Daniele Daminelli

Milano, 21.11.2017

"Variable renewable energy sources integration in electricity systems – How to get it right"

CESI

Shaping a Better Energy Future

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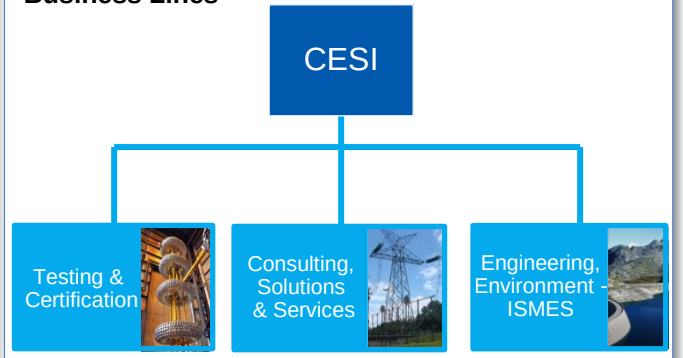
800+ experienced professionals to offer our clients high-end and tailored solutions

Business Lines



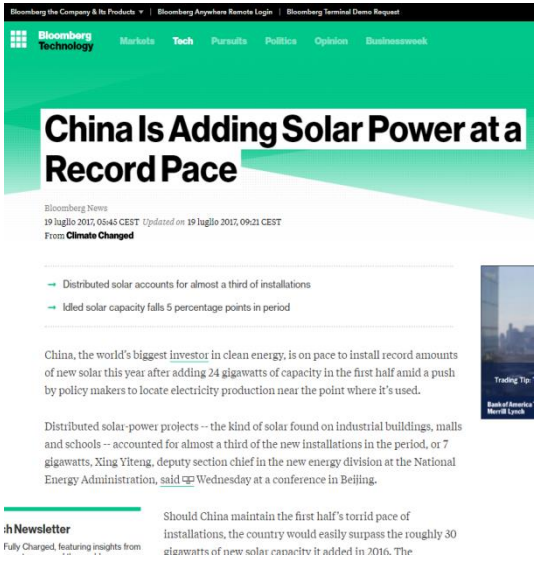
Shareholders

Terna, enel, ABB, PRYSMIAN, SEVES, TOSHIBA Transmission & Distribution Europe

Plenty of RES news – 1

23 May 2017

29 Aug 2017



19 Jul 2017

Source: Independent, Oilprice.com, Bloomberg,

Plenty of RES news – 1

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German PV auction reaches record low price of €4.91c/kWh (Germany)

18 Oct 2017

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The German Federal network regulator (*Bundesnetzagentur* or BNetzA) published the results of the October 2017 solar PV auction 110 bids with a total volume of 754 MW and the average bid size was 6.9 MW. Only 20 bids won the round and a total capacity of 2 maximum bidding price during this tender was previously set at €8.84c/kWh. The average bidding rate dropped further by €75c/kV and reached €4.91c/kWh (€49.1/MWh). The highest bid achieved €5.06c/kWh and the lowest one €4.29c/kWh. Three out of the 20 s higher than 20 MW.

The last tenders took place in January 2017 and June 2017 while the awarded capacities amounted respectively 200 MW and 201 M becoming increasingly competitive and showed strong cost reduction. In June 2017, bidding rates dropped to an average of €5.66c 2017), while the highest aggregate value of the tender reached only €5.9c/kWh (€6.00c/kWh in January).

Since the beginning of 2017, solar and wind power projects bigger than 750 kW have to compete in tenders in order to secure pow contracts are no longer available.

18 Oct 2017

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Offshore wind power cheaper than new nuclear

By Roger Harrabin
BBC environment analyst

11 September 2017 | Business | Share

Energy from offshore wind in the UK will be cheaper than electricity from new nuclear power for the first time.

11 Sep 2017

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CHILE

Renewables push prices to record low in Chile tender

3 November 2017 by Tom Azzopardi | Be the first to comment

CHILE: Wind and solar have dominated the latest electricity supply tender, with contracts awarded at an average price of $32.50/MWh, compared with $47.30/MWh in the previous tender.

Enel dominated the auction with wind and solar capacity bids

Energy minister Andres Rebolledo attributed the price drop to increased competition following a change in rules, noting the average price achieved marks a fall of 75% from the peak of $130/MWh reached in 2013.

GOOGLE TRANSLATE | Seleziona lingua

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MORE ON THIS TOPIC

Latest Argentina tender seven times oversubscribed

Enel Chile seeks to buy EGP assets

3 Nov 2017

Source: Businessgreen, FT, Bloomberg, Bloomberg, BBC

World Leaders on Climate Change

"Climate change is destroying our path to sustainability. Ours is a world of looming challenges and increasingly limited resources. Sustainable development offers the best chance to adjust our course"
Ban Ki-moon, *già Segretario Generale dell'ONU*

"There's one issue that will define the contours of this century more dramatically than any other, and that is the urgent threat of a changing climate"
Barack Obama, *44º Presidente degli Stati Uniti d'America*

"To protect the environment is to protect productivity and to improve the environment is to boost productivity"
Xi Jinping, *Presidente della Repubblica Popolare Cinese*

"Energy transition is drawing a new world, a world that is low in carbon but rich in opportunities"
Jean-Claude Juncker, *Presidente della Commissione Europea*

"We must now agree on a binding review mechanism under international law, so that this century can credibly be called a century of decarbonisation" **Angela Merkel**, *Cancelliere federale della Germania*

"We need to invent a new growth model. To be fair and sustainable, it must be environmentally friendly and increase social mobility" **Emmanuel Macron**, *Presidente della Repubblica Francese*

Trump on climate

6 Dec 2009

If we fail to act now, it is scientifically irrefutable that there will be catastrophic and irreversible consequences for humanity and our planet.

Donald J. Trump
Donald J. Trump Jr
Eric F. Trump
Ivanka M. Trump


THE NEW YORK TIMES, SUNDAY, DECEMBER 6, 2009

Dear President Obama
& The United States Congress,

Tomorrow
leaders from 192 countries
will gather at
The UN Climate Change Conference
in Copenhagen
to determine
the fate of our planet.

As business leaders we are optimistic that President Obama is attending Copenhagen with emissions targets. Additionally, we urge you, our government, to strengthen and pass United States legislation, and lead the world by example. We support your effort to ensure meaningful and effective measures to control climate change, an immediate challenge facing the United States and the world today. Please don't postpone the earth. If we fail to act now, it is scientifically irrefutable that there will be catastrophic and irreversible consequences for humanity and our planet.

We recognize the key role that American innovation and leadership play in stimulating the worldwide economy. Investing in a Clean Energy Economy will drive state-of-the-art technologies that will spur economic growth, create new energy jobs, and increase our energy security all while reducing the harmful emissions that are putting our planet at risk. We have the ability and the know-how to lead the world in clean energy technology to thrive in a global market and economy. But we must embrace the challenge today to ensure that future generations are left with a safe planet and a strong economy.

Please allow us, the United States of America, to serve in modeling the change necessary to protect humanity and our planet.

In partnership,

If you want to go quickly, go alone. If you want to go far, go together. african proverb

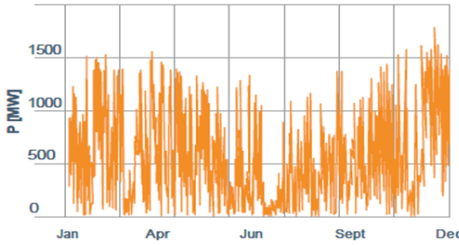
Business leaders, sign onto this initiative: businessleadersforenvironmentalchange.us

Image: New York Times

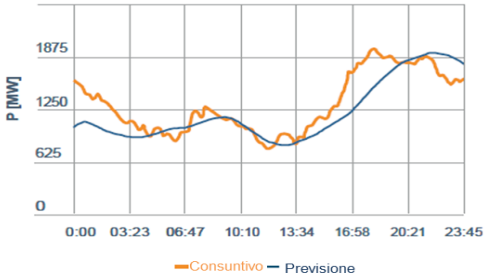
Variable Nature of Wind and Sun

Wind production variability in Ireland

Yearly

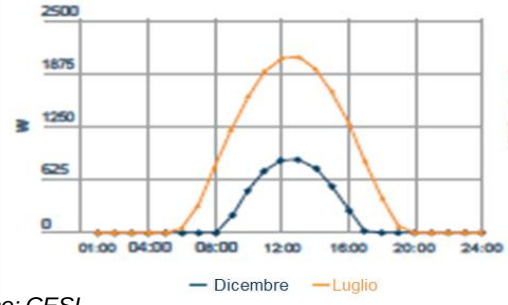


Daily

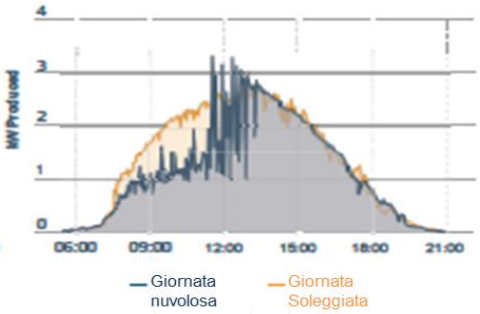


Solar PV production variability in Central Italy

Seasonality

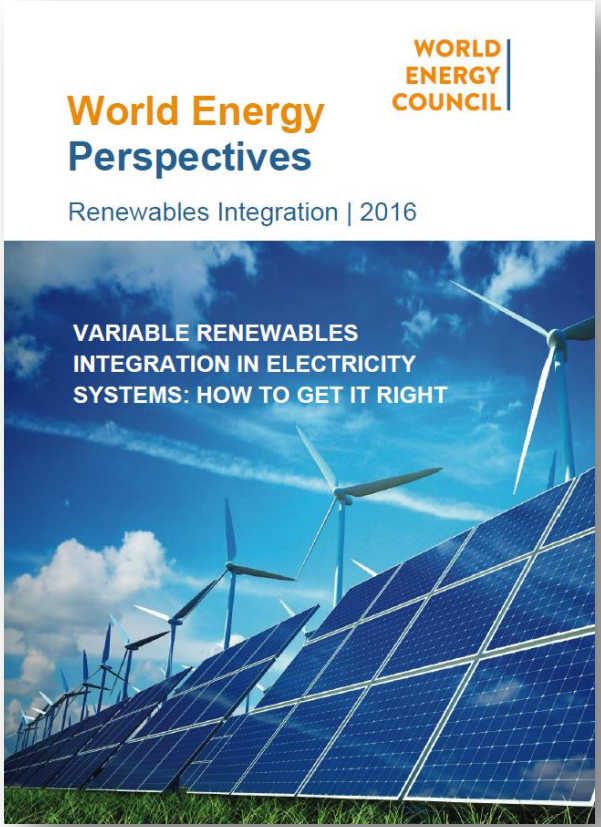


Daily



Source: CESI

WEC-CESI Report



1. CURRENT STATUS OF VRES

2. LESSONS LEARNED FROM THE CASE STUDIES

2.1 Power mix of the 32 country case studies

2.2 RES regulations, policies and economics

2.3 Impacts of VRES on the electrical power system

- Impacts on traditional fleets
- Impacts on the electricity market
- Impacts on the transmission and distribution grid
- Impacts on consumers

3. MEASURES FOR A SMOOTHER VRES INTEGRATION

Technologies

Market redesign

4. KEY MESSAGES

ANNEX 1 - EXAMPLES OF COSTS OF WIND AND SOLAR PV SYSTEMS AND RESULTS OF RECENT AUCTIONS

ANNEX 2 - COUNTRY CASE STUDIES SUMMARIES

32 Country Case Studies

1. Algeria
2. Brazil
3. China
4. Colombia
5. Denmark
6. Ecuador
7. Mexico
8. Egypt
9. France
10. Germany
11. India
12. Indonesia
12. Ireland
13. Italy
14. Japan
15. Jordan
16. Kazakhstan
17. Korea (Rep. of)
18. Mexico
19. New Zealand
20. Nigeria
21. Philippines
22. Poland
23. Portugal
24. Romania
25. Russian Federation
26. South Africa
27. Spain
28. Thailand
29. Tunisia
30. United Kingdom
31. United States of of America
32. Uruguay

• 89% of total installed VRES generating capacity
• 87% of VRES electricity production

Renewables now account for ~30% of global installed power and 24% of global electricity production

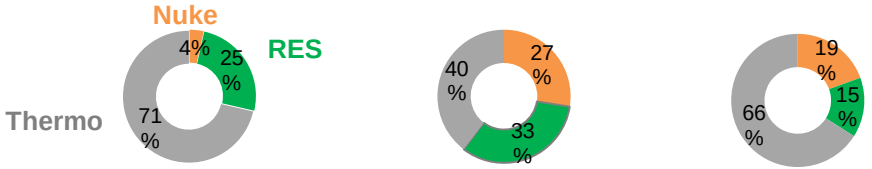
World global power capacity additions and energy production by source 2004-2016

Source	Installed Capacity 2004 [GW] and (%) share		Installed Capacity 2016 [GW] and (%) share		Average Annual Growth Rate (%)	2016 Production [TWh] and (%) share		Average Equivalent Operating Hours [h]
Hydro	715GW	18.80%	1,096 GW	16.3%	4%	4,023TWh	16.2%	3,671
Wind	48GW	1.30%	487GW	7.3%	21%	960TWh	3.9%	1,971
Biomass	39GW	1.00%	112GW	1.7%	9%	468TWh	1.9%	4,179
Solar	3GW	0.10%	303GW	4.5%	47%	333TWh	1.3%	1,099
Geothermal	9GW	0.20%	13GW	0.2%	3%	94TWh	0.4%	7,231
Total Renewables	814GW	21.4%	2,017GW	30.1%	8%	5,878TWh	23.7%	2,914
Total Conventional (Oil, Gas, Coal) and Nuclear	2,986GW	78.6%	4,690GW	69.9%	4%	18,938TWh	76.3%	4,038
TOTAL	**3,800GW**	**100%**	**6,707GW**	**100%**	**5%**	**24,816TWh**	**100%**	**3,700**

Source: CESI based on REN21

2016 Key Energy Stats

	China	Europe	United States
Population (Million)	1,404	512	322
CO2 Emission (Million tonnes)	9,123	3,681	5,350
CO2 Emission per capita (metric tons per capita)	6.5	7.2	16.6
Electricity Demand (TWh)	6,142	3,406	4,350
Electricity Consumption per capita (kWh per capita)	4.4	6.7	13.5
Installed Capacity (GW)	1,646	1,007	1,182
RES Installed Capacity (GW)	545 (33%)	487 (48%)	215 (18%)
VRES Installed Capacity (GW)	226	260	116
Wind (GW)	149	155	81
Solar PV (GW)	77	105	35
Electricity Demand breakdown by source (%)			

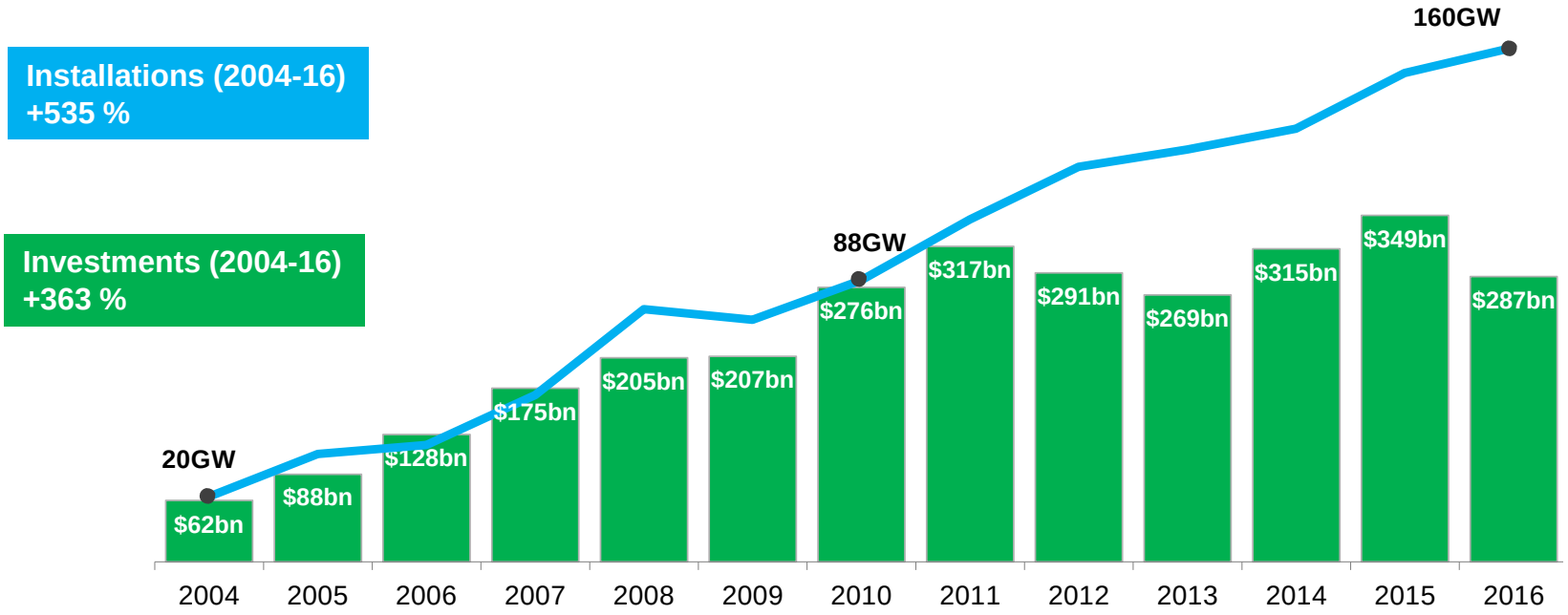


Note: EU 27 includes United Kingdom

Source: World Bank, BP, IRENA, EDGAR EU

RES have become a big business

Investments in clean capacity (bn$) and installed capacity (GW)

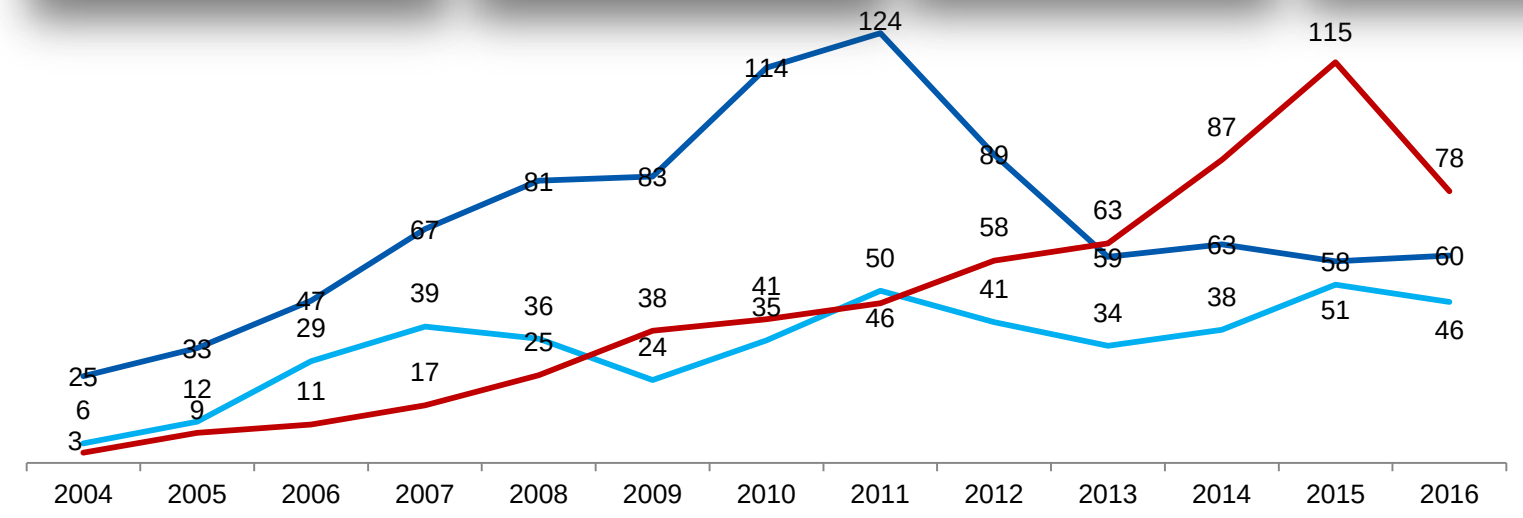


Operators are now installing more capacity with the same amount of money

Source: Bloomberg New Energy Finance

Europe has lost its RE leading position

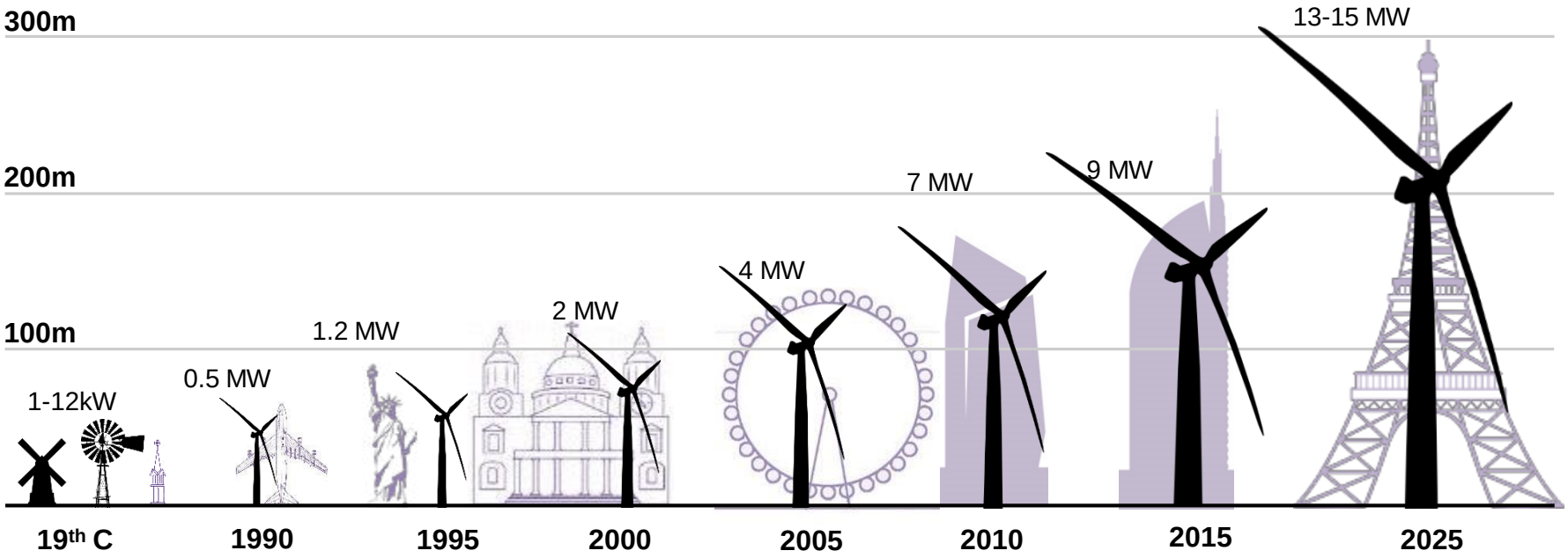
Global new investment in renewable energy, 2004-2016 (USD billion)



Source: FS UNEP, 2017

The Combination of improving technologies…

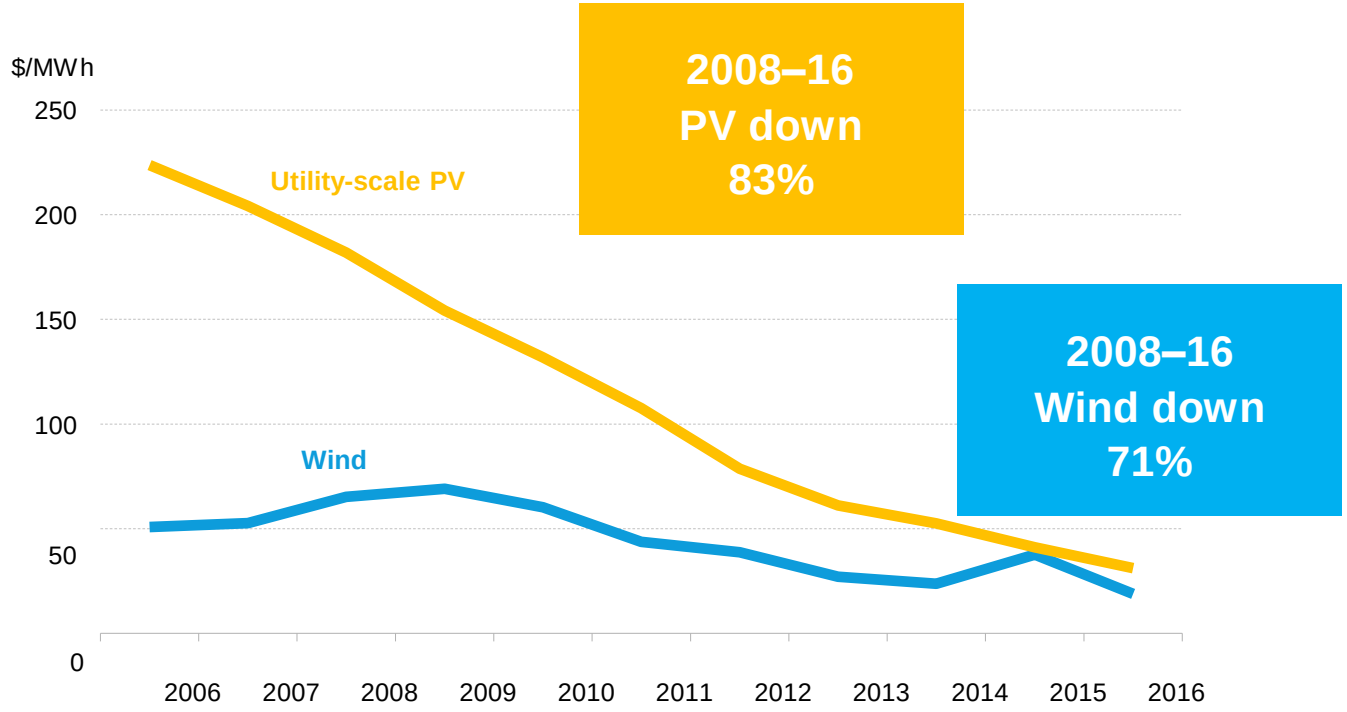
Evolution of height (m) and rated power (MW) of wind



Source: Various

…and cost reductions…

Average US PPA prices evolution ($/MWh) of wind and solar

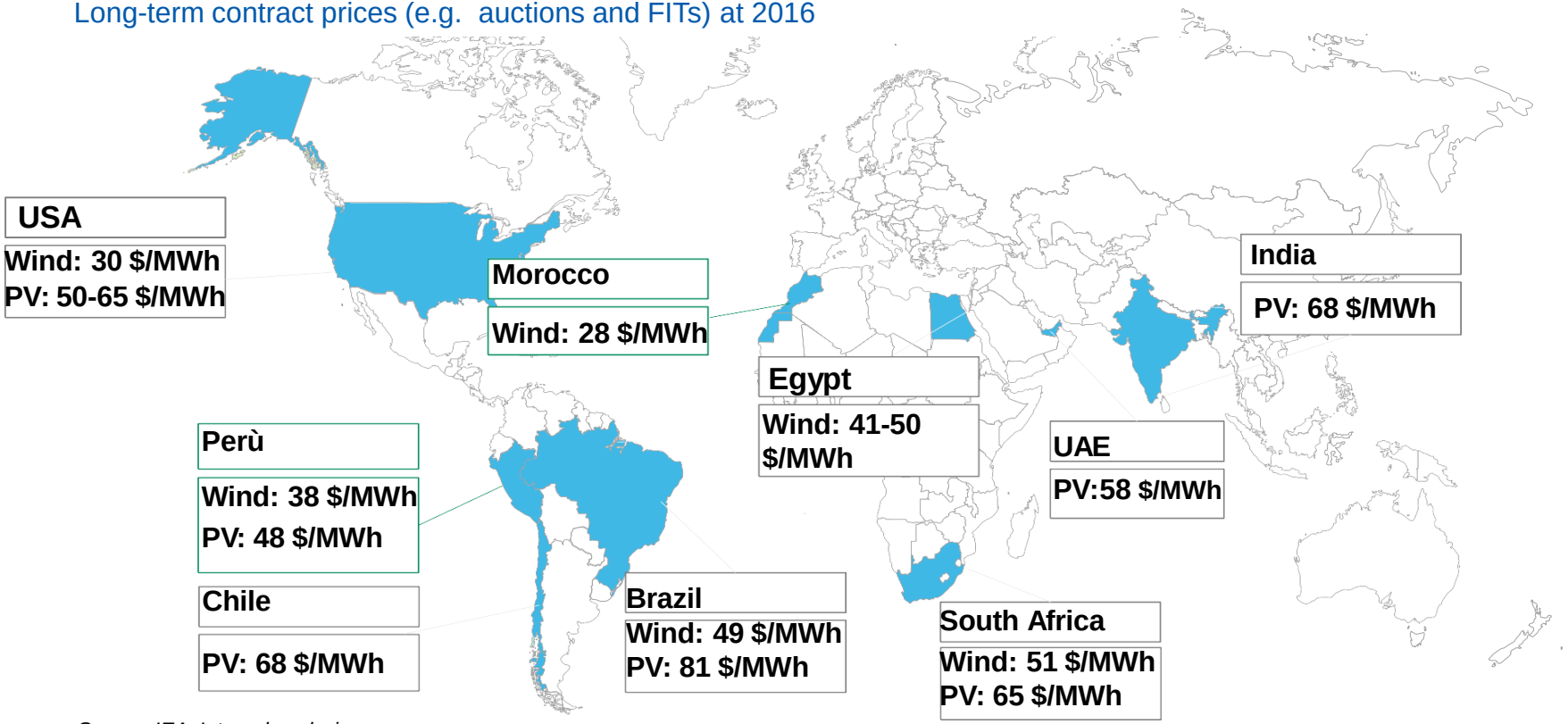


Source: U.S. Department of Energy (LBNL), Bloomberg New Energy Finance

Note: Levelized, time-of-day adjusted contract price shown in real 2015 USD. 2016 PV PPA price based on preliminary data and subject to review.

…is driving wind and solar PV to reach new lows

Long-term contract prices (e.g. auctions and FITs) at 2016



Source: IEA; Internal analysis

VRES world records (2017 update)

Solar PV

Country: United Arab Emirates
Bidder: Marubeni and Jinko Solar
Signed: 2017
Construction: 2019
Price: US$ 2.42 c/kWh

Onshore wind

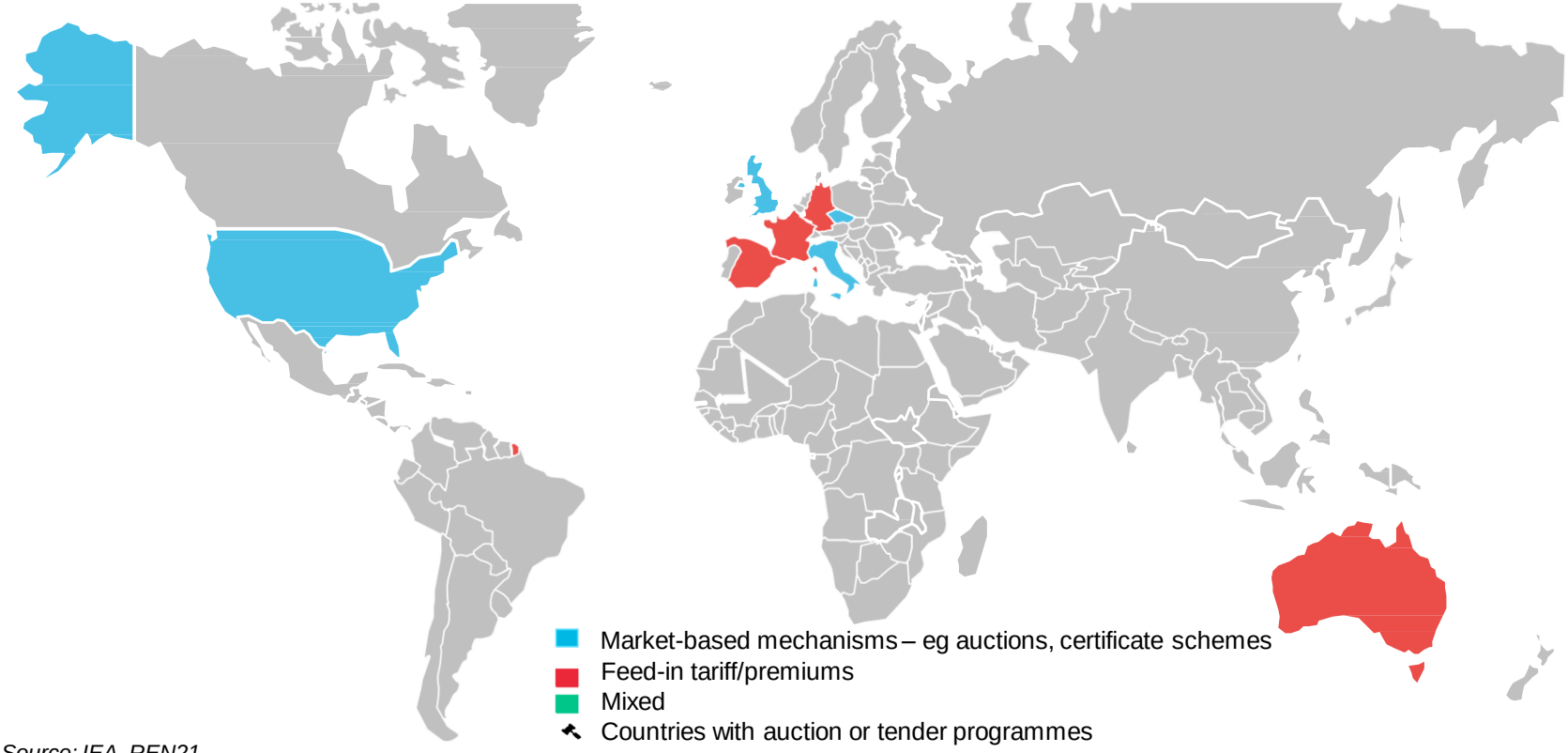
Country: Morocco
Bidder: Enel Green Power
Signed: 2016
Construction: 2018
Price: US$ 3.0 c/kWh

Offshore wind

Country: Germany
Bidder: DONG/EnBW
Signed: 2016
Construction: 2024
Merchant Price: US$ 4.9 c/kWh

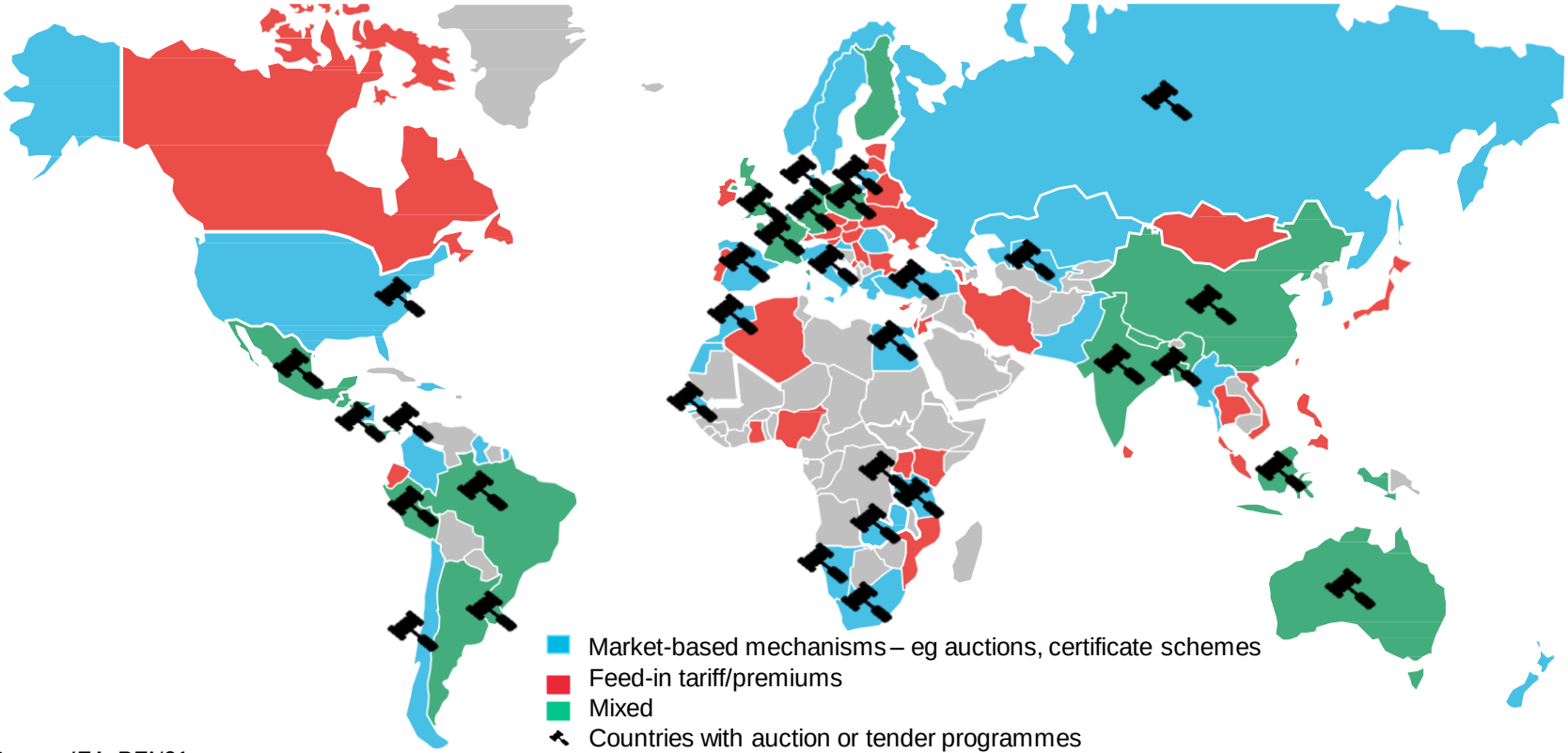
Source: Bloomberg New Energy Finance; Images Siemens; Wikimedia Commons; Masdar

Countries with Renewable Energy support policies in place
10 | 2000



Source: IEA, REN21

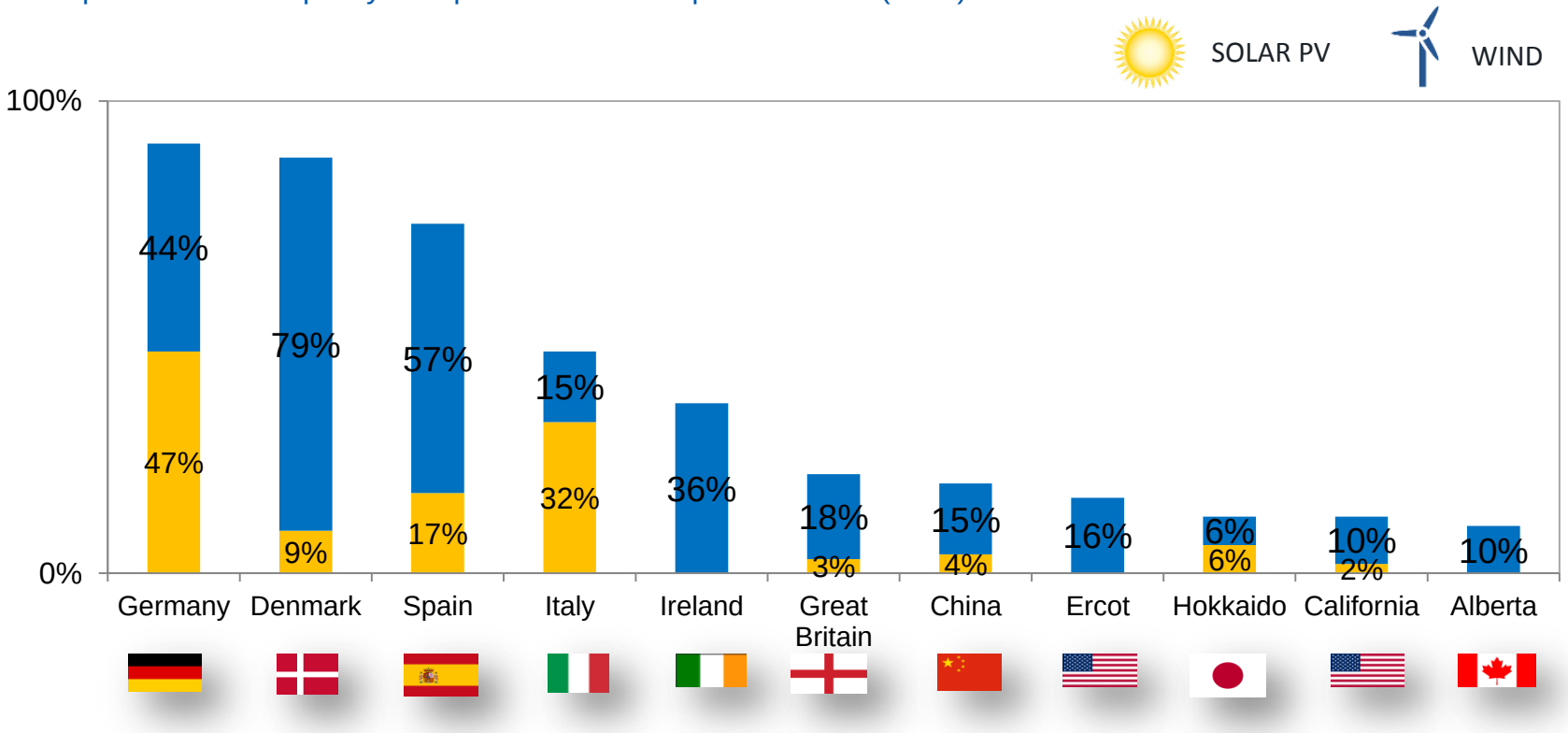
Countries with Renewable Energy support policies in place 176 | 2016



Source: IEA, REN21

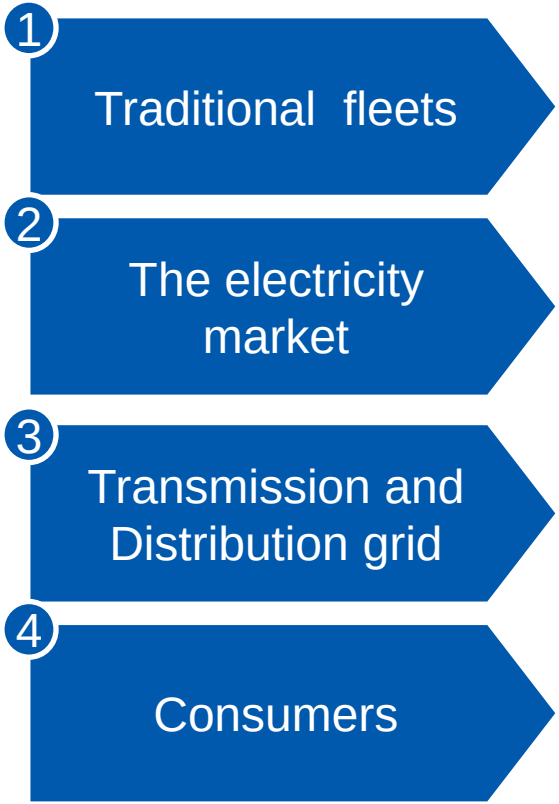
Variable Renewable can cover a significant portion of the demand

VRE penetration – Capacity as a percent of annual peak demand (2015)



Source: WEC, Mott MacDonald and system operators

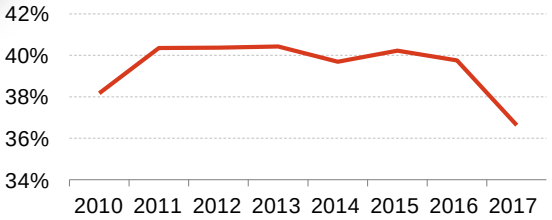
Impacts of VRES on the electrical power system



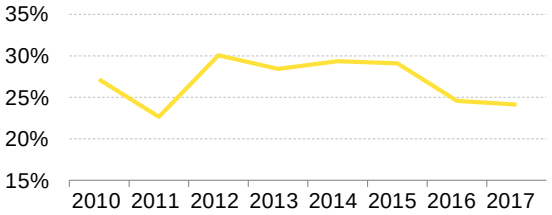
1 Shrinking operating hours of conventional power plants

Capacity factors of US thermal power plants

Texas



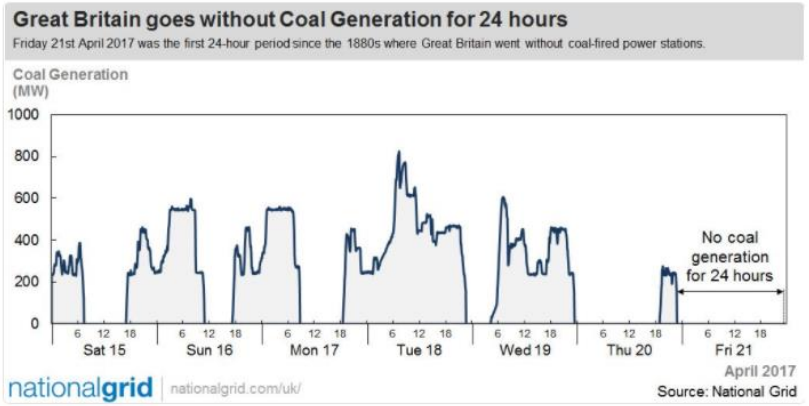
California



National Grid Control Room ✓
@NGControlRoom

Segui

National Grid can confirm that for the past 24 hours, it has supplied GB's electricity demand without the need for #coal generation.

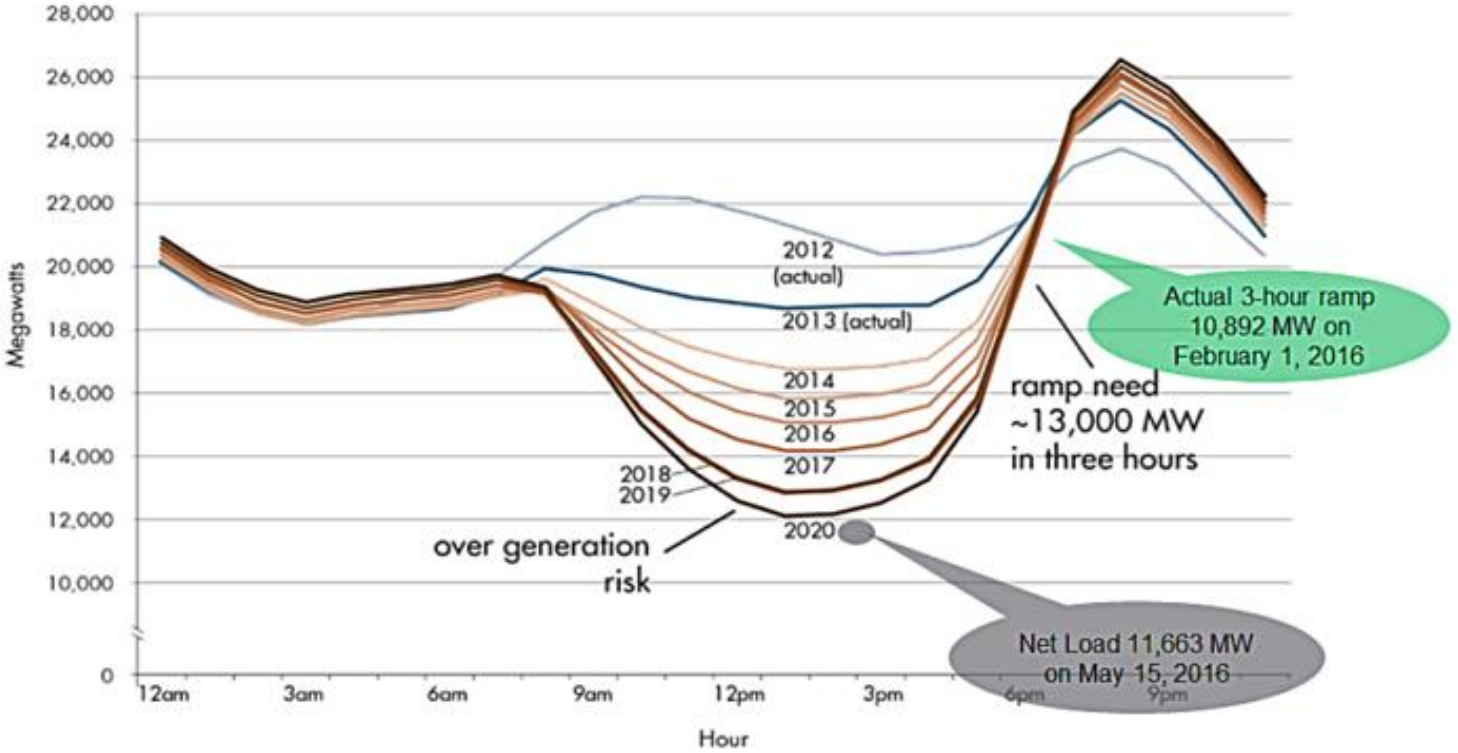


15:11 - 21 apr 2017

Note: Includes coal and gas capacity. 2017 is based on YTD generation and operational capacities reported in January. Excludes backup capacity.

❶ Increased ramping requirements (“duck curve”)

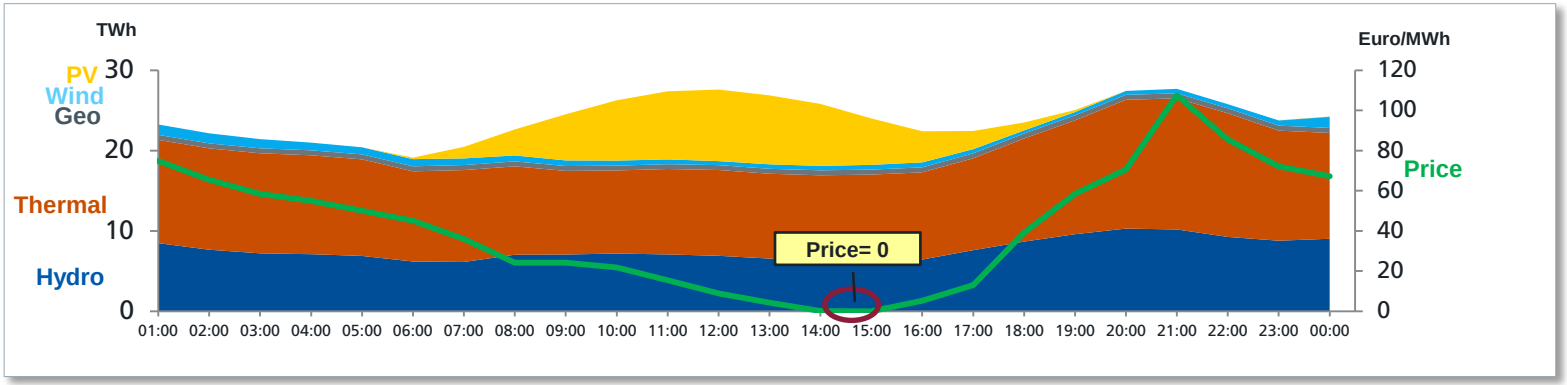
California Load Curve (MW) Net of Wind and Solar production



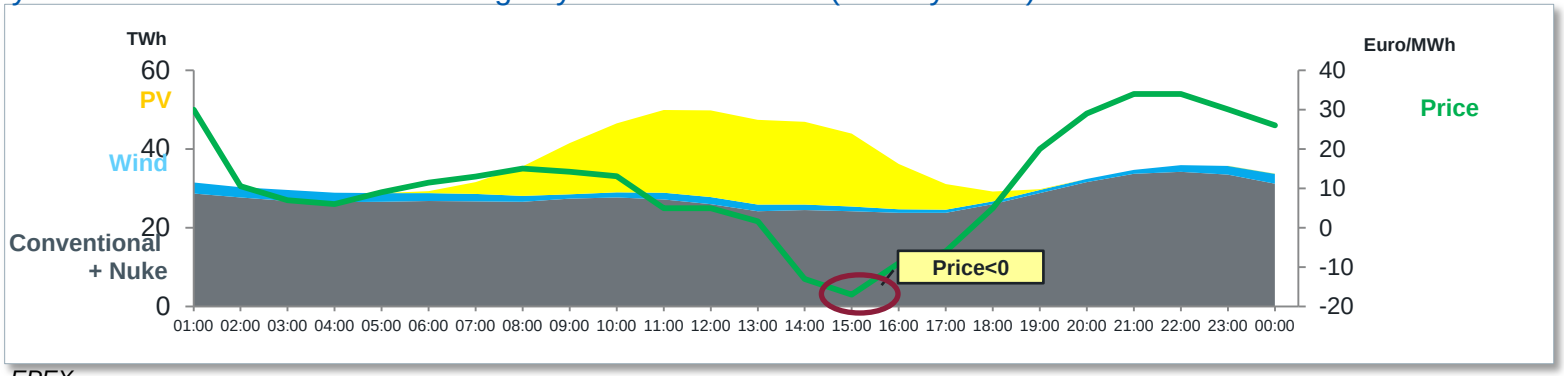
Source: CAISO

❷ A null or <0 price on the day-ahead market on a sunny day

Italian Day Ahead Market – Demand coverage by source and Price (1st May 2013)



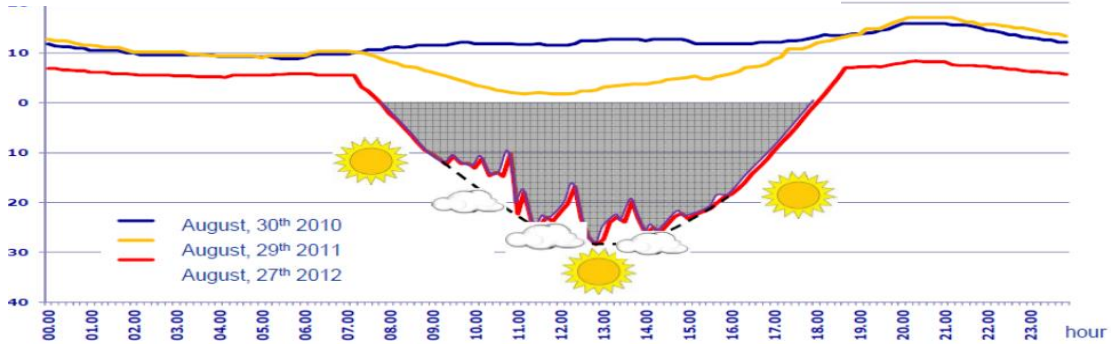
German Day Ahead Market – Demand coverage by source and Price (5th May 2013)



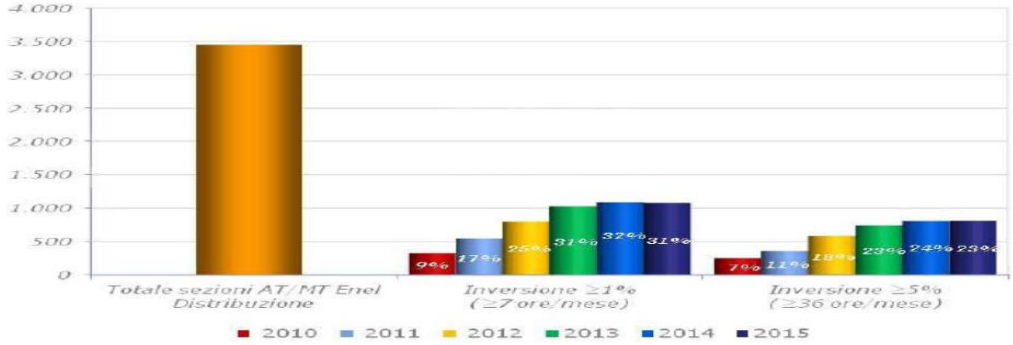
Source: GME, EPEX

❸ Impact of VRES in a primary HV/MV substation power reversal

HV/MV Substation (Ginosa) Puglia

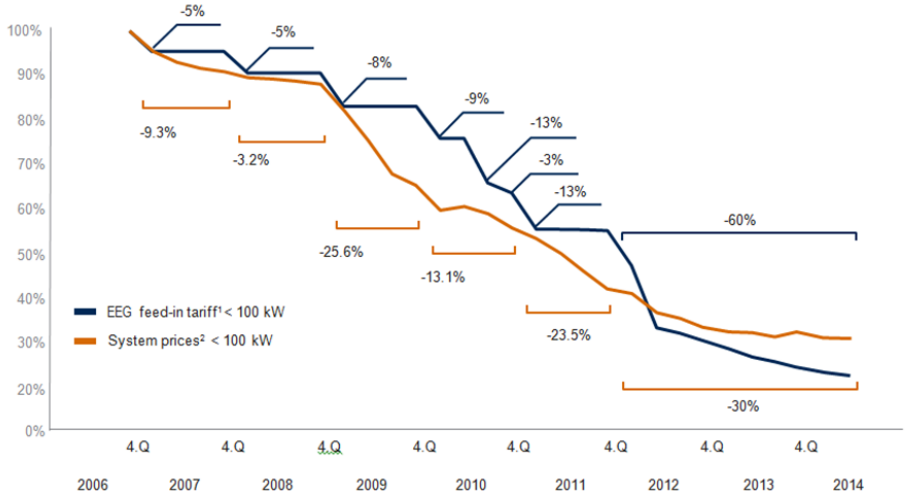


Power flow reversal in primary substations



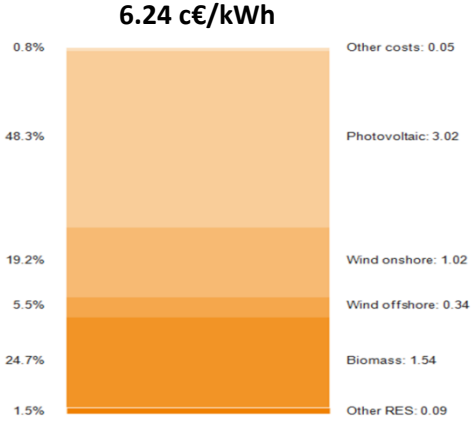
Source: ENEL Distribuzione

Development of PV feed-in tariffs, module costs and capacity additions



1 The EEG compensation: the compensation classes were in the second quarter 2012 brought in line with the amended EEG law. Previously until the end of the first quarter 2012, PV installations with the output of 30–100 kWp were included.

2 System prices: the average price paid by the end user for fully installed roof panels without USt.



~24 billion Euro/year

Source: BSW-Solar, Beta

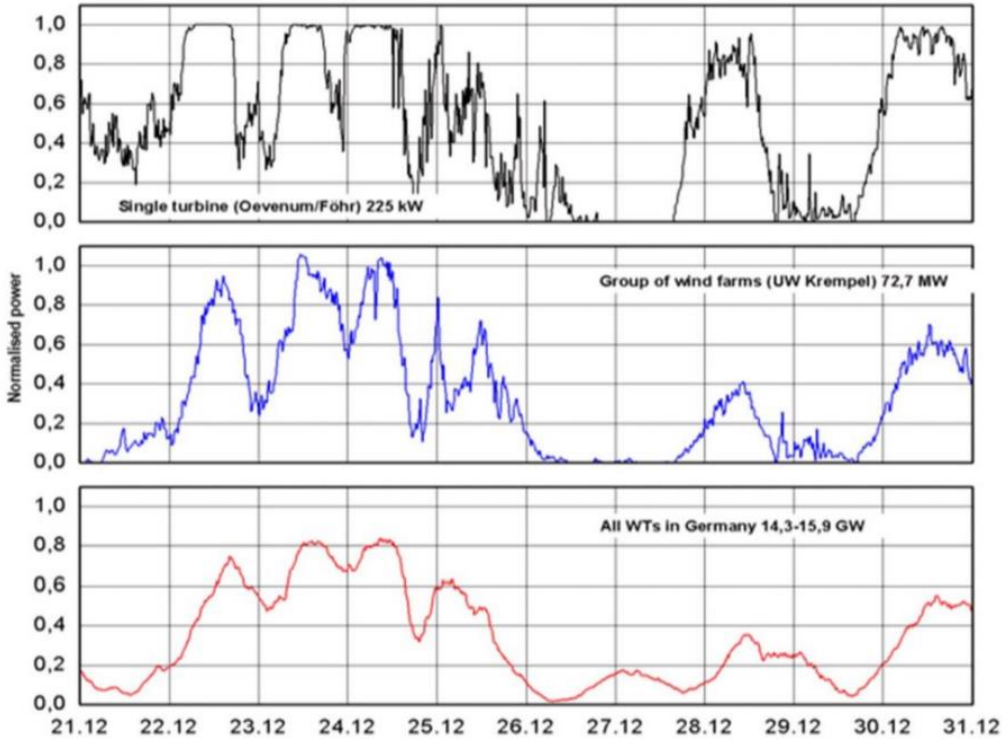
Measures for a smoother VRES integration

- Improved forecasting
- Optimisation of operating reserve
- Greater flexibility of conventional generation
- Dynamic transfers
- Expansion of local transmission and distribution grids
- Cross-border interconnections
- Energy storage systems
- Demand response

- Revision of emissions trading schemes
- Capacity payments
- Sub-hourly market closures
- Negative market prices
- Nodal pricing
- Larger balancing areas
- Aggregate bids of RES power plants
- Green energy transmission corridors
- TSO /DSO's coordination rules
- Role of private investors

Aggregating VRE over a large geographical area reduces variability

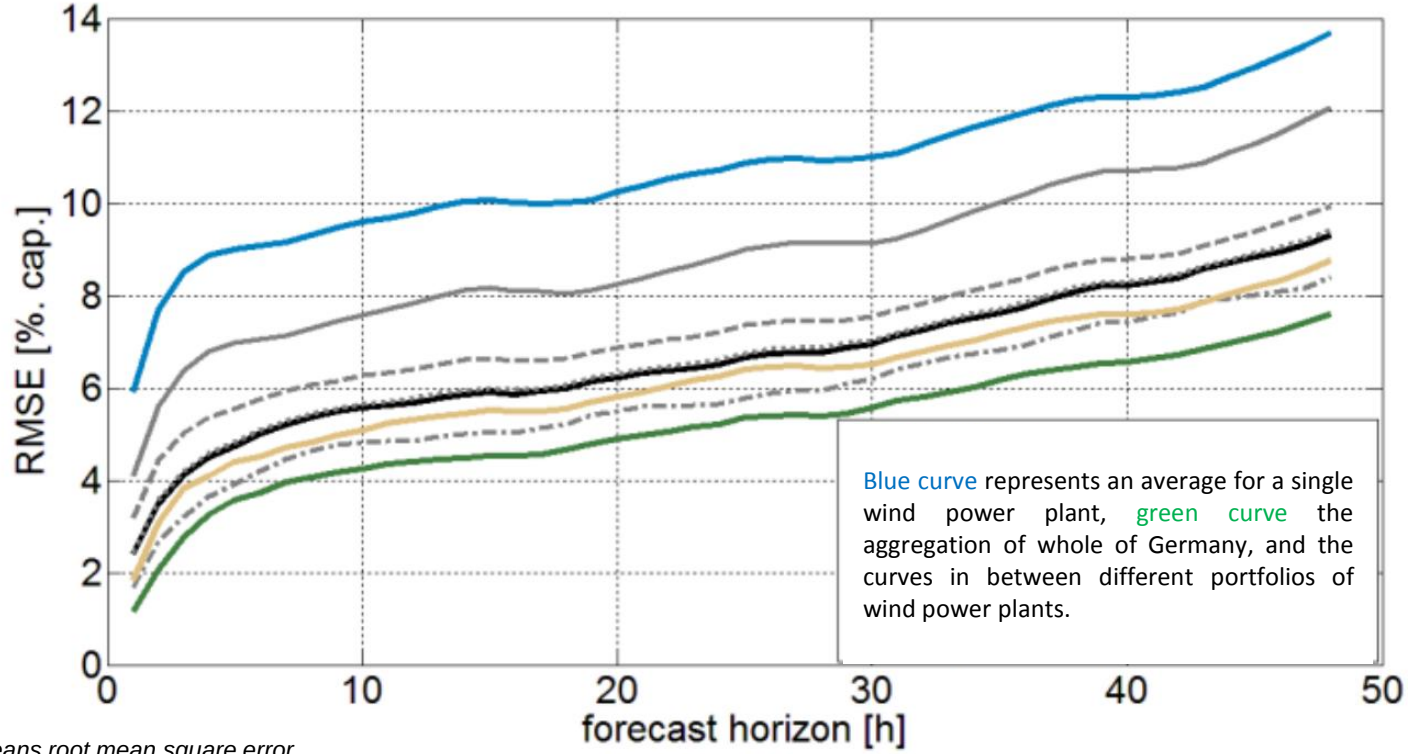
Smoothing by aggregating



Source: Stein, 2011

Reducing gate closure times is equivalent to increase wind forecast accuracy

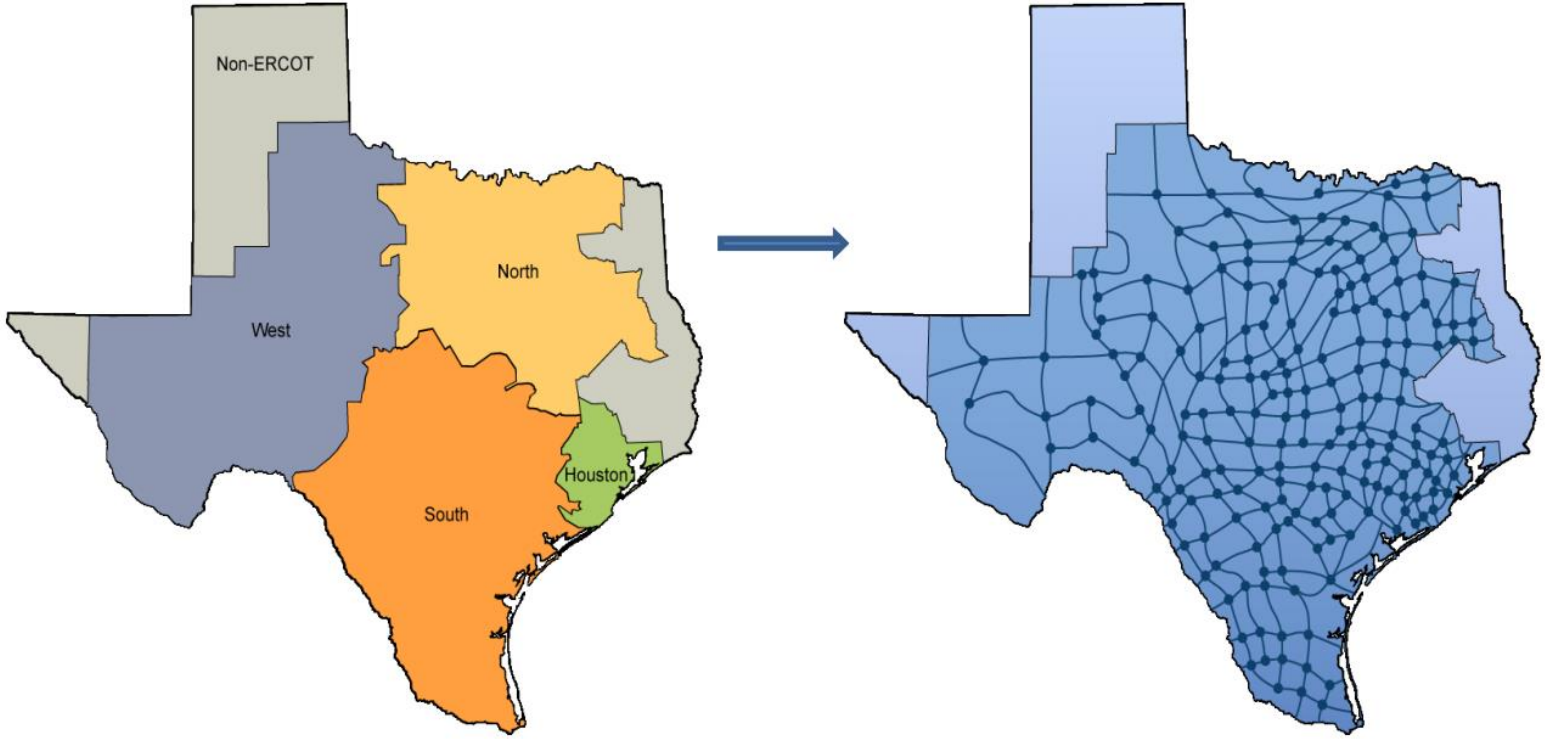
Average error is increasing as the time horizon to forecast is increasing



RMSE means root mean square error
Source: Dobschinski, 2014

ERCOT moved from zonal to nodal pricing

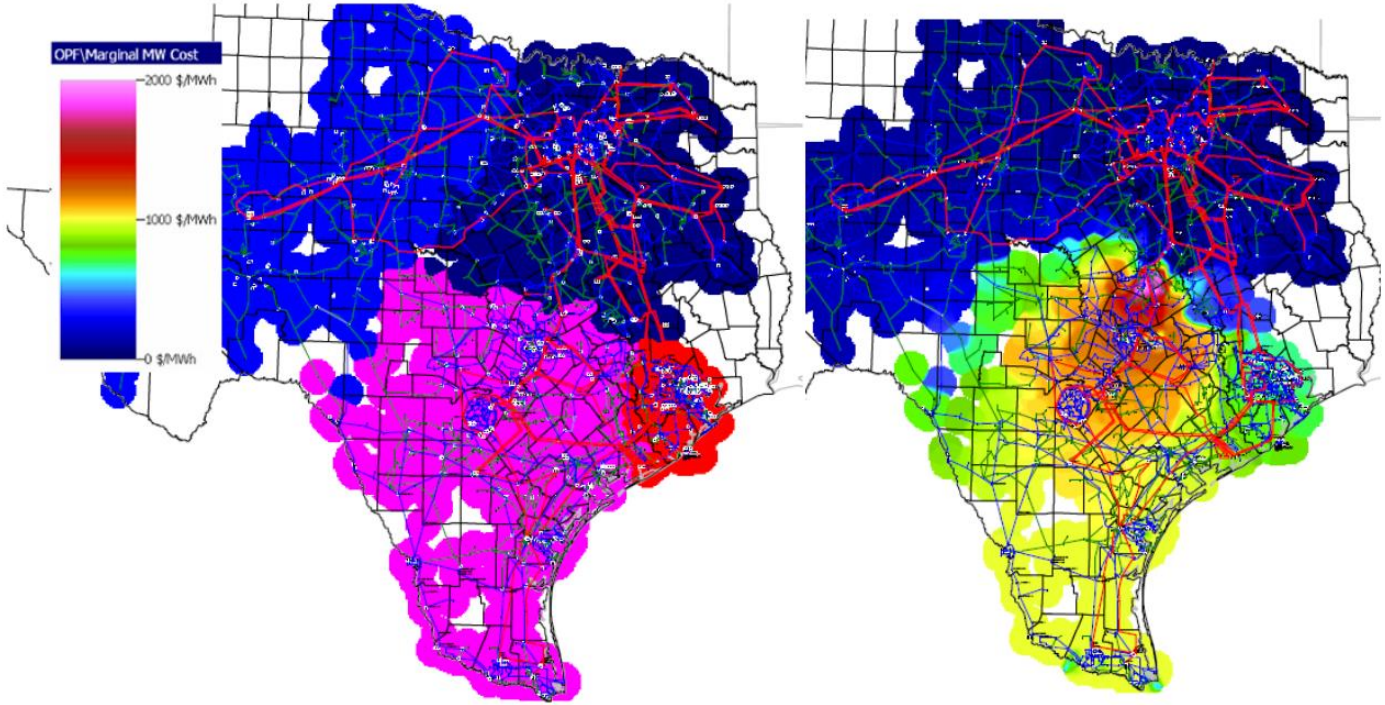
ERCOT zonal VS nodal (LMP) grid representation



Source: ERCOT

LMP incentivize infrastructure development in the right places, increase dispatch efficiency and reduce prices

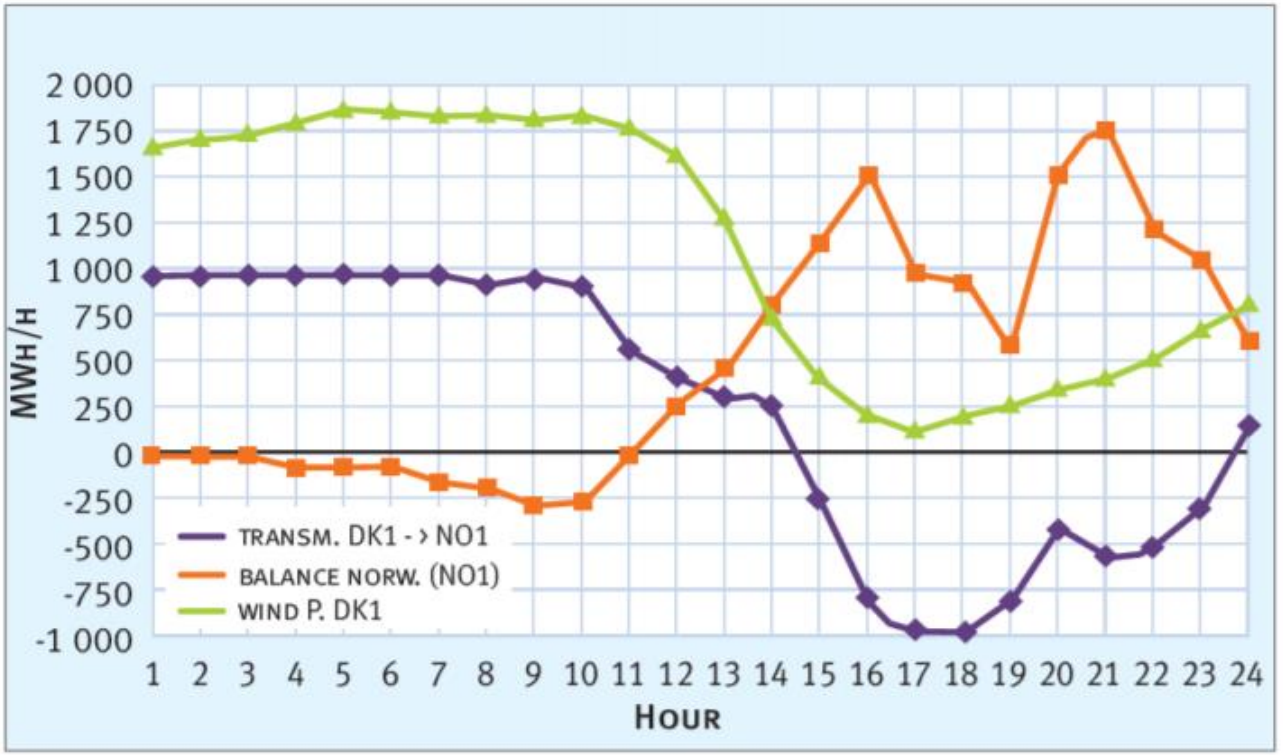
ERCOT zonal VS nodal (LMP) grid representation



Source: ERCOT

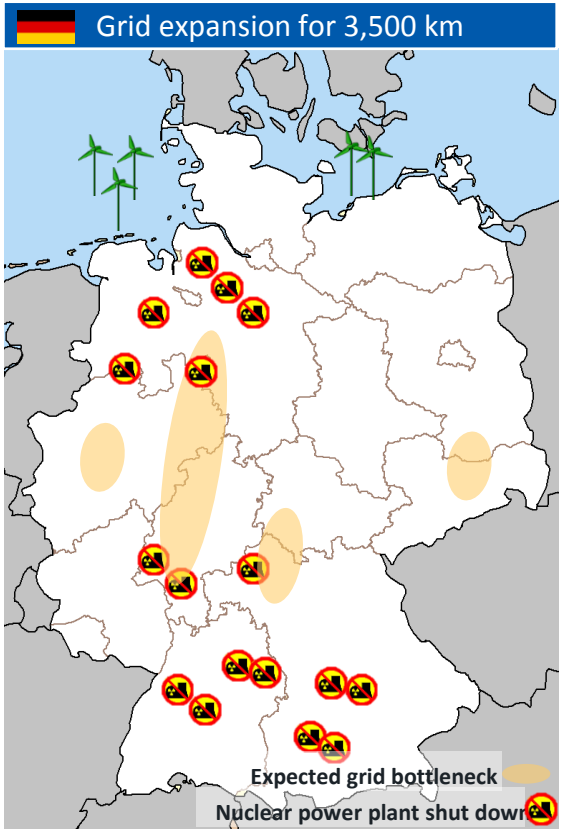
Handling a storm front in the Nordic system exploiting cross-border interconnections

Wind Production and Balance of Flows



Source: Eurelectric

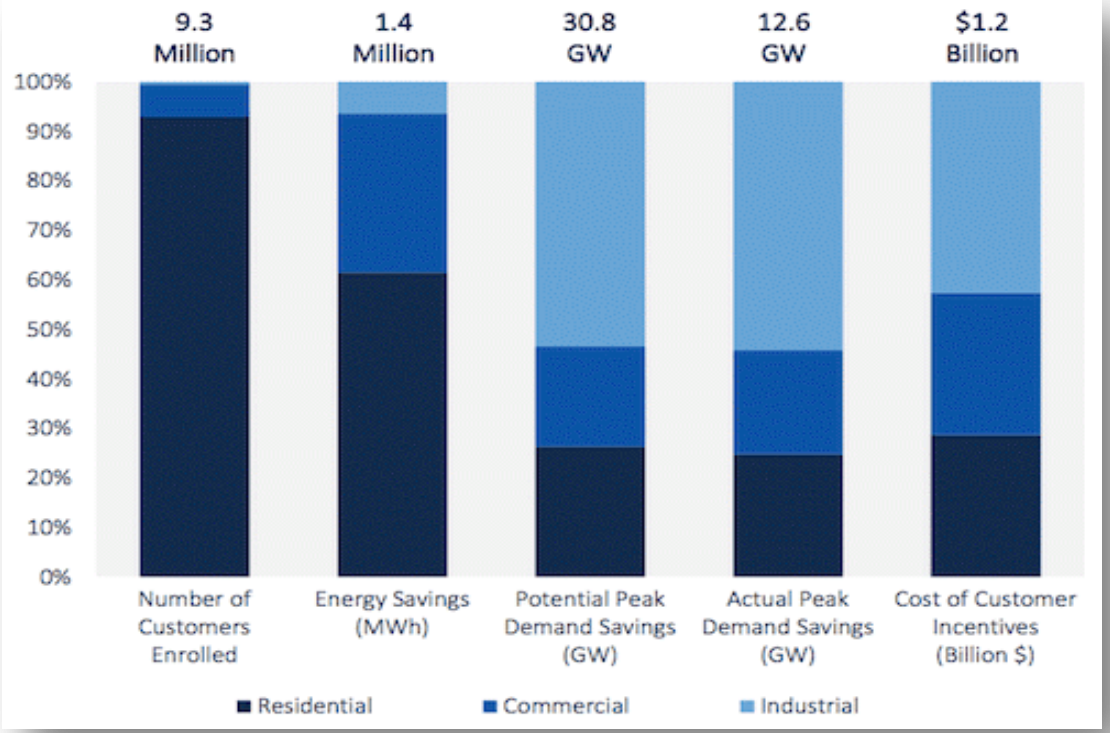
ENTSOE foresees 40,000 km of new lines to accommodate RES with investment worth 80 Billion Euro



Source: German Grid Development Plan

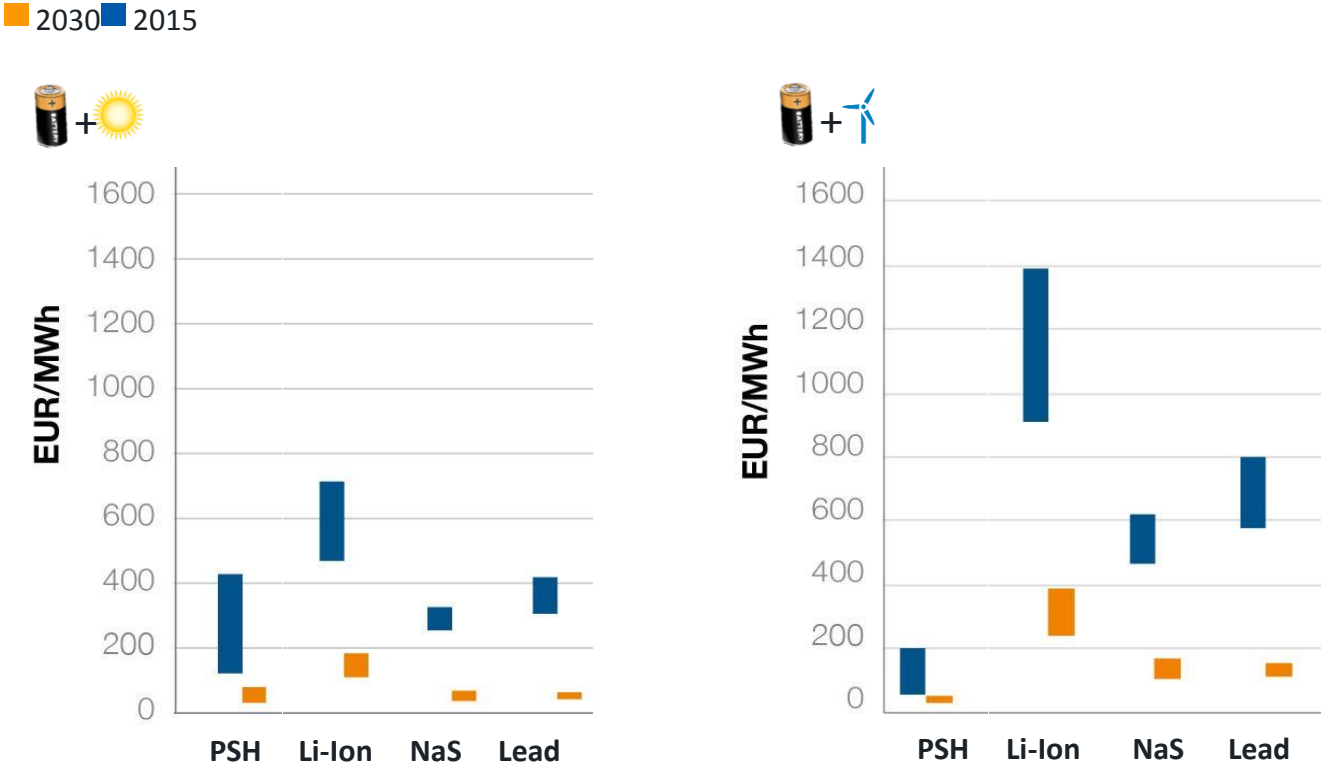
9.3 Million U.S. Customers are Enrolled in Demand Response

Sectorial Composition and Breakdown of Demand Response



Source: GTM Research, Google Nest

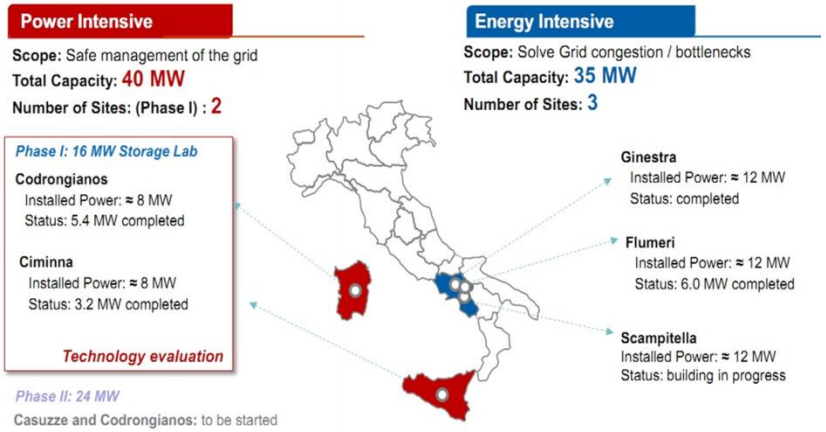
Comparing levelised cost of storage co-located for 2015 and 2030



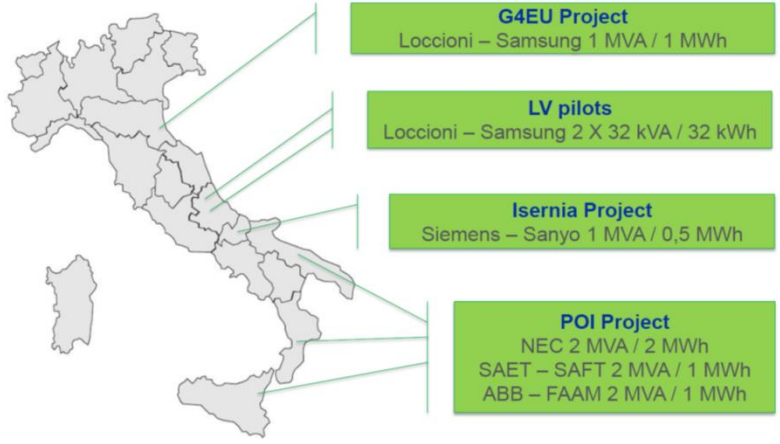
Source: Bloomberg Net Energy finance, WEC 2016

Energy storage technologies can be a game-changer and contribute to addressing the intermittency challenge.

Italian Transmission system operator Terna storage pilot projects



ENEL (by far the largest distribution system operator in Italy) storage pilot projects



Source: Terna, ENEL

Final Remarks [1/3]

- RES and particularly **variable RES as wind and PV have had, are having and will have explosive development**
- RES and specifically wind and PV **have become a big business** overtaking the investments in conventional generating plants
- **Combination of technology** /construction developments and **volumes are driving down CAPEX and OPEX** costs of variable VRES
- **Variability** and average low equivalent hours of operation per year of PV and also in many countries for wind, **pose challenges to their extensive development**

Final Remarks [2/3]

- **A holistic approach to overall electrical system design** is a key to success – Each country power system is unique even if some general statements can be drawn. **Sophisticated technical, economic and regulatory analyses** on a case-by-case basis must be conducted over an adequate period of time
- **The implications of reductions in subsidies** or other support schemes must be carefully analysed to avoid a drastic reduction on VRES investments as results of incentive reductions(eg some EU countries)
- The **right location with high wind and solar factors** and low grids connection costs for new large VRES project is a key to success

Final Remarks [3/3]

- **Regulatory bodies have a fundamental role** in both development of VRES and typology of counter measures to smooth the impact on the power system
- **VRES** are in any case **a pathway for climate change mitigation**, but also investments that **reduce dependence on imported fuel, improve air quality, increase energy access and security of supply, promote economic development, and create jobs**.
- In countries where an electricity market exists they have **contributed to the reduction of pool price** even if for some categories of clients this has not been reflected in their bills
- **Cautions on extrapolations to other countries of auctions $/kWh values** got in nations with very high levels of wind and insolation and very low local costs
- **Working together**, the main energy stakeholders will be able to meet all current challenges facing RES integration in electricity systems **by learning about both positive and negative experiences of other countries.**