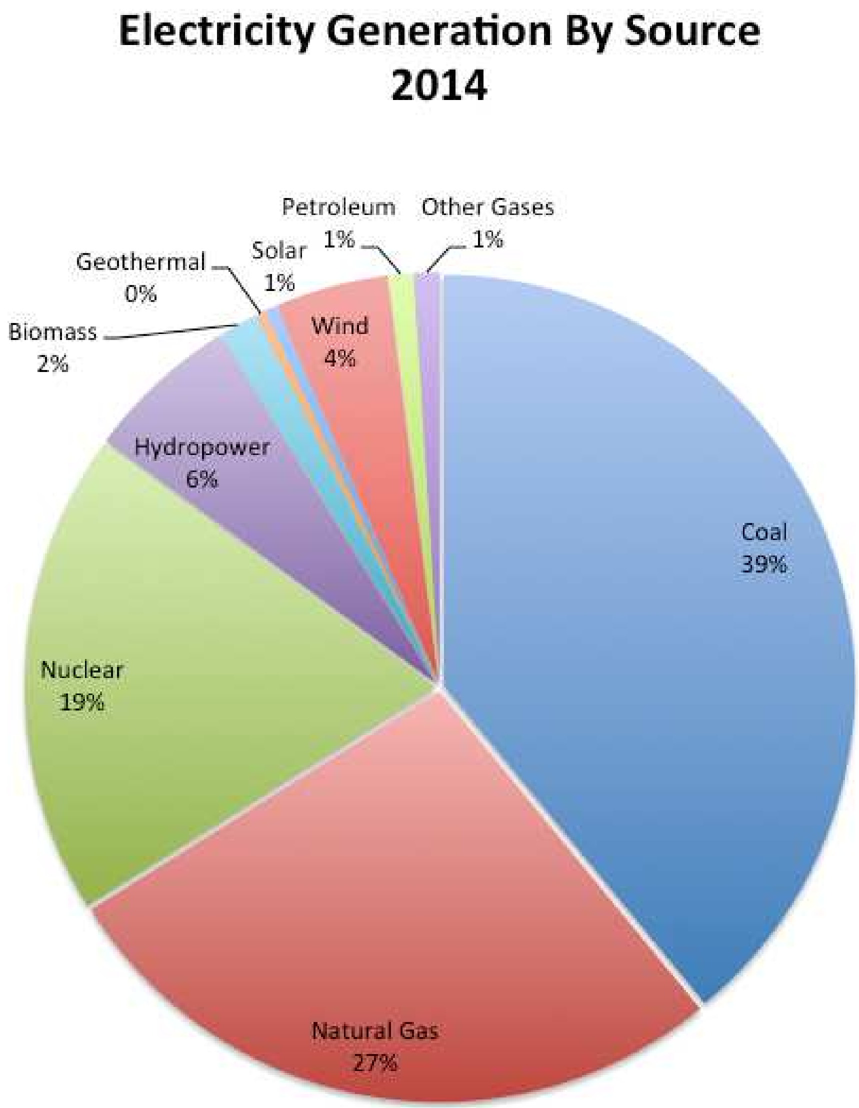


Why isn't working:

- **2 - Renewable energies diffusion is just at the beginning**

We aboslutly need to power the World with renewable energy like solarn power and other forms of renewable energies.
A 100% Renewable energy future is possible, there are still country, regions and cities around the world that are 100% RE powerd, for example:

- The entire Paraguay, Costa Rica, Congo and Albania
- By 2030 Scotland, all north Europe, Haway, Ireland and many others

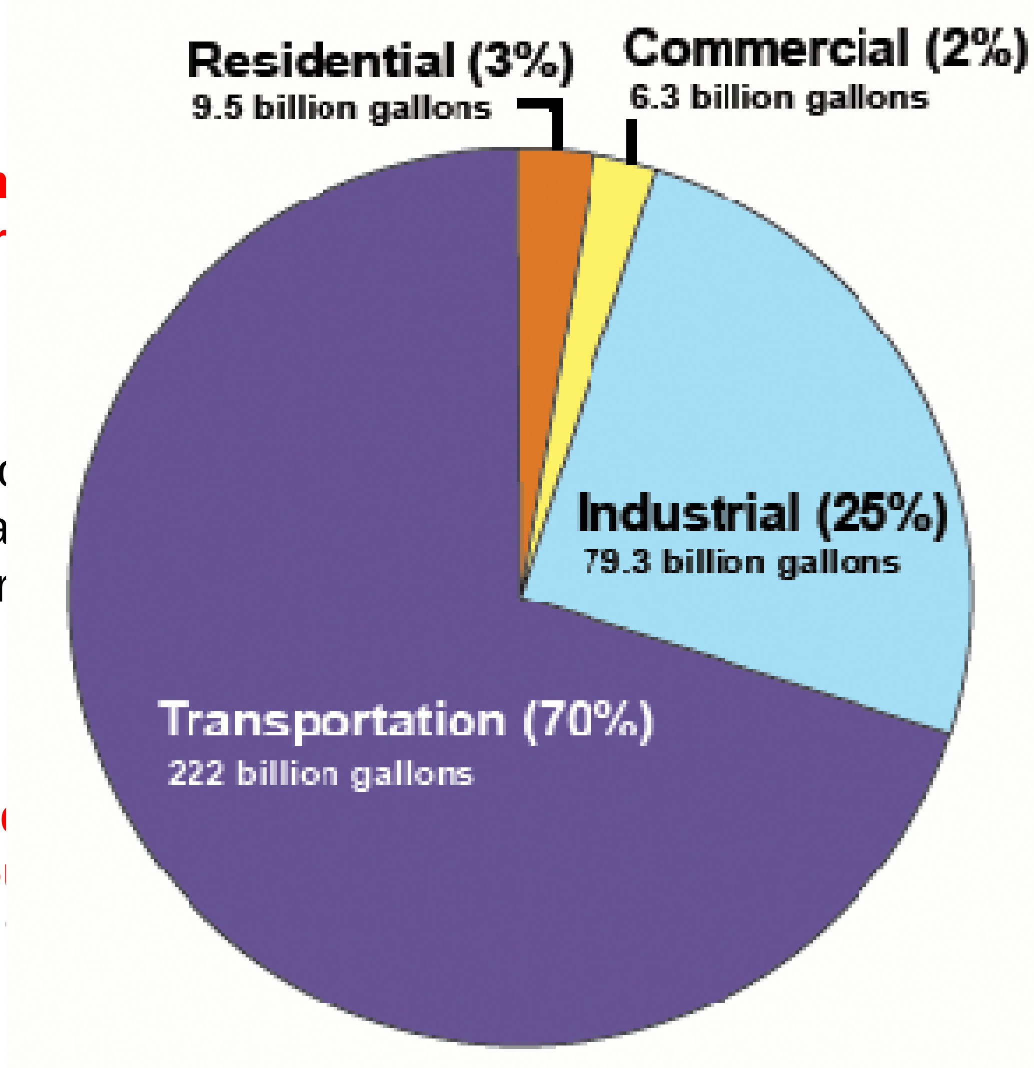


Why isn't work:

- **3 - 60% of the pollution con from transports, and transpor still oil based.**

The big challange will be electrification of transpo because the big usage of oil a so on, of the pollution, comes fr there.

The future challange will electrification of transport an Where to come this big amo of energy to charge veichles?



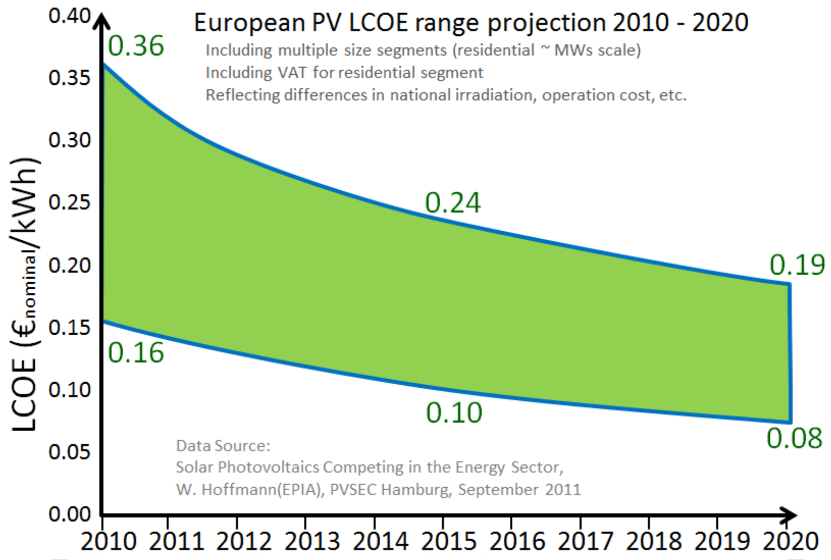
GRID PARITY, IN PV, OCCURS WHEN THE COST FO ENERGY FROM PHOTOVOLTAIC IS EQUAL TO THE COS OF ENERGY FROM THE GRID

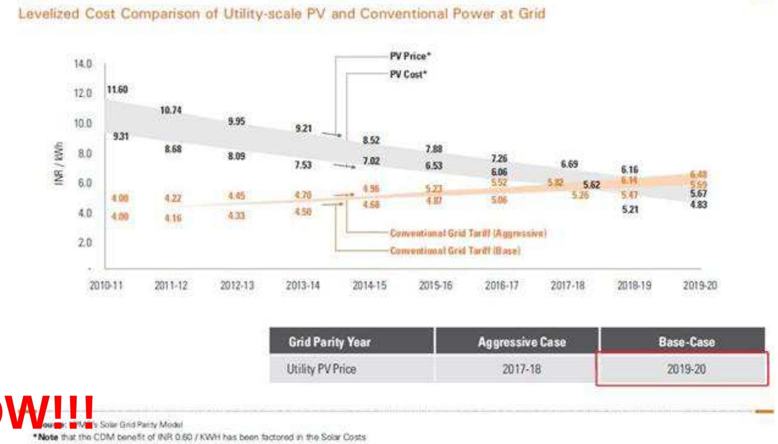
- **2012:** The first nation to face grid parity were place were the cost of electricty was high and the solar irradiance too. In 2012 the first nations were: Spain, California and Hawaii islands

- **2013:** Grid parity reaches Greece, Italy, south of Germany and south Europe in general

- **2014:** the oil price starts to fall, grid parity nations still remain the same due to cost of PV decrease.

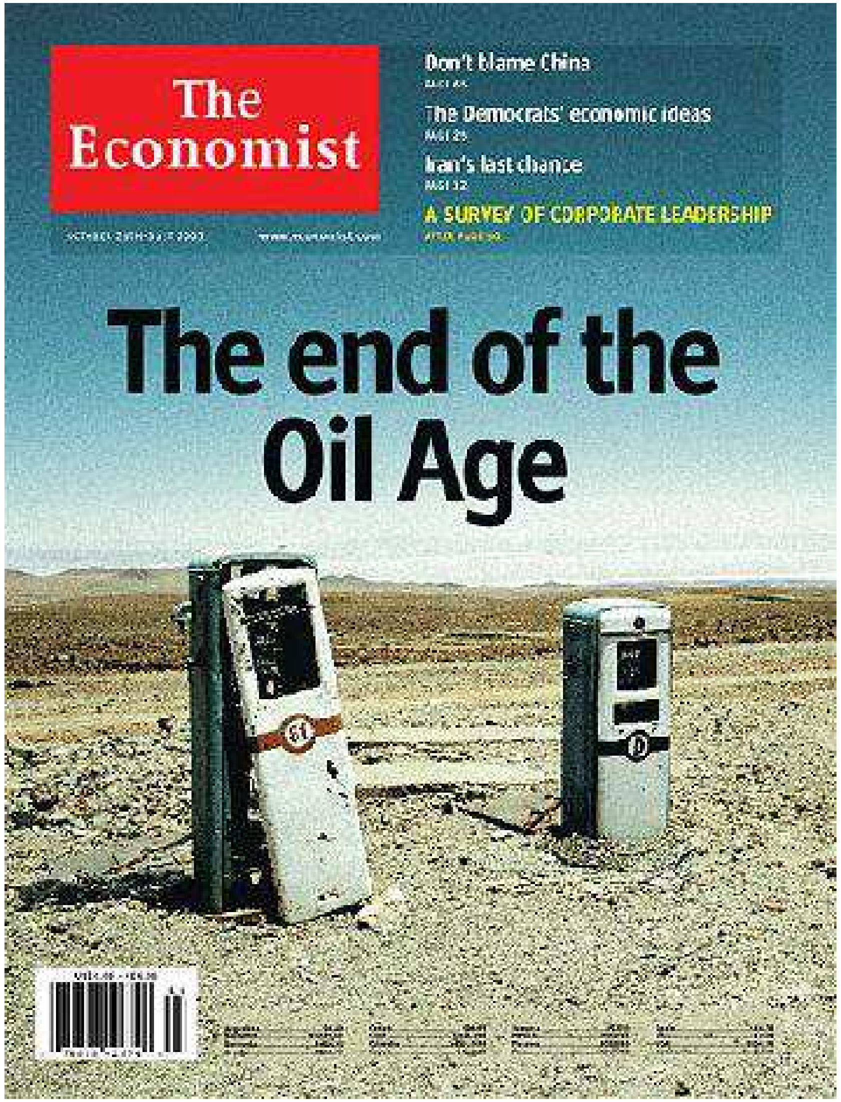
- **2015 – 2017: Grid parity EXPECTED in 70% of world countries according to PV magazine. [18]**

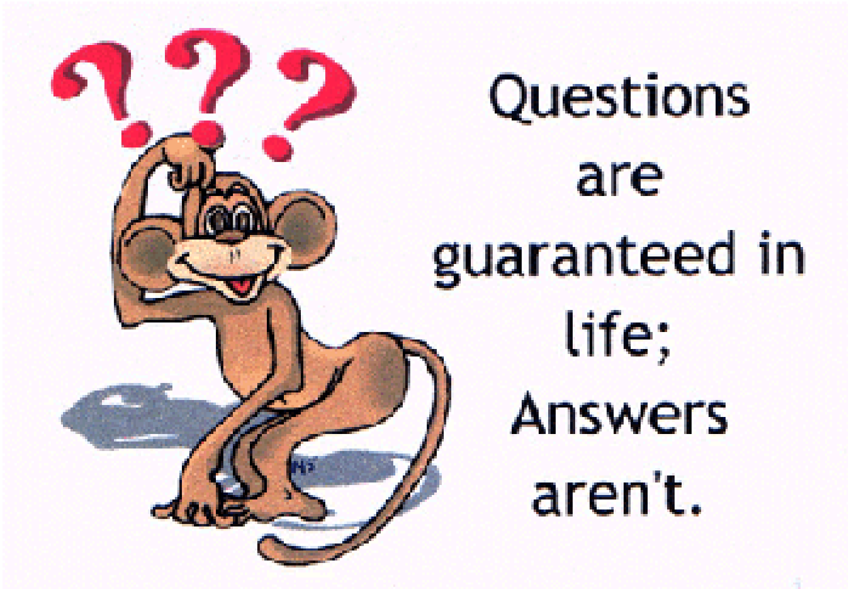




THE MOMENT IS NOW!!!

END OF PART 3 – QUESTION?

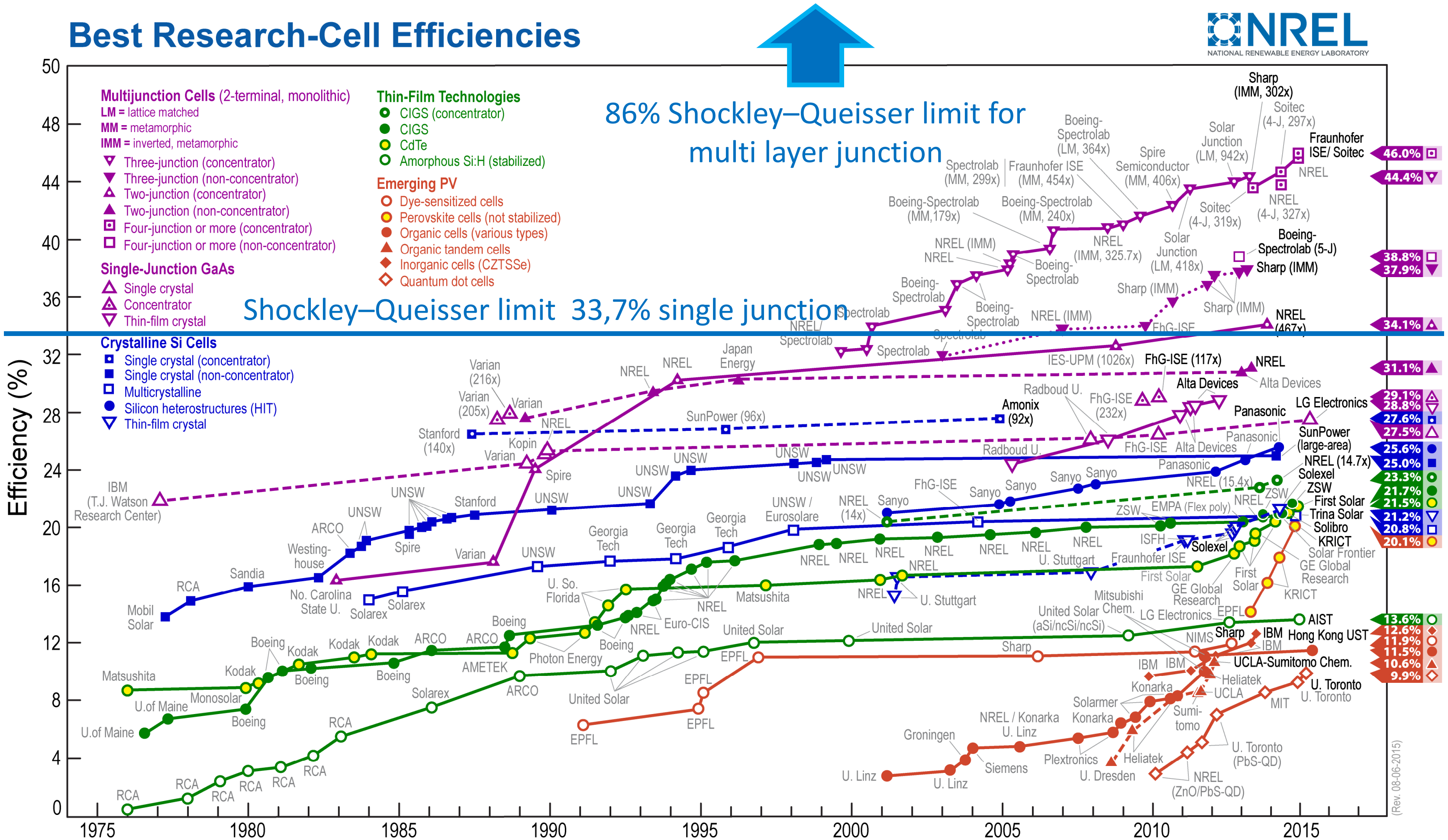




Photovoltaic market will evolve on two different ways:

- **By rising module efficiency**
- **By decreasing PV module price**

Month after month this will bring photovoltaic technology closer to the grid parity and to the economic convenience.



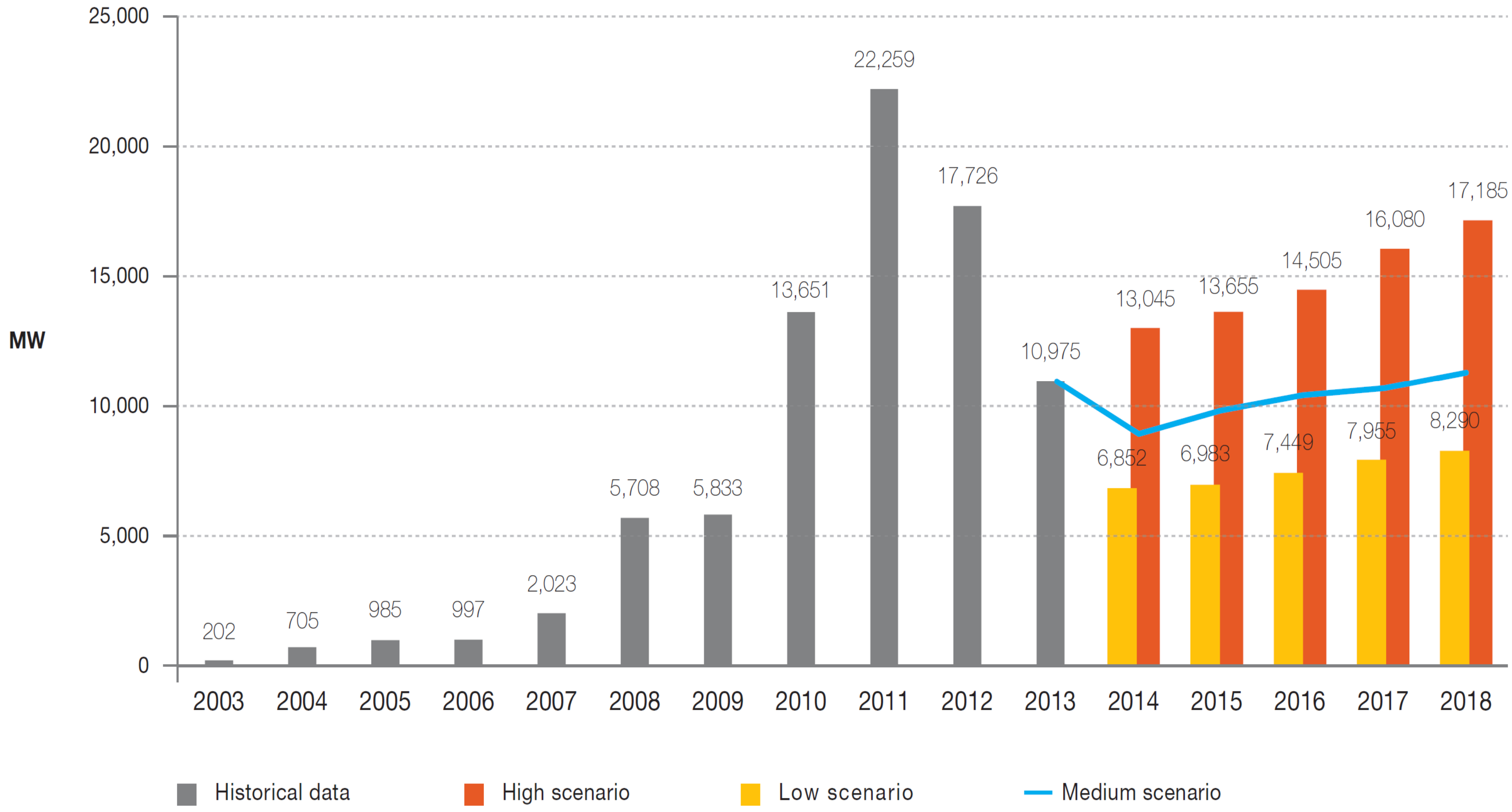


Figure 12 - European annual PV market scenarios until 2018

Part 4 – Where are we going – photovoltaic market trends

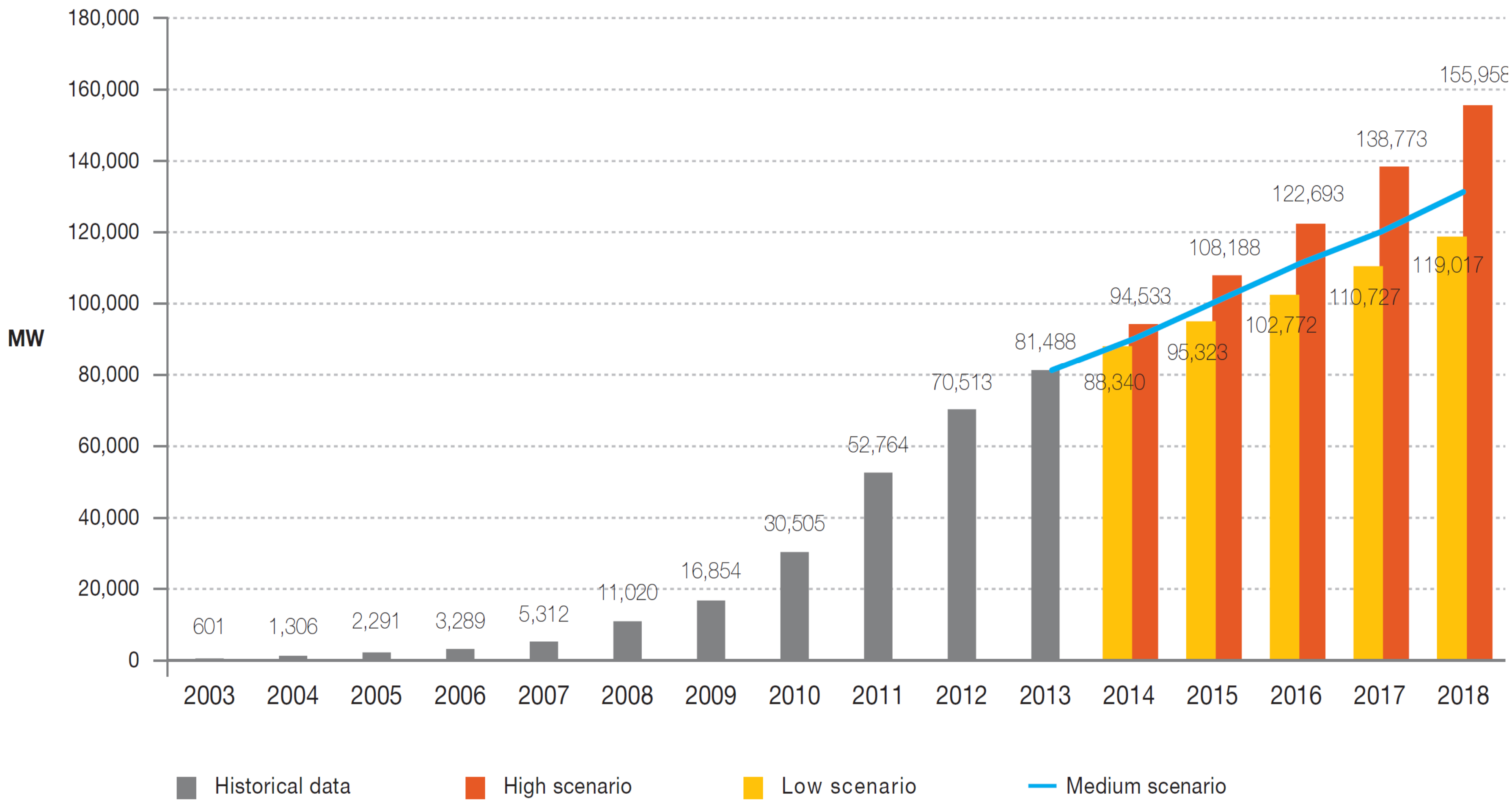
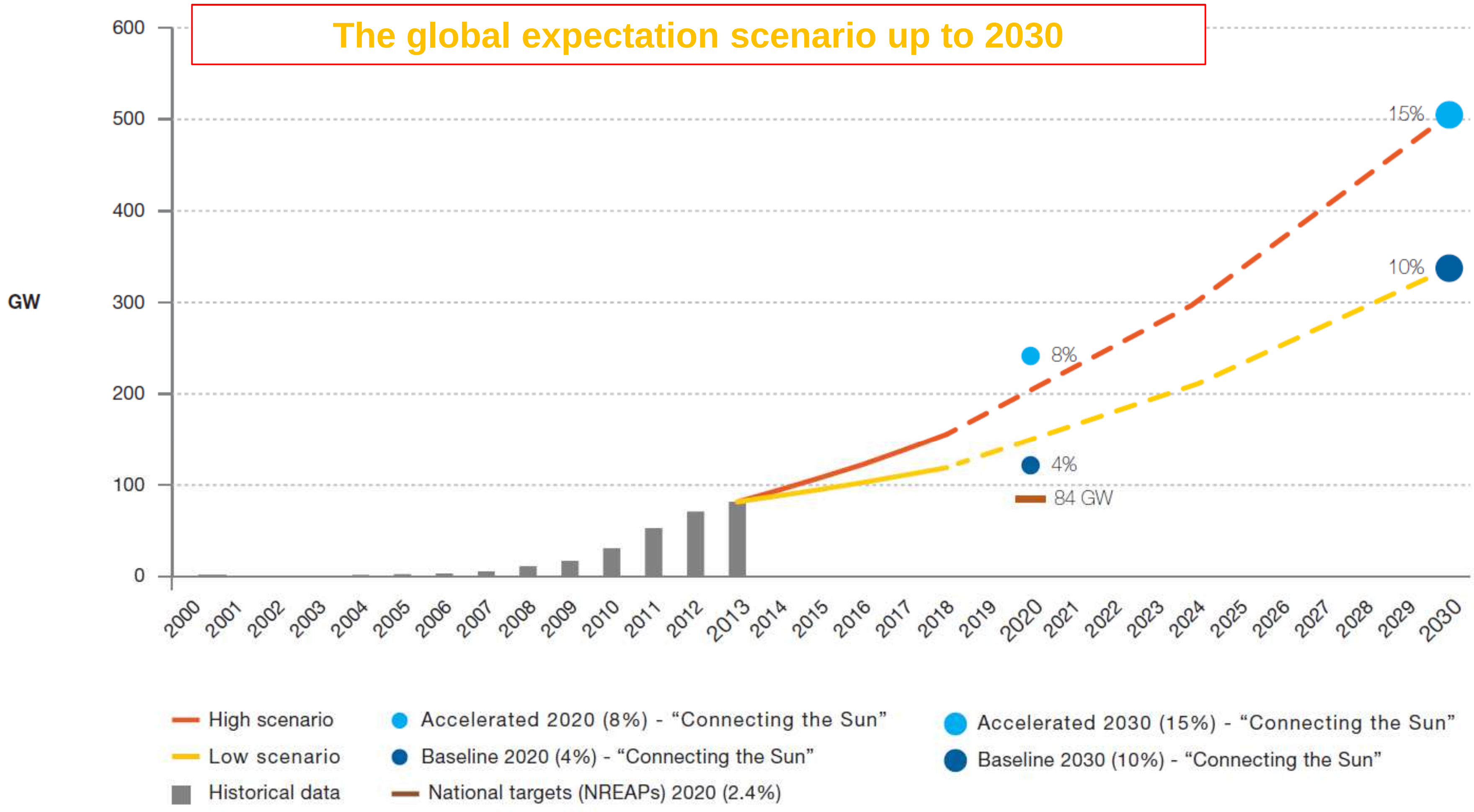


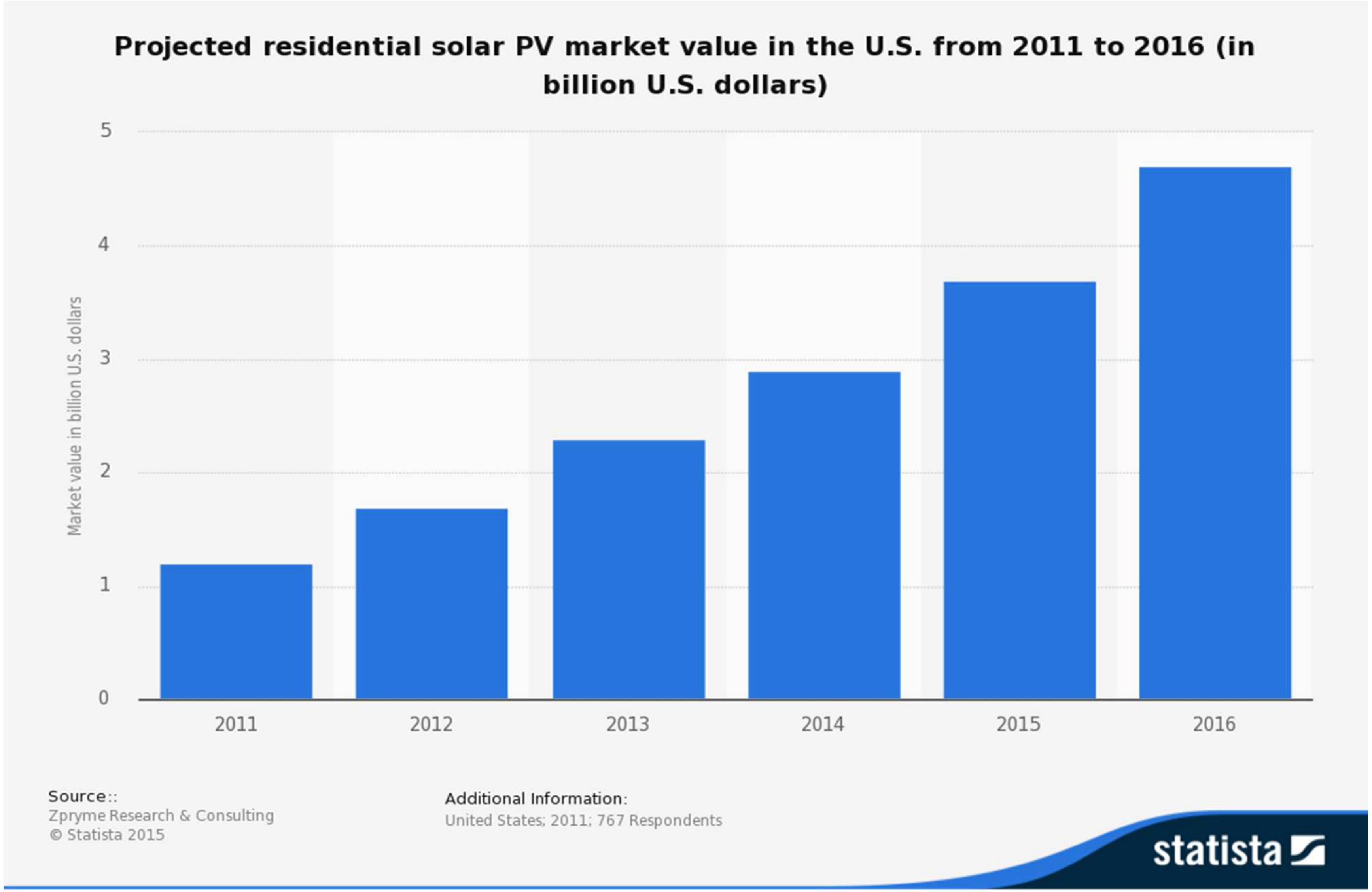
Figure 13 - European cumulative PV market scenarios until 2018

Part 4 – Where are we going – photovoltaic market trends



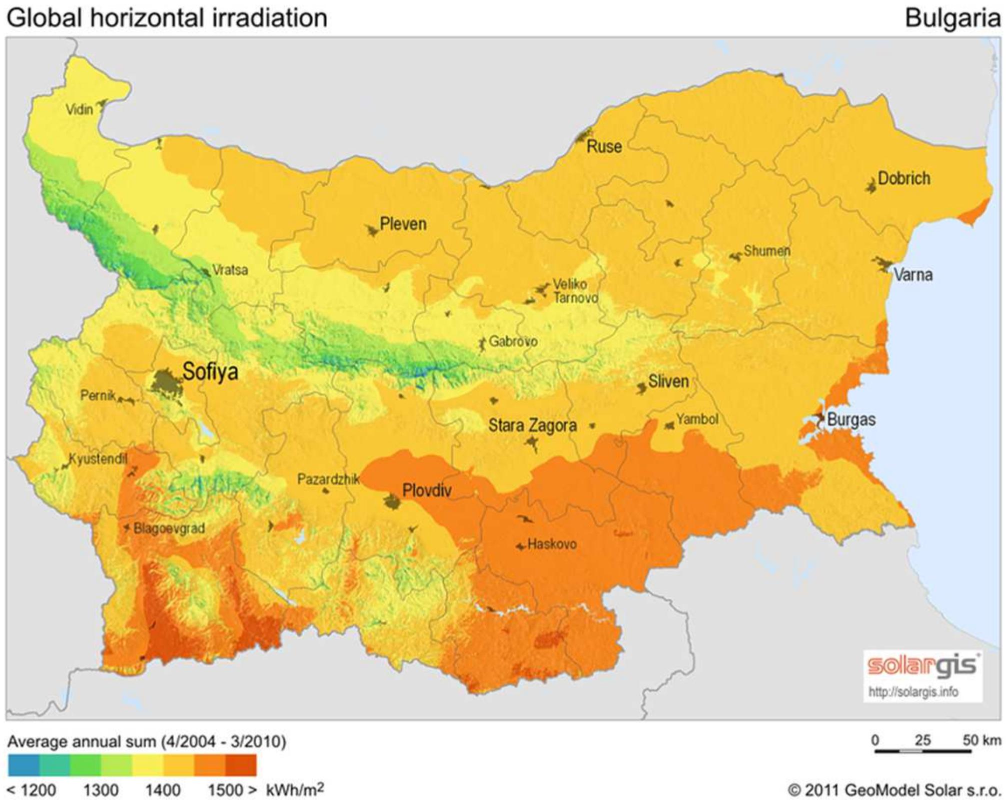
EPIA, "Connecting the Sun: Solar photovoltaics on the road to large-scale grid integration", 2012.
The percentage indicates the share of electricity demand.

And never forget the value of changing to solar

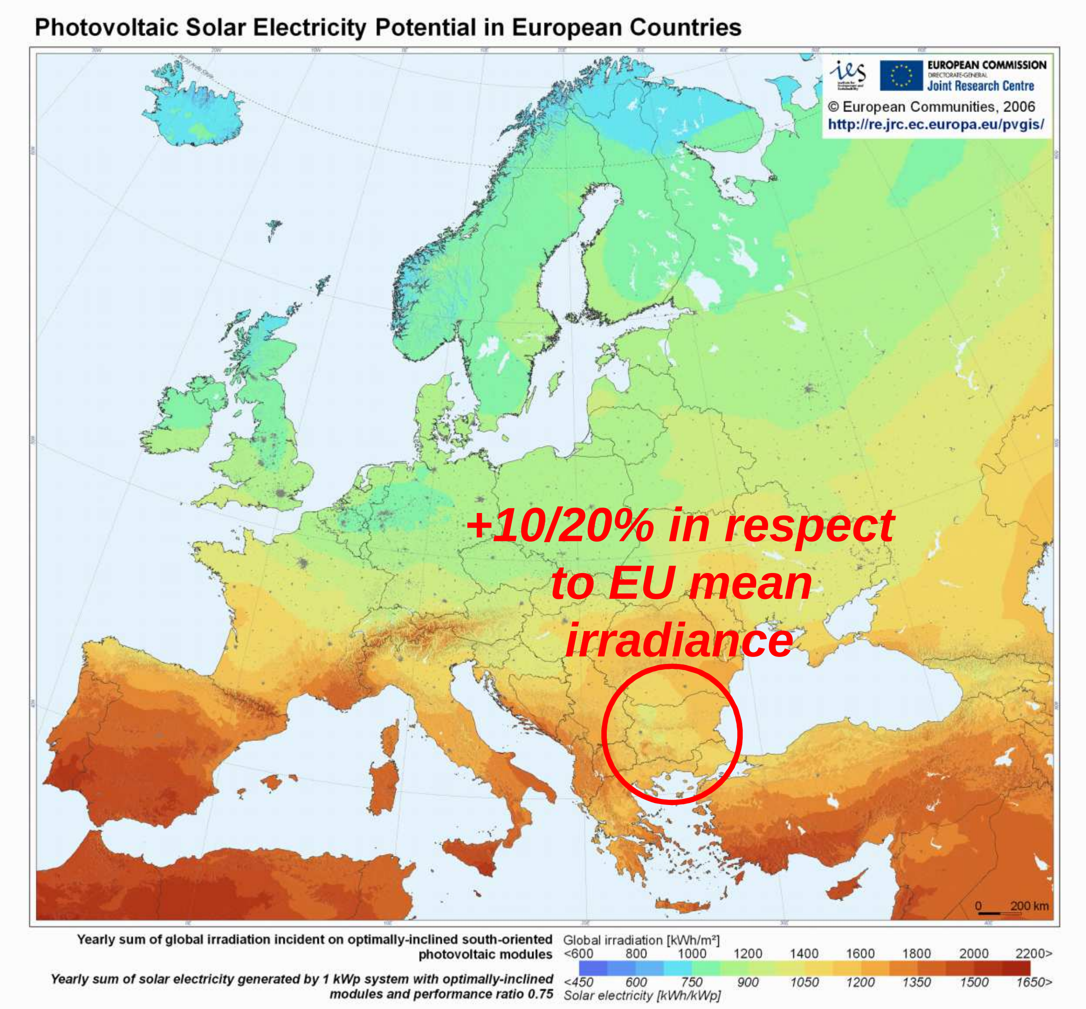


Photovoltaic in Bulgaria have followed what happened to the rest of EU countries and instituted a feed in tariff of 0,30 €/kWh in 2011. The irradiance is optimal and even the land configuration in most of the country.

Year	Photovoltaics	
	Power [MWp]	Energy [GWh]
2008	1.4	
2009	5.7	3.3
2010	35	15
2011	141	120
2012	1,010	n.a.
2013	1,020	1,349
2014	1,022	1,245
Source: IEA-PVPS/EPIA for capacity, *Photovoltaic Barometer*for generation,previous		



If we assign the average EU irradiation to 1300 kWh/m² Bulgaria has a potential above 10% and more in respect to EU potential**.**

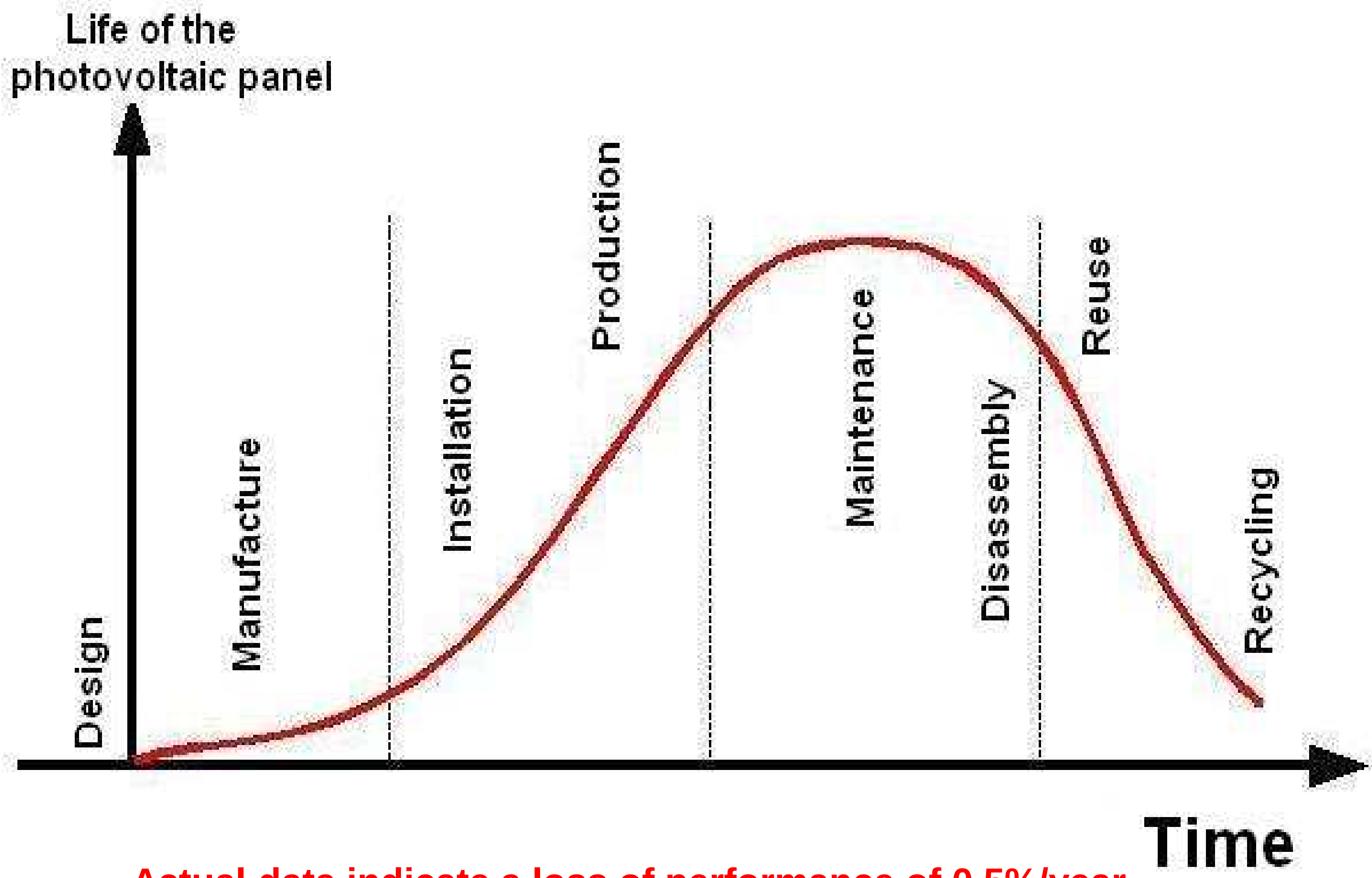


On Bulgaria , EIPA wrote on his last annual report:

"Very unstable environment. Retroactive grid fees revoked and re-established. Incentives for residential and commercial projects available but administrative procedures complicate and slow."

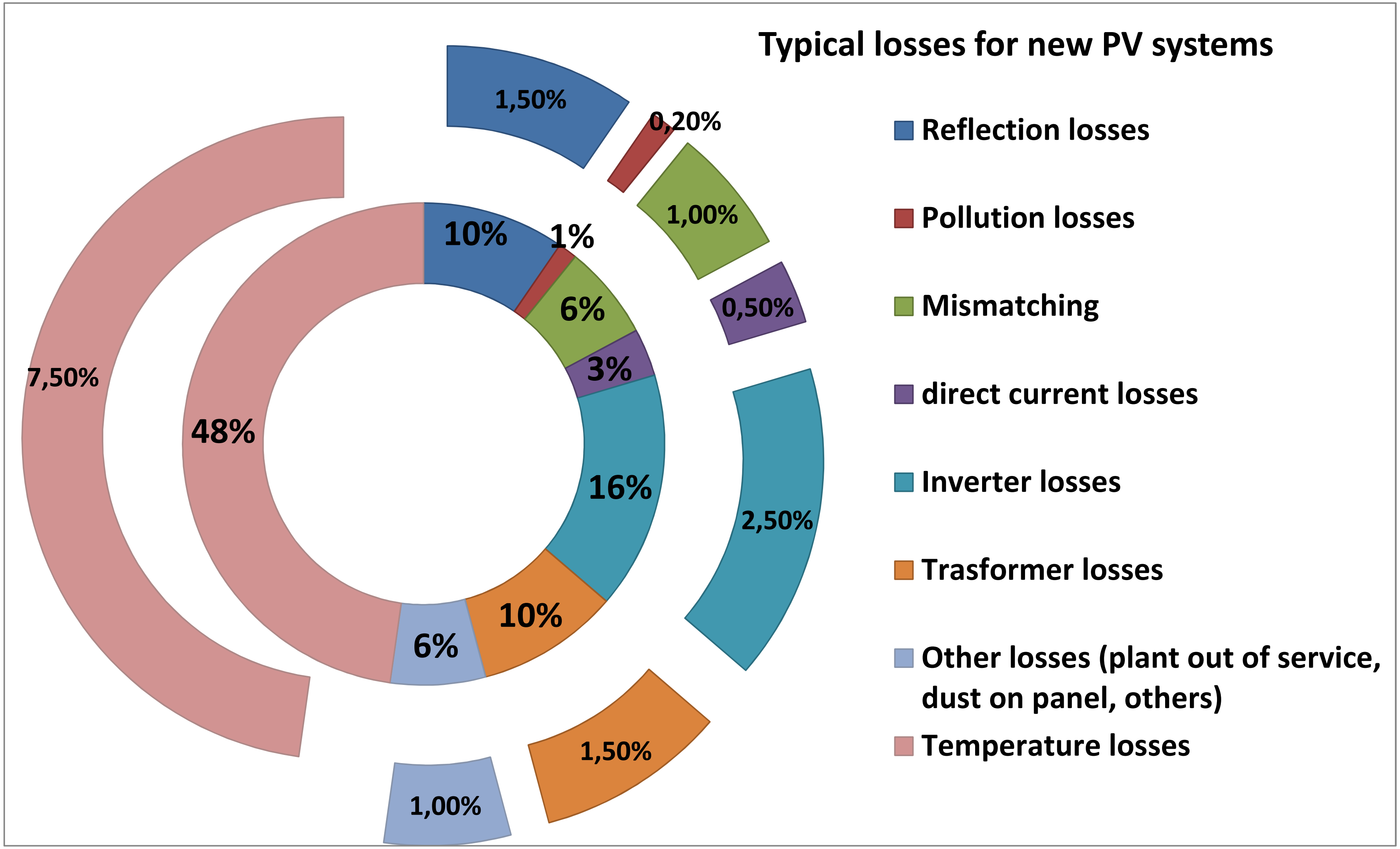
Source : EIPA PV report 2015 - [14]

Part 4 – Miscellaneous – photovoltaic panels aging



Actual data indicate a loss of performance of 0,5%/year

What we need to improve and how?



What we need to decrease losses:

- **Reflection losses:** new solar glass design and material, anti reflective paint
- **Pollution losses:** better sealing of PV arrays, more vacuum proprieties
- **Mismatching:** higher precision in doping process in order to reduce power unbalances
- **Direct current losses:** higher voltage operation (higher risk) – up to 1500 V operation of DC voltage per module. Risk of PID aging
- **Inverter losses:** higher voltage and consequence lower current reduce losses even in the inverter, better MPPT systems, higher speed in DC switching
- **Transformer losses:** Higher voltage and lower current helps transformer, the efficiency is near 99% even now.
- **Temperature losses:** developing in substrate, doping and voltage level in solar cell, slim materials, chemical research

CONCLUSION AND REFERENCES:

Today the roole of PV in global scenario is simply the most rising form of energy actually on the market and the one with best projections.

WHY this is happing:

- Low cost of energy due to PV cost decreasing will continue
- The assurance that oil price can't be as low as now forever and this will help the grid parity achievement in all over the world
- The climate change and the enormous impact of humankind on the planet will force progressively all governments to sustain alternative energy as PV.

HOW can it happen

1. By spread the knowledge
2. By diffuse and root the idea of renewable energy as the only solution
3. By installing locally in small but numerous and distributed PV plants without consuming any other soil area

THE REVOLUTION IS ALREADY STARTED EVERYWERE.
SO THE ANSWER TO WHEN QUESTION IS…NOW!

CENTRALIZED VS DISTRIBUTED ENERGY – A CRUCIAL CONCEPT

Distribute energy philosophy:

- Energy saving is a near needed, people produce energy and wants to be independent
- More security for the network due to the high number of generation point
- Few network usage, less losses, less need of maintenance, less pollution
- Less costs for people
- Knowledge of energy meaning in more person

Centralized energy philosophy:

- Power in few hands, people doesn't have the control
- Grid utilization high with losses, maintenance, failure
- The system is fragile
- High cost for the community independently from energy usage
- People are far away for the problem of energy needs

THE END

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