RES4Africa Knowledge Platform

Technical flexibility solutions for grids with high-VRES penetration

CESI

RES4AFRICA FOUNDATION

Technical challenges for VRES integration

The Variable Renewable Energy Renewables (VRES) have different characteristics in comparison to conventional generation
The integration of VRES technology requires more flexibility for the power system

Renewable sources (challenges dependent on the nature of the source)

- Supply fluctuations
- Supply uncertainty
- Low capacity factor
- Location specificity

Converter based units (challenges dependent on the connection tech)

- Reduction of power system inertia
- Impact on power quality
- Change in fault behaviour
- Change in reactive power capability

Distributed generation (challenge dependent on distribution level)

- Change in voltage profile and two-way power flows
- Impact on system protections
- Low visibility & Controllability
- Hosting capacity estimation

The risk of VRES curtailment

VRES curtailment: types and causes

VRES curtailment is the **deliberate reduction of VRES power** output below what could have been produced due to:

System constraints:

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

→ Power system curtailment: system balance

Network constraints:

- ✓ VRES cut to alleviate network bottlenecks
- ✓ (in)adequate transmission capacity

→ Network curtailment: lack of adequate grid infrastructures

The risk of VRES curtailment

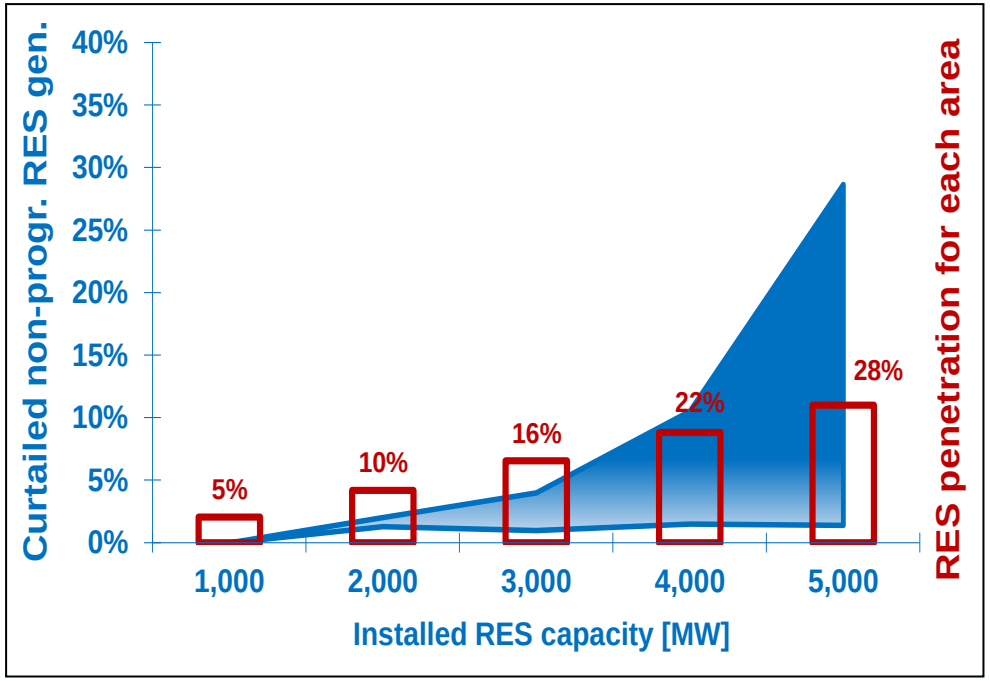
VRES curtailment: types and causes

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 VRES generation

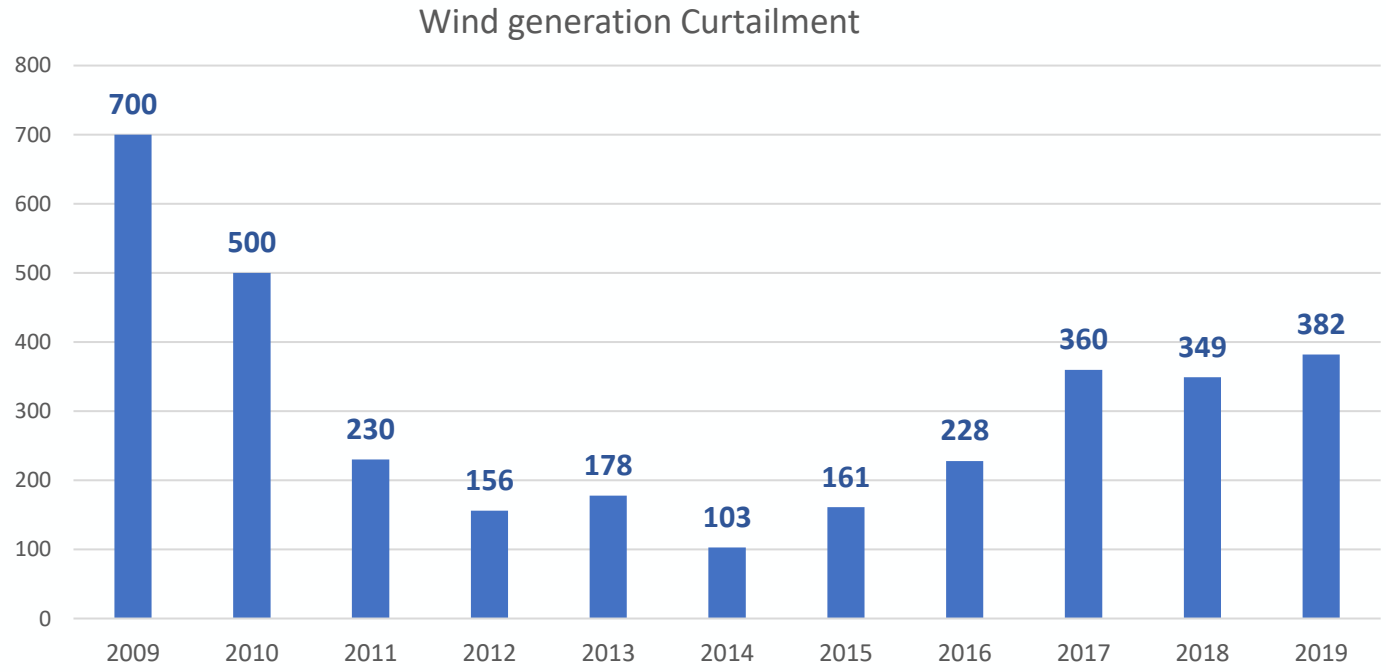
Example: small power system



Source: CESI elaboration

Typical VRES curtailment in a power system

Wind curtailment in Italy



Wind generation (GWh)	6.542	9.125	9.856	13.407	14.897	15.178	14.844	17.689	17.565	17.557
Gen. curtailment (%)	10,7%	5,5%	2,3%	1,1%	1,2%	0,7%	1,1%	1,2%	2,0%	2,2%

Reduced curtailment thanks to:

- Grid reinforcements
- Increased flexibility of plants

Source: Terna and CESI elaborations

How to reduce VRES curtailment?

VRES curtailment

Cost of VRES curtailment

- VRES are generally compensated even when curtailed
- Lost of green power

vs

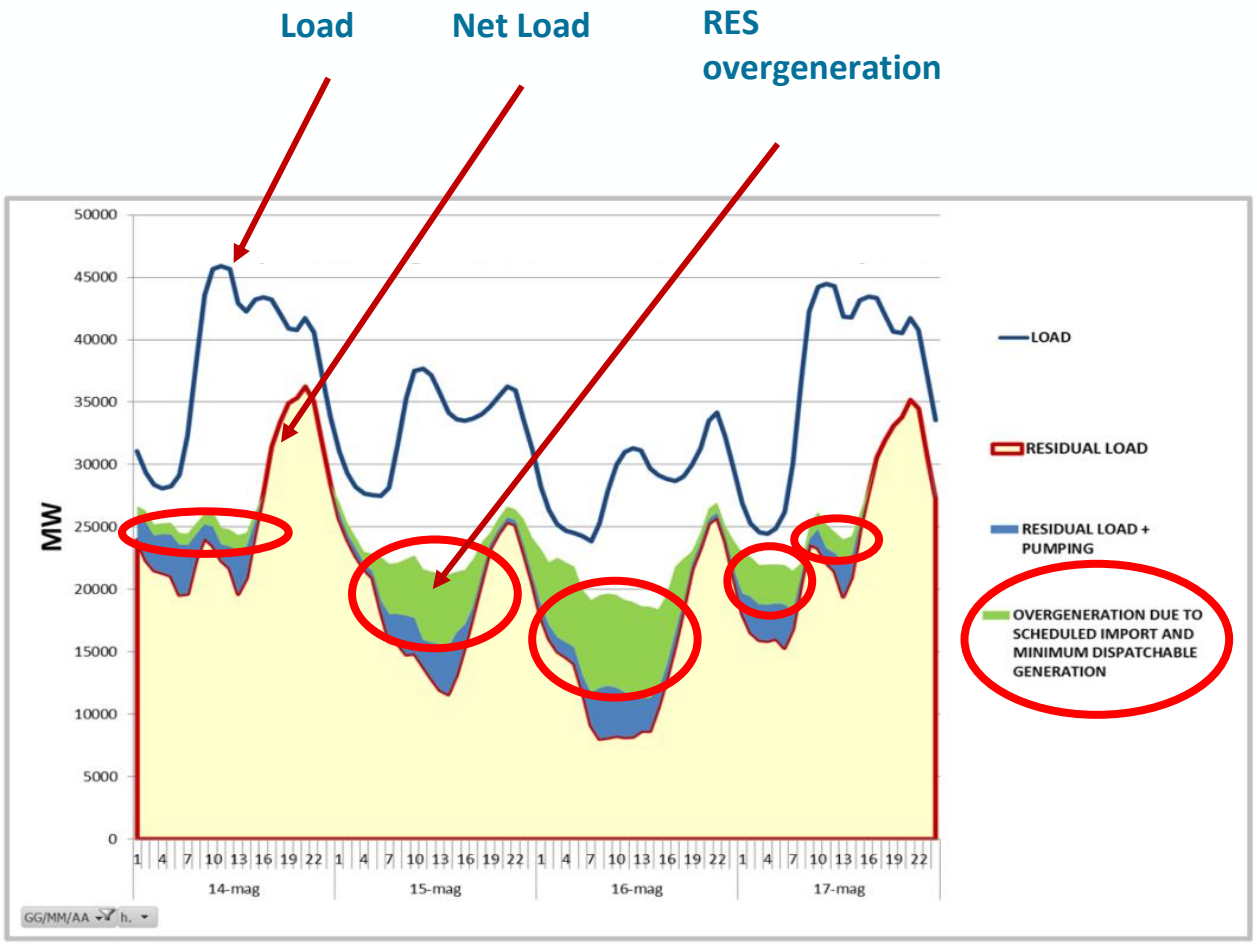
Cost of solutions to implement

- Infrastructure costs
- Storage costs
- Plants flexibility costs

VRES curtailment accepted up to a maximum value (e.g. 2-5% of annual energy produced)

The risk of over-generation

Power system balance and risk of over-generation



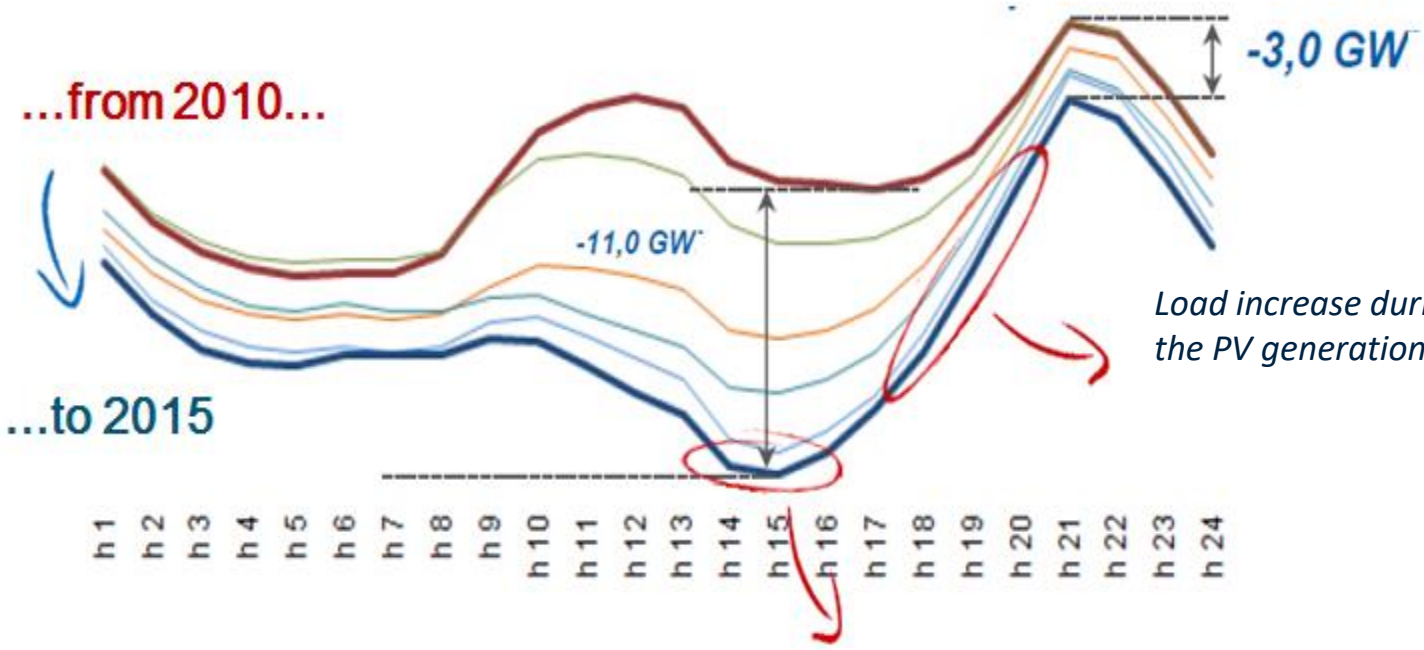
- **Net load is:** the difference between load demand and VRES production

- Difficulties in balancing the system during critical hours with high VRES generation, especially during holidays (high VRES, low load)

The challenges to assure the power system balance

Net load: example for Italy

Average net load on Sunday in April



Load increase during the evening when the PV generation is decreasing

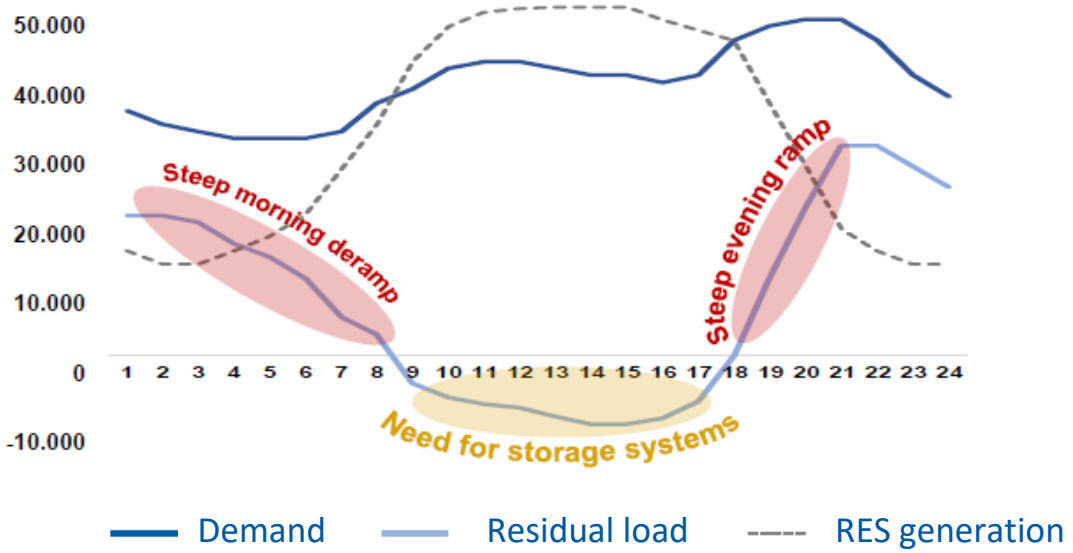
Limited downward reserve

Problems to control the network voltage profiles

Source: Terna

The challenges to assure the power system balance

Steep up and down ramps



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

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

Impact of VRES on Power System balance

Risk of overgeneration and steep ramps: how to manage them?

- **Reducing constraints** on the operation of existing conventional power plants:
  - Increased flexibility
  - Reduction of essential and must-run plants as much as possible

- The development, for the future, of **new more flexible** conventional power plants compared to existing ones

- **Exporting overproduction** to neighboring countries (or reducing imported power)

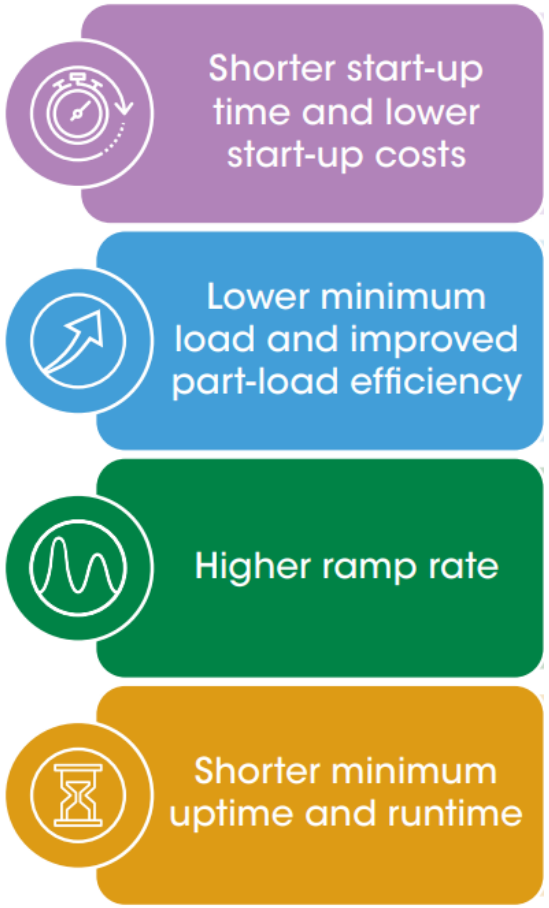
- The development of **storage systems**

- Increase the **system reserve**

- **Diversification** of renewable energy sources

The system flexibility

Increased power plants flexibility



Type of point		Start-up time*	Start-up cost (USD/MW instant start)	Minimum load [% Pnom]	Efficiency (at 100% load)	Efficiency (at 50% load)	Avg. ramp rate [% Pnom/min]	Minimum uptime	Minimum downtime
Hard coal	Average plant	2–10 h[a]	> 100	25–40%[a]	43%	40%	1.5–4%[a]	48 h	48 h
	Post flexibilisation	80 min–6 h[a]	> 100	10–20%[b]	43%	40%	3–6%[a]	8 h	8 h
Lignite	Average plant	4–10 h[a]	> 100	50–60%[a]	40%	35%	1–2%[a]	48 h	48 h
	Post flexibilisation	75 min–8 h[c]	> 100	10–40%[b]	40%	35%	2–6%[c]	8 h	8 h
CCGT	Average plant	1–4 h[a]	55	40–50%[a]	52–57%	47–51%	2–4%[a]	4 h	2 h
	Post flexibilisation initiatives	30 min–3 h[a]	55	20–40%[c]	52–57%	47–51%	8–11%[c]	4 h	2 h
OCGT	Average plant	5–11 min	< 1–70	40–50%	35–39%	27–32%	8–12%	10–30 min	30–60 min
	Post flexibilisation/ advanced plant	5–10 min	< 1–70	20–50%	35–39%	27–32%	8–15%	10–30 min	30–60 min
ICE[c]	Average plant	5 min	< 1	20% (per unit)	45–47%	45–47%	> 100%	< 1 min	5 min
	Post flexibilisation/ advanced plant	2 min	< 1	10% (per unit)	45–47%	45–47%	> 100%	< 1 min	5 min

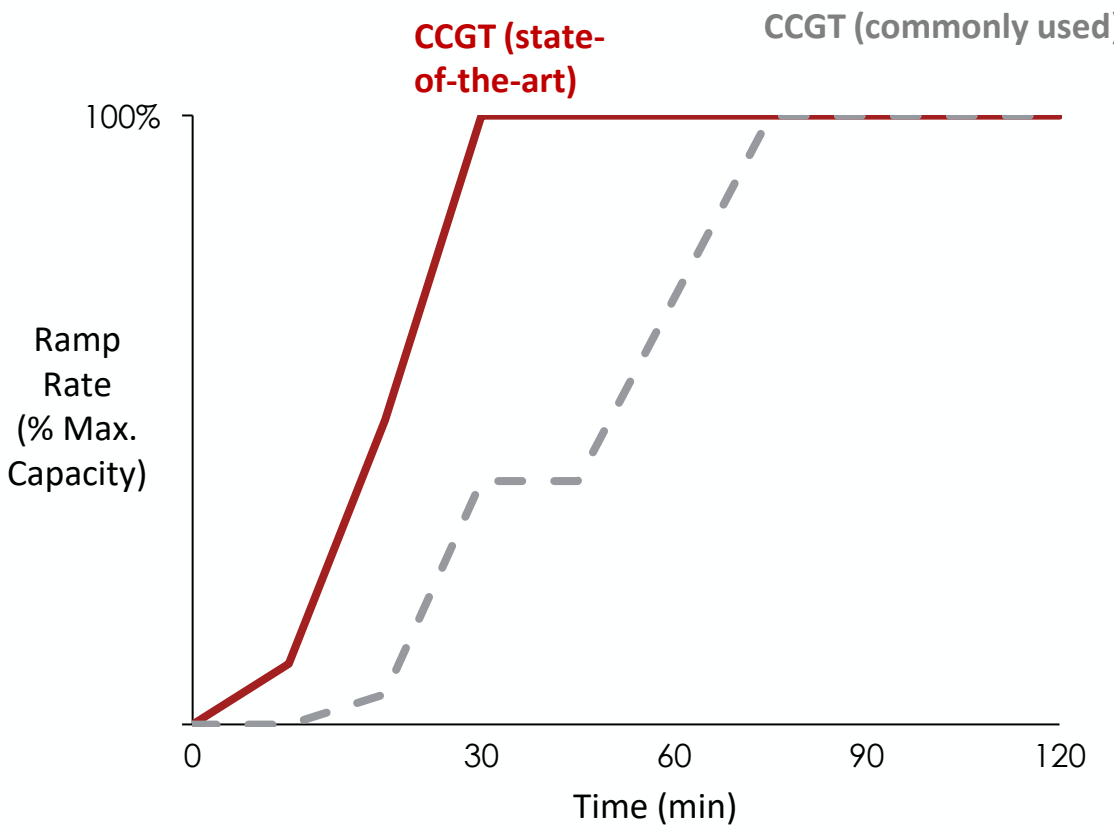
* Start-up times are longer for cold start-up (plant shut for more than 48 hours) than for hot start-up (plant shut for less than 8 hours).

Source: IRENA (2019), Innovation landscape brief: Flexibility in conventional power plants, International Renewable Energy Agency, Abu Dhabi

The system flexibility

Increased flexibility: retrofitting CCGT plants

Ramp rates and start-up times of CCGT plants: can improve their flexibility by decreasing start-up time by 50%



CCGT Flexibility Solutions

Upgrade Old Plants

An upgrade to CCGT plants, can significantly reduce the plant's hot start times (e.g. from >60 to <40 min) by allowing a parallel start-up of the gas turbine and the steam turbine

Operate as OCGT

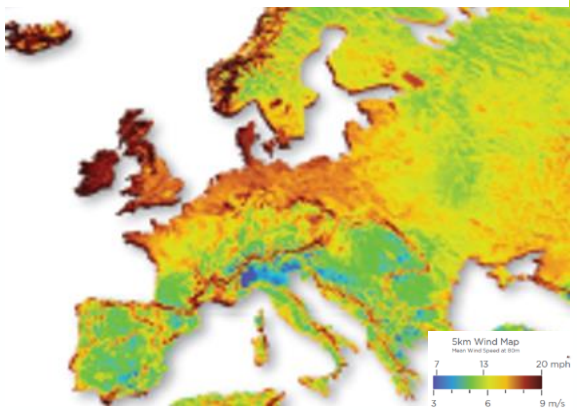
Newer multi-mode combined-cycle plants can be operated in OCGT mode during fast start-up transients to increase flexibility

Network congestion: flexibility in the planning of the transmission grid

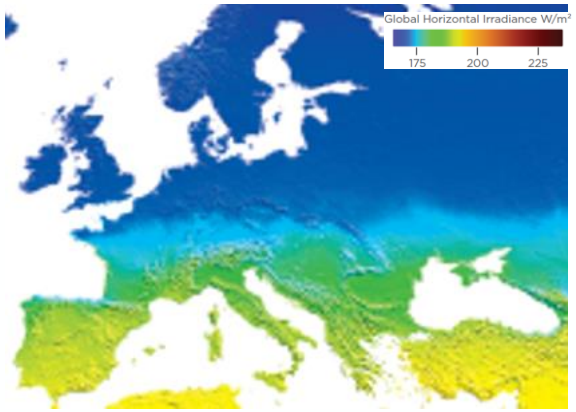
From imported Oil and Gas…to exploitation of local VRES

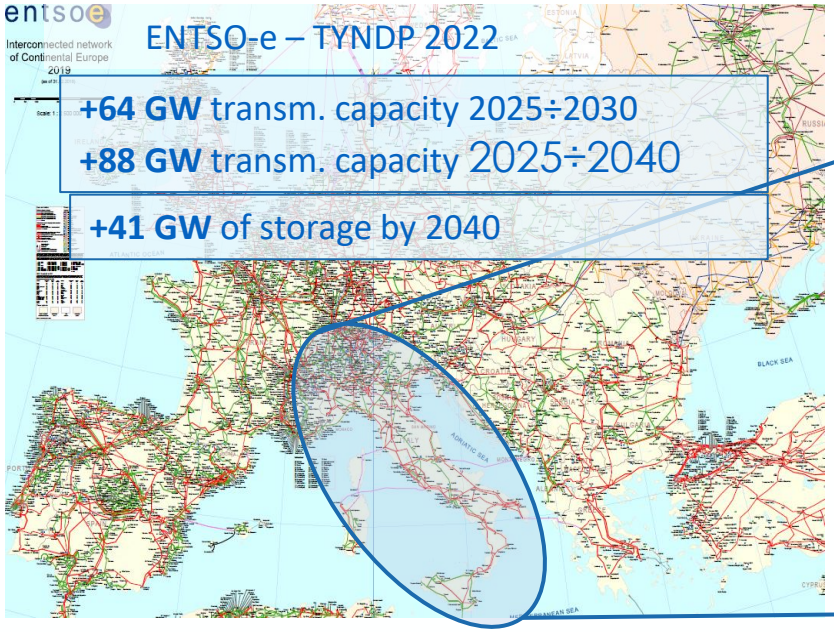
consequent growing effort in transmission capacity

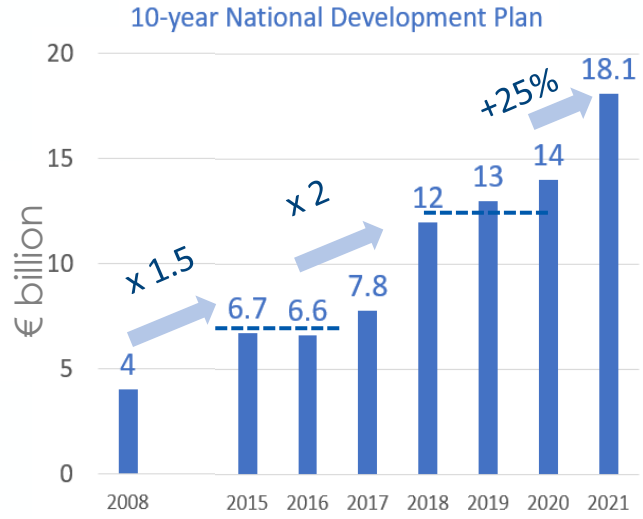
Wind producibility



Solar producibility





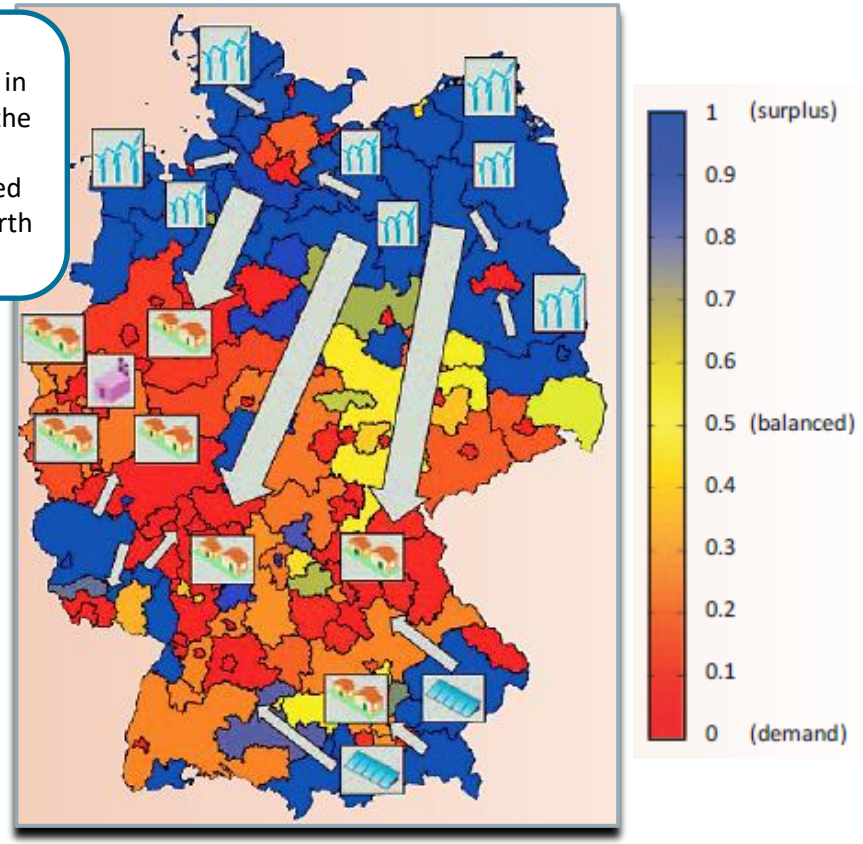


Network congestion: flexibility in the planning of the transmission grid

Example of Germany

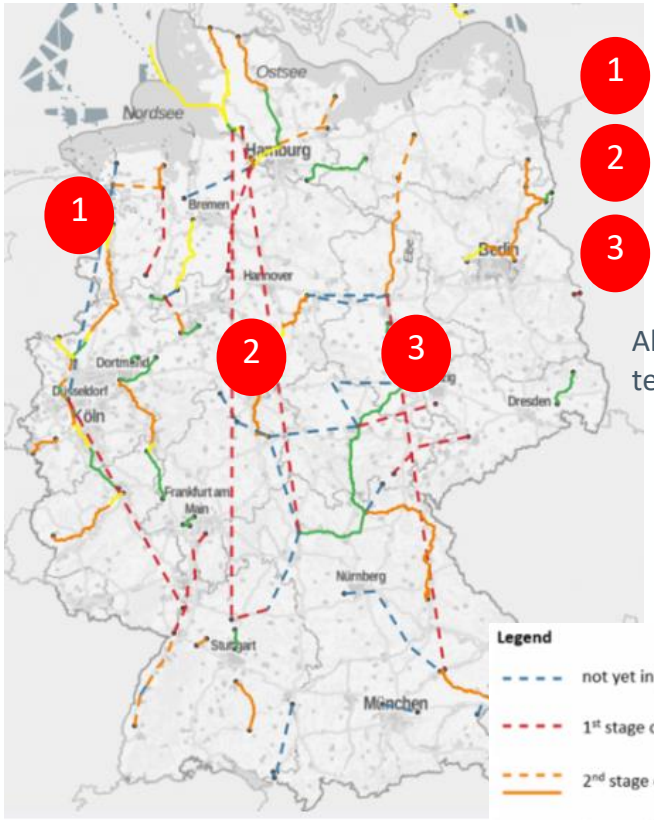
Regional electricity supply/demand in Germany*

Wind generation in the north, PV in the South
Load concentrated in the Centre-North



*Source: IEA

German transmission development plan**



1 A-Nord

2 Süd Link (x2)

3 Südost Link

All links in HVDC technology

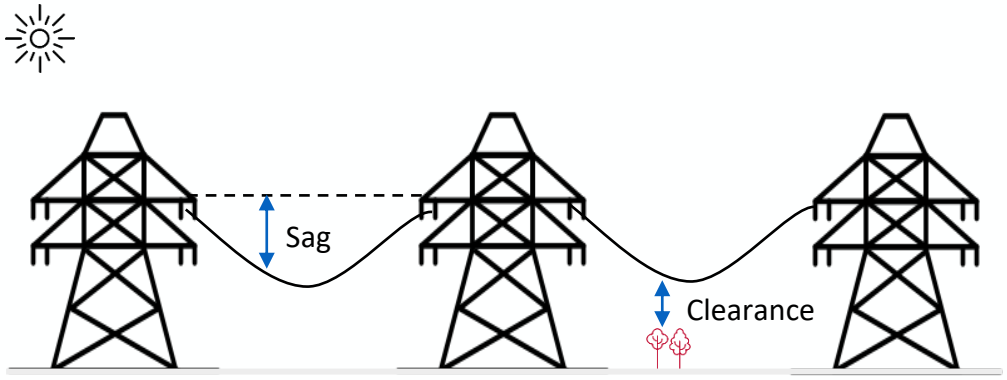
Three main transmission grid corridors foreseen to connect generation and consumption

**Source: Autorité de régulation allemande

The flexibility in the operation of the transmission grid

Transmission Thermal Line Rating

Transmission lines are given thermal line ratings that determine their maximum power carrying capacities



Thermal Limits

Maximum conductor temperature to prevent conductor overheating which leads to sagging

Maximum sag to maintain enough clearance

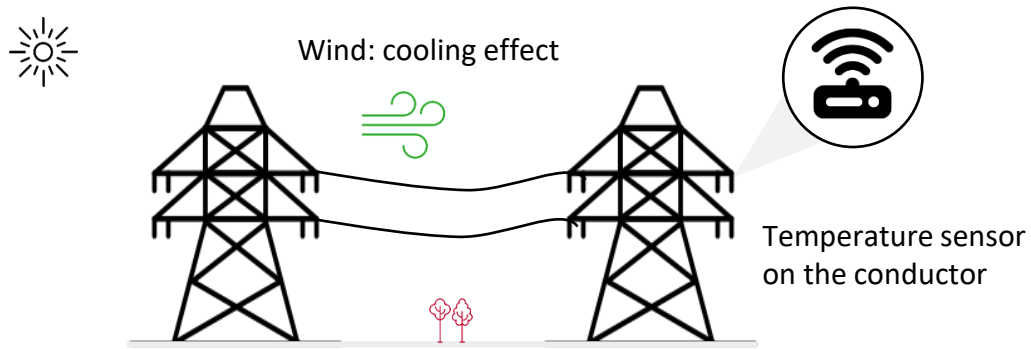
Static Line Rating

- Transmission lines are rated according to **the worst possible weather conditions** to minimize exceeding thermal limits
- The conservative assumption leads **to underutilization of transmission lines**, because suboptimal weather conditions rarely last an entire day

The flexibility in the operation of the transmission grid

Dynamic Line Rating to increase VRES integration levels

Transmission Thermal Line Rating: mitigates grid congestion, enhances flexibility and increases transmission efficiency



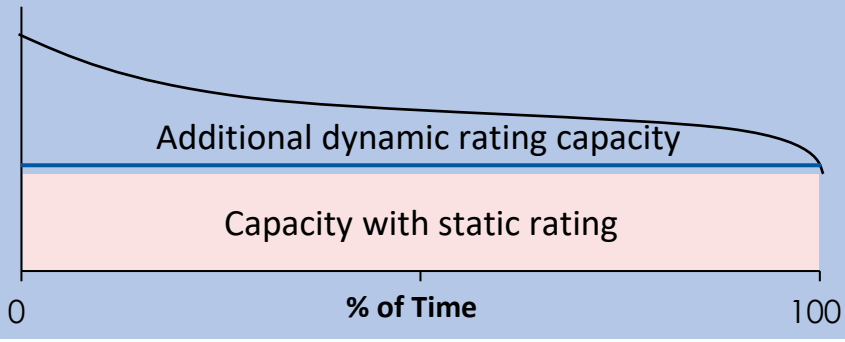
Dynamic Line Rating (DLR)

Technology uses a real-time monitoring system to constantly calculate the varying rating of a transmission line due to the changes in weather conditions

Congestion relief: Utilize small increases in line ratings resulting from favorable weather to switch loads from congested lines

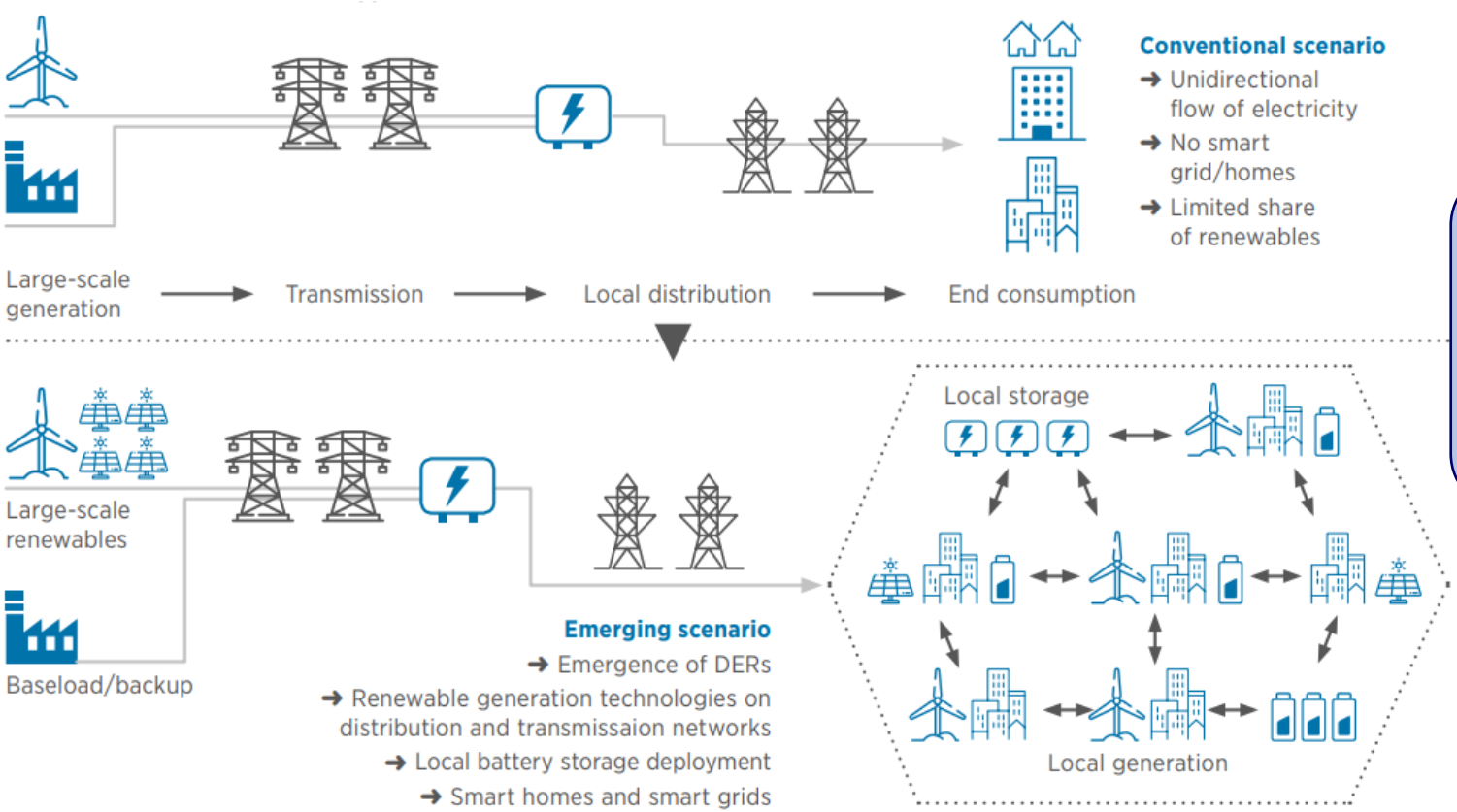
Asset protection: Provide real-time data to grid operators allowing fast & informed decisions in case of sudden changes in weather

Transmission efficiency: Increase the capacity of the existing grid anywhere from 10%-30% for more than 90% of the time



The correlation of transmission and distribution grid

Integration between TSO-DSO



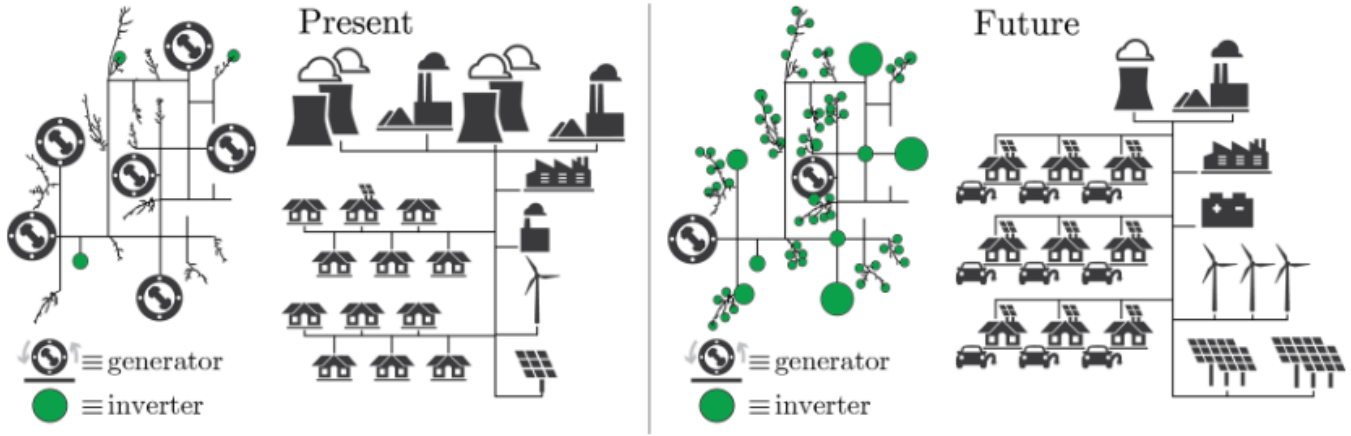
Interaction of TSO and Regulators with new actors

For TSO, need for appropriate tools to interact with system resources not directly connected to the transmission grid

Grid support through advanced Power Electronics and Smart Inverters

Grid-forming Inverter Controls

Existing power systems are dominated by synchronous generators with large rotational inertia and contain a small amount of inverter-interfaced generation. Next-generation inverter controls will enable architectures that are dominated by inverter-based resources



Source: NREL

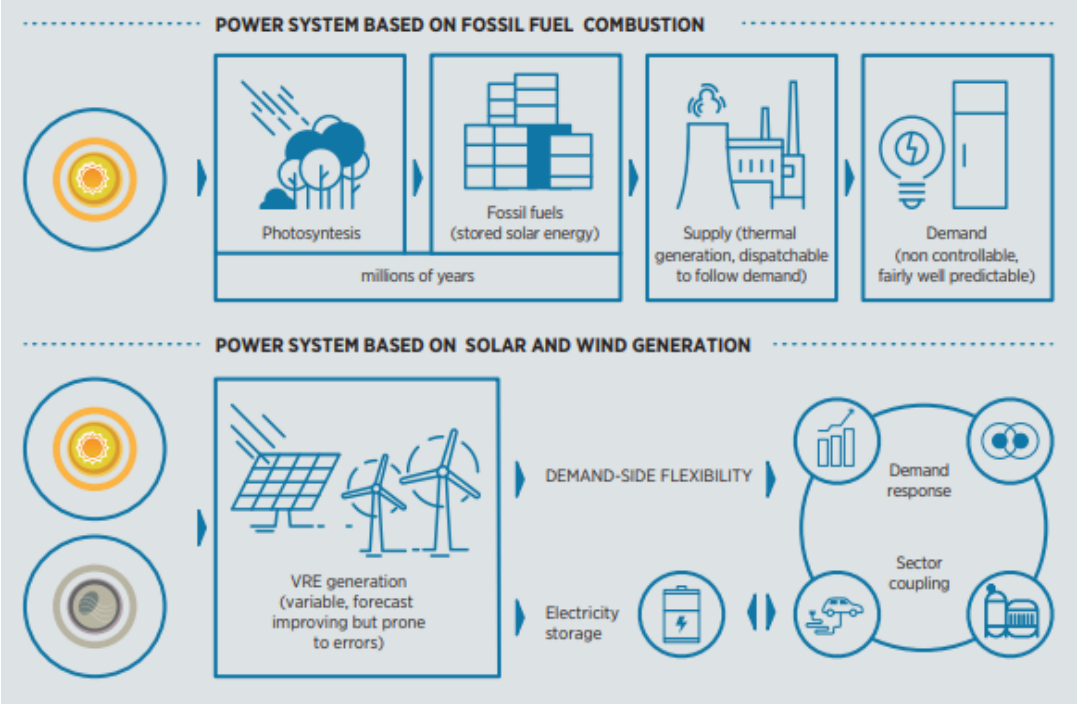
Grid-forming controls for distributed inverters enable reliable control of low-inertia power systems with large numbers of inverter-based resources, including:

- Sinthetic/Virtual Inertia provided by RES or BESS (or HVDC)
- Short circuit currents contributions
- Black Start Capabilities
- Other services

Demand Side Management/Flexibility

DSM is an important **flexibility option to facilitate system integration of VRE** with an impact on the load residual curve

- Electricity consumers simply move any demand, that is less important at any given time, to a time with more electricity generation
- This also means that flexible consumers may choose not to use electricity at times when generation is low and the price presumably high.
- Thus, flexible consumers reduce their electricity bills while simultaneously contributing to the green transition



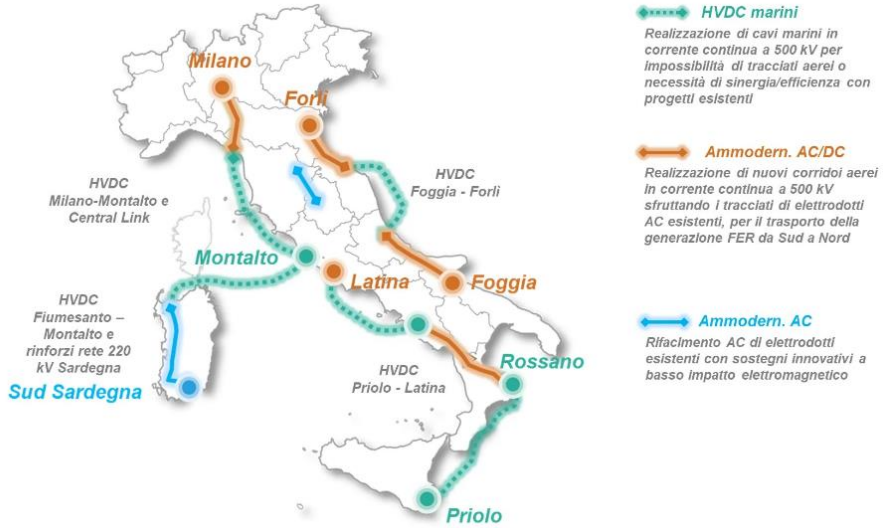
Source: IRENA

Offshore Grids and HVDC Interconnections

- Connection of offshore Wind Generation may **evolve from point-to-point connections to meshed offshore grids** allowing more reliability and better utilization/loading of the lines

Source: HITACHI

- **HVDC links** may be used to transport VRE generation from the production to the main consumption sites, covering long distances and undersea paths, achieving effective, competitive and sustainable solutions



Source: Hyperlink Terna

Conclusions

Possible solutions to overcome barriers and maximize VRES capacity

- Appropriate dimensioning/operation and cost/remuneration of adequate **reserve capacity** of conventional programmable plants
- Assure more **flexibility of conventional power plants** in terms of
  - Permitted upward/downward gradients (MW/min)
  - Reduced technical minima
  - Minimum number of hours for the “in service” and “shut-down”
- Assure to have **adequate transmission /distribution infrastructures** in order not to have bottlenecks for the collection of the whole VRES generation
  - The **development of interconnections** will help the integration of more VRES capacity

Conclusions

Possible solutions to overcome barriers and maximize VRES capacity

- To apply a **day-ahead forecast of renewable generation** as well as systems in order to manage in real-time possible imbalances
- Develop **energy storage systems**, like pumping, batteries, etc.
  - Batteries can be used also for dynamic performances
- Coordinate the actions between the **TSO and DSOs**
- Establish and assure the respect of the **grid connection requirements** for RES PP (frequency limits, voltage regulation, reactive power, LVRT/HVRT, …)
- Think about the adoption of **synchronous compensators** for enhancing the system inertia
- **Grid-forming inverters** to enable reliable control of low-inertia power systems
- Implement **Demand-Side Management** flexibility options
- Deploy **meshed grids for offshore** wind generation and **HVDC links** for VRE integration

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