THE BREAKTHROUGH OF PHOTOVOLTAICS

Alessandro Massi Pavan

MANCHESTER 1824
The University of Manchester
School of Electrical and Electronic Engineering

Summer School on Energy
Giacomo Ciamician

Manchester

October 18th, 2017

awarenergy
www.awarenergy.eu

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 21st 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 21st century, current energy systems do not meet these challenges"

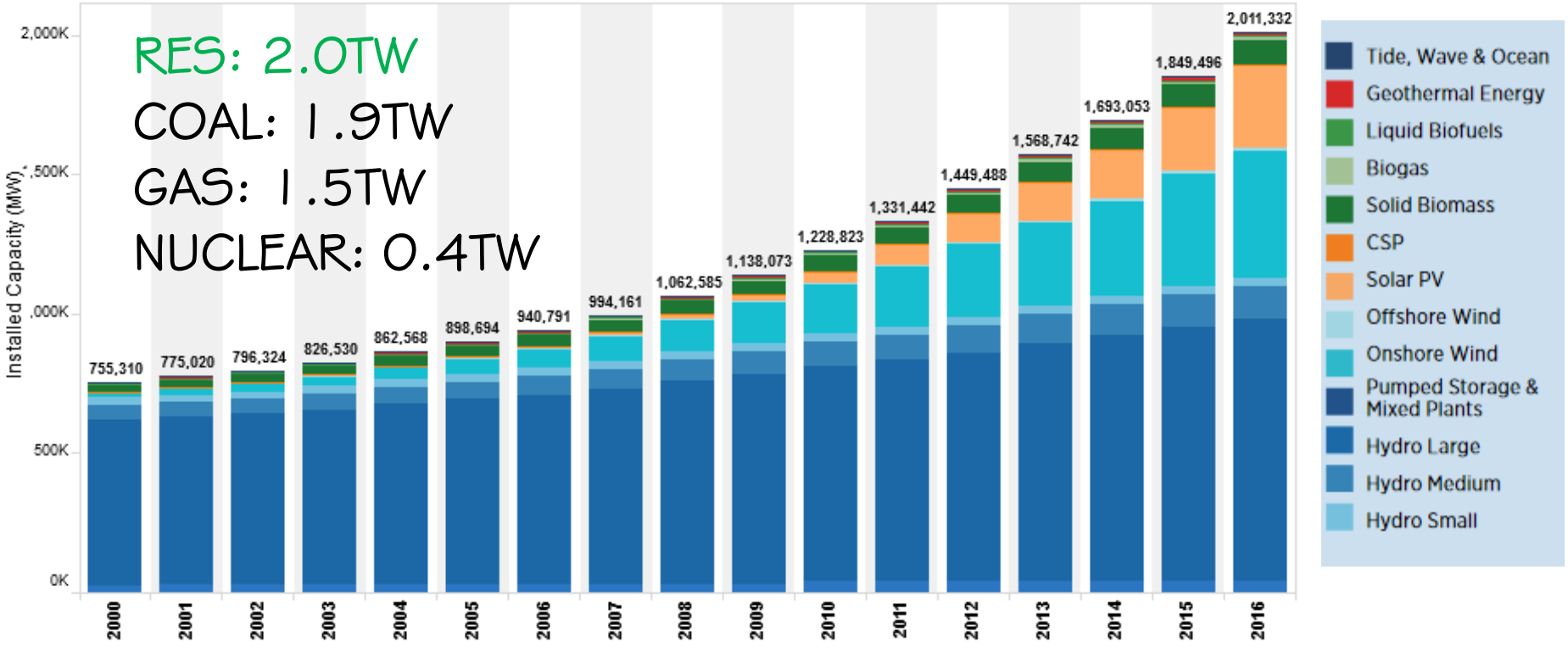
"A major transformation is required to address these challenges and to avoid potentially catastrophic future consequences for human and planetary systems"

Global Energy Assessment (GEA) 2013

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

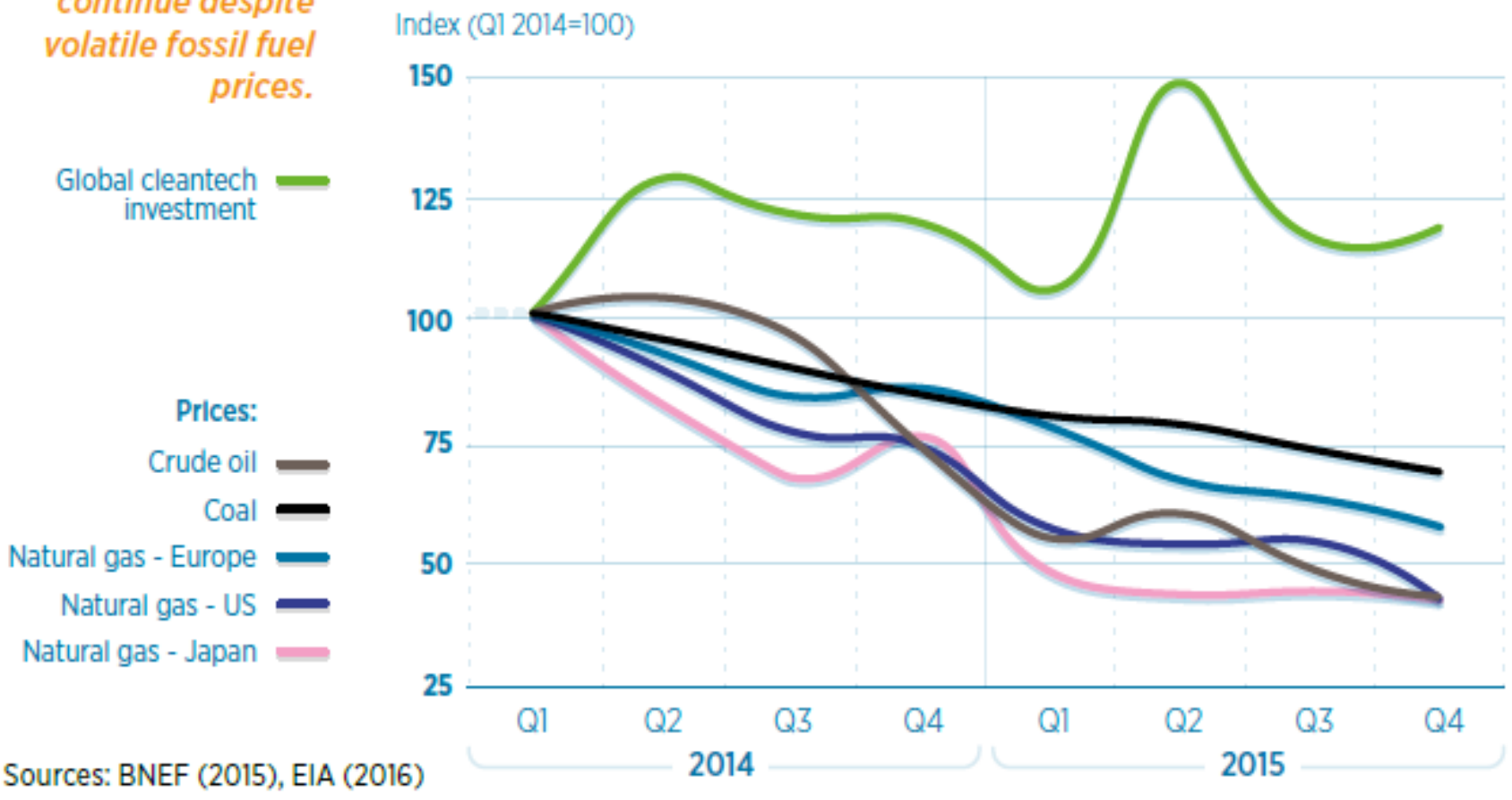


http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=16

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

Bloomberg Markets Tech

BUSINESS INSIDER UK TECH

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

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

ANSA ENGLISH EDITIONS Mediterraneo NuovaEuropa

ANSAen Latest News

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

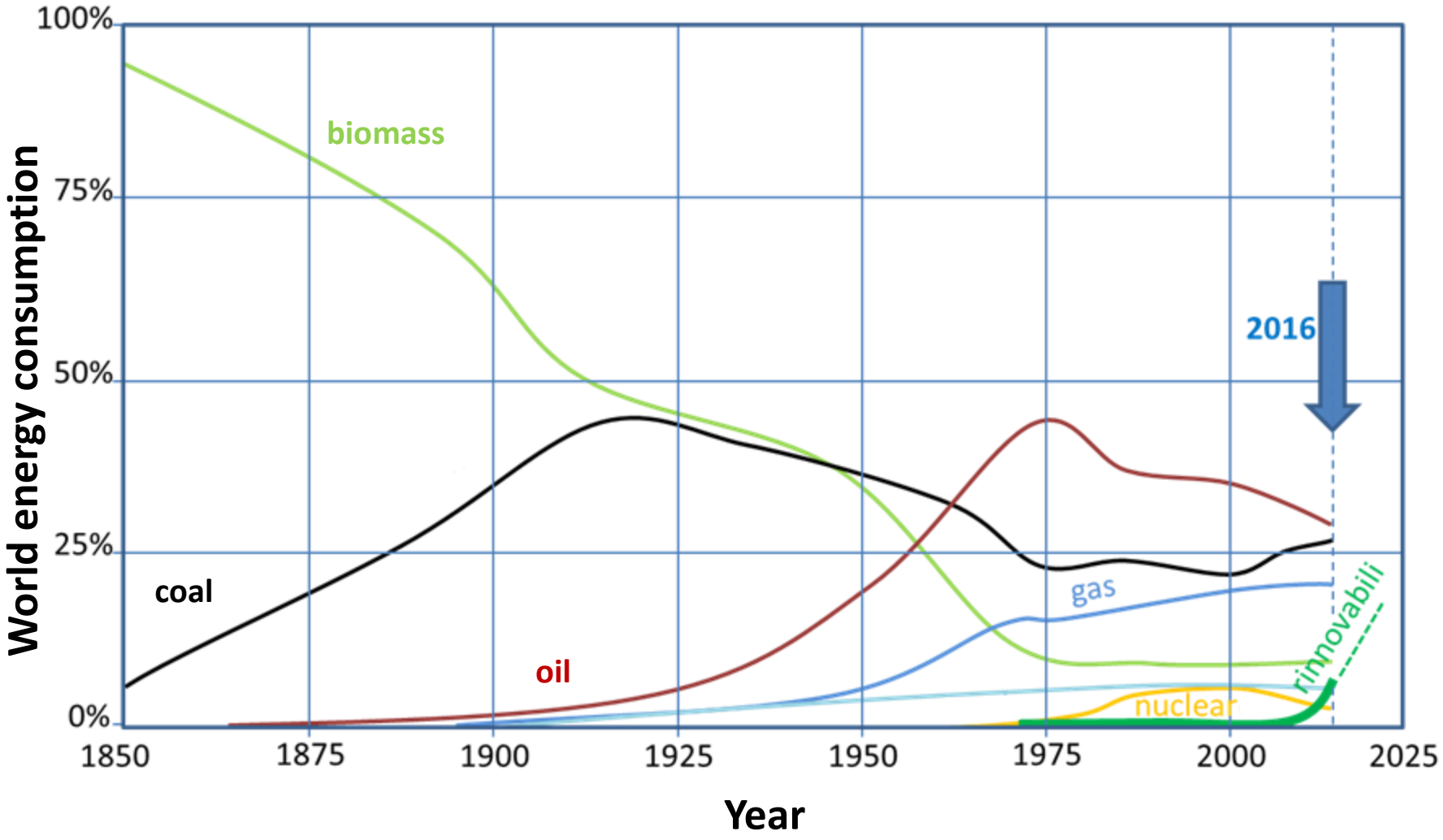
) - Rome, July 27 - Italy met 87% of its electricity demand via produced from renewable sources on May 21, a new record, erraris, the CEO of power-grid company Terna, said on day.

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)

REN21, 2013 and 2014, REN 23, 2014
IRENA Renewable power generation costs in 2014

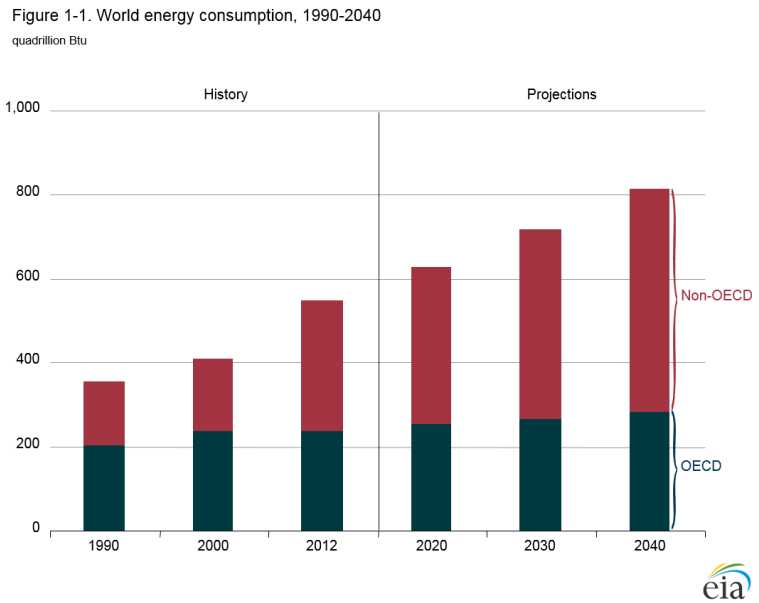
ENERGY TRANSITIONS



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

SCARCITY OF NATURAL RESOURCES



Estimates of world crude oil and NGLs resources *billion barrels*

Average Oil Demand (2013-2035): 100

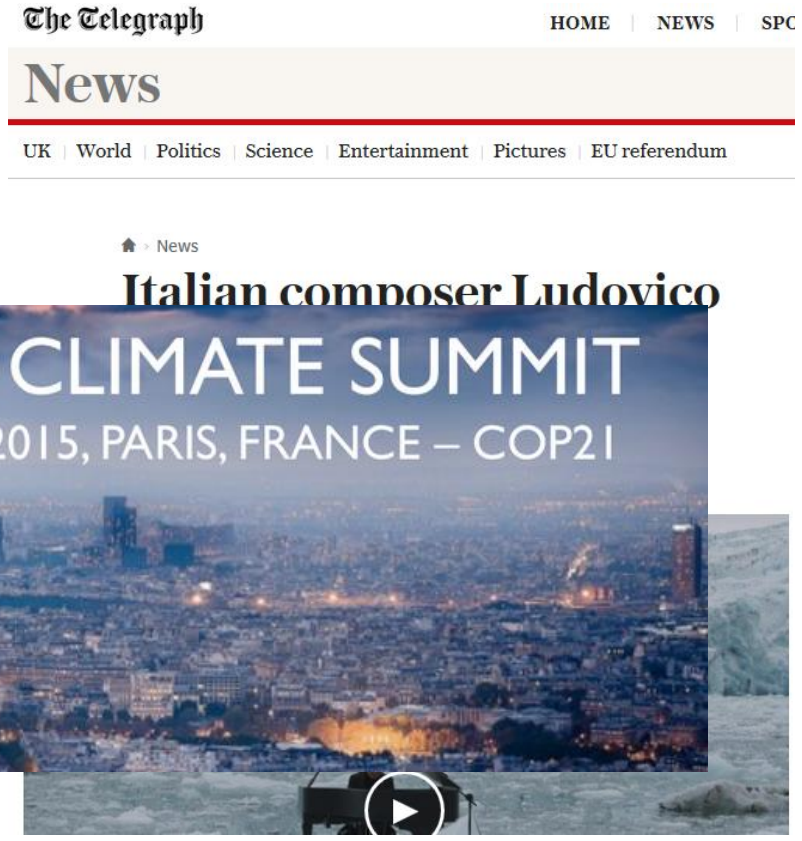
		Non-OPEC	Total world
Cumulative production to 2010 (a)	446	695	1,142
Proved reserves (b)			1,467
Reserves to be added ultimately (c)	**617**	**620**	**1,237**

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

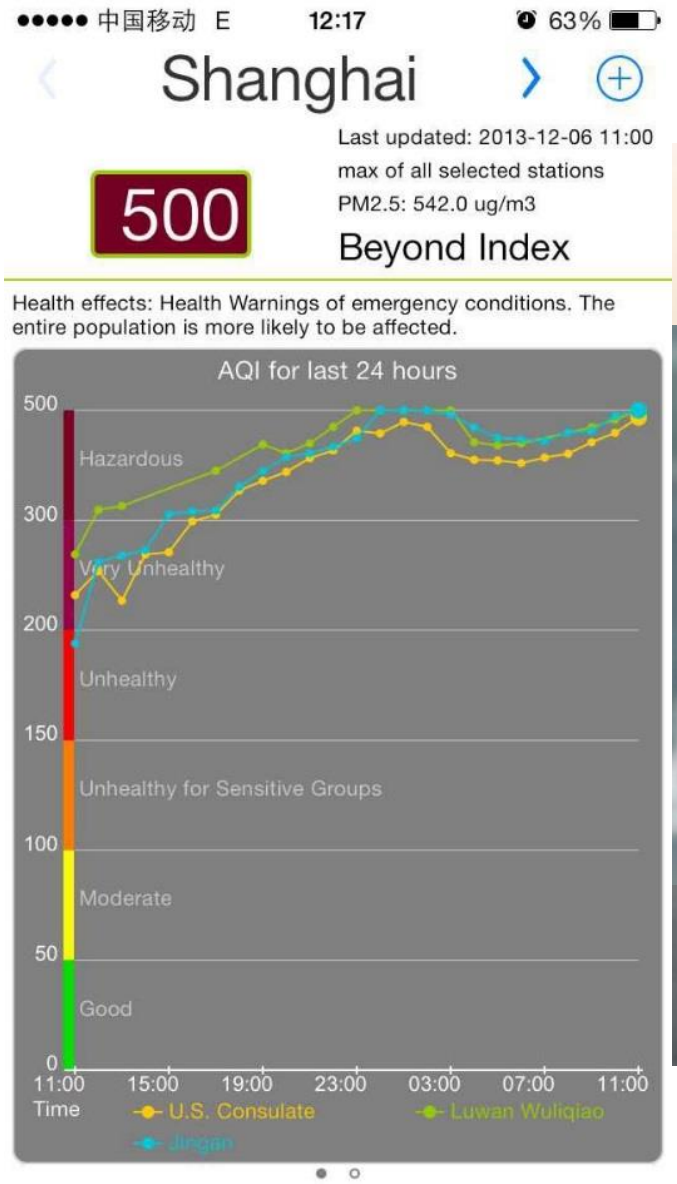
World Oil Outlook – OPEC 2012

Total reserves: 2,704

CLIMATE CHANGE



QUALITY OF LIFE



DROP IN RES COSTS

sign in | become a supporter | subscribe | search | jobs | dating | more | UK edition

theguardian

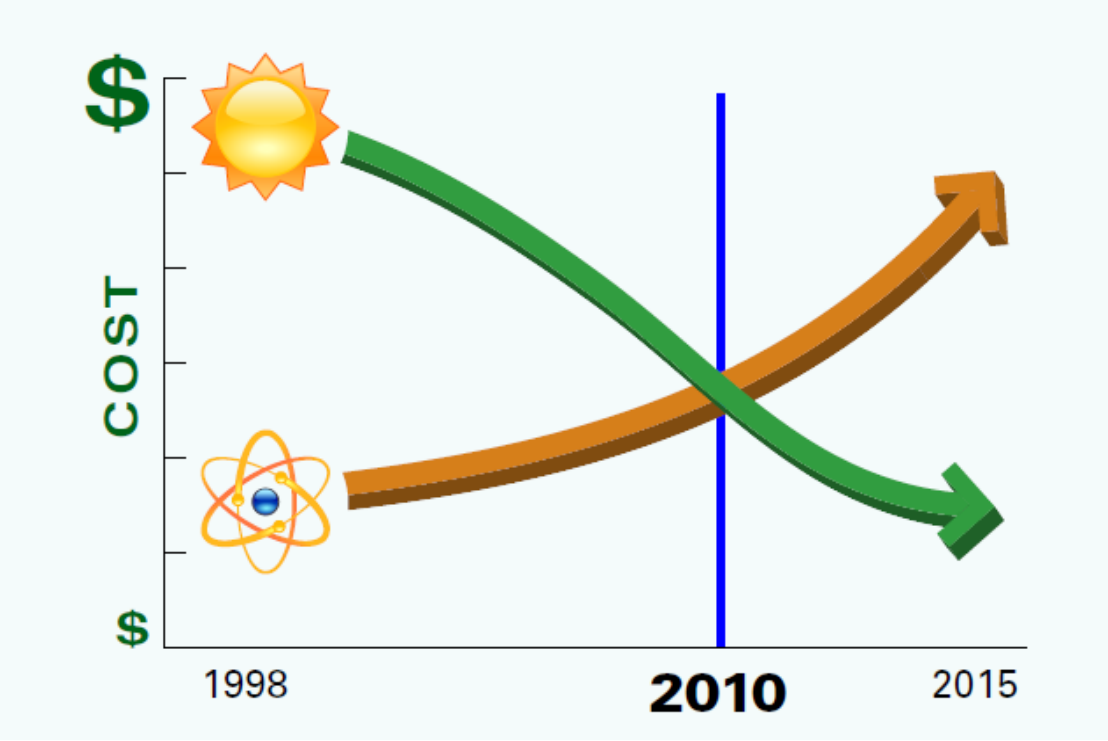
UK | politics | world | sport | football | opinion | culture | business | lifestyle | fashion | environment | tech | travel | all

home › environment › energy | pollution | climate change | wildlife

Renewable energy

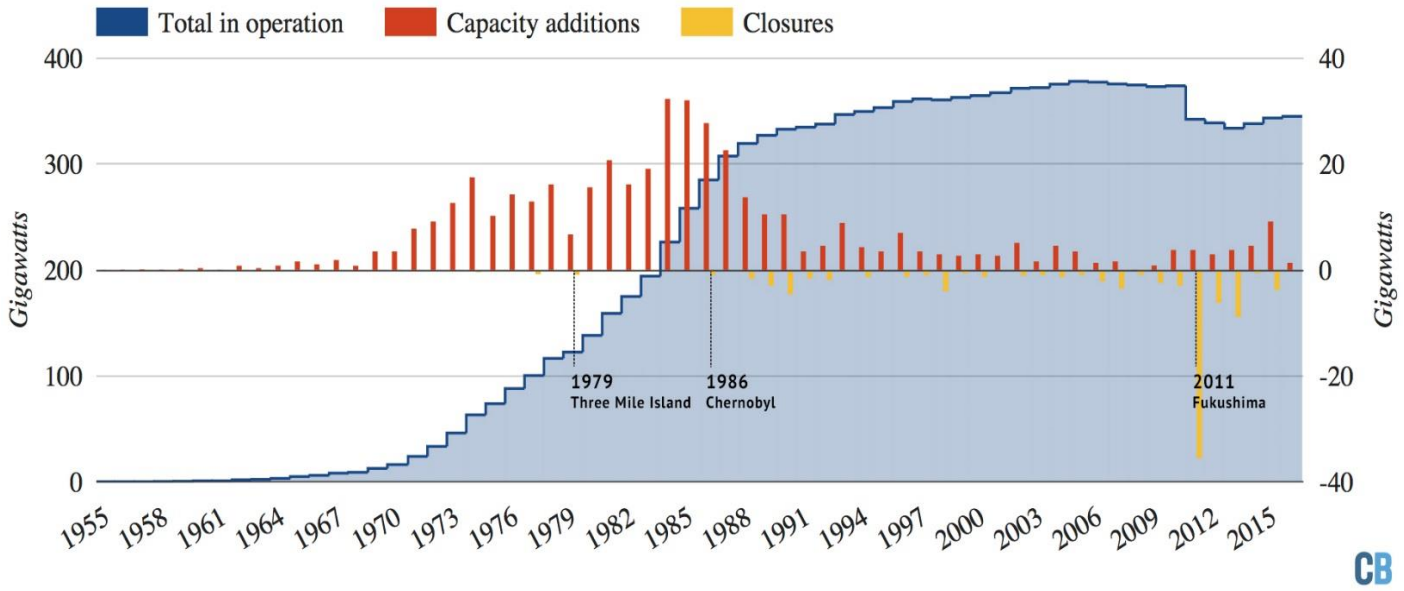
'Specta
costs l

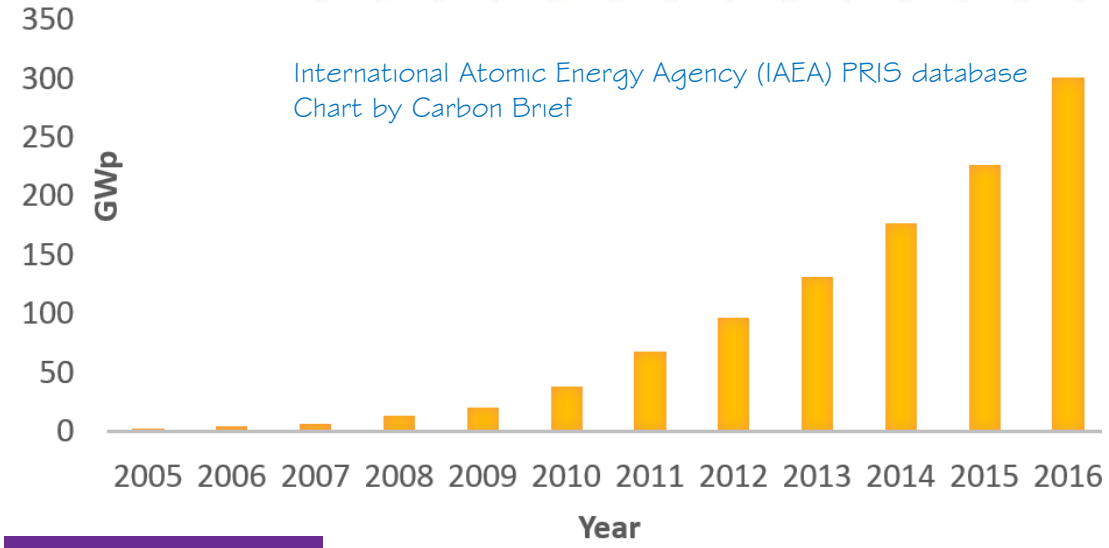
Falling solar



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

DROP IN RES COSTS





FACTORS OF CHANGE

SCARCITY OF NATURAL RESOURCES

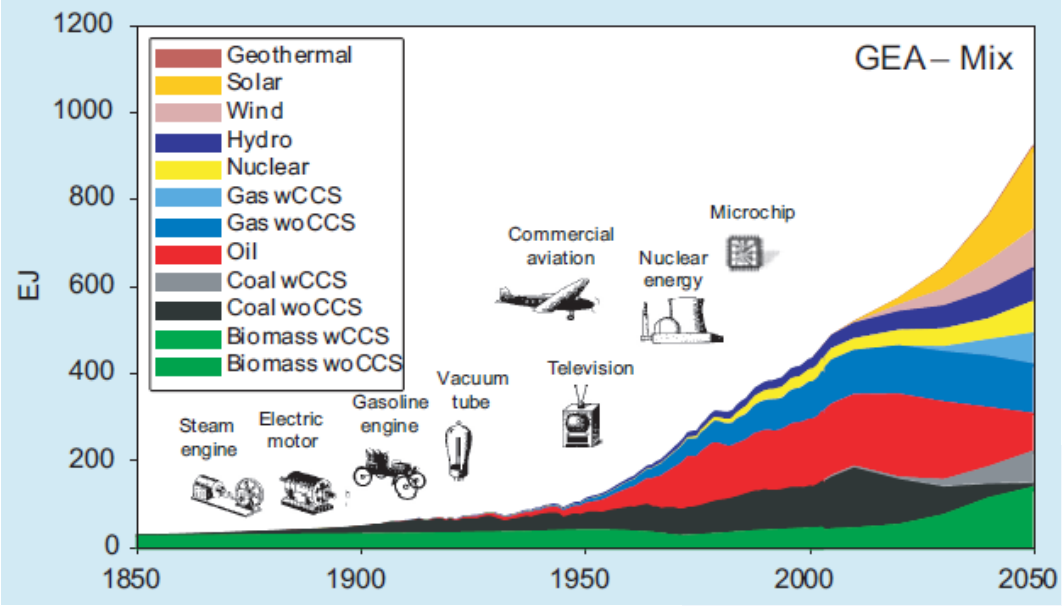
CLIMATE CHANGE

QUALITY OF LIFE

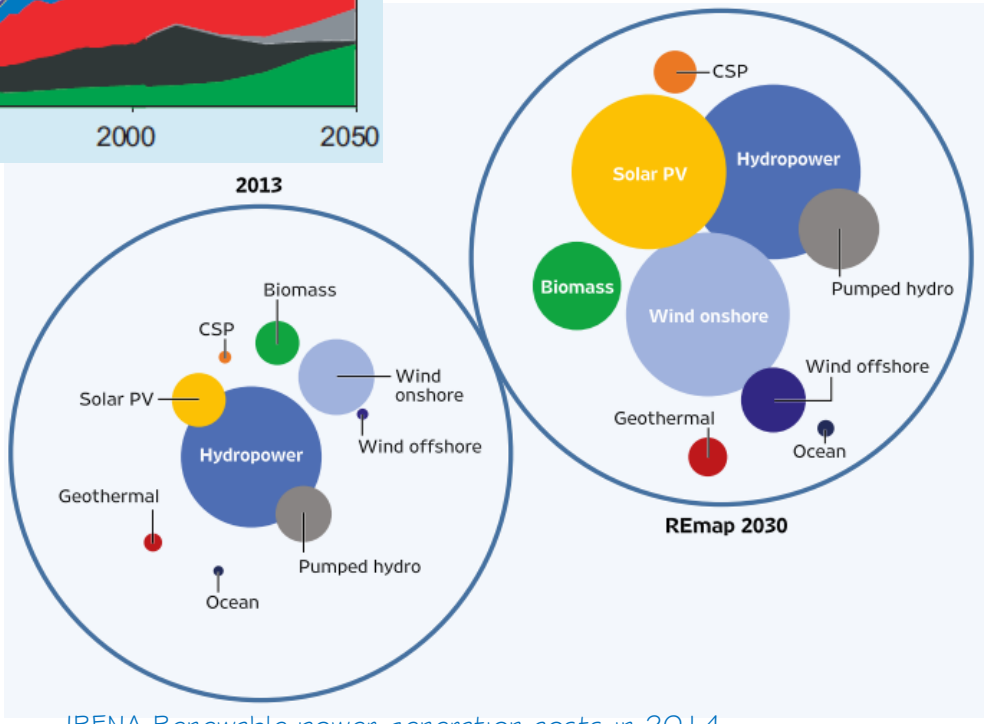
DROP IN RES COSTS

SPEED OF INSTALLATION!!!

FUTURE ENERGY MIX



Global Energy Assessment (GEA), 2013



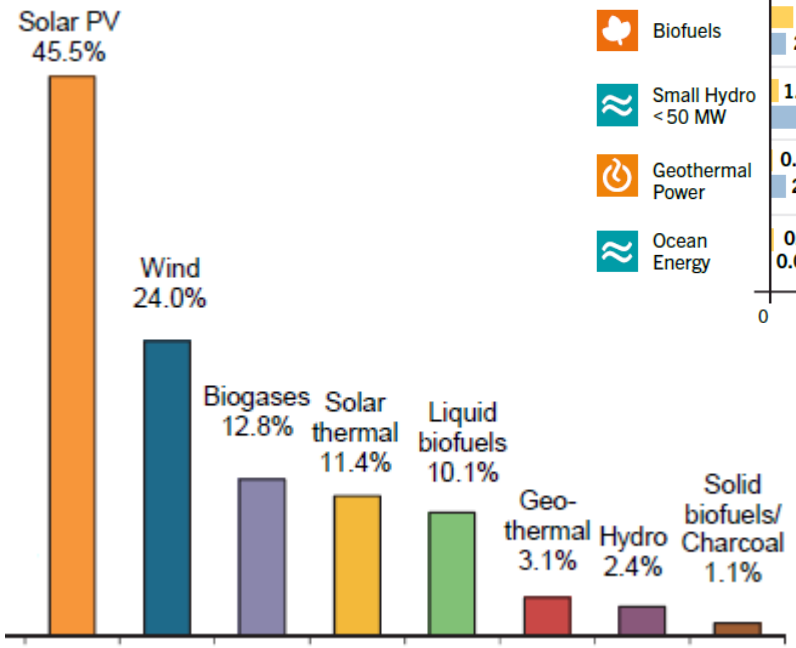
IRENA Renewable power generation costs in 2014

OUTLINE

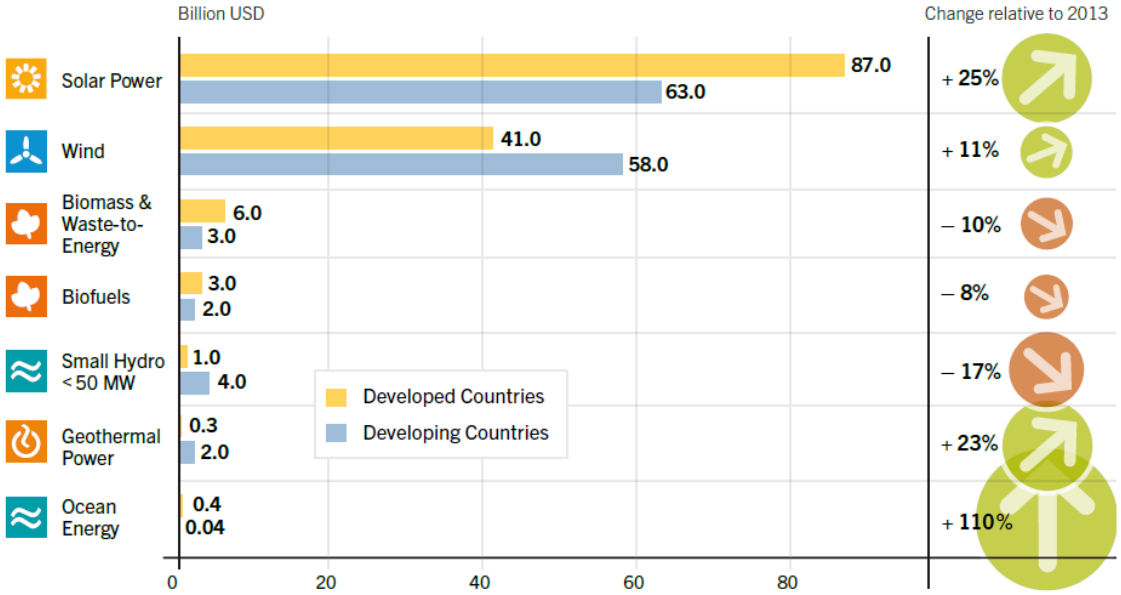
- Introduction (a boom in RES)
- Five causes of the boom
- The role of photovoltaics
- History and breakthrough of PV
- The future of photovoltaics
- Conclusions

THE ROLE OF PHOTOVOLTAICS

Investments in 2014



IEA, Renewables information: overview statistics, 2017

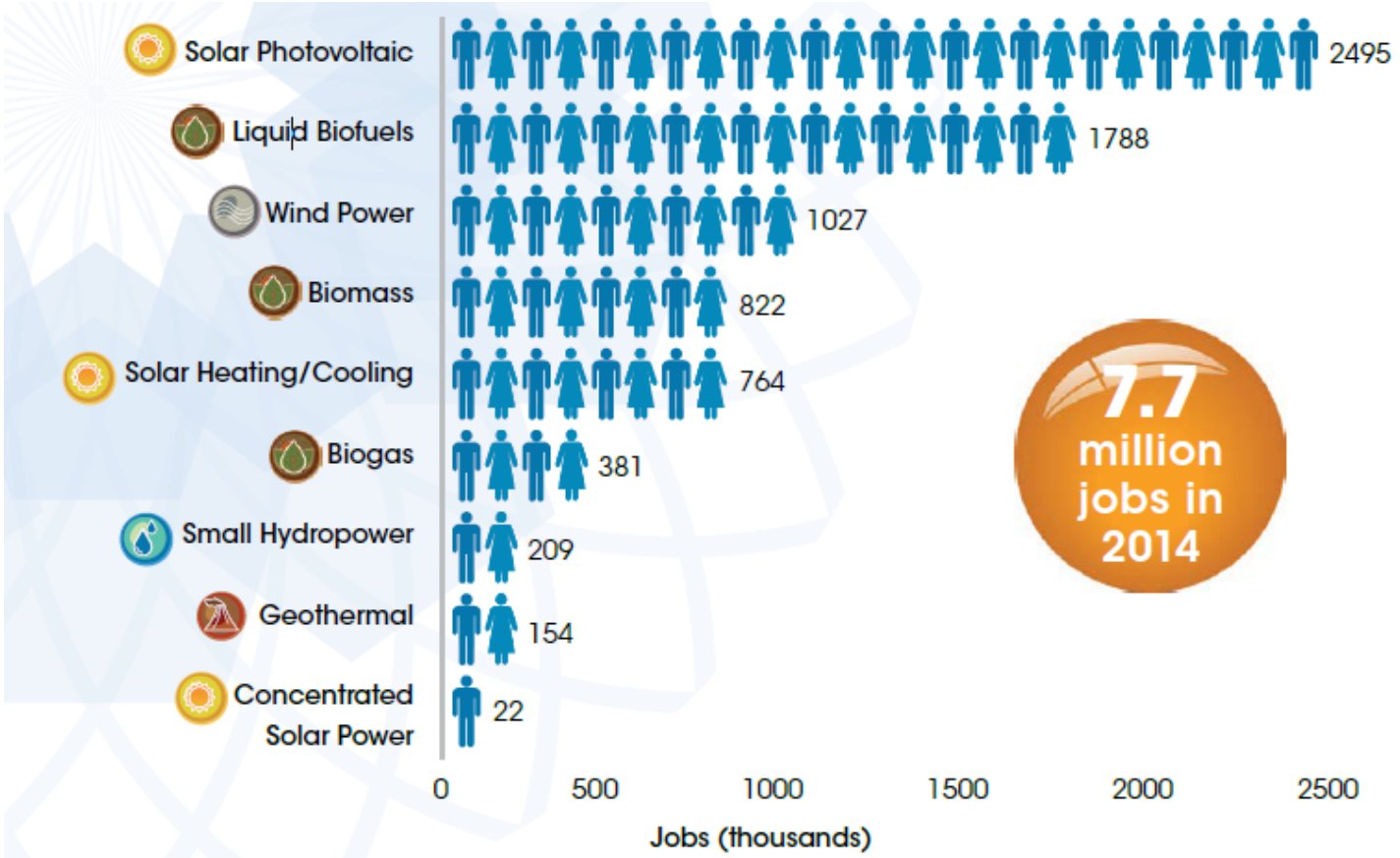


IRENA, Renewable power generation costs in 2014

Average annual growth rates of world renewables from 1990 to 2015

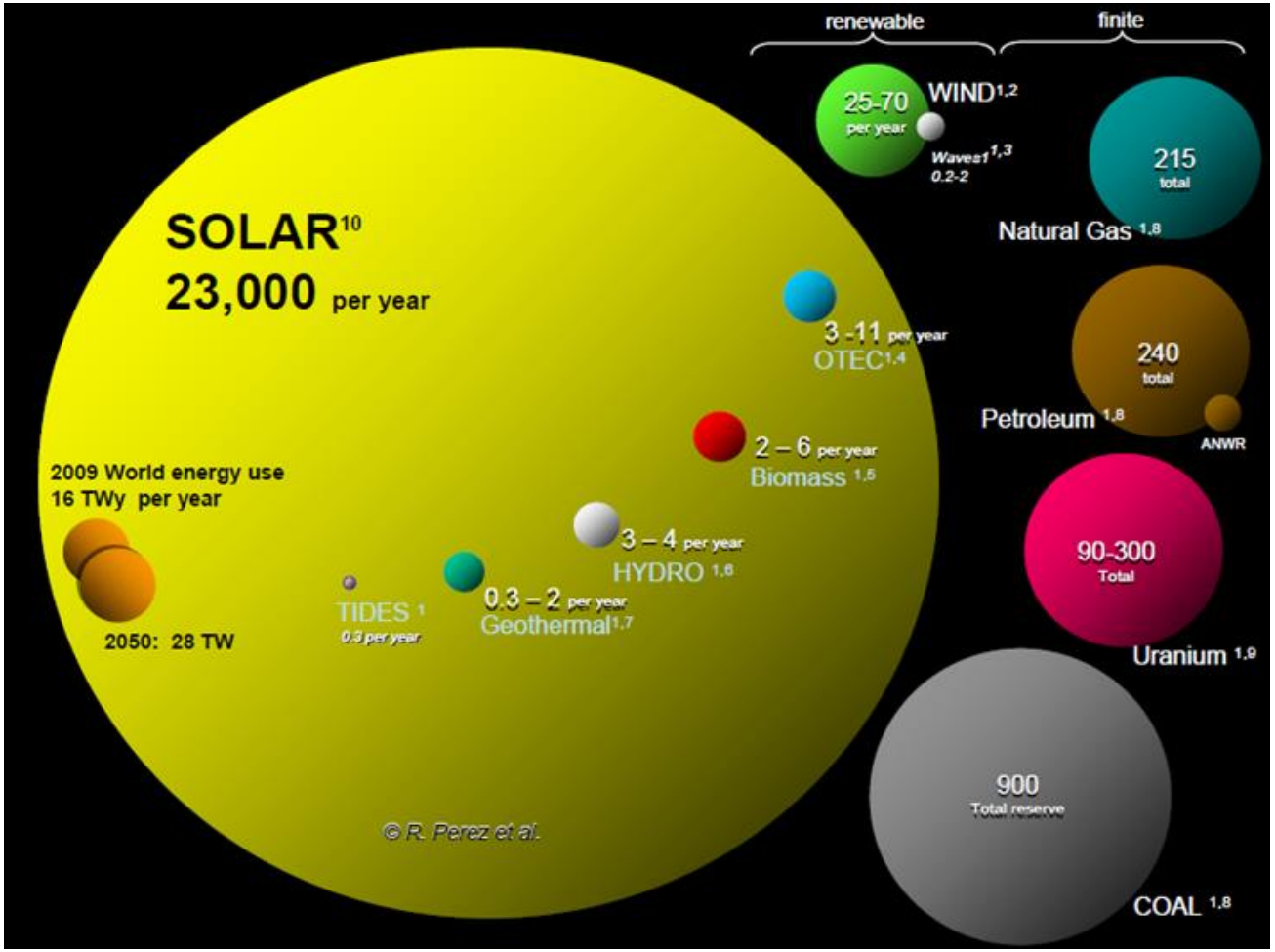
MANCHESTER 1824
The University of Manchester

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

THE PHOTOCHEMISTRY OF THE FUTURE[1]

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."

MANCHESTER 1824
The University of Manchester

ADVANTAGES OF PHOTOVOLTAICS

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

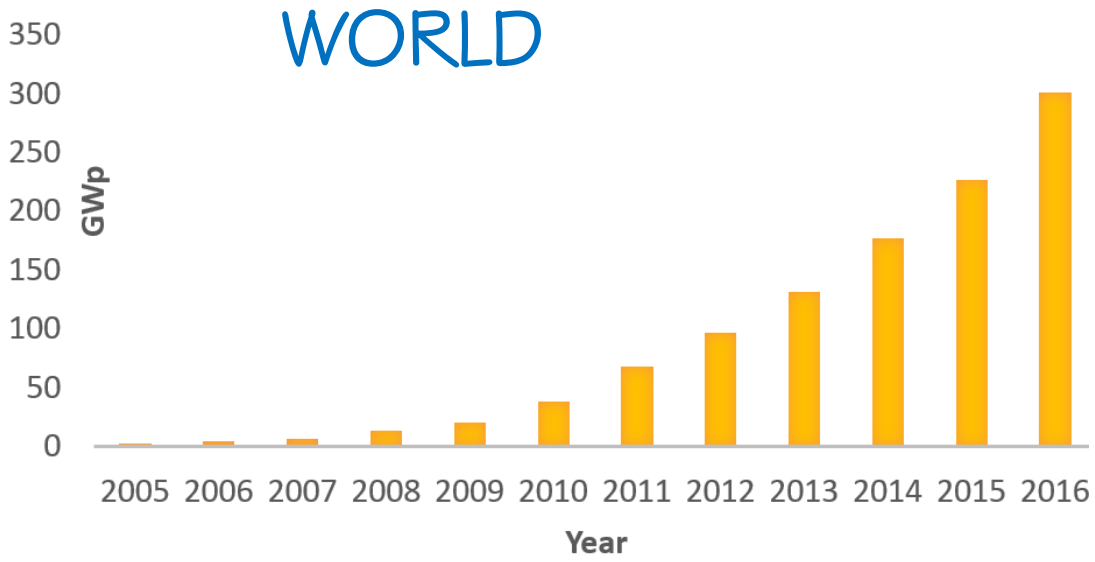
ADVANTAGES OF PHOTOVOLTAICS

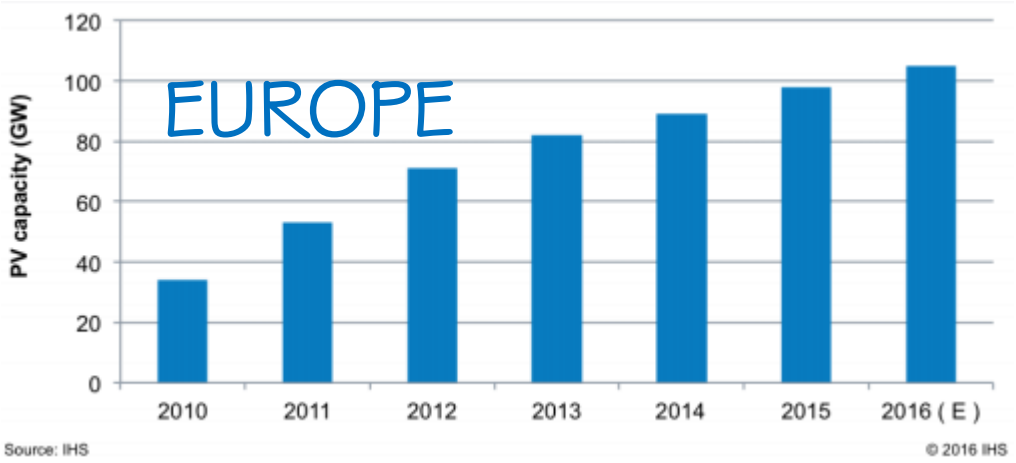
- Can be integrated into new and existing buildings
- High public acceptance
- New distributed and no specialized jobs
- Choice and control
- Daily output peak can match the local demand
- Distributed generation (can be installed at nearly any point-of-use)

FALSE MYTHS

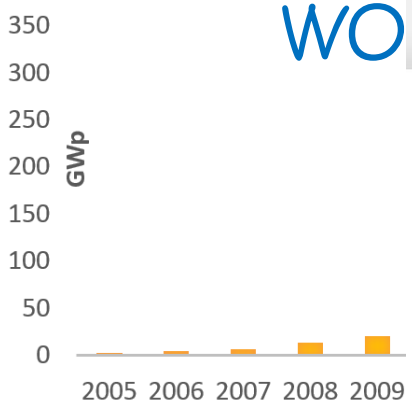
- PV is too expensive
- PV modules never recover the energy required in making them
- No more R&D is needed
- PV requires too much land to ever meet significant fraction of world needs
- PV industry is polluting
- PV efficiency is a problem

PV CUMULATIVE POWER





PV CUMULATIVE POWER



WO

The Economist | World politics | Business & finance | Economics | Science & technology | Culture

Graphic detail

Charts, maps and infographics

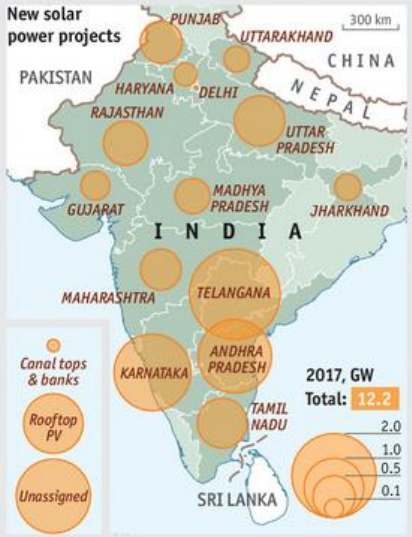
Previous | Next | Latest Graphic detail | All latest updates

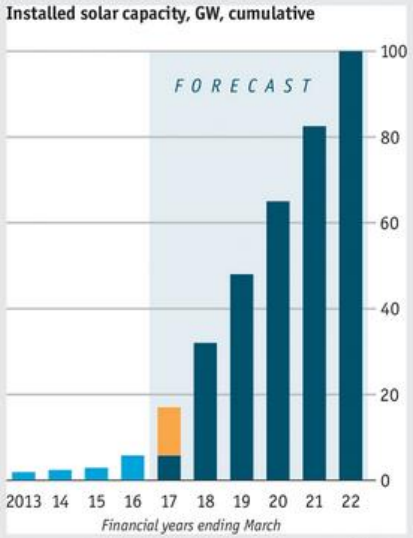
Daily chart

Indian solar power

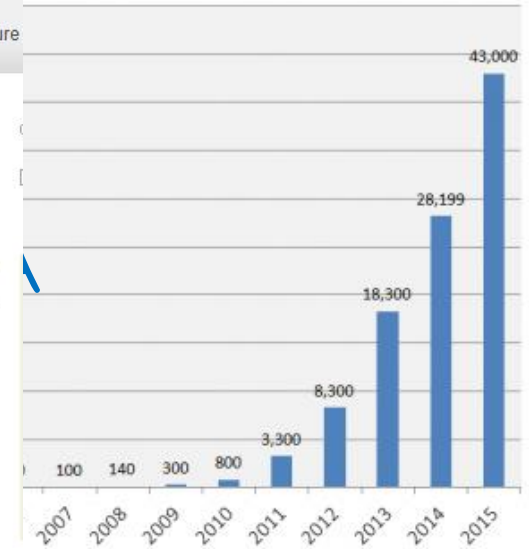
Jun 6th 2016, 16:30 BY THE DATA TEAM | Timekeeper | Tweet

Solar power in India

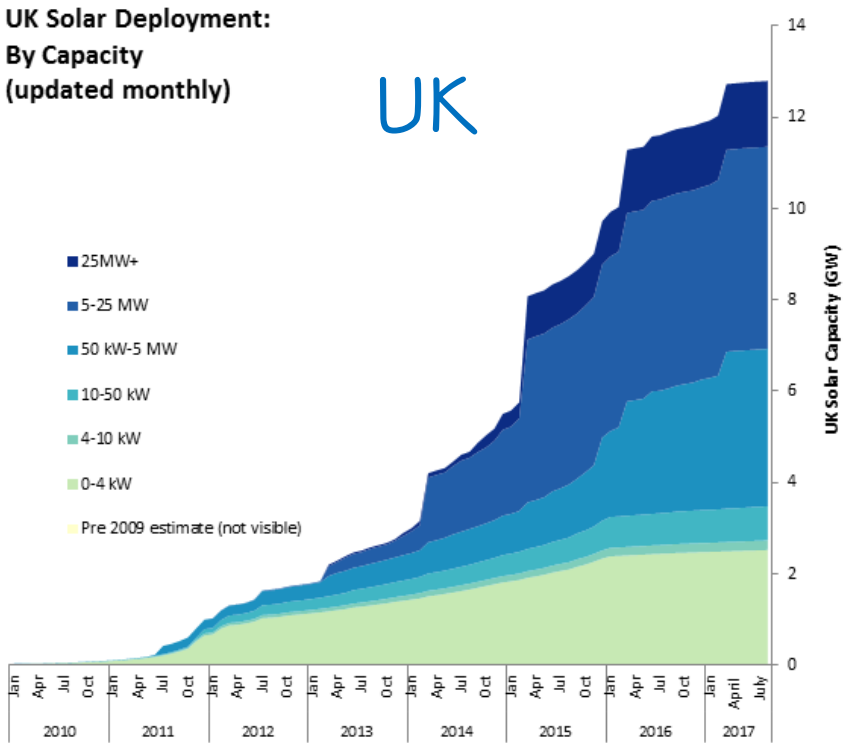




1992 1996 2000 2004 2008 2012



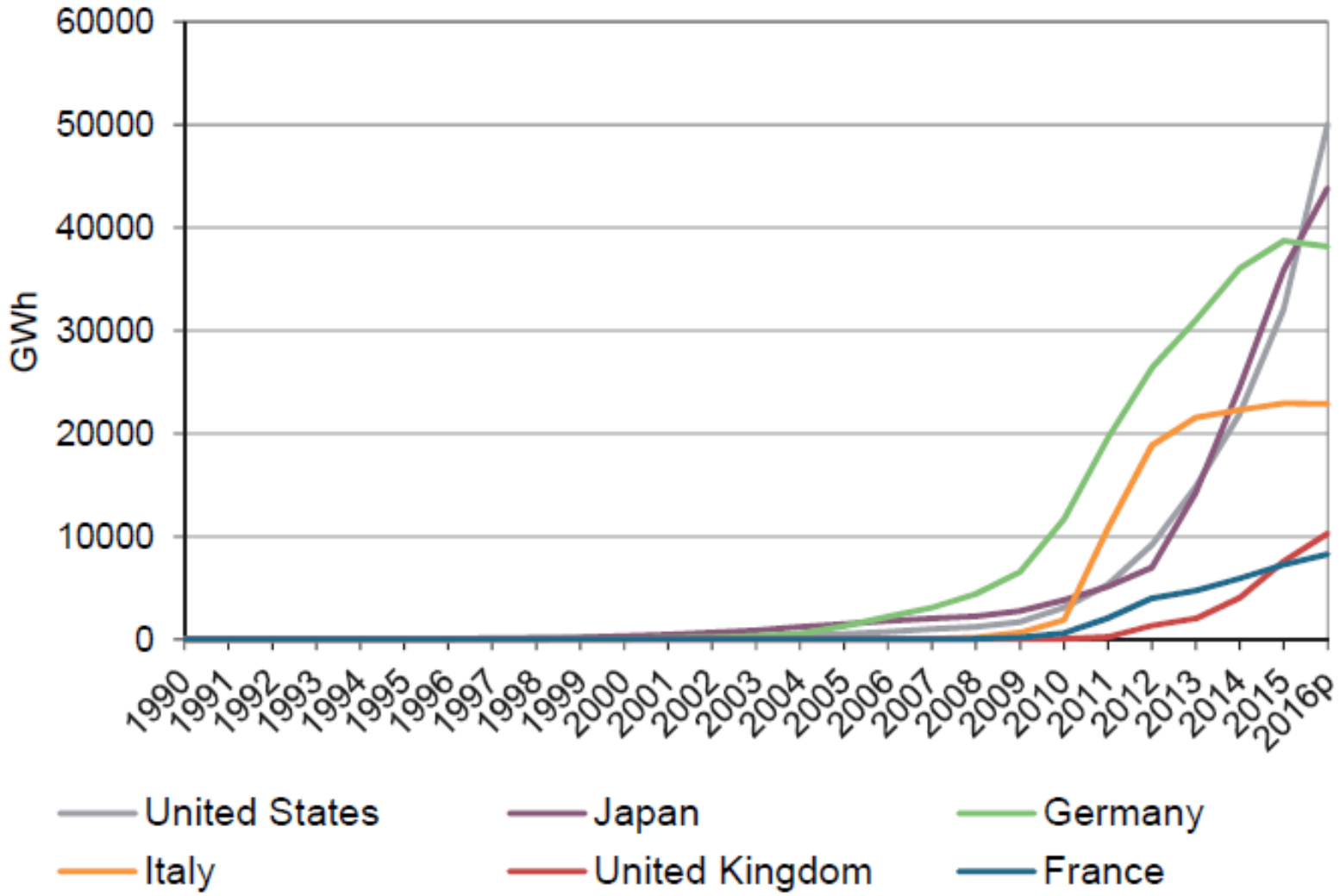
PV CUMULATIVE POWER



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

www.gse.it

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 – 1MW

2017 – 1,000MW

345 MW	India *Charanka,*	Charanka Park PV power plant	2012-2015

www.pvresources.com - http://www.q-cells.com/en/

C&I ROOFTOP PV SYSTEMS

Power [1]	Location	Description [2]	On Grid
			2012
		toen	2010
			2010-2011
			2015
		Unite	
11 MW	Spain, *Martorell*	Seat facilit	
10.6 MW	France, *Flins*	Renau	
10.5 MW	France, *Sandouville*	Renau	

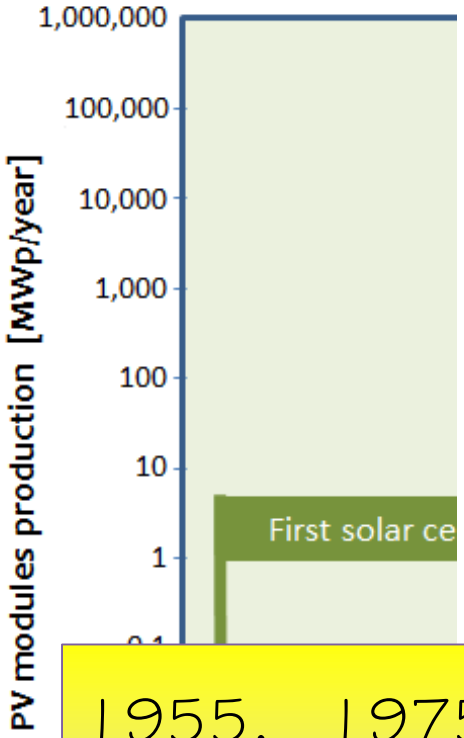
www.pvresources.com
http://www.riverclack.com/
Courtesy of Barbara Terreni
Hanwa Q Cells

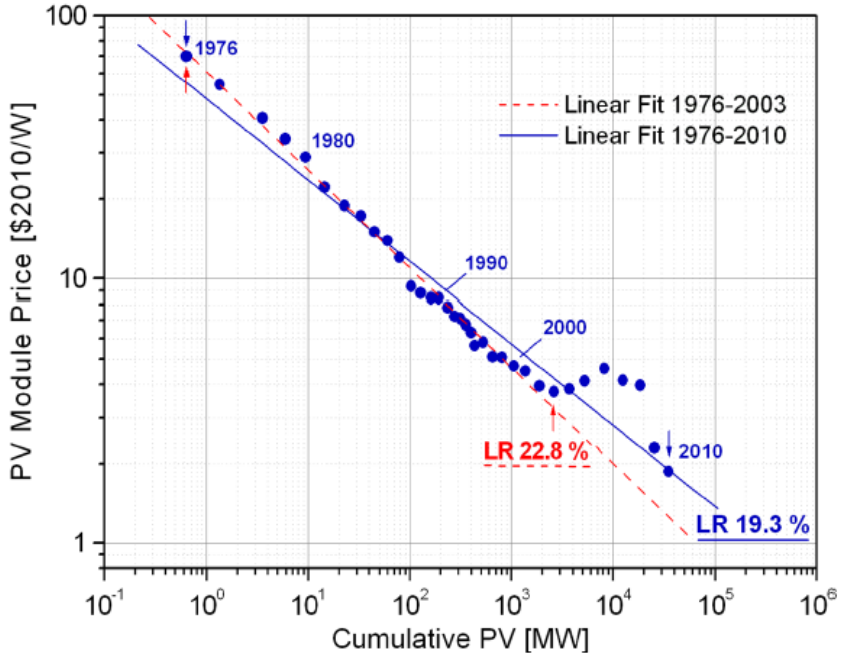
MANCHESTER 1824
The University of Manchester

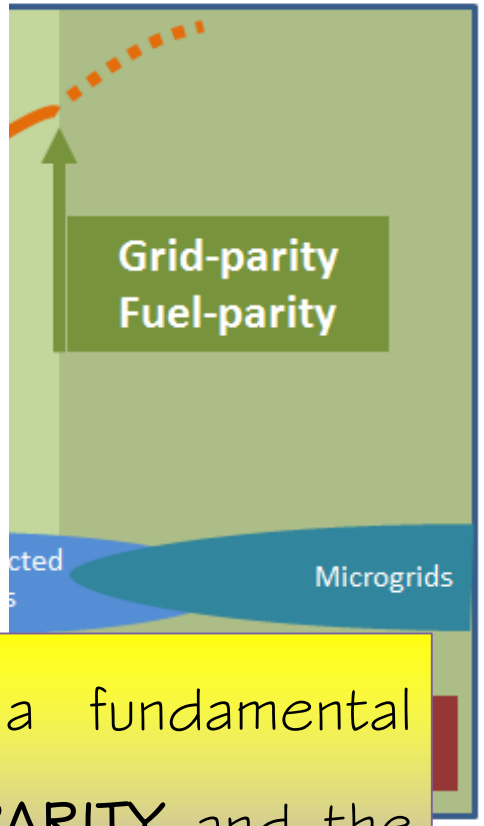
OUTLINE

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

HISTORY OF PHOTOVOLTAICS







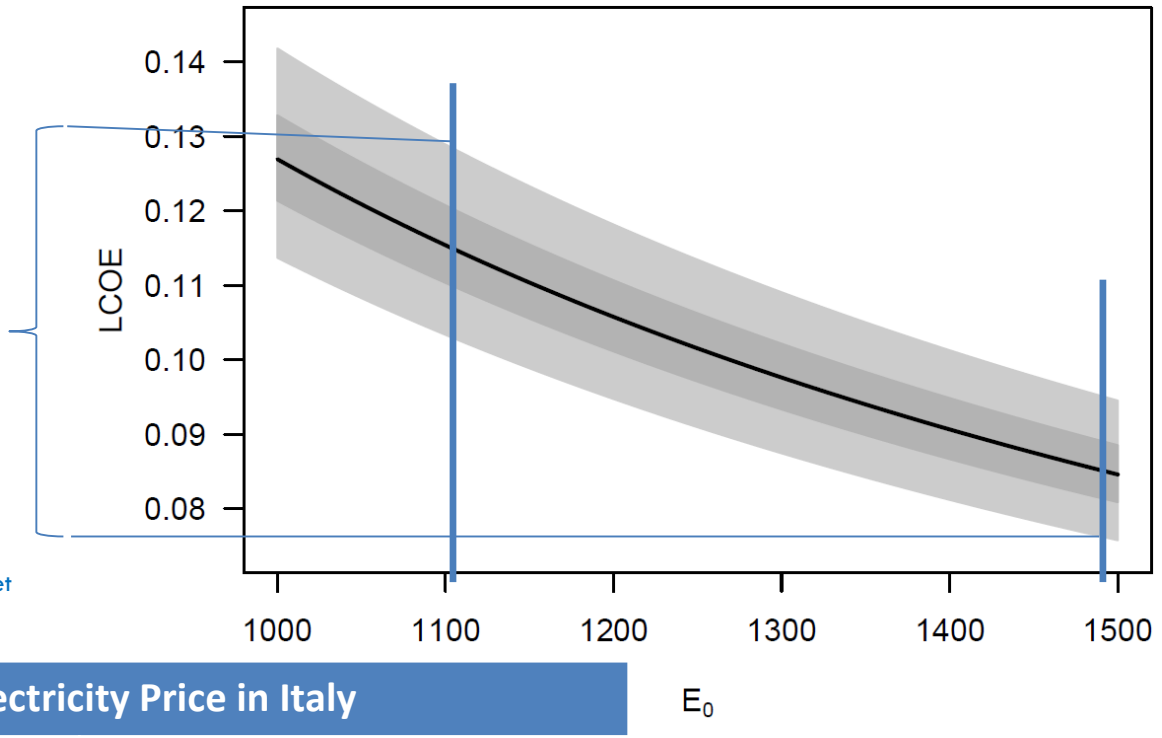
1955, 1975, 1995, … 2015 marks a fundamental milestone in the history of PV: THE **GRID PARITY** and the **FUEL PARITY** occurring in many countries of the world!!!

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



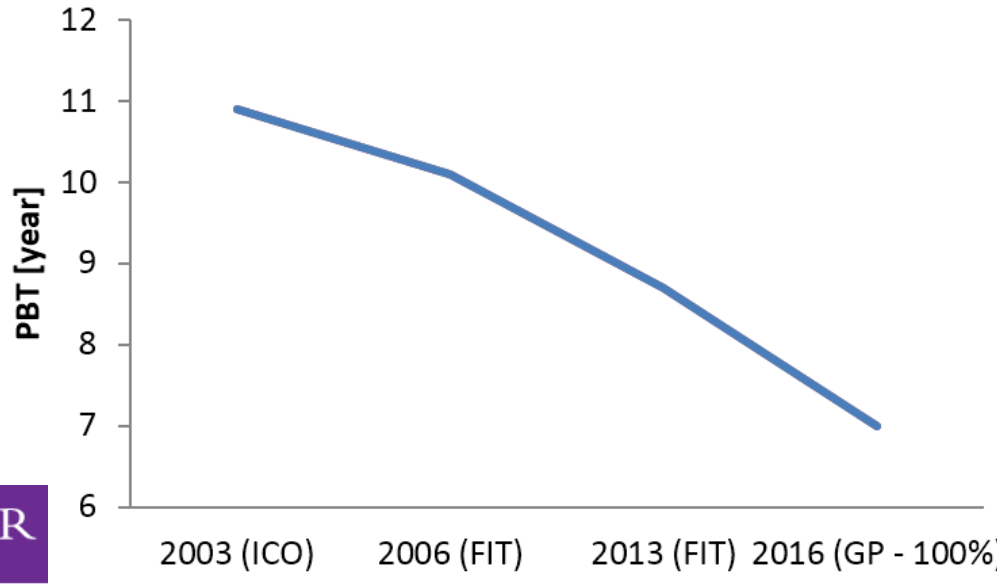
F. Pauli, G. Sulligoi, V. Lughi, A. Massi Pavan
Grid Parity in the Italian C&I electricity market
IEEE ICCEP, Alghero, 2015

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

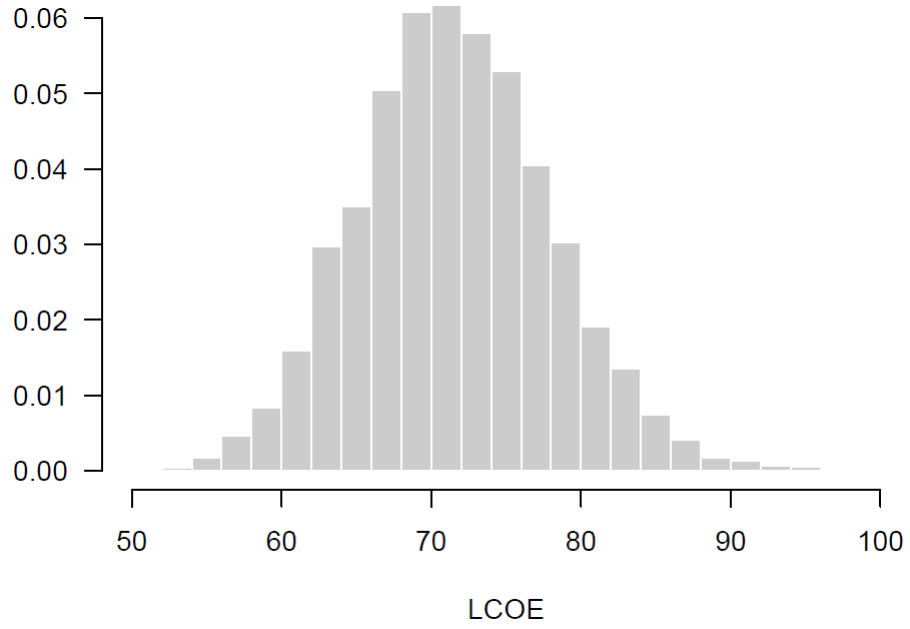
PV IS MOST CONVENIENT THAN EVER

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

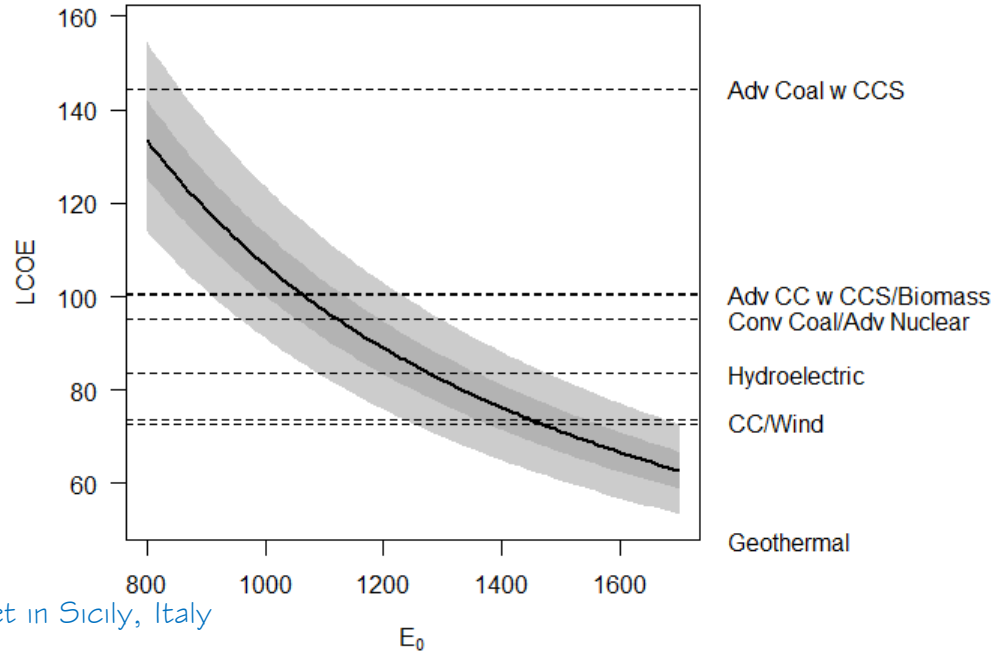


FUEL PARITY – AN EXAMPLE



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

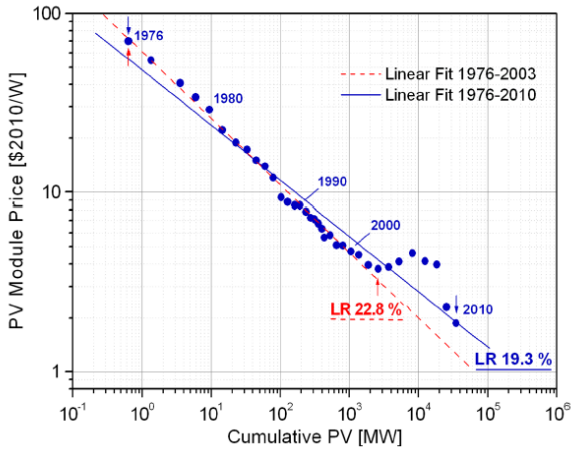
OUTLINE

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

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

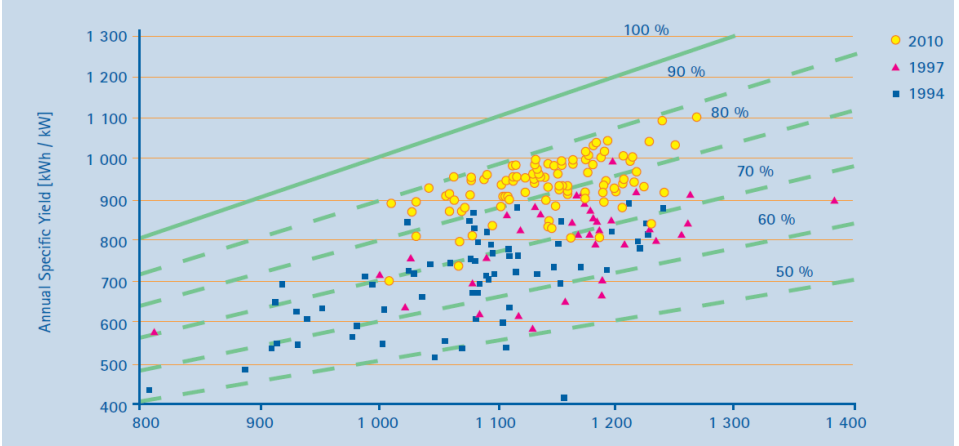


BOS (Balance Of the System)

All costs except the

PV modules

TODAY PERFORMANCES

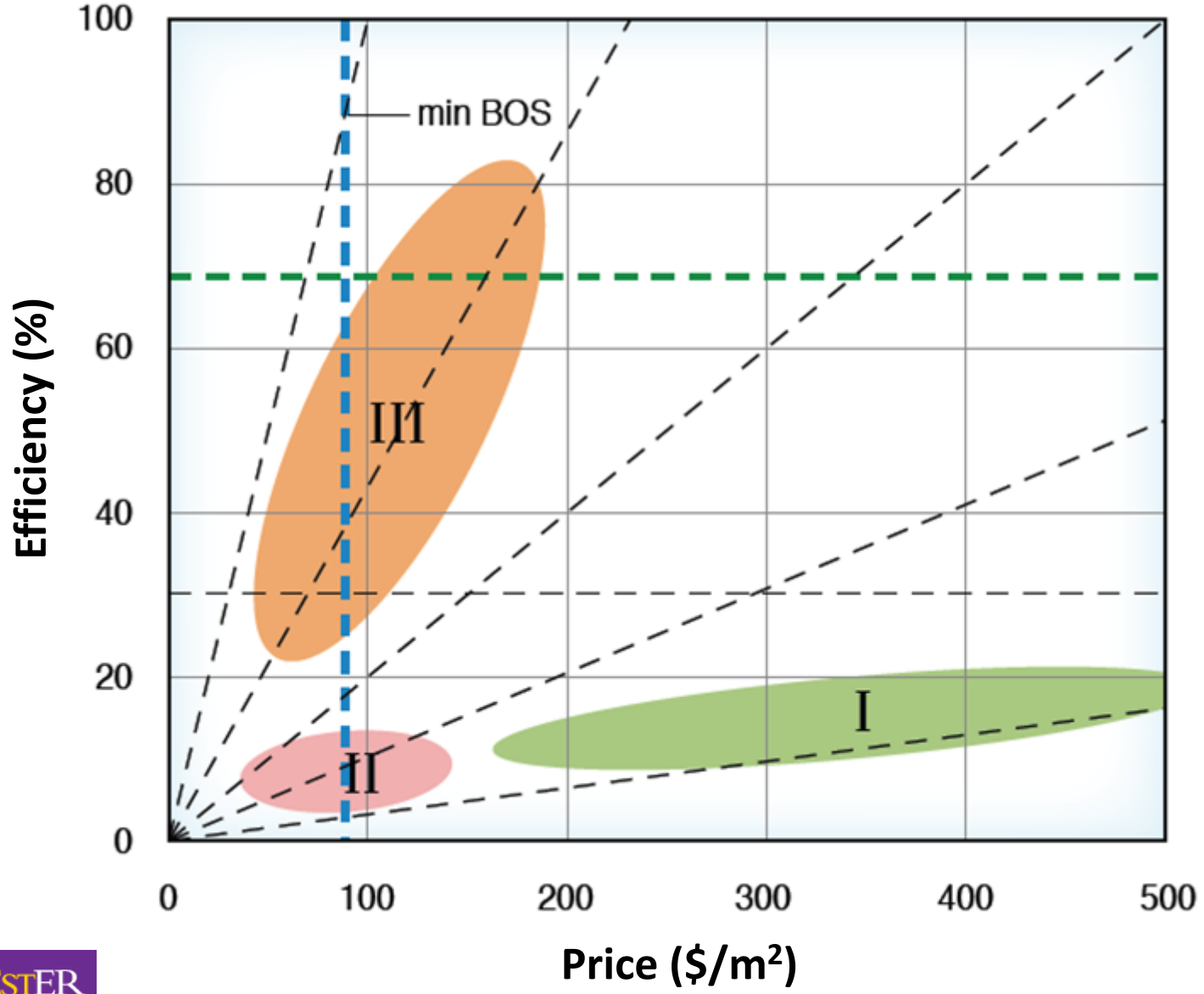


IEA PVPS Annual report 2012

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



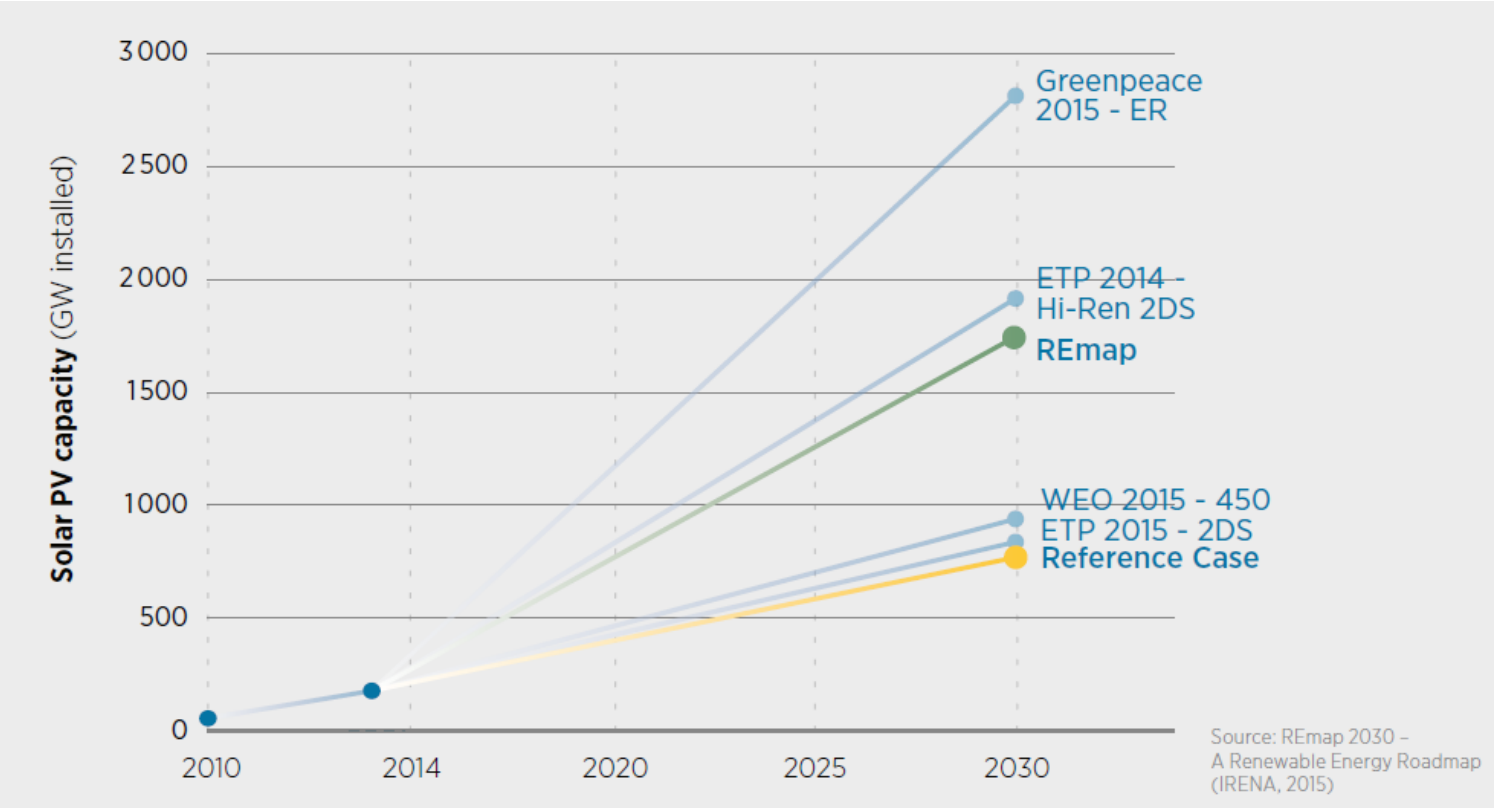
SUMMARIZING …

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

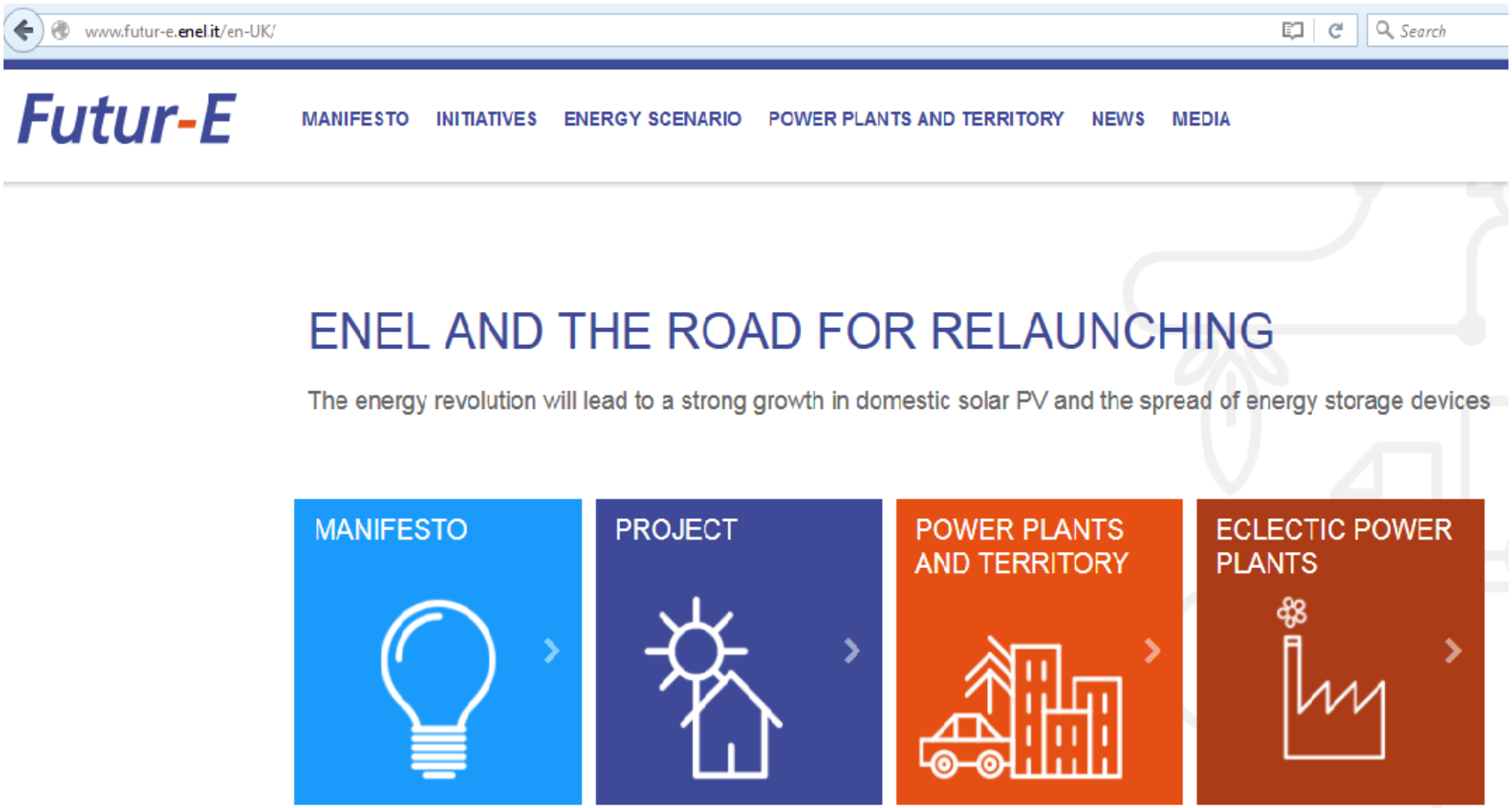
BOS COST REDUCTION – ECONOMIES OF SCALE – NEW TECHNOLOGIES FORECASTED LCOEs (2025)	
Residential and C&I (€/kWh)	0,053 – 0,098
Utility Scale – Sicily (€/kWh)	0,025 – 0,037

CAPACITY FORECASTING



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

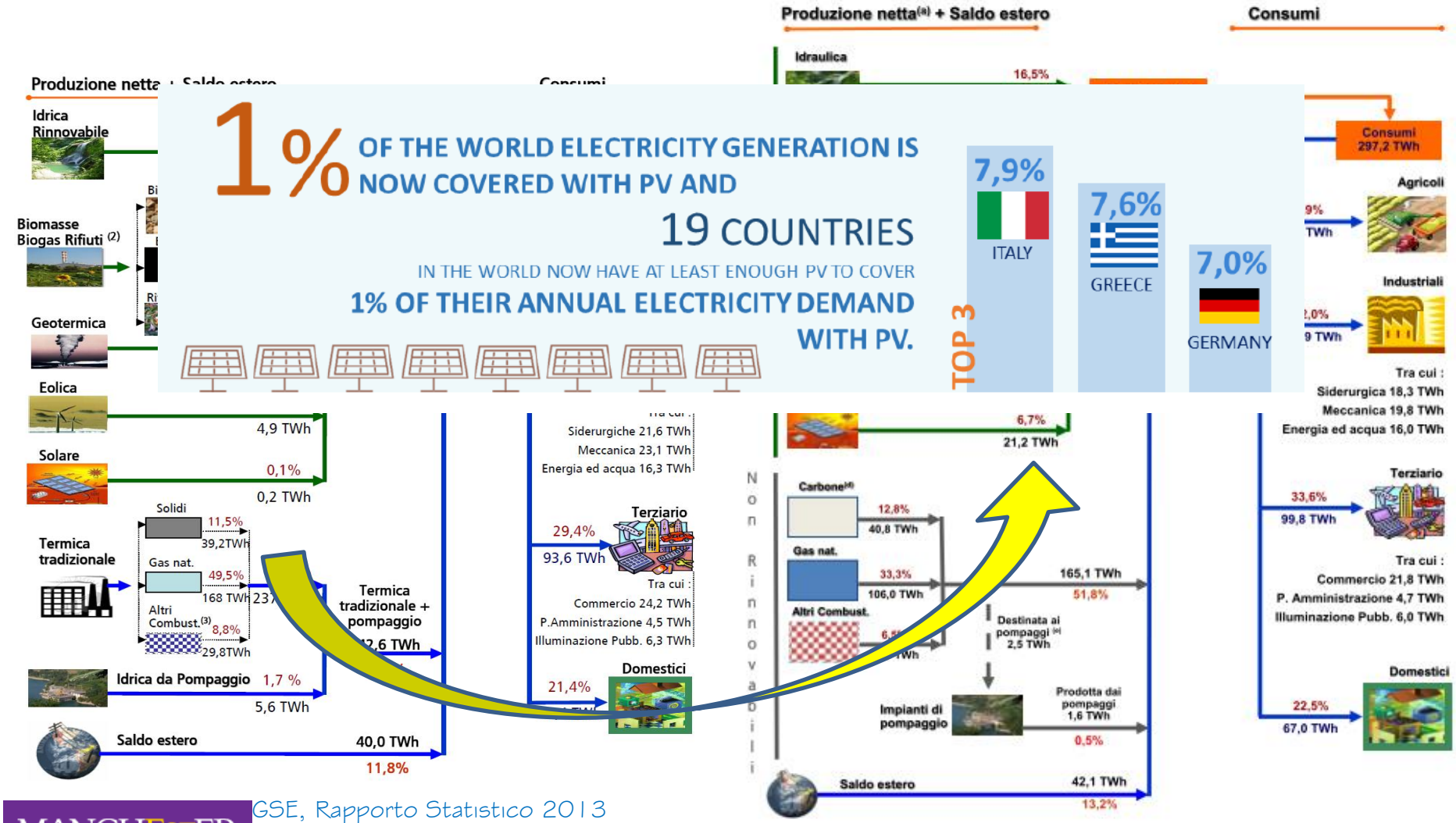
THE ROLE OF DSOs



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



1% OF THE WORLD ELECTRICITY GENERATION IS NOW COVERED WITH PV AND

19 COUNTRIES

IN THE WORLD NOW HAVE AT LEAST ENOUGH PV TO COVER 1% OF THEIR ANNUAL ELECTRICITY DEMAND WITH PV.

TOP 3

7,9% ITALY

7,6% GREECE

7,0% GERMANY

GSE, Rapporto Statistico 2013

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

YIELD AT DIFFERENT LOCATIONS

LOCATION	Yield (kWh/kWp)	Relative Yield With respect to Berlin (%)
Manchester	880	92
London	1,000	104
Berlin	960	100
Milan	1,210	126
Rome	1,450	151
Palermo	1,540	160

PVGIS, JRC European Commission