Non-programmable RES and their impacts on power systems: the Italian case

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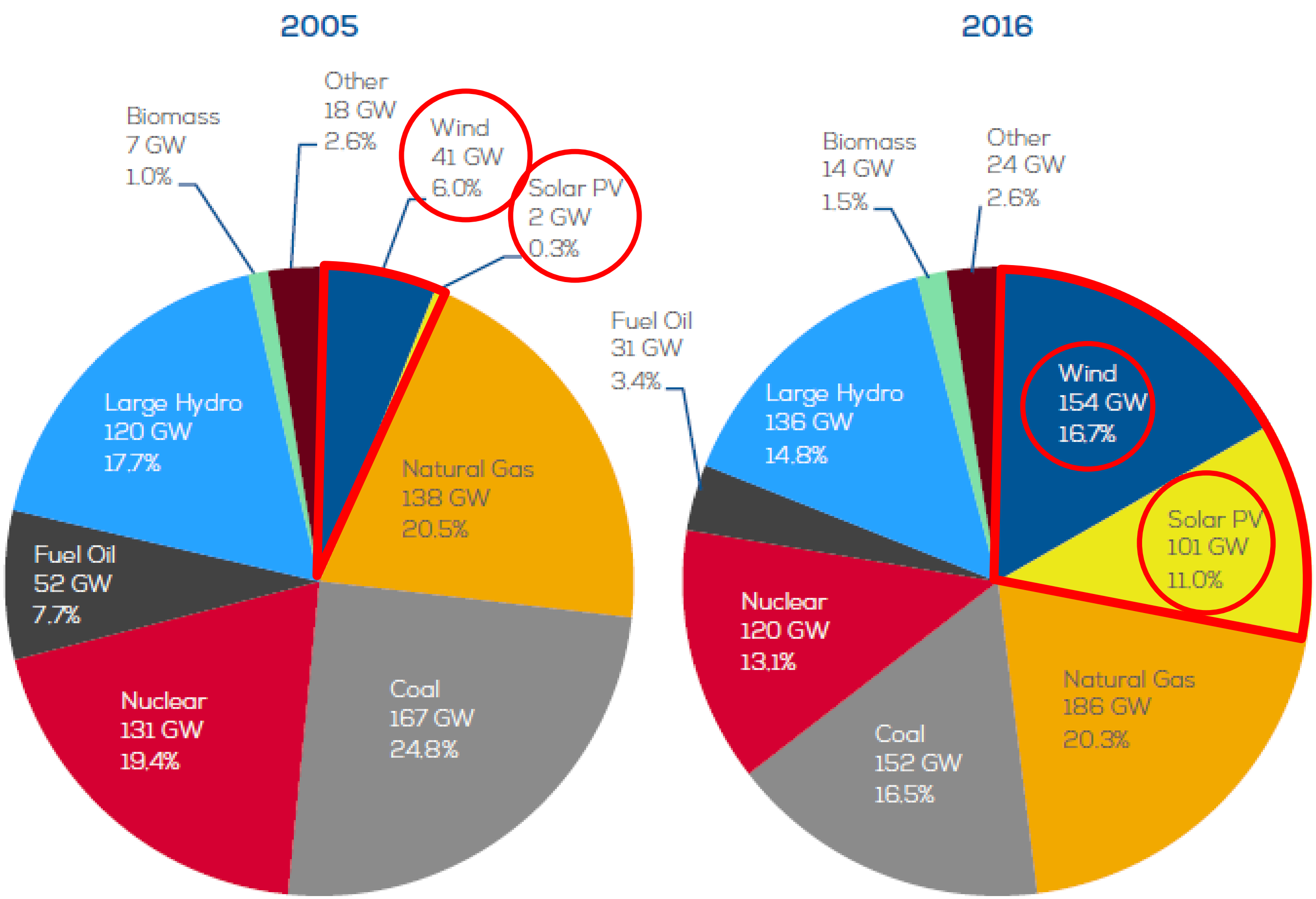
Share of installed capacity in EU (2005 – 2016)

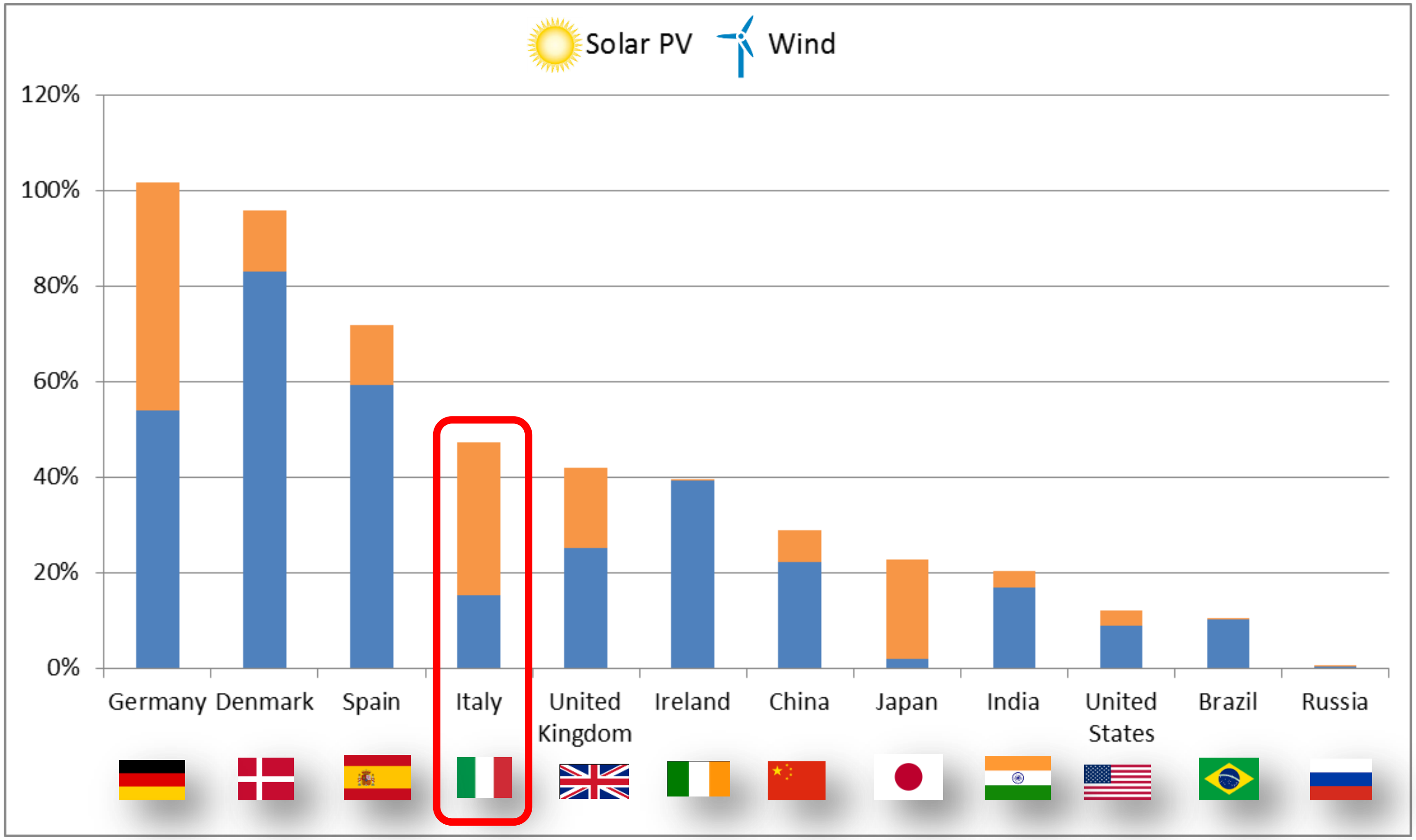
- **Wind** is now the **2nd largest** power generating capacity in the EU
- **Solar PV** exceeded **100 GW** installed capacity



Source: WindEurope, 2017

VRES penetration – capacity as a percent of peak demand

Variable Renewable can cover up to 50% of the Italian demand



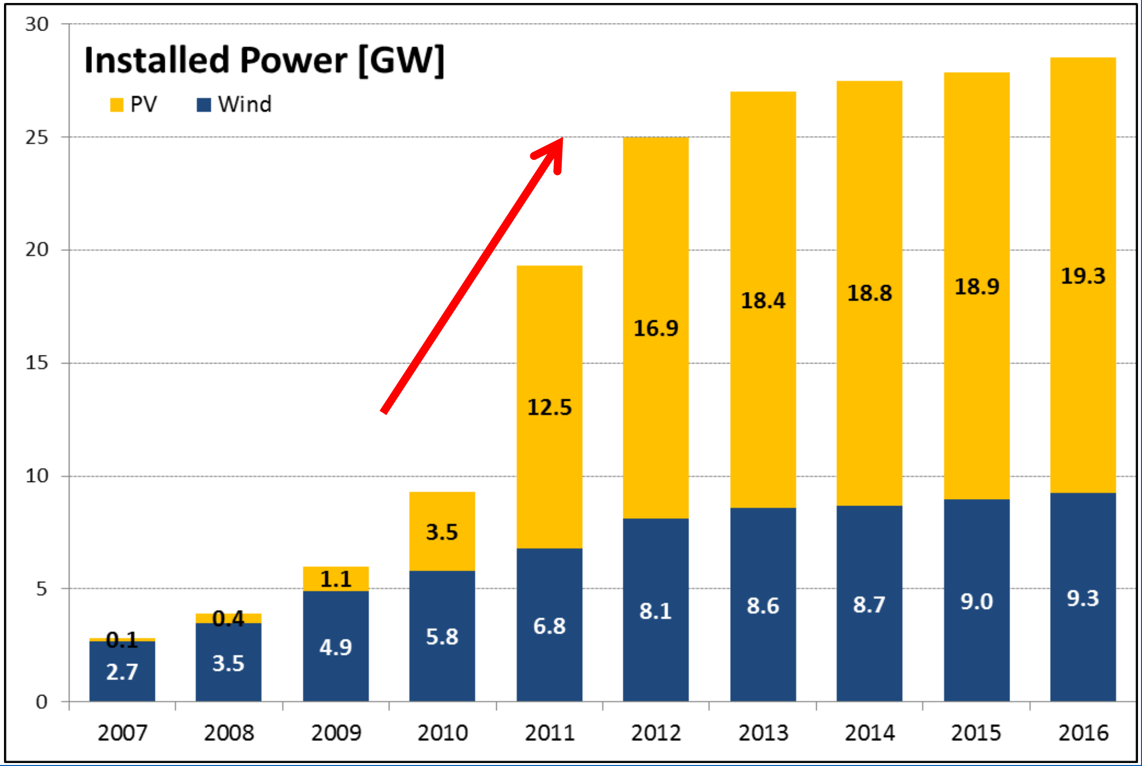
Source: WEC RES System integration KN, 2015

Evolution of VRES in the last 10 years in Italy

Significant growth of VRES in the last 10 years

- Wind around 9 GW, Solar (PV) around 19 GW (end 2016)
- Significant increase over 2 years (270% from 2010 to 2012)
- Large part of VRES (95% of PV and 5% of wind) is connected to the distribution network

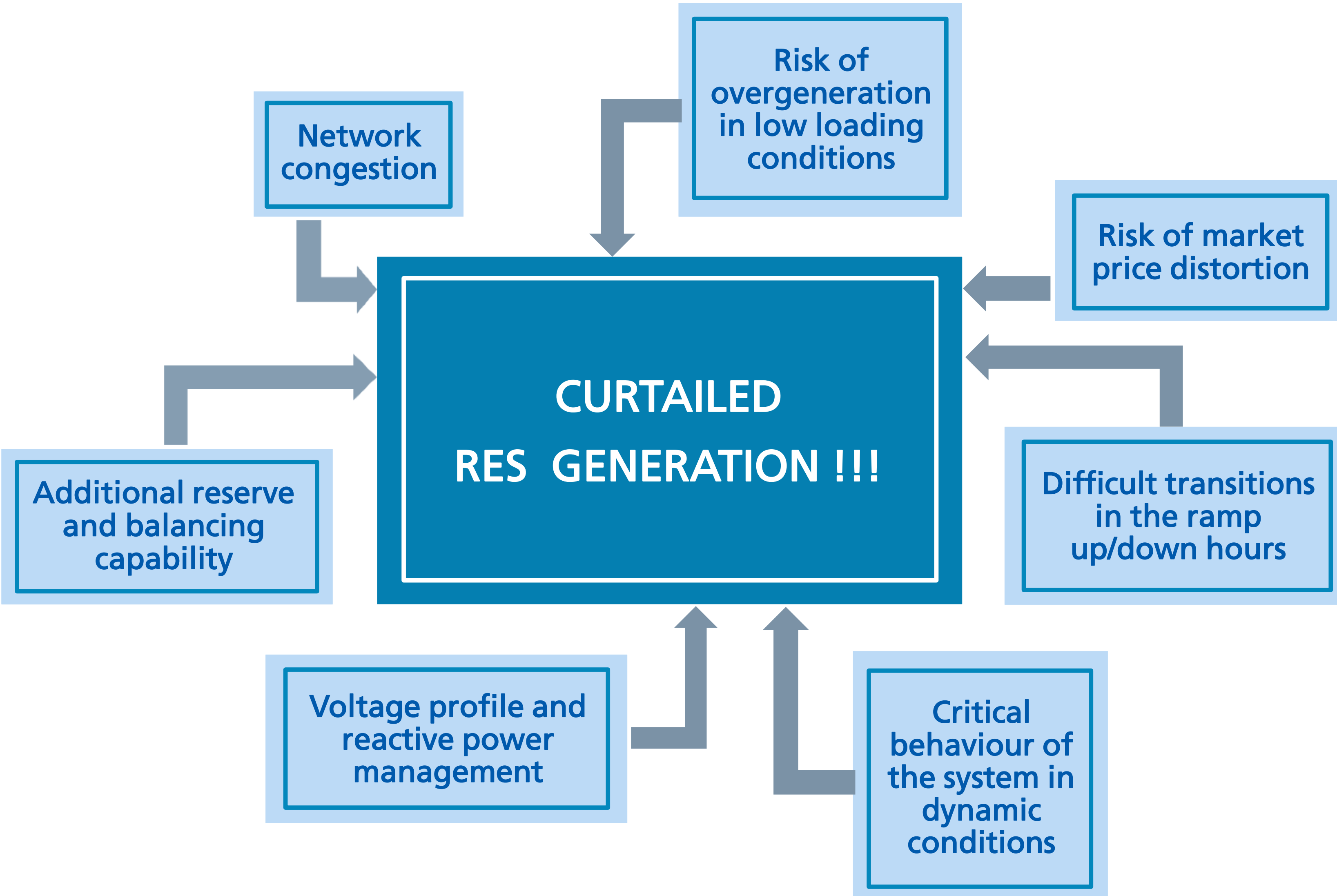
Current Status	
Total installed generation capacity	118.4 GW
Total VRES generation capacity	28.0 GW
Peak load	59.4 GW
Minimum load	18.6 GW
Electricity production	270.7 TWh
Electricity net import	46.3 TWh



Non-programmable RES and their impacts on power systems: the Italian case

- ❑ System wide impact
  - Barriers to overcome
  - Additional reserve and balancing capability
  - Difficult transitions in the ramp up/down hours
  - Impact on power market mechanisms
  - Risk of overgeneration
- ❑ Network and local impacts
  - Network congestion
  - Critical behaviour of the system in dynamic conditions
  - Voltage profile and reactive power management
- ❑ Possible solutions
- ❑ Situation in Italy
- ❑ Coping with exceptional events: solar eclipse

Barriers to overcome to enhance generation from non-programmable RES



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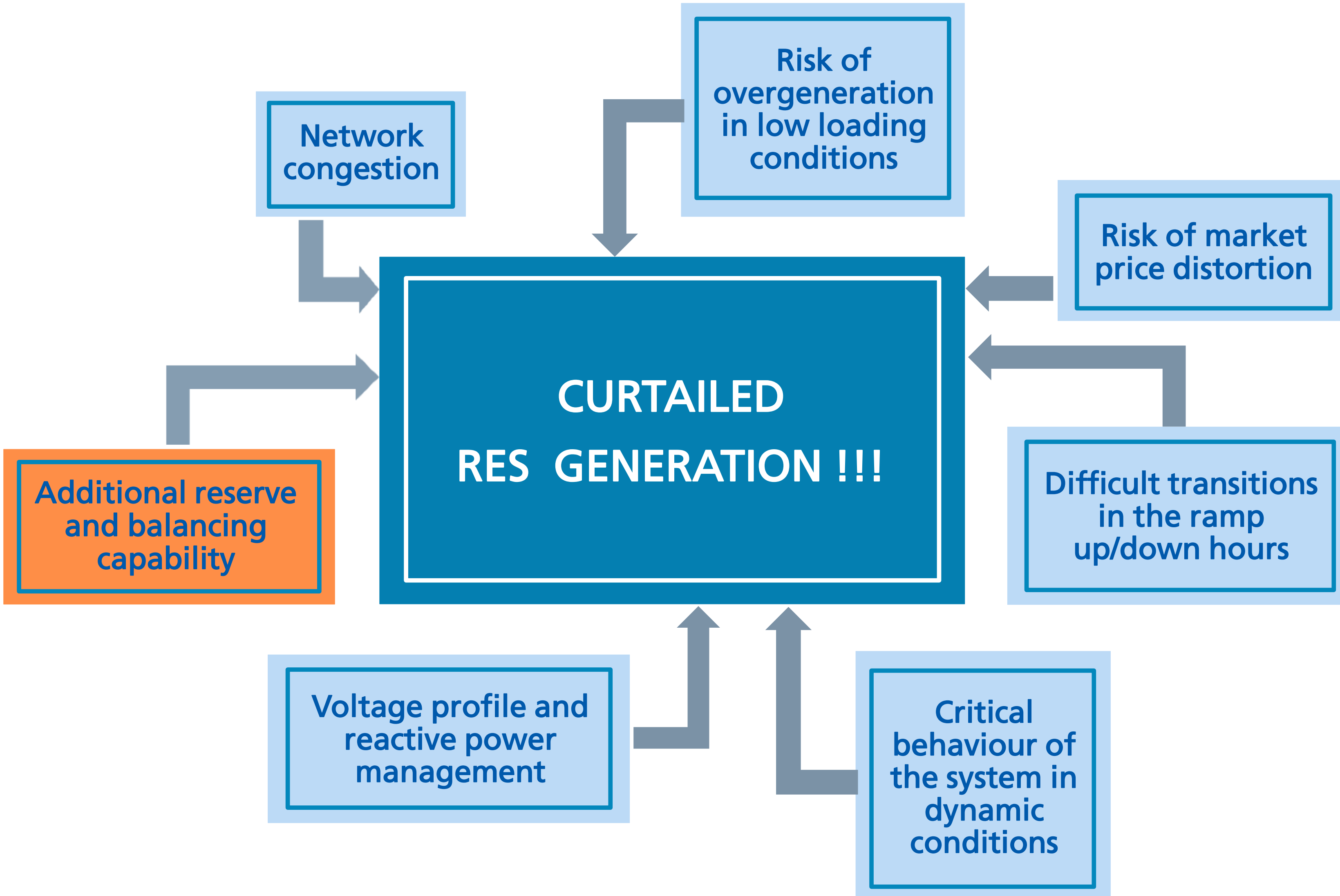
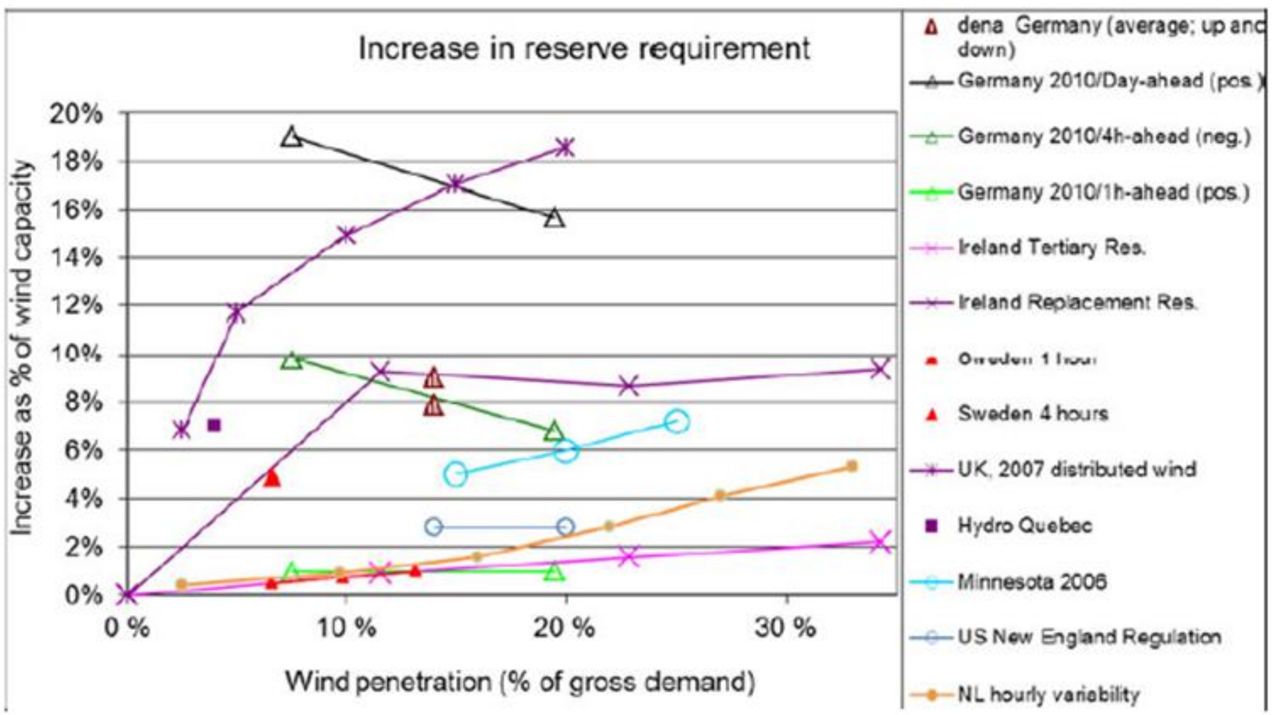


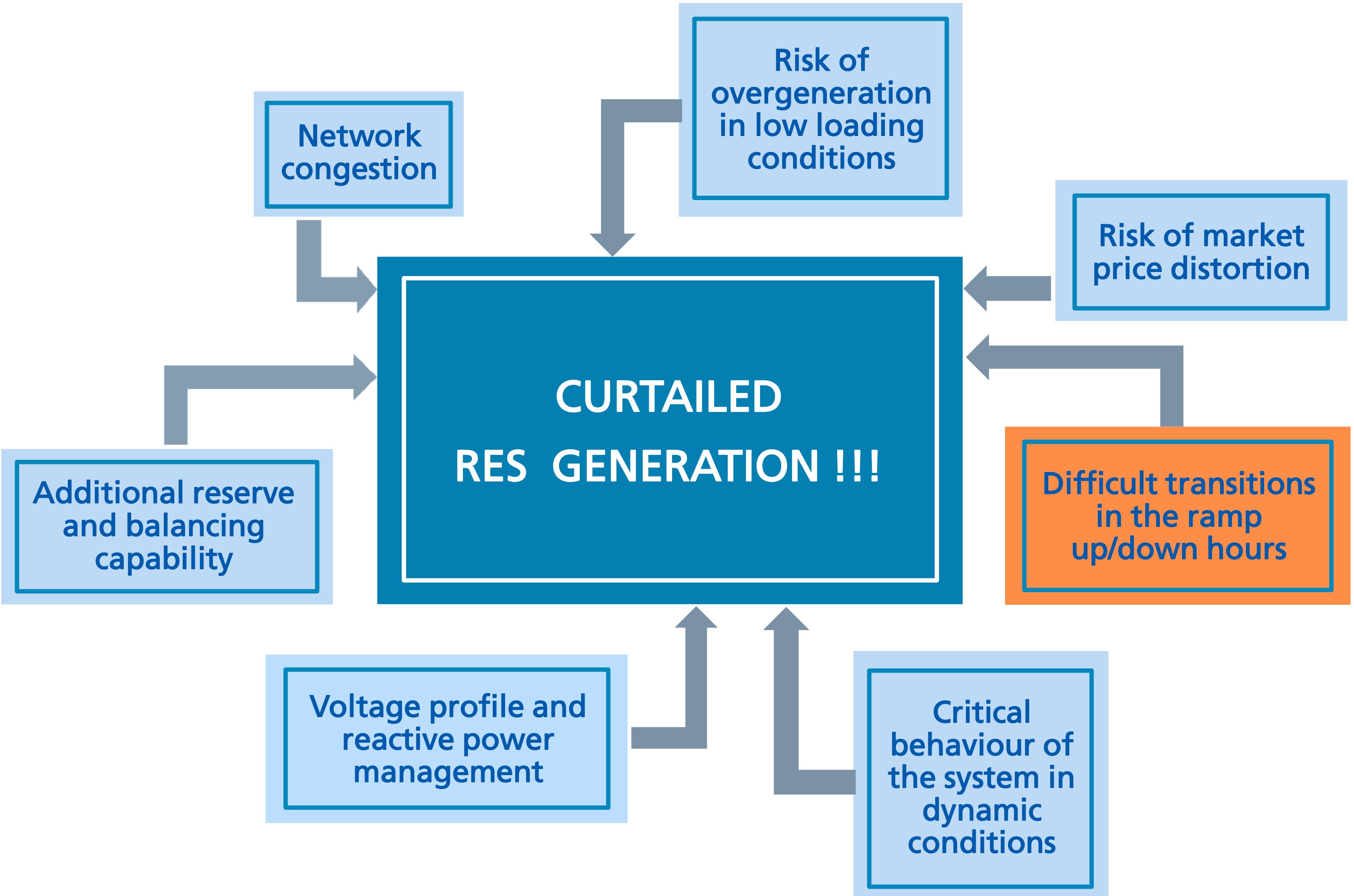
Additional Reserve and Balancing Capability

- **Need for Additional Reserve to cope with the intermittency of non-programmable RES generation**
  - Additional reserve [%]: percentage of wind generation
  - Penetration: wind production [MW] / demand



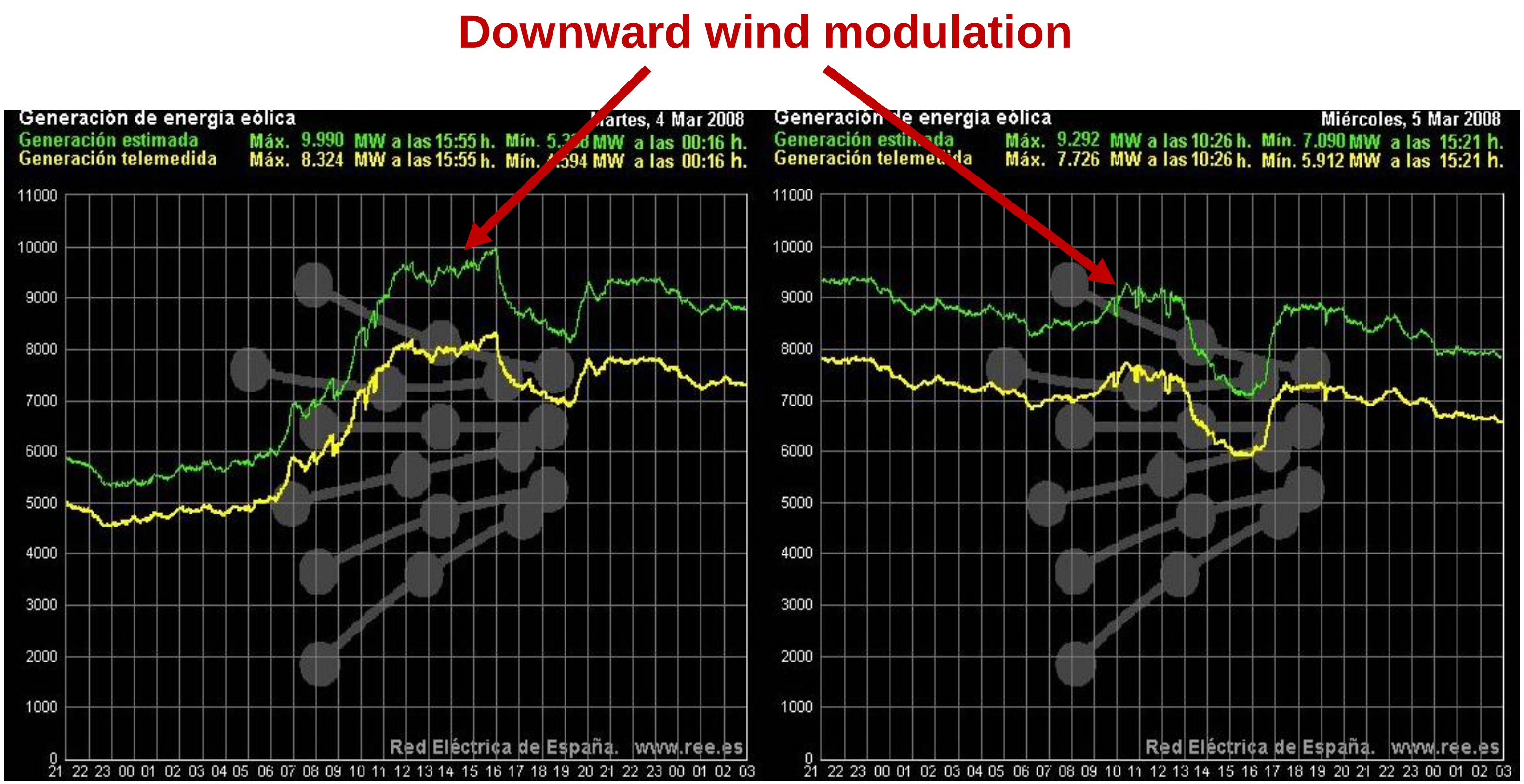
Source: IEA-Wind

Barriers to overcome to enhance generation from non-programmable RES



Difficult upward/downward transitions

- **Possible Voltage problems**

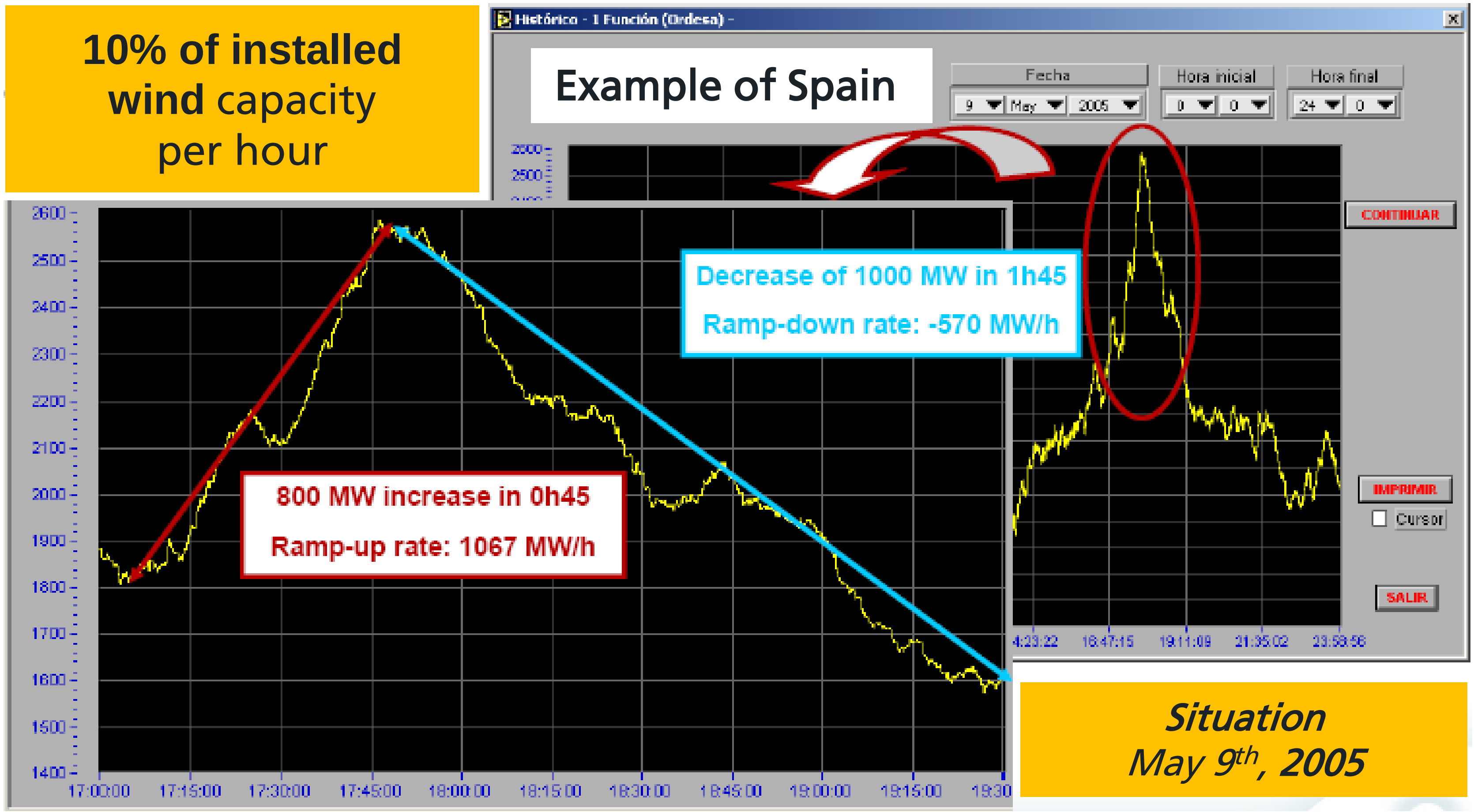


Wind generation in Spain on 4th and 5th March 2008 (source REE)

Difficult upward/downward transitions

- Coping with sharp variations of RES generation

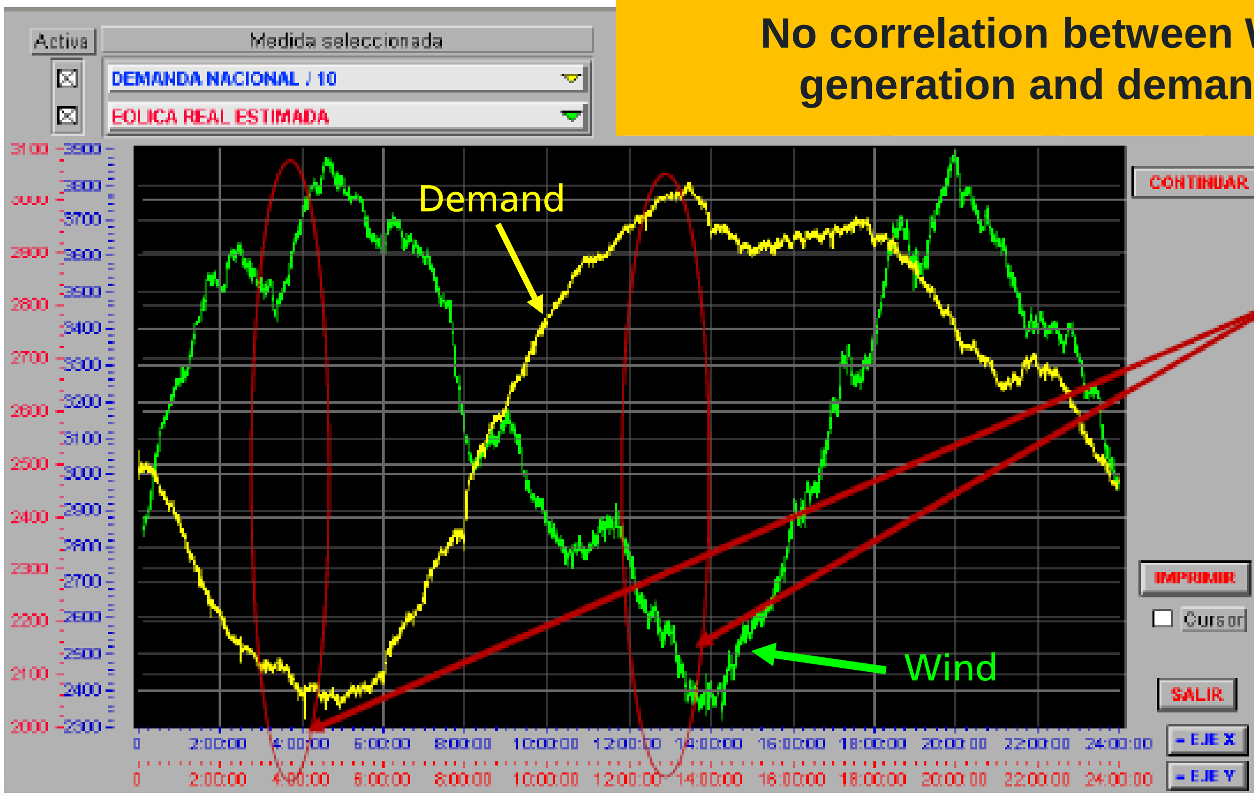
10% of installed **wind** capacity per hour



Situation
May 9th, 2005

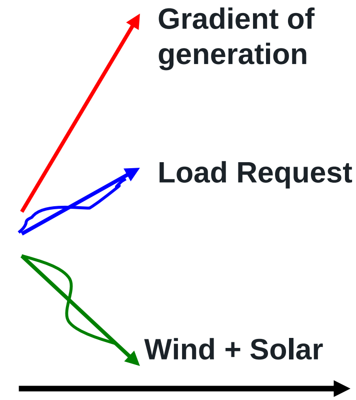
Difficult upward/downward transitions

No correlation between Wind generation and demand!!!



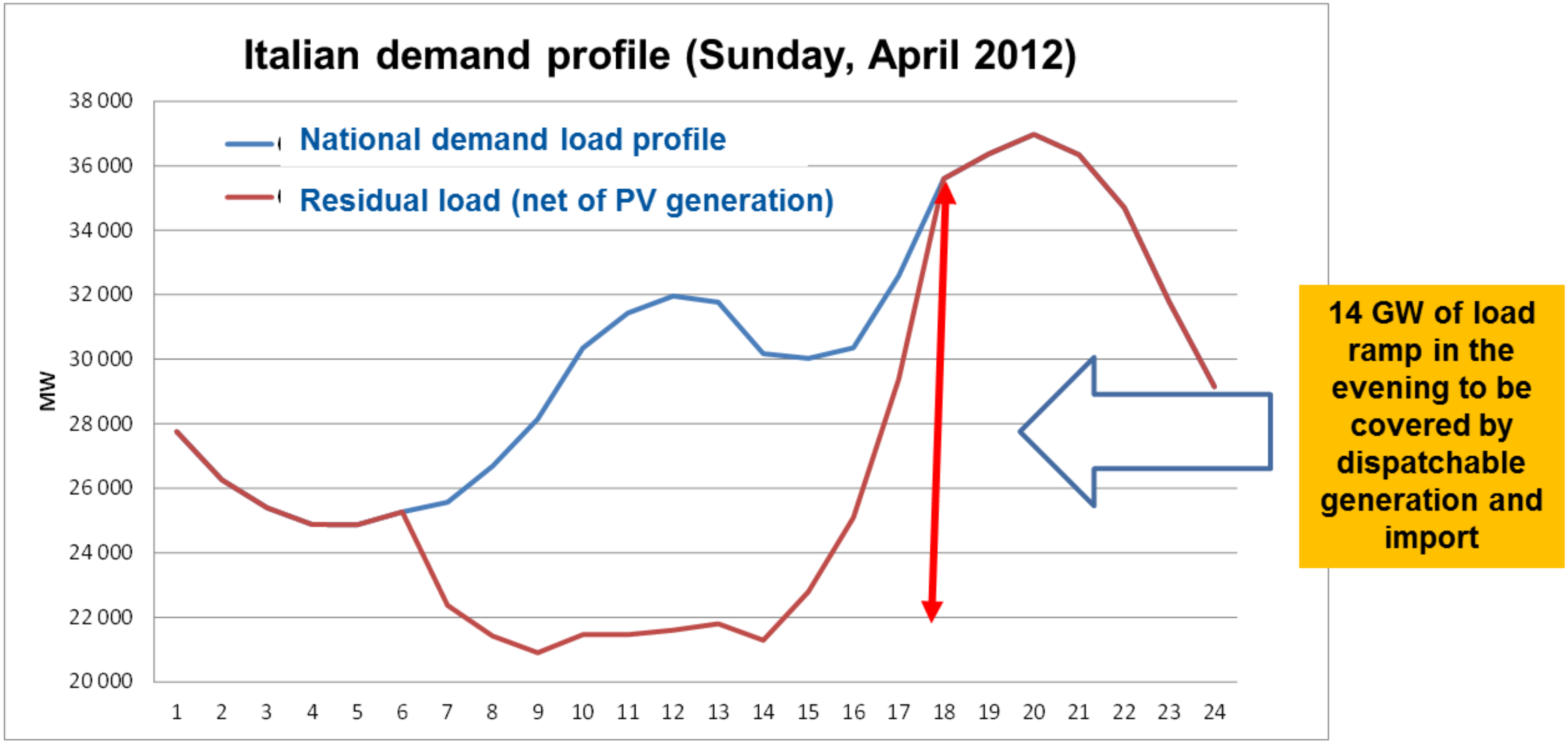
(Example of Spain)

Difficult transitions during load ramp up/down



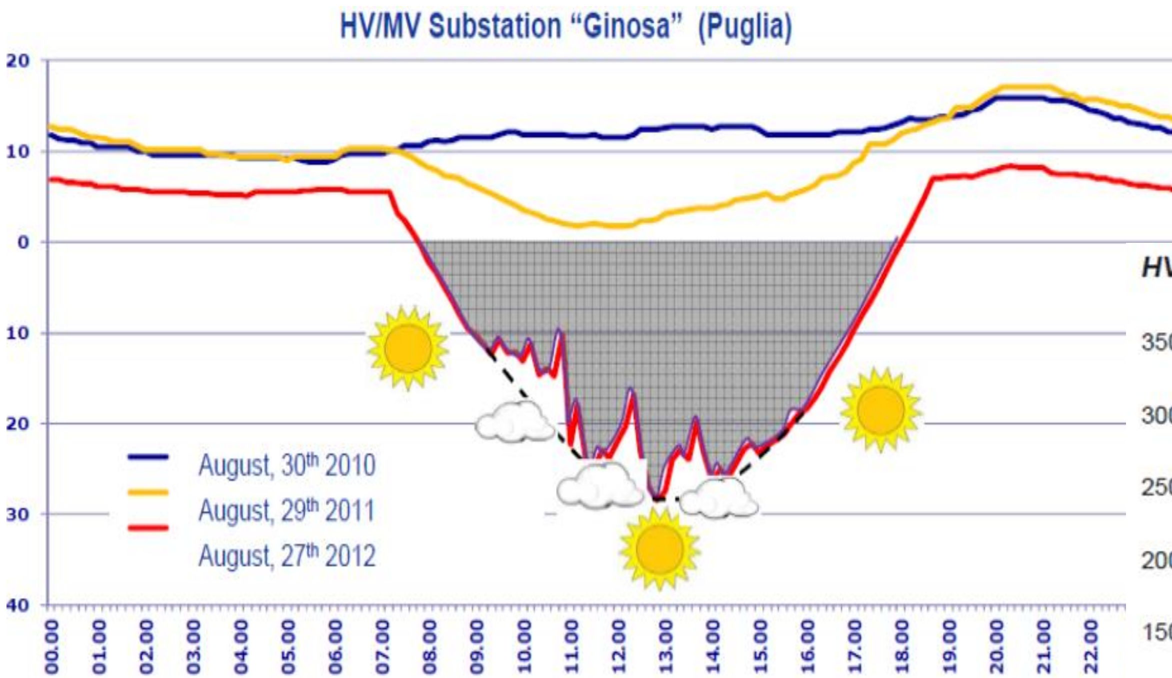
Difficult upward/downward transitions

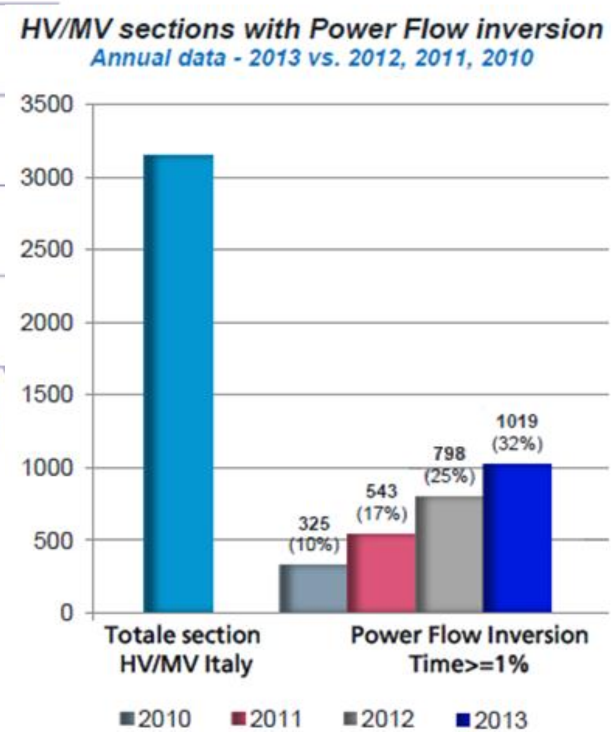
- **Load following in case of enhanced PV generation**



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

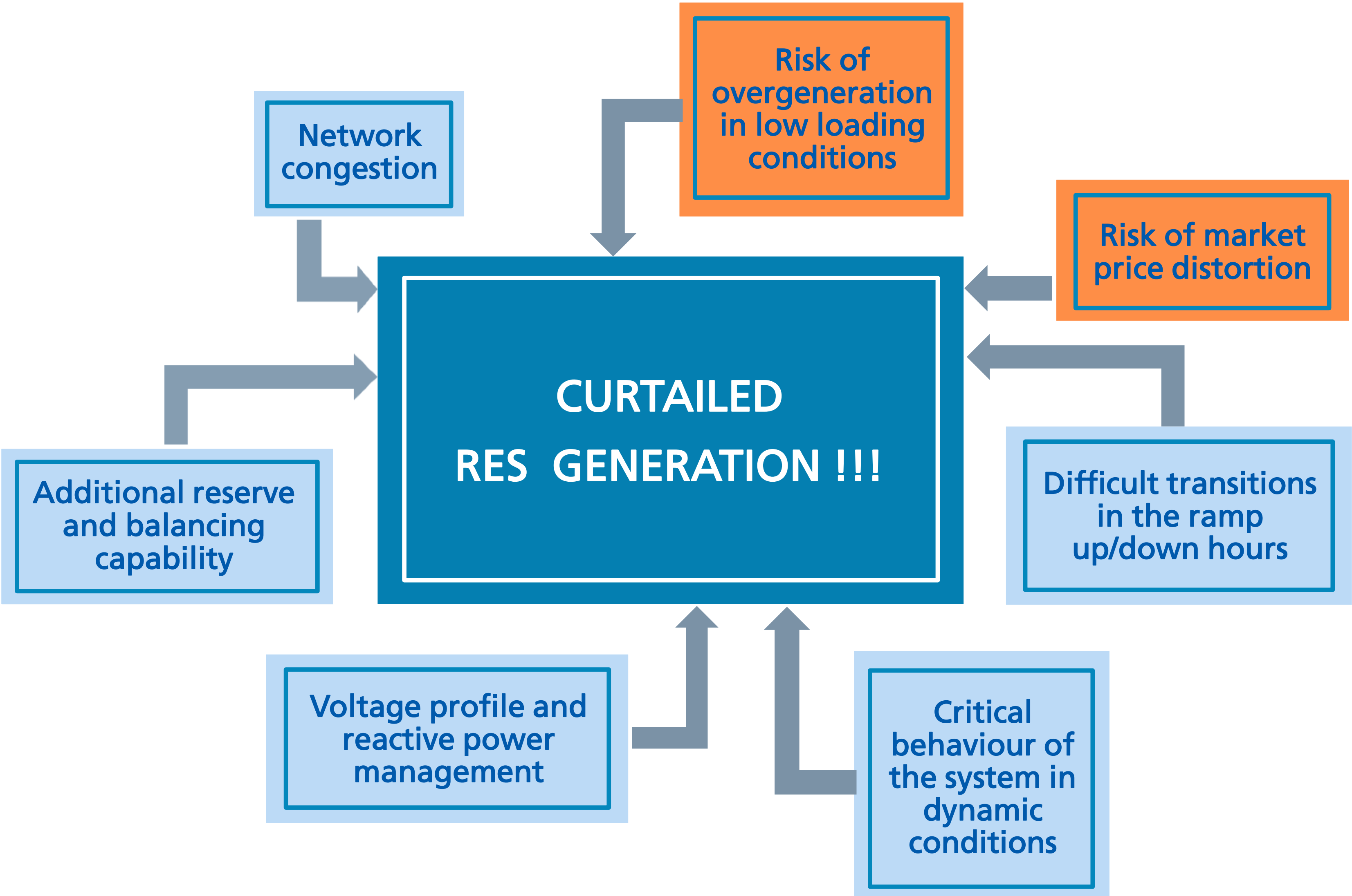
Power flow reversal in primary substations





Source: ENEL Distribuzione

Barriers to overcome to enhance generation from non-programmable RES

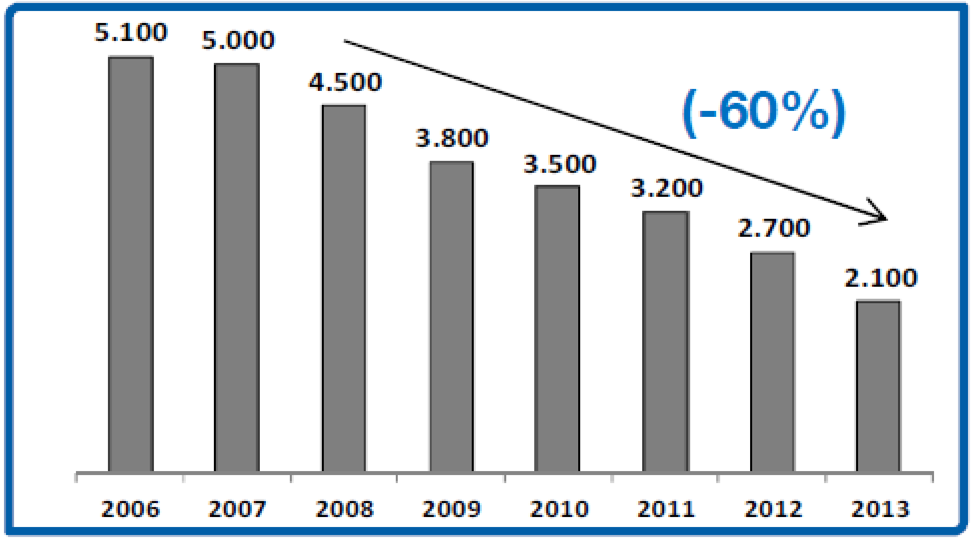


Impact on the whole system generation

- VRES cover a significant share of the system generation
- Dispatching priority for RES
- Load consumption is nearly constant

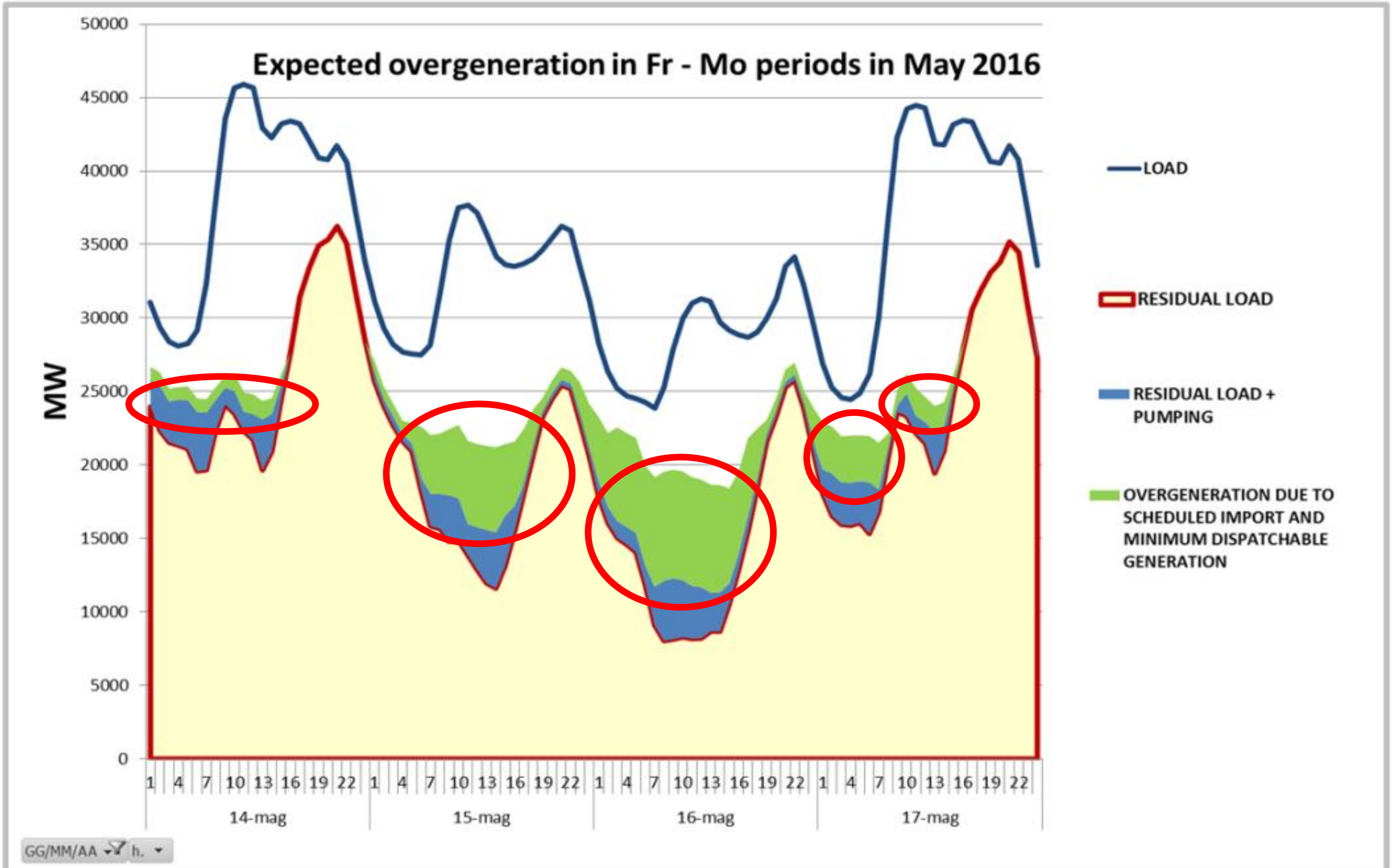
Conventional power plants were partially replaced

Italian Study Case



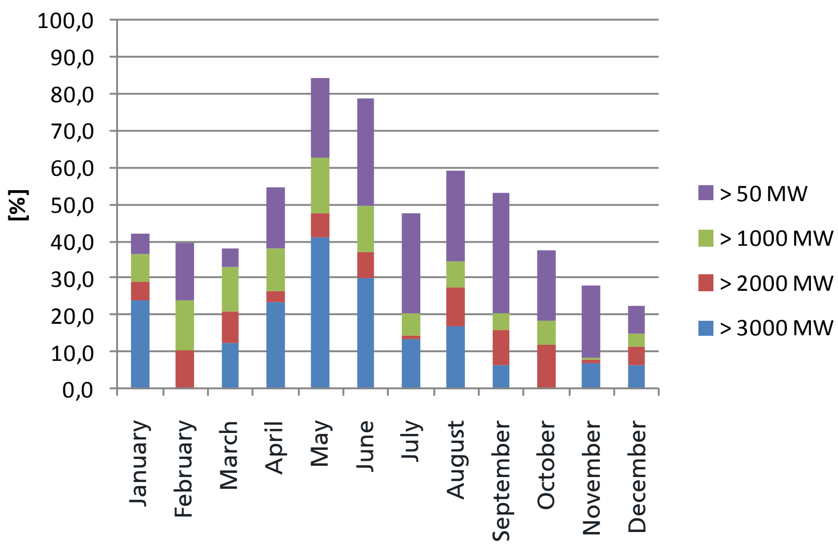
Hours reduction of CCGT

Risk of overgeneration



Risk of overgeneration
Example of Italian System

Overgeneration problems over weekends or public holidays



% of hours with overgeneration during weekends or public holydays

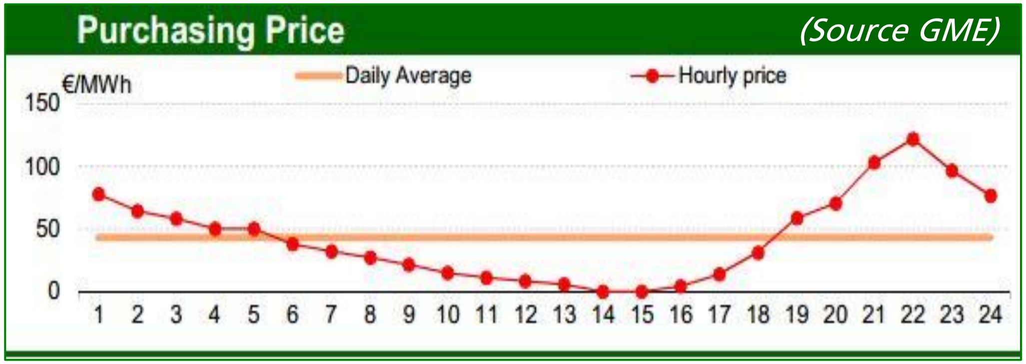
Countermeasures to reduce the risk of overgeneration:

- Full exploitation of existing resources (maximizing existing pumping, reduction of power imported from neighbouring countries)
- Modulation of non-programmable RES generation
- Improve the forecast and management of distributed generation (on-site generation)
- Increase of energy storage capacity

Impact on power market mechanisms
Example of Italian market

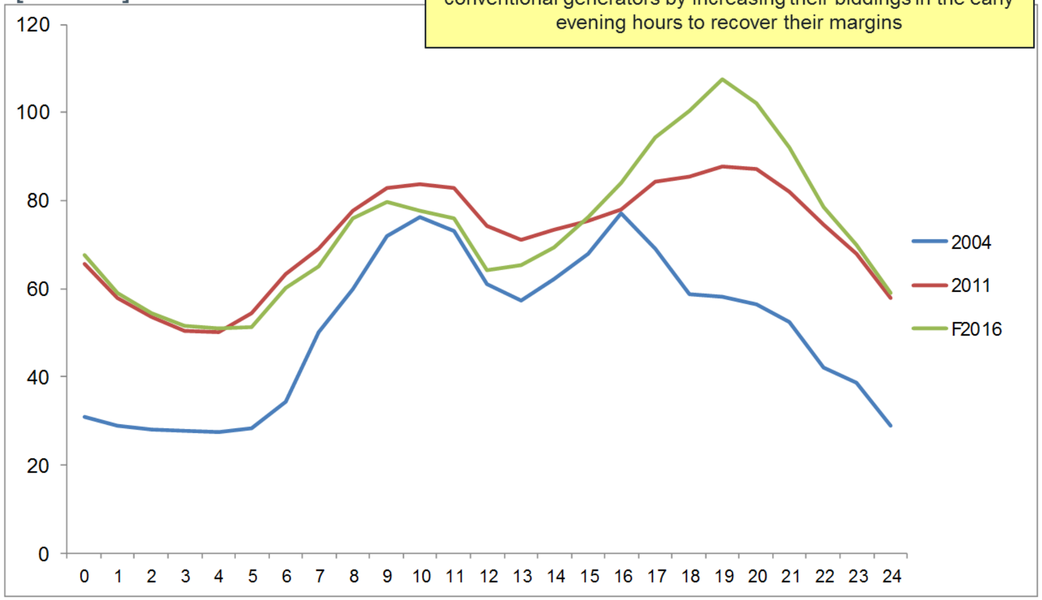
What happened in the **Italian day-ahead market** on June 16th, 2013:

- Minimum price: **0,00 €/MWh** (for 2 hours – 2:00 and 3:00 pm)
- Maximum price: 121,91 €/MWh (25.8% of offered energy supply by GSE)



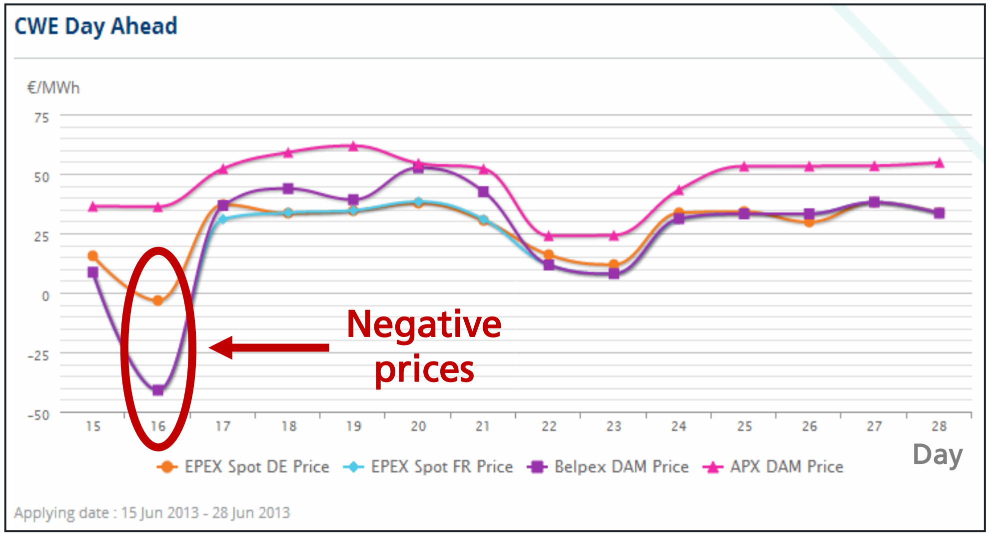
The reduction of market prices in daylight hours, caused by a massive PV generation, is compensated by owners of conventional generators by increasing their biddings in the early evening hours to recover their margins

Italian intraday price [€/MWh]



Impact on power market mechanisms
Example of Central Western European (CWE) region

- **Negative baseload prices were observed in the Central Western European (CWE) region on June 16th, 2013:**
  - ➢ France -40,99 €/MWh
  - ➢ Belgium -40,99 €/MWh
  - ➢ Germany -3,33 €/MWh



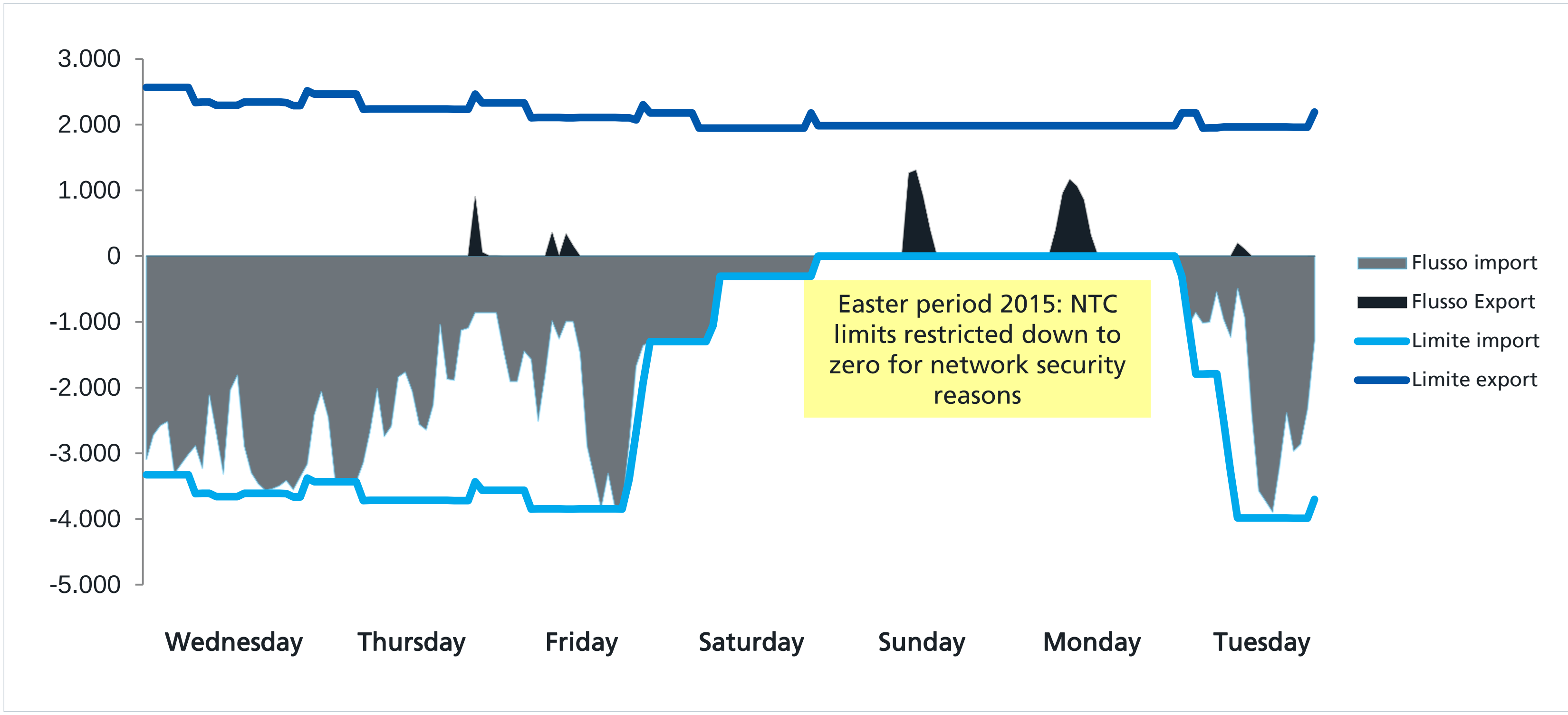
- **Low consumption and high levels of “non-flexible generation” (nuclear, hydro, wind, PV) in France, Germany and Belgium caused a generation surplus**

- **The Netherlands (price 36,16 €/MWh) did not face a surplus, but could not absorb more energy from the rest of CWE since the Netherlands imported the whole day at a level equal to its globally set import limit from Germany and Belgium.**

Source: APX, Belpex and EPEX Spot

Impact on the cross-border trading
Restrictions on the NTC

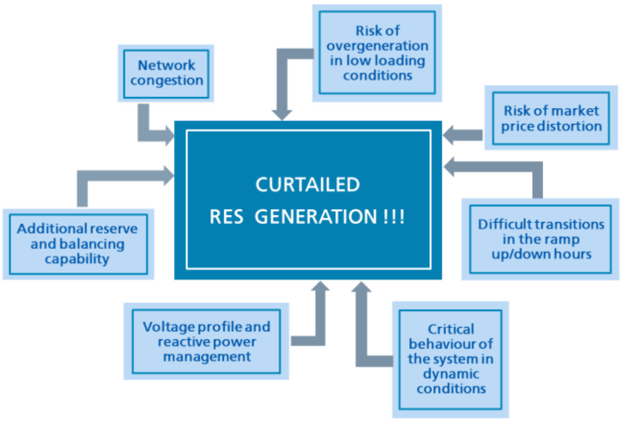
Net Transfer Capacity on the three borders (Slovenia, France and Austria)
01/04/2015-07/04/2015



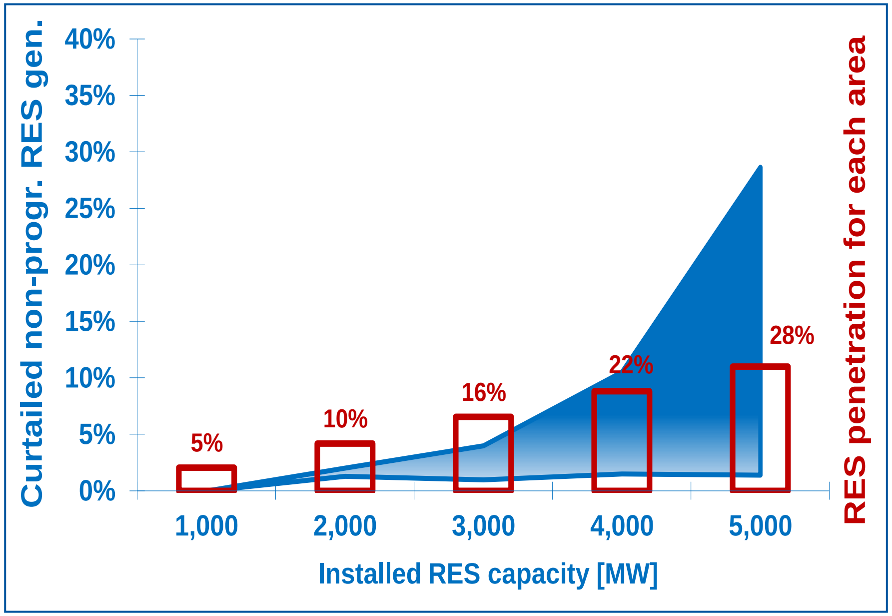
Over Generation estimated at 2024 for VRE (Variable Renewable Energy) 5.5TWh/yr. This amount of curtailed RES generation can be reduced to 700 GWh/yr through a flexibility of cross-border exchanges to fulfill balancing constraints

Risks of RES generation curtailment

- **Risks of curtailment depending on:**
  - (In)flexibility of power plants
  - (in)adequacy of the transmission /distribution infrastructures (including cross-border lines)
  - Possibility of energy storage
  - Demand responsiveness



Different feasible penetration levels of non-programmable RES generation



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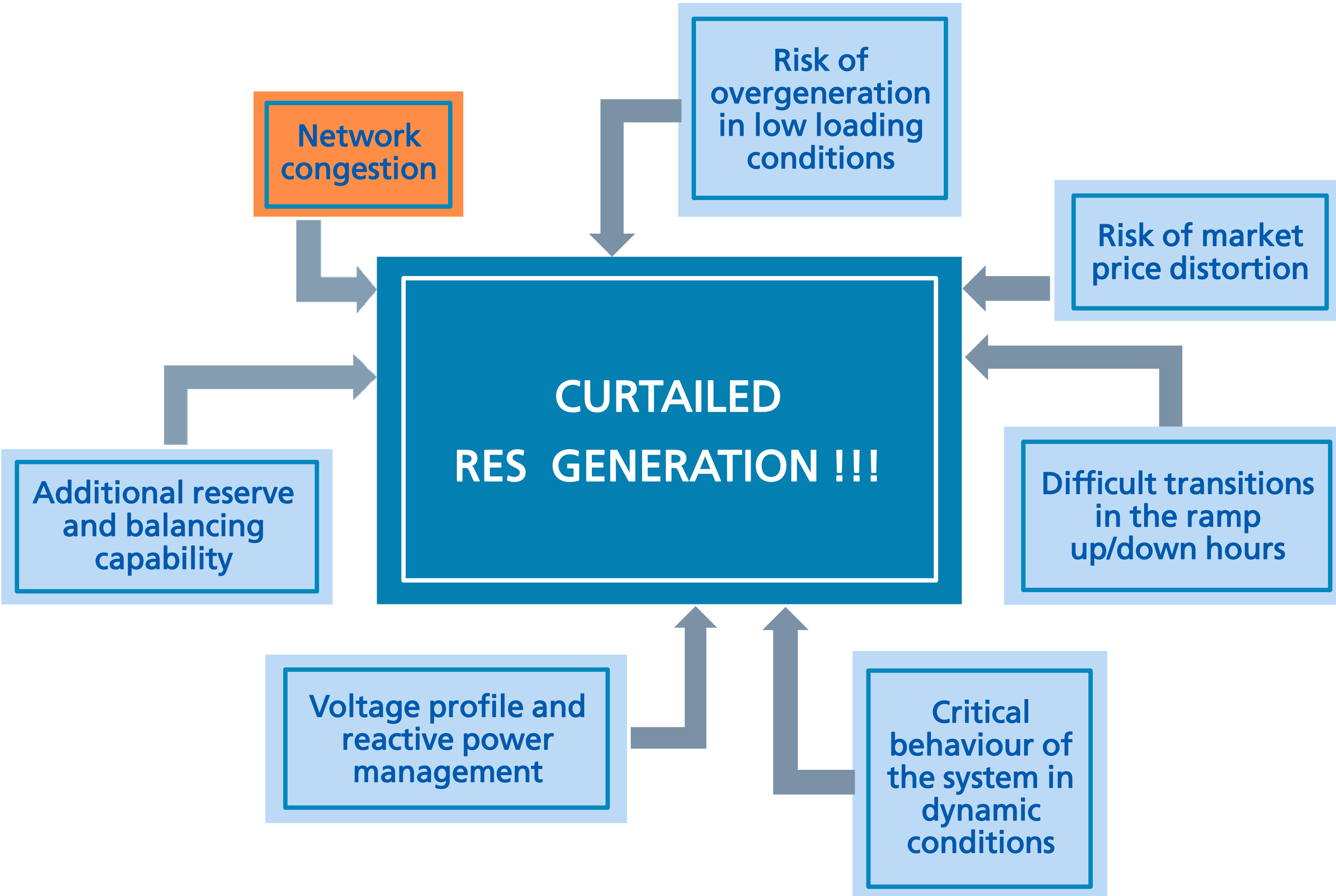
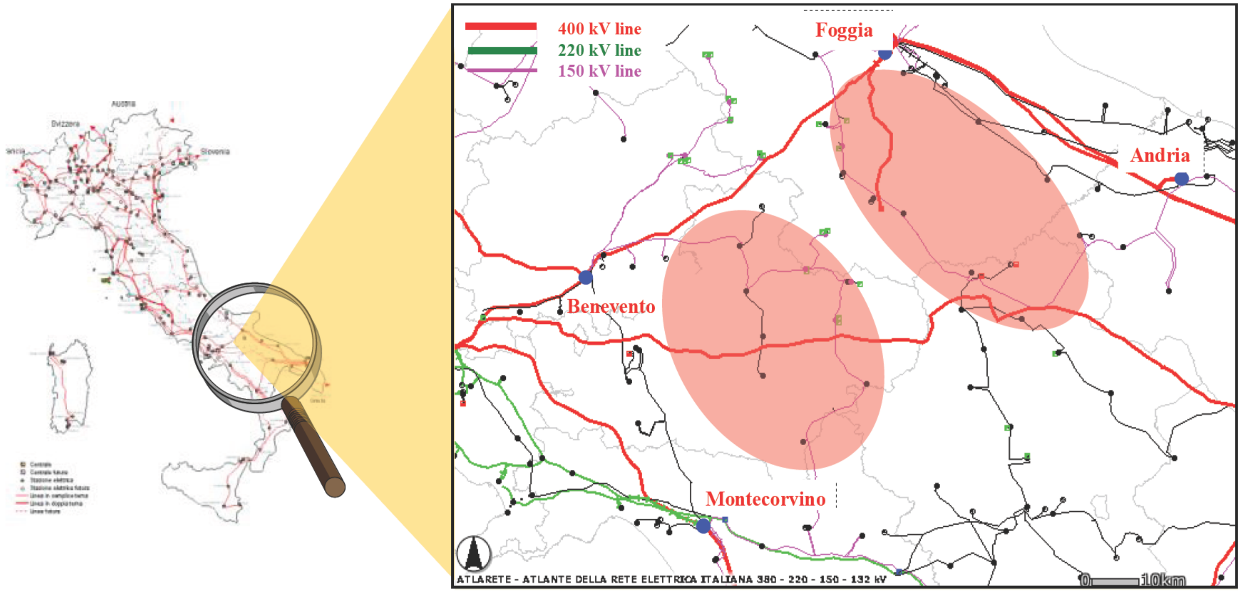


Network congestion caused by RES generation

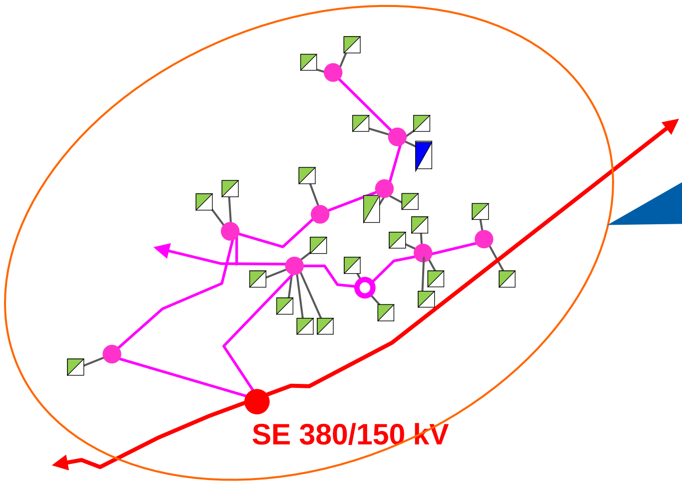
- Renewable Energy Sources are mostly location dependent – often remote locations w.r.t. the demand centres
- No correlation between demand and non-programmable RES generation location - power flowing on longer patterns through the network with risk of creating “scattered” congestion also relatively far away from RES generation areas



Expected congestion in the 150 kV of the Italian peninsular regions due to WF (year 2009) – (source: CIGRE, CESI-Terna paper)

Network congestion caused by RES generation
Example applied to the Italian system

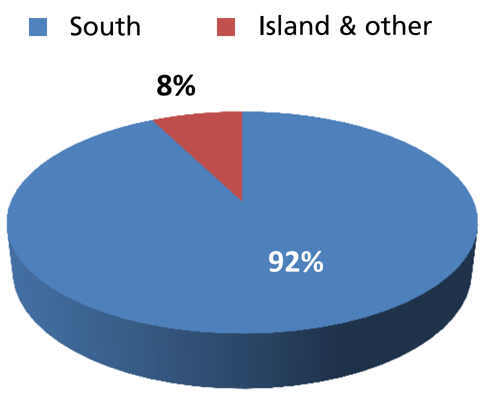
▪ Overloads in the High Voltage network (150kV)



Area with surplus of wind installed capacity and deficit in load and network infrastructures

▪ RES production constraints:

- ➢ The secure and reliable operation of the HV transmission network (150 kV)
- ➢ Line overloads in the 150 kV network when high productions from RES occurred
- ➢ Network developments needed to solve some critical conditions in the Extra High Voltage (EHV) network

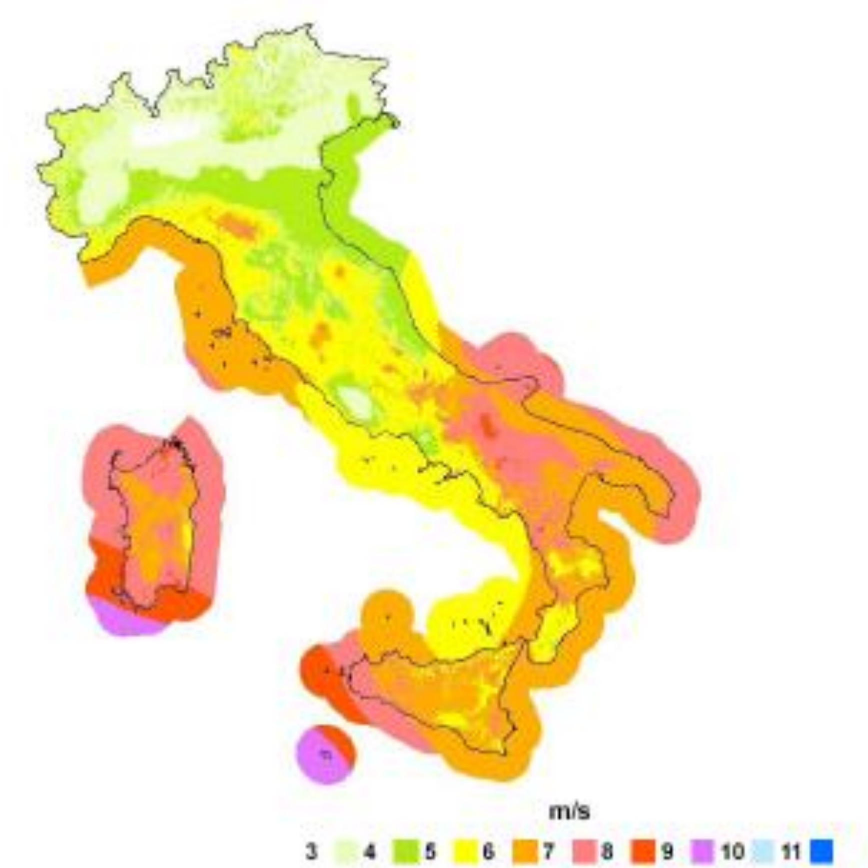


Wind generation - Italy

Source: Terna

Network congestion caused by RES generation
Example applied to the Italian system

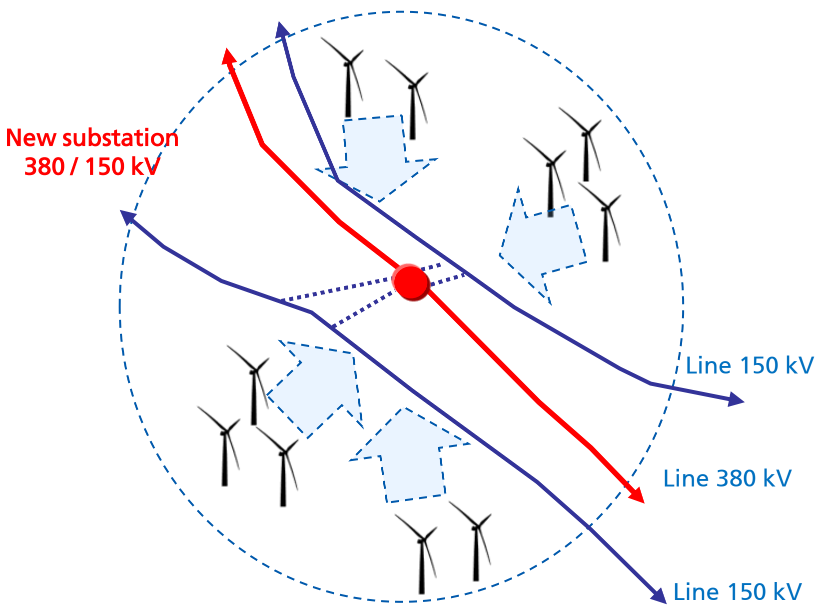
- ## Distribution of average wind speed and potential production (from Wind Atlas)



Source: Terna

Network congestion caused by RES generation
Example applied to the Italian system

- **Clusters for RES power plants**
- **Current problems in the network planning:**
  - Optimization of RES clusters maximizing the exploitation of the existing infrastructures, including the 380 kV level
  - Increase the meshing of EHV and HV network to reduce network congestion
  - Reduce the environmental impact of the new 150 kV infrastructures



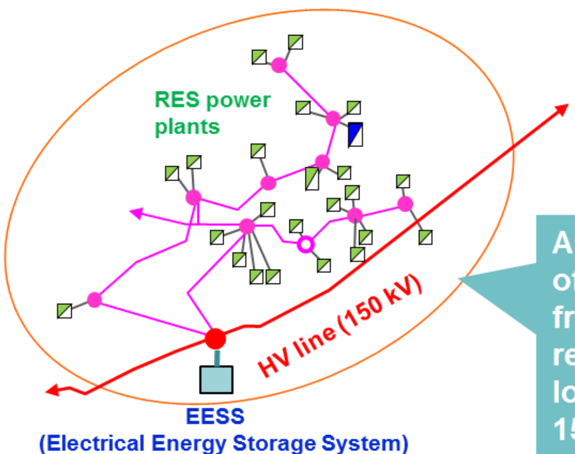
Production Area: over 200 MW

Layout of substation 380/150 kV

Source: Terna

Network congestion caused by RES generation Example applied to the Italian system

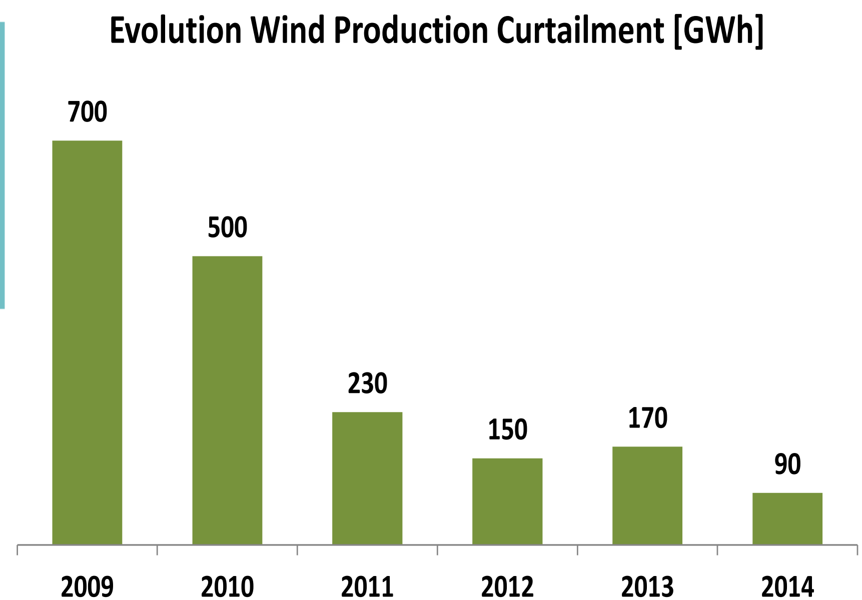
▪ Actions taken to reduce wind generation curtailment due to network constraints



Area with surplus of installed power from RES with respect to the local load and 150kV network transfer capacity

One of the areas with local congestion caused by wind power in South of Italy

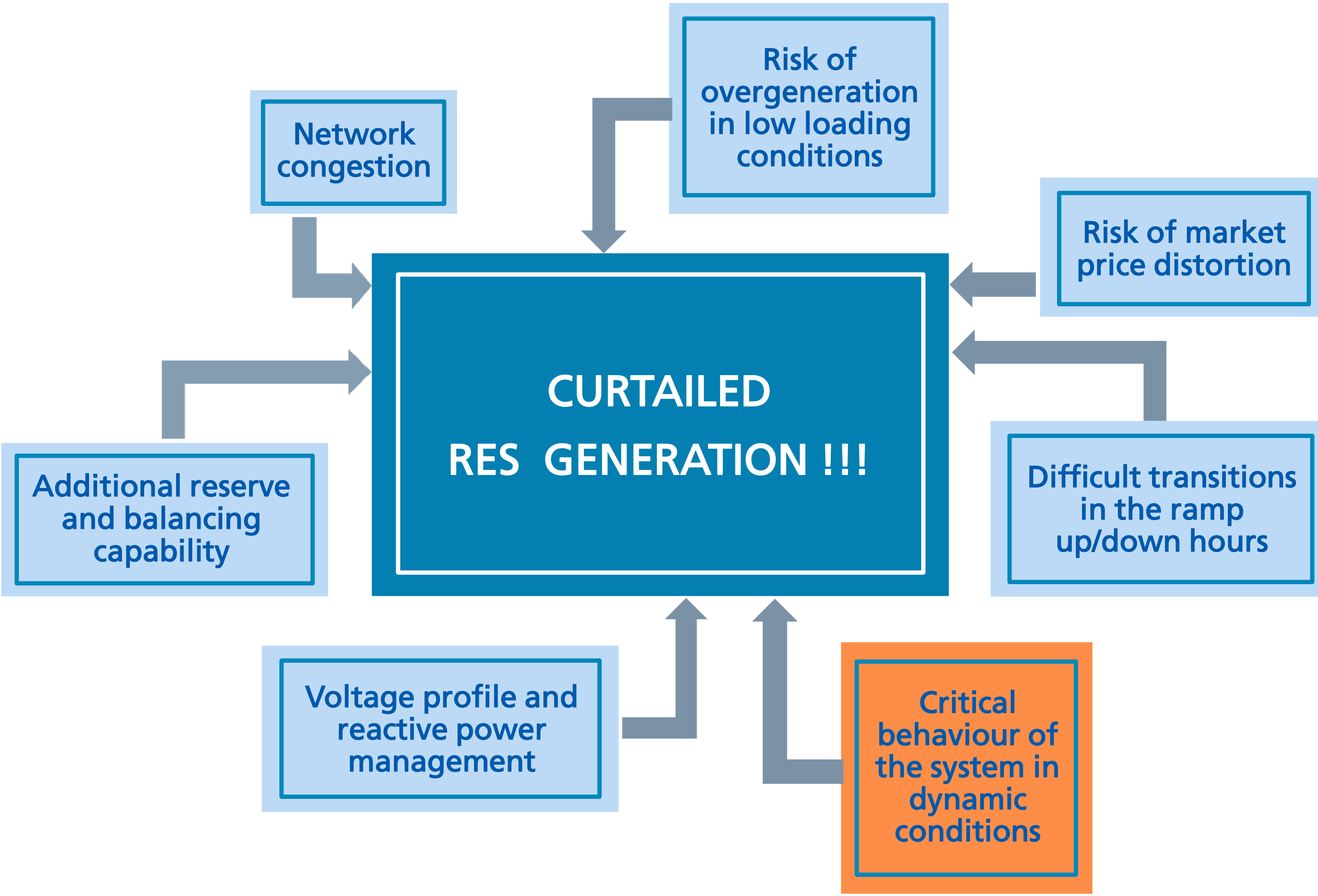
Source: Terna



	2009	2010	2011	2012	2013	2014
(1)	*6542*	*9125*	*9856*	*13407*	*13707*	*14048*
(2)	*10.7%*	*5.4%*	*2.3%*	*1.1%*	*1.2%*	*0.7%*

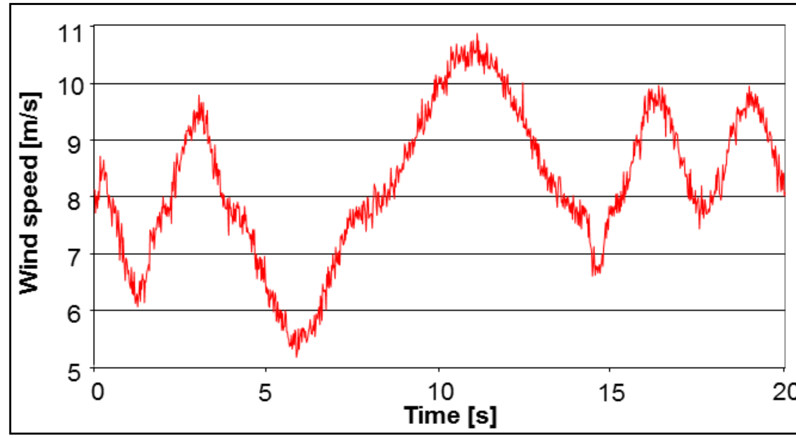
Note: (1) Actual production (2) Curtailed production

Barriers to overcome to enhance generation from non-programmable RES

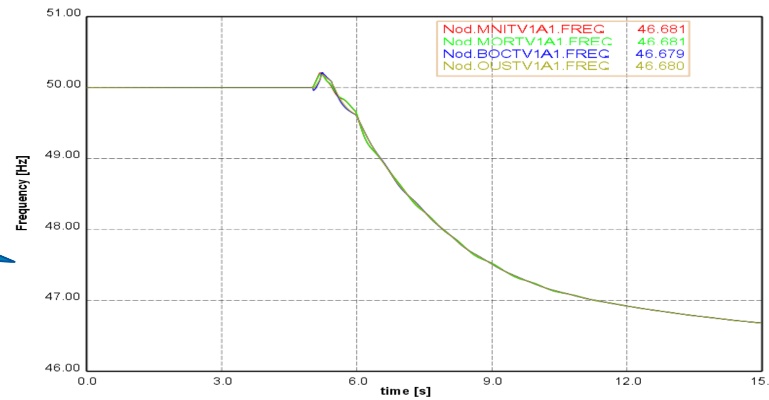


Critical behaviour of the system in dynamic conditions

- **Critical dynamic behaviour caused by:**
  - ➢ Intermittency in RES generation causing a higher stress on the conventional units to balance the system
  - ➢ Faults (e.g.: short circuits on a network component)



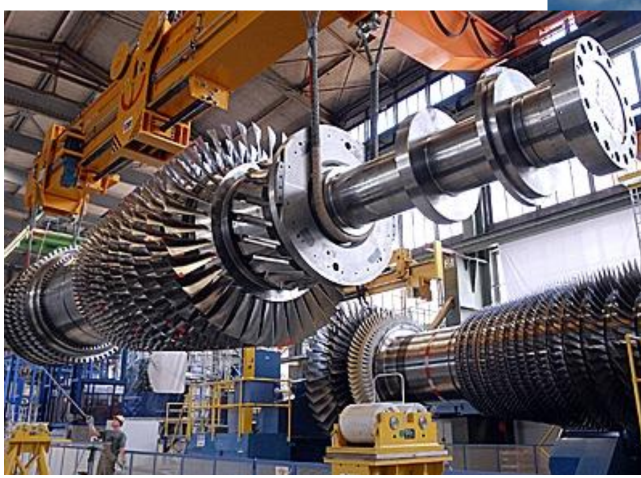
Frequency (Hz)



Risk of cascading effect leading to the system collapse

Critical behaviour of the system in dynamic conditions

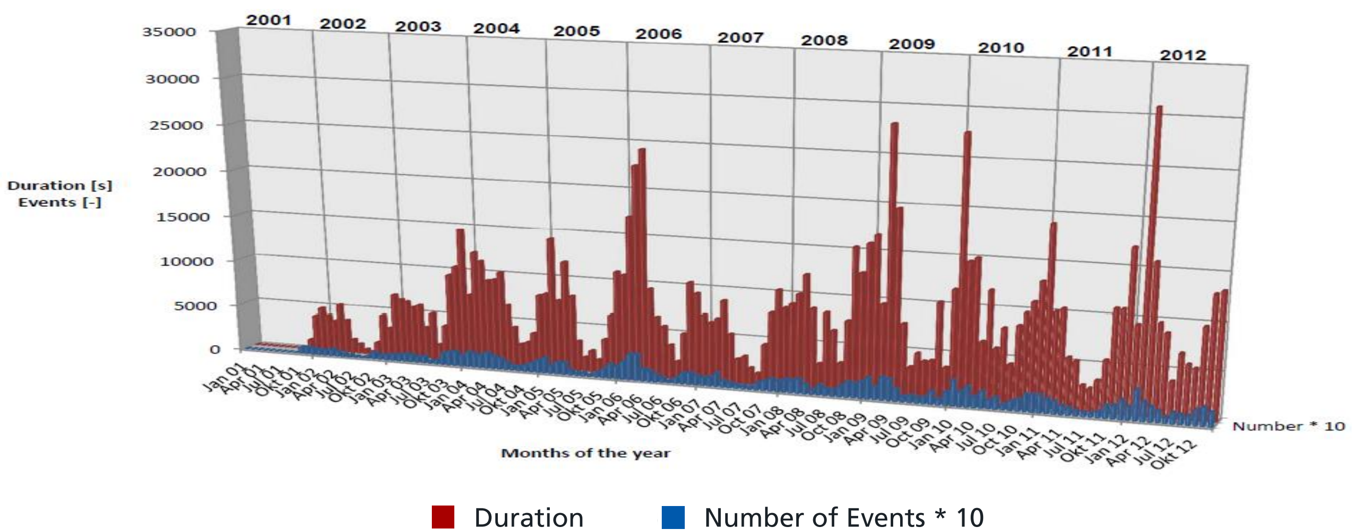
- **Total inertia of the power system degraded with the increased share of wind and solar power plants ➡ large frequency deviations from nominal value during disturbances**



From rotating generators with high inertia to static productions with zero inertia

Critical behaviour of the system in dynamic conditions

- **Risk of over-frequency (not included in the current ENTSO-E policies)**
  - ➢ This risk increases due to the limited control capabilities of RES power plants and the need for maintaining the regulating power in the system
  - ➢ the periods with over-frequency operation (50.1 Hz) longer than 30-40’ are becoming more frequent
  - ➢ the risk of accidents during such periods has increased



Source: Terna

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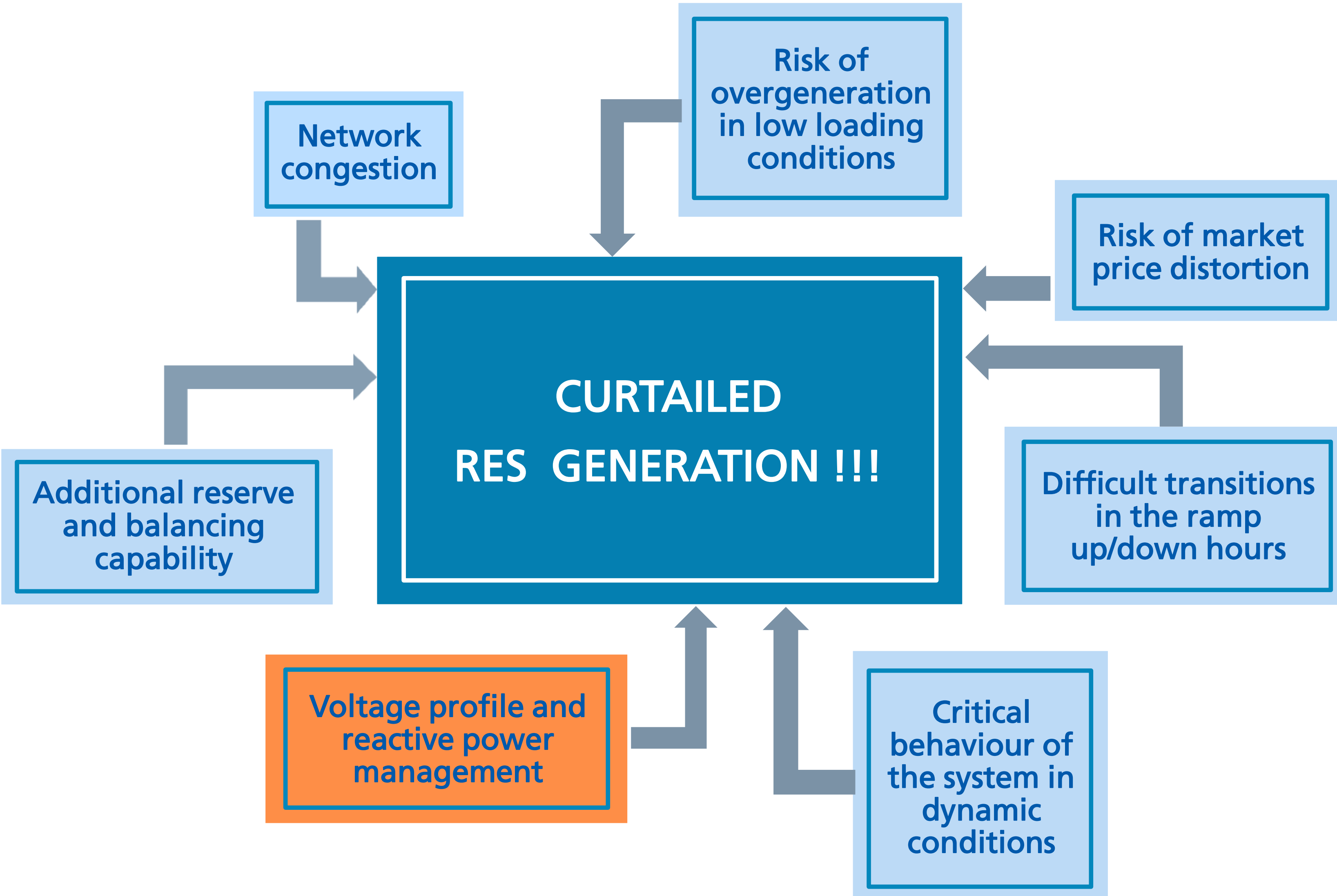
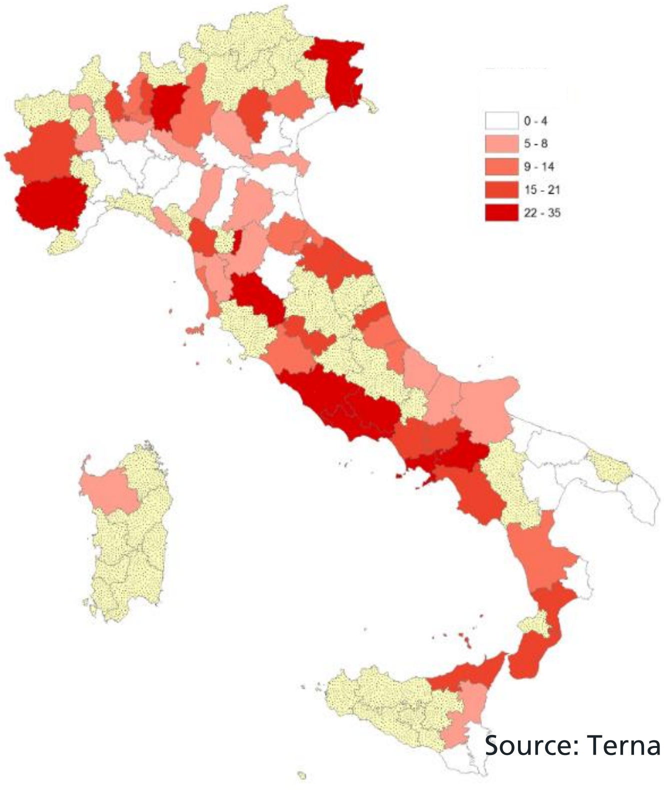


Voltage profile and reactive power management Italian example

- High Voltages in low load conditions and high production by RES
- The high production from RES reduces the loading of EHV lines, increasing the voltages in the EHV network (equivalent load of the EHV network is reduced)

Critical zones

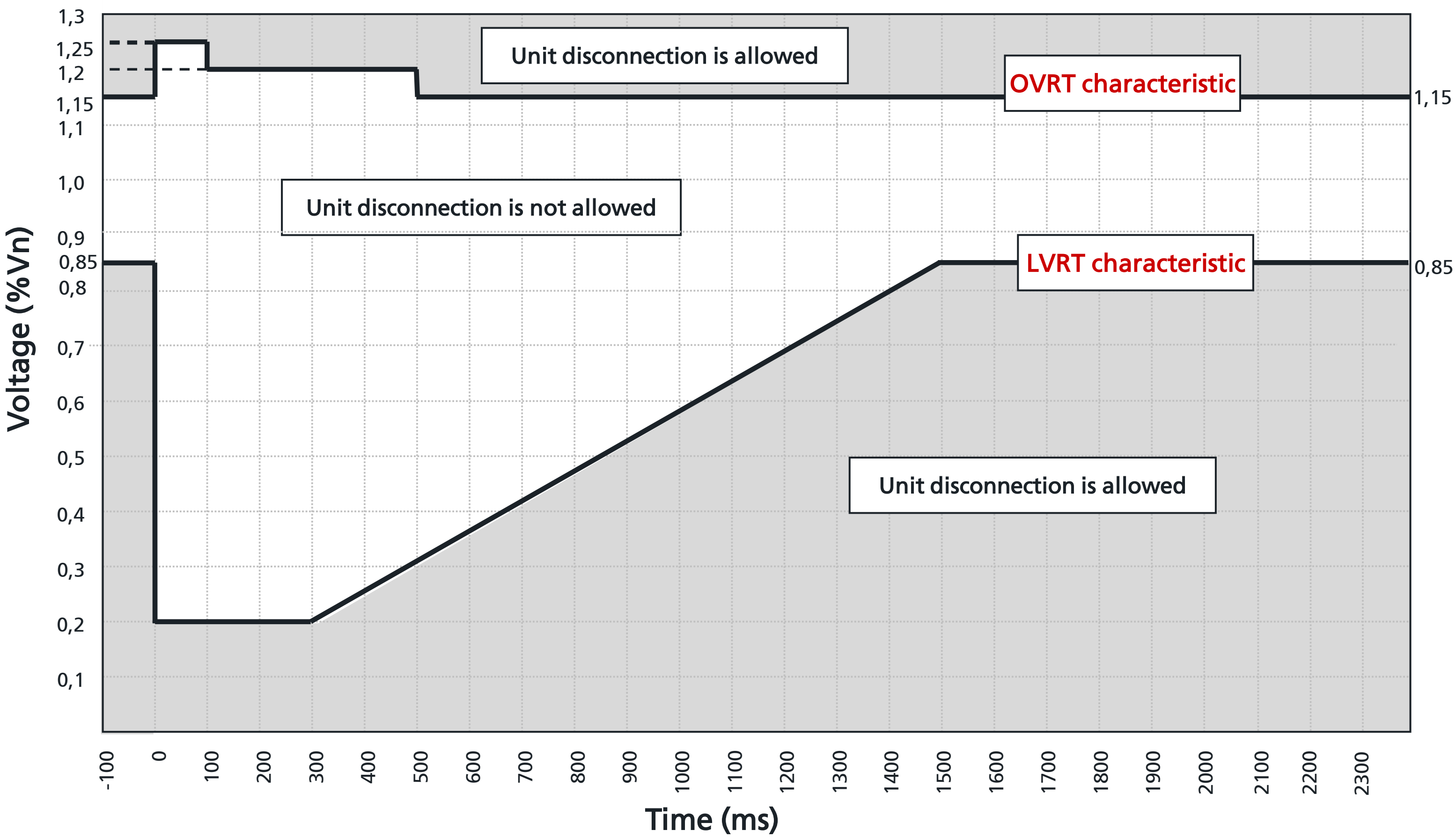


Source: Terna

Frequency (%) of voltages > 410 kV (hours with low load, July 2011 – June 2012)

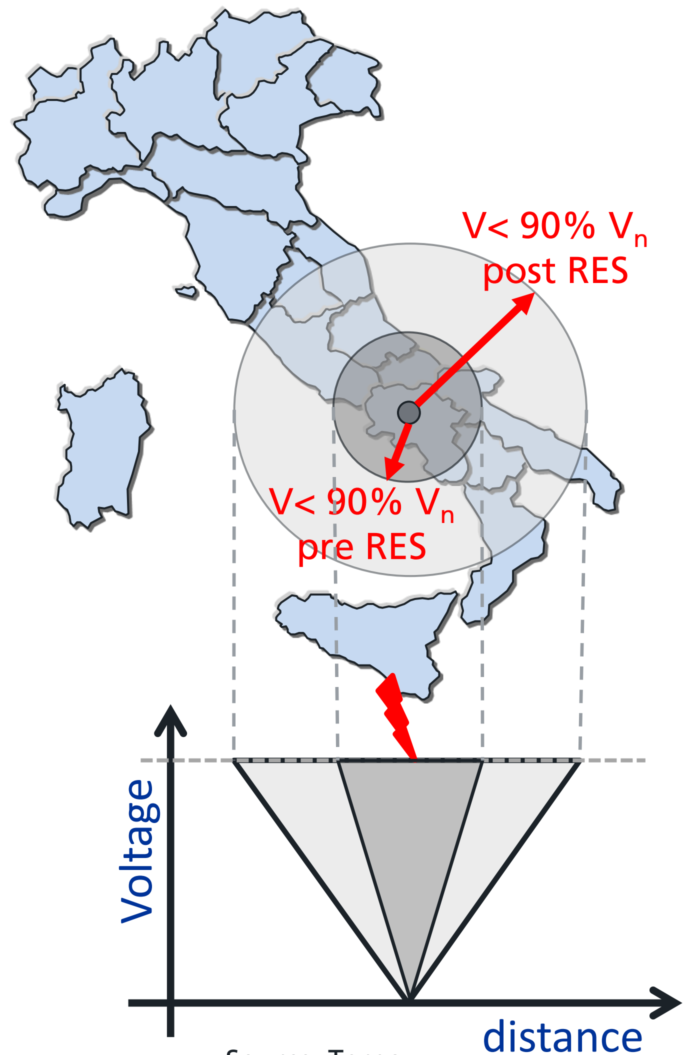
Voltage profile and reactive power management

- **Low Voltage Ride Through (LVRT) and Over Voltage Ride Through (OVRT) characteristics**



Voltage profile and reactive power management

- Impact of the Distributed Generation (DG) on the Voltage
- Icc WPP (fully converters) ≈ 1.1 ÷ 1.5 In
- Icc WPP (DFIG) ≈ 1.5 ÷ 2.0 In
- Icc PV units ≈ 1.1 In
- Icc synchronous generators ≈ 4 ÷ 5 In
- The replacement of rotating generators with RES generators decreases the short circuit current (Icc) and increases the area with disturbances on the voltage figures



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Possible solutions

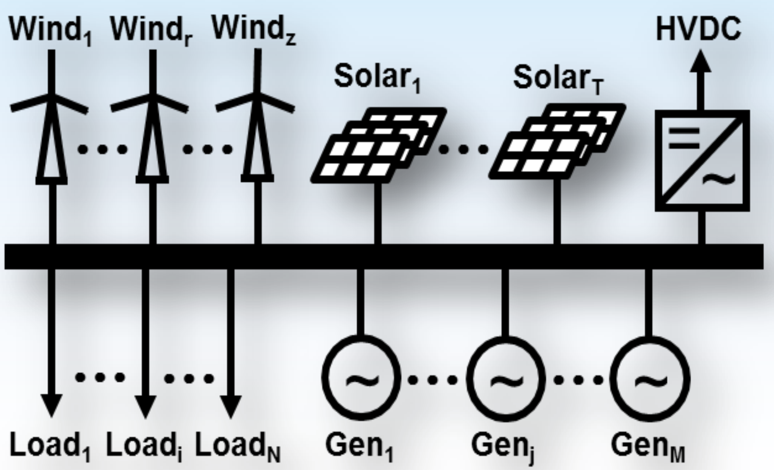
Maximisation of RES generation penetration while minimising the risk of curtailment: a FOUR-LAYER TOP-DOWN APPROACH

1. Reserve Criterion
2. Network connection / Static Analysis
3. Reliability Analysis
4. Dynamic Analysis

Possible solutions

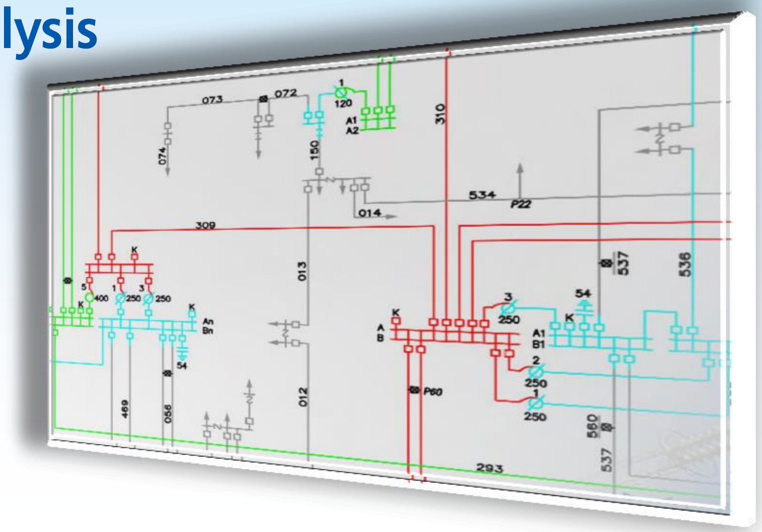
1. Reserve criterion

- First evaluation of maximum RES penetration that can be accepted by the system taking into account the additional reserve to face the unpredictability of RES



2. Network connection / Static analysis

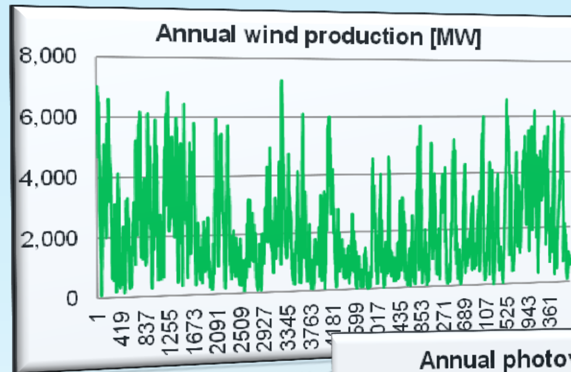
- Distribution of RES energy production capacity
- The best connection points of RES units on the network

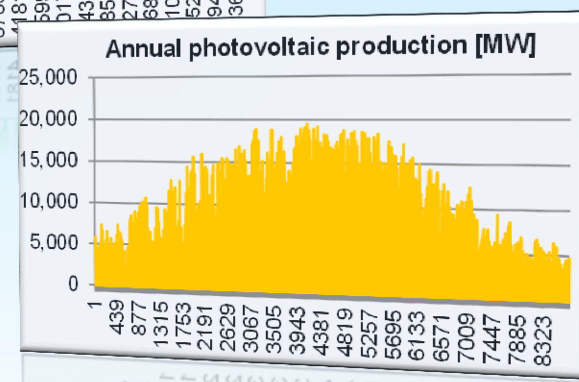


Possible solutions

3. Reliability analysis

- Three meaningful “Risk Indices”:
  - Loss Of Load Expectation
  - Loss Of Load Probability
  - Expected Energy Not Supplied

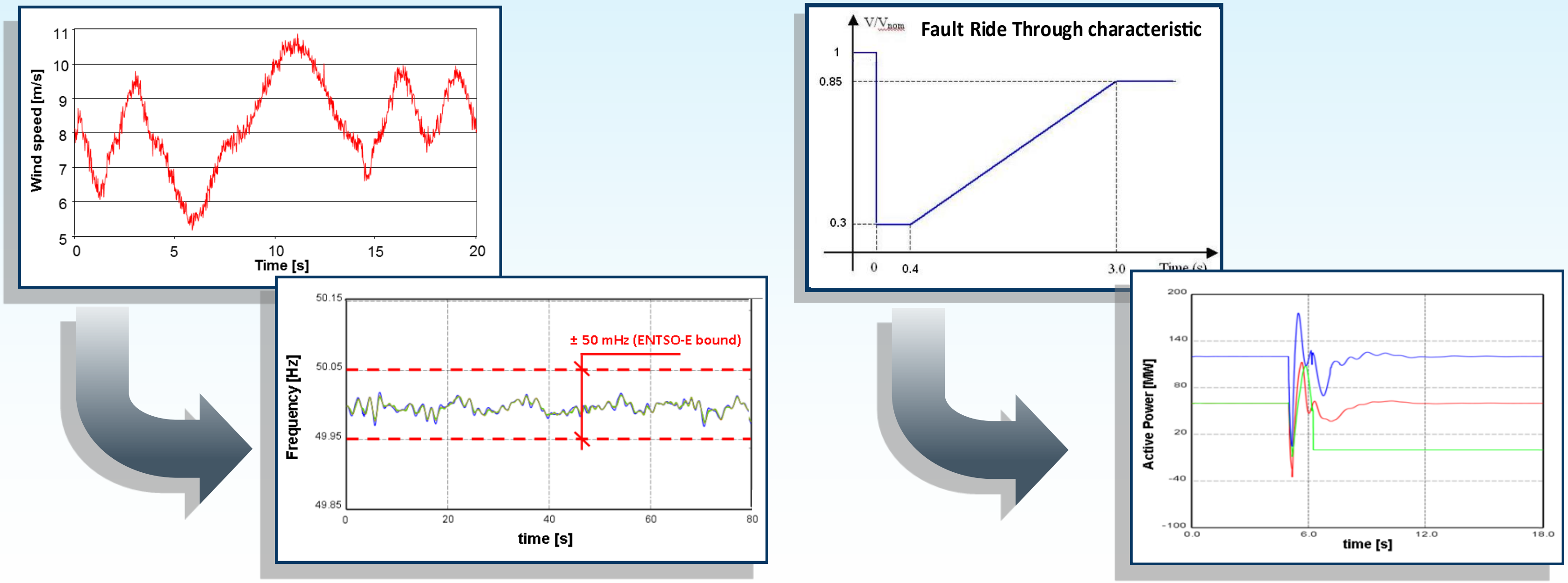




- Reliability of the system to fulfil power demand
- <u>The maximum RES penetration</u> compliant with reliability standards
- Wind /solar curtailment due to network element overloads, lack of interconnection or minimum stable operation of conventional units in low load condition
- Possible network reinforcements, new storage devices and reserve margins able to preserve the static reliability and the security of the system

4. Dynamic Analysis

- Measures to avoid any RES production restriction due to dynamic constraints
  - Check the fluctuations due to RES production intermittency
  - Analysis of network response to major fault events



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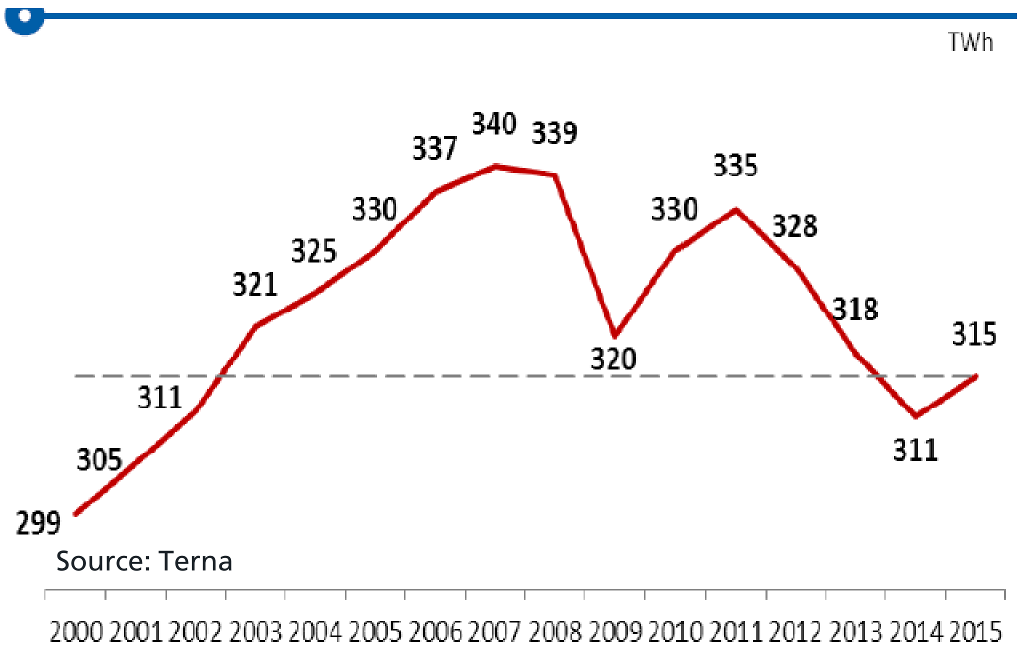
Non-programmable RES and their impacts on power systems: the Italian case

Electricity demand evolution in Italy from 2000 to 2015



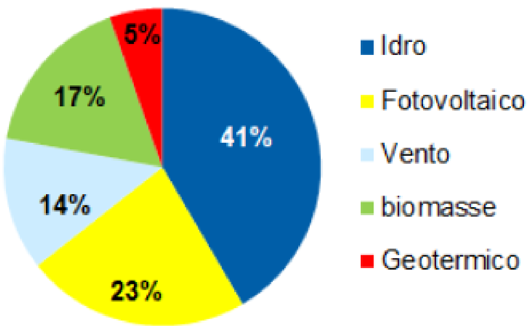
2015 outcomes:

- +1.3% w.r.t. 2014, -7.1% w.r.t. 2008
- **A step back of 12-13 years: back to the 2002-2003 demand level**
- Internal demand in 2015 supplied for 15% by imported energy and for 85% from national production

Non-programmable RES and their impacts on power systems: the Italian case

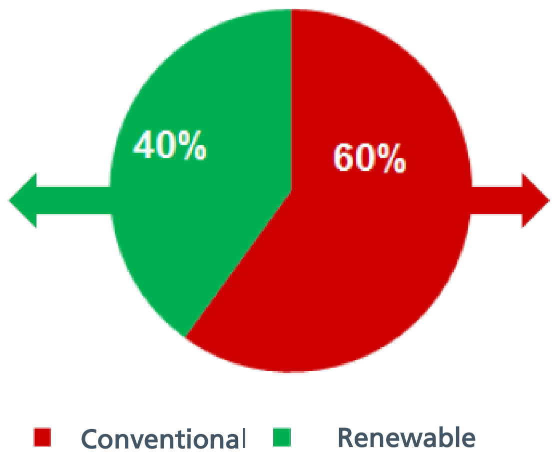
Generation mix in 2015

Renewable
107,8 TWh

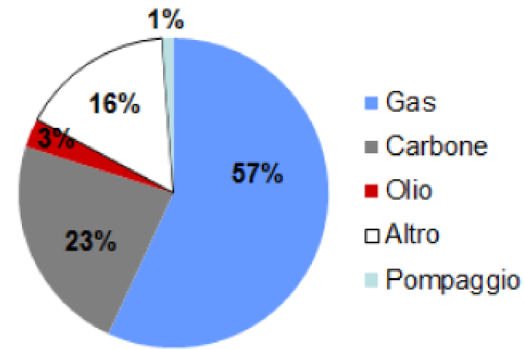


Source: Terna

Total generation
270,7 TWh



Conventional generation
162,9 TWh

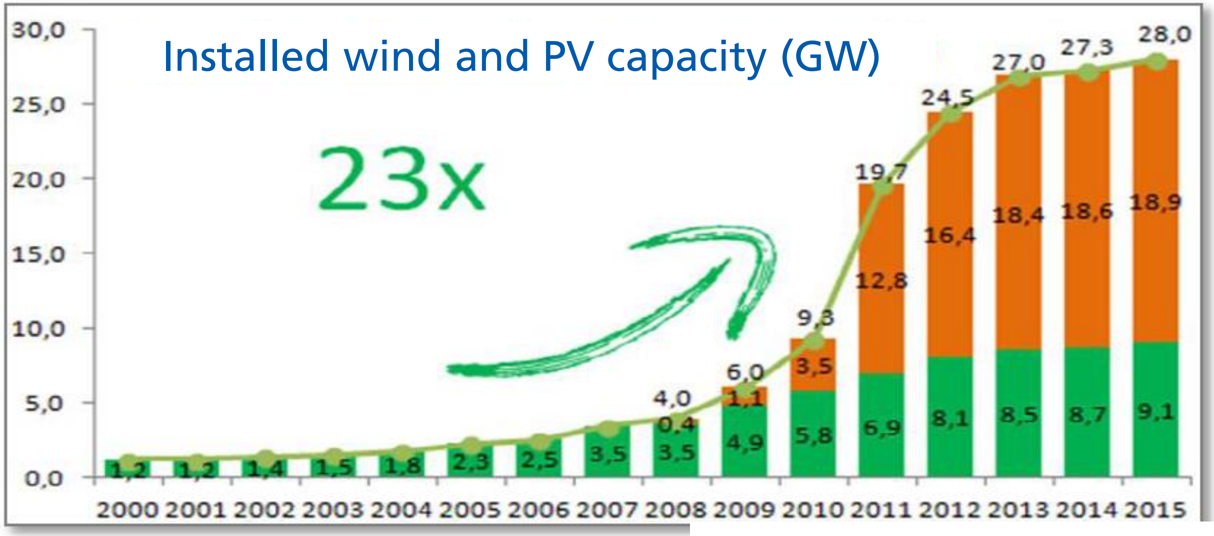


Thermal production is still the main source of power generation (>50%)

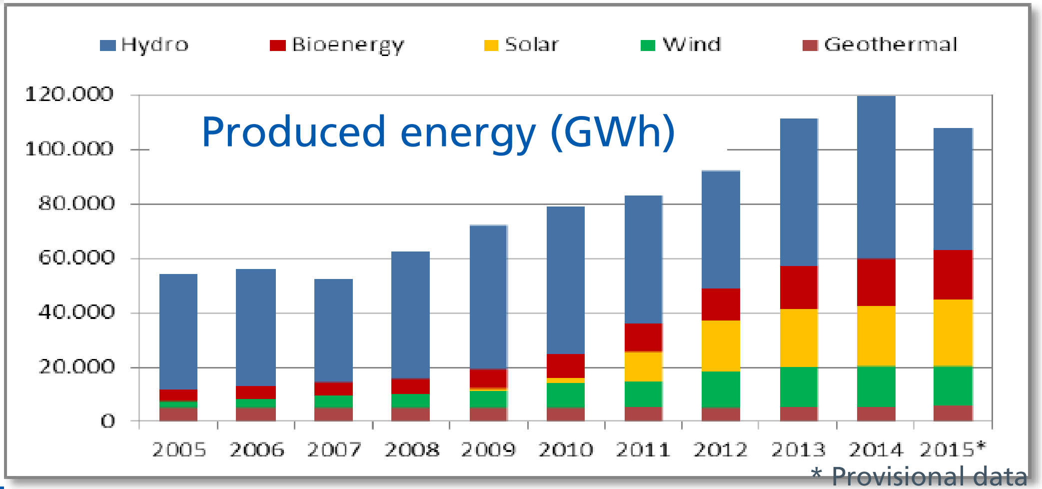
- +22 GW of new power plants from 2002 to 2012, 43% of which in the South
- **NG accounts for 57% of total produced energy**
- Modern and efficient CCGT

Non-programmable RES and their impacts on power systems: the Italian case

Evolution of RES generation



Source: Terna



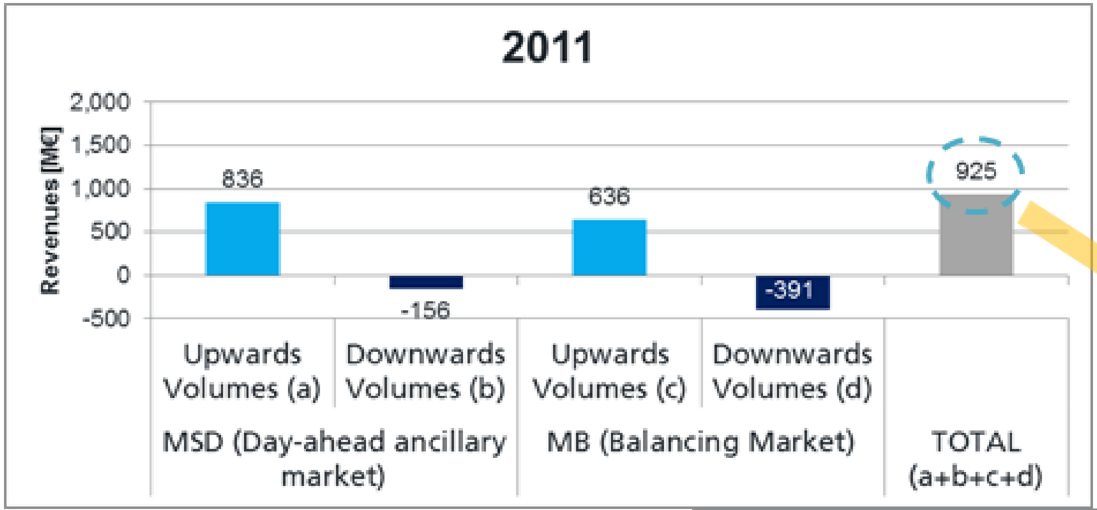
* Provisional data

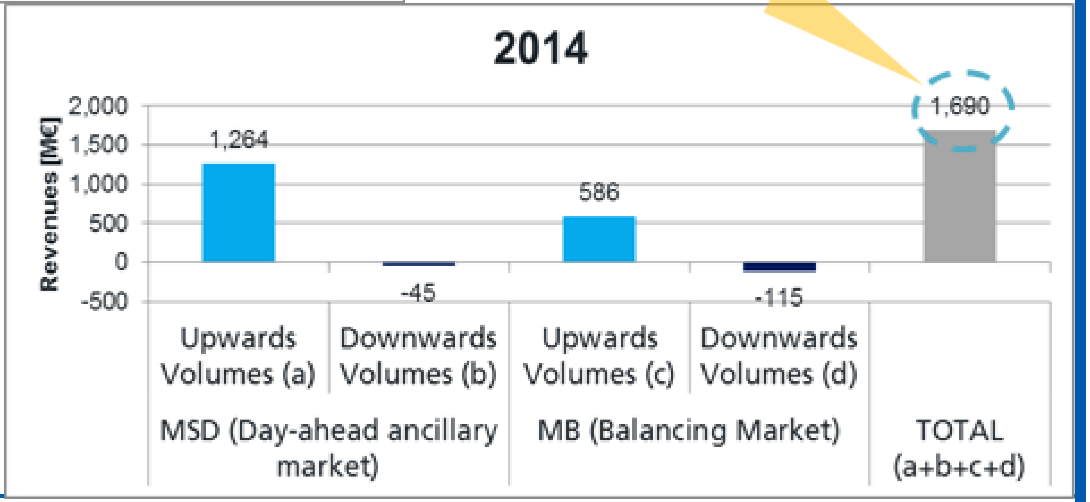
Impact of non-programmable RES generation in Italy

Main issues:

- Risk of «over-generation»
- Need for additional reserve
- Network congestions and power flow inversion
- Load following – need for conventional generation flexibility
- Impact on the day-ahead hourly market
- Impact on the ancillary service market
- Dynamic stability and quality of supply issue

Need for additional reserve - Impact on ancillary service market



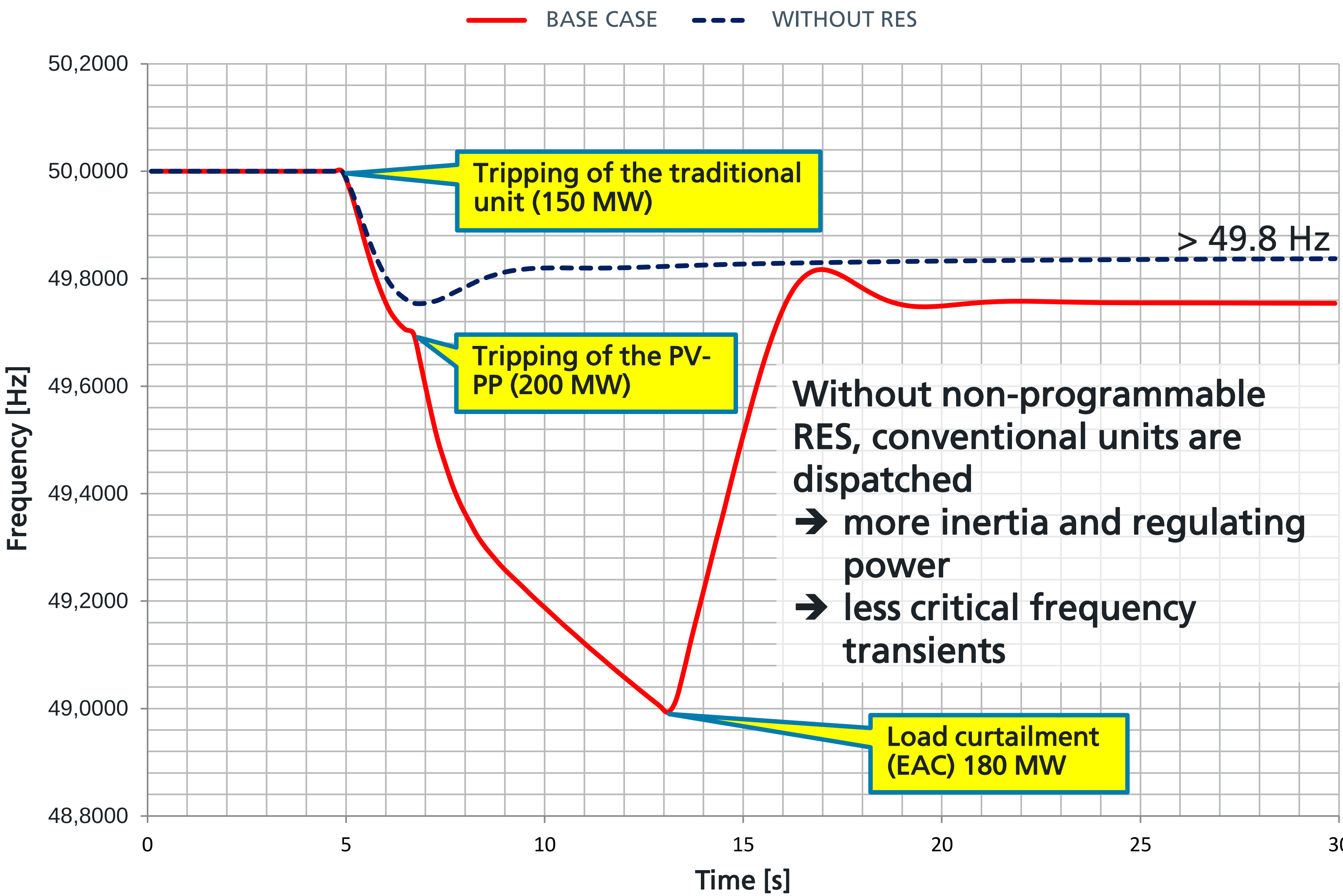


Critical behaviour of the system in dynamic conditions
Example of the Sicilian power system

- **Scenario May 18th, 2011, h10 a.m.**
- **Island operation of the Sicilian power system (out of service of the links with the rest of Italian network):**
  - Demand 2250 MW
  - Wind production 260 MW (installed capacity 1700 MW)
  - Photovoltaic production 200 MW (400 MWp)
- **Generation tripping**
- **Frequency transients under 49.7 Hz**
- **Tripping of Photovoltaic Power Plant (PV-PP)**
- **Load curtailment**

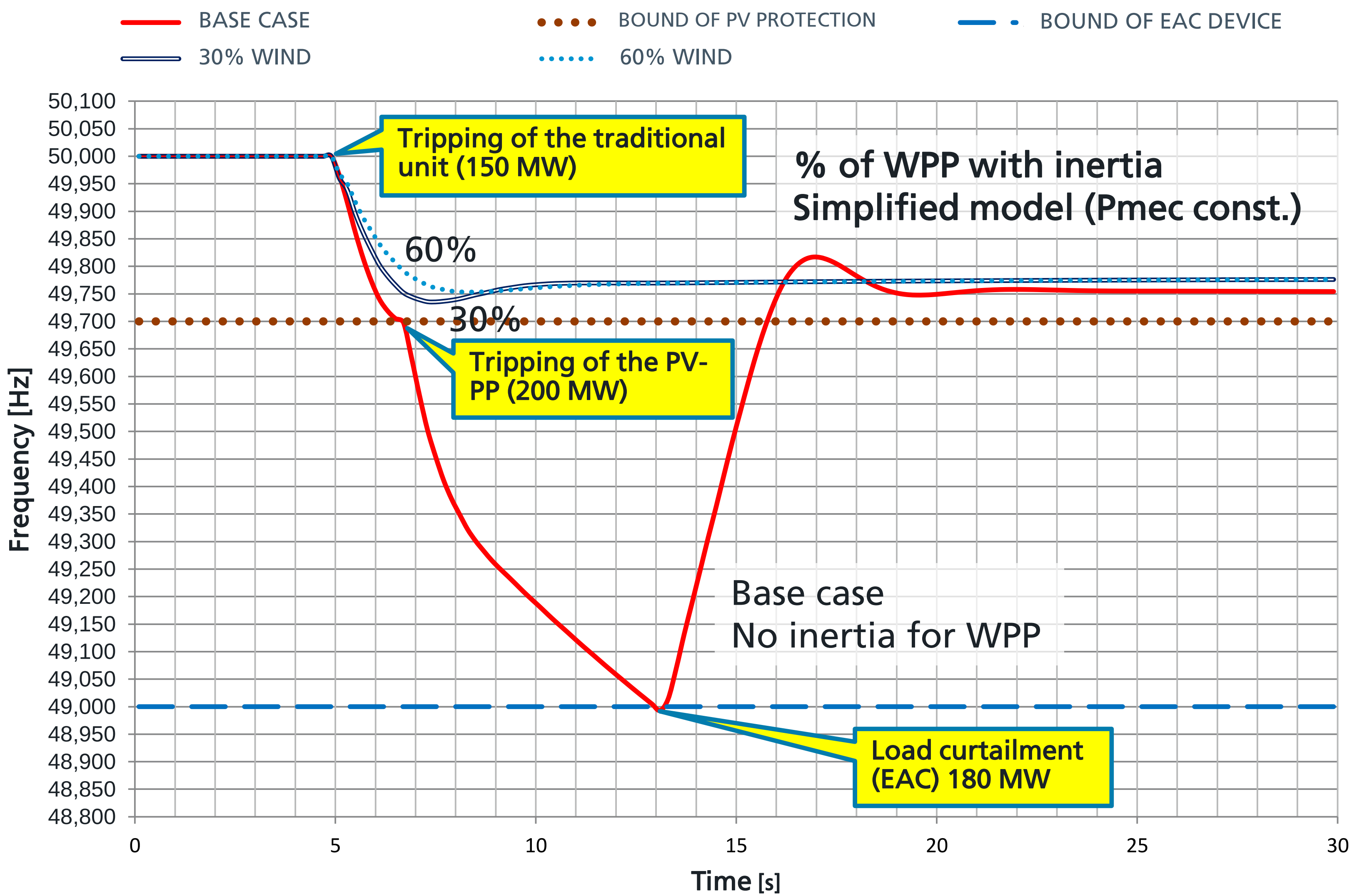
Source: RSE (Ricerca sul Sistema Elettrico)

Example of the Sicilian power system
Case (0) – Only with traditional generation



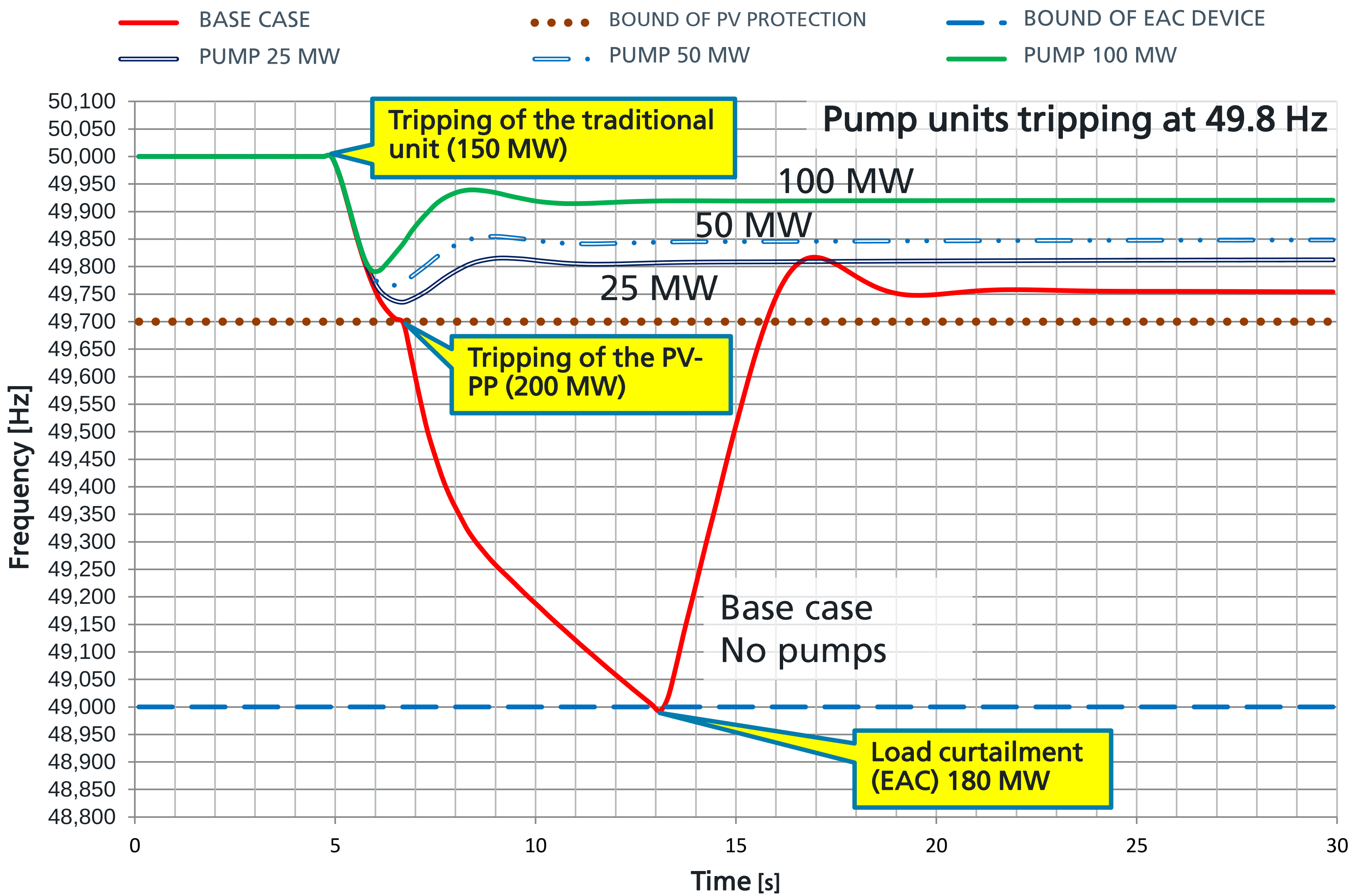
Source: RSE (Ricerca sul Sistema Elettrico)

Example of the Sicilian power system
Case (1) – Wind retrofitting with inertia



Source: RSE

Example of the Sicilian power system
Case (2) – Pump units operation (Storage)

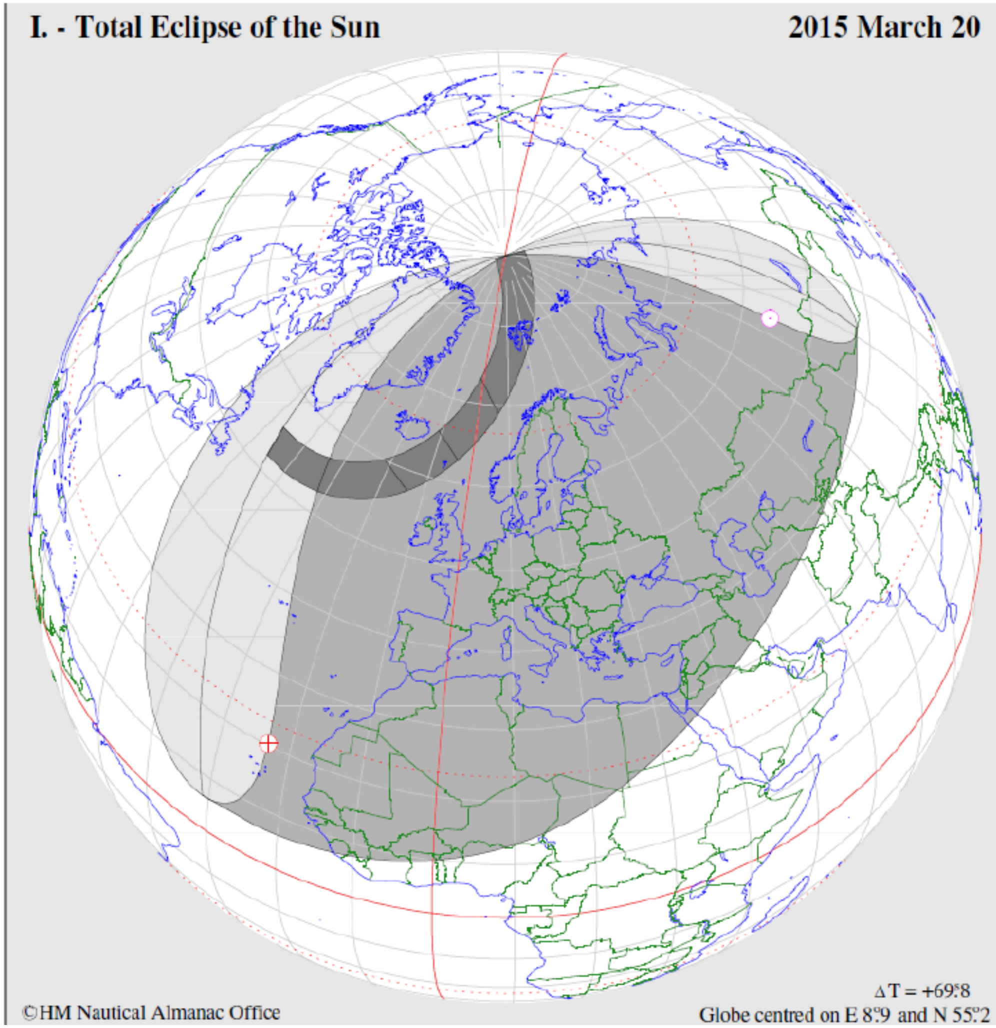


Source: RSE

Non-programmable RES and their impacts on power systems: the Italian case

- ❑ System wide impact
  - Barriers to overcome
  - Additional reserve and balancing capability
  - Difficult transitions in the ramp up/down hours
  - Impact on power market mechanisms
  - Risk of overgeneration
- ❑ Network and local impacts
  - Network congestion
  - Critical behaviour of the system in dynamic conditions
  - Voltage profile and reactive power management
- ❑ Possible solutions
- ❑ Situation in Italy
- ❑ **Coping with exceptional events: solar eclipse**

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015



Source: http://astro.ukho.gov.uk/eclipse/0112015/

- ✓ Installed PV capacity in the European synchronous area: **90GW**
- ✓ Potential PV infeed reduction due to the eclipse: **30 GW**
- ✓ Very high ramps down and up

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

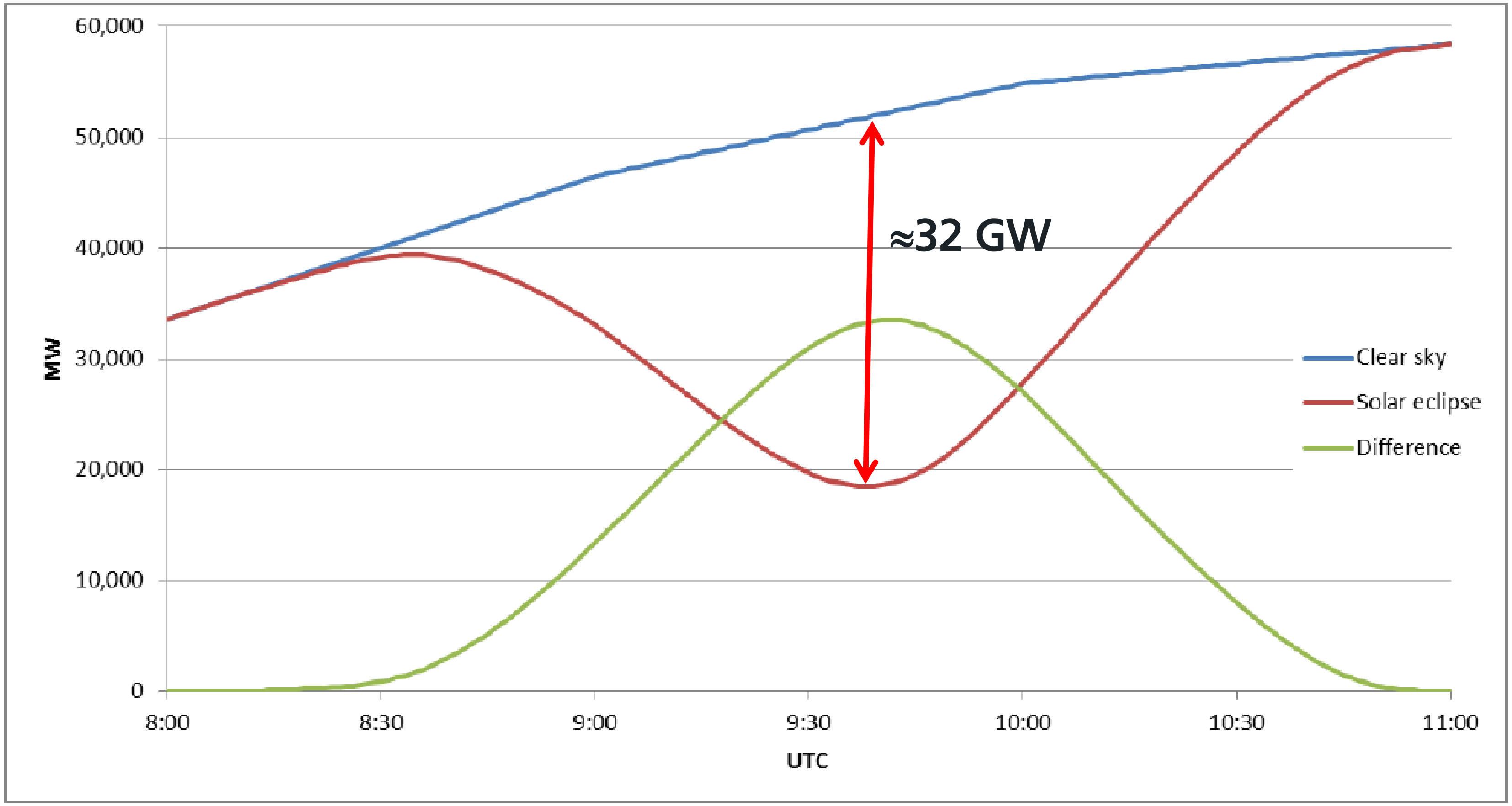
	Start eclipse UTC	End eclipse UTC	Max obscuration	Location
Austria	08:31	10:52	62%	Klagenfurt
Belgium	08:27	10:45	80%	Brussels
Bosnia	08:35	10:54	51%	Sarajevo
Bulgaria	08:44	10:59	40%	Plovdiv
Croatia	08:33	10:53	58%	Zagreb
Czech Republic	08:36	10:57	69%	Prague
Denmark	08:40	10:58	83%	Arhus
France	08:20	10:38	77%	Orleans
Germany	08:33	10:52	76%	Kassel
Greece	08:38	10:51	37%	Larisa
Hungary	08:39	10:59	58%	Budapest
Italy	08:24	10:44	59%	Florence
Luxembourg	08:27	10:46	76%	Luxembourg
Netherlands	08:30	10:48	80%	Nijmegen
Poland	08:45	11:05	67%	Lodz
Portugal	08:02	10:12	70%	Coimbra
Romania	08:48	11:05	47%	Brasov
Serbia	08:39	10:58	51%	Belgrade
Slovakia	08:41	11:01	61%	Banska Bystrica
Slovenia	08:31	10:52	60%	Ljubljana
Spain	08:05	10:18	67%	Madrid
Switzerland	08:24	10:44	70%	Berne
Turkey	09:01	11:03	25%	Ankara

Source: ENTSOE

Duration and max solar obscuration in the continental European countries on 20th March 2015

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

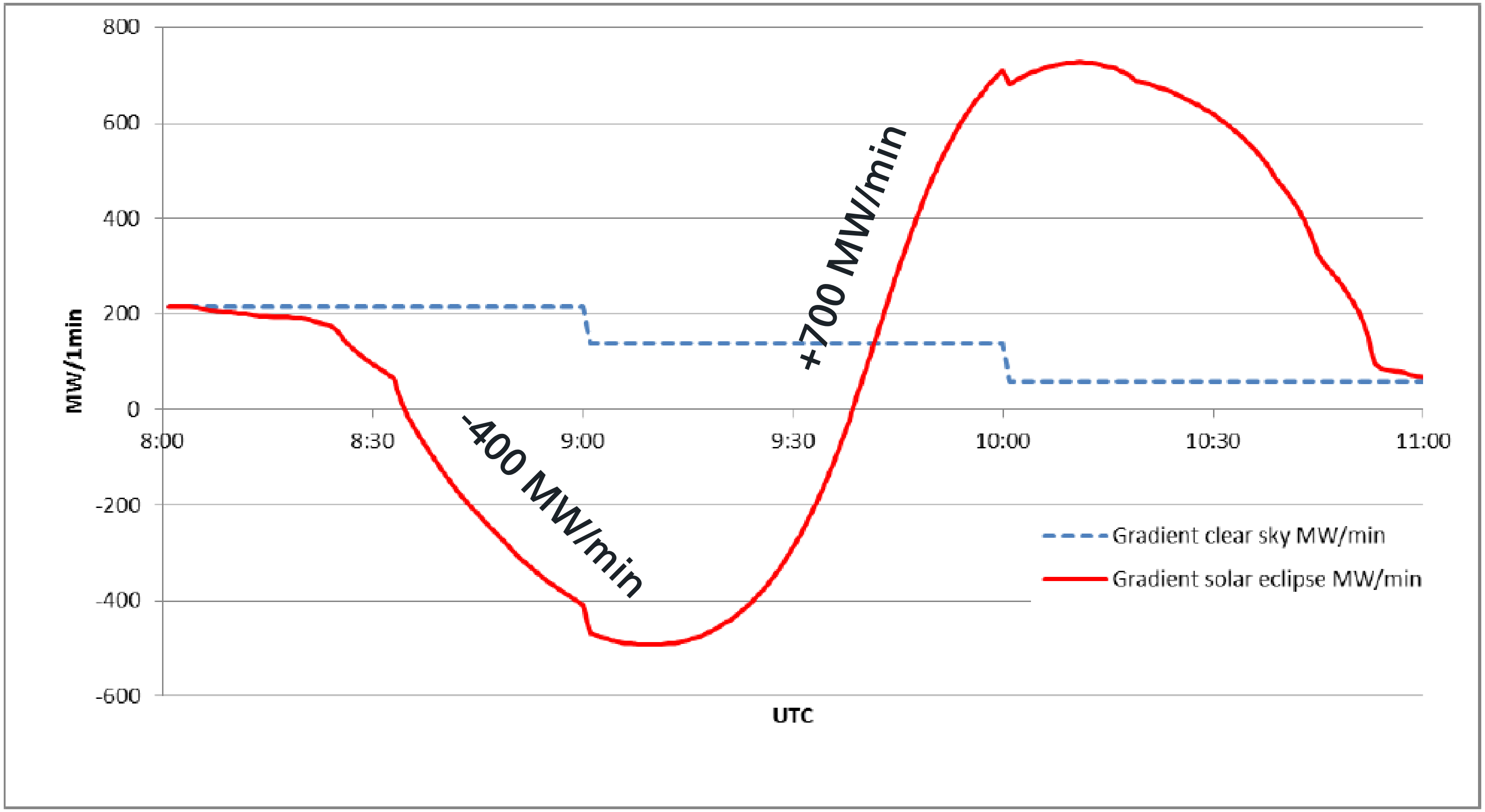
Comparison of expected infeed from solar on March 20 during clear sky conditions with and without solar eclipse (ex-ante simulation)



Source: ENTSOE

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

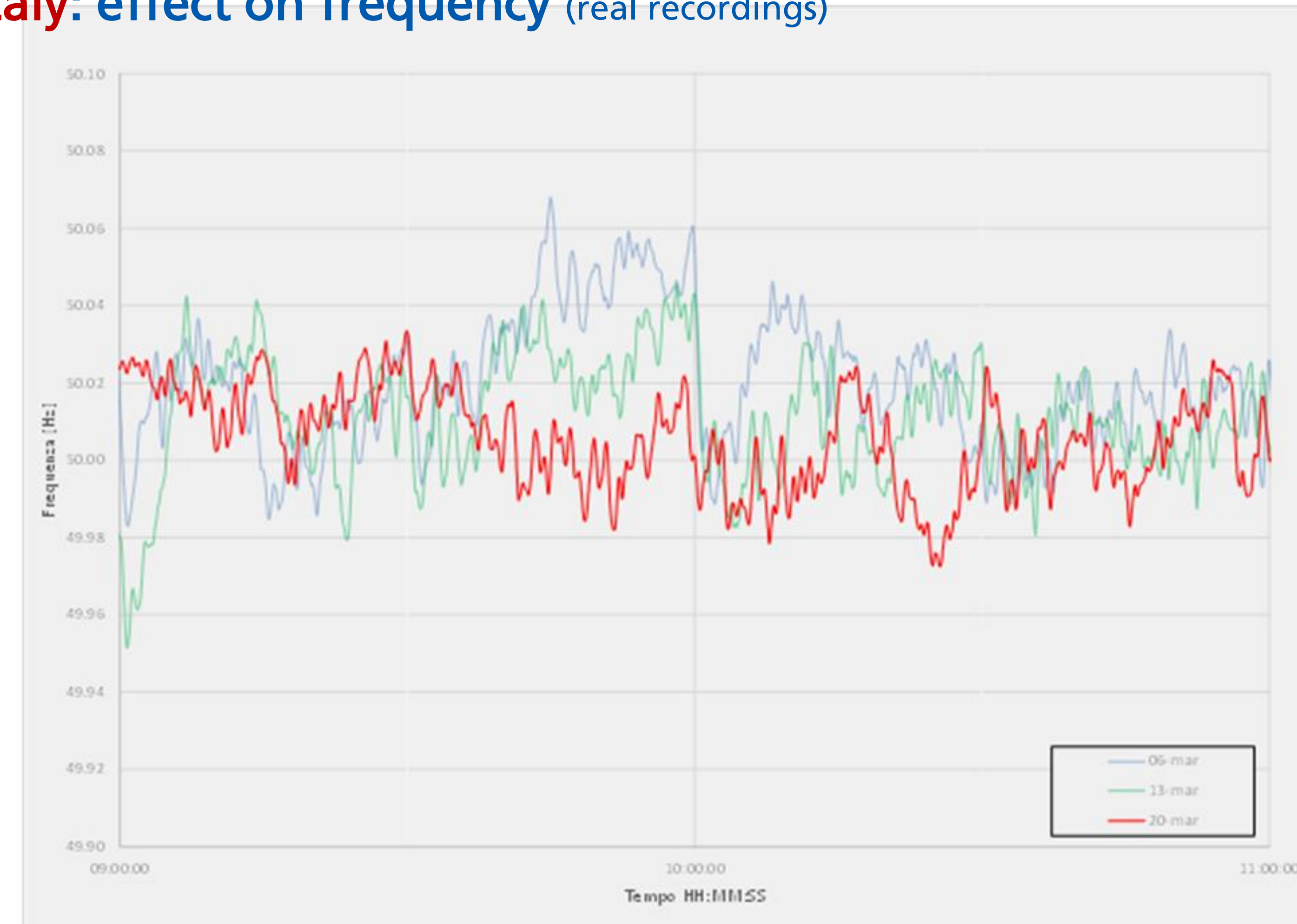
Effect on PV power infeed gradients (ex-ante simulation)



Source: ENTSOE

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

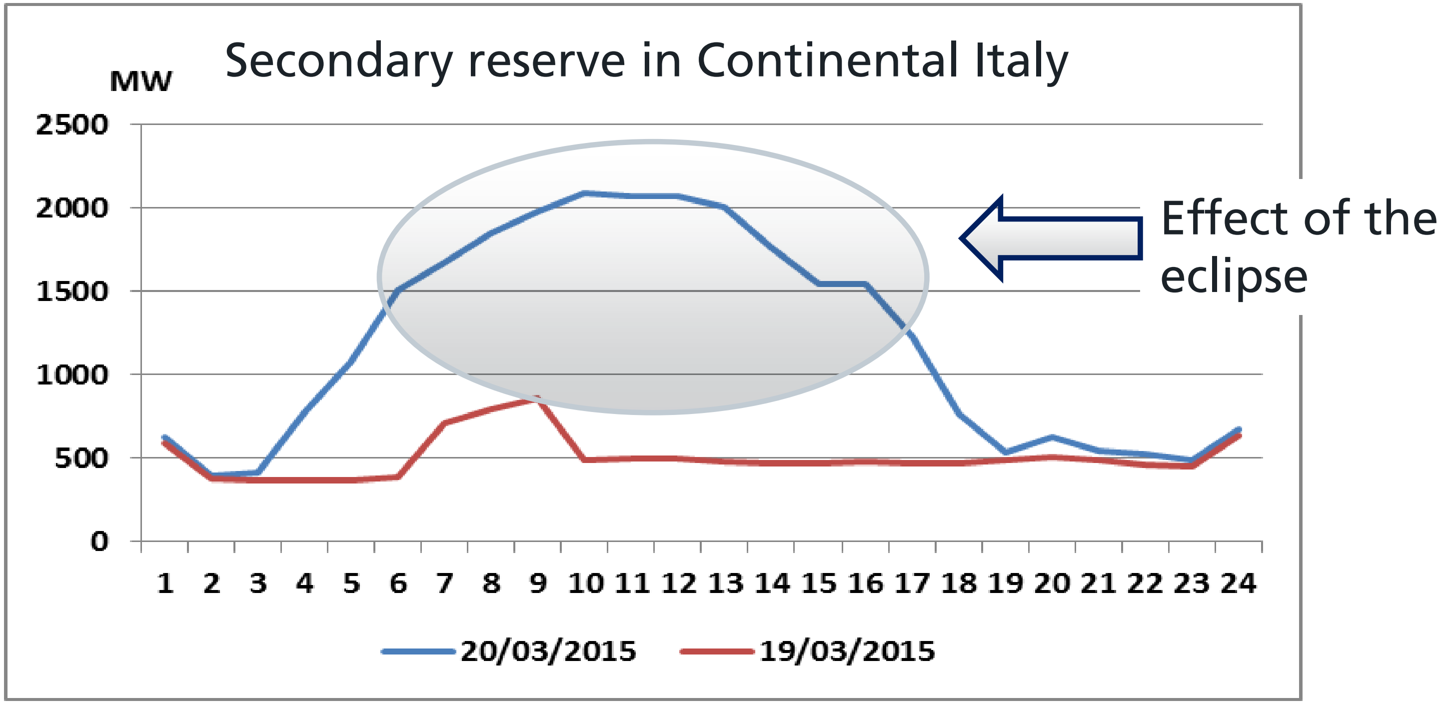
Focus on Italy: effect on frequency (real recordings)



Frequency behaviour during the minutes of max obscuration

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

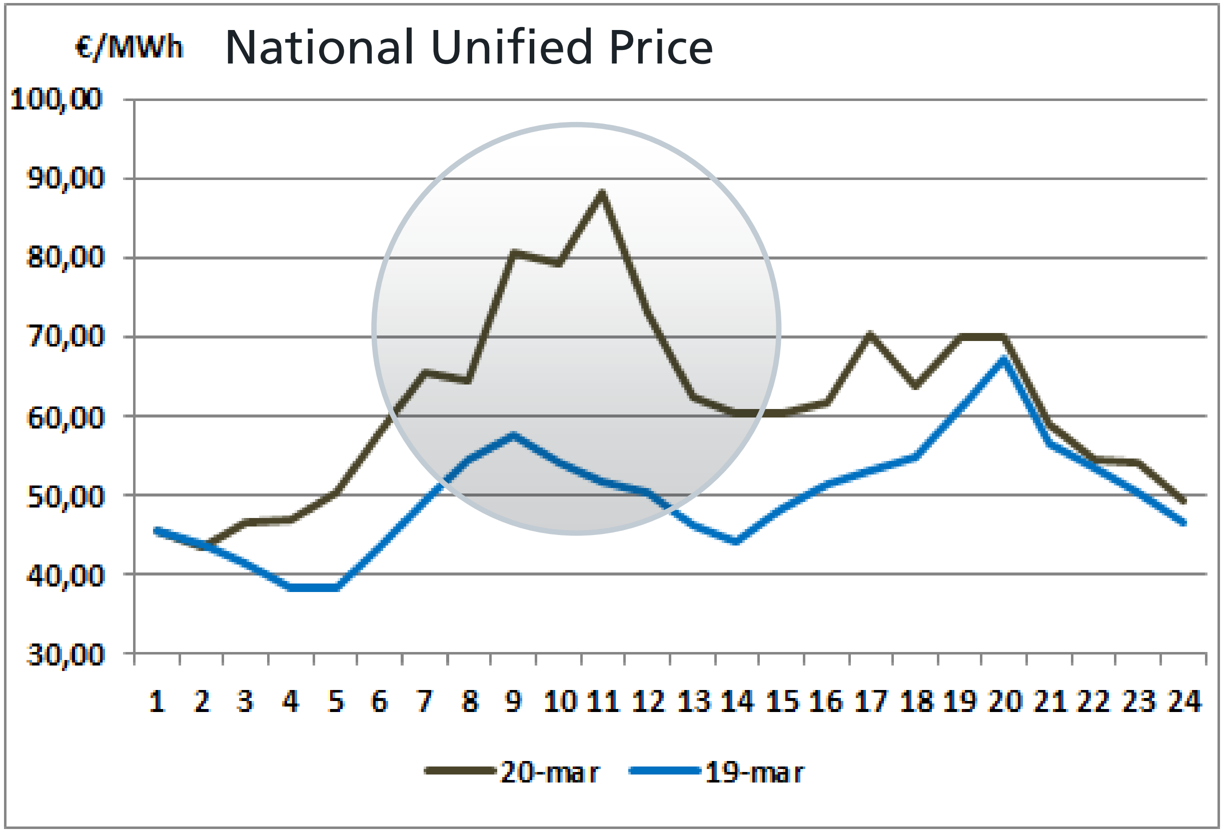
Focus on Italy: effect on ASM (secondary reserve)



Extra-cost to purchase secondary reserve (ex-ante): 1,5 M€ (+67% w.r.t. the previous day)

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

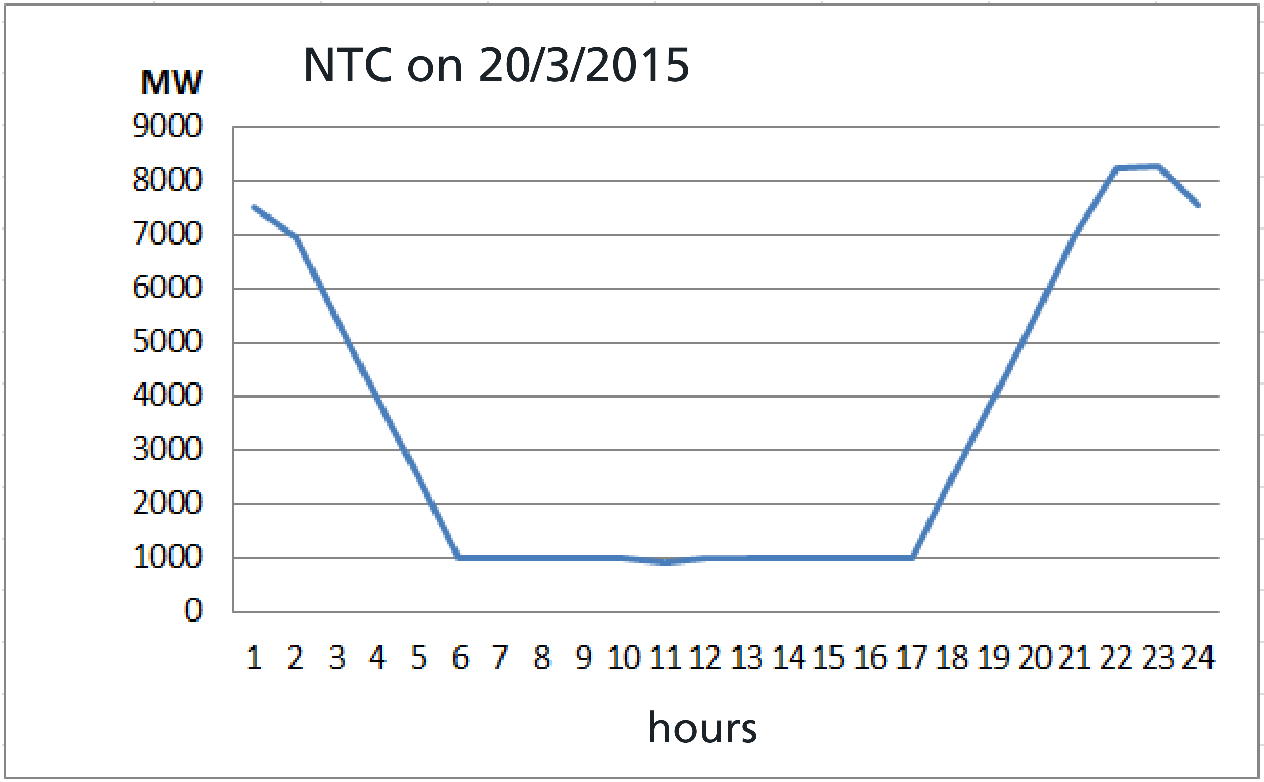
Focus on Italy: effect on Day-ahead market



Average daily Delta price: 11,5 €/MWh
Extra-disbursement for the customers: 10 M€ !

Coping with exceptional events in presence of VRE generation: the partial solar eclipse occurred in Europe on 20th March 2015

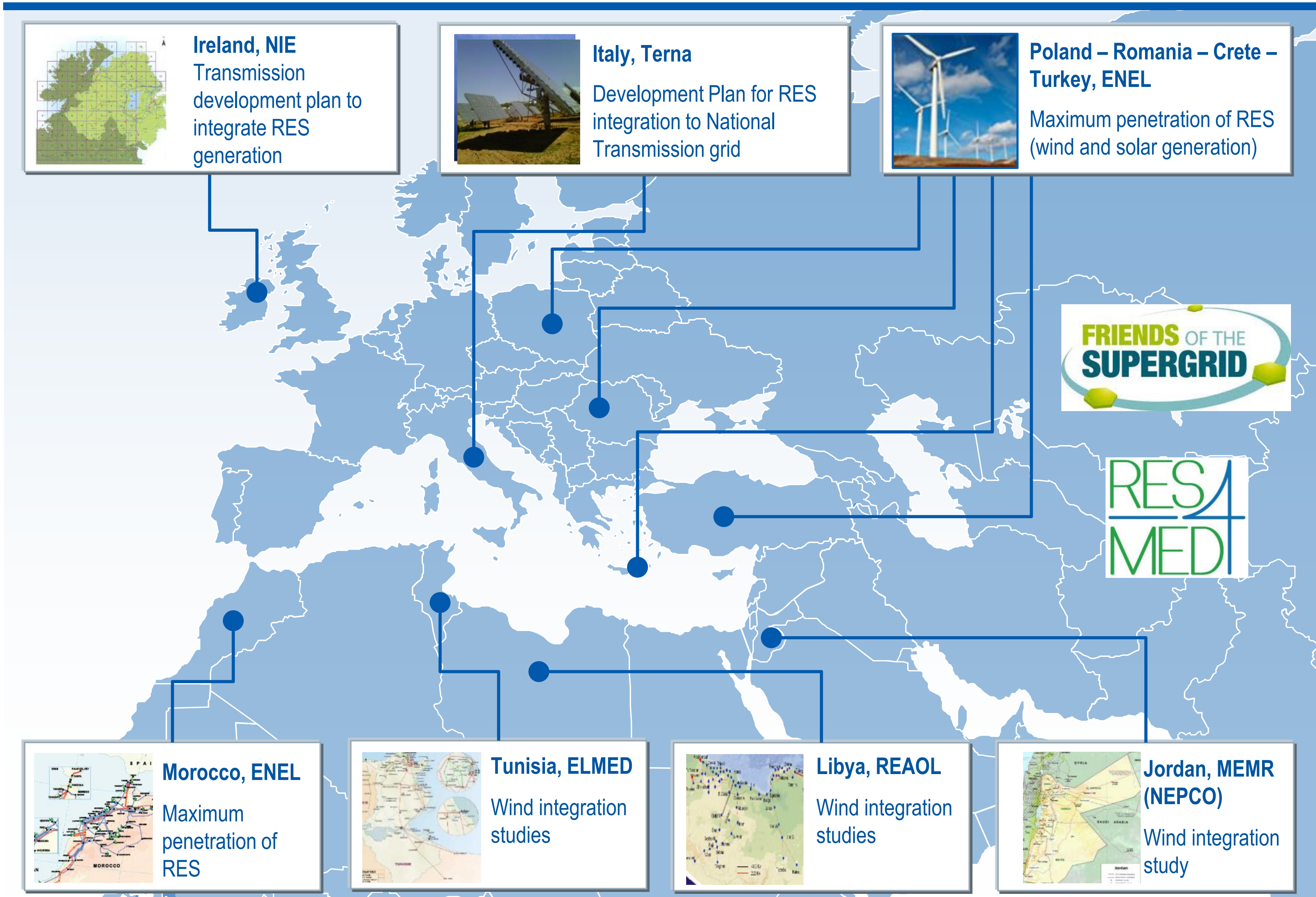
Focus on Italy: further actions taken ex-ante



Reduction of NTC for power import: down to 1 GW

Preventive disconnection of 4,4 GW PV

CESI experience



Ireland, NIE
Transmission development plan to integrate RES generation

Italy, Terna
Development Plan for RES integration to National Transmission grid

Poland – Romania – Crete – Turkey, ENEL
Maximum penetration of RES (wind and solar generation)

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Tunisia, ELMED
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Libya, REAOL
Wind integration studies

Jordan, MEMR (NEPCO)
Wind integration study

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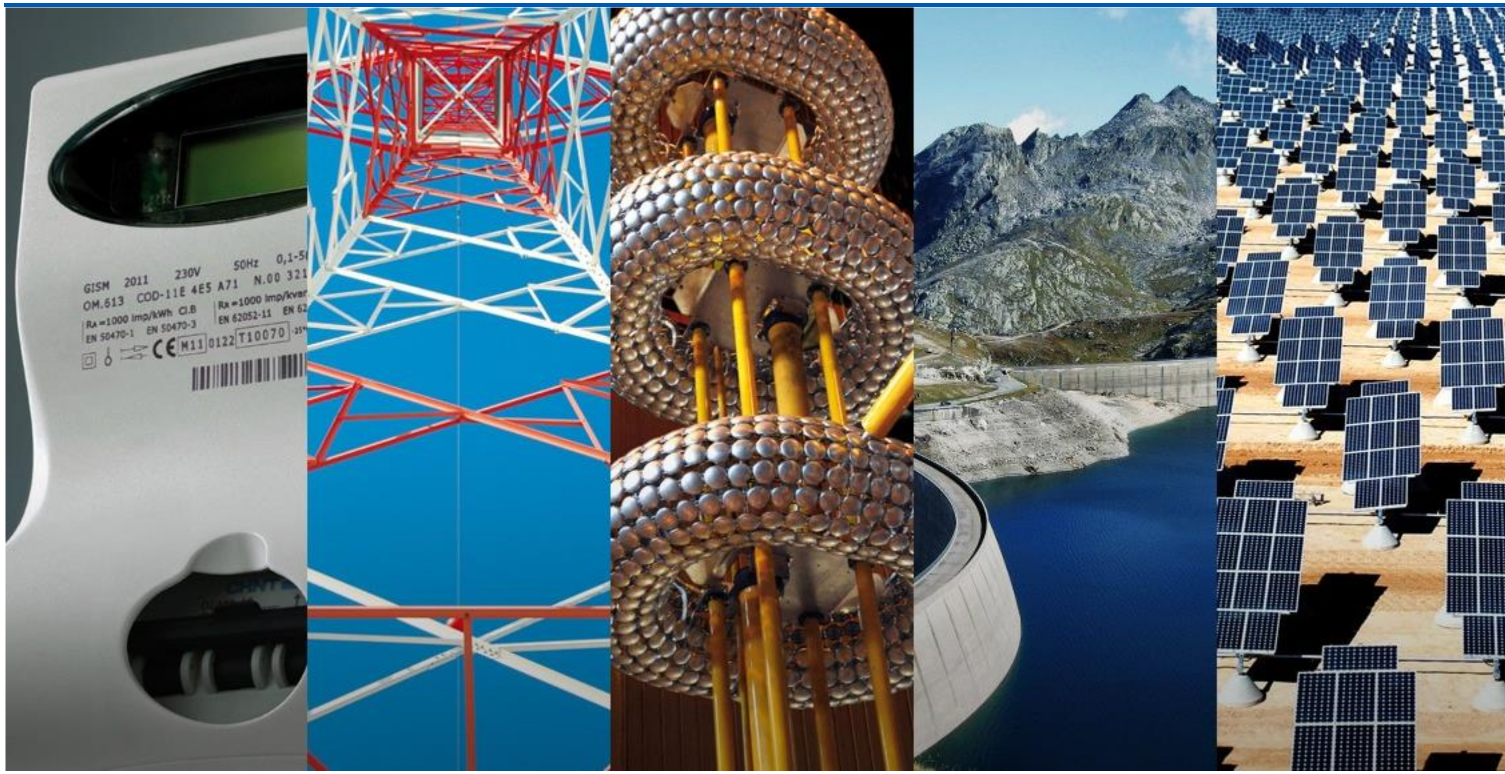

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