Summer School on Energy Giacomo Ciamician

Electric energy storage

Prof. Nicola Fergnani

Politecnico di Milano

Kreuzbergpass, Sexten (BZ), Italy

JUNE 5TH – 10TH, 2024

awarenergy
www.awarenergy.eu

dipartimento di ingegneria e architettura

Levi Cases

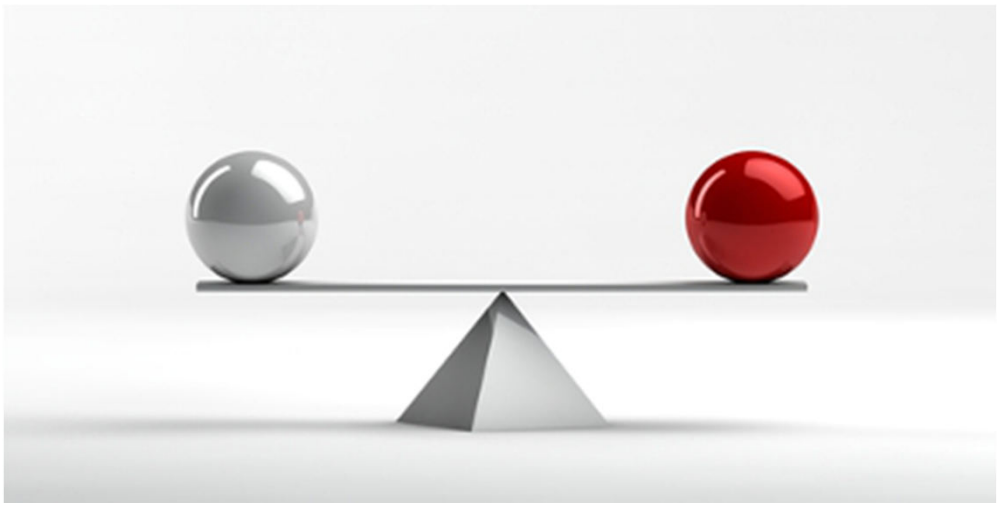
Centro Interdipartimentale
per l'Energia, l'Ambiente e i Trasporti
Giacomo Ciamician

IEEE Industrial Electronics Society
IES Italy Chapter

ALOT
INNOVATION FOR SUSTAINABILITY

Why we need storage systems?

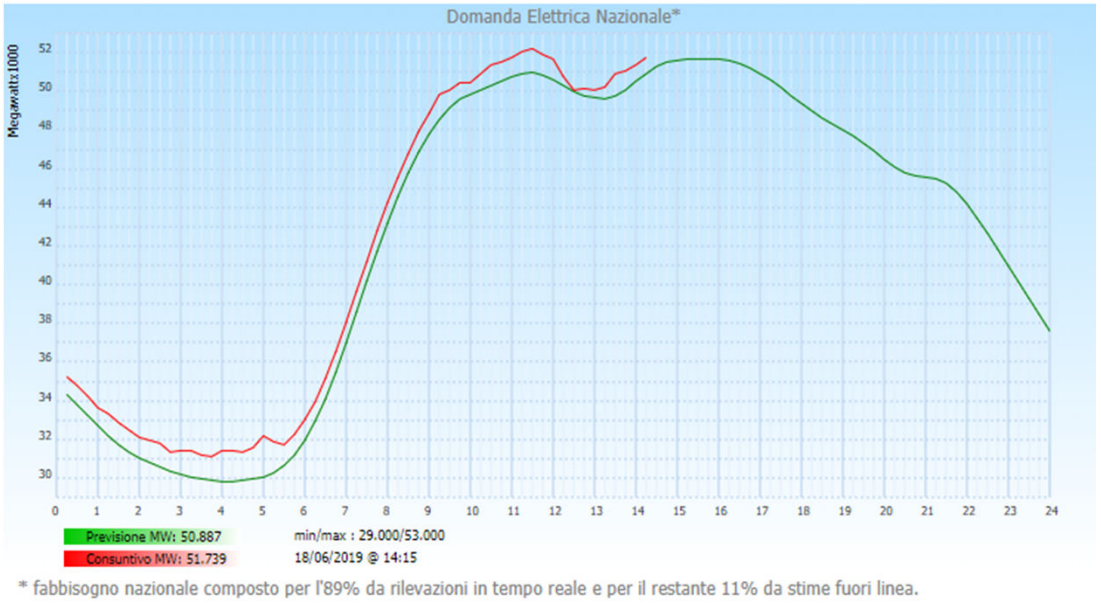
Production = Consumption



Every hour, minute, second..

Why we need storage systems?

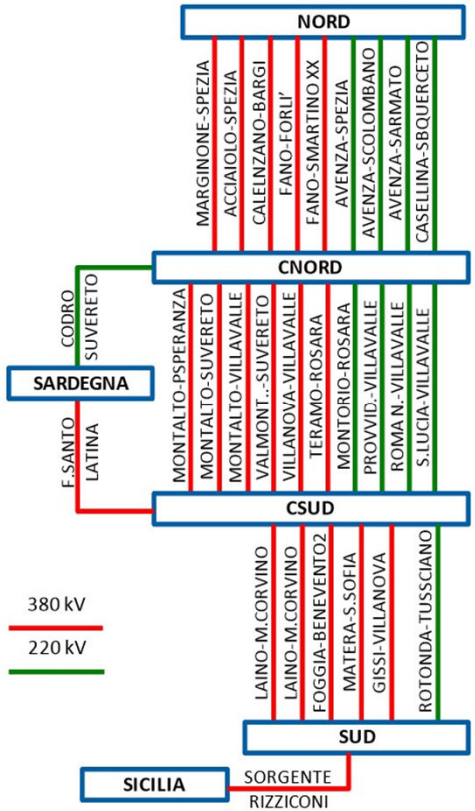
Failures

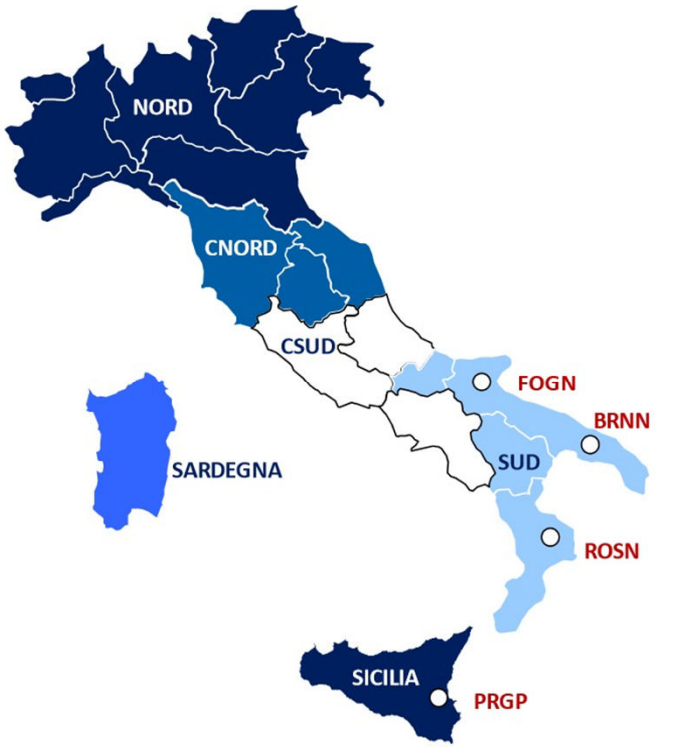


Demand forecast approximation

Inertia of thermal plants

Why we need storage systems?





Assetto zonale in vigore dal 1 gennaio 2012

The Grid

- Strongly meshed in the northern area, less in the central-southern part
- **63.595** km of high voltage electricity circuits
- **22** cross-border interconnection lines (3 merchant lines)
- **475** substations
- **5114** bays
- **656** transformers
- **1640** meters is the world record-breaking depth of the SA.PE.I. undersea cable

System Control

Controlled plants (connected to the transmission grid)

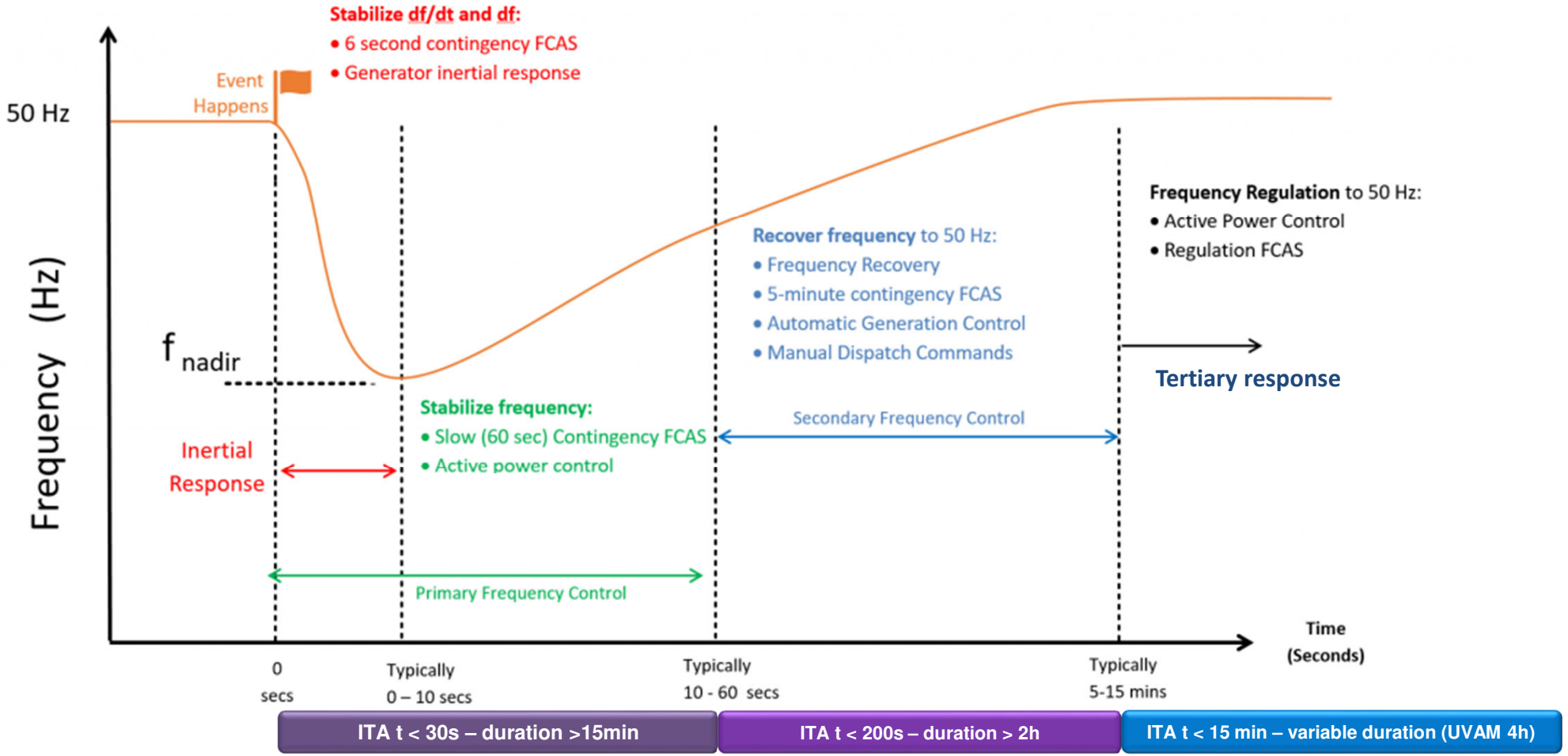
- ≈**1.000** Production Plants > 10 MVA

Information managed every day

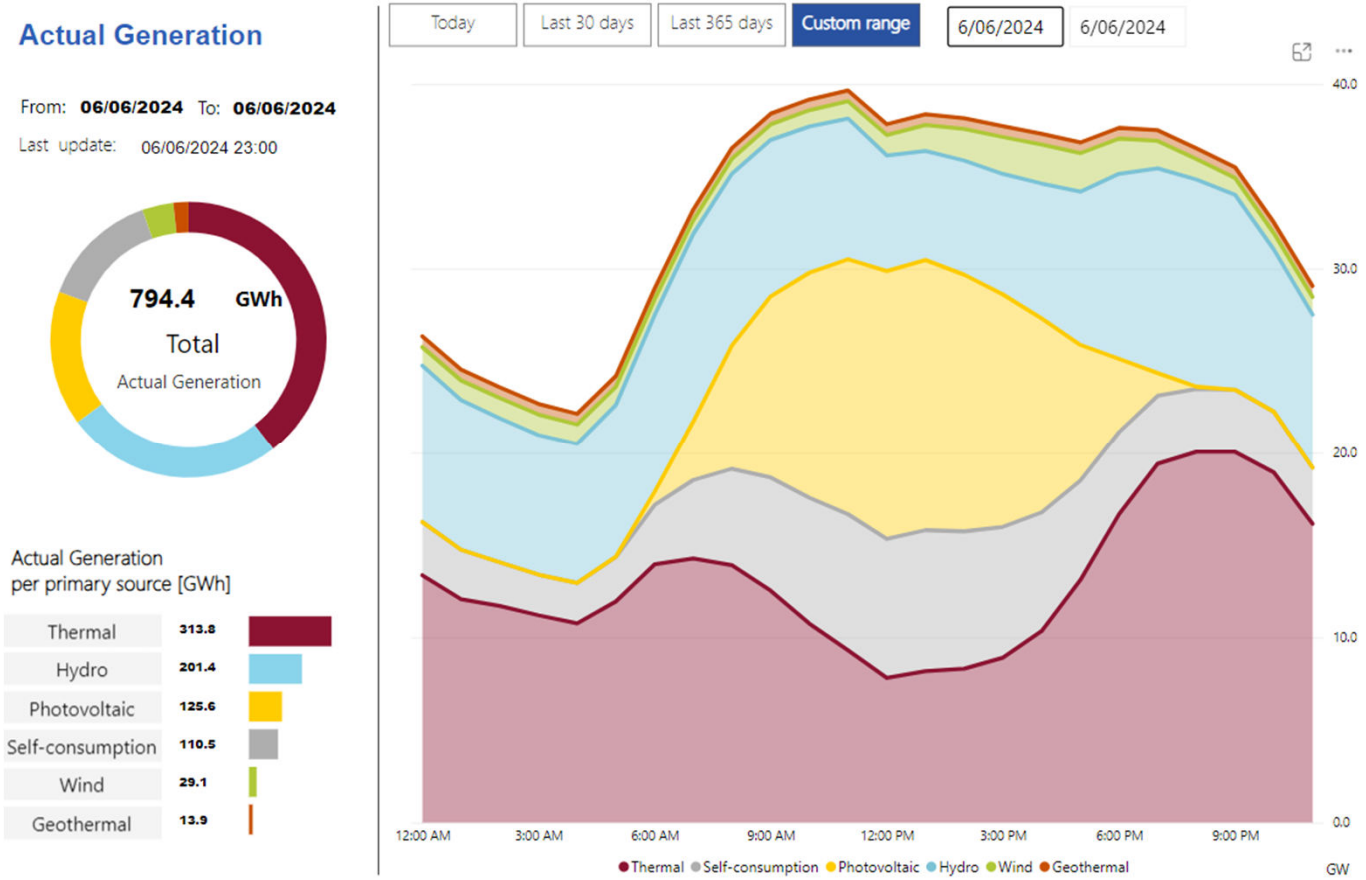
- ≈ **45.000** Monitored measurements (every 2, 4, 20 s)
- ≈ **160.000** Monitored signals (on event)
- ≈ **1.000** Dispatching orders from NCC to production plants
- ≈ **1.000** Switching orders from Switching Centers

- ≈ **550.000** Distributed Generation plants connected through Distributor grids

The need of grid services



Who is providing flexibility today?



Fossil-fuel plants:

- Programmable
- Variable response time

Hydro storage plants:

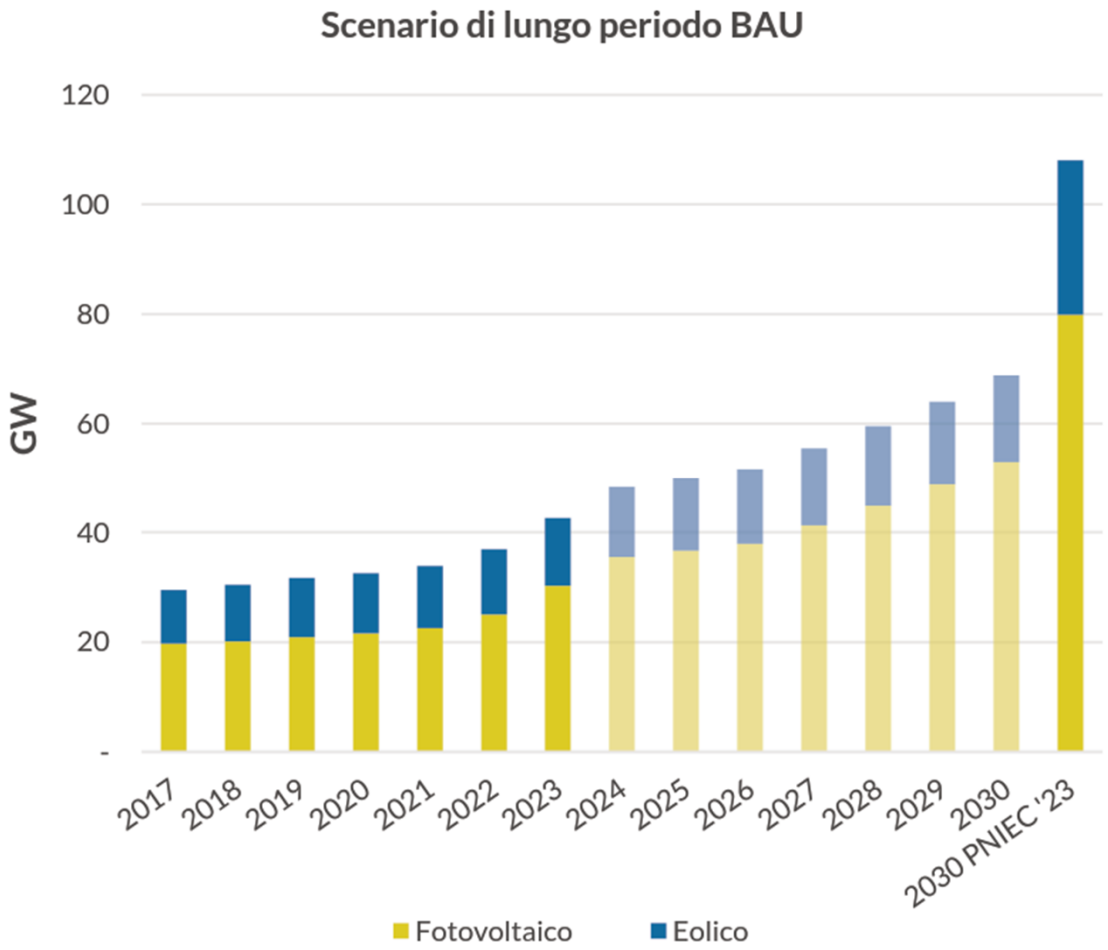
- Programmable
- Fast ramp-up and ramp-down

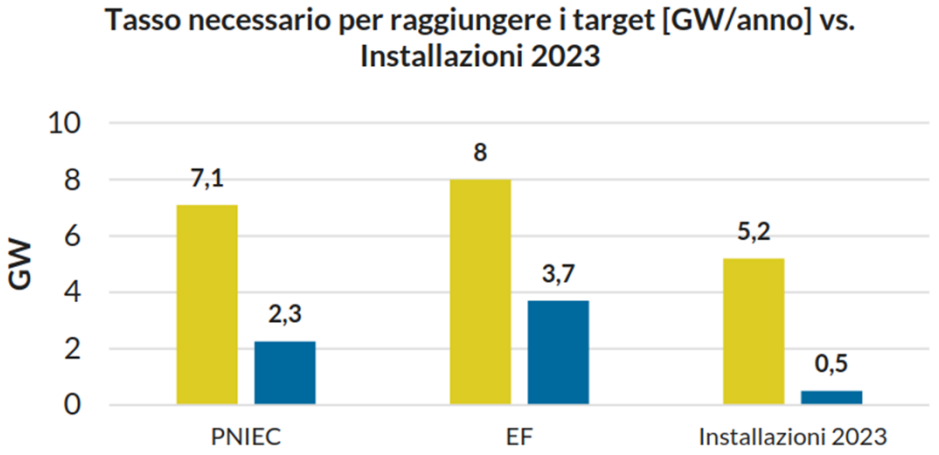
https://www.terna.it/it/sistema-elettrico/transparency-report/actual-generation

Future challenges with increasing RES

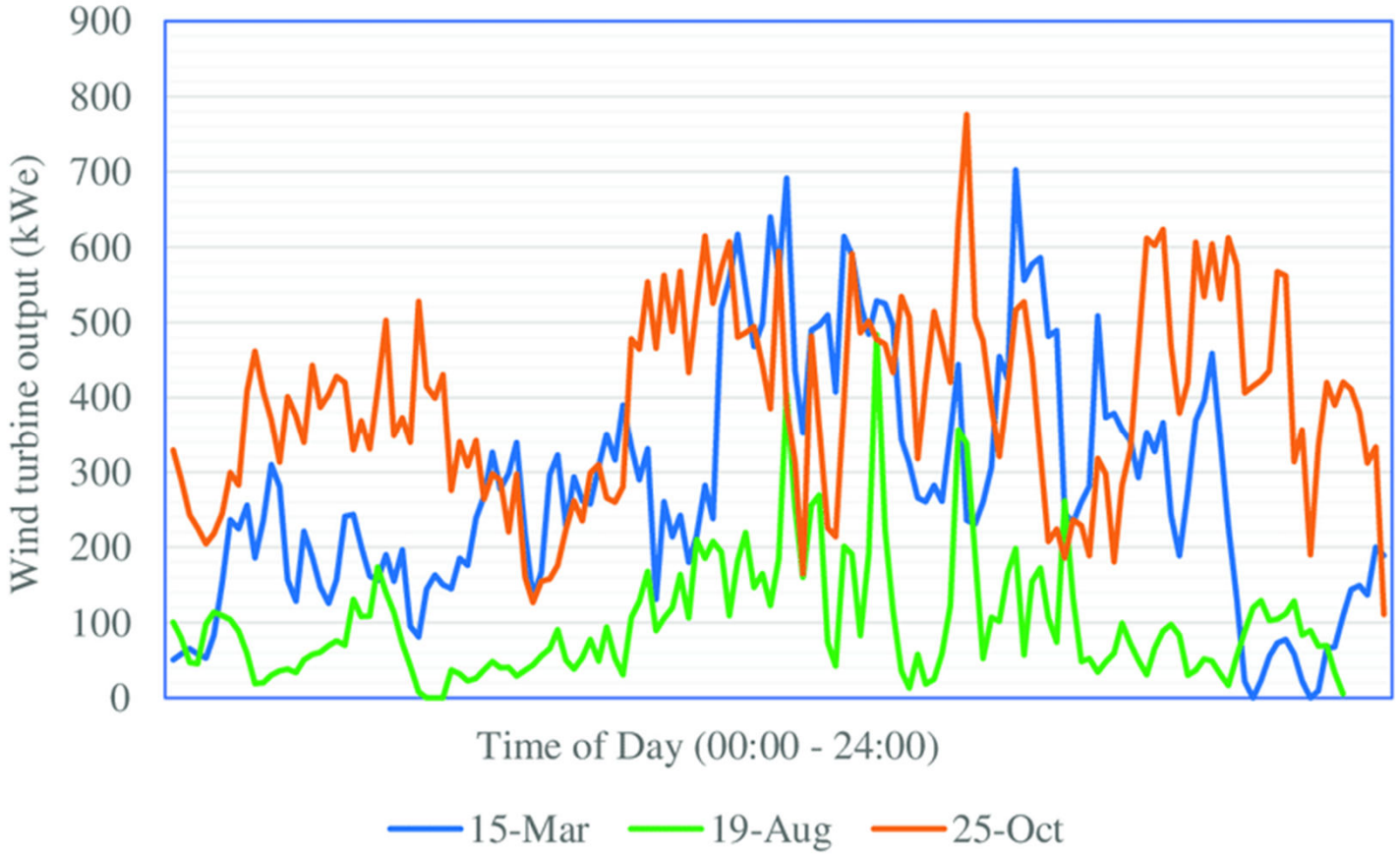
ENERGIA CLIMA 2030

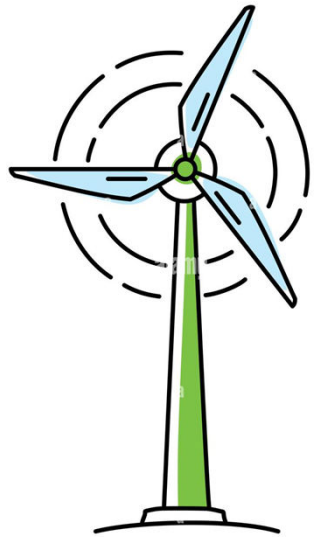
Piano Nazionale Integrato per l'Energia e il Clima





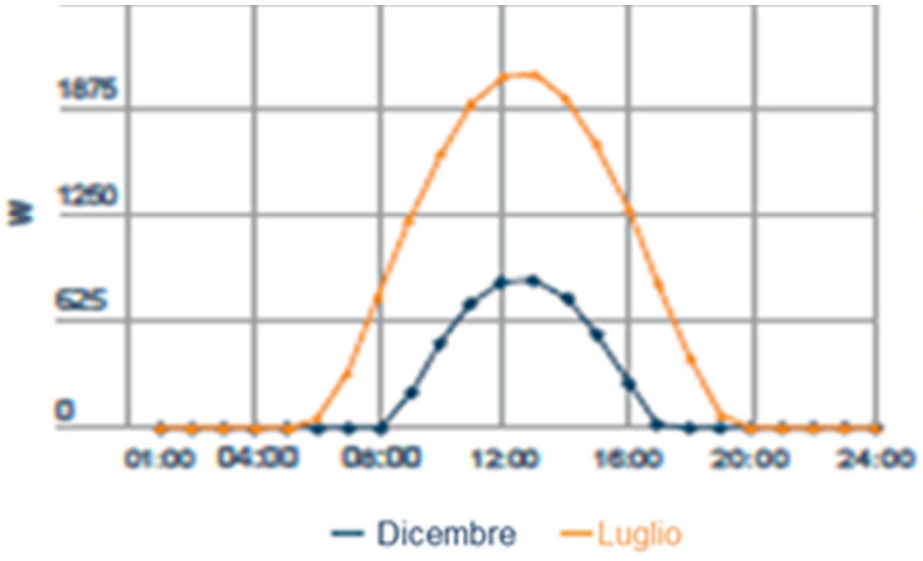
Future challenges with increasing RES



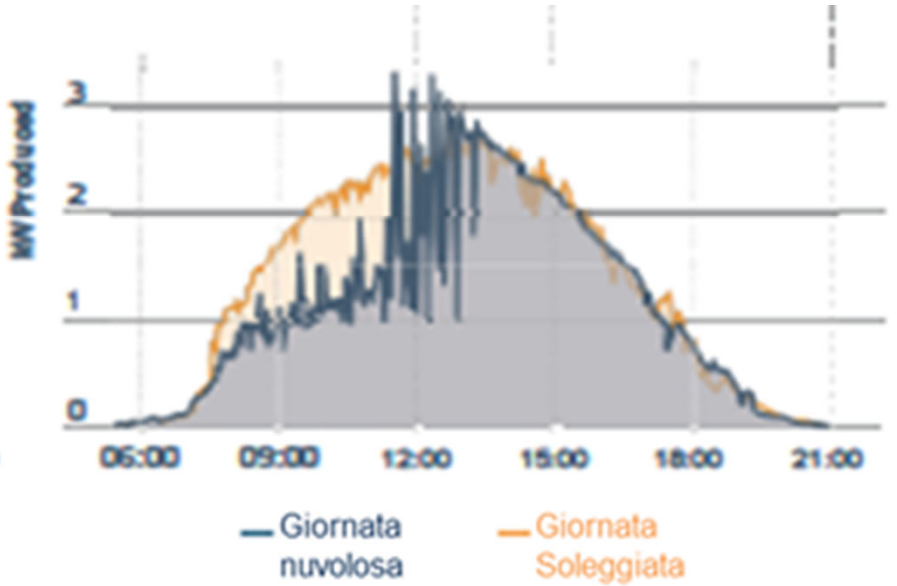


Future challenges with increasing RES

Season variations



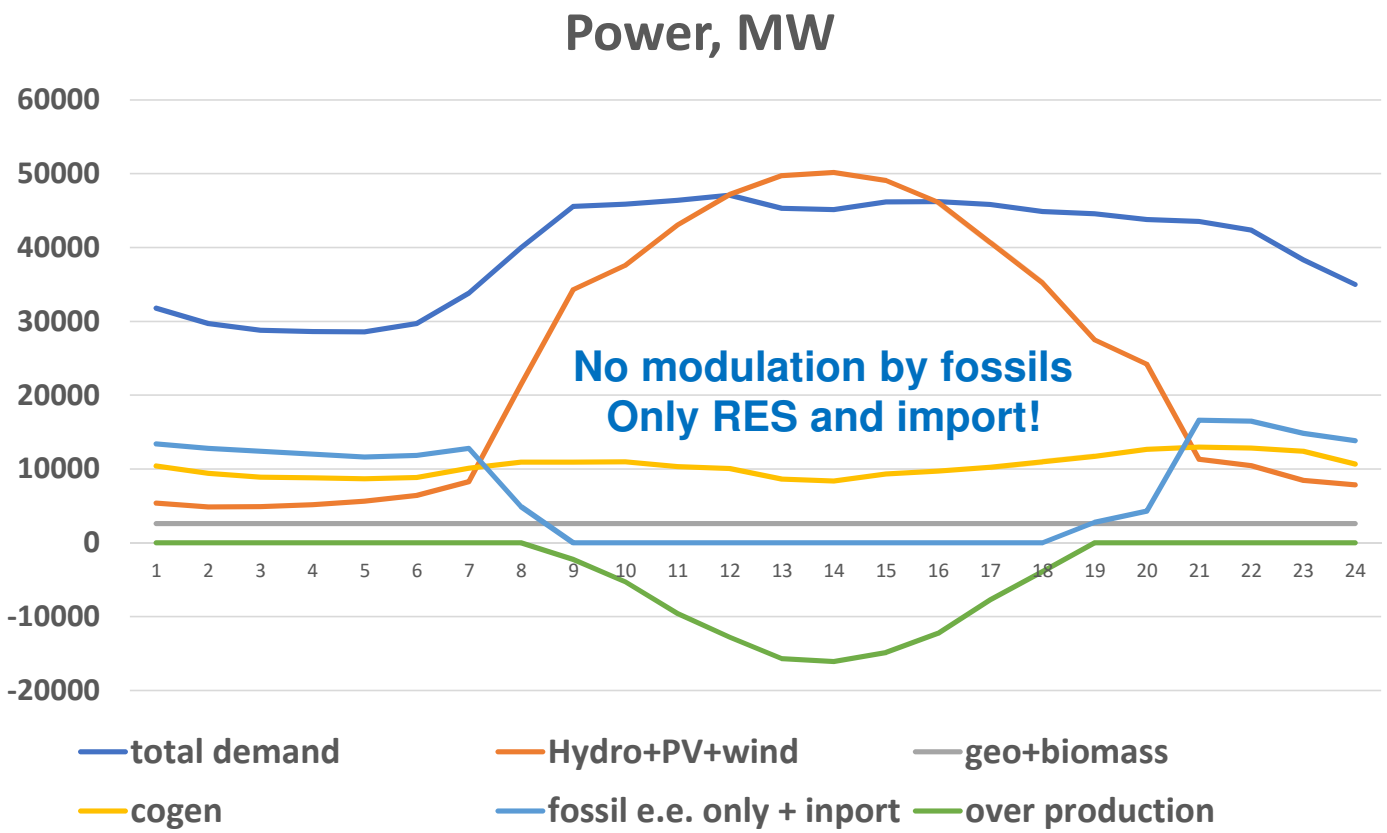
Daily variations



RES Production forecast approximation

Who will provide flexibility tomorrow?

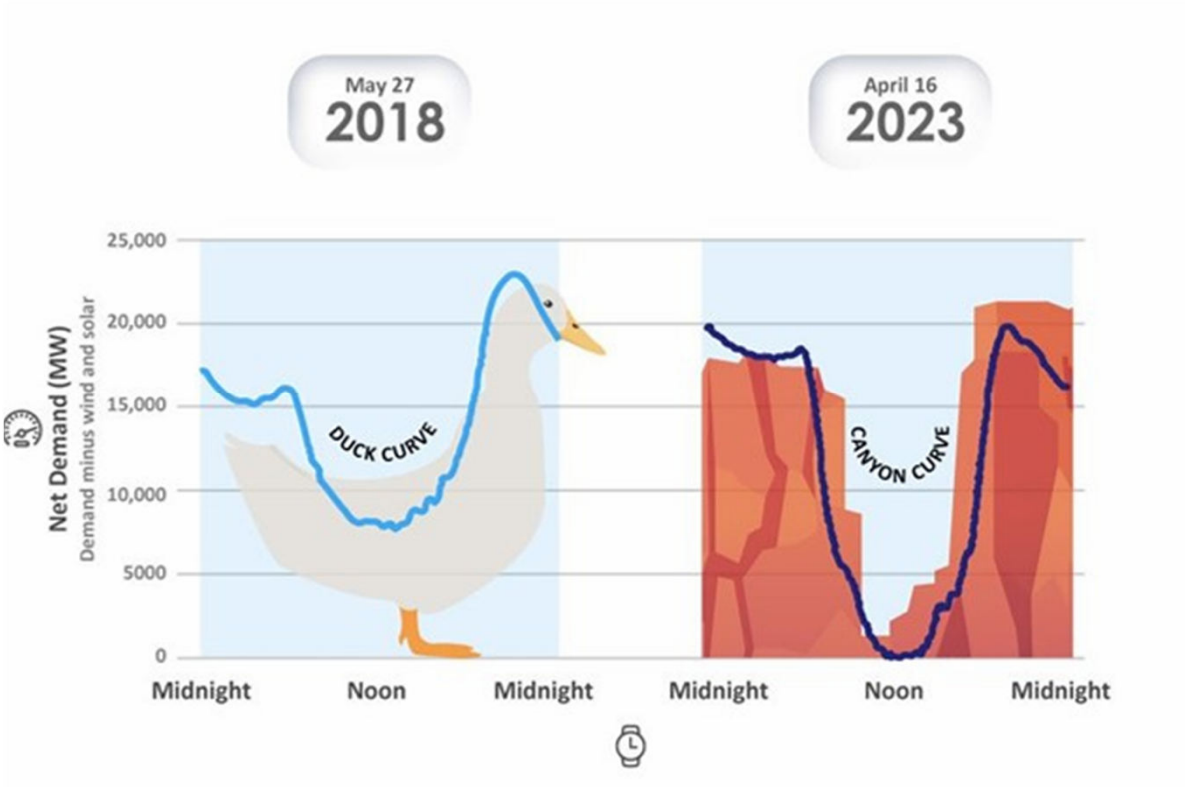
Power demand and production (MW) in an average day in **May** 2030.



Overproduction > 10% total demand, 16 GW on peak

Who will provide flexibility tomorrow?

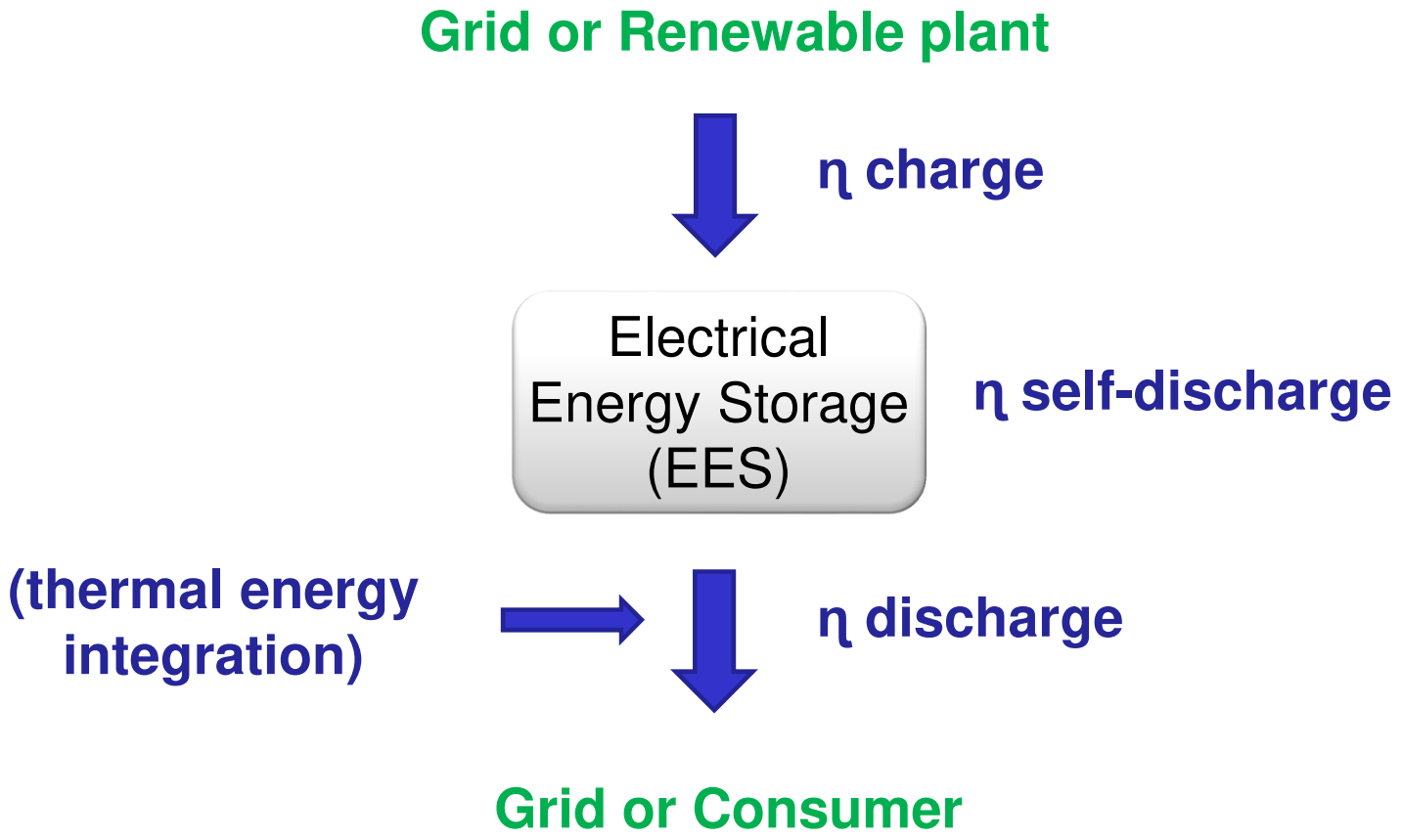
Italian grid May 2030: even worse than California



Solutions:

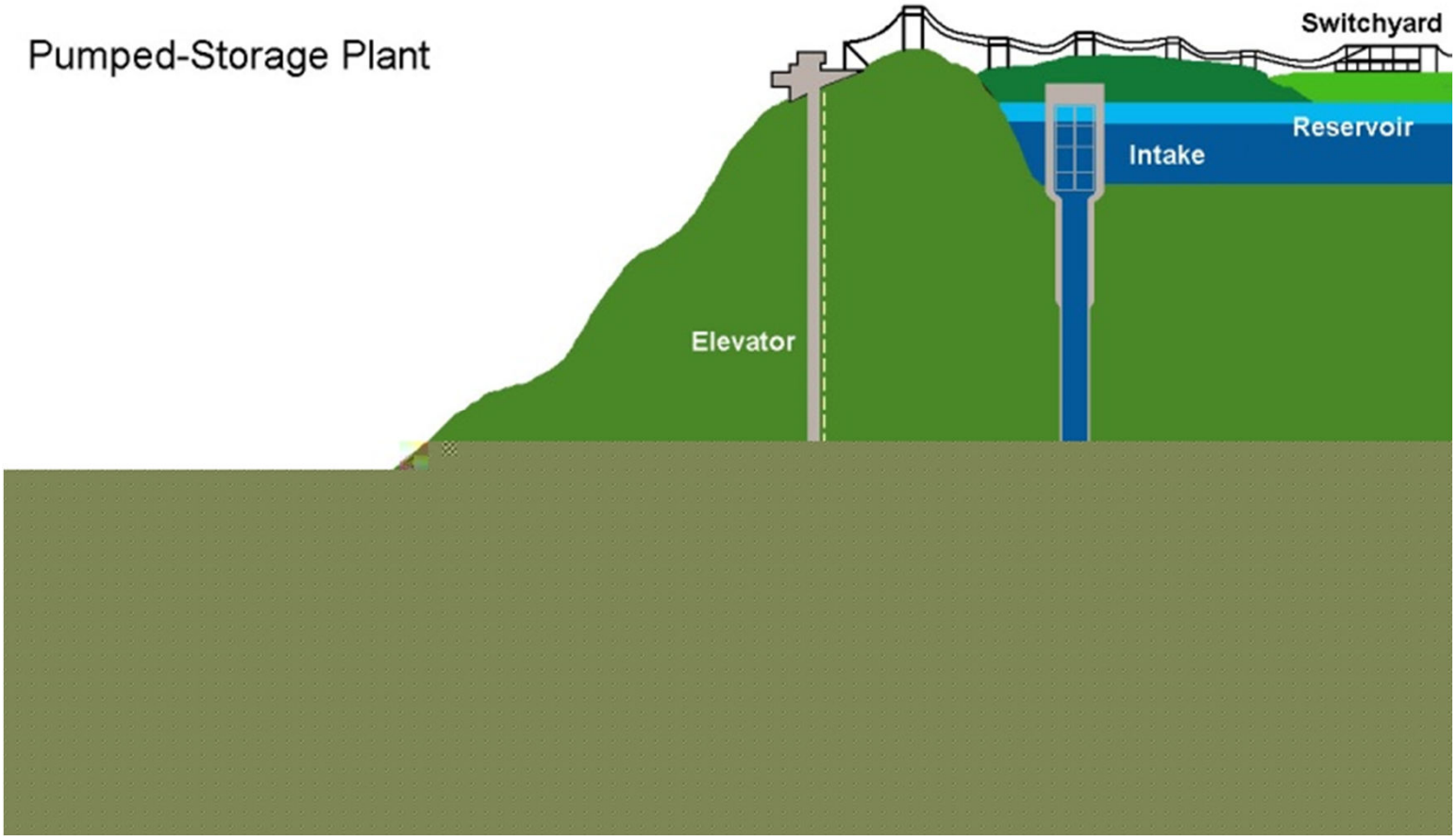
- Capacity market
- Programmable RES
- Energy storage
- Demand-side response

Storage systems



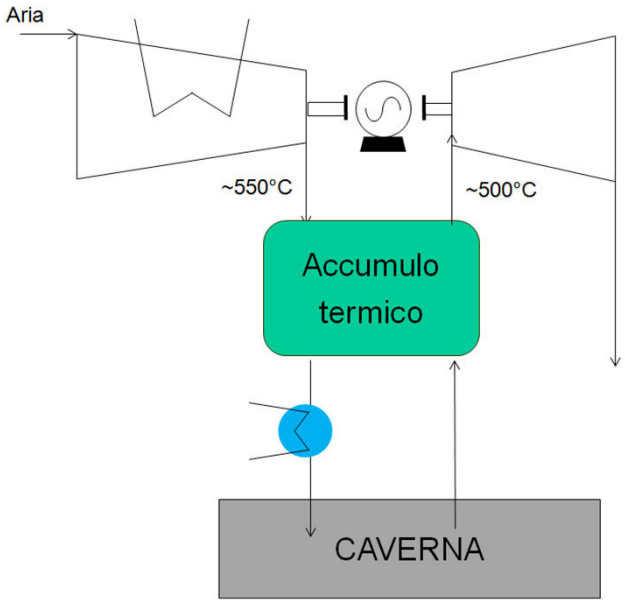
Storage systems

PUMPED HYDRO

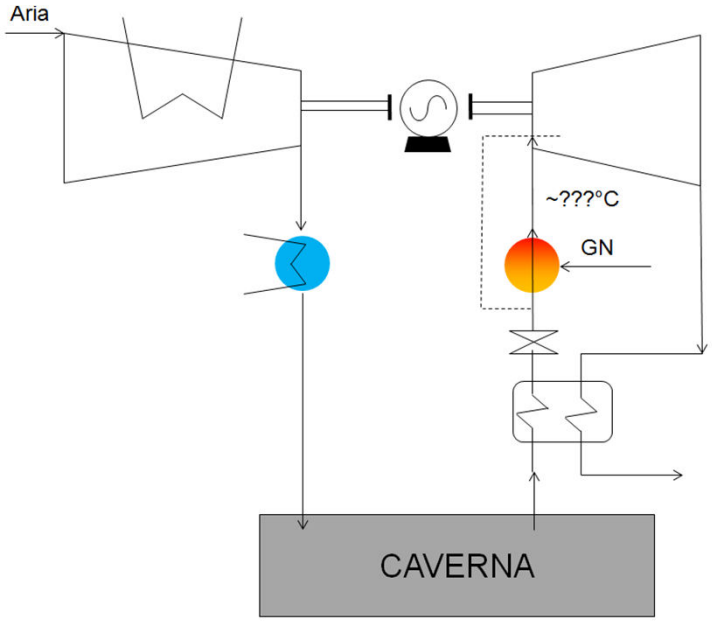


Lithium battery storage

CAES

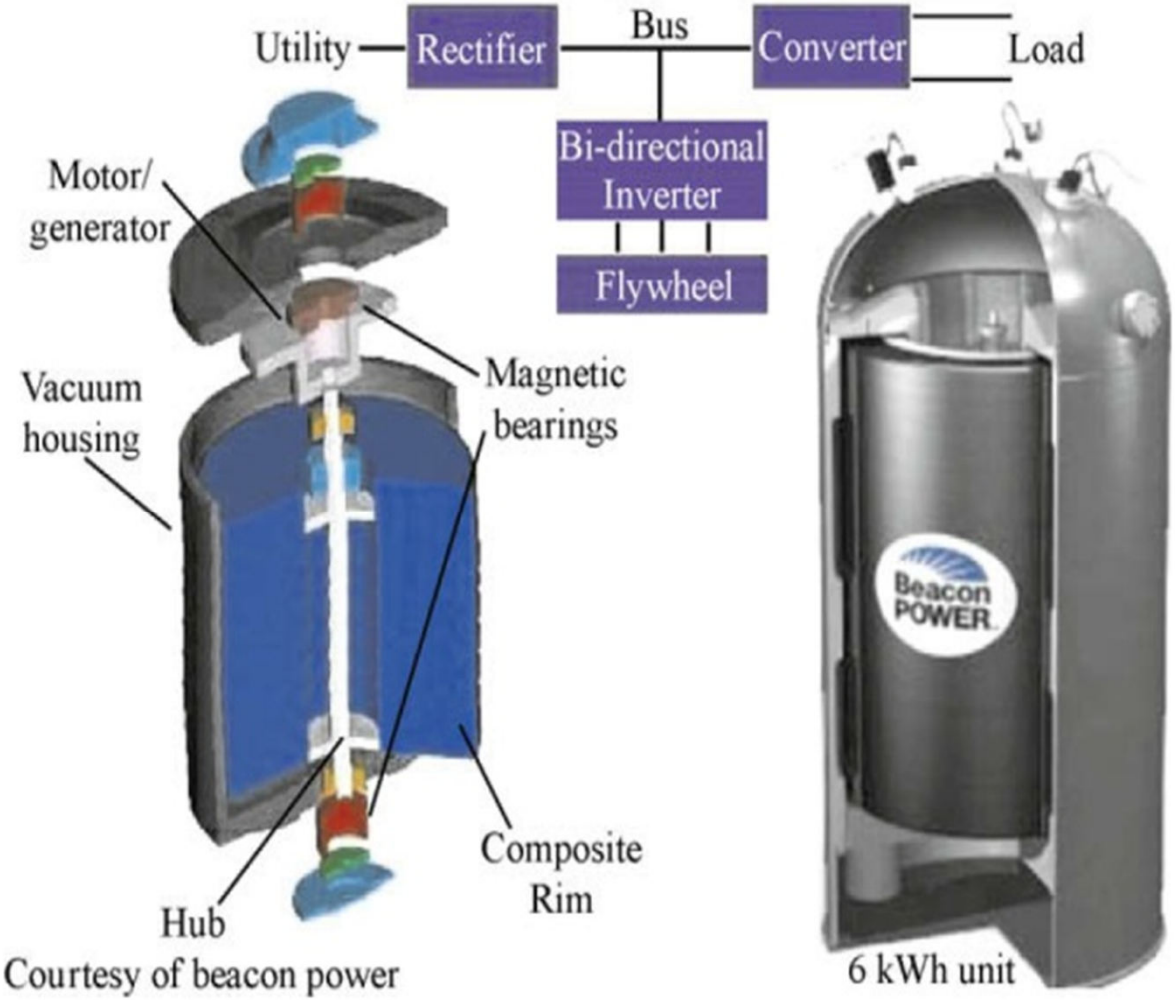


Adiabatic CAES
Pout < Pin



Non-adiabatic CAES
Pout > Pin

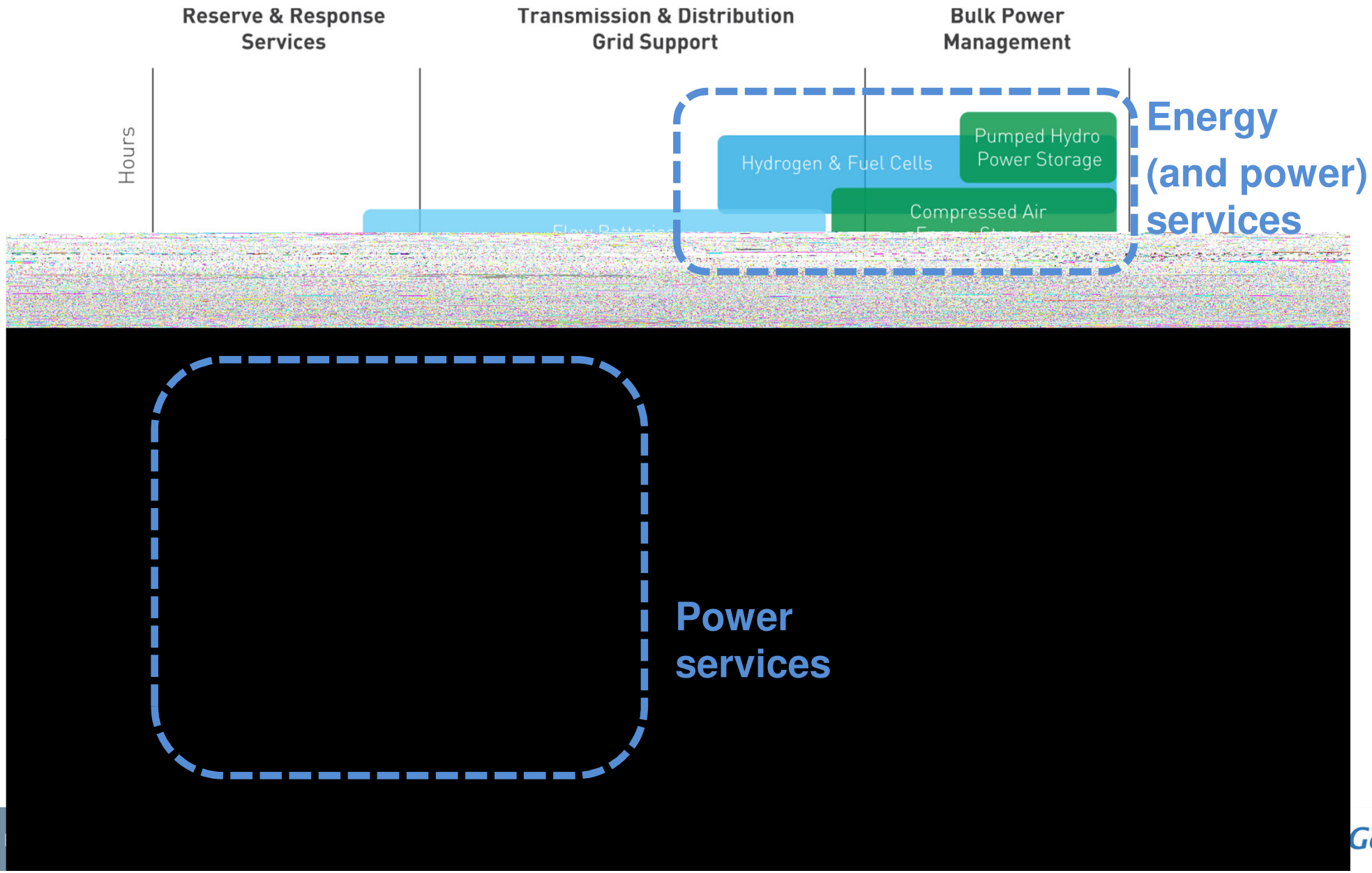
Flywheels


Utility
Rectifier
Bus
Converter
Load
Bi-directional Inverter
Flywheel
Motor/ generator
Vacuum housing
Magnetic bearings
Composite Rim
Hub
Courtesy of beacon power
Beacon POWER
6 kWh unit

Storage systems features

- **Power density [W/kg]**
- **Energy density [Wh/kg]**
- **Specific cost to power [€/kW]**
- **Specific cost to energy [€/kWh]**
- **Roundtrip efficiency**
- **Scalability**
- **Service life [years and cycles]**
- **Dismantling costs and env. impacts**
- Self-discharge losses
- Performance decay in different conditions
- Construction time
- Reliability and availability

No single technology to meet all requirements

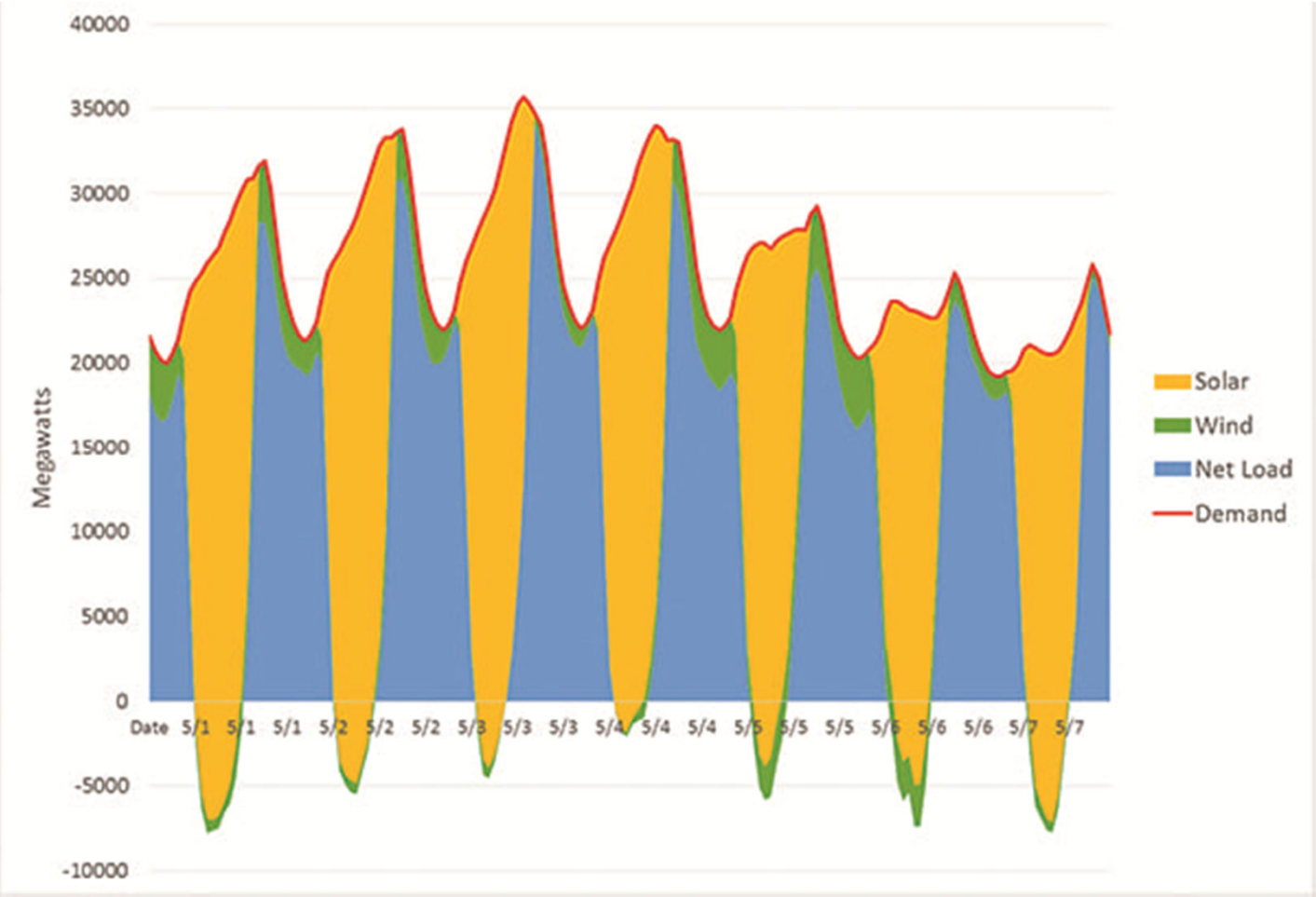

Reserve & Response Services
Transmission & Distribution Grid Support
Bulk Power Management
Hours
Hydrogen & Fuel Cells
Pumped Hydro Power Storage
Compressed Air
Energy (and power) services
Power services

Power services

From seconds to minutes:
Services to distribution and transmission network operators for **grid balancing** and **frequency regulation**

From minutes to hous:
Balancing services on the grid

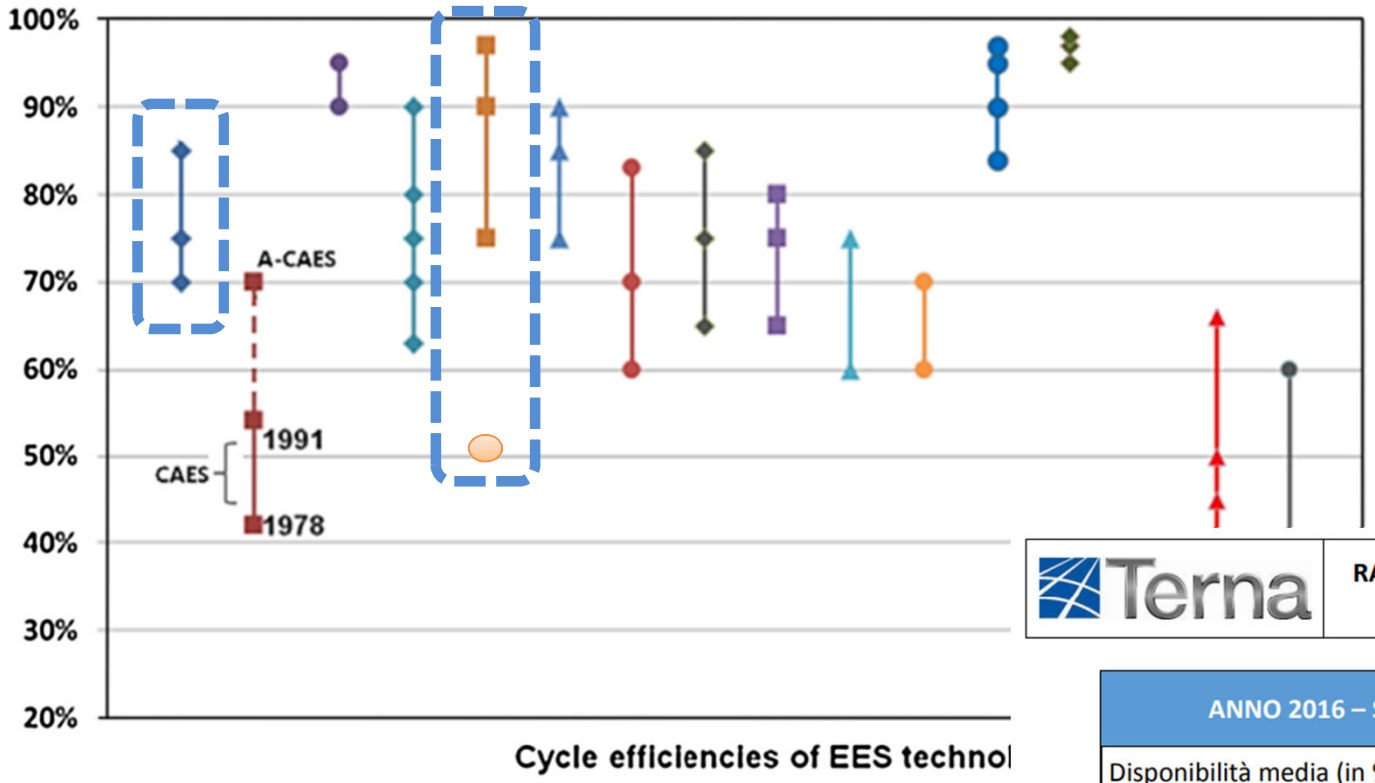
Energy services



From several hours to weeks or months:

Renewable energy dispatchability

Storage systems efficiency



- Pumped hydroelectric storage
- Compressed air energy storage
- Flywheel
- Lead-acid battery
- Lithium-ion battery
- Sodium-sulphur battery
- Nickel-cadmium battery
- Vanadium redox flow battery
- Zinc bromine flow battery
- Polysulfide bromine flow battery
- Capacitor
- Supercapacitor

Terna	RAPPORTO PUBBLICO DELLA SPERIMENTAZIONE – PROGETTI STORAGE ENERGY INTENSIVE	07/04/2017
		Rev.00

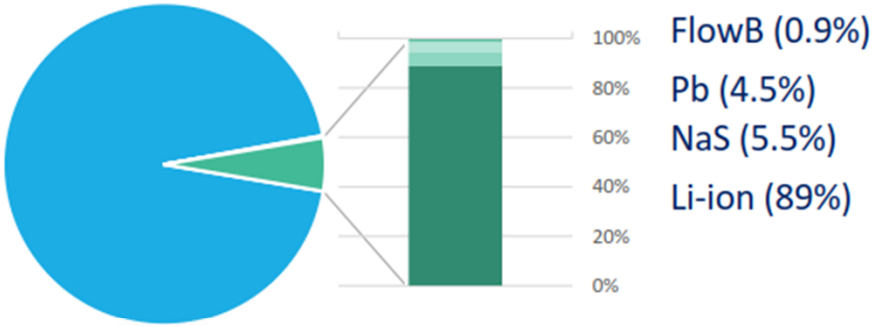
ANNO 2016 – SANC	GINESTRA	FLUMERI	SCAMPITELLA	TOTALE
Disponibilità media (in % taglia nom.)	73,0%	85,6%	86,0%	81,5%
Disponibilità media (MW)	8,8	10,3	9,3	28,4
Perdite energetiche (GWh)	8,16	7,60	7,49	22,0
Rendimento complessivo	49,9%	46,2%	51,7%	50,7%

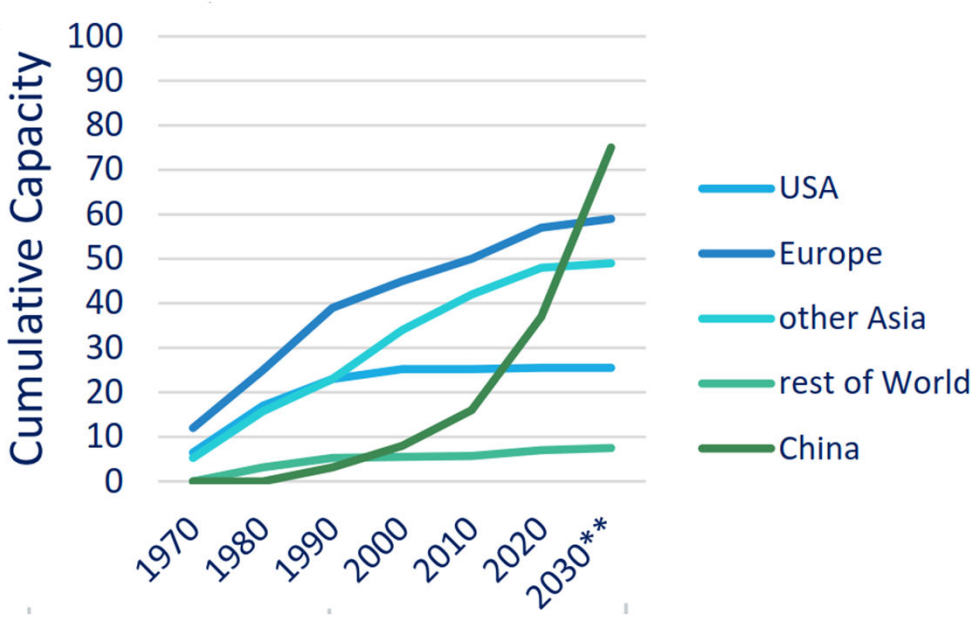
X. Luo et al. / Applied Energy 162 (2016) 589–600

Storage systems

Nowadays basically three technologies cover the whole energy storage market

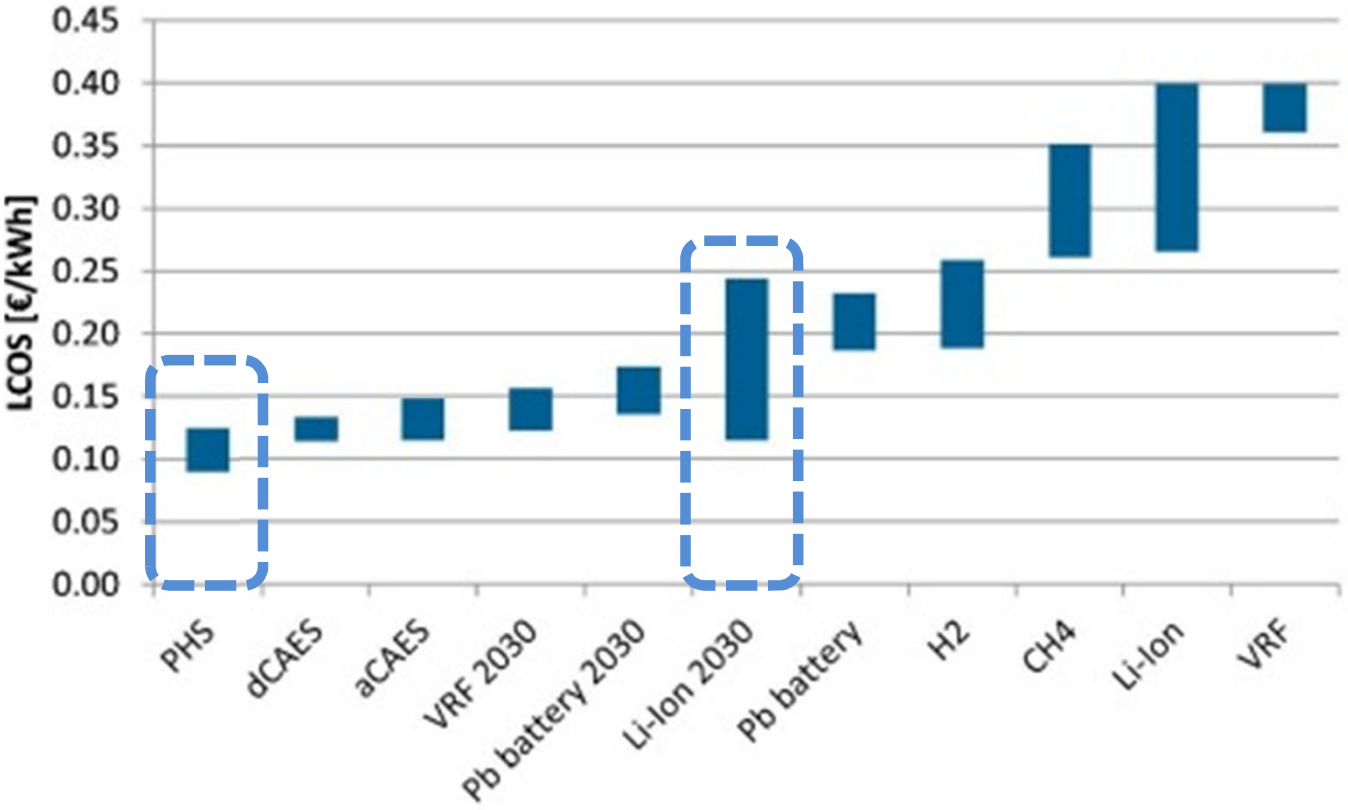
- **Pumped hydro energy storage** **(94.5%)**
  - Orography limitations
  - Visual impact
- **Electrochemical Batteries** **(5.3%)**
  - Degradation over time
  - Short lifetime
  - Power/capacity ratio
- **Flywheels** **(0.2%)**
  - Short discharge time
  - Little energy density





Storage systems

Levelized Cost of Storage

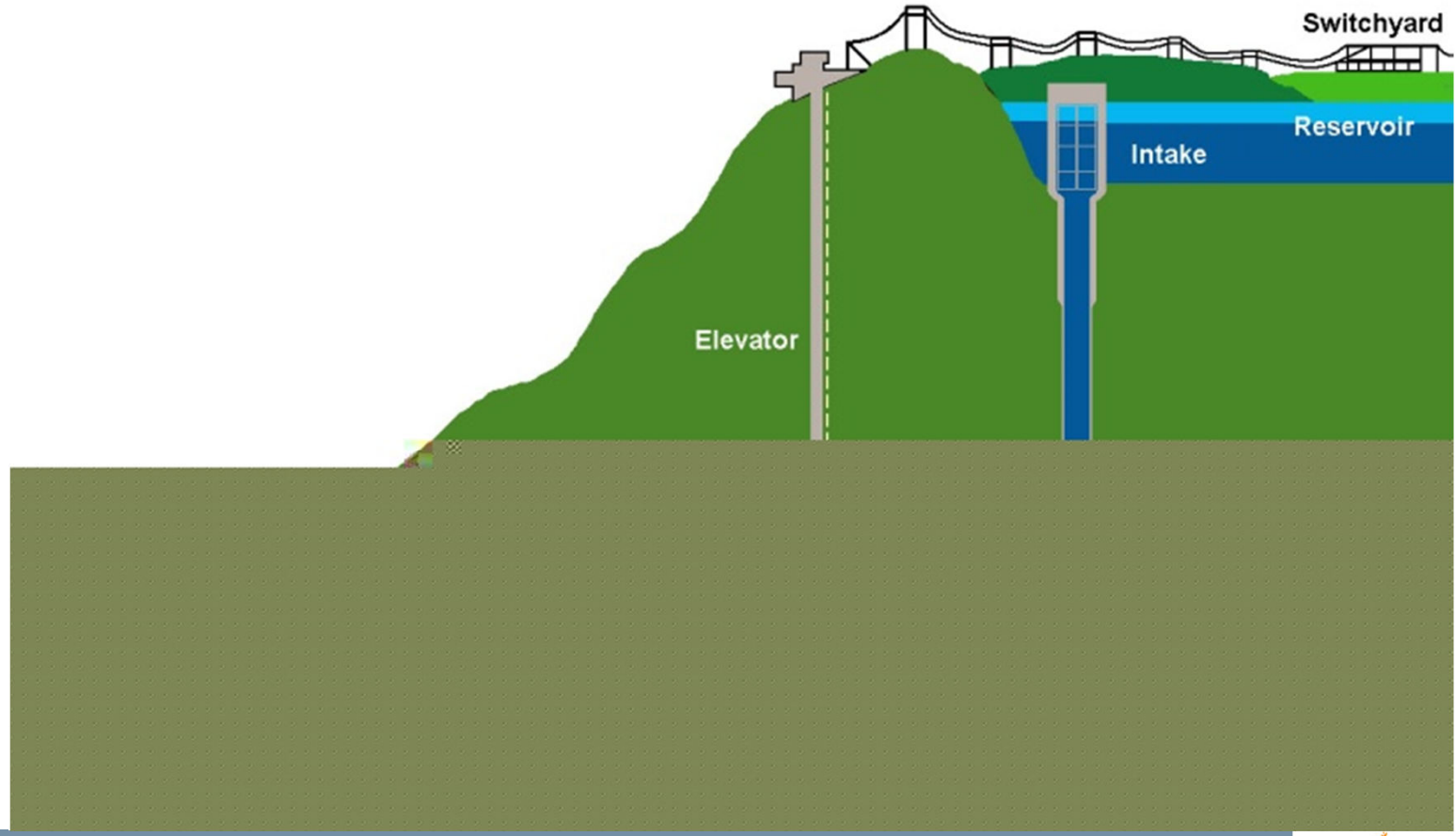


+ roundtrip efficiency losses!

Levelised Cost of Storage for Pumped Heat Energy Storage in comparison with other energy storage technologies, 2017

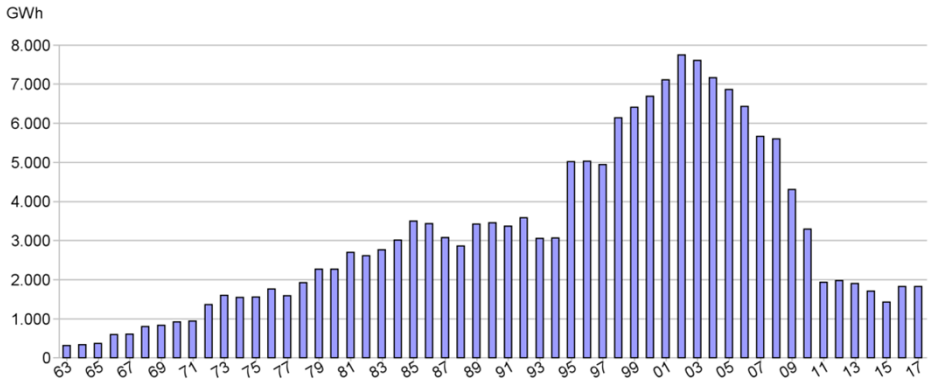
Key message

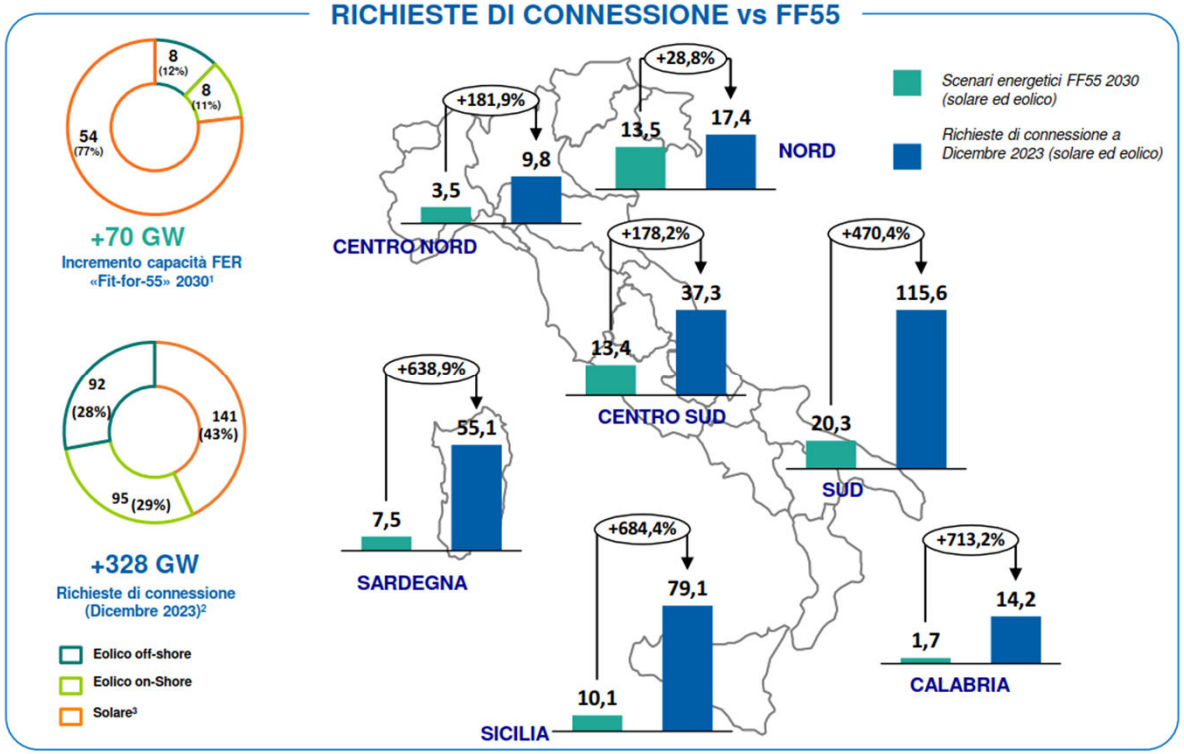
It’s very important to promote use optimization, maintenance and new installation of Pumped Hydro Storages



Key message

Italy faces a geographic constraint to effectively use PHS: 5.3 GW out of 7.6 GW are located in the north of Italy





Production from pumped hydro in Italy:

- Lower price diffrential
- Monopoly of Enel

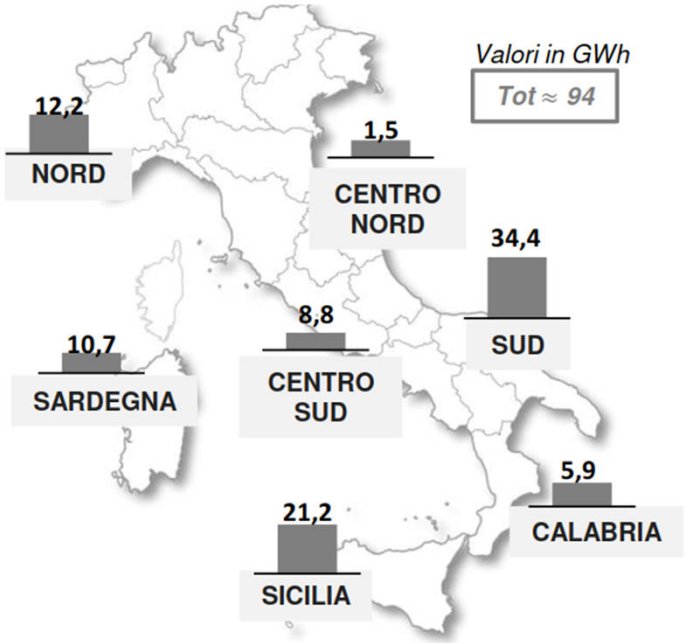
Key message

Italy faces a geographic constraint to effectively use PHS

INCREMENTO CAPACITÀ DI TRASPORTO PER INTEGRAZIONE FER

› Sviluppo di infrastrutture abilitanti e innovative: il progetto **Hypergrid** consentirà un **incremento della capacità di trasporto** tra le zone di mercato **di circa 17 GW** in più rispetto a 7 GW già previsti nel PdS '21

SCENARI ENERGETICI FF55 2030 DEL DDS 2022 – ACCUMULI



› L'integrazione delle nuove FER previste dalle policy europee (Fit-for-55) sarà garantita anche grazie allo **sviluppo di circa 94 GWh di nuovi accumuli**

Emerging alternatives: VPP

Efficient use of distributed storage (and production) systems already in place

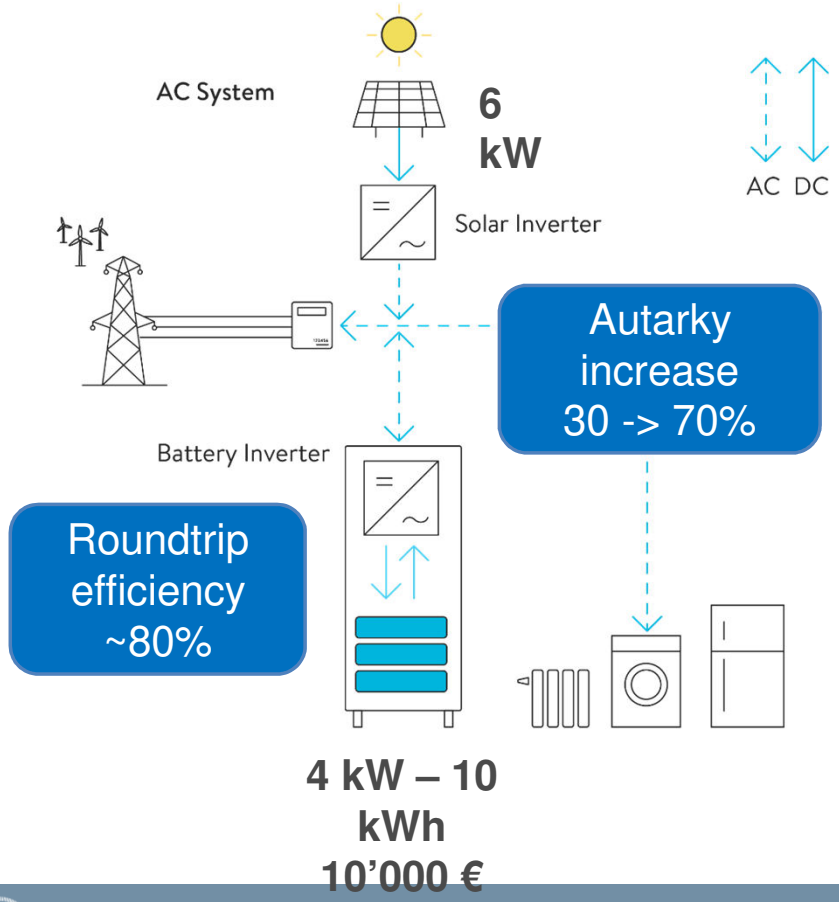
- **Data exchange**
- **Remote control**
- **Owner agreement**

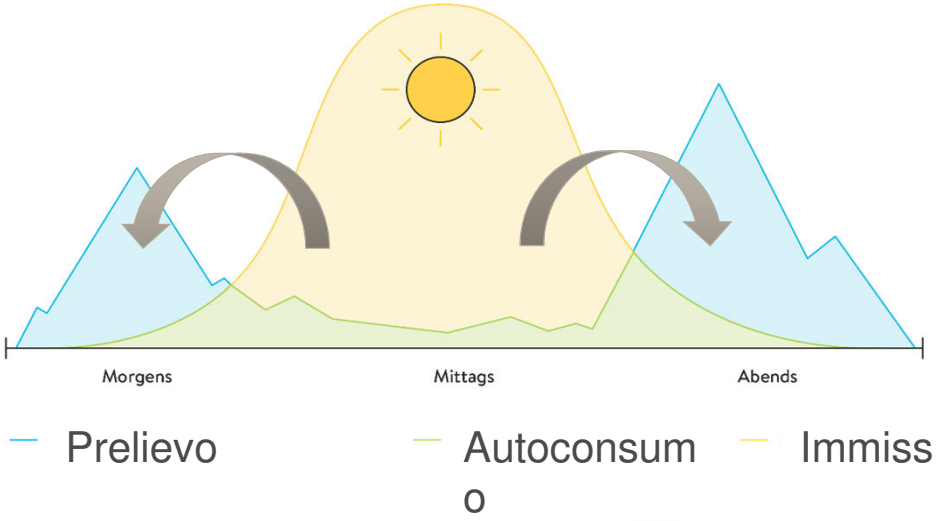
sonnen

energy is yours

Emerging alternatives: VPP

What is the normal use of a residential storage?





Savings:

- System fees 40~100 €/MWh
- Delta price PUN – CAP
- Roundtrip losses = - PUN * 0.20

25 ~ 200 €/MWh

UVAM project

UVAM is paid to provide on-demand up-lift flexibility to the grid through:

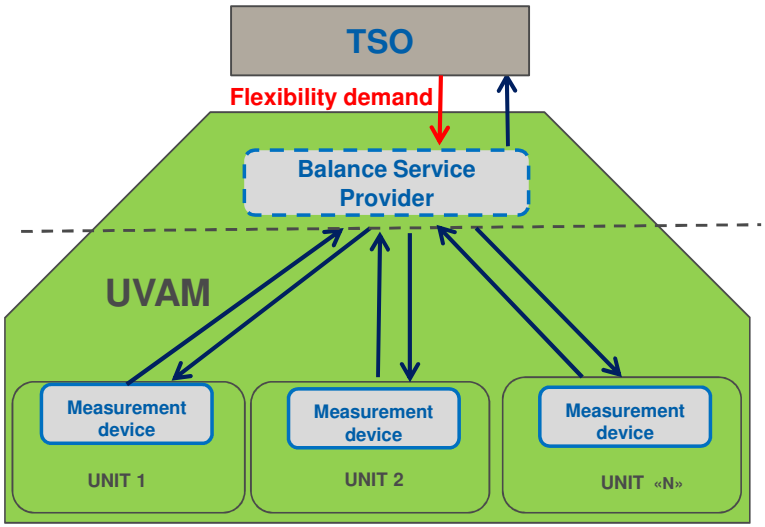
- **Load reduction** from Consumption Units
- **Increase of energy injection** from Production Units or enabled Energy storages

UVAM is managed by a Balance Service Provider which has a direct communication with the TSO (TERNA)

- **Fixed compensation**
- **Variable compensation**

Energy bonus for the customer

sonnen
energy is yours



UVAM project

UVAM (Mixed Aggregated Virtual Units) is a virtual aggregate of units which may include:

- **Consumption units (UC)**
- **Production units (UP)**
- **Energy storages, e-mobility (ES)**

Requirements:

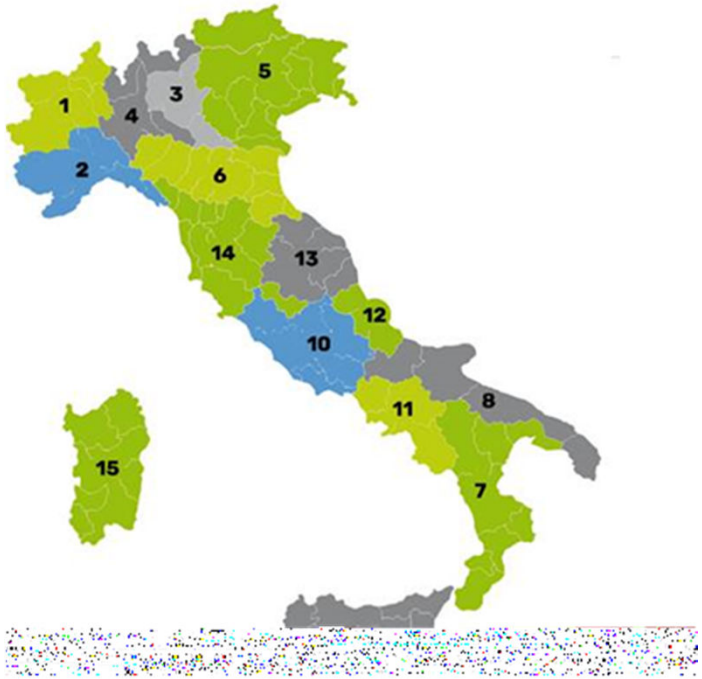
- Minimum size of UVAM = **1MW** of modulation capacity
- The units aggregated in the UVAM must be located in the **same area**

Scope:

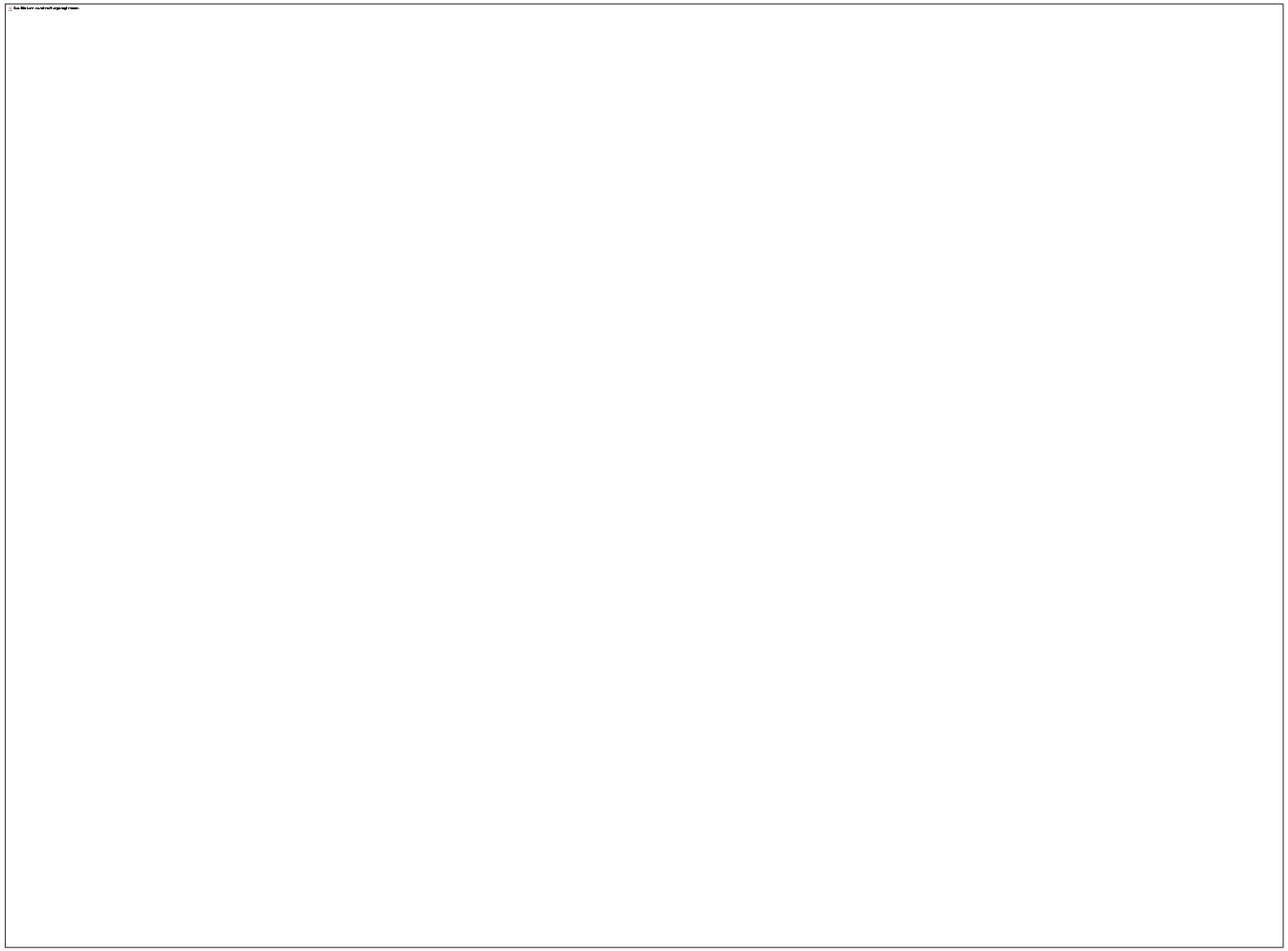
- Supply tertiary and real time balancing reserve to the grid

Revenue:

- Fixed daily revenue for the availability to provide the service
- Variable revenue in case of activation (few times in a year)



UVAM project



sonnen

energy is yours

Conclusions

- **Grid balancing resources are always needed** on the system (today the target is mainly achieved through programmable plants)
- **Today we miss a solution to achieve cheap, scalable and efficient energy storage!**
- The higher the share of non-programmable RES,
  the higher the need for grid balance services
- **Power and energy services** involve different ES technologies with different roles
- **Batteries and VPP will play an important role** for power services
- **Pumped Hydro plays and important role** for energy services

Conclusions

To allow high penetration of non programmable renewables we need all the possible solutions:

- **Flexible generation from fossil fuels**
- **Best use of programmable renewables**
- **Grid and interconnection extension**
- **Demand side response, also through VPPs**
- **Energy storage development, also through new technologies**

Summer School on Energy Giacomo Ciamician

Thank you!

Prof. Nicola Fergnani

Politecnico di Milano

Kreuzbergpass, Sexten (BZ), Italy

JUNE 5TH – 10TH, 2024