Workshop on Long Duration Energy Storage 2.0

Research and Industry meeting on Electrochemical Long Duration Energy Storage
Friday 28/07/202 – University of Padua – Dept Industrial Engineering

Are we Heading to Long Duration Energy Storage in the path to Net Zero?

Coal phase out enhanced Lithium, Gas phase out will enhance LDES (long duration Energy Storage)

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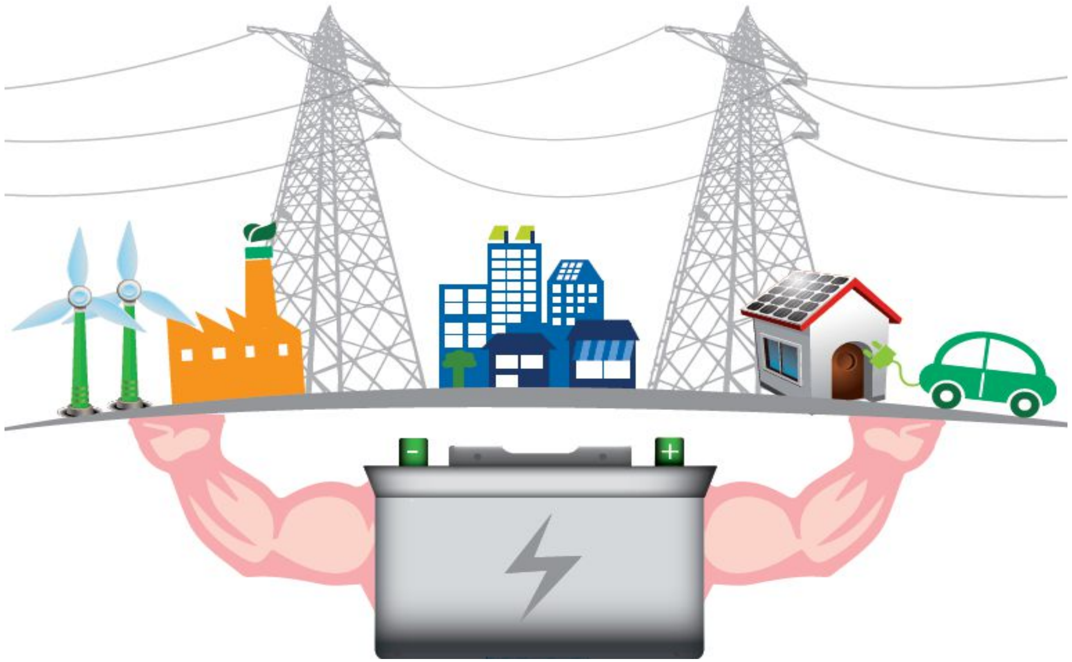
Are we Heading to Long Duration Energy Storage in the path to Net Zero?

AGENDA

1. Transition to Sustainable Future & Energy Storage
2. Digitally Smart, Storage is the solution for many applications
3. Long Duration Energy Storage the last step to net zero
4. «Full Intraday flexibility» and «Multiday and multiweek flexibility»
5. Prospects of Vanadium Flow Batteries (focus on Full Intraday)
6. Conclusions



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Transition to Sustainable Future & Energy Storage

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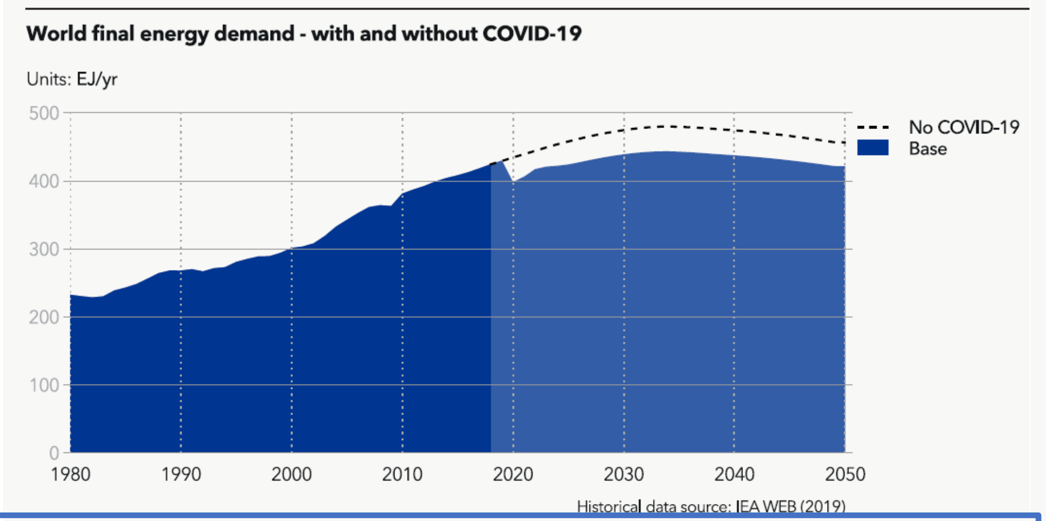
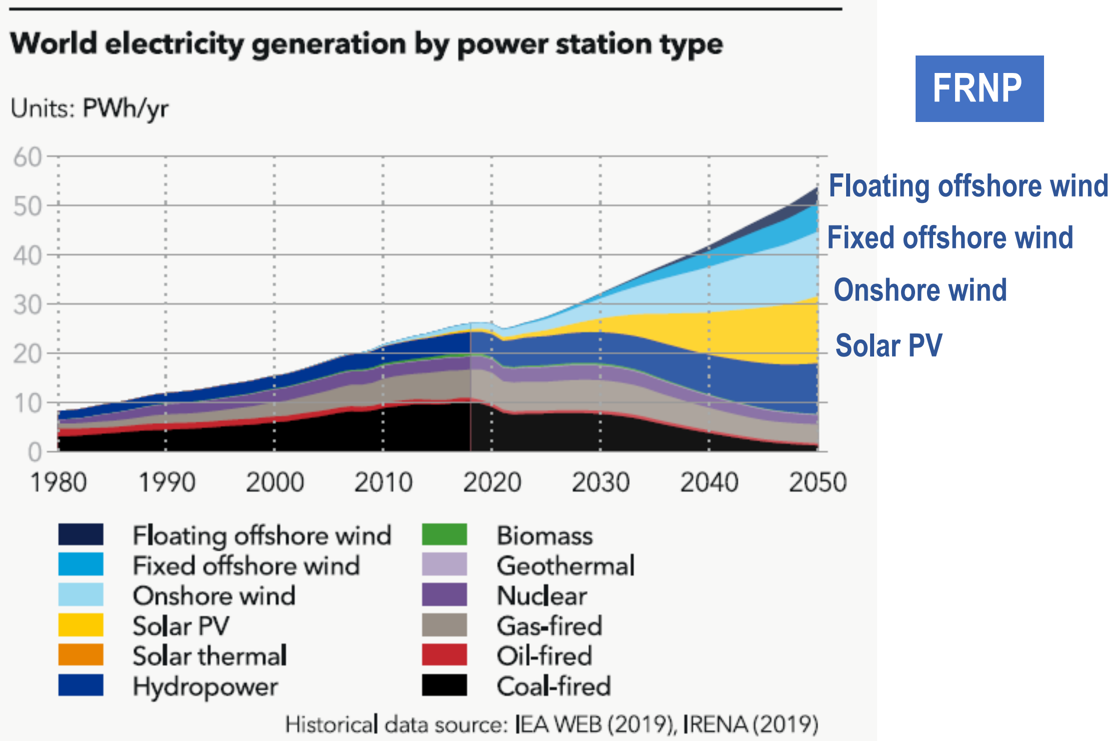
Zero net emissions and Growing Energy Demand will require more Renewables





FRNP

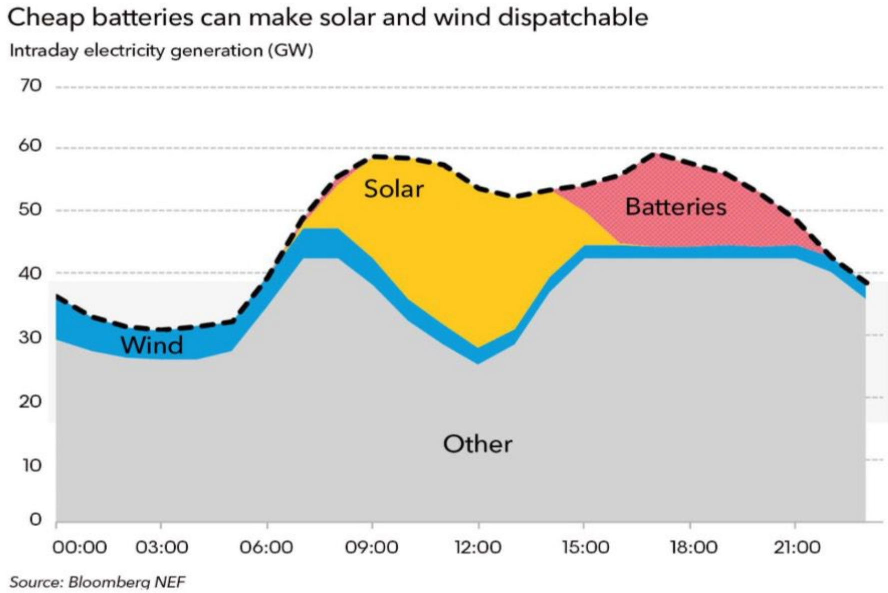
Even if COVID has slowed the race, global energy demand is growing

And if we really want to decarbonise ....

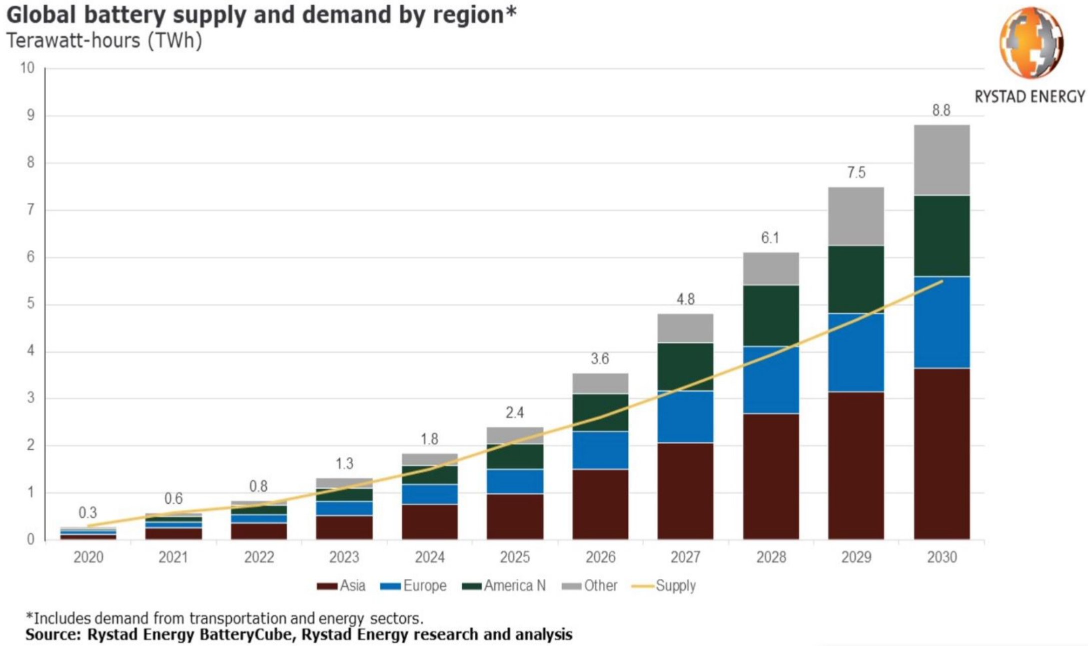
We have to learn how to manage VRE (variable, non predictable Renewable Energy)

The future is of unpredictable renewables and the storage necessary for the stability of the electricity system

To manage Renewables, Storage is required (the critical Enabler)



Batteries make wind and solar more grid friendly

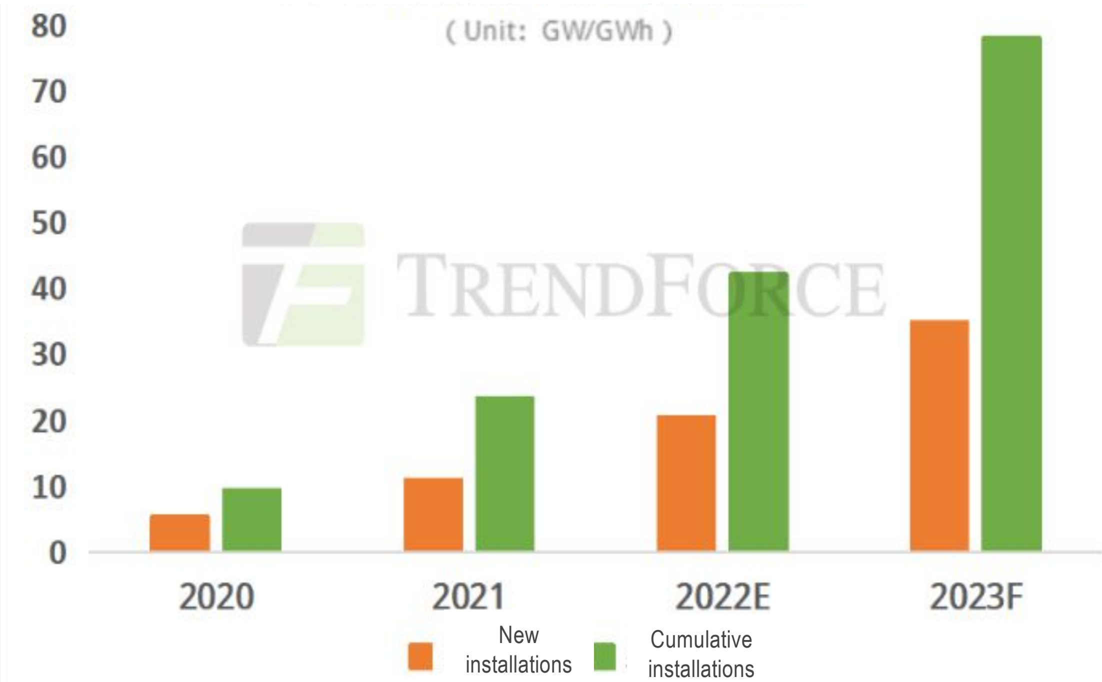


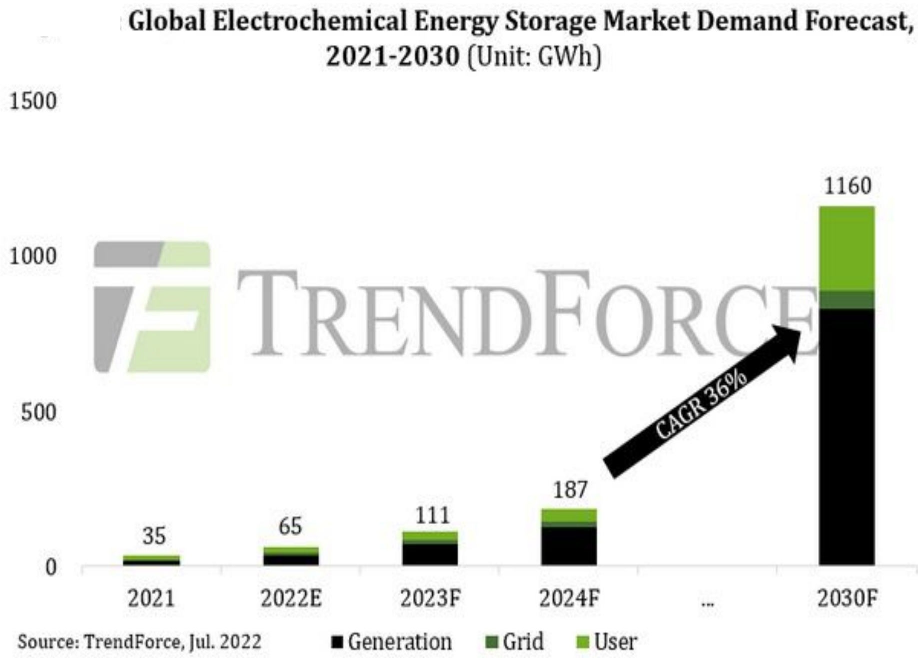
Great prospects for Storage are expected

In 2021, the world demand for batteries almost doubled compared to 2020, (from 300GWh, to 580 GWh).

For 2030, 8.8 TWh is expected to be 15 times higher than today, development is driven by electric vehicles with 4.9 TWh (55% of the total) and around 2.5 TWh for energy storage systems.

Global Energy Storage Trend





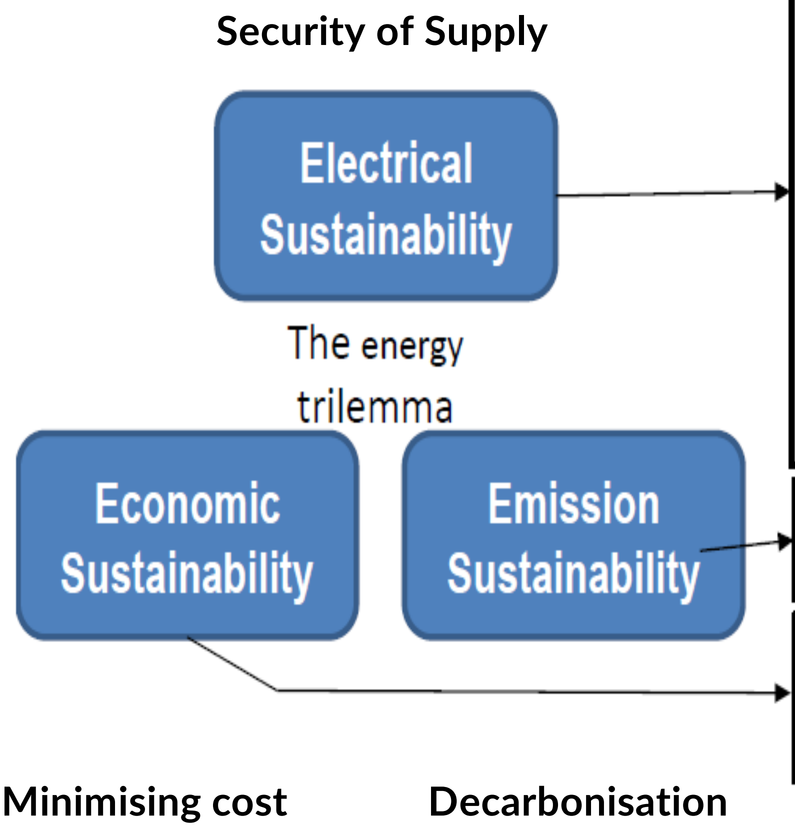
According to data from TrendForce, with the support of favorable policies and a strong market demand, the **new installations of global energy storage reached a record:**

New energy storage installations in 2022 arrived at 20.5GW.

According to TrendForce data, New energy storage installations in 2022 showed a YoY growth rate of 53.4%. **The global energy storage market develops stably and has a strong demand.**

It is expected that the new installations expected to reach 34.9GW/77.9GWh in 2023.

Storage can help navigate the so-called energy trilemma.



Peak Capacity
- Ensuring adequate capacity during peak times

Flexible Capacity
- Ramping up rapidly as more intermittent renewable capacity comes online

Frequency Response and Inertia
- Frequency response is essential to counteract deviations if they occur.
- Inertia prevents sharp delta frequency, increasing resilience to energy imbalances

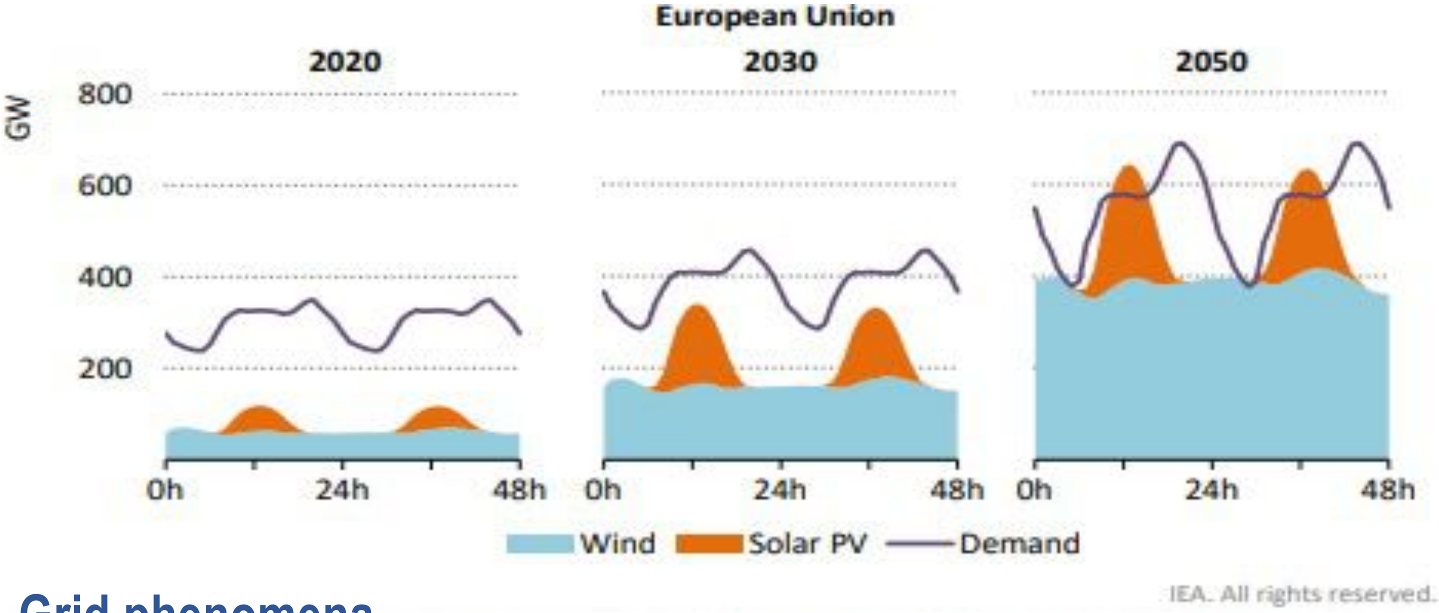
Voltage
- Managing stable Voltage (with reactive power) it is possible to prevent faults & blackouts

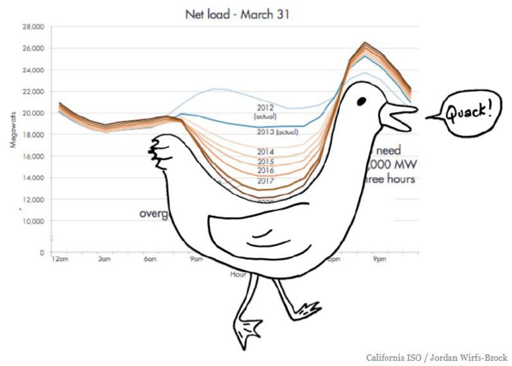
Black Start
- Black Start is vital in case of shutdown. (being thermal assets no longer available)

Enabler Fossil to Renewables
- Storage is essential to get the power system from fossil-power to renewables

Revenues for Investors
- Storage revenues can come from the energy trading (Arbitrage), from the restricted market (Ancillary for dispatching services) and from the regulated market

RES growing & Thermal decreasing ➔ Need of new flexibility





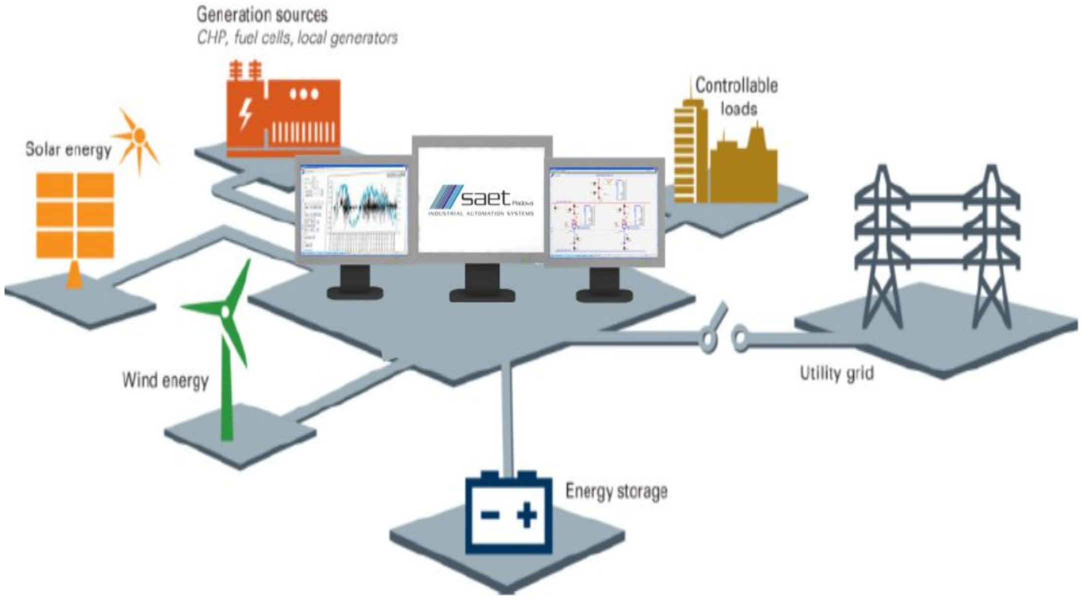
Residual Load as Californian Duck
The daytime hours will be covered almost exclusively by renewable sources.

Grid phenomena

- Grid Congestions
- Reduction of regulation Power Reserve
- Progressive reduction of System Inertia
- Progressive grow of Overgeneration
- Evening Ramp

All of these call for new solutions to create flexibility in electricity supply and demand over different durations. Batteries provide the ability to adjust supply and demand to balance the system.

To increase RES means to provide the relevant flexibility



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Digital Smart Storage is the solution for many applications

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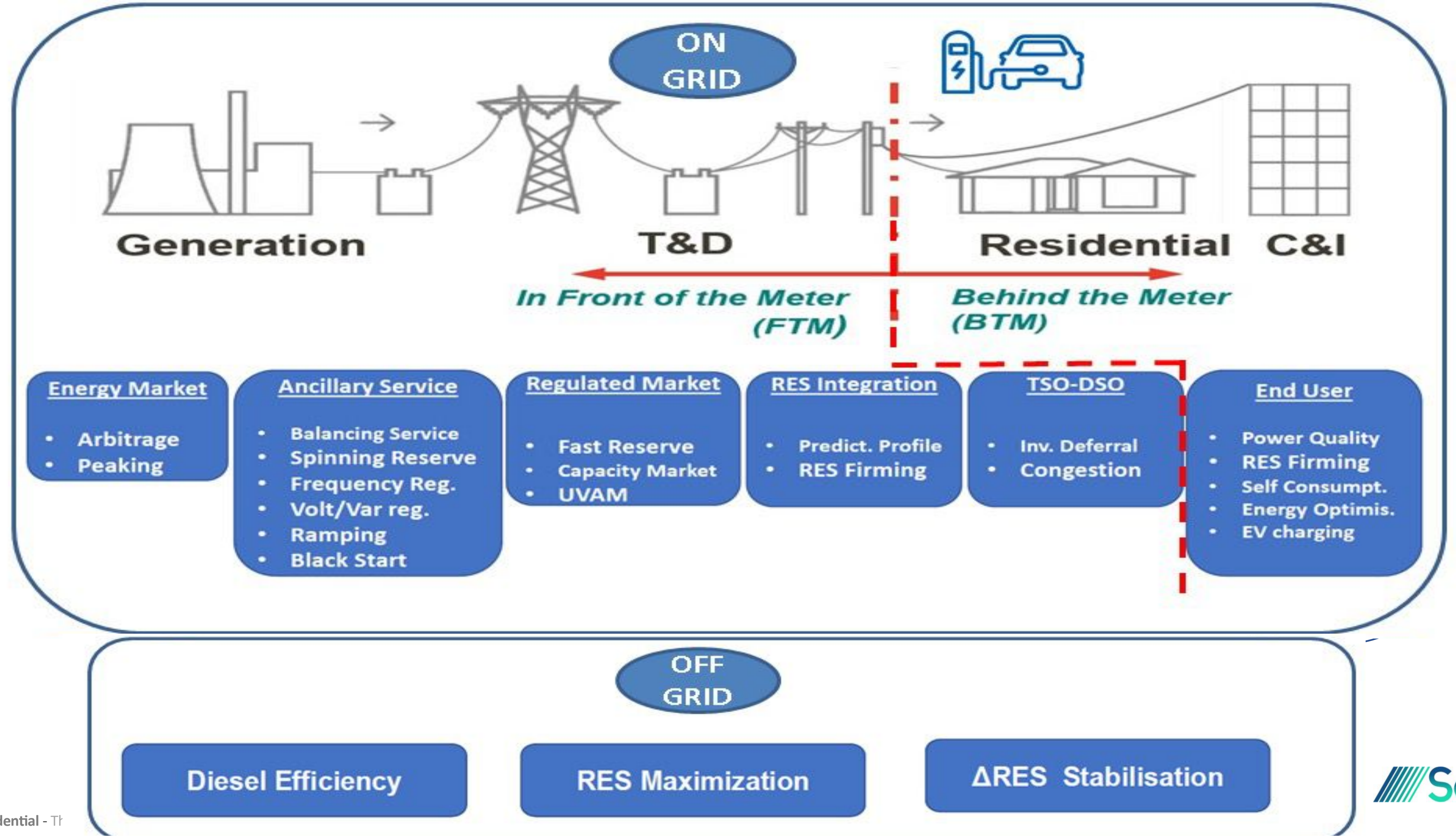
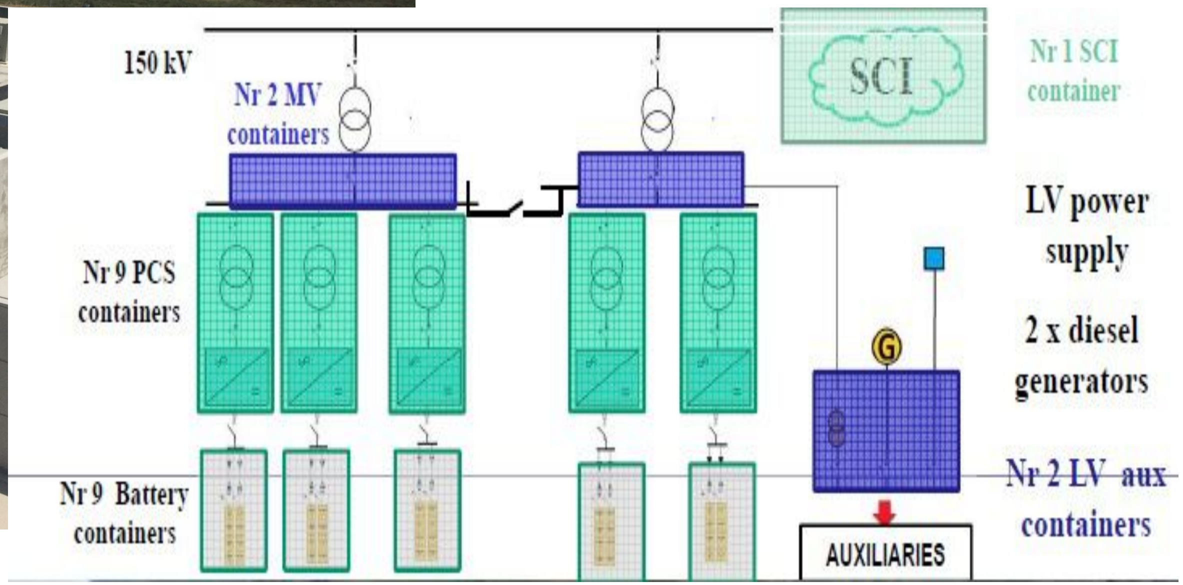
The functions of STORAGE, «digitally Smart»



Grid Congestion Application: Terna in Scampitella (BN) 10,8MW-72MWh

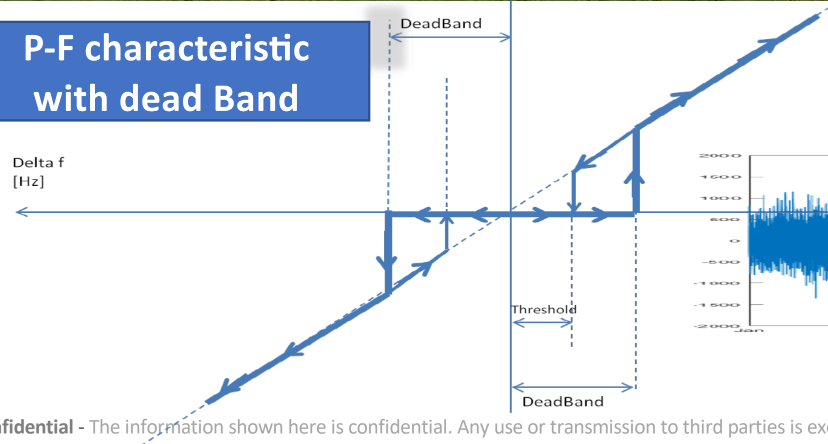
The capacity of 72 MWh allows to storage Energy, during overloads (conditions for all wind farms along same OHL) . As a result we got in 2017, 6 GWh reduction in wind Energy Curtailment in that area



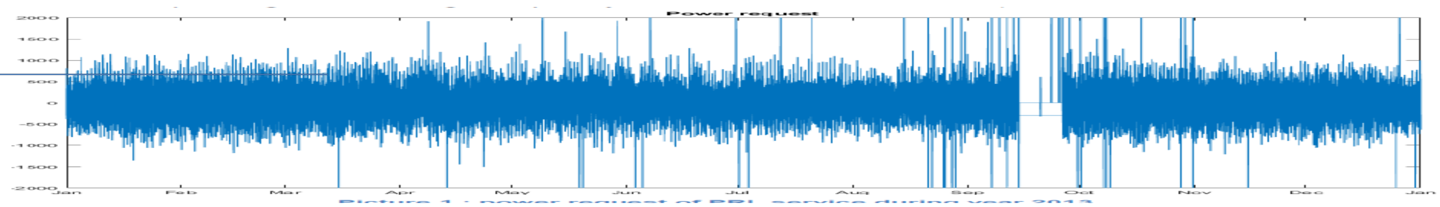
Remuneration is to avoid Wind Energy Curtailment

Frequency Power Regulation: 2,5MW-3,2MWh in EVN Vien

P-F characteristic with dead Band



Primary Regulation



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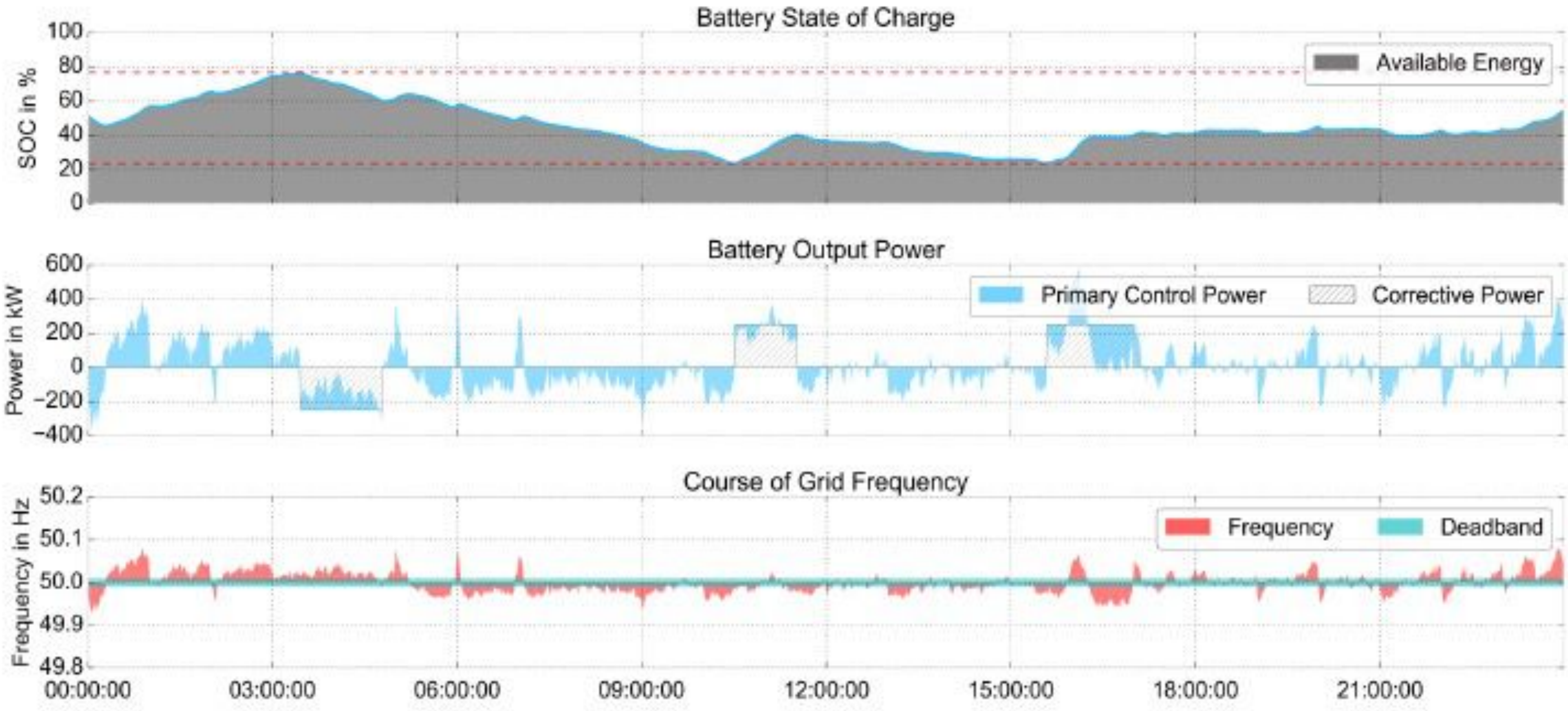
Primary Regulation application 2,5MW-3,2MWh



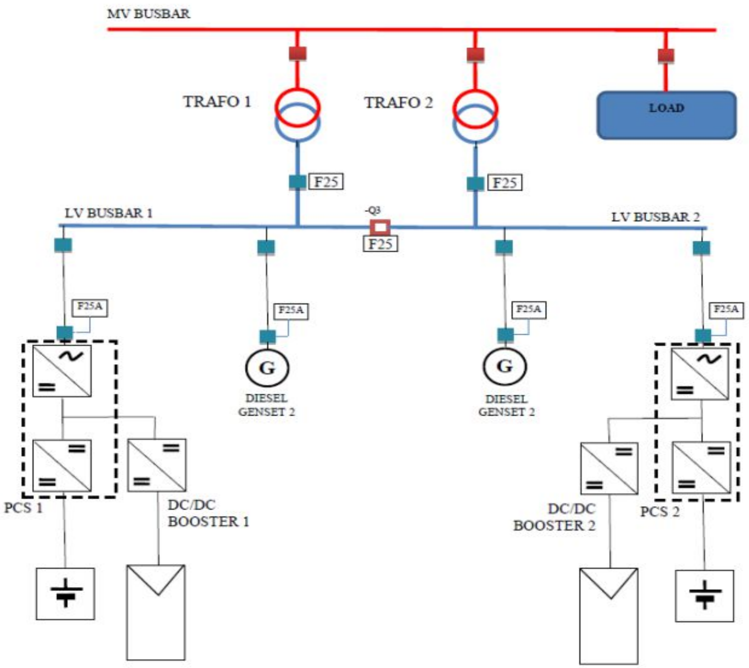
Application for «Syntetic Inertia» : Verbund Vien 1MW-500kWh

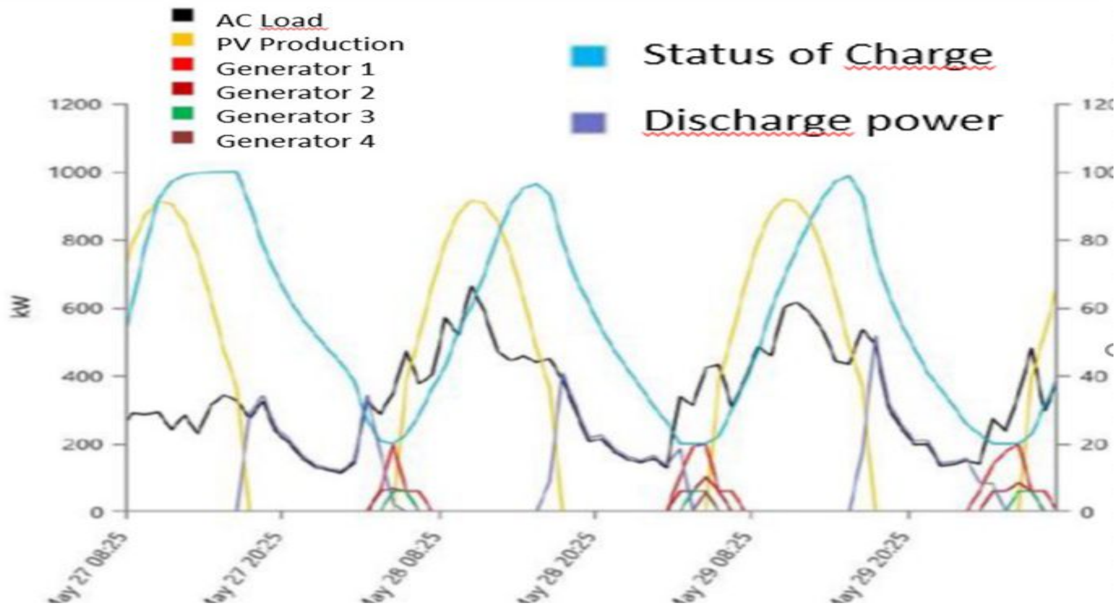
The regulation logic of the ESS can react in the first instants of the perturbation as a function proportional to the derivative of the frequency, replicating in a "synthetic" way the inertial response of the synchronous machines.

$$\frac{\Delta P_e}{P_n} = -k_{SRI} \cdot \left(\frac{\Delta f}{\Delta t}\right)$$

Inertia counteracts sudden changes in frequency and is provided by synchronous machines with large and heavy rotating generators, and synthetically by Energy Storage Systems

Self Consumption Optimisation 3MW-PV-3MWh Battery-1,6MW Diesel Kigali Rwanda





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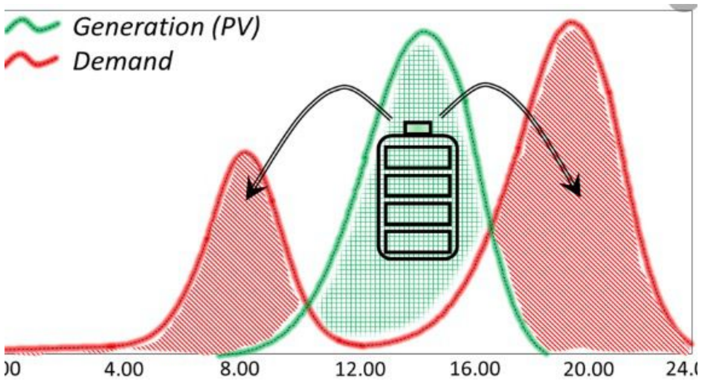
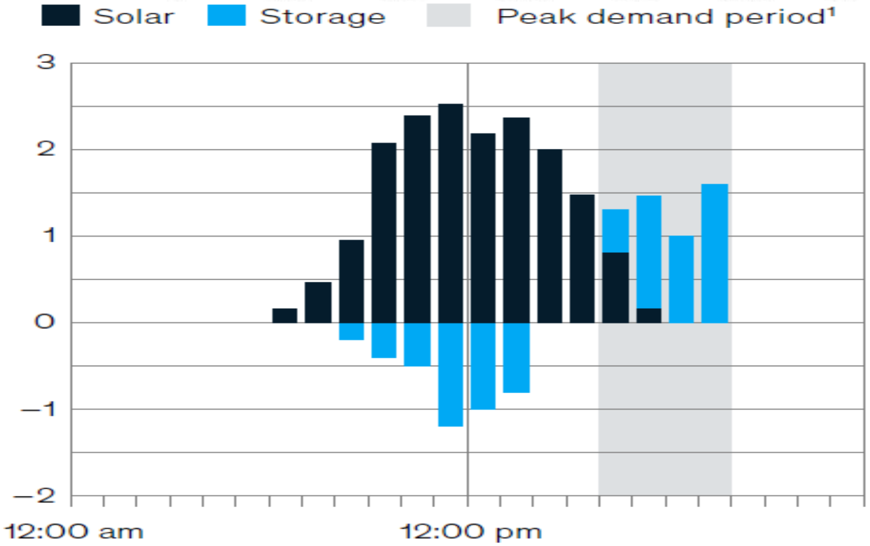


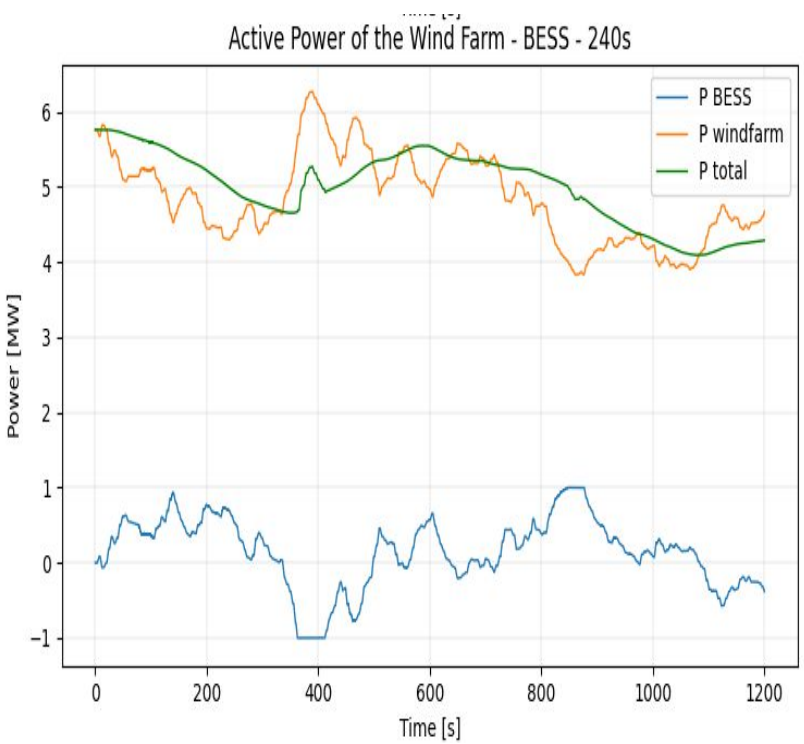


Overgeneration Reduction

Evening Ramp Mitigation

Storage makes "the California duck" more dispatchable. It allows to store the mid-day over-generation, while the demand for power with a rapid ramp on the duck's neck is met by the batteries capable of providing a rapid reaction to the peak demand.

RES FIRMING Application with 1MW -1MWh Storage + 7MW Wind Electra Capo Verde



The RES Firming function is implemented in this 1MW-1MWh BESS :

- EMS measures the real-time power of the wind farm.
- From this value the EMS calculates the output correction power of the BESS to equalize the total output
- A dead band is set to avoid BESS active power exchange caused by minimal fluctuations in wind generation.
- The total output (green) is remarkably smoothed. Without BESS, the output would have been that of the wind farm (orange)

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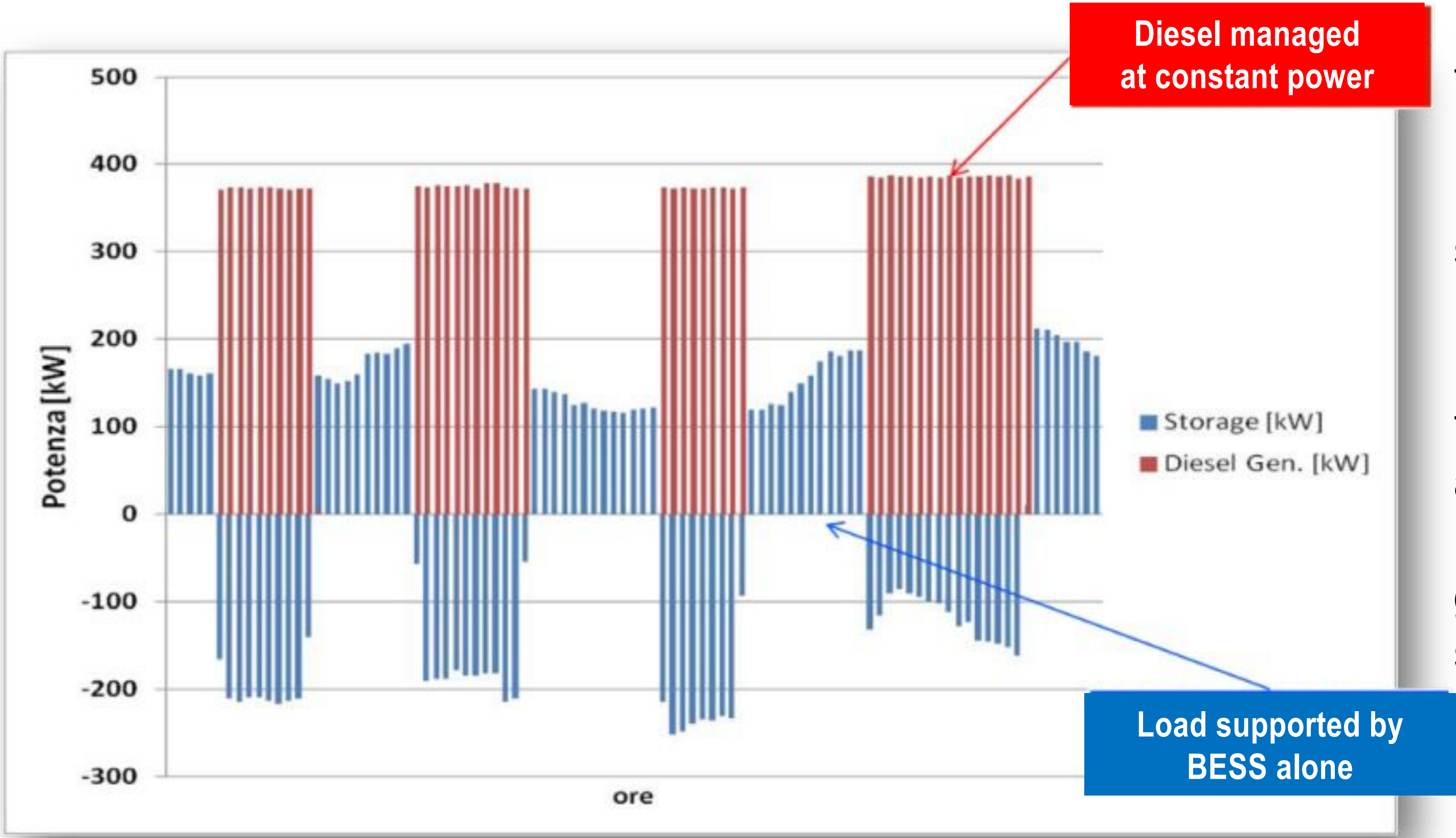
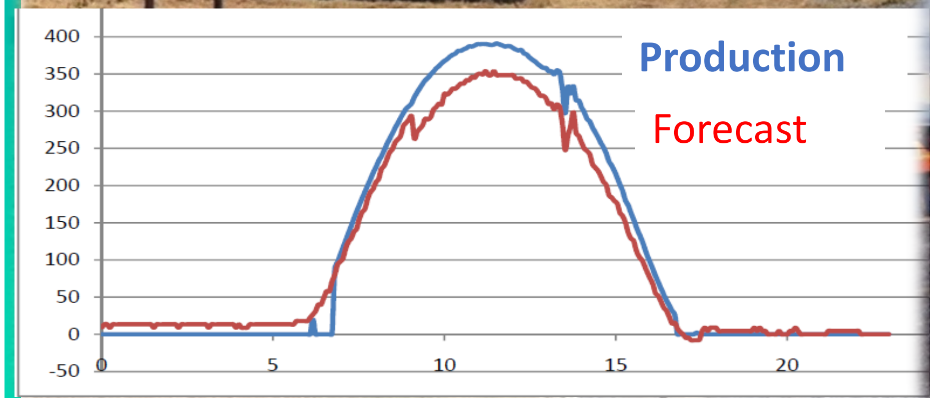
Efficiency Application of an isolated Diesel with Energy Storage



It is possible to manage the diesel at constant power around the full load, accumulating the surplus to charge the battery; when the battery is close to full capacity, the diesel is switched off and adjusted with the battery alone. In this off grid application you saves fuel and often the transport logistics

Application to get more predictable the PV generation plant

Storage to compensate the error between real production and forecast in order to get a predictable production schedule



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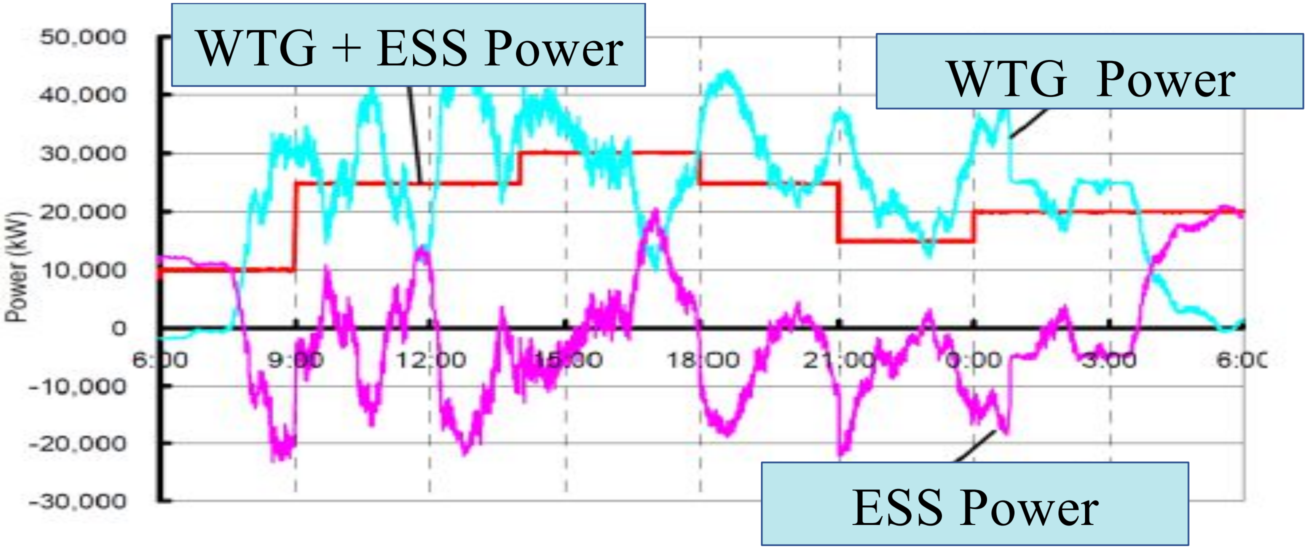
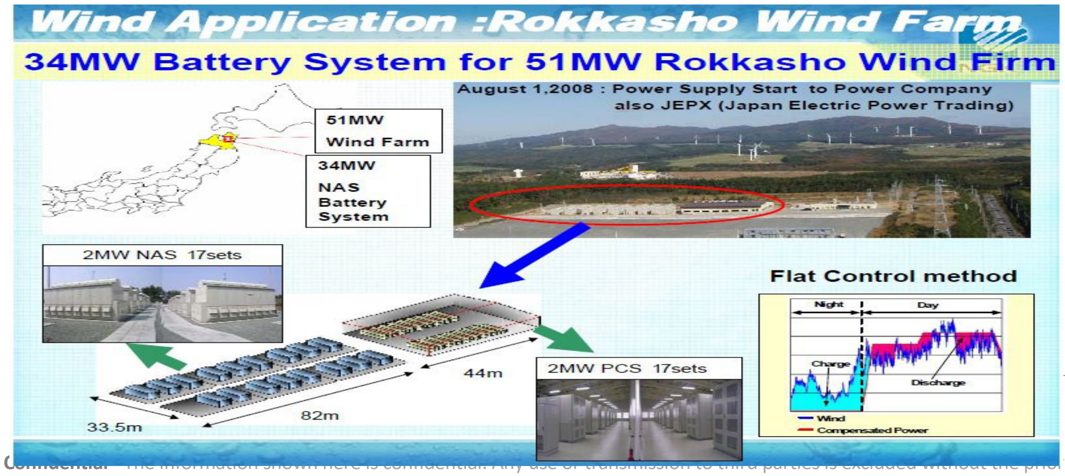
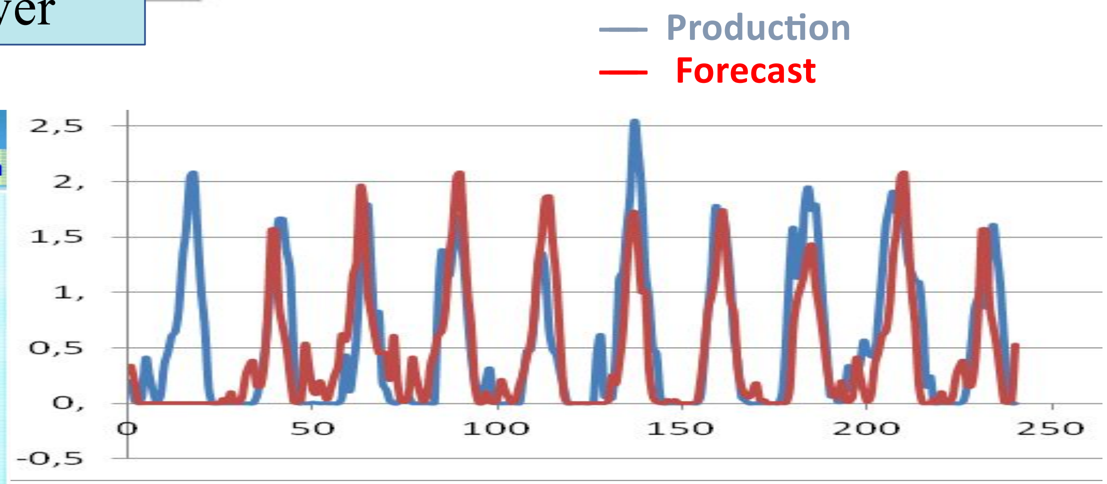
34 MW -150 MWh BESS for a 51 MW Wind Farm (NGK)



Wind Farm Production becomes within the scheduled Production Profile

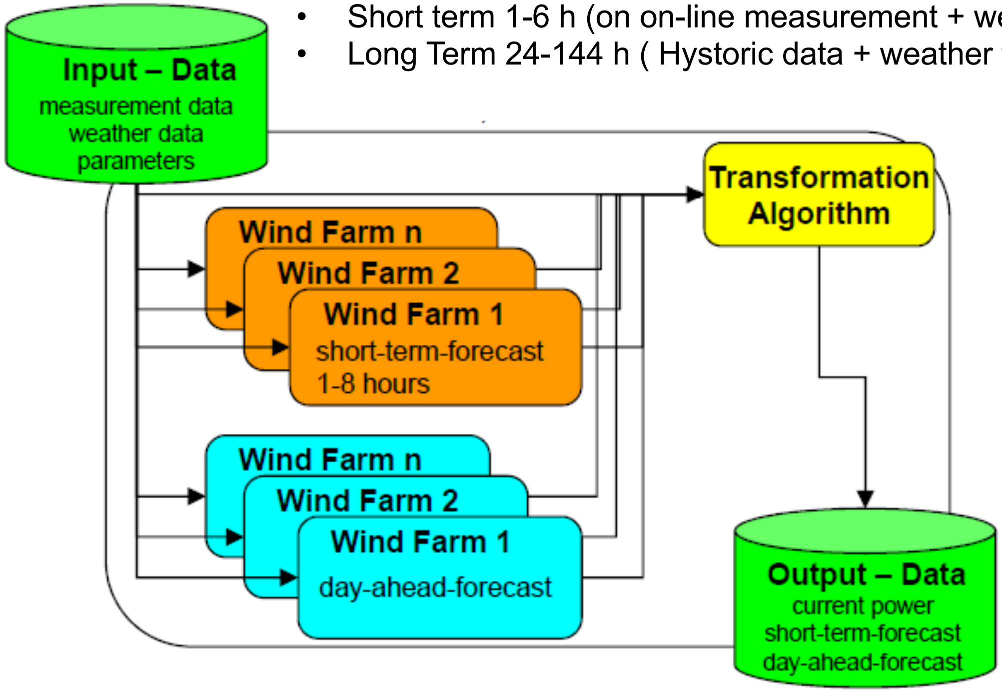


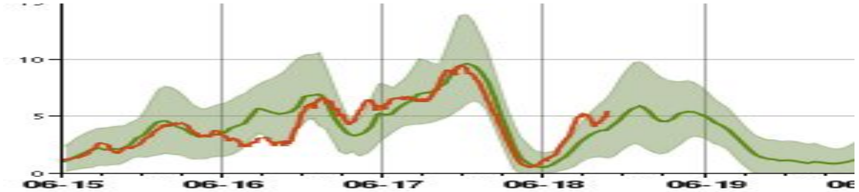


Wind MULTI-FARM Forecast optimization

Wind Farm Forecast on different time horizont :

- Short term 1-6 h (on on-line measurement + weather forecast)
- Long Term 24-144 h (Hystoric data + weather forecast)





Wind Forecast 24 h in advance : within average range 10 % and con Delta max 30-40%.

It is possible to create a Wind Farm group in a large VPP (Virtual Power Plant), with a much more accurate production schedule

Not single Farm inbalance, but VPP program

Integration VRE for Predictable Profile

Fast Reserve Unit FRU - TSO Terna tender

Pilot Project «Fast Reserve Unit»

A new ultra-rapid service (< 1 s) to support INERTIA of the grid

Mechanism of operation

- Ultra-fast activation (<1 second from the frequency deviation event) with the ability to continuously adjust the power profile required for 30 seconds and perform a linear ramp down to zero power within a default time of 5 minutes
- Continuous and automatic frequency adjustment
- Proportional frequency response, even non-linear, on event and continuous
- Possibility of remote activation by interlocking the Defense System
- Graduality in issuing the grant to reduce disturbances on the network

Requirements

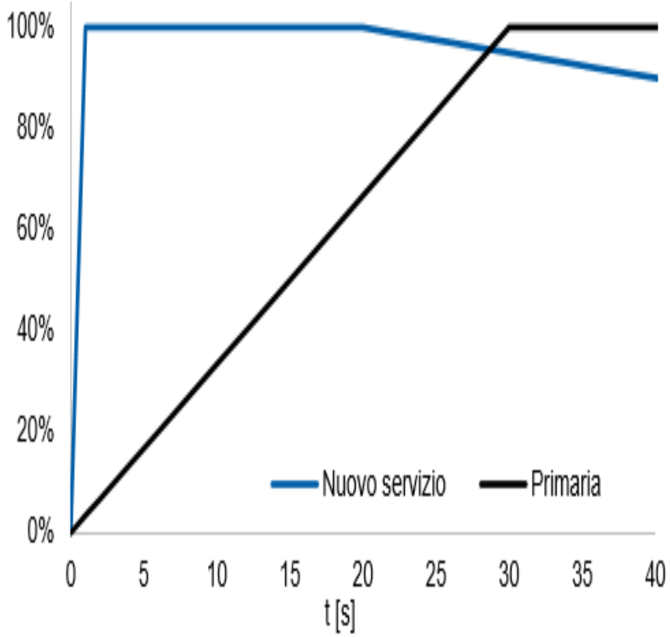
- Minimum size (aggregate) at least equal to 5 MW.
- Maximum size equal to 25 MW
- Minimum duration at full power equal to 15 minutes both up and down
- Equipment in the PMU, UVRF, UPDM control system
- Number of hours of service availability: 1000 hours / year.
- Activations will be triggered by Terna (D-7 for "Alert" and D-2 for "Confirmation")

On December 2020 Terna awarded 250 MW in the auction on the Fast Reserve pilot project which allows batteries to create an ultra-fast frequency reserve, creating an increasingly important service for the grid with the increasing in wind and solar contribution to energy demand.

The supply offer was six times higher than the demand.

53 international operators participated in the auction, with 117 plants presented for a total qualified power value of 1,327.3 MW.

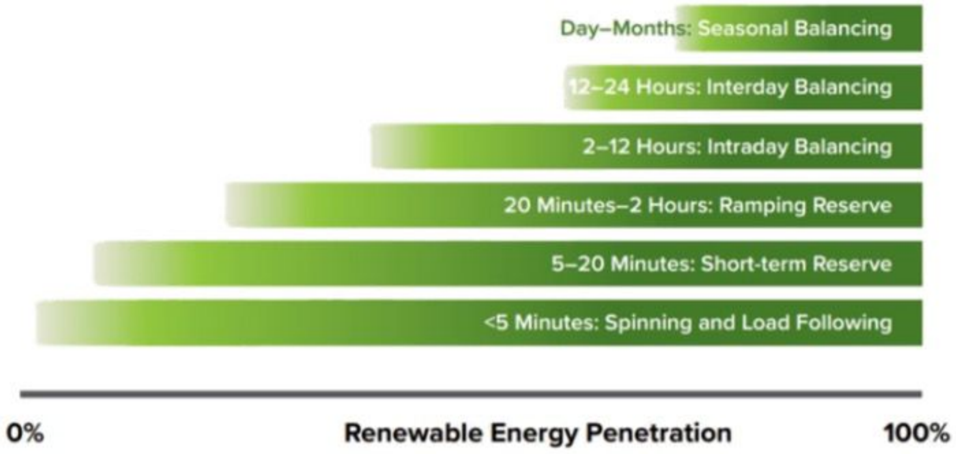
The assignees are 17 out of 23 units with 250MW



Falck Renewables one of the awarded company asked SAET to provide the BES for the Fast Reserve Unit

FRU FALCK VADO LIGURE

7,5MW-8MWh in commissioning phase



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Long Duration Energy Storage the last step to net zero

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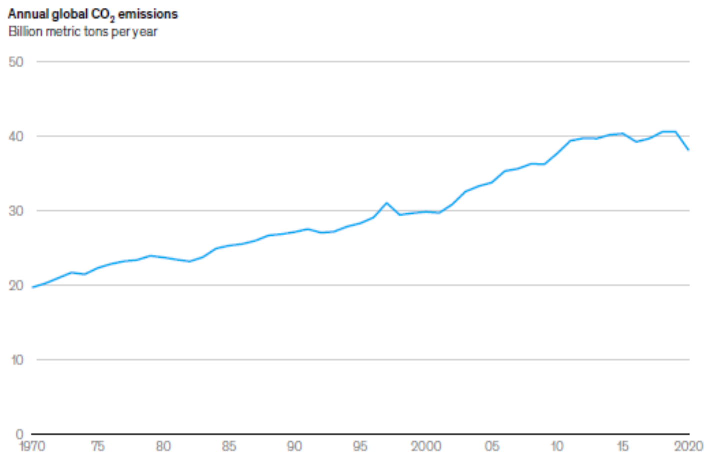
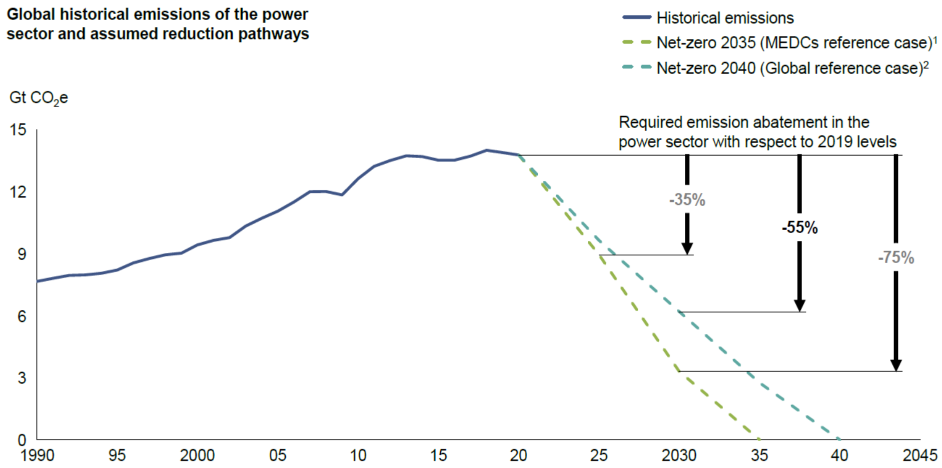
In the transition to Net Zero the “last mile” is the most difficult





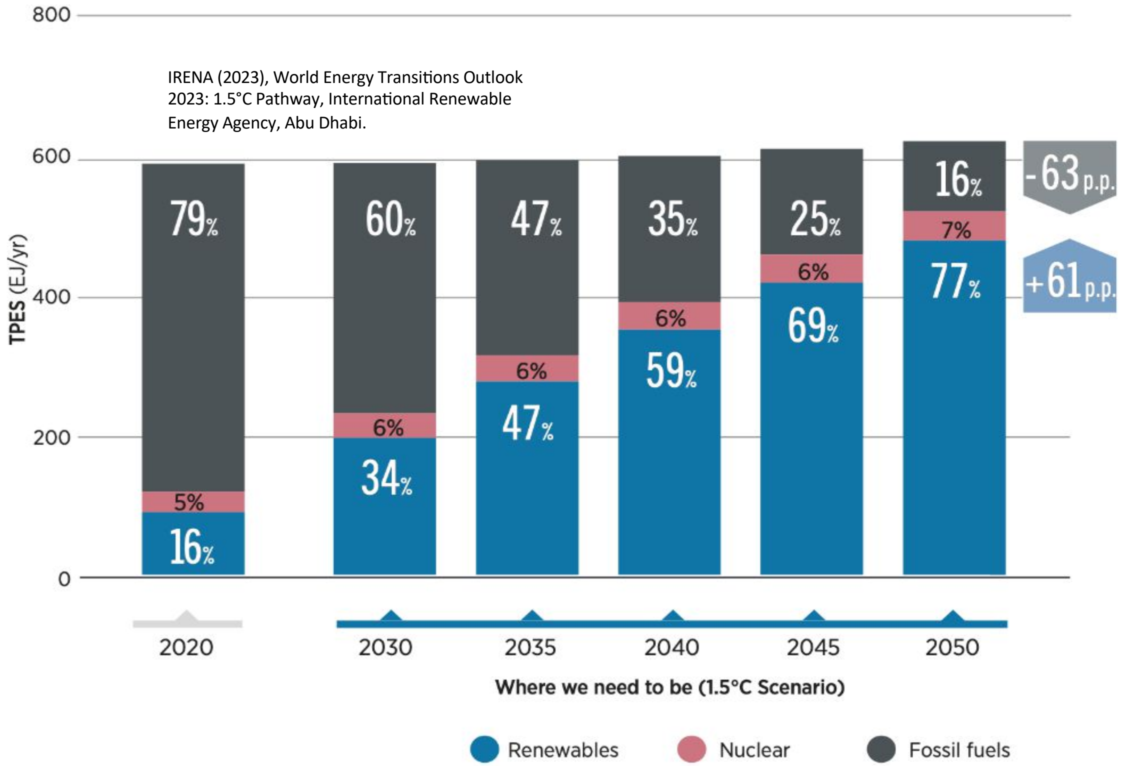
Over the past 50 years, CO2 emissions have continued to rise. Now the decarbonization path that is our common target at a global level, has different temporal hypotheses to reach climate neutrality. The European Union has committed to reducing greenhouse gas emissions by 55% compared to 2019 by 2030. In this process of decarbonization, ENERGY STORAGE has played a fundamental role of flexibility to date in supporting intermittent renewables. But while **at the beginning, the Power Intensive Storage Systems were the most effective** for the electrical system (frequency regulation, virtual inertia, power reserve), **in the further reduction Energy Intensive Storage and LDES Long Duration will become more relevant**.

Long Duration Energy Storage will be needed for the last mile.

Let's say that the storage requirement remains relatively low up to a share of about 80% from renewables, but increases substantially towards 100% from renewables, with an increasing importance of storage at long term for seasonal balancing.

Where we need to be (1,5°C) [in 2030 and 2050]

The diagram of **Total primary energy supply by energy carrier group, 2020-2050 under the 1.5°C Scenario** shows the share of renewable energy in the world's primary energy supply grows **from 16% in 2020 to 77% in 2050** under the 1.5°C Scenario, requiring an annual growth rate thirteen times the current rate



This growth is expected to stabilize primary energy supply due to increased energy efficiency and the growth of renewables. The energy mix will change drastically in the process, with a net gain of 61 percentage points of renewable energy share, driven by a mix of end-use electrification, renewable fuels and direct use. Achieving this level of renewable energy penetration is critical to meeting global climate goals and will require significant investment and policy support, as well as continued innovation.

By 2050 [according to IRENA], most of the world's power (77%) will be generated from renewable sources.

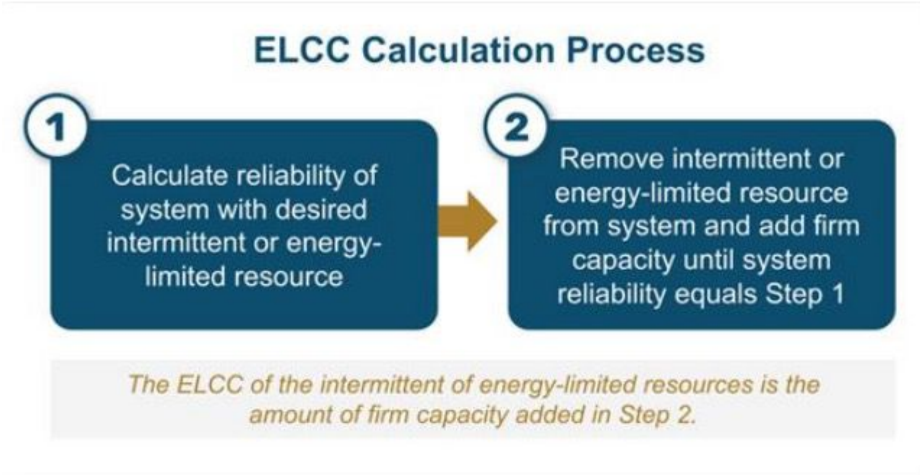
RES Penetration and "resources adequacy"…
Effective Load Carrying Capability

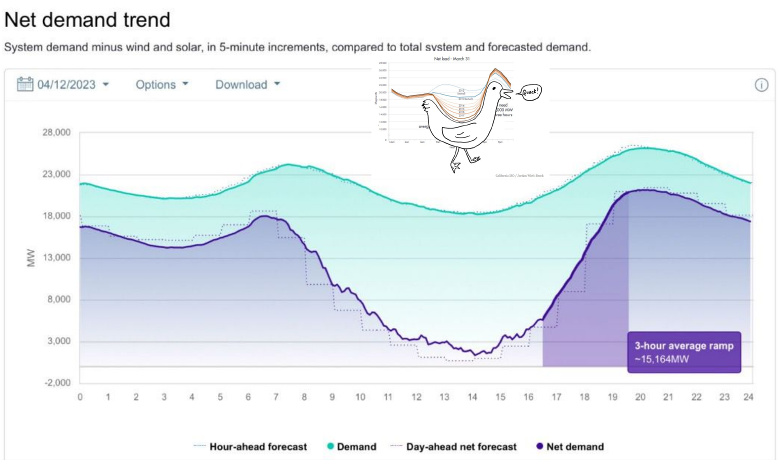
RES penetration force the Electrical System to measure itself in a new parameter for determining resource adequacy.

The integration of increasing levels of renewables and storage does require more advanced techniques for measuring the contribution of different types of resources towards this adequacy requirement.

Effective Load Carrying Capability

The Effective Load Carrying Capability ELCC is a measurement of a resource's ability to produce energy when the grid is most likely to experience electricity shortfalls.



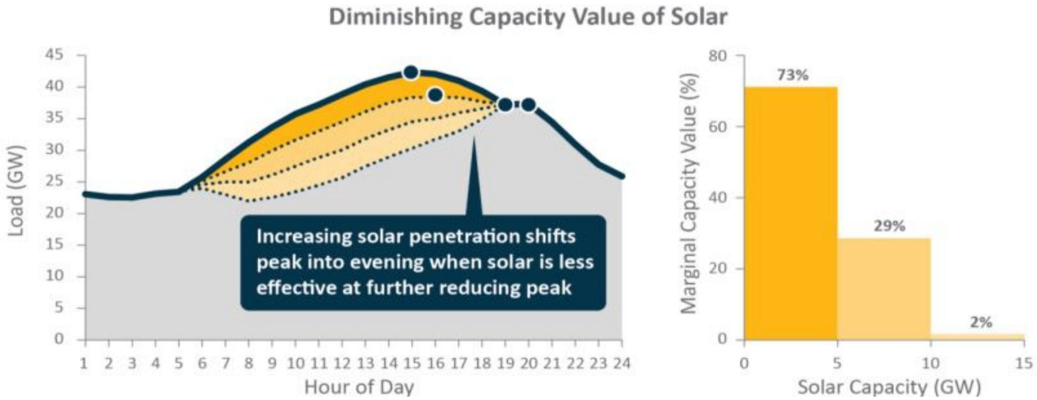


Increasing solar penetration shifts the peak, into evening hours when solar is less effective in further reducing peak

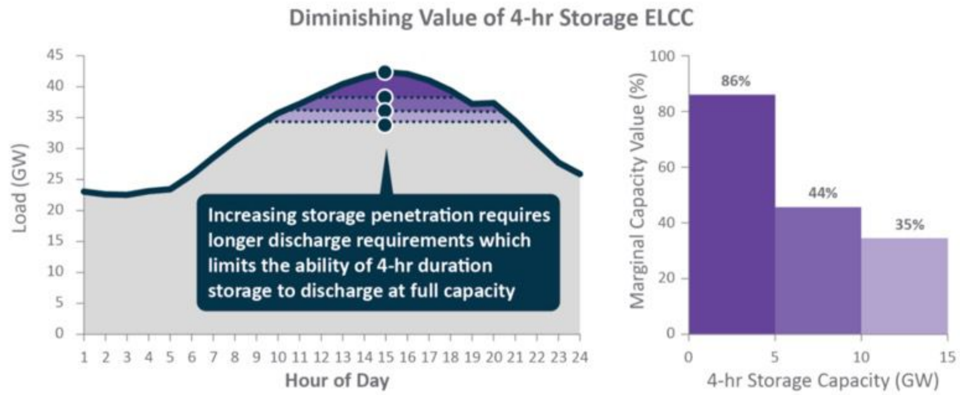
Saturation Effects at Increasing Penetration

The first effect "measured" by Effective Load Carrying Capability is the diminishing marginal returns.

Continuing to add more and more "Resource" we produce lower and lower marginal benefits.



ELCC declines as more Solar Energy comes online



ELCC declines as more Storage Energy comes online

The finite duration of Storage limits its ability to meet demand across extended periods → Long Duration

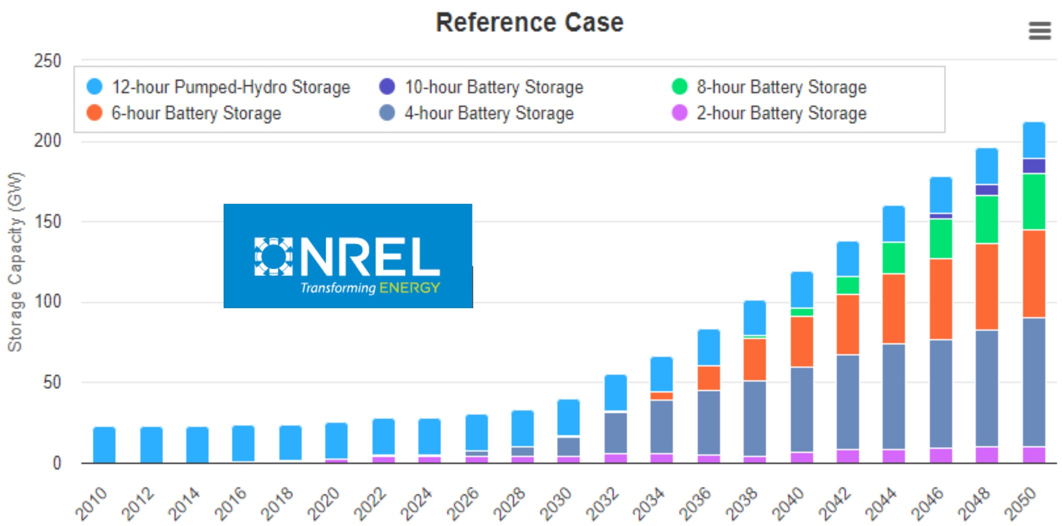
The marginal Capability of storage will continue to decline as more is added to the system → Long Duration

Storage with progressively increasing duration is needed to sustain a high capacity value → Long Duration

Saturation Effects at Increasing Penetration will get storage duration extension

Are we Heading to Long Duration Energy Storage ?

Average duration of new utility-scale energy storage systems deployed in the U.S.,2013–2021 (hours). Chart data derived from the U.S. Energy Storage Monitor Q3 2021 report by Wood Mackenzie and the Energy Storage Association

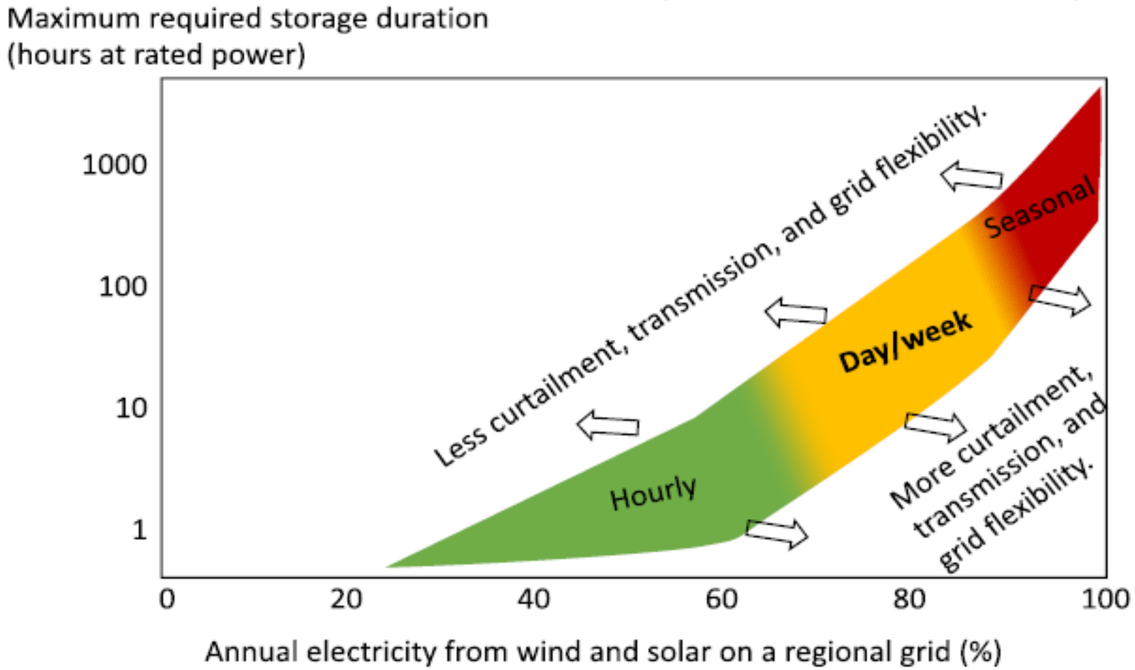


Deployed energy storage capacity will continue to grow significantly over the next few decades. Over time, longer duration technologies will be deployed as these options develop and (hopefully) become more cost-effective. Source: NREL.

By 2050, NREL expects around 9.5 gigawatts of 10-hour battery storage to be deployed.

- 6-hours Battery storage Commercial Liftoff ~ 2034
- 8-hours Battery storage Commercial Liftoff ~ 2038

Saturation Effects at Increasing Penetration will get storage duration extension



Relationship between RES penetration and Energy Storage Duration to adjust the unbalance . Source from [5]

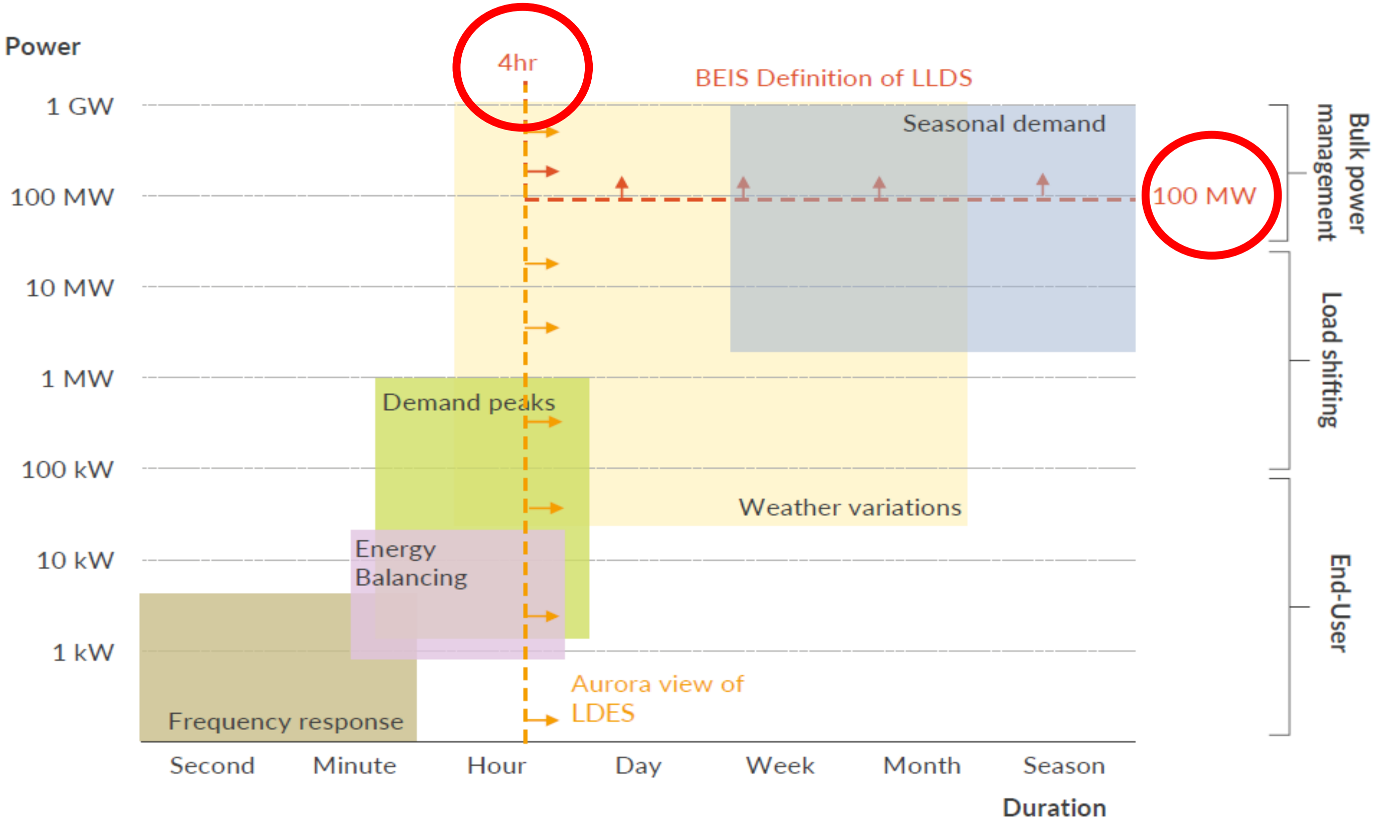
Flexibility needs will change as we approach to net zero

In the context of these studies, [6] provides a qualitative relationship between the maximum storage duration required to meet demand and the fraction of annual energy from wind and solar. Variable generation resources create a mismatch between electricity generation and use; as the amount of variable generation on the grid grows, so too do mismatches.

BESS around 25% is still 1 h duration,
it will be about 10h up to 50%-60% renewables (see green area in the Fig),
It will be about 100 h up to 80%
It will be about 1000 h up to 95%
development will be "huge" to reach 100% (see "seasonal" red area).

growing importance of long-term storage for seasonal balancing

Storage Duration in BESS new requirements (over 100MW-4h)



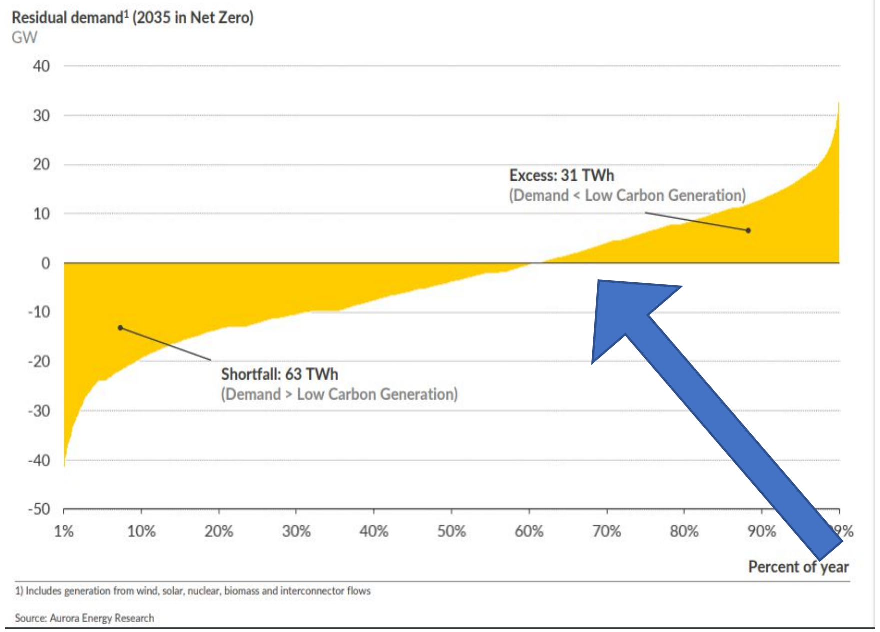
Duration from 4h to “seasonal”

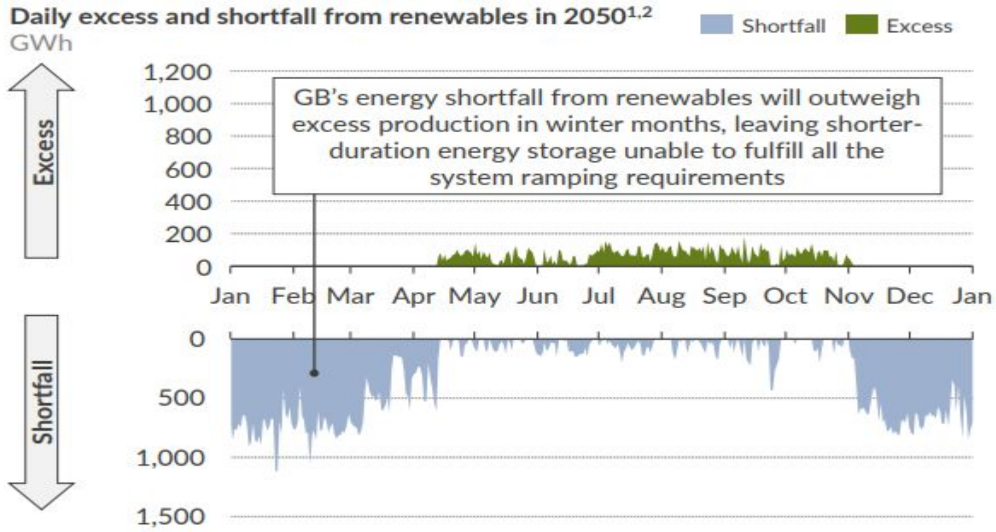
Power from 100MW to GW

The new thresholds of utility-scale energy storage Energy Storage Large Scale from 100MW to GW

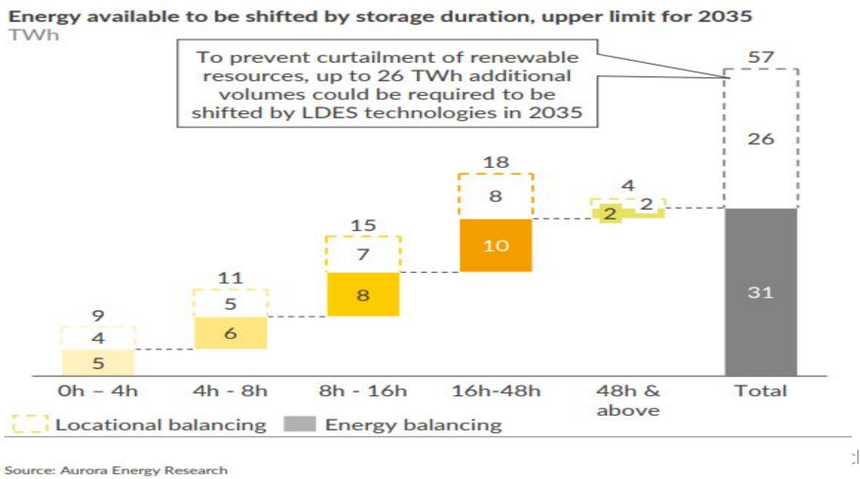
Another very interesting study about long duration storage specific for Great Britain has been performed by Aurora Energy Research [7] : their view of LDES is shown in the picture highlighting the duration of the Storage, with a "watershed" of 4h, and with very long-lasting "seasonal" needs for duration, and also Power “watershed” of 100MW

Long Duration Energy Storage required for Grid management without Gas





Notes from Aurora Energy Research *"Long duration electricity storage in GB"* report



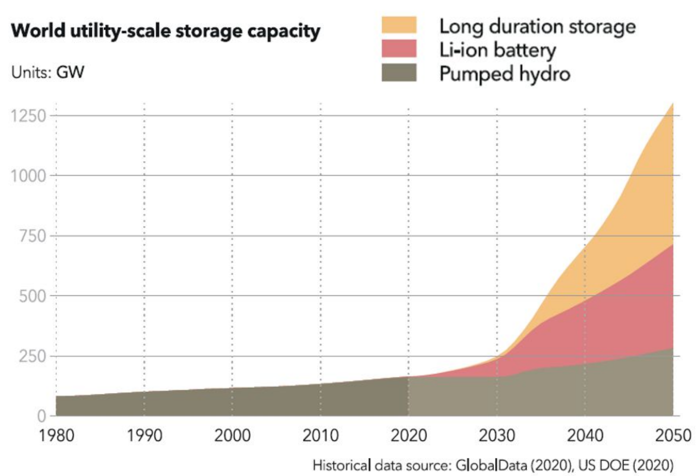
- Periods of overgeneration will be more frequent over the years, but the deficit duration will probably be greater than the excess duration;
- Without an LDES policy this excess energy could be curtailed.
- Further power cuts could also occur due to transmission line limits.
- With simulation different time shift necessary to not cut was evaluated:
- the 26 TWh capacity is distributed <4h, 4h-8h, 8h-16h, 16h-48h, > 48h

LDES Technologies : typical parameters

Energy storage form	Technology	Market readiness	Max deployment size, MW	Max nominal duration, Hours	Average RTE[1] %
Mechanical	Novel pumped hydro (PSH)	Commercial	10–100	0–15	50–80
	Gravity-based	Pilot	20–1,000	0–15	70–90
	Compressed air (CAES)	Commercial	200–500	6–24	40–70
	Liquid air (LAES)	Pilot (commercial announced)	50–100	10–25	40–70
	Liquid CO_2	Pilot	10–500	4–24	70–80
Thermal	Sensible heat (eg, molten salts, rock material, concrete)	R&D/pilot	10–500	200	55–90
	Latent heat (eg, aluminum alloy)	Commercial	10–100	25–100	20–50
	Thermochemical heat (eg, zeolites, silica gel)	R&D	na	na	na
Chemical	Power-to-gas-(incl. hydrogen, syngas)-to-power	Pilot (commercial announced)	10–100	500–1,000	40–70
Electrochemical	Aqueous electrolyte flow batteries	Pilot/commercial	10–100	25–100	50–80
	Metal anode batteries	R&D/pilot	10–100	50–200	40–70
	Hybrid flow battery, with liquid electrolyte and metal anode	Commercial	>100	25–50	55–75

Net-zero power: Long duration energy storage for a renewable grid | LDES Council, McKinsey & Company

LDES technologies are not yet commercially mature, but a great development is espected : DOE (US Department of Energy) predicts that LDES technologies (excluding Pumped Hydro) will have the same volume of applications as lithium-ion batteries in 2050.



Long Duration Energy Storage could be a valid alternative to gas plants and " Peakers", providing reliable capacity in "non windy sunny" days (periods of low RES production) and could be the solution for the "last mile"

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«Are we Heading to Long Duration Energy Storage in the path to Net Zero?»

«Full Intraday flexibility» and
«Multiday and multiweek flexibility»

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LDES Functions

Teoretically all Storage functions could be performed by LDES, but only two main groups are relevant:

GRID AUXILIARY SERVICES

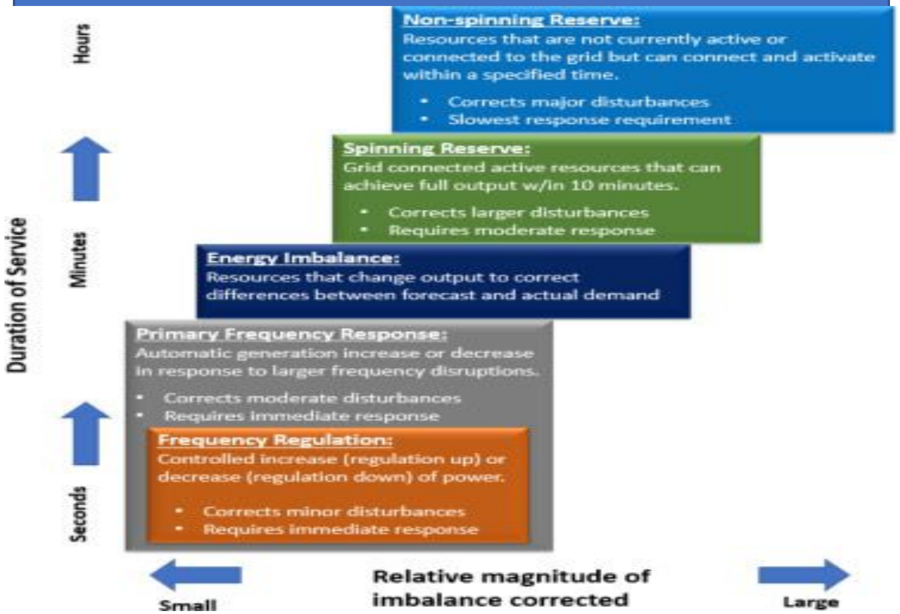
(Normally as a second function of shifting)

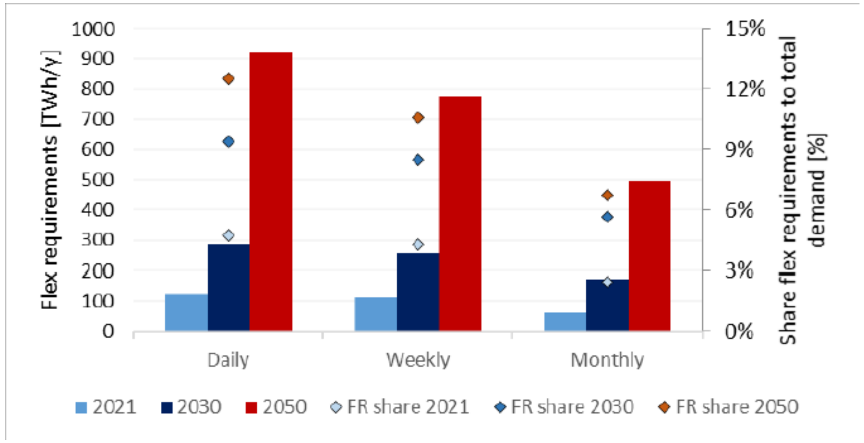
- Inertia
- Fast Frequency Response (FRU)
- Reactive Power / Voltage Control
- Short Circuit improvement
- Black Start

ENERGY SHIFTING

(for Arbitrage, Peaking, Congestion, RES Support)

- For daily balancing VRE → INTRDAY → 8-24 h
- For multiday imbalance → MULTI-DAY/Week → 24-200 h
- For avoiding congestion → MULTI-DAY/Week → 24-200 h
- For Seasonal imbalance → Seasonal duration → 200-2000 h
- For extreme wather events → Seasonal duration → 200-2000 h



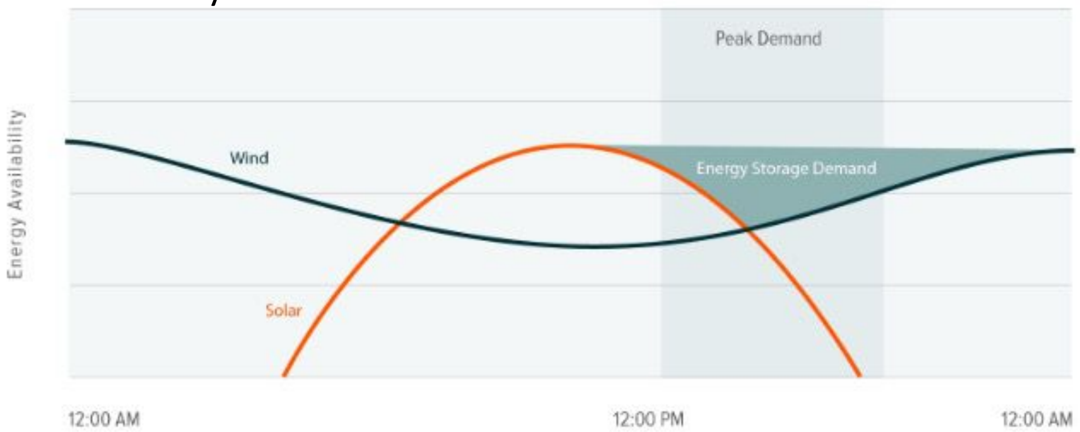


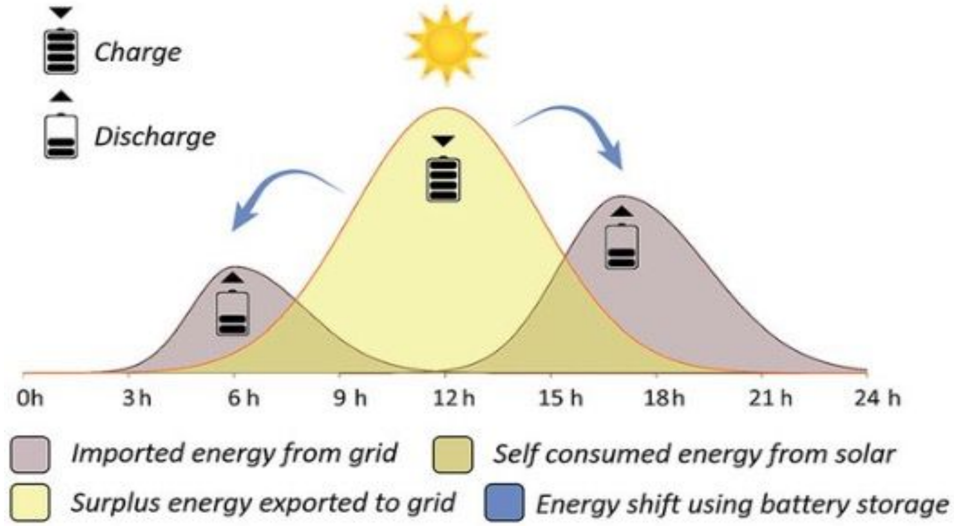
Daily, weekly and monthly flexibility requirements in the EU in 2021, 2030 and 2050. Source: JRC Flexibility

Searching for a specific node, the weather cycle time of Net Load

(Energy deficit- Energy surplus)

The natural cycle time Periods of the net load (Load minus local VRE) is surely the day (24h) for PV areas, but mainly also for windy areas. .



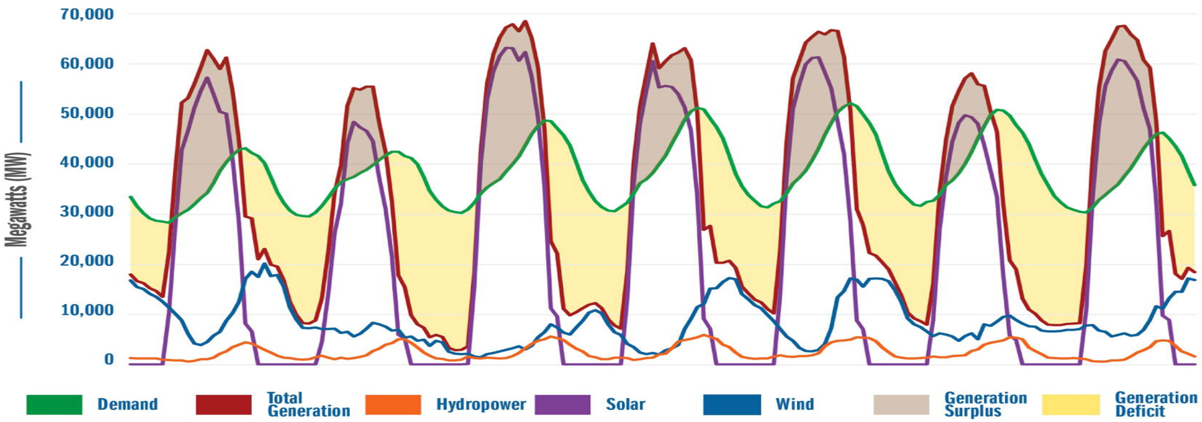


Within INTRA-DAY shifting for balancing energy deficit and energy surplus time periods, the duration of the required storage is varying between:

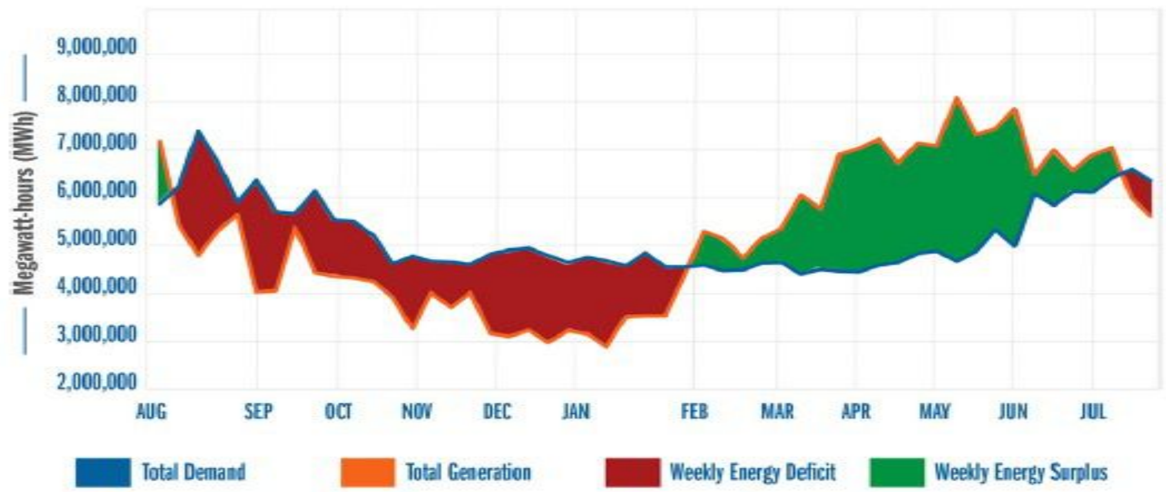
Intraday 0-4 h (SHORT DURATION)

Intraday 6-24 h (LONG DURATION)

MULTY DAY Observed Energy deficit- Energy surplus in a «solar» heavy area



Illustrative load and resource balance for California under full decarbonization, weekly resolution.



In "solar" heavy areas the 24h cycle is relevant: daily surplus is 85% balanced in net surplus of generation from mid-February until early August, is 84 % balanced in net deficit from early August to mid-February.

10-20 h Intraday shifting
100-200 h Weekly shifting
1000-2000 h seasonal shifting

Illustrative load and resource balance for California under full decarbonization, annual resolution.

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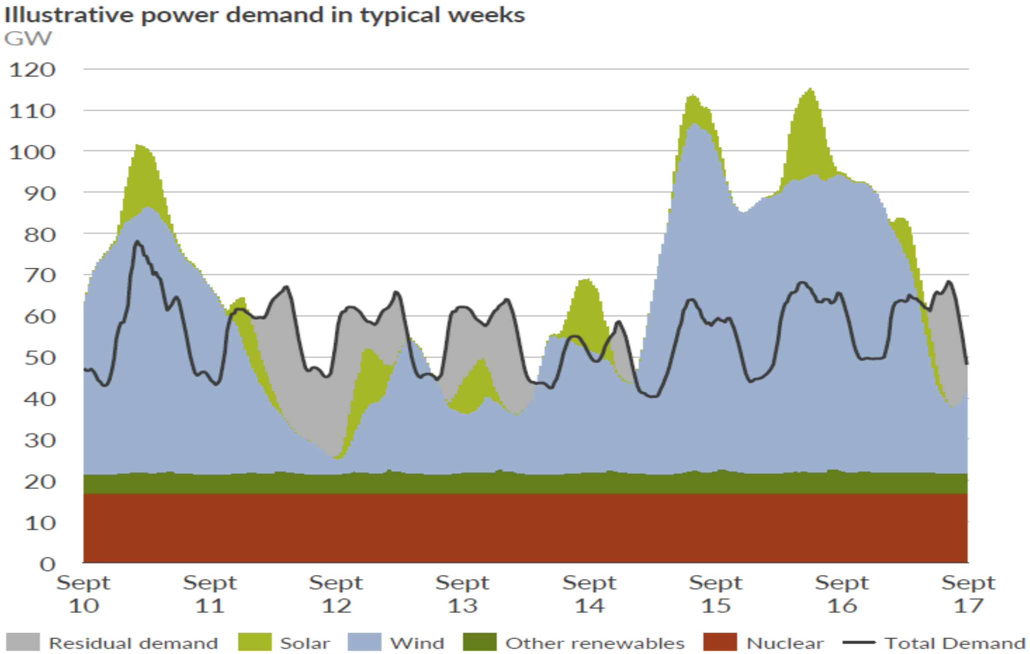
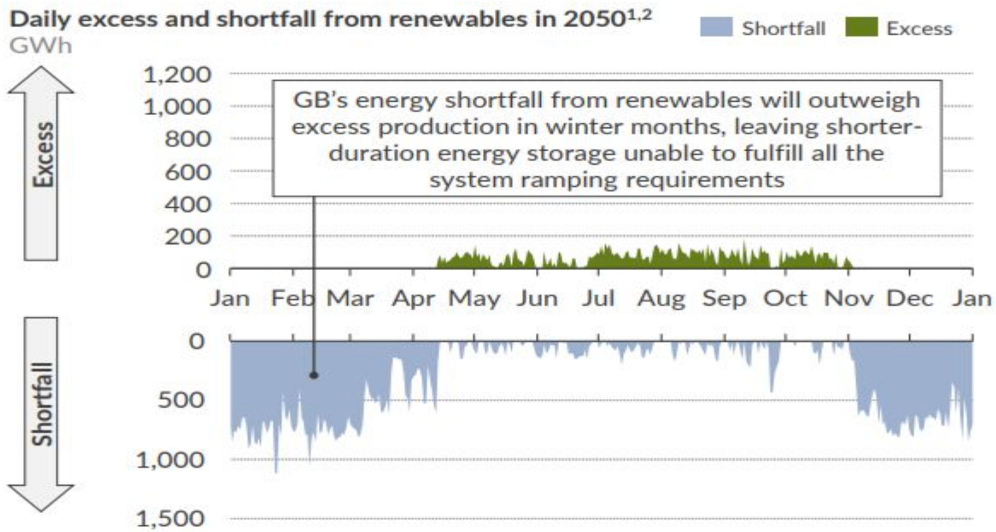
MULTI DAY Observed Energy deficit- Energy surplus in a «windy» heavy area

Illustrative load and resource balance for UK (Aurora research) under full decarbonization, weekly and annual resolution.





In "windy" heavy areas the 24h cycle is still relevant but daily and weekly energy shifting will be required to balance supply and demand across high and low wind weeks.
Long-duration storage technologies will be requested to respond to supply and demand variations caused by daily peaks, weather events and seasonal patterns. For UK, this primarily means intraday, interday, weekly and seasonal shifting.

10-20 h Intraday shifting
100-200 h Weekly shifting
1000-2000 h seasonal shifting

An overall conclusion about typical duration

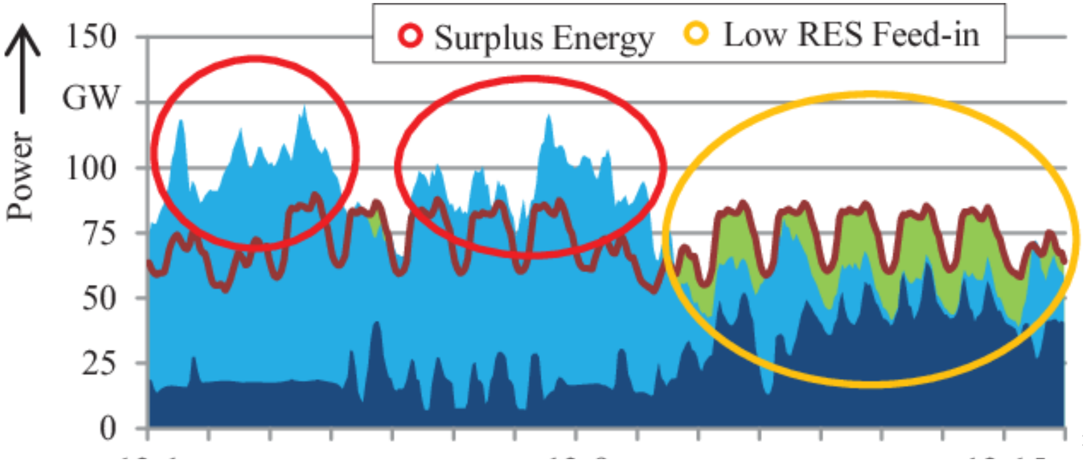
With new decarbonization and RES growing the great distance in the **depth and breadth of mismatches between Energy generation and consumption are simply too large to manage without the support of LDES technologies.**

It is difficult to generalize the needs in duration (because depending by specific conditions) but it seems that a simple trend can be considered with main two types of LDES:

- one type that manages daily cycles and provides up to 20 h of storage,
- another that manages seasonal cycles and provides storage measured in days or weeks.

It is important that grid planning processes begin to conduct more detailed modeling of decarbonized grid operations identifying the type, scale, and timing of LDES needs.

Solar PV deployment increases the need for daily flexibility needs, while wind penetration drives the weekly flexibility needs. Demand patterns as well as wind and solar PV generation profiles all drive seasonal flexibility needs.



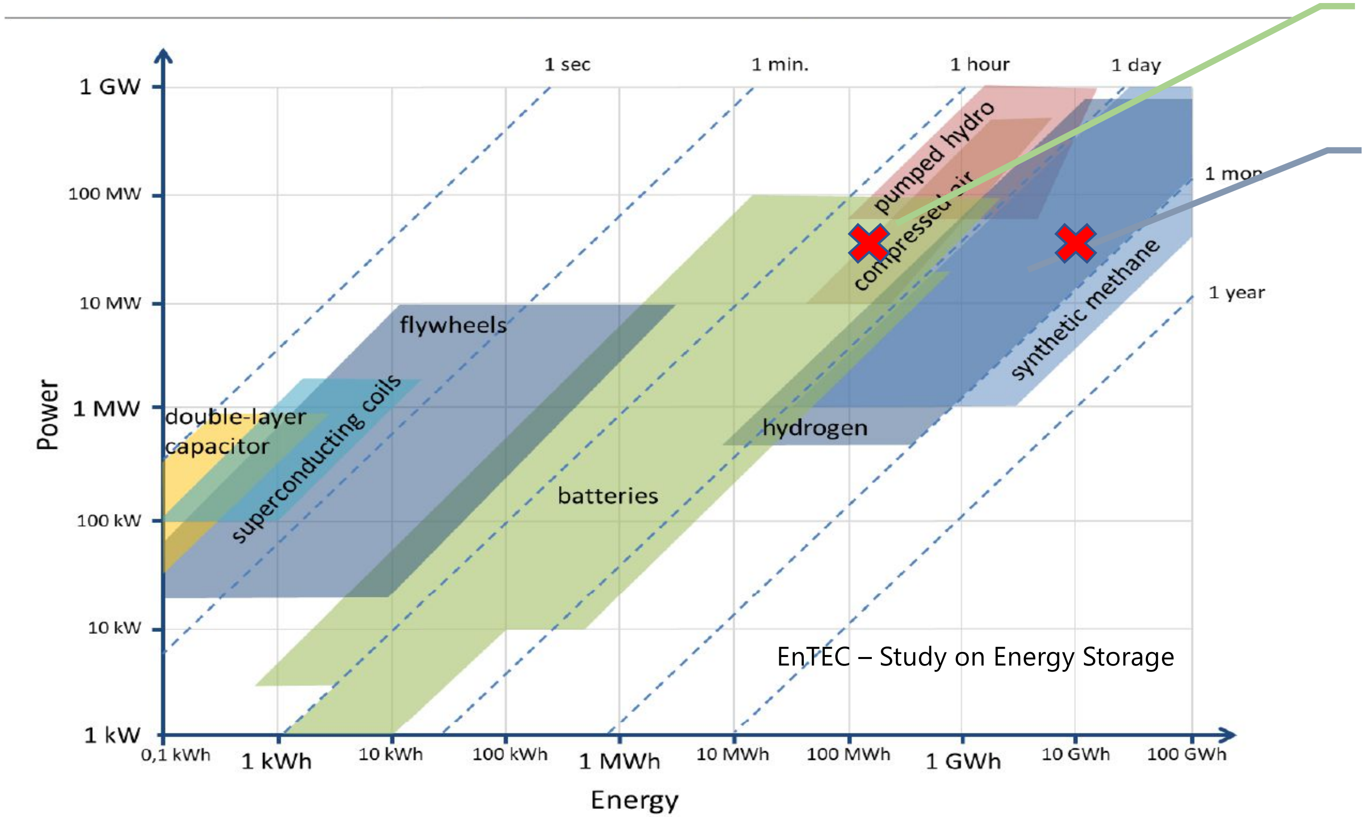
10-20 h Intraday shifting

100-200 h Weekly shifting
1000-2000 h seasonal shifting

What about energy storage technologies for these duration?

«Full Intraday flexibility» and «Multiday and multiweek flexibility» seem to be the two main focus

Power and energy ranges of different storage technologies



Possible Candidate

Intraday 10-20 h	VFB Vanadium Flow Batteries
Interaday 100-200 h Seasonal 1000-2000 h	H2 + Gas to Power

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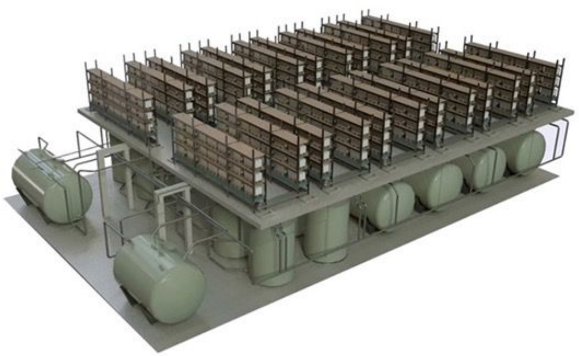

Vanadium flow batteries

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Prospects of Vanadium Flow Batteries (focus on Full Intraday)

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CONCLUSIONS

YES we are Heading to “Long Duration

Conclusions (1)

The extremely challenging net zero goal for the electricity system requires a strong **growth in renewables with consequent grid management criticalities** that can be positively addressed with BESS technologies.

With rapid and digitally smart control, storage is able to mitigate the main grid problems by introducing a degree of **flexibility** necessary for the transition.

Decarbonisation is highly impacting electrical system and if nuclear and gas are not considered **LDES become crucial**.

While "phase out of coal" enhanced Power Intensive Energy Storage (1 s settling time of high pressure valve), the new "phase out of Gas" will impact on "slower" activation times with the need of long shifting.[***Coal phase out enhanced Litium, Gas phase out will enhance LDES***]

The duration needs seem to focus on two main types of LDES : the first 10-20 h duration, the second 100-2000 h .
[VFB] [H2 + Fuel cell]

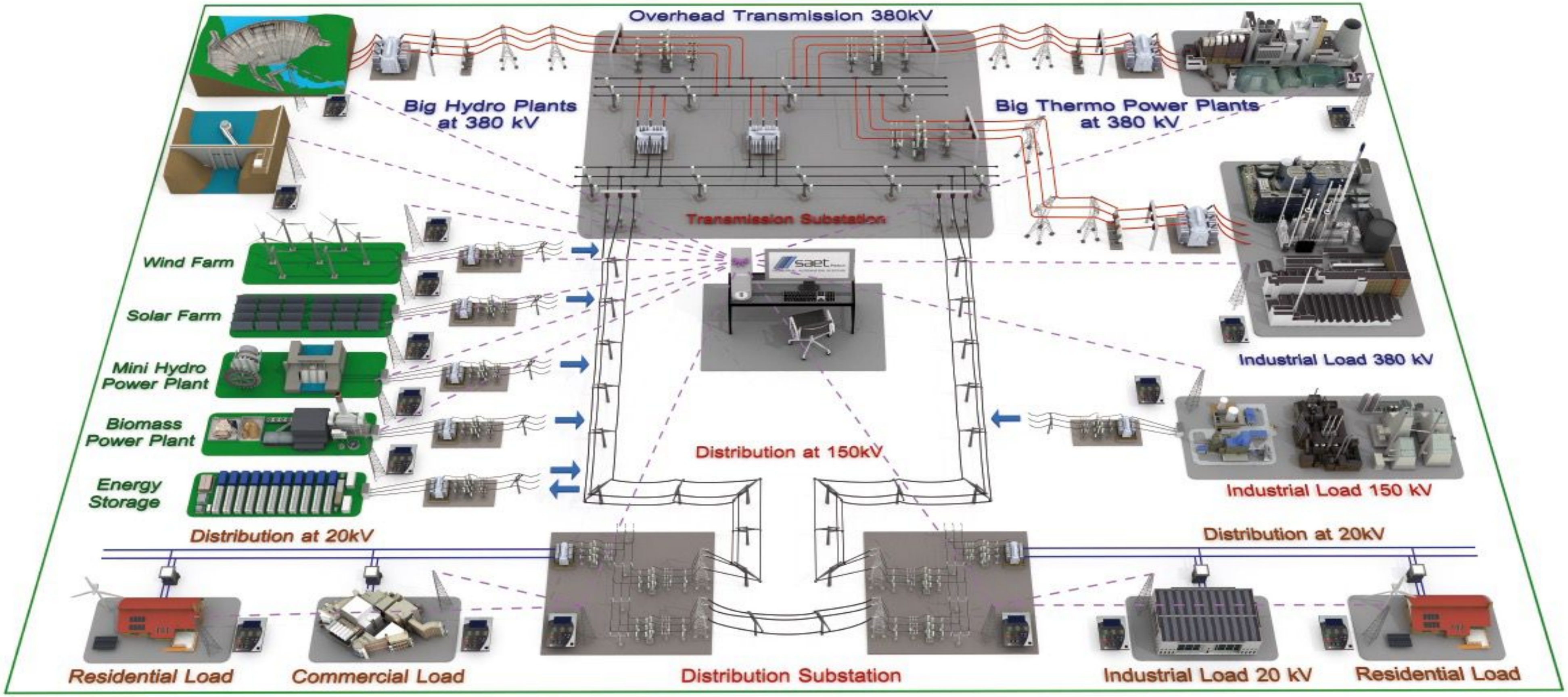
Vanadium Flow battery is the main candidate for the first type up to 20h , with optimal technical performances and sustainability.

Conclusions (2)

Our conclusion is that Digitally smart and with the LONG DURATION option, Storage can really support Renewables up to Net Zero by becoming the key factor in the energy transition, and we are really Heading to “Long Duration” .

As energy demand grows across sectors of our economy, it’s crucial that we understand the key role long-duration energy storage can play in reducing the energy industry’s reliance on fossil fuels and meet our needs with solutions that are better for our communities and our planet.

Can We Smart Your Grid?



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Thank you

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