# SPAIN'S SOLAR REVOLUTION REVISITED (SIX YEARS LATER)

Pedro A. Prieto
ISBPE. Montana
June 20th., 2017

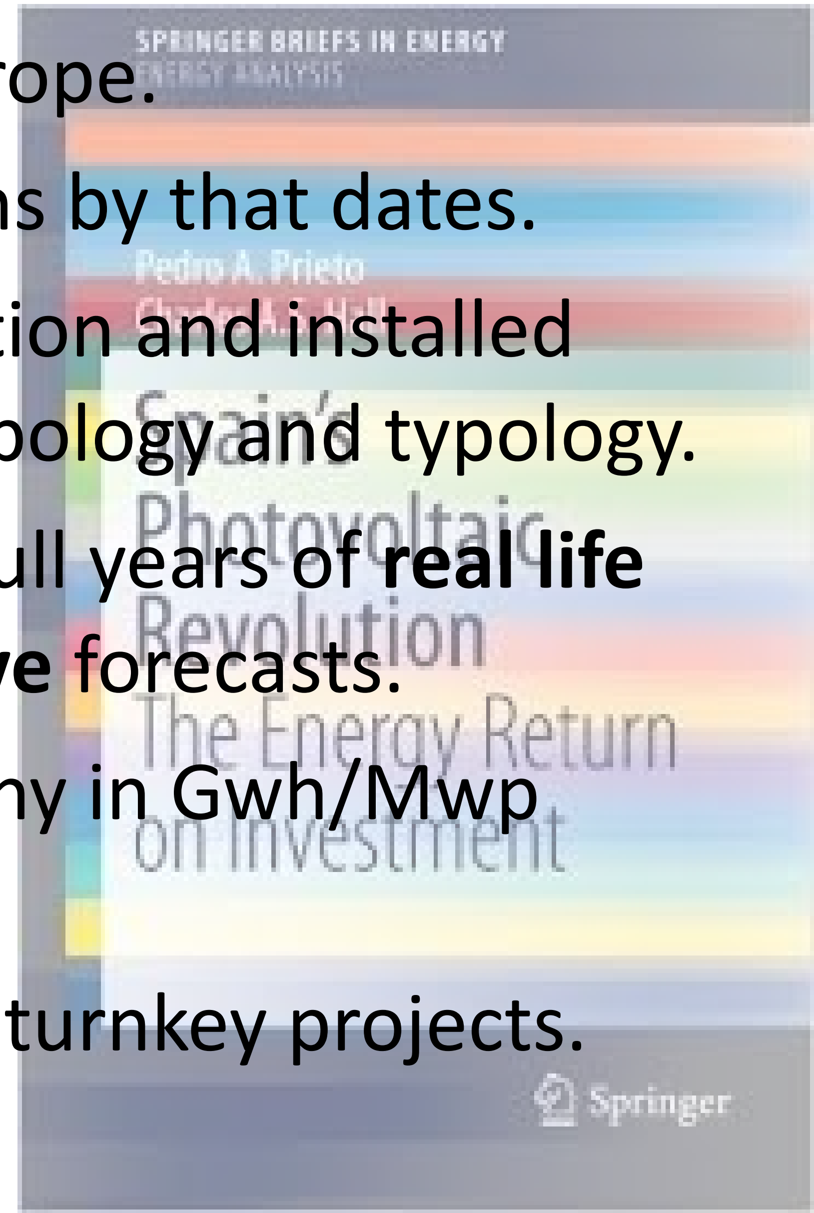
aeren spain

# INDEX

aeren spain

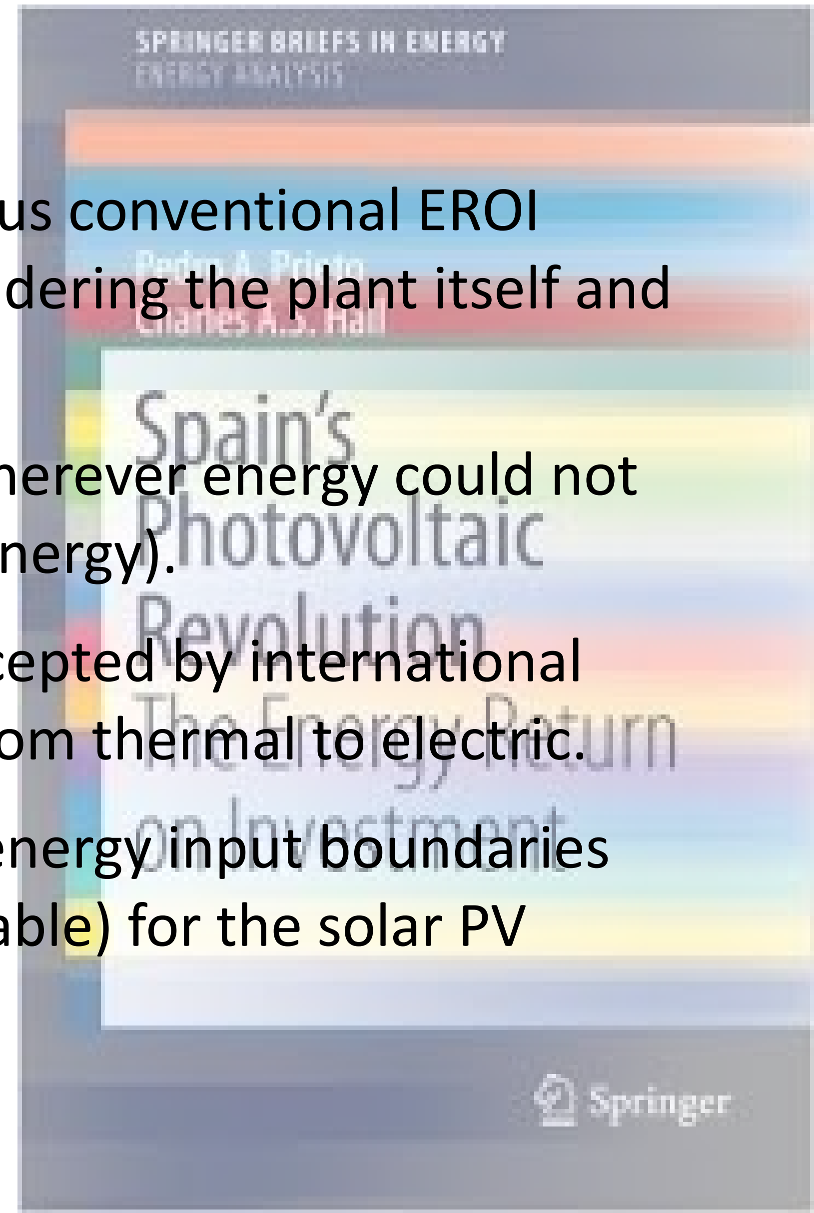
# What we did, How we started

- The best irradiated country in Europe.
- Second to Germany in installations by that dates.
- Very accurate and official generation and installed power by month, year, region, topology and typology.
- **Retrospective** analysis on three full years of **real life** operation, rather than **prospective** forecasts.
- Much more efficient than Germany in Gwh/Mwp installed.
- Rich experience on the field with turnkey projects.



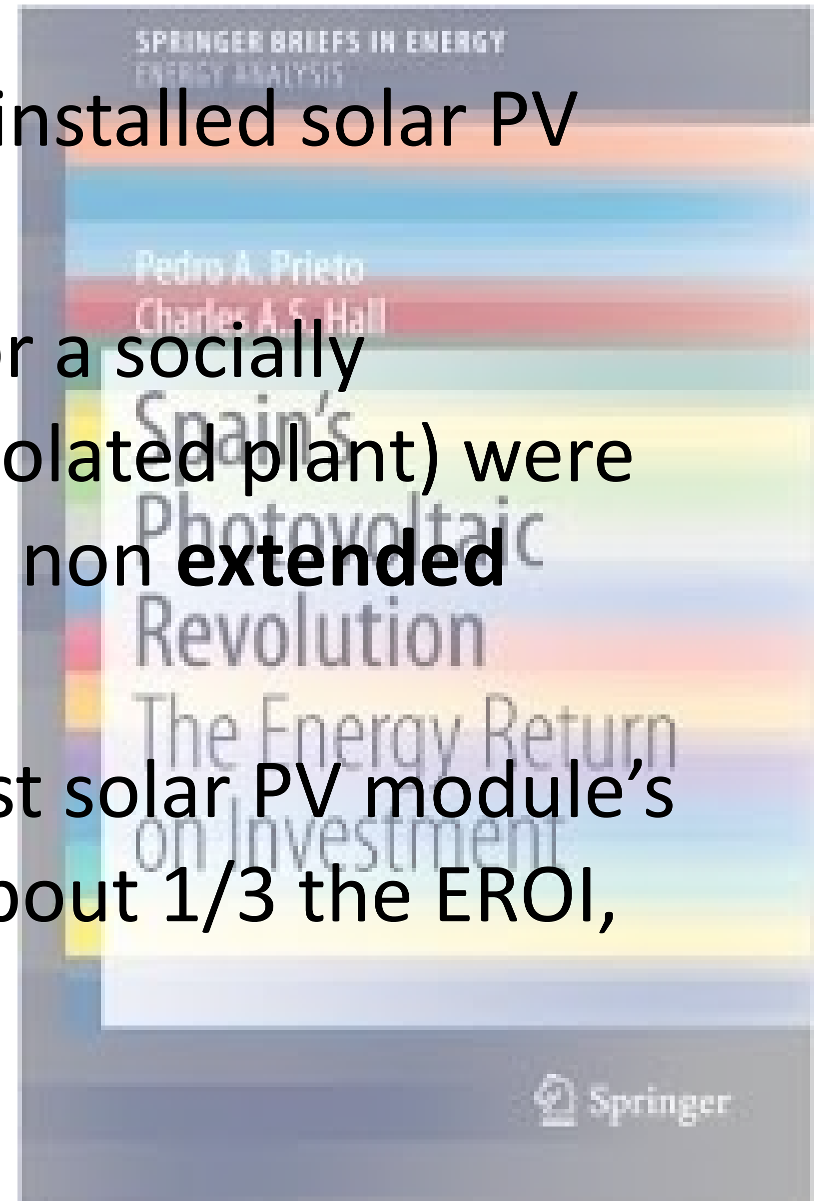
# What we did, How we started

- Methodology employed:
  - Give for good the EROI average of previous conventional EROI studies on solar PV plants, basically considering the plant itself and a minimum BoS in the best case.
  - Use equivalences of money to energy, wherever energy could not be deducted easily. (Money as a lien of energy).
  - Use energy equivalences as generally accepted by international standards, rather than anticipating 3:1 from thermal to electric.
  - Consider the extended, societal related energy input boundaries that inherent (sine qua non or indispensable) for the solar PV systems to work.



aeren spain

# What we concluded



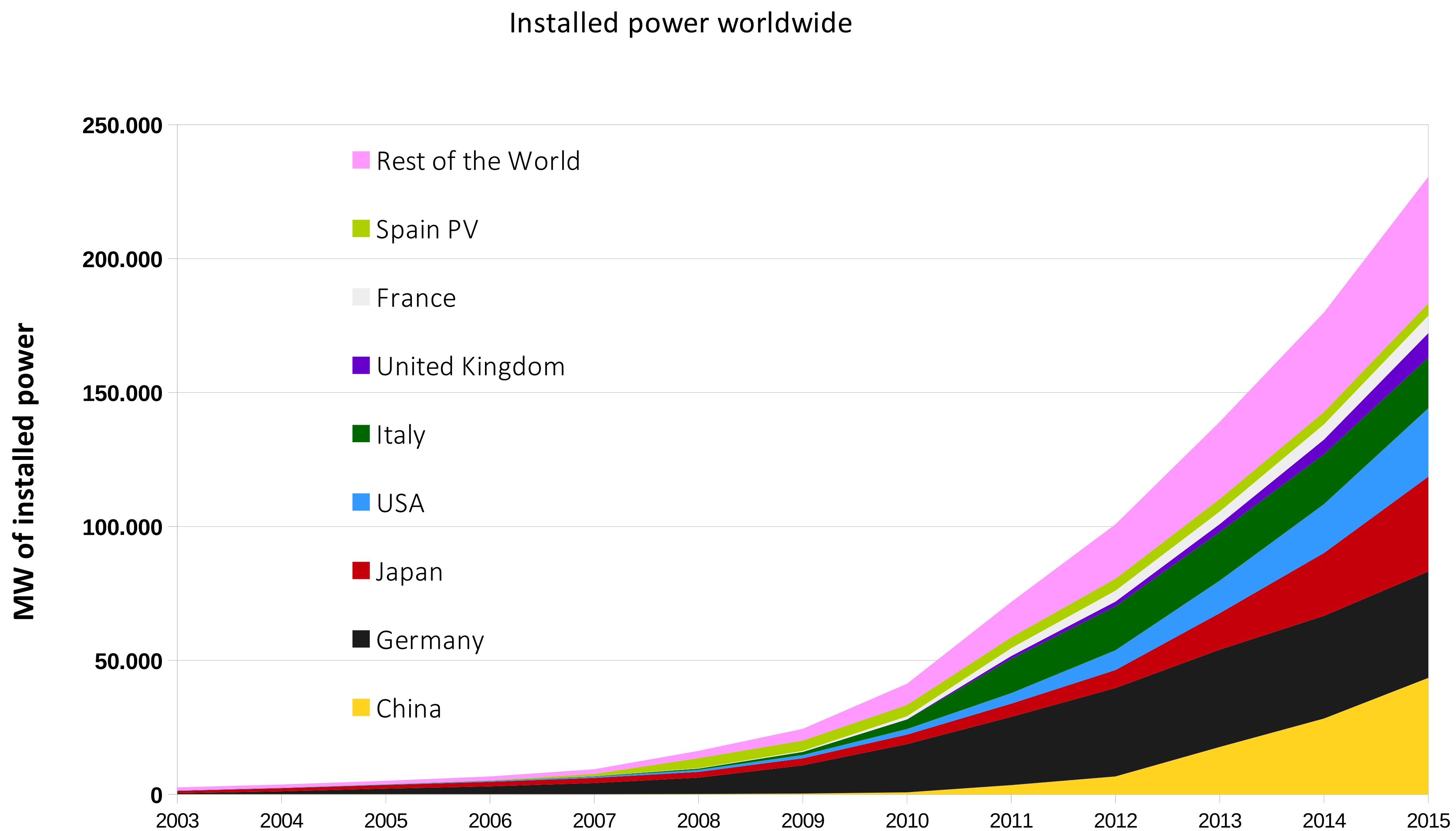

- The total EROI for Spain 4 GW of installed solar PV power offered a 2-3:1
- About 2/3 of the energy inputs for a socially integrated solar PV system (not isolated plant) were in the indispensable and sine qua non **extended energy input** boundaries.
- Therefore, further advances in just solar PV module's efficiencies could only improve about 1/3 the EROI, as best.

# The Spanish Legaistalive Labyrinth for the Renewable Program

aeren spain

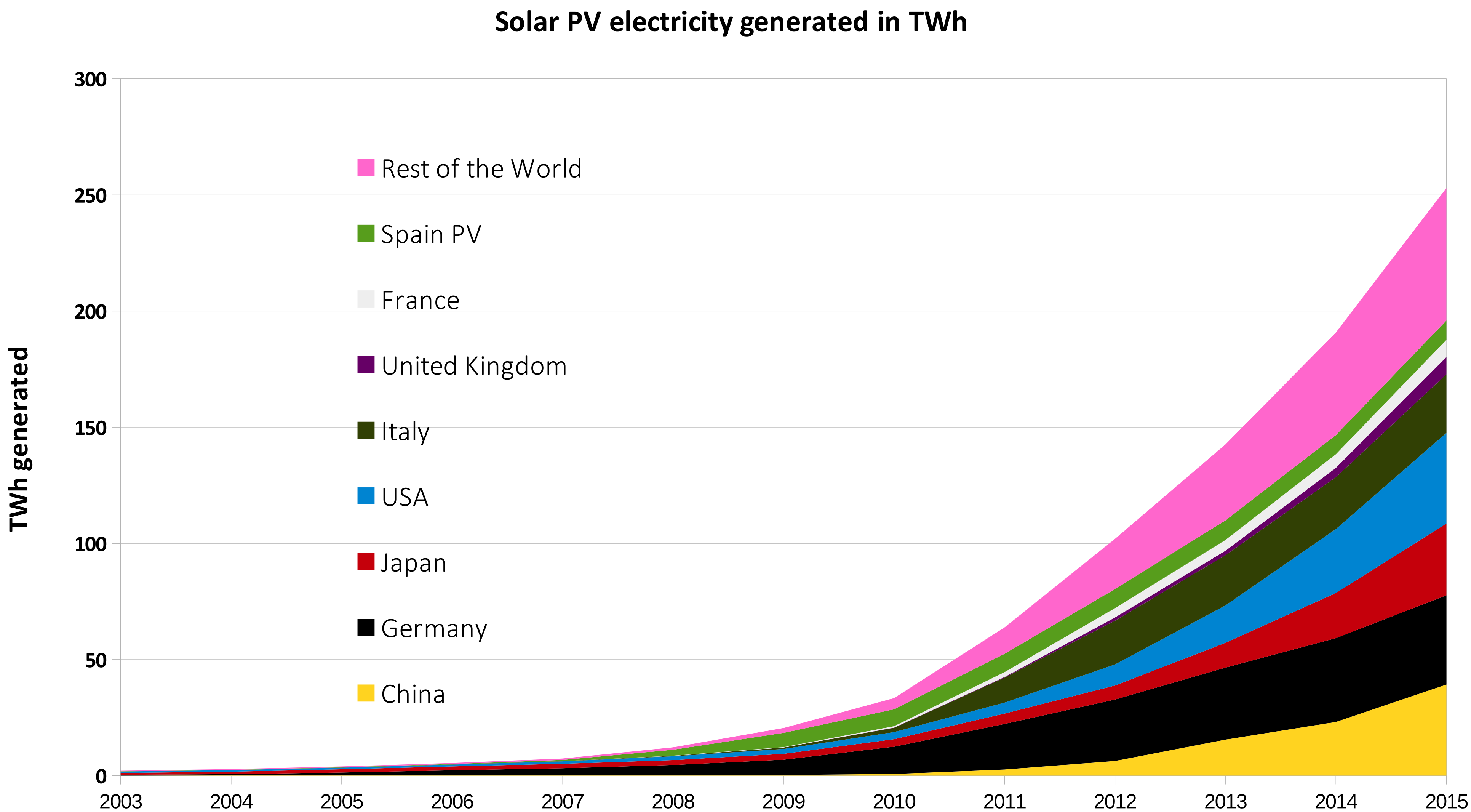
| | LEGISLATION | Government | POWER MW | PURPOSE/OBJECTIVES |
|---|---|---|---|---|
| 1 | RD436/2004 | PP (Conservative) | 10 | 380MW to 2010 575% of publi price 25 years at 44c€/kWh |
| 2 | Order 20070120 | PSOE (Social Dem) | 129 | Trying to discriminate parks bigger than 100 kW |
| 3 | RD661/2007 | PSOE (Social Dem) | 215 | Delete 460%. Fix a premium -0.5% CPI. Deadline 9/2008 |
| 4 | RD 1578/2008 | PSOE (Social Dem) | 2,028 | Preinscription registers. Folie. Reselling positions. Speculation |
| 5 | RD6/2009 | PSOE (Social Dem) | 3,472 | Several adjustment measures. Social bonus, Crisis acknowl. |
| 6 | Order ITC/3519/2009 | PSOE (Social Dem) | 3,502 | Access tolls from 2010 changes in premium tariffs |
| 7 | RD 1003/2010 | PSOE (Social Dem) | 3,750 | Antifraud Decree. Checking plants beyond deadline |
| 8 | RD 1565/2010 | PSOE (Social Dem) | 3,806 | 7% tax on income. EU was asking to reduce deficit |
| 9 | RD 14/2010 | PSOE (Social Dem) | 3,840 | On Christmas Eve 30% reduction of 2011,2012,2013 productions and 10% forever, by limiting the n.º of hours/year Mwp to Mwn. First defaults and promises of limiting damages |
| 10 | Order ITC/688/2011 | PSOE (Social Dem) | 3,943 | Access tolls from April 2011 and specific premium limits |
| 11 | RD 1544/2011 | PSOE (Social Dem) | 4,208 | Refining the access tolls to squeeze a little bit more |
| 12 | RD 1699/2011 | PSOE (Social Dem) | 4,250 | Regulates connections to the grid for small power installations |
| 13 | Order IET/3586/2011 | PP (Conservative) | 4,250 | Released on Year end by night. More access tolls and limits |
| 14 | RDL 1/2012 | PP (Conservative) | 4,274 | Preasignment quotas and new incentives suspended |
| 15 | RDL 29/2012 | PP (Conservative) | 4,509 | Tariff changes in the Spanish Fool's Day under the cover of a Decree to protect Maid's Social Security. Limiting dates and execution periods. Introducing the substantial modification concept |
| 16 | RDL 02/2013 | PP (Conservative) | 4,549 | More limits to the CPI referred to constant taxes or food (from 3% this year to -0.028%. Qualified as "urgent measures" |
| 17 | RD 09/2013 | PP (Conservative) | 4,604 | Urgent measures to financially stabilize the electric system |
| 18 | Order IET/1045/2014 | PP (Conservative) | 4670 | New parameters for payments. 50,000 plants matrix Payments basically organized by type of plant, location and power |

# A Global Present View in solar PV




Source: BP Statistical Review of World Energy 2016

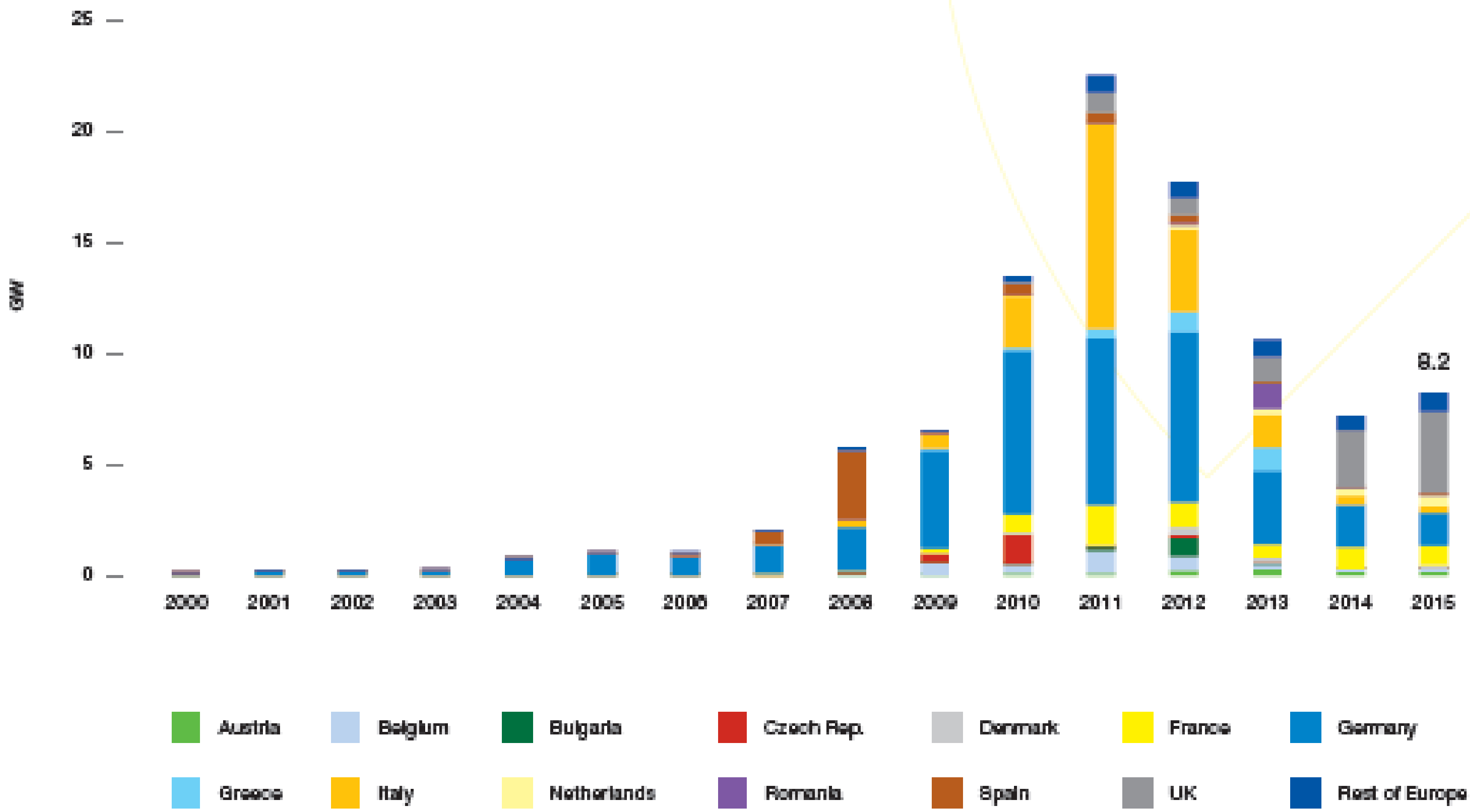
# A Global Present View in solar PV




Source: BP Statistical Review of World Energy 2016

# An European View in solar PV

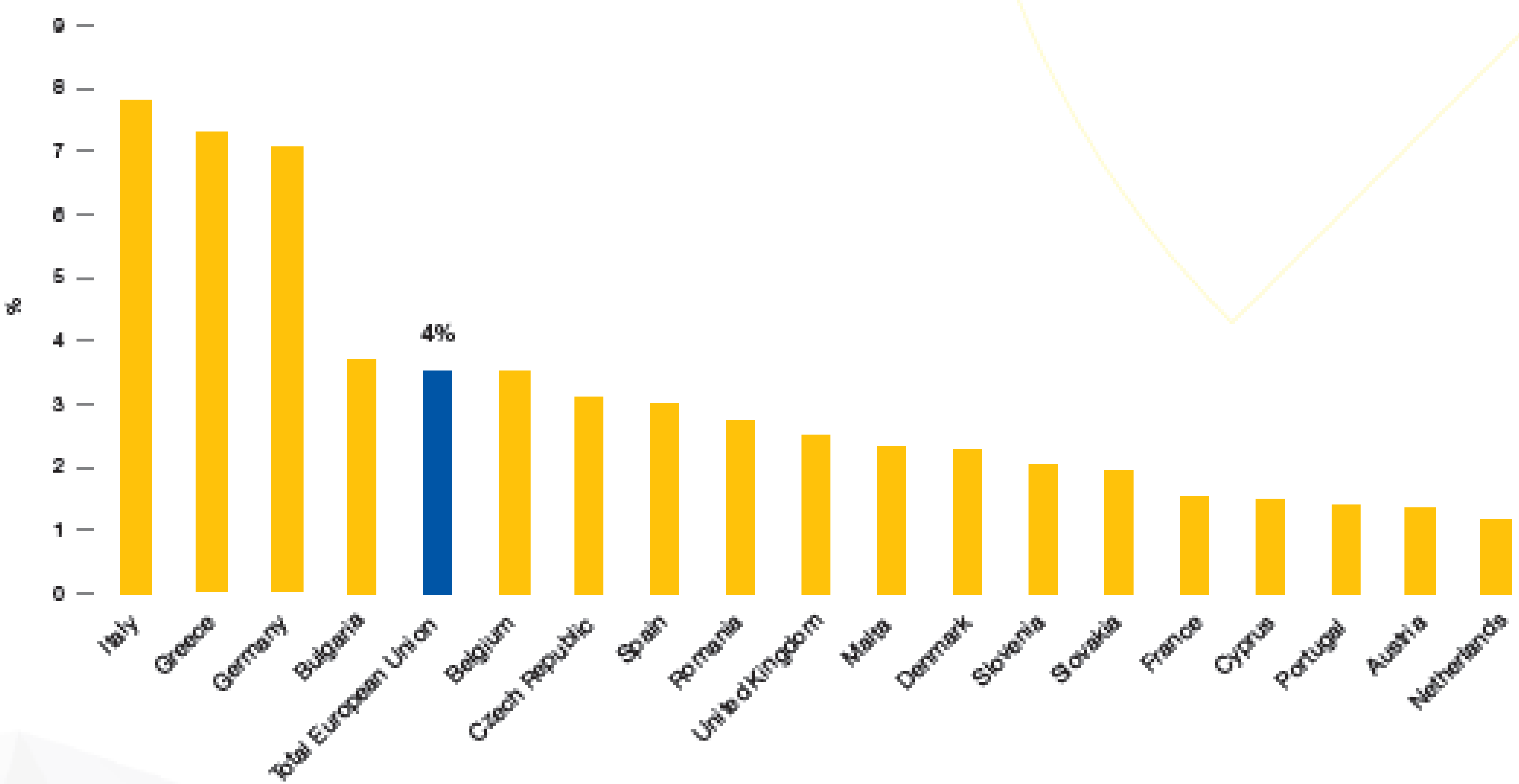
FIGURE 14 EVOLUTION OF EUROPEAN ANNUAL SOLAR PV INSTALLED CAPACITY 2000 - 2015 FOR SELECTED COUNTRIES




Source: Solar Power Europe Global Market Outlook 2016. Page 26

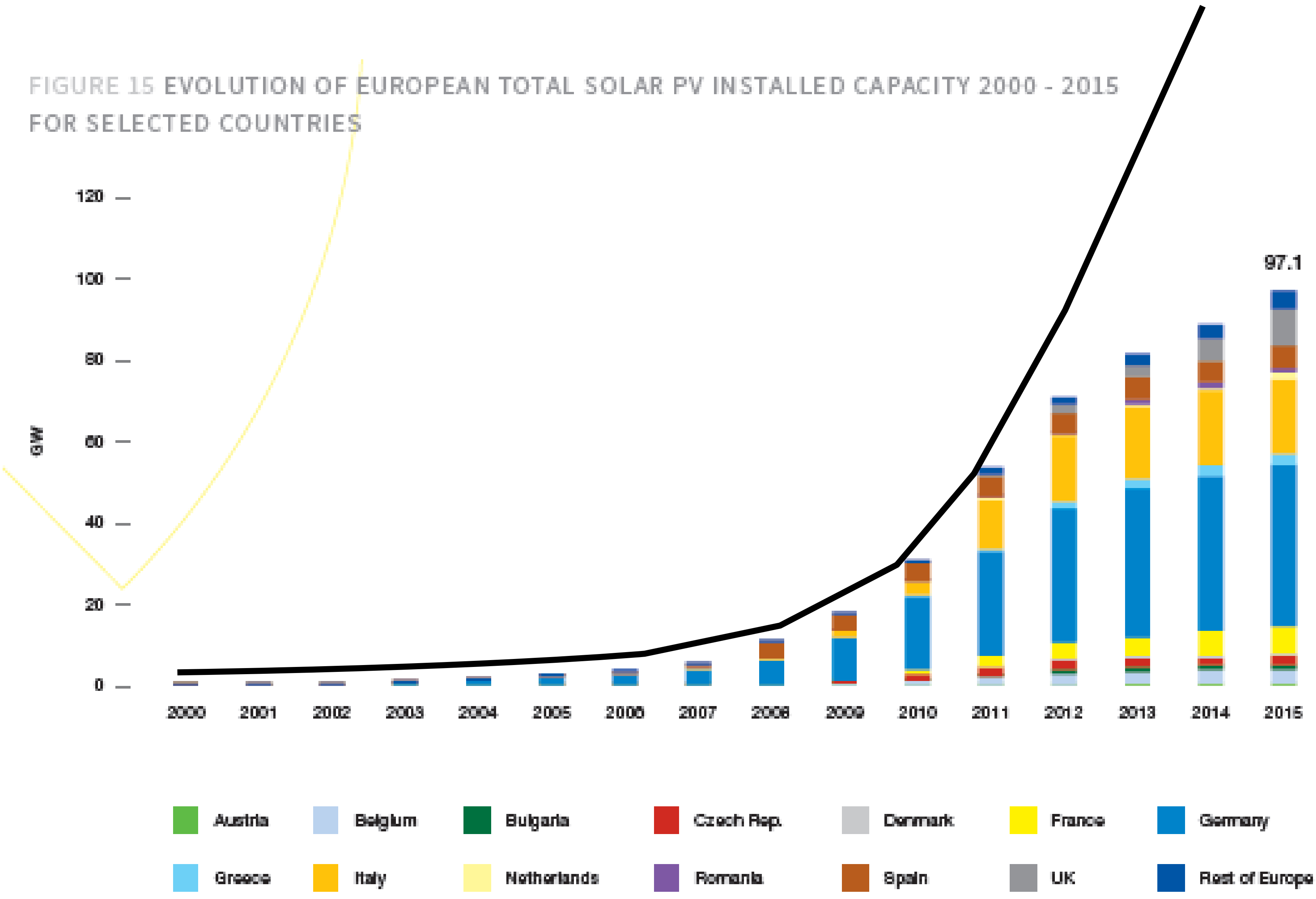
# An European View in solar PV

FIGURE 21 PV CONTRIBUTION TO THE ELECTRICITY DEMAND IN THE EU-28 IN 2015



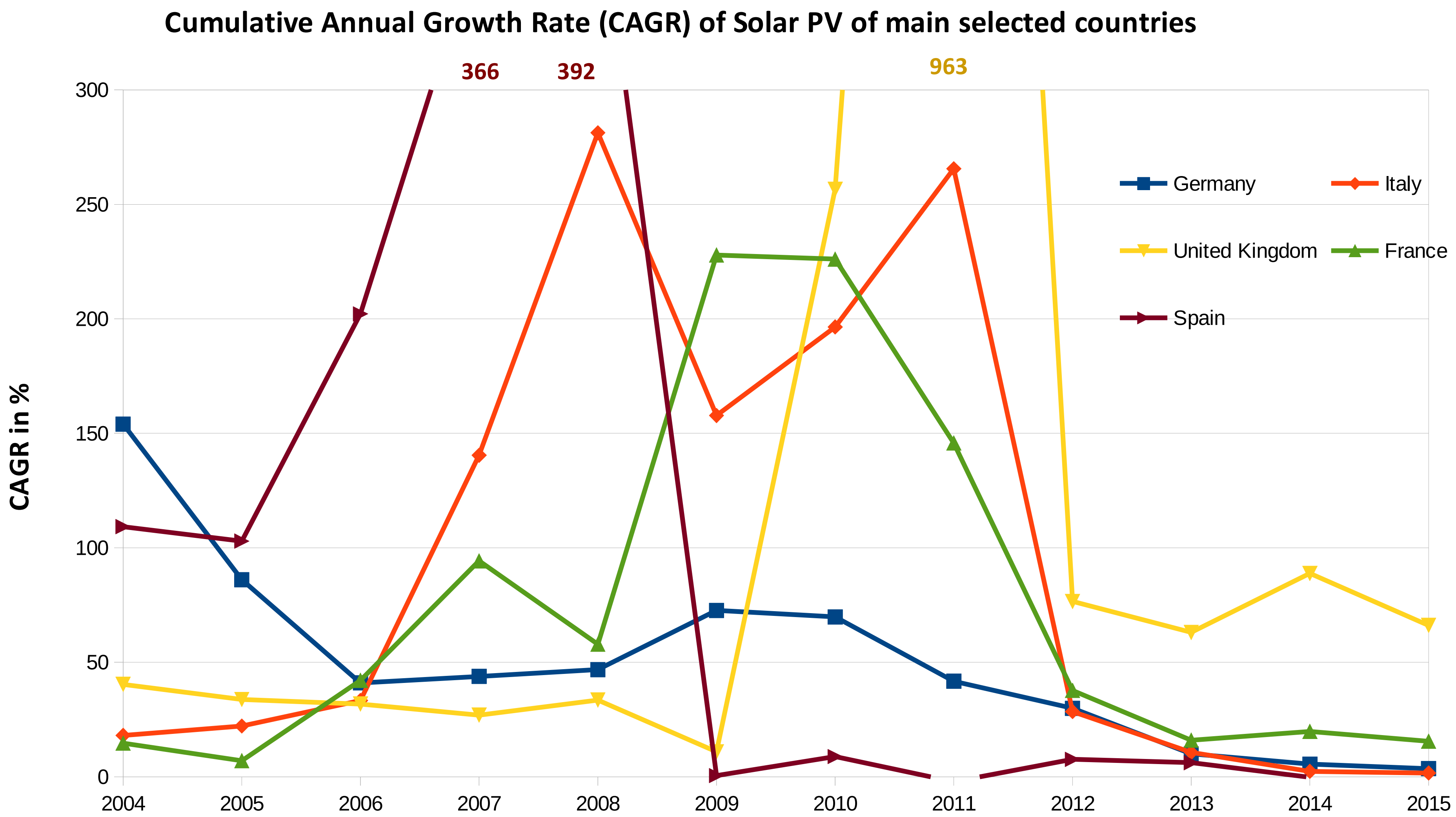

Source: Solar Power Europe Global Market Outlook 2016. Page 34

# An European View in solar PV



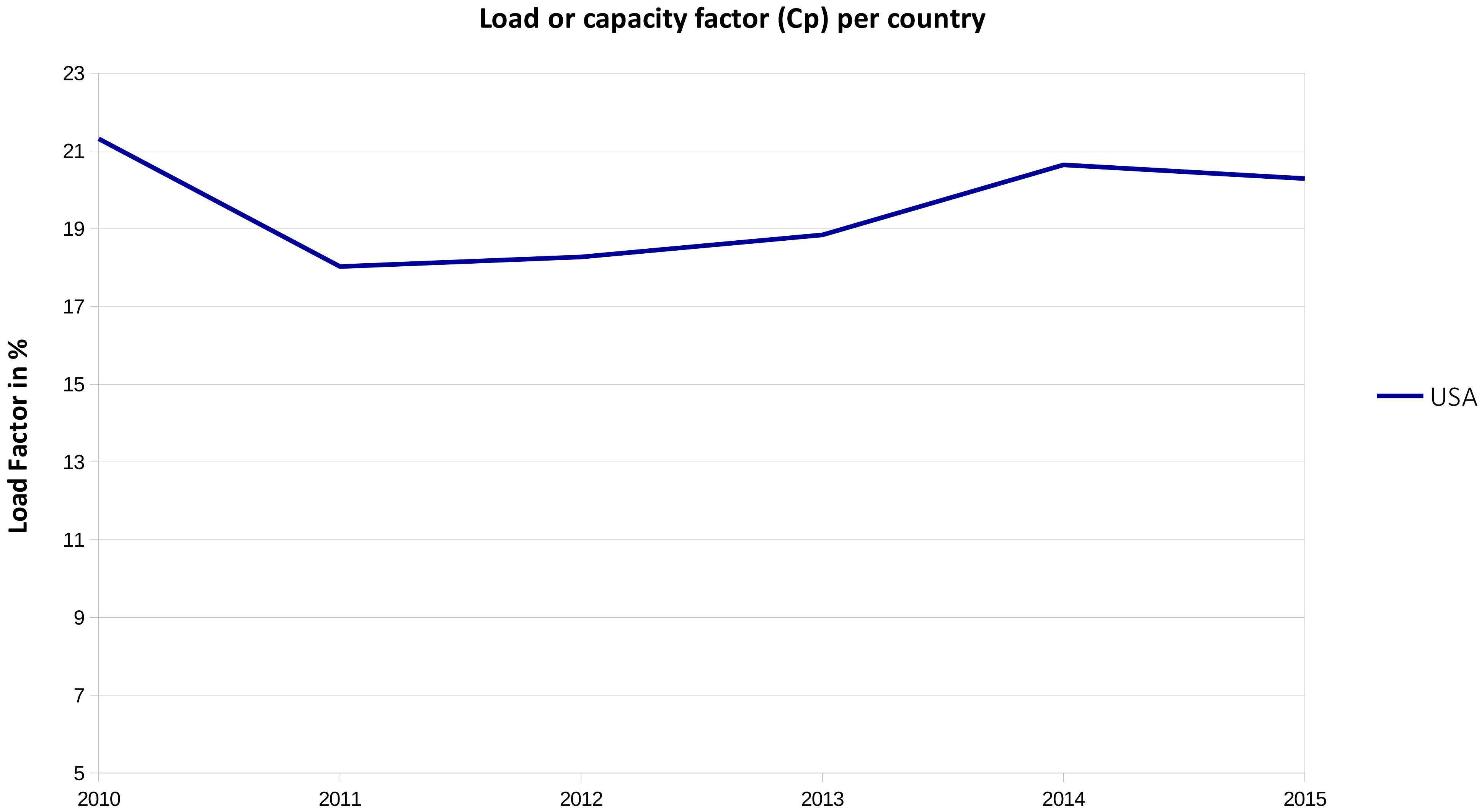

Source: Solar Power Europe Global Market Outlook 2016. Page 27

# An European View in solar PV



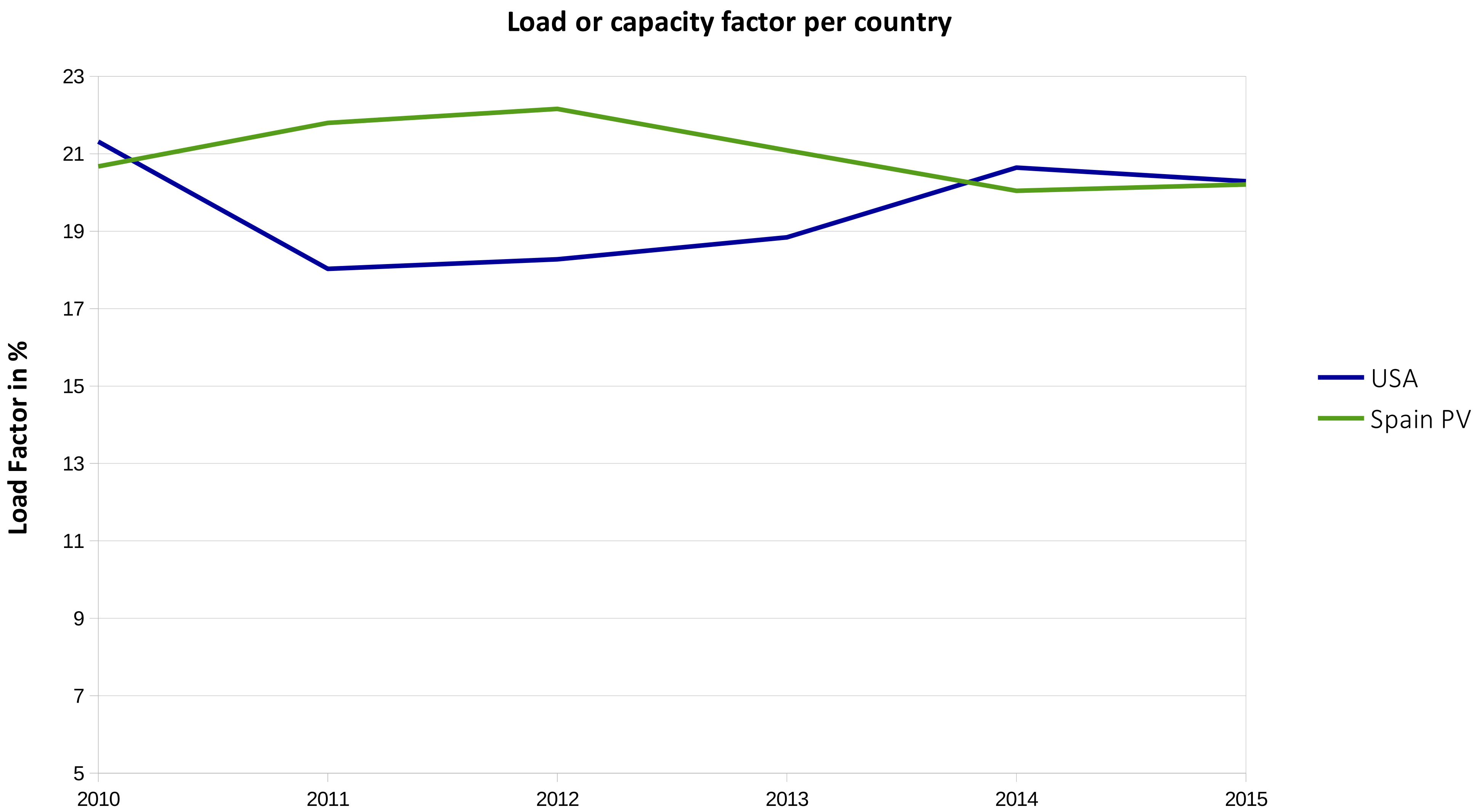

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



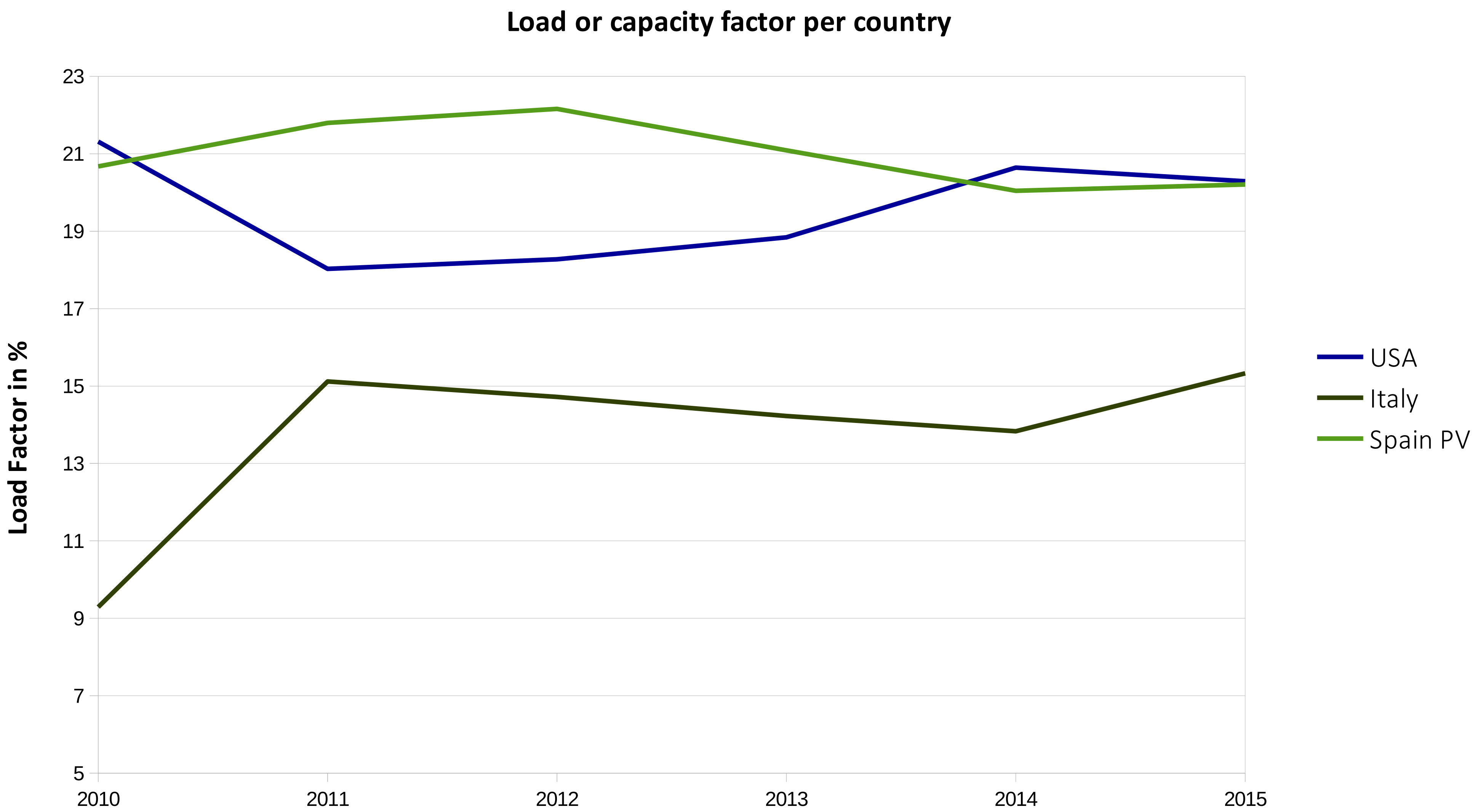

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



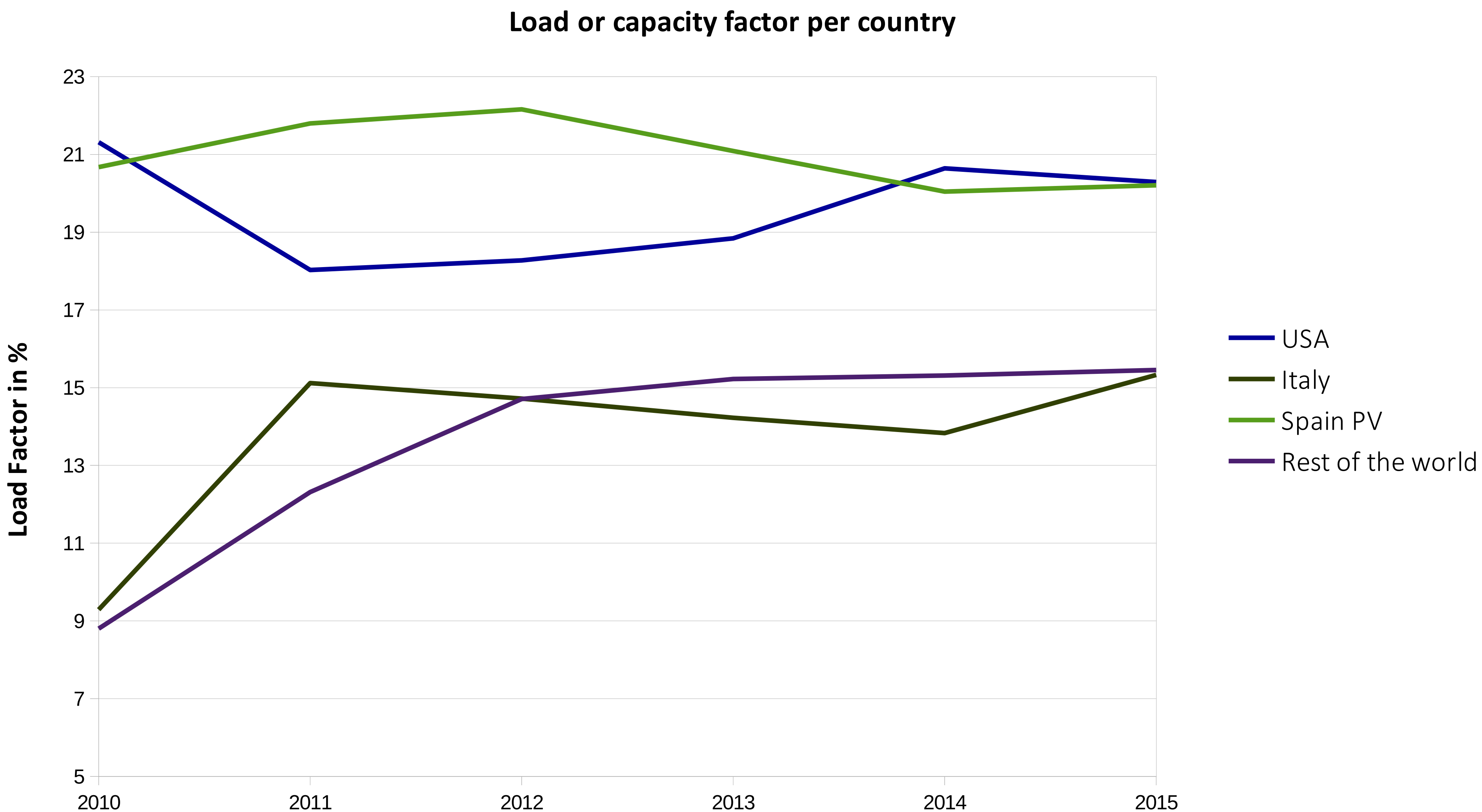

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



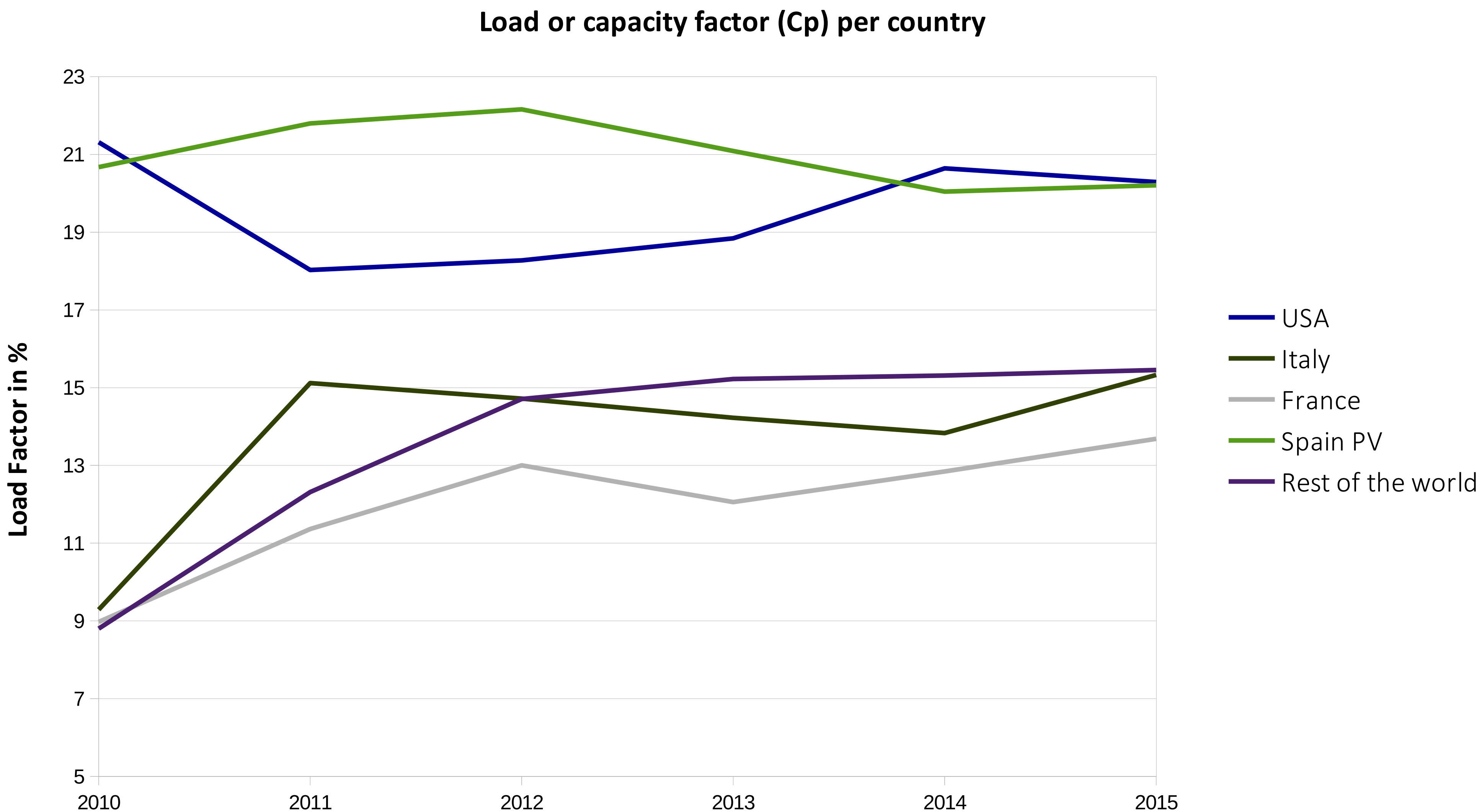

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



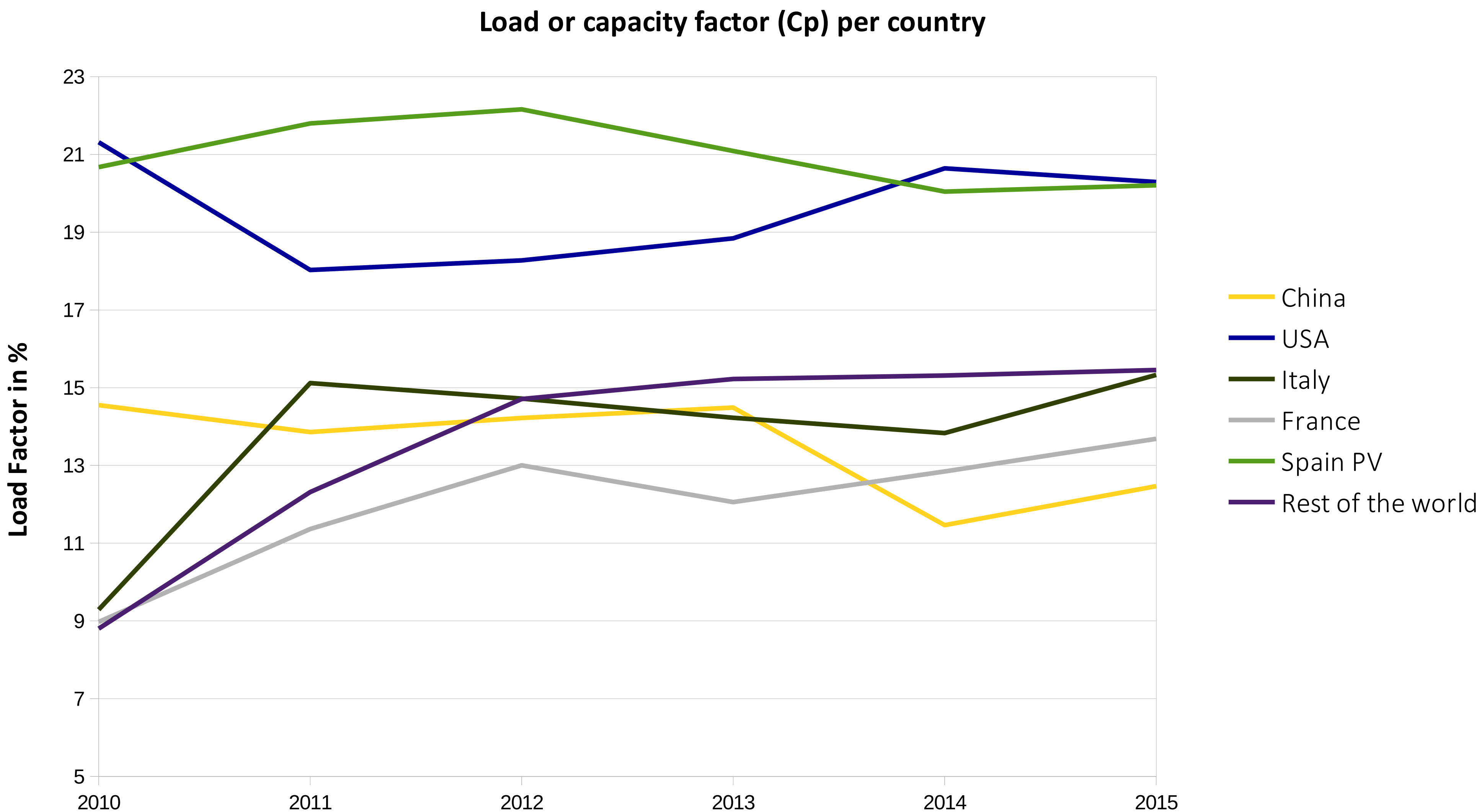

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



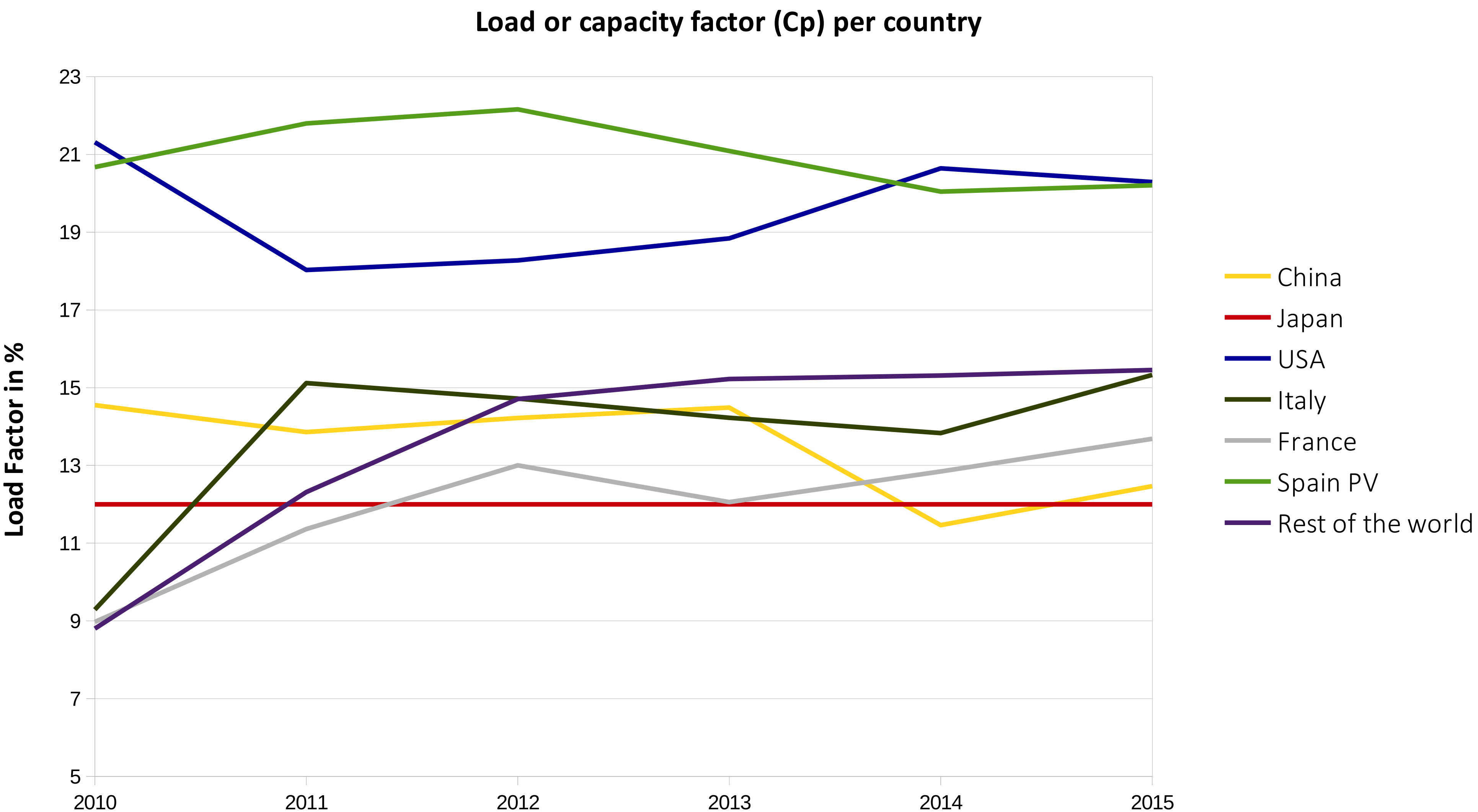

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



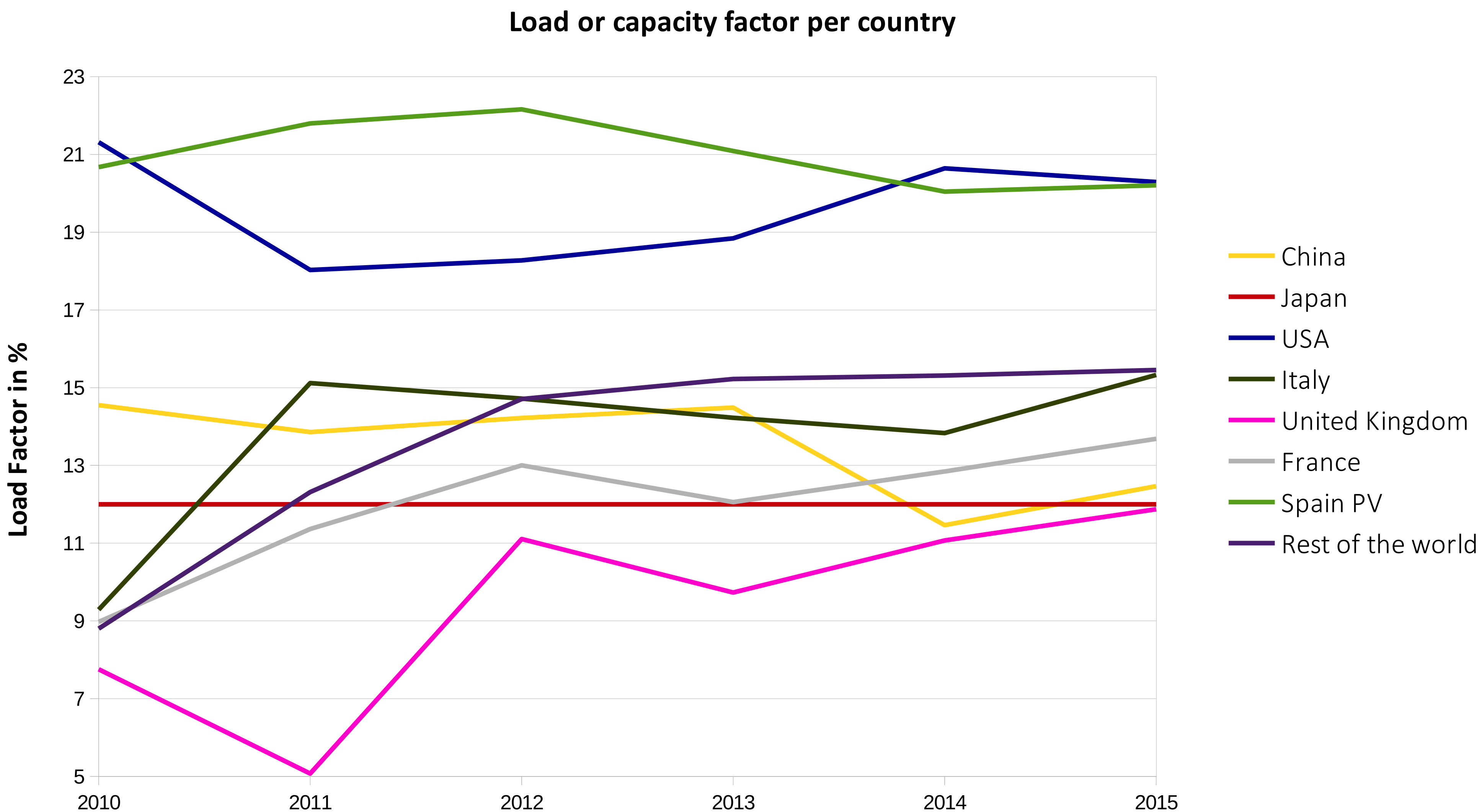

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



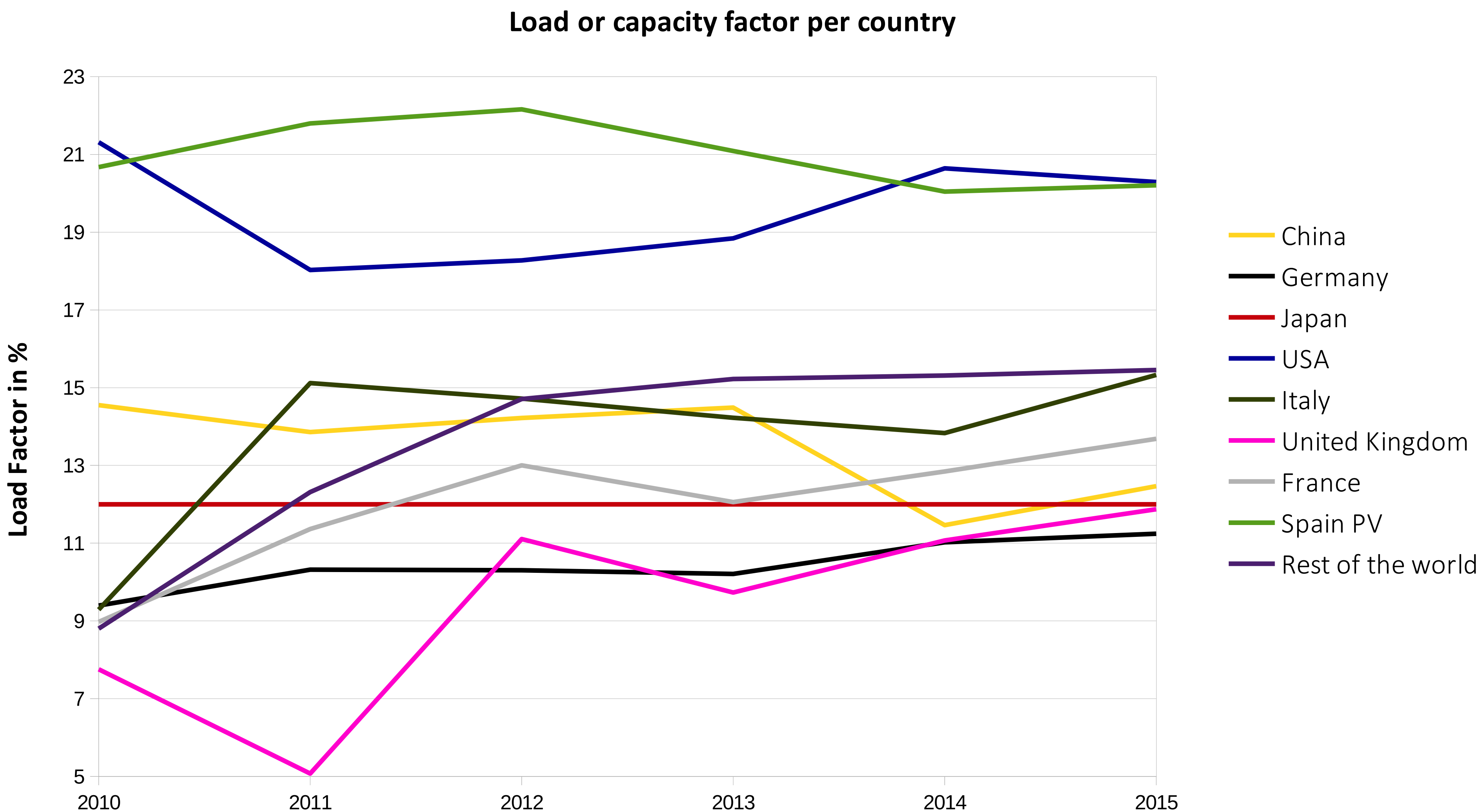

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV



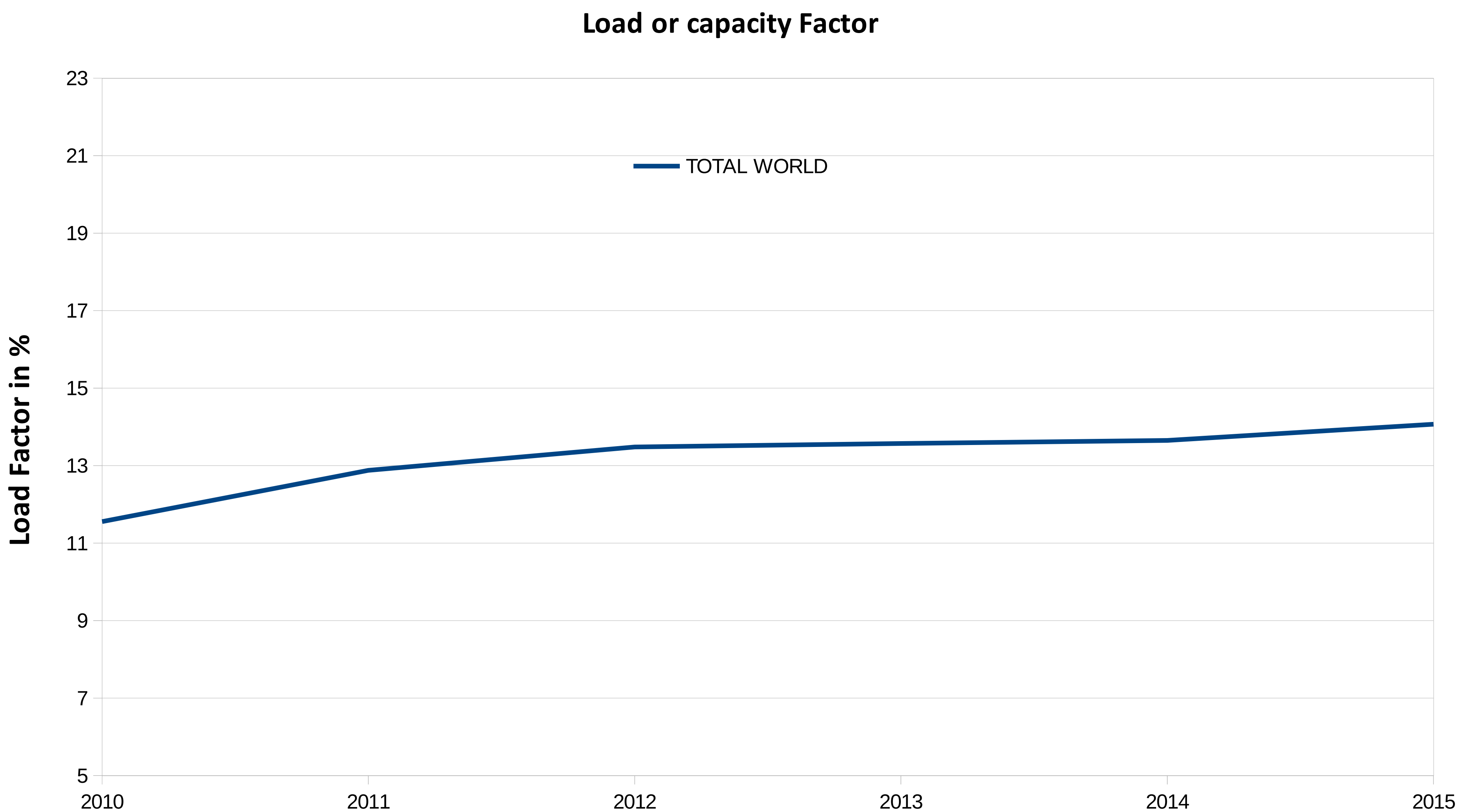

Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV




Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV




Source: BP Statistical Review of World Energy 2016

# A Global View on solar PV

## Solar PV Manufacturing Market Share

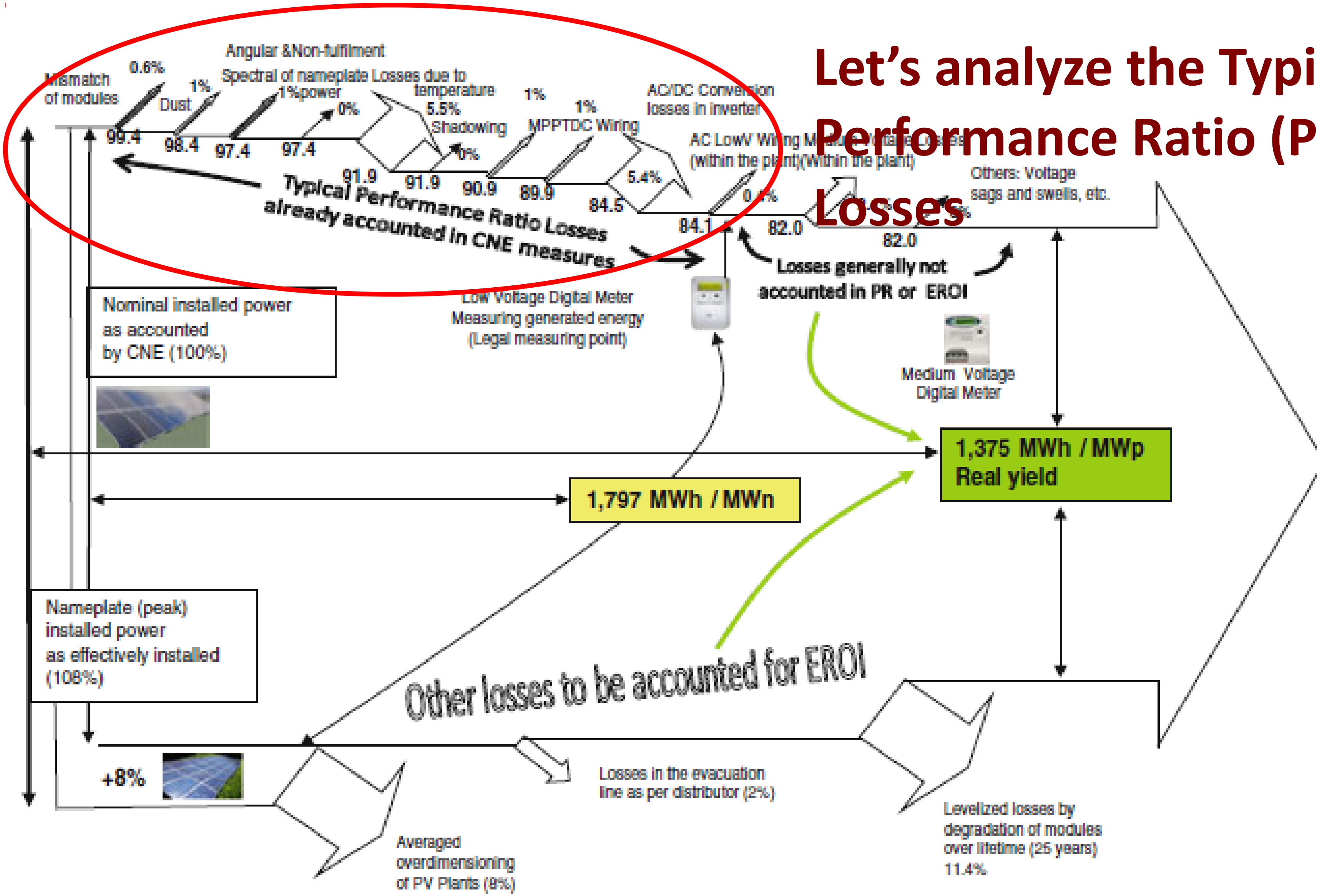
| Year | Japan | Europe | | | USA | ROW |
|---|---|---|---|---|---|---|
| 2003 | 49,0% | 26,0% | | | 13,0% | 12,0% |
| | Japan | Europe | China | Taiwan | USA | ROW |
| 2007 | 34,0% | 28,0% | 15,1% | 6,7% | 6,7% | 9,3% |
| | Japan | Europe | China+Taiw | | USA | ROW |
| 2016 | 2,0% | 4,0% | 78,0% | | 3,0% | 13,0% |

Sources: European Commission in 2003. EPIA/Greenpeace in 2007. Fraunhofer Institute PV October Report in 2016

# The Energy Return (Er)

aeren spain

**Let's analyze the Typical Performance Ratio (PR) Losses**




Sankey diagram of solar PV energy in Spain

# The Energy Return (Er)

## Life Cycle Assessment Considerations

- IEA PVPS Task 12 considers **30 years.**
- Manufacturers guarantee the power **25 years.**
- Manufacturers guarantee the modules **5-10 years**.

  The later guarantee supersedes the former.

- From the European Association PV CYCLE it could rather be inferred a shorter life cycle.[1] **18 years.**

The "Quality Monitor, 2013" of the TUV Rheinland (Germany) gives some 30% of modules with serious deficiencies
Photon magazine (January 2013) states
that 70% of modules have minor defects.

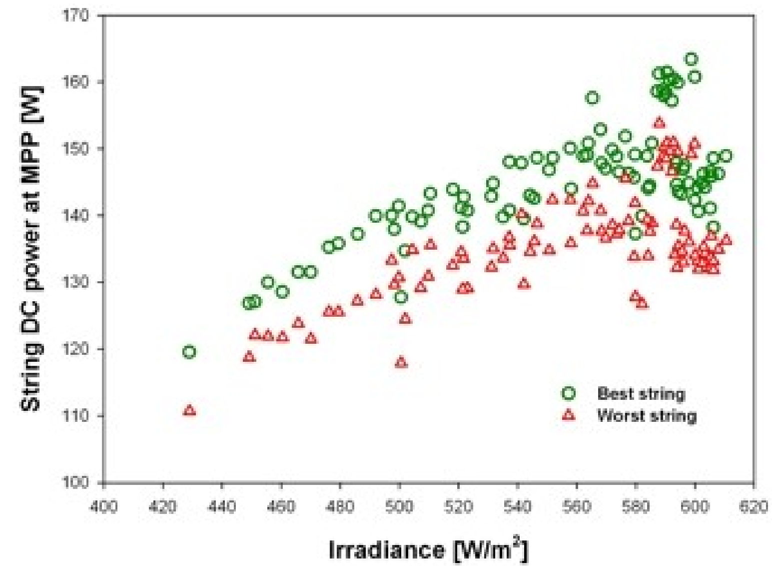
The original case study assumed **25 years.**

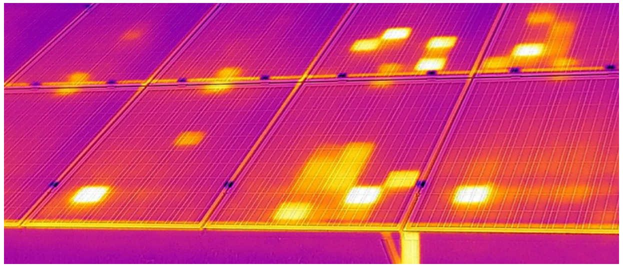
1. European Association PV CYCLE (PV CYCLE – Operational Status Report – Europe calculated about 10,000 Tons of failed and wasted modules by 2014.
   This could correspond to some 80 MW the ooverall installed capacity in 1997 in Europe. Calculated by Ferroni & Hopkirk in . Energy Return on Energy Invested (ERoEI) for Photovoltaic Solar Systems in Regions of Moderate Insolation
2. From Quality Monitor 2013 of TUV Rheinland.http://www.tuv.com/media/01_presse_2/all_languages_pressemeldungen/Handout_Media_TUeV_Rheinland_Quality_Monitor_Solar_2013.pdf

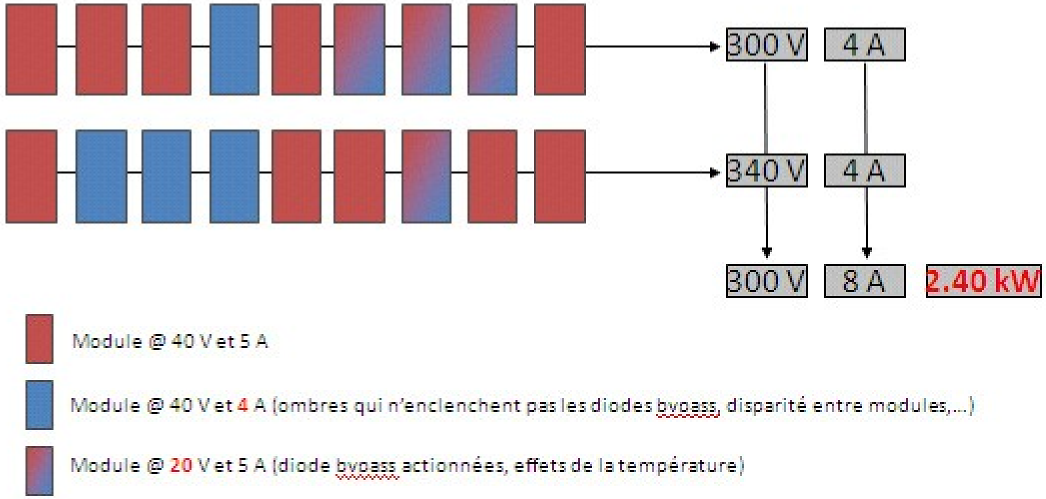
# The Energy Return (Er)

## Losses by Mismatch of Modules

Assumed in the Case Study
to be 0.6%






Sources: University of Southampton. Sustainable Energy Research Group.
http://www.ehw-research.com/en/smart-power-booster/production-optimization

# The Energy Return (Er)

aeren
spain

## Losses by Dust

Estimated 1% in the Case Study

(Some manufacturers consider potential losses as much as 4-12% average. In severe conditions, as much as 25%)

Some 20% calculated in the Mohammedia University premises

Conservative

Source: Atersa. Mantenimiento de plantas eléctricas. http://www.atersa.com/img/201379183726.pdf
Mohammedia University. Casablanca. Morocco.

# The Energy Return (Er)

## Angular Losses

The Case Study
Estimated 1%

Likely Conservative

Sources: Solar Farm Les Mees Plateau, France
Photo of the IEA Methodology Guidelines of LCA Photovoltaic Electricity
Renewables 2016. Global Status Report

# The Energy Return (Er)

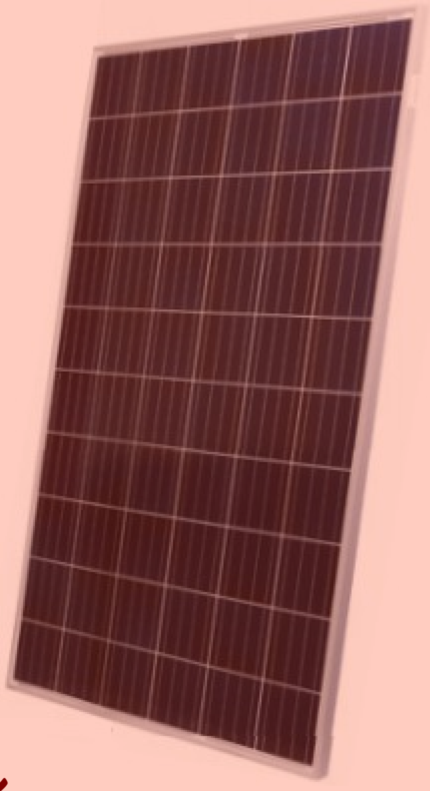
## Non-fulfillment of power

The Case Study considered no losses (0%)

Initial tolerances used to be +/-5%.
Now they tend to be 0/+5 W but…

They offer the power based on
850 $w/m^2$ irradiance

- Air Mass =0.5 and
- temperature at 20ºC



Conservative

# The Energy Return (Er)

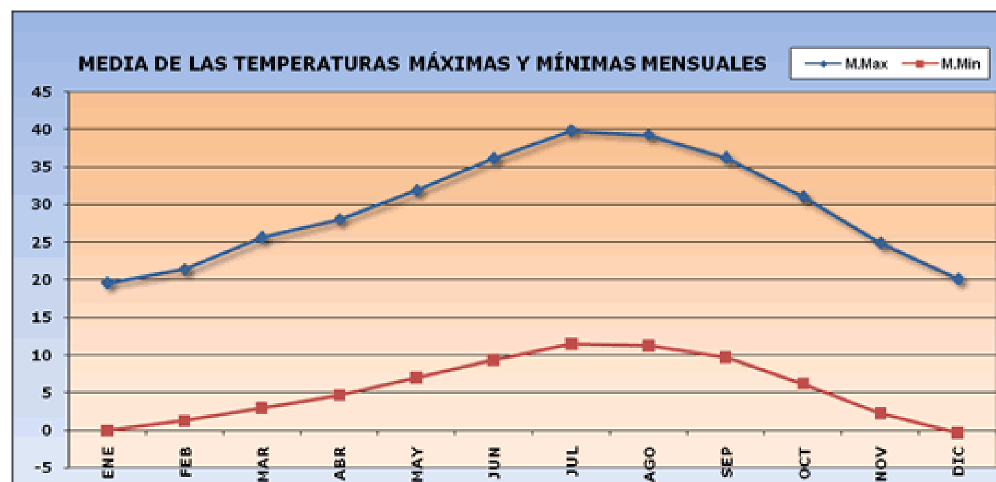
## Losses due to temperature

The Case Study considers 5.6% losses

**Temperature Characteristics**

| | |
|---|---|
| Nominal Operating Cell Temperature (**NOCT**) | 45±2°C |
| Temperature Coefficient of Pmax | -0.41 %/°C |
| Temperature Coefficient of Voc | -0.33 %/°C |
| Temperature Coefficient of Isc | 0.067 %/°C |

**At 40ºC 8.2% losses**




Sources: Suntech. http://shangde.fanyacdn.com/imglibs/files/stp265_wem(mc4_265_260_255).pdf
Instituto Meteorológico Nacional. España

# The Energy Return (Er)

aeren spain

## Losses for shadowing

The Case Study considered no losses (0%)

Conservative


Source: Euan Mearns. Energy Matters. http://euanmearns.com/rooftop-pv-panels-point-where-the-roof-points/ And own ellaboration

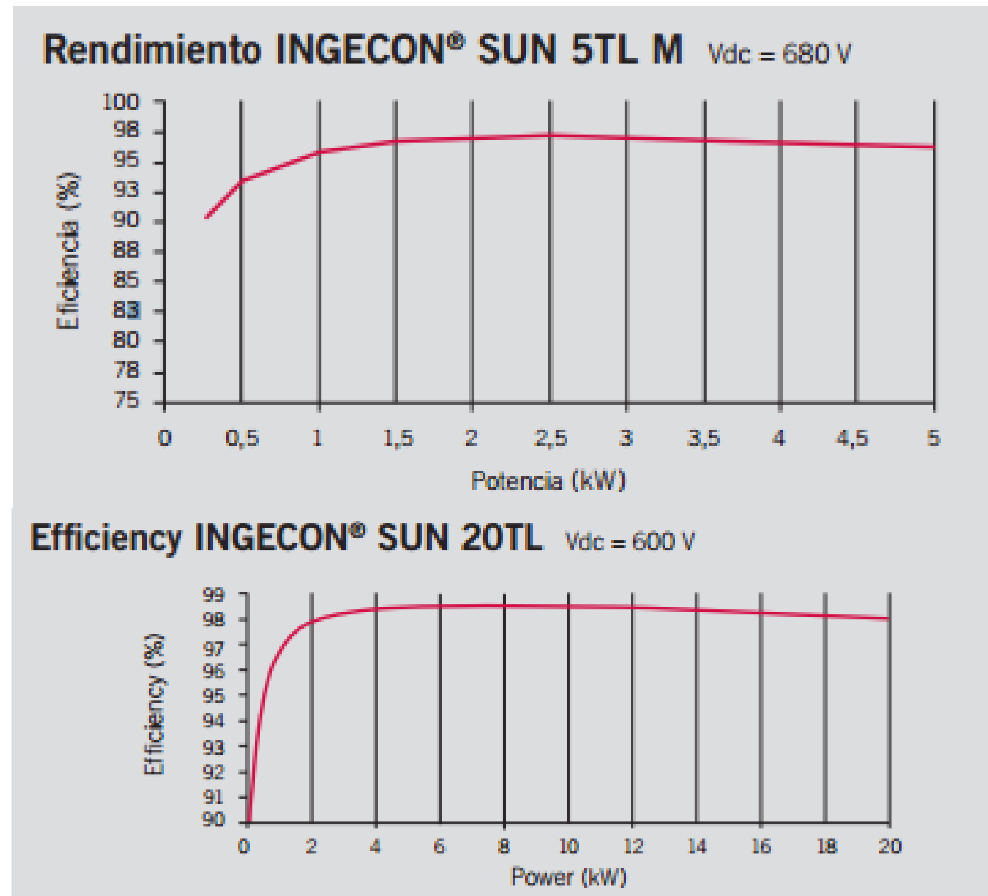
# The Energy Return (Er)

## Losses in the inverters

The Case Study considered 5.4% losses.

Present first class inverters have improved to offer euroefficiencies from 97 to 98%..

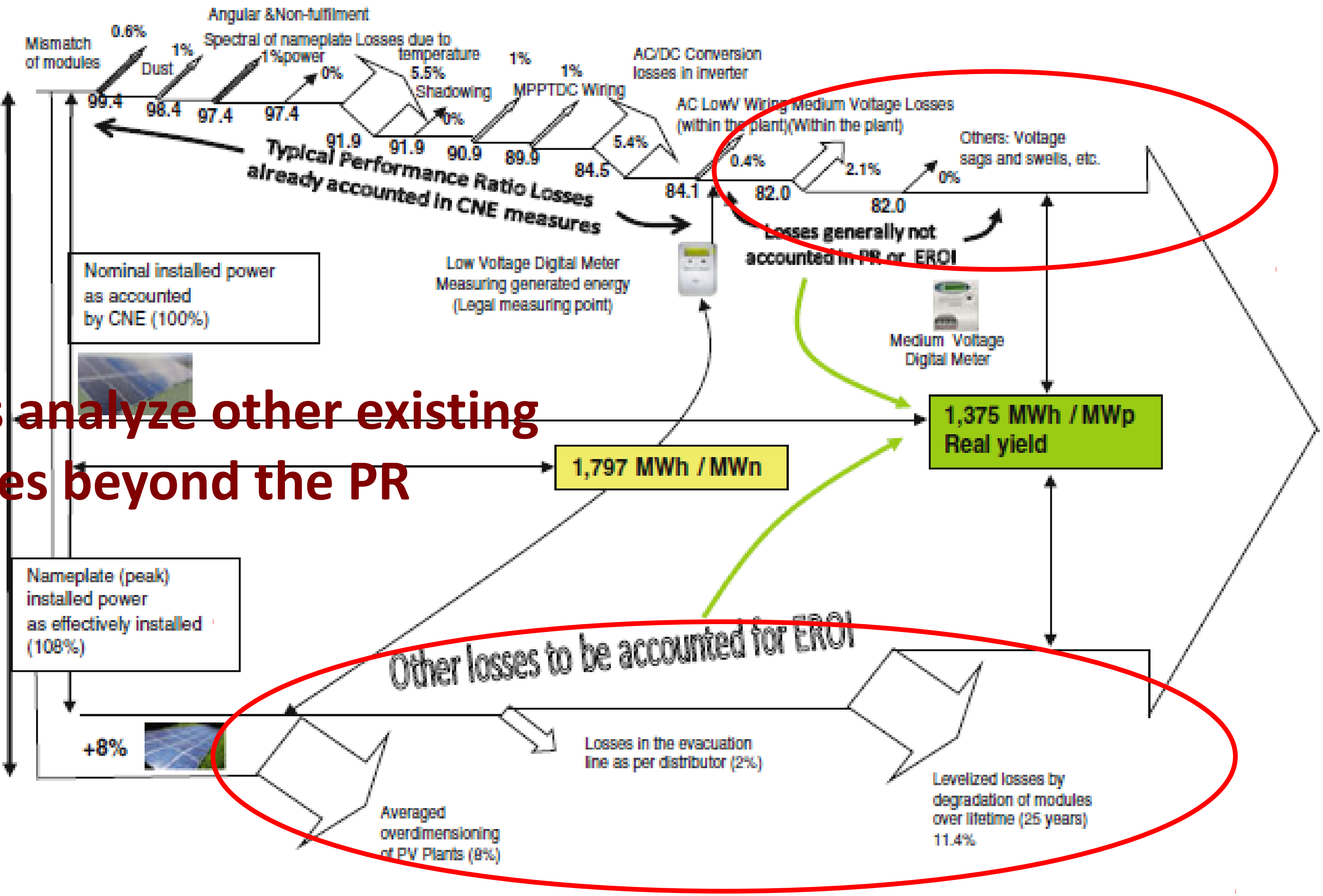
But specs indicate that for each ºC of increase, (over 20ºC) the output power will be reduced at the rate of 1.8%




Some inverter cabins support 50-55ºC in summer

Source: Ingeteam inverters

# The Energy Return (Er)



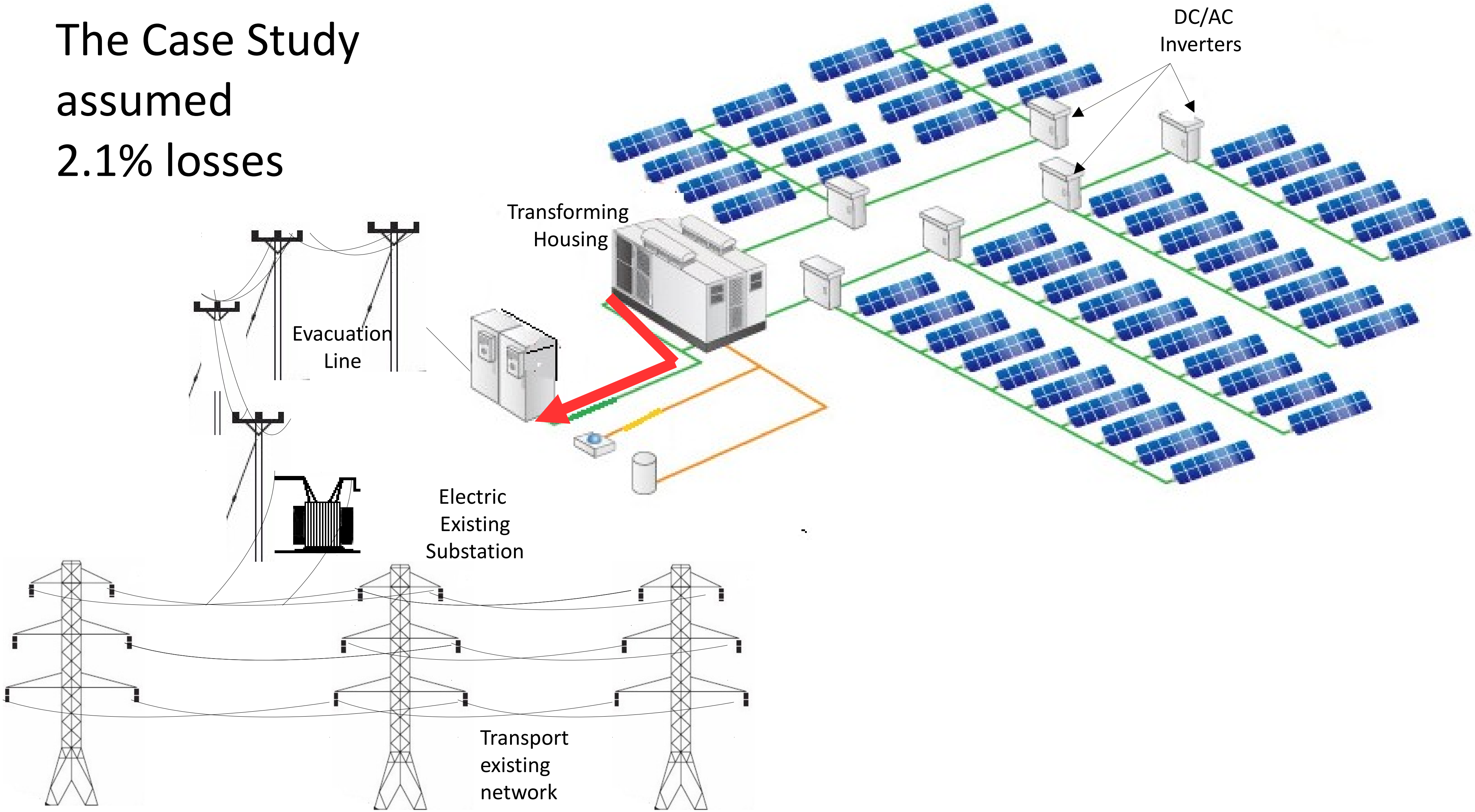

**Let's analyze other existing Losses beyond the PR**

Sankey diagram of solar PV energy in Spain

# The Energy Return (Er)

## Losses in Medium Voltage line within the plant

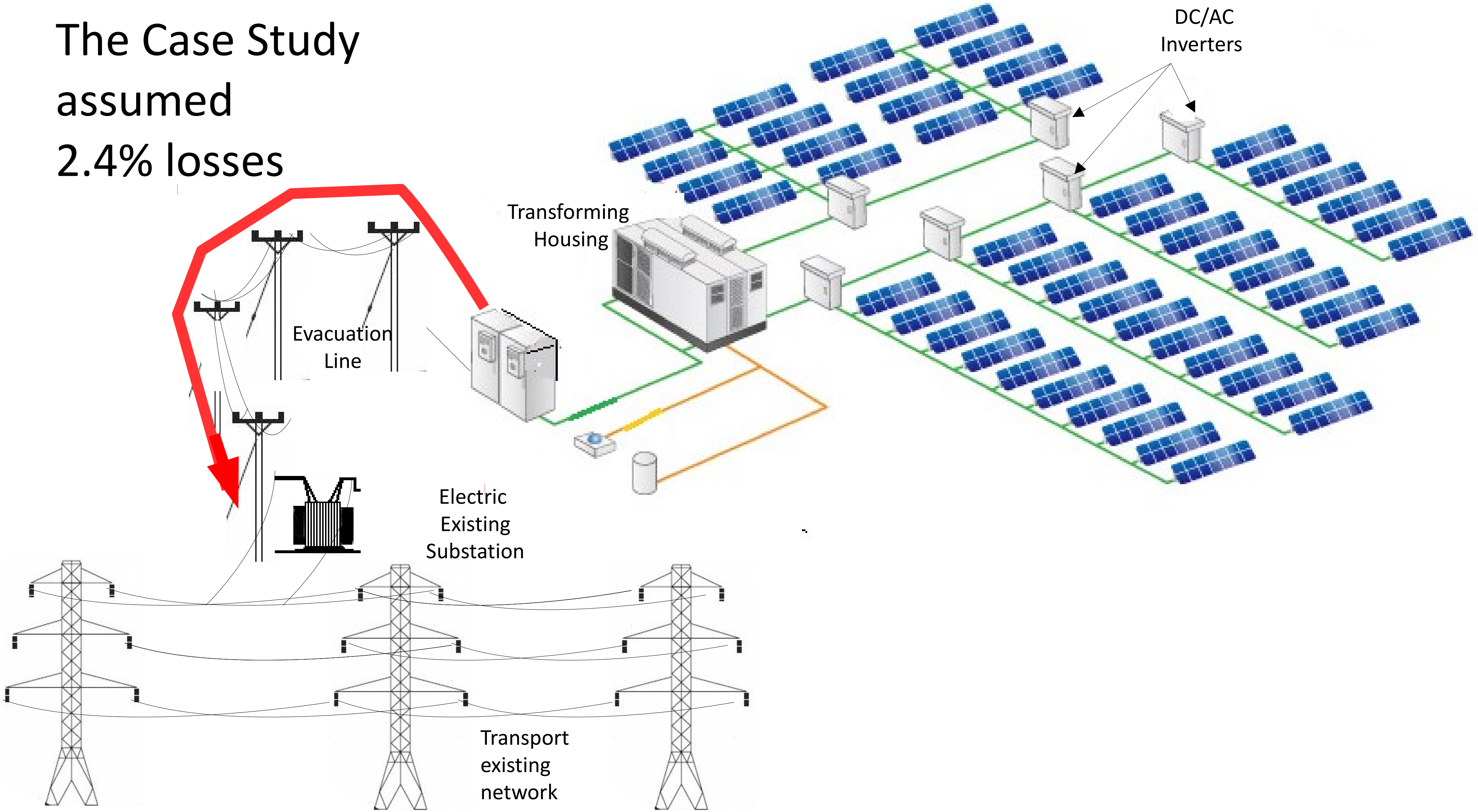
The Case Study
assumed
2.1% losses



# The Energy Return (Er)

## Losses in the Evacuation Line

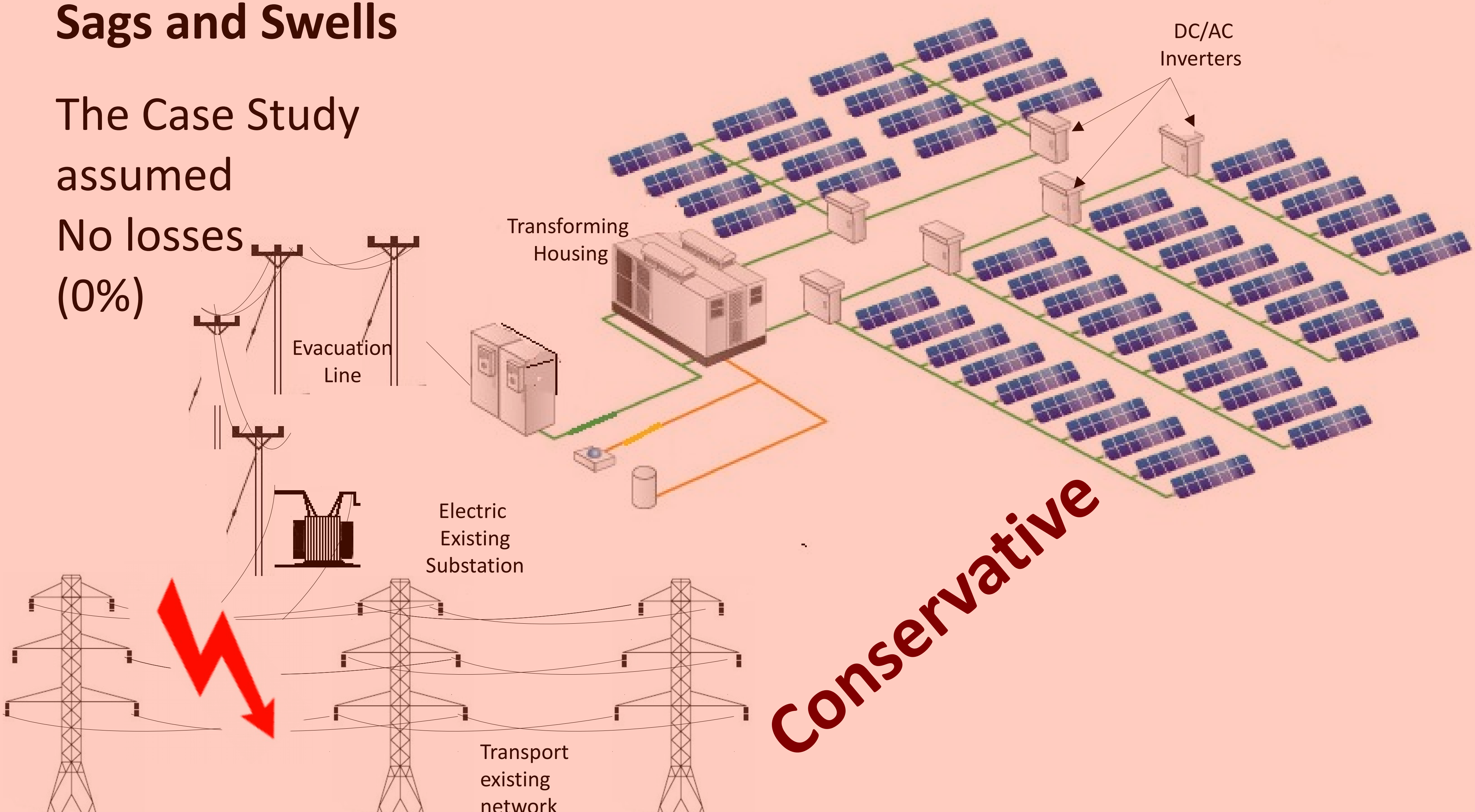
The Case Study
assumed
2.4% losses



# The Energy Return (Er)

## Losses due to Voltage and Frequency Sags and Swells

The Case Study assumed No losses (0%)



# The Energy Return (Er)

aeren spain

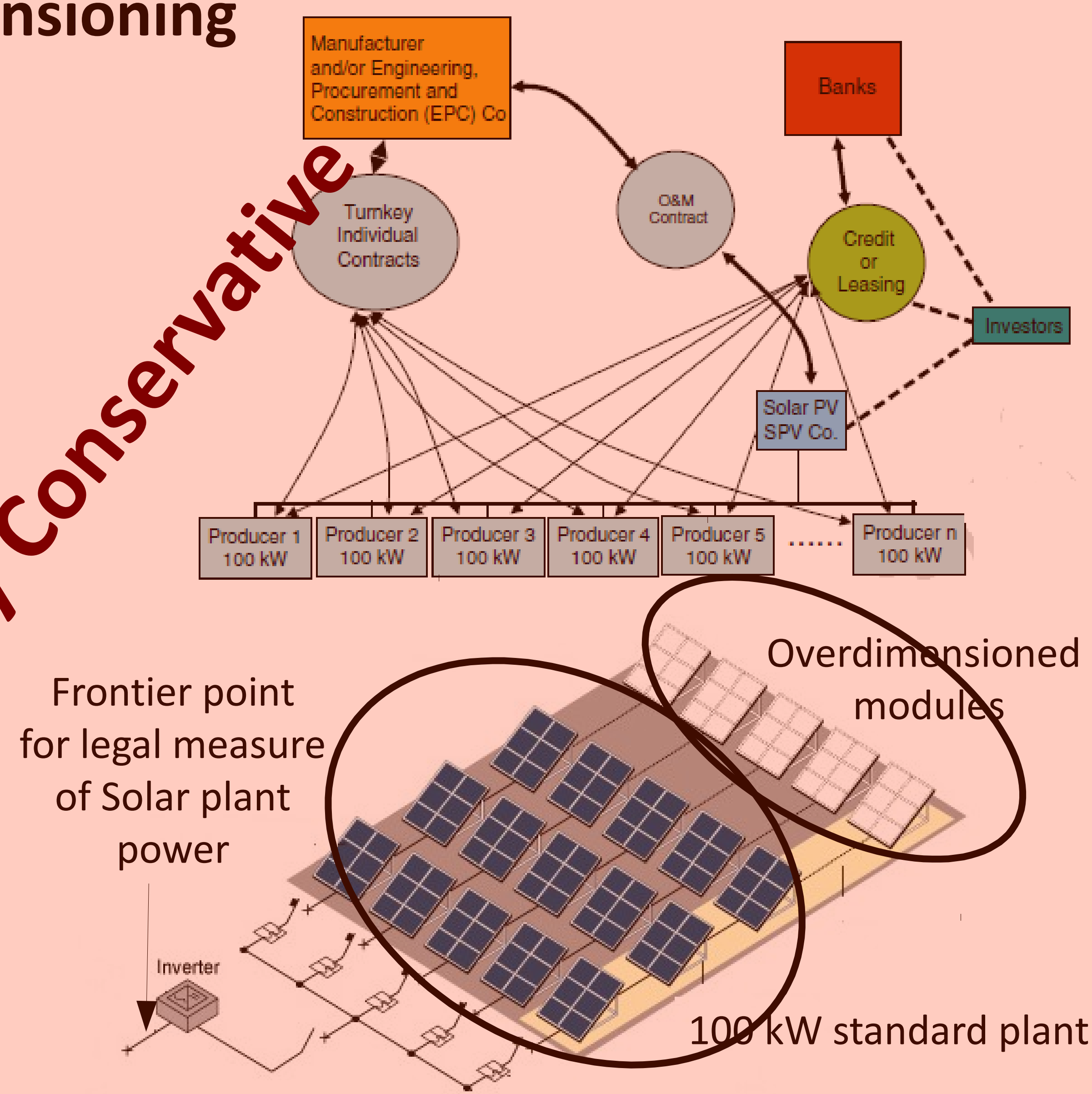
## Losses due to Overdimensioning

For the plant owner it was initially legal to overdimension, provided no more than 100 kW output will exceed at the inverter output.

The Case Study assessed an 8% overdimensioning I.e. 100 kWn = 108 kWp

The industry admitted later up to 20% overdimensioning In national average

**Very Conservative**

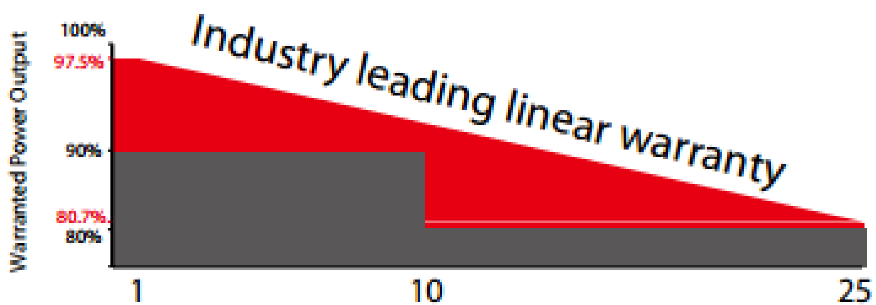


# The Energy Return (Er)

## Losses due to Degradation of Modules Over Time

The Study Case assumed 11.4% along 25 years cycle

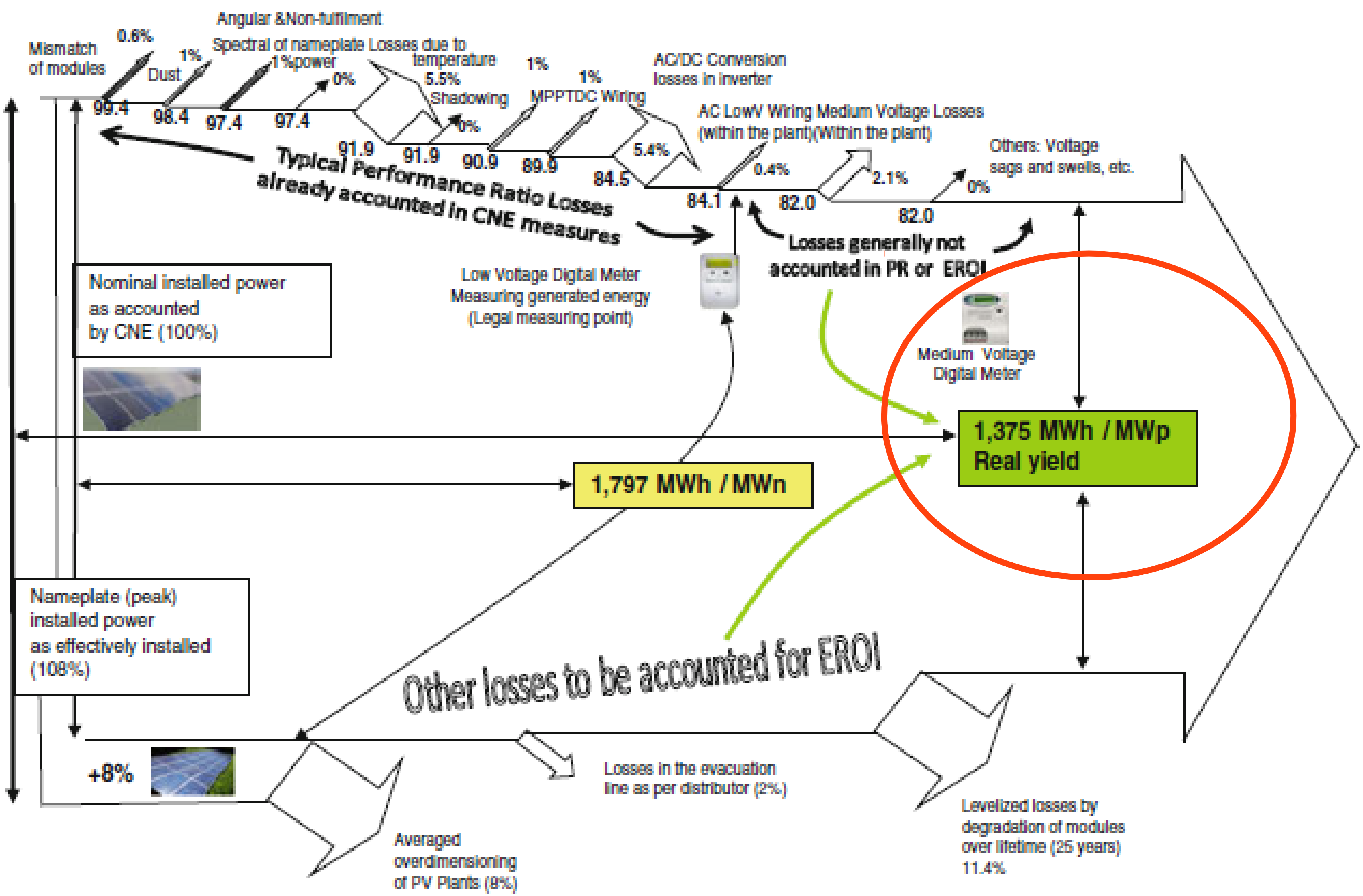
**Industry-leading Warranty based on nominal power**




- 97.5% in the first year, thereafter, for years two (2) through twenty-five (25), 0.7% maximum decrease from MODULE's nominal power output per year, ending with the 80.7% in the 25th year after the defined WARRANTY STARTING DATE.****
- 12-year product warranty
- 25-year linear performance warranty

Source: Suntech.
http://shangde.fanyacdn.com/imglibs/files/stp265_wem(mc4_265_260_255).pdf

# The Energy Return (Er)



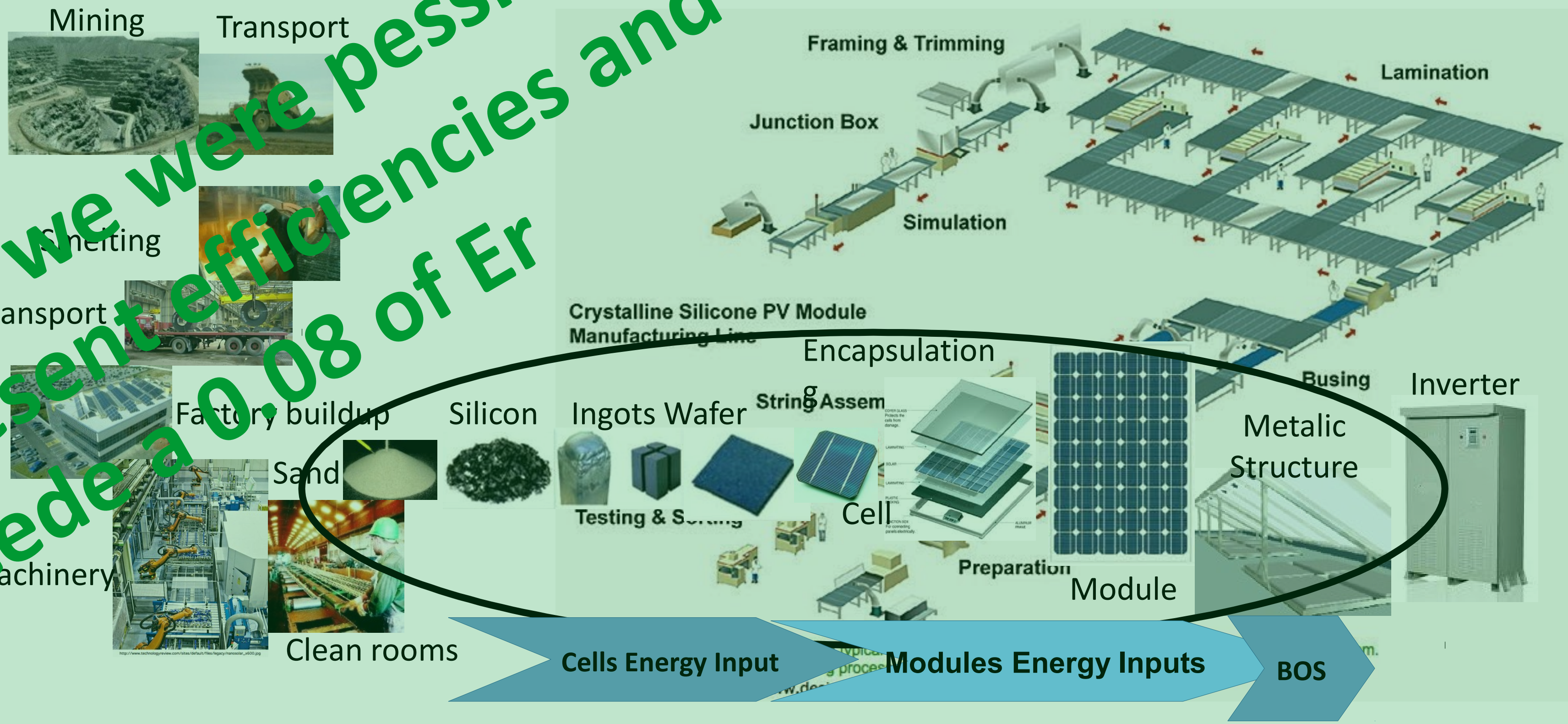

Sankey diagram of solar PV energy in Spain

# The Energy Invested (Ei) *Factor $a_7$*

aeren
spain

## Energy spent on wafers, cells, modules...the Conventional EROI

**Assume we were pessimistic on present efficiencies and concede a 0.08 of Er**




The Case Study accepted for this a sensible average of most Conventional solar PV resulting EROIs to date in **0.12% of Er**

# The Energy Invested (Ei) *Factor $a_1$*

aeren spain

**Energy spent on Accesses, Foundations, Canalizations, Perimeter fences, Land Levelling, etc.**




The Case Study calculated as 1.1% of **Er** on **energy** basis

# The Energy Invested (Ei) *Factor* $a_2$

## Energy spent on Evacuation Lines and Rights of Way

- Permits ('Permisology')
- Underground laying
- Protected places (LIC/ZEPA)
- Right of ways contracts
- Water streams crossing conditions
- Remote controlled switch-off by the electric power utility (OCR)
- Electric substations permits
- Power lines conditions


The Case Study calculated as 0.1% of **Er** on **money to energy** equivalent

# The Energy Invested (Ei) *Factor $a_3$*

**Energy spent on O&M**
**Operation & Maintenance**

## Pessimistic.
## Corrected to
## 5% of Er

The Case Study calculated as 7.7% of **Er** on **money to energy** equivalent

# The Energy Invested (Ei) *Factor $a_4$*

aeren
spain

## Energy spent on washing and cleaning

The Case Study calculated as 0.2% of **Er** on **energy** basis

**Pessimistic. Corrected to 0.1% of Er**

# The Energy Invested (Ei) *Factor $a_5$*

## Energy spent on Self-consumption

The Case Study calculated as 0.5% of **Er** on **energy** basis

**Pessimistic. Corrected to 0.3% of Err**

# The Energy Invested (Ei) *Factor $a_6$*

aeren spain

## Energy spent on Security and Surveillance

The Case Study calculated as 2.4% of **Er** on **money and labor to energy** equivalent

**Pessimistic Corrected to 0.6% of Er**

# The Energy Invested (Ei) *Factor* $a_8$

aeren spain

## Energy spent on Transportation

For Equipment.
For Engineering and R&D&i
For Commercial and Marketing
For O&M

The Case Study
calculated as 1.9% of **Er**
on **energy** basis

# The Energy Invested (Ei) *Factor $a_9$*

aeren spain

## Energy spent on Premature Phase Out of Unamortized Manufacturing Equipment

The Case Study calculated as 2.8% of **Er** on **money to energy** equivalent

**Conservative Reformulated at 3%**

# The Energy Invested (Ei) *Factor $a_{11}$*

## Energy spent on Insurances


Insurances usually cover fire, Acts of God, Theft, Vandalism, Civil Responsibility, workers, etc.

There are frequent clashes between insurance companies and owners and promoters on how to determine the responsibility of a given claim.

The Case Study calculated as 0.5% of **Er** on **money to energy** equivalent

# The Energy Invested (Ei) *Factor $a_{12}$*

## Energy spent on Fairs, Exhibitions, Promotions, Conferences, etc.

A common approach for marketing and commercial expenses of the manufacturing sector is that they run on about 10-12% of the overall costs.

**Pessimistic. Reduced to 0.3% of Er**

The Case Study calculated as 0.5% of **Er** on **money to energy** equivalent


# The Energy Invested (Ei) *Factor* $a_{13}$

aeren
spain

## Energy spent on Administration Expenses

Take care of presenting balance sheets, P&L Statements, VAT declarations, bank accounts follow-up and other administrative expenses, etc.

The Case Study calculated as 0.7% of **Er** on **money to energy** equivalent

**Slightly conservative. Corrected to 0.8% of Er**

# The Energy Invested (Ei) *Factor $a_{14}$*

## Energy spent on Municipality, Autonomous, and State Taxes, Levies and Duties on Production, etc.

Most of the solar PV plants have paid as much as **4% of total project cost**.

Besides, a state tax on electricity production takes 7% of all income

The Case Study calculated as 0.3% of **Er** on **money to energy** equivalent


**Conservative. Corrected to 0.4% of Er**

# The Energy Invested (Ei) *Factor $a_{15}$*

aeren spain

## Energy spent on long-term rents or Ownership

From 17,000 €/ha in ownership
and 1,000 €/Ha/year in renting

Some lands sharply increased
in value, specially when demand
raised and for locations close to
a substation with idle capacity.

Talent spotters and
intermediaries
grew like mushrooms.


The Case Study
calculated as 0.2%
of **Er** on **money to
energy** equivalent

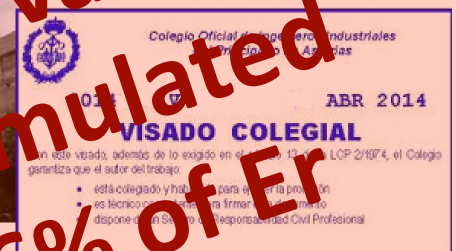
# The Energy Invested (Ei) *Factor $a_{16}$*

aeren
spain

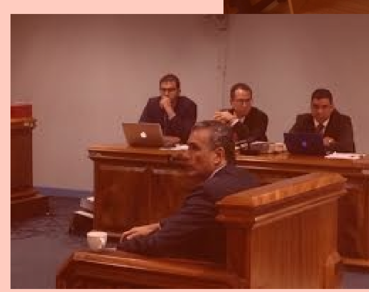
## Energy spent on Services of Indirect Labor (Direct excluded)

- Consultants
- Notary Public
- Public Register
- Civil Servants/Public Officers
- Engineering Colleges
- Legal Firms

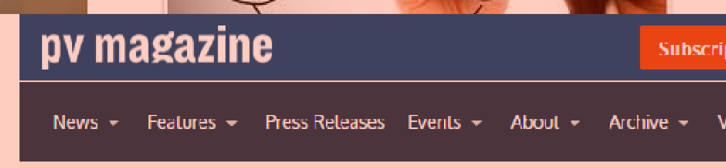
**Conservative.**
**Reformulated to 0.6% of Er**







The Case Study calculated as 0.4% of **Er** on **money to energy** equivalent




**Spain loses its first renewable energy case in international courts**

Spain must pay €128 million for cuts to compensation for concentrating solar power (CSP) plants as ordered by the World Bank's ICSID, where many other cases for investors in solar PV and other renewable energy projects are pending.

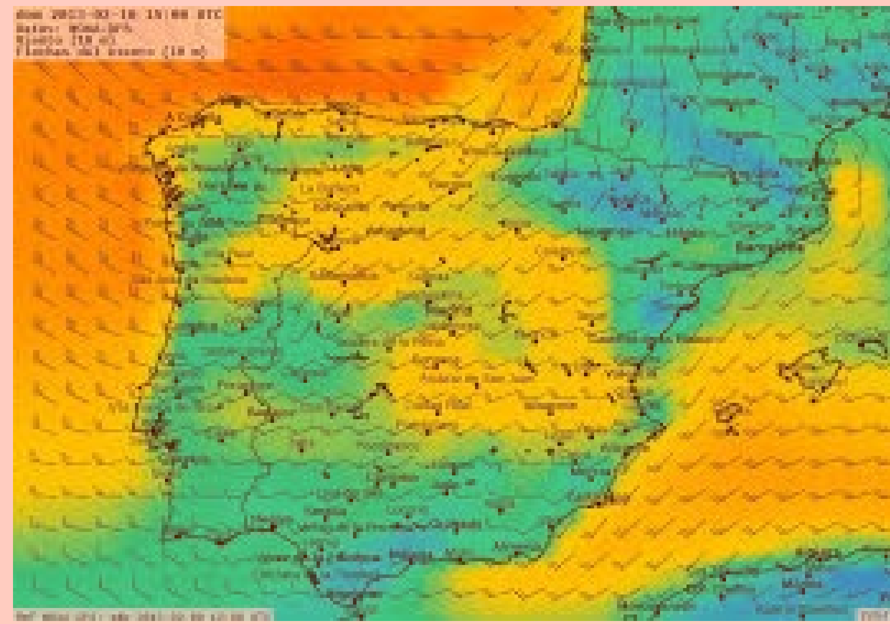
MAY 5, 2017 BLANCA DÍAZ LÓPEZ

# The Energy Invested (Ei) *Factor $a_{17}$*

## Energy spent on the Agent Representative

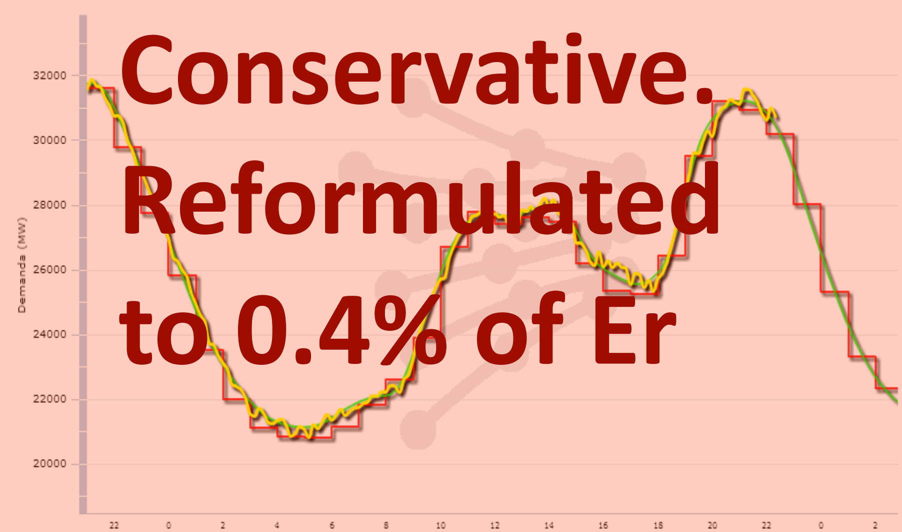
A legal obligation to contract. It sells electricity to the market

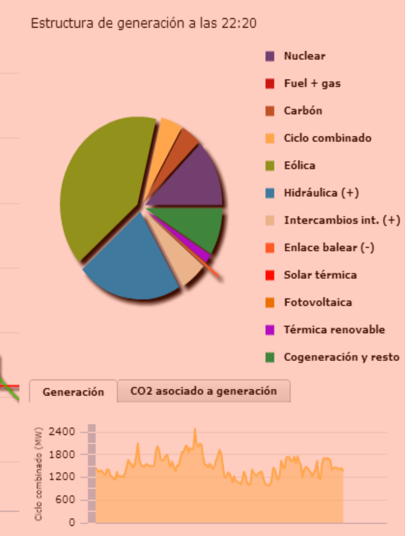
It assumes responsibility and penalties on behalf of energy generators for generation deviations +/-5% on daily basis (one day in advance) and also on hourly basis (one hour in advance)



The Case Study calculated as 0.1% of **Er** on **energy** deducted basis

**Conservative. Reformulated to 0.4% of Er**



# The Energy Invested (Ei) *Factor* $a_{18}$

## Energy spent on Stealing and Vandalism



The Case Study calculated as 0.2% of **Er** on **money to energy** equivalent

# The Energy Invested (Ei) *Factor* $a_{19}$

## Energy spent on Communications, Remote Control and Management

**Pessimistic Reformulated To 0.1% of Er**


The Case Study calculated as 0.33% of **Er** on **money to energy** equivalent

# The Energy Invested (Ei) *Factor $a_{20}$*

## Energy spent on Pre-inscription, inscriptions, Registration Bonds and Fees

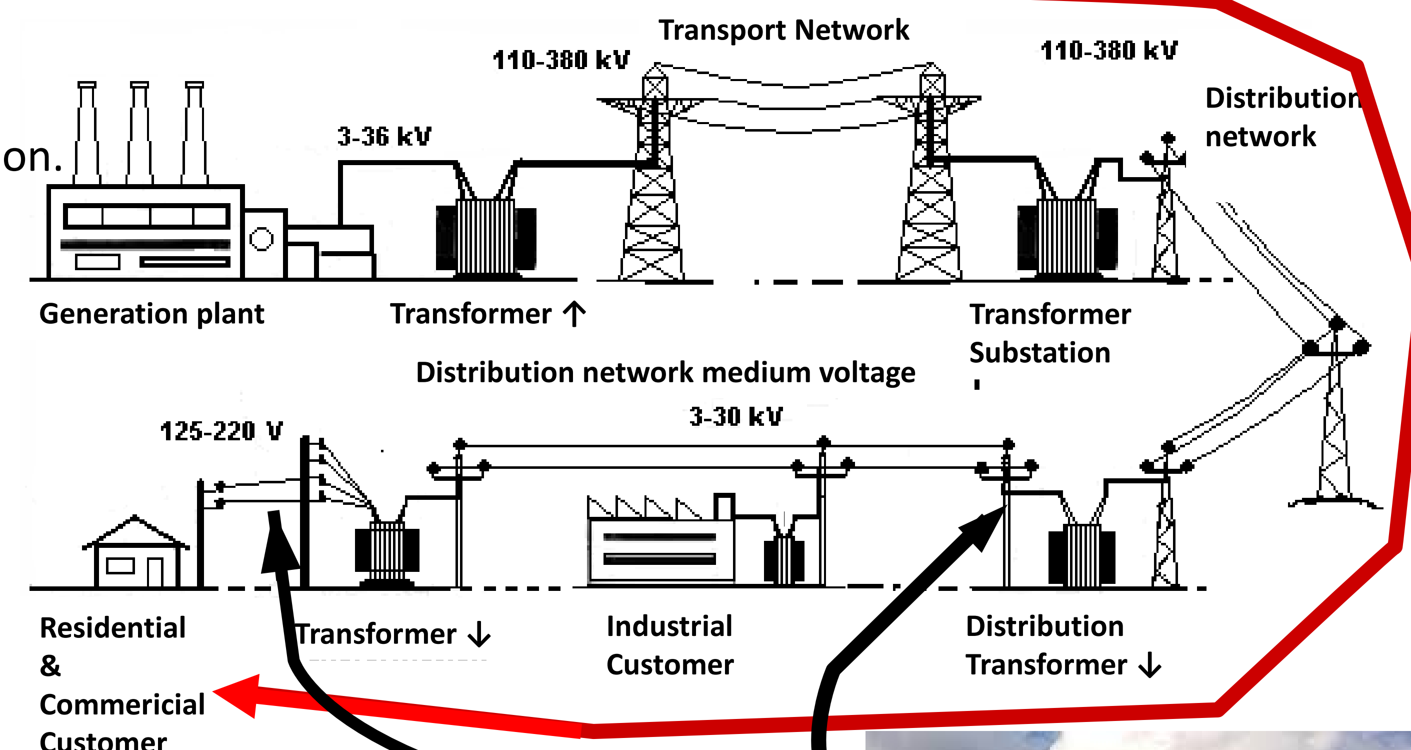
- Costs of about 1,250 M€ bonds for preinscription and inscription for 6 months about 8 million euros in 2009
- Cost of feasibility study to be carried out by the utility were about 8 million euros in 2009

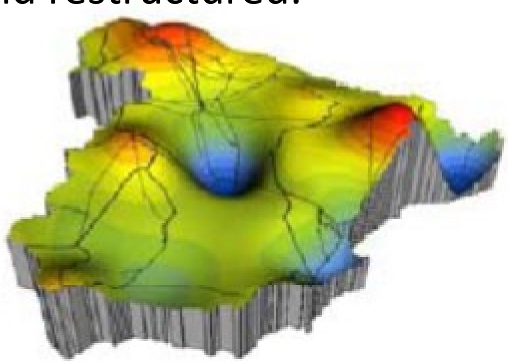

- **Neglected both amounts in the Case Study (0%)**

# The Energy Invested (Ei) *Factor $a_{21}$*

## Energy spent on Electrical Network, Power Lines Restructuring

Networks are already deployed for a given top-down, usually unidirectional general distribution. The injection of loads in bottom-up form, need the network to be readjusted and restructured.



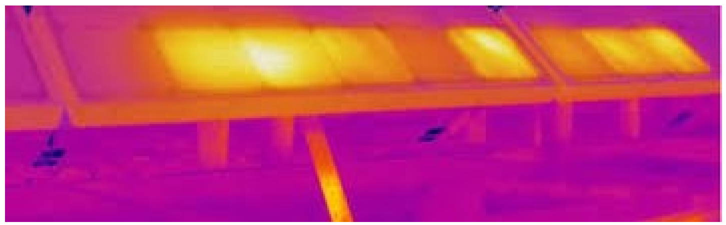



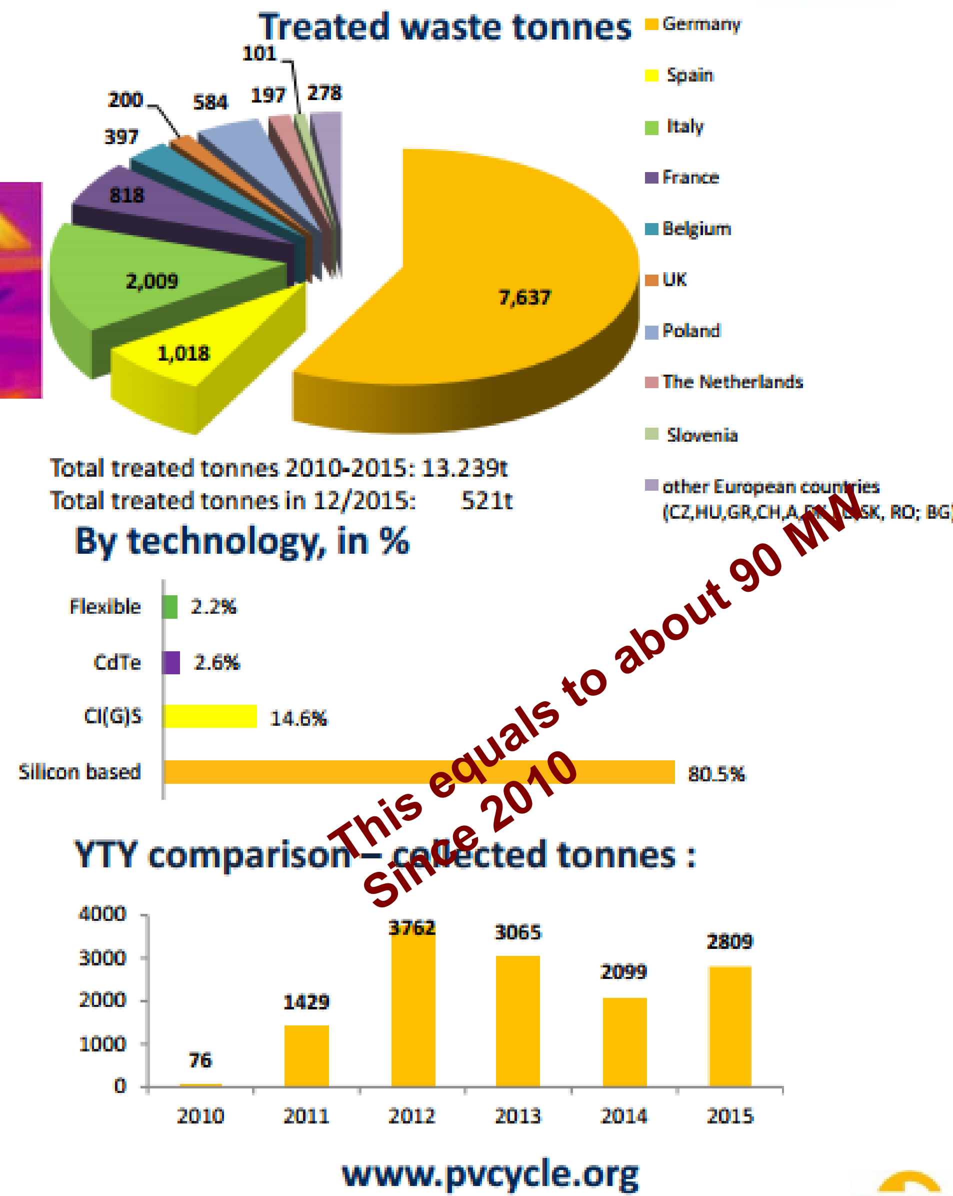
The Case Study calculated as 3.5% of **Er** on **money to energy** equivalent

# The Energy Invested (Ei) *Factor $a_{22}$*

aeren spain

## Energy spent on Faulty Modules, Inverters, Trackers

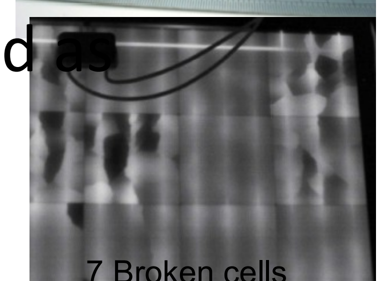





This equals to about 90 MW since 2010

- In 2014 some 40 MW were installed and about 40 MW were decommissioned in Spain.
- Germany has similar or worst figures (30% serious deficiencies and 70% minor defects)






The Case Study calculated as 0.8% of **Er** on **energy to energy** equivalent

PV CYCLE

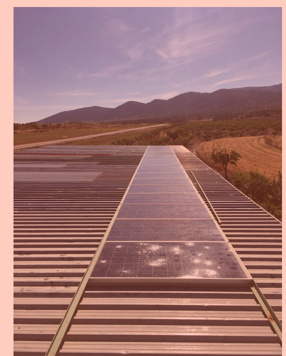
# The Energy Invested (Ei) *Factor $a_{24}$*

aeren spain

## Energy lost on Force Majeure, Acts of God, Windstorms, Lighting, Flodding, Hailstorms

Investment Funds are assuming that "only" 2-3% of the plants will not honor long term land rental contracts for these causes.

A 20 MW solar Plant in Beneixama (Alicante) had to replace 30,000 modules out of a total Of 90,000 due to a heavy hailstorm



The Case Study calculated no losses (0%) of Ei

**An Energy to energy equivalent**

**Conservative Reformulated to 0.1% of Er**

# Provisional Conclusions

aeren spain

| | | | INITIAL | REVISITED |
|---|---|---|---|---|
| E | | Performance Ratio (PR) | 0,84 | 0,75 |
| 47e | | | | |
| | ITEM | ENERGY INPUTS OR ENERGY SPENT ON | INITIAL | REVISITED |
| E | a7 | Wafers, cells, modules..the Conventional EROI | 0,12 | 0,08 |
| E | a1 | Accesses, Foundations, Canalizations, Perimeter Fences, Land Levelling | 0,011 | 0,011 |
| $/E | a2 | Evacuation Lines and Rights of Way | 0,010 | 0,010 |
| $/E | a3 | Operation and Maintenance | 0,077 | 0,050 |
| E | a4 | Washing and Cleaning | 0,002 | 0,001 |
| E | a5 | Self-Consumption of the Plant | 0,005 | 0,003 |
| $-L/E | a6 | Security and Surveillance | 0,024 | 0,006 |
| E | a8 | Transportation (various types) | 0,019 | 0,021 |
| $/E | a9 | Premature Phase Out of Unamortized Manufacturing Equipment | 0,028 | 0,030 |
| $/E | a11 | Insurances | 0,005 | 0,005 |
| $/E | a12 | Fairs, Exhibitions, Promotions, Conferences | 0,005 | 0,003 |
| $/E | a13 | Administration Expenses | 0,007 | 0,008 |
| $/E | a14 | Municipality, autonomous, State Taxes, Levies and Duties on Production, etc. | 0,003 | 0,004 |
| $/E | a15 | Long term rent or Ownership of Land | 0,002 | 0,002 |
| $/E | a16 | Services of Indirect Labor (direct excluded) | 0,004 | 0,006 |
| E/E | a17 | Agent Representative | 0,001 | 0,004 |
| $/E | a18 | Stealing and Vandalism | 0,002 | 0,002 |
| $/E | a19 | Communications, Remote Control and Mgmt | 0,003 | 0,001 |
| | a20 | Pre-inscriptions, inscriptions, bonds, fees | 0 | 0 |
| $/E | a21 | Electrical Network Power Lines Restructuring | 0,035 | 0,035 |
| E/E | a22 | Faulty Modules, Inverters, Trackers | 0,008 | 0,008 |
| E/E | a24 | Force Majeure, Acts of God, Windstorms, Lighting, Flodding, Hailstorms | 0 | 0,010 |
| | | | | |
| | | ENERGY SPENT FROM TOTAL ENERGY GENERATED | 0,371 | 0,300 |

**But...**

# The Energy Invested (Ei)

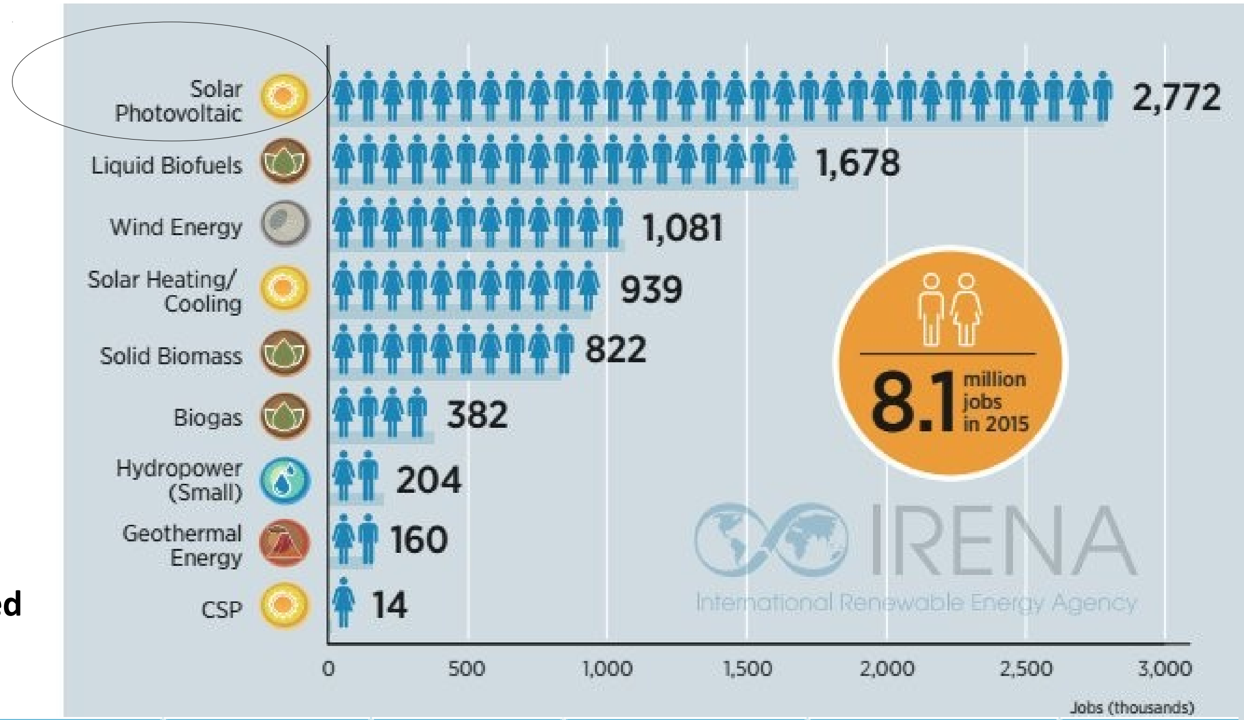
aeren spain

## Direct Labor. (Not included. Only Sensitivity Analysis)

- About 19 million occupied workers In 2008
- About 142 million Toe in 2008 of primary energy
- About 7.5 Toe per occupied worker
- About 90 MWh per occupied worker
- Assume 20,000 workers in the Solar PV sector y/y and 20,000 once in Lifetime of solar plants .
- 180 Gwh consumed for people in that solar PV sector
- They were able to produce/install and operate about 2,700 Mwp in 2008.
- Generating 3,712 Gwh

- **The sensitivity analysis of the Case Study resulted in a minimum of 5% of total ER (Eout)**

FIGURE 1: RENEWABLE ENERGY EMPLOYMENT BY TECHNOLOGY




| TECHNOLOGY | MCI (Jobs per newly installed MW) | O&M (Jobs per MW) | REGION | YEAR OF ESTIMATION | SOURCE |
|---|---|---|---|---|---|
| Solar PV | 17.9 | 0.30 | OECD countries (Average values) | Various (2007-2011) | Source 1 |
| | 69.1 | 0.73 | South Africa | 2007 | Source 2 |
| | 25.8 | 0.70 | South Africa | NA | Source 3 |
| | 20.0 | 0.2 | United States | 2011 | Source 4 |

Source: Irena. Renewable Energy and Jobs. http://www.irena.org/rejobs.pdf

# The Energy Invested (Ei)

aeren spain

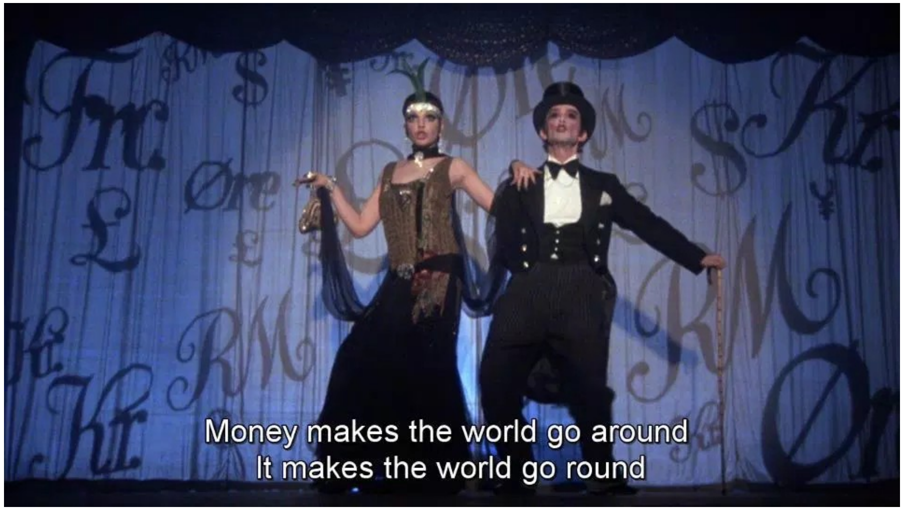
## Financial Direct Costs. (Not included. Only Sensitivity Analysis)

Virtually all solar PV plants were financed. The scheme of credits or leasings, basically as follows (Typical leasing):

A plant costs **100**
**20** out of pocket
**80** of leasing
**16 as interests in 10 years**

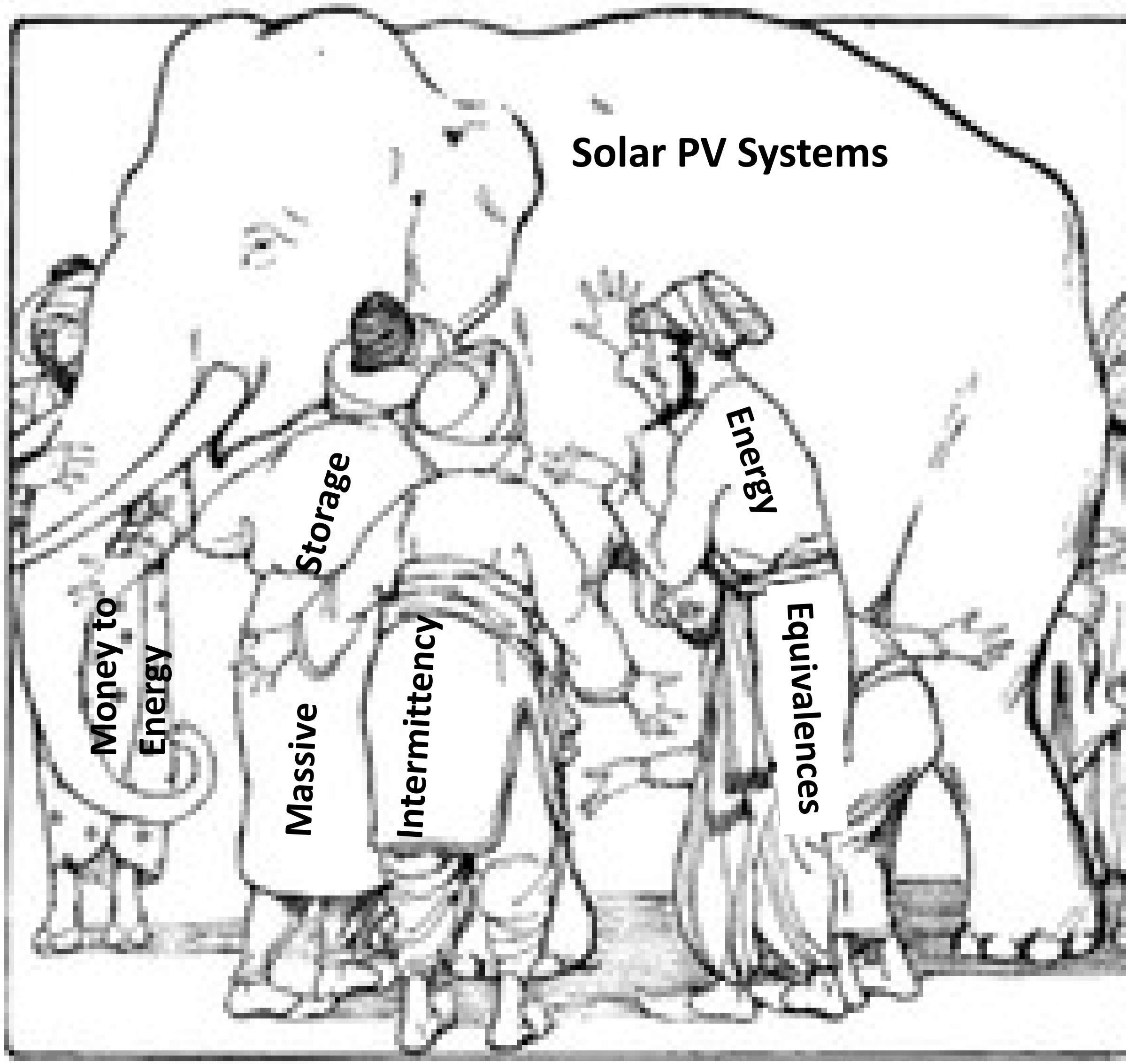
**For a contract signed in 2006**
**Interest: EURIBOR +.075%**
**3.67% interest**
**Opening Commission: 0.4%**
**10 years repayment.**
**1 year of grace**

If money is a proxy of energy, how much energy is the extra 16 (that could be sometimes as high as 100) from the initial 100 of interests?



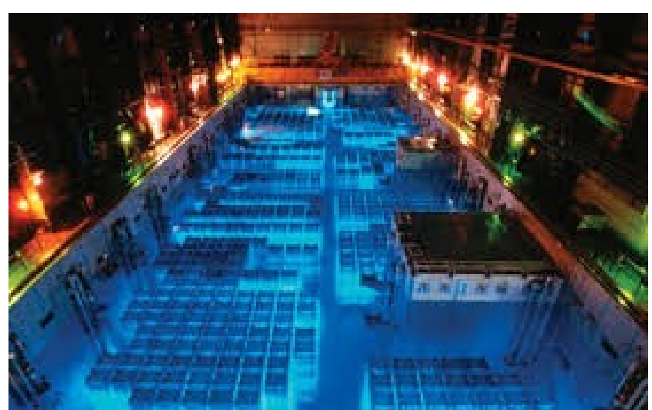
# The Parable of the Blind Men and the Elephant

aeren spain



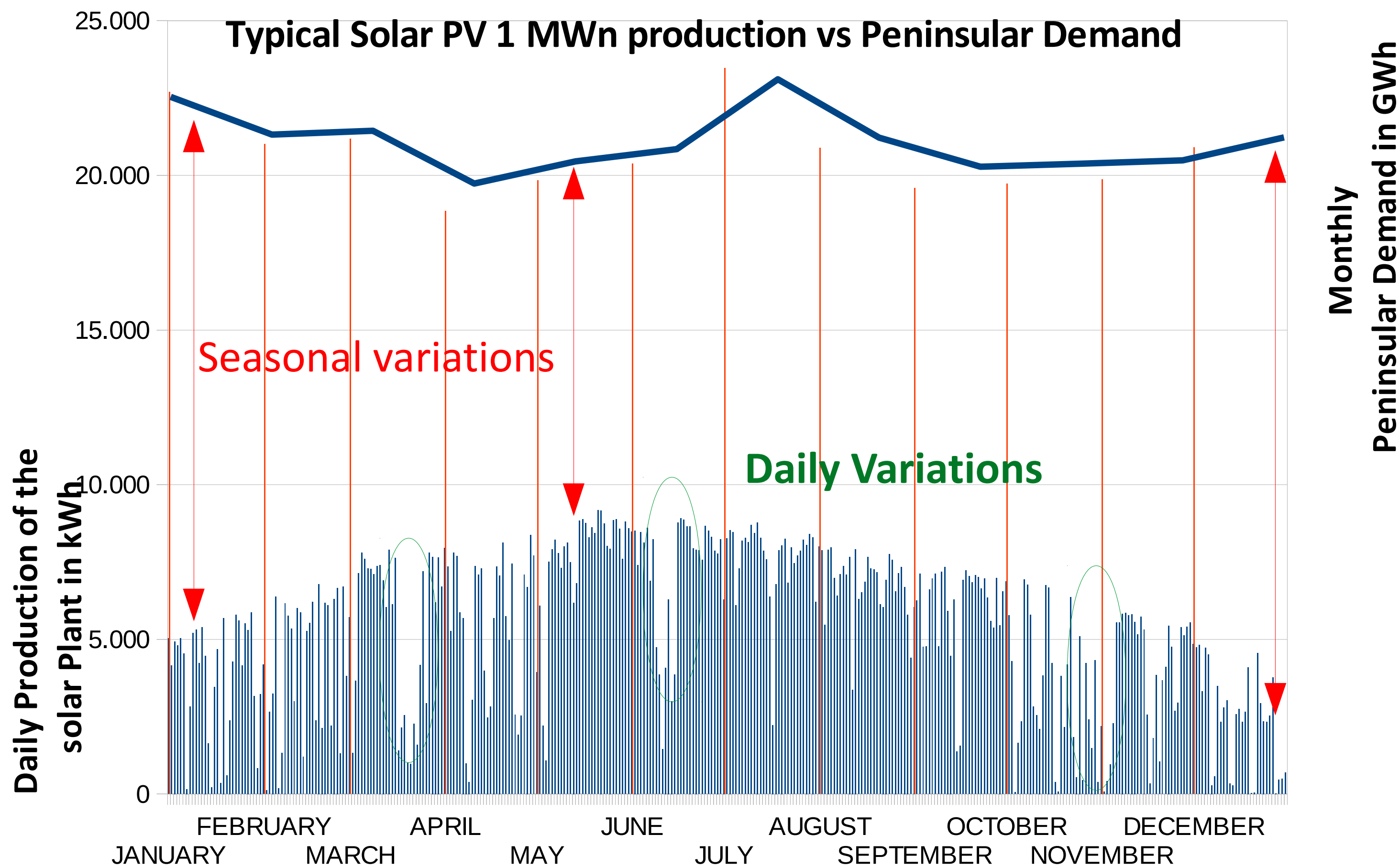
# The Energy Invested (Ei)

**How fossil, nuclear fuels and hydro avoid intermittencies and solve the massive storage needs….**



# The Energy Invested (Ei)

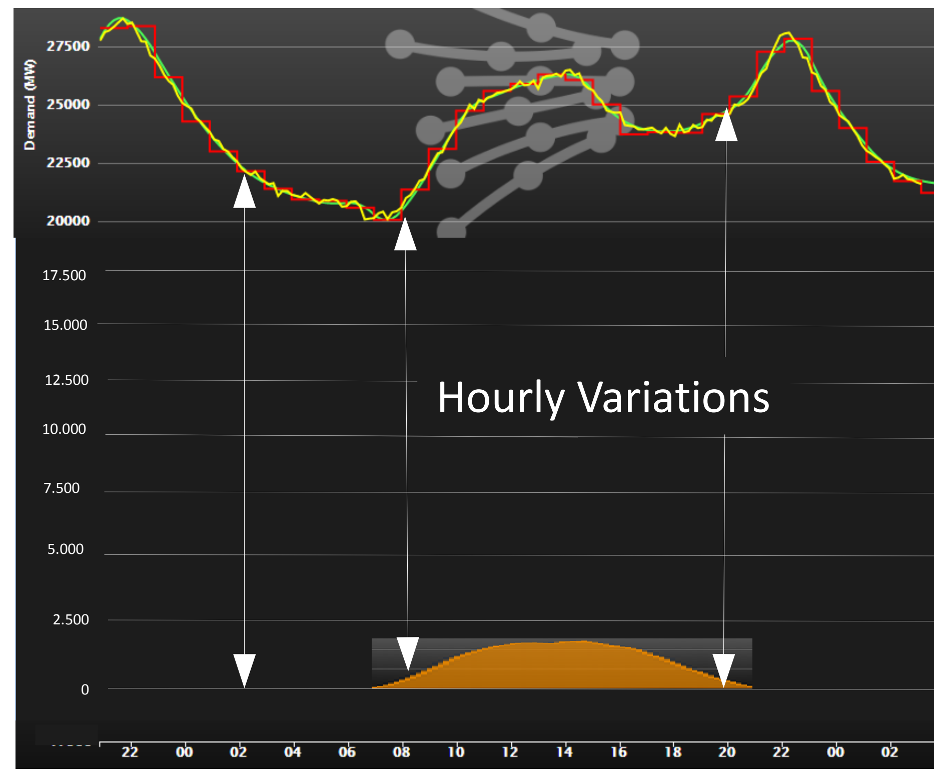
## The Solar PV intermittencies and the cost of solving them

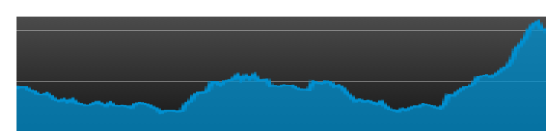



Source: Own elaboration from an operative 2 axis trackers plant in Mid-Spain and Red Electrica de España Peninsular Demand in 2016

# The Energy Invested (Ei)

## The Solar PV intermittencies and the cost of solving them



Source: Red Electrica de España Peninsular Demand  of May 28th. 2017 with solar PV contribution this day

# The Energy Invested (Ei) *Factor $a_{23}$*

aeren spain

## Associated Energy Costs to Injection of Intermittent Loads: Network Stabilization associated Costs (Combined Cycles)

Gas Fired plants designed to work 5,500 hours/year (**62.7% load factor**). In 2011 were working at 23.2%

Now the degradation went from 23% of total Capacity or Load Factor of 2011 to about 10-11% in 2015 and 2016

| Combined Cycle Gas Fired Power Plants. Spain | | | |
|---|---|---|---|
| Year | Installed Power (MW) | Generated Energy (Gwh) | Capacity Factor (%) |
| 2002 | 0 | 0 | |
| 2003 | 4.394 | 14.990 | 38,9 |
| 2004 | 8.285 | 28.974 | 39,9 |
| 2005 | 13.134 | 50.916 | 44,3 |
| 2006 | 16.376 | 66.986 | 46,7 |
| 2007 | 22.097 | 72.461 | 37,4 |
| 2008 | 23.054 | 96.005 | 47,5 |
| 2009 | 23.635 | 83.895 | 40,5 |
| 2010 | 26.844 | 68.828 | 29,3 |
| 2011 | 27.123 | 55.074 | 23,2 |
| 2012 | 27.144 | 42.873 | 18,0 |
| 2013 | 27.206 | 28.963 | 12,2 |
| 2014 | 27.206 | 25.869 | 10,9 |
| 2015 | 27.199 | 30.217 | 12,7 |
| 2016 | 26.670 | 29.787 | 12,7 |

The Case Study calculated as 3.9% of **Er** on **money to energy** equivalent

**Conservative. Reformulated to 4.7% of Er**

Source: Red Eléctrica de España. Www.ree.es Annual Reports 2002 through 2016 and own ellaboration

# The Energy Invested (Ei) *Factor $a_{10}$*

aeren spain

## Associated Energy Costs to Injection of Intermittent Loads:

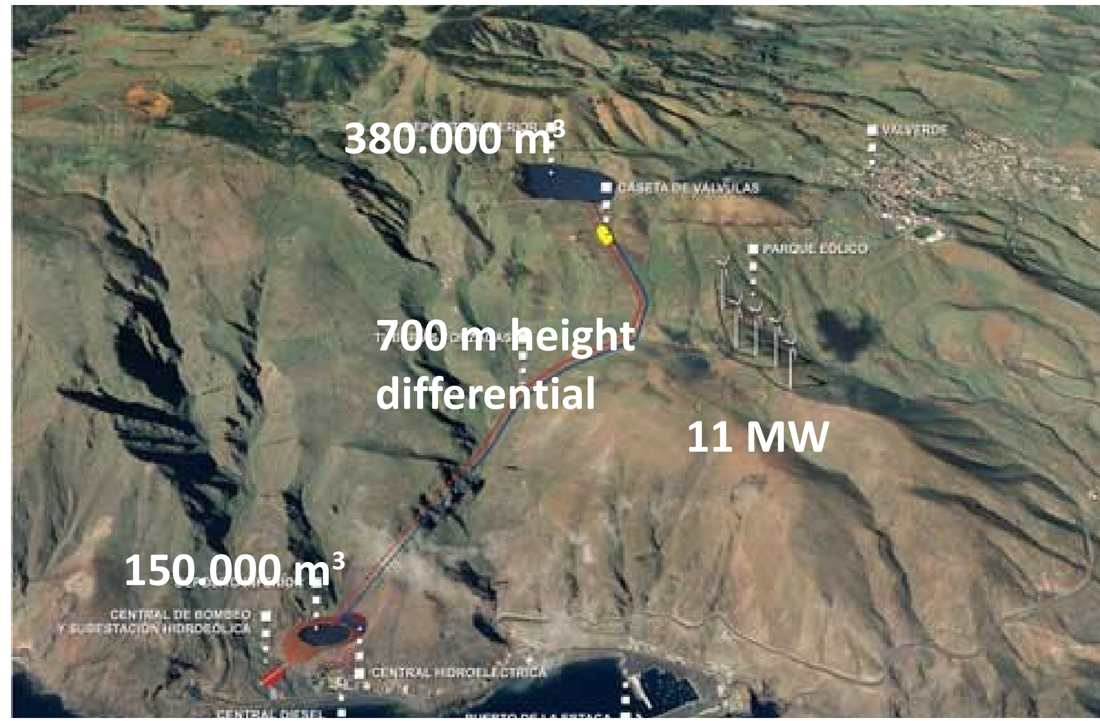
## Pump up Storage

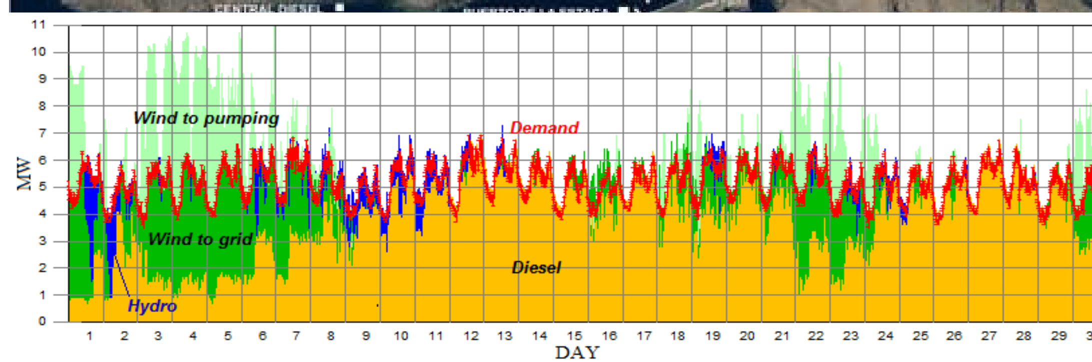
70-80% round trip efficiency
(30-20% losses)

38.1% averaged (2015-2017)
electricity generation
(max. 65%, min. 13%)

8.8.% averaged total energy
demand

10,000 Euros cost per
Inhabitant. 152-198 $/MWh




The Case Study did not include
any energy expense

**(but it may represent the go-no go
For a 100% renewables case)**

Sources: Gorona del Viento. Cabildo de EL Hierro island. Canarias. and Euan Mearns at http://euanmearns.com/el-hierro-april-2017-performance-update/ and https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf

# The Energy Invested (Ei) *Factor $a_{10}$*

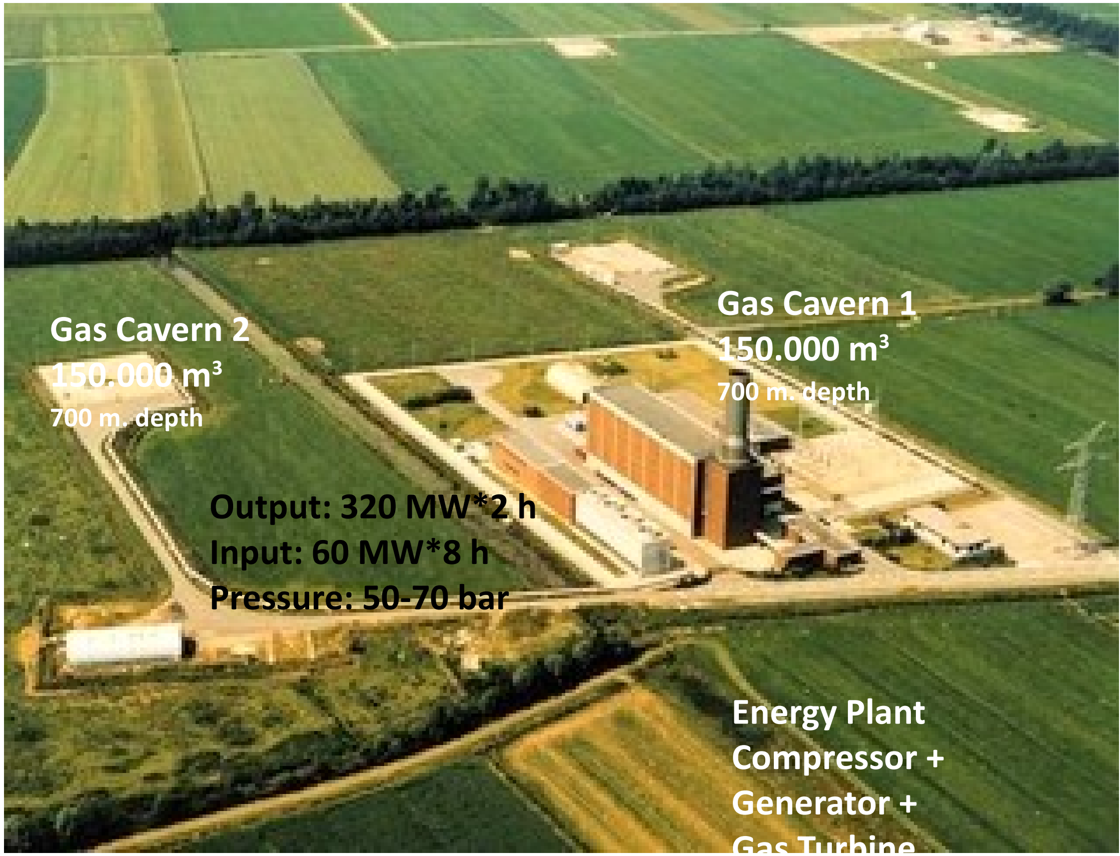
aeren spain

## Associated Energy Costs to Injection of Intermittent Loads: Compressed Air Energy Storage (CAES)

42-56% round trip efficiency (Diabatic)
70% round trip efficiency (Adiabatic)

Erection cost is very variable and site specific:
300-600 $/kW
400-800 $/kW
1,000-1,250 $/kW
Operation costs are also variable
116-140 $/MWh

It may be more expensive than pump hydro technique
**(and may represent the go-no go for a 100% renewables case)**

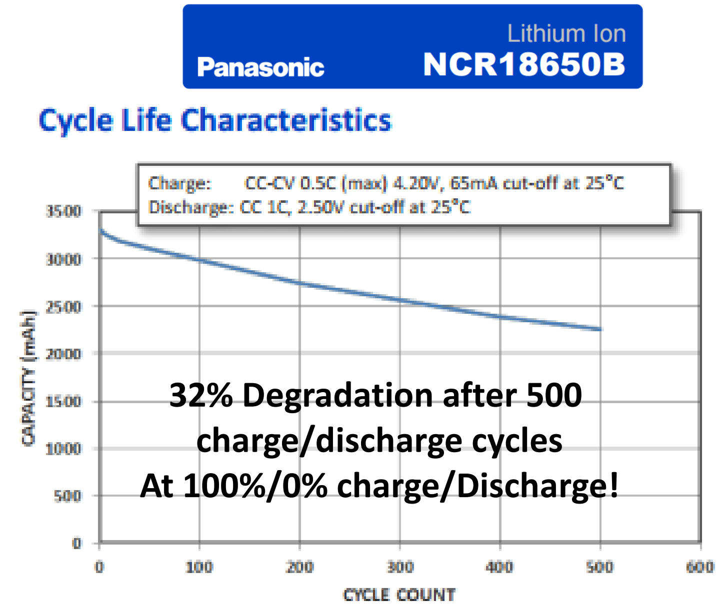



Sources: Franz Crotogino. KBB. Germany June 15th. School of Engineers. Seville. Grid Scale Energy Storage. Pumped hydro, compressed air and Hydrogen Energy Storage Technologies at http://energystoragesense.com/compressed-air-energy-storage/
https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf

# The Energy Invested (Ei) *Factor $a_{10}$*

aeren spain

## Associated Energy Costs to Injection of Intermittent Loads: Storage in Batteries




Ta'u Island in American Samoa. Example

790 inhabitants

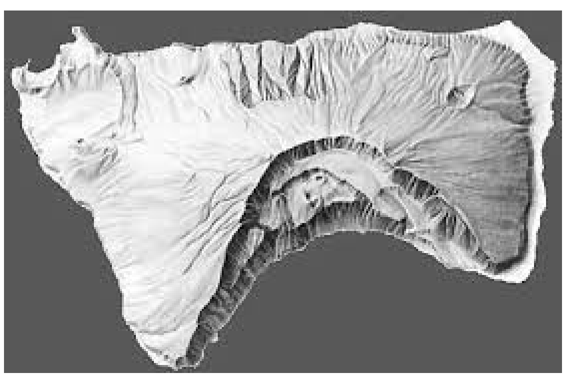
8-10 M$project. The annual GDP of the island

1.4 Mwp solar plant

6,000 kWh storage in 60 Tesla Powerpack batteries

40% of generated energy is curtailed

Still 4 days/year (1%) batteries are completely discharged



7,104 Panasonic 18650B compose the Tesla S Battery (85 kW.h version)
Of 45,000 $ and 540 Kg

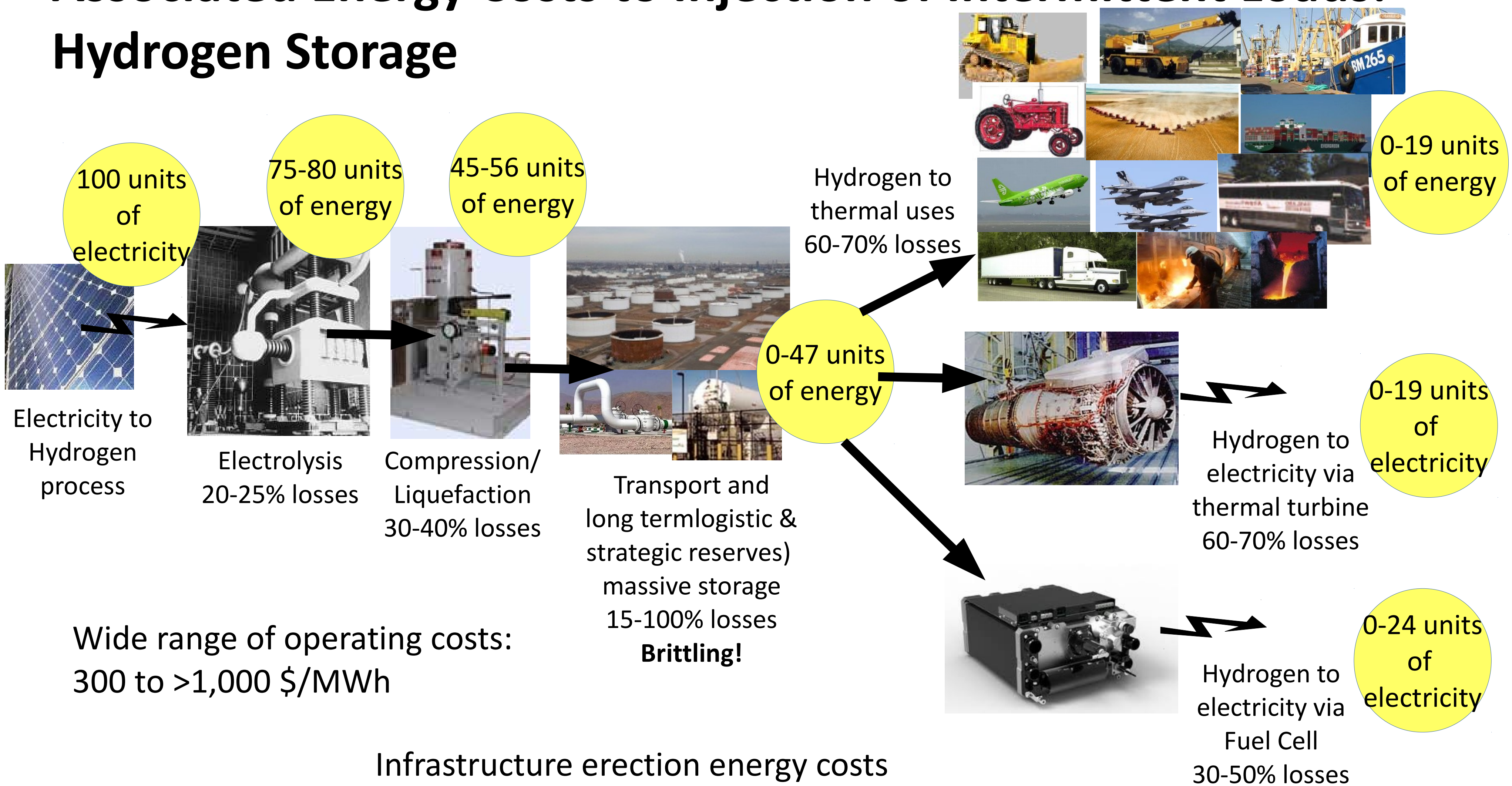
267-561 $/MWh

7,500 charge/discharge at 94%/6%
28,000 charge/discharge at 90%/10%
35,000 charge/discharge at 80%/20%
40,000 charge/discharge at 70%/30%

Sources: Panasonic. Tesla. Various. Evandmore.com http://blog.evandmore.com/lets-talk-about-the-panasonic-ncr18650b/ and own elaboration
https://www.lazard.com/media/438042/lazard-levelized-cost-of-storage-v20.pdf

# The Energy Invested (Ei) *Factor $a_{10}$*

## Associated Energy Costs to Injection of Intermittent Loads: Hydrogen Storage




Wide range of operating costs:
300 to >1,000 $/MWh

Infrastructure erection energy costs are excluded here

# The Energy Invested (Ei)

aeren spain

## Massive Storage Implications and Costs

Cost of massive Storage is very difficult to ascertain. Each technology has several options, changes on time and costs may differ a lot depending on specific scenarios and costs of infrastructures needed.

Not necessarily massive production will lead to lower costs.

Comparison of Energy Storage Options for 100% electric generation scenarios

| | Hydrogen PEM (*) | Pumped Hydro | Batteries | Compressed Air Energy Storage (CAES) |
|---|---|---|---|---|
| Electric Consumption Vs Generation | 2,5:1 | 1,25:1 | 1,05:1 | 1,2-1,5:1 |
| Round Trip Efficiency (Short term) | <40% | ~75% | 70-90% | 42-50% |
| Ramp up time (in minutes) | 0 | <3 | 0 | <15 |
| Volumetric Density in kWh/m³ | 180-300 | 1 | 150 | 2,5 |
| Footprint | Small | Very Big | Small | Small to Big |
| Type of Energy Storage | Chemical | Physical | Chemical | Physical |
| Generalized Practice. Small Scale | NO | YES | YES | Yes D/No A |
| Generalized Practice. Massive Scale | NO | YES. Limited | NO | NO |
| Expected Lifetime in Years | 10-15 | 40 Equip. 150 Dam | 5-10 | 40 Equip. 100 Cavern |
| Costs/MW installed | n/a | 5-7 | 5-7 | 1 (**) |

Notes:

(*) Proton Exchange Membrane (PEM) type only included. Refueling infrastructure excluded
(**) Assuming the salt caverns with enough capacity already exist just below surface of the plant (230 MW*2hours)

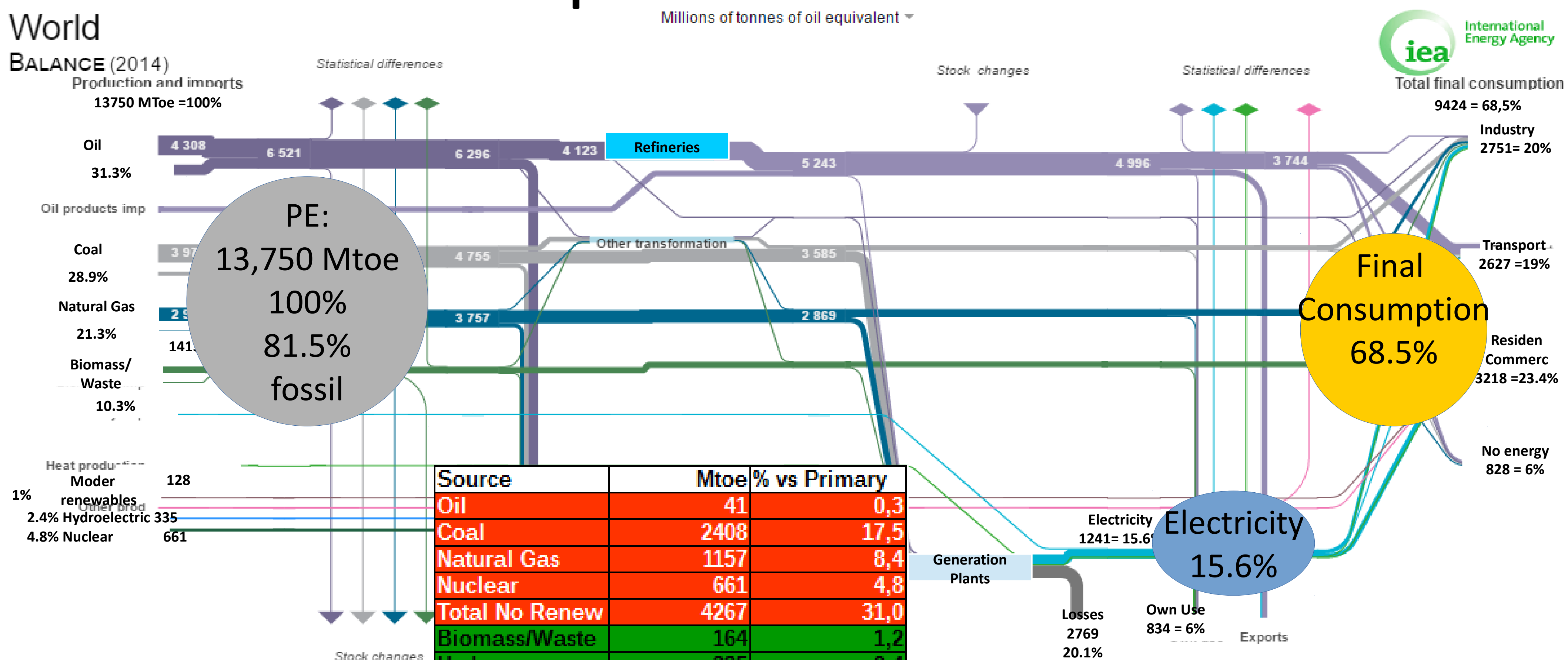
Pumped hydro seems to be the most reliable and lower in costs

But 100% supply security implies, at least, some 3 to 5 times more cost than the solar system cost itself

**Massive Storage may be the tipping point for the go-no go decision in 100% renewables**

# Energy Equivalences

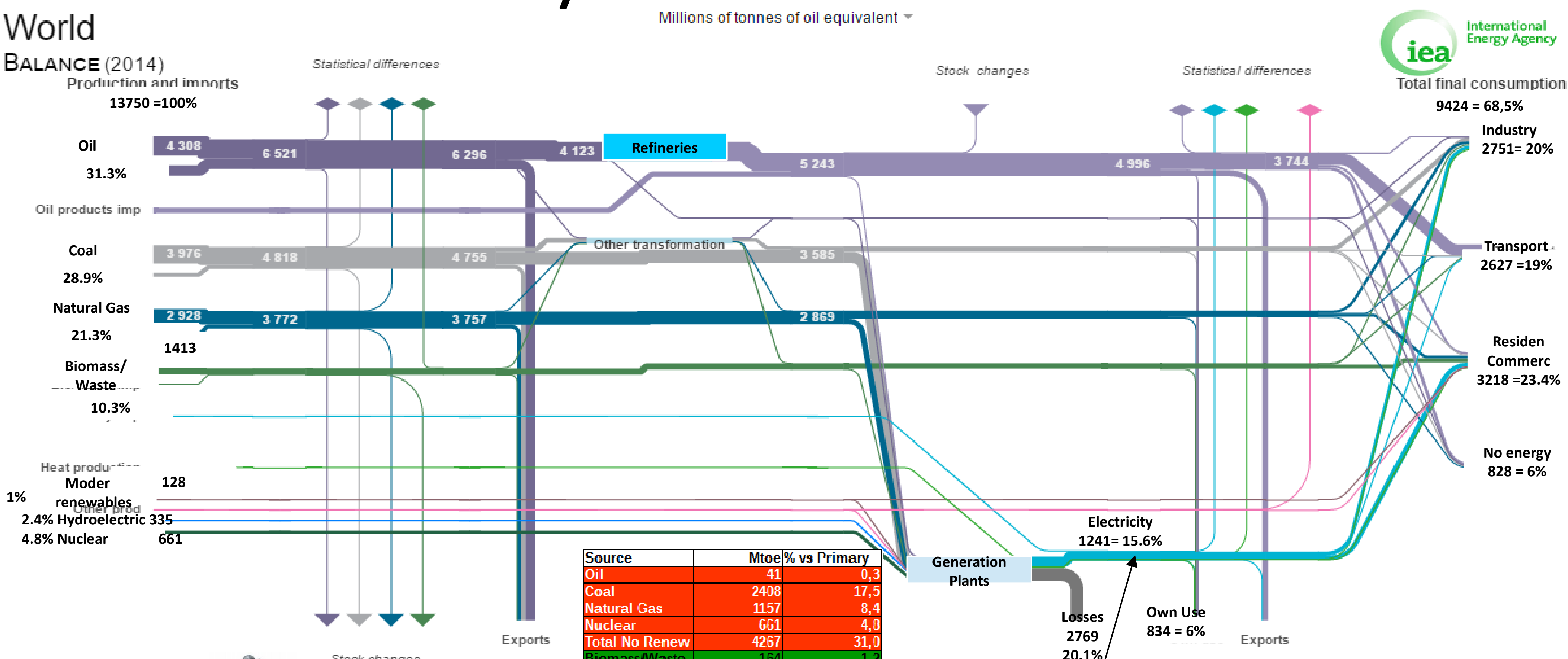
## Thermal-Electric Equivalences




| Source | Mtoe | % vs Primary |
|---|---|---|
| Oil | 41 | 0,3 |
| Coal | 2408 | 17,5 |
| Natural Gas | 1157 | 8,4 |
| Nuclear | 661 | 4,8 |
| Total No Renew | 4267 | 31,0 |
| Biomass/Waste | 164 | 1,2 |
| Hydro | 335 | 2,4 |
| Modern Renew | 144 | 1,0 |
| Total Renew | 643 | 4,7 |
| Grand Total | 4910 | 35,7 |

# Energy Equivalences

## Direct Transformity




| Source | Mtoe | % vs Primary |
|---|---|---|
| Oil | 41 | 0,3 |
| Coal | 2408 | 17,5 |
| Natural Gas | 1157 | 8,4 |
| Nuclear | 661 | 4,8 |
| Total No Renew | 4267 | 31,0 |
| Biomass/Waste | 164 | 1,2 |
| Hydro | 335 | 2,4 |
| Modern Renew | 144 | 1,0 |
| Total Renew | 643 | 4,7 |
| Grand Total | 4910 | 35,7 |

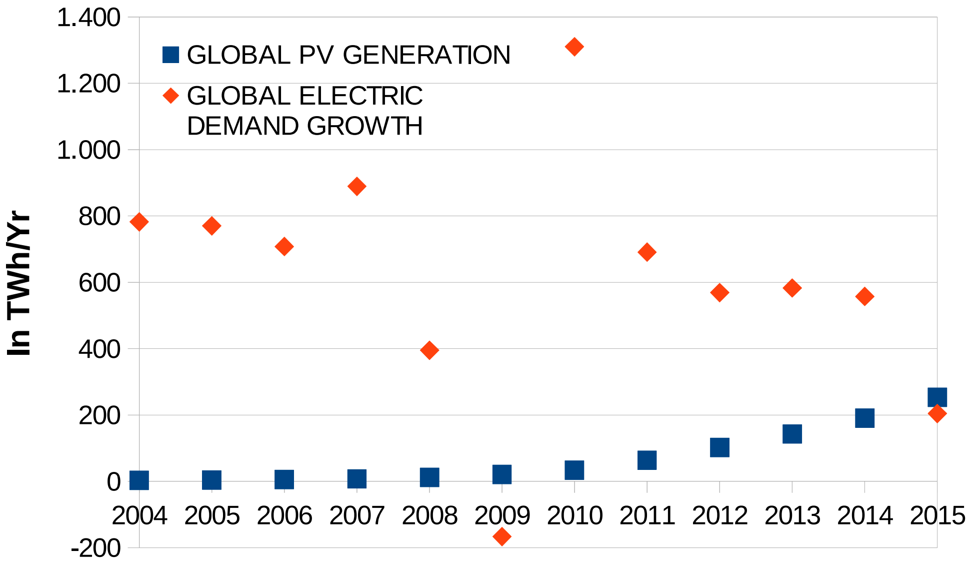
One unit of renewable energy injected here as electricity….

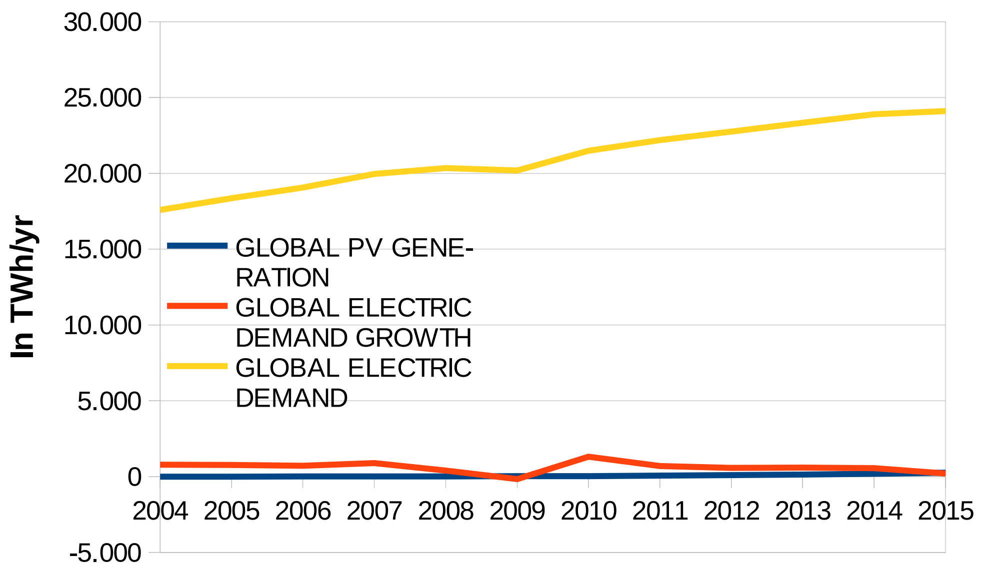
…saves about 2.6 to 3 units of Primary Energy (PE) consumed here….DIRECT TRANSFORMITY

# Solar PV Energy  Contribution

Global Solar PV generation was less than the annual electricity Growth demand y/y, except in 2015.

Solar PV is mostly a fossil fuel extender

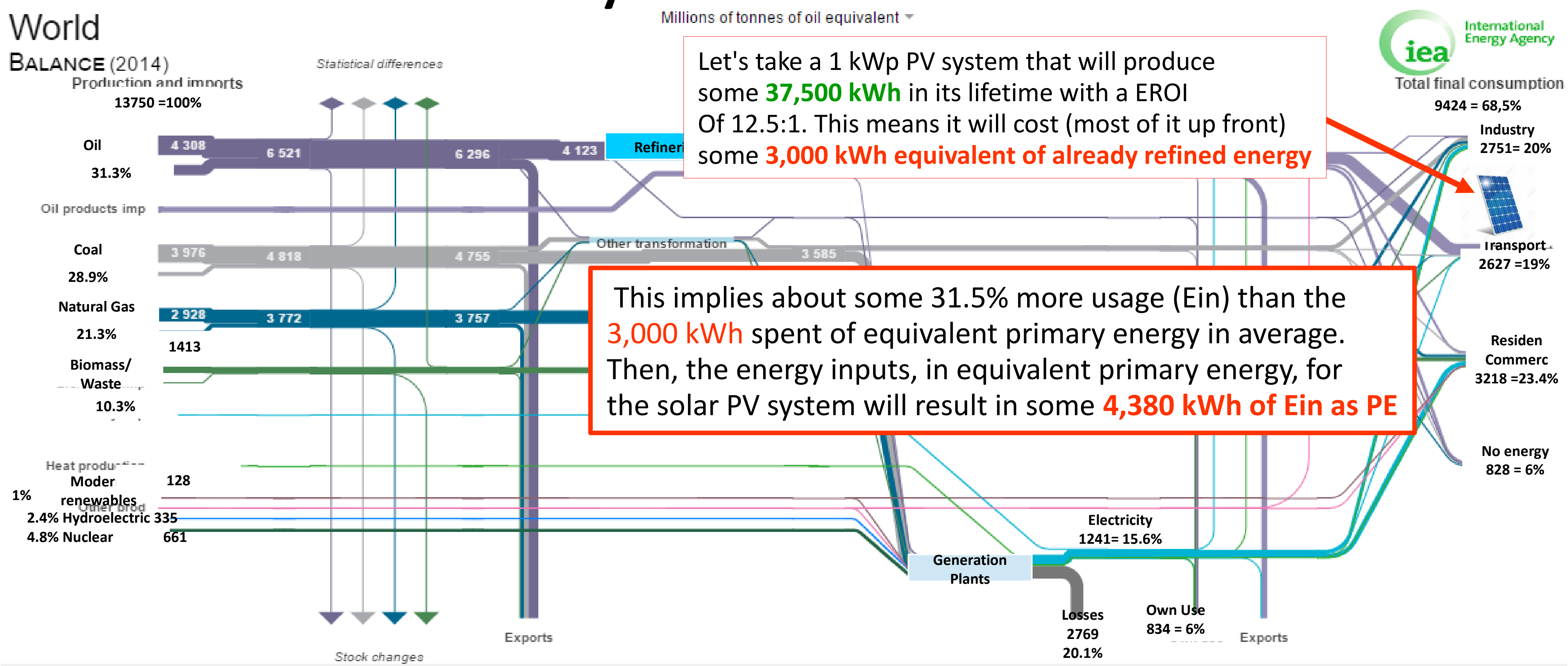



Source: BP Statistical Review of 2016

# Energy Equivalences

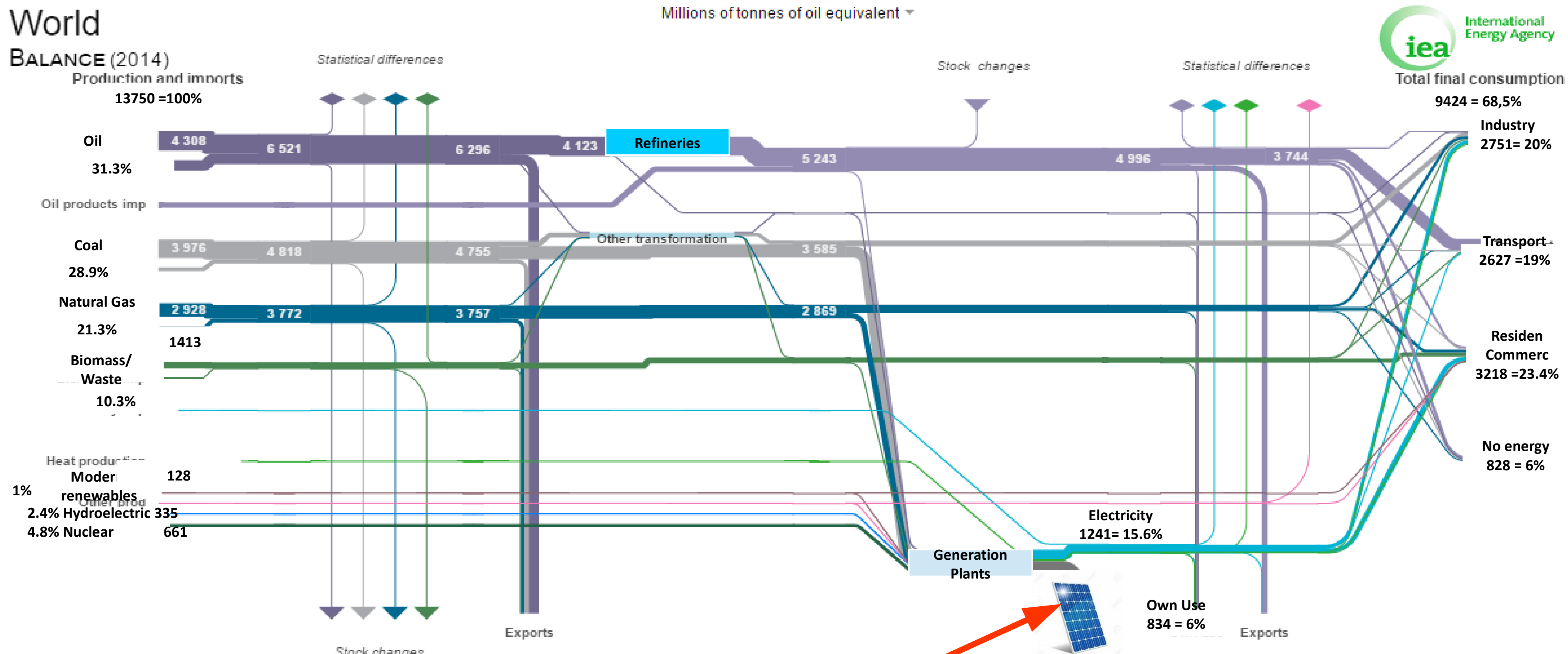
## Reverse Transformity




Let's take a 1 kWp PV system that will produce some **37,500 kWh** in its lifetime with a EROI Of 12.5:1. This means it will cost (most of it up front) some **3,000 kWh equivalent of already refined energy**

This implies about some 31.5% more usage (Ein) than the 3,000 kWh spent of equivalent primary energy in average. Then, the energy inputs, in equivalent primary energy, for the solar PV system will result in some **4,380 kWh of Ein as PE**

# Energy Equivalences

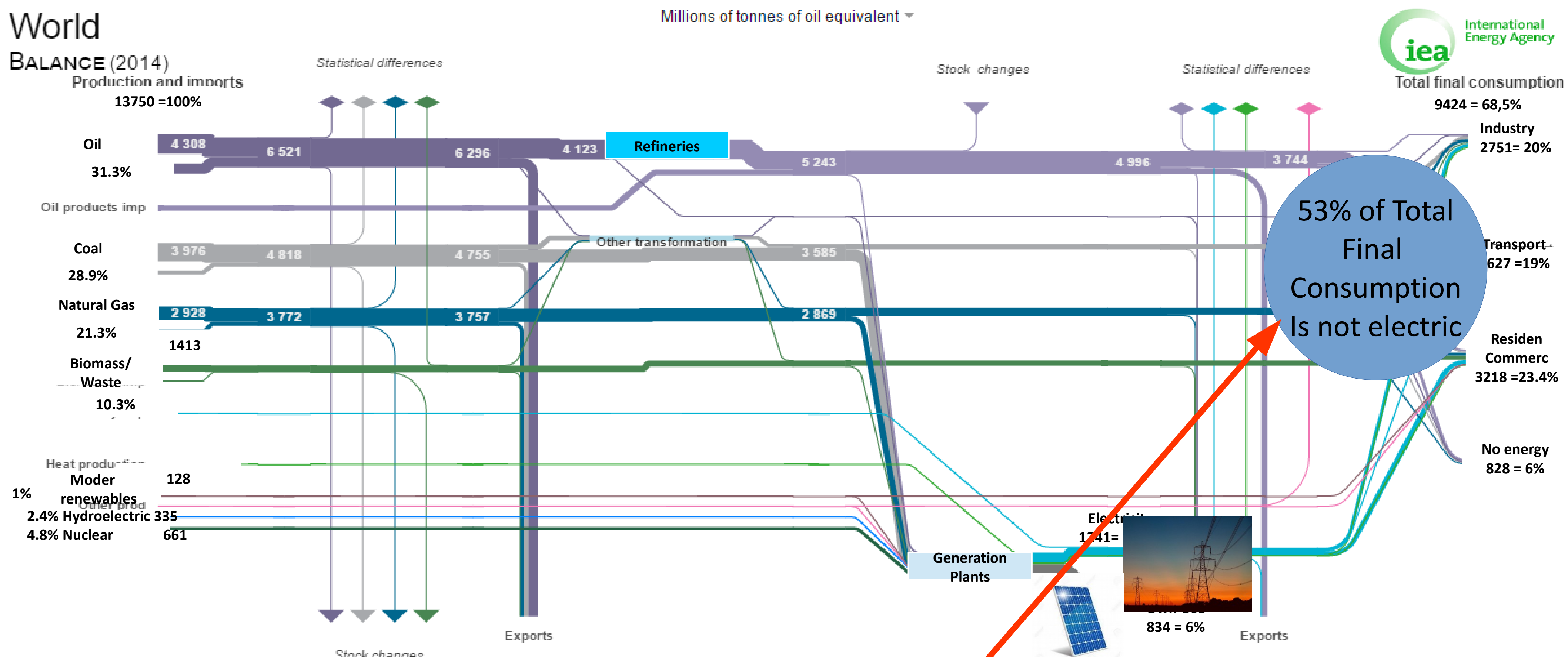



Now, let's put a solar PV system here to generate electricity.

We have now a system with a **credit of 37,500 kWh** brought from the 25 years of generation to today and a **debt of 4,380 kWh of PE**, mostly created the first year

# Energy Equivalences

aeren spain



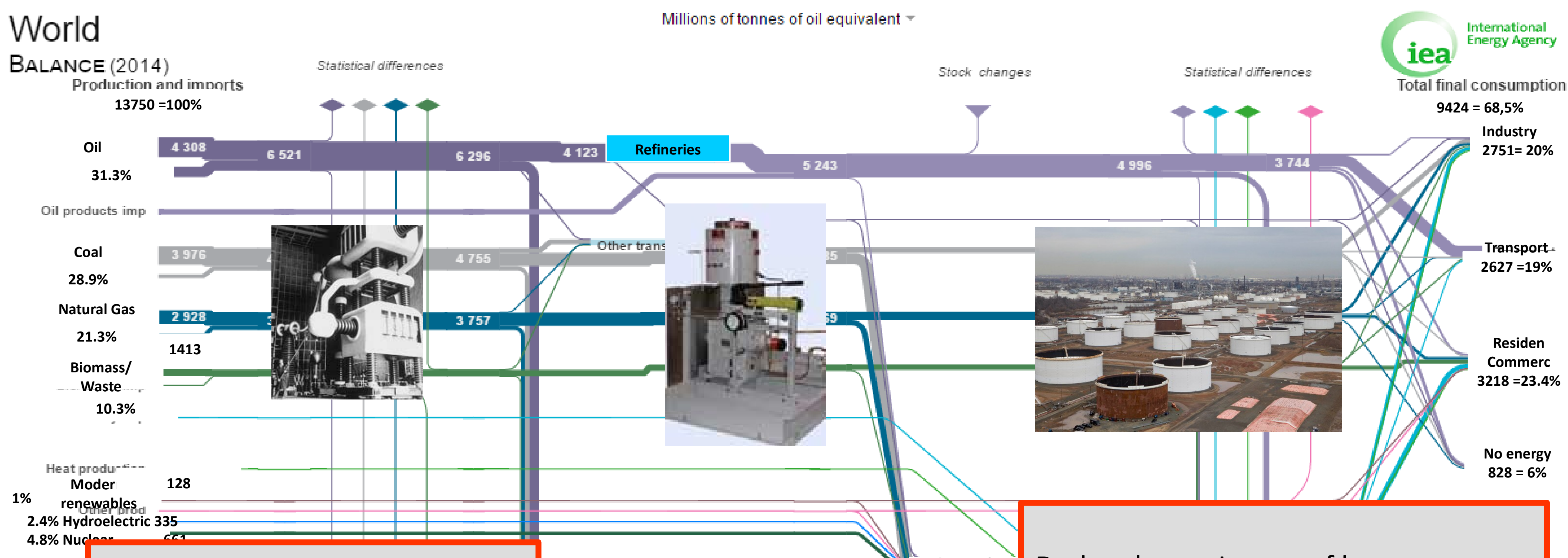

Put the solar PV system to serve some 53% of the **non electric** Total Final Consumption

Deduct 5-10% loses in the electricity transport and distribution of 1 kWp system

**CREDIT LEFT: 33,750-30,000 kWh**

**ORIGNAL DEBT: 4,380 kWh**

# Energy Equivalences




Deduct losses of 20-30% making electrolysis to obtain hydrogen as energy vector for non electric functions.

**CREDIT LEFT: 27,000-21,000 kWh**
**ORIGNAL DEBT: 4,380 kWh**

Deduct losses of 30-40% to compress/liquefy Hydrogen for handling

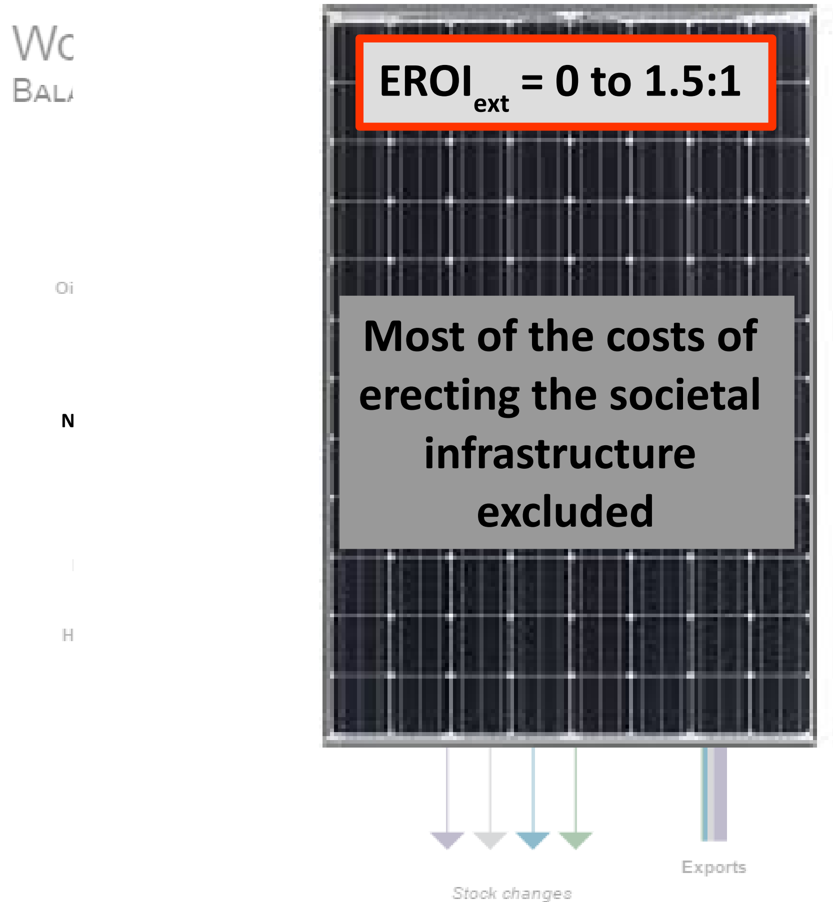
**CREDIT LEFT: 18,900-12,600 kWh**
**ORIGNAL DEBT: 4,380 kWh**

Deduct losses Losses of between 15% and 100% for leaks depending on logistic stored time.

Losses for brittling effects excluded

**CREDIT LEFT: 16,065- 0 kWh**
**ORIGNAL DEBT: 4,380 kWh**

# Energy Equivalences




**$EROI_{ext}$ = 0 to 1.5:1**

**Most of the costs of erecting the societal infrastructure excluded**


Most of the functions will use hydrogen as energy vector for the many non electric functions in thermal form.
Deduct losses here between 60% and 70%

**REAL FINAL YIELD: 6,430- 0 kWh**
**ORIGNAL DEBT: 4,380 kWh**

# Money to Energy Equivalences

aeren
spain

**How to Tackle monetary costs as energy?**

Money as a proxy of energy?
Is money a lien of energy?
Is or represents money a call on future energy?

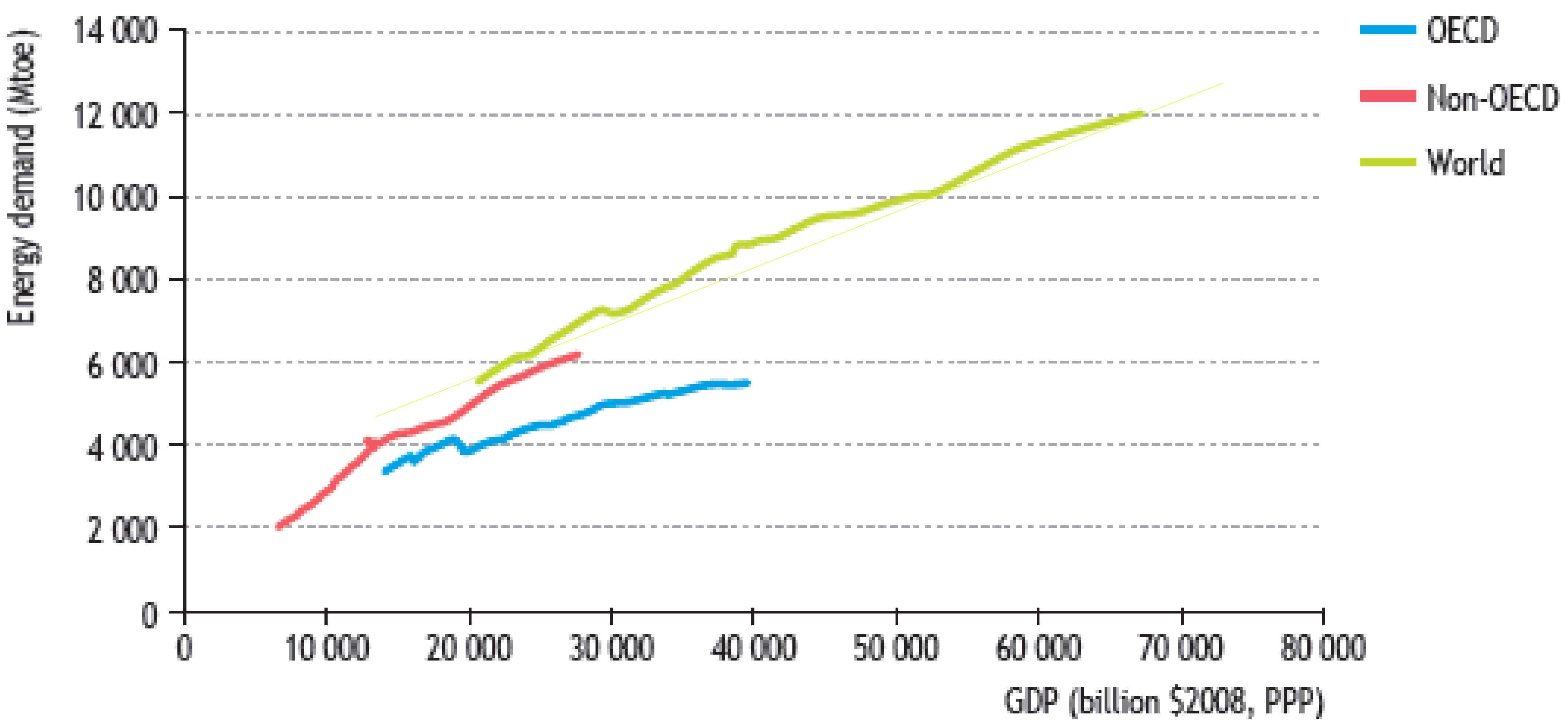
Dividing the total primary energy used by total GDP gives a rough estimate: 7.16 MJ/euro or 1.99 kWh/euro. (Spain 2010) (World 2015)

Energy intensities vary much depending on the sector

# Money to Energy Equivalences

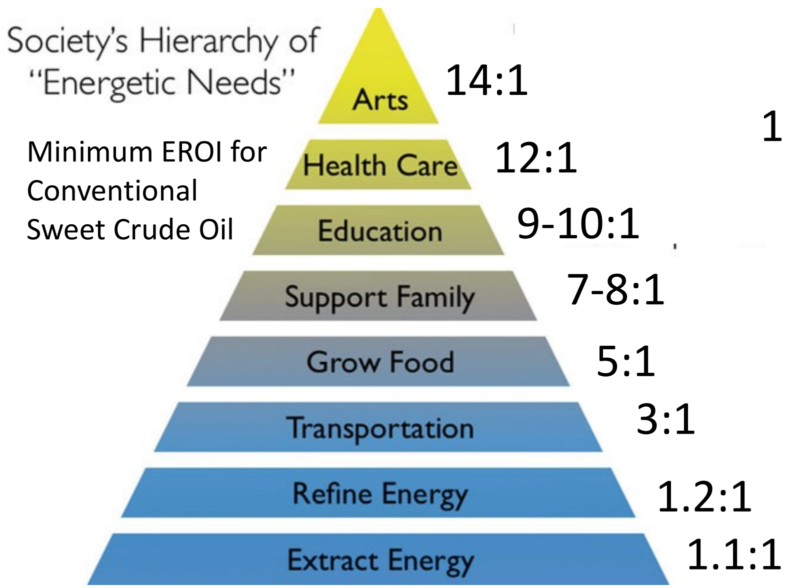
## How to Tackle monetary costs as energy?

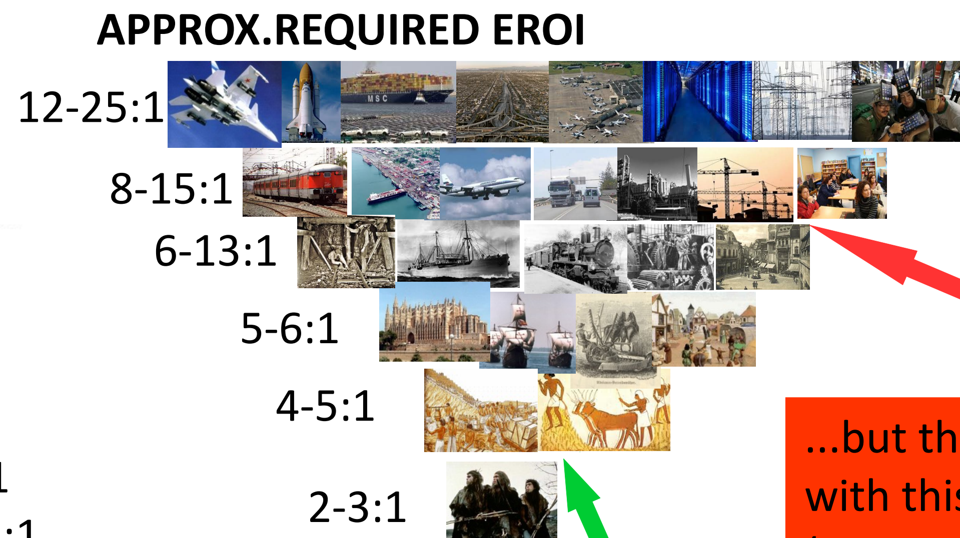
Figure 2 • Primary energy demand and GDP, 1971-2007




Source: International Energy Agency (IEA). WOrld Energy Outlook (WEO) 2009. Page 59

# Conclusions




...but they need a society with this EROIext level (at worst)

**Solar PV modules have a global EROIext of this level (as best)....**

Source: Charles Hall adapted by Lambert & Lambert 2012

aeren
spain

# Thanks for your attention

Pedro A. Prieto
pappspain@gmail.com

# CSP Facts in Spain

aeren
spain

# CSP Facts in Spain

## Four main types of CSPs

One axis tracking system parabolic-through mirrors, focusing to a pipe in the linear focus carrying a fluid to central deposits to generate Steam and produce electricity

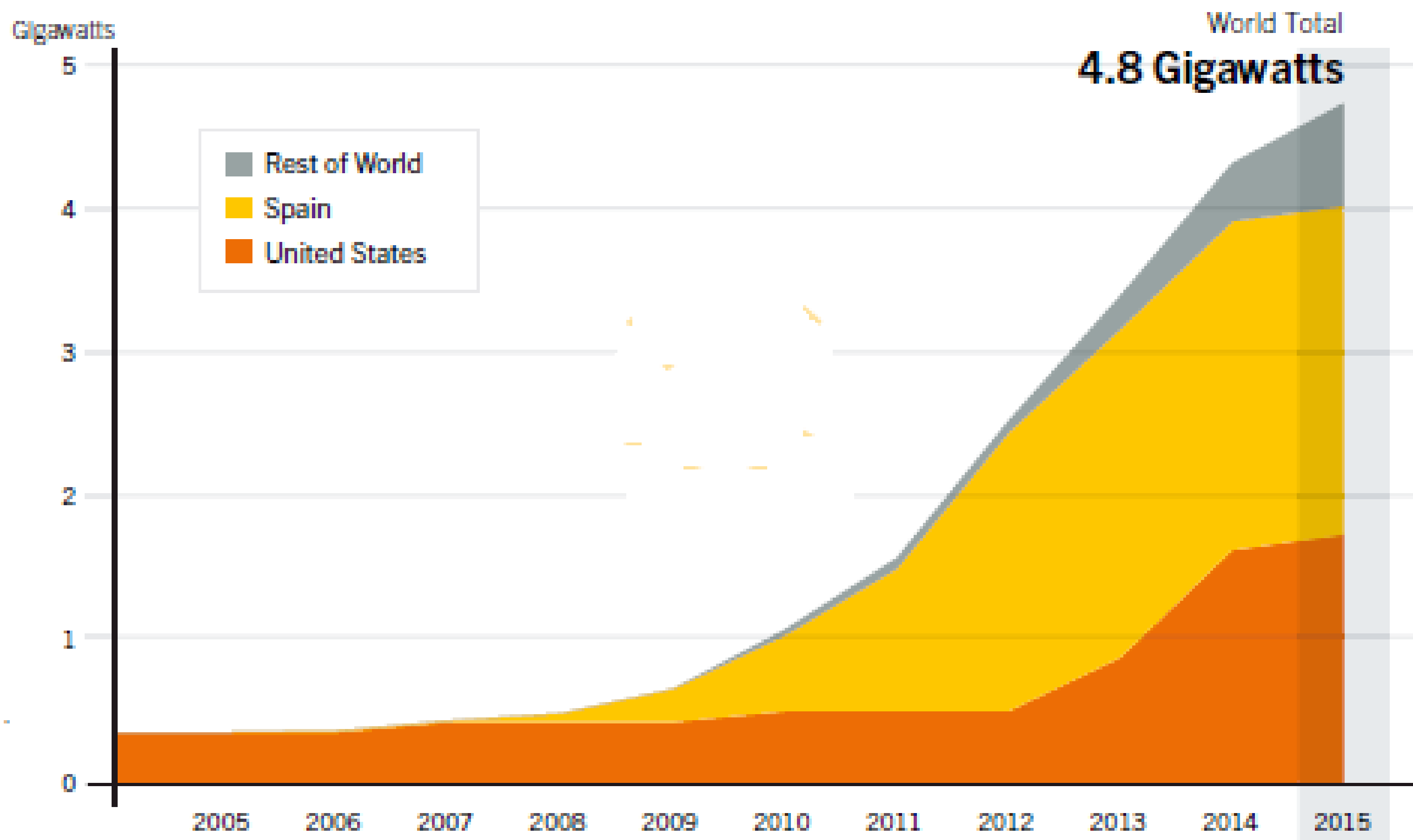
Two axis tracking systems with mirrors focusing on a central oven in a tower to generate steam and produce electricity.

Sterling parabolic two axis tracking mirrors focusing on the hot spot of a Sterling machine.

Fresnel mirrors focusing on an axis

# CSP Facts in Spain

## Spain has about half of the global installed power in CSP




Sources: Renewables 2016. Market and Industry Trends, Protermosolar, CSP Today

# CSP Facts in Spain

## CSP Plants in Spain per
- **Owner**
- **Location**
- **Power**
- **Technology**
- **Storage facilities**

| Owner | Name | Location | Province | Power (MW) | Technology | Storage |
|---|---|---|---|---|---|---|
| Abengoa Solar | PS10 | Sanlúcar la Mayor | Sevilla | 10 | Tower Sat. Steam | 1 |
| RREEF/ANTIN/COBRA | Andasol 1 | Aldeire | Granada | 50 | CCP | 7,5 |
| Novatec | Puerto Errado I | Calasparra | Murcia | 1,4 | Fresnel | 0,5 |
| Abengoa Solar | PS20 | Sanlúcar la Mayor | Sevilla | 20 | Tower Sat. Steam | 1 |
| Iberdrola | Ibersol Puertollano | Puertollano | Ciudad Real | 50 | CCP | n/a |
| RREEF/ANTIN/COBRA | Andasol 2 | Aldeire/la Calahorra | Granada | 50 | CCP | 7,5 |
| Acciona/ Mitsubishi Corp. | La Risca | Alvarado | Badajoz | 50 | CCP | n/a |
| COBRA | Extresol-1 | Torre de Miguel Sesmero | Badajoz | 50 | CCP | 7,5 |
| COBRA | Extresol-2 | Torre de Miguel Sesmero | Badajoz | 50 | CCP | 7,5 |
| Abengoa Solar | Solnova 1 | Sanlúcar la Mayor | Sevilla | 50 | CCP | n/a |
| Abengoa Solar | Solnova 3 | Sanlúcar la Mayor | Sevilla | 50 | CCP | n/a |
| Renovab SAMCA, S.A. | La Florida | Badajoz | Badajoz | 50 | CCP | 7,5 |
| Abengoa Solar | Solnova 4 | Sanlúcar la Mayor | Sevilla | 50 | CCP | n/a |
| Acciona/ Mitsubishi Corp. | Majadas | Majadas | Cáceres | 50 | CCP | n/a |
| Renovables SAMCA | La Dehesa | La Garrovilla | Badajoz | 50 | CCP | 7,5 |
| Acciona Mitsubishi Corp. | Palma del Río II | Palma del Río | Córdoba | 50 | CCP | n/a |
| COBRA | Manchasol-1 | Alcázar de San Juan | Ciudad Real | 50 | CCP | 7,5 |
| Torresol | Gemasolar | Fuentes de Andalucía | Sevilla | 20 | Tower w/ salts | 15 |
| COBRA | Manchasol-2 | Alcázar de San Juan | Ciudad Real | 50 | CCP | 7,5 |
| Abengoa/JGC Corp | Palma del Río I | Palma del Río | Córdoba | 50 | CCP | n/a |
| Valoriza/Siemens | Lebrija 1 | Lebrija | Sevilla | 50 | CCP | n/a |
| Millenium/RWE/Others | Andasol 3 | Aldeire/la Calahorra | Granada | 50 | CCP | 7,5 |
| Abengoa Solar/EON | Helioenergy 1 | Écija | Sevilla | 50 | CCP | n/a |
| Torresol | Arcosol 50 | San José del Valle | Cádiz | 50 | CCP | 7,5 |
| Elecnor/Eiser/Aries | Astexol II | Badajoz | Badajoz | 50 | CCP | n/a |
| Torresol | Termesol-50 | San José del Valle | Cádiz | 50 | CCP | 7,5 |
| Novatec, others | Puerto Errado II | Calasparra | Murcia | 30 | Fresnel | 0,5 |
| Abengoa Solar/EON | Helioenergy 2 | Écija | Sevilla | 50 | CCP | n/a |
| Elecnor/Eiser/Aries | Aste 1A | Alcázar de San Juan | Ciudad Real | 50 | CCP | n/a |
| Elecnor/Eiser/Aries | Aste 1B | Alcázar de San Juan | Ciudad Real | 50 | CCP | n/a |
| Abengoa/JGC Corp | Solacor 1 | El Carpio | Córdoba | 50 | CCP | n/a |
| Abengoa/JGC Corp | Solacor 2 | El Carpio | Córdoba | 50 | CCP | n/a |
| Ibereolica | Morón | Morón de la Frontera | Sevilla | 50 | CCP | n/a |
| Abengoa Solar | Helios 1 | Puerto Lapice | Ciudad Real | 50 | CCP | n/a |
| Abengoa Solar/ITOCHU | Solaben 3 | Logrosán | Cáceres | 50 | CCP | n/a |
| Plenium/FCC/Mitsui | Guzmán | Palma del Rio | Córdoba | 50 | CCP | n/a |
| Ibereolica | Olivenza 1 | Olivenza | Badajoz | 50 | CCP | n/a |
| Ortiz –TSK–Magtel | La Africana | Fuente Palmera | Córdoba | 50 | CCP | 7,5 |
| Acciona | Orellana | Orellana | Badajoz | 50 | CCP | n/a |
| Abengoa Solar | Helios 2 | Puerto Lapice | Ciudad Real | 50 | CCP | n/a |
| COBRA | Extresol-3 | Torre de Miguel Sesmero | Badajoz | 50 | CCP | 7,5 |
| Abengoa Solar/ITOCHU | Solaben 2 | Logrosán | Cáceres | 50 | CCP | n/a |
| Abantia /Comsa EMTE | Termosolar Borges | Borges Blanques | Lleida | 22,5 | CCP + Hybrid Biom | n/a |
| Abengoa Solar | Solaben 1 | Logrosán | Cáceres | 50 | CCP | n/a |
| Nextera-FPL | Termosol 1 | Navalvillar de Pela | Badajoz | 50 | CCP | 9 |
| Plenium/FCC/Mitsui | Enerstar | Villena | Alicante | 50 | CCP | n/a |
| COBRA | Casablanca | Talarrubias | Badajoz | 50 | CCP | 7,5 |
| Nextera-FPL | Termosol 2 | Navalvillar de Pela | Badajoz | 50 | CCP | 9 |
| Abengoa Solar | Solaben 6 | Logrosán | Cáceres | 50 | CCP | n/a |
| RREEF/STEAG/OHL | Arenales | Morón de la Frontera | Sevilla | 50 | CCP | 7 |
| **TOTAL: 50** | | | | | **2303,9** | |

Source: Protermosolar,

# CSP Facts Worldwide

aeren spain

| Name | Owner | Country | Location | MW | Technology | Storage (hours) | Start year |
|---|---|---|---|---|---|---|---|
| Hassi-R'mel | Sonatrach | Argelia | Hassi R'mel | 25 | Parabolic Trough/ISCC | no | 2011 |
| Minera el Tesoro | Abengoa Solar | Chile | | 10 MWth | Parabolic Trough thermal | no | 2013 |
| ISCCS Al Kuraymat | NREA | Egipto | Al Kuraymat | 20 | Parabolic Trough/ISCC | no | 2011 |
| Indian Institute of Technology CSP Project | Abengoa | India | | 3 | Parabolic Trough | no | 2011 |
| Bikaner | ACME | India | Bikaner | 2,5 | Torre | no | 2011 |
| Godawari | Godawari Green Energy Limited | India | Naukh | 50 | Parabolic Trough | no | 2013 |
| Reliance Areva CSP 1 | Reliance Power AREVA | India | | 125 | Fresnel | | 2014 |
| ISCC Marruecos | ONE | Morocco | Ain Beni Mathar | 20 | Parabolic Trough/ISCC | no | 2011 |
| KaXu Solar One | Abengoa | South Africa | Poffader | 100 | Parabolic Trough | 3 | 2015 |
| Shams 1 | Abengoa Solar/Masdar/Total | UAE | Madinat Zayed | 100 | Parabolic Trough | no | 2013 |
| SEGS Power Plants | FPL | USA | California | 390 | Parabolic Trough | no | 1985 |
| Maricopa | Tessera Solar | USA | Arizona | 1,5 | Disco | no | 2007 |
| Holaniku | Keahole Solar Power | USA | Hawaii | 2 | Parabolic Trough | 2 | 2009 |
| Martin Next Generation | FPL | USA | Florida | 75 | Parabolic Trough | no | 2009 |
| Saguaro | Arizona Public Service | USA | Arizona | 1,16 | Parabolic Trough | no | 2009 |
| Kimberlina | Ausra | USA | California | 5 | Fresnel | no | 2009 |
| Sierra Sun Tower | eSolar | USA | California | 5 | Torre | no | 2009 |
| Cameo hybrid | Xcel Energy | USA | Colorado | 2 | Parabolic Trough | no | 2010 |
| Nevada Solar One | Acciona | USA | Nevada | 64 | Parabolic Trough | 0,5 | 2007 |
| Holaniku at Keyhole Point | Keahole Solar Power, LLC | USA | Keahole, Hawai | 2 | Parabolic Trough | no | 2009 |
| Solana | Abengoa Solar | USA | Arizona | 280 | Parabolic Trough | 6 | 2013 |
| Genesis Solar | NextEra Energy | USA | California | 250 | Parabolic Trough | no | 2013/2014 |
| Ivanpha | BrightSource | USA | California | 392 | Tower | no | 2013 |
| Mojave | Abengoa Solar | USA | California | 280 | CCP | no | 2014 |

Source: Protermosolar,

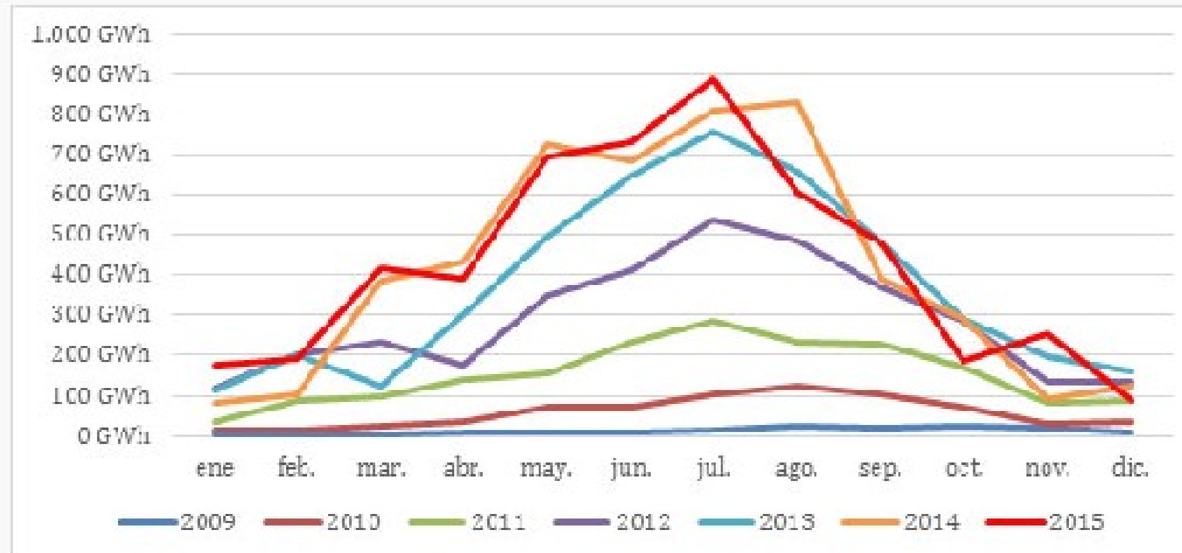
# CSP Facts in Spain

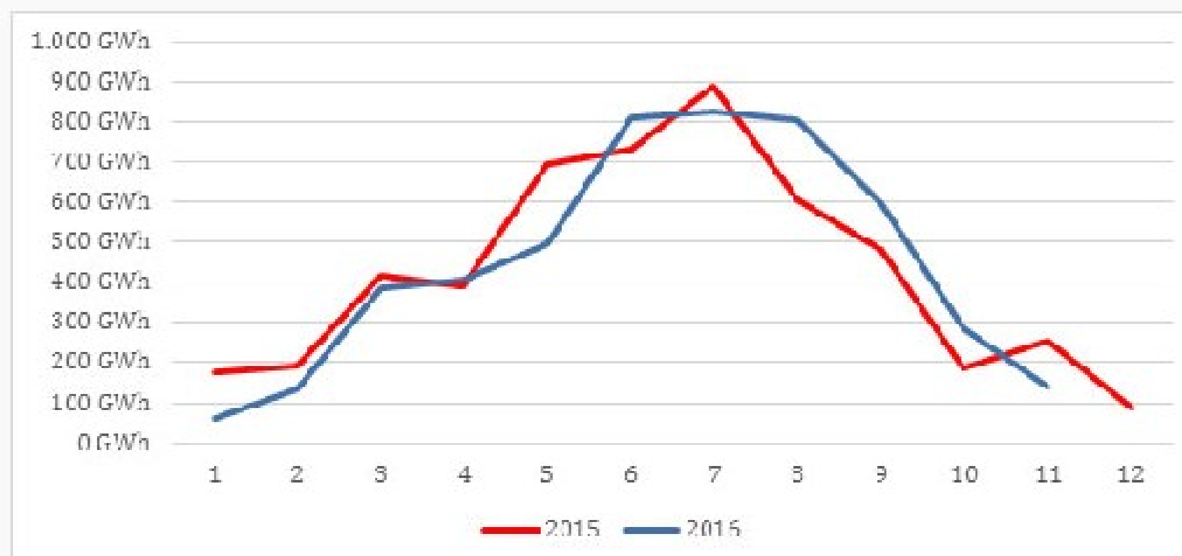
aeren spain

Spain generates some 2% of its national yearly demand with CSP

Gas fired plants backup are permitted up to 15% of the total generation.

Biomass backup is in experimental phase



# CSP Facts in Spain

Water needs are as important as for conventional thermal plants and a limiting factor.

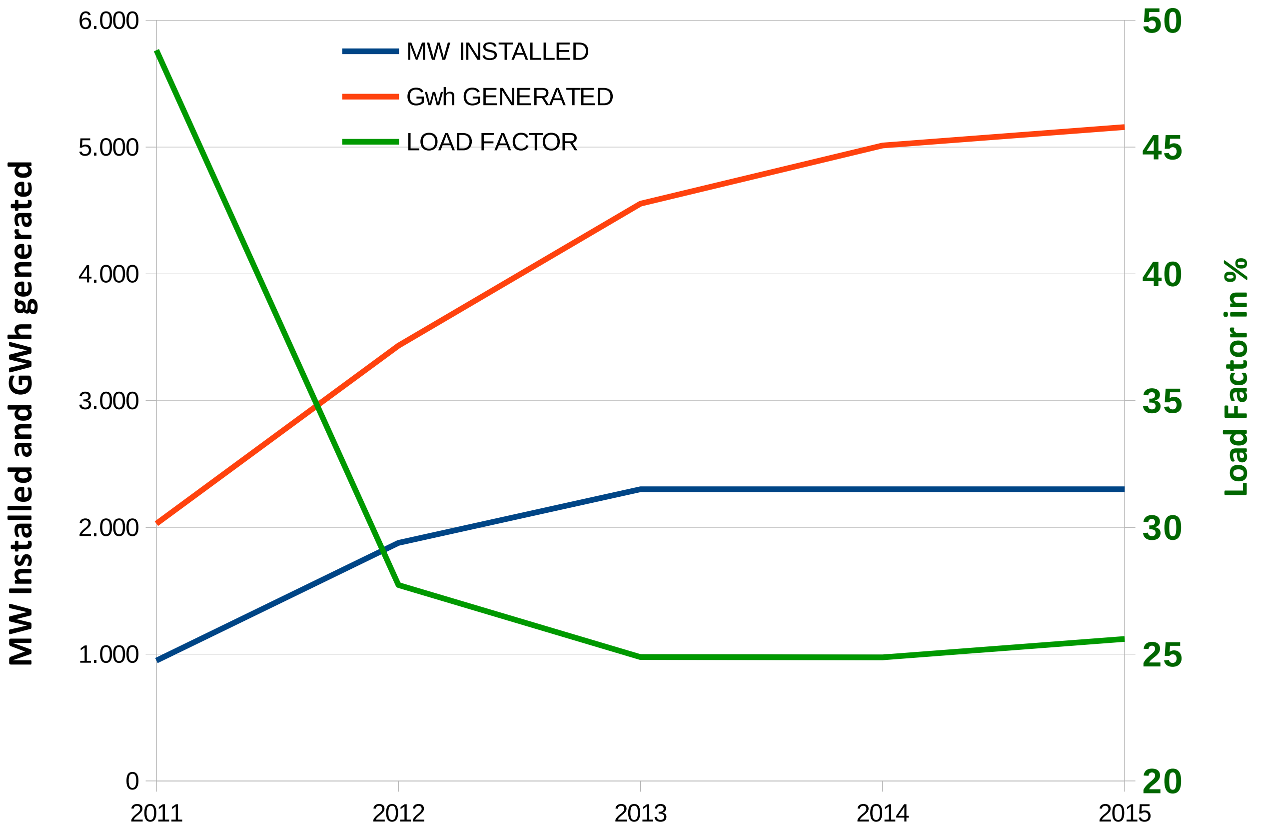
50 MW typical needs some 6 litres/sec. Or 300,000 m3 of fresh water per year

# CSP Facts in Spain

aeren spain

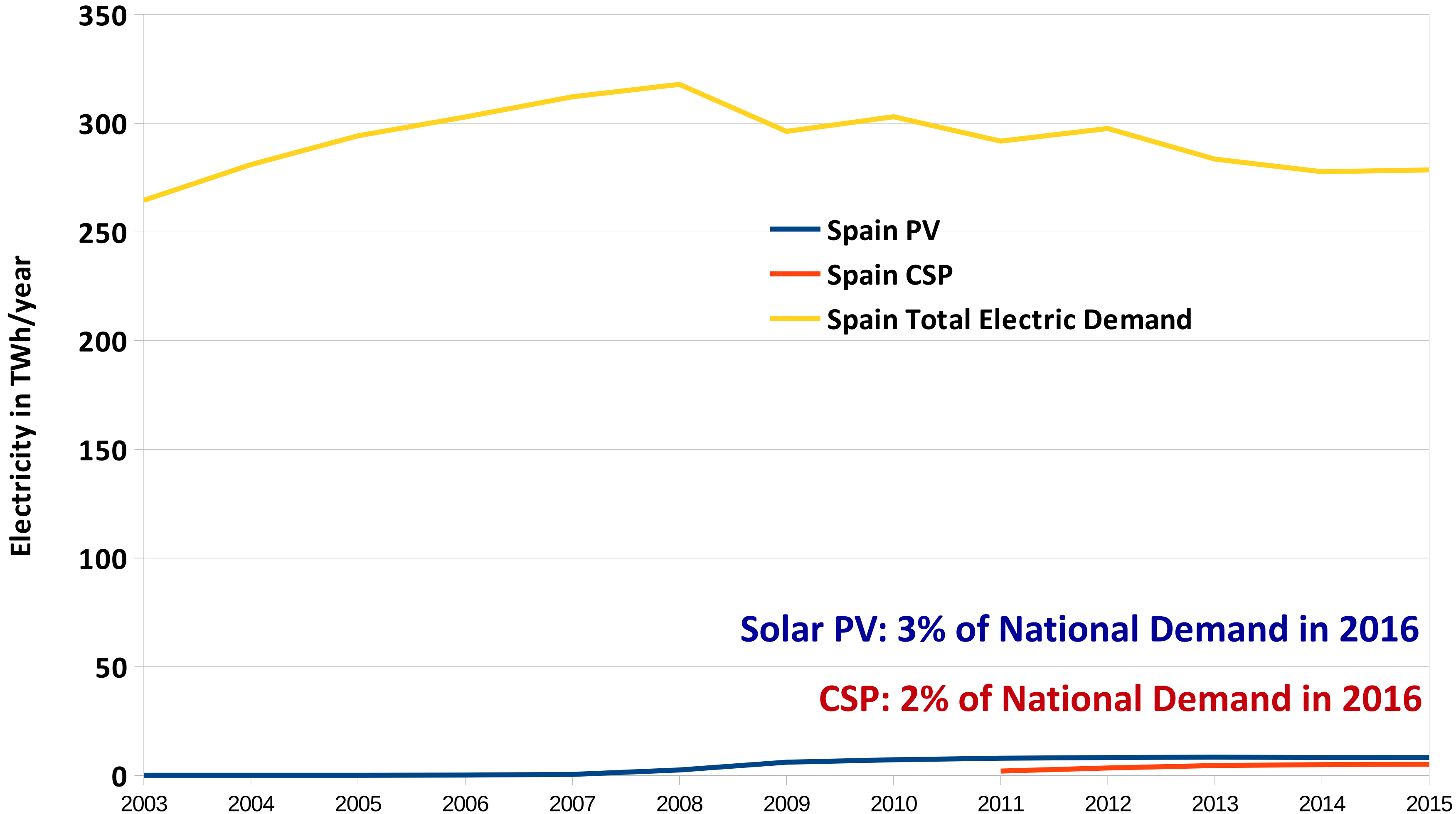
**The learning curve has been substantially better than that of the USA.**

**The Capacity Factor includes the backup with gas fired plants**




Source: Red Eléctrica de España. Www.ree.es. Informes Sistema Eléctrico 2009-2016

# CSP Facts in Spain




Source: BP Statistical Review 2016 and Red Eléctrica de España. Www.ree.es. Informes Sistema Eléctrico 2009-2016

# Energy Intensities for renewables and others

| Power Density in | W/m² |
|---|---|
| Biofuels | 0,45 |
| Phytomass | 1 |
| Middle Eastern Oil Fileds | 10000 |
| N. American Oil Fields | 1.000-2.000 |
| Natural Gas (conventional) | 1.000-10.000 |
| Coal | 1.000-10.000 |
| Coal | 250-500 |
| Fast Growing Trees plantations | 0,1-1-1,2 |
| Bioenginered trees | 2 |
| Harvesting mature virgin forests | 0,22-0,,25 |
| Crop residues | 0,05 |
| Ethanol | 0,25 |
| Biodiesel | 0,12-0,18 |
| Solar PV | 2,7 |
| Wind turbines | 1,2-10 |
| Hydropower | 3 |
| Wood chips from Forests | 0,6 |

| Power Density in | W/m² |
|---|---|
| Nuclear | 56 |
| Average US Natural Gas well | 53 |
| Solar PV | 6,7 |
| Wind Turbines | 1,2 |
| Biomass Fueled Power Plant | 0,4 |
| Corn Ethanol | 0,05 |

| Power Density | In W/m² |
|---|---|
| CSP | 1,5-8 |
| Solar PV | 2-10 |
| Wind | 1-10 (<1) |
| Biofuels | 0,1 |

| USA CSP plants | Technology | Storage | Power Density (We/m2) |
|---|---|---|---|
| Maricopa | Dish Stirling | no | 4,17 |
| Tooele Army Depot | Dish Stirling | no | 0,06 |
| Nevada Solar One | Parabolic | 0,5h | 7,5 |
| Solana Generating | Parabolic | 6h | 9,69 |
| Genesis | Parabolic | no | 8,7 |
| Martin Next Generation | Parabolic | no | 3 |
| Mohave | Parabolic | no | 8,26 |
| SEGS I-IX | Parabolic | no | 6,69 |
| Crescent Dunes | Tower | 10h | 1,29 |
| Ivanpah 1, 2, 3 | Tower | no | 5,25 |
| Sierra Sun | Tower | no | 0,4 |
| | | | |
| **UAE CSP Plant** | | | |
| SHAMS | Parabolic | no | 6,25 |
| | | | |
| **Spain CSP plants** | | | |
| Andasol 1,2,3, Granada | parabolic | 7,5 | 6,26 |
| Valle 1,2, Cádiz | parabolic | 7,5 | 7,02 |
| La Africana, Córdoba | parabolic | 7,5 | 6,46 |
| Borges Lérida | parabolic | no | |
| Enerstar Villena, Alicante | parabolic | no | |
| Puerto Errado 1,2, Murcia | fresnel | 0,5h | |

| 100% Renewbles, CSP Proposals | Proposed Twe of CSP | On Total Required for 100% Renew. Scenario | Cp |
|---|---|---|---|
| García-Olivares 2016 | | 12 | 0,4-0,75 |
| Jacobson-Deluchi 2011 | 2,3 | 11,5 | |
| Greenpeace 2015 | 1,6 | 9,7 | 0,63 |
| WWF | 1 | 8,3 | |
| Jacobson 2016 | 1,8 | 11,8 | 0,53 |
| De Castro-Capellan | Not relevant | | 0,25 |

Sources: Smil, Vaclav 2017 Vaclav Smil: Energy Transitions: History, Requirements, Prospects. Bryce, Robert 2009. Power Hungry: The Myths of "Green" Energy and the Real Fuels of the Future. de Castro, Carlos et al and De Castro, Carlos and Capellanes various