



UNIVERSITÀ  
DEGLI STUDI DI TRIESTE

*Dipartimento di Ingegneria e Architettura*

# GENERAZIONE DISTRIBUITA DI ENERGIA ELETTRICA LA SVOLTA SEGNATA DAL FOTOVOLTAICO (Introduction to Photovoltaics)

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040 - 5587970



Summer School on Energy  
Giacomo Ciamician

Trieste, 20 - 23 marzo 2018

# ENERGY: A KEY GLOBAL CHALLENGE

“Energy is essential for human development and energy systems are a crucial entry point for addressing the most pressing global challenges of the 21<sup>st</sup> century, including sustainable economic and social development, poverty eradication, adequate food production and food security, health for all, climate protection, conservation of ecosystems, peace and security”

“Yet, more than a decade into the 21<sup>st</sup> century, current energy systems do not meet these challenges”

“A major transformation is required to address these challenges and to avoid potentially catastrophic future consequences for human and planetary systems”

Global Energy Assessment (GEA) 2013

Scienza e Tecnologia dei Materiali Elettrici e Fotovoltaici AA2017-2018

I - Introduction to Photovoltaics - ALESSANDRO MASSI PAVAN

The energy transition from fossil fuels to renewables is already ongoing, but it will be a long and difficult process because the energy system is a gigantic and complex machine (with an extraordinary economic inertia)

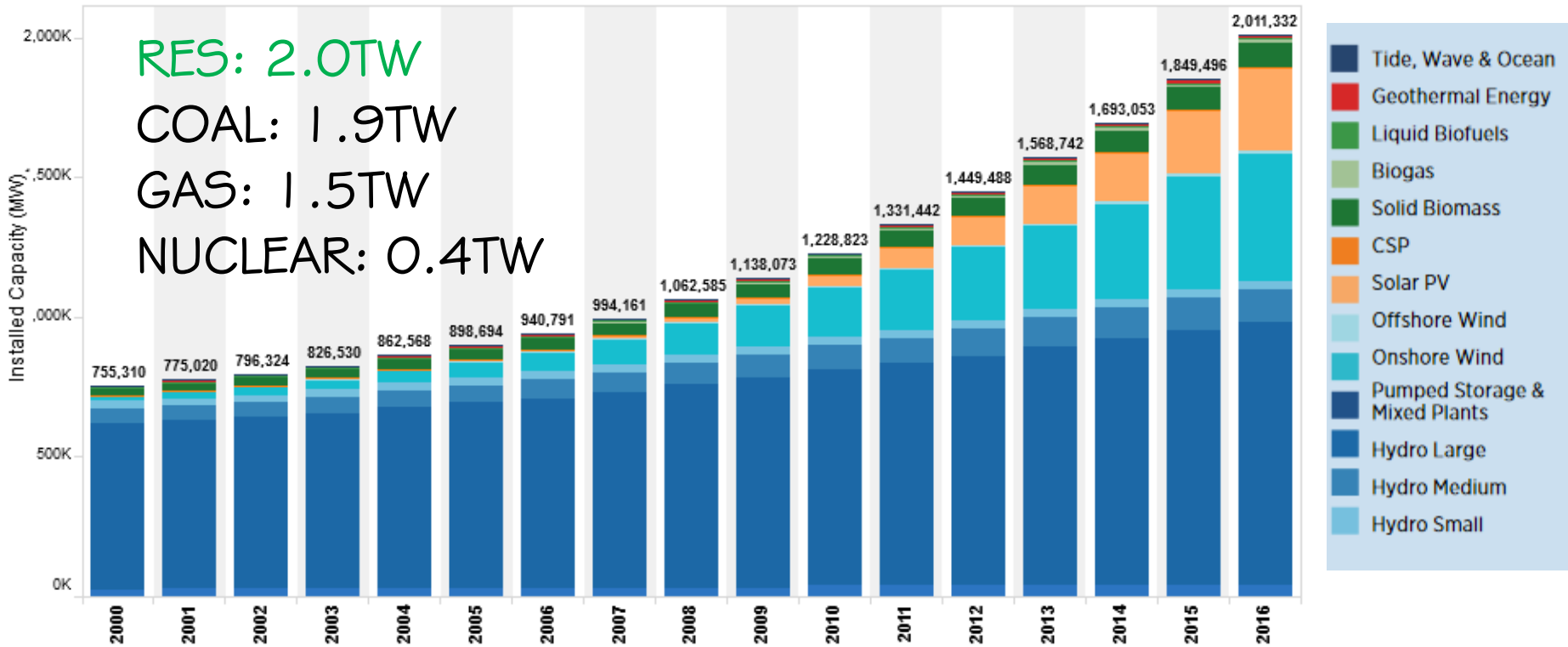
Today, key renewables data show the remarkable growth of solar electricity ...

Whatever will happen, the age of hydrocarbons and coal entered its final stage. When this century will be concluded, nothing will ever be the same

# OUTLINE

- Introduction (a boom in RES)
- Five causes of the boom
- The role of photovoltaics
- History and breakthrough of PV
- The future of photovoltaics
- Conclusions

# A BOOM IN RENEWABLES

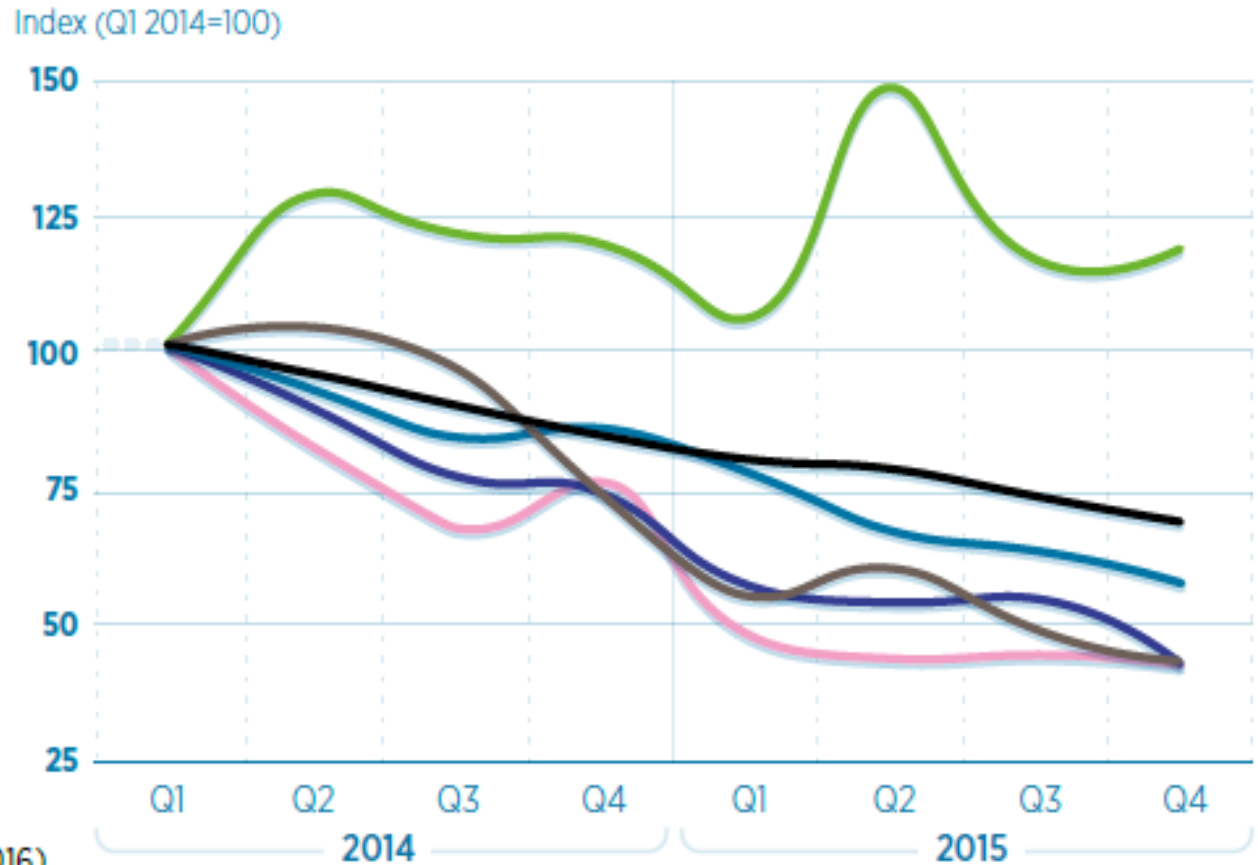
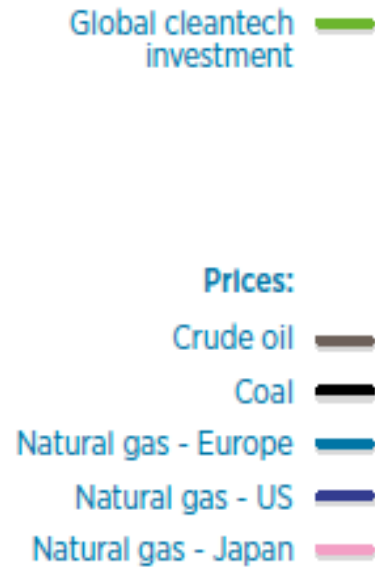


<http://resourceirena.irena.org/gateway/dashboard/?topic=4#subTopic=16>

# A BOOM IN RENEWABLES

IRENA A roadmap for a renewable energy future, 2016

*Investments  
in renewables  
continue despite  
volatile fossil fuel  
prices.*



Sources: BNEF (2015), EIA (2016)

# A BOOM IN RENEWABLES

## An entire region of China just ran on 100% renewable energy for 7 days

Leanna Garfield  
Jun. 27, 2017, 5:20 PM 1,001

FACEBOOK LINKEDIN TWITTER EMAIL PRINT

ics Business Science&Technology LifeStyle + Sport

Pope Francis • Colombia • dioxins alarm • vaccines

## Italy sets record of 87% of electricity via renewables rd of 87% of electricity via

21 says Terna CEO



CLICK TO ENLARGE +  
) - Rome, July 27 - Italy met 87% of its electricity demand via produced from renewable sources on May 21, a new record, erraris, the CEO of power-grid company Terna, said on day.

### 9% Government Backed Bond

Invest In Renewable Energy Bonds. 9% Per Annum, Government Backed.  
securedbonds.co.uk/energy-bonds/

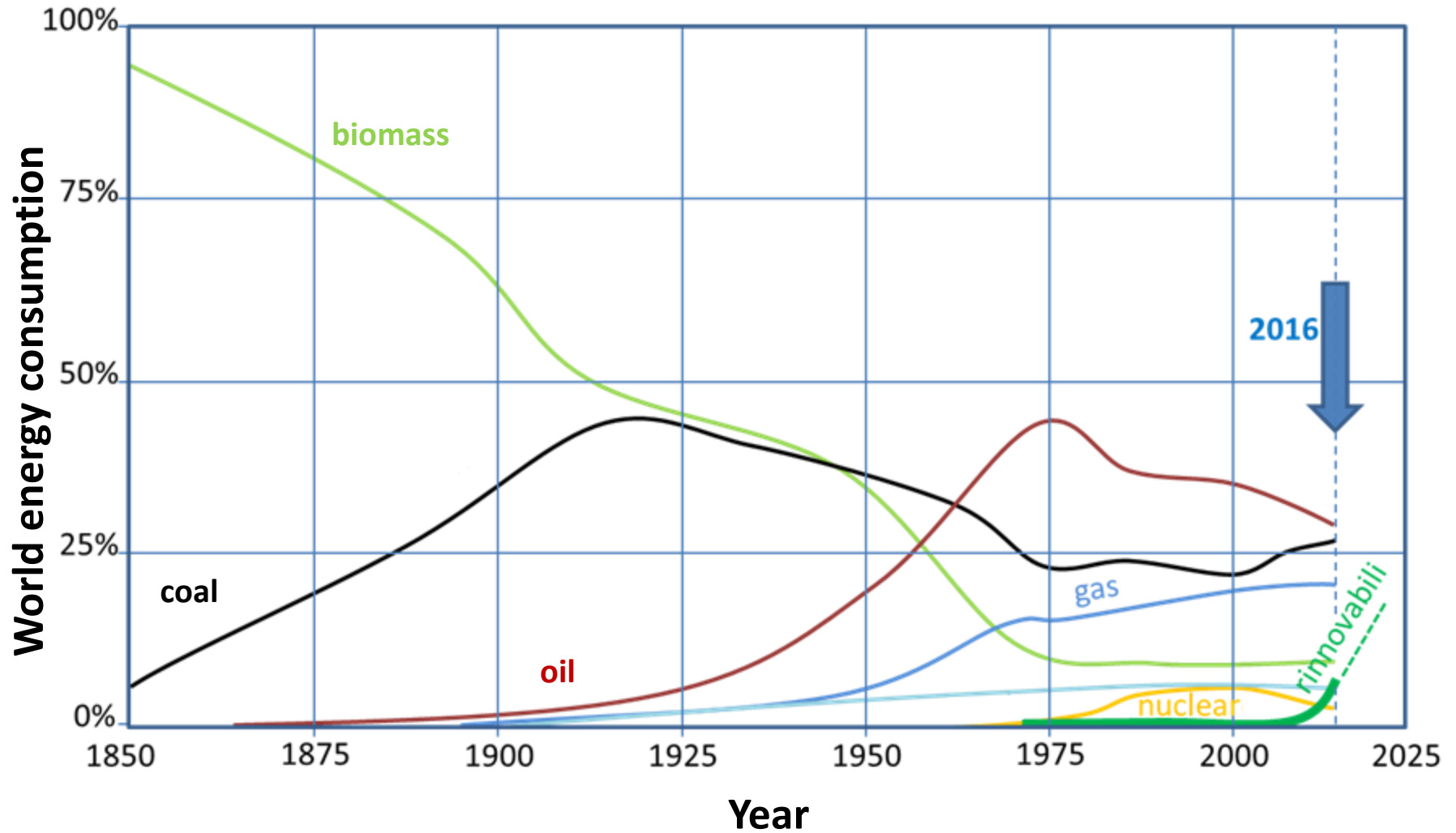
From Pittsburgh to Frankfurt, cities around the world are pledging to stop burning fossil fuels for electricity by 2050 or sooner.  
But the Chinese province of Qinghai has already reached that goal, according to news outlet

# TRANSFORMATION HAS STARTED!

- Electricity is the fastest-growing final form of energy and the power sector contributes more than any other to the reduction in the share of fossil fuels
- More than half (56%) (120GW) of the world's new electric generating capacity added in 2013 was renewable (72% in EU)
- 2013: China's new renewable power capacity surpassed new fossil fuel and nuclear capacity for the first time (38% in 2010)



# ENERGY TRANSITIONS



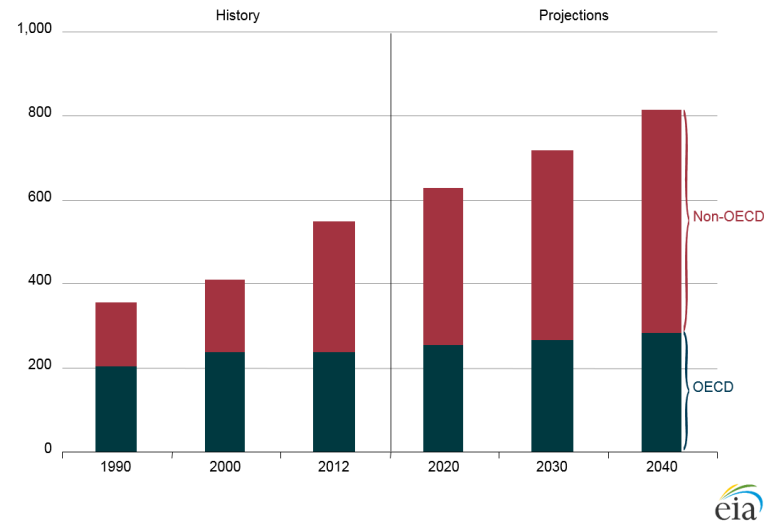
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# SCARCITY OF NATURAL RESOURCES



Figure 1-1. World energy consumption, 1990-2040  
quadrillion Btu



## Estimates of world crude oil and NGLs resources

billion barrels

Average Oil Demand (2013-2035): 100

	OPEC	Non-OPEC	Total world
Cumulative production to 2010 (a)	446	695	1,142
Proved reserves (b)			1,467
Reserves to be added ultimately (c)	617	620	1,237

YEARS TO GO ARE  $2,704/100 = 27!!!$

World Oil Outlook – OPEC 2012

**Total reserves: 2,704**

# LA CORSA PER LE RISORSE

**Bloomberg** Our Company

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## Oil, Food, Water: Is Peak?



Millions of Barrels Per Day

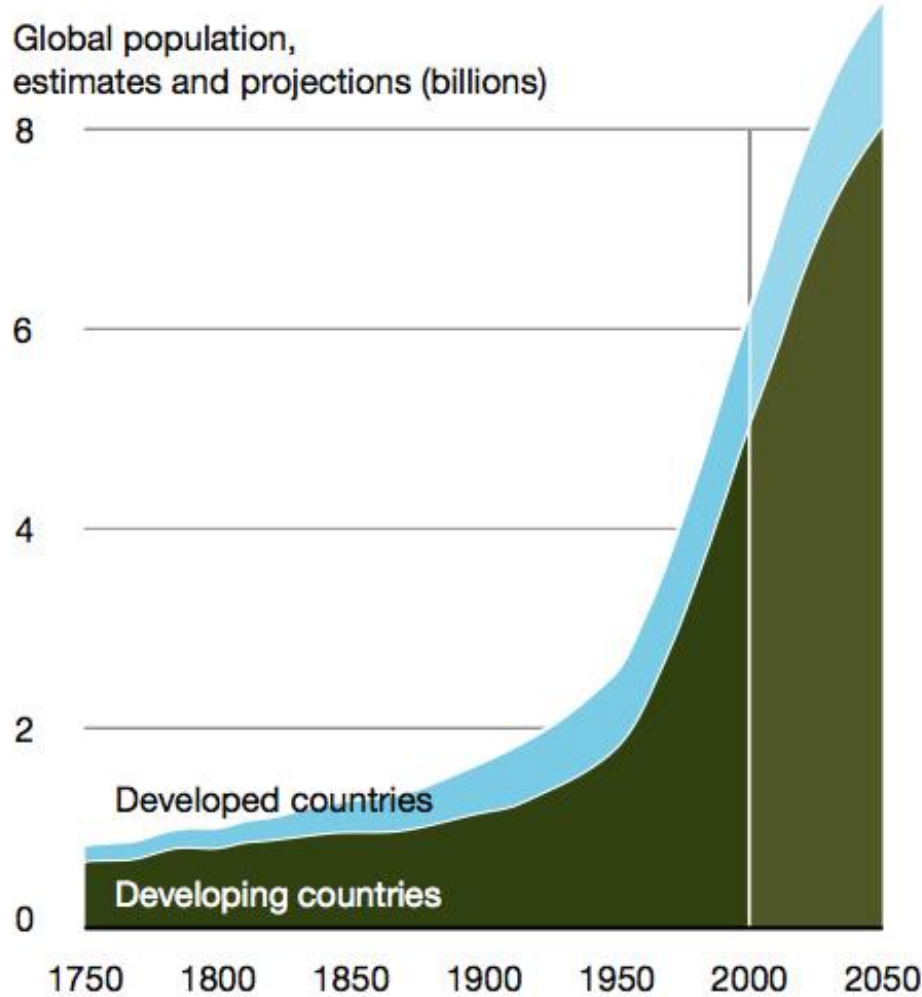
Thousands of Chinese people gather at Asia's biggest float festival in southwest China's Sichuan province on July 20, 2010. The STR/AFP/Getty Images

By Eric Roston | Feb 6, 2012 6:11 PM GMT

[f](#)
[t](#)
[in](#)
[g+](#)
47 COMMENTS

An unprecedented crisis faced America. Oil prices have soared in the past few years, resulting in foreign oil addiction and embarrassing the nation into consciousness imp...

Global population, estimates and projections (billions)



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1970-2011 | VIDEO | SUBS

SEARCH



# CLIMATE CHANGE



The Telegraph

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## News

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### Italian composer Ludovico





# RISCALDAMENTO GLOBALE

L'influenza dell'uomo sul sistema climatico è chiara e le recenti emissioni di gas serra da parte dell'uomo sono le più alte della storia

I recenti cambiamenti climatici hanno avuto impatti diffusi sull'uomo e sui sistemi naturali

Il riscaldamento del sistema climatico è inequivocabile, molti dei cambiamenti osservati non hanno precedenti nei millenni precedenti. L'atmosfera e gli oceani si sono riscaldati, la quantità di ghiaccio e neve è diminuita, il livello del mare è aumentato

# QUALITY OF LIFE

中国移动 E 12:17 63%

Shanghai

Last updated: 2013-12-06 11:00

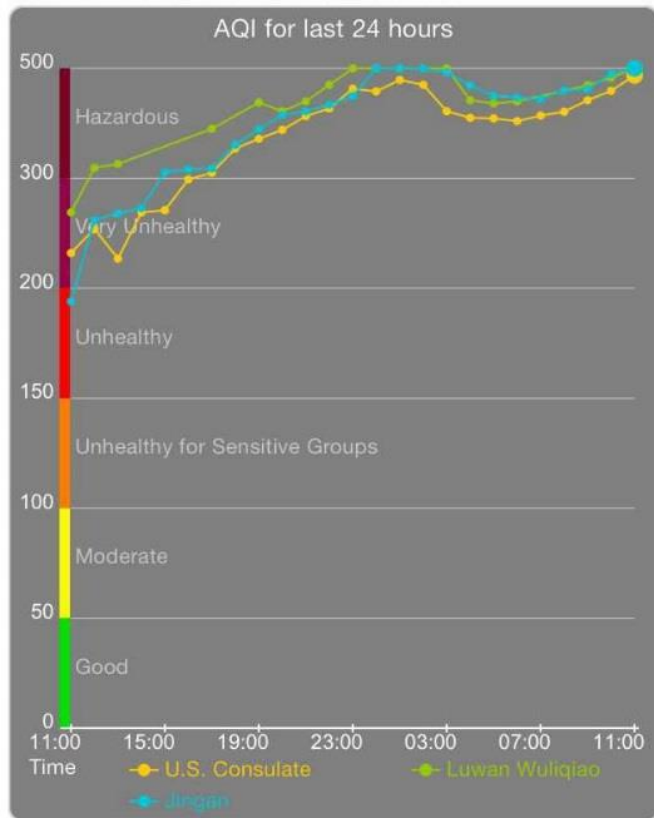
max of all selected stations

PM2.5: 542.0 ug/m3

500

Beyond Index

Health effects: Health Warnings of emergency conditions. The entire population is more likely to be affected.



# DROP IN RES COSTS

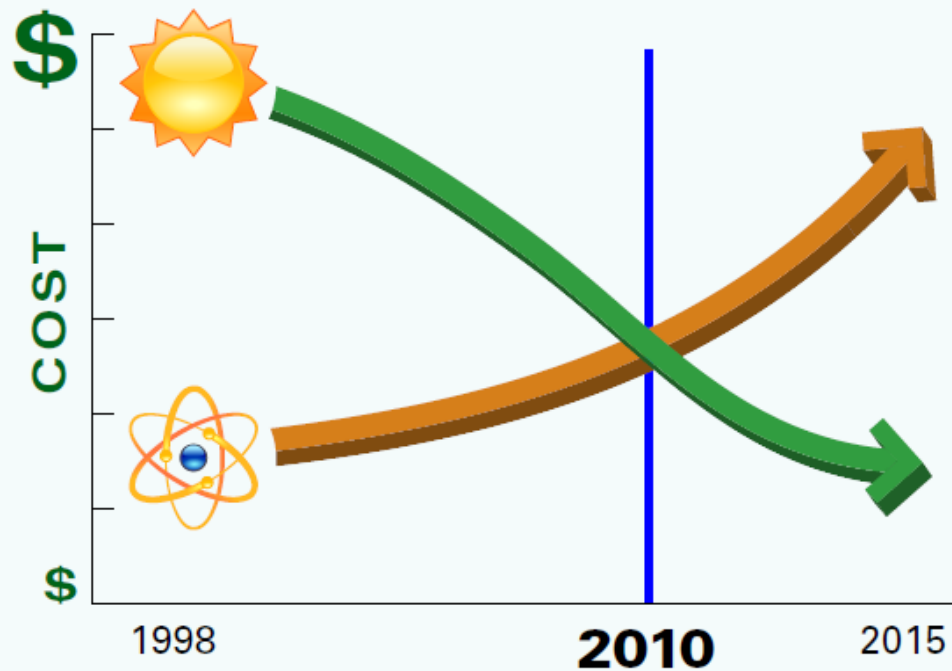
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### Renewable energy

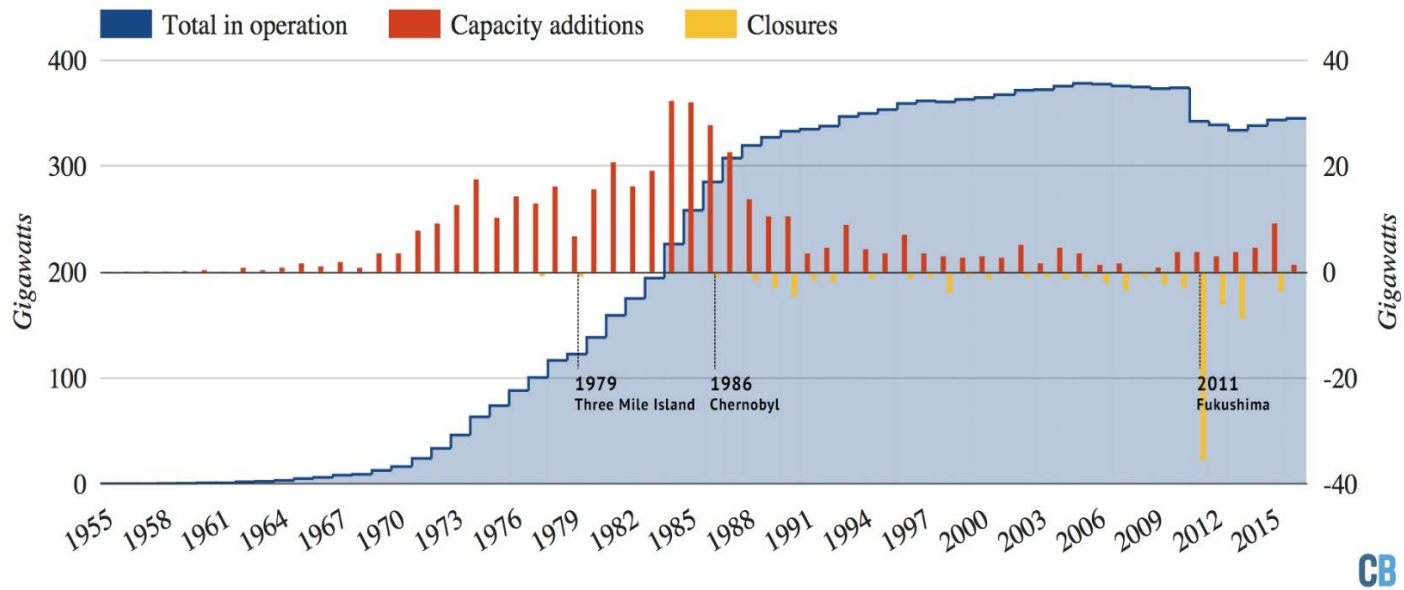


Solar and nuclear costs – the historic crossover  
J.O. Blackburn, S. Cunningham 2011

Scienza e Tecnologia dei Materiali Elettrici e Fotovoltaici AA2017-2018  
I - Introduction to Photovoltaics - ALESSANDRO MASSI PAVAN

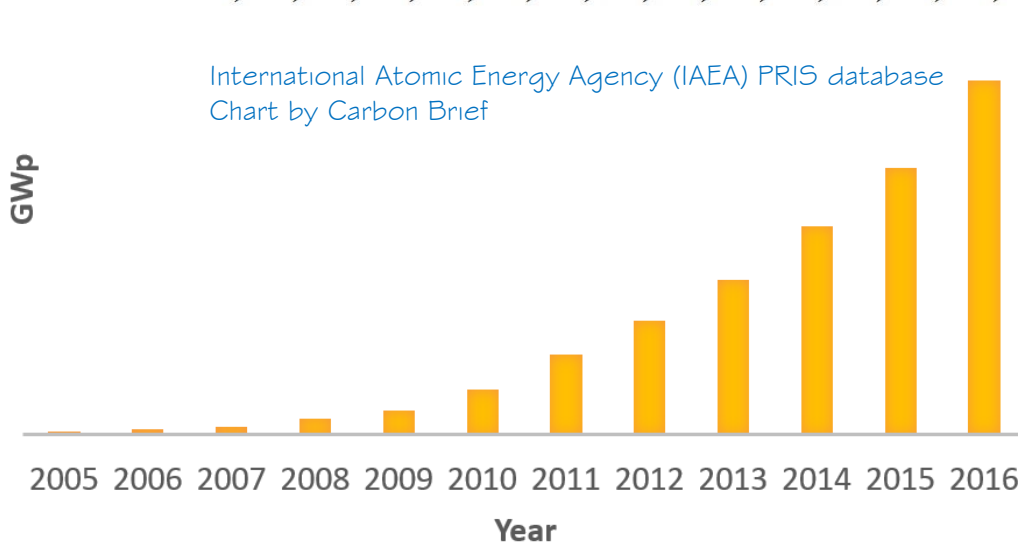


# DROP IN RES COSTS



International Atomic Energy Agency (IAEA) PRIS database  
Chart by Carbon Brief

CB



# FACTORS OF CHANGE

SCARCITY OF NATURAL RESOURCES

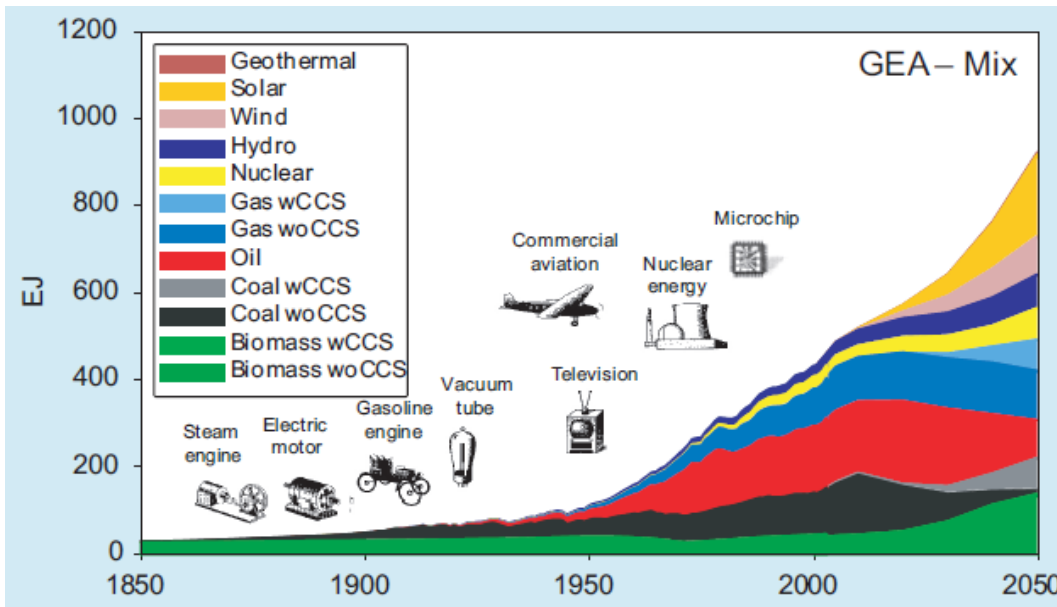
CLIMATE CHANGE

QUALITY OF LIFE

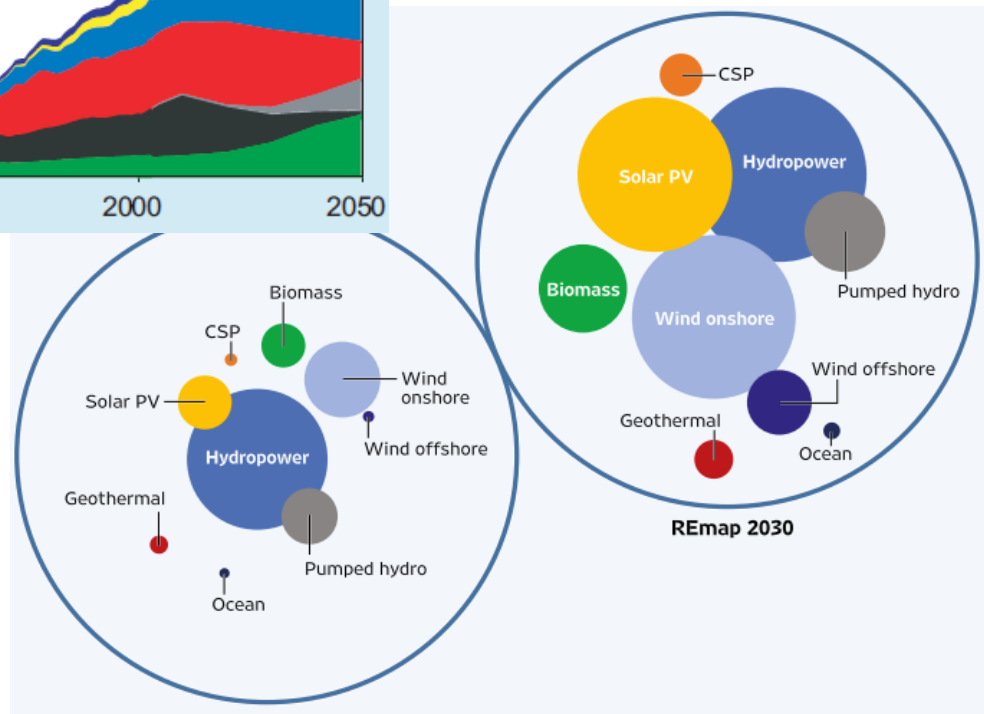
DROP IN RES COSTS

**SPEED OF INSTALLATION!!!**

# FUTURE ENERGY MIX



Global Energy Assessment (GEA), 2013

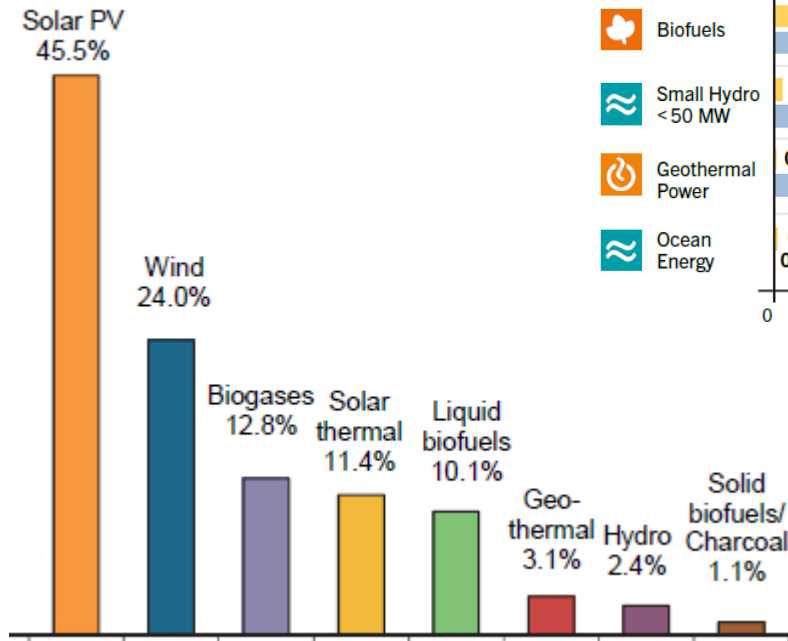


# OUTLINE

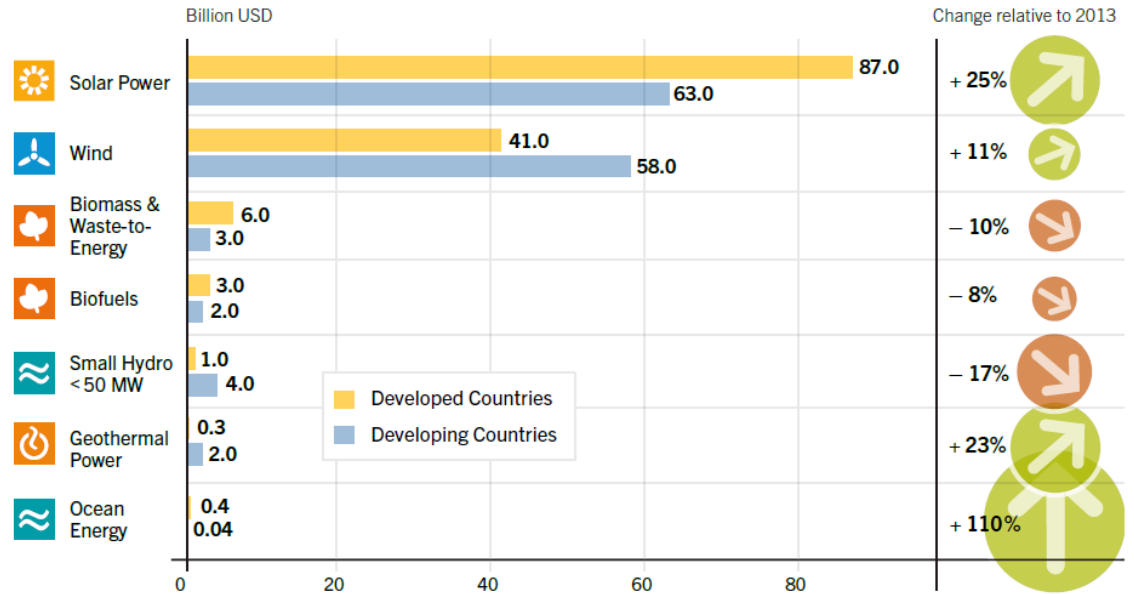
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# THE ROLE OF PHOTOVOLTAICS

## Investments in 2014



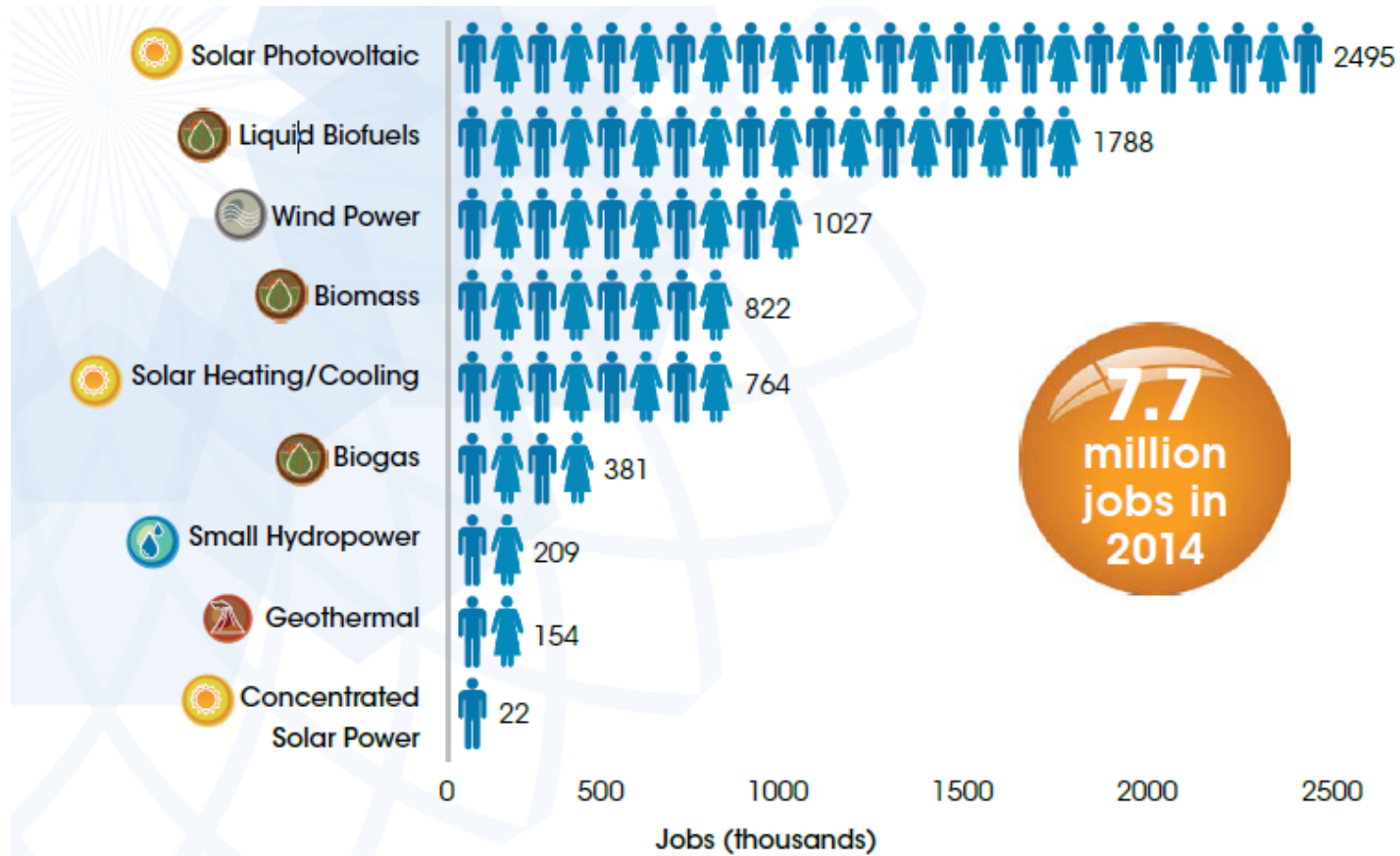
IEA, Renewables information: overview statistics, 2017



IRENA, Renewable power generation costs in 2014

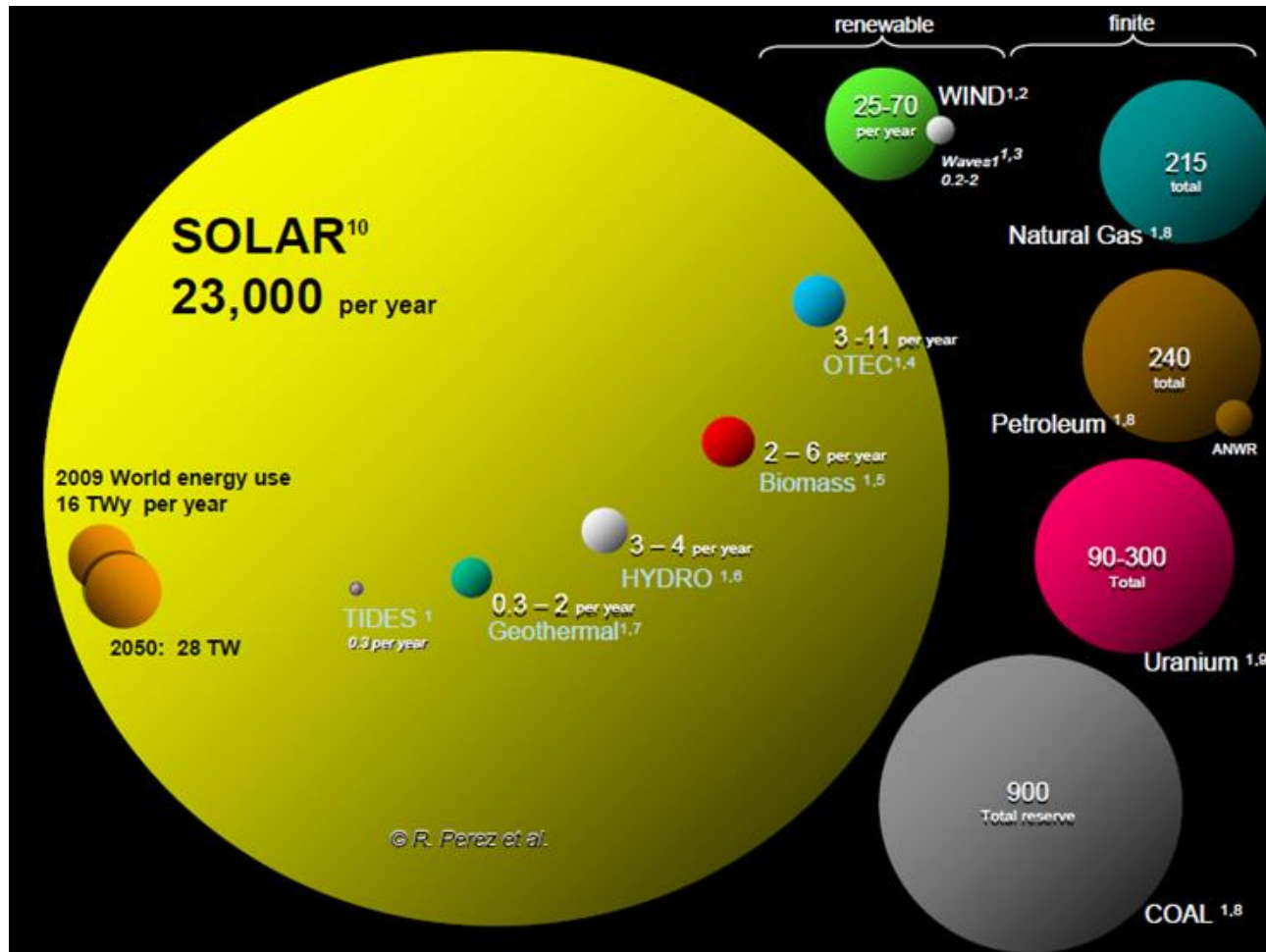
Average annual growth rates of world renewables from 1990 to 2015

# THE ROLE OF PHOTOVOLTAICS



IRENA Renewable Energy and Jobs – Annual Review 2015

# UNLIMITED ENERGY SOURCE



Perez R, Perez M. A fundamental look at energy reserves for the planet. IEA 2009

# AN «ANCIENT IDEA»

# SCIENCE



FRIDAY, SEPTEMBER 27, 1912

## CONTENTS

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## *THE PHOTOCHEMISTRY OF THE FUTURE*<sup>1</sup>

MODERN civilization is the daughter of coal, for this offers to mankind the solar energy in its most concentrated form; that is, in a form in which it has been accumulated in a long series of centuries. Modern man uses it with increasing eagerness and thoughtless prodigality for the conquest of the world and, like the mythical gold of the Rhine, coal is to-day the greatest source of energy and wealth.

"...if our black and nervous civilization, based on coal, shall be followed by a quieter civilization based on the utilization of solar energy, that will not be harmful to progress and to human happiness."



# ADVANTAGES OF PHOTOVOLTAICS

- 😊 Fuel source is vast and essentially infinite
- 😊 Very low O&M costs
- 😊 Reliability and durability
- 😊 Easy and quick installation
- 😊 Modular technology
- 😊 No moving parts (no noise)
- 😊 No emissions

# ADVANTAGES OF PHOTOVOLTAICS

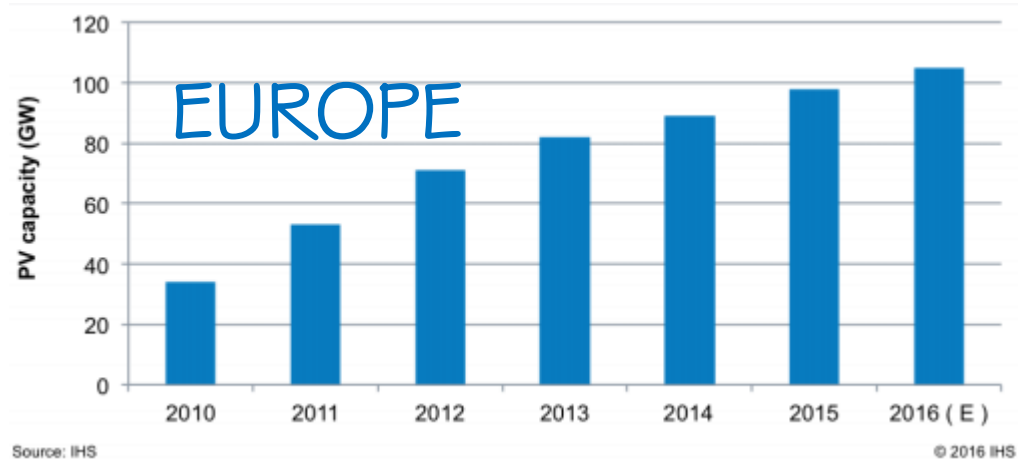
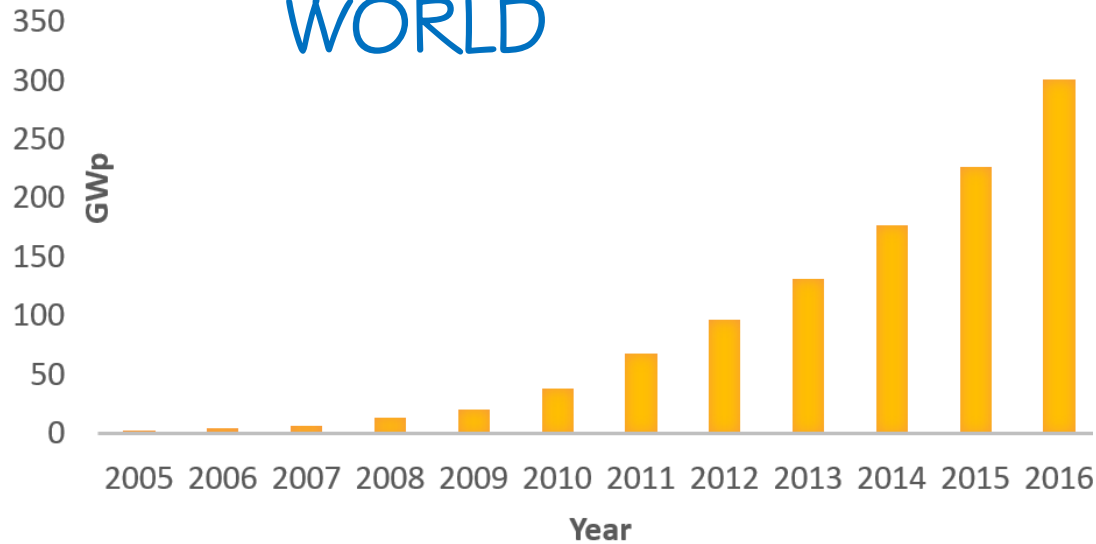
- 😊 Can be integrated into new and existing buildings
- 😊 High public acceptance
- 😊 New distributed and no specialized jobs
- 😊 Choice and control
- 😊 Daily output peak can match the local demand
- 😊 Distributed generation (can be installed at nearly any point-of-use)

# FALSE MYTHS

- 👷 PV is too expensive
- 👷 PV modules never recover the energy required in making them
- 👷 No more R&D is needed
- 👷 PV requires too much land to ever meet significant fraction of world needs
- 👷 PV industry is polluting
- 👷 PV efficiency is a problem

# PV CUMULATIVE POWER

WORLD



Source: IHS

© 2016 IHS

# PV CUMULATIVE POWER

WO

## Graphic detail Charts, maps and infographics



Previous Next Latest Graphic detail

All latest updates

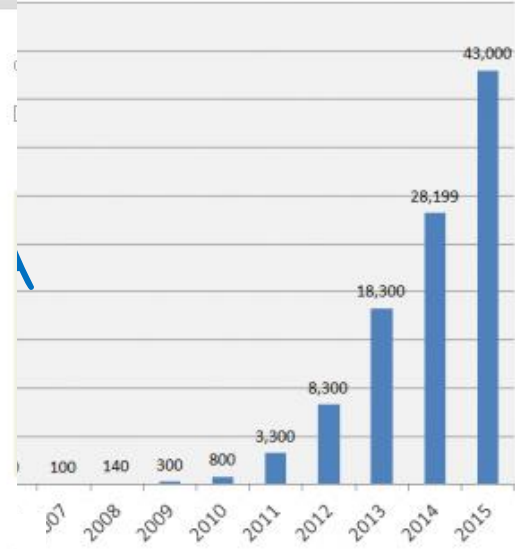
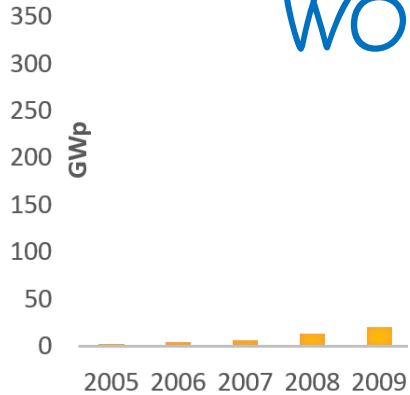
### Daily chart

## Indian solar power

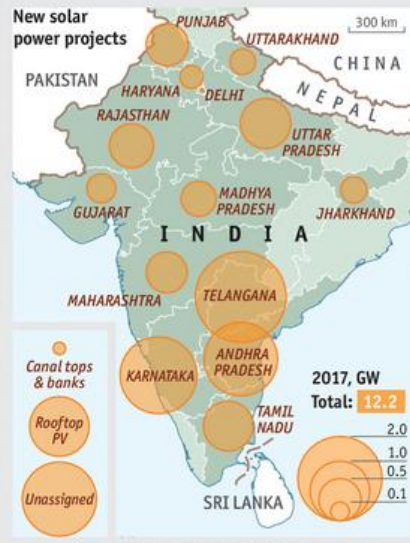
Jun 6th 2016, 16:30 BY THE DATA TEAM



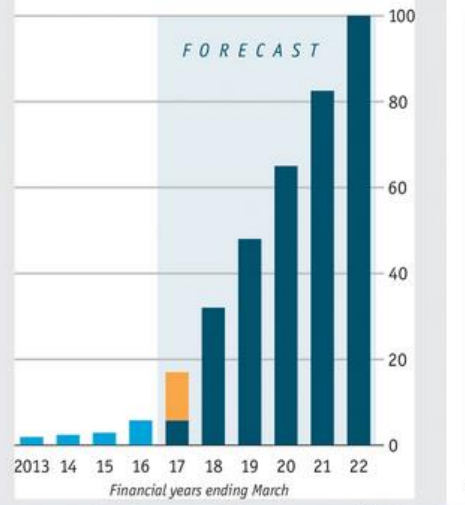
Tweet



### Solar power in India



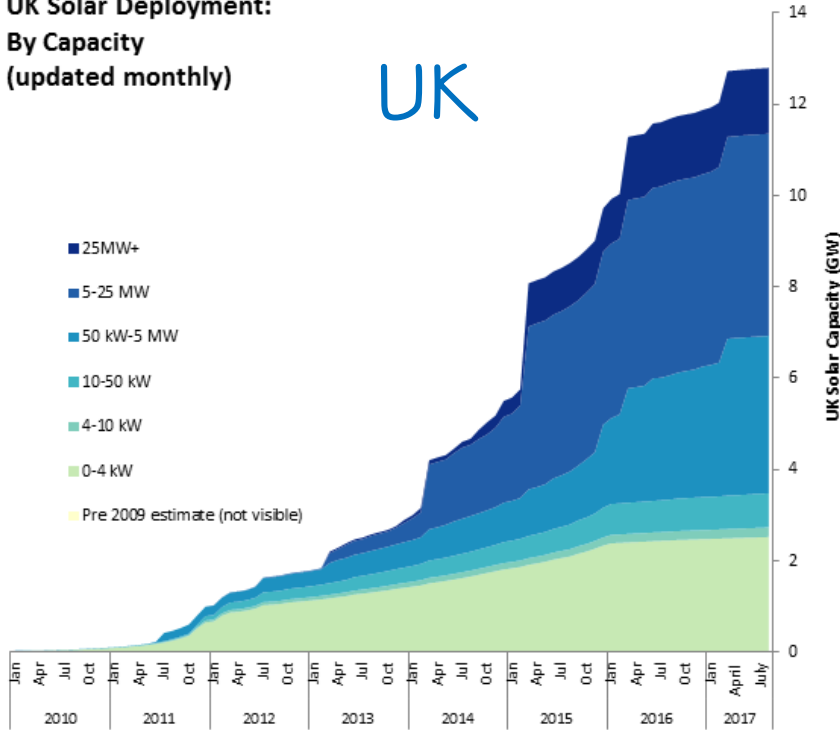
### Installed solar capacity, GW, cumulative



# PV CUMULATIVE POWER

UK Solar Deployment:  
By Capacity  
(updated monthly)

UK



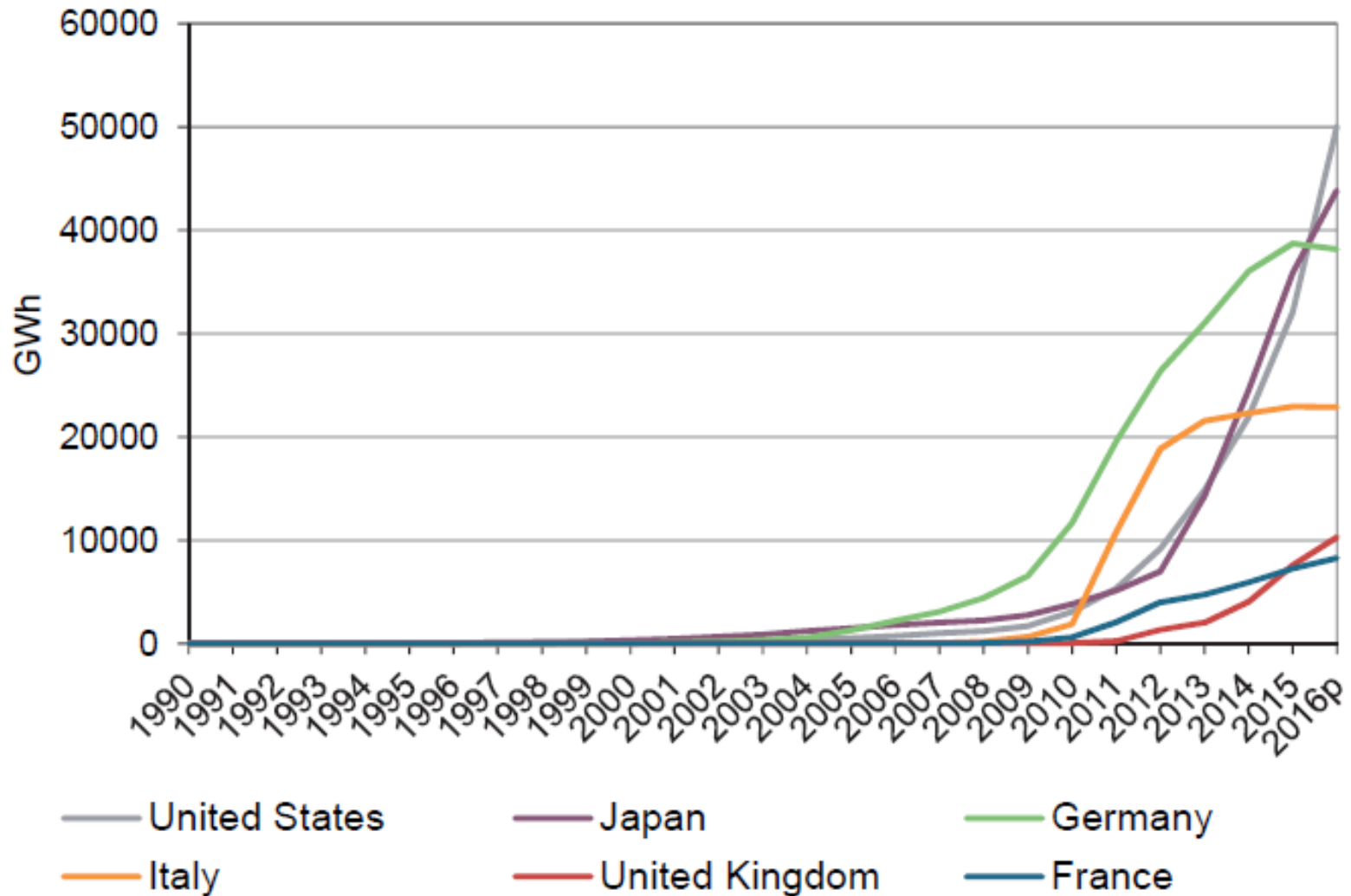
<https://www.gov.uk/government/statistics/solar-photovoltaics-deployment>

www.gse.it

ITALY



# PV ELECTRICITY IN SIX COUNTRIES



Renewables information: overview statistics, 2017

# PV POWER PER CAPITA (2016)

COUNTRY	Installed Power [GW]	Population [Millions]	Wp/per capita	Growth (%)
Germany	42	81	518	4
Italy	19	60	317	2
Japan	28	127	220	25
Europe	149	742	200	5
UK	13	66	197	20
USA	40	319	125	58
China	78	1360	57	79
India	9	1250	7	79
-----	-----	-----	---	---
World	302	7571	40	32



# GROUND-MOUNTED PV SYSTEMS



2000 – 0.02MW

2008 – 1 MW

2017 – 1,000MW



345 MW

 India  
Charanka,

Charanka Park  
PV power plant

2012-2015

# C&I ROOFTOP PV SYSTEMS

Power [1]

Location

Description [2]

On Grid

2012

toen

2010

2010-2011

2015



11 MW

 Spain,  
Martorell

10.6 MW

 France,  
Flins

10.5 MW

 France,  
Sandouville

Unite

Seat  
facilit

Renau

Renau

[www.pvresources.com](http://www.pvresources.com)

<http://www.riverclack.com/>

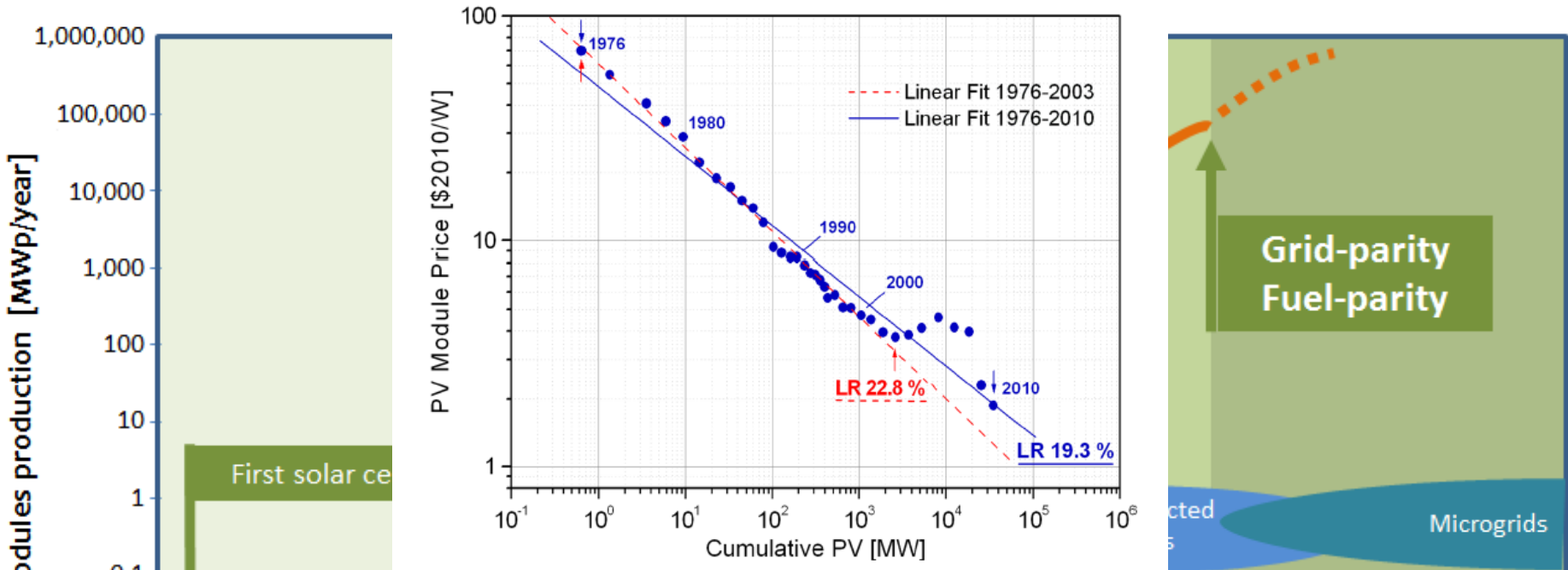
Courtesy of Barbara Terreni  
Hanwa Q Cells

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# HISTORY OF PHOTOVOLTAICS



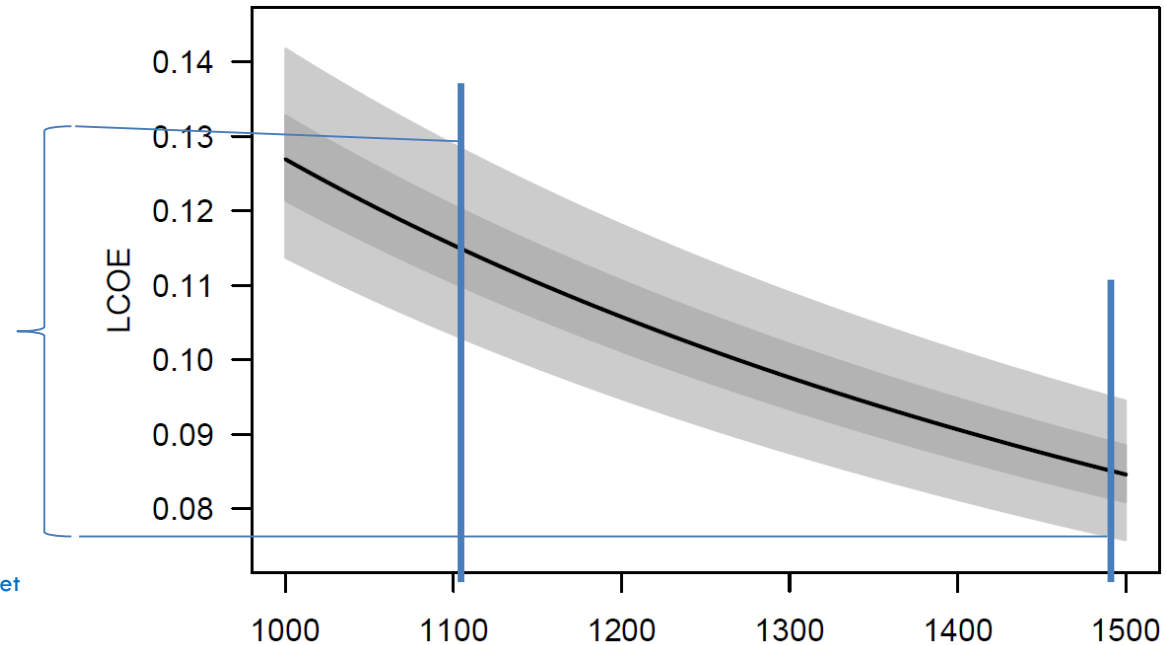
1955, 1975, 1995, ... 2015 marks a fundamental milestone in the history of PV: THE GRID PARITY and the FUEL PARITY occurring in many countries of the world!!!

# GRID AND FUEL PARITIES

- The grid-parity occurs when the price of electricity for the end consumer is lower than the generation cost from PV
- The fuel-parity occurs when the cost of electricity from PV is comparable with the one from conventional technologies (such as thermoelectric and hydroelectric power plants)

# GRID PARITY – AN EXAMPLE

The Grid Parity is achieved for any condition and type of customer



F. Pauli, G. Sulligoi, V. Lughi, A. Massi Pavan  
Grid Parity in the Italian C&I electricity market  
IEEE ICCEP, Alghero, 2015

Average electricity Price in Italy	
Type of customer	Price [€uro cent/kWh]
Residential - Trieste	20.8
Residential – Rome, Palermo	28.3
Commercial - Industrial	19.3

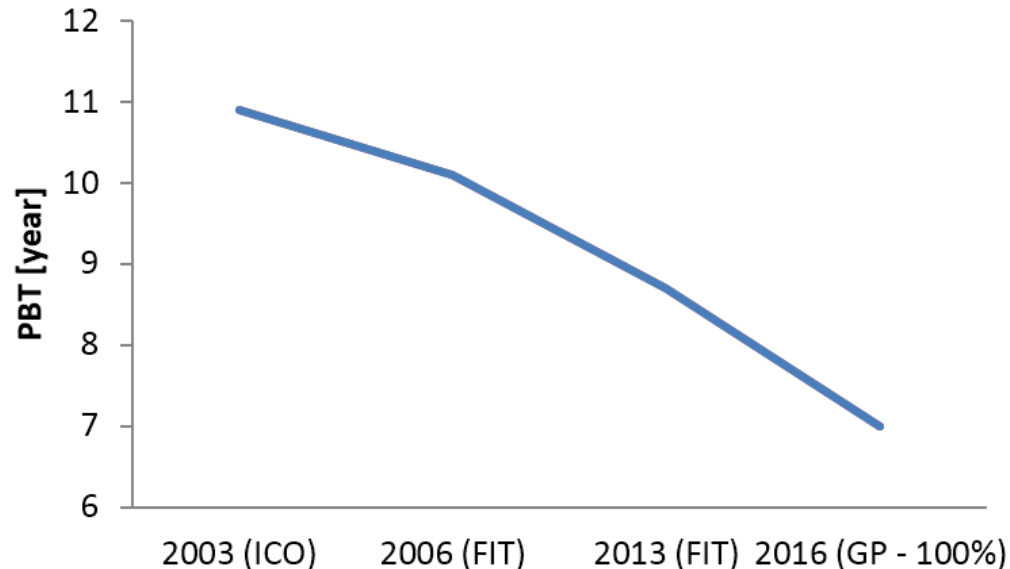
$E_0$

# PV IS MOST CONVENIENT THAN EVER

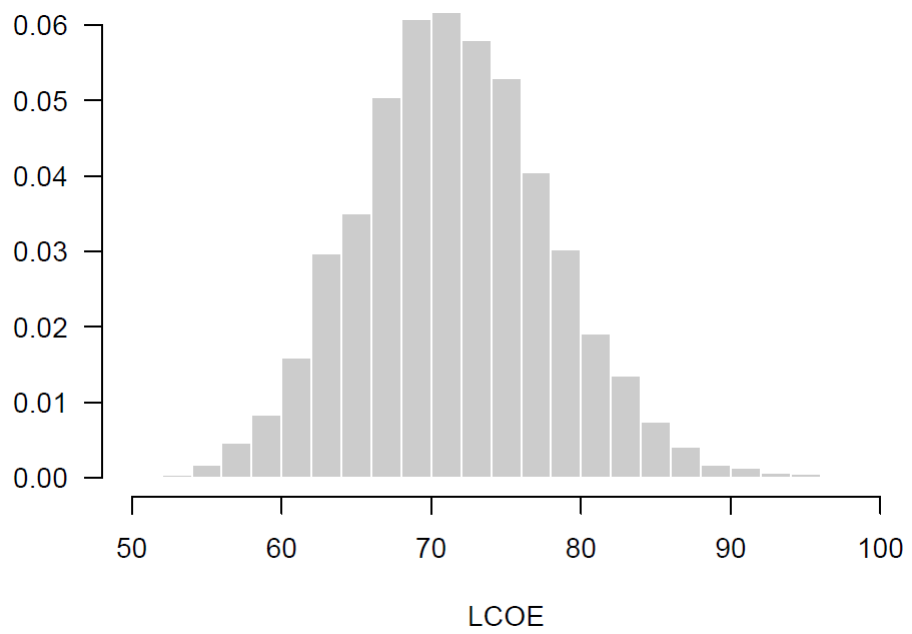
YEAR	Electricity Price [€/kWh]	Overnight Capital Cost [€]
2003 – Initial Capital Outlay	0.170	8,500.00
2006 – First feed-in tariff	0.198	7,000.00
2013 – Last feed-in tariff	0.251	2,400.00
2016 – No incentives	0.253	1,400.00

A. Massi Pavan, M. Chiandone, V. Lughì, G. Sulligoi

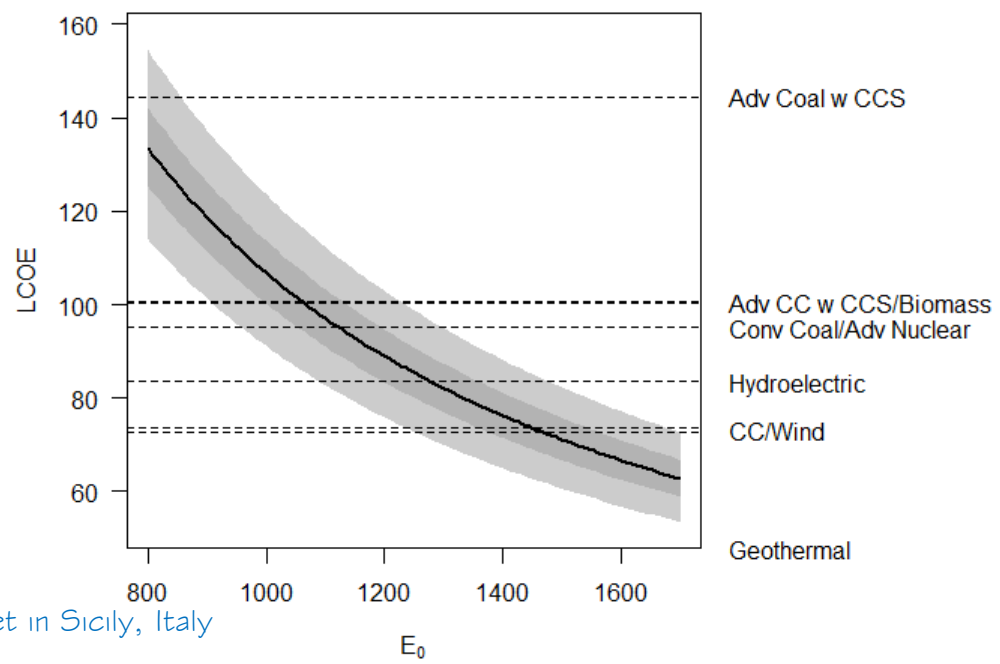
Despite the attainment of grid-parity the Italian PV market does not take off. An analysis IET RPG, 2014



# FUEL PARITY – AN EXAMPLE



MEDIAN VALUE OF LCOE  
71.3 €/MWh



A. Massi Pavan et al.  
Leading the way toward fuel parity in pv: the utility-scale market in Sicily, Italy  
EEEIC, 2016



# GRID AND FUEL PARITY PV BREAKTHROUGH

- In Europe the **grid-parity** is obtained for almost all the residential and C&I applications
- In high irradiance areas (Sicily) the Utility-Scale PV plants are approaching the **fuel-parity**

The end of incentives phase and the new opportunities represented by the grid and fuel-parity pave the transition from the childhood to maturity of the photovoltaic market

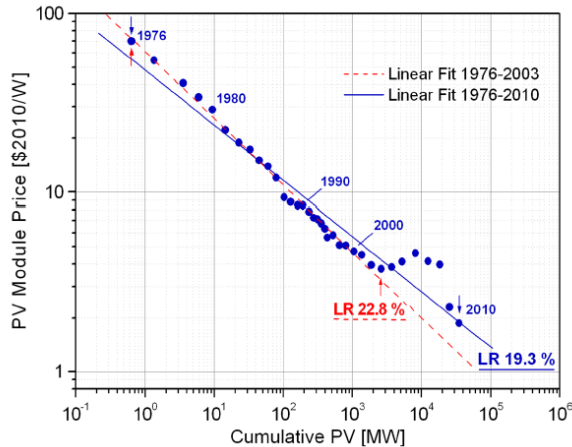
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# TOWARD GLOBAL GRID AND FUEL-PARITY

$$LCOE = \frac{OCS \times CRF + FO\&MC}{\frac{E_0}{N} \times \sum_{k=1}^N \left(1 - \frac{d_r \times (k-1)}{100}\right)}$$

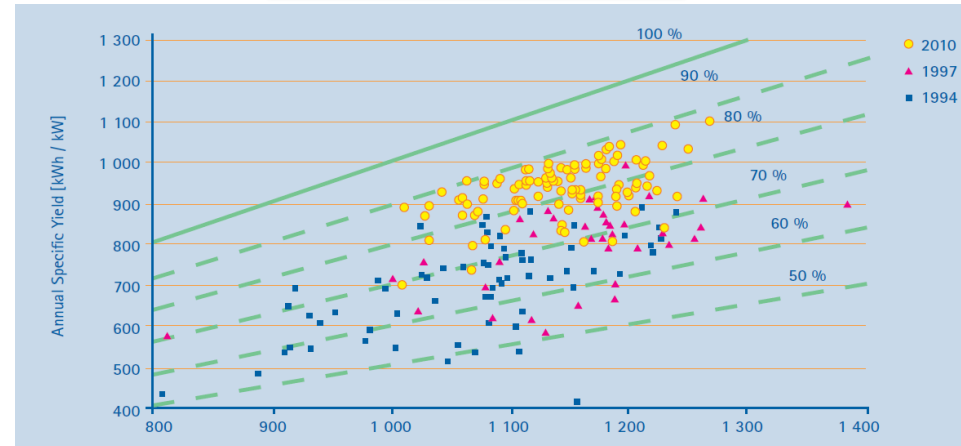
YESTERDAY  
MODULES



BOS (Balance Of the System)

All costs except the  
PV modules

TODAY  
PERFORMANCES

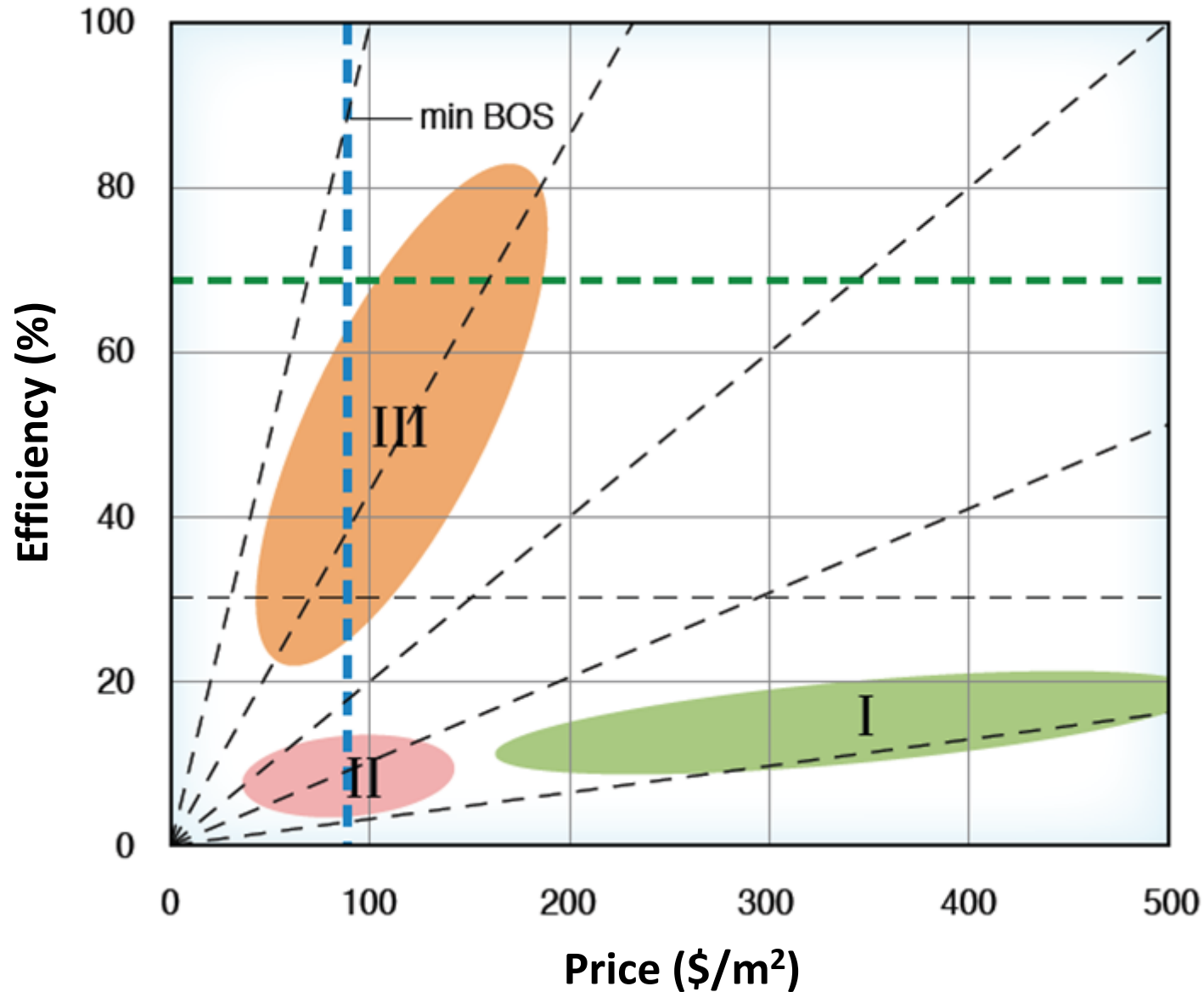


IEA PVPS Annual report 2012

TOMORROW - BOS

	Modules [€/Wp]	BOS [€/Wp]	System [€/Wp]	BOS/system [%]
1990	10	2,5	12,5	20
2000	5,5	1,5	7	21
2011	1,1	1,3	2,4	54
2012	0,6	0,85	1,45	61
Reduction [%]	94	38	88	/

# TOWARD GLOBAL GRID AND FUEL-PARITIES



# SUMMARIZING ...

## GRID-PARITY - RESIDENTIAL AND COMMERCIAL/INDUSTRIAL (C&I)

(Italian) Electricity Price (€/kWh)	0,193 – 0,283
Photovoltaic LCOE (€/kWh)	0,075 – 0,140

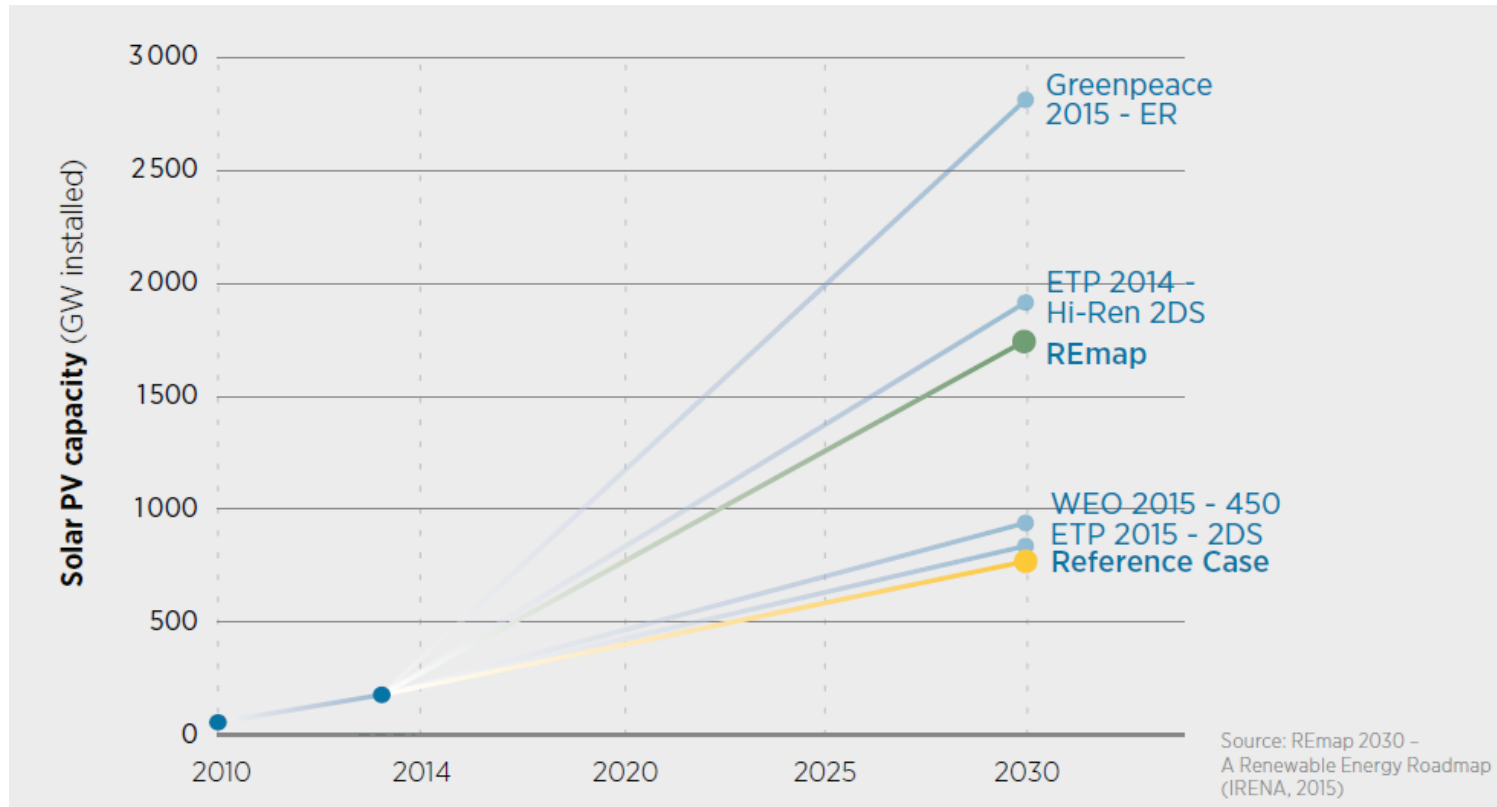
## FUEL-PARITY - UTILITY SCALE SYSTEMS

Cost of electricity by different sources (€/kWh)	0,045 – 0,150
Cost of electricity from a PV Utility Scale (€/kWh)	0,058 – 0,085

## BOS COST REDUCTION – ECONOMIES OF SCALE – NEW TECHNOLOGIES FORECASTED LCOEs (2025)

Residential and C&I (€/kWh)	0,053 – 0,098
Utility Scale – Sicily (€/kWh)	0,025 – 0,037

# CAPACITY FORECASTING



IRENA – The power to change: solar and wind cost reduction potential to 2025

# THE ROLE OF DSOs

## ENEL AND THE ROAD FOR RELAUNCHING

The energy revolution will lead to a strong growth in domestic solar PV and the spread of energy storage devices

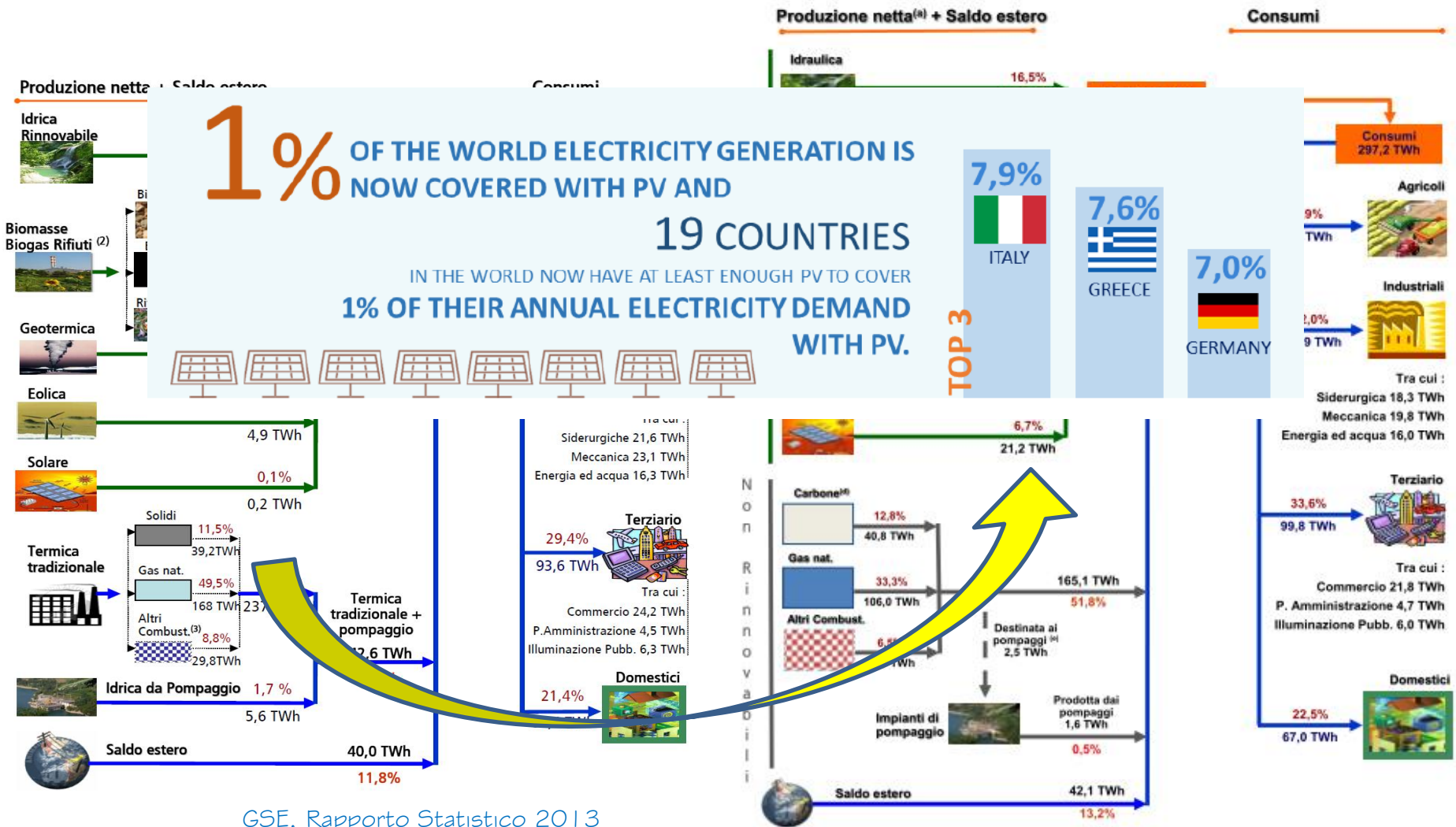


# CONCLUSIONS

- RES are pushing the energy sector
- The PV market is the fastest growing in the RES sector
- Europe led this growth in the past, while today China, Japan and USA are the drivers of the market
- The attainment of the grid and fuel parities represent a fundamental milestone in the history of this solar technology
- The PV LCOE will continue to drop in the future and the market seems having in the near future the potential to do not stop growing exponentially



# POWER SUPPLY CHAIN ITALY 2003 - 2013



GSE, Rapporto Statistico 2013

Scienza e Tecnologia dei Materiali Elettrici e Fotovoltaici AA2017-2018

I - Introduction to Photovoltaics - ALESSANDRO MASSI PAVAN





“It is the greatest of all mistakes to do nothing because you can only do little”

# THE ROLE OF THE COST OF MONEY

UTILITY SCALE PV PLANT	
OCS [€/Wp]	1,200,00
O&MC [%]	4%
Yield [kWh/kWp]	1,496
Module degradation rate [%/year]	0.7

