ELECTRIC POWER SYSTEMS CHALLENGES WITH HIGH RENEWABLE PENETRATION

Experience and Perspectives from CESI and EnerNex

EnerNex

A CESI Company

Webinar Presenters

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Summary

➡ *Introduction of EnerNex and CESI*

- *RES generation in the U.S.: current situation and future perspectives*
- *RES generation in Europe: current situation and future perspectives*
- *Challenges in operating power systems with high penetration of RES generation:*
  - ✓ *how to ensure reliability*
  - ✓ *how to warrant stability in dynamic conditions*
- *Possible solutions*
- *Conclusions and debate*

EnerNex, A CESI Company

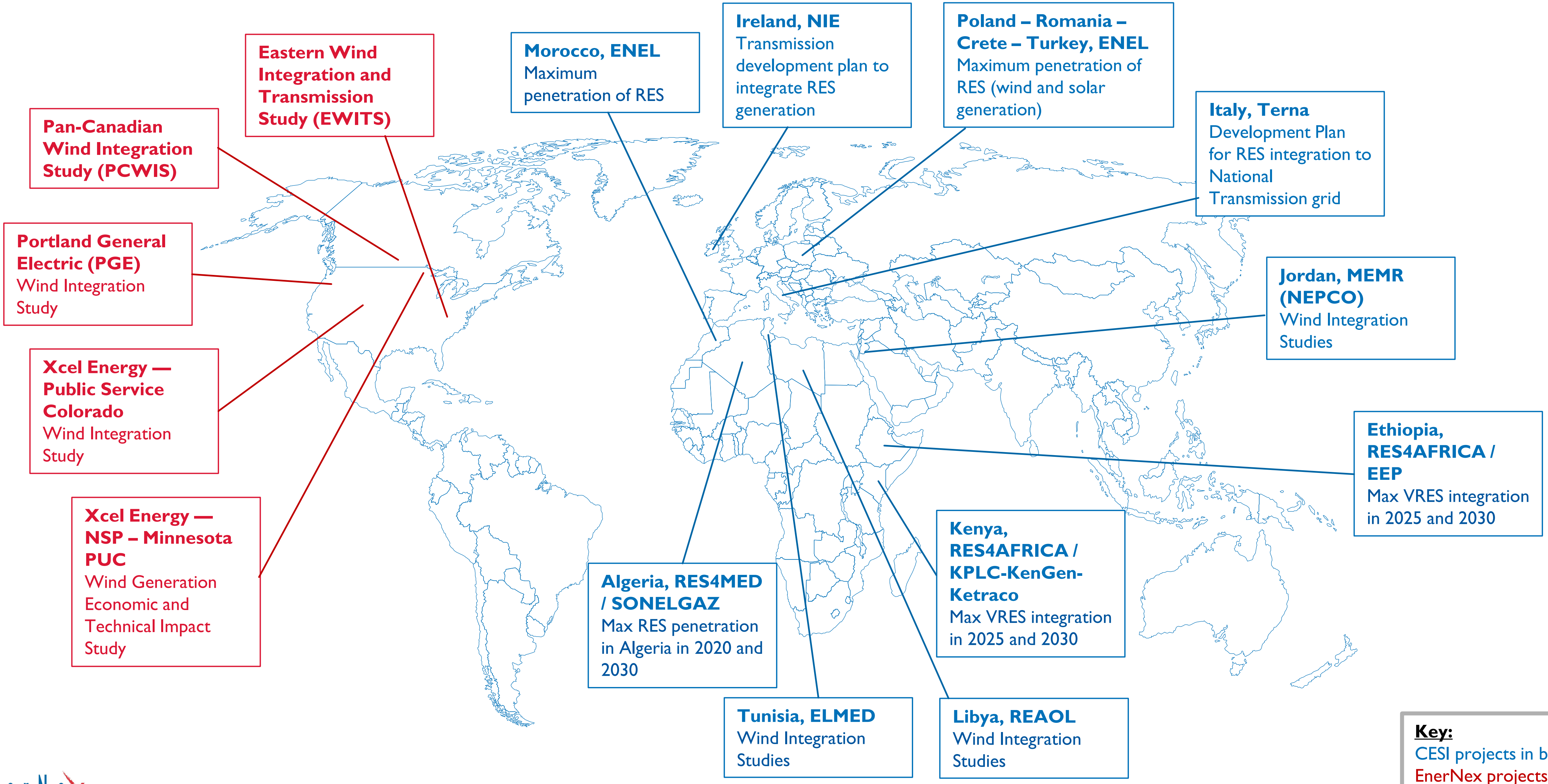
CESI acquired majority share of EnerNex in June 2018

- Headquartered in Milan, Italy
- 800+ employees
- Actively working in over 40 countries world-wide
- 60% consulting and 40% testing

EnerNex will continue its focus on the North American market

- Build on existing core services
- Expand portfolio through synergies with CESI

CESI and EnerNex: Renewable Energy Integration Background



Key:
CESI projects in blue
EnerNex projects in red

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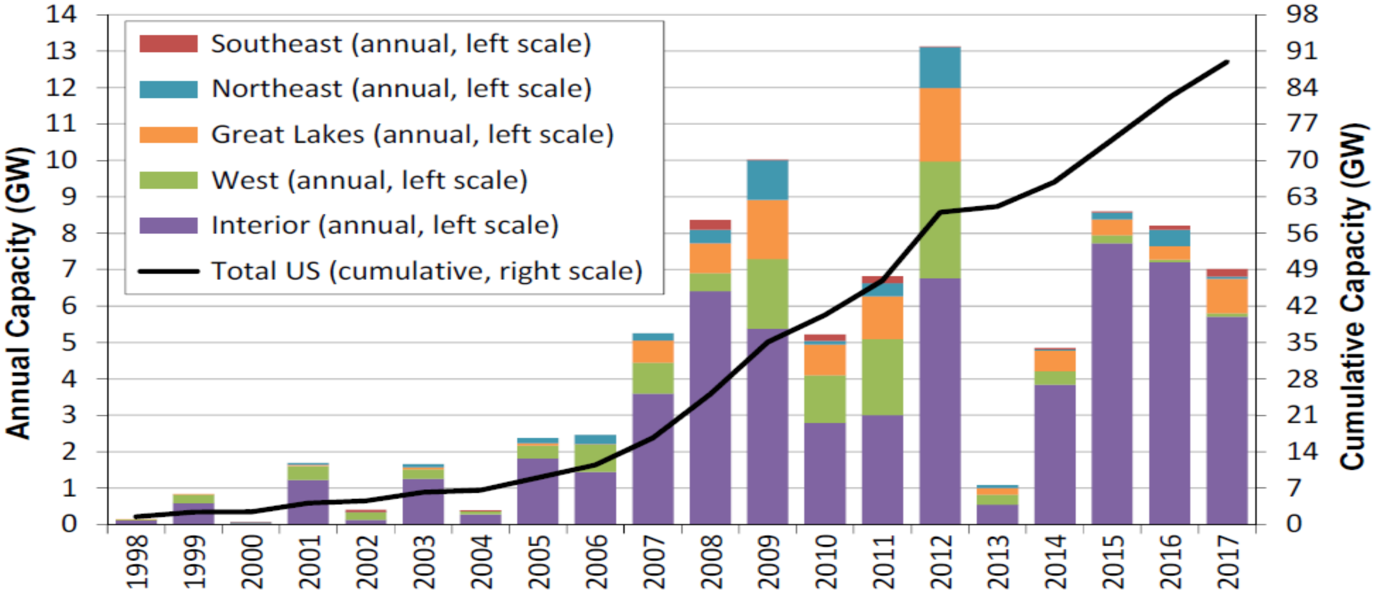
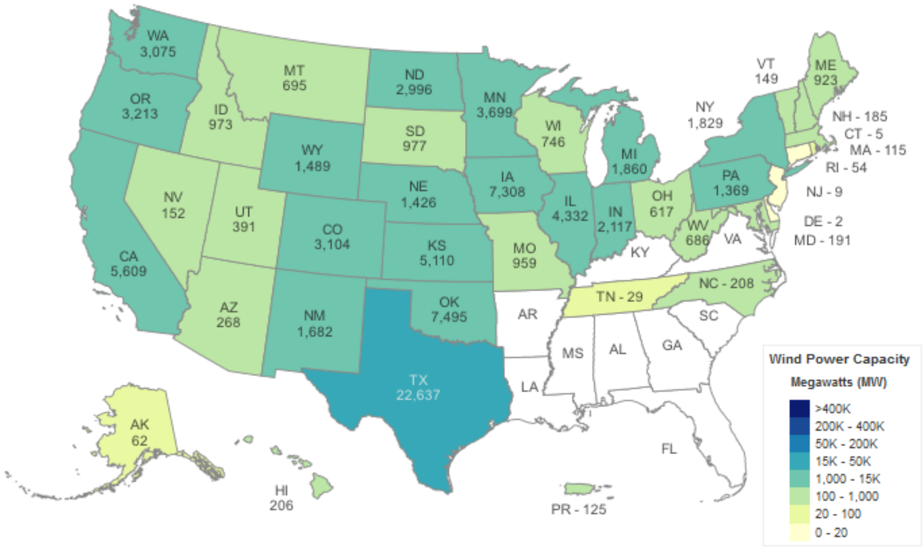
U.S. Installed Wind Generation Capacity: 90 GW+ by End of 2018



- $11 billion invested in wind power project additions in 2017
- Over 80% of new 2017 capacity located in the Interior region
- Partial repowering trend: 2,131 MW of existing plants retrofitted w/ longer blades

Source: LBNL 2017 Wind Market Report

Q4 2017 Installed Wind Power Capacity (MW)



Total Installed Wind Capacity: 89,078 MW

Source: American Wind Energy Association Market Report

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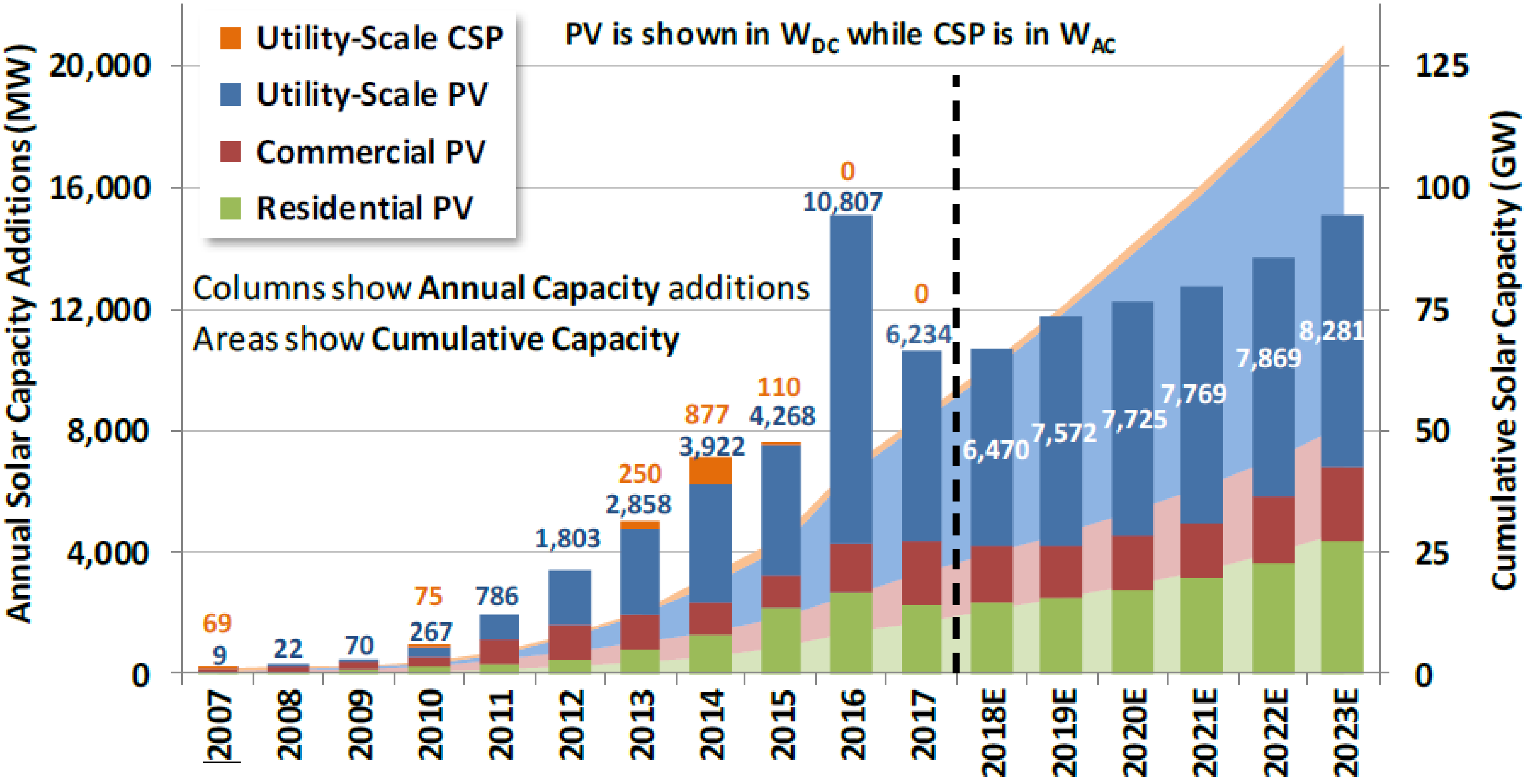
Solar is Coming on Quickly…

Dominated by PV

PV Applications

- Utility scale
- Commercial
- Residential

60 GW+ by end of 2018



Source: GTM/SEIA (2010-2018), LBNL's "Tracking the Sun" and "Utility-Scale Solar" databases

Figure 1. Historical and Projected PV and CSP Capacity by Sector in the United States[4]

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Some Recent Industry Trends (US)

- Solar PV system prices continue to fall
- Wind plant prices also on a downward trajectory
- Carbon constrained future, coal plant retirements and nuclear plant operating costs continue to drive concern for capacity adequacy
- Low energy market prices drive electricity market redesign efforts in US and Europe
- Capacity flexibility issue gaining importance
- Operating grid with high penetrations of variable renewables is overarching topic in industry

- Lazard reports on lowest unsubsidized energy costs* for:
  - Rooftop residential solar: $187/MWh
  - Simple Cycle GT: $156/MWh
  - Nuclear: $112/MWh
  - Coal: $60/MWh
  - Combined Cycle GT: $42/MWh
  - Utility scale solar: $43/MWh
  - Wind energy: $30/MWh
- Other reports from industry pubs on recent PPA prices:
  - Utility scale solar: $23-$40/MWh
  - Wind energy: $11-$24/MWh

** 2017 report*

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For Some, the Future is Now…

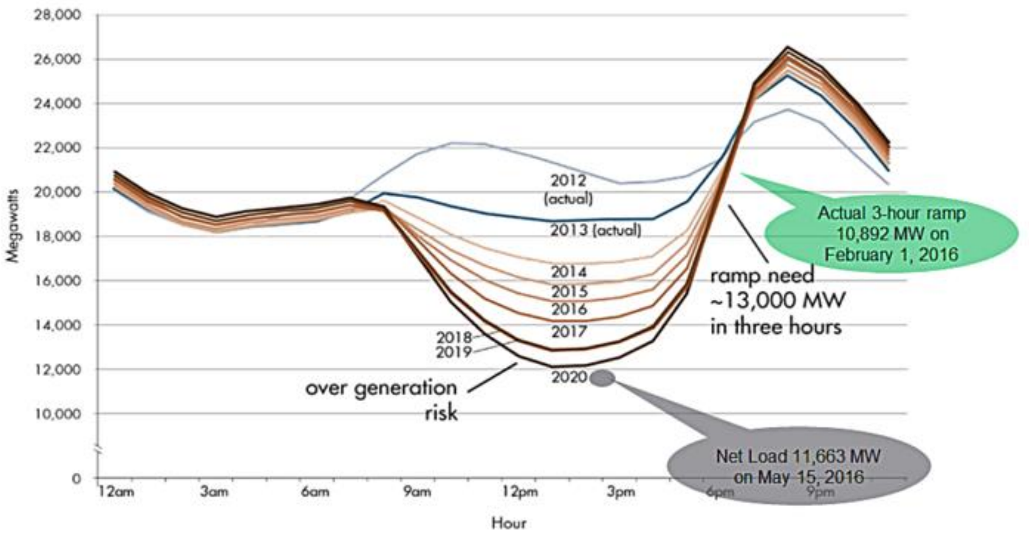
High penetrations of renewable generation are or will be a reality in many regions of the U.S.

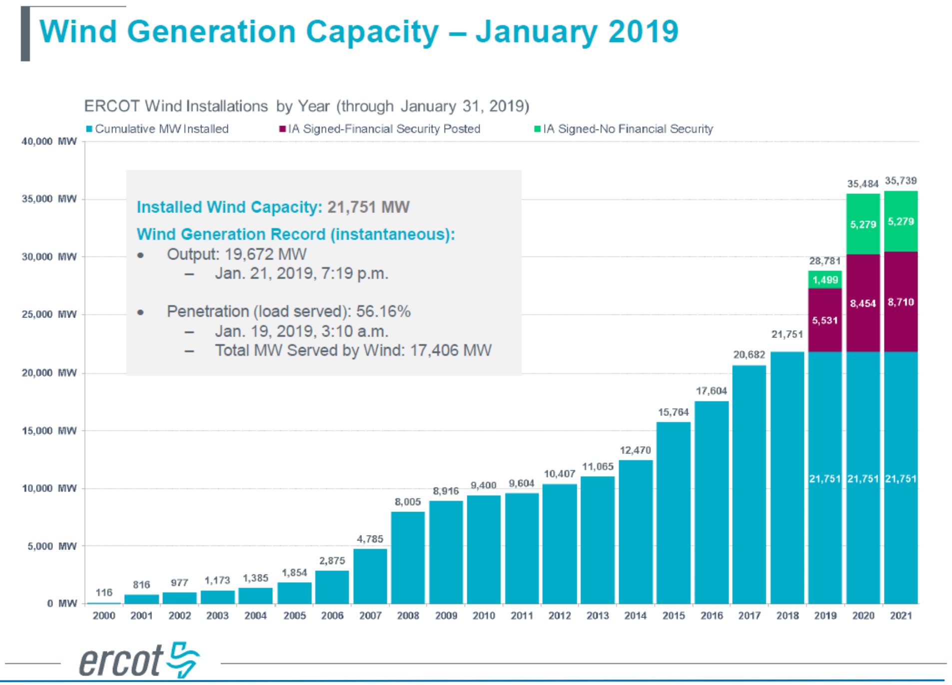
- ERCOT
- Hawaii
- CAISO
- SPP

Solar PV is helping to push the envelope (e.g. CA "duck curve")

Distribution system impacts of DER are major concern

While much knowledge has been gained, and comfort developed with current levels of renewables, what happens when it is pushed further?





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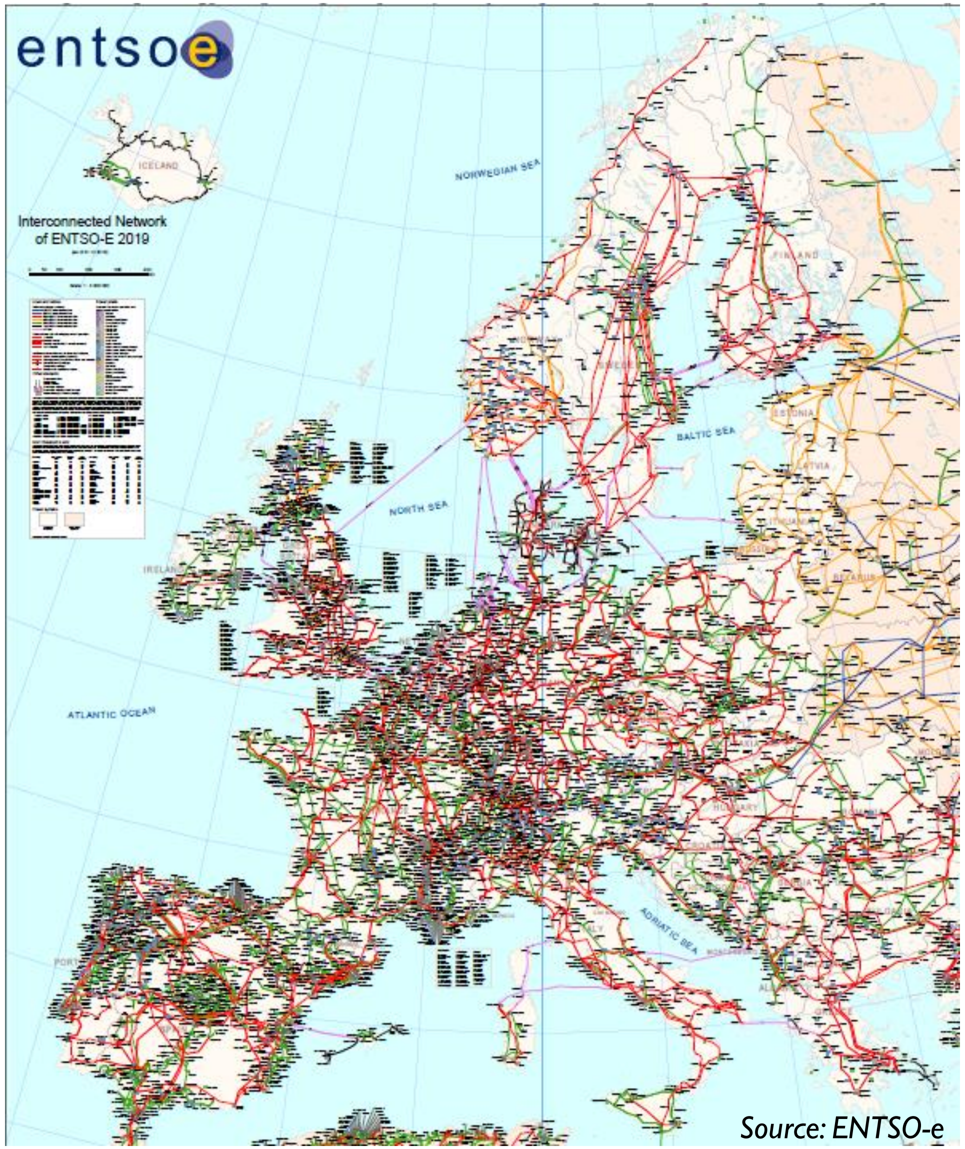
ENTSO-e: the European Interconnected Power System - Key Figures



Source: ENTSO-e

Key figures*

- ✓ *Consumption:* ***3,329 TWh***
- ✓ *Peak load:* ***542 GW*** *(Jan. 18th, 2017)*
- ✓ *Net gen. capacity (NGC):* ***1,1152 GW***
- ✓ *Cross-border exchanges**:* ***467 TWh***

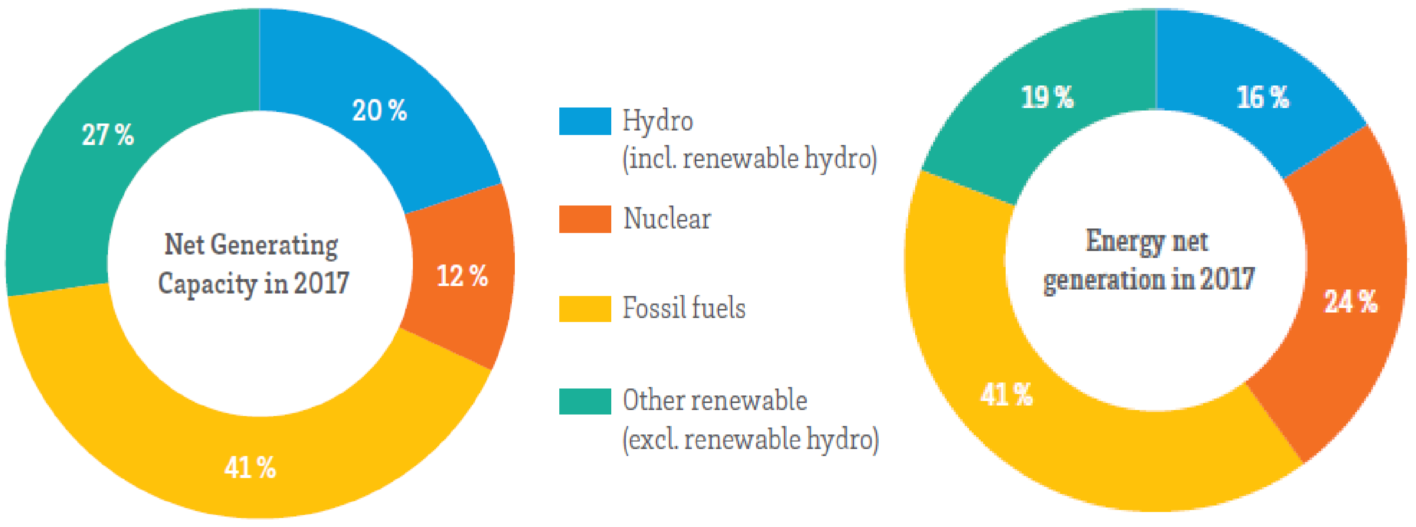
- ✓ *Circuit length:*
  - o *AC lines:* ***474,000 km***
  - o *AC cables:* ***5,100 km***
  - o *DC cables:* ***8,600 km***

- ✓ *Cross-border lines:*
  - o *AC:* ***393***
  - o *DC:* ***30***

** Data referred to year 2017* *** including exchanges with non ENTSO-e countries (Russia, Morocco, etc.)*

ENTSO-e: the Generation Mix

Generation mix comparison between 2017 and 2016



Source: ENTSO-e

Fast evolution of the generation mix:

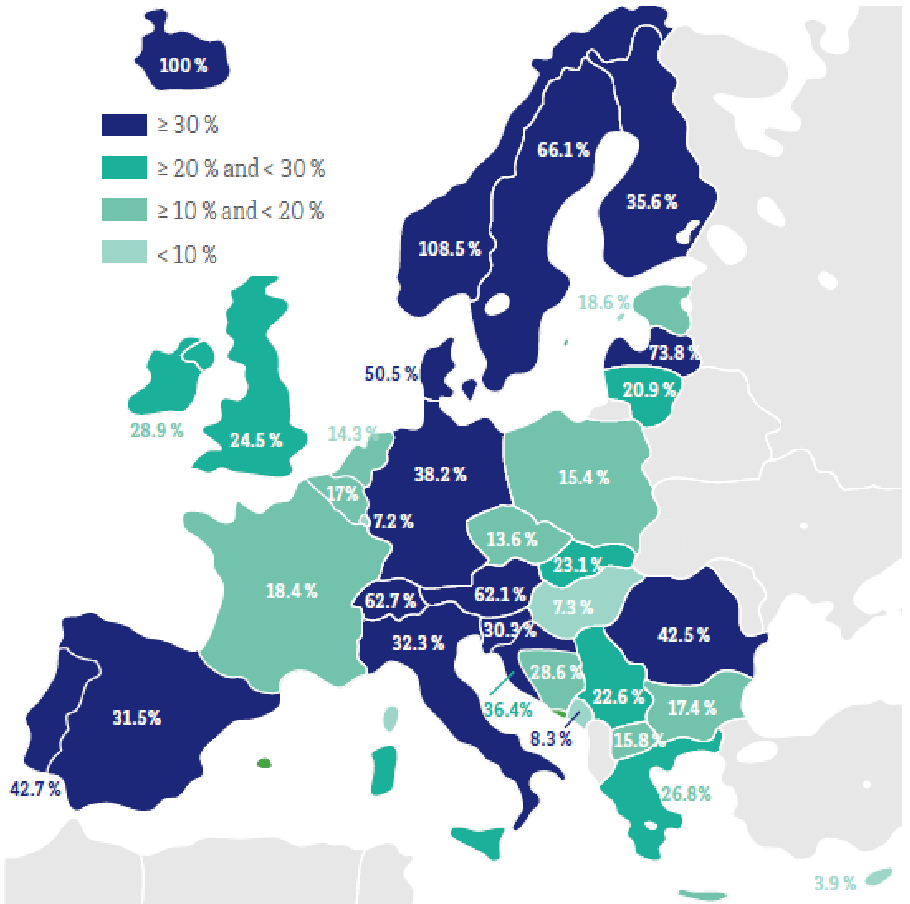
✓ *Decline in thermal NGC:*

- ✓ -2.3% nuclear;
- ✓ -3.1% fossil;

✓ *Robust growth of V-RES:*

- ✓ Wind NGC: **+9.8%**
- ✓ Solar NGC: **+6.1%**

Share of consumption covered by RES gen.



Fragmented situation across Europe with highly decarbonized power systems thanks to **hydro resources** (e.g.: Norway, Sweden, Latvia, Switzerland, Austria)

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Looking Ahead: Roadmap Towards Power Sector Decarbonization in Europe

2020
climate and energy package

23 April 2009

2030
Framework for climate and energy policies

23 October 2014

25 February 2015

2020-2030
Energy Union Package

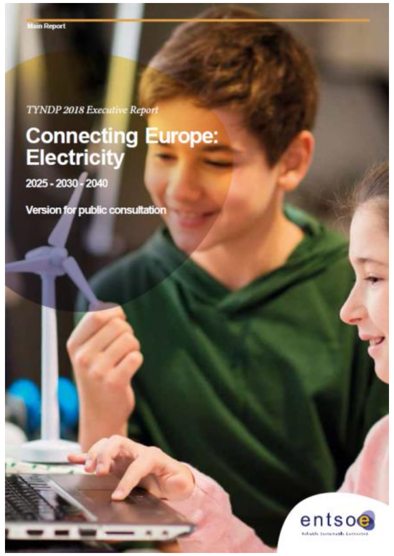
2050
Roadmap for moving to a low-carbon economy

Europe: key figures of the last TYNDP 2018

The Power Sector is the forerunner in the decarbonisation process

	2030	2040
RES PENETRATION (*)	48 to 58% (now 35%)	65 to 81%
CO_2 EMISSION CUTS (**)	65 to 75% (now 29%)	80 to 90%

(*) yearly RES production over the total electric consumption
(**) compared to the 1990 emissions



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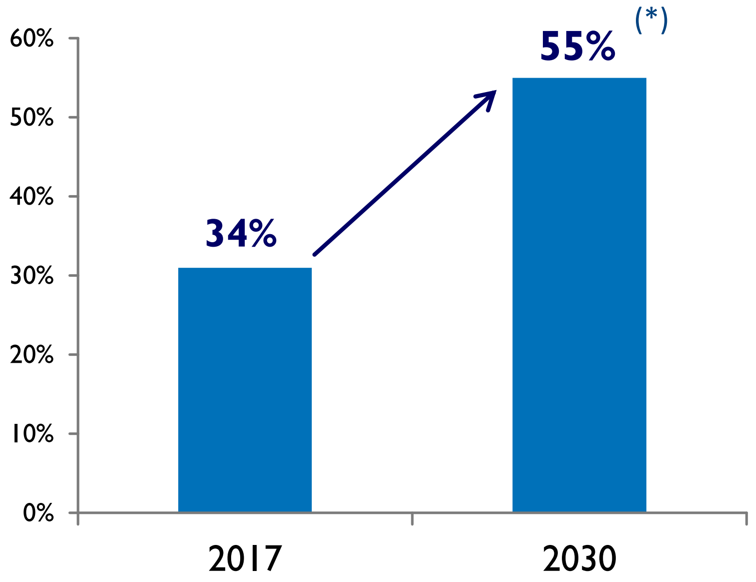
Challenges to Deal with Highly Decarbonized Power Systems Shall be Addressed Now

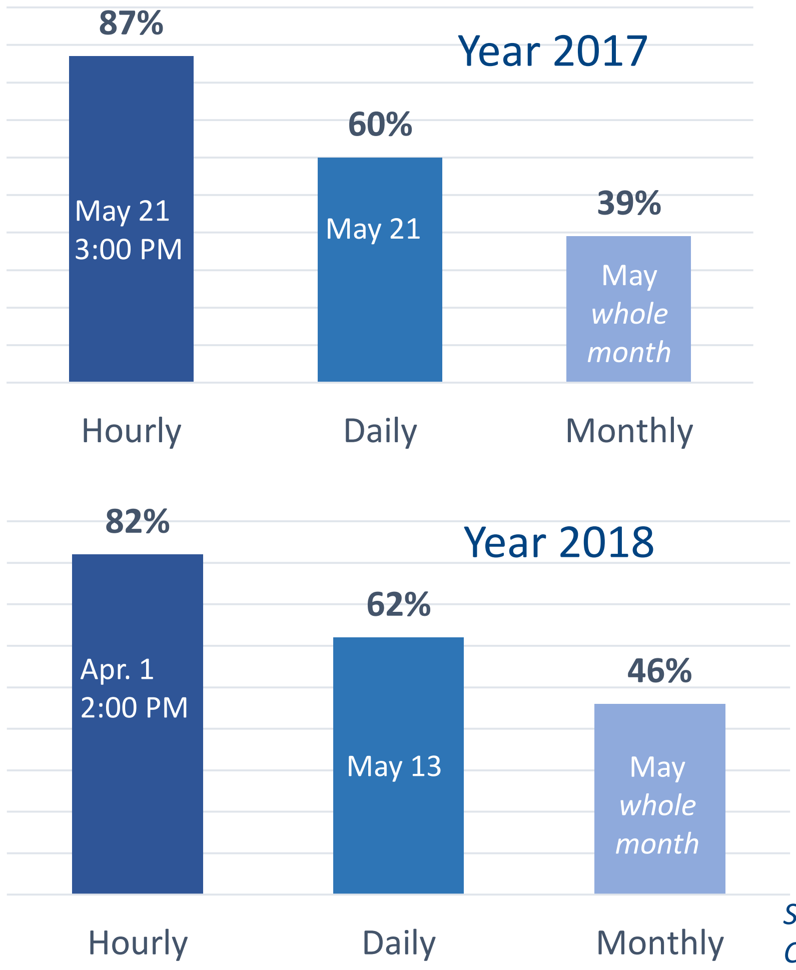
The future is coming soon…

despite a still moderate RES penetration, peaks of RES generation, namely V-RES, are already occurring now

Italy



RES-e penetration over the internal demand



Source Terna
CESI elaborations

(*) National Energy Strategy (SEN) 2017

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Challenges to Deal with Highly Decarbonized Power Systems Shall be Addressed Now

- Additional reserve & balancing capability
- Difficult up/down ramp hours
- Over-generation risk
- More challenging frequency regulation

- TSO/DSO interaction
- Incentive framework

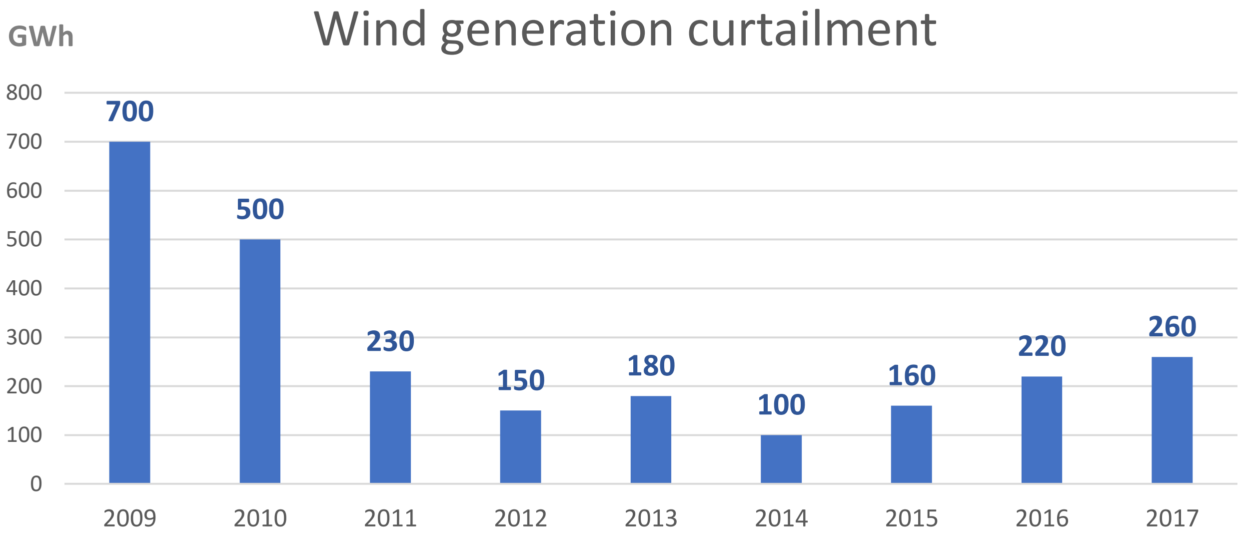
- Reduction of GHG emissions

- Network congestions
- Voltage profile & reactive power management
- System protection

- Risk of day-ahead market price distortion
- Enhanced effort in the Ancillary Service Market to ensure security margins

NEED FOR COMBINED ACTIONS TO MINIMIZE RENEWABLE GENERATION CURTAILMENT WHILE MAINTAINING SYSTEM SECURITY

Challenges in Operating Power Systems with a High Share of RES Generation: Situation Experienced in Italy

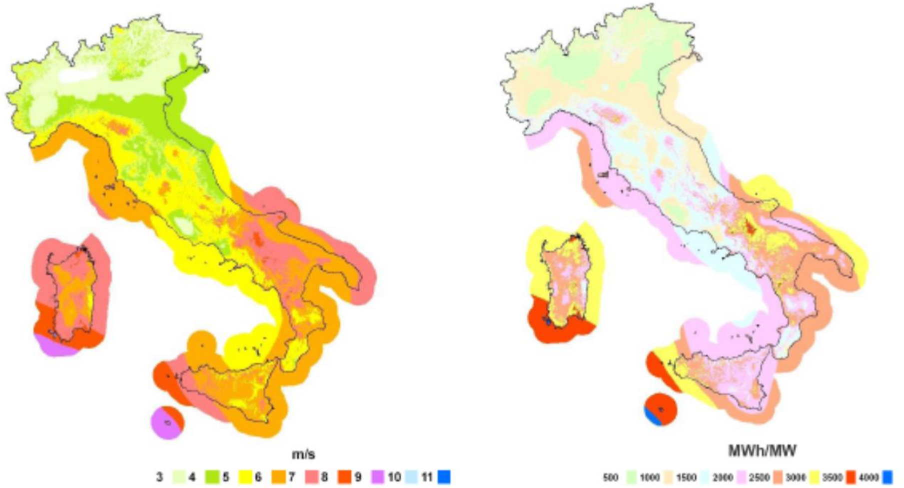


	2009	2010	2011	2012	2013	2014	2015	2016	2017
Wind generation (GWh)	6.542	9.125	9.856	13.407	14.897	15.178	14.844	17.689	15.111
Gen. curtailment (%)	10,7%	5,5%	2,3%	1,1%	1,2%	0,7%	1,1%	1,2%	1,7%

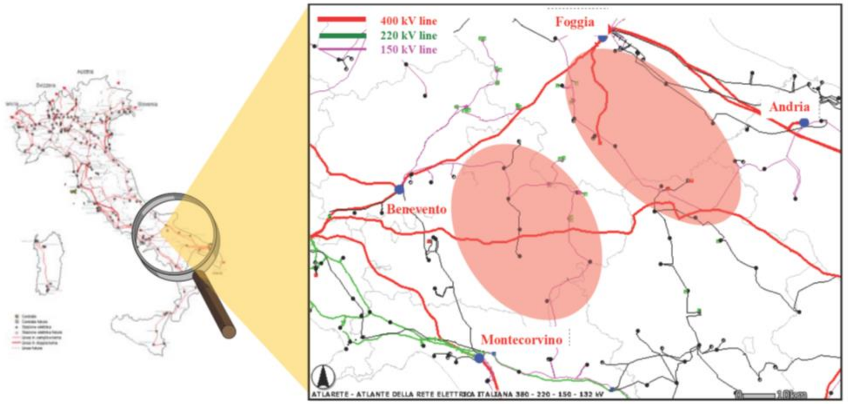
Source: Terna and CESI elaborations

Main causes of wind gen. curtailment:

- ✓ Congestion at HV network
- ✓ Congestion at EHV network
- ✓ Balancing problems



Wind generation concentrated in the far South and the Islands

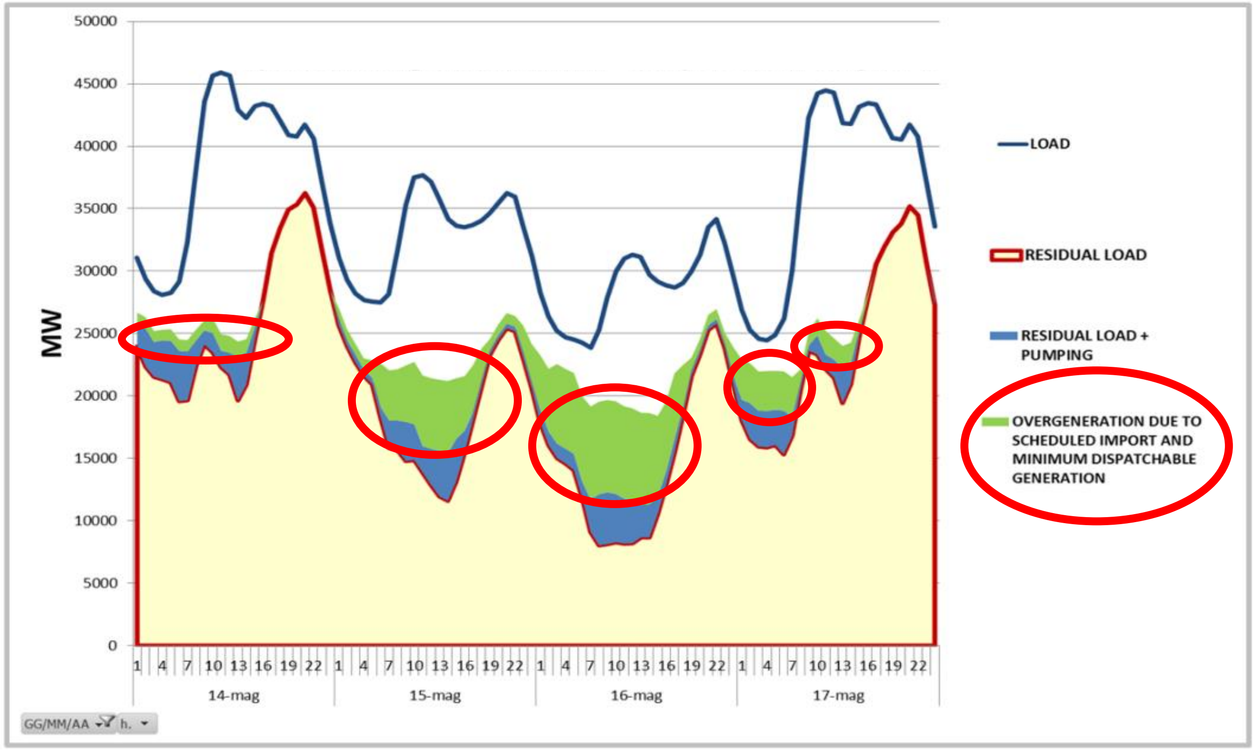


Congestion on the 150 kV grid

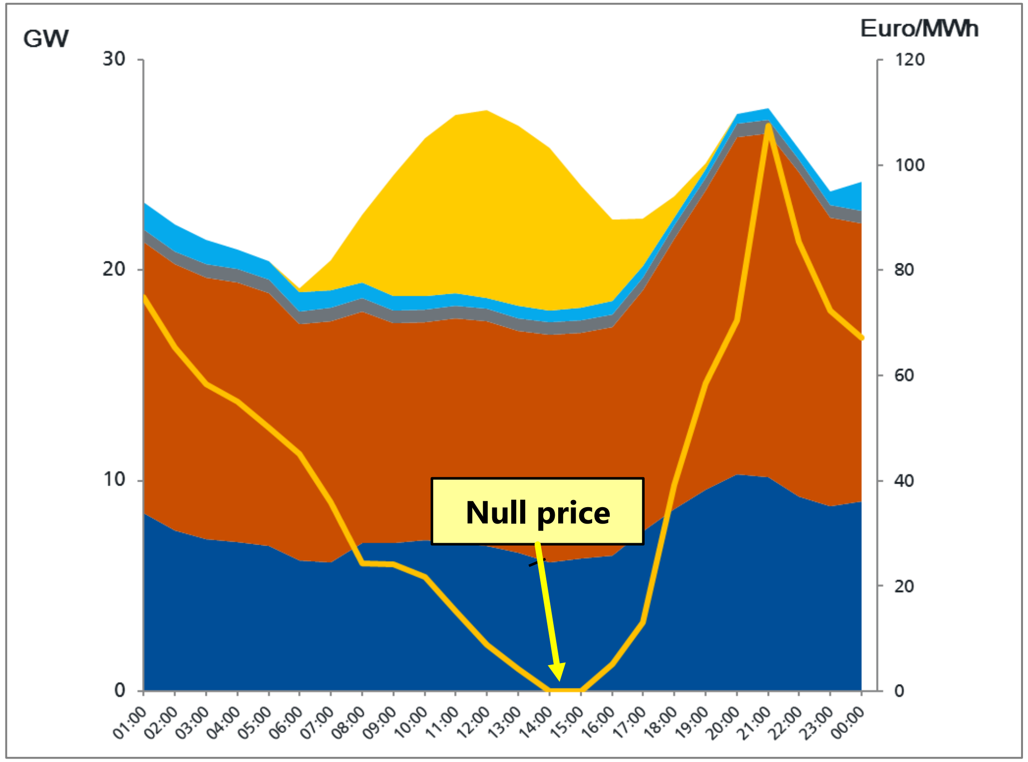
Risk of Overgeneration in Low Loading Conditions Causing Immediate Impact on the Energy Markets and Affecting the Operators Behaviors

SYSTEM-WIDE IMPACTS

MARKET IMPACTS



Difficulties in balancing the system during critical hours with high V-RES generation



Market price distortion due to the priority given to RES generation

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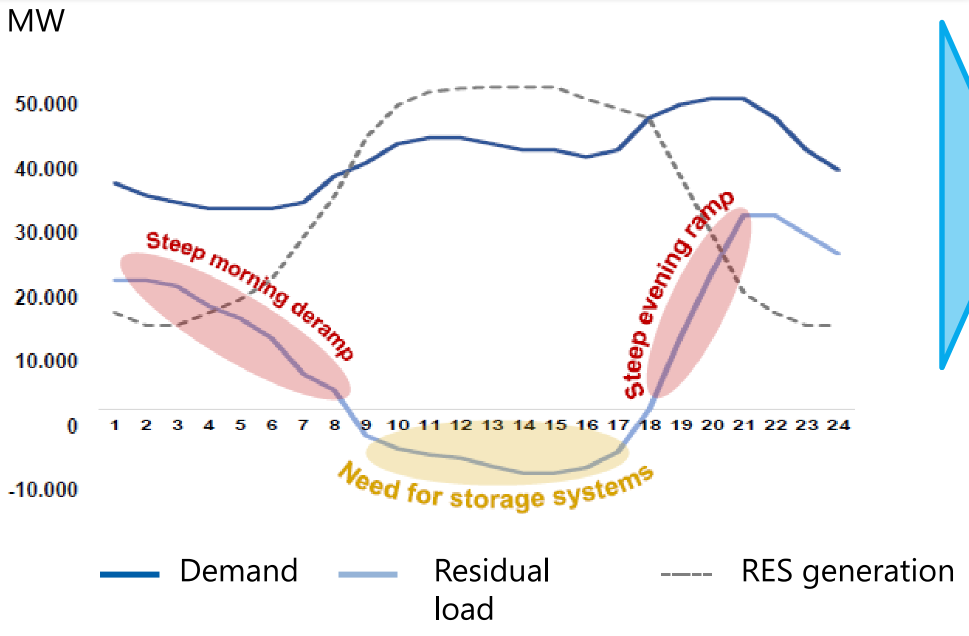
Need for Higher System Flexibility

- RES generation growth will be largely based on variable energy sources (wind and solar) calling for an **enhanced system flexibility**:
  - ✓ storage capacity √ **other solutions** (e.g.: changing operation paradigms, DR, etc.)
- **New paradigms for storage** facilities, not only hydro pumping, but:
  - ✓ **Utility scale batteries; √ clusters of EV; √ non conventional devices (CAES, cryogenics energy storage, etc.)**

SYSTEM-WIDE IMPACTS

Example of residual load with high RES penetration Simulation at 2030*



- ❑ Ramps up until 10000 MW/h in 2030
- ❑ Up to 15÷20 GW of RES generation would be curtailed in many occurrences without appropriate energy storage facilities

** Simulation applied to Italy referring to the National Energy Strategy*

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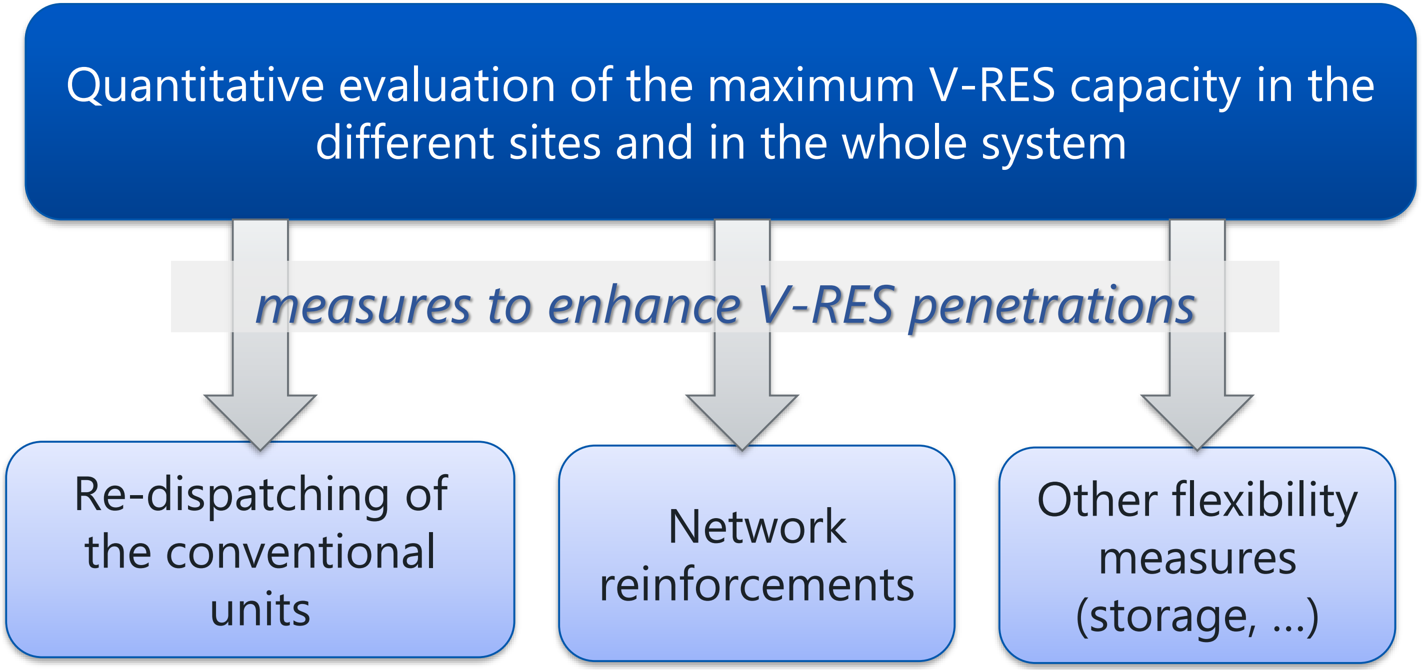
How to Address the Risk of Over-Generation and Network Congestion: a Probabilistic Approach Shall be Adopted

The objective of the probabilistic analysis is the assessment of the following indicators on a time horizon of one year:

- Risk of not meeting instantaneous demand (MW)
- Risk of Energy Not Supply (MWh)
- RES generation curtailment due to network overloads (bottleneck) / balancing constraints (MWh)



- **Probabilistic simulations able to cover, as much as possible, all the expected conditions over a whole year of system operation**

  - ✓ **GRARE** –Grid Reliability and Adequacy Risk Evaluator – computational tool developed by CESI on behalf of the Italian TSO, Terna (see appendix)

- **The adequacy of the electric system is determined by means of a simulation model that use the *"Monte Carlo"* probability method, where:**

  - ✓ Many possible system configurations are defined in a random manner on the basis of unavailability rates generation units, lines and transformers
  - ✓ The actions by the system operator are simulated in order to obtain either the best reliability of the supply or the best compromise between security of supply and economic use of resources
  - ✓ The intermittency of wind and solar generation is taken into account, as well as their forecast errors, together with the forecast error of power demand

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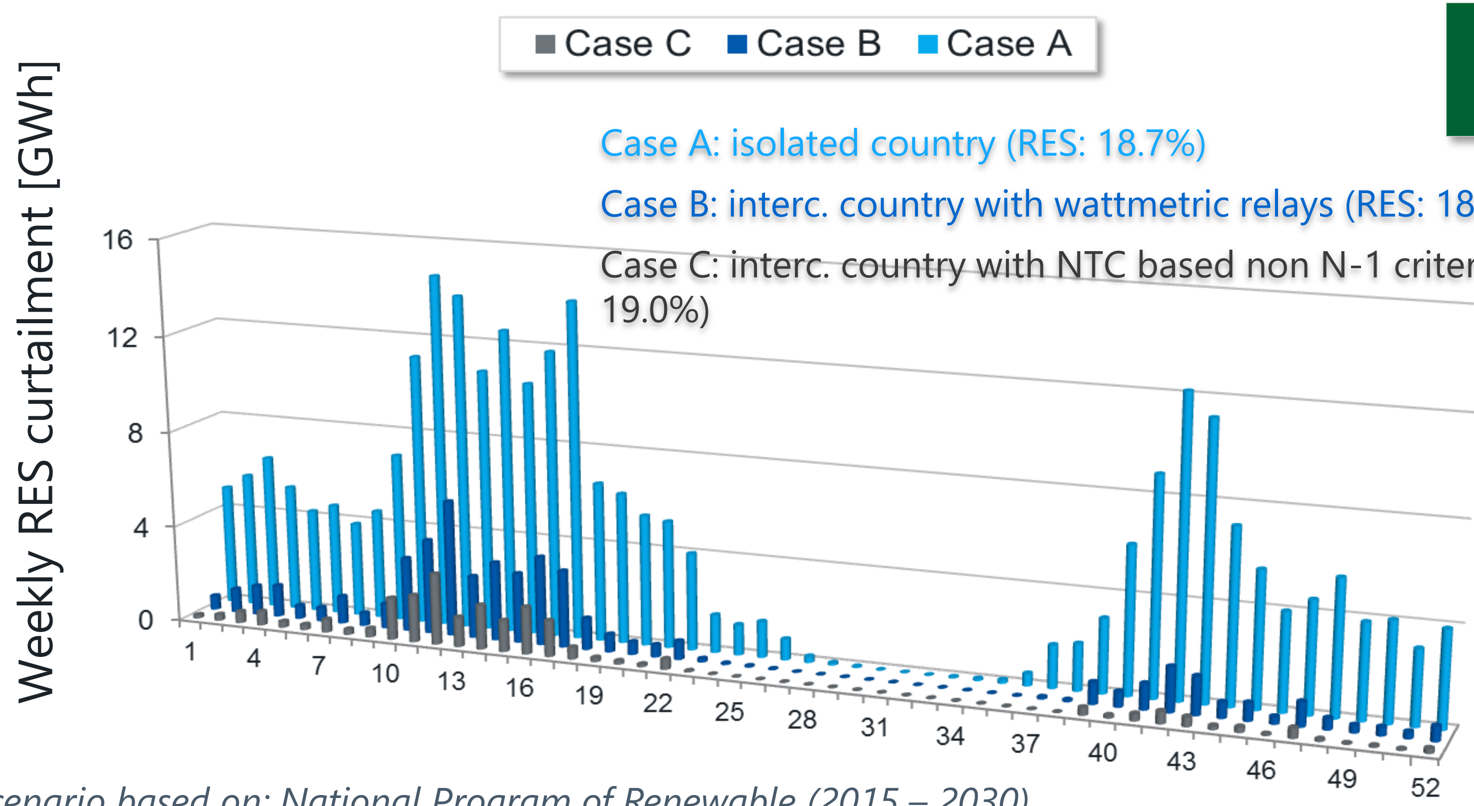
Example Applied to a Possible 2025 Scenario
Assessment of Weekly RES Curtailments in Algeria – Role of Interconnections



Case A: isolated country (RES: 18.7%)

Case B: interc. country with wattmetric relays (RES: 18.9%)

Case C: interc. country with NTC based non N-1 criterion (RES: 19.0%)

Scenario based on: National Program of Renewable (2015 – 2030)

Key role of interconnections to reduce renewable generation curtailment

- ✓ **Spring and autumn** are the seasons with the maximum RES curtailment risk
- ✓ In all weeks **the presence of interconnection reduces in a significant way the risk of RES curtailments**

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Tools and Mechanisms for Integrating Renewables

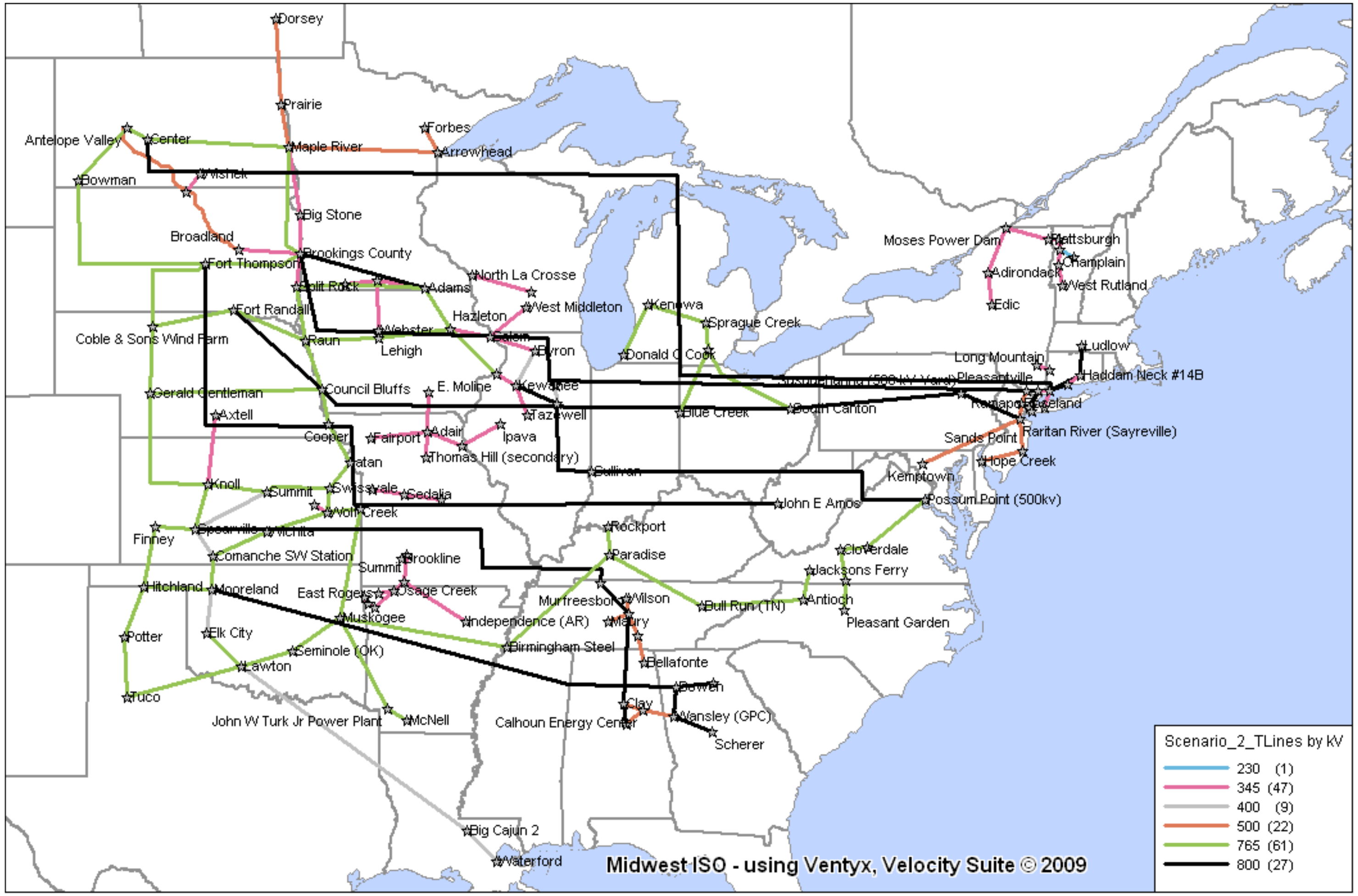
Transmission

System Flexibility

- Generation fleet
- Demand participation
- System control (large BAs)

What about storage?

- Provides valuable flexibility
- Costs was high relative to other sources of flexibility; equation may be changing, however



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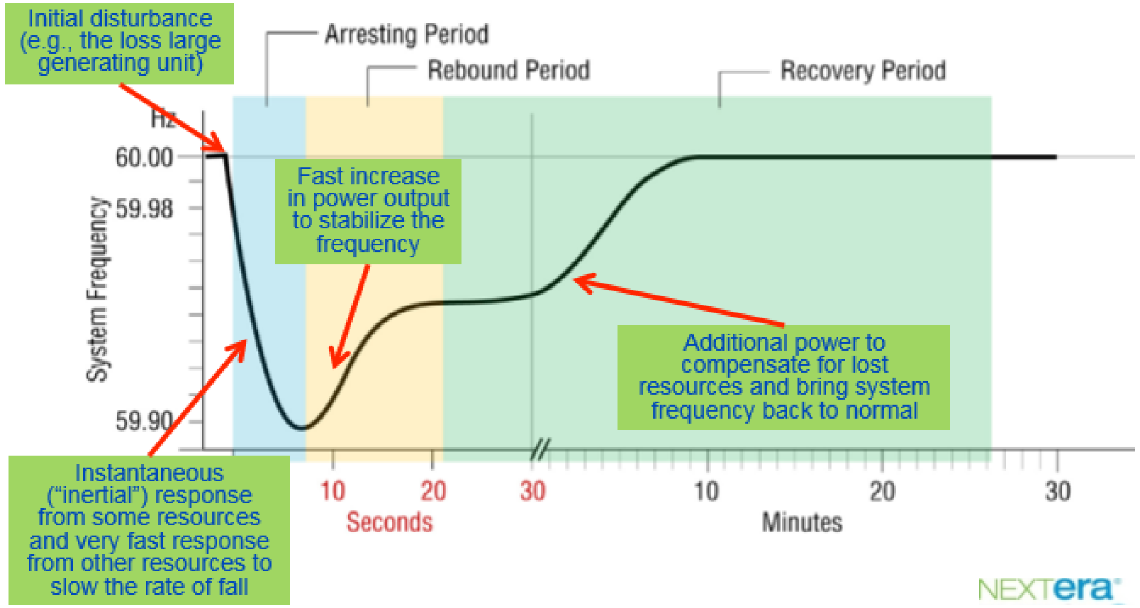
US: NERC Focus on Essential Reliability Services (ERS)

- ERS Task Force launched in 2014 to assess reliability risks from changing generation fleet
- Identified grid characteristics critical for reliability that must be maintained
  - Frequency support
  - Voltage control
  - Balancing/ramping (flexibility)
- Determined that:
  - All new resources should have the capability to support voltage and frequency
  - Coordination of NERC reliability standards with Distributed Energy Resources (DERs) equipment standards such as IEEE 1547
  - Forecasting, visibility and participation of DERs as an active part of the bulk power system must be further examined

Critical Behavior of the System in Dynamic Conditions

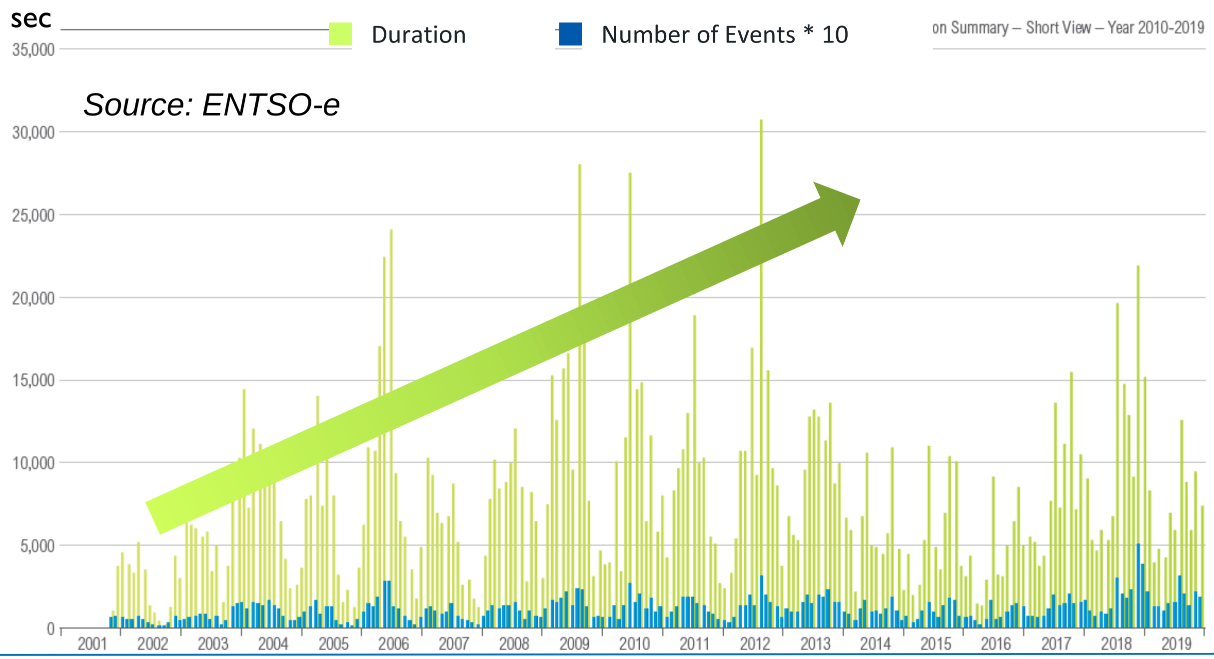
- **Total inertia of the power system declines with the increased share of wind and solar power plants ➡ larger frequency deviations from nominal value during disturbances**



From rotating generators with high inertia to static productions with zero inertia = faster frequency changes in response to sudden imbalances

Critical Behavior of the System in Dynamic Conditions

- ***Risk of higher frequency deviations***
  - This risk increases due to the limited control capabilities of RES power plants and the need for maintaining the regulating power in the system
  - In the ENTSO-e continental area the periods with over-frequency operation (50.1 Hz) longer than 30-40' have become more frequent
  - the risk of accidents during such periods has increased



Solutions for the future

- Dynamic reactive power is available from today's utility scale inverters and turbines (and small PV inverters, too) – Standard feature of wind turbines for over 8 years – Already provided by almost all utility-scale wind & solar plants
- ERCOT requires frequency response from wind – An available option from utility-scale wind & solar vendors
- Hydro Quebec requires inertial response from wind – "Synthetic inertia" is an option on most new wind turbines (uses wind turbine's kinetic energy for very rapid power injection)
- Most OEMs are aware of these coming requirements, and are designing equipment accordingly

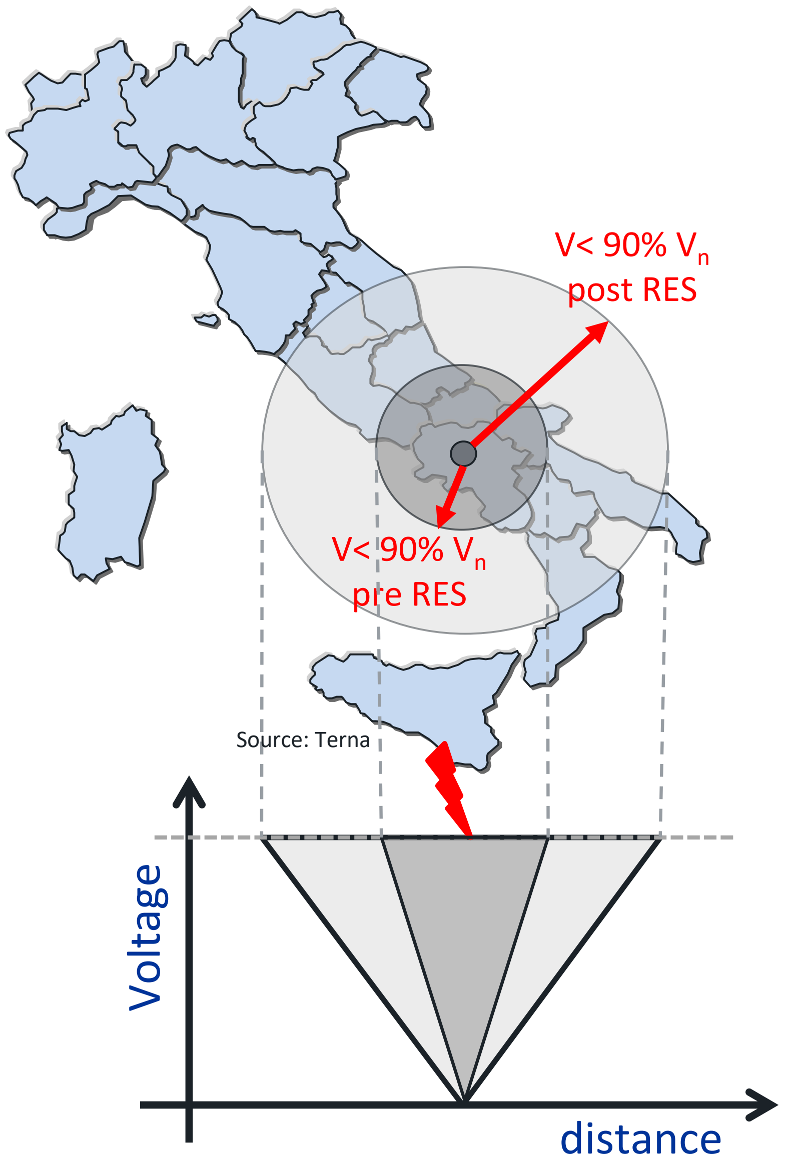
Voltage Profile and Reactive Power Management

- Impact of the RES generation on the Voltage

- **Isc WPP (fully converters)** ≈ **1.1 -> 1.5 In**
- **Isc WPP (DFIG)** ≈ **1.5 -> 2.0 In**
- **Isc PV units** ≈ **1.1 In**

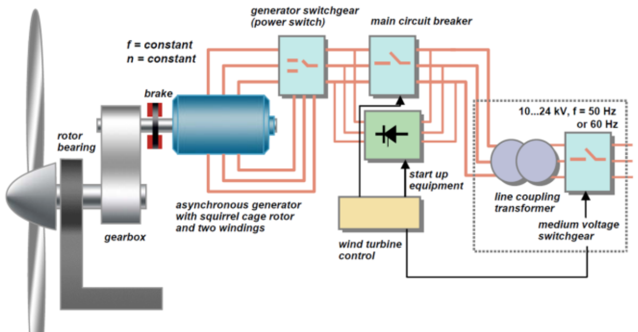
- **Isc synchronous generators ≈ 4 -> 5 In**

- The replacement of rotating generators with RES generators decreases the short circuit current (Isc) and increases the area affected by disturbances on the voltage profile
- At high levels of renewable penetration, traditional protection schemes are challenged (i.e. those based on high short-circuit currents)

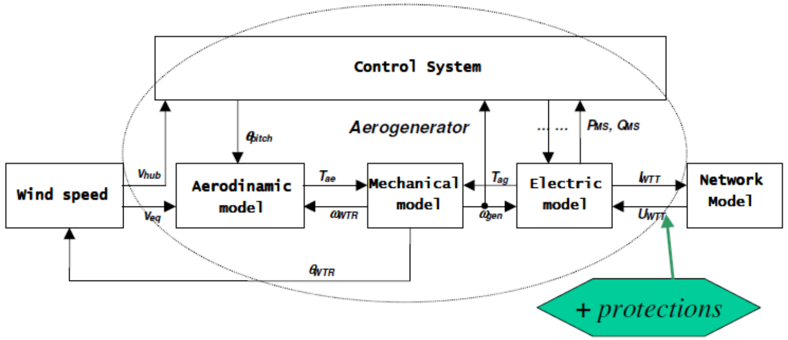


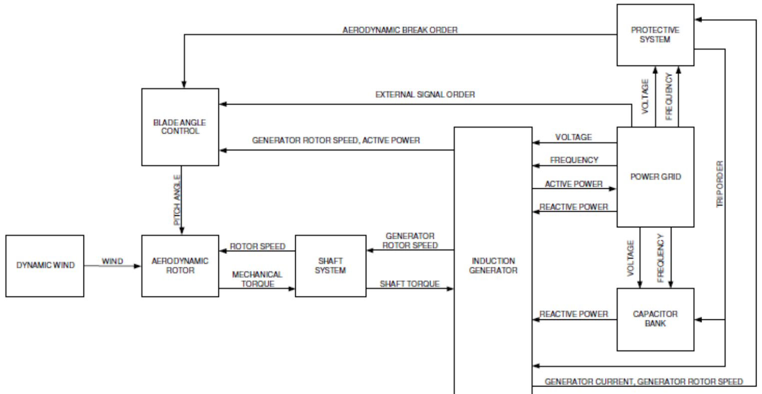
Needs for Going Forward

- ✓ With increasing renewable generation, along with other evolutionary changes, power systems are becoming much **more complex**
  - ✓ Non-conventional generation
  - ✓ Changes on the demand side
  - ✓ Emerging technologies (e.g. Evs)
- ✓ The ability to analyze, plan, and adapt longstanding practices must also evolve **to keep pace**
- ✓ Are already running into some limitations
  - ✓ Conventional bulk system analysis tools (e.g. positive sequence RMS analysis)
  - ✓ Appropriate models for new technologies
  - ✓ Compartmentalization of bulk system and distribution planning & operations



(Source ABB Motors&Drives, Finland ©)





Courtesy of the national TSO of Denmark

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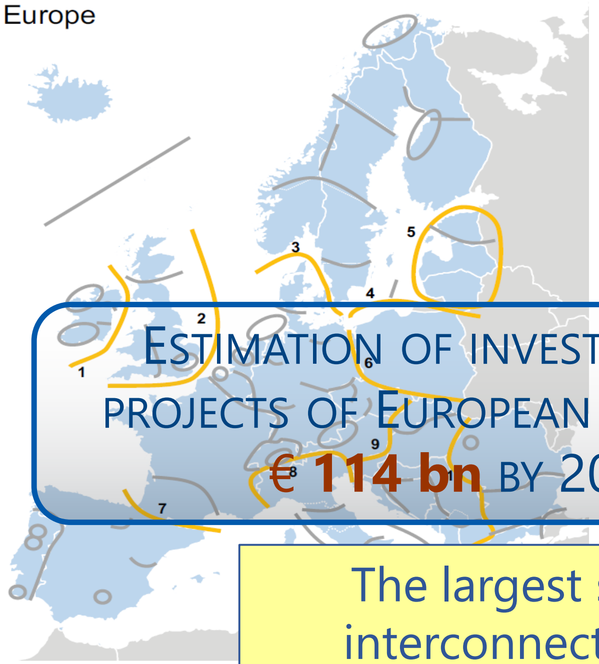
Evolution Towards Fully Decarbonized Power Systems

Solutions to ensure reliability and security: a mix of solutions shall be put in place

Investments in transmission networks

- ✓ Interconnections (enhanced cross-border power flows caused by periodical surplus or shortfall of RES generation)
- ✓ Var compensation equipment (voltage profile and Q management)
- ✓ Synchronous compensators (inertia)



ESTIMATION OF INVESTMENTS IN PROJECTS OF EUROPEAN RELEVANCE: **€ 114 bn** BY 2030

The largest share of interconnections are justified by the integration of RES generation

Market integration

- ✓ Cross-border ancillary markets
- ✓ Capacity market
- ✓ Participation of new resources to the markets (EV, VPP)
- ✓ Evolution of the structure of the markets (e.g.: continuous negotiation) and introduction of new products

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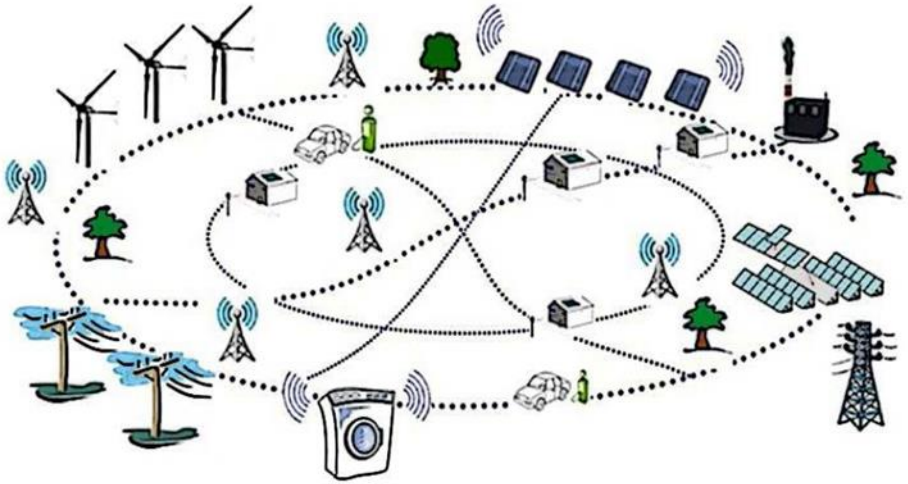
Evolution Towards Fully Decarbonized Power Systems

Solutions to ensure reliability and security: A mix of solutions will be needed

Flexibility

- ✓ New hydro pumping
- ✓ Utility scale batteries
- ✓ Clusters of EV
- ✓ Non-conventional devices (CAES) and solutions (power-to-gas)
- ✓ …



TSO/DSO integration and digitalisation

- ✓ Demand response
- ✓ Distributed Generation
- ✓ Distributed Storage
- ✓ Concept of prosumers / energy communities
- ✓ ….

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Conclusions: Key Messages

- A fast evolution of generation mix towards a high share of RES generation is being witnessed in many regions of the world
- Operating practices, markets must move beyond energy only (or primarily) as renewable penetrations alter the make-up of the system
- Renewable energy is increasingly attractive on several fronts, and growing penetrations will be increasingly disruptive to some of the longstanding industry practices
- The last two decades have demonstrated our industry's ability to anticipate, learn, and adapt. Those traits will be very important going forward.
- Electrification of final uses is also speeding, particularly in the transport sector (EV)

- Need to anticipate challenges due to massive V-RES deployment, and maybe transform them into opportunities (e.g.: power-to-gas instead of V-RES gen curtailment)
- Consider non-conventional solutions such as EV in V2G mode to provide ancillary services
- Need for a continuous improvement in modelling and simulation tools: probabilistic approaches become mandatory to tackle uncertainty in generation and load behavior

Thank you

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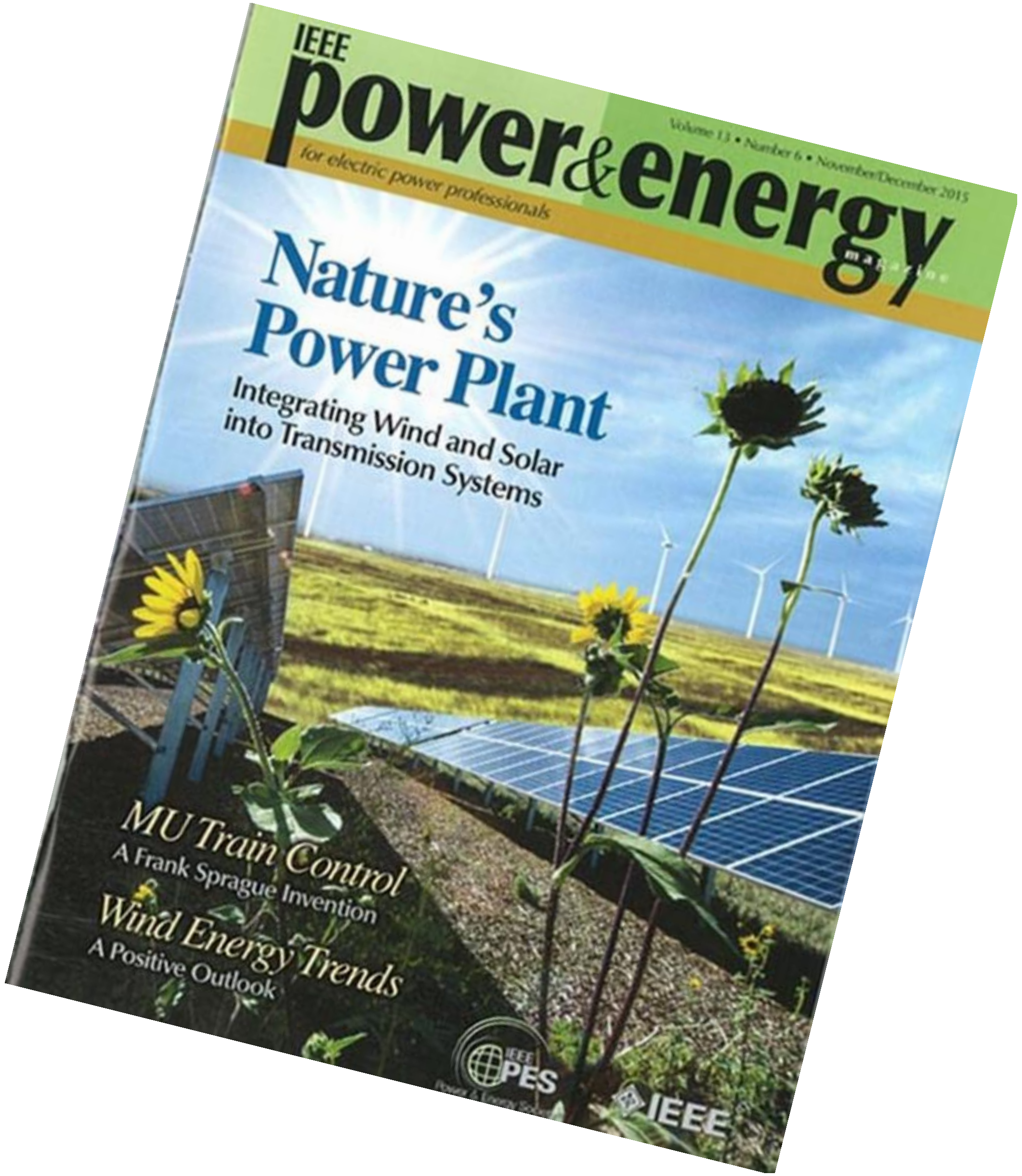

Q&A

At this time, please submit your questions for the presenters in the chat box.

Thank you for attending our webinar!

The slides from today, along with on-demand access to this presentation, will be emailed within 24 hours of the close of this webinar.

THANK YOU!

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ADDITIONAL SLIDES

About the Presenters

Bruno Cova

CESI Systems Planning Project Director

Bruno Cova has a MSc in Electrical Engineering. Since 1986 he has been working in Milan for CESI, a consultancy company focused on electrical system design, testing and certification. At present, he's the director of Systems Planning Unit. He has extensive experience of transmission planning and feasibility studies relevant to power system interconnections and generation from renewable sources, notably in Europe, the southern and eastern Mediterranean region and some countries of Latin America and sub-Saharan Africa.

Bruno Cova has been engaged for years in international associations such as CIGRE and WEC (World Energy Council). At present, he's CIGRE distinguished member and the Italian officer at CIGRE Study Committee C1 "Power System Development and Economics."

About the Presenters

Robert Zavadil, PE

EnerNex Chief Operating Officer

Bob Zavadil is a nationally recognized expert in electric power system issues for wind generation. His clients in the wind generation industry range from turbine designers and manufacturers to project developers and operators, along with transmission service providers and independent transmission system operators. He has extensive experience with new and emerging technologies for electric power generation, delivery, and utilization, including distributed generation and power electronics-based equipment and hence, is able to provide expert advice on all kinds of studies related to renewable power plants.

He has over forty years of experience in the electric power industry. He has supervised multiple wind integration and interconnection studies in bulk power systems and is actively involved in the majority of the modeling activities at EnerNex.

Bob is a member of the IEEE Power & Energy, Power Electronics, and Industrial Applications Societies, and serves as Vice-Chair of the IEEE PES Wind and Solar Power Coordinating Committee.

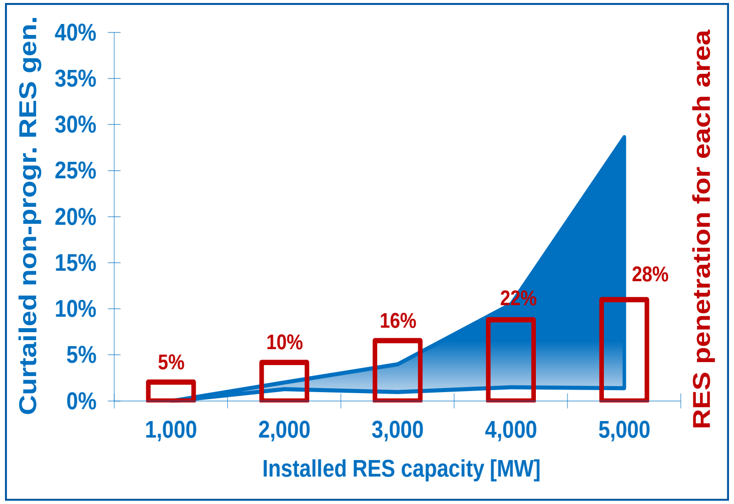
Assessment of RES curtailment risk

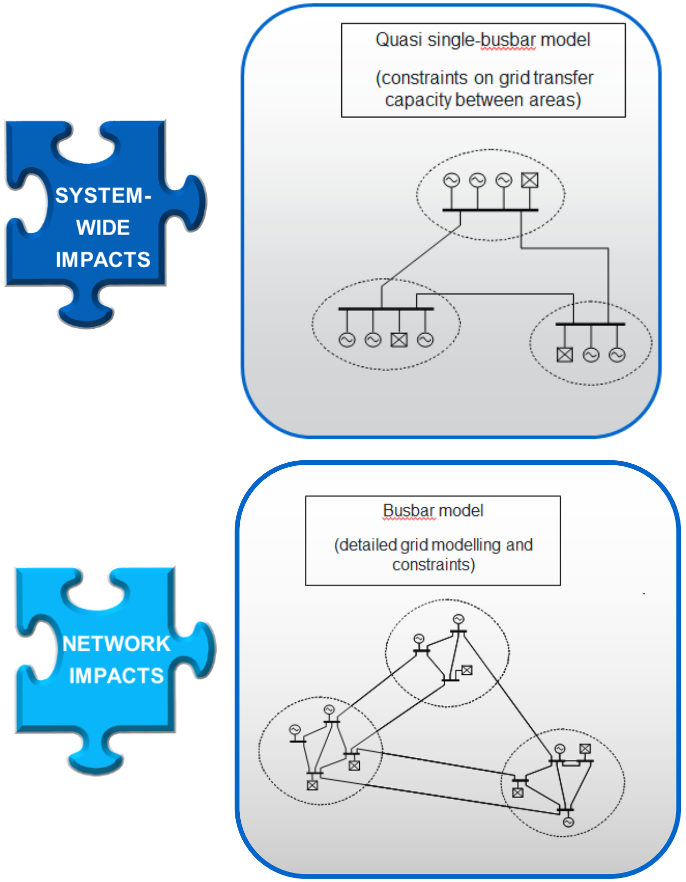
RES Curtailment due to operating constraints:

- ✓ the minimum reserve margin
- ✓ (in)flexibility of traditional generation fleet

RES Curtailment due network constraints:

- ✓ RES cut to alleviate network bottlenecks





Risk of V-RES generation curtailment strongly non linear if no measures are undertaken when increasing installed RES capacity

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GRARE – Grid Reliability and Adequacy Risk Evaluator - Main Applications

GRARE tool is property of Terna and is developed by CESI

More details on: *www.cesi.it/grare*

GRARE

GRID RELIABILITY AND ADEQUACY RISK EVALUATOR

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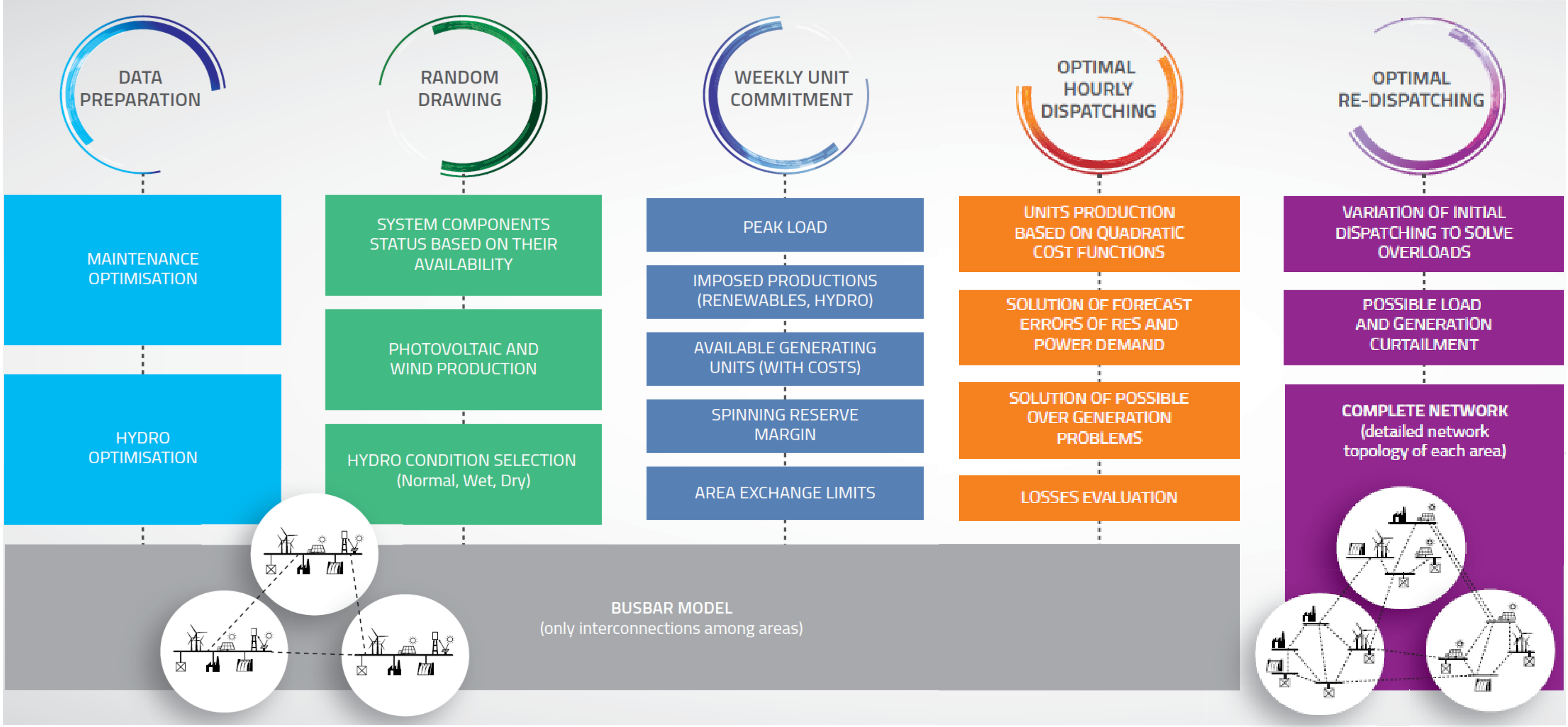
GRARE – Grid reliability and Adequacy Risk Evaluator- The computational process



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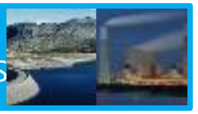
- Engineering, Environment - ISMES 

Utilities & RTOs

enel, Terna, EDF, Eni, Rte, State Grid, dewa, entsoe, Los Angeles Department of Water & Power, IBERDROLA

OEMs and Consulting

EPRI Electric Power Research Institute, McKinsey&Company, SIEMENS, ABB, Burns & McDonnell, accenture High performance. Delivered.

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