Analysis of innovative VRES plant control for a better exploitation reducing curtailments

with the scientific contribution of the

Shaping a Better Energy Future

Foundation

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Aim of the study

VRES are subject to risk of curtailments in some operational conditions, when the generation available in the system is higher than the demand considering the system constraints

Two actions can have a positive impact on reducing this risk:

- Participation of VRES to Ancillary Services Markets (ASM)
- Improved control of VRES generation

This presentation describes recommendations and possible results deriving from the implementation of such actions in the operation of the VRES plants, aimed at reducing their curtailments and maximizing their exploitation without affecting system security

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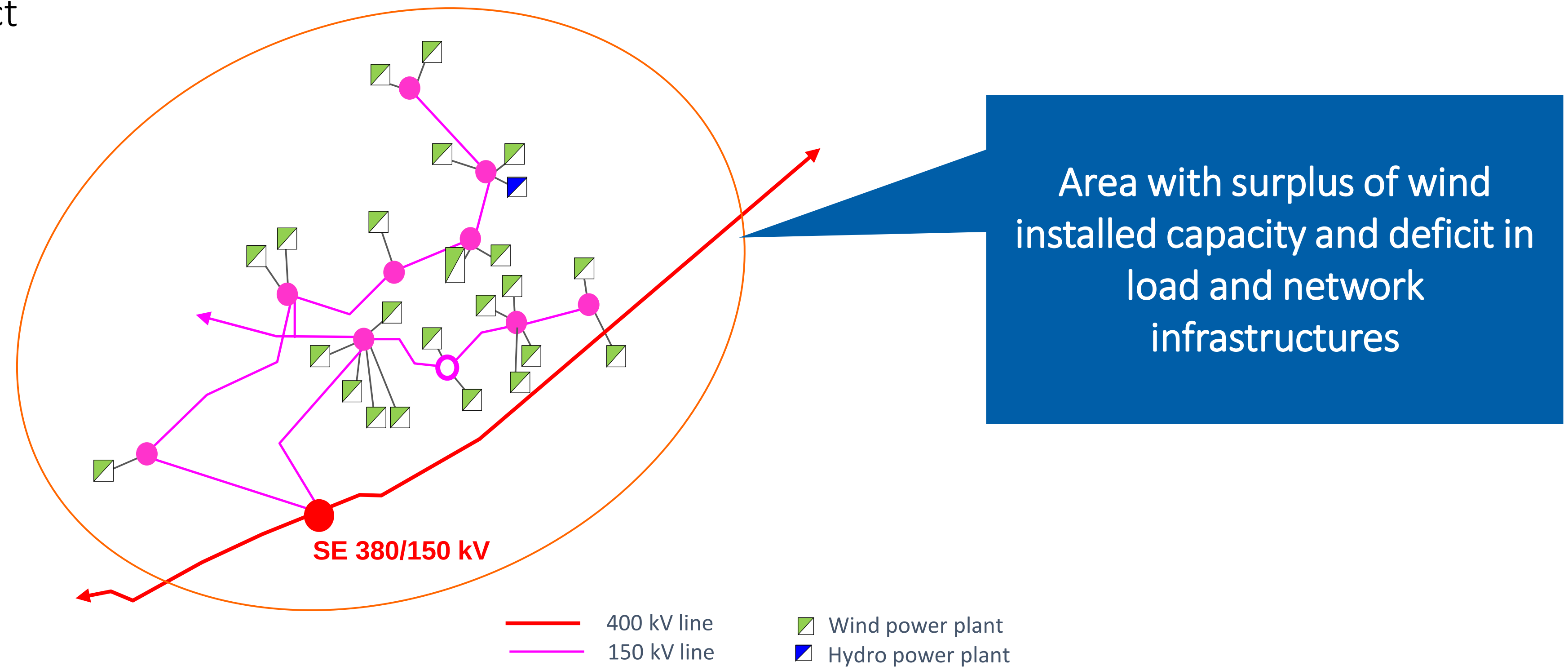
VRES curtailment risk (1/2)

With increasing VRES penetration in a power system, some critical situations for the system might happen more frequently:

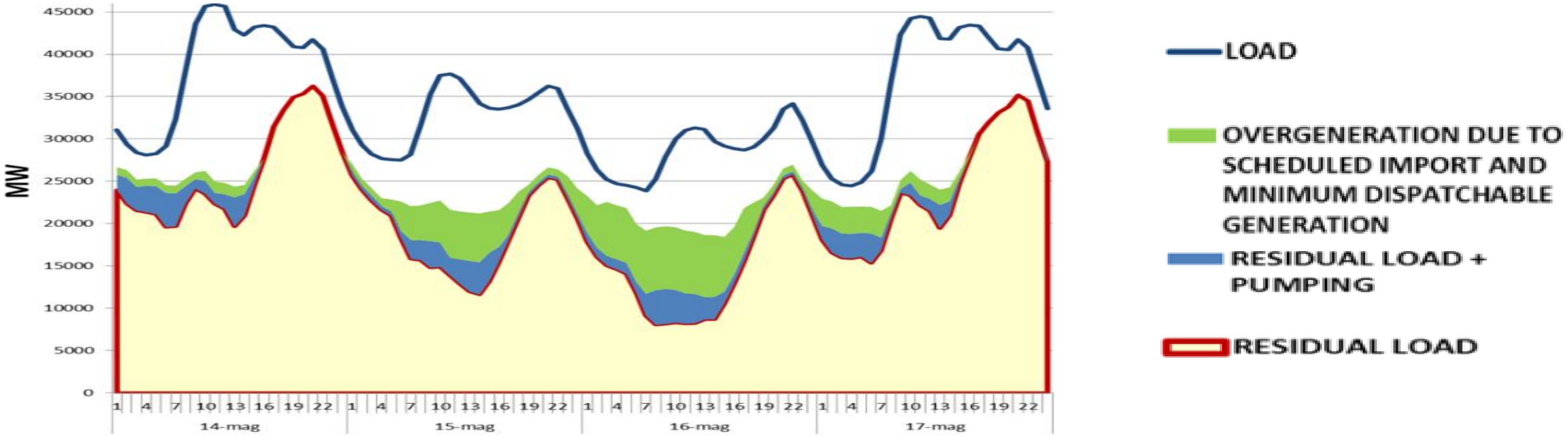
- **Local congestions** of transmission or distribution network on which VRES production has a direct and significant impact



VRES curtailment risk (2/2)

With increasing VRES penetration in a power system, some critical situations for the system might happen more frequently:

- OverGeneration (OG): with high RES generation, it is possible that the residual demand (load – RES) is lower than the non-interruptible generation, i.e. thermal generation associated to production processes, minimum thermal generation needed for the security of the power system (system reserve, voltage regulation, inertia, etc.) and scheduled import



To solve local congestions or OG, VRES production curtailment might be required to bring the system back in a more secure condition

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Participation of VRES in Ancillary Services Markets

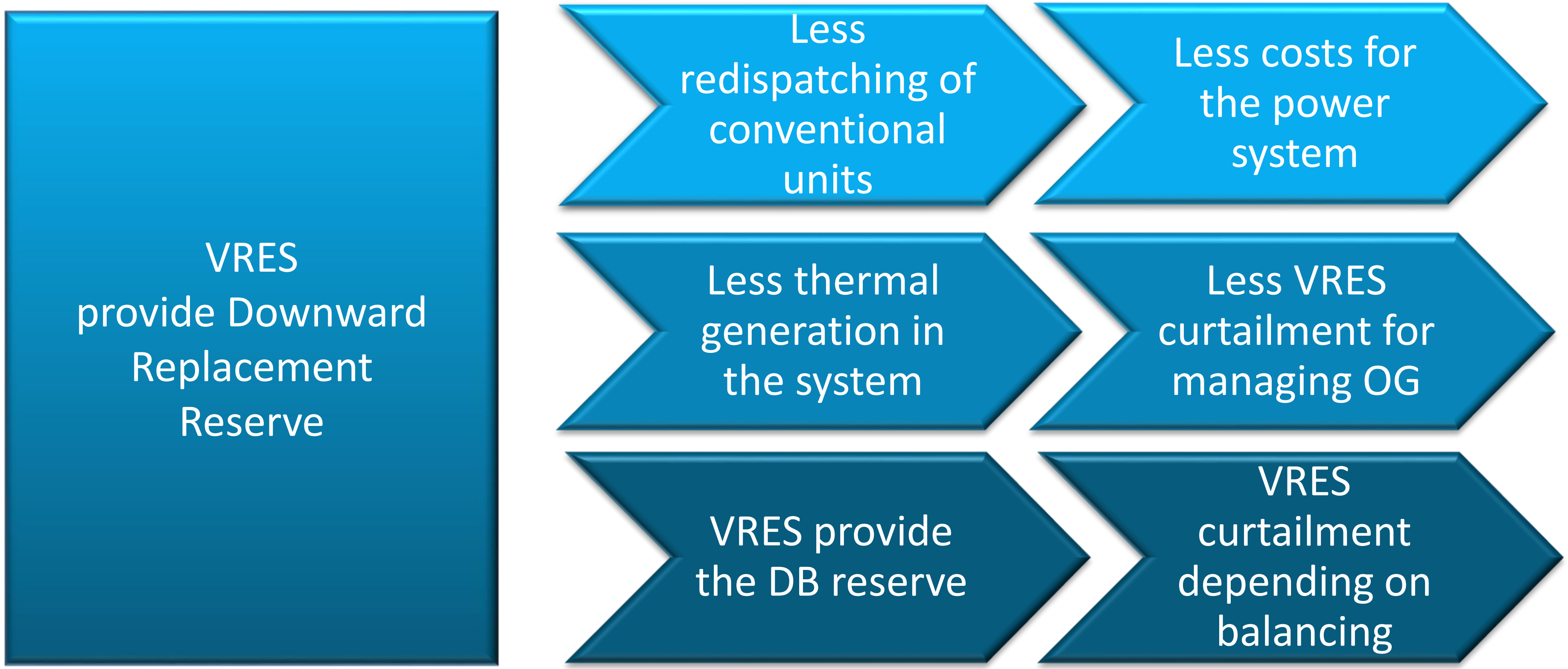
VRES contribution to the Downward Replacement Reserve (DRR) and to Downward Balancing (DB) might have different effects:

- Decrease the costs of the Ancillary Services Markets (ASM), because it is possible to redispatch less thermal generation. In fact, during the hours with scarcity of reserve, it is necessary to redispatch upward some conventional power units and to redispatch downward other conventional power units, in order to create the desired reserve margins. Instead, if VRES generation provides part of the replacement system reserve, the ASM will redispatch fewer resources
- Reduce the system Over-Generation (OG) problem (and hence the consequent VRES curtailment) because less thermal generation in service is required for creating the desired reserve margins. In fact, the conventional power units provide a DRR equal to the difference between their dispatched power and their minimum. If VRES provide part of the DRR, conventional power units can be dispatched closer to their minimum reducing the total amount of must-run generation
- Increase conditions in which VRES are curtailed on ASM, because they participate actively and can be reduced if necessary

  VRES have advantage if risk of curtailment on ASM when they contribute to DRR is lower than risk of OG in case they don't participate to ASM

Participation of VRES in Ancillary Services Markets

Graphical summary of possible advantages of VRES contribution to the DRR and to DB:



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Evolution of the Ancillary Services Market in Italy

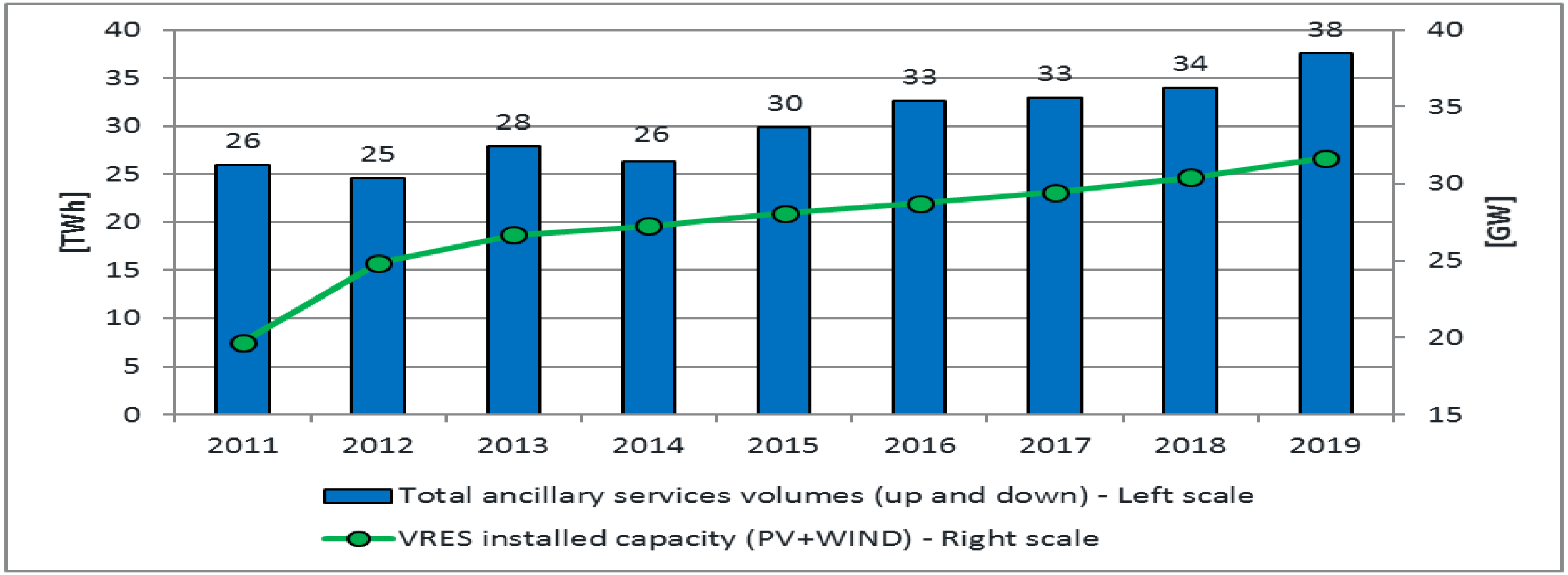
In the last ten years, the development of VRES in Italy has been affecting the ASM for different reasons:

- **Reduction of the number of generators in operation in the Day Ahead Market (DAM)**
  - The abrupt growth of VRES generation combined with the stagnating electricity demand, has been reducing the number of generators in operation in the DAM and hence dispatchable without additional start-ups in the ASM
  - Less resources means less probability to have satisfied the reserve margins without re-dispatching actions

- **Need of larger reserve margins**
  - Larger margins are necessary since the variability and the uncertainty that is inherent in the VRES is added to the ones already present in the existing system

Evolution of the Ancillary Services Market in Italy

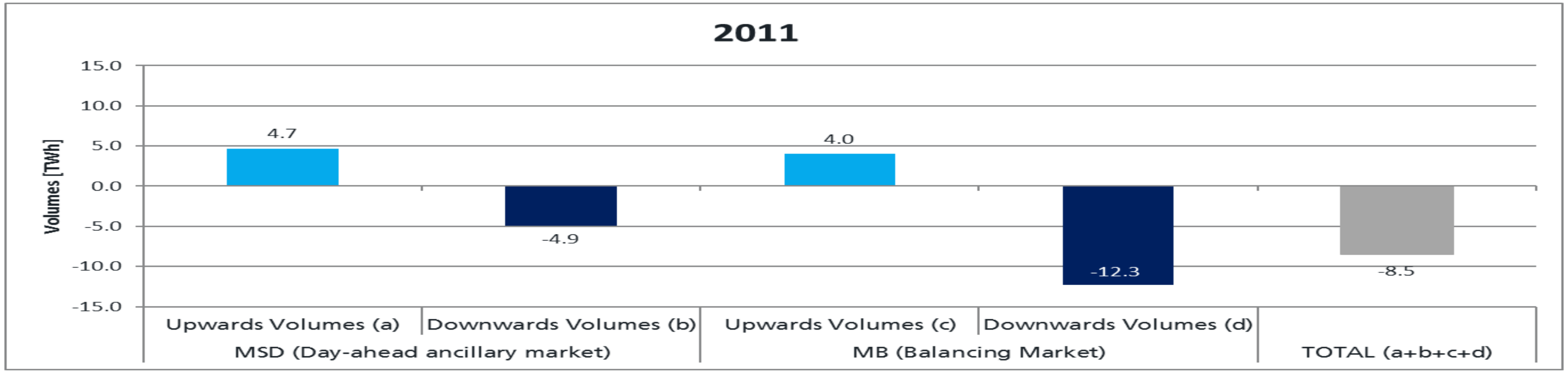
In the graph the total upwards and downwards volumes moved in ASM and the VRES installed power are shown

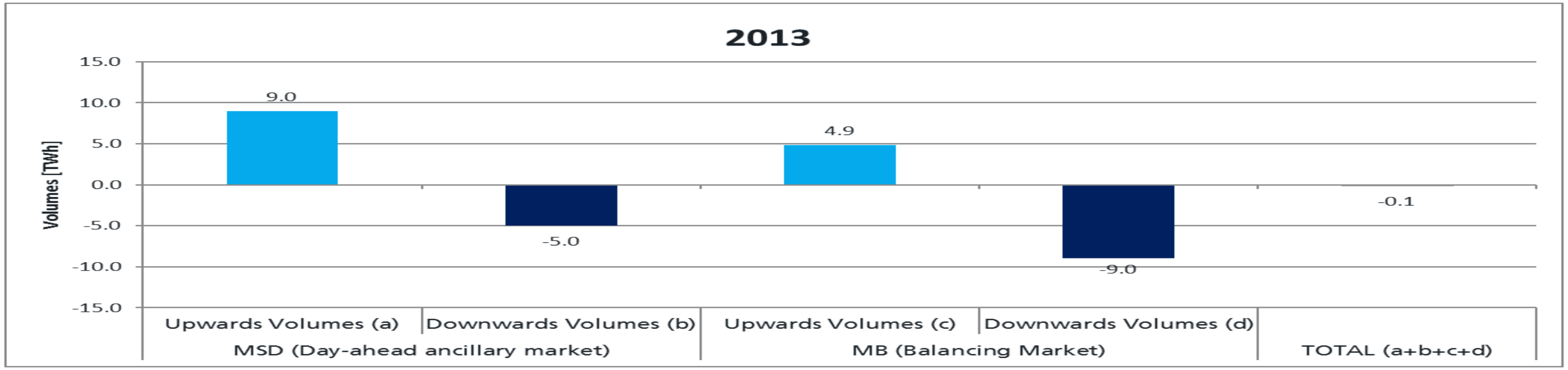


In the last years the amount of energy required in ASM showed an increasing trend following among others the growth of VRES installed capacity

Evolution of the Ancillary Services Market in Italy

- Detailed upwards and downwards volumes on the day ahead ASM (MSD) and on the real time (MB) sessions





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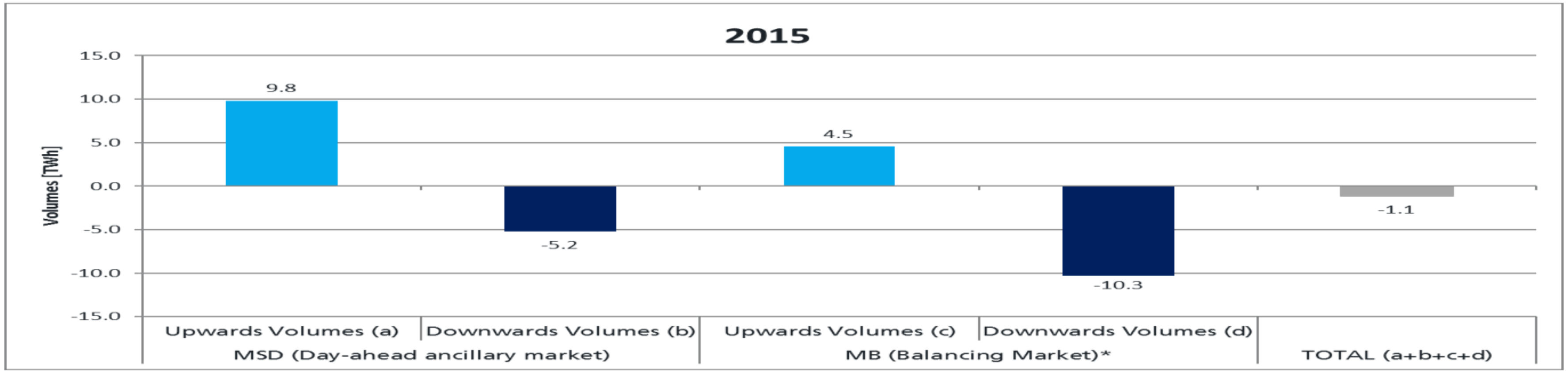

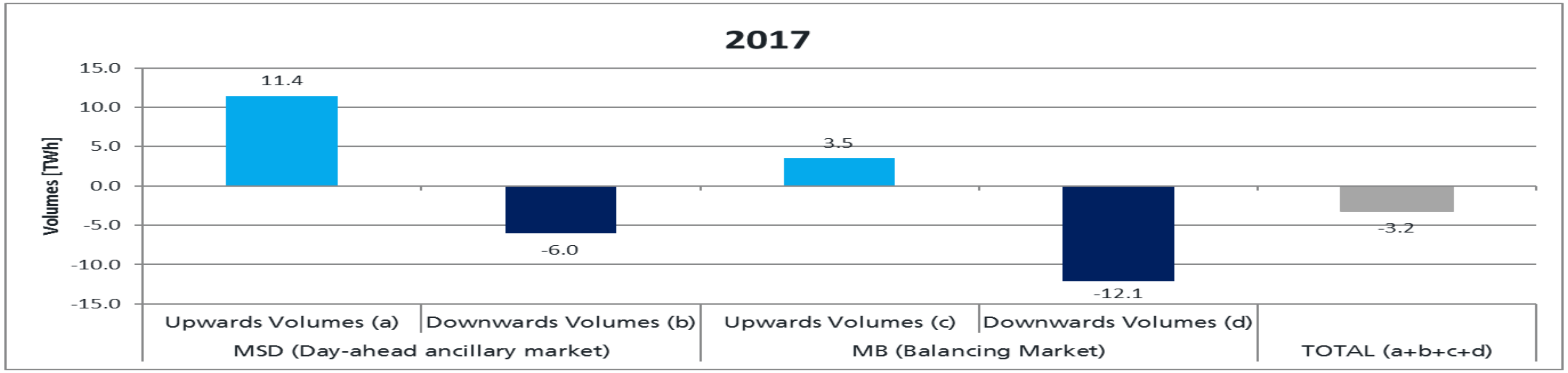

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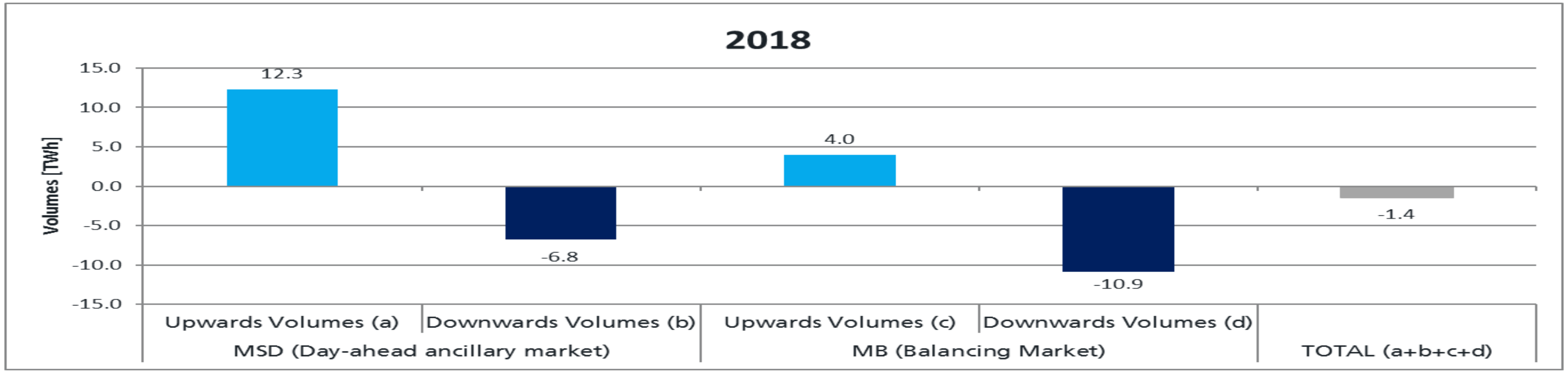
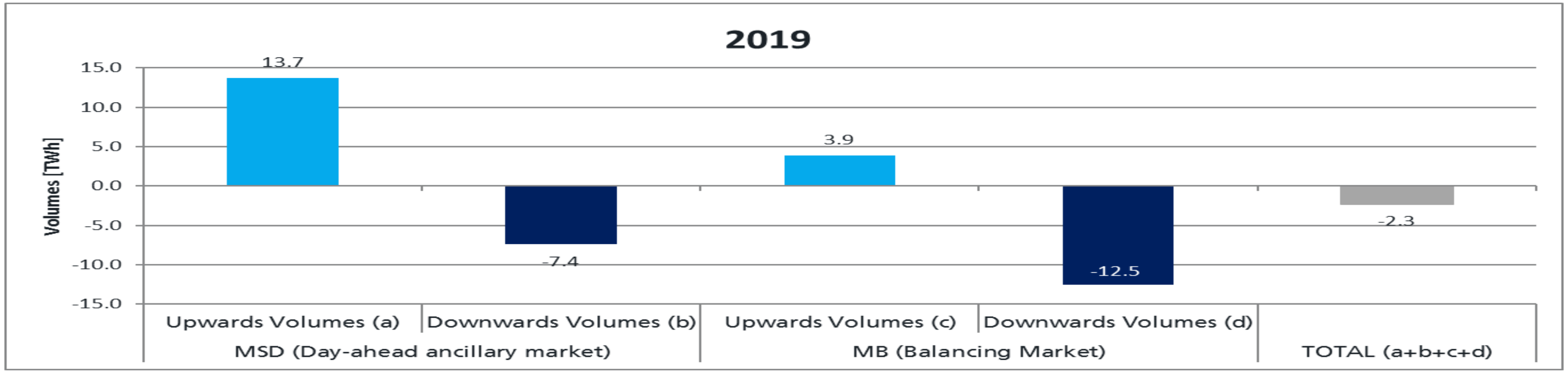




Evolution of the Ancillary Services Market in Italy

- Detailed upwards and downwards volumes on the day ahead ASM (MSD) and on the real time (MB) sessions

From previous graphs it is possible to note that

- Upward volumes in the MSD (day ahead) session have increased because with increasing VRES installed power there is a greater need to create rotating reserve
- The increase of generation in MSD causes unbalance with respect to the demand which is compensated in the MB session, closer to real time, during which some power plants are required to reduce their production

Applied measures for a more efficient integration of VRES in Italy

Immediate action to solve critical conditions of Italian power system:

- Need for curtailments of wind power plants connected to HV network to solve congestions, and consequently introduction from 2011 of a compensation for the curtailed energy due to system criticalities
- RIGEDI (DIstributed GEneration Reduction): to maintain the regulation capacity of the power system under critical conditions, all the PV and wind power plants connected at the MV grids with a rated power equal or above 100 kW must be enabled to be disconnected from the network upon TSO/DSO's request (implemented in years 2012-2014)

Long term evolution of regulatory frameworks

- Evolution of Ancillary Services Market (according to ARERA Resolutions 300/17, 372/17, 383/18, 422/18): enlarging the set or resources allowed to provide ancillary services, enabling also resources connected at distribution level
  Pilot Projects involving demand, generators and storage, also aggregated in Virtual Units in the same market area, which allow the participation of small projects (size between 1-10 MW) to ASM

Possible contribution of VRES to Ancillary Services Market Italian case

Analyses of expected Italian market trend were carried out in presence of controllable VRES plants (wind and PV connected to the HV network and some additional PV plants on distribution network) enabled to participate in the ASM aimed at:

- examining hourly market-based simulations - on one year time horizon – of Italian Day-Ahead Market (DAM) and ASM operation at 2023 and 2030

and

- focusing on
  - avoided thermal re-dispatching for procuring the downward replacement reserve (DRR) margins
  - effects of VRES contribution to the downward balancing (DB) service
  - reduction of the over-generation (OG)

together named "improved efficiency of ASM"

Possible contribution of VRES to Ancillary Services Market Italian case

Improved efficiency of ASM and VRES balancing:

- If available, VRES provide a contribution equal to the difference between the DRR demand and thermal DRR available without re-dispatching actions, offering the part of DRR not covered by thermal power plants
- As VRES offer DRR, in case of need they can be called as resources for downward balancing actions (of course after all the DRR offered by thermal plants). In this case a VRES curtailment occurs

The increased efficiency in the ASM thanks to the controllable VRES projects has two results:

- A lower thermal generation and redispatching required to ensure DRR
  → benefit for the system as less resources are moved and paid
- Possible curtailments for VRES
  → higher risk for VRES

Possible contribution of VRES to Ancillary Services Market Italian case

Reduction of the Over-Generation

- As a consequence of the VRES contribution to the DRR and DB and the lower thermal generation and redispatching required to ensure DRR, the Over Generation conditions in the system are reduced. Thermal plant can work closer to their minimum, and more space is available to additional VRES

As a summary, when VRES take part in the ASM there are two effects:

- VRES can produce more energy as less thermal generation is required in the system and less OG conditions happen
- VRES can be subject to curtailment in the ASM, if significant downward actions are needed

Participation in the ASM is generally convenient for VRES as the opportunity to generate more usually exceeds the risk of curtailments. Proper analysis (similar to the ones presented in the next slides) should be performed in any case to assess actual benefits for the system

Schemes for proper compensation of VRES curtailments should be applied based on the actual benefits attained by the system

Possible contribution of VRES to Ancillary Services Market Italian case

1. Reduction of thermal re-dispatching for procuring DRR margins

Analysed case:

Simulation of the Italian Day-Ahead Market (DAM) at 2023, with hourly resolution, comparing the need for thermal redispatching to create proper DRR margins in case VRES do not participate in ASM and in case wind and PV connected to HV network can contribute

Constraints on start-up of thermal power plant and on secondary reserve are also taken into account
After the clearing of DAM, availability of DRR is checked and thermal generation redispatched upward if needed

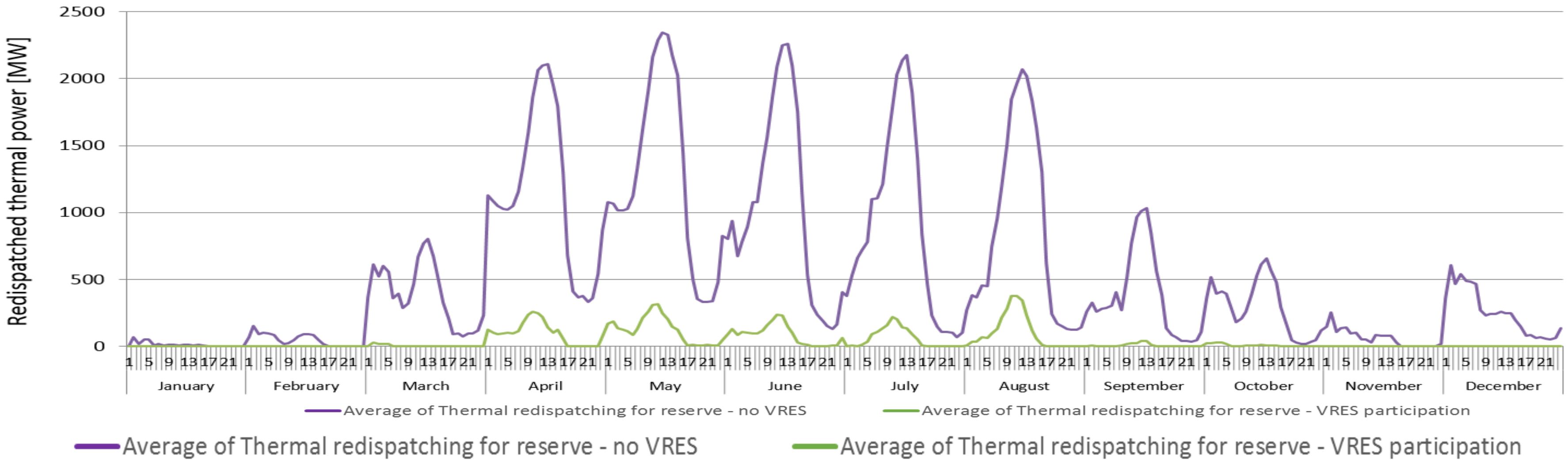
- Results are provided as average values of redispatched thermal energy during the day in the different months
- Lower redispatched thermal energy means a more effective and efficient market, as less resources have to be moved and paid
- If less thermal generation is redispatched to ensure DRR, lower OG problems are expected

Possible contribution of VRES to Ancillary Services Market Italian case

1. Reduction of thermal re-dispatching for procuring DRR margins

Results

- A significantly lower amount of thermal energy needs to be re-dispatched when VRES participate in ASM (green line) as DRR is already enough
- Furthermore, the needs of re-dispatching are mainly concentrated during the period April–August, when VRES (PV) generation is higher and possible variations to be compensated wider



Possible contribution of VRES to Ancillary Services Market Italian case

2. Reduction of OG

Analysed case:

Simulation of Italian market with 2 GW PV at distribution level contributing to the ASM in addition to wind and PV connected to HV network at 2030

The results of the simulations are the following:

- Thermal energy to be re-dispatched reduced by 185 GWh; VRES are asked to reduce the production on DB for about 65 GWh
- Lower OG for about 120 GWh (which would correspond to an equal VRES production curtailment if VRES do not participate in ASM)
- The net benefit in terms of reduced VRES curtailment in this case is therefore about 55 GWh

In terms of economic advantage, the result of the two effects provides positive benefits for the system for about € 30 million

In other conditions with less available thermal generation, VRES might be curtailed more than the benefit deriving from the OG reduction. In any case, the advantage for the system would be positive thanks to savings in thermal redispatching

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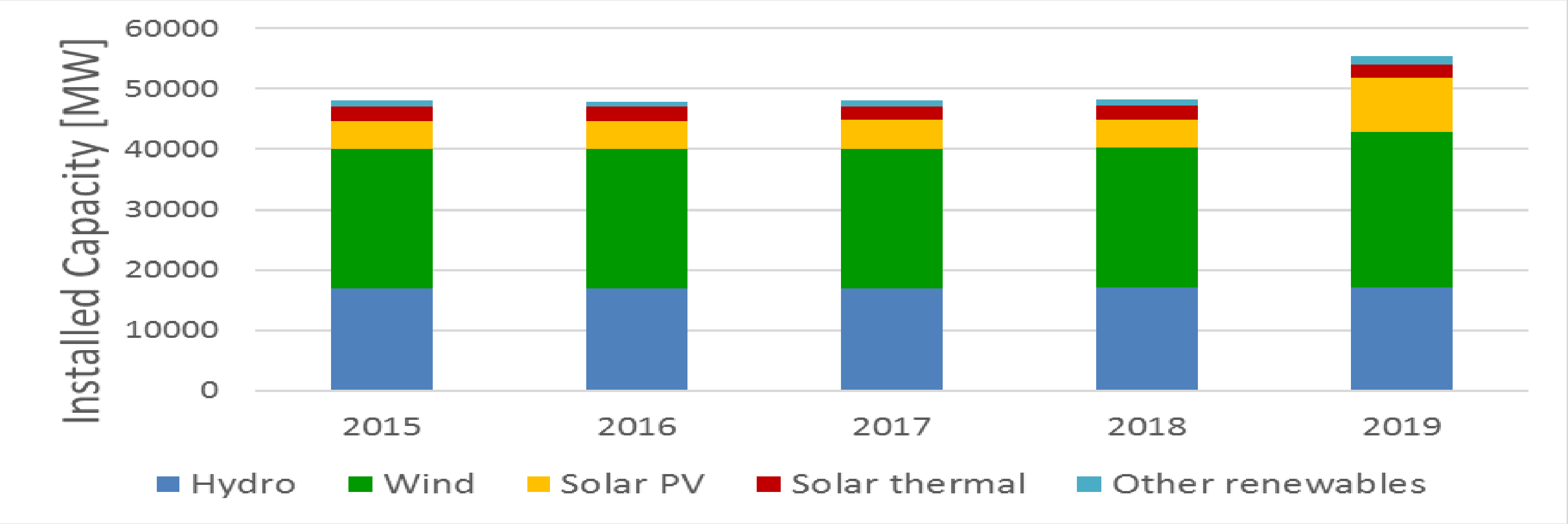
Possible contribution of VRES to ASM Spanish case

Analysis of Spanish market data

Data available - energy in balancing markets from 2015 to 2019
- redispatched energy per technology from 2015 to 2019

The main change in installed RES capacity over the last five years was a significant increase of PV and wind power plants in 2019

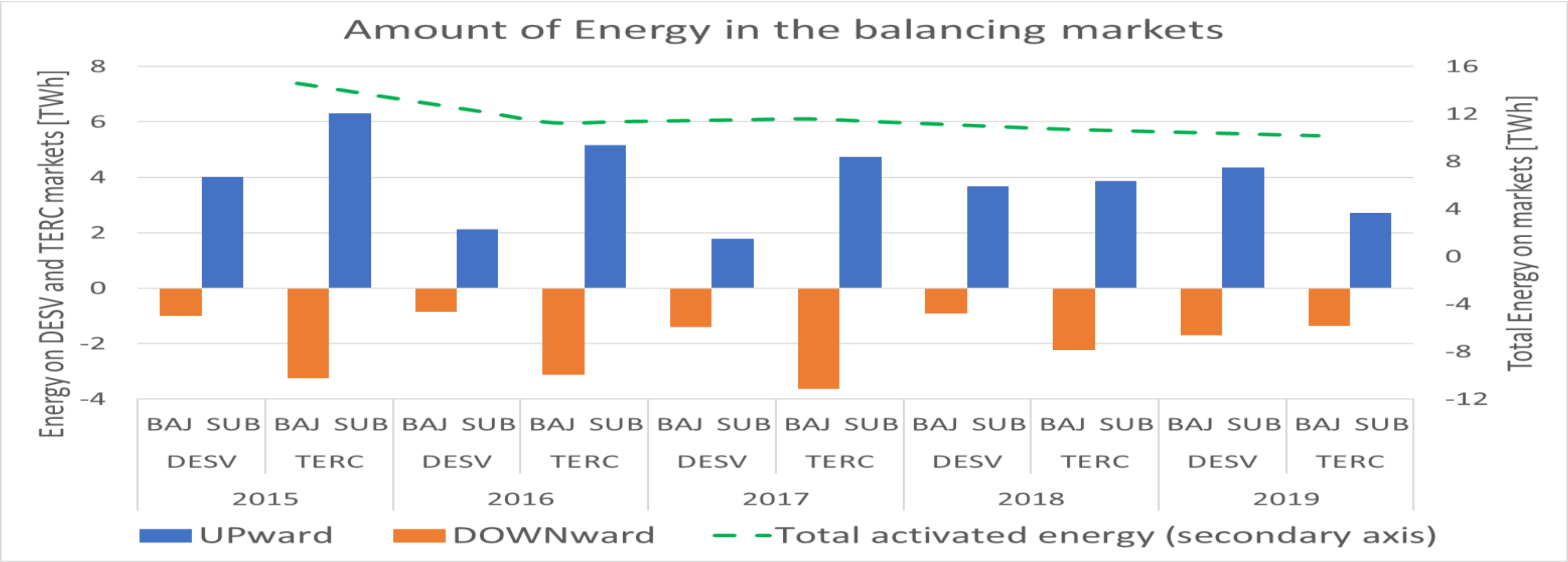


Source: https://www.ree.es/es/datos/publicaciones/informe-de-energias-renovables/informe-2019

Possible contribution of VRES to ASM Spanish case

The amount of energy in the balancing market both upwards and downwards shows a slight decrease over the last years

The green dotted line ("Total activated energy") is the sum of the absolute values moved upward and downward for DESV and TERC markets, which are aimed at, respectively, managing unbalances and tertiary reserve



Possible contribution of VRES to ASM Spanish case

Main factors which can contribute to the reduction of the total energy in the balancing markets are:

- Improved load and generation (in particular VRES) forecasts
- Higher amount of resources allowed to participate in the markets, reducing possible constraints
- Different renewable resources conditions (especially average wind speed and turbulence) over the years

Curtailments of VRES in Spain vary in the period 2015-2019, but remain always very limited, around 100 GWh or lower. Curtailments for wind are in the range 0.1%-0.2% of the total available production, and for PV even lower

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Take-away for Argentina and Chile analysed scenario

The optimal amount of VRES installed capacity calculated for the Argentina-Chile cluster[1] in the breakthrough in VRES technologies scenario has been assessed assuming:

- improved predictability of operational conditions
- ability of the system to cope with big and fast variations of the demand or the generation

The less binding system constraints and the presence of battery storage systems allowed to increase the optimal amount of VRES installed capacity, reaching almost 26 GW in Argentina and 15.5 GW in Chile

Some possible means to obtain such condition are:

- improved methods for weather and production forecasts
- regulatory framework to reduce forecasts errors (e.g. clusters of different plants and technologies)
- fast power production control of the generation fleet
- wider capabilities of generators (i.e. lower minimum for thermal plants)
- presence of energy storage systems

[1] Report available at: https://www.enelfoundation.org/topic/a/2019/05/new-series-of-studies-on-potential-for-renewable-development-and/chile-and-argentina

Take-away for Argentina and Chile analysed scenario

Under these assumptions,

- reserve needs are limited, thermal generation can be run at the technical minimum to ensure only upward reserve, as downward is provided also by VRES
- risk of VRES curtailments due to overgeneration in the countries is minimized
- VRES production is reduced to solve network constraints only in situations where thermal redispatching is not effective or too expensive

The presence of distributed battery storage systems helps the operation

- reducing the unbalances: they can compensate lower or higher VRES production with respect to forecasted profile
- ensuring fast primary reserve response in case of sudden frequency variation (e.g. synthetic inertia)

Take-away for Argentina and Chile analysed scenario

In order to increase the level of optimal VRES penetration in the system it is necessary to:

- Improve load and generation forecasts, to reduce unnecessary reserve which does not leave room to further VRES
  Distributed storage systems might help in keeping possible variations low
- Increase the amount of resources, also distributed, allowed to provide ancillary services such as frequency regulation, voltage regulation and ramp balancing
  Also in this case, storage system might play an important role
- Improve the possible control of the generation fleet, e.g. by means of remote signals for the limitation of P from the control room of the network operator
  This allows a very precise and optimized operation of the whole system, minimizing the risk of VRES generation curtailments
  In Spain, the CECRE control system (Centro de Control de Energías Renovables) is active since 2006. Today it receives every 12 seconds real-time information from all the VRES power plant >5 MW and, if necessary, can limit their production in less than 15 minutes

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Main features of Control System

The main features required to improve the operation of the power system with large VRES are related to their observability and controllability:

- direct control of the VRES plants in terms of at least P limitations
- VRES production forecasts to prepare the system for optimized operation

Infrastructures are required:

- at centralized level, to collect data from power plants, elaborate it in the optimal generation dispatching and send proper commands if required
- at the power plants, to collect data from the field, communicate with the generators and with the centralized control system

The interoperability between TSO and DSO grids also must be improved and requires the exchange of a large amount of information to allow the best exploitation of the resources and the network
This can also enable additional hosting capacity for further VRES in the system, maintaining the quality and reliability of the services

Main features of Control System

Additional features supporting the improvement of the system operation and the maximization of the hosting capacity for further VRES, especially on distribution network, are related to:

- Power system observability and controllability:
  - Optimal coordinated voltage control
  - Automated management of transmission network constraints
- Transmission and distribution grid automation:
  - MV fault localization
  - Dynamic Line rating
  - Enhanced MV automation (in case of failure)
  - Anti-islanding on MV grids
- Enhanced cross-border interconnection management:
  - New cross-border data exchange to improve operational performances

Main features of Control System

Power plant control

To allow their active participation to ASM, the VRES power plant must be controllable in real time by TSO/DSO, and at least the following info should be exchanged through communication link with proper backup:

- P, Q (or V) setpoints by remote, to reduce production when necessary and support voltage control
- Status of the power plant and available P and Q (including short term forecasts depending on the natural resource) to allow real time optimal dispatching

Many other features can be required for a more flexible and proactive control of the VRES plants, for instance:

- The possibility to select among different control modes or set different reaction time to external events to support grid stability
- More detailed information about the status of the plant and each component
- More measures of main electrical parameters at the power plant level

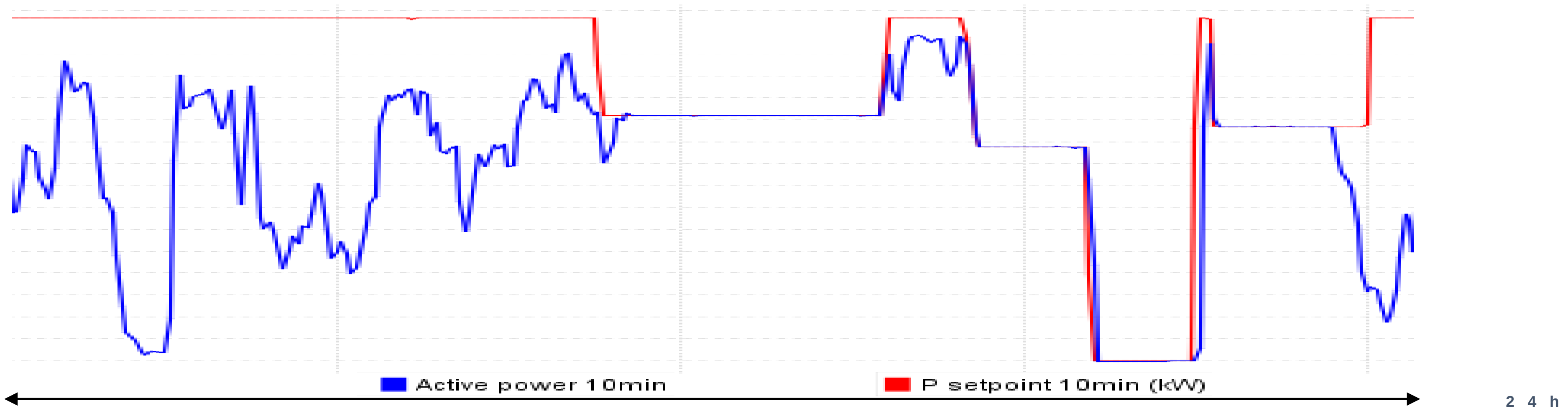
Main features of Control System

<u>Example of P control of real power plants</u>

In the real measurements shown below (10 min average values), the wind power plant receives the P setpoint (red line) from external source, for instance the TSO

The power plant control system manages the operation of the wind turbines to ensure that the overall generation of the plant at the connection point (blue line) does not exceed the limitation

The control of the production is very accurate especially when the natural resource is high. The activation of the reduction can be fast, taking place in less than 1 minute



Main features of Control System

Production forecasts

Improved production forecasts over all time horizons (long-, mid- and short-term) is essential for the optimization of the system operation:

- Reduction of forecast errors means less variability and less reserve need
- More reliable availability of the generation allows a more optimized dispatching of the resources
- Real time generation control minimizes the VRES curtailments because they are applied only when strictly necessary and for the minimum time

The VRES generation control must ensure accuracy of production forecasts to communicate to TSO/DSO. Forecasts applied to groups of generators, maybe of different technologies or even located in different geographical positions, might reach more precise results than when applied to single generators or power plants
If allowed by regulation, this approach can be preferable, also leaving more flexibility in the participation in ASM

Main features of Control System

<u>Example of production forecasts managed centrally</u>

Risk of critical operational conditions with sharp changes in VRES generation can be detected in advance and the system prepared with proper reserve or defining necessary limitations

The figure shows a strong forecasted variation of wind production (almost 1 GW increase and decrease in 2 ½ hours). Actions on other generators (thermal, hydro) might be required to maintain a secure system operation

Example of Spain - wind production forecasts

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Regulation development – Italian Case

In Italy, since the massive growth of VRES installation, especially PV in 2011, regulation has been modified to ensure a secure operation of the power system

In 2012, introduction of the possibility by TSO/DSO to disconnect distributed VRES generation with power >100 kW in case of emergency
It is not a control of the production, but a last action to reduce VRES generation in case of critical unbalances in the system

The Network Code has been revised in many parts and Annexes, requiring improved technical capabilities of VRES generators and enhanced control system and data exchange

Technical Standard CEI 0-16 concerning connection of generators to MV and HV networks has been continuously updated with the involvement of TSO, DSOs, Plants Owners and Industry

Regulation development – Italian Case

Standard CEI 0-16 introduced some detailed description of VRES power plant controller and the data to be exchanged with TSO/DSO (Annex O and Annex T, submitted to public inquiry in 2017 but not yet official due to the difficulty in the introduction of specific requirements on controllers and information exchange models)

Even if not prescriptive, these Annexes represent a good reference of what probably will be required in the future by TSO/DSO to optimize the system operation increasing the coordination among the plants

Stand-alone functions have to be implemented at local level, which operate when no external setpoints are sent by TSO/DSO and must also remain active in case the power plants are not reachable through the communication link. This strategy allows to set the operational behaviour of the VRES plants during normal operation (no setpoints sent by remote) and even when the data connection is lost

Proper functional tests on the ability to follow setpoints, reaction time, operation during failure in the communication link are also foreseen

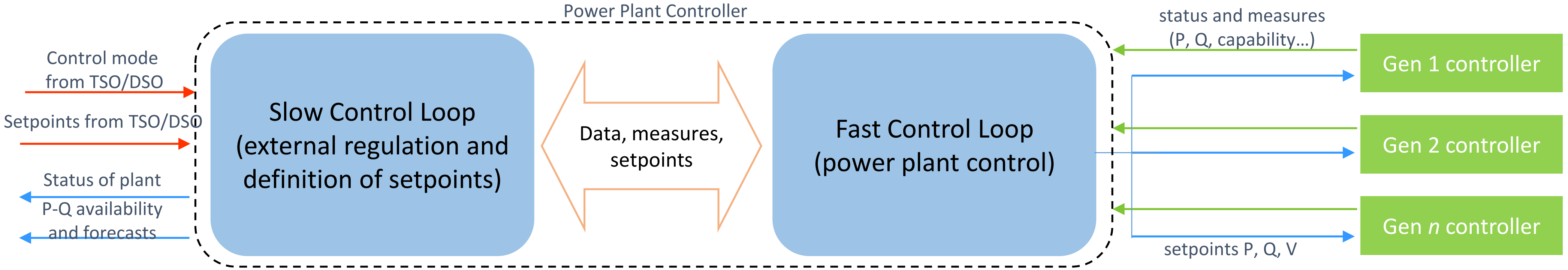
Improved control of VRES generation

- Different communication protocols are available for power plants
  - The most used one is the protocol IEC 618506
  - For wind power plants: IEC 61400-25 applies
- Protocols define the structure how data must be transferred.
  The list of data to be exchanged is defined depending on the needs

In case a Company owns different power plants, a good practice is the creation of a control room and data collection centre, connected with all the plants with the proper communication infrastructure and protocol, which analyses and stores the data in real time, and can also be the interface towards the TSO/DSO. If allowed in the regulatory framework, the operation of some or all power plants can be managed in an aggregate way, communicating to TSO/DSO the main values (including real-time P/Q productions, forecasts and capability) resulting for the whole group of plants.
The possibility to control groups of power plants also of different technologies can improve the accuracy of forecasts, especially if dispatchable sources are available within the group.

Improved control of VRES generation

In CEI 0-16 Standard, different control loops for fast regulation at power plant level and for slower definition of setpoints (also receivable by remote) are under evaluation. A graphical representation is provided, listing only the few main data to be exchanged



The Fast Control Loop is often executed by equipment provided by the manufacturer of the generators such as PV inverters and wind turbines and ensures the communication between the different generation units and their coordination as a single power plant

The Slow Control Loop ensures the correct interface towards TSO/DSO and the execution of slower control functions, which might define automatic P/Q setpoints based on the status of the network or receive active control commands by TSO/DSO

Different solutions possible depending on the available technology

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Regulation development – Spanish Case

In Spain, special attention has been put on the centralized control of the VRES plants.
Starting from 2005, specific regulations have been released to introduce a RES control centre (called CECRE) which is the interface between the control of the power system and all the Generation Control Centres (called CCGs) to which the RES power plants are connected

CCGs must have

- proper communication connection with CECRE and RES generators
- implementation of specific control features
- 24/7 availability of personnel

CECRE receives main data from each power plant every 12 seconds, including P, Q, V, wind speed and status of the connection to the grid. It assesses the possible integration of RES power in the system depending on the conditions, and defines limitations if necessary

Regulation development – Spanish Case

The connection to a CCG and to CECRE was mandatory for all the RES power plants >10 MW, and from 2015 this limit has been reduced to 5 MW, also for groups of plants (RD 413/2014)

Proper technical requirements and tests for the assessment of the capabilities are defined in the existing regulation

Regulation development – Spanish Case
Case study: Enel participation in ASM

At the end of 2015 Enel, first in Spain, requested permission to start with the tests for enabling the participation in deviation management and tertiary regulation markets

By October 2016 Enel had qualified 18 wind plants for more than 500 MW and at the end of 2016 almost all the plants (>1,600 MW) were qualified

Special attention was paid to:

- Available project technical information and electrodynamic models
- Real-time remote power control including optimization of shutdown/start-up of wind farms in short period (<15 mins) and capacity to sustain a given set point with minimal deviation (<10%)
- Forecasts and dispatching of maximum producible power for at least 4h
- Automation of the systems used to distribute real time power curtailments submitted by the TSO and to enable the agile start/stop of generating units dependent on energy price margins
- Development of business model and IT systems for automated bidding and plants operation in accordance to market and maintenance paradigms

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Take-away for Argentina and Chile analysed scenario

Optimization of VRES integration in power systems can be achieved by means of proper control systems dedicated to real time control and mid- and short-term production forecasts

Good reference cases worldwide, especially in more mature markets where VRES already achieved high penetration and are still growing due to challenging targets aimed at supporting the decarbonization of the power systems

Chile, Argentina and the other countries in South America with high VRES potential should benefit from the experience of the countries with already high installed PV and wind capacity. Tailored solutions for each power system have to be developed, according to specific characteristics (for instance, higher availability of PV or wind, presence of hydro power plant with storage, distribution of the VRES resource in the territory), but best practices for data exchange, forecasts, P and Q control can be shared among different countries.

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Conclusions and Recommendations

- VRES plants can bring a great benefit in the system operation when participating in ASM with downward reserve, thanks to the lower need of reserve from traditional plants (leaving room to higher VRES penetration) and possible cost saving from reduced thermal generation redispatching

- Even if VRES accept the risk to be called to reduce the production, their actual curtailments might be lower than in case the downward reserve is provided only by thermal generation as less Over-Generation occurs. The final result depends on the operational conditions of the system, and in particular by the availability of resources (other than VRES) to be reduced

- In all the analysed cases, there is economic benefit for the system due to lower thermal redispatching need, even if sometimes VRES curtailments might increase. The presence of energy storage systems (e.g. batteries) can further enhance the optimal amount of VRES plants, limiting need for redispatching and curtailed energy

Conclusions and Recommendations

- Proper regulatory framework must be in place, allowing the presence of VRES in the ASM. Also the rules for the definition of the price for the downward balancing reserve might need to be reviewed, as VRES do not have any cost saving due to avoided fuel consumption

- For an optimal exploitation of the available resources, especially in ASM, real time data exchange is essential to allow TSO/DSO to examine them and plan the short term operation of the system

- As a minimum, VRES power plants must be able to accept external P-Q setpoints, sent by the TSO/DSO when needed. P reduction only in case the downward balancing reserve must be activated, Q (or V) setpoint for local voltage control

- Essential for a proper short term planning is the communication of the status of the power plant, the short term production forecasts, the P and Q capability (i.e. the ranges in which the power plant can operate)

- International protocols for communication are also defined for different types of power plants. The creation of a control room connected to many plants is beneficial for their control and interface towards TSO/DSO

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Glossary

ARERA: The Italian Regulatory Authority for Energy, Networks and Environment

ASM: Ancillary Services Market

CECRE: Control Centre of Renewable Energies set up in Spain by the TSO Red Electrica de Espana (REE)

DAM: Day-Ahead Market

DB: Downward Balancing

DRR: Downward Replacement Reserve

DSO: Distribution System Operator

GCC: Generation Control Centre, control centre in Spain for the interface between CECRE and the power plants

MB: Mercato Bilanciamento (Italian Balancing Market)

MSD: Mercato Servizi Dispacciamento (part of the Italian ASM)

Glossary

OG: Over Generation, condition of a system in which the load is lower than the must-run generation (minimum power of thermal units considering security constraints and provision of downward reserve, run-of-river hydro plants, PV and wind) plus (minus) the import (export). This condition requires the curtailment of renewable generation to ensure security of the power system

P setpoint: signal provided to a power plant with the maximum active power P (typically in p.u.) which can be produced in a specific moment

Q setpoint: signal provided to a power plant with the value of reactive power Q (typically in p.u. or cosphi or as V target), which must be exchanged with the network in a specific moment

RES: Renewable Energy sources

TSO: Transmission System Operator

UVAM: Unità Virtuali Abilitate Miste, i.e. Virtual Units composed by more generators and load enabled to participate to the Italian Energy Market as single unit

UVAS: Unità Virtuali Abilitate Storage, i.e. Virtual Units with Storage facilities enabled to participate to the ASM as single unit

VRES: Variable Renewable Energy Resources (mainly PV and wind)

Foundation

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