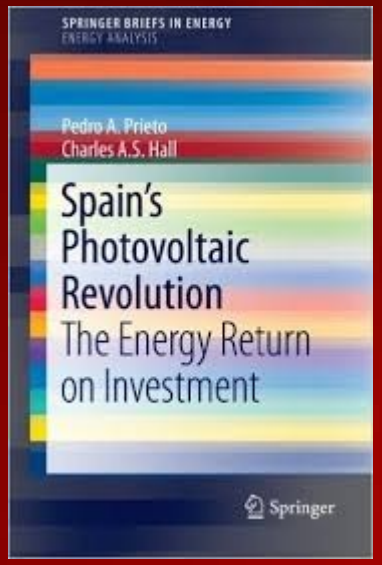
The net EROI for solar PV: a case study for Spain



Des HOUCHES
March 7th. 2016
Pedro A. Prieto

ÉCOLE DE PHYSIQUE des HOUCHES

UNIVERSITÉ Grenoble Alpes

Why Spain?

The author's own experience in design, development consulting, contracting and constructing over 30 MW

And plenty of available data from the industry

Why Spain?

Because it has a reasonable, stable and balanced electric network, a good management and the country works almost like and electric island

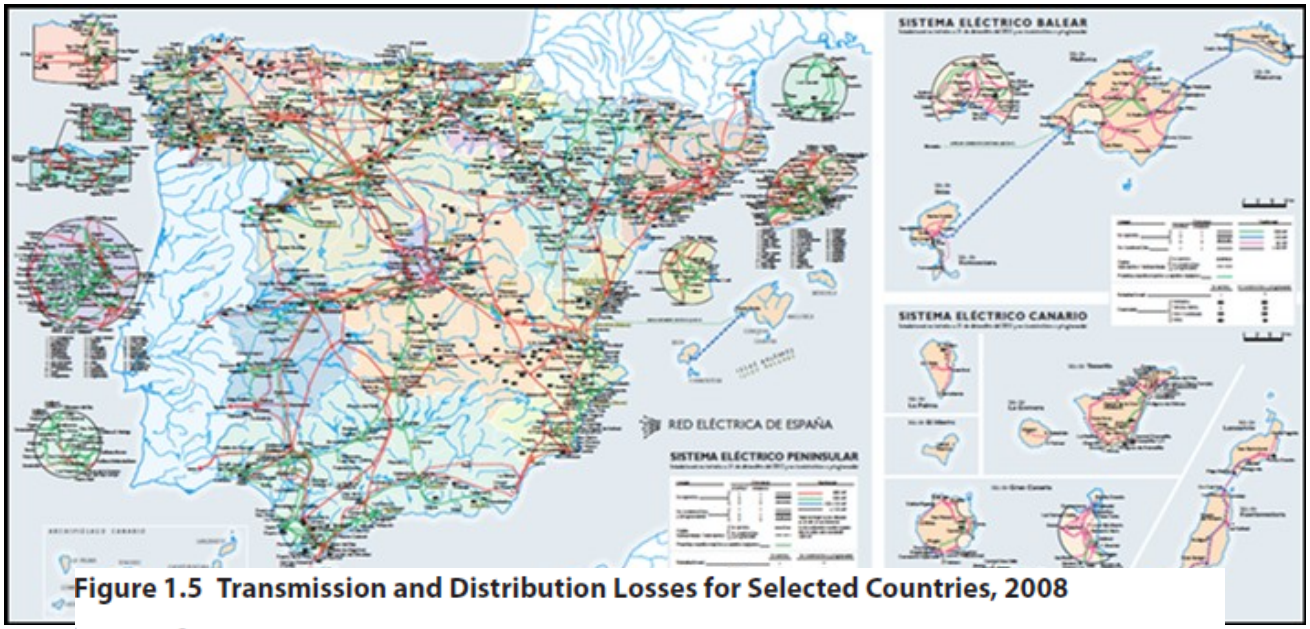
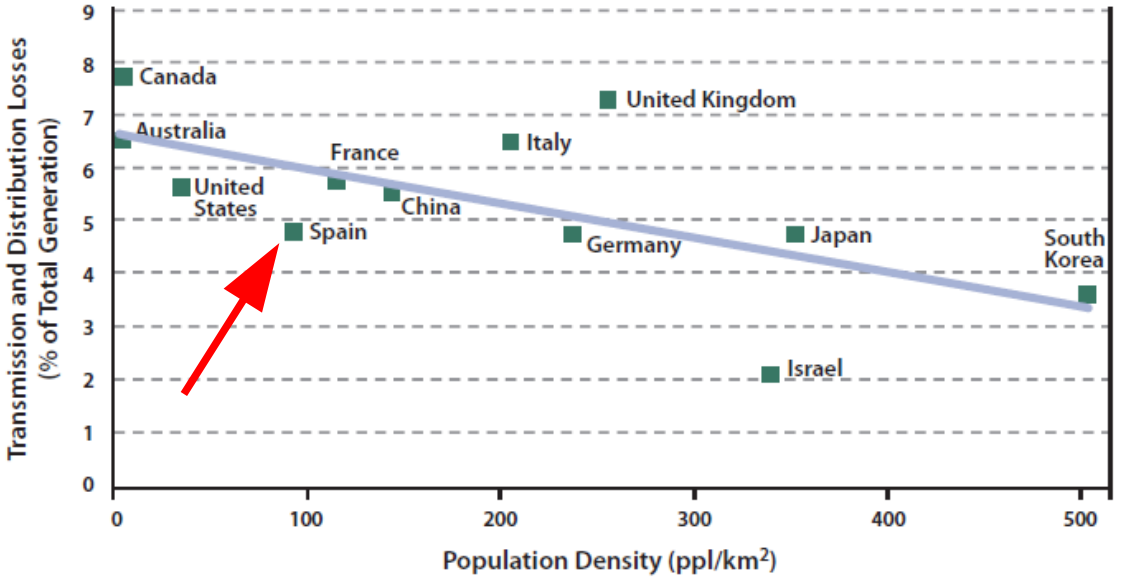


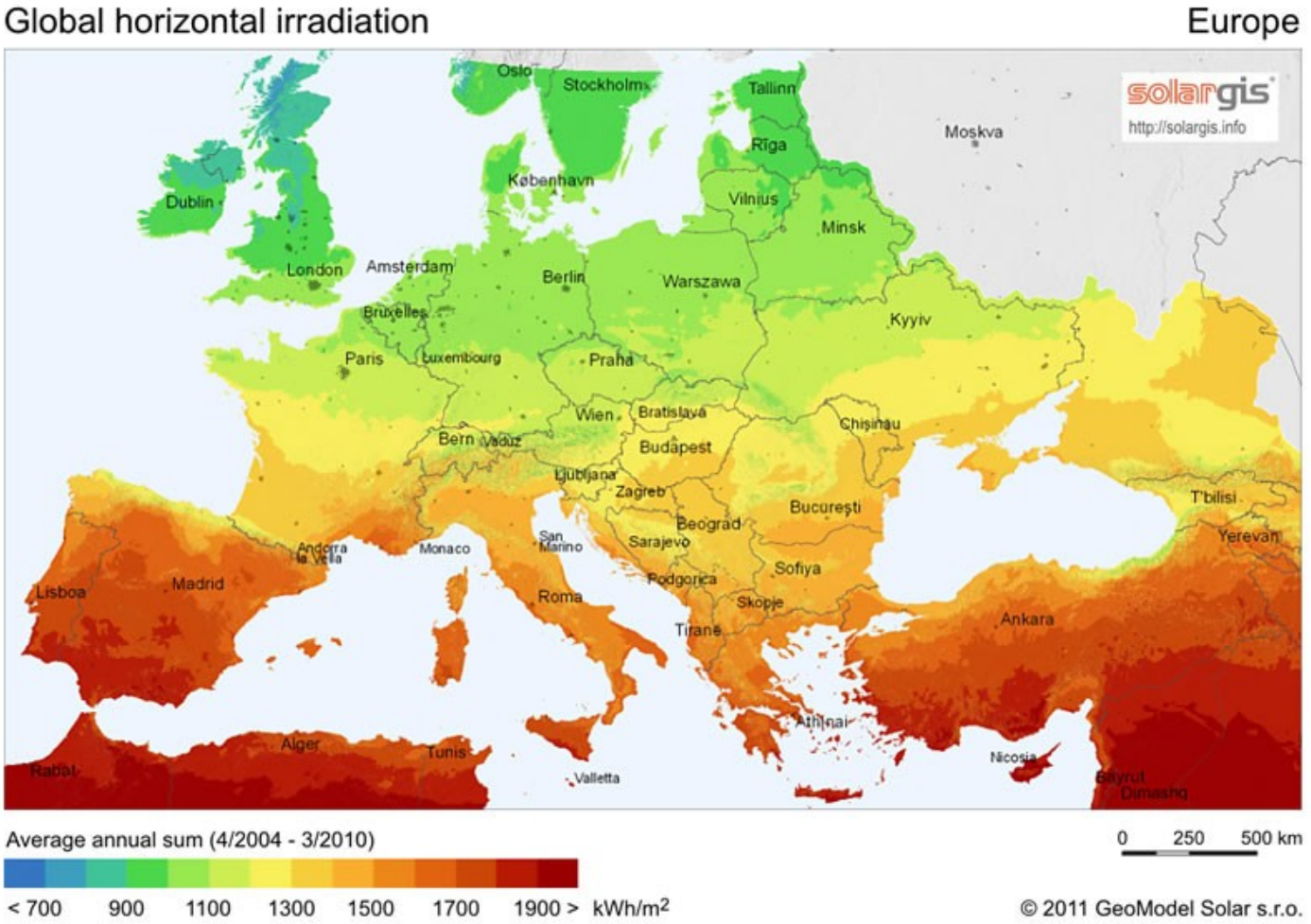
Figure 1.5 Transmission and Distribution Losses for Selected Countries, 2008



Source: World Bank Development Indicators, http://data.worldbank.org/indicator.

Why Spain?

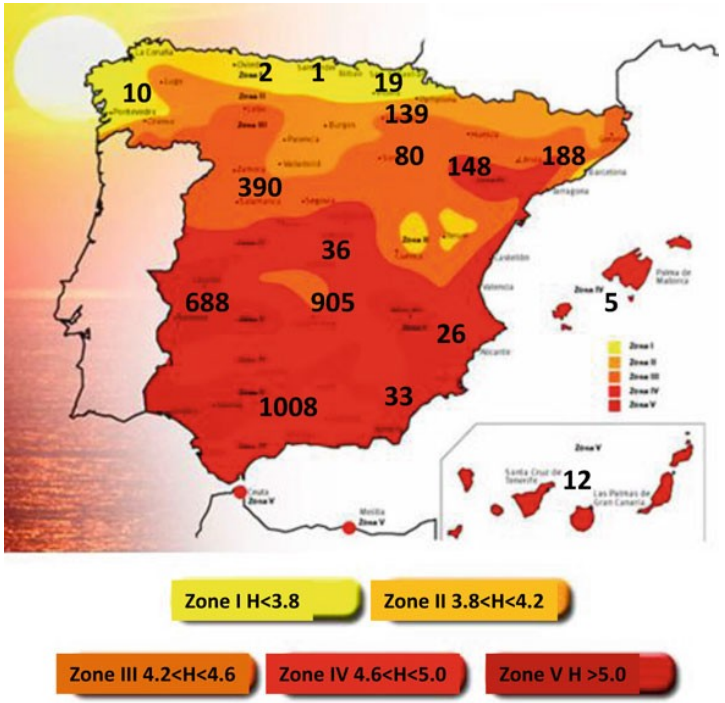
- The best irradiation in Europe.



Why Spain?

- Very accurate generation and installed power data per month and per region

		SOLAR PV			SOLAR CSP			WIND		
		Sold Energy (GWh)	Installed Power (MW)	Nº Installat.	Sold Energy (GWh)	Installed Power (MW)	Nº Installat.	Sold Energy (GWh)	Installed Power (MW)	Nº Installat.
2013	January	443	4.541	60.205	113	2.000	44	6.304	22.697	1.317
	February	524	4.559	60.351	204	2.000	44	5.356	22.697	1.318
	March	560	4.621	60.593	123	2.000	44	5.744	22.721	1.320
	April	756	4.638	60.687	294	2.050	45	4.403	22.750	1.323
	May	866	4.638	60.686	499	2.050	45	3.943	22.750	1.323
	June	925	4.638	60.686	647	2.050	45	3.850	22.766	1.325
	July	969	4.638	60.686	753	2.100	46	2.865	22.766	1.325
	August	892	4.638	60.687	659	2.150	47	3.432	22.785	1.329
	September	755	4.639	60.688	479	2.250	49	3.217	22.785	1.328
	October	631	4.639	60.690	292	2.300	50	3.973	22.785	1.328
	November	505	4.640	60.701	199	2.300	50	6.422	22.785	1.328
	December	432	4.640	60.698	158	2.300	50	4.924	22.785	1.328
Total 2013		8.260			4.422			54.432		



		SOLAR PV		SOLAR CSP		WIND	
		Sold Energy (GWh)	Installed Power (MW)	Sold Energy (GWh)	Installed Power (MW)	Sold Energy (GWh)	Installed Power (MW)
2013	ANDALUCIA	1.571	868	1.986	997	6.887	3.255
	ARAGON	309	167			4.857	1.794
	ASTURIAS	1	1			1.049	476
	BALEARES	120	78			6	4
	CANARIAS	280	162			348	146
	CANTABRIA	2	2			75	35
	CASTILLA LA MANCHA	1.697	920	678	349	8.557	3.795
	CASTILLA Y LEON	843	490			12.764	5.521
	CATALUÑA	422	262	74	23	3.229	1.293
	CEUTA Y MELILLA	0	0				
	COMUNIDAD VALENCIANA	552	344	10	50	2.528	1.193
	EXTREMADURA	1.107	561	1.632	849		
	GALICIA	20	15			9.550	3.353
	LA RIOJA	130	86			1.074	448
	MADRID	96	64				
	MURCIA	795	436	43	31	544	263
	NAVARRA	291	160			2.505	1.016
	PAIS VASCO	28	25			460	194
Total 2013		8.262	4.640	4.422	2.300	54.432	22.785

Why Spain?

- The best and most accurate official data on generation and installed base.
- Massive and stable deployment (~ 4 GW).
- Three complete years of monitoring (2009-2011)

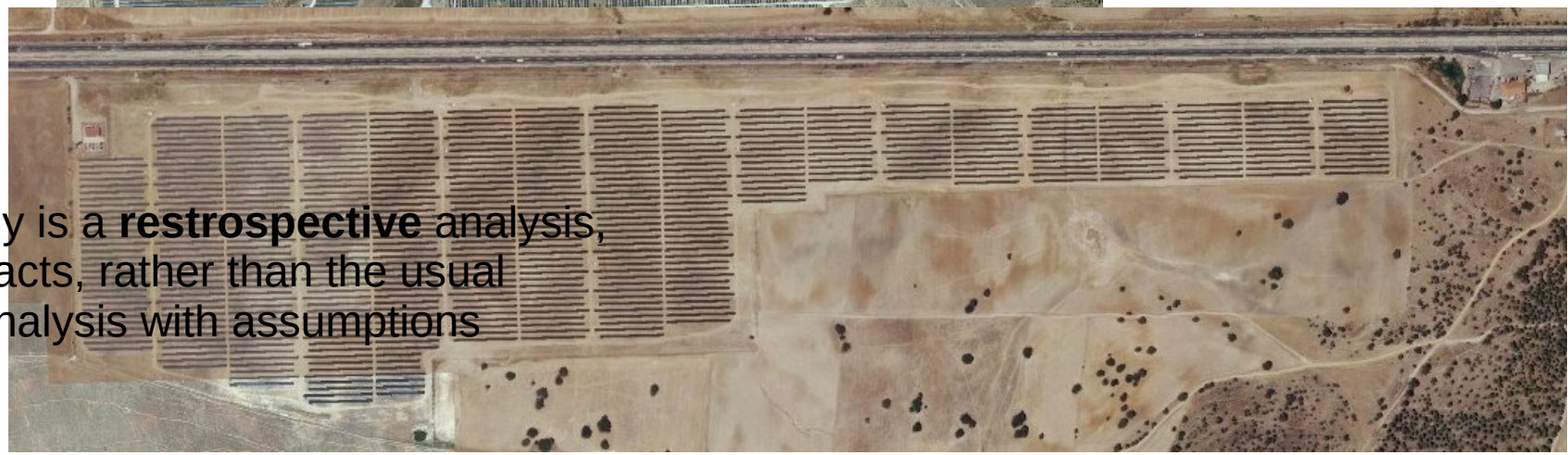
	SOLAR PV					
YEAR	Sold Energy (GWh)	Installed Power (MW)	Nº Instalations	Total Premium (in K€)	Total Average Premium (cent€/kWh)	Equivalent Premium (K€)
2008	2.528	3.398	51.310	1.155.068	45,321	990.830
2009	6.074	3.397	52.099	2.868.288	46,236	2.634.217
2010	6.398	3.837	55.014	2.896.765	45,278	2.650.386
2011	7.415	4.246	57.972	2.665.168	35,942	2.281.656
2012	8.158	4.538	60.160	3.006.657	36,855	2.613.031
2013	8.262	4.640	60.698	2.928.642	35,449	2.561.333

	SOLAR CSP					
AÑO	Sold Energy (GWh)	Installed Power (MW)	Nº Instalations	Total Premium (in K€)	Total Average Premium (cent€/kWh)	Equivalent Premium (K€)
2010	692	532	13	211.503	30,584	184.872
2011	1.779	999	23	518.926	29,165	426.901
2012	3.433	1.950	43	1.091.087	31,781	925.439
2013	4.422	2.300	50	1.308.334	29,584	1.111.713

	WIND					
AÑO	Sold Energy (GWh)	Installed Power (MW)	Nº Instalations	Total Premium (in K€)	Total Average Premium (cent€/kWh)	Equivalent Premium (K€)
2008	32.128	16.323	731	3.226.384	10,041	1.155.818
2009	38.275	18.861	1.098	3.065.472	8,009	1.621.278
2010	43.144	19.706	1.138	3.366.282	7,803	1.965.412
2011	41.862	21.069	1.216	3.657.242	8,736	1.711.055
2012	48.329	22.636	1.302	4.096.870	8,477	2.053.020
2013	54.432	22.785	1.328	4.418.240	8,117	2.393.927

Why Spain?

Plenty of accurate information on all types of energy and economic costs of all types of installations



The Case Study is a **restrospective** analysis, basically with facts, rather than the usual **prospective** analysis with assumptions

Why Spain?

There are many freely and available up-to-date technologies chosen by the investors as they considered more convenient

STRUCTURE OF THE ANALYZED FIELDS	%
TOPOLOGY	
Fixed Plants	63
One Axis Trackers	13
Two Axis Trackers	24
TIPOLOGY	
Rooftop Installations	2,2
On the Ground Inst	97,8
SIZE	
<2 MW	36
2-5 MW	20
>5 MW	44
TECHNOLOGY	
Crystaline Silicon	97,3
Thin Film	2,1
HCPV	0,6

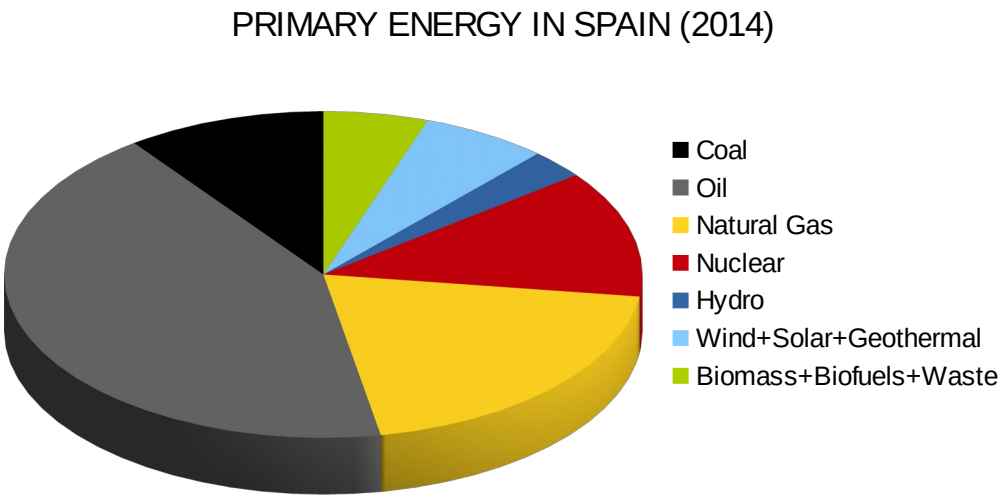
Source: July 2009 report on the status of PV in Spain. Asociación de la Industria Fotovoltaica, ASIF (today ANPIER)

A curious comparative

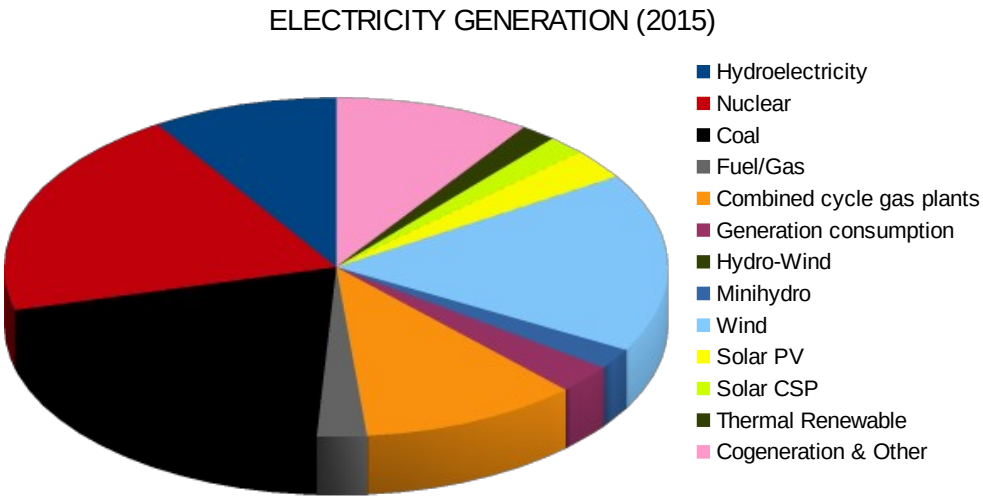
2 GW nuclear power plant (85% load factor) versus 23 MW solar PV plant (22% load factor) in Almaraz (Cáceres)

The Energy System in Spain

PRIMARY ENERGY SPAIN 2014	Ktoe	%
Coal	11975	10%
Oil	50740	43%
Natural Gas	23664	20%
Nuclear	14933	13%
Hydro	3361	3%
Wind+Solar+Geothermal	7617	6%
Biomass+Biofuels+Waste	6296	5%
TOTAL	**118586**	**100%**

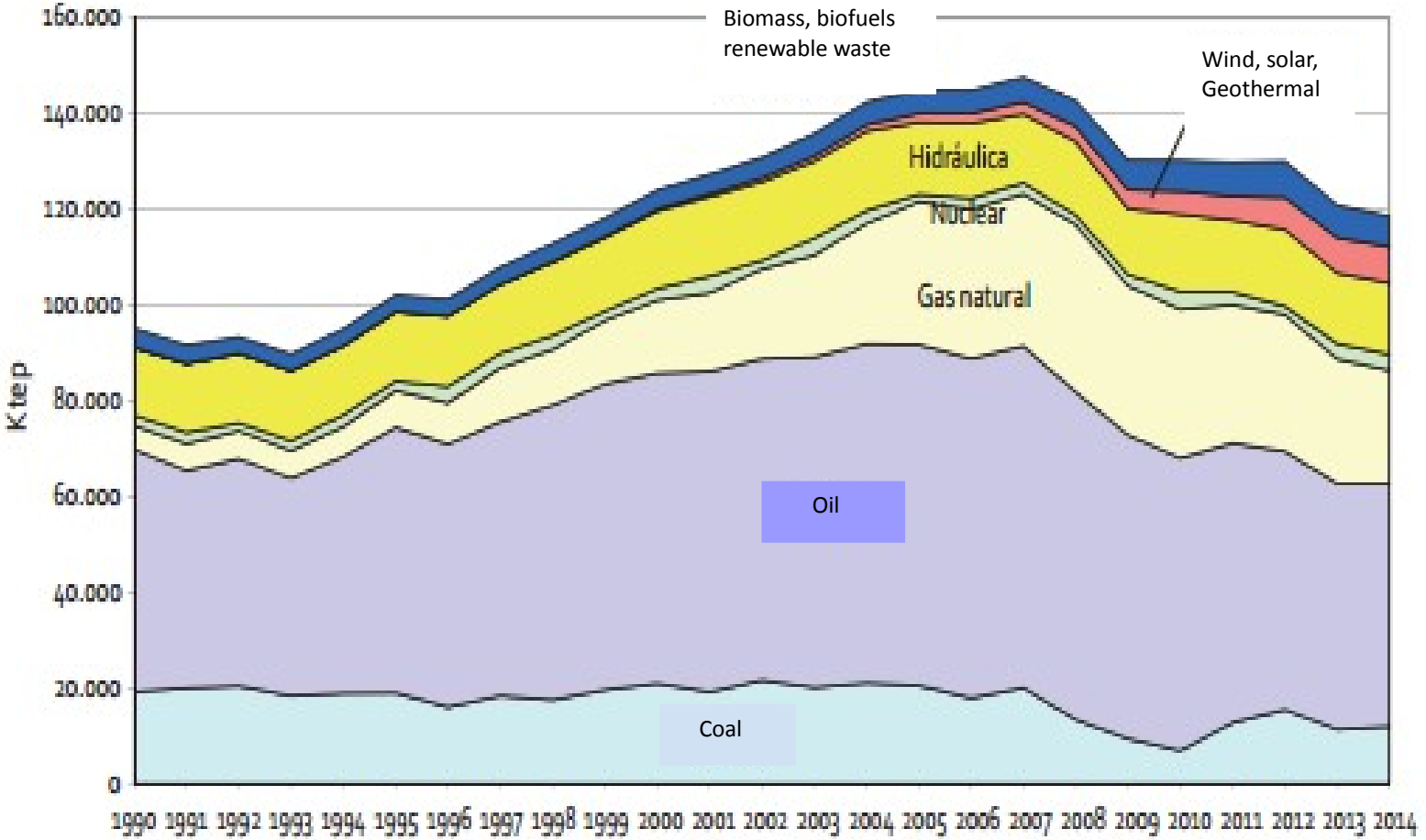


ELECTRIC SYSTEM SPAIN 2015	Gwh	%	MW Inst.	%	LOAD FACTOR
Hydroelectricity	25733	9,60%	18669	17,24%	15,73%
Nuclear	56796	21,19%	7866	7,26%	82,43%
Coal	56672	21,14%	11482	10,60%	56,34%
Fuel/Gas	6891	2,57%	2784	2,57%	28,26%
Combined cycle gas plants	30217	11,27%	27199	25,11%	12,68%
Generation consumption	-7838	-2,92%			
Hydro-Wind	9	0,00%	12	0,01%	8,56%
Minihydro	5663	2,11%	2109	1,95%	30,65%
Wind	48380	18,05%	23003	21,24%	24,01%
Solar PV	8264	3,08%	4667	4,31%	20,21%
Solar CSP	5158	1,92%	2300	2,12%	25,60%
Thermal Renewable	4930	1,84%	989	0,91%	56,90%
Cogeneration & Other	27183	10,14%	7219	6,67%	42,98%
NET GENERATION	**268058**	**100%**	**108299**	**100%**	**28,26%**
Pump up Consumption	-4497	-1,68%			
International Exchanges	-467	-0,17%			
DEMAND IN BARS	**263094**				
TOTAL RENEWABLE	**125320**	**46,75%**			



Sources: El libro de la energía 2014. Ministerio de Industria. http://www.minetur.gob.es/energia/balances/Balances/LibrosEnergia/La_Energ%C3%ADa_2014.pdf
REEEl sistema eléctrico español 2015. http://www.ree.es/sites/default/files/downloadable/avance_informe_sistema_electrico_2015_v2.pdf

Evolution of Primary energy in Spain

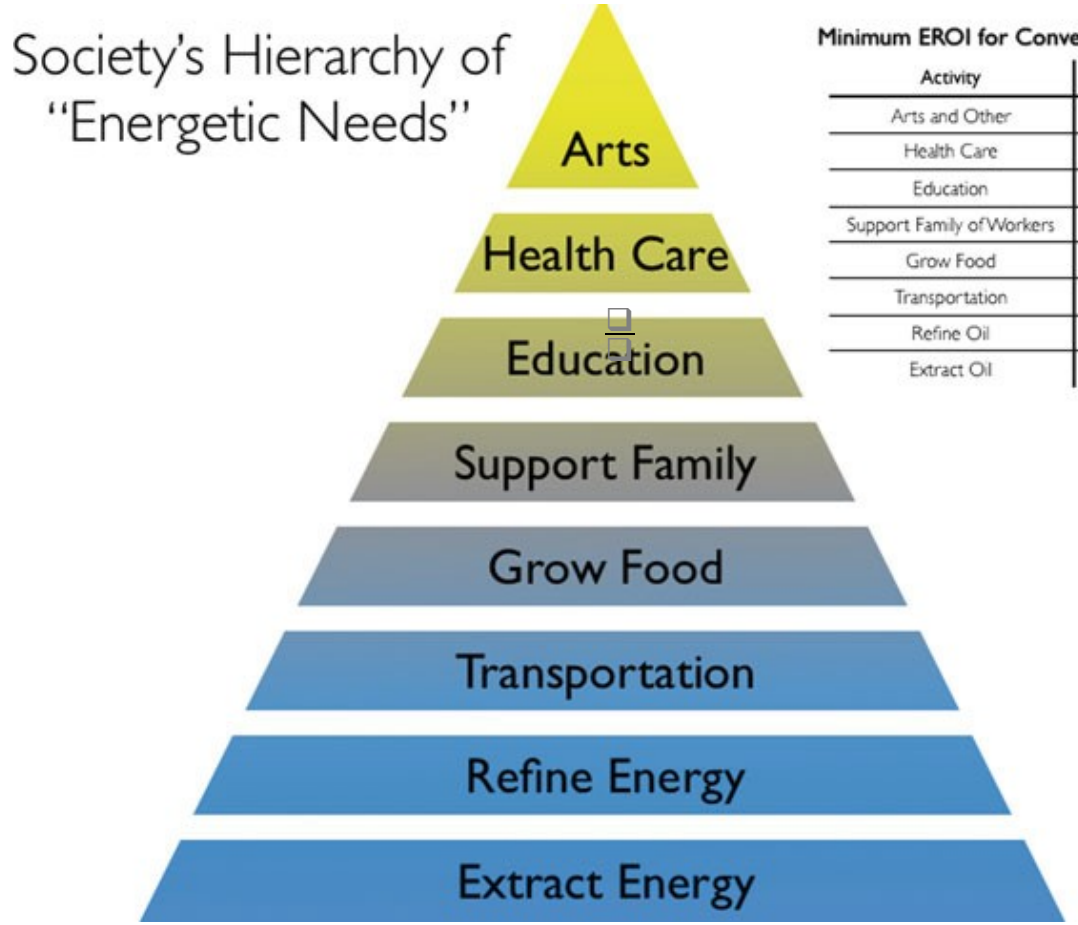


Source: Ministry of Industry. El Libro de la Energía 2014. Page 312. http://www.minetur.gob.es/energia/balances/Balances/LibrosEnergia/La_Energ%C3%ADa_2014.pd

The Spanish Legislative Labyrinth for the Renewable Program

	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

The Pyramid of Energetic Needs and Required EROIs



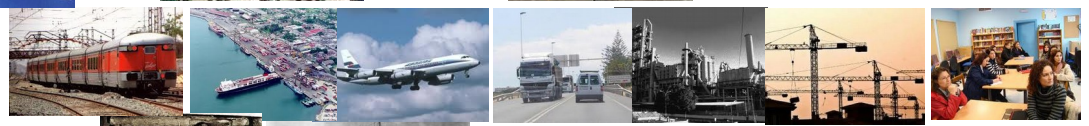
Minimum EROI for Conventional Sweet Crude Oil

Activity	Minimum EROI Required
Arts and Other	14 : 1
Health Care	12 : 1
Education	9 or 10 : 1
Support Family of Workers	7 or 8 : 1
Grow Food	5 : 1
Transportation	3 : 1
Refine Oil	1.2 : 1
Extract Oil	1.1 : 1

Source: Charles Hall adapted by Lambert & Lambert 2012

The Social Inverted Pyramid on the Energy Needs (Minimum EROI)

Industrial and Technological society EROI 12-25



Industrial Developed Society EROI 8-15

Initial Industrial Society EROI 6-13

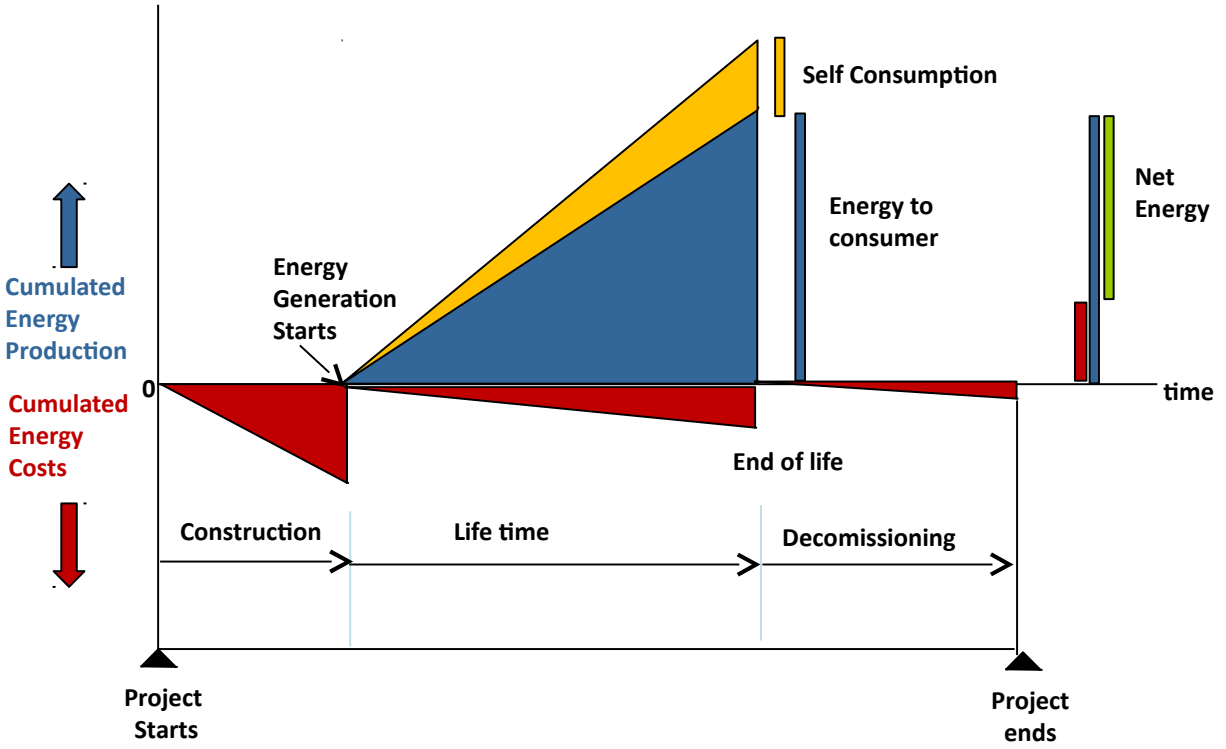
Advanced Agricultural Society EROI 5-6

Minimum EROI Strip Required for Civilization

Primitive Agriculture and cattle EROI 4-5

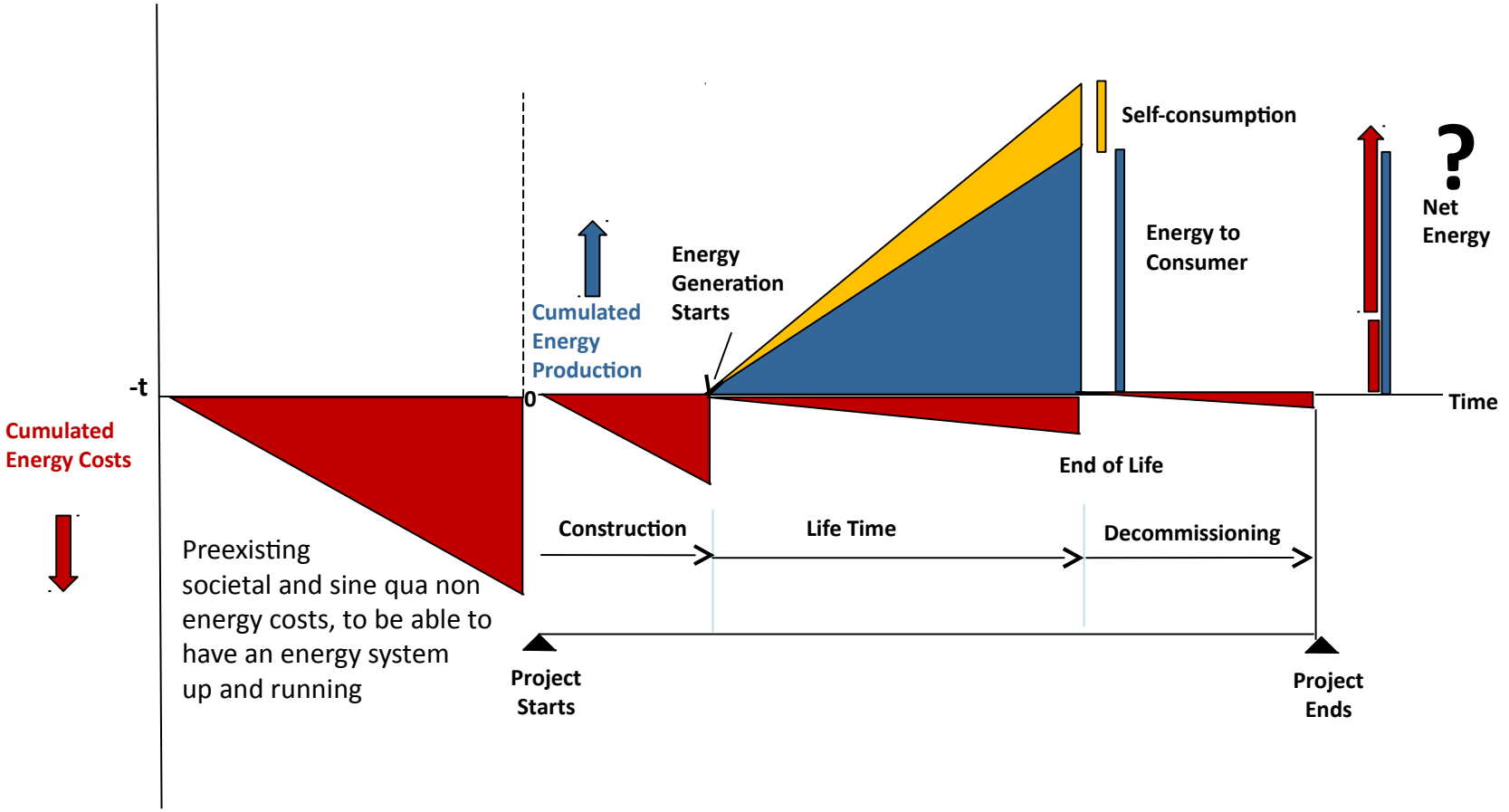
Hunter Gatherers Metabolic Level EROI 2-3

Classic EROI Vision of an Energy System

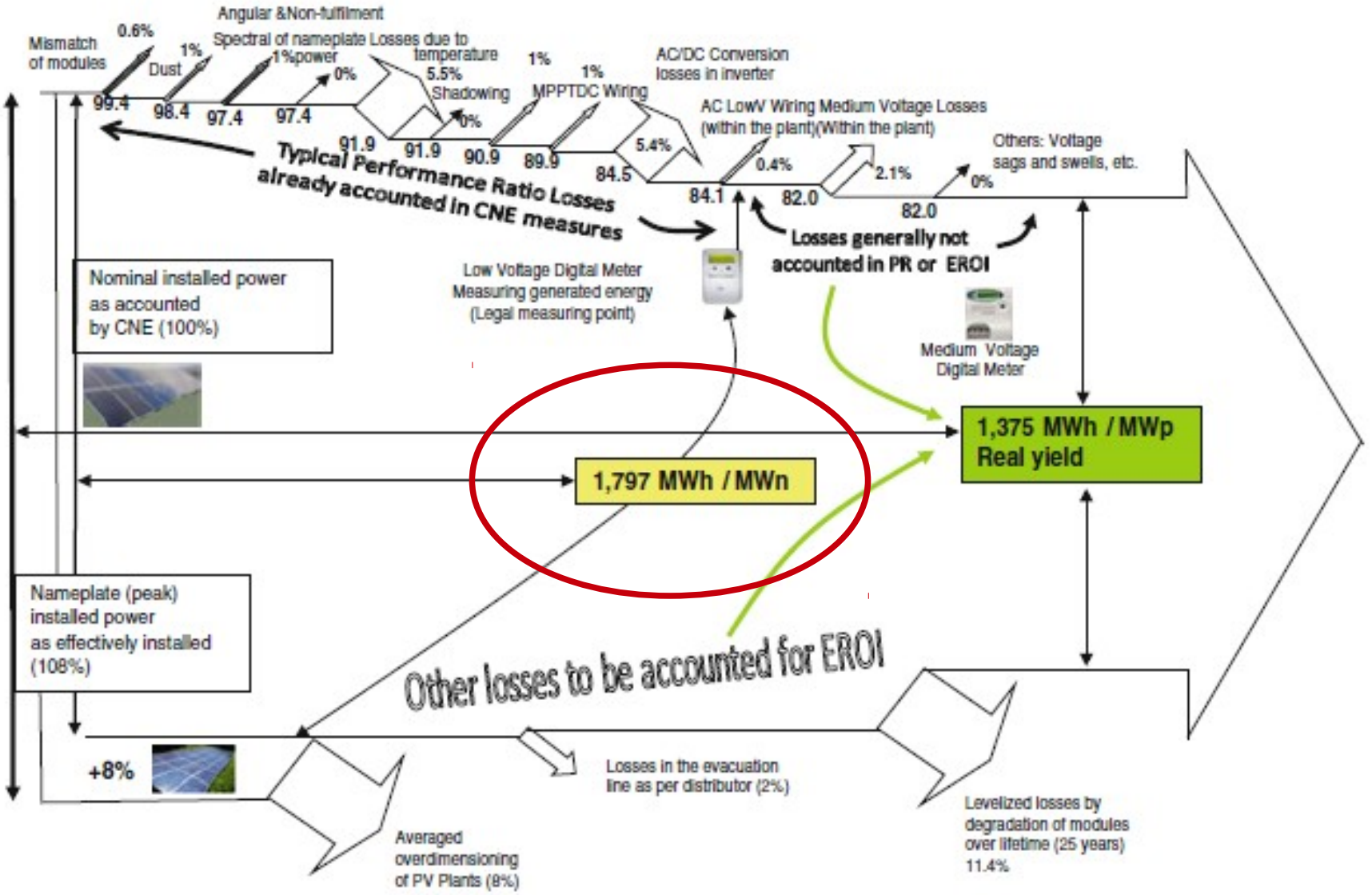


Source: Energy from Wind: A Discussion of the EROI Research. Cutler cleveland. Quoted by Nate Hagens at http://www.theoildrum.com/node/1863

A More Holistic Vision of a Modern Energy System



The Energy Return (E_{out})



Sankey diagram of solar PV energy in Spain

The Energy Return (E_{out})

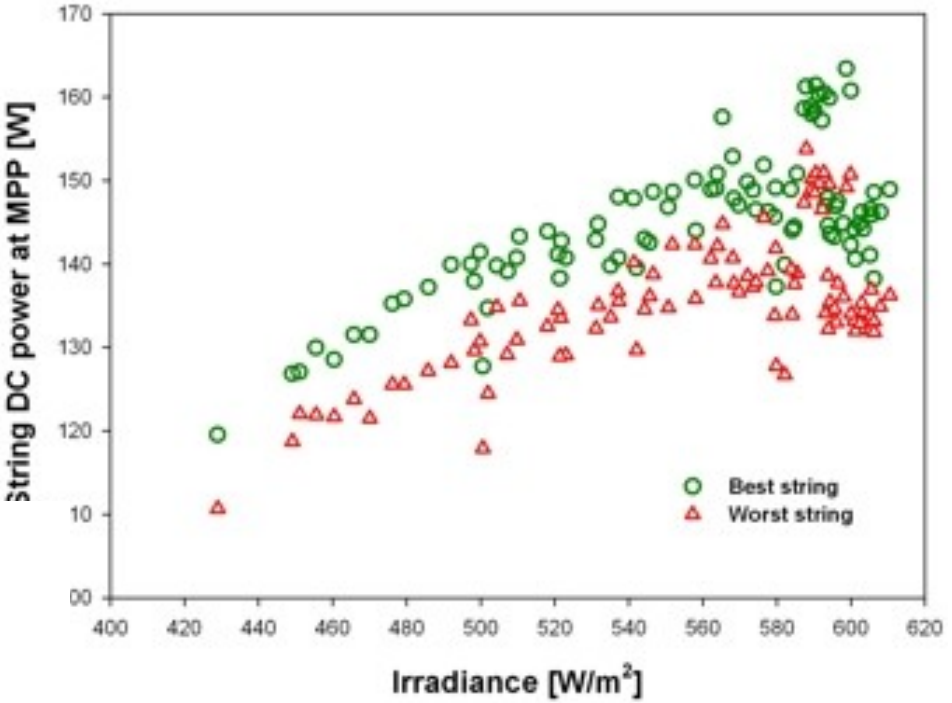
Life Cycle/Assessment of solar PV

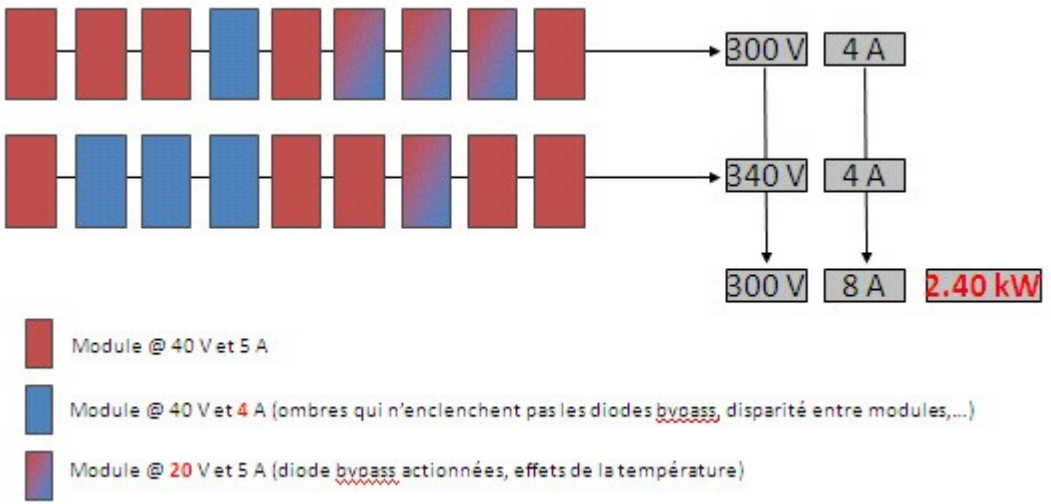
- IEA PVPS Task 12 considers **30 years.**
- Manufacturers guarantee the power **25 years.**
- Manufacturers guarantee the modules **5-12 years**.
- The later guarantee supersedes the former.
- From the European Association PV CYCLE it could rather be inferred a shorter life cycle.[1] **18 years**
- The "Quality Monitor, 2013" of the TUV Rheinland (Germany) gives some 30% of modules with serious deficiences
- Photon magazine (January 2013) states that 70% of modules have minor defects.
- The case study made a conservative assumption **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.
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 (E_{out})
Losses by Missmatch of Modules

Assumed in the Performance Ratio (PR) to be 0.6%





Sources: University of Southampton. Sustainable Enerrgy Reseaaarch Group. http://www.energy.soton.ac.uk/files/2013/06/mismatch_string_power.jpg
http://www.ehw-research.com/en/smart-power-booster/production-optimization

The Energy Return (E_{out})
Losses by Dust

Estimated in 1%

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

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

The Energy Return (E_{out})
Angular losses

Estimated in a 1%

The Energy Return (E_{out})
Non-fulfilment of power

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
Air Mass =0.5 and
temperature at 20ºC

The Case Study has considered a conservative 0%

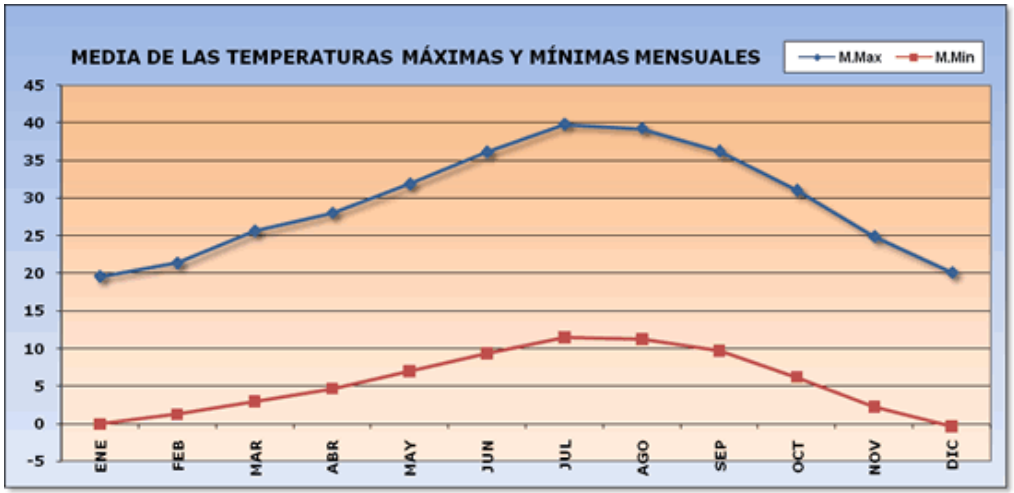
The Energy Return (E_{out})
Losses due to temperature

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

The Case Study considers 5.6% losses



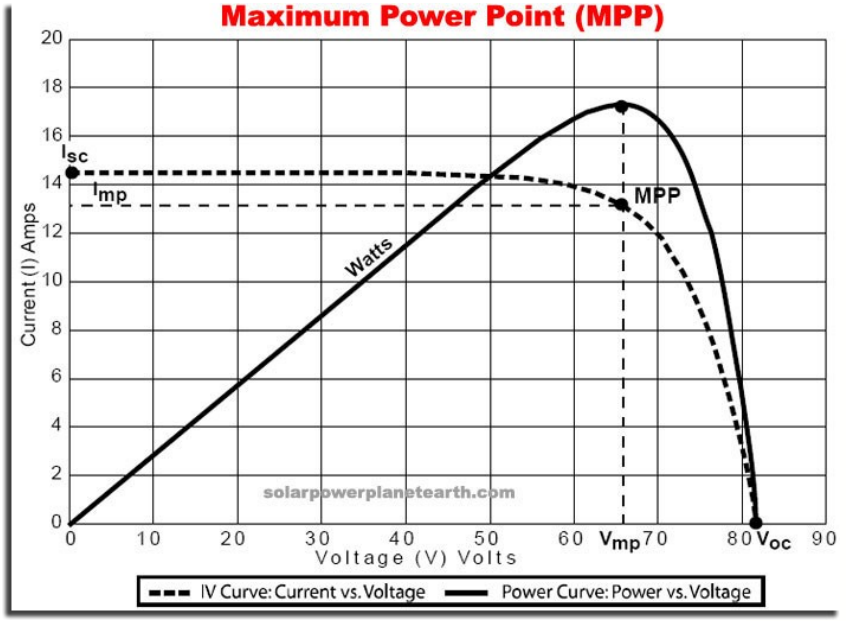
Source: Suntech. http://shangde.fanyacdn.com/imglibs/files/stp265_wem(mc4_265_260_255).pdf

The Energy Return (E_{out})
Losses for Shadowing

The Case Study considers a very conservative 0%

Source: Euaan Mearns. Energy Matters. http://euanmearns.com/rooftop-pv-panels-point-where-the-roof-points/

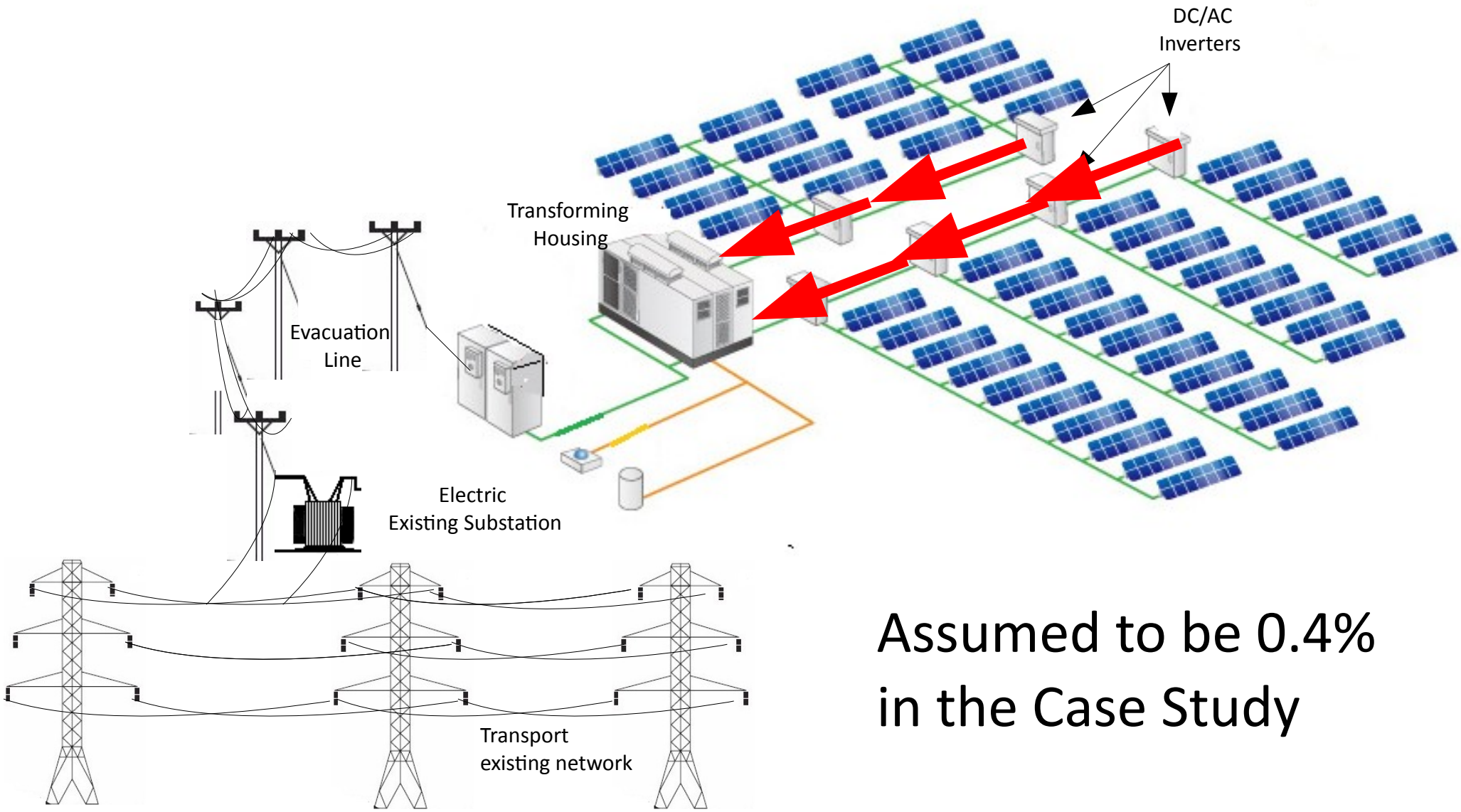
The Energy Return (E_{out})
Inverter (MPTT) Losses



Assumed to be 5.4% in the Case Study

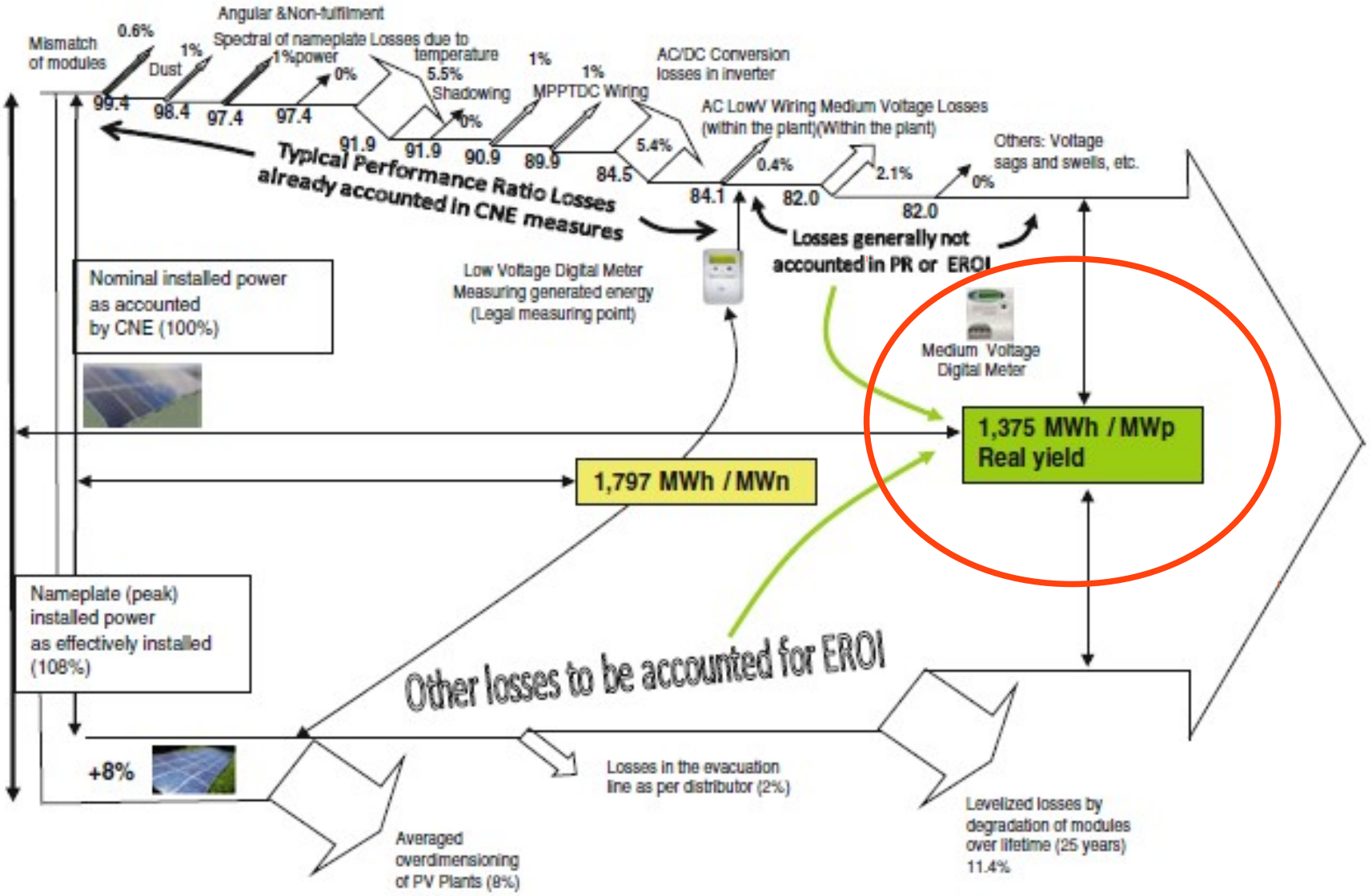
Source: for the photo. Ingeteam. Inverter 50-100 kW. Maximum efficiency at 97.5%. For the Graph solarpowerplanetearth.com

The Energy Return (E_{out})
AC Low voltage wiring losses



Assumed to be 0.4%
in the Case Study

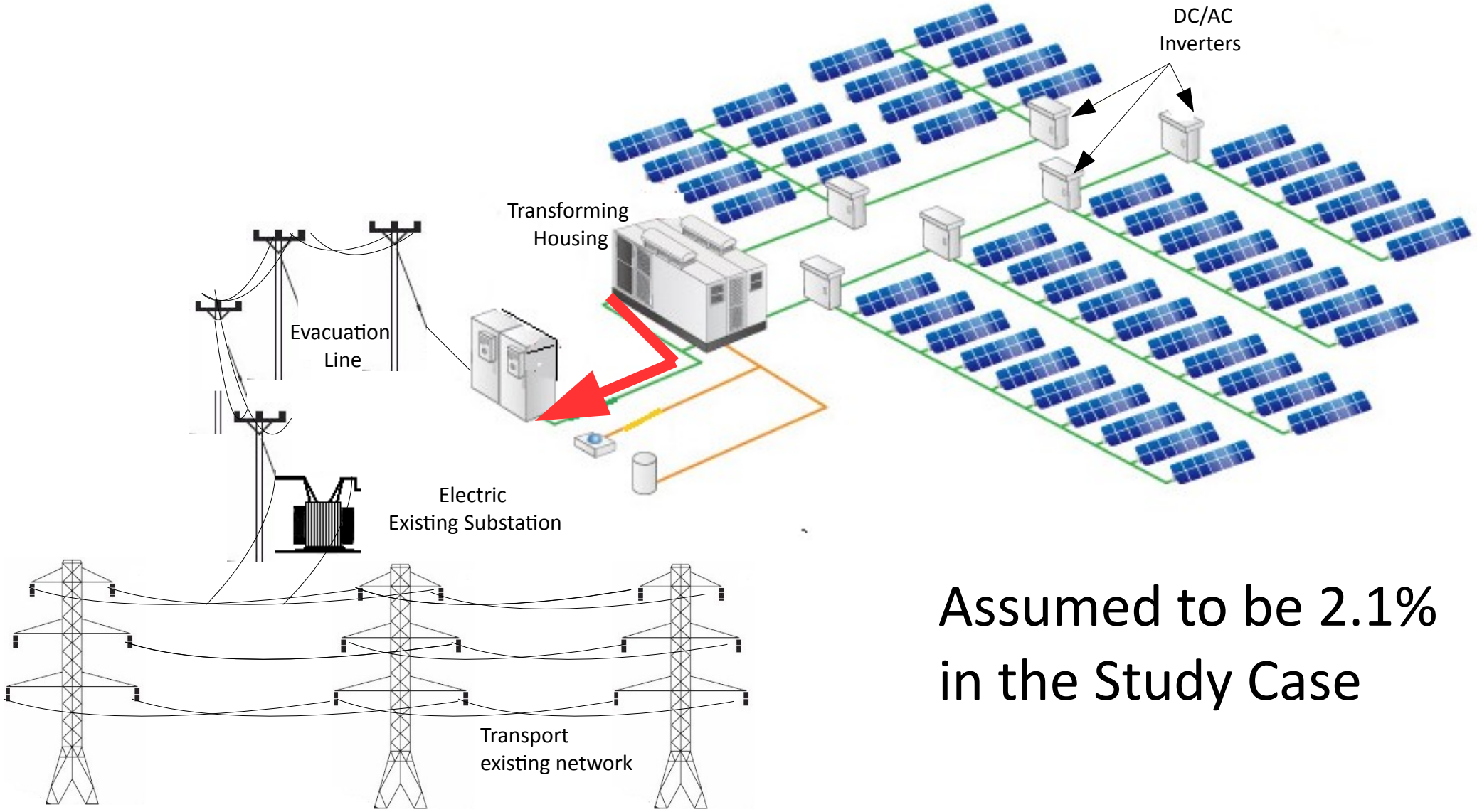
The Gross Energy Return (E_{out})



Sankey diagram of solar PV energy in Spain

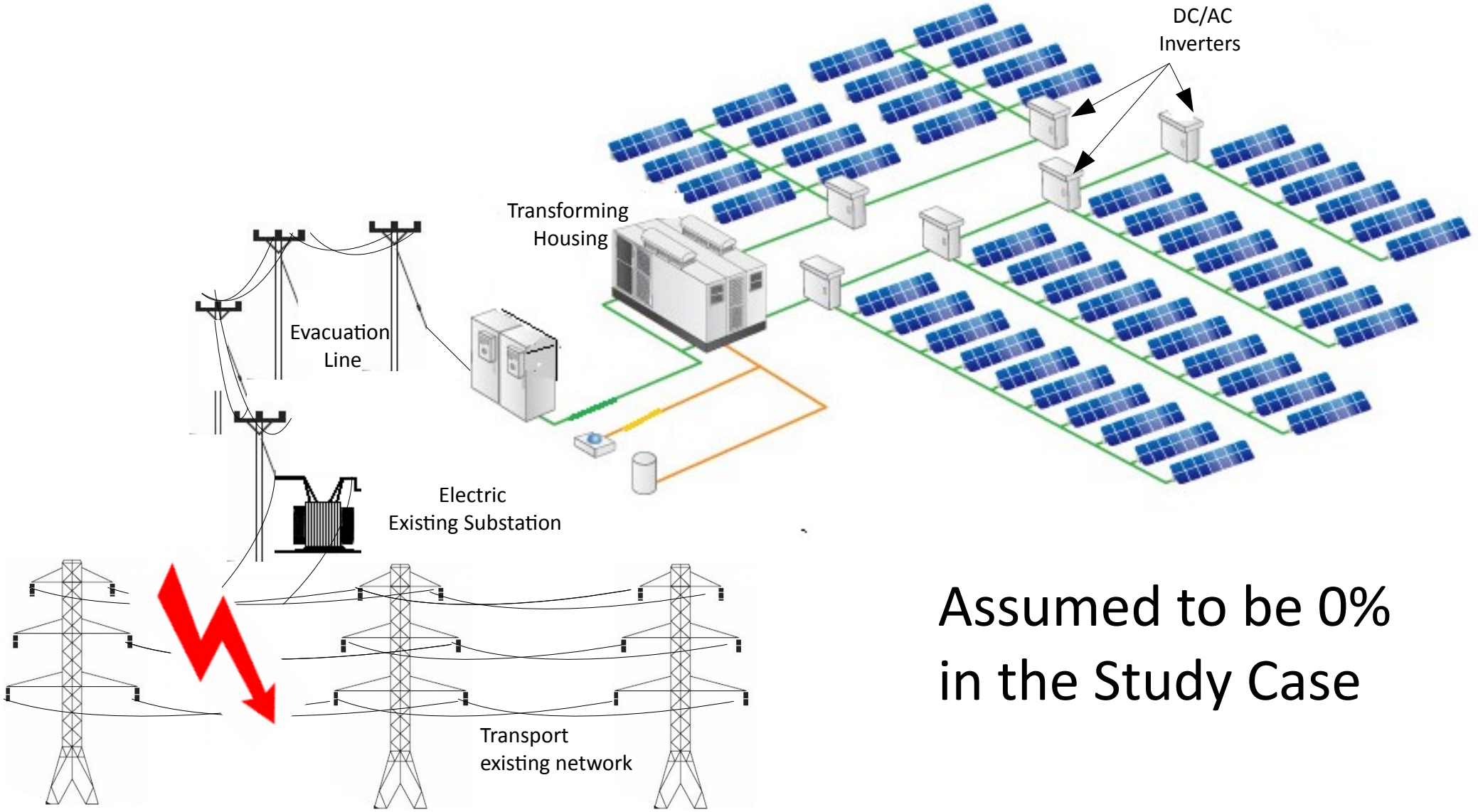
The Energy Return (E_{out})

Medium Voltage Losses within the Plant



Assumed to be 2.1%
in the Study Case

The Energy Return (E_{out})
Voltage Sags and Swells losses



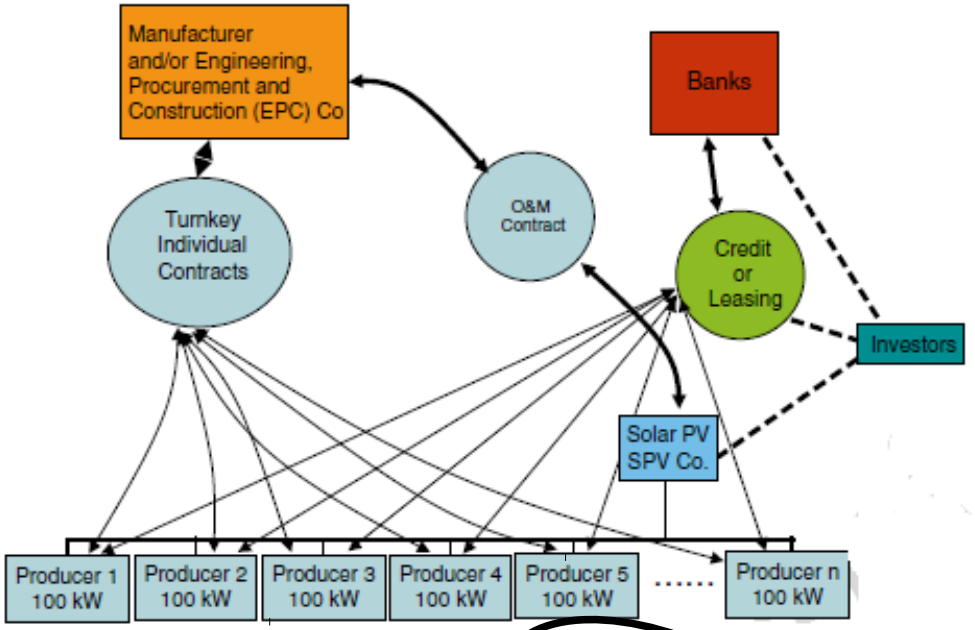
Assumed to be 0%
in the Study Case

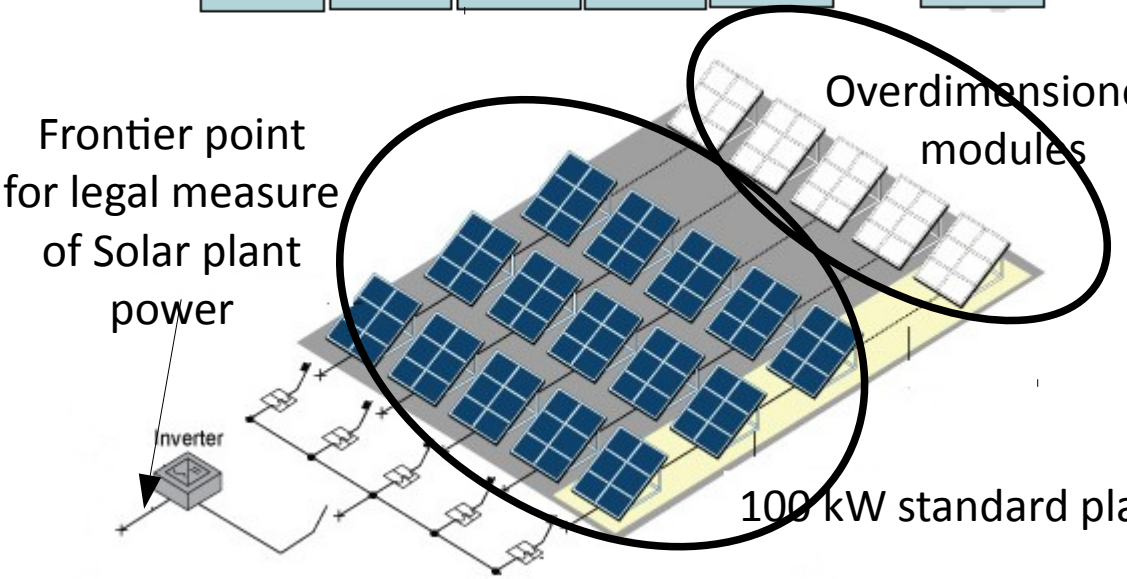
The Energy Return (E_{out})
Averaged overdimensioning

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

The study case assessed
conservatively an 8%
overdimensioning
I.e. 100 kWn = 108 kWp

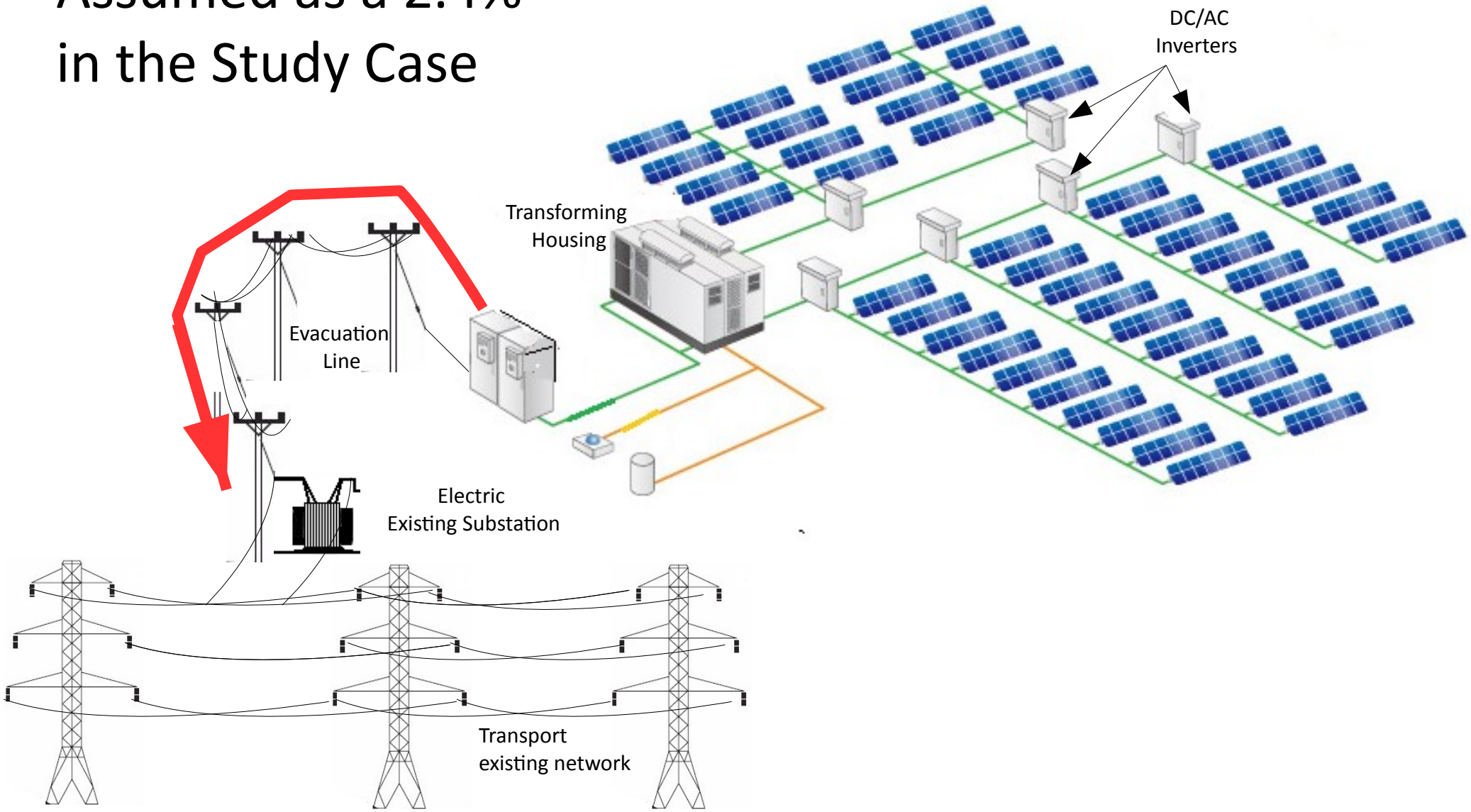
The industry admitted later
up to 20% overdimensioning





The Energy Return (E_{out})
Evacuation Line Losses

Assumed as a 2.4%
in the Study Case

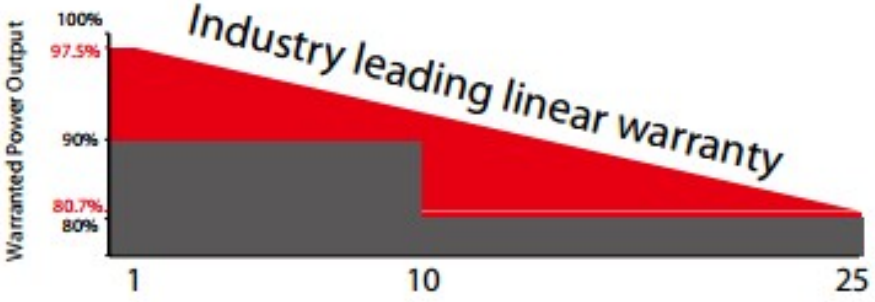


The Energy Return (E_{out})

Degradation of modules over time

Averaging the degradation of module's power over time, was assummed to be in a 11.4% along the 25 years life cycle

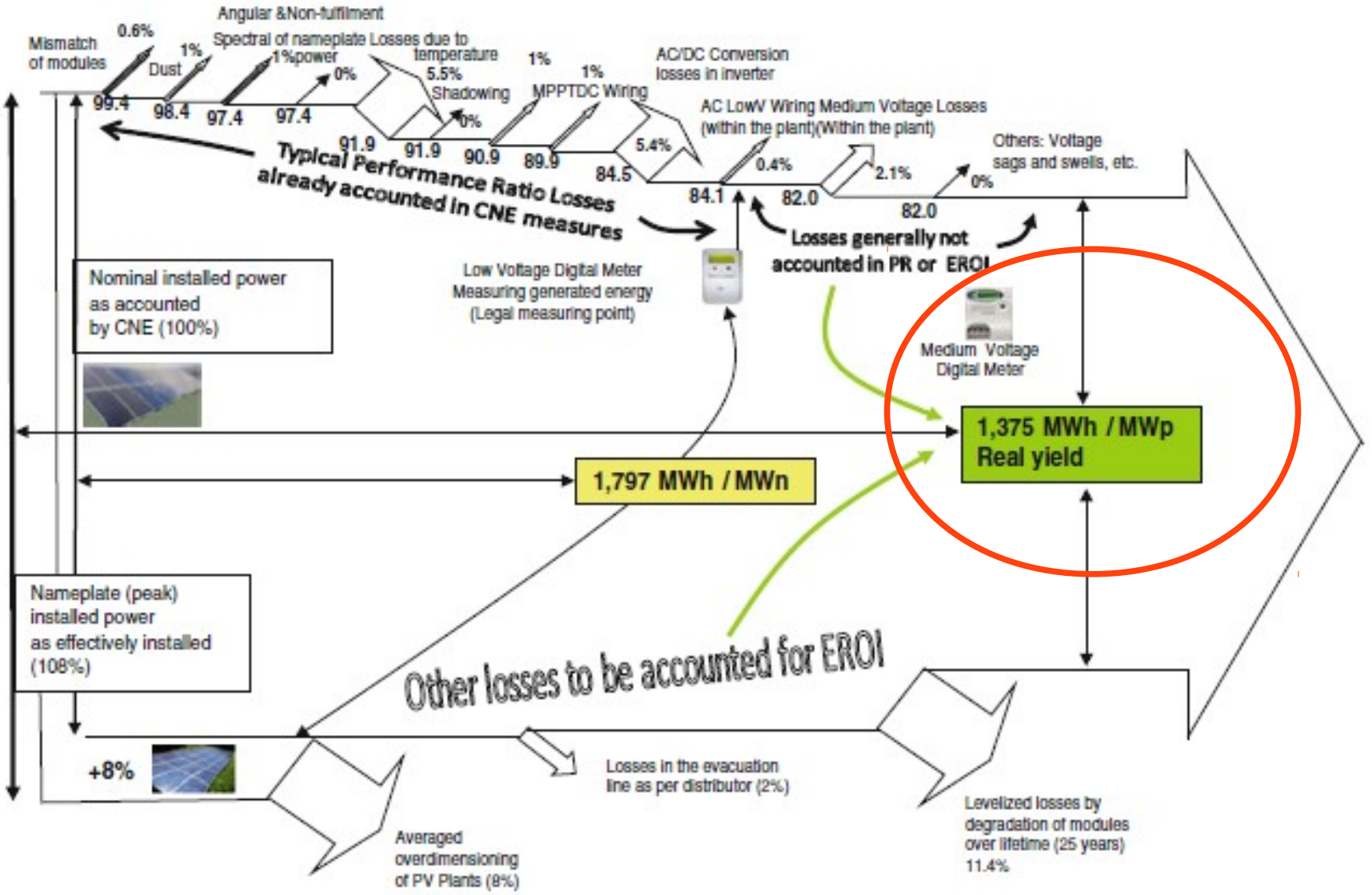
Industry-leading Warranty based on nominal power



- 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

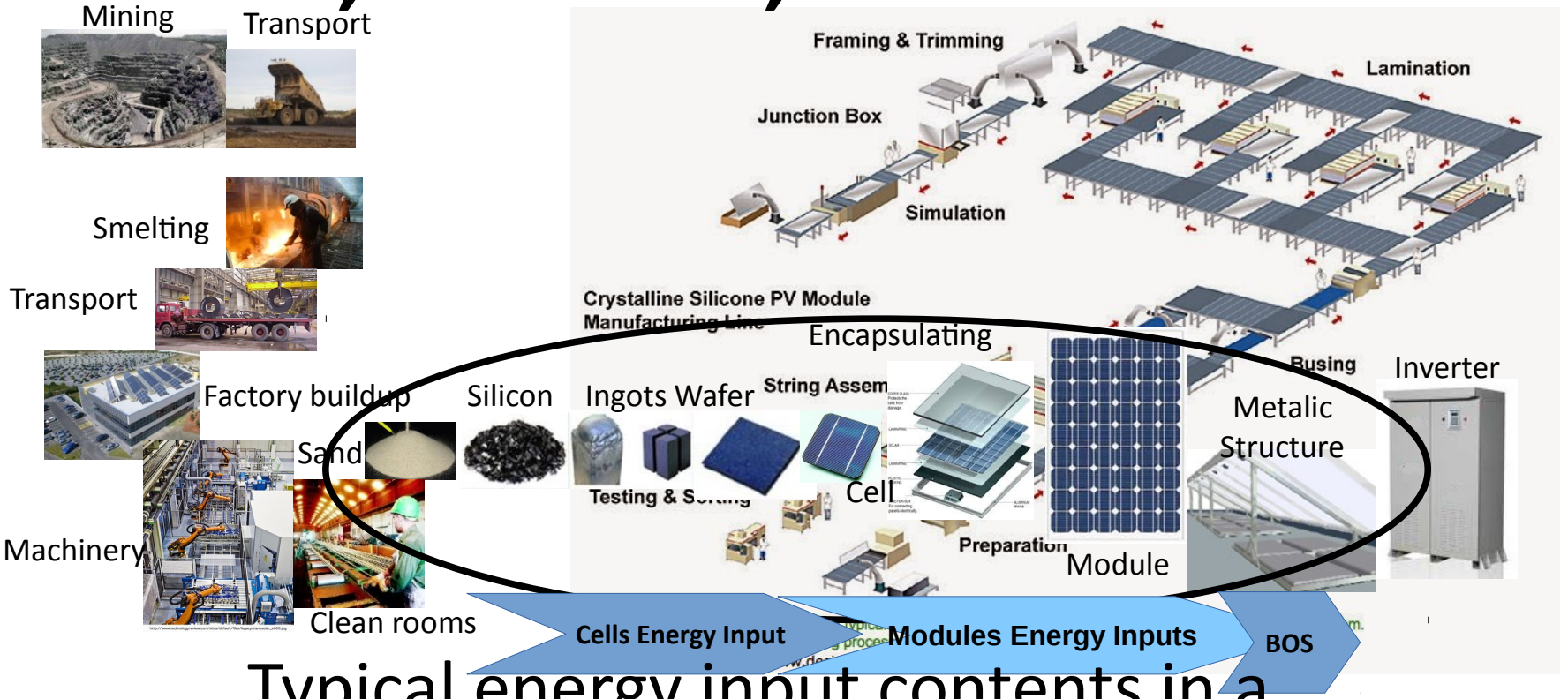
The Net Energy Return (E_{out})



Sankey diagram of solar PV energy in Spain

The Energy Invested (E_{in})

Cells, Modules, ….The Core



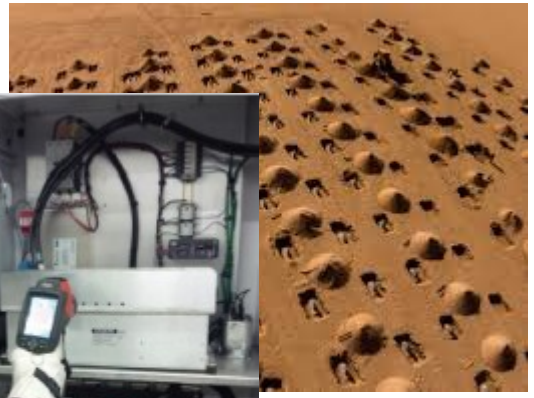
Typical energy input contents in a conventional Solar PV EROI assessment

The study gave for granted for this parameters/elements a sensible average of the most common conventional solar PV EROI published studies → **ER/EI =8.3**

The Energy Invested (E_{in})

Societal Energy expenses

Accesses, foundations, canalizations, perimeter fences



Calculated as 1.1% of total ER (Eout)

The Energy Invested (E_{in})

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
-

Calculated as 0.1% of total ER (Eout)

The Energy Invested (E_{in})

O&M Energy inputs

Calculated as 7.7% of total ER (Eout)

The Energy Invested (E_{in})

Module washing and cleaning

Calculated as 0.2 % of total ER (Eout)

The Energy Invested (E_{in})

Self Consumption

Calculated as 0.5% of total ER (Eout)

For some plants with trackers it is sometimes as much as 1-4% of generated energy, depending if electricity is market or premium priced

The Energy Invested (E_{in})

Security and Surveillance

Calculated as 2.4%
of total ER (Eout)

The Energy Invested (E_{in})

Transportation
For Equipment.
For Engineering & R&D&I
For Commercial, Marketing
For O&M

Calculated as 1.9%
of total ER (Eout)

The Energy Invested (E_{in})

Equipment Stealing and Vandalism

Calculated as 0.2% of total ER (Eout)

The Energy Invested (E_{in})

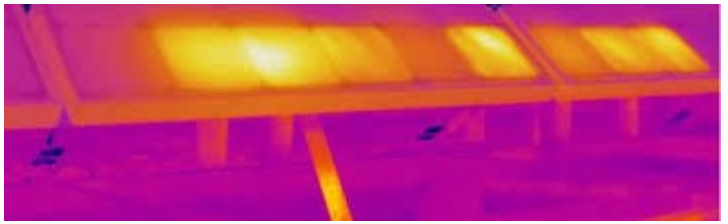
Communications, remote control and management

Calculated as 0.03% of total ER (Eout)

Broken Sealant

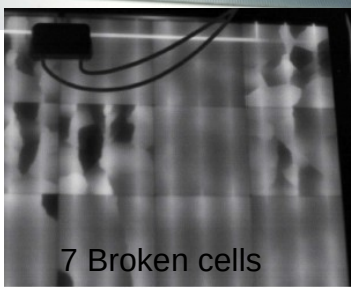
The Energy Invested (E_{in})

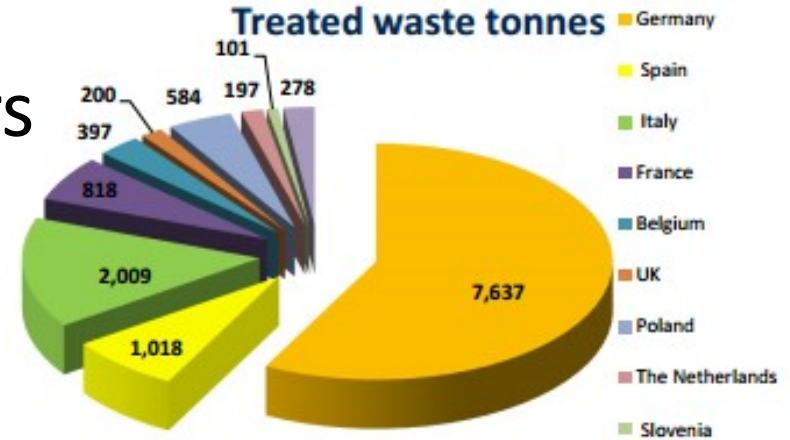
Faulty Modules, inverter, trackers

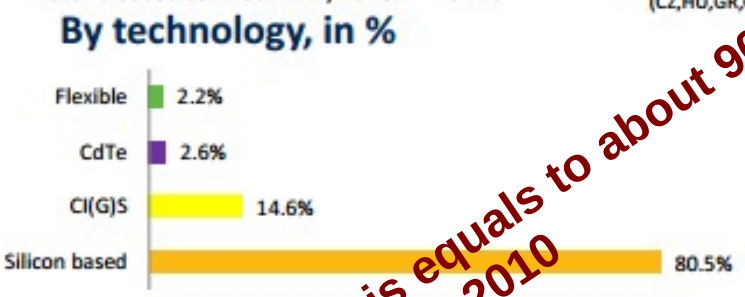


In 2014 some 40 MW were installed and about 40 MW were decommissioned in Spain

Germany has similar or worst figures (30% serious deficiencies and 70% minor defects)







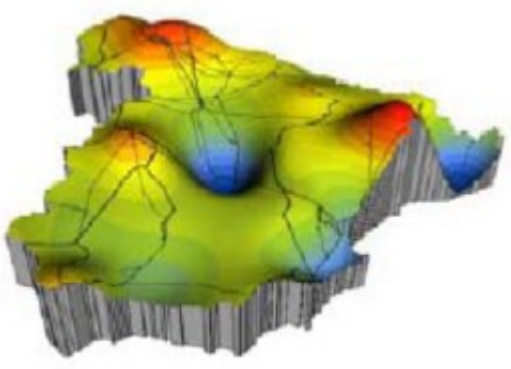
This equals to about 90 MW Since 2010

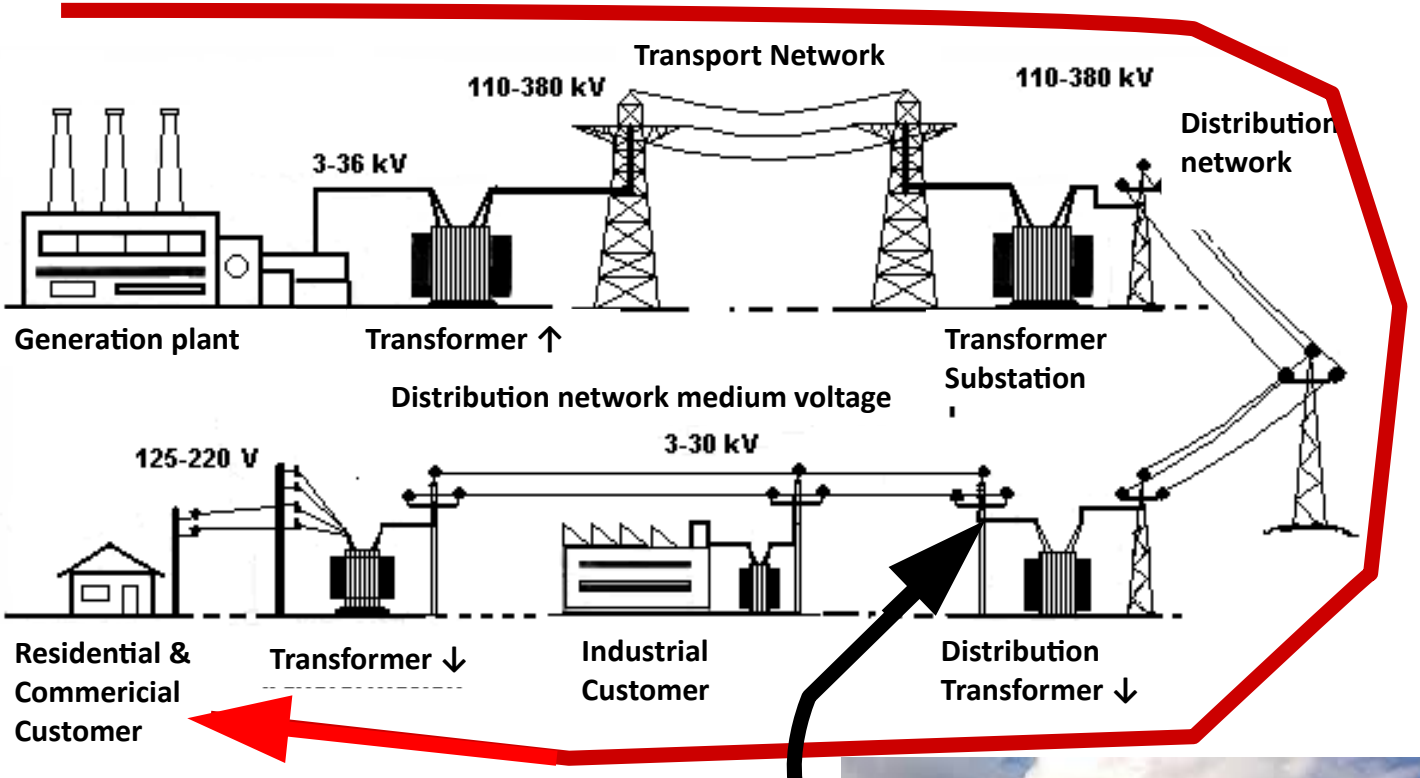
Calculated as 0.8% of total ER (Eout)

The Energy Invested (E_{in})

Electrical Network/Power lines Restructuring

Calculated as 3.5% of total ER (Eout) as proportional share to the national grid costs linked tototal PV energy generated with respect to total





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

The Energy Invested (E_{in})

Force Majeure/Acts of God: wind storms, lighting, flooding, hail

**Calculated as 0%
of total ER (Eout)
in a very conservative
estimate**

The Energy Invested (E_{in})

Premature Phase Out of unamortized Manufacturing Equipment

Calculated as 2.8% of total ER (Eout)

Technological ultra-fast phase out,
idle production,
long term plans clashing with short term market or governmental movements

Financial costs of these items have not been considered

The Energy Invested (E_{in})

Insurances

Insurances usually cover fire, Acts of God, theft, vandalism, Civil Responsibility (evacuation lines), workers

Calculated as 0.5% of total ER (Eout)

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

The Energy Invested (E_{in})

Administration Expenses

Calculated as 0.7%
of total ER (Eout)

Take care of presenting balance sheets,
P&L Statements, VAT declarations,
bank accounts follow-up, taxes, levies, etc.

The Energy Invested (E_{in})

Indirect Labor (Direct Excluded)

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

Calculated as 0.4% of total ER (Eout)

The Energy Invested (E_{in})

Municipality taxes, duties and levies

Calculated as 0.3% of total ER (Eout), Very conservative assumption, as most of the plants have paid as much as **4% of total project**

The Energy Invested (E_{in})

Cost of land long term rent or ownership

**Calculated as 0.2%
of total ER (Eout)**

From 17,000 €/ha in ownership

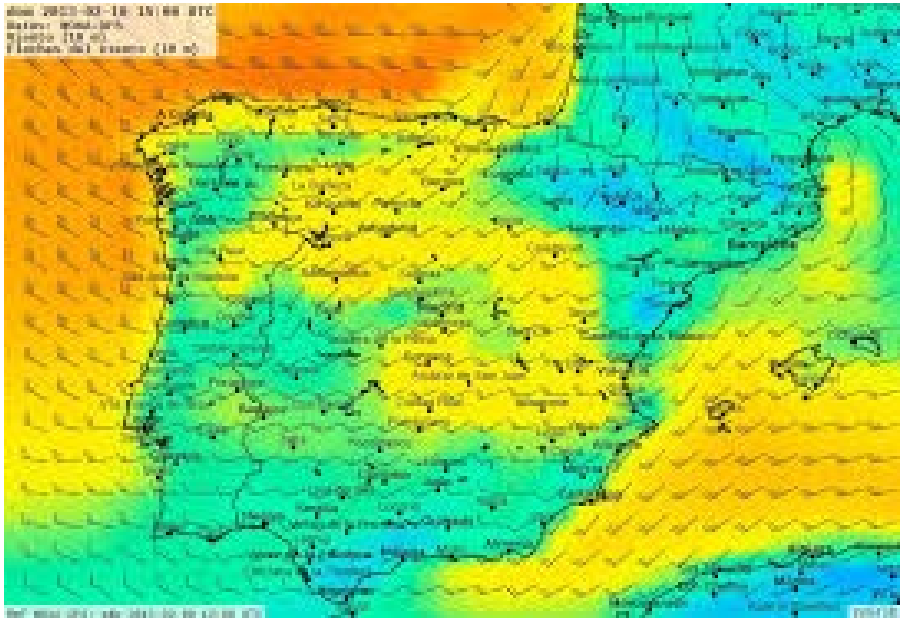
and 1,000 €/Ha/year in renting

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 Energy Invested (E_{in})

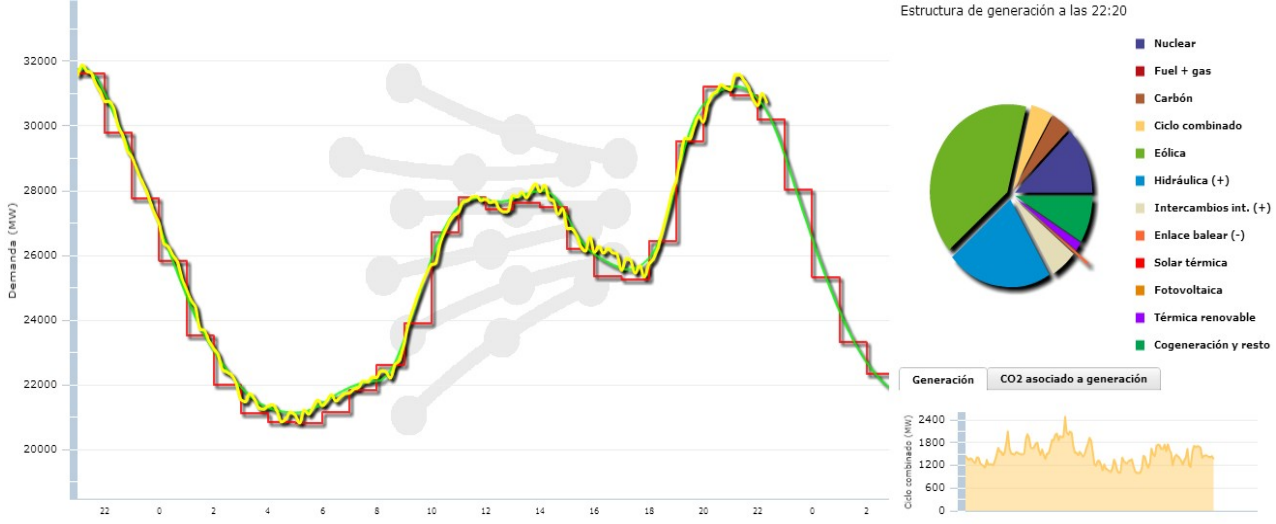
Agent Representative



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)

Calculated as 0.1 % of total ER (Eout)



The Energy Invested (E_{in})

Preinscription, inscription, 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

Calculated as 0 % of total ER (Eout)

The Energy Invested (E_{in})

Fairs, Exhibitions, Promotions. Conferences. etc.

Calculated as 0.5 %
of total ER (Eout)

A very conservative approach for marketing and commercial expenses of that industry sector that run on about 10-12% of the overall costs

The Energy Invested (E_{in})

Network Stabilization. Combined Cycles indirect costs

Spain initiated a program to reduce emissions as per the Kyoto Protocol commitments by phasing out coal plants and replacing them by combined cycle. As renewables enter first in the network, combined cycle are working at 20% of the designed power

1997 Kyoto Agreement

2005 Kyoto Entry into force

Combined Cycle Gas fired Power Plants

Year	Installed Power (MW)	Generated Energy (Gwh)	Load Factor in %
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	28.983	12,2
2014	27.206	25.869	10,9
2015	27.199	30.217	12,7

Calculated as 3.9 % of total ER (Eout)

Combined Cycle power plants were originally designed to work in a stable form some 5,500 hours/year (62.8% load factor)

The Energy Invested (E_{in})

Network Stabilization. Pump up or other massive storage Systems

Pump up systems loss some 25% of the turbined energy

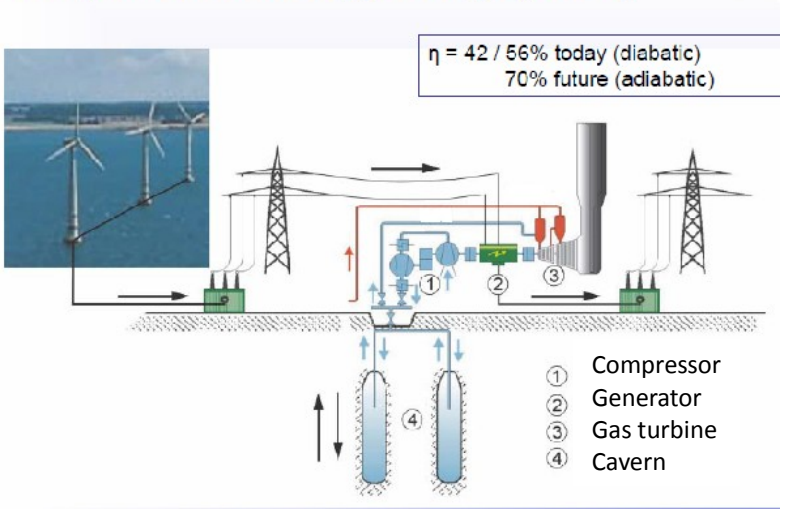
Other massive storage systems even more

Not all the sites are adequate for them

Left out of calculations for lack of public consensus

Massive deployment of intermittent (stochastic) renewable Energy sources could have an extra cost to decide the go-no go for renewable systems

Compressed air energy storage (CAES)



Sources: El Hierro island. Cabildo. And Fritz Crotogino. KBB Germany

The Energy Invested (E_{in})

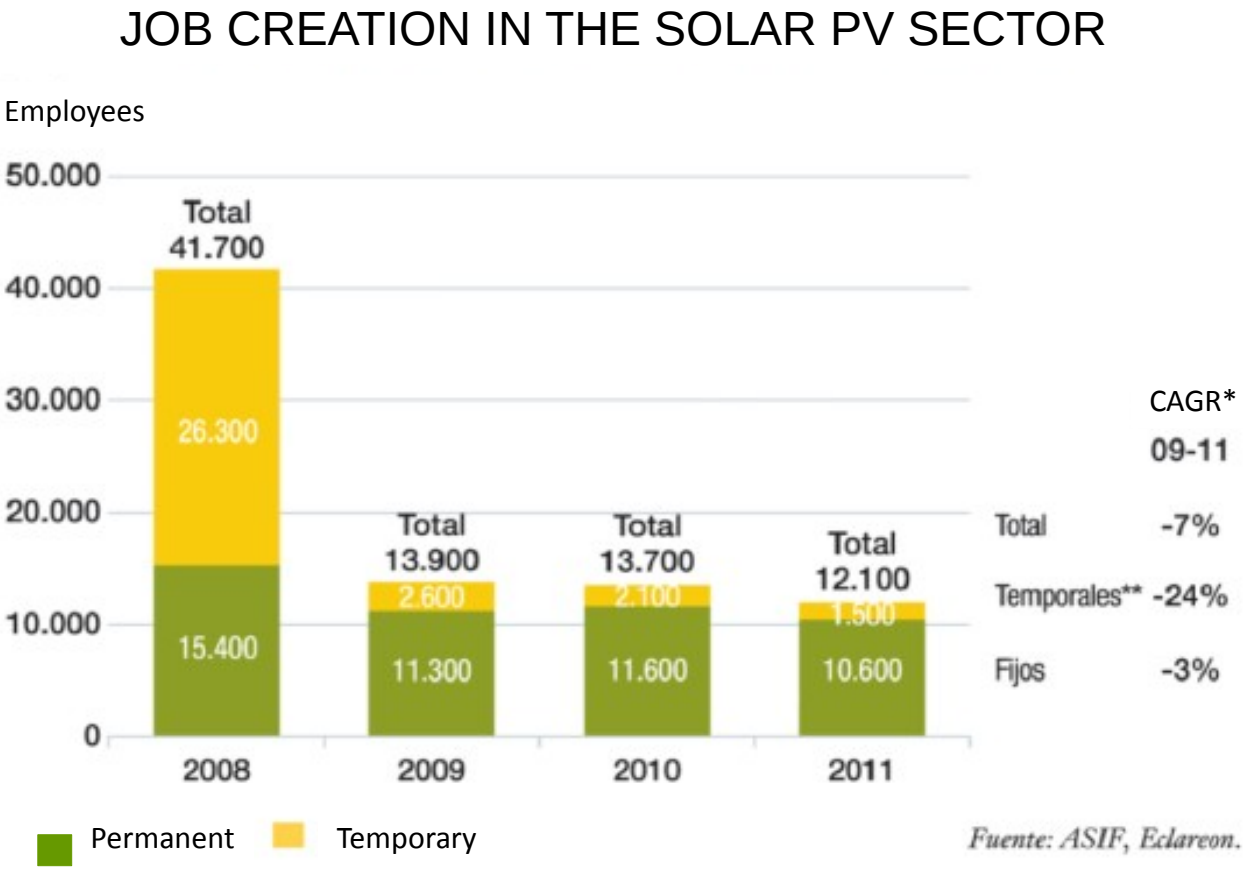
Direct Labor. Sensitivity Analysis

There are several methods to correlate energy spent and employment.

I/O Tables are most common

Spain does not publish I/O Tables

A simplified and conservative method is to correlate total active-occupied workers in a country with total primary energy consumed.



Source: Memoria Asociación de la Industria Fotovoltaica (ASIF) June 2011

The Energy Invested (E_{in})

Direct Labor. 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

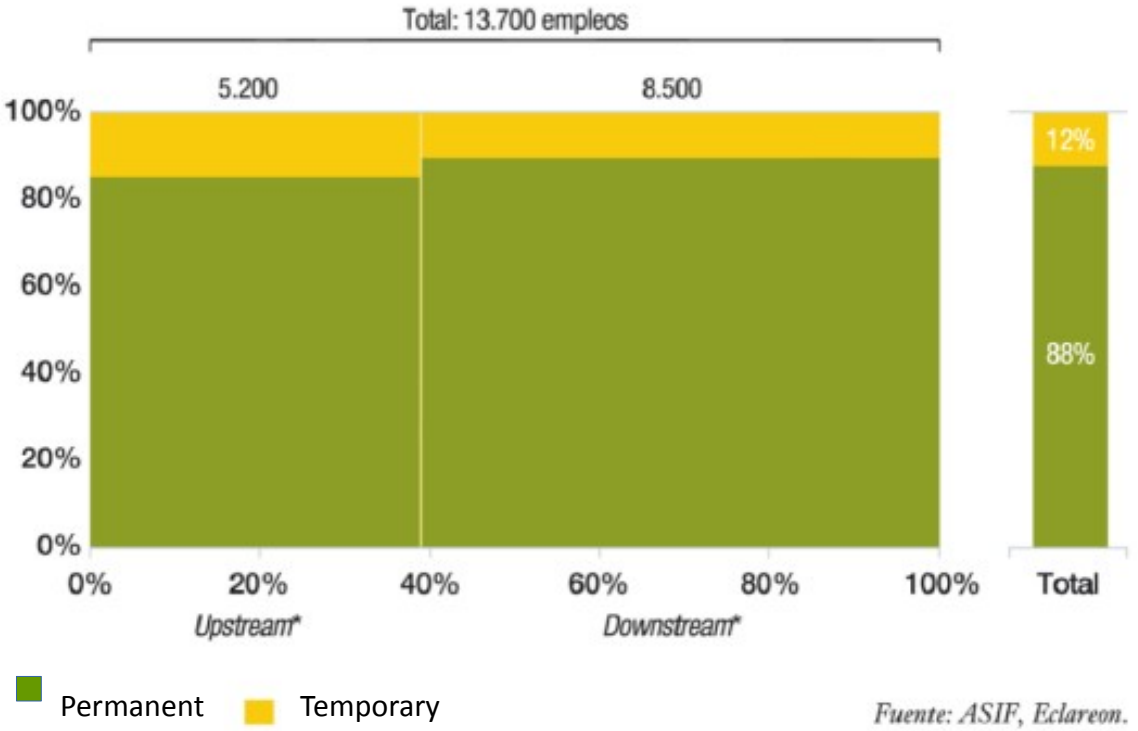
Assume 20,000 workers in the Solar PV sector y/y and 20,000 once in solar plants lifetime

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

This is minimum 5% of total ER (Eout)

EMPLOYMENT BREAKDOWN IN THE SOLAR PV SECTOR IN 2010



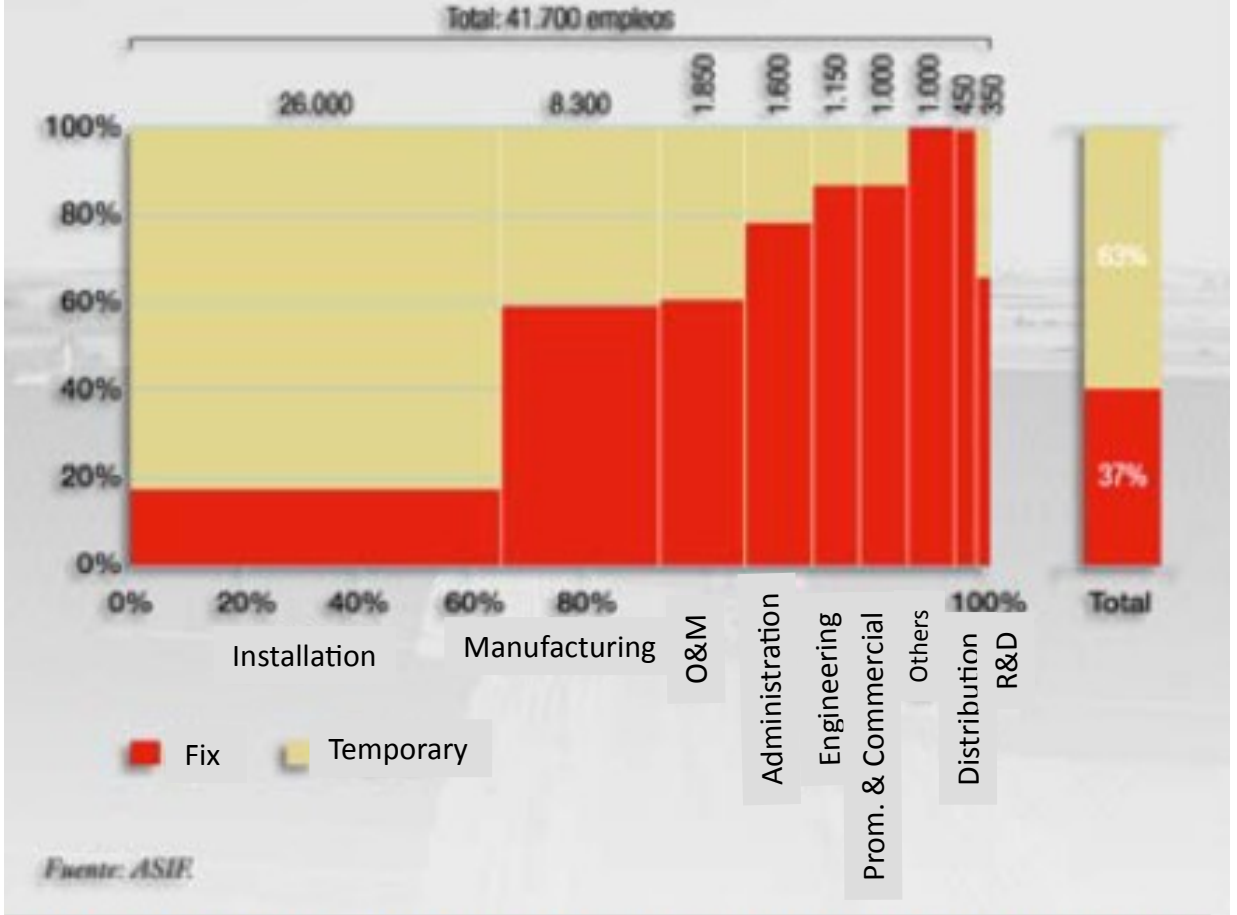
Note: "Upstream includes employment devoted to the high value chain sector, mainly components manufacturing and R&D activities.
Downsrteam includes employments devoted to the low value chain, mainly those related to services (Distribution, Engineering, Procurement and Construction (EPC) O&M, etc.)

Source: Memoria Asociación de la Industria Fotovoltaica (ASIF) June 2011

The Energy Invested (E_{in})

Direct Labor. Sensitivity Analysis

EMPLOYMENTS IN SOLAR PV SECTOR DURING THE 2008 PEAK OF ACTIVITY PER CONTRACT AND ACTIVITY TYPE



Except in installation, employment is basically permanent

Source: Presentación Informe (ASIF) August 2009

The Energy Invested (E_{in})

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?

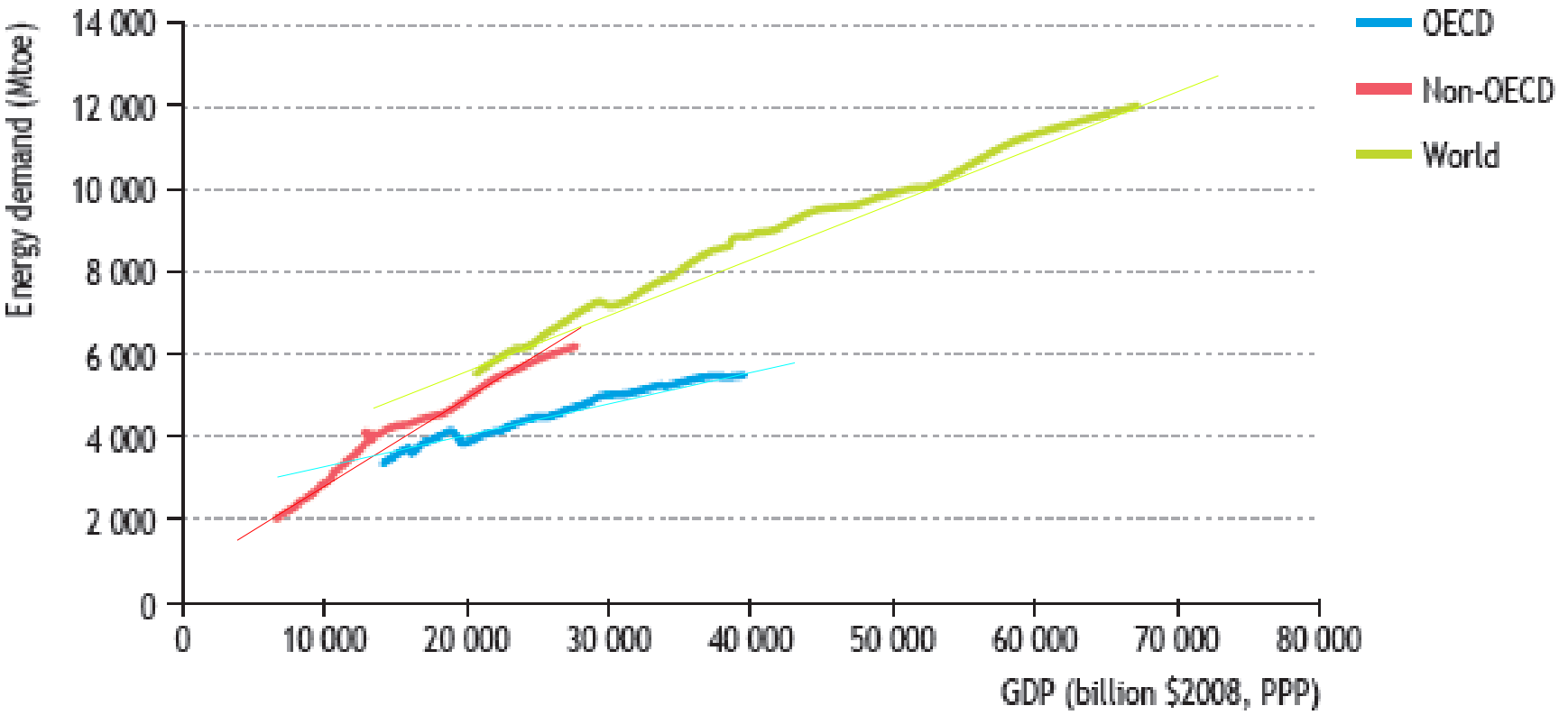
Dividing the total primary energy used by total GDP gives a rough estimate: 7.16 MJ/euro or 1.99 kWh/euro. (Spain 2010) (World 2015)

Energy intensities vary much depending on the sector

The Energy Invested (E_{in})

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

The Energy Invested (E_{in})

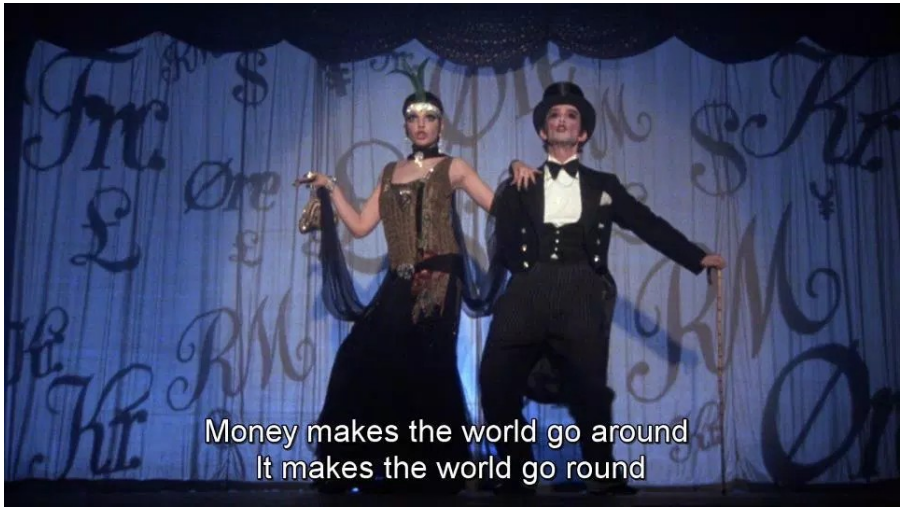
Financial Direct Costs. (Only as sensitivity analysis)

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 Energy Invested (E_{in})

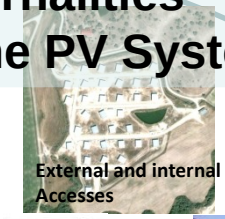
2. The Module Processes

+ Tempered Glass + Copper+ Soldering + Tedlar + EVA + Connect. Box + Cabling +encapsulating Packing box, etc.

1/3

3. Externalities of the PV System

Transformers

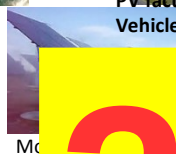

External and internal Accesses

PV factories.Parkings Vehicle fleet

Ministries, regulatory bodies, banks financial entities, municipalities, insurances, administration, etc., etc.

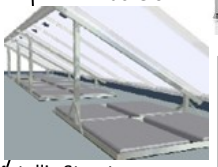
Trackers

DC/AC Inverters

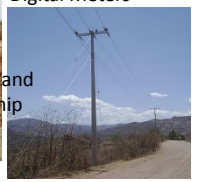


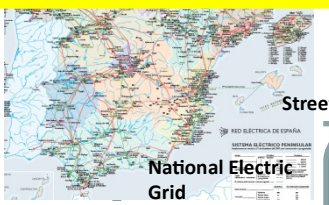
2/3

Industrial media


Metallic Structure

Digital Meters


Evacuation Lines


National Electric Grid

Streets, roads, motorways

Machinery and Transport in all the value chain

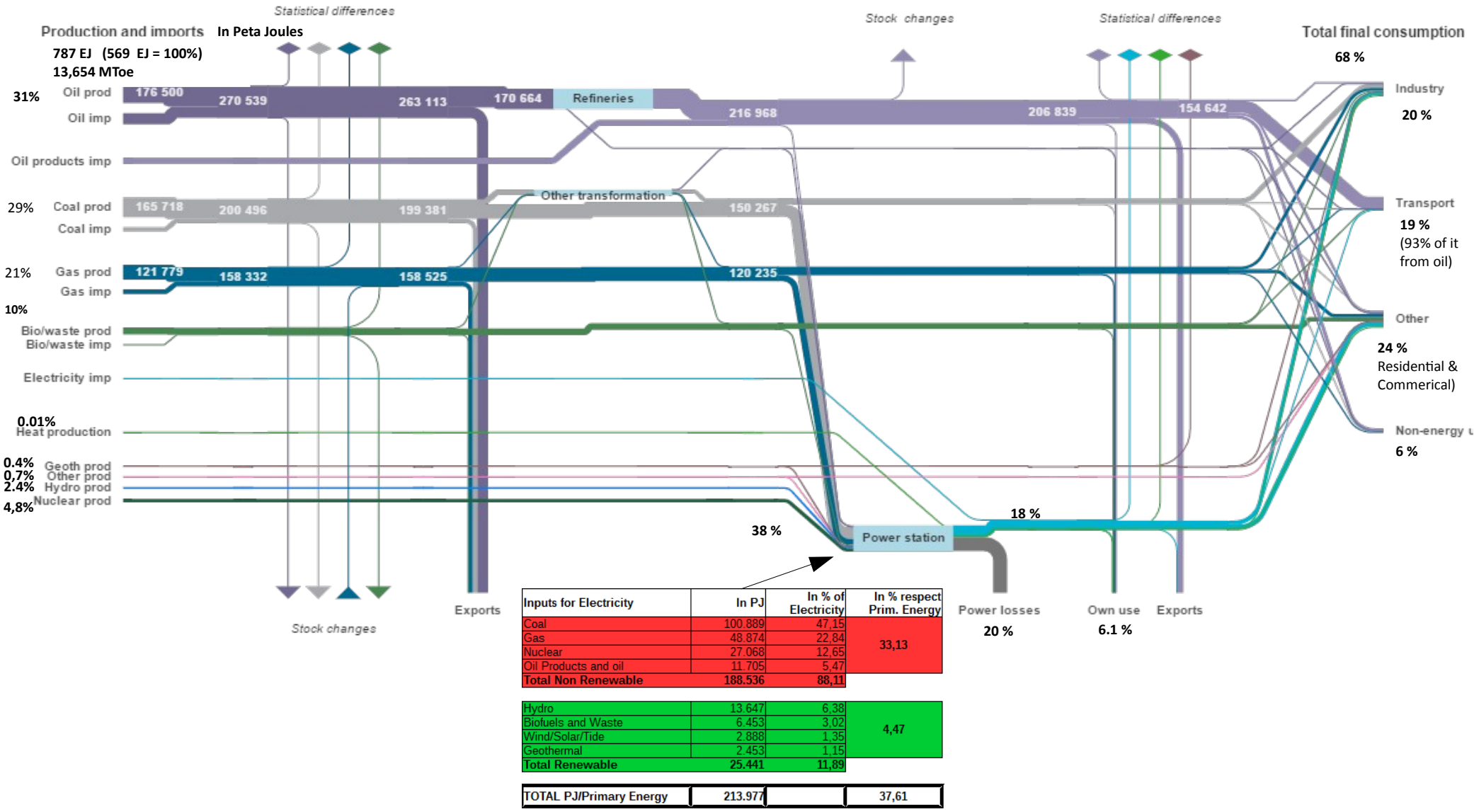
Skilled labor in all the value chain

4. Societal Areas of **SINE QUA NON** energy inputs

Cell Energy Invested → PV Module Energy Invested → PV Balance ofSystem Energy Invested → Societal Balance of System (BoS)

- Hidden, ignored, underestimated Energy Input costs. Complete BoS in all the social process

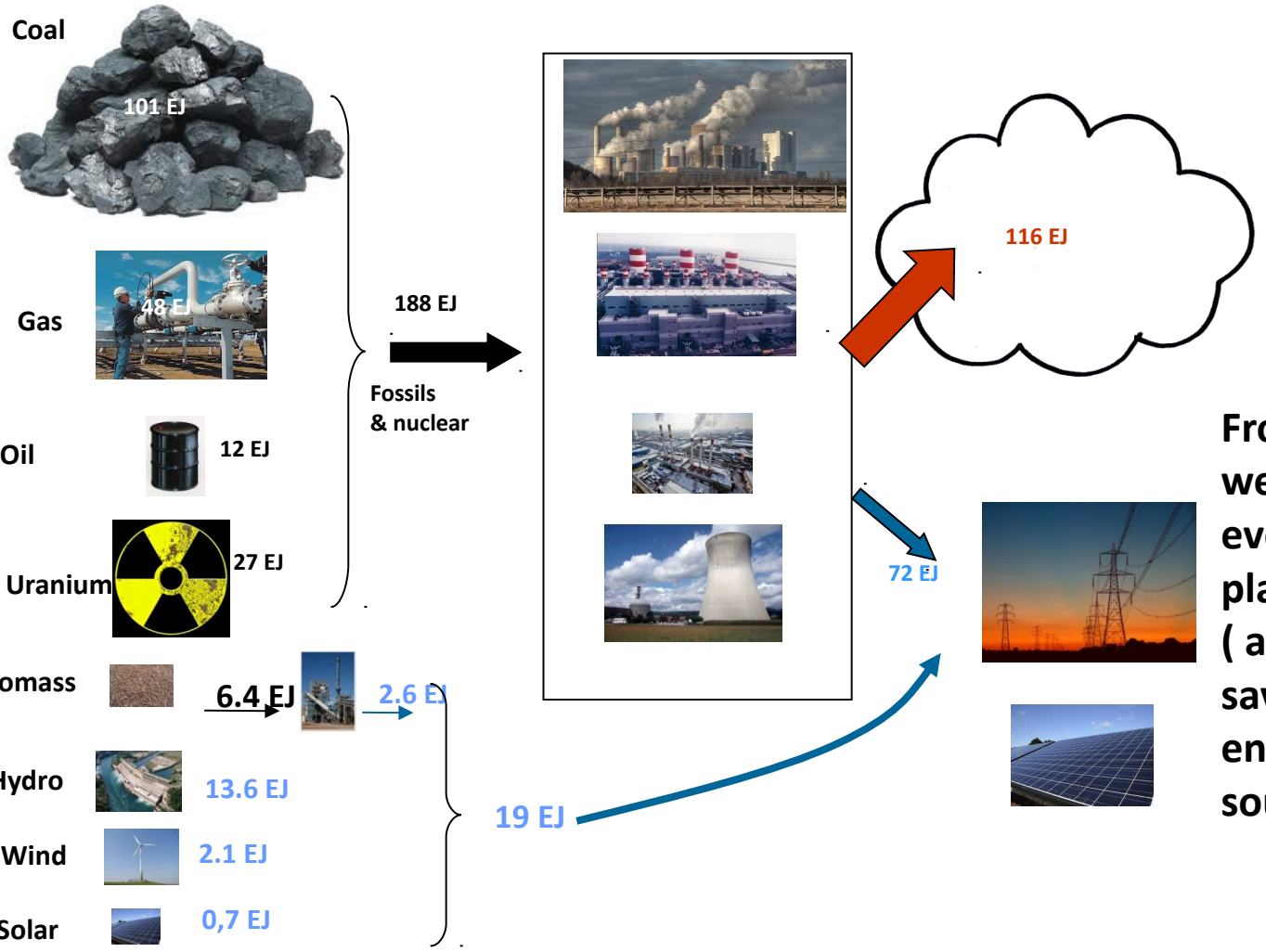
The Flow of Global Energy as per the IEA



Inputs for Electricity	In PJ	In % of Electricity	In % respect Prim. Energy
Coal	100.889	47,15	33,13
Gas	48.874	22,84	
Nuclear	27.068	12,65	
Oil Products and oil	11.705	5,47	
Total Non Renewable	**188.536**	**88,11**	
Hydro	13.647	6,38	4,47
Biofuels and Waste	6.453	3,02	
Wind/Solar/Tide	2.888	1,35	
Geothermal	2.453	1,15	
Total Renewable	**25.441**	**11,89**	
TOTAL PJ/Primary Energy	213.977		37,61

Source: Sankey Diagram IEA 2013. http://www.iea.org/sankey/

Direct 'Transformity'

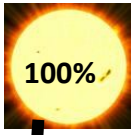


From direct 'Transformity' we can conclude that from every EJ generated in solar plants grid connected, (as final exergy), we could save about 2.6 EJ of primary energy from non renewable sources

Reverse 'Transformity' 2

Non electric uses of primary energy. Total: 354 EJ or 62% from a total of >569 EJ/year

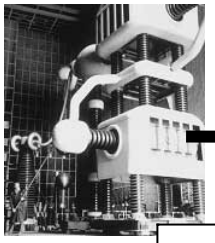
Sun 100 Energy units



PV modules deliver 15 units of energy. Be this starting point = 100

Transmission lines
5 to 10% losses

95-90



Electricity used to produce hydrogen by electrolysis
20-30% losses

76-63

Hydrogen is compressed or liquefied to be stored
30-40% losses

53-38

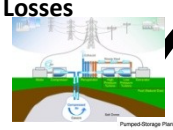
Hydrogen is lost in transport and/or storage. 15 to 100% depending on time and logistcis

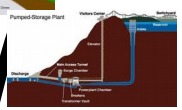
45-0

The fuel cell converts hydrogen again into electricity
30 to 50% losses

31-0

Massive energy storage in caverns or others
15-30% Losses





Pump up
30% losses

Massive accumulation methods

80-63

Electrified Land Transport

72-49

Electro-Stations

Accumulation in batteries+ electric motor
10-20% losses

Direct combustion converts hydrogen In motion with about 60-70% losses because the Carnot cycle

12-0

Societal functions hardly replaceable with electricity

Conclusions

APPROX. REQUIRED EROI

12-25:1

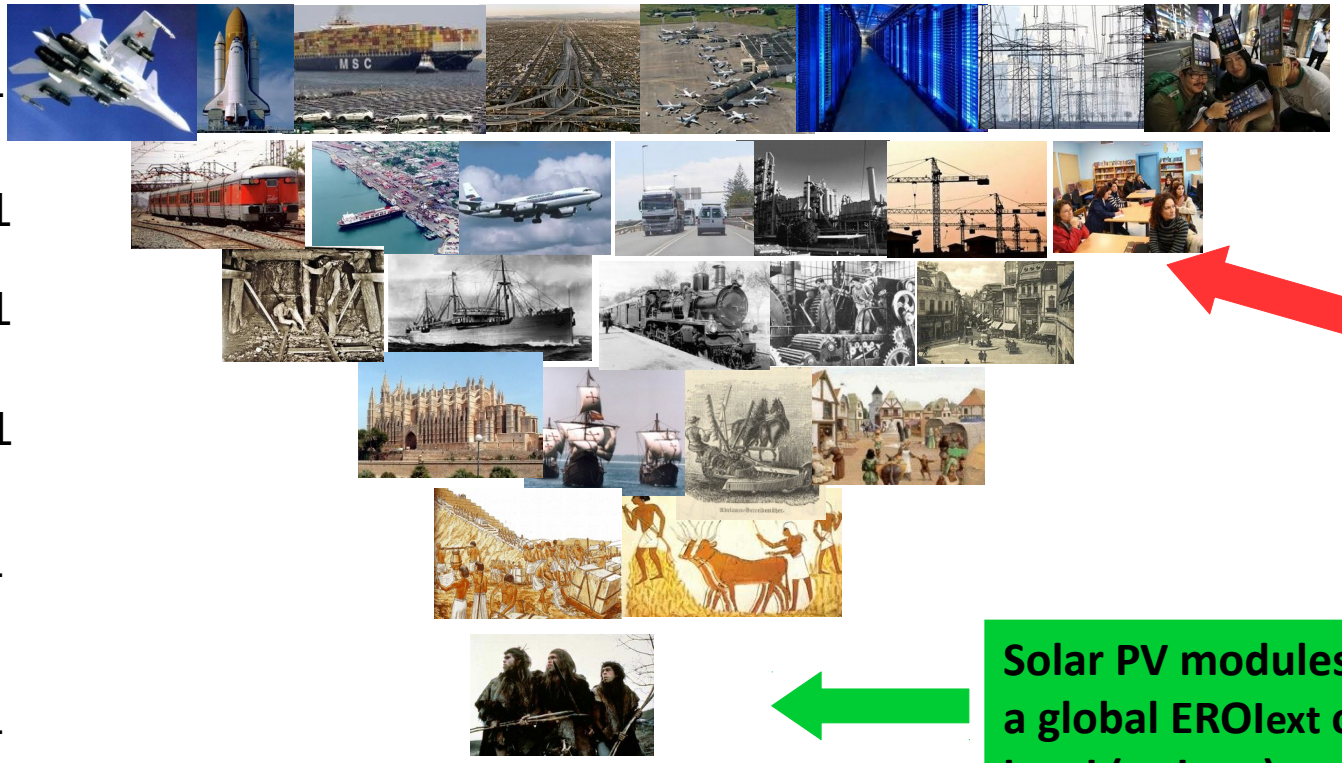
8-15:1

6-13:1

5-6:1

4-5:1

2-3:1



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

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

Conclusions

12-25:1

8-15:1

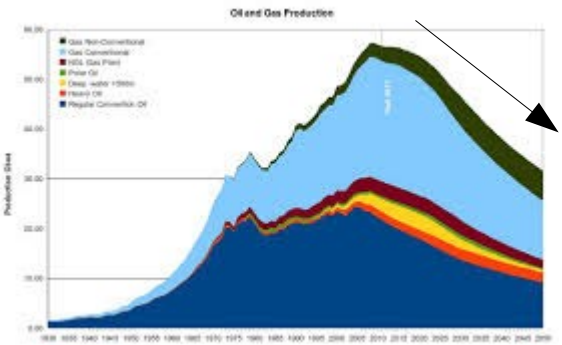
6-13:1

5-6:1

4-5:1

2-3:1

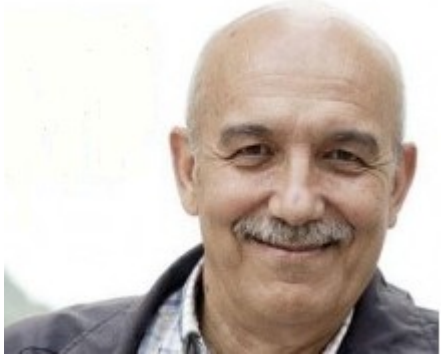
As fossil fuels approach their peaks or go past peak and their EROI's go down, the building blocks of our modern society will start falling apart.



Modern Renewables do not seem to be able to sustain the present world infrastructure

Conclusion

Merci beaucoup
pour votre attention



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Germany vs Spain

SPAIN	SOLAR PV			GERMANY	SOLAR PV		
Year	Annual yield (GWh)	Installed Power (MW)	MWh/MW	Year	Annual yield (GWh)	Installed Power (MW)	MWh/MW
2000	1	2	604	2000	64	76	842
2001	2	4	425	2001	76	186	409
2002	5	7	626	2002	162	296	547
2003	9	11	793	2003	313	435	720
2004	18	23	776	2004	556	1105	503
2005	40	47	843	2005	1282	2056	624
2006	105	146	718	2006	2220	2899	766
2007	484	690	701	2007	3075	4170	737
2008	2.528	3.398	744	2008	5520	6120	902
2009	6.074	3.397	1788	2009	6578	10566	623
2010	6.405	3.841	1668	2010	11729	17320	677
2011	7.398	4.246	1742	2011	19300	25000	772
2012	8.138	4.509	1805	2012	28500	32800	869

SPAIN	WIND POWER			GERMANY	WIND POWER		
Year	Annual yield (GWh)	Installed Power (MW)	MWh/MW	Year	Annual yield (GWh)	Installed Power (MW)	MWh/MW
2000	4688	2296	2042	2000	7550	6097	1238
2001	6930	3508	1976	2001	10509	8750	1201
2002	9602	5066	1895	2002	15786	11989	1317
2003	12060	6324	1907	2003	18713	14604	1281
2004	16086	8532	1885	2004	25509	16623	1535
2005	21187	10095	2099	2005	27229	18390	1481
2006	23166	11897	1947	2006	30710	20579	1492
2007	27601	14536	1899	2007	39713	22194	1789
2008	32128	16323	1968	2008	40574	23826	1703
2009	38232	18865	2027	2009	38639	25700	1503
2010	43127	19710	2188	2010	37793	27191	1390
2011	41861	21059	1988	2011	46500	29075	1599
2012	48020	22591	2126	2012		31332	