

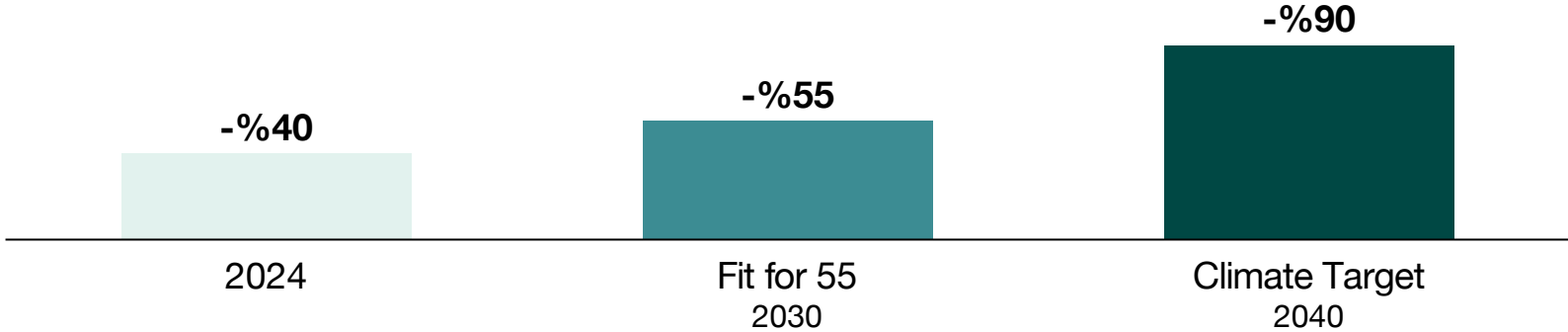
Terna Energy System Change and Grid Modernization

Luca Marchisio

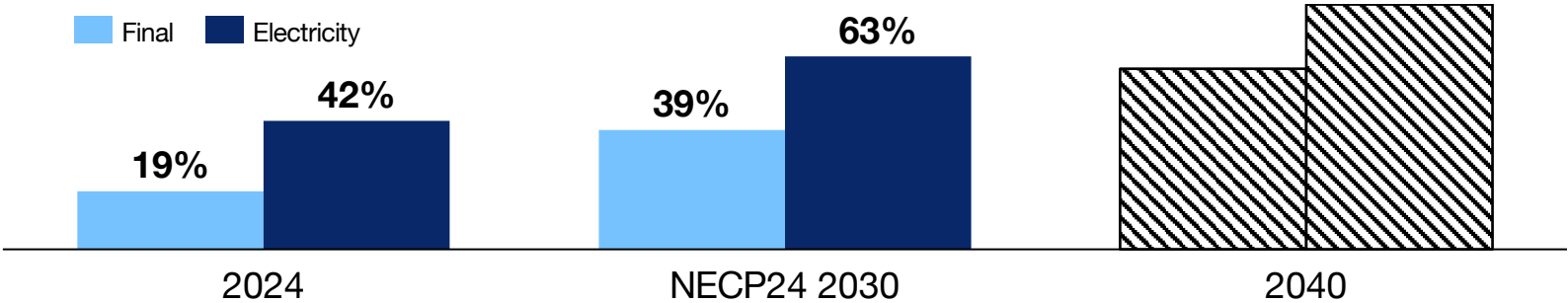
May 22, 2026

European targets and implications for Italy

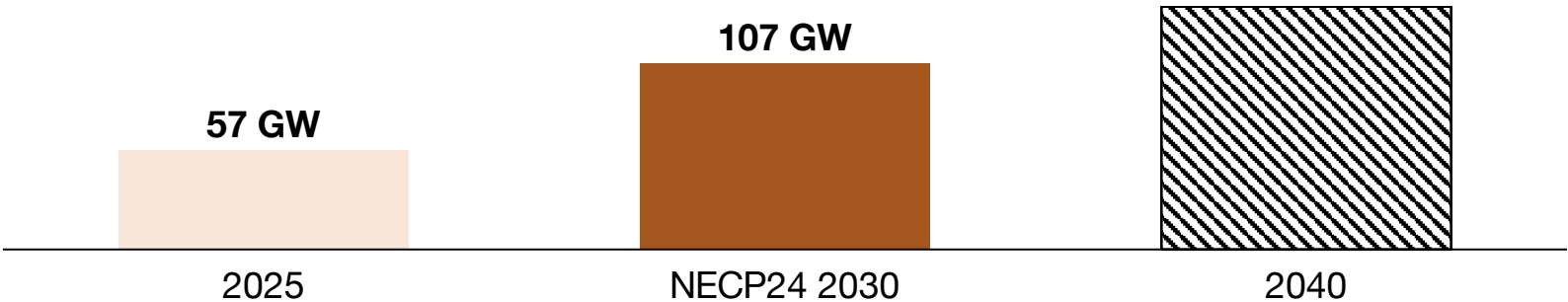
1 Reduction of CO_{2eq} emissions vs 1990 (EU)



2 RES share in final and electricity consumption (IT)



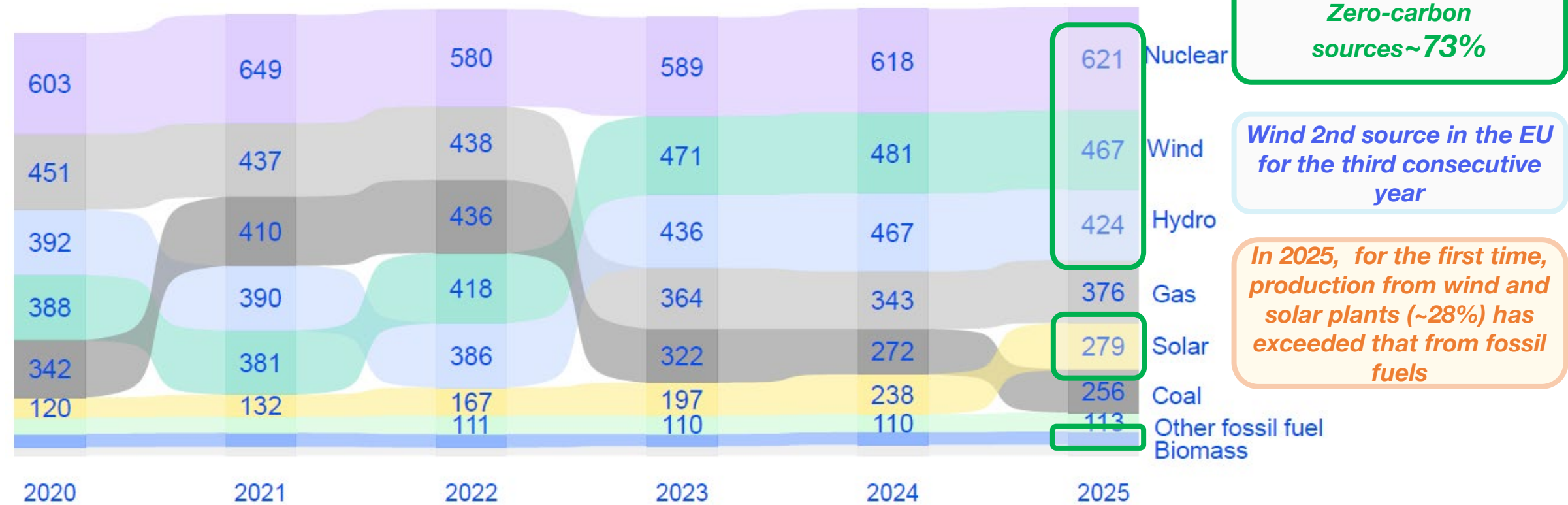
3 Solar and wind capacity (EN)



Renewables and electrification are the enabling tools for decarbonization

Evolution of the electricity generation mix in Europe

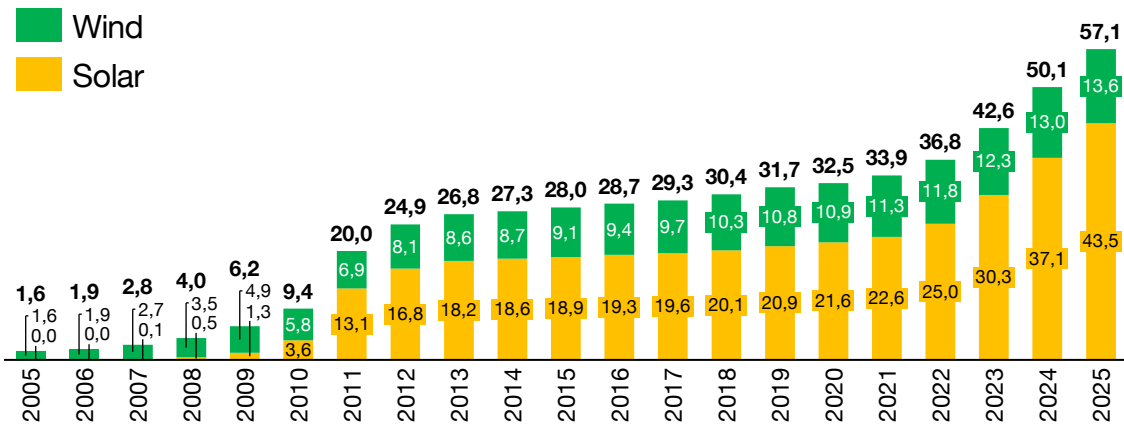
Electricity generation by source in the EU-27 + Norway [TWh]



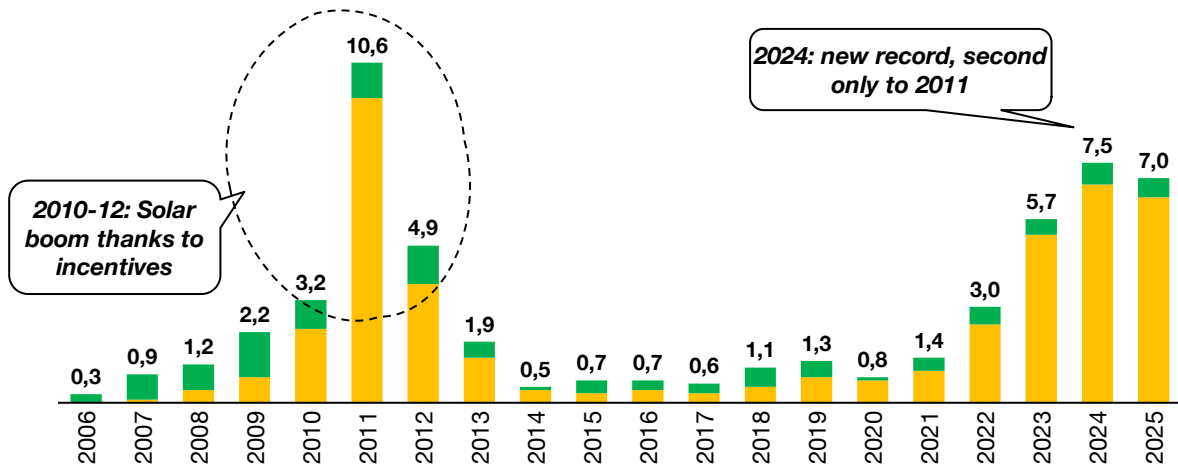
The European electricity sector is already largely decarbonised: 73% of electricity production in 2025 is emissions-free. In addition, for the first time, wind and solar generation surpassed that from fossil fuels

Recent evolution of the Italian electricity system

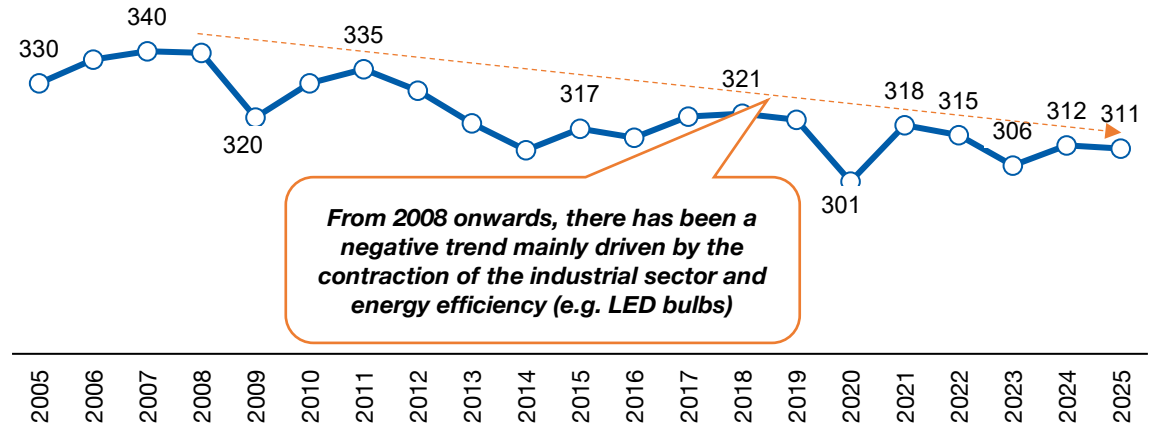
Total installed capacity wind and solar (GW)



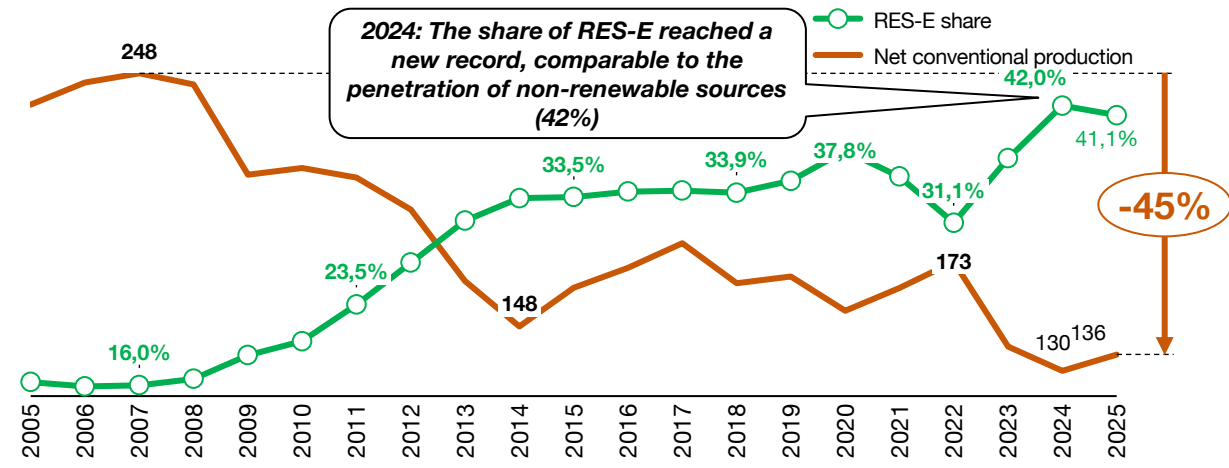
Annual wind and solar installed capacity (GW)



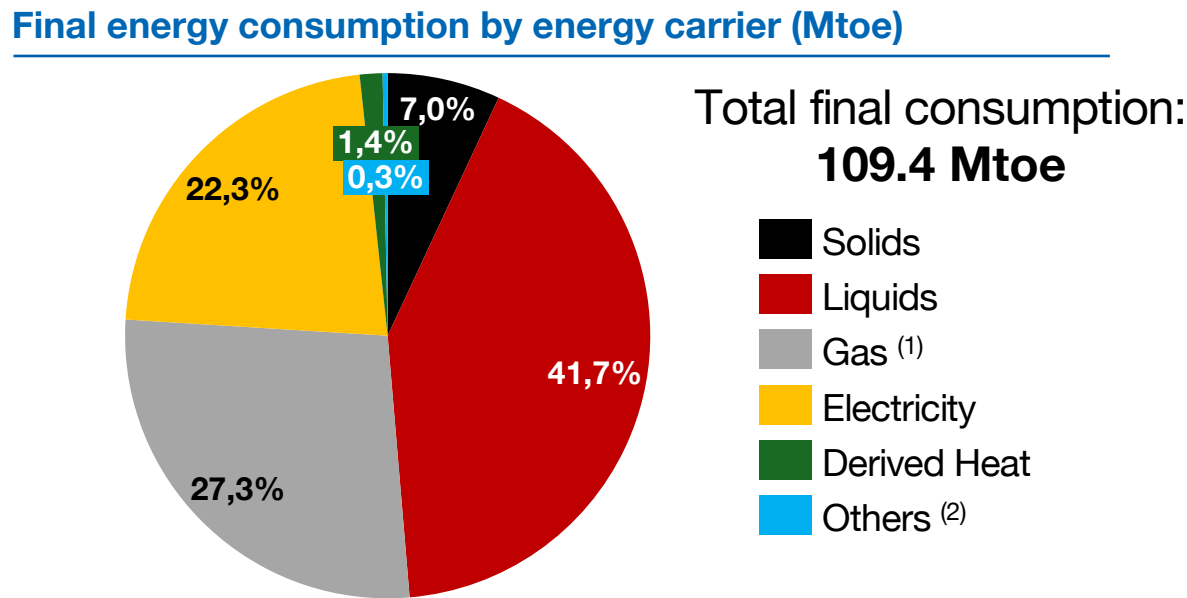
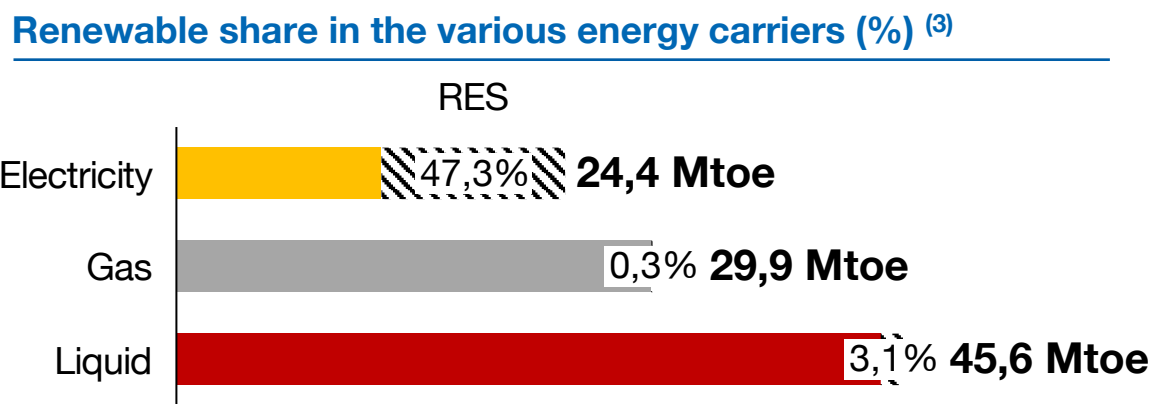
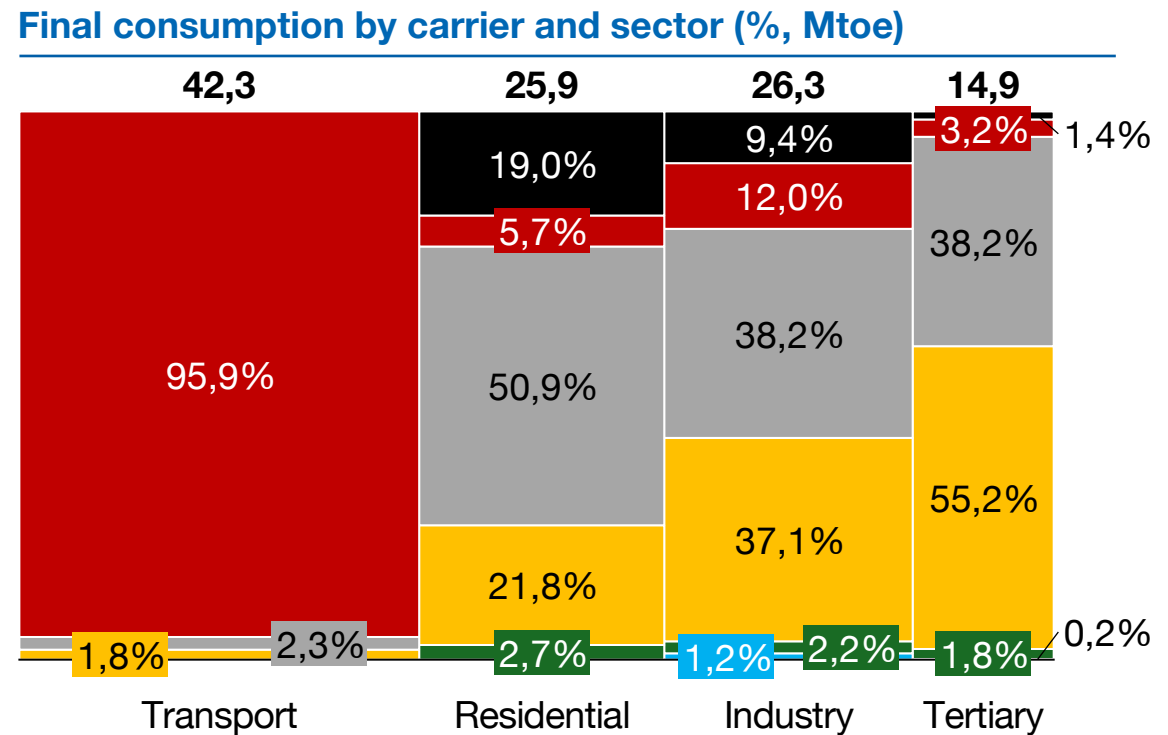
Electricity demand (TWh)



Net conventional thermal power generation¹ (TWh) and RES share (%)



National energy balance in 2024

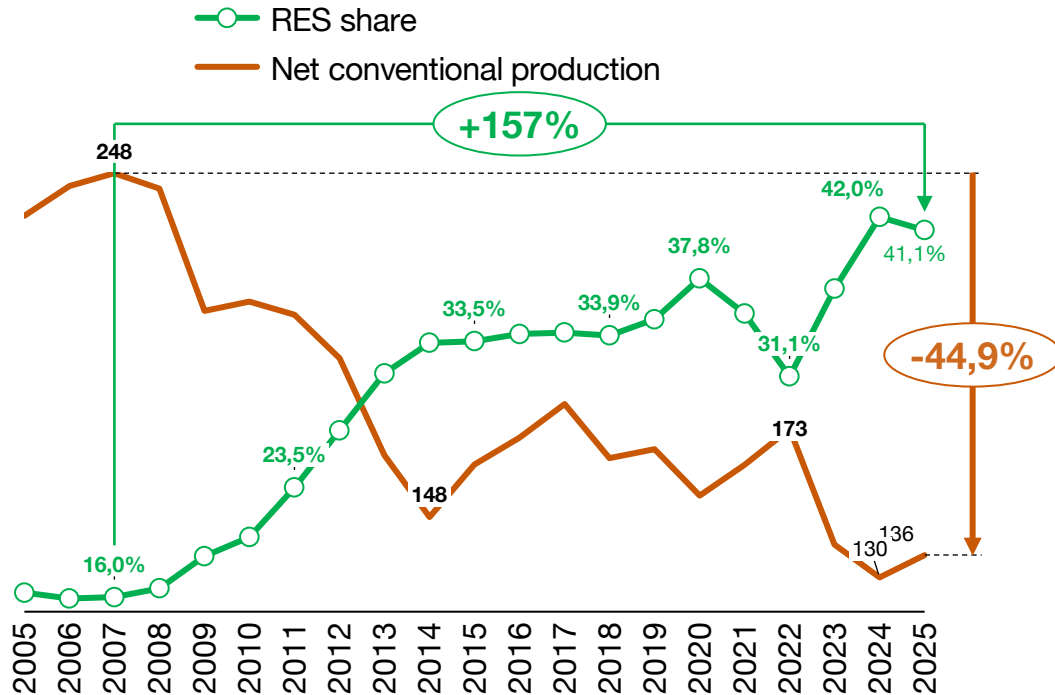


Liquid fuels, gaseous fuels and electricity are the three main carriers for covering final consumption.

From a sectoral point of view, liquids have an almost total dominance in transport, while electricity is the main vector in the tertiary sector.

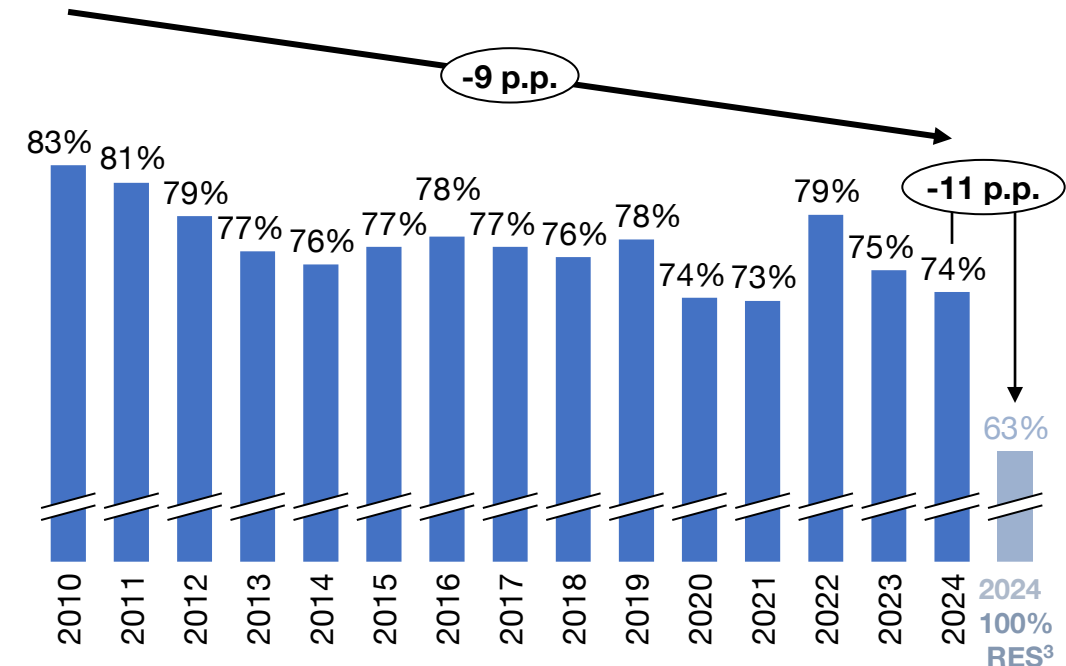
Evolution of the Italian electricity system and energy dependence

Conventional production¹ (TWh) and RES share (%)



Energy dependence² in Italy (%)

Downward trend also influenced by the outbreak of the conflict in Ukraine and the subsequent reduction in natural gas consumption

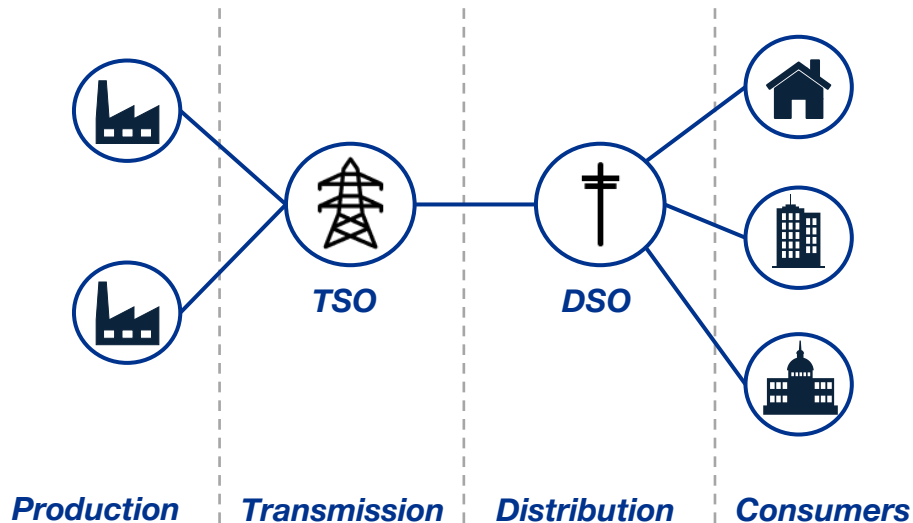


Renewables are an indispensable, but not sufficient, lever for energy independence. Even with 100% RES share in electricity consumption, in 2024 the percentage of energy dependence would have been 63%.

The electrification of consumption, therefore, becomes an essential condition

Evolution of the Electricity System towards greater complexity

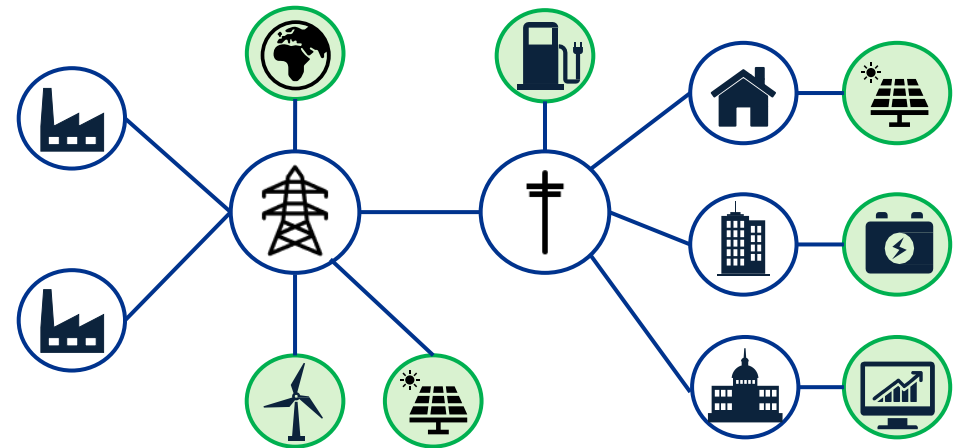
TRADITIONAL MODEL



- Increase in consumption and renewable generation on distribution and transmission networks
- Installing local storage
- Diversification of the portfolio of resources with the introduction of new market players (e.g. aggregators) into the market



NEW (SMART) MODEL



From centralization to decentralization: in spite of this trend, this evolution further increases (instead of reducing) the need for a central TSO for managing the secure operation of the system and optimising grid planning

Managing the new electricity system

System needs

Resources

Balancing – temporal granularity

Adequacy: An electricity system is considered adequate when it has sufficient resources to meet demand

Overgeneration: systematic need to curtail generation when generation exceeds demand

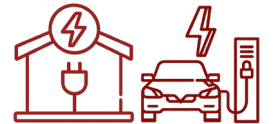
Production



Storage



Demand



Balancing – geographical granularity

As production zones are usually far from consumption areas, it is important to guarantee **increased transport capacity** to physically connect production with consumption

Grid



Ensuring operational security

Three dimensions of the electricity system need to be properly addressed through **grid components**:

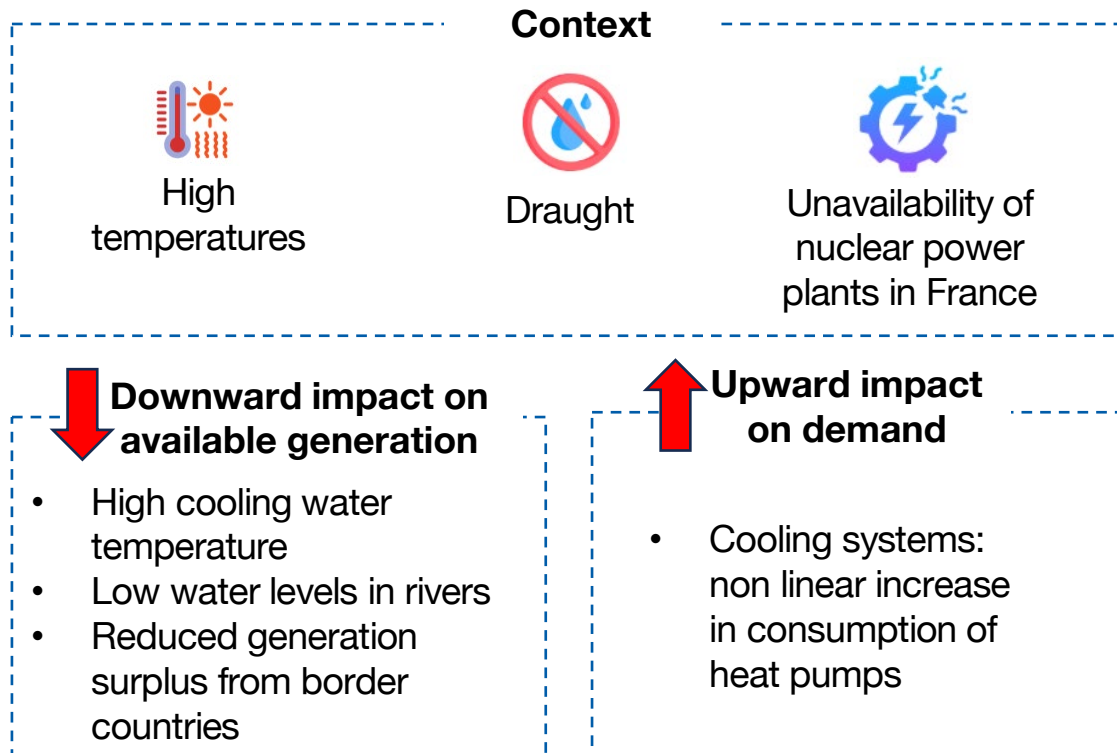
- System inertia
- Voltage regulation and short-circuit capacity
- System stability

Technologies
for regulation
and stability

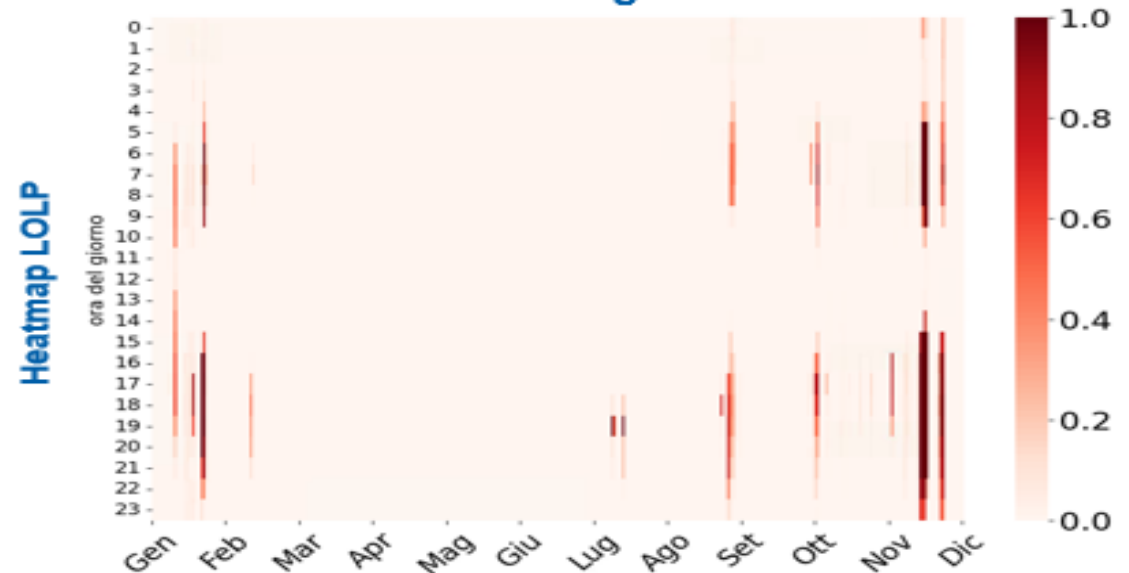


The risk of adequacy (1/2)

The adequacy in the Italian electricity system in July 2022¹



2030 probability distribution of load shedding²

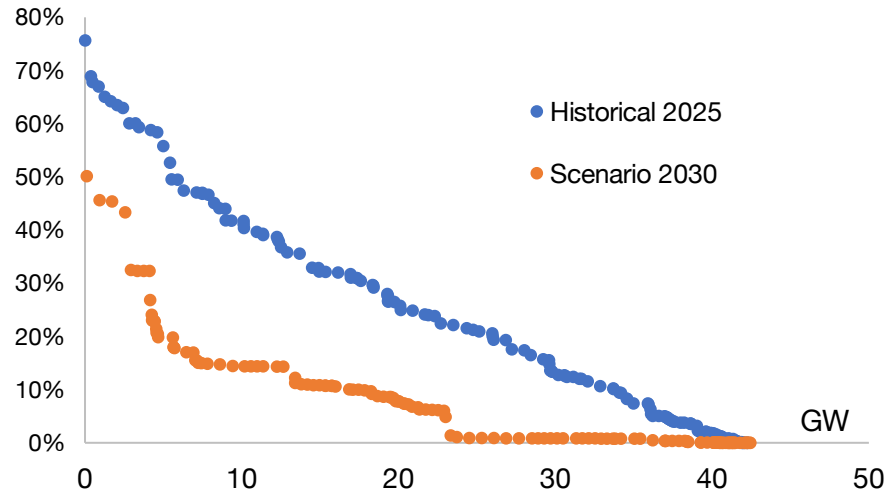


By 2030, the most critical hours should occur mainly in the evening hours and in winter. This is due to both lower solar production, as well as to the increased usage of heat pumps for heating

The risk of adequacy depends on exogenous events, but it also changes over time as both the electricity mix and the consumption profiles evolve

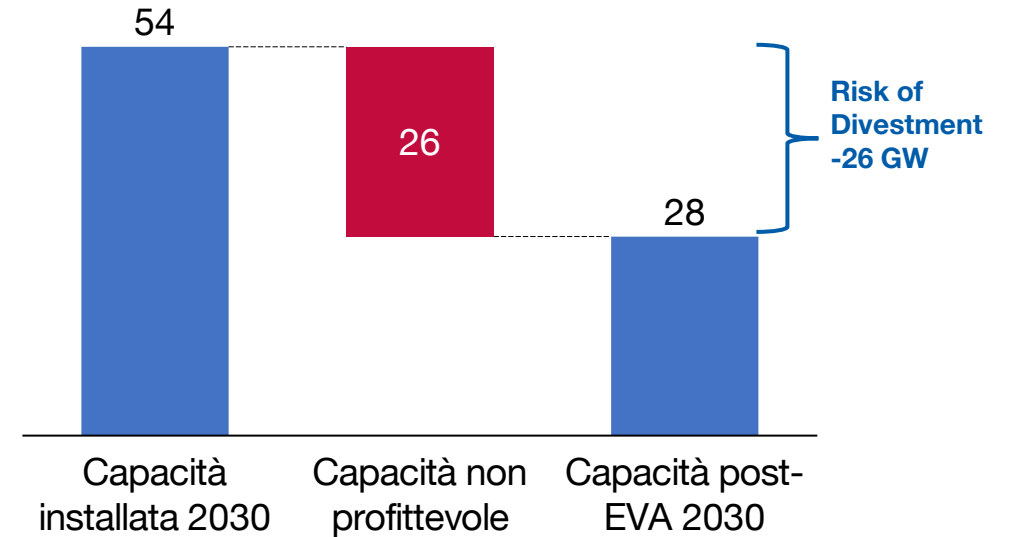
The risk of adequacy (2/2)

The capacity factor of thermal plants



Due to the increase in renewables and storage, **more than 20 GW of thermoelectric plants will have less than 1,000 hours of operation per year by 2030**

The Economic Sustainability Analysis (EVA)

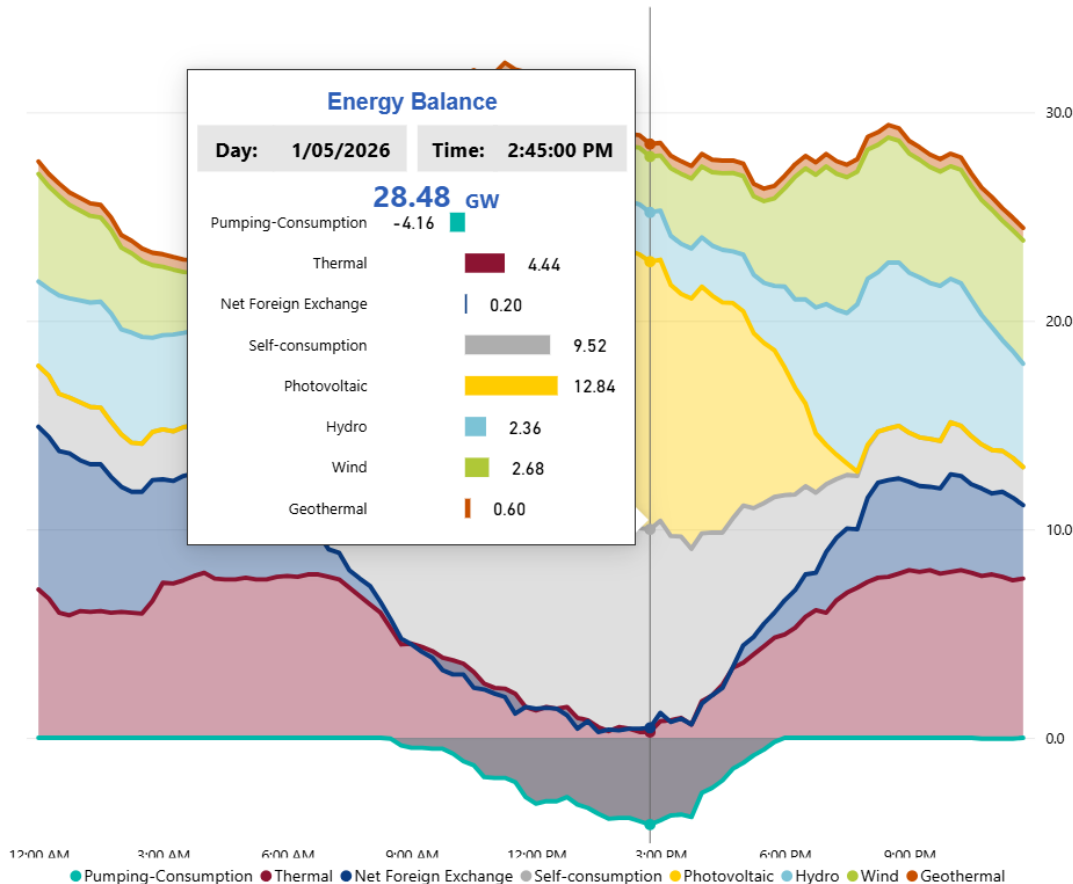


The consequent reduction in the profit margin on the energy market leads to a **risk of decommissioning (up to 26 GW) due to economic unsustainability**. This, in turn, would lead to 155 hours of LOLE¹ by 2030

The Capacity Market will be essential to economically support the capacity necessary to ensure the adequacy of the electricity system

Downward flexibility: focus on a critical day

The management of a critical day: May 1, 2026



On May 1st in Italy between 14:00 and 15:00, the energy balance was met as follows:

- 4,4 GW of thermal generation, almost completely absorbed by around 4,2 GW of pumped storage consumption.
- No foreign exchange: the Net Transfer Capacity (NTC) was set near to zero, to avoid any import flows and thus ensure the safety of the system.
- Several GWs of wind and solar generation were curtailed (resources in high voltage)
- In addition, it was necessary to activate the RIGEDI procedure (for resources in Medium Voltage >100kW)
- The residual demand was entirely met by renewable sources. This includes approximately 9,5 GW attributed to instantaneous self-consumption from rooftop PV, which is not directly measured but rather estimated (totally unknown not only in real time but also ex-post because there are no meters installed).

Low electricity demand combined with high renewable generation requires renewables curtailment as an essential measure to ensure system balance and operational safety. It is important to measure and control distributed resources

The resources available for curtailment



Wind

		Capacity	# of assets
✓	HV	12,5 GW	438
✓	MV	1,1 GW	859
✗	LV	0,2 GW	4.878



PV

		Capacity	# of assets
✓	HV	5,5 GW	285
✓	MV	21,4 GW	39.576
✗	LV	17,6 GW	2.081.544



Storage

		Capacity	# of assets
✓	HV	1,9 GW	45
✓	MV	0,1 GW	1.104
✗	LV	5,6 GW	904.933

- Resources in High Voltage (HV) can be curtailed in real-time

- Resources in Medium Voltage (MV) (>100kW) participate in the RIGEDI procedure – activated ex-ante and with low reliability
- Ongoing installation of CCI²

- Low Voltage (LV) and MV resources (<100kW) are not monitored or controlled
- Self-consumption from residential PV is not known (not even ex-post) with certainty due to lack of meters

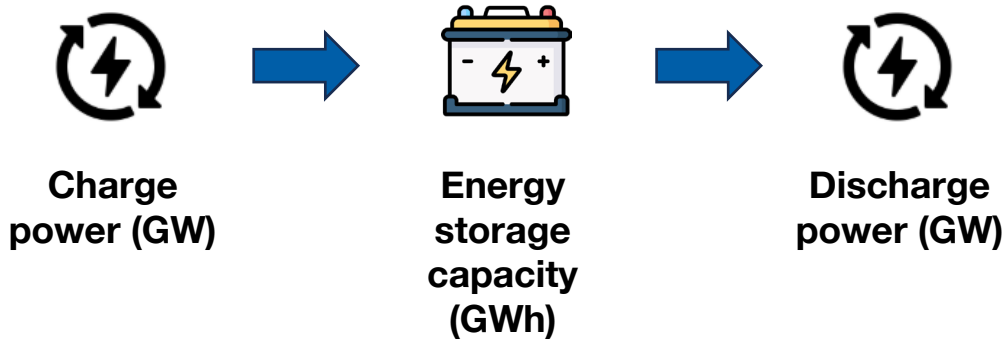
Distributed assets, if not properly monitored and controlled, constitute a threat rather than an opportunity for the electricity system



STORAGE

Technical and performance parameters of electricity storage

Key parameters for provision of system balancing services



Discharge duration (h) is the ratio between the discharge energy (measured at the connection point) and the discharge capacity



Net Round-trip Efficiency [%]: this is equal to the energy, expressed in MWh, that can be fed into the grid for each MWh that the SdS has previously withdrawn from it

Other characteristics

- Service life
- Degradation
- Construction time
- Provision of (synthetic) inertia
- Voltage regulation
- Contribution to short-circuit levels
- Operating temperature
- Self-discharge
- Technical minimum
- System black start support
- Harmonic pollution

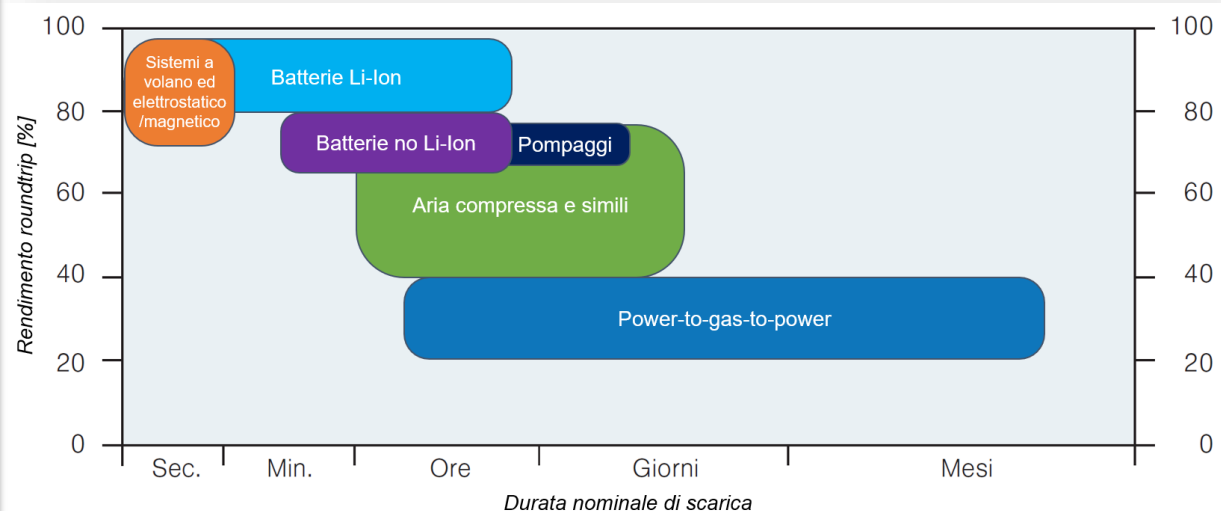
To meet the flexibility needs of the system, a high efficiency is of utmost importance



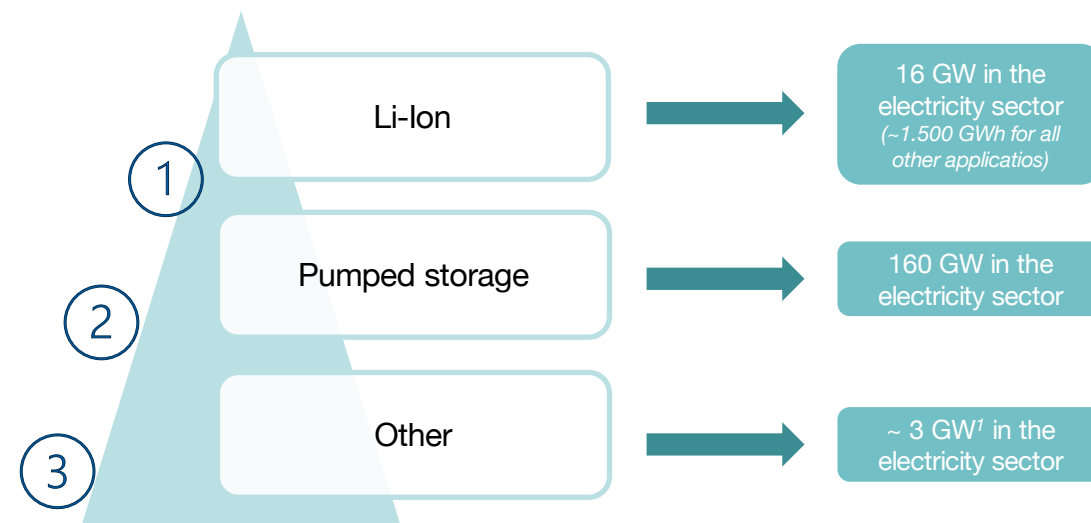
STORAGE

Focus on efficiency and maturity of storage technologies

Round-trip efficiency



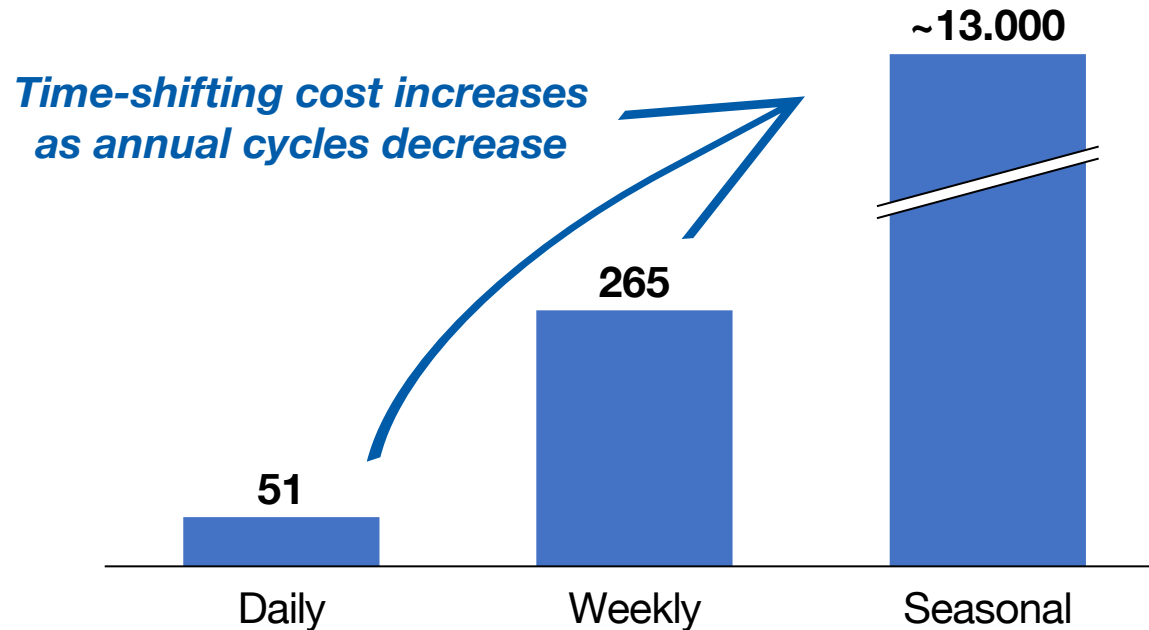
Technical and commercial maturity



The round-trip efficiency of lithium batteries and pumped storage is very high. Furthermore, these are the only two technologies, worldwide, which are fully technically and commercially mature

The cost of storage

- The time-shifting cost¹ of a single battery depends on the equivalent number of cycles per year
€/MWh

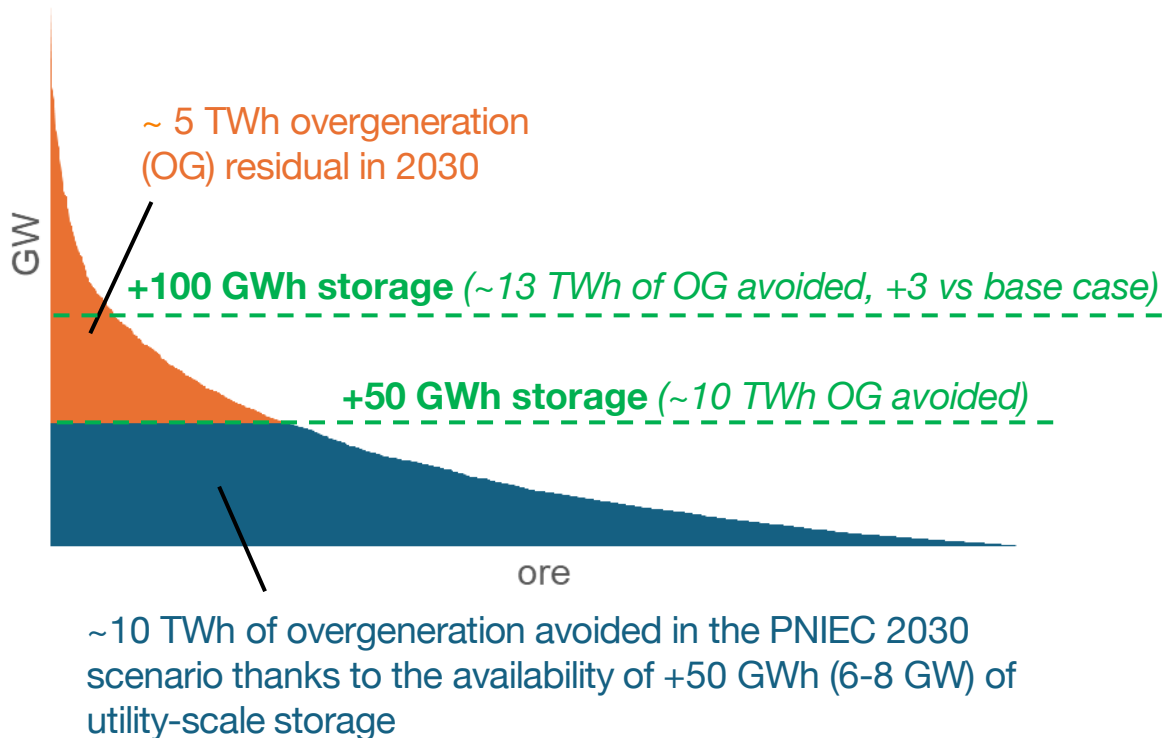


Moving from a daily cycle to a weekly one, the time-shifting cost of the single MWh stored and then "returned" to the system increases from 51 €/MWh up to 265 €/MWh, reaching 13,000 €/MWh in the extreme case of a single annual cycle (e.g. a "seasonal" storage)

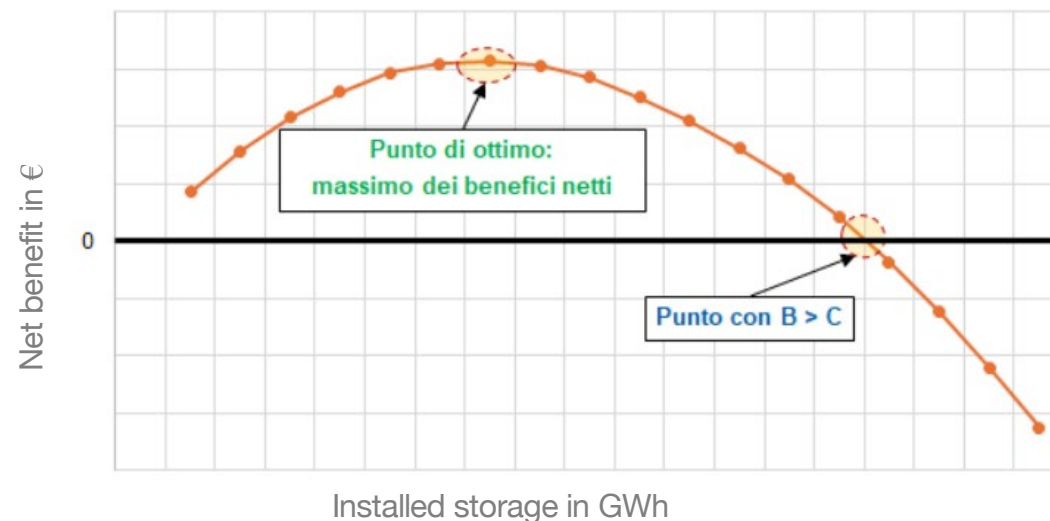
The time-shifting cost increases significantly as the number of cycles decreases. Therefore, the use of batteries for seasonal electricity storage is not economically sustainable

Impact of storage on RES integration

Curtailment duration curve



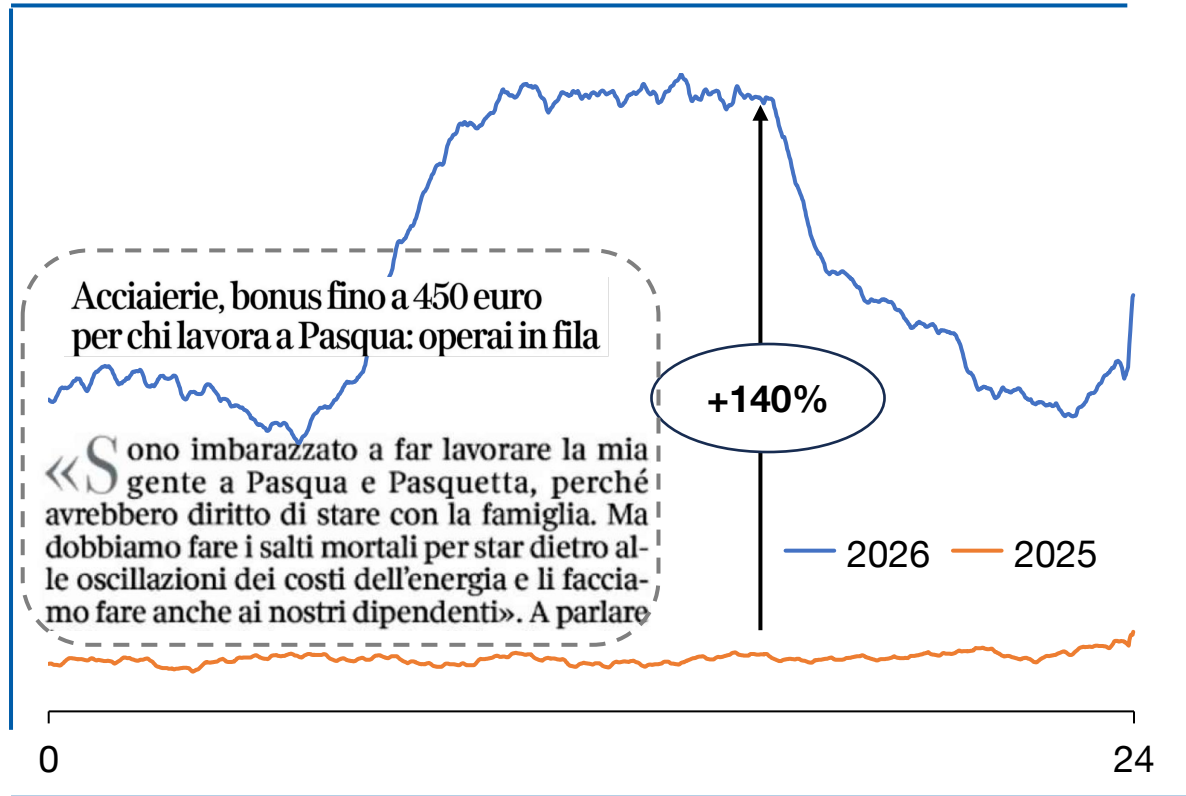
Illustrative trend of net benefits as storage capacity increases¹ (B = benefits, C = costs)



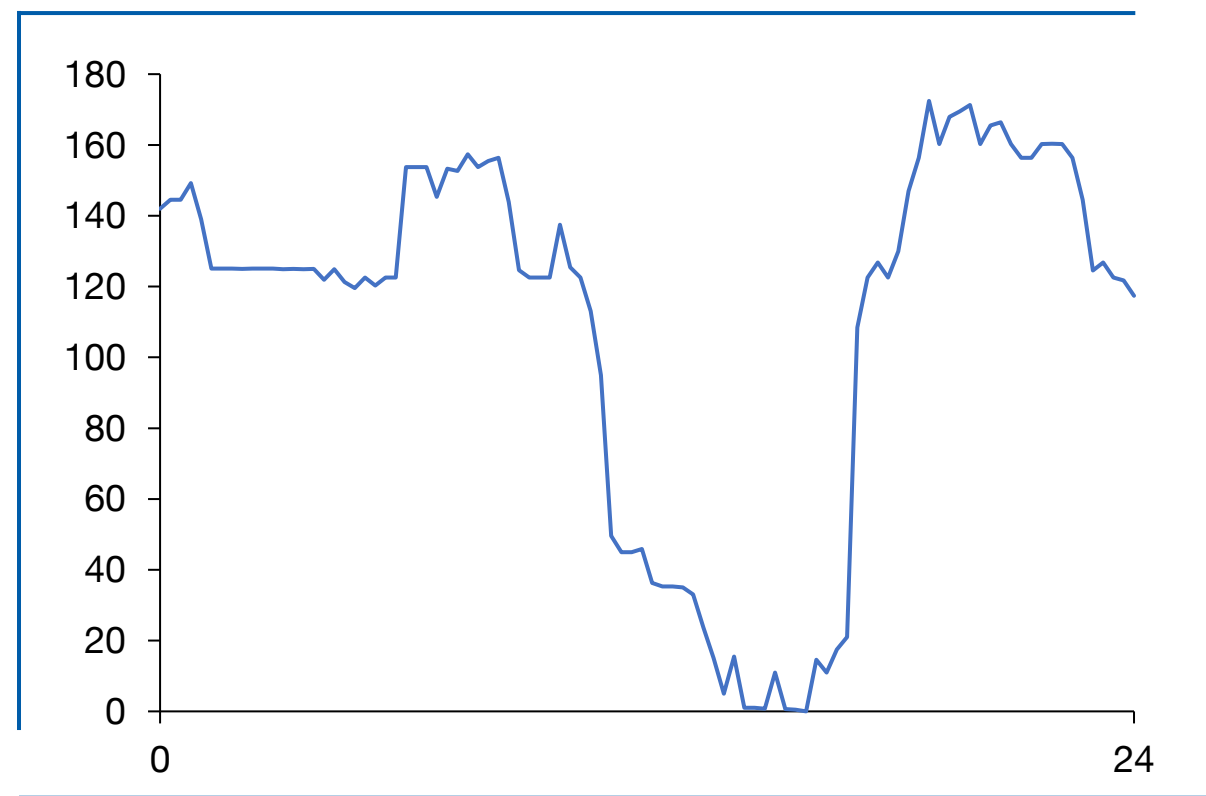
As storage capacity increases, overgeneration decreases in a non-linear manner, with decreasing marginal contributions. The economic optimal of the system therefore always implies a significant share of residual overgeneration

Modulation of consumption

Consumption of steel factories during Easter Monday, 2025 vs 2026

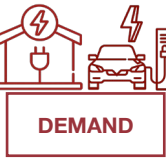


PUN Index GME, Easter Monday 2026 (€/MWh)

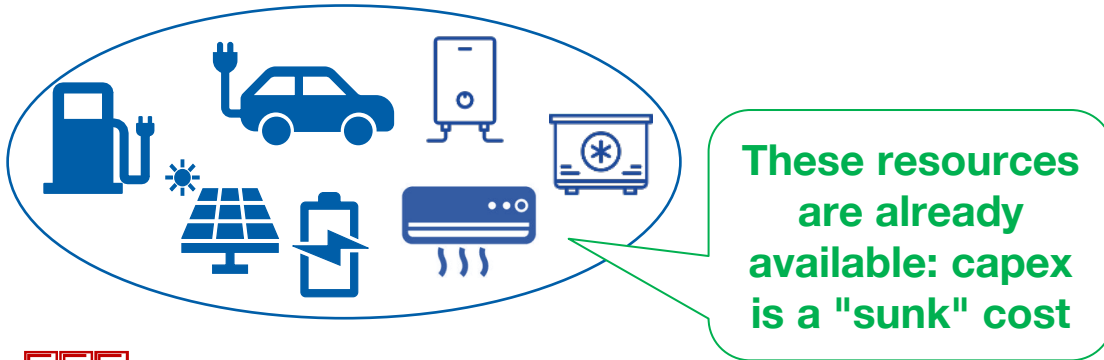


The modulation of consumption has ensured the security of the electricity system during critical days (Easter and Easter Monday)

Barriers to participation of distributed resources and impact on the system



Distributed resources and cogeneration



Technical barriers

Technology standards

Measurability

Observability

Controllability

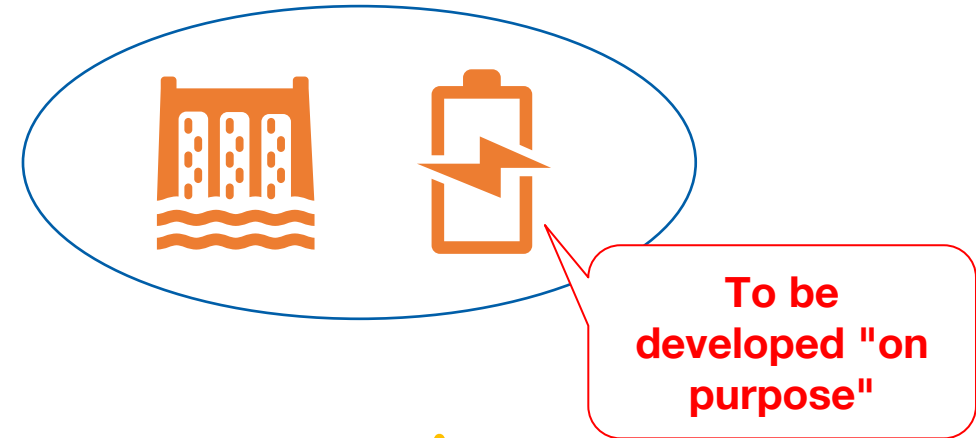
Lack of operational flexibility



Economic barriers

Sustainability of the business model

Storage utility-scale



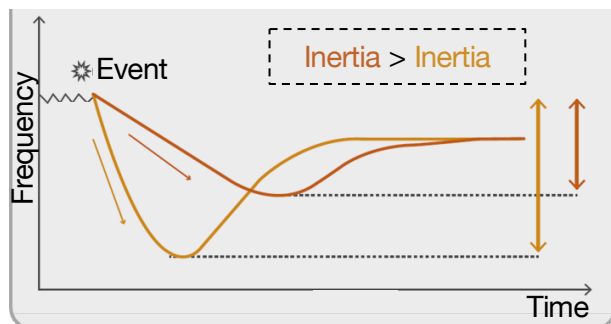
If we do not exploit all the potential resources that already exist, we must develop new storage systems on an industrial scale, leading to a more expensive electricity system

Managing the operational security of the electricity system



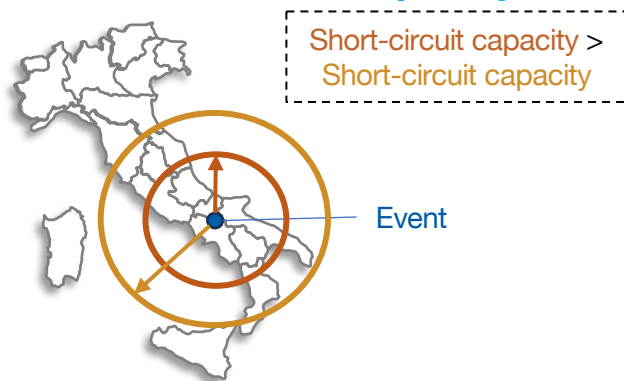
In a context characterised by the increasing penetration of renewable sources and the progressive reduction of conventional generation, three dimensions of the electricity system need to be properly addressed

System Inertia



- **The inertia slows down the deviation of the frequency** following a disturbance event (e.g. power plant outage) and ensures the “robustness” of the system
- The impact of inertia is quantified by two parameters: the Rate Of Change Of Frequency and the maximum excursion of frequency (zenith and nadir)

Voltage regulation and short-circuit capacity



- **Keeping the voltage within operating limits** is important to ensure the proper functioning of all devices connected to the network
- **Short-circuit capacity mitigates the impact of grid events** on voltage profiles.

System stability

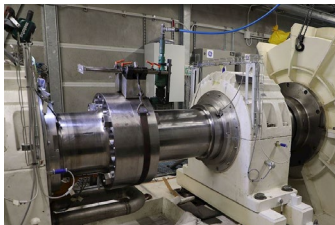
- **A system is stable** when it is able to maintain its operational status under normal operating conditions, or **when it is able to return to acceptable operating conditions after an event**
- Different types of stability: frequency, voltage, converter-driven, resonance, and oscillatory



SECURITY

Grid technologies for the regulation and stability of the system

Synchronous compensators



Rotating machines, similar to generators, which provide mechanical inertia and short-circuit capacity



17 compensators

Reactors



These assets are particularly suitable for managing periods with high-RES generation (high voltage)



16 reactors

Statcom



Based on power electronics, they inject/absorb reactive power and contribute to system stability



5 Statcom

Resistors



Similar to Statcom, they also absorb active power, keeping the system stable and also supporting black-start capability



1 Resistor

Control & defence systems



Real time monitoring (WAMS), grid stabilising systems (WADC), other monitoring tools etc



Various systems

System Inertia



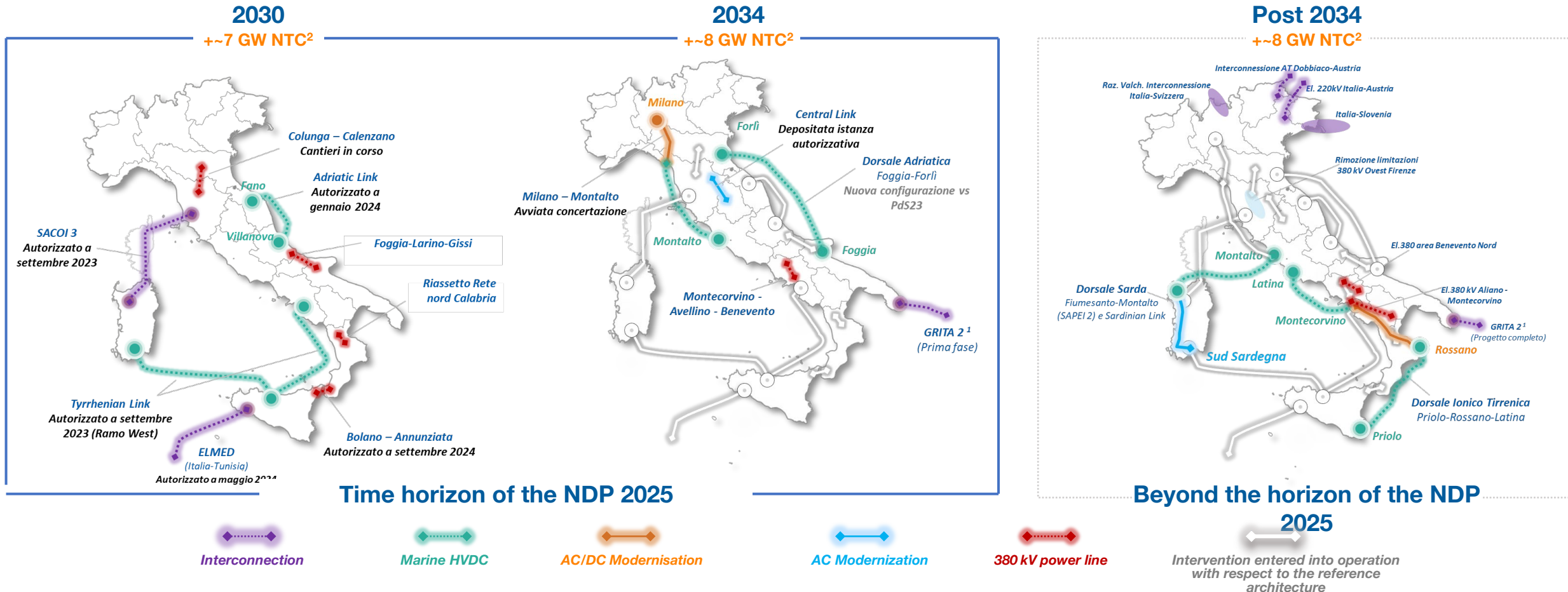
Voltage regulation and short-circuit capacity



System stability



Focus on 10 years grid development plan

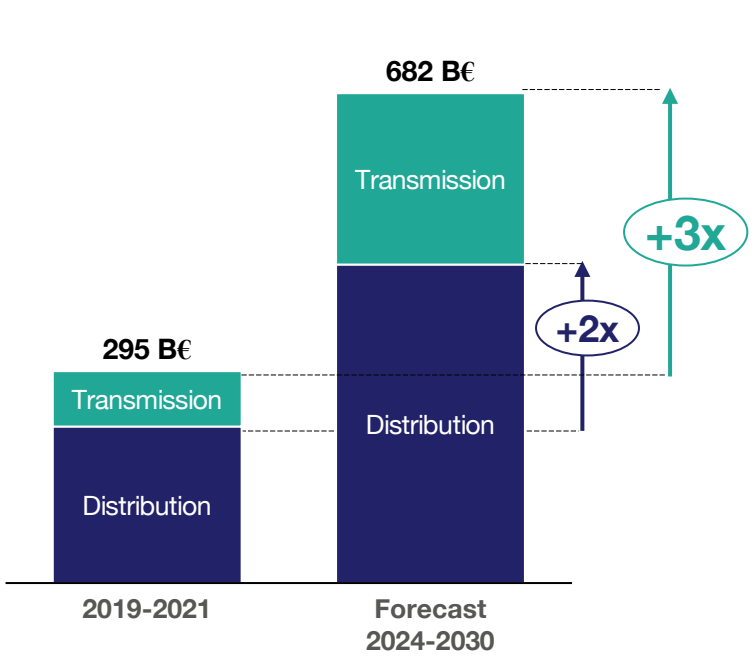


The Italian Hypergrid has been designed to maximize the increase in transportation capacity for each euro spent (MW/€) combining all available solutions (AC, DC).

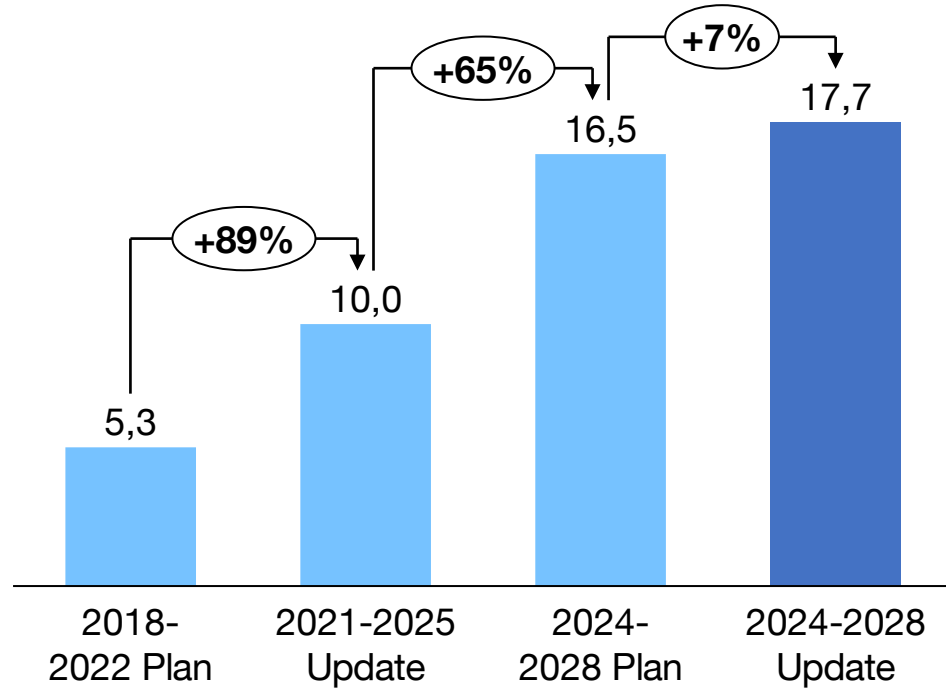
Increasing investment needs

Increasing investment at global level to develop the electricity grid

Investments in Transmission vs Distribution¹



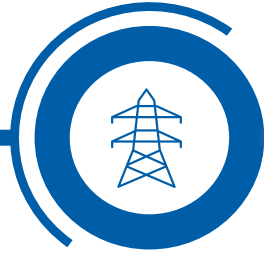
Terna's Industrial 5Y CAPEX Plans are becoming more challenging. It is paramount to ensure that cost and execution remain under control



Increasing grid investment is needed to enable the decarbonisation of the electricity system

Enabling Factors For The Energy Transition

System requirements



Grid Developments & operational security

- Connect increasing number of distributes assets and **increase transport capacity**
- **Install electrical machines** to ensure operational security



RES Development

- **42% RES penetration in 2025**
- **2030 target: 63% RES penetration and -55% CO2 emissions**



New storage capacity

- Objectives by 2030: 50 **GWh new utility-scale storage capacity**



Adequacy & OG management

- **Resources available to balance the system in periods with high demand and low-RES production, or vice-versa**

Regulated tools

REGULATION

Regulation must evolve to guarantee CAPEX efficiency but also financial sustainability

LONG-TERM SUPPORT SCHEMES

Fundamental to support financial sustainability of RES developers
RES MUST participate to real-time markets to provide flexibility (curtailment)

LONG-TERM SUPPORT SCHEMES

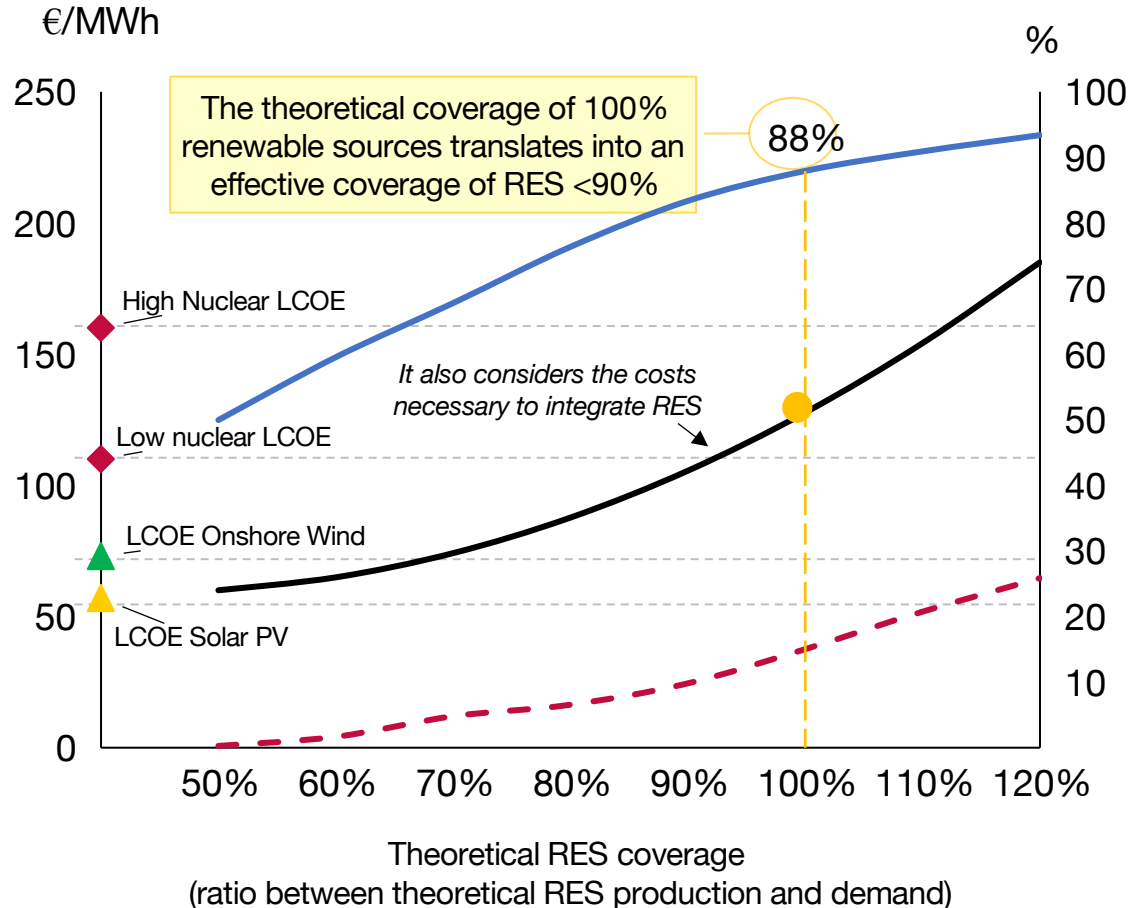
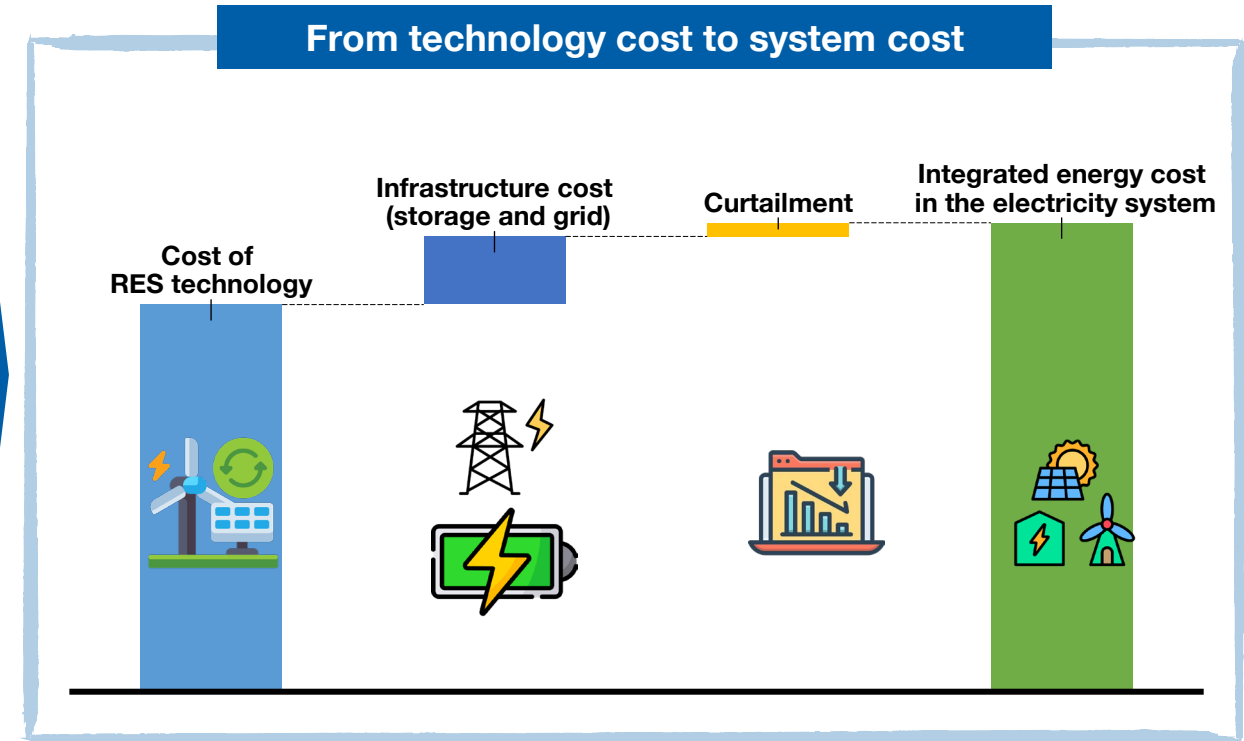
For the same reason, fundamental to support financial sustainability.
Risk must be allocated to those who can best manage it.

LONG-TERM MARKETS

Capacity market for the adequacy
Modulation of consumption: increasing/reducing demand when needed

Considerations on the long term marginal cost of RES integration

— Integrated RES marginal cost (left axis) — Effective RES coverage (right axis) - - Curtailment (right axis)



With more than 70-80% of RES penetration, the marginal cost of energy integrated into the system grows steeply as a result of the increase in overgeneration and the necessary investments in storage and grid infrastructure

Long-term energy scenarios: technology screening

Fully mature technologies

Solar

- LCOE (global average)¹ from ~250 €/MWh in 2014 to ~50 €/MWh in 2024, up to ~20 €/MWh by 2050
- Increasing adoption of tracking technologies with bi-facial panels



Onshore wind

- LCOE (global average)¹ from ~140 €/MWh in 2014 to ~70 €/MWh in 2024, up to ~36 €/MWh by 2050
- Development of bigger/taller wind turbines



Storage (BESS)

- CAPEX (global average)¹ from ~1000 k€/MWh in 2010 to <300 k€/MWh in 2024
- Results 1°MACSE auction: CAPEX 80-100 k€/MWh²



Not yet mature (technically or commercially)

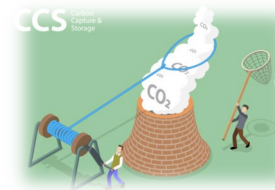
New nuclear (SMR, AMR)

- Cost range is very wide
- Modularity allows economy of scale
- Cogeneration potential is very attractive for industrial applications
- Flexibility is required for integrating this technology in the electricity system



Gas with CCS

- Cost for capturing CO₂ depends on the utilisation rate of this technology
- High logistical constraints (grid and storage infrastructure)



Floating offshore wind

- LCOE today still very high and is not competitive yet against other alternatives
- Technology challenges are significant when dealing with big projects



Thank you

Luca Marchisio
Head of Strategy

