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Variable Renewables Electricity Systems Integration: how to get it right

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WORLD ENERGY COUNCIL

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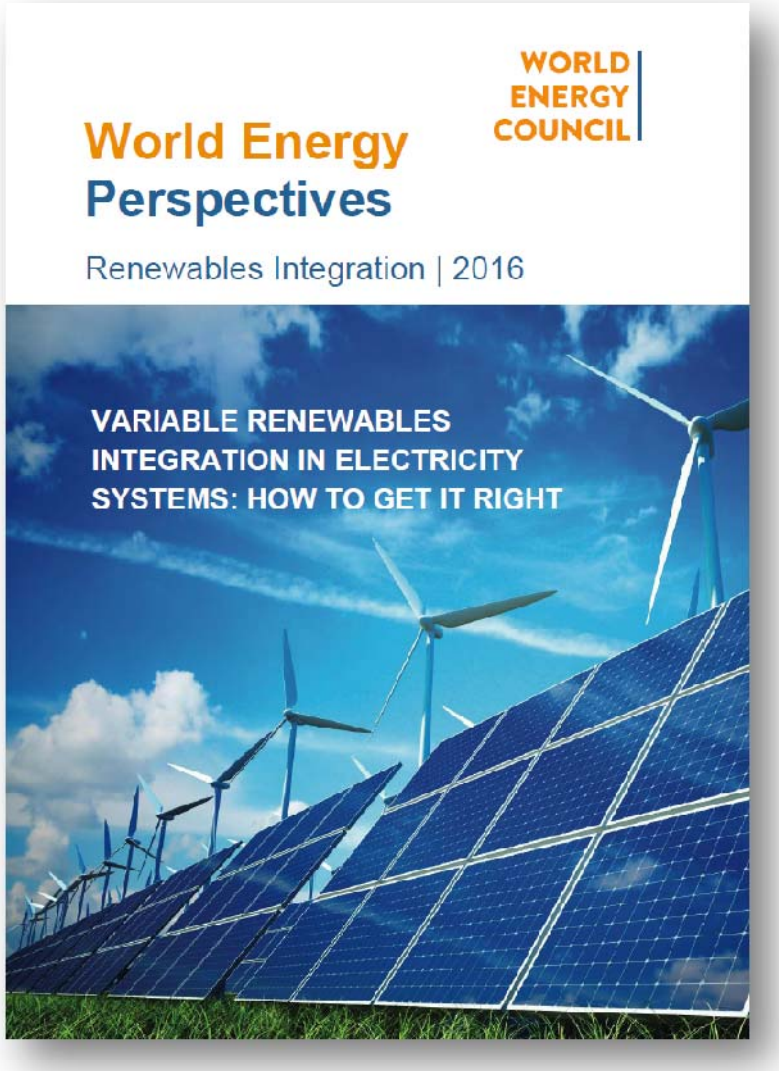
Shaping a Better Energy Future

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

Report from WEC Study Group "RES Integration" launched after 2 years of activities in September 20th 2016- Work supported by WEC Global Partner CESI ,Italy



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

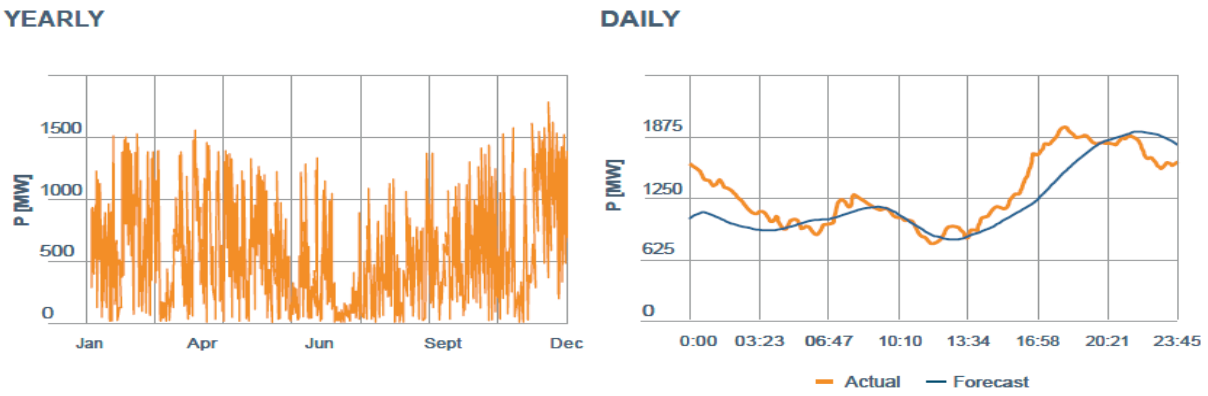
32 COUNTRY CASE STUDIES

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

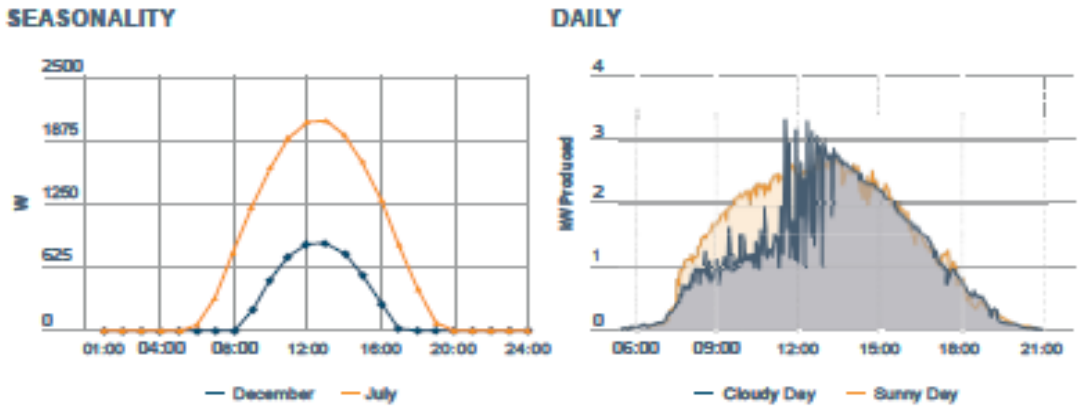
- **89% of total installed VRES generating capacity**
- **87% of VRES electricity production**

Variable Nature of Wind and Sun

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



Renewables in the Global Energy System

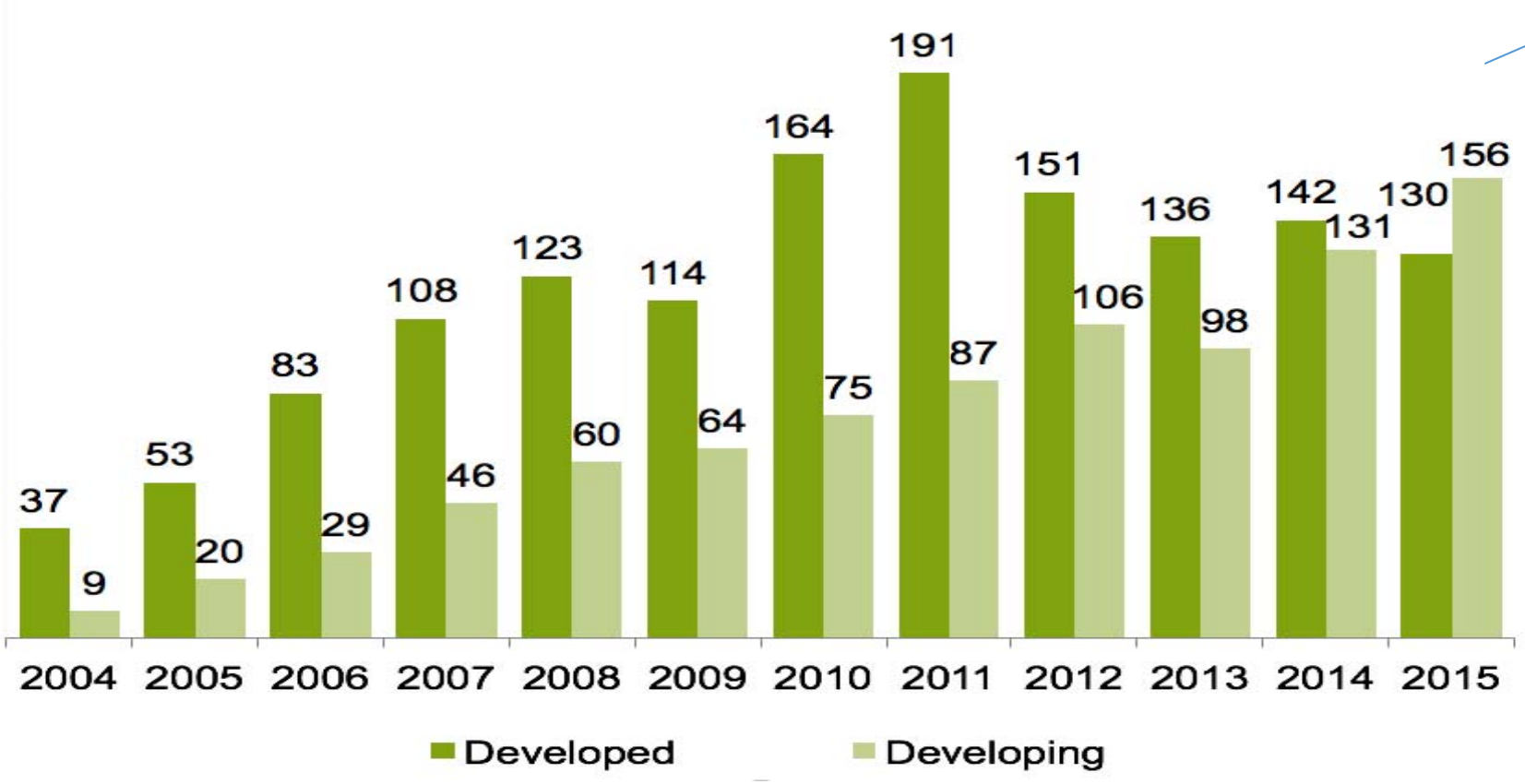
World global power capacity additions and energy production by source 2004-2014

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**

ESI, based on REN21 (2015)

Global new investment in RES plants lower than 50 MW

– Developed vs developing countries, 2004-2015 (USD billion)

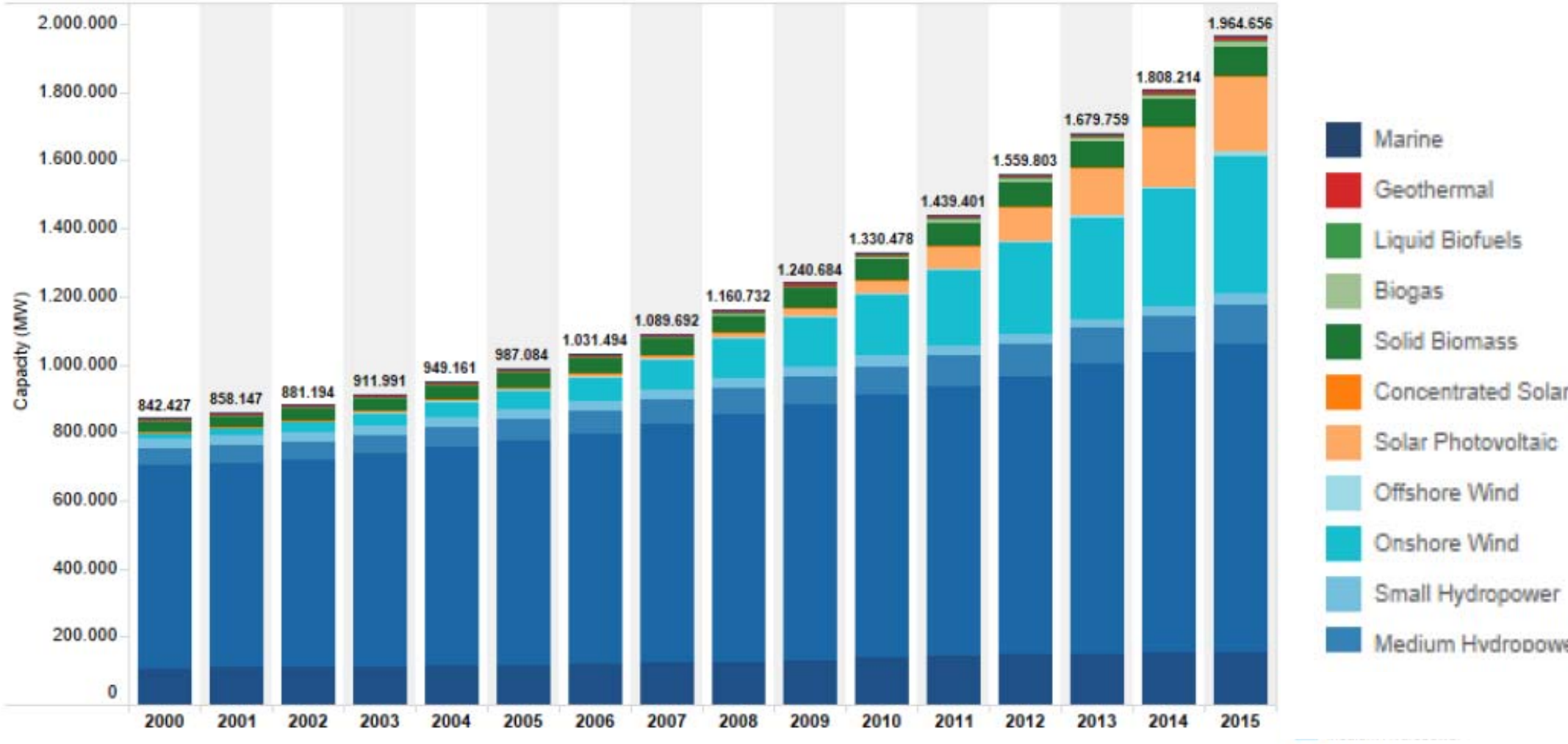


EU is loosing its leading position to ASIA. China accounts 36% of the total RES investments

(46) (73) (112) (154) (183) (178) (239)(278) (257) (234) (273) (286)

Source: BNEF, 2015

RENEWABLE CUMULATIVE INSTALLED RENEWABLES CAPACITY BY TECHNOLOGY IN THE PERIOD 2001–2015



ource: IRENA, 2016

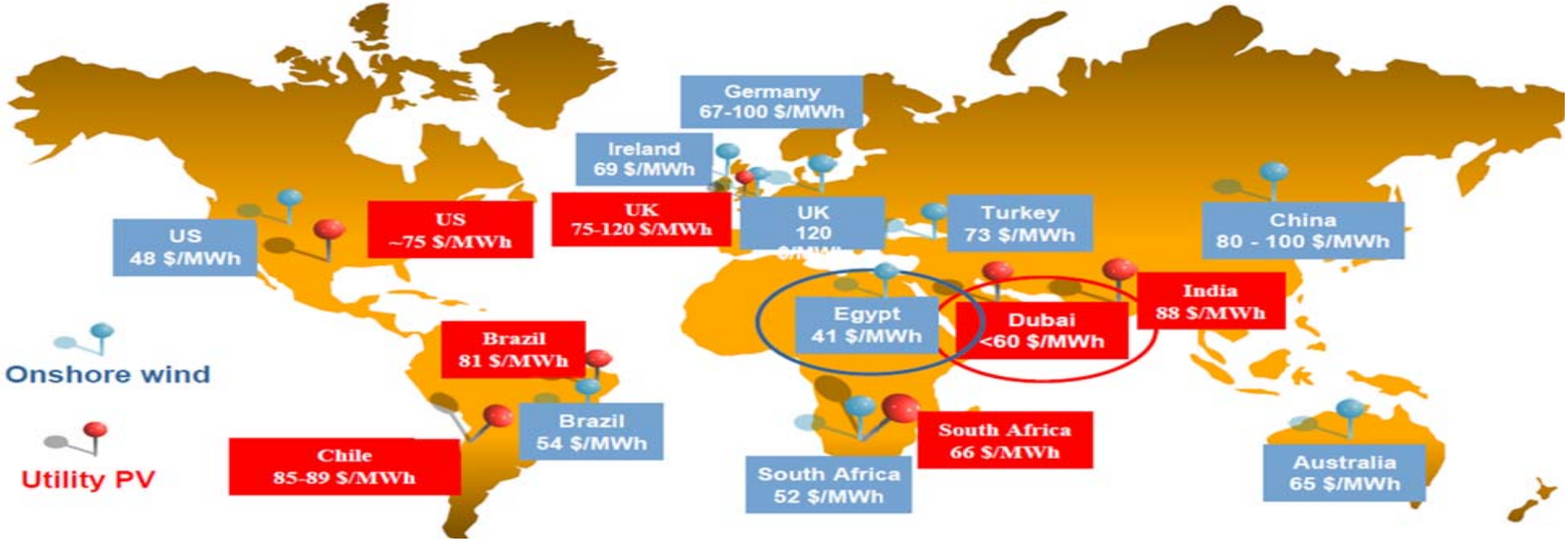
WIND AND SOLAR PV CUMULATIVE INSTALLED CAPACITY DEVELOPMENT FROM 2011-2015. EUROPE HAS FACED A DRASTRICAL DECLINE

		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%**

ource: BNEF, 2015

Wind and solar PV reach new lows

Long-term contract prices (e.g. auctions and FITs) at June 2015



- 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.

ource: IEA, 2016

Wind and solar PV reach new lows

- **The above prices are old after only 1 year**.

  At May 2016 ,auctions:

  -**Morocco wind 28 $/MWh** **-UAE 30 $/MWh**

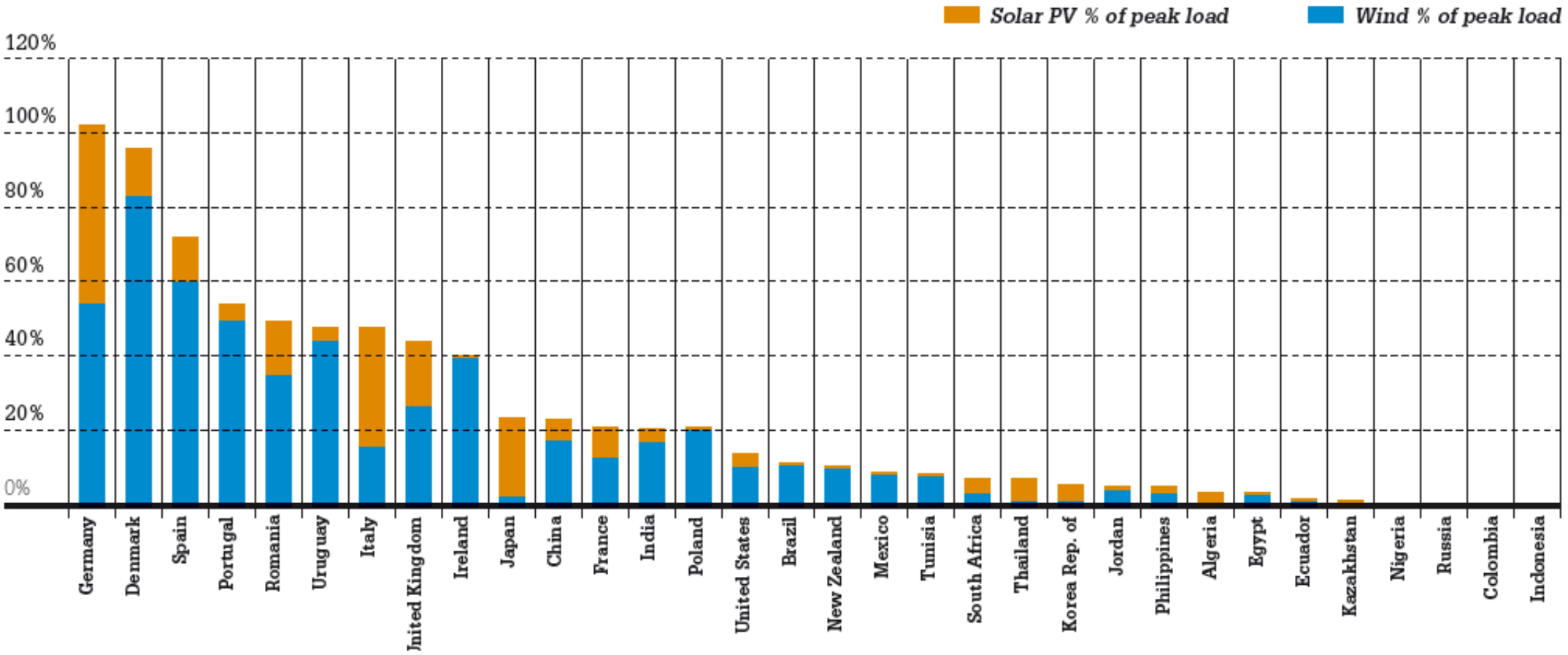
- **Cannot be used as average values**, since they are affected by the local costs and load factor values for wind and solar plants.

- **Morocco high wind load factor close to 60%** (the average in Italy is 18-24%).

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

VRES INSTALLED CAPACITY HAS SIGNIFICANT PROPORTION ON THE DEMAND IN VARIOUS COUNTRIES

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



Regulation policies and economics

- VRES regulation and policies present differences in the 32 Countries, but VRES enjoy priority of dispatch in most of them.
- The use of various support and incentive schemes has 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) that are in used in many countries and are fixed for specified time periods (e.g. 20 years in Germany and Italy).

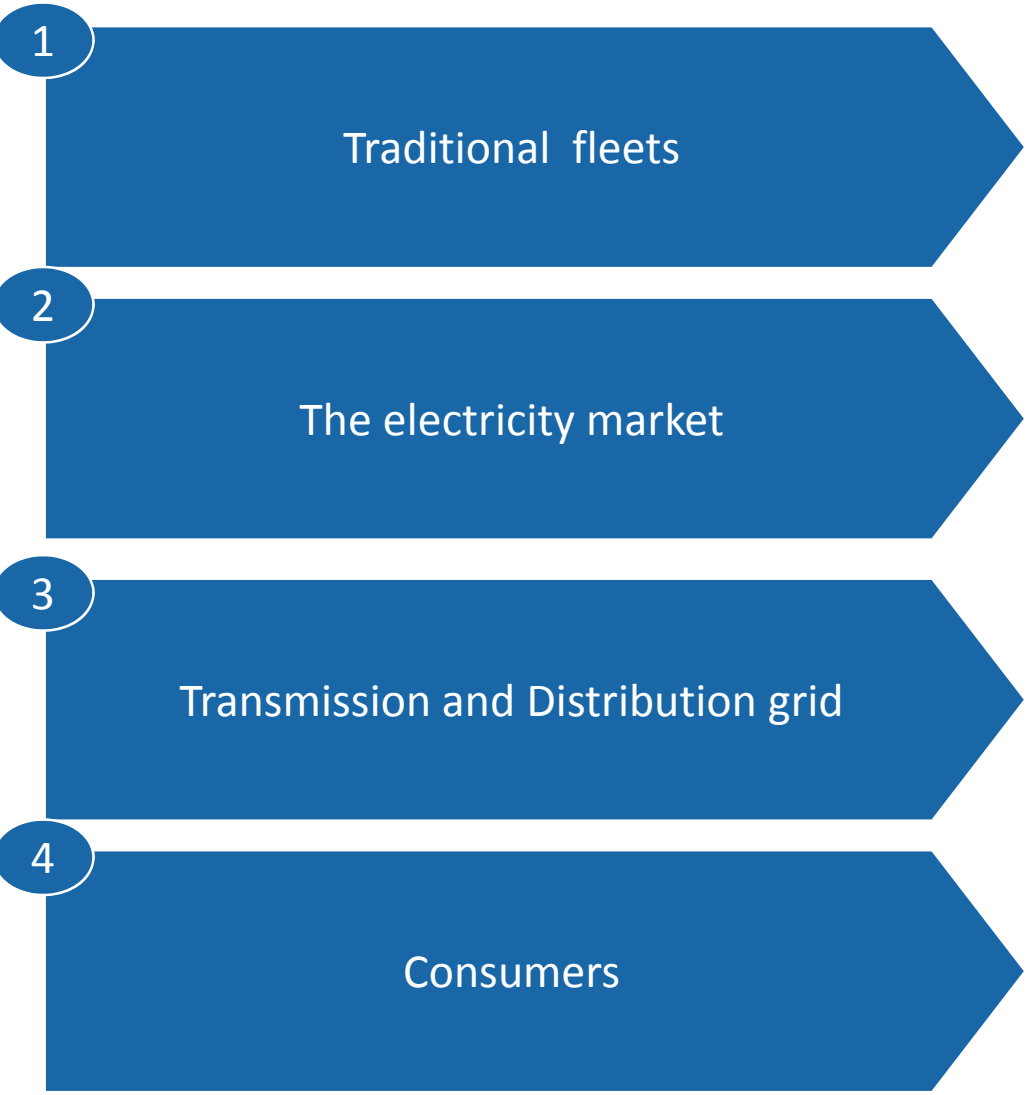
Regulation policies and economics

- **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 with 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 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 each**; auctions also **for wind** plants will be introduced **in 2017.**
- **Italy** Incentives for VRES in Italy used to consider **Green Certificates, FIT, FI premium tariff. PV incentives** were introduced **in 2005 with 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 decreased from more than 10 GW in 2011 to around 0.5 GW of new capacity additions in 2015**. **Now** there are **only auctions for very reduced global yearly capacity of large plants and tax deductions for small plants**.

Regulation policies and economics

- **Japan** **Feed in tariff** for wind and solar falls in the range **between 300–350 USD/MWh and now up to 450** to push VRES development **considering nuclear concern** and strong reduction in its production.
- **New Zealand** **A unique market arrangement based on a carbon price which avoid incentives to RES, combined with a nodal price that takes into account eventual additional costs on the T&D (e.g. losses and congestion) due to plants localization**.
- **South Korea** **Additional green certificates** are **added to utilities which install wind power plants combined with Energy Storage Systems.**
- **USA** **Differences for different utilities and regions**: incentives are **Federal** (Tax Credit and Production Tax Credit), **State** (e.g. Net metering) and **Local** (rebate and financing options, green power rates).

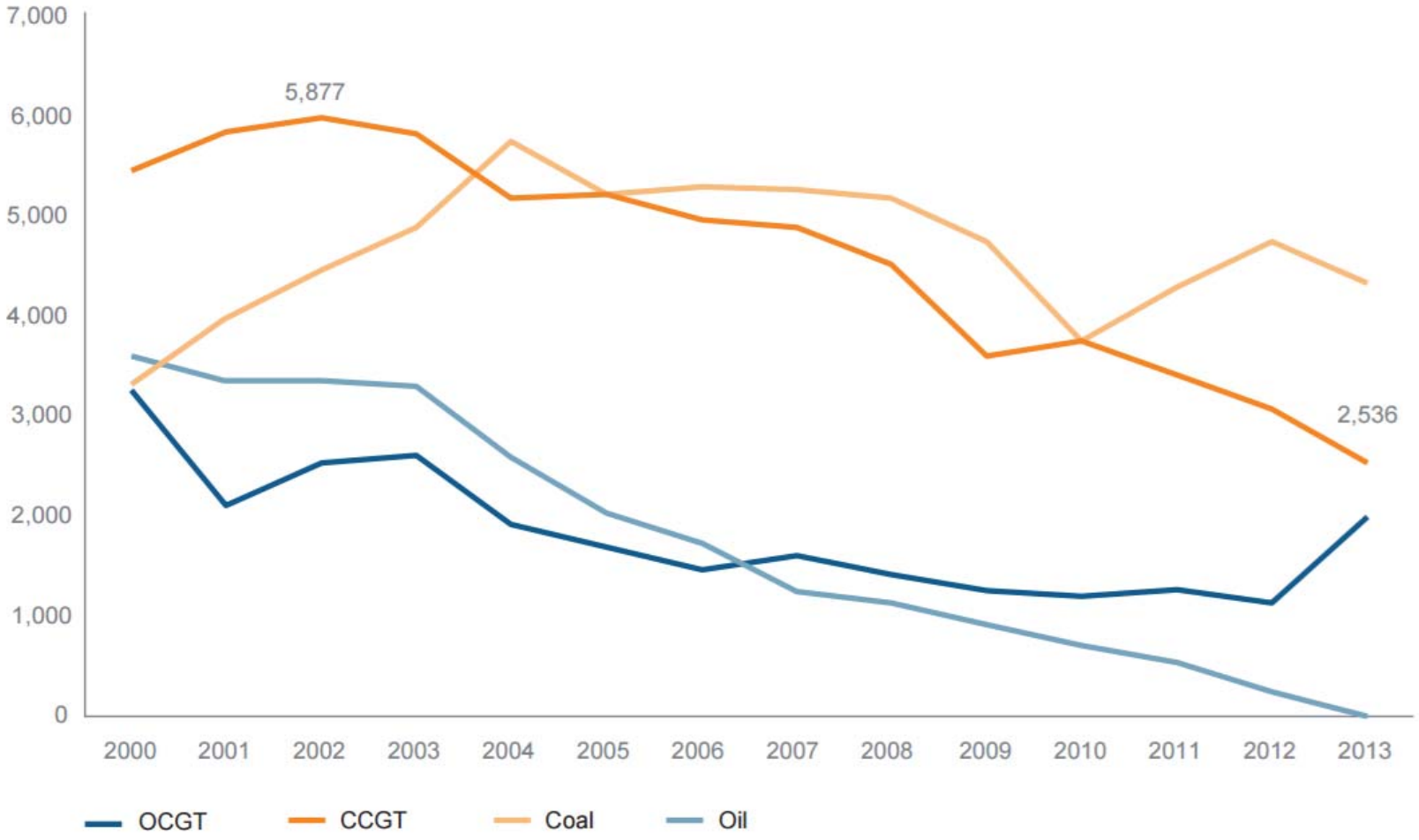
Impacts of VRES on the electrical power system



Impacts of VRES on the electrical power system

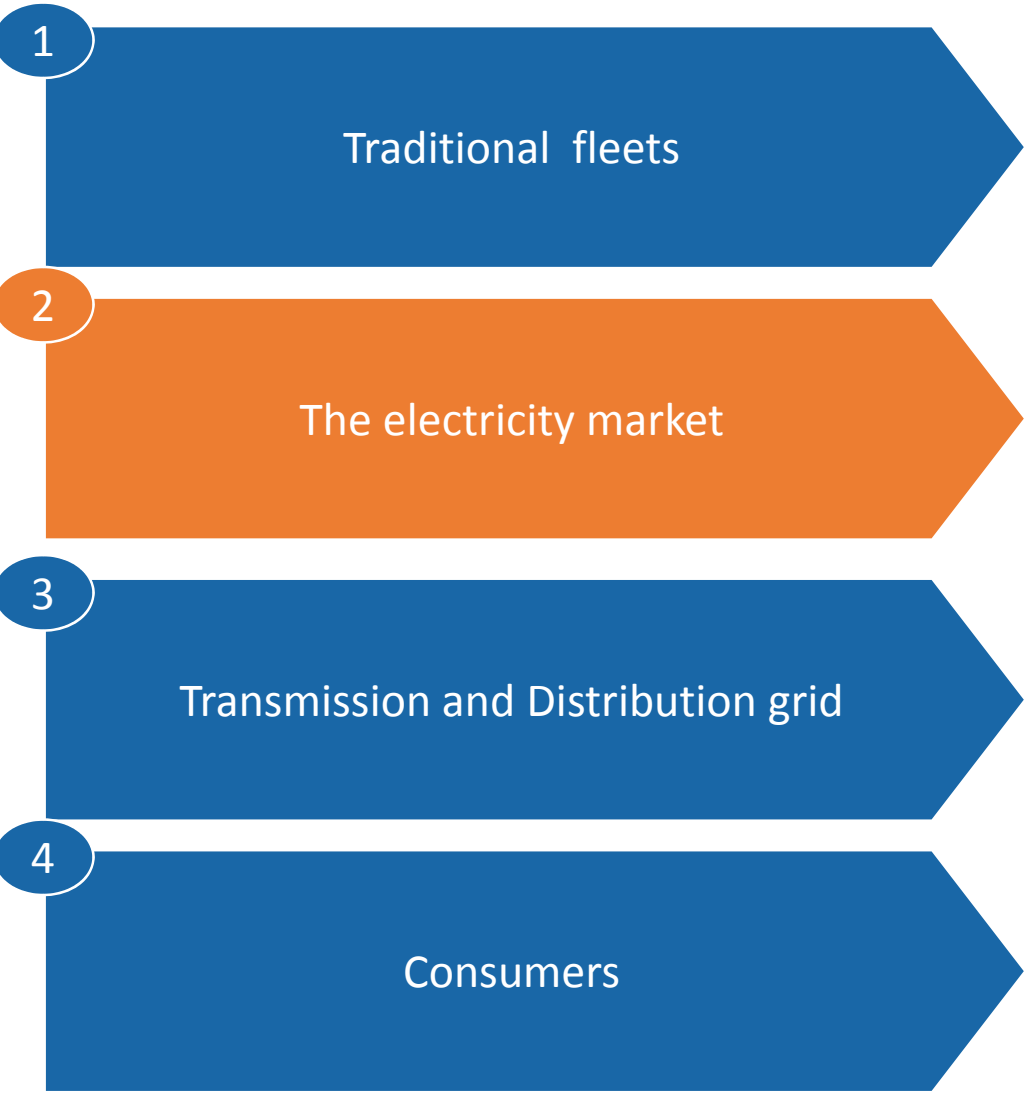
1. Traditional fleets
2. The electricity market
3. Transmission and Distribution grid
4. Consumers

Shrinking operating hours of CCGT plants (eg. Italy)



ource: AEEGSI

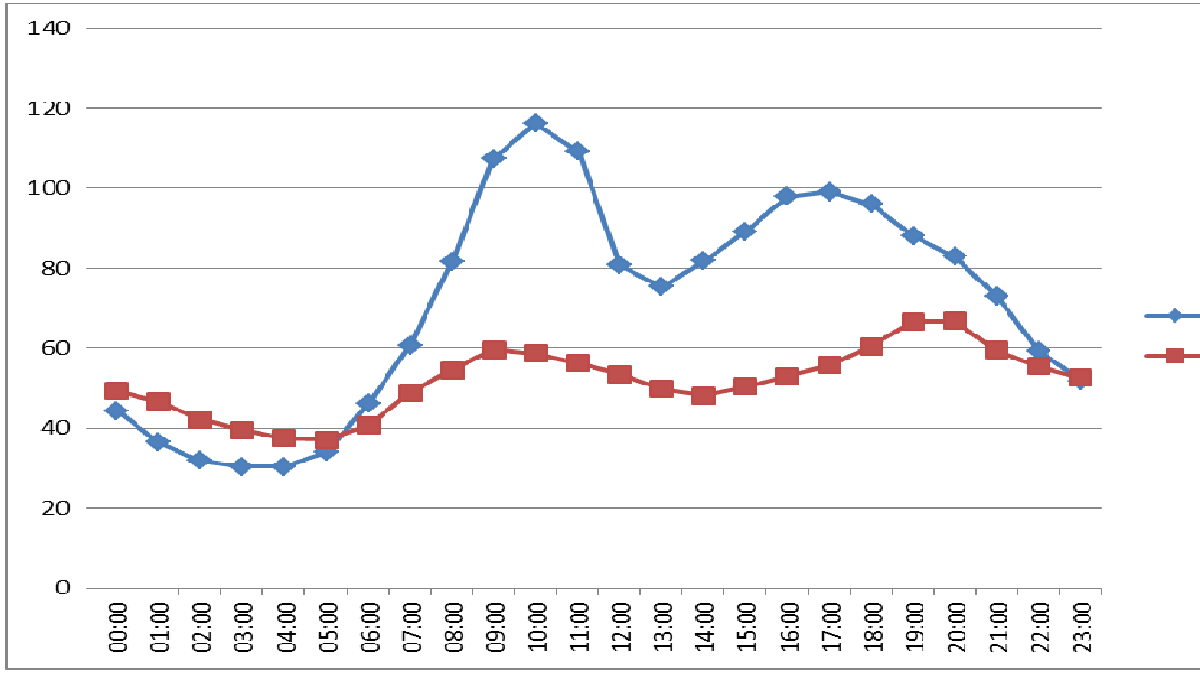
Impacts of VRES on the electrical power system



VRES has caused a drastic collapse of PUN (national average pool price) combined also with gas price reduction-
Max daily price in the evening after sunset –Italy case

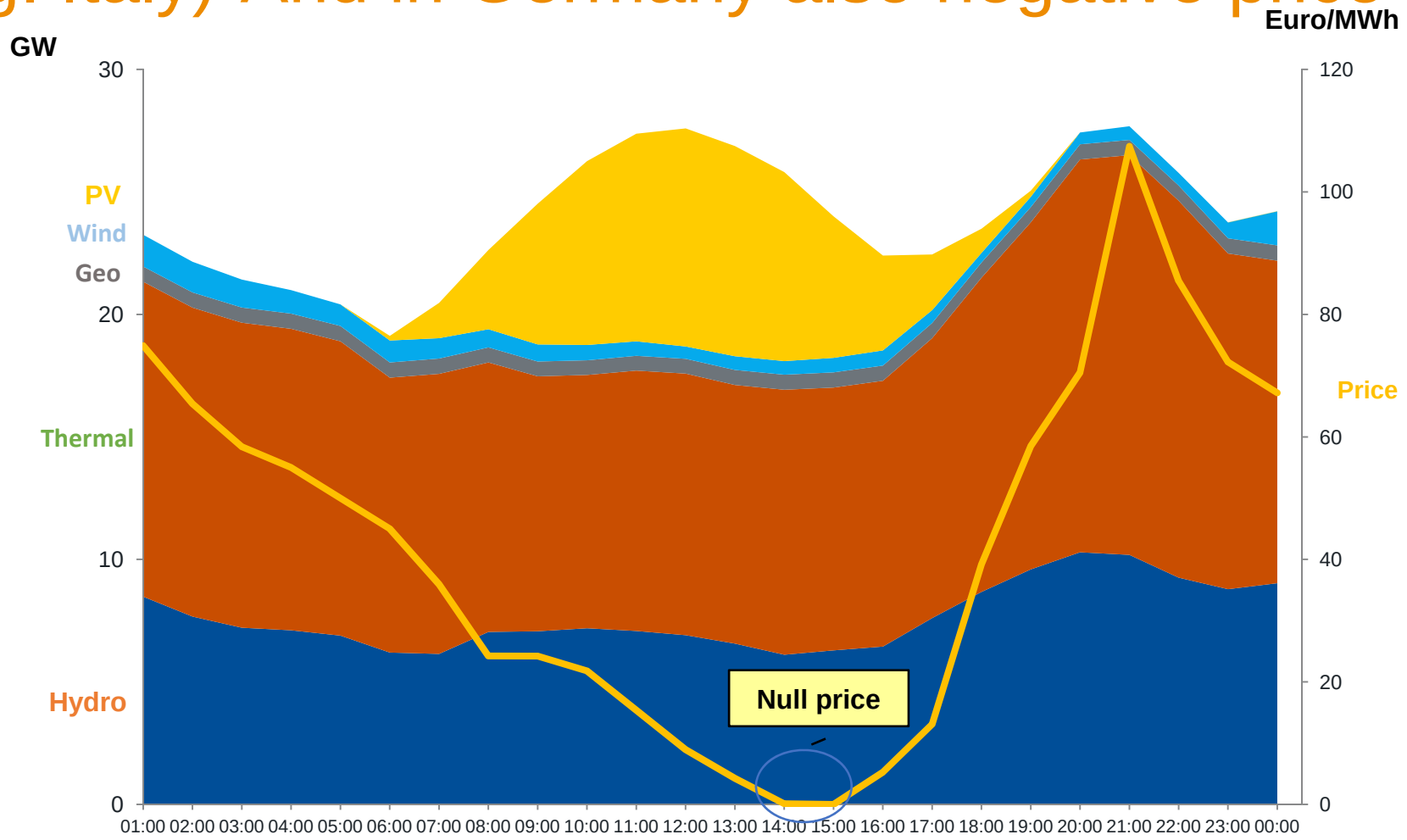
Average

Daily



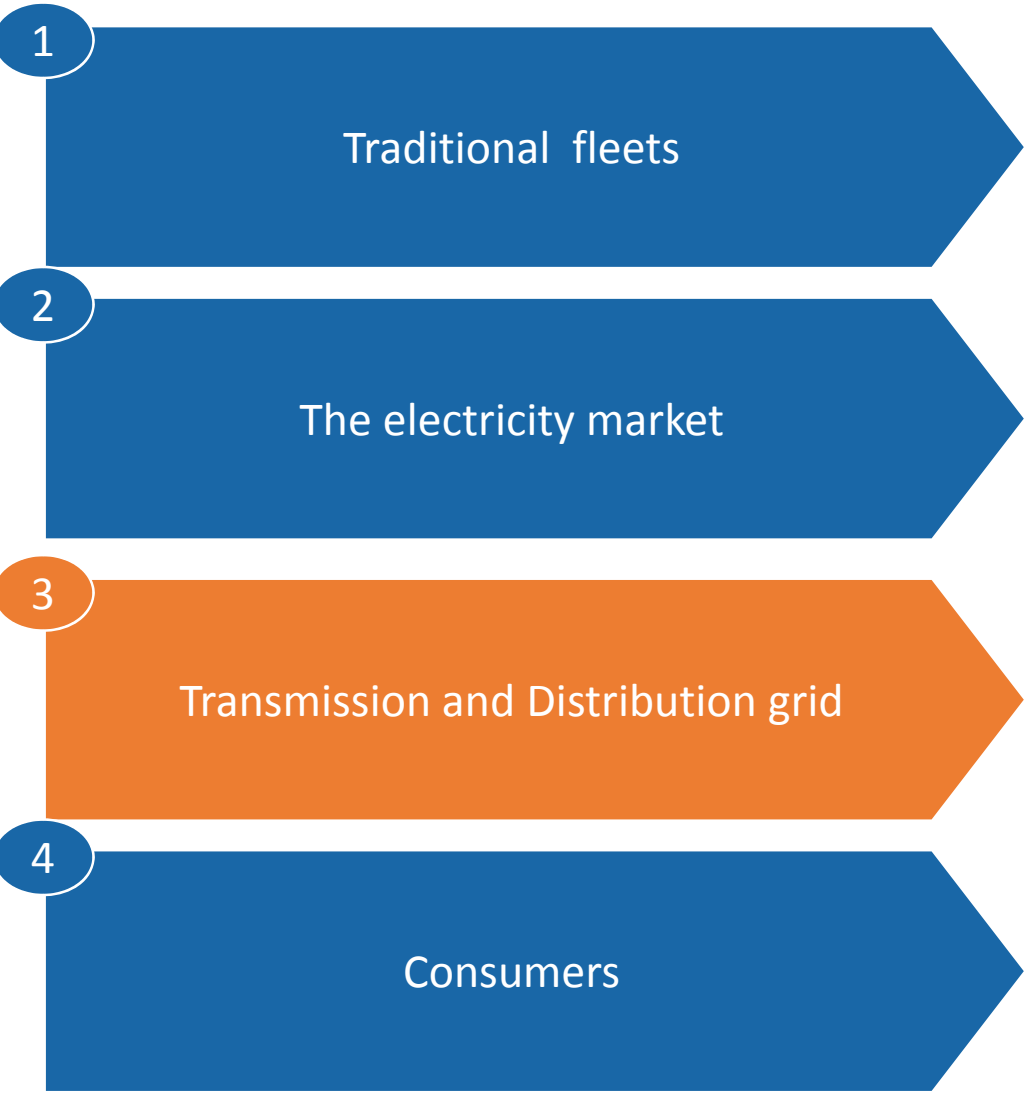
Source: GME

A null price on the day-ahead market on a sunny summer day (eg. Italy)-And in Germany also negative price



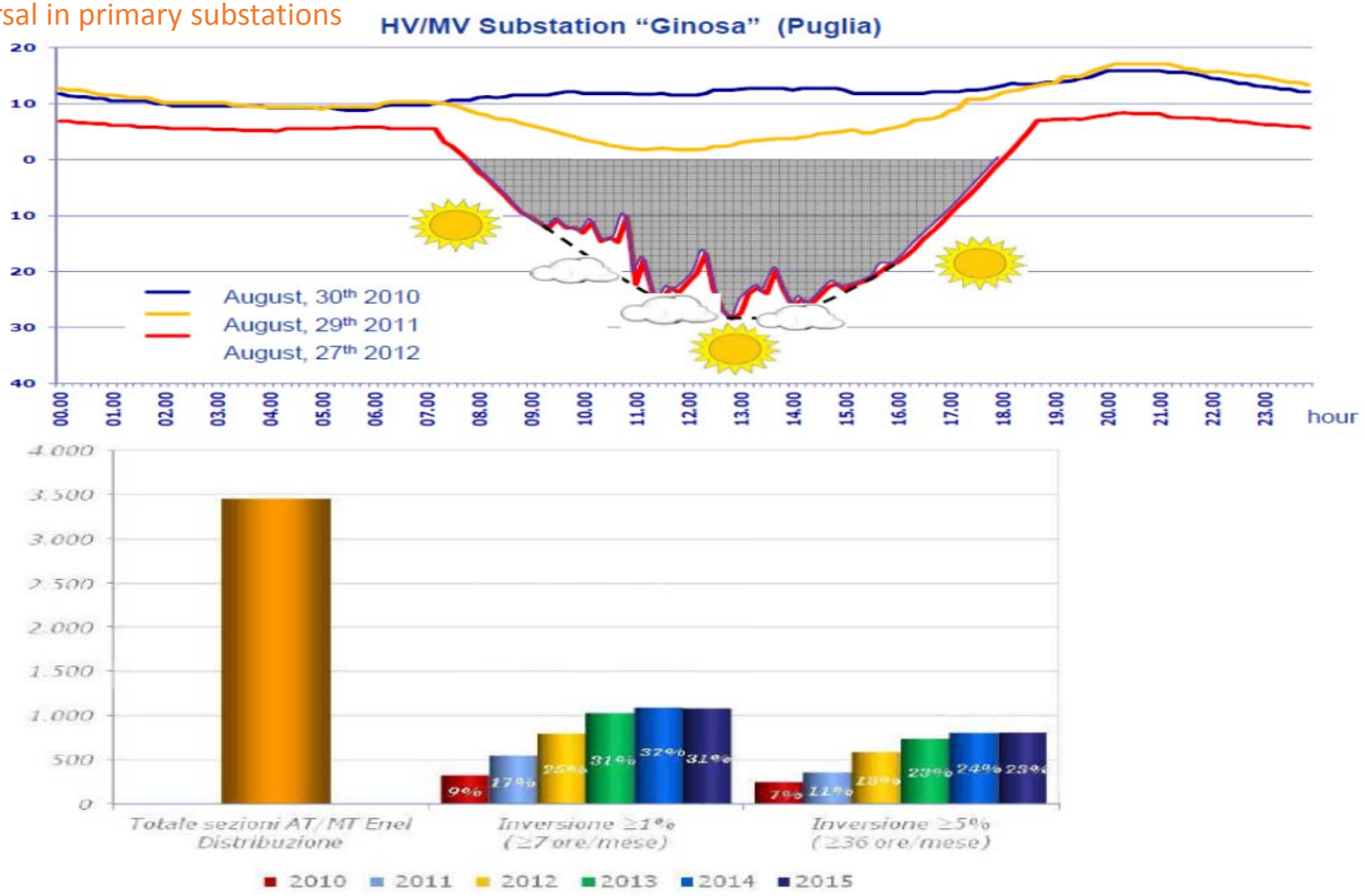
Source: Terna, GME

Impacts of VRES on the electrical power system



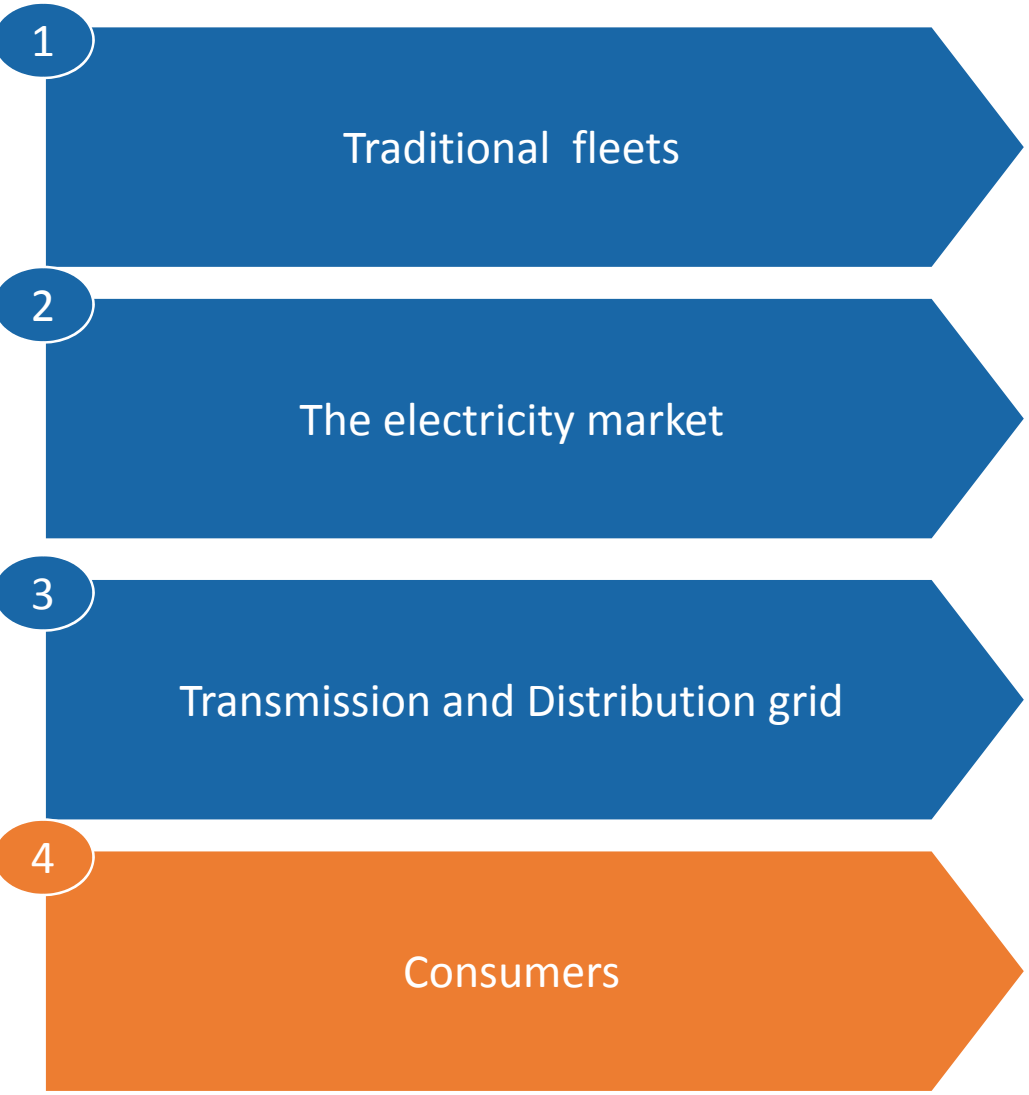
The increase in the number of primary substations with power flow inversion impacts the existing measuring and protection systems-Example of Italy

Power flow reversal in primary substations

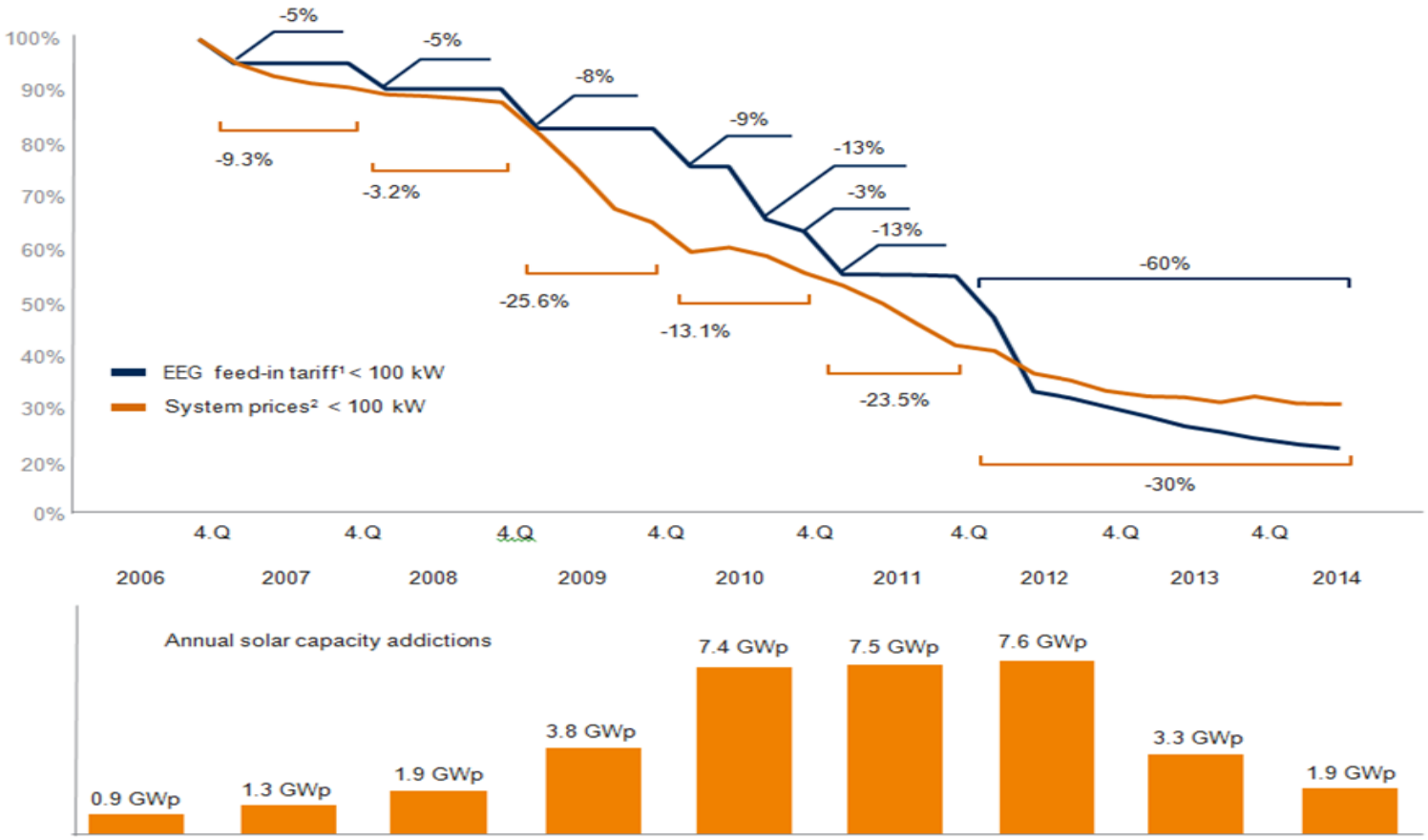


Source: ENEL Distribuzione

Impacts of VRES on the electrical power system



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



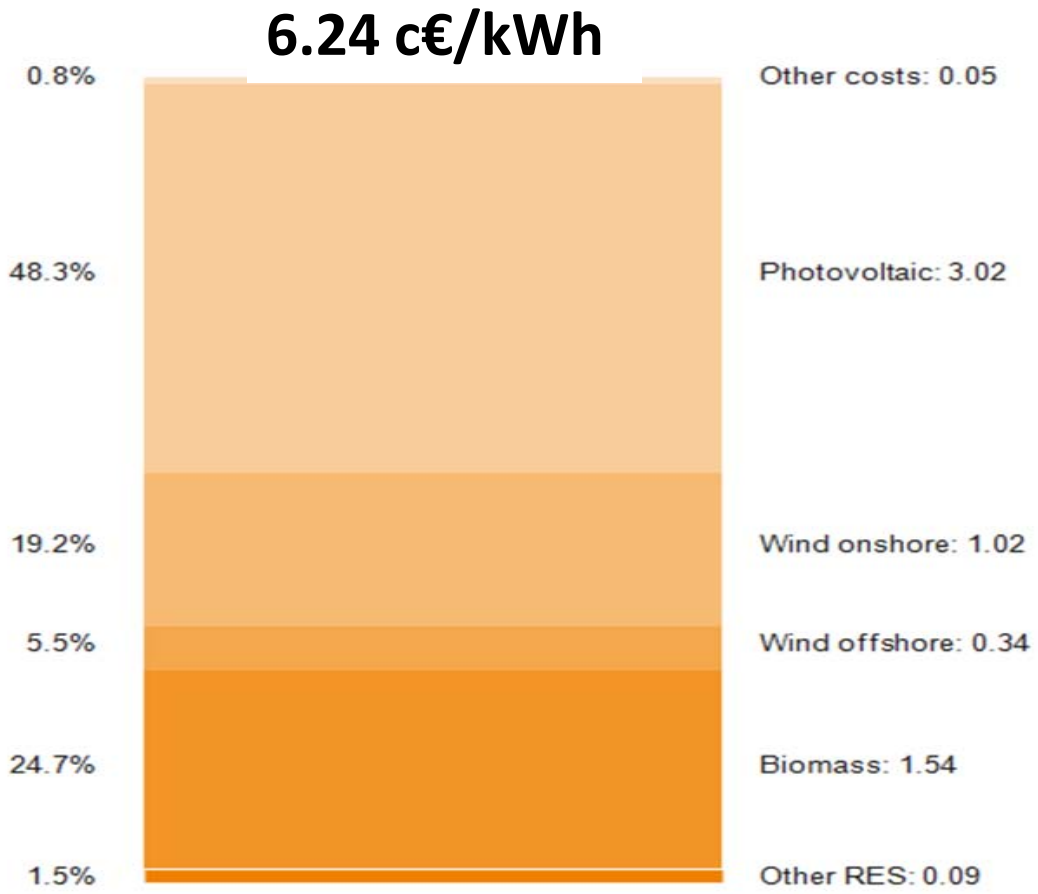
1 The EEG compensation: the compensation classes were in the second quarter 2012 brought in line with the amended EEG law. Previously until the end of the first quarter 2012, PV installations with the output of 30–100 kWp were included.

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

ource: BSW-Solar, Beta

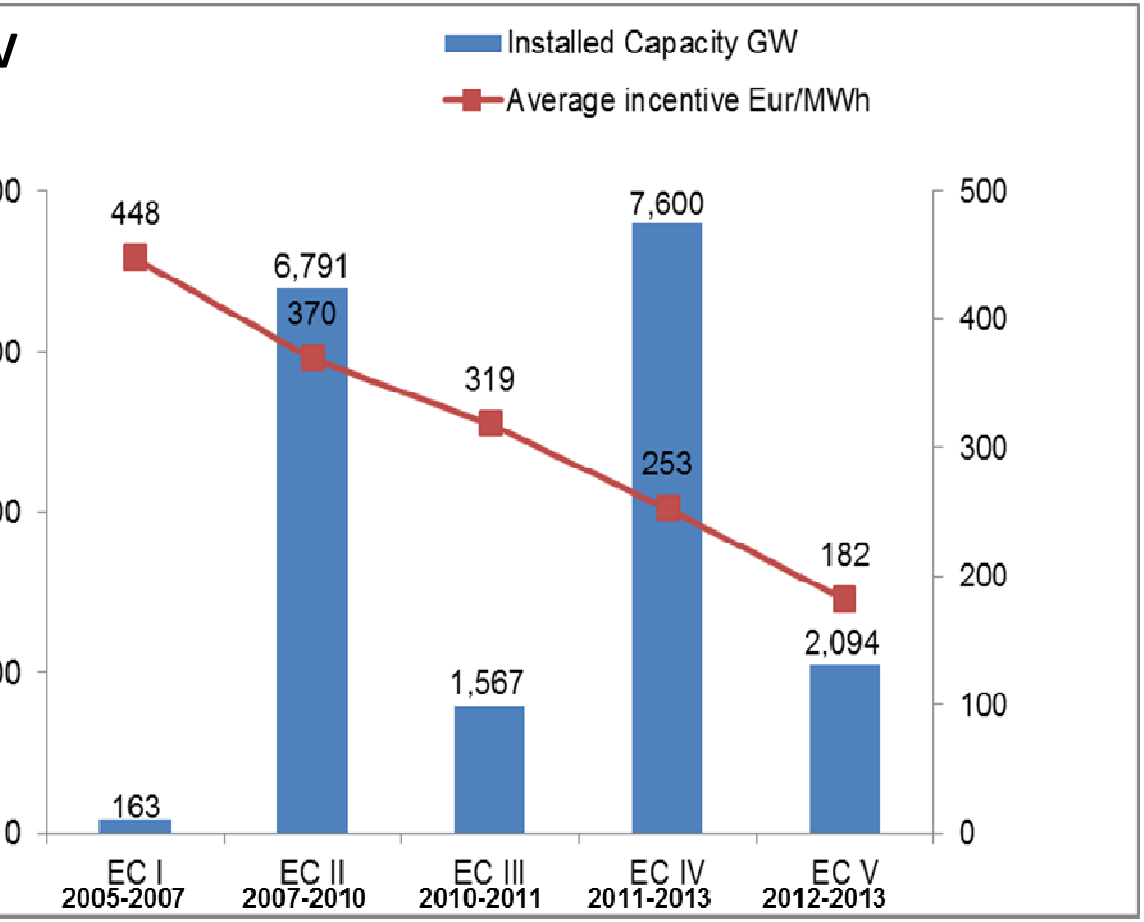
EEG-levy 2014 is ca. 6.24 c€/kWh (eg. Germany)

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.

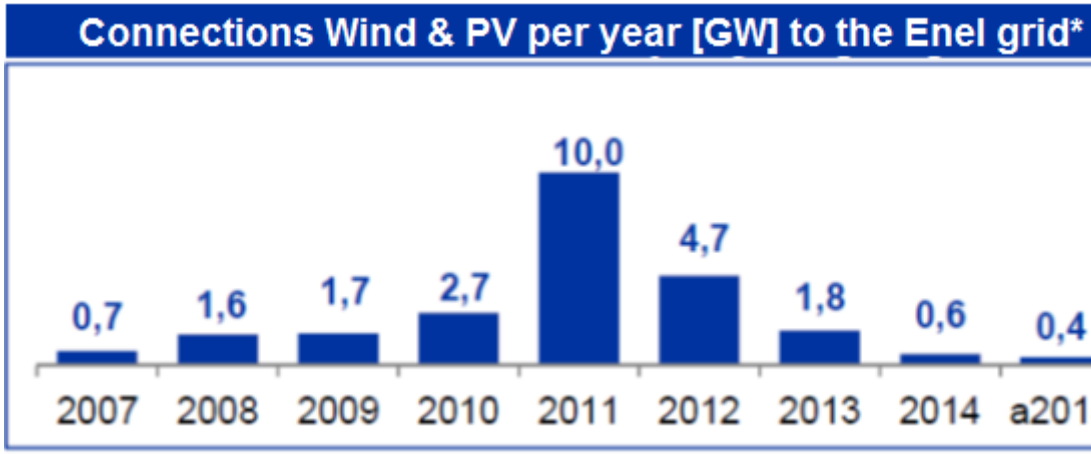


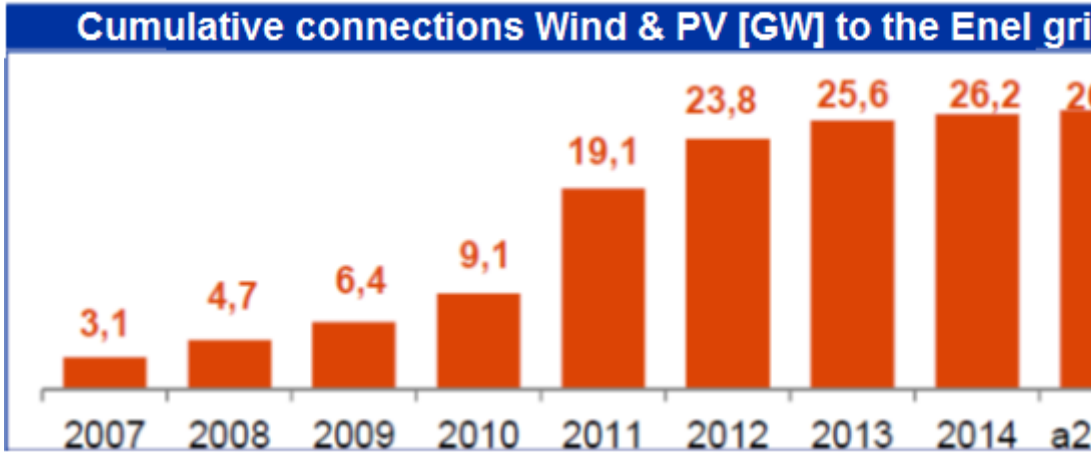
ource: BDEW

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



ource: BDEW





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

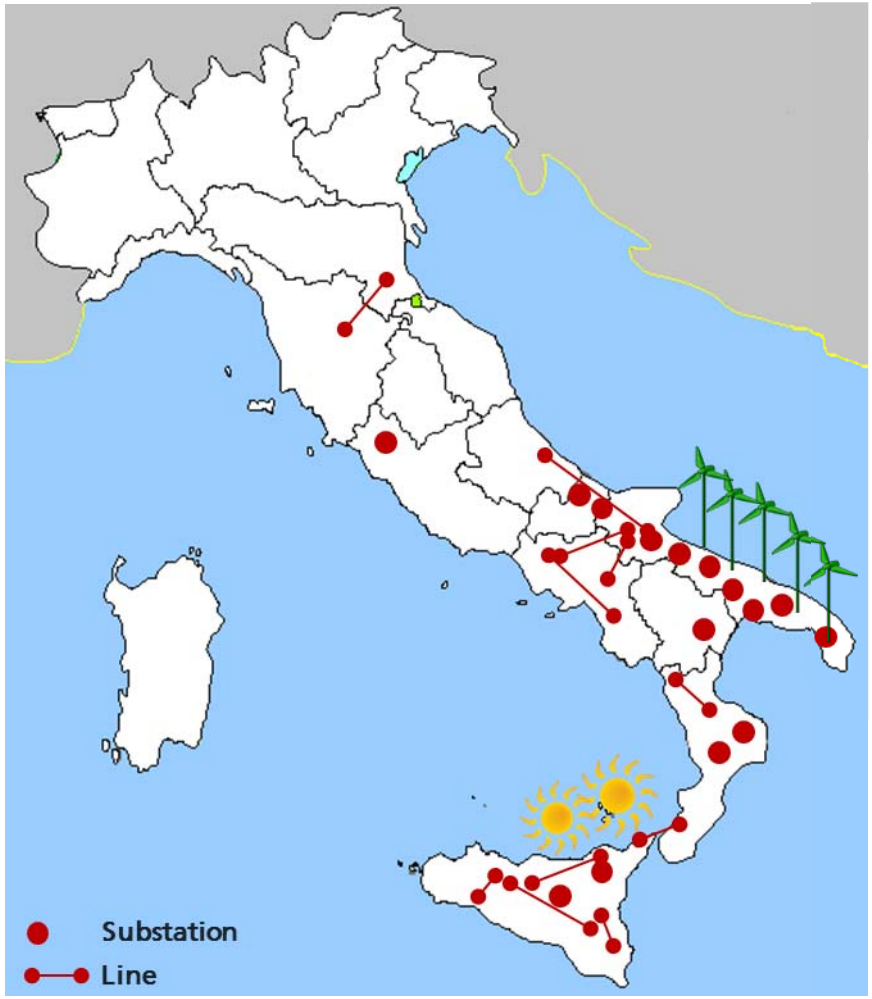
Measures for a smoother VRES integration

- 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 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

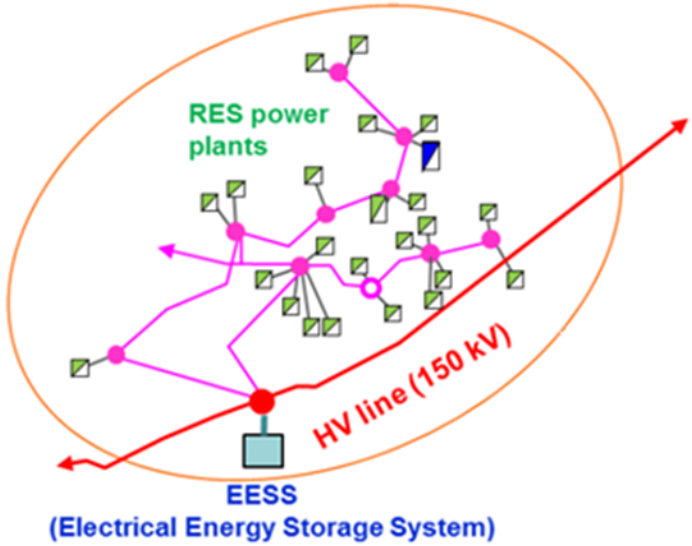
TECHNOLOGIES MARKET DESIGN

Local congestion in South of Italy calls for 8 bn Euro of investments in grid reinforcement and expansion in the next decade



Source: Terna

Local generation exceeds sub-transmission capacity



TECHNOLOGIES MARKET DESIGN

Italian Transmission system operator storage pilot projects

Power Intensive

Scope: Safe management of the grid

Total Capacity: 40 MW

Number of Sites: (Phase I) : 2

Phase I: 16 MW Storage Lab

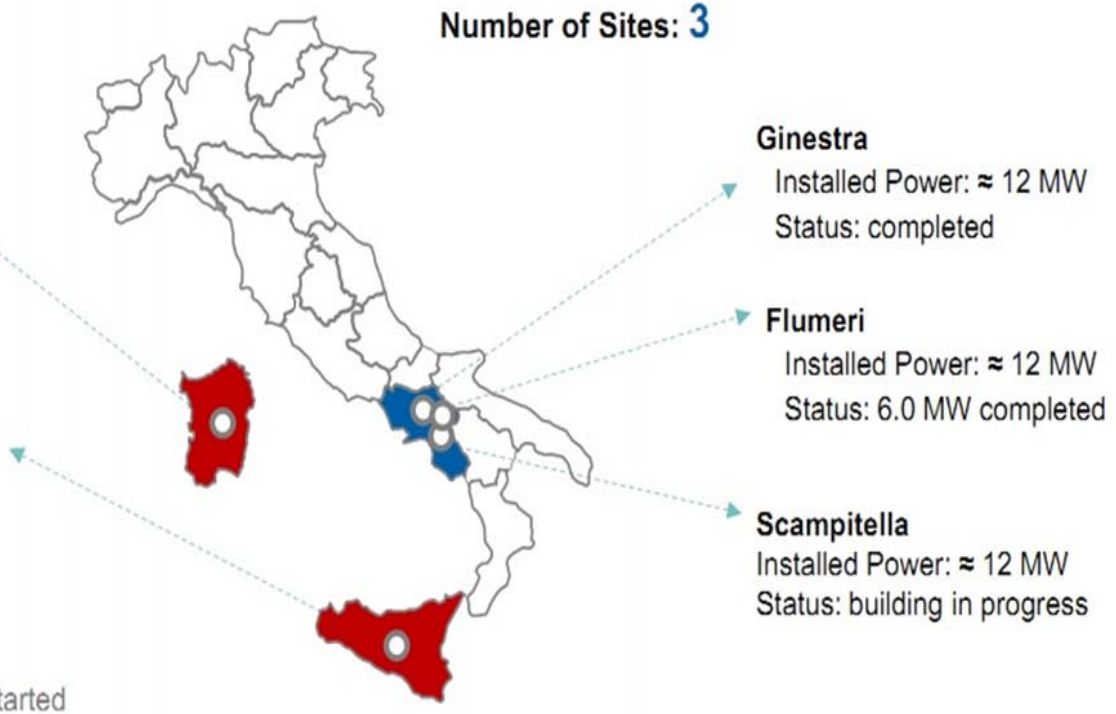
Codrongianos
Installed Power: ≈ 8 MW
Status: 5.4 MW completed

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

LESSON LEARNED [1/2]

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 VRES pose challenges to their extensive development-DSO's, TSO's and owners of power plants succeeded to manage electrical systems with no impact on their reliability even in presence of high % of VRES.

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(e.g. some EU countries)

LESSON LEARNED [2/2]

The right location with high wind and solar factors and low grids connection costs for new large VRES project is a key to success

Regulatory bodies have a fundamental role in both development of VRES and typology o counter measures to smooth the impact on the power system

VRES are in any case a pathway for climate change mitigation, but also investments tha reduce dependence on imported fuel, improve air quality, increase energy access and security of supply, promote economic development, and create jobs.

VRES 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

Further information

ownload the free report from the Council's website:
ttps://www.worldenergy.org/publications/

Thank you