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Making the Electricity System Work

Variable Renewables Electricity Systems Integration

get it right

Alessandro Clerici | July 24/2017 Varenna

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Variable Renewables Electricity Systems Integration: how to get it right

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VARIABLE RENEWABLES INTEGRATION IN ELECTRICITY SYSTEMS: HOW TO GET IT RIGHT

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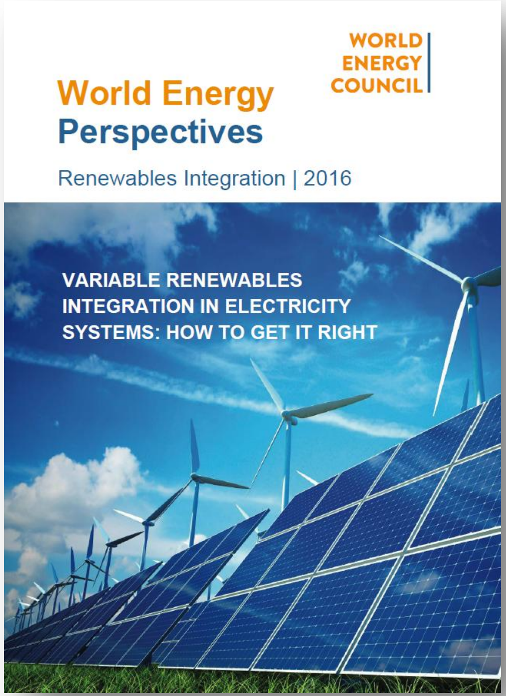

1. **CURRENT STATUS OF VRES**
2. **LESSONS LEARNED FROM THE CASE STUDIES**

2.1 Power mix of the 32 country case studies
2.2. RES regulations, policies and economics
2.3 Impacts of VRES on the electric power system
- Impacts on traditional fleets
- Impacts on electricity market
- Impacts on 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

World Energy Council's Study Group "RES Integration" established in 2014 supported by the Council's Global Partner CESI S.pA. (Italy), report launched on 20 September 2016

32 COUNTRY CASE STUDIES

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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 global installed VRES generating capacity**
- **87% of VRES global electricity production**

Variable Nature of Wind and Sun

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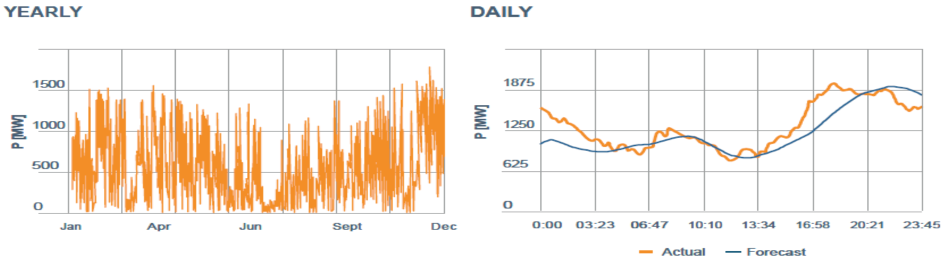
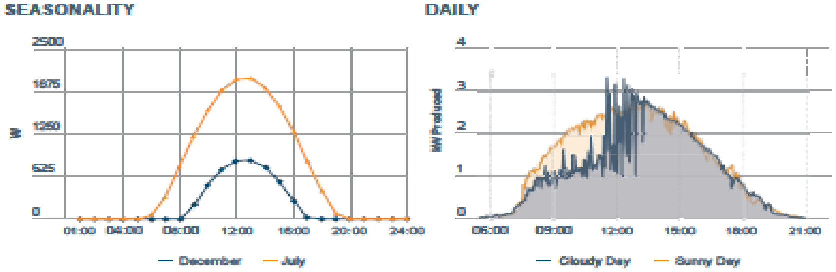
YEARLY AND DAILY VARIABILITY IN IRELAND OF GLOBAL WIND FLEET POWER PRODUCTION



SEASONAL AND DAILY VARIATION OF THE POWER GENERATION FOR A SMALL PV PLANT IN CENTRAL ITALY



Source: CESI

Renewables in the Global Energy System

World global power capacity additions and energy production by source 2004-2014

Source	Installed Capacity 2004 [GW] and (%) share		Installed Capacity 2014 [GW] and (%) share		Average Annual Growth Rate (%)	2014 Production [TWh] and (%) share		Average Equivalent Operating Hours [h]
Hydro	715GW	18.8%	1,055 GW	17.1%	4%	3,898TWh	16.6%	3,694
Wind	48GW	1.3%	370GW	6.0%	23%	728TWh	3.1%	1,967
Biomass	39GW	1.0%	93GW	1.5%	9%	423TWh	1.8%	4,545
Solar	3GW	0.1%	181GW	2.9%	51%	211TWh	0.9%	1,168
Geothermal	9GW	0.2%	13GW	0.2%	4%	94TWh	0.4%	7,225
Total Renewables	814GW	21.4%	1,712GW	27.7%	8%	5,353TWh	22.8%	3,127
Total Conventional (Oil, Gas, Coal) and Nuclear	2,986GW	78.6%	4,468GW	72.3%	4%	18,127TWh	77.2%	4,057
TOTAL	**3,800GW**	**100%**	**6,180GW**	**100%**	**5%**	**23,480TWh**	**100%**	**3,799**

Updated figures (end 2016):

Wind global installed capacity 487GW

Solar PV global installed capacity 302 GW

Source: CESI, based on REN21 (2015)

Global new investment in RES

excluding large hydro plants >50 MW, USD billion

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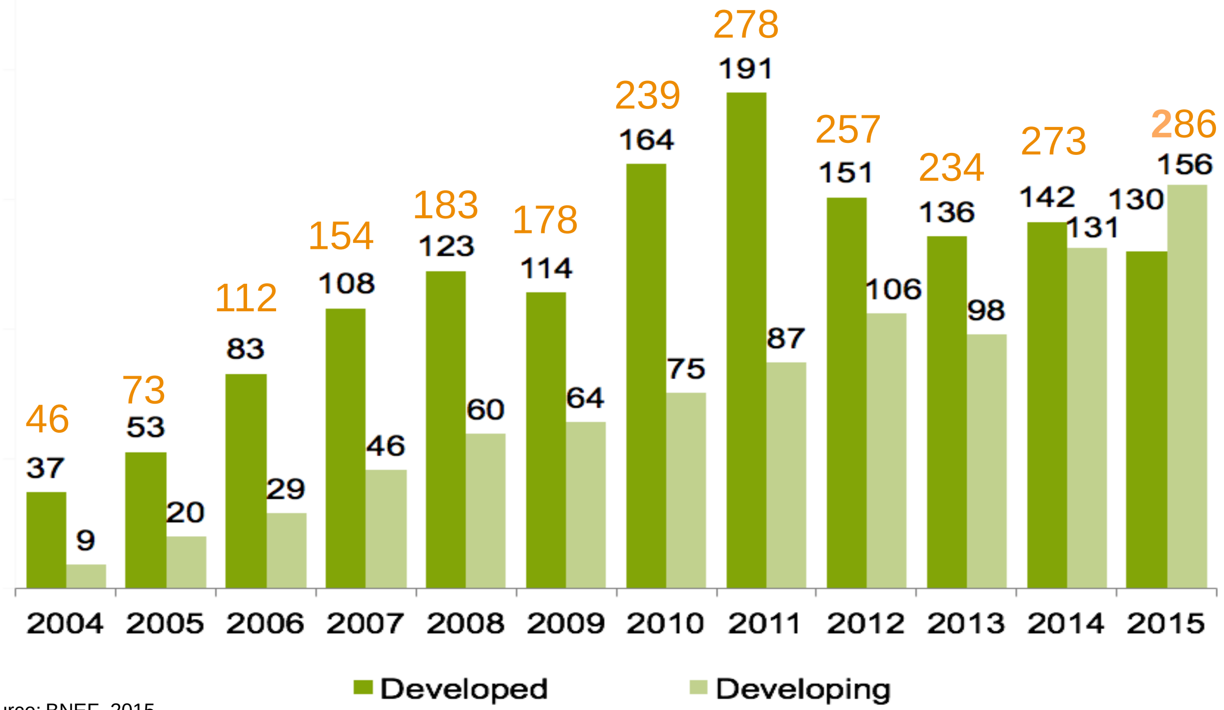


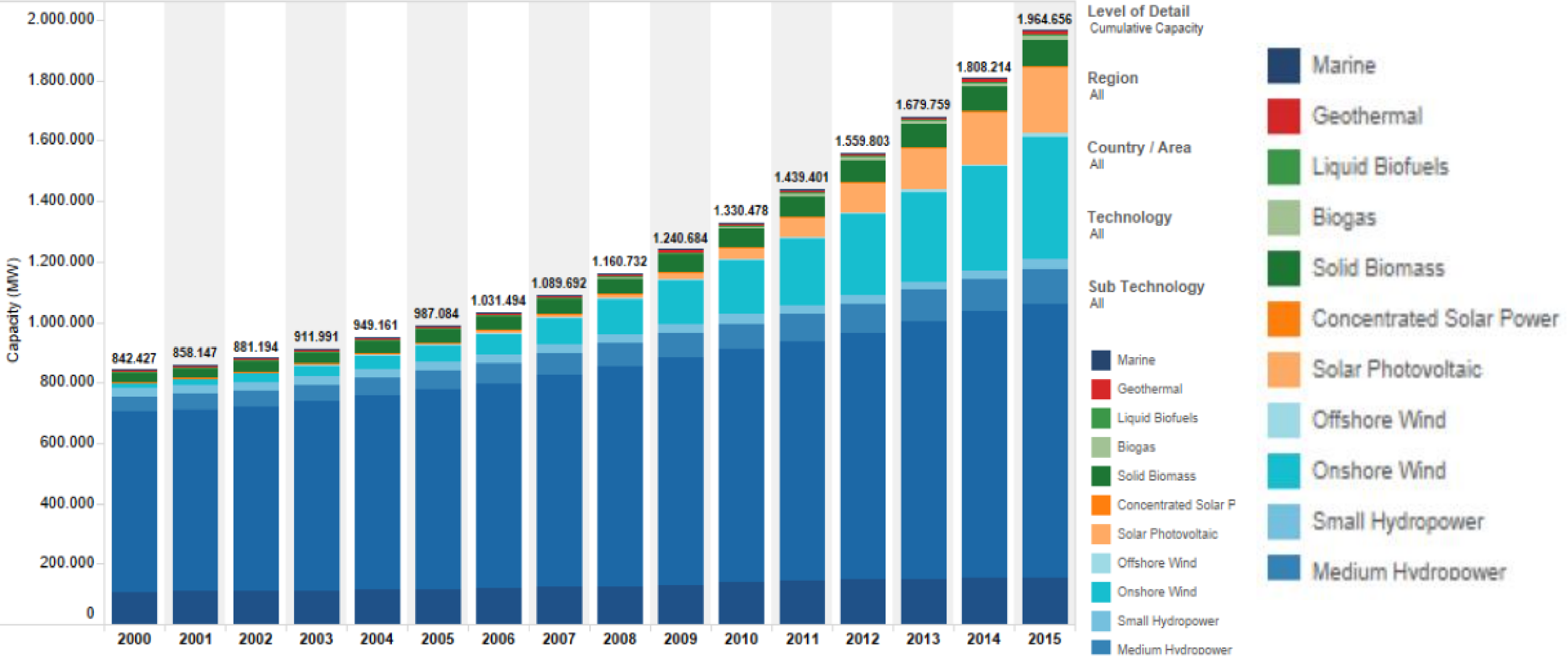
Source: BNEF, 2015

Cumulative global investment in RES 2004-2015

In 2016, new investment in RES has dropped by 18% from the record of USD286 billion in 2015. Installed capacity increased by 8%, due to falling prices.

EU is loosing its leading position to ASIA. China accounts 36% of the total RES investments

Cumulative Installed Renewables Capacity by Technology in the Period 2001–2015



Source: IRENA, 2016

Wind and Solar PV Cumulative Installed Capacity Development from 2011-2015. Radical Decline in Europe

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		2011	2012	2013	2014	2015
	Europe	52	70	81	88	96
SOLAR PV	**World total**	69	100	139	181	222
	EU	75%	70%	58%	49%	43%
	Europe	95	108	119	131	144
WIND	**World total**	239	283	318	370	432
	EU	40%	38%	37%	35%	33%
	Europe	147	178	200	219	240
TOTAL	**World total**	308	383	457	551	654
	EU	48%	46%	44%	40%	37%

Source: BNEF, 2015

Wind and Solar PV Contract Prices Drop to New Lows (IEA June 2015)

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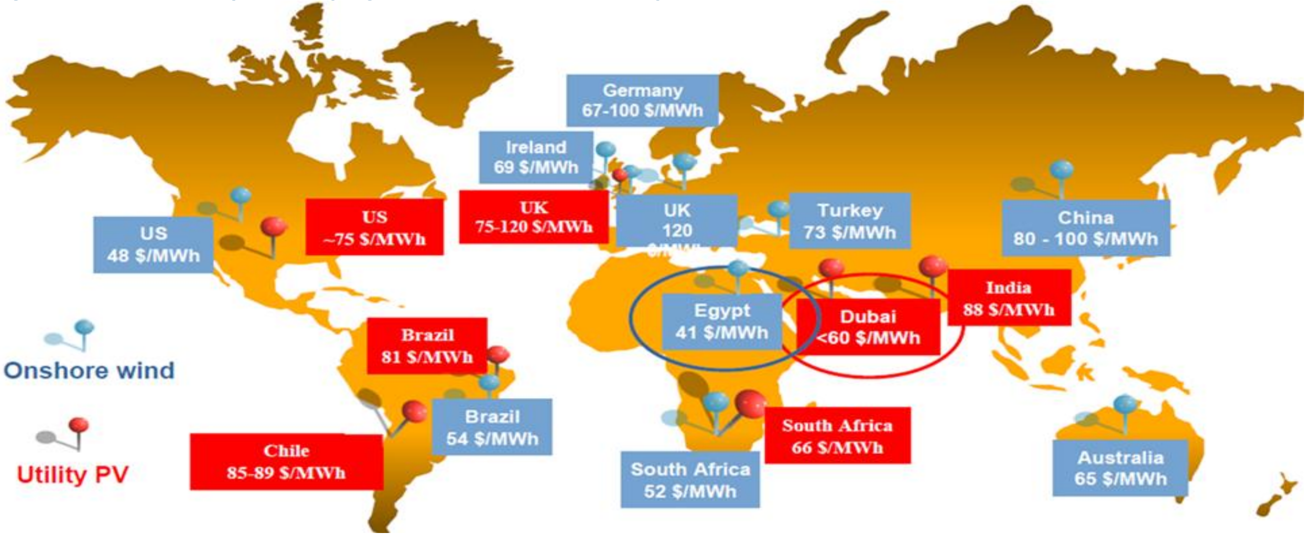
Long-term contract prices (e.g. auctions and FITs)



- Rapid reduction in capital costs due to high volume of RES investments and fast technology development.
- Solar PV show the greatest reduction of prices, by 50% between 2010 – 2014 in OECD and even greater in non-OECD countries
- In some countries solar PV power plants with capacity above a few MW the minimum EPC contract value is around 1,000 USD/kW.

Source: IEA, 2016

Wind and solar PV drop to new lows

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- **Auction prices a year ago (May 2016)**

  Morocco: wind 28 USD/MWh

  UAE: solar PV 30 USD/MWh

- **And a year later (February 2017)**

  PV in UAE and Mexico 24 USD/MWh

These prices cannot be considered as average values, since they are affected by the local costs, load factors for wind and solar plants, type of auction and financing costs.

In Morocco wind load factor is close to 60% (cf 18-24% average in Italy).

Solar PV plants in Dubai and Mexico have load factors which are more than double of those in the UK

Leading Countries in Wind and Solar Power 2015

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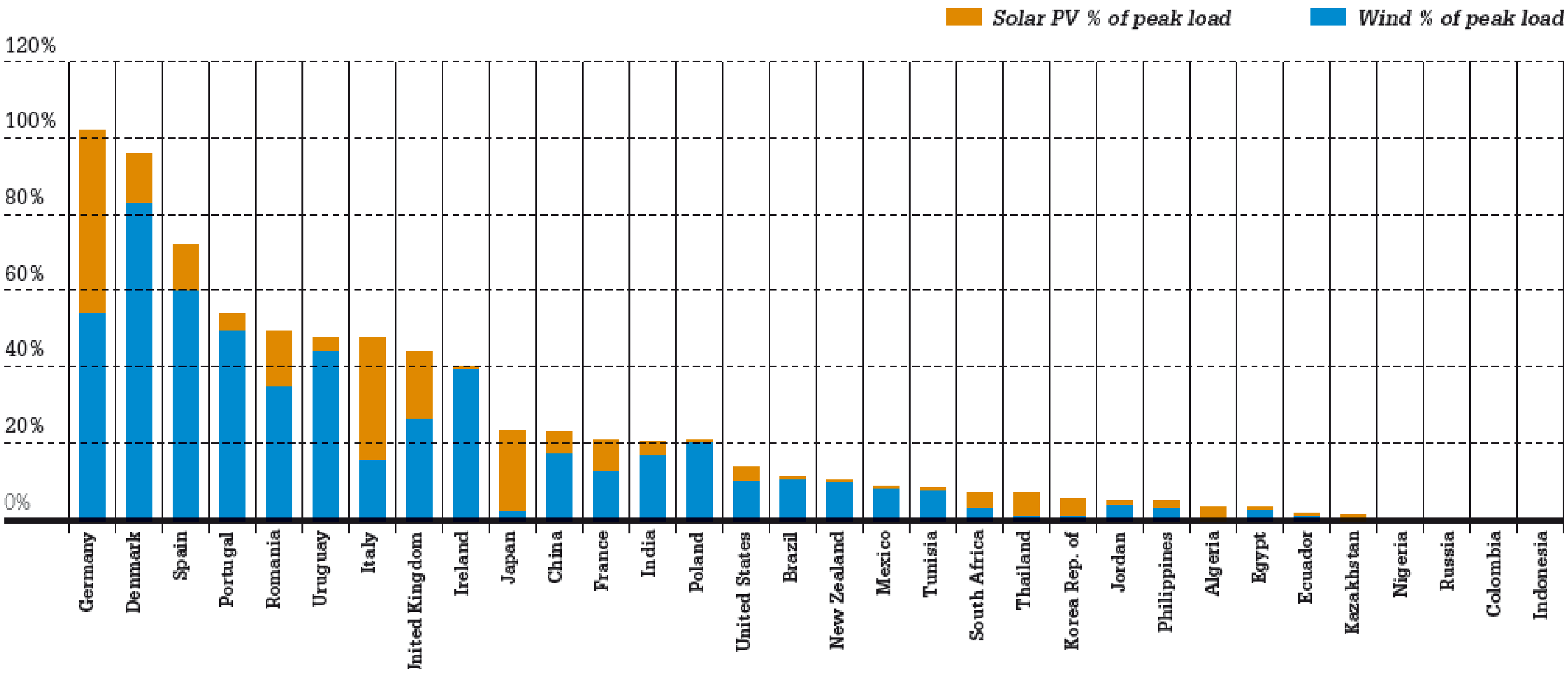
	1	2	3	4	5
Installed capacity, wind	China 145 GW	USA 73 GW	Germany 45 GW	India 25 GW	Spain 23 GW
Installed capacity, solar PV	China 43 GW	Germany 40 GW	Japan 33 GW	USA 26 GW	Italy 19 GW
Installed capacity, VRES	China 188 GW	USA 98 GW	Germany 85 GW	Japan 36 GW	India 30 GW
Share of VRES in generation	Denmark 52%	Portugal 24%	Ireland 23%	Spain 23%	Germany 20%
VRES as % of peak demand	Germany 102%	Denmark 96%	Spain 72%	Portugal 54%	Romania 49%

Installed VRES Capacity has a Significant Share of Demand in Different Countries

VRES cumulative installed capacity by Country as percent of the national peak load



Source: Council Report

Regulation, Policies and Economics

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- VRES regulation and policies demonstrate a number of **differences in the 32 countries** covered in the report, **but VRES enjoy priority of dispatch in most of them.**
- The use of various support and **incentives schemes** for renewables have a **strong impact on the VRES development** and success.
- **Financial incentives** have been widely used for promotion of VRES. **The most popular form is Feed in Tariffs (FIT)** with fixed prices used in many countries for specified time periods (e.g. 20 years in Germany and Italy).

Regulation policies and economics

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Brazil Country-wide **auctions for all types of power sources** for long term contracts (Power Purchasing Agreements). **In 2015, wind power was the cheapest** electricity **source at 50 USD/MWh**.

Egypt **Bilateral agreements**. RES equipment and spare parts are **exempted from custom duties and sales taxes.**

Germany **The FIT has been the basic incentive**. The **reduction of PV feed-in tariffs has resulted in reduced capacity additions** in recent years. Moreover**, a cap on the installed PV capacity of 52 GW** has been introduced. Once this cap is reached, new PV units will no longer be supported by the feed-in tariff. **In 2014 auctions for PV have been introduced for plants above 6 MW**; auctions also **for wind** plants will be introduced **in 2017.**

Italy Incentives for VRES in Italy used to include **Green Certificates, FIT, FI premium tariff. PV incentives** were introduced **in 2005 with a high FI premium tariff of 450€/MWh;** impressive growth in new installations. **As soon as the incentives** for both wind and PV **were drastically reduced or withdrawn**, the annual growth of **VRES dropped from more than 10 GW in 2011 to around 0.5 GW of new capacity additions in 2015**. **Now** there are **only auctions for a strictly limited yearly capacity of large plants and tax deductions for small plants**.

….continued
Regulation policies and economics

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Japan Feed in tariff for wind and solar was in the range of **300–350USD/MWh and now up to 450USD/MWh** to speed up VRES development due to concerns about **nuclear** and thus strong reduction in nuclear production.

New Zealand A unique market arrangement based on a carbon price which avoids incentives to RES, combined with a nodal price that takes into account eventual additional costs for the T&D (e.g. losses and congestion) due to plants location.

South Korea Additional green certificates are granted to utilities which install wind power plants combined with Energy Storage Systems.

USA Different depending on utilities and states: incentives are **Federal** (Tax Credit and Production Tax Credit), **State** (e.g. Net metering) and **Local** (rebate and financing options, green power rates).

Impacts of VRES on the electric power system

1. Traditional fleets
2. The electricity market
3. Transmission and Distribution grid
4. Consumers

Impacts of VRES on the electrical power system

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1

Shrinking operating hours of CCGT plants (eg. Italy)

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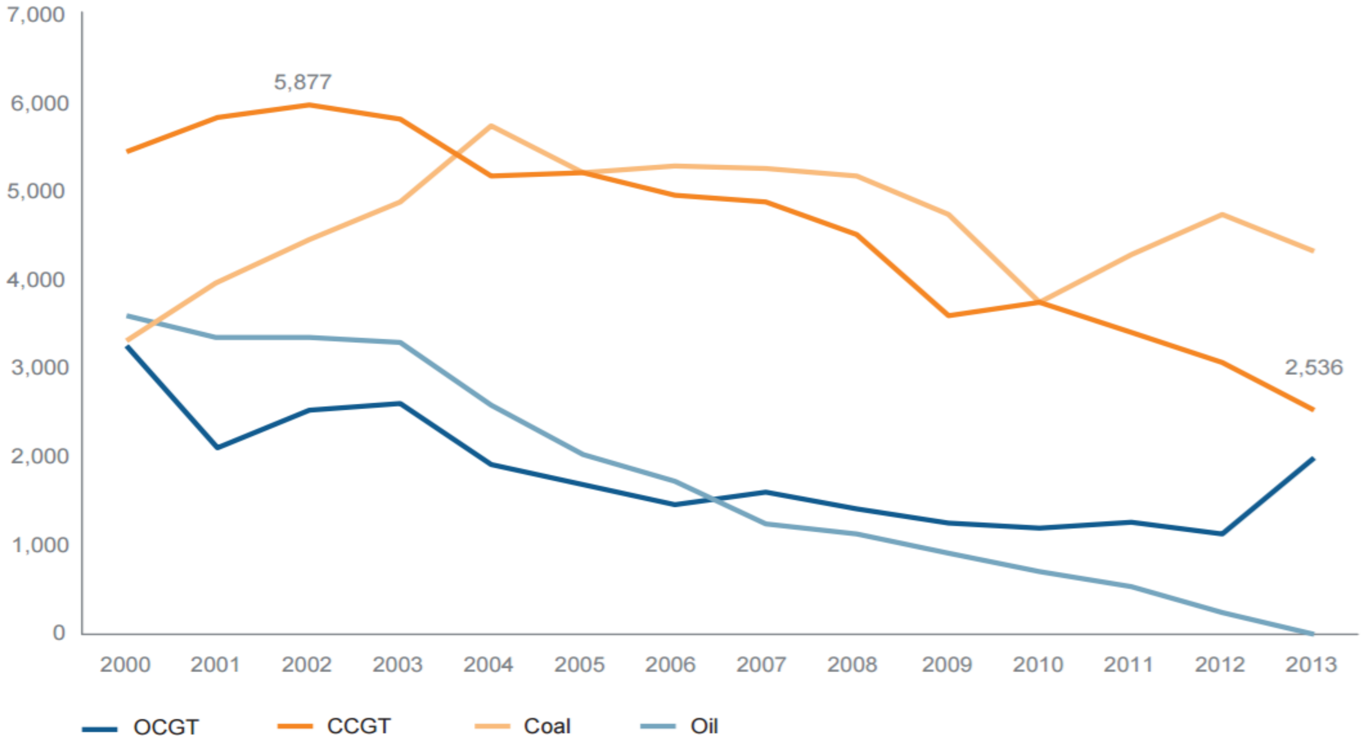
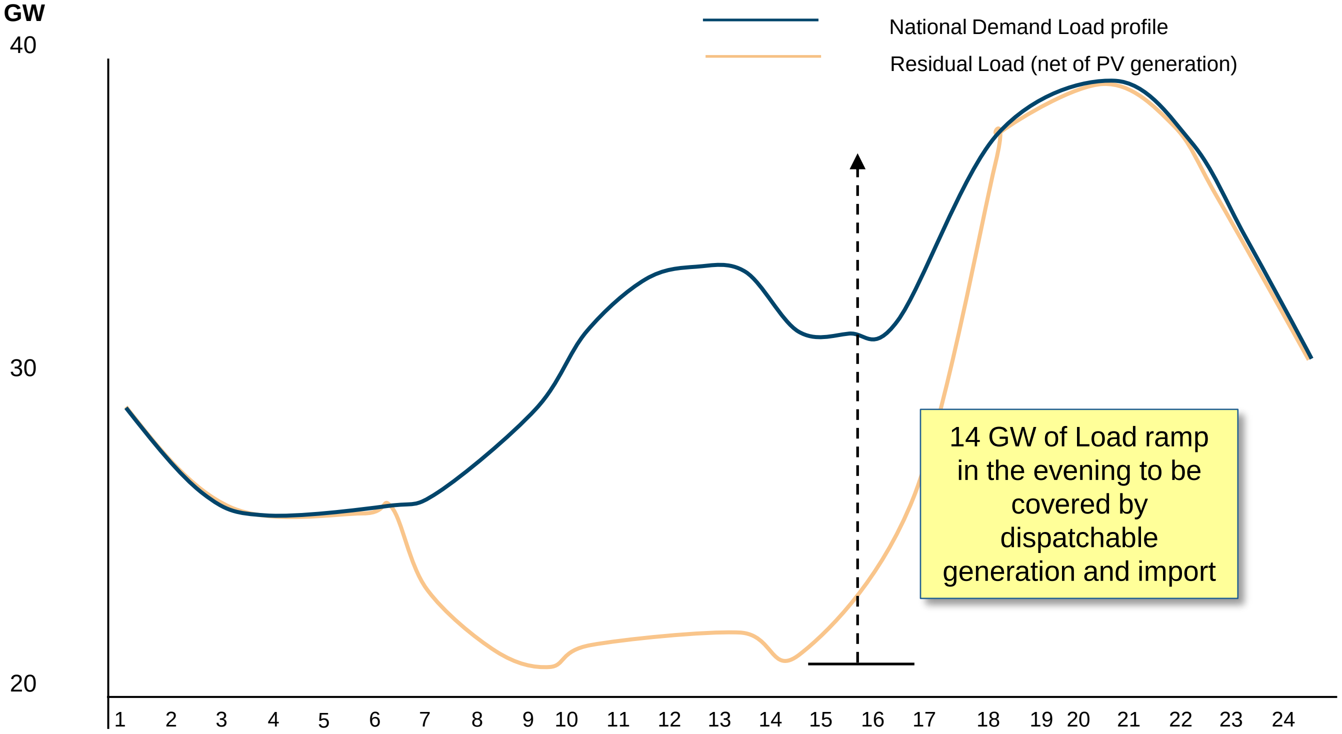


Source: AEEGSI

Sharp variation of RES generation (e.g. Italy)



Source: Terna

Impacts of VRES on the electrical power system

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1. Traditional fleets
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2

Max Daily Price in the Evening after Sunset – Italy

Growing volumes of VRES combined with gas price reduction resulted in a drastic collapse of PUN (national average pool price)

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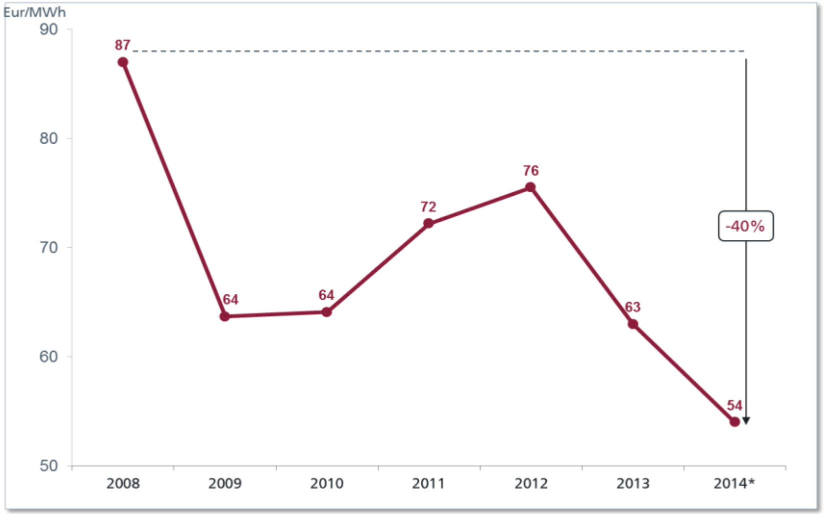
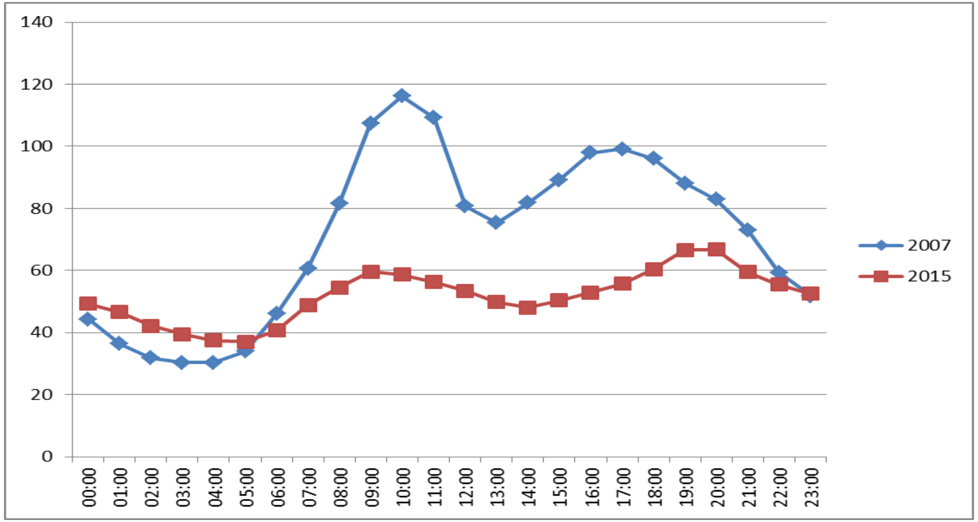
Average



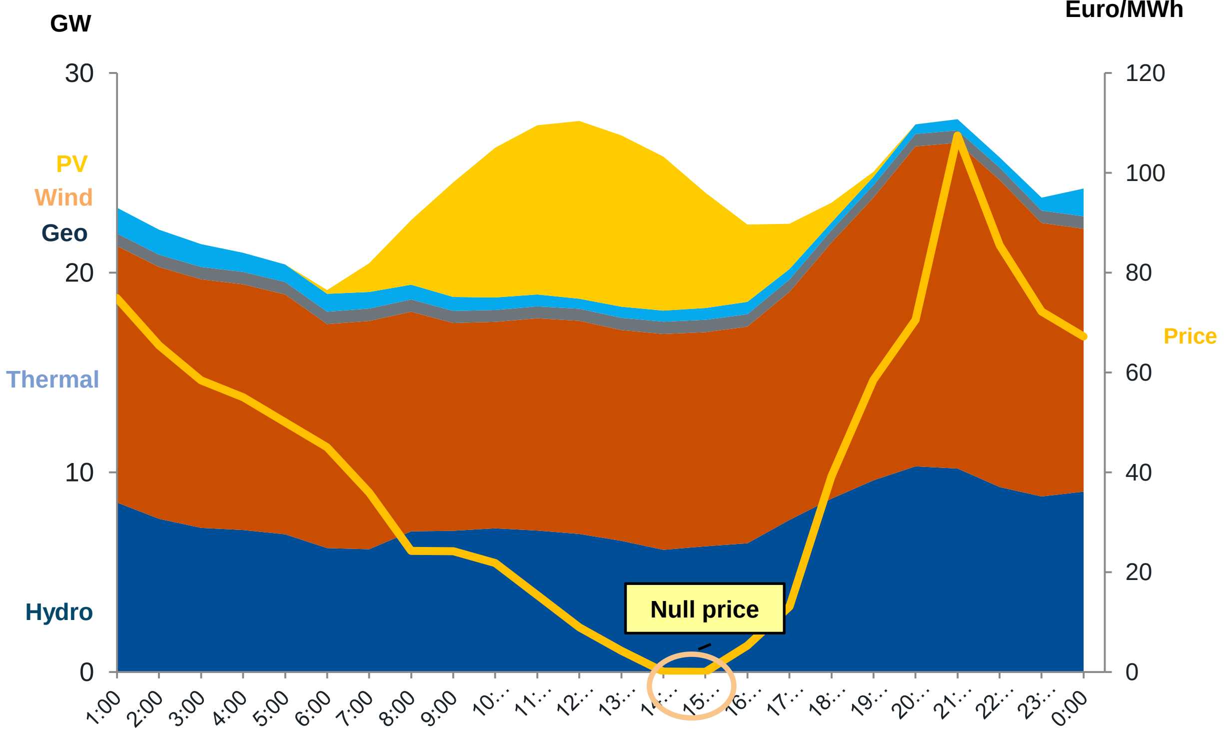
Daily



Source: GME

2

A zero price in the day-ahead market on a sunny summer day (e.g. Italy) and negative prices in Germany



Source: Terna, GME

Impacts of VRES on the electrical power system

1. Traditional fleets
2. The electricity market
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The increase in the number of primary substations with power flow inversion impacts the existing measuring and protection systems- Example of Italy

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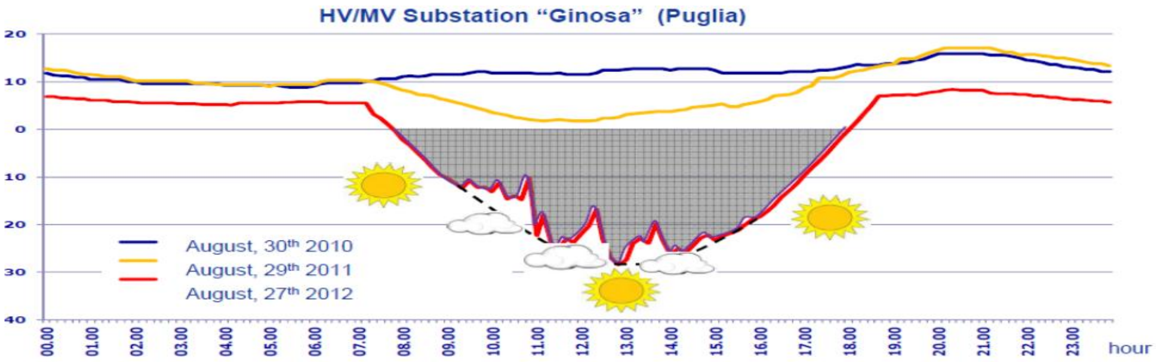
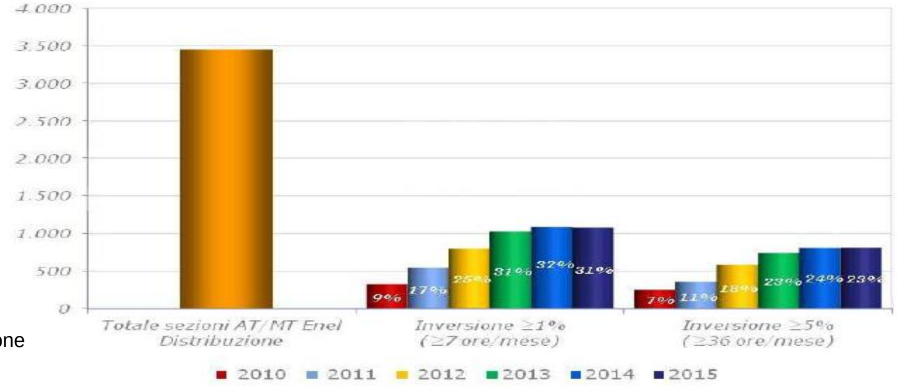
Power flow reversal in primary substations

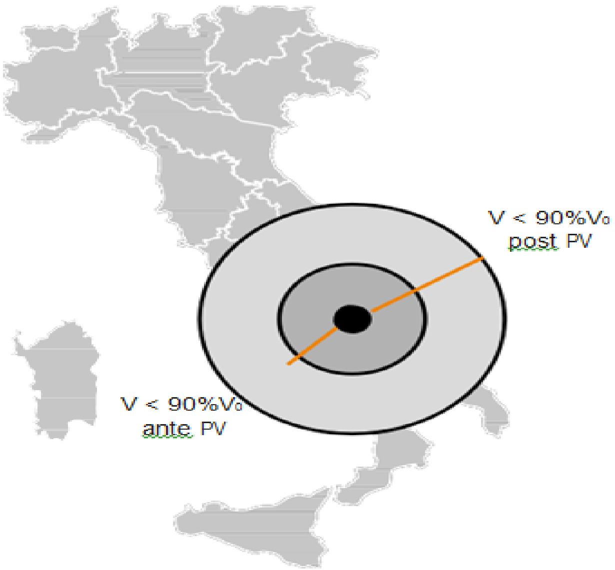


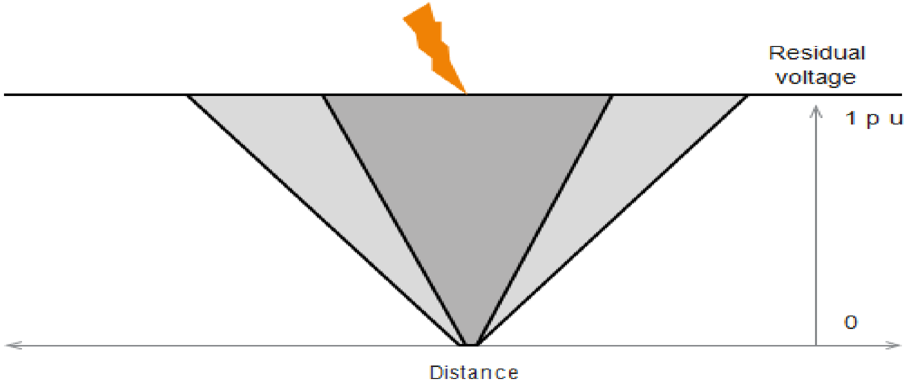


Source: ENEL Distribuzione

3

Voltage drops caused by a fault





Due to reduction of rotating machines connected to Transmission grid, there is less Shortcircuit-Power available and therefore voltage dips generated at T-level have larger impact. (In this simulation the spatial distribution of DG has been assumed homogenous.)

Source: Terna

Impacts of VRES on the electrical power system

1. Traditional fleets
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4

Development of PV feed-in tariffs, module costs and capacity additions (e.g. Germany)

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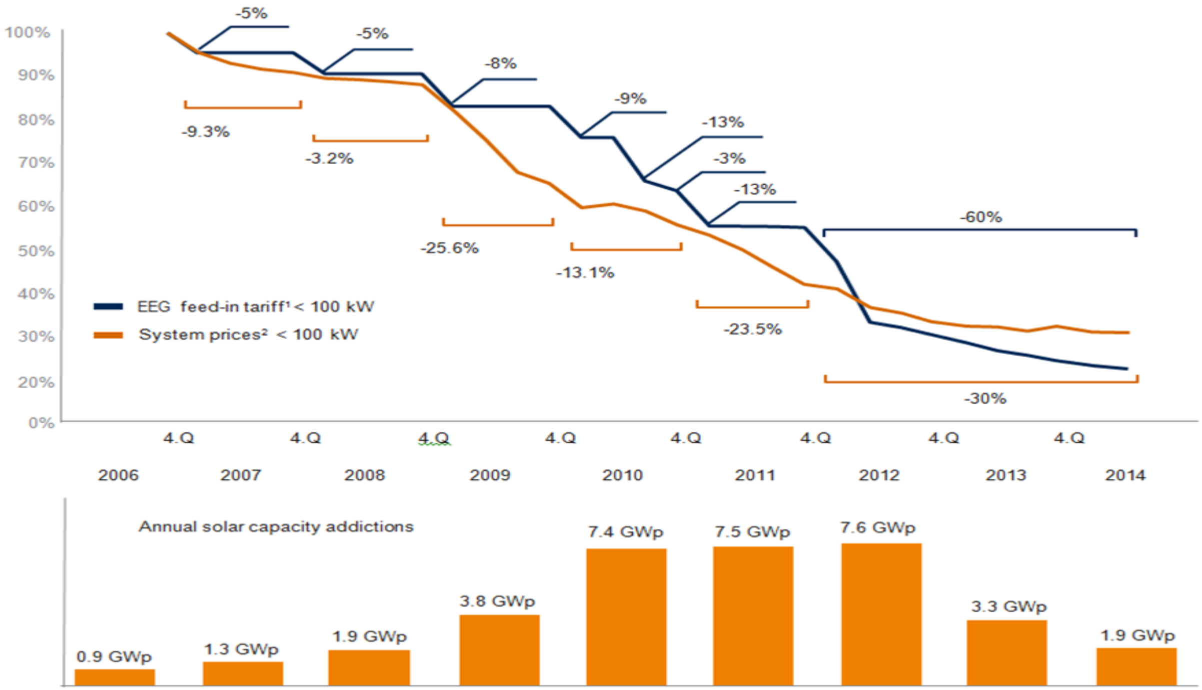

1 The EEG compensation: the compensation classes were in the second quarter 2012 brought in line with the amended EEG law. Previously until the end of the first quarter 2012, PV installations with the output of 30–100 kWp were included.

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

Source: BSW-Solar, Beta

4

EEG-levy introduced in 2014 is about 6.24€c/kWh (eg. Germany)

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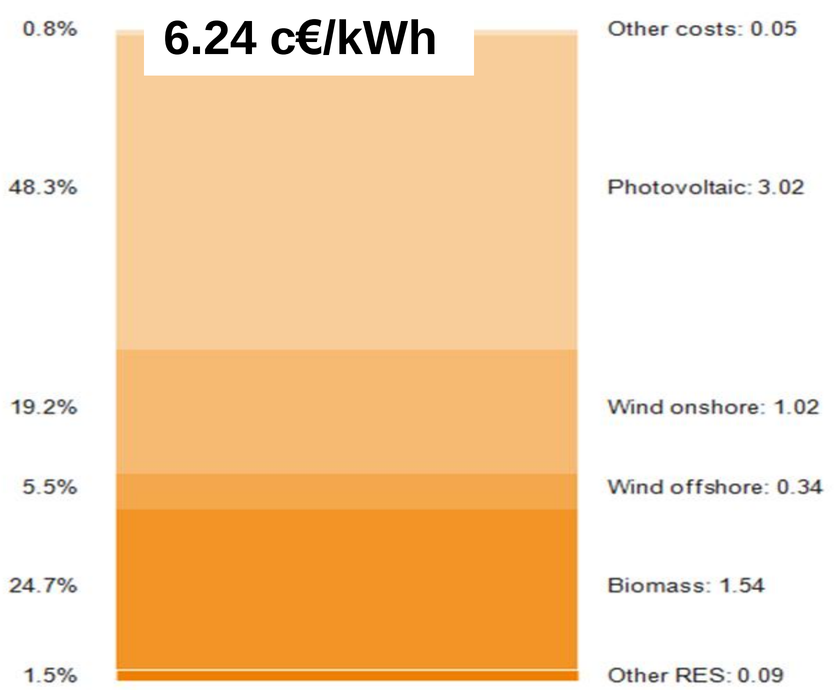
The proceeds from the introduction of EEG in 2014 totalled 23.6 billion Euros and will be used to 100% for the promotion of renewables. 97.4% go directly to the operators of the EEG plants, 1.8% to direct marketing of the EEG power and 0.8% to cover the necessary administrative costs.



Source: BDEW

4

Evolution of the PV incentives with different feed-in scheme and connections (Wind & PV) to the Enel distribution system in Italy

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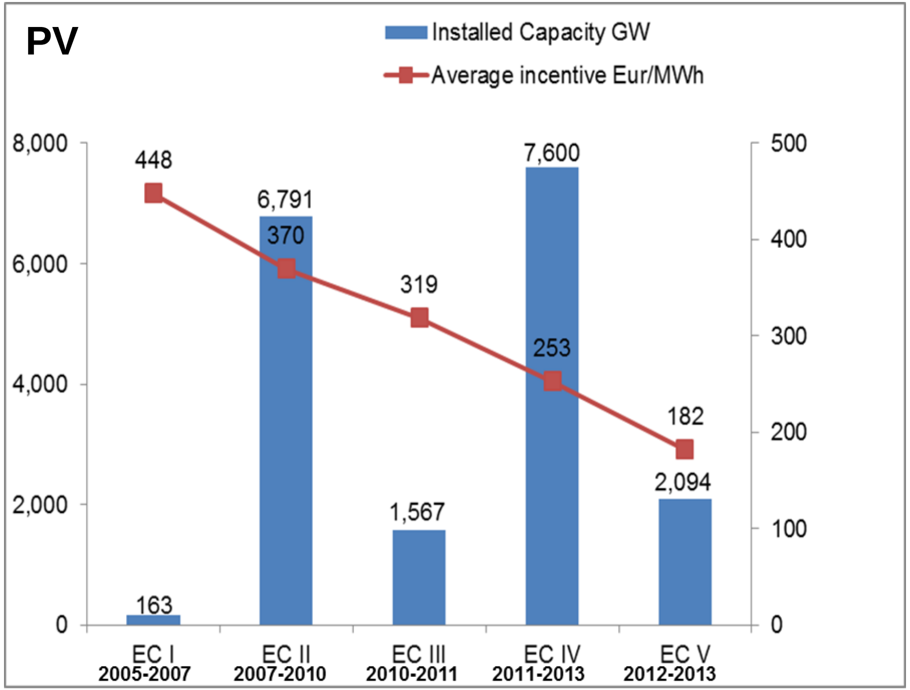

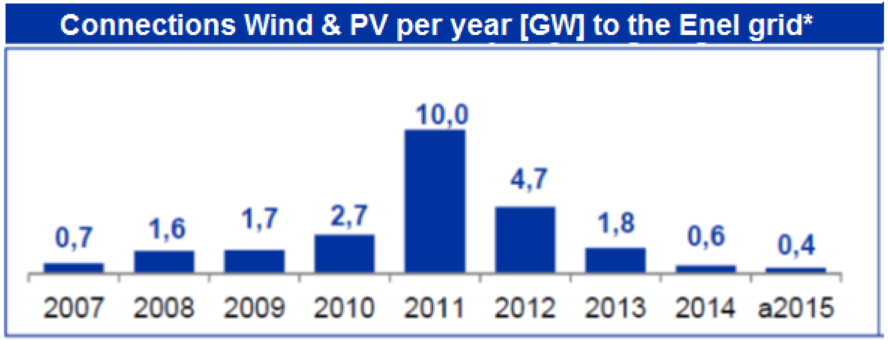

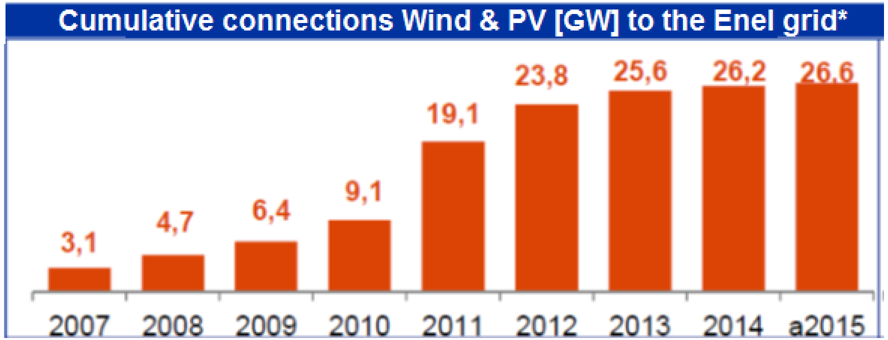

*Enel DSO covers more than 85% of the Italian distribution grid

Source: BDEW

Measures for a smoother VRES integration

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TECHNOLOGIES

- 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

MARKET DESIGN

- Revision of emissions trading schemes
- Capacity market
- 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

Local congestion in South of Italy requires - an 8bn Euro investment in grid reinforcement and expansion in the next decade

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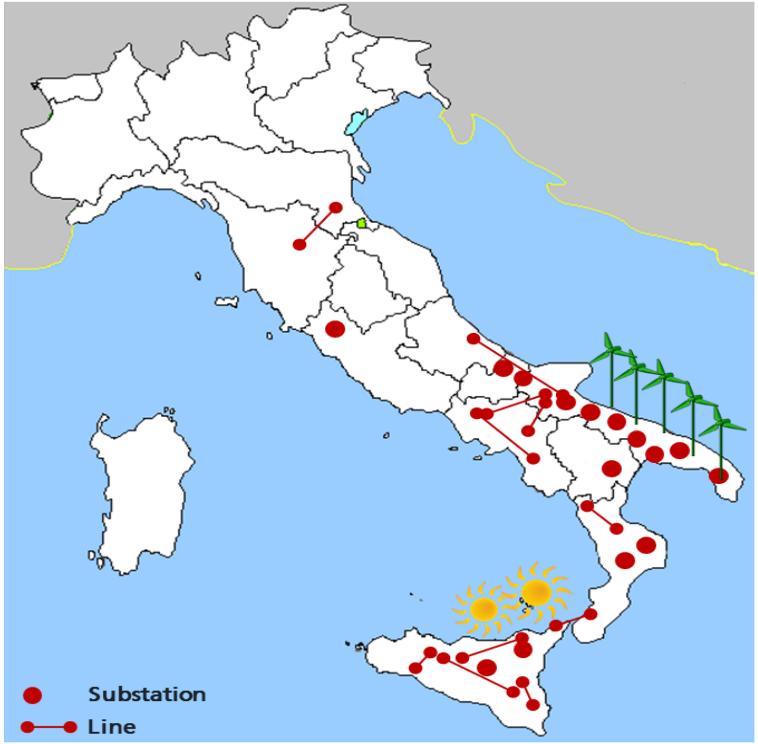
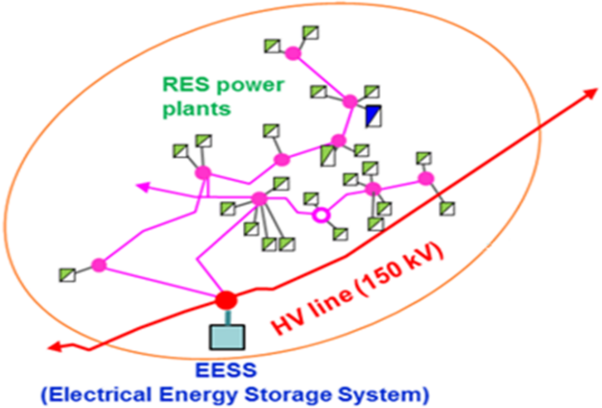


Source: Terna

Local generation exceeds sub-transmission capacity



Italian Transmission system operator- storage: pilot projects

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Power Intensive

Scope: Safe management of the grid

Total Capacity: 40 MW

Number of Sites: (Phase I) : 2

Phase I: 16 MW Storage Lab

Codrongianos
Installed Power: ≈ 8 MW
Status: 5.4 MW completed

Ciminna
Installed Power: ≈ 8 MW
Status: 3.2 MW completed

Technology evaluation

Phase II: 24 MW

Casuzze and Codrongianos: to be started

Energy Intensive

Scope: Solve Grid congestion / bottlenecks

Total Capacity: 35 MW

Number of Sites: 3

Ginestra
Installed Power: ≈ 12 MW
Status: completed

Flumeri
Installed Power: ≈ 12 MW
Status: 6.0 MW completed

Scampitella
Installed Power: ≈ 12 MW
Status: building in progress

MWh/MW ratios in the range 0.5-1

MWh/MW ratios in the range 4 to 8

Source: Terna

Lessons Learned [1/2]

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- RES and particularly variable RES (wind and solar PV) have experienced and are set to continue an explosive growth
- 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 solar PV and in many countries also wind, pose challenges to their large-scale development but so far DSO's and TSO's have been able to manage electric power systems without an impact on reliability even with high % of VRES.
- A holistic approach to overall electrical system design is a key to success - Each country's power system is unique, even if some general conclusions can be drawn.
- Sophisticated technical, economic and regulatory analysis on a case-by-case basis must be conducted over an adequate period of time
- The implications of reduction of subsidies or other support schemes must be carefully analysed to avoid a drastic reduction of VRES investments (e.g. some EU countries)

Lessons Learned [2/2]

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- The right location with high wind and/or solar load factors and low grid connection costs for new large VRES projects is a key to success
- Regulatory bodies have a fundamental role in both development of VRES and typology of measures to smoothen their impact on the power system
- VRES are a pathway for climate change mitigation, but they also reduce dependence on imported fuel, improve air quality, increase energy access and security of supply, promote economic development and job creation
- VRES have contributed to the reduction of electricity pool prices even if for some categories of clients this has not been reflected in their bills
- Extrapolation of low auction values (USD/kWh) should be done with caution, as the low prices are based on countries with high wind and solar load factors and 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

Annex 1: Capex - Opex - Auction Results

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- **CAPEX for domestic PV of a few kW capacity: from 1,000USD/kW in India to 3,500-4,000 USD/kW in Japan and USA**
- **CAPEX for PV plants above a few MW:** from below **1,000USD/kW in Africa, the Middle-East, India and Latin America to 2,700USD/kW in Japan.**
- ***Load factor* for PV** from around 10% in UK to 30% in some countries of South America, the Middle East and Africa.
- ***Load factor* for wind plants** in Morocco up to 55%;in Italy average 18% (the part of kWh cost due to CAPEX triple)

O&M Services Costs

O&M services are US Dollars (USD) or Euro (€) per MW or kW installed

- **For wind plants,** O&M increases with plant age. A ***"full service" contract* in Europe between 20 and 30 USD/kW –** For a low *load factor* e.g. 18% as in Italy, the cost was 12.5-18.7 USD/MWh
- **For PV plants**, the report provides published data from Italy - for plants above **2.5 MW and 1,350 equivalent hours: the cost was up to 45USD/MWh**:
  - 56% O&M (including spare parts, billing, panels cleaning, etc.)
  - 18% land renting when not included in CAPEX,
  - 10% insurance *"all risks"*,
  - 10% telecommunications and monitoring,
  - 6% security guards

Summary of main auctions' prices in Europe in June 2016 (from the report)

- **Germany: 70 - 85 €/MWh for PV plants above 6 MW**
- **France (results confirmed at end 2015 for PV plants totalling 800MW): "roof top" systems average of 130 €/MWh**
  «on the ground plants» average of 120€/MWh
- **UK** published in **February 2015 results** (for 15 wind projects "on shore" totalling 750 MW and 5 solar PV plants totalling 72 MW):
  - » **80- 83£/MWh for wind and**
  - » **50 - 80 £/MWh for solar PV**

Auctions in Europe after RES report

Results of last auctions in May 2017

- **France: PV plants** on the ground totalling 160 MW, in South of country average value **62.5 €/MWh for onshore wind plants, auctions for 3GW in 3 years are being issued with a price reference** of **72€/MWh**
- **Germany: 27 PV projects** totalling 163 MW: average price **69€/MWh**. **For plants in other countries which deliver energy to Germany prices are different, for example, a plant in Denmark received 53.8€/MWh**
- **Italy: at the last auction for wind plants, all 3 winning suppliers settled at 66€/MWh**

Last Auctions in Europe after RES report

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- ***Germany's* first competitive *auction* for *offshore wind* projects** must be the first unsubsidised *offshore wind* project in the world. The energy agency selected four offshore wind projects with a combined capacity of 1,490MW. All four projects are in the North Sea. **The award price on top of the wholesale electricity price was 0 Euro cent/kWh for one of the projects, the average was 0.44 Euro cents /kWh and the highest price accepted was 6.00 Euro cents/ kWh. Grid connection is not included in the bid price.**

- **The first onshore wind tender in Germany, under the reformed "EEG" renewable energy law, awarded 807 MW at an average price of Euro 57.1/MWh.** In Germany, the pay-as-bid mechanism grants bidders the prices they have offered until the overall tender volume is met. The German system offers a guaranteed price for 20 years

- **The Spanish government at end of May 2017 awarded contracts for supply of 2,979MW of wind capacity at 43.0 Euros (USD 47.8) / MWh,** (the lowest level ever awarded in an onshore wind tender in Europe.)

Further information

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A free copy of the report can be downloaded from the World Energy Council's website: https://www.worldenergy.org/publications/

Thank you

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