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Session 1
Generals and EU experience

Impact of non-programmable RES (VRE) generation on the power system

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Division Consulting, Solutions & Services

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Session 1

Generals and EU experience

- 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
  - Coping with exceptional events

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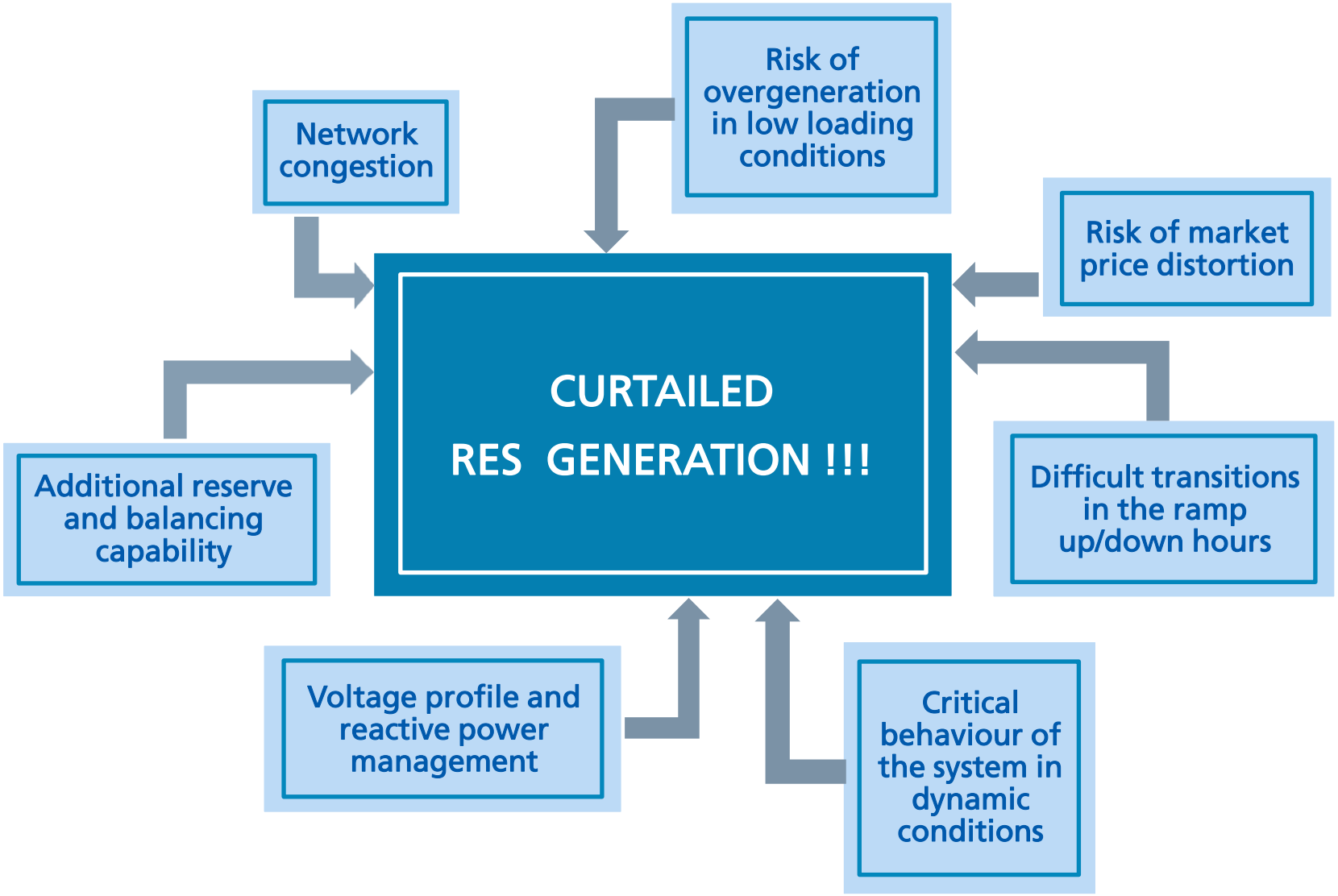
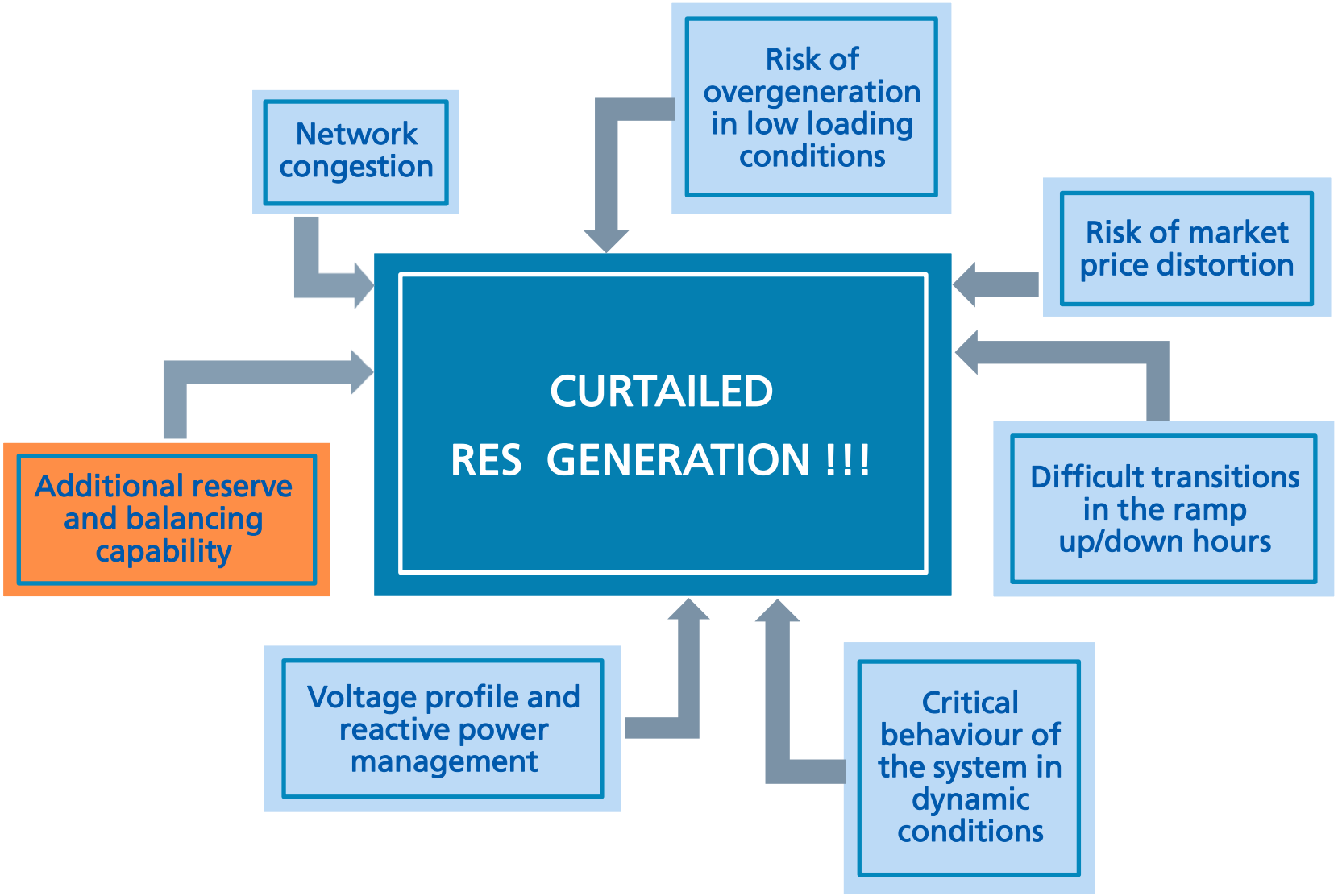
Barriers to overcome to enhance generation from non-programmable RES



Barriers to overcome to enhance generation from non-programmable RES

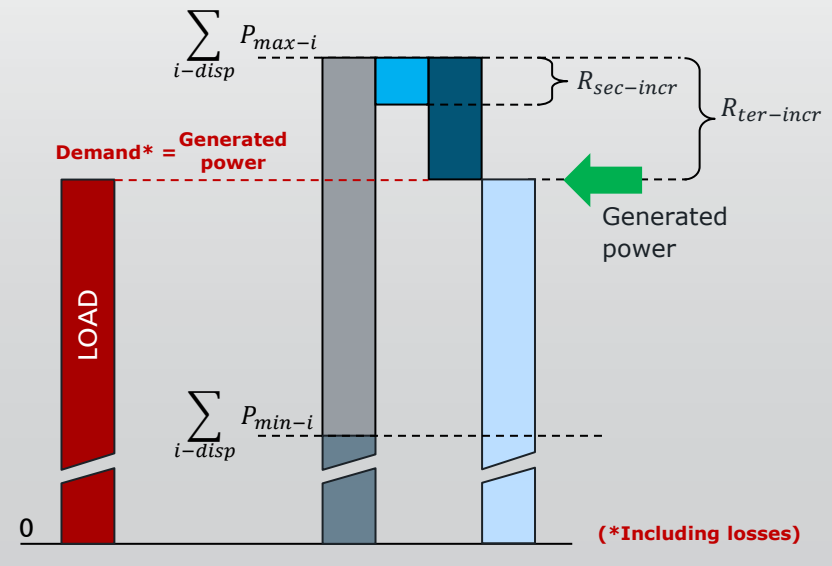


Additional Reserve and Balancing Capability

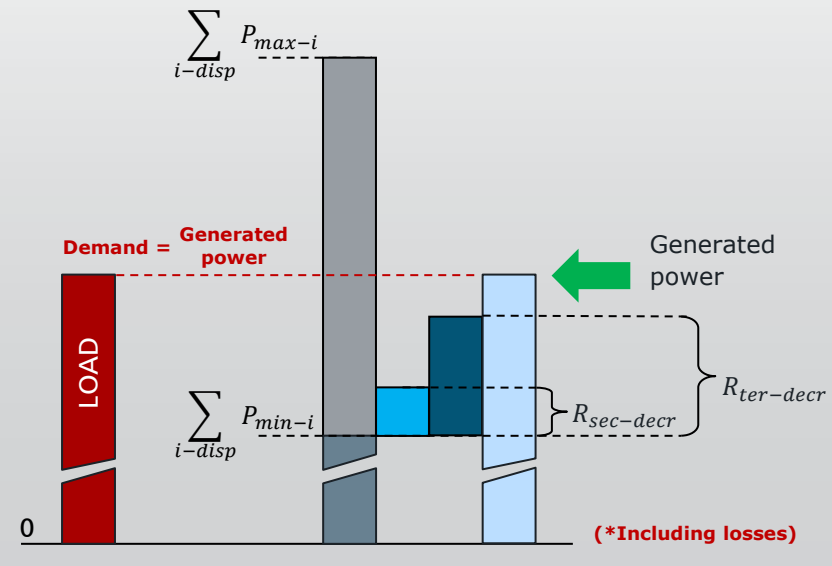
- **Secondary reserve*** $R_{sec} = \sqrt{10 \cdot L_{max} + 150^2} - 150$
- **Tertiary reserve*** $R_{ter-incr} = L_{max} \cdot 0.08$ **(daily)**

(Example of reserves according to ENTSO-E rules)*

➢ **In Peak Load condition these reserves define the maximum thermal generation**

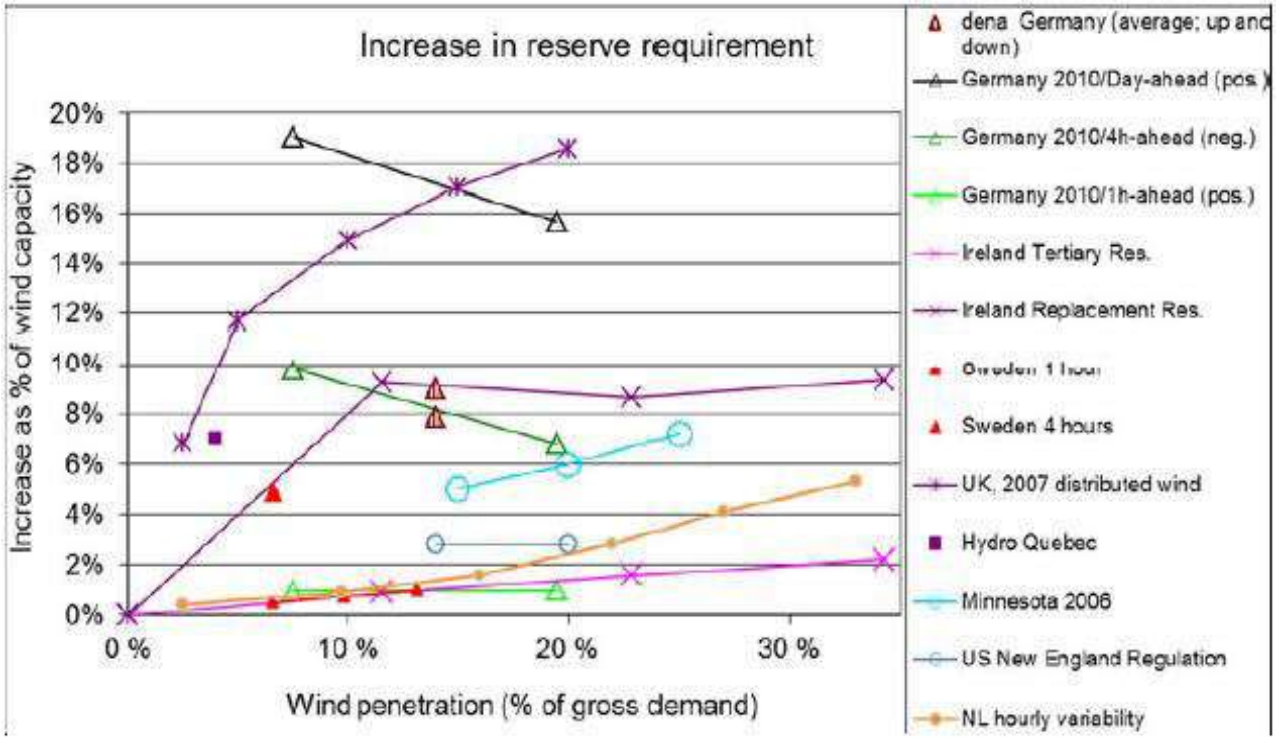


➢ **In Low Load condition these reserves define the minimum thermal generation**



Additional Reserve and Balancing Capability

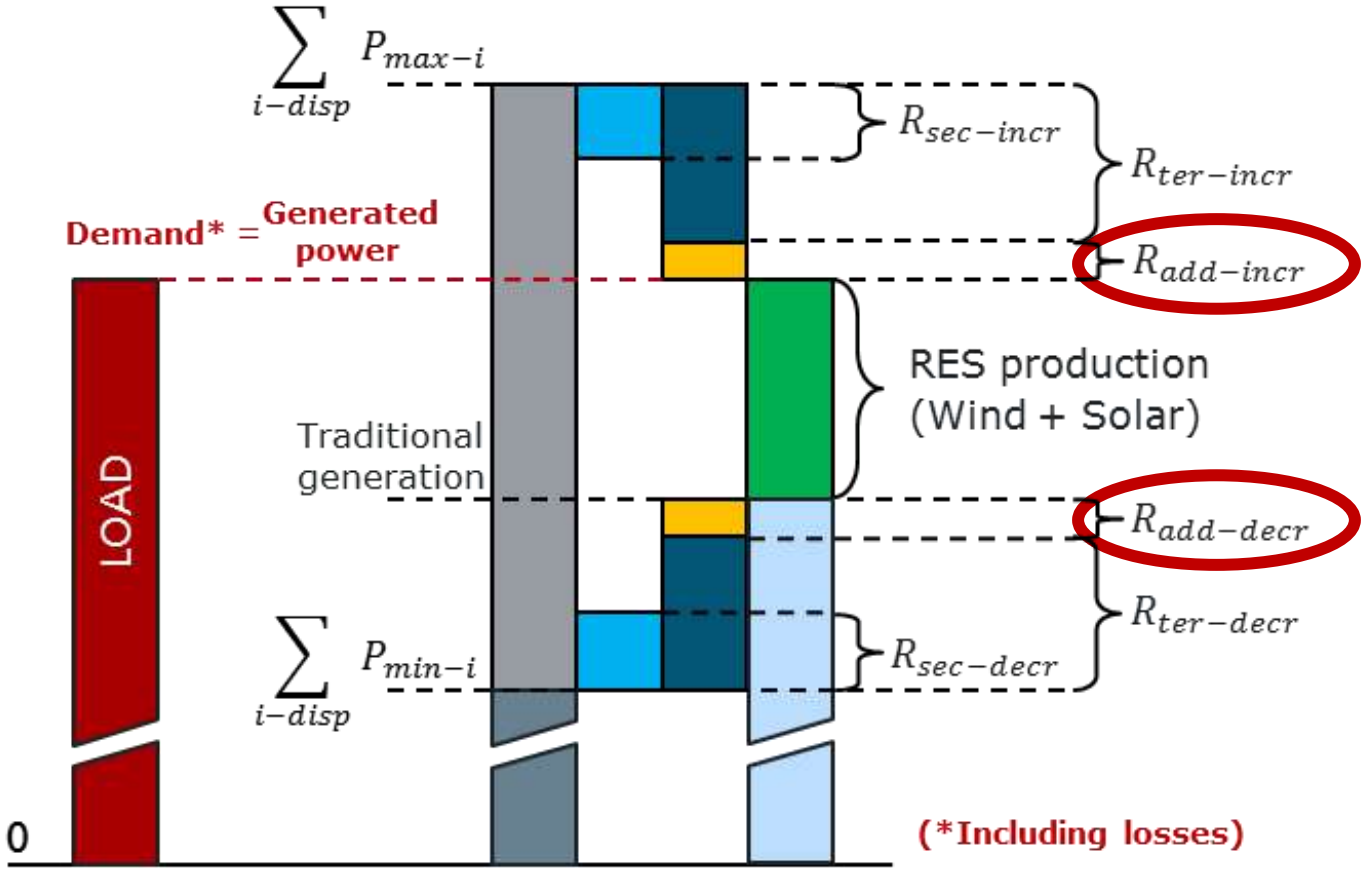
- **Need for Additional Reserve to cope with the intermittency of non-programmable RES generation**
  - Additional reserve [%]: percentage of wind generation
  - Penetration: wind production [MW] / demand



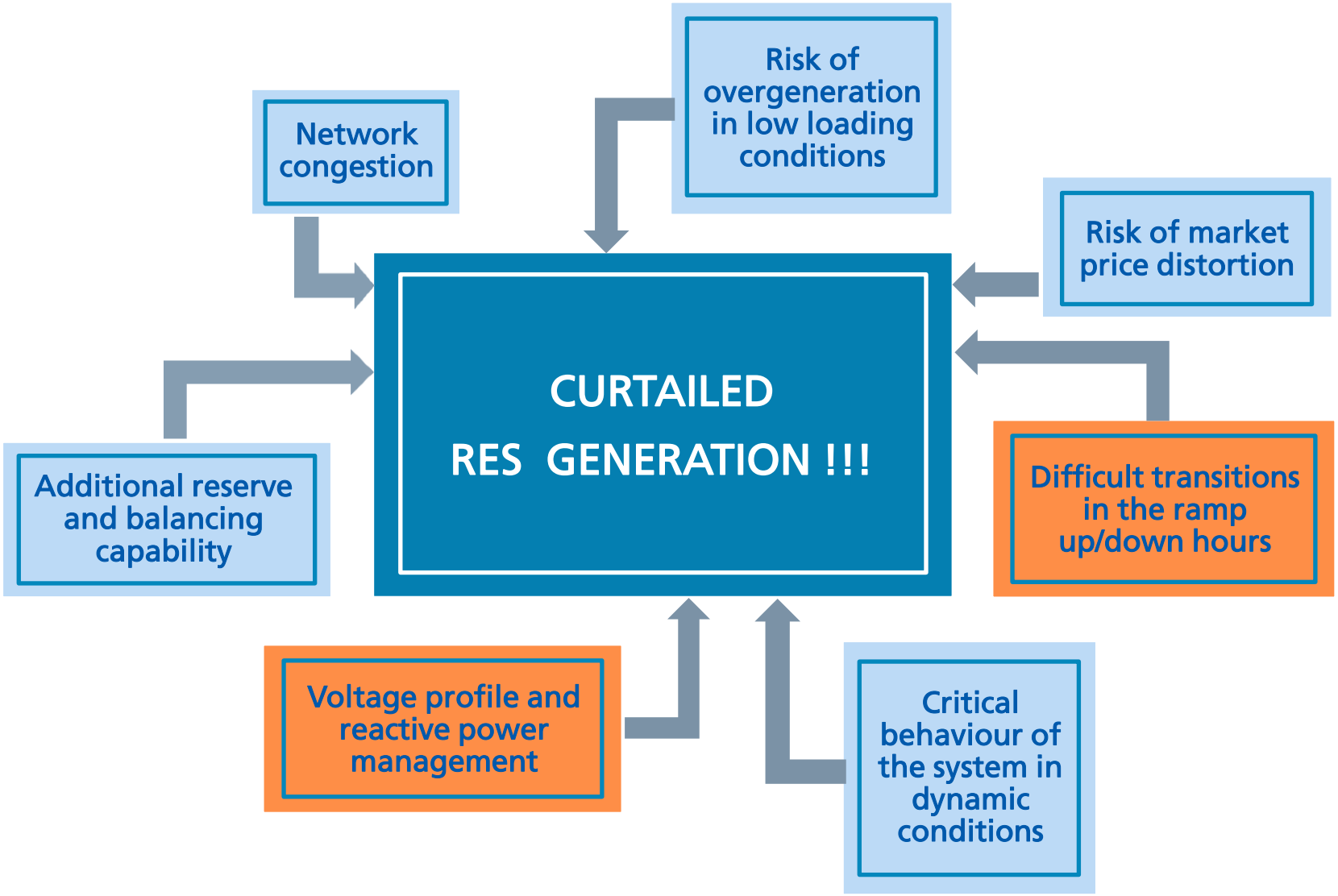
Source: IEA-Wind

Additional Reserve and Balancing Capability

- **Maximization of RES penetration considering also additional reserve**



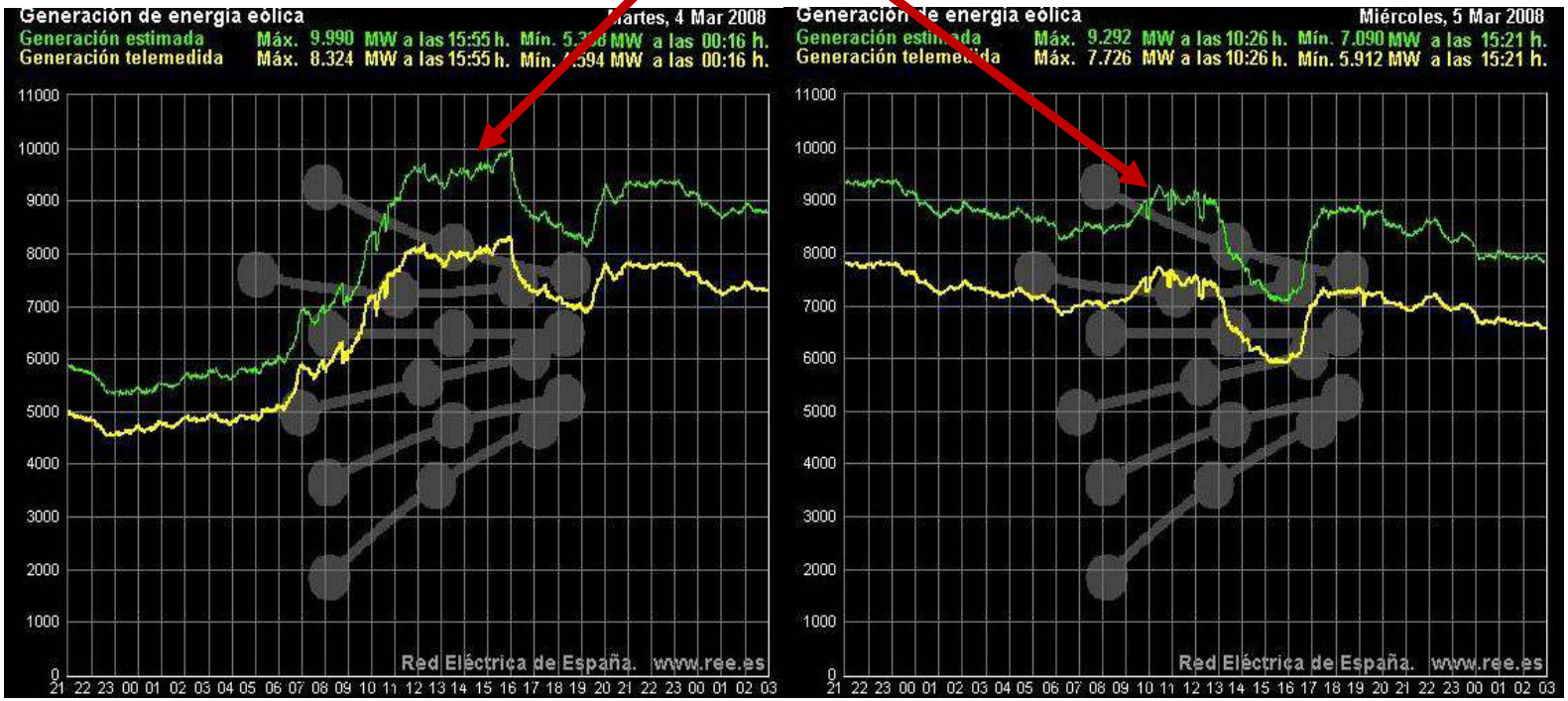
Barriers to overcome to enhance generation from non-programmable RES



Difficult upward/downward transitions

- **Possible Voltage problems**

Downward wind modulation

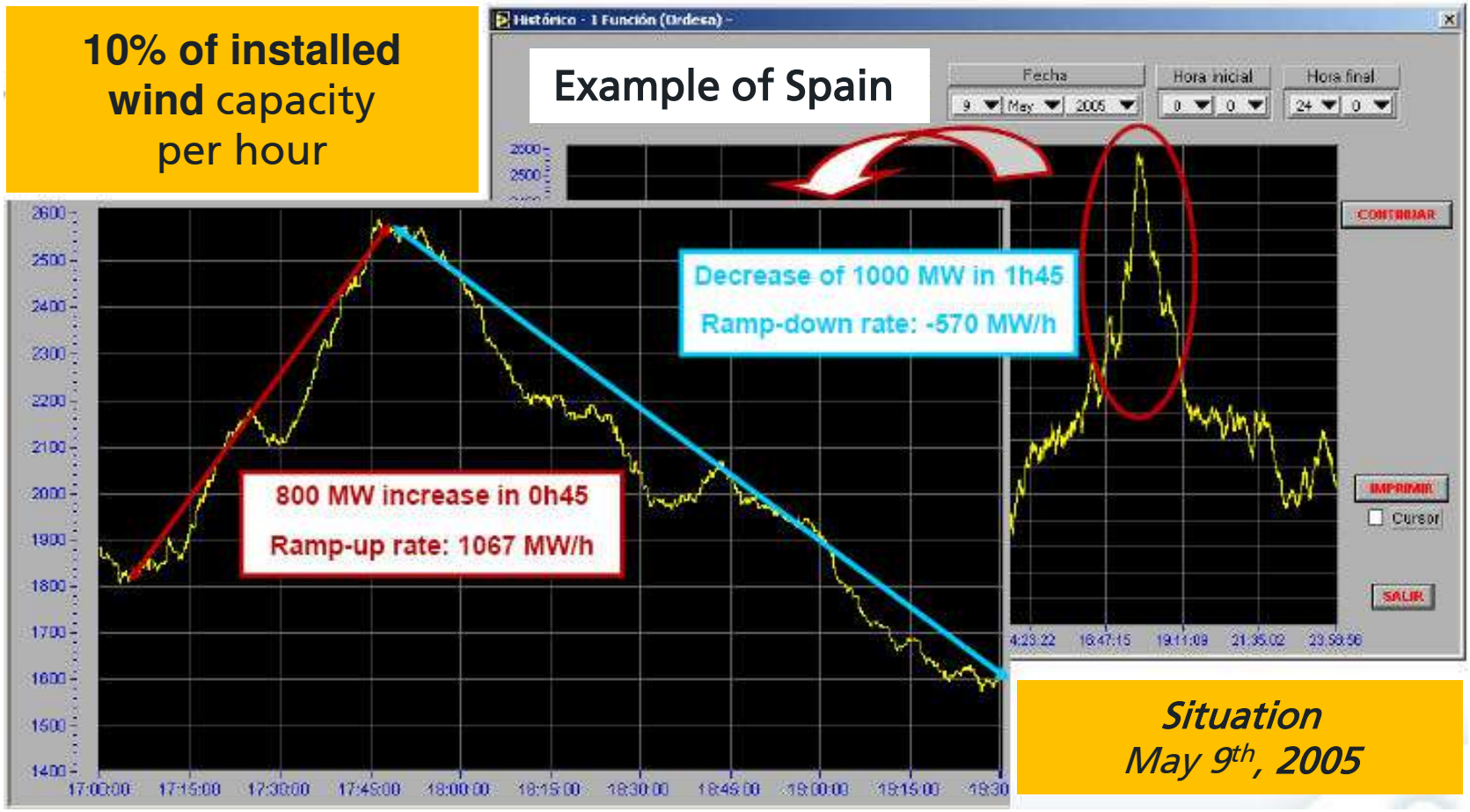


Wind generation in Spain on 4th and 5th March 2008 (source REE)

Difficult upward/downward transitions

- **Coping with sharp variations of RES generation**

10% of installed wind capacity per hour

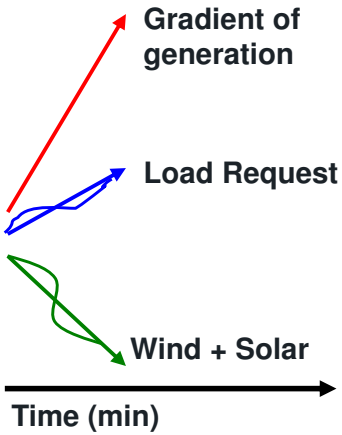


Situation
May 9th, 2005

Difficult upward/downward transitions

No correlation between Wind generation and demand!!!

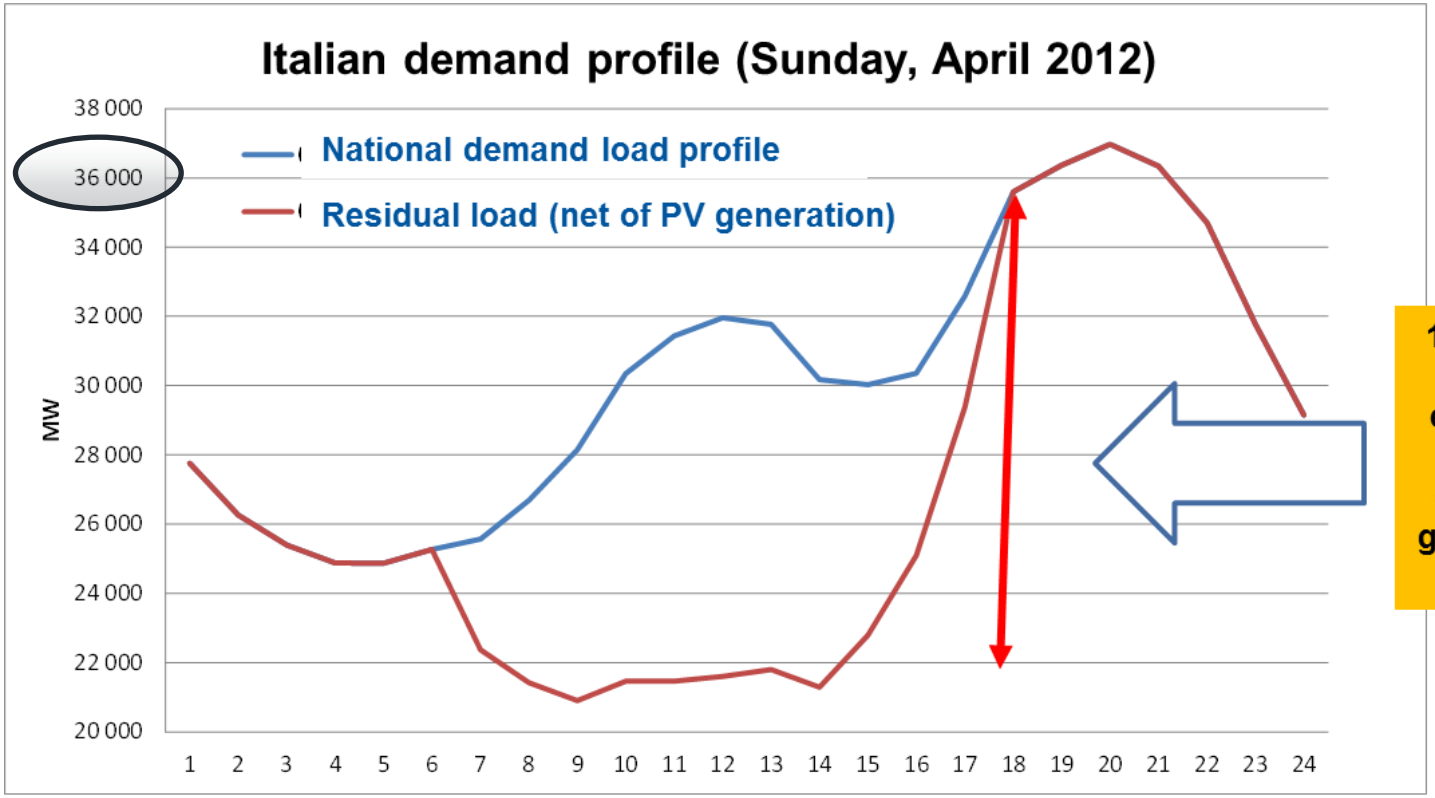
Difficult transitions during load ramp up/down



(Example of Spain)

Difficult upward/downward transitions

- **Load following in case of enhanced PV generation (1/2)**

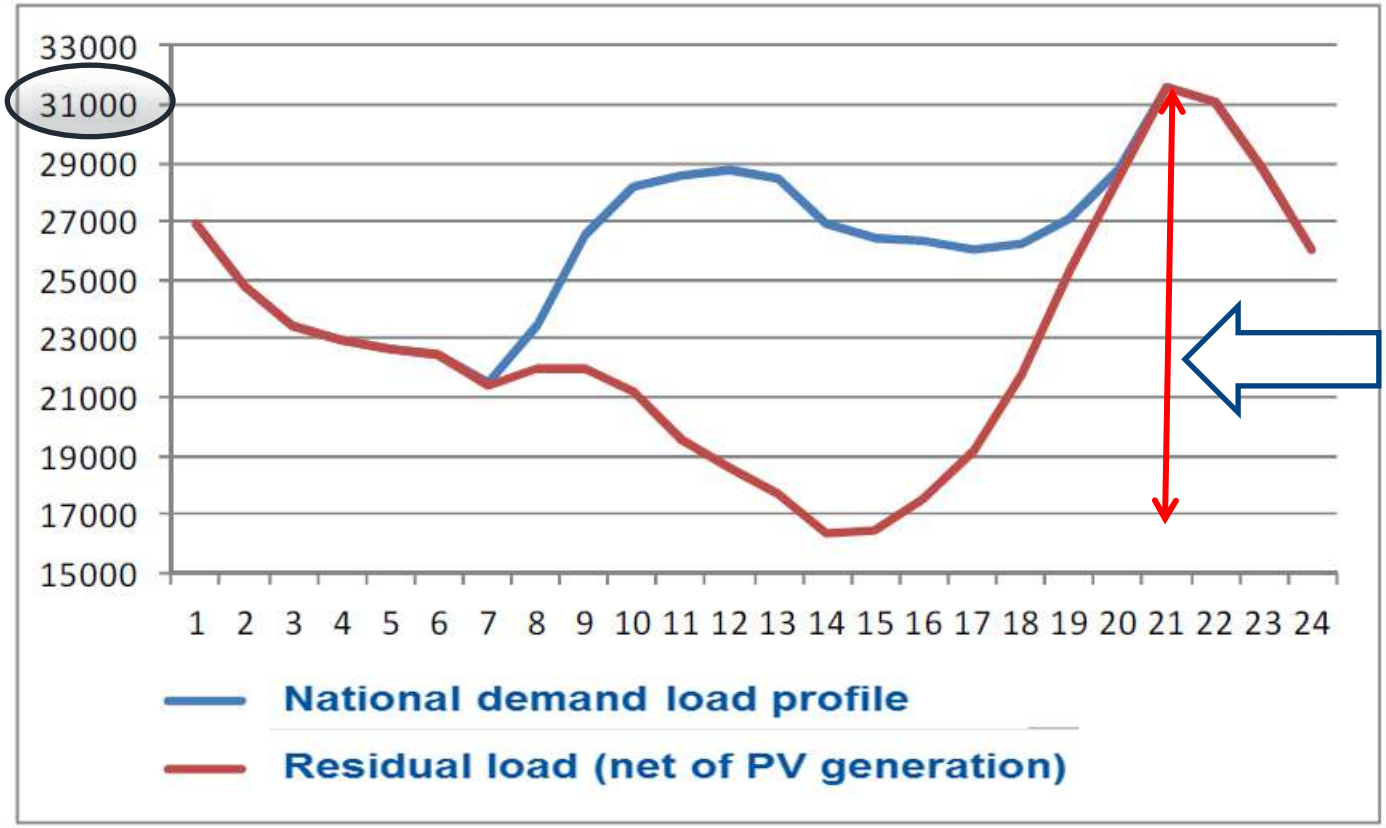


14 GW of load ramp in the evening to be covered by dispatchable generation and import

Difficult upward/downward transitions

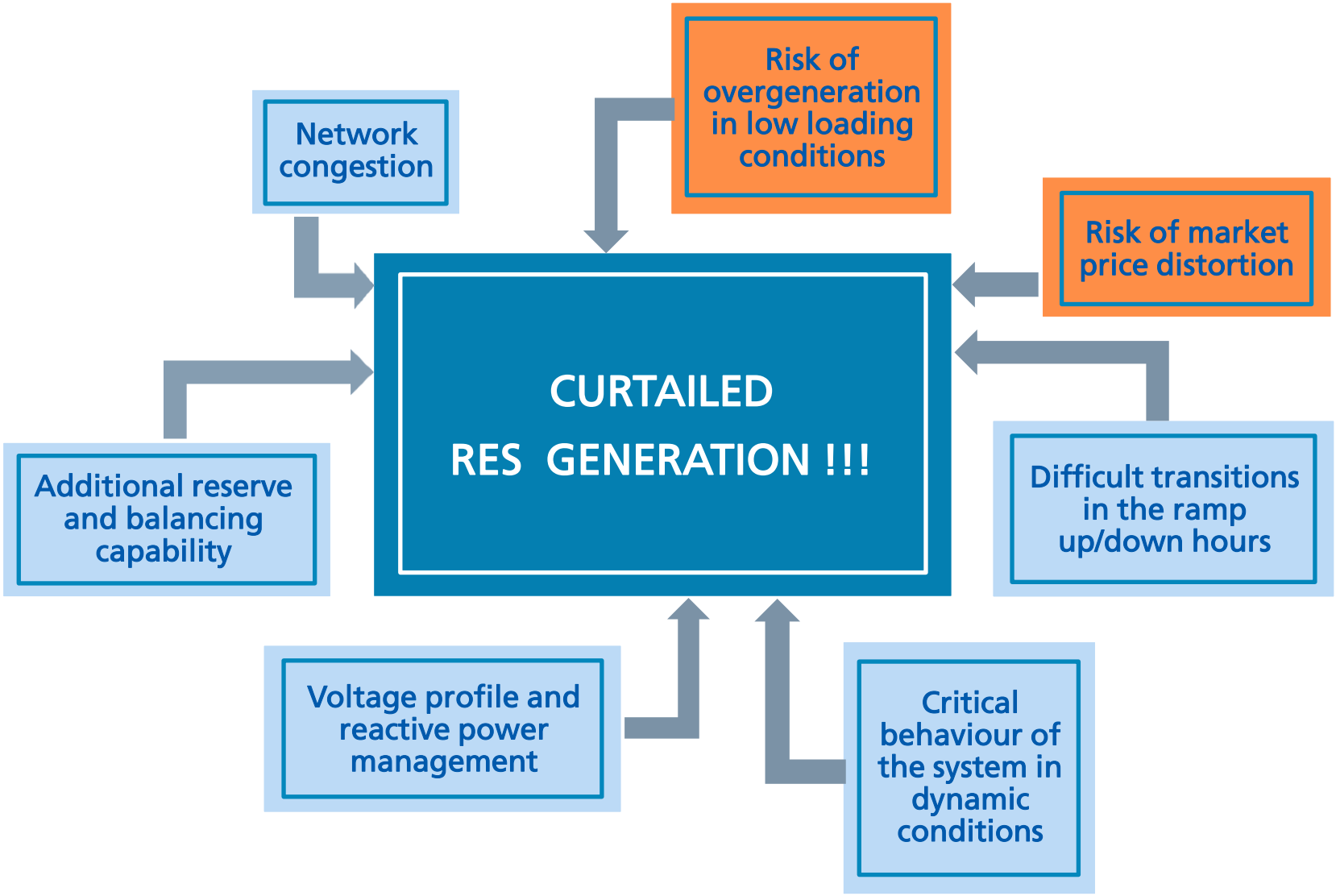
- **Load following in case of enhanced PV generation (2/2)**

Italian demand profile in a typical Summer Sunday in 2014

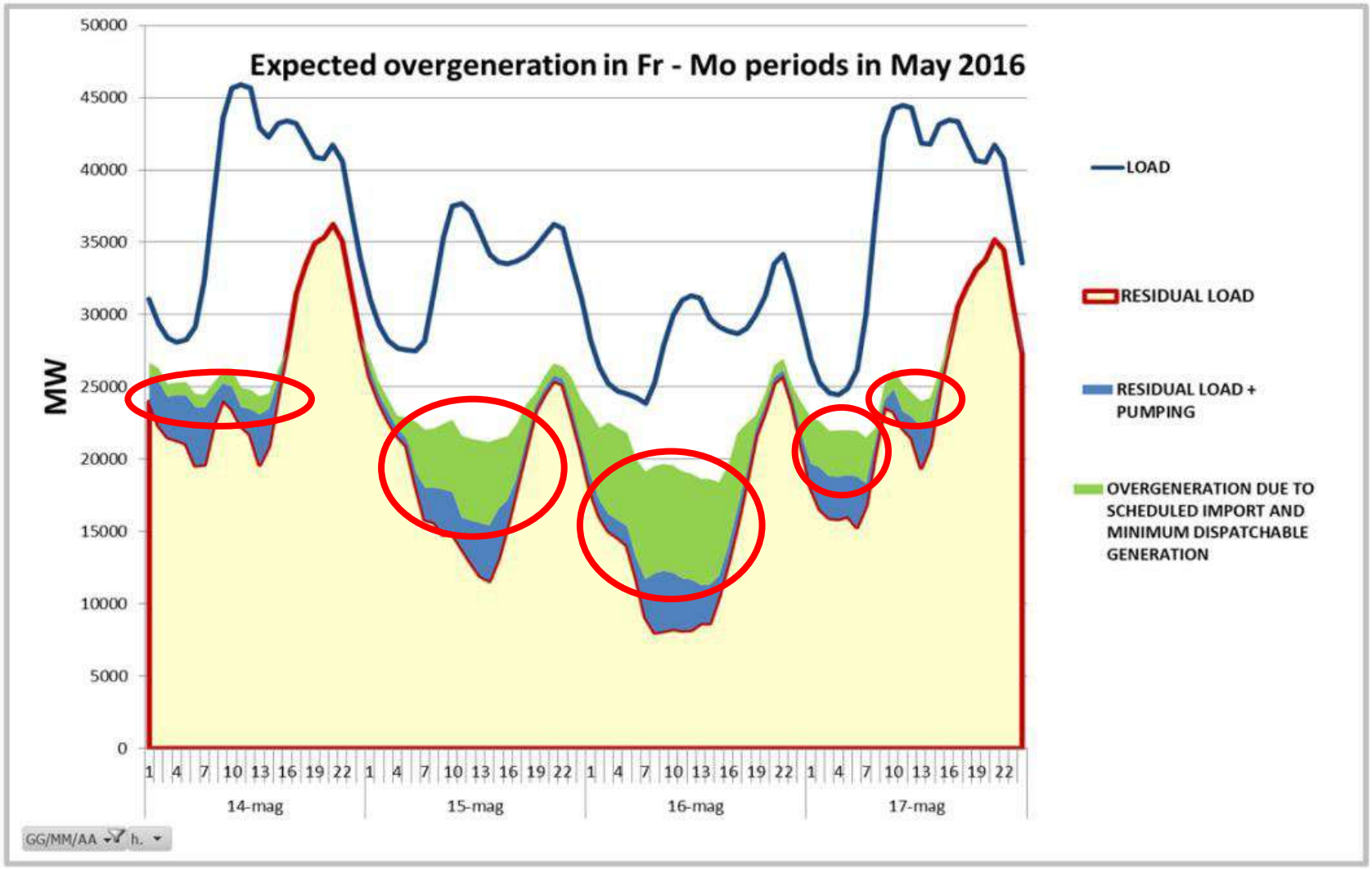


15 GW of ramp in the afternoon to be covered with a reduced set of dispatchable units (see reduced peak load)

Barriers to overcome to enhance generation from non-programmable RES

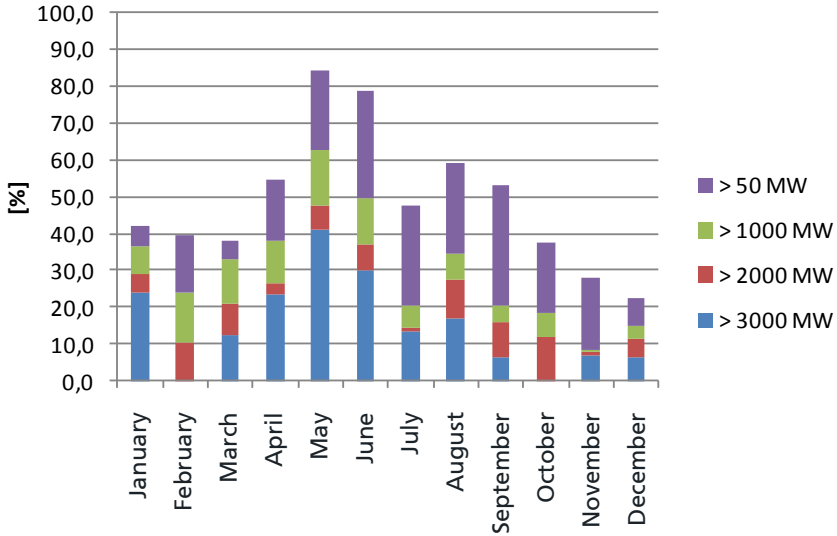


Risk of overgeneration



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:

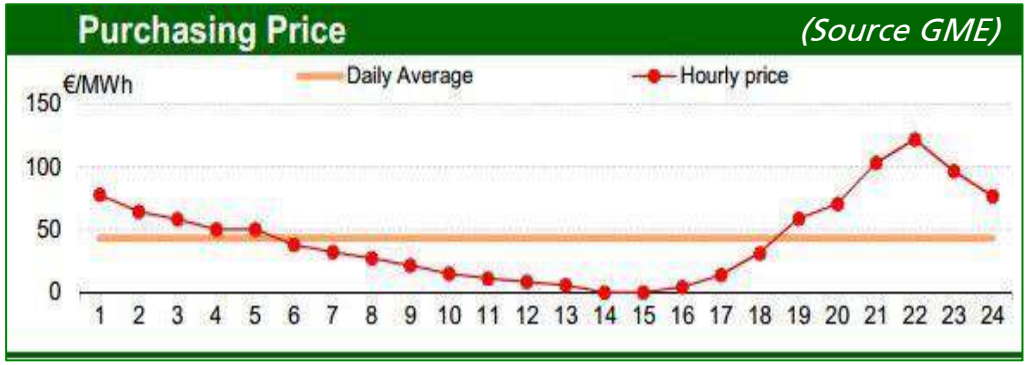
- Full exploitation of existing resources (maximizing existing pumping, reduction of power imported from neighbouring countries)
- Modulation of non-programmable RES generation
- Improve the forecast and management of distributed generation (on-site generation)
- Increase of energy storage capacity

Source: Terna

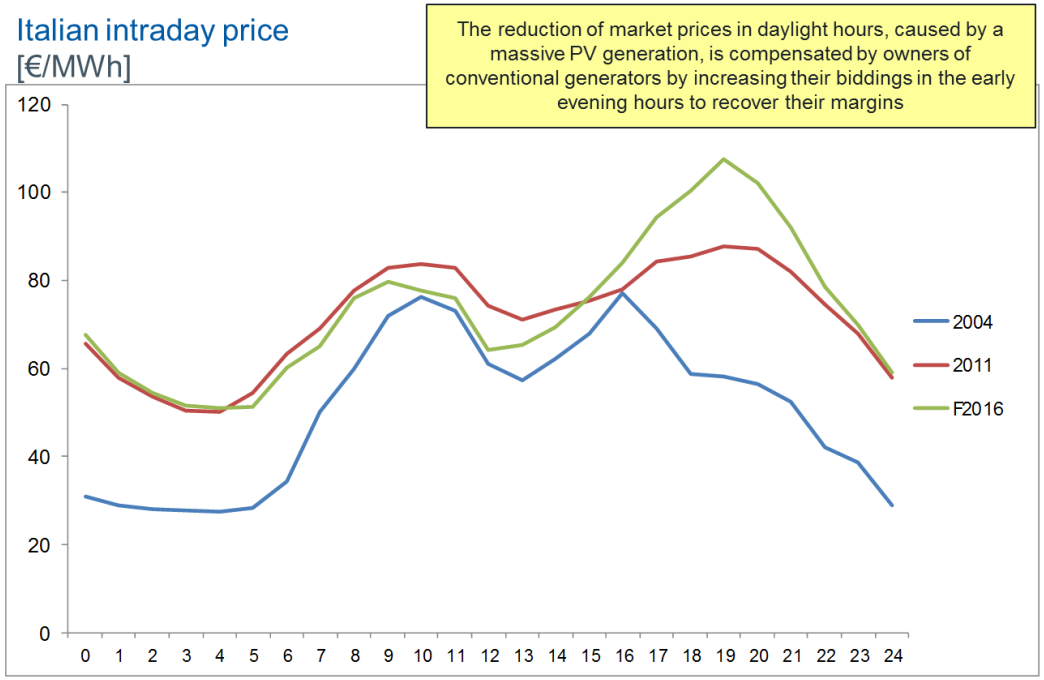
Impact on power market mechanisms
Example of Italian market

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)

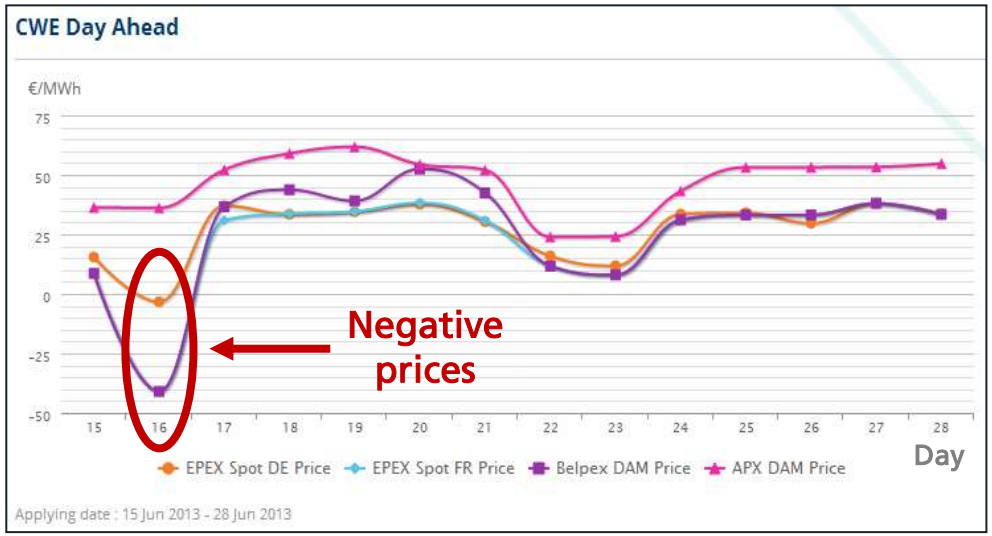


Italian intraday price [€/MWh]



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



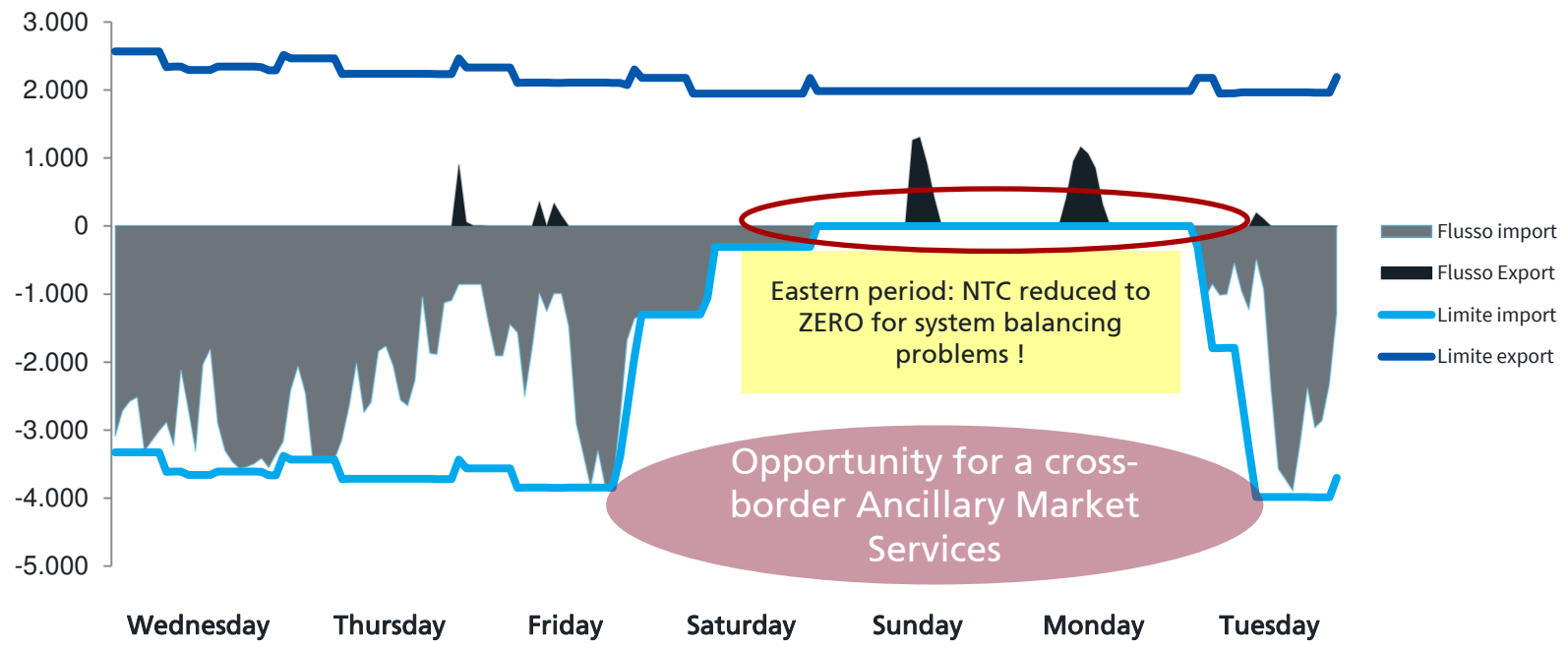
- **Low consumption and high levels of "non-flexible generation" (nuclear, hydro, wind, PV) in France, Germany and Belgium caused a generation surplus**

- **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

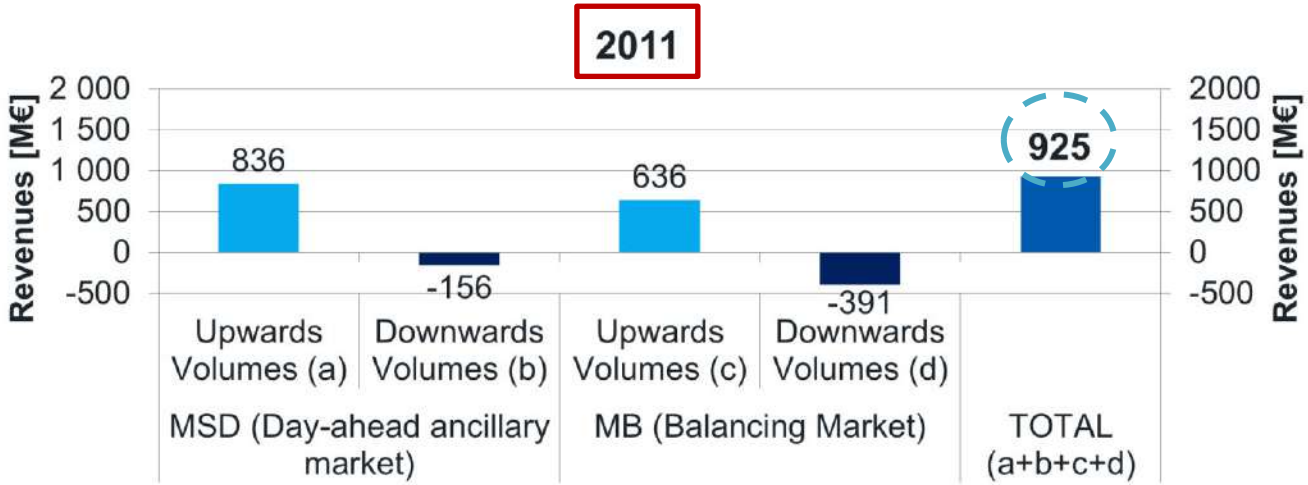
Impact on NTC arising from non-programmable RES (VRE) generation

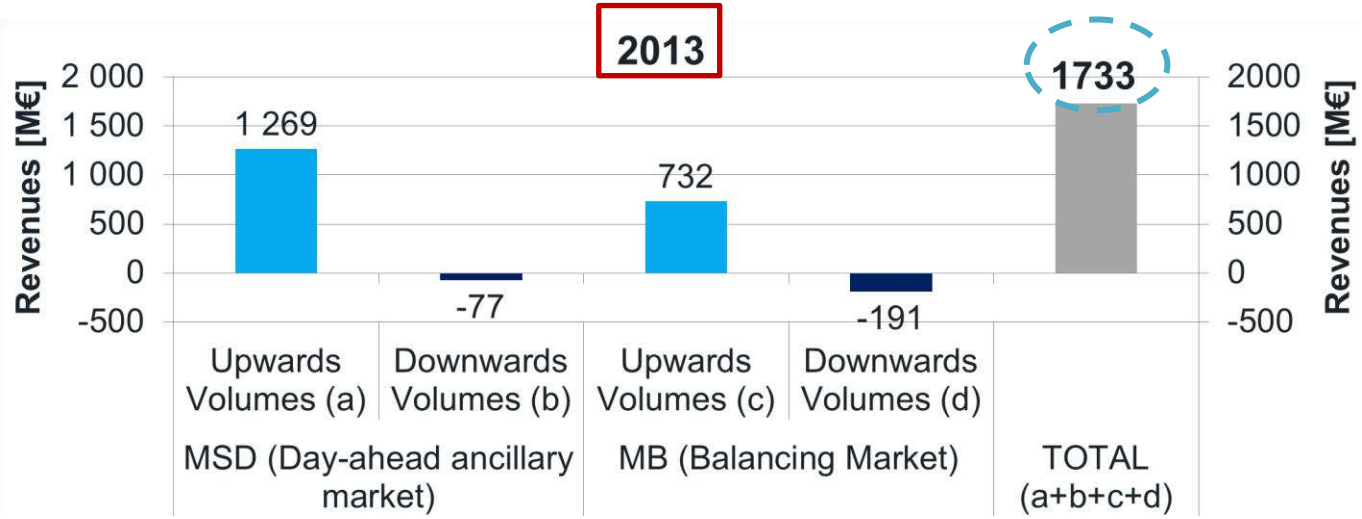
Net Transfer Capacity on the three borders (Slovenia, France, Austria) 01/04/2015-07/04/2015



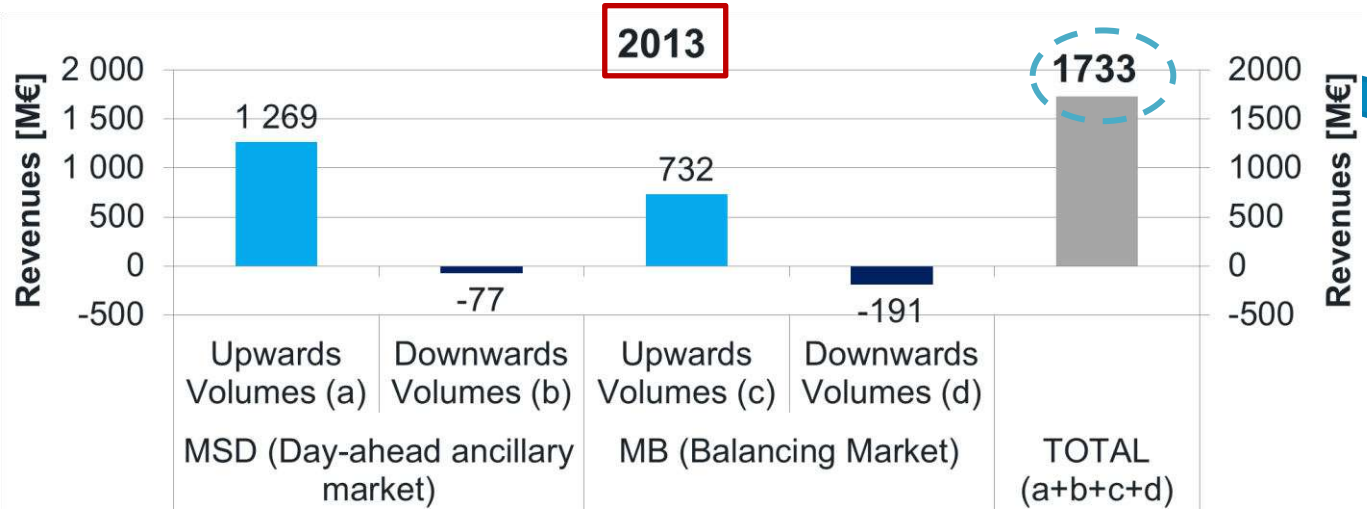
Over Generation in 2024 due to VRE 5.5 TWh/yr – possibility to reduce it to 700GWh/yr through modulation of the cross-border exchanges for balancing

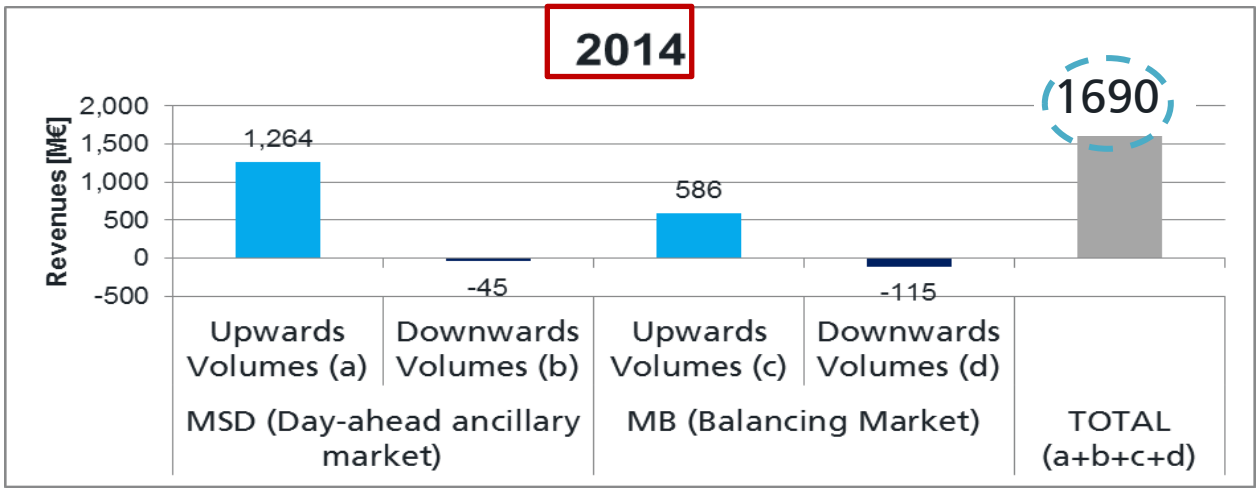
Impact of RES generation on the Ancillary Services Market





Impact of RES generation on the Ancillary Services Market

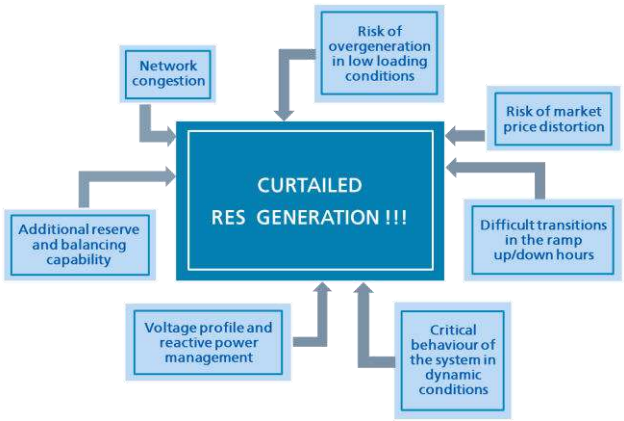




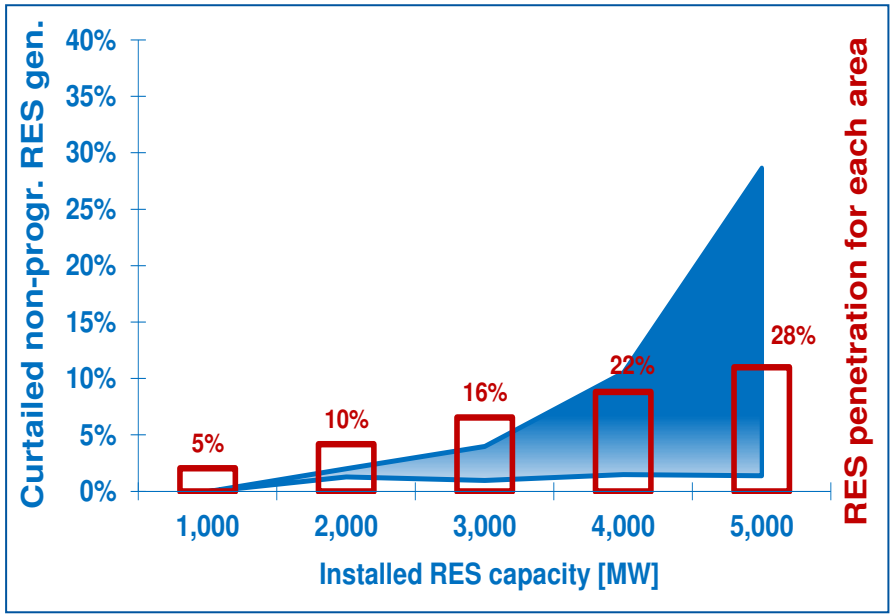
Disbursement in ASM stabilised in 2014 due to action taken by TSO and a slow down in RES generation installation.

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



Session 1

Generals and EU experience

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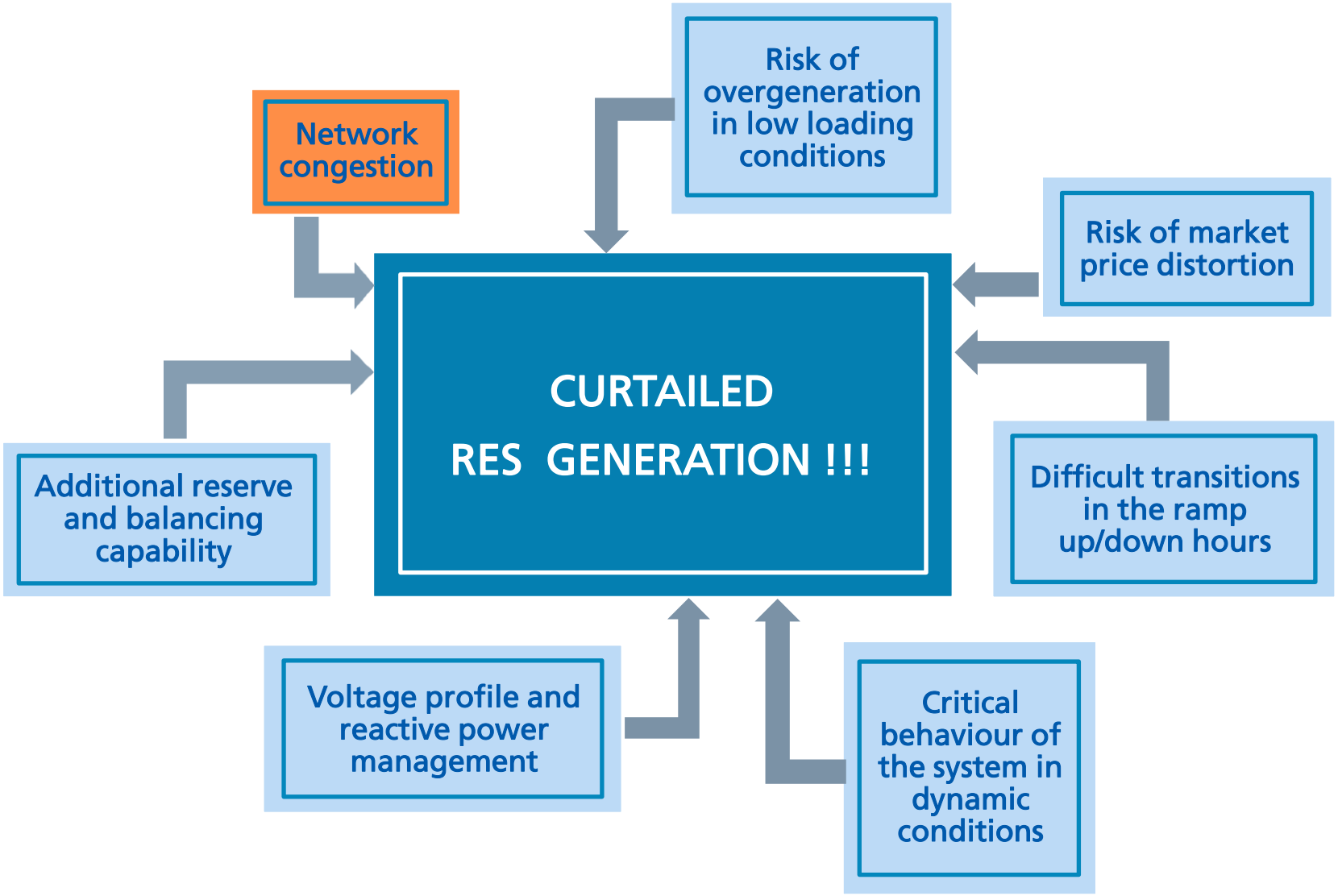
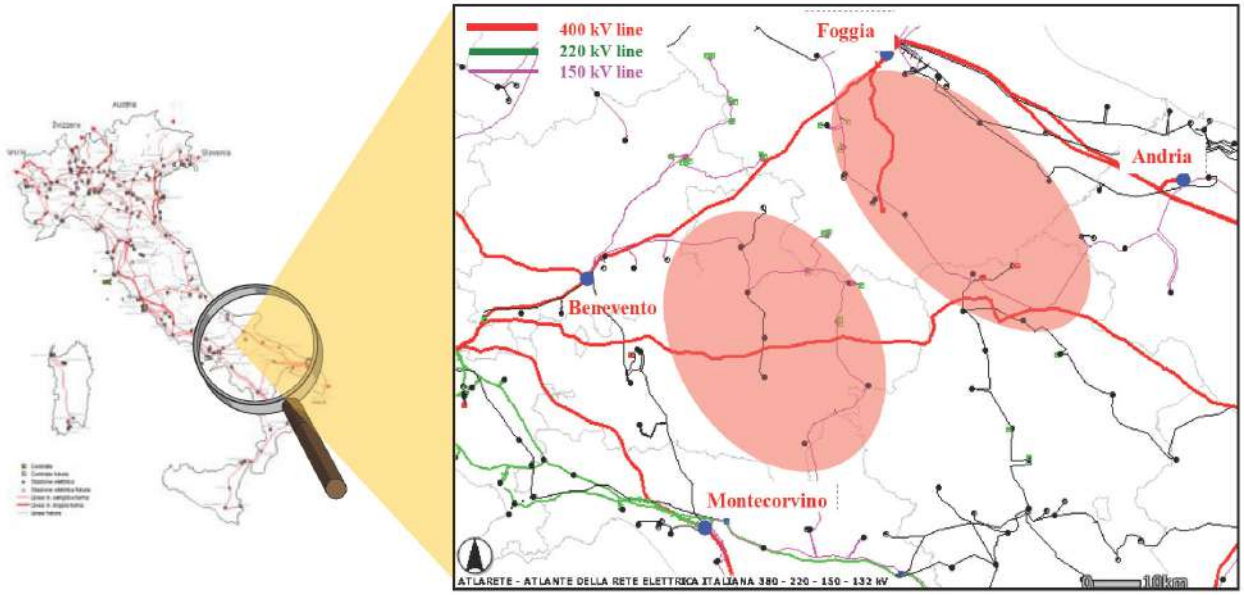
Barriers to overcome to enhance generation from non-programmable RES



Network congestion caused by RES generation

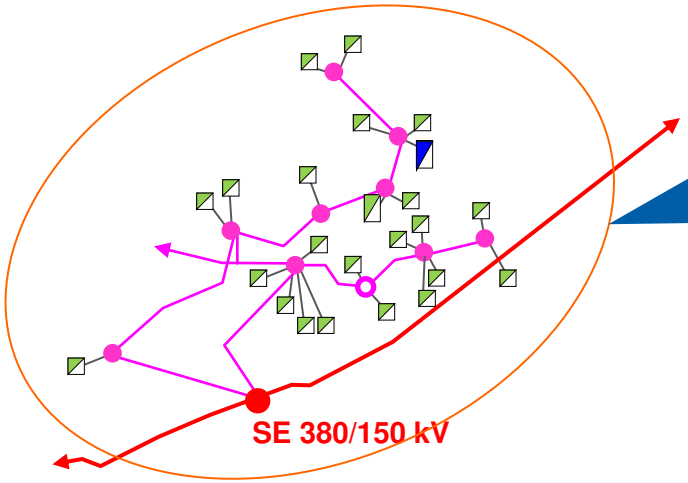
- **Wind location dependent – often remote locations w.r.t. the demand centres**
- **No correlation between demand and non-programmable RES generation location - power flowing on longer patterns through the network with risk of creating "scattered" congestion also relatively far away from RES generation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



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

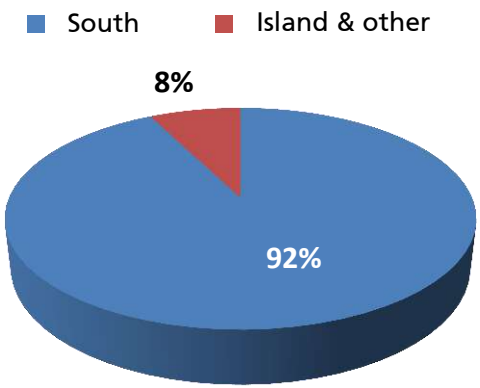
Network congestion caused by RES generation
Example of Italian system (1/2)

- **Overloads in the High Voltage network (150kV)**



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

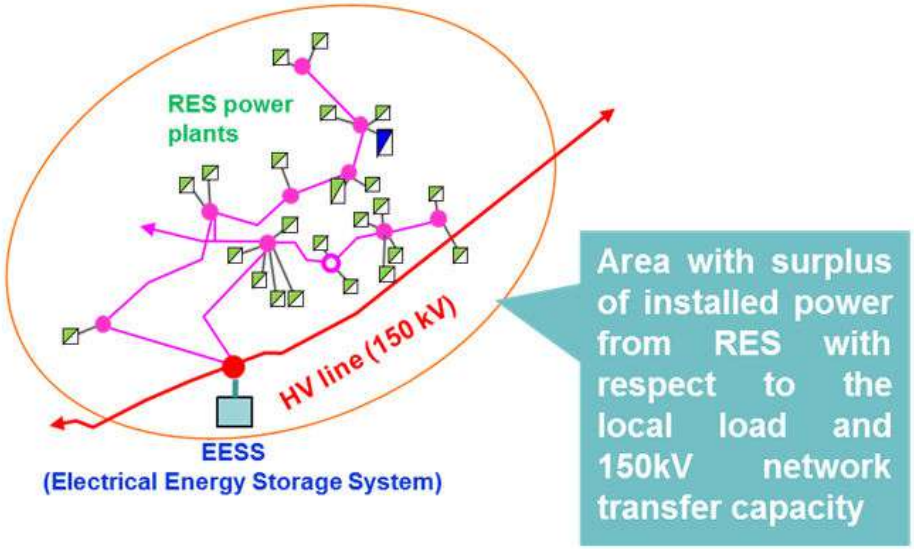
- **RES production constraints:**
  - The secure and reliable operation of the HV transmission network (150 kV)
  - Line overloads in the 150 kV network when high productions from RES occurred
  - Network developments needed to solve some critical conditions in the Extra High Voltage (EHV) network



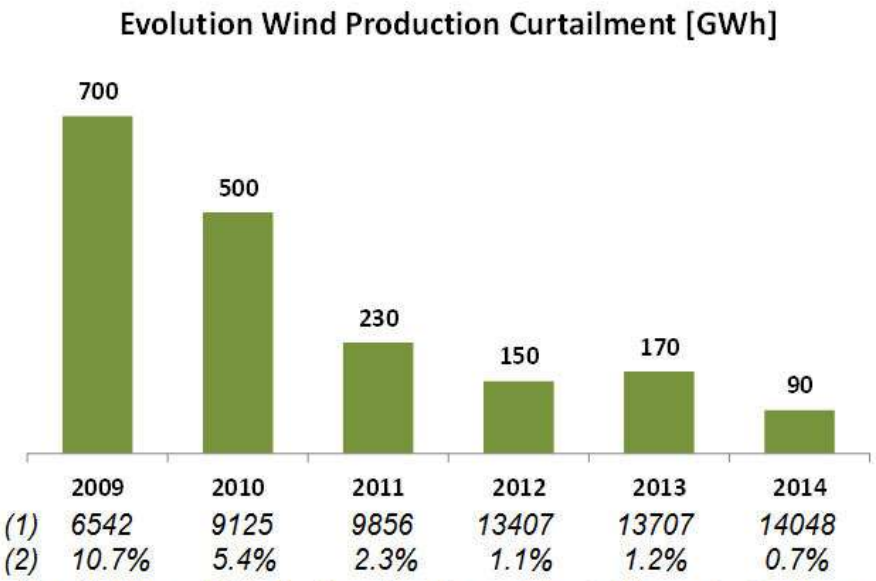
Source: Terna

Network congestion caused by RES generation
Example of Italian system

- **Effect on wind generation curtailments due to actions on transmission grid and local energy storage**



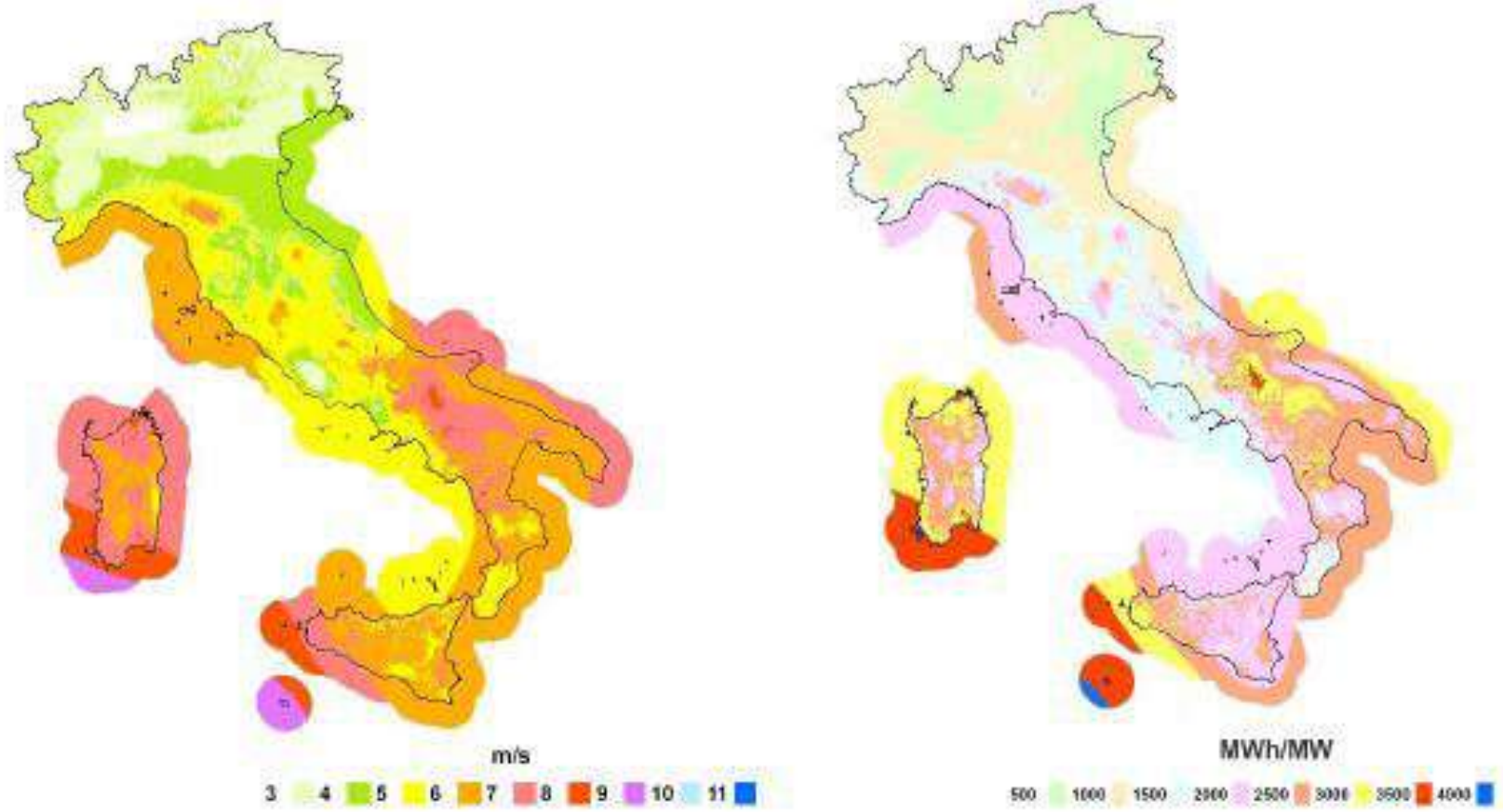
One of the areas with local congestion caused by wind power in South of Italy (source: Terna)



Evolution Wind Production Curtailment (source: Terna). (1) Actual production (2) Curtailed production

Network congestion caused by RES generation
Example of Italian system

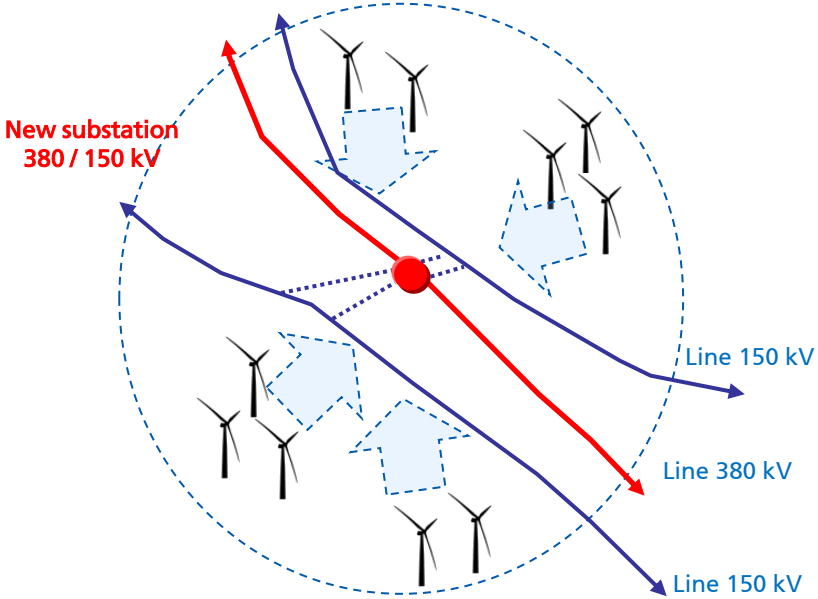
- **Distribution of average wind speed and potential production (from Wind Atlas)**



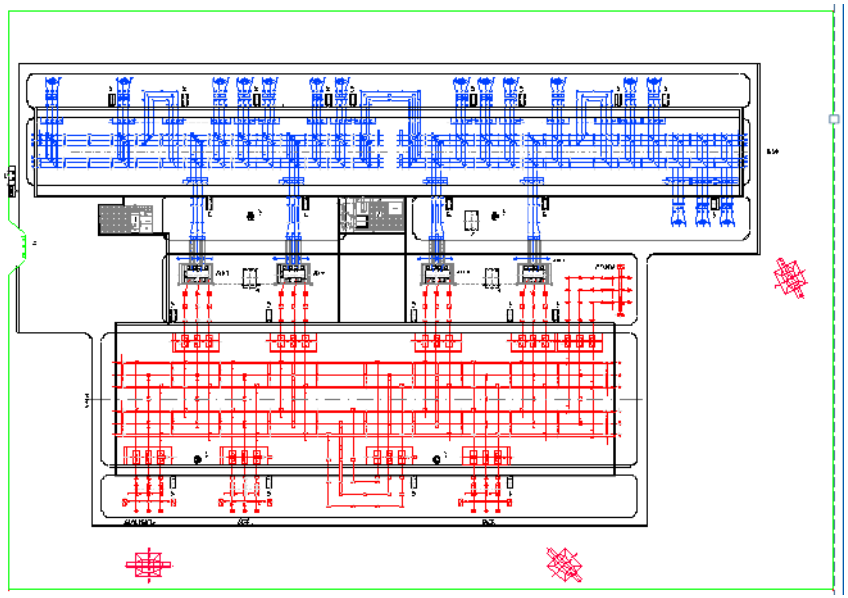
Source: Terna

Network congestion caused by RES generation
Example of 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



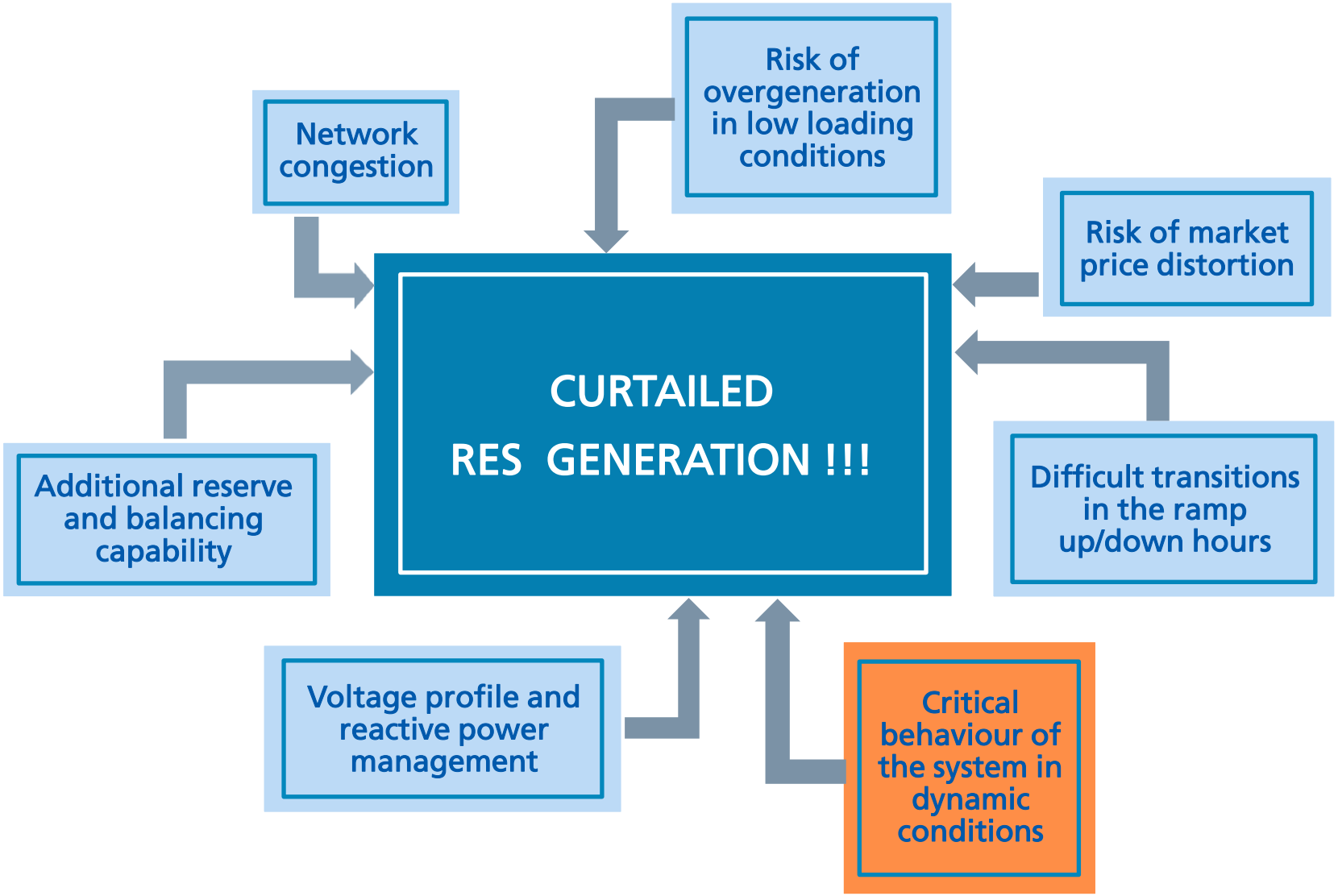
Production Area: over 200 MW



Layout of substation 380/150 kV

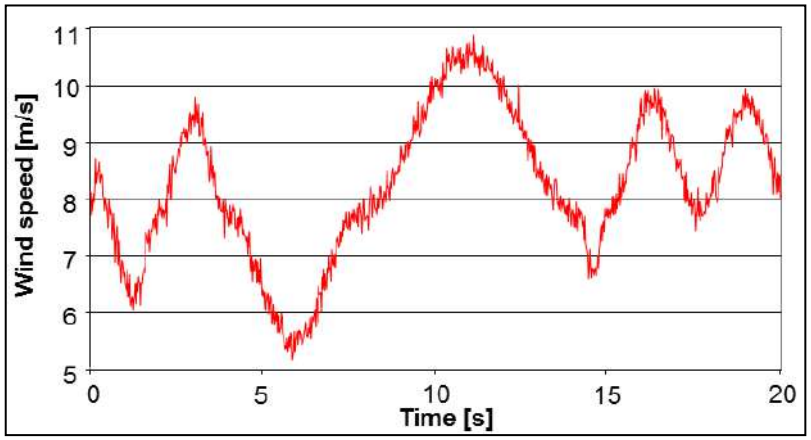
Source: Terna

Barriers to overcome to enhance generation from non-programmable RES



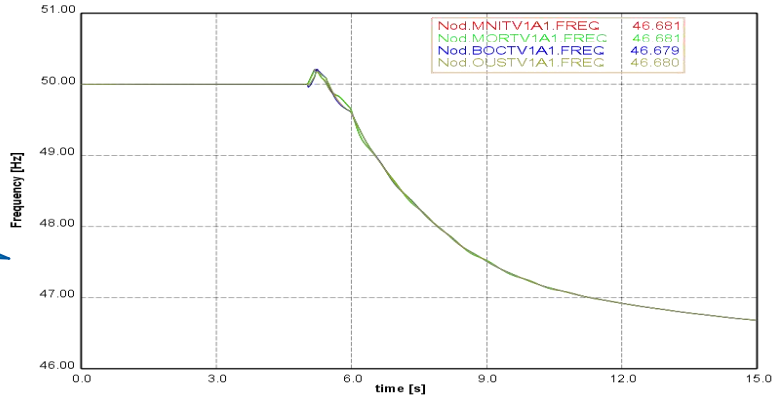
Critical behaviour of the system in dynamic conditions

- **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)



Risk of cascading effect leading to the system collapse

Frequency (Hz)



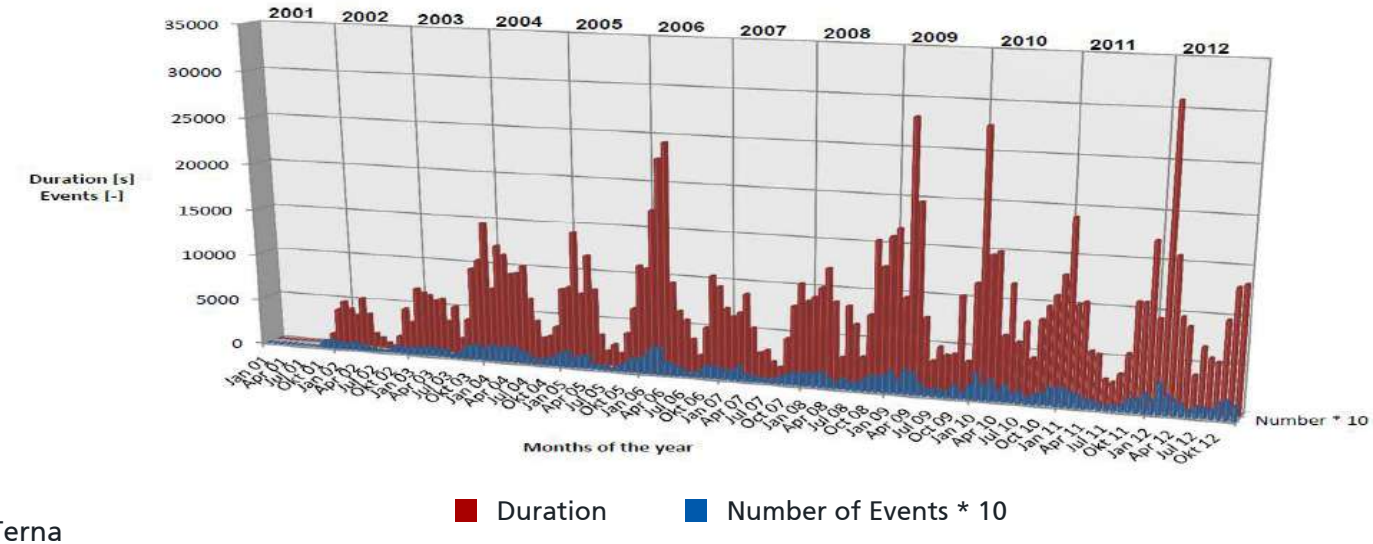
Critical behaviour of the system in dynamic conditions

- **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



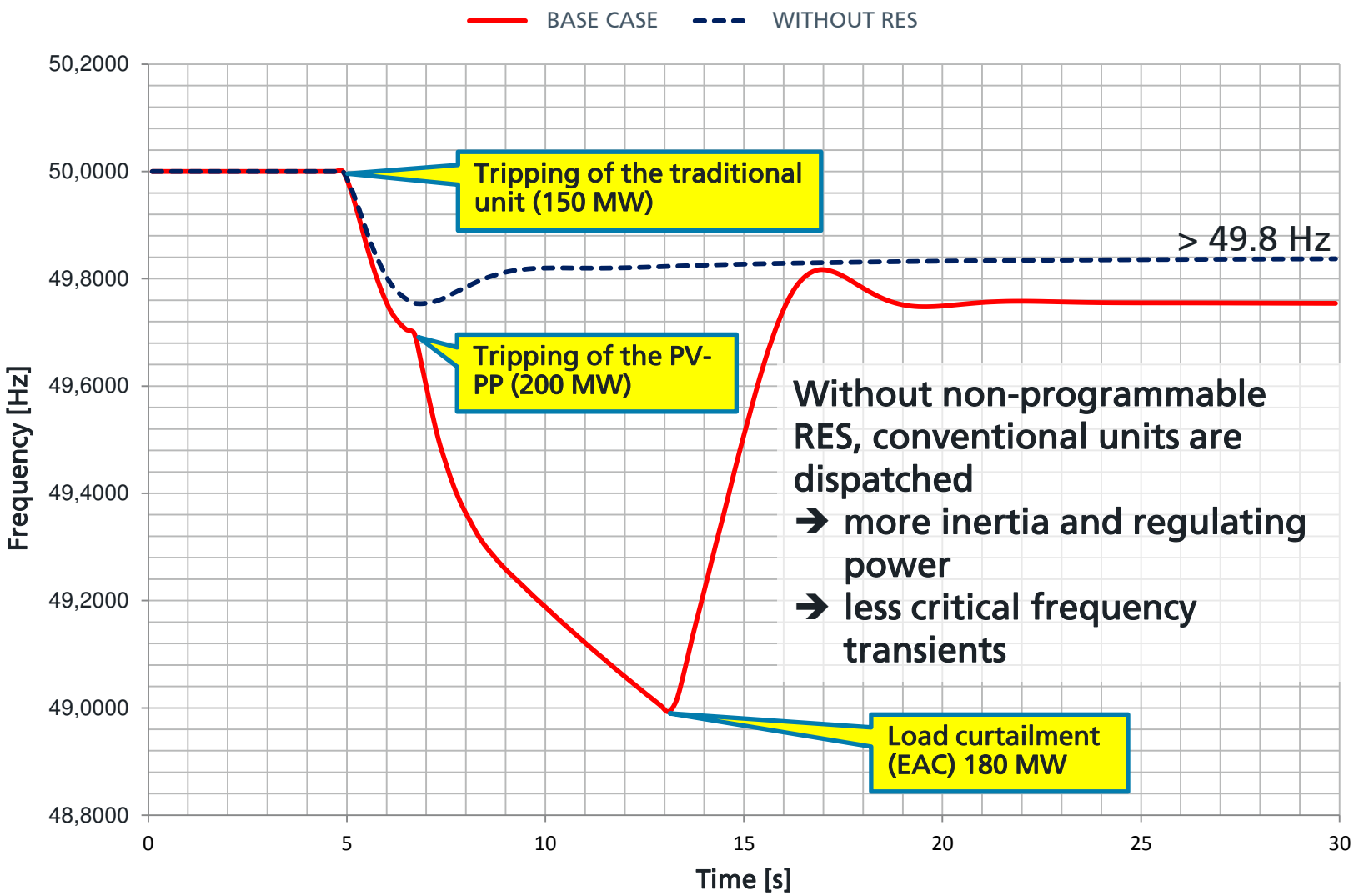
Source: Terna

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**

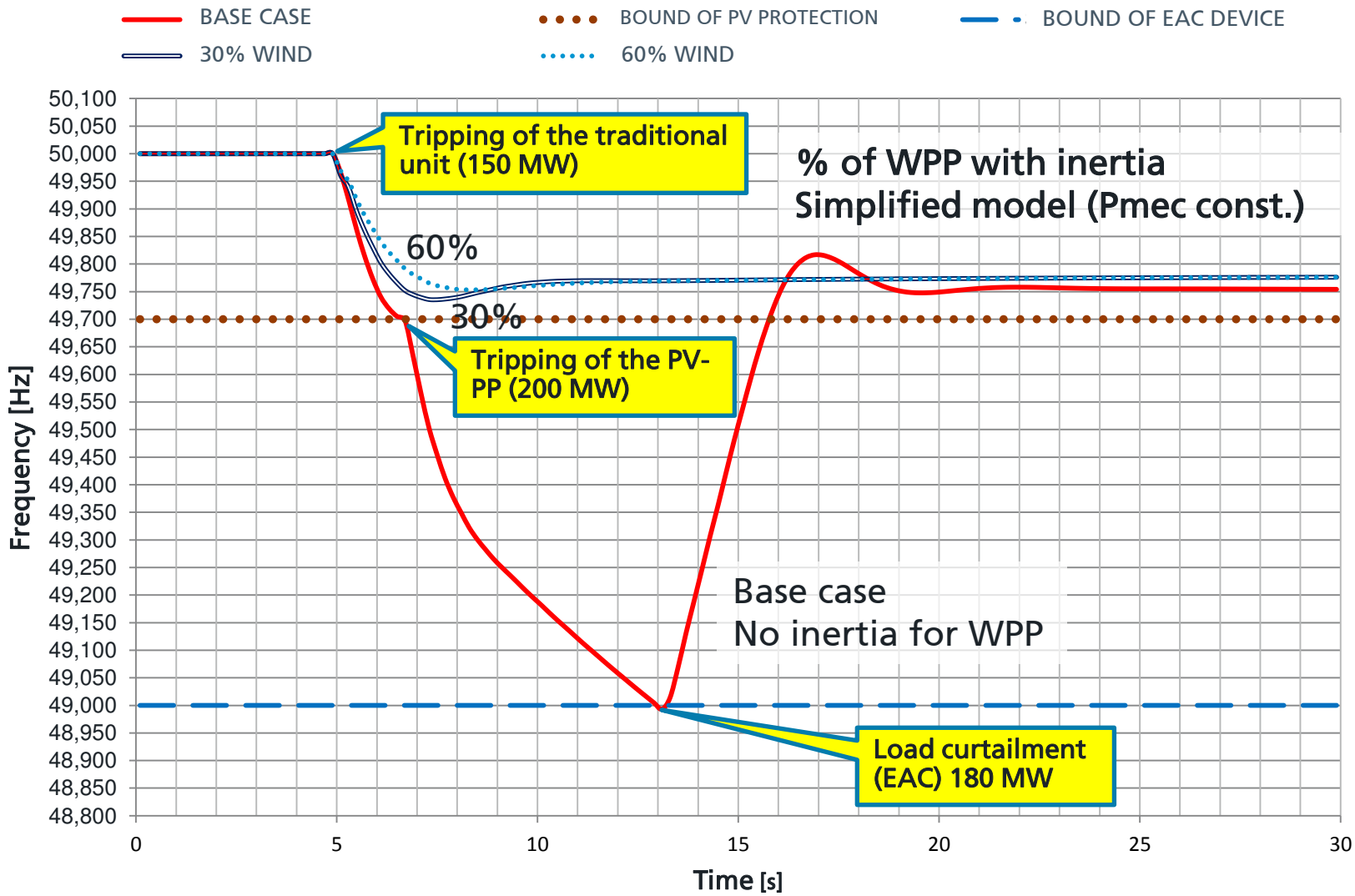
Source: RSE (Ricerca sul Sistema Elettrico)

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



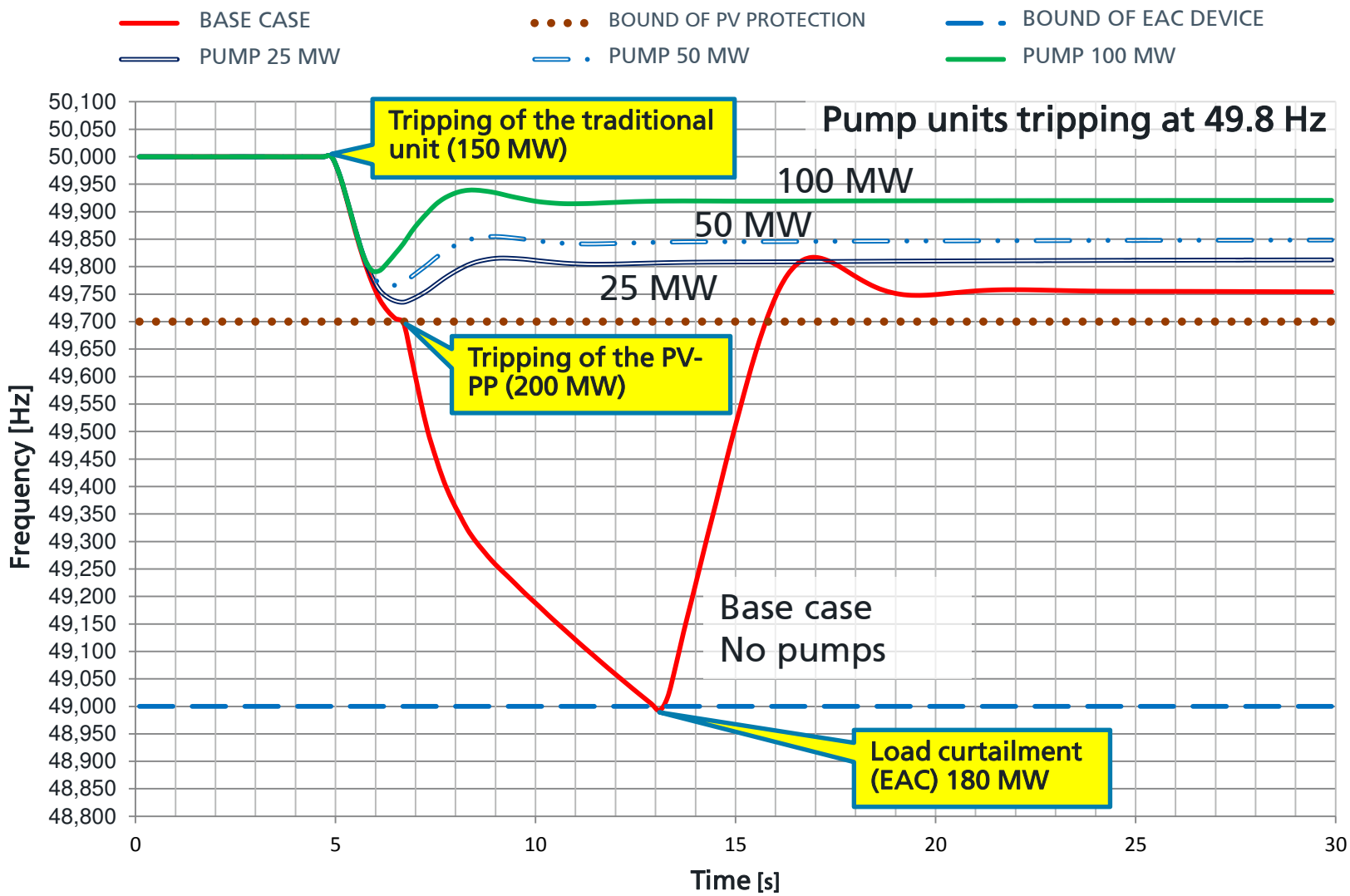
Source: RSE (Ricerca sul Sistema Elettrico)

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



Source: RSE (Ricerca sul Sistema Elettrico)

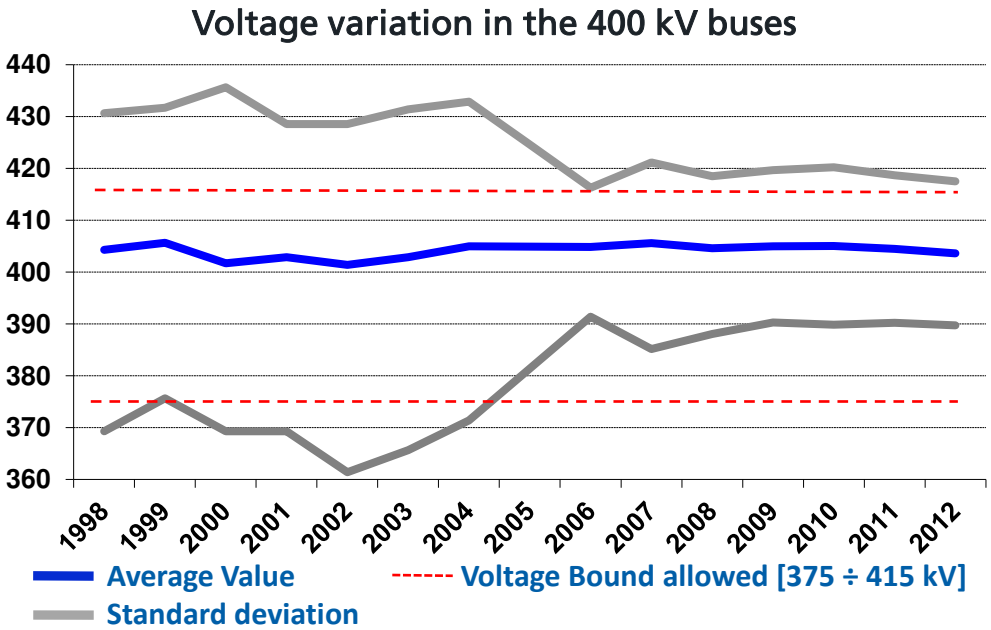
Example of the Sicilian power system
Case (2) – Pump units operation (Storage)



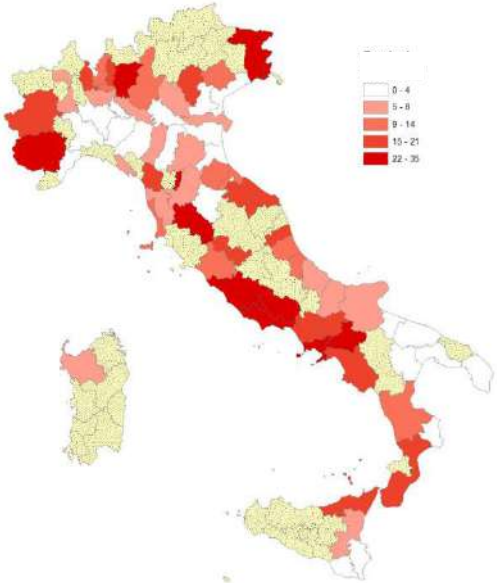
Source: RSE (Ricerca sul Sistema Elettrico)

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

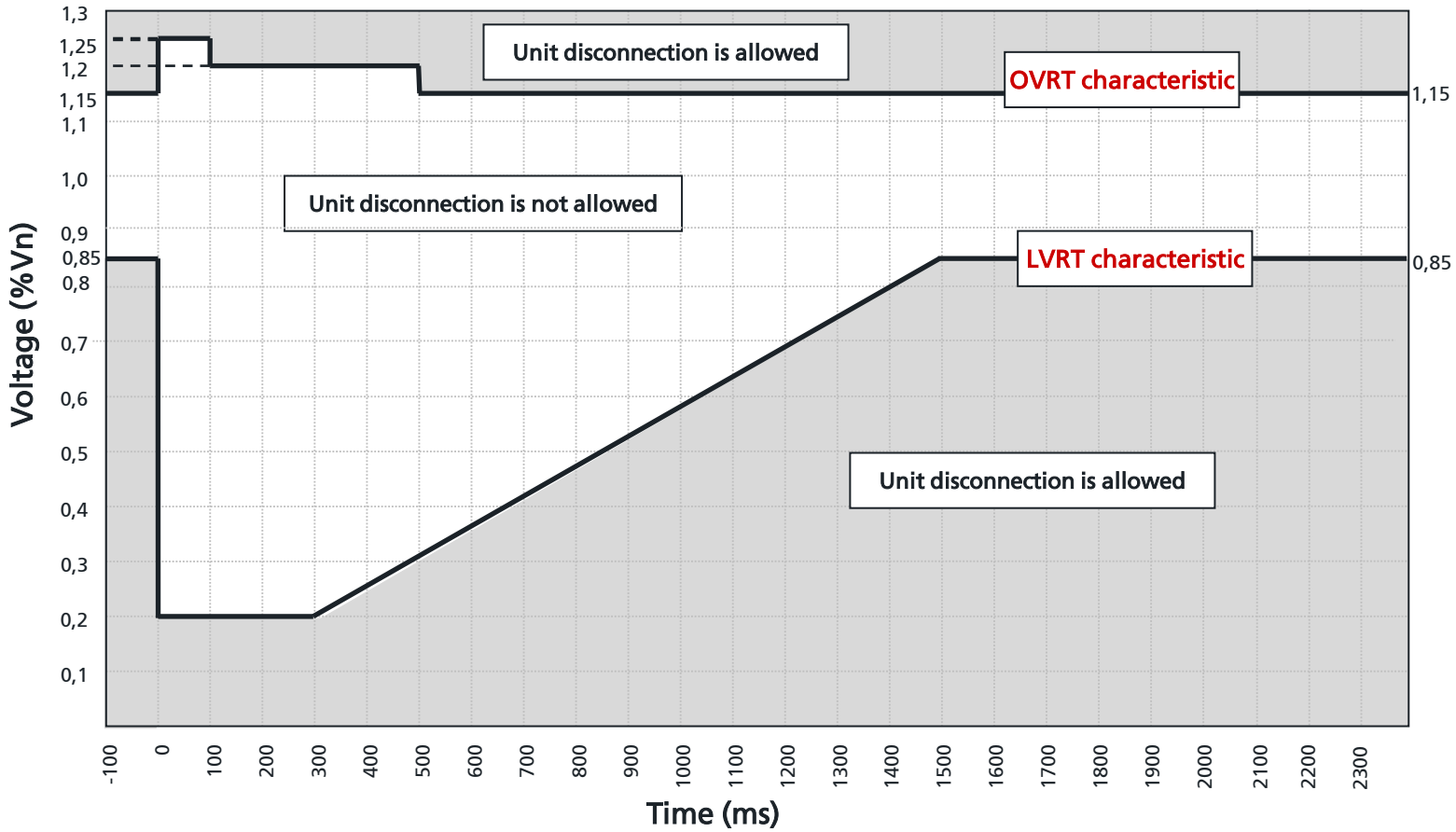


Frequency (%) of voltages > 410 kV (hours with low load, July 2011 – June 2012)

Source: Terna

Voltage profile and reactive power management

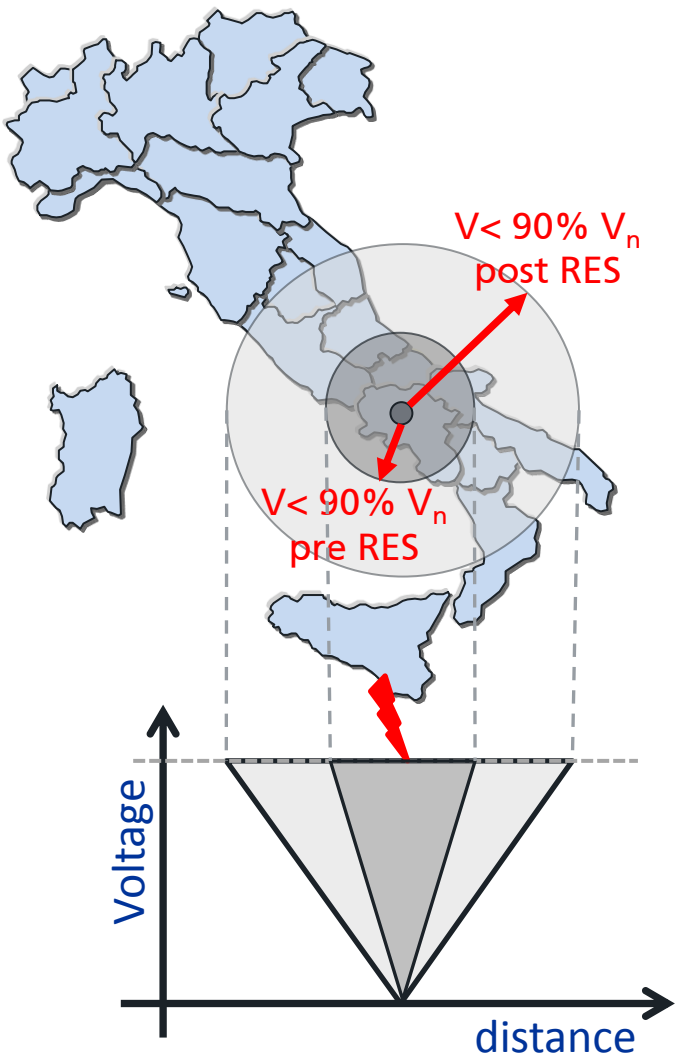
- **Low Voltage Ride Through (LVRT) and Over Voltage Ride Through (OVRT) characteristics**



Source: Terna

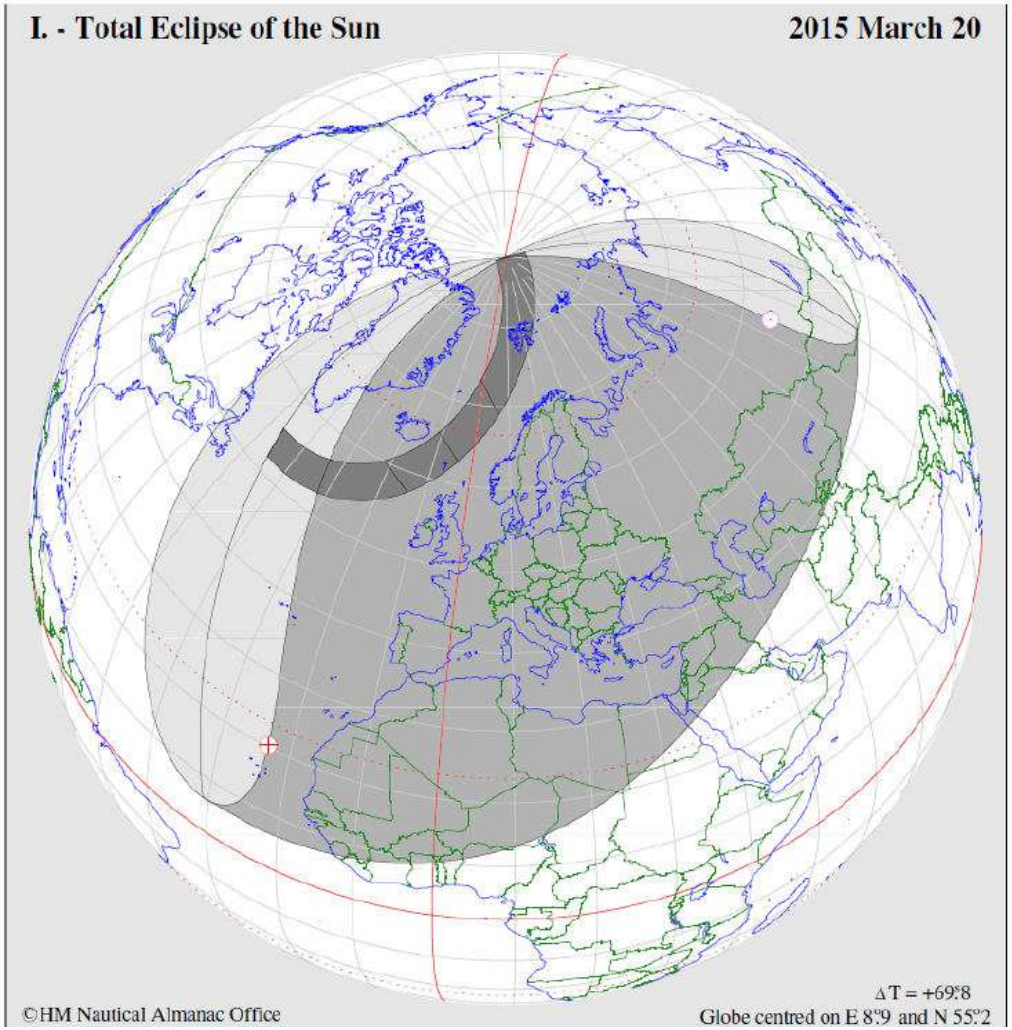
Voltage profile and reactive power management

- 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



Source: Terna

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



- ✓ 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

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

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

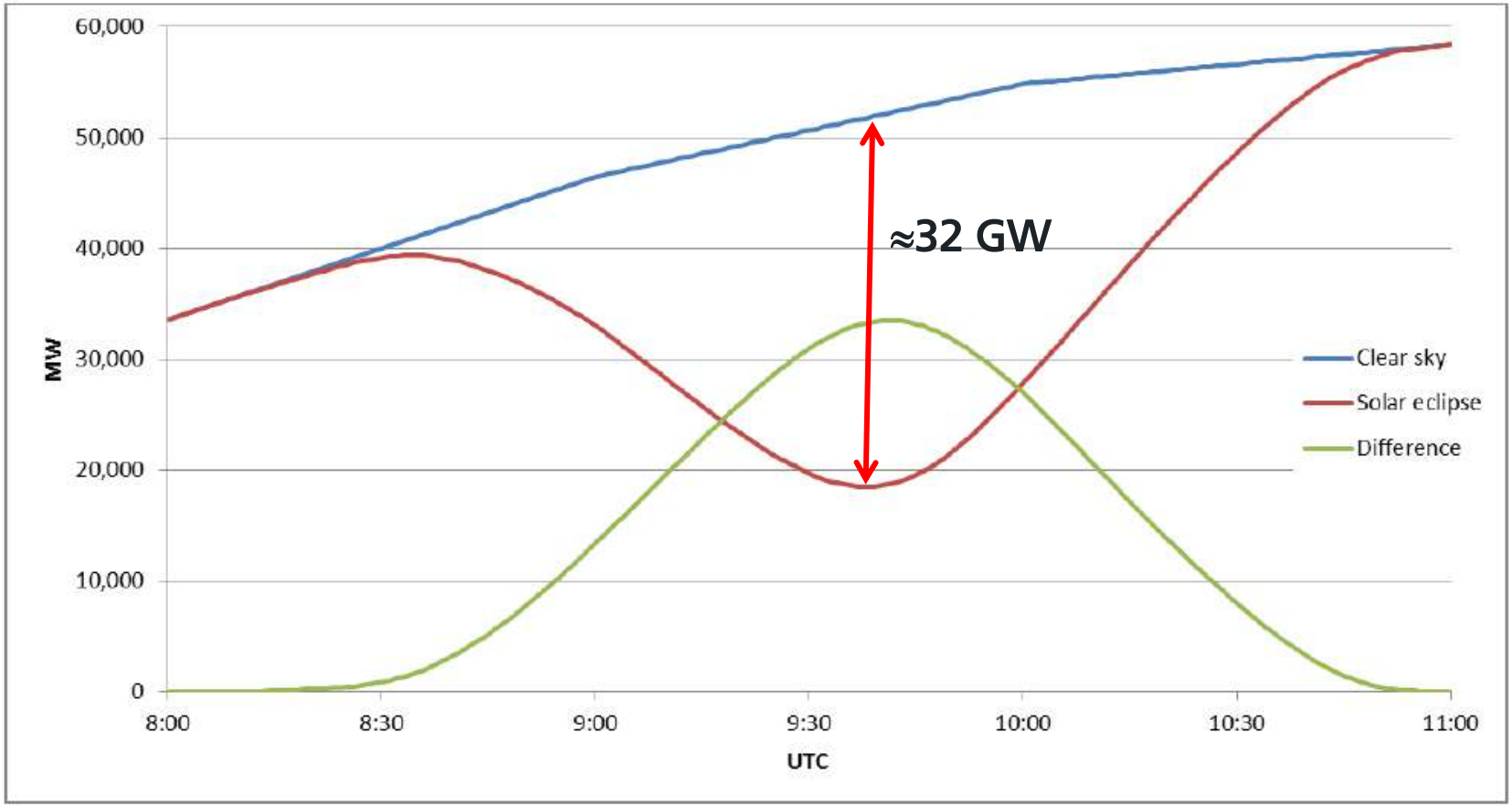
	Start eclipse UTC	End eclipse UTC	Max obscuration	Location
Austria	08:31	10:52	62%	Klagenfurt
Belgium	08:27	10:45	80%	Brussels
Bosnia	08:35	10:54	51%	Sarajevo
Bulgaria	08:44	10:59	40%	Plovdiv
Croatia	08:33	10:53	58%	Zagreb
Czech Republic	08:36	10:57	69%	Prague
Denmark	08:40	10:58	83%	Arhus
France	08:20	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

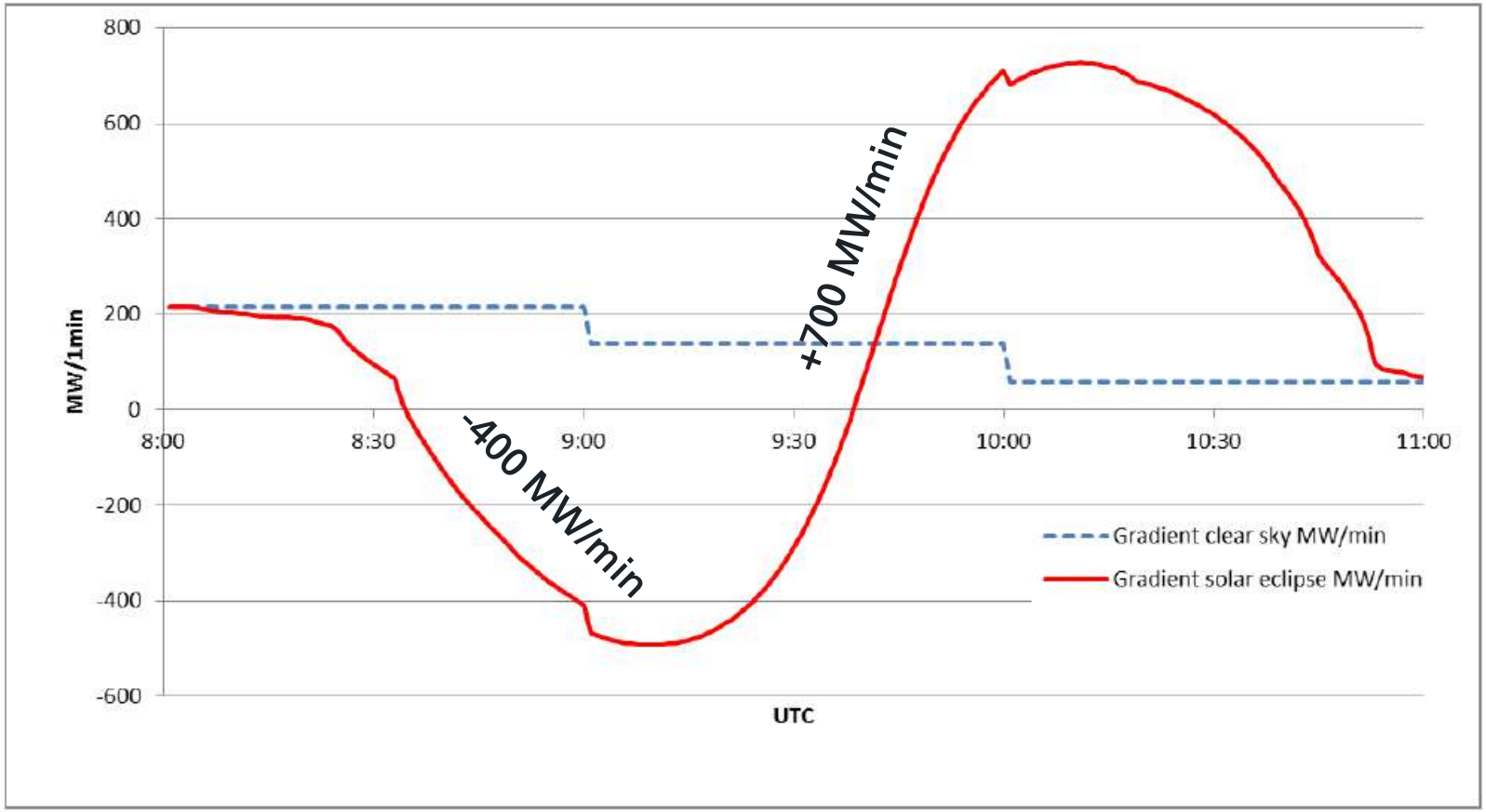
Comparison of expected infeed from solar on March 20 during clear sky conditions with and without solar eclipse (ex-ante simulation)



Source: ENTSOE

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

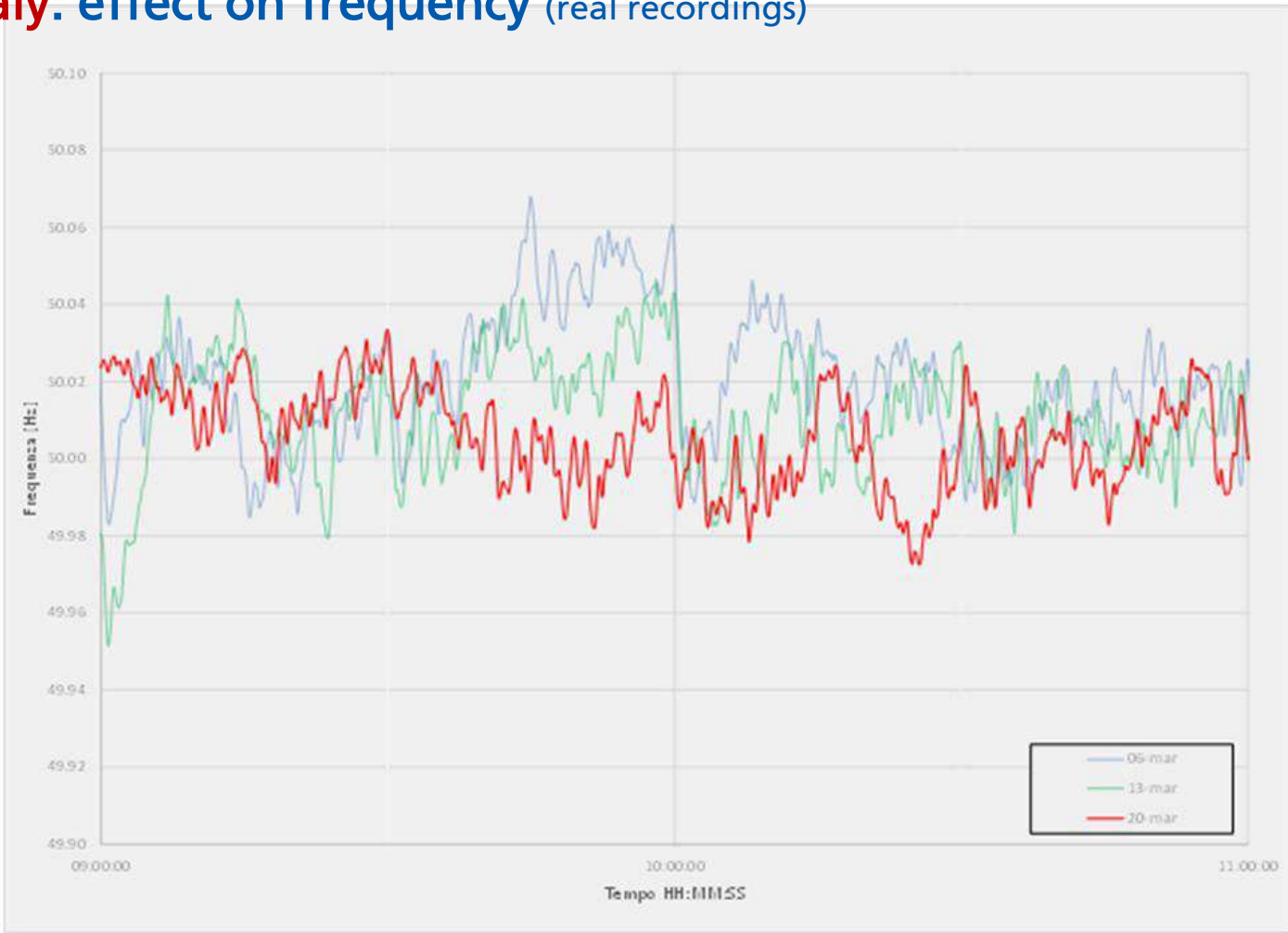
Effect on PV power infeed gradients (ex-ante simulation)



Source: ENTSOE

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

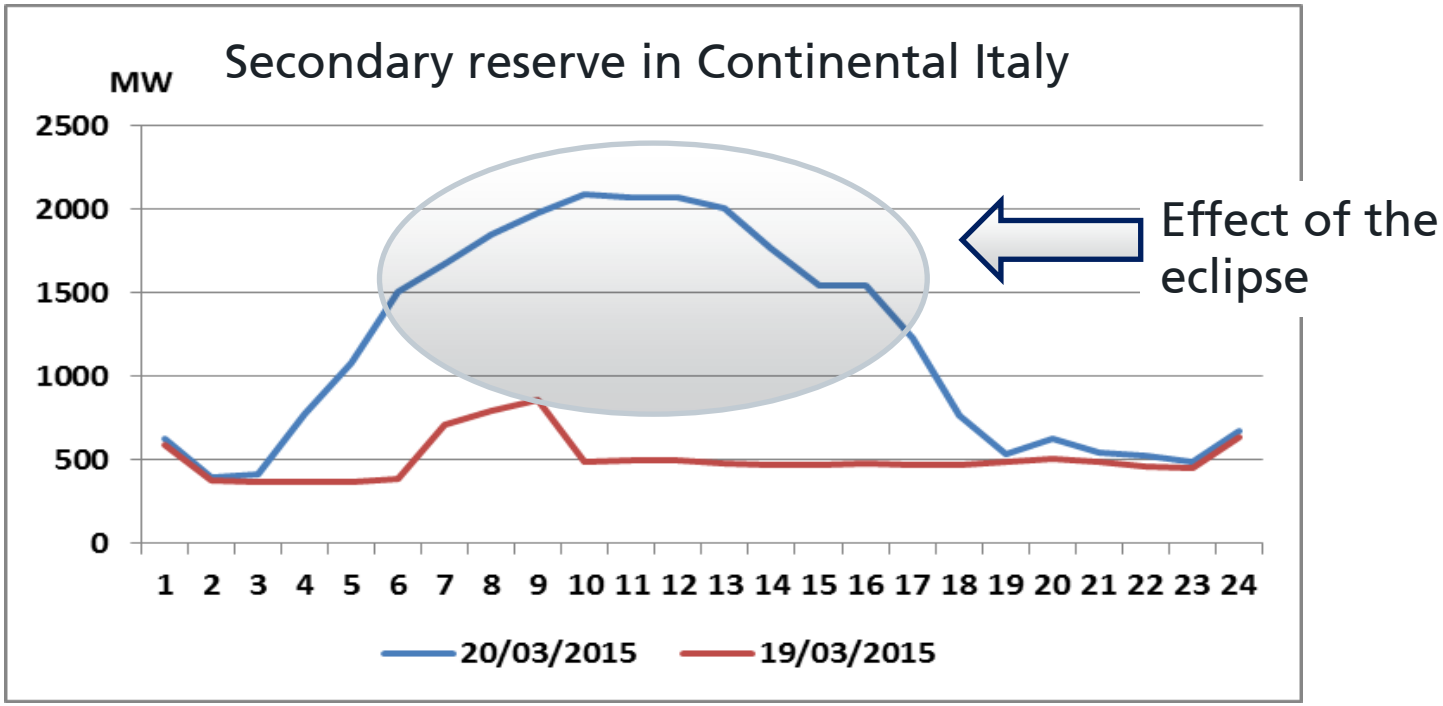
Focus on Italy: effect on frequency (real recordings)



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

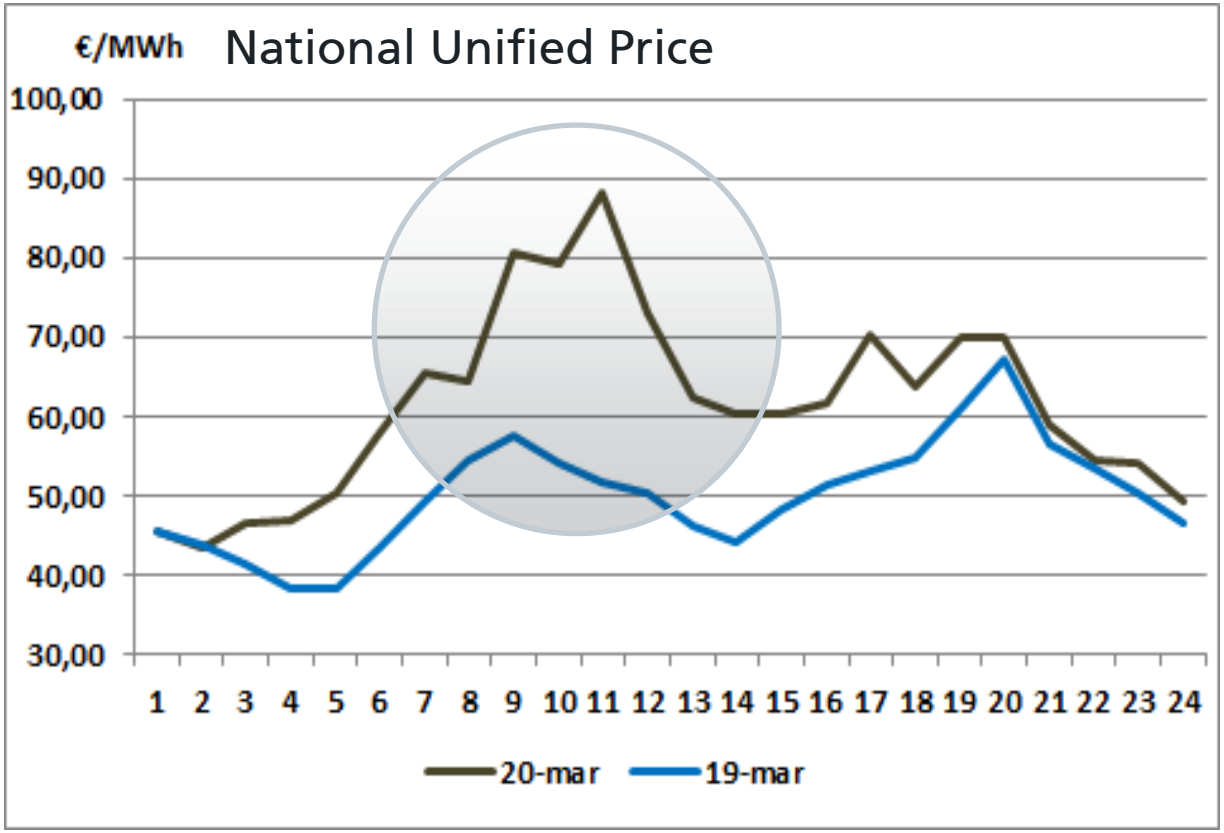
Focus on Italy: effect on ASM (secondary reserve)



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

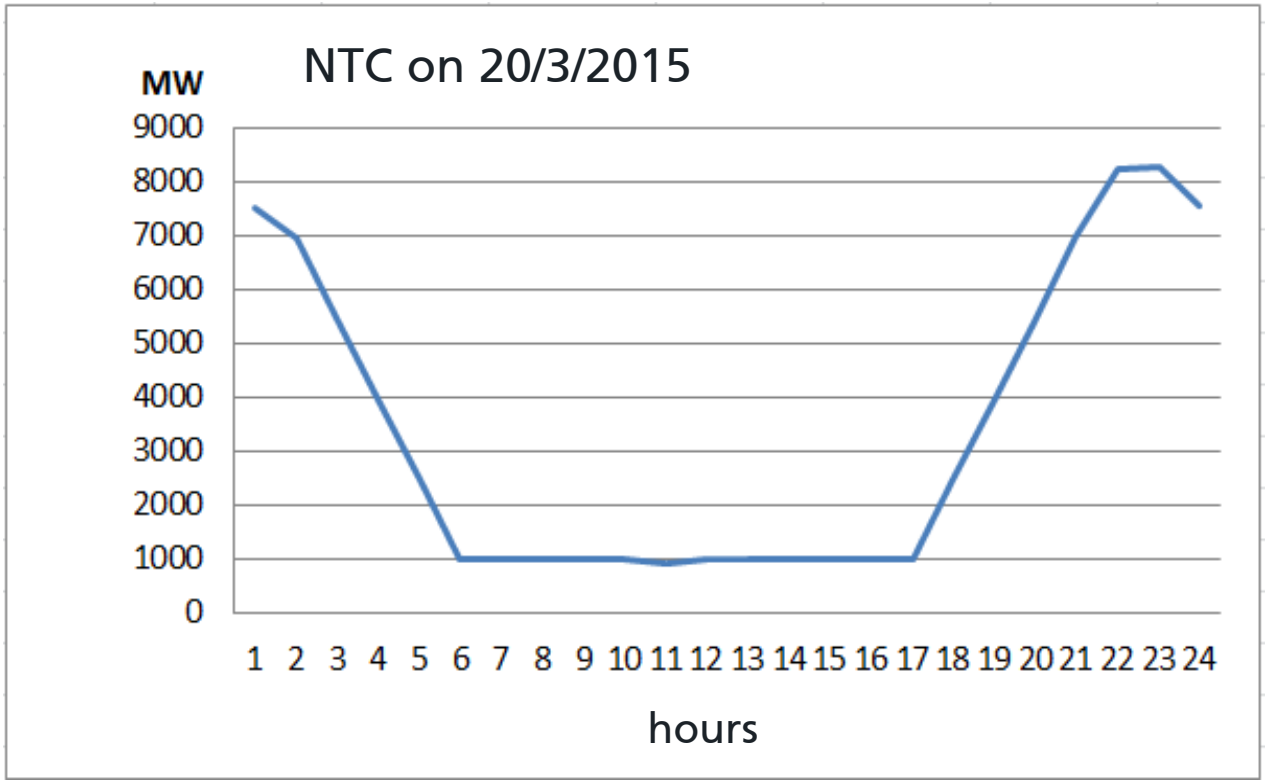
Focus on Italy: effect on Day-ahead market



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

LOOKING AHEAD:
Evolution of RES generation capacity mix in Europe

Load demand trend: four visions recently formulated by ENTSO-E

Vision (year 2030)	Demand incl. Pumping (TWh)	RES penetration	CO2 reduction
V1 Slow Progress	3610	41%	42%
V2 Money Rules	3712	40%	36%
V3 Green Transition	4167	49%	62%
V4 Green Revolution	4327	60%	78%

Peak demand evolution: slow growth in the next decade. CAGR of January peak load ≈1% per year.

Source: ENTSO-E

LOOKING AHEAD:
Decarbonisation targets in Europe

EU targets

2020

20% CO_2 reduct.
20% RES

Proposed in January 2014 by the "Barroso EC; approved by the European Council on Oct. 24th

2030

"at least" 40% CO_2 reduct.
27% RES

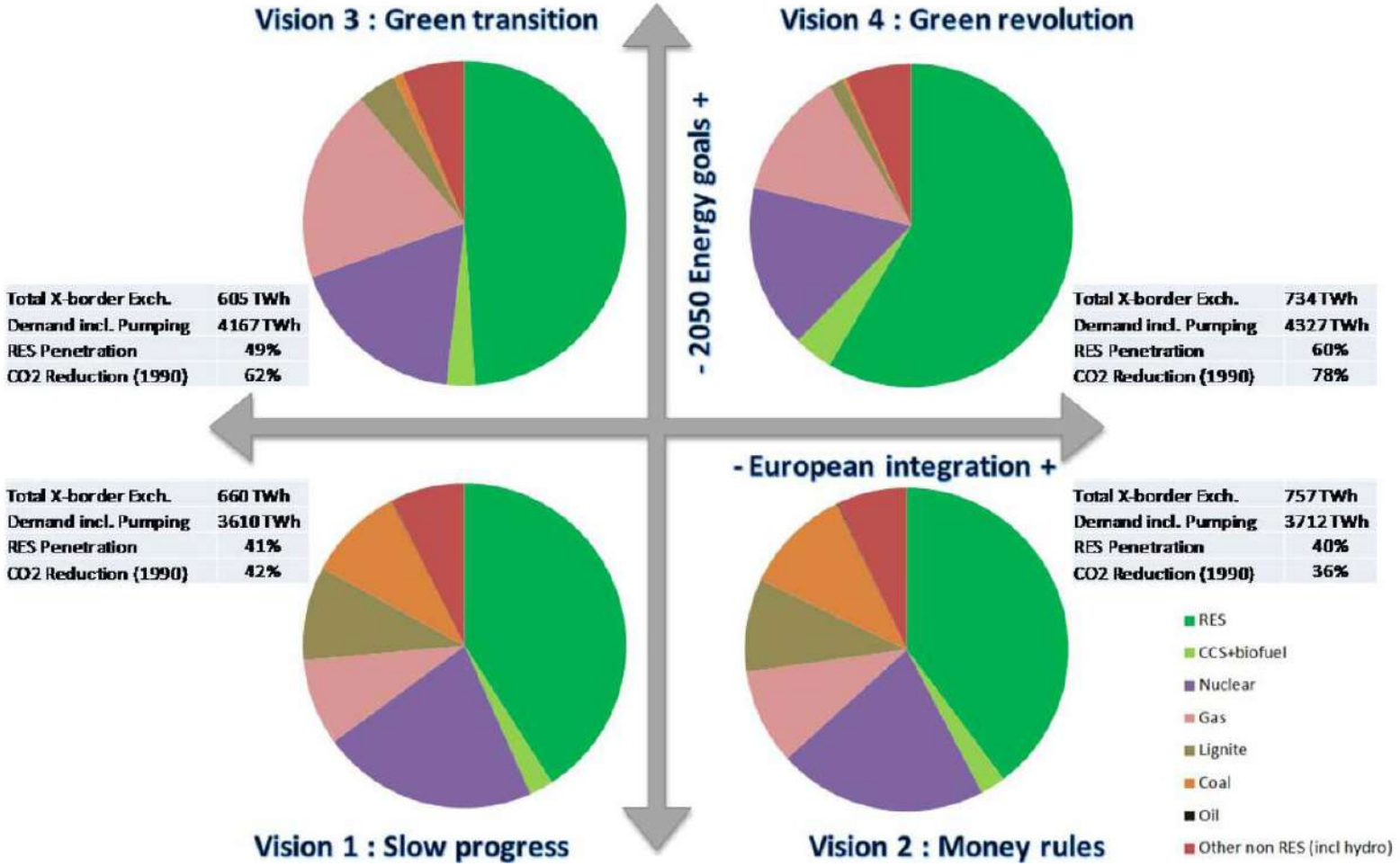
2050

80% / 95% CO_2 reduct.

Full decarbonisation of the power sector

LOOKING AHEAD:
Decarbonisation targets in Europe

Longer term trends



Source: ENTSO-E and CESI elaborations

** Installed RES capacity, compared to less than 230 GW today*

LOOKING AHEAD:
RES generation as the main driver for grid development in Europe

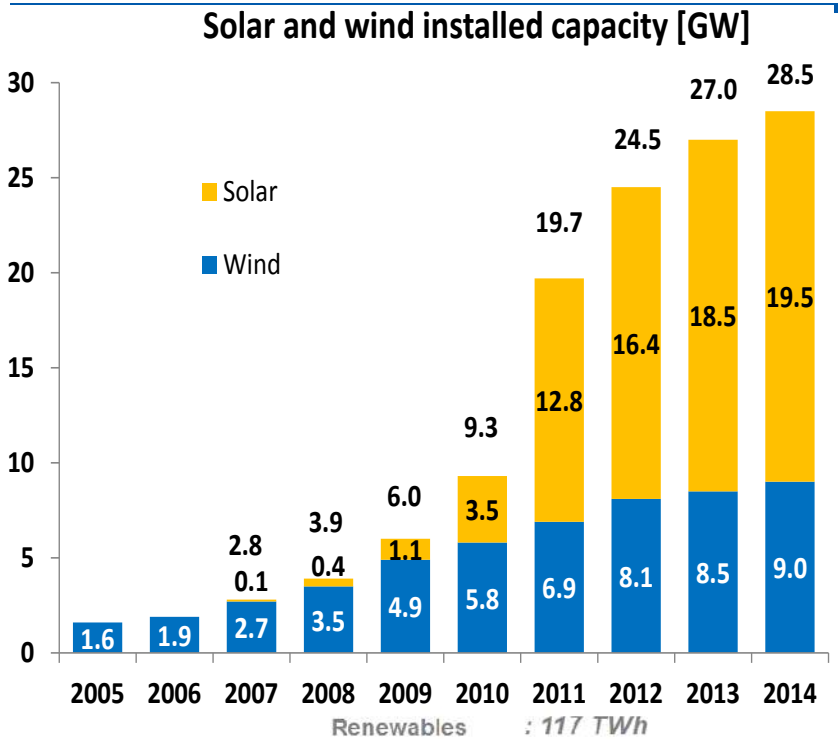
The dramatic change in the generation mix is prompting for substantial investments in the transmission grids.

The TYNDP 2014 of ENTSO-E estimates about 150 b€ of investments by 2030 in transmission grid expansion.

The vast majority of new transmission reinforcements is related to the integration of RES generation: "*approximately 80% of the projects of pan-European significance help integrate RES either by directly connecting RES or by transporting RES power to end-consumers*" *

** ENTSO-E TYNDP 2014*

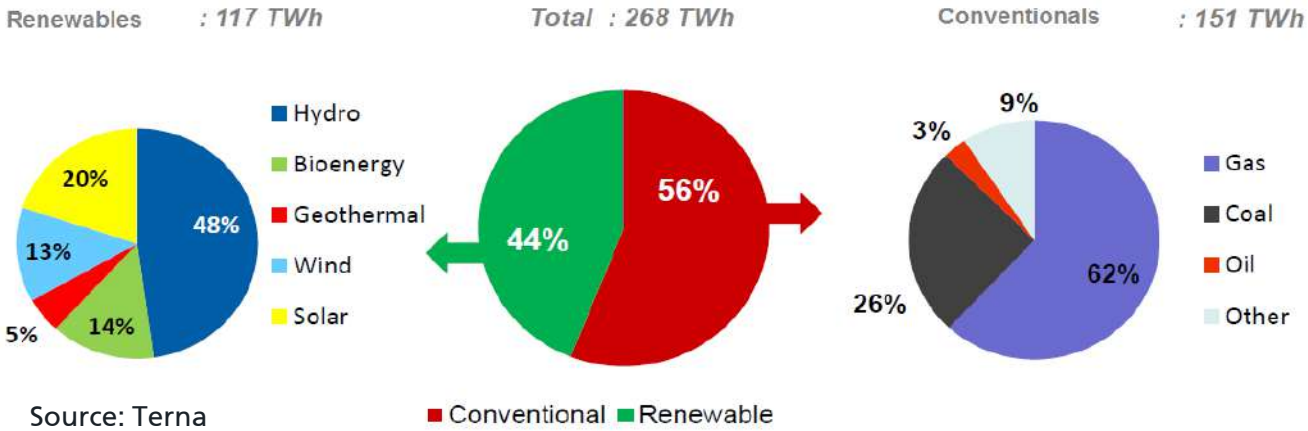
Situation in Italy



Forecasted VRE installation:

- 5-years ahead:
  - 23.5 GW PV
  - 12.7 GW wind
- 10-years ahead:
  - 29.8 PV
  - 15.6 wind

Italian electricity production by fuel in 2014



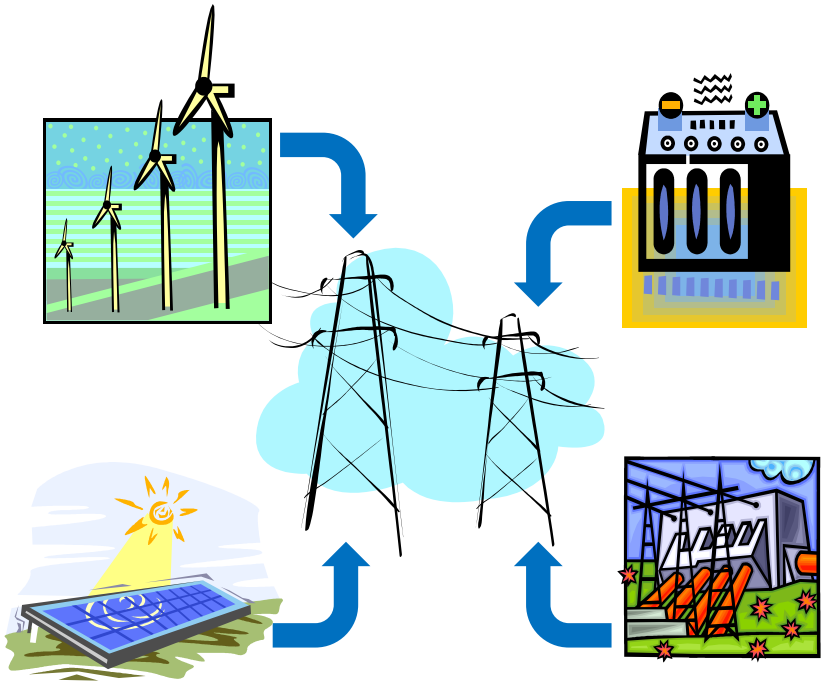
Source: Terna

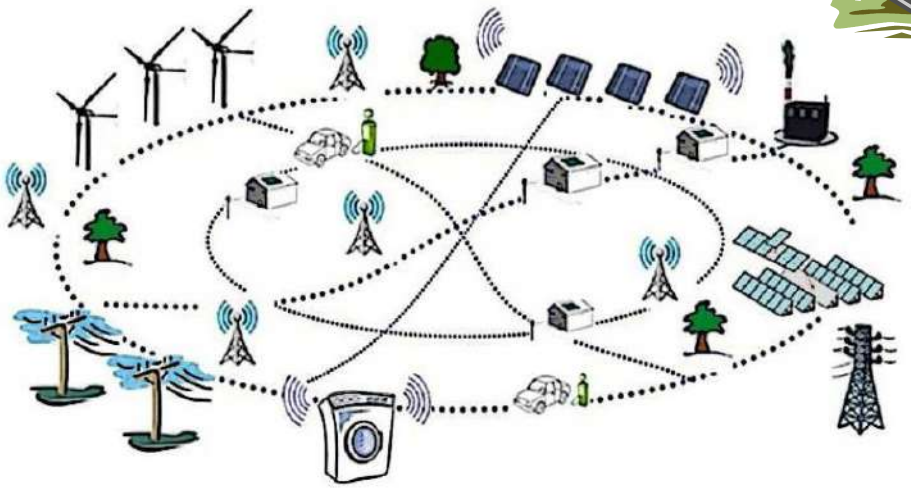
Possible solutions to overcome barriers and maximise penetration of RES generation

- **Energy storage**

Two levels:

1. small scale to smooth high frequency low amplitude intermittency: batteries at s/s
2. large scale for system wide stabilisation: hydro pumping / different policies for unit commitment (higher rate of start up/ shut down of unit : OC TG)

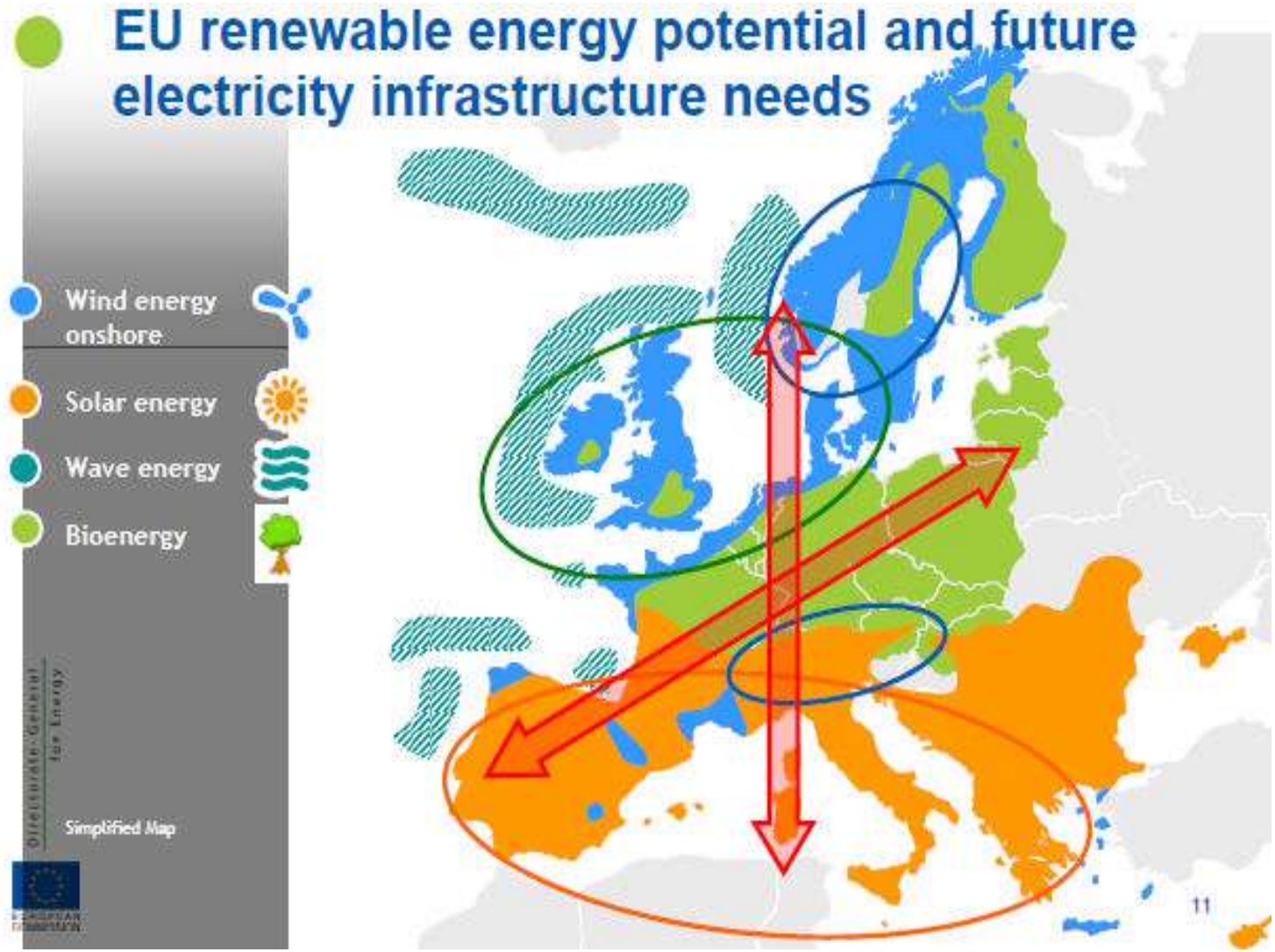




- **Demand responsiveness**

Demand response from users ……. including electric vehicles

The role of transmission infrastructure: the electricity highways



Source: EC

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