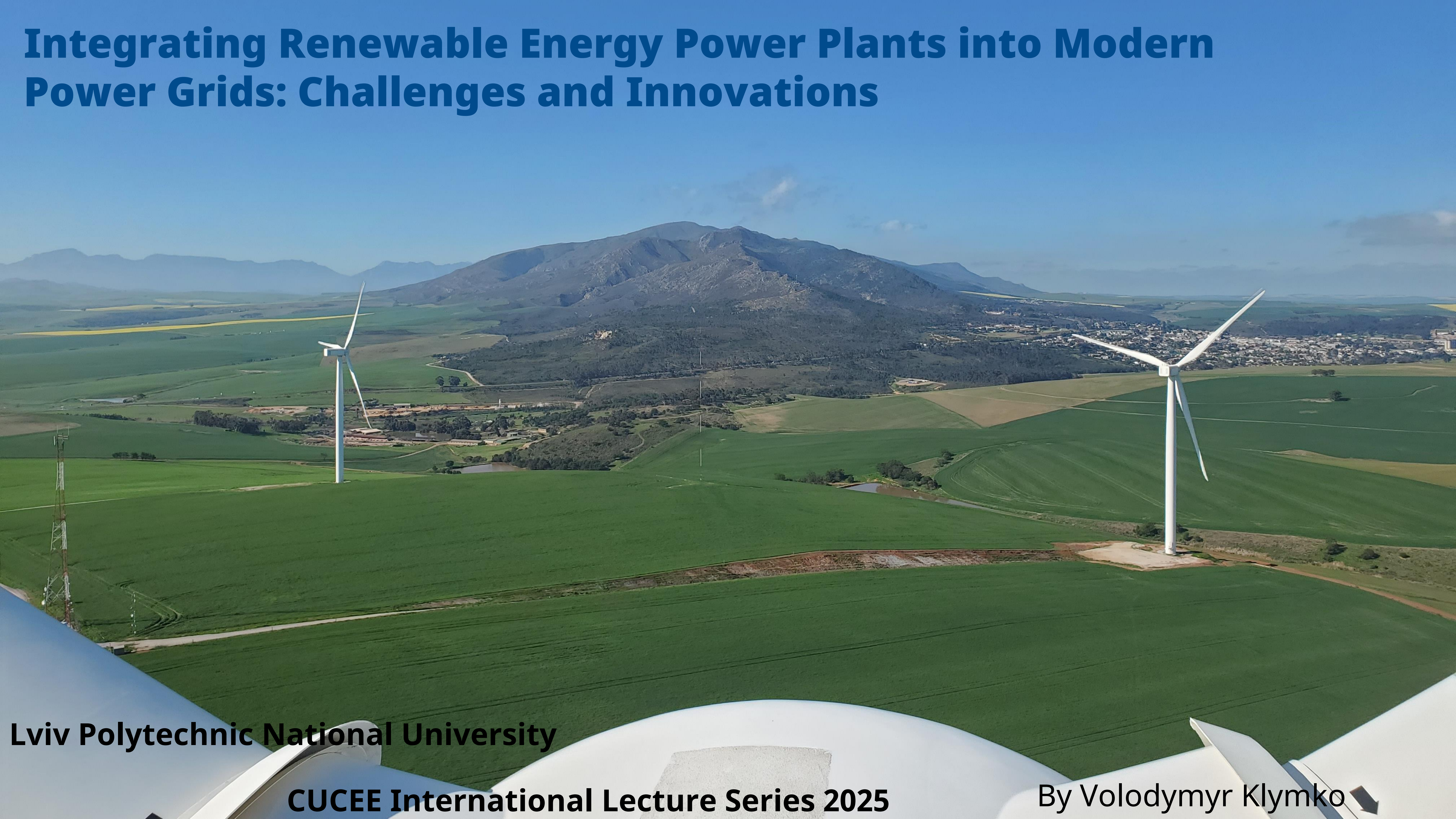
Integrating Renewable Energy Power Plants into Modern Power Grids: Challenges and Innovations



Lviv Polytechnic National University

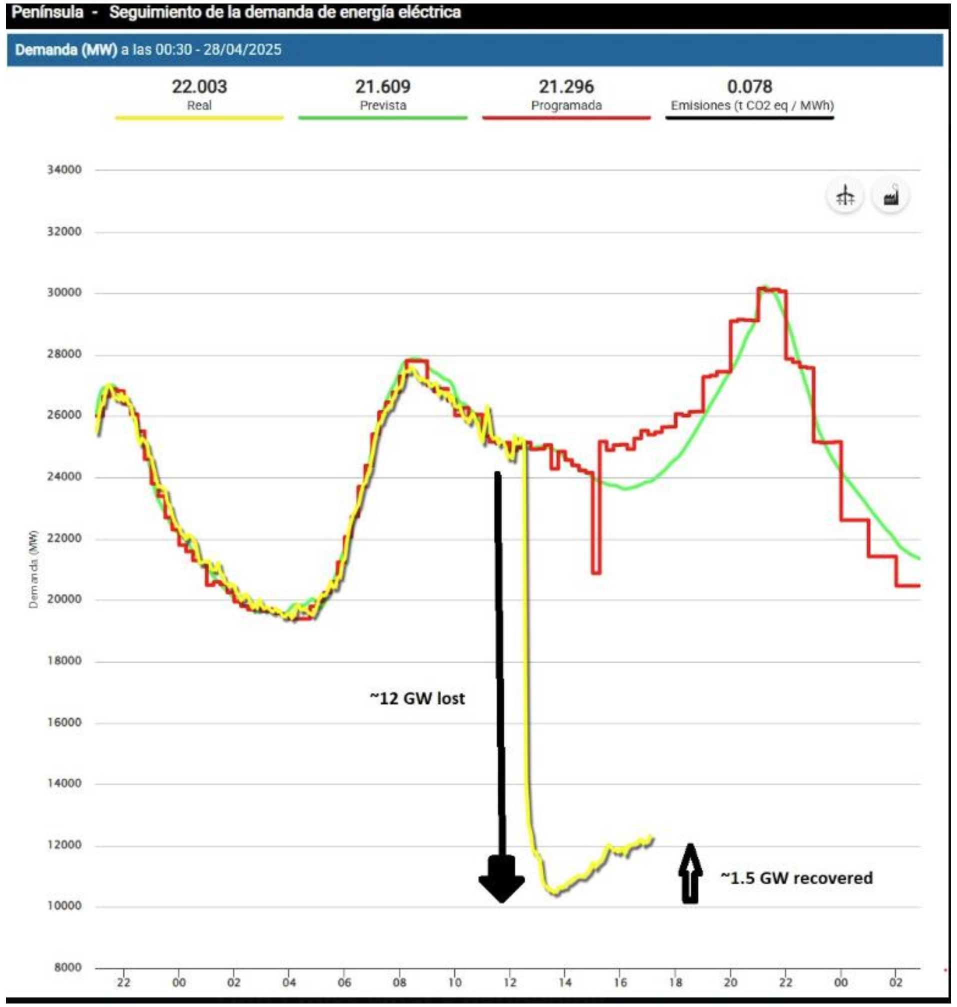
CUCEE International Lecture Series 2025

By Volodymyr Klymko

QUOTE OF THE DAY

“Successful engineering is all about understanding how things break or fail.”

- Henry Petroski



Agenda

- Introduction
- Overview of the Current Landscape in the Renewables Sector
- Status of the Wind Industry
- Fundamentals of Wind Power Generation
- Status of the Solar Industry
- Fundamentals of Solar Power Generation
- Batteries and their role
- Introduction to Hybrid Plants
- Issues in balancing power in the grids
- Practical aspect. A view on the industry
- Grid compliance (active and reactive power flows)
- Traders
- SCADA and monitoring
- Discussion

Highlights

Clean power surpasses 40% of global electricity generation for the first time since the 1940s (generation from all low-carbon power sources – renewables + nuclear)

China, India are the top two of CO2 emissions from electricity consumption in 2024

Share of renewables in final energy consumption is 20% by 2030. However, almost 75% of global energy demand will still be met by fossil fuels

2030 forecast has two main drivers: solar PV and China

China is set to cement its position as the global renewables leader, accounting for 60% of the expansion in global capacity to 2030

New solar capacity added between now and 2030 will account for 80% of the growth in renewable power globally by the end of this decade

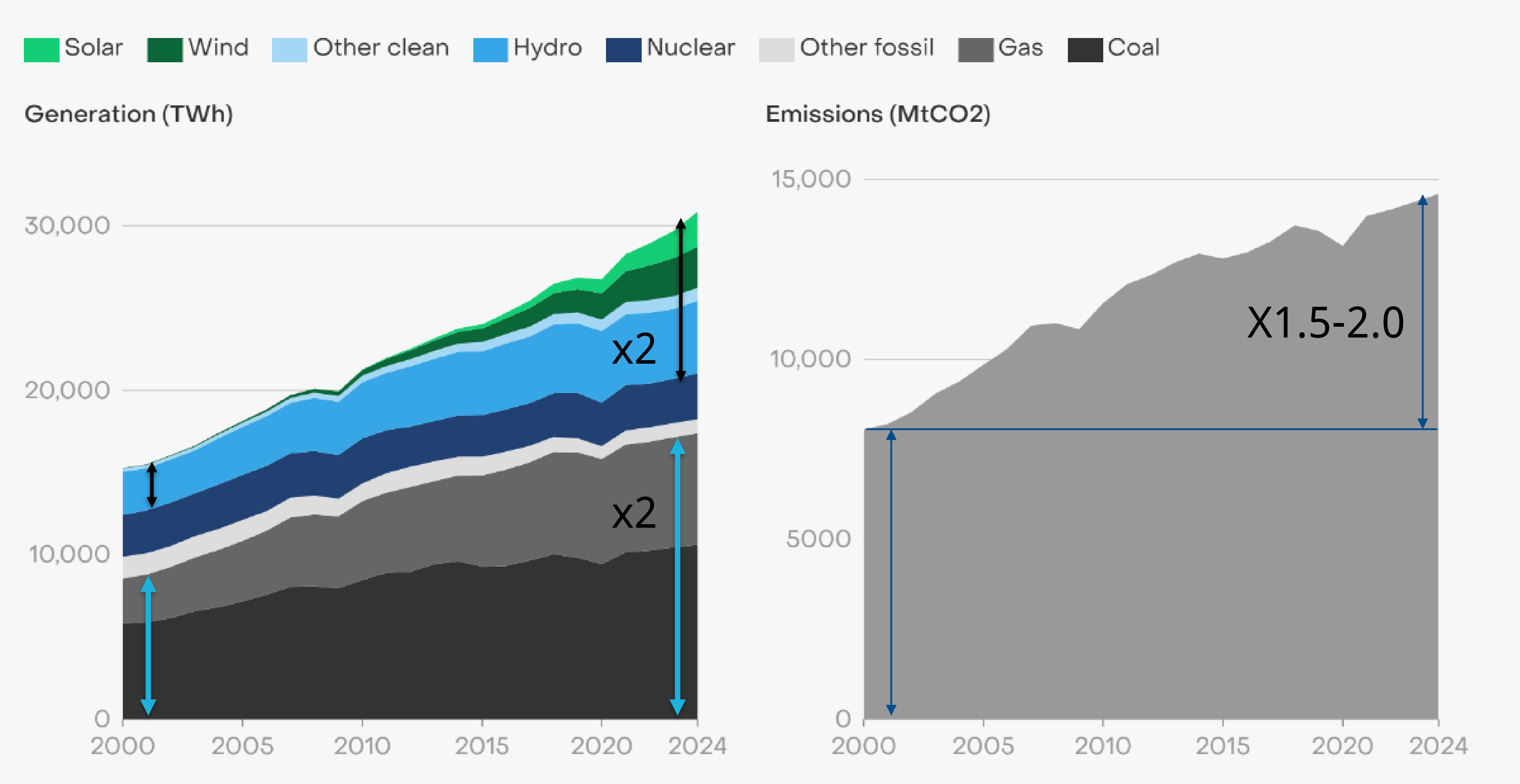
China is by far the largest installer of wind power in the world

orks invasion of Ukraine made EU countries to shift towards more electricity generation from renewables and to reduce gas and oil usage significantly

The European Union and the United States are both forecast to double the pace of renewable capacity growth between 2024 and 2030, while India sees the fastest rate of growth among large economies

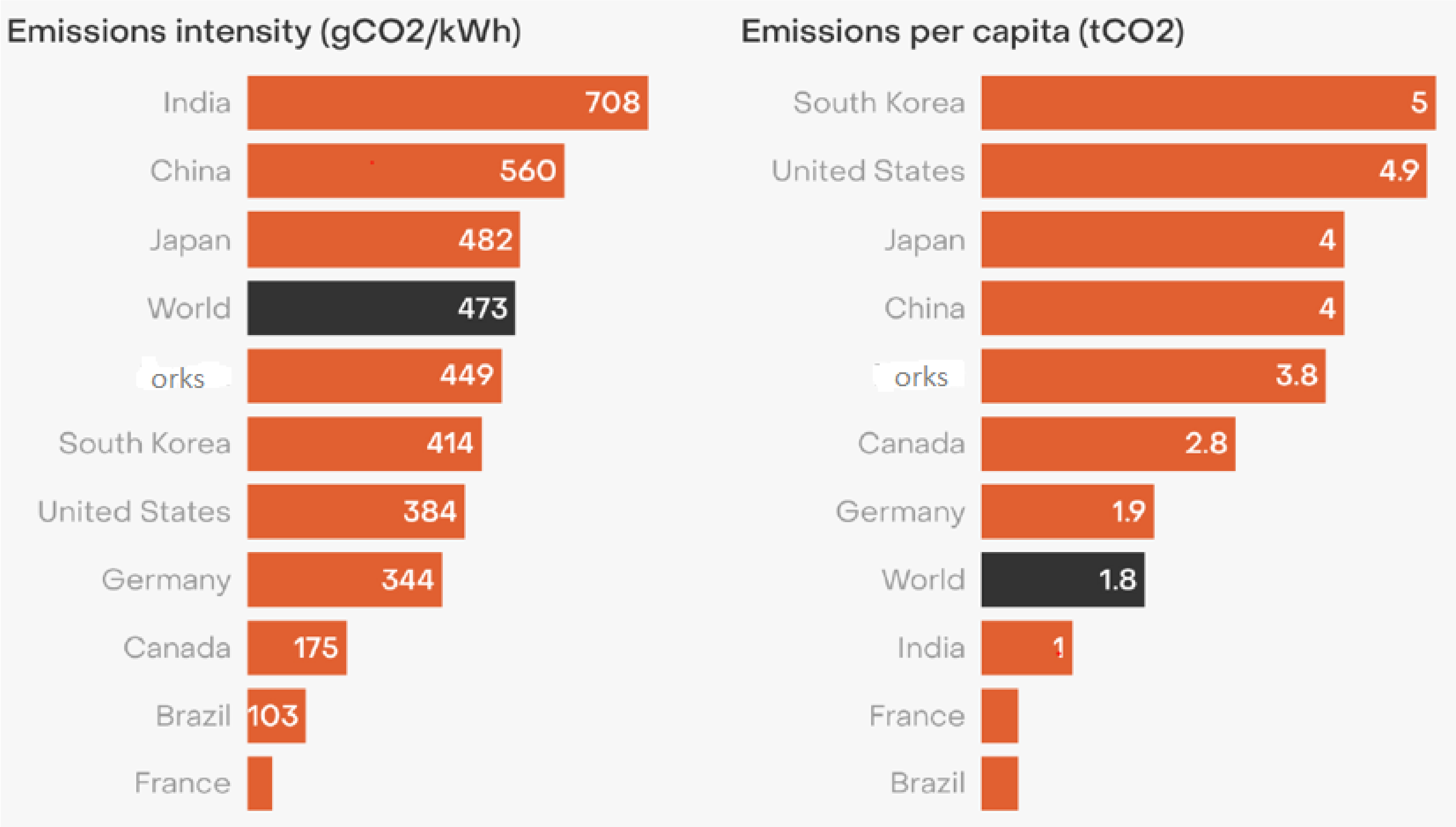
The biggest renewable hybrid plant as of now is located in India (Khavda plant)

Global power generation and emissions (2000-2030)

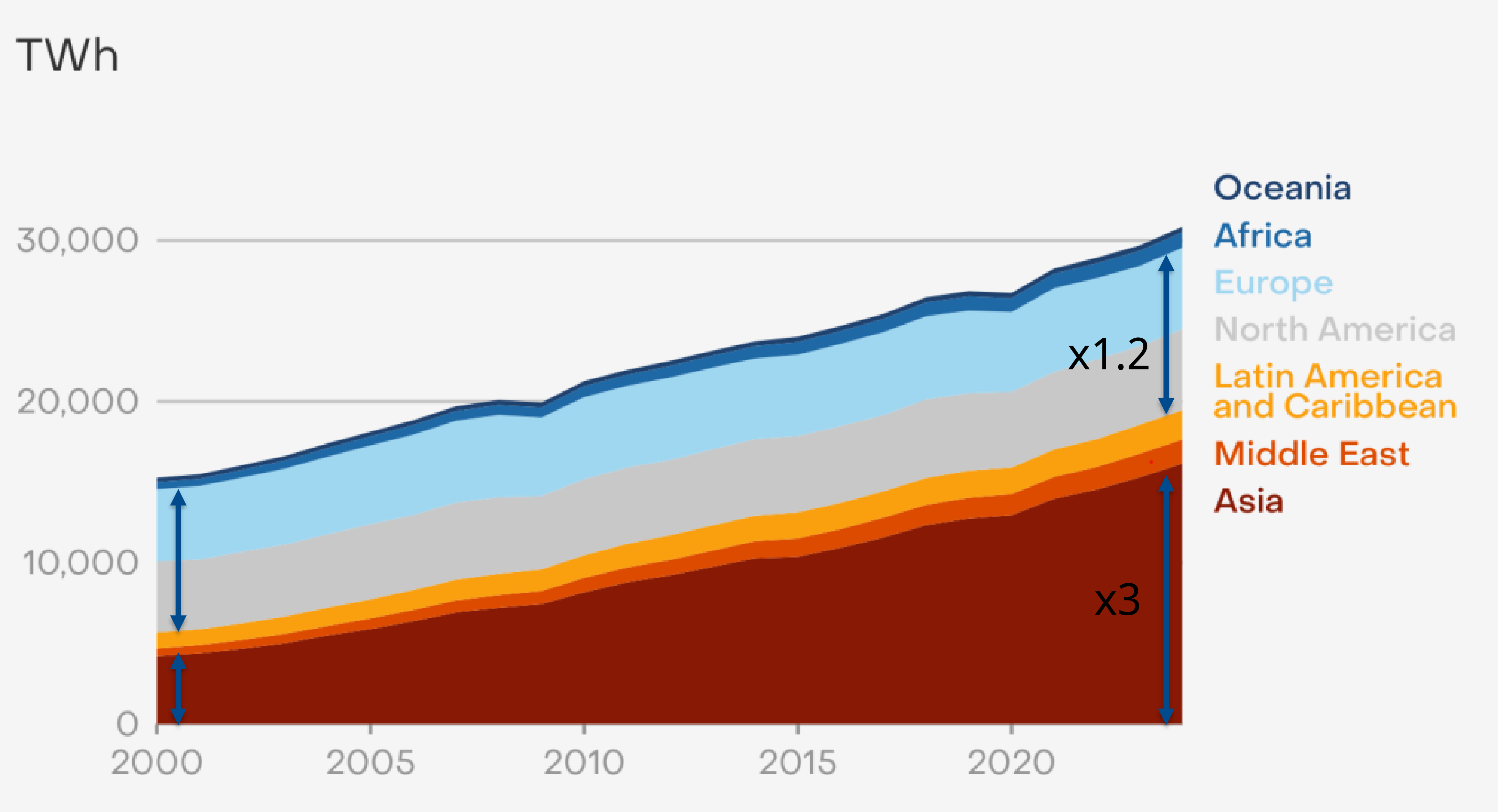


Other renewables: bioenergy, concentrated solar power, geothermal energy – less than 3% and remains unchanged

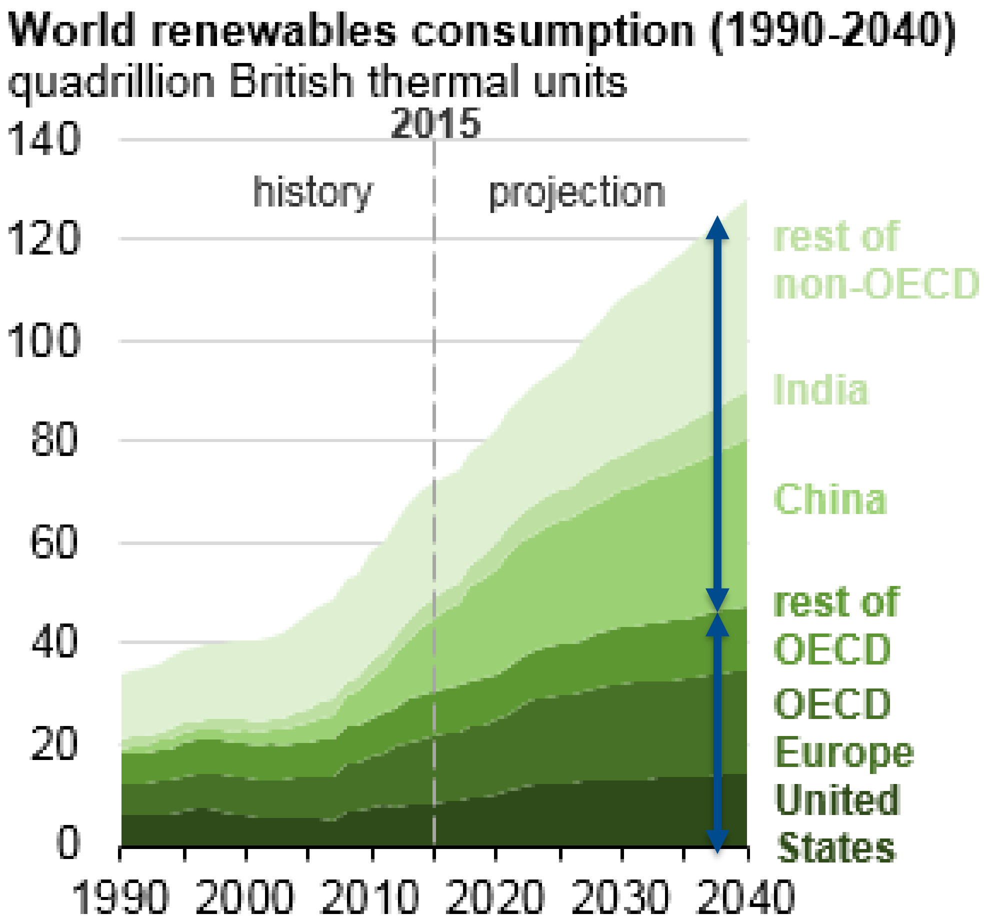
Emissions of top electricity consumers in 2024

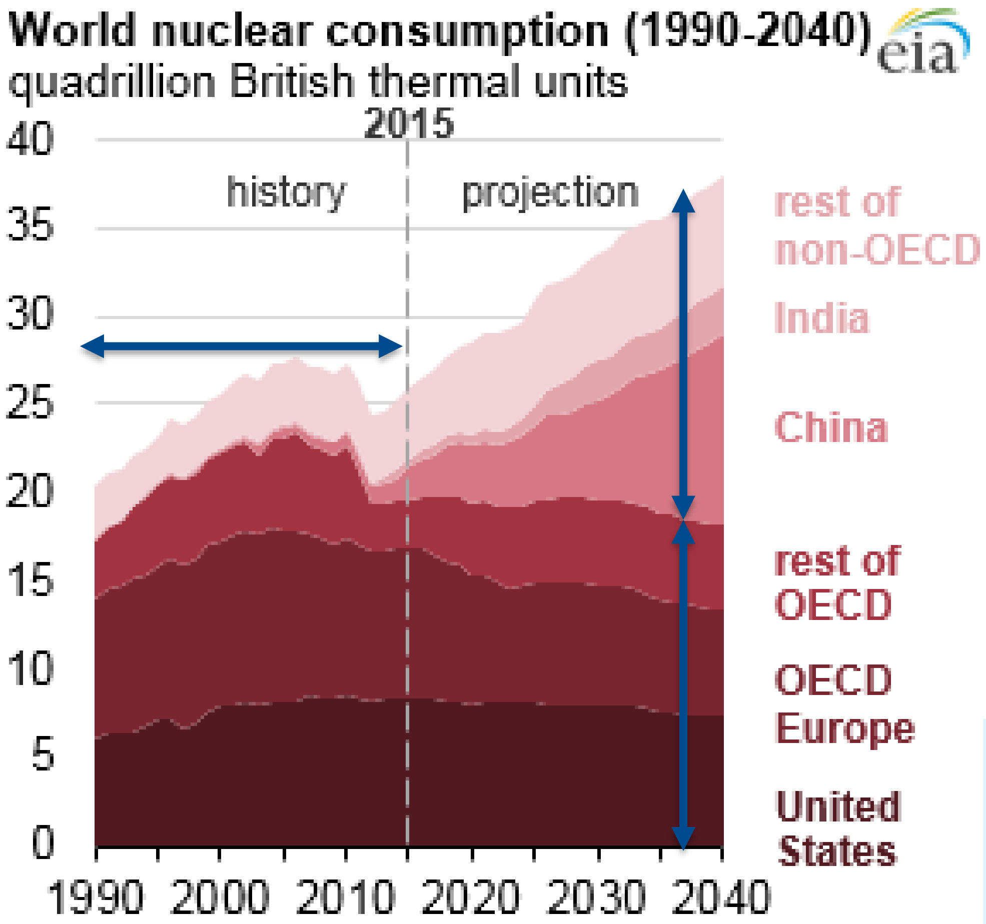


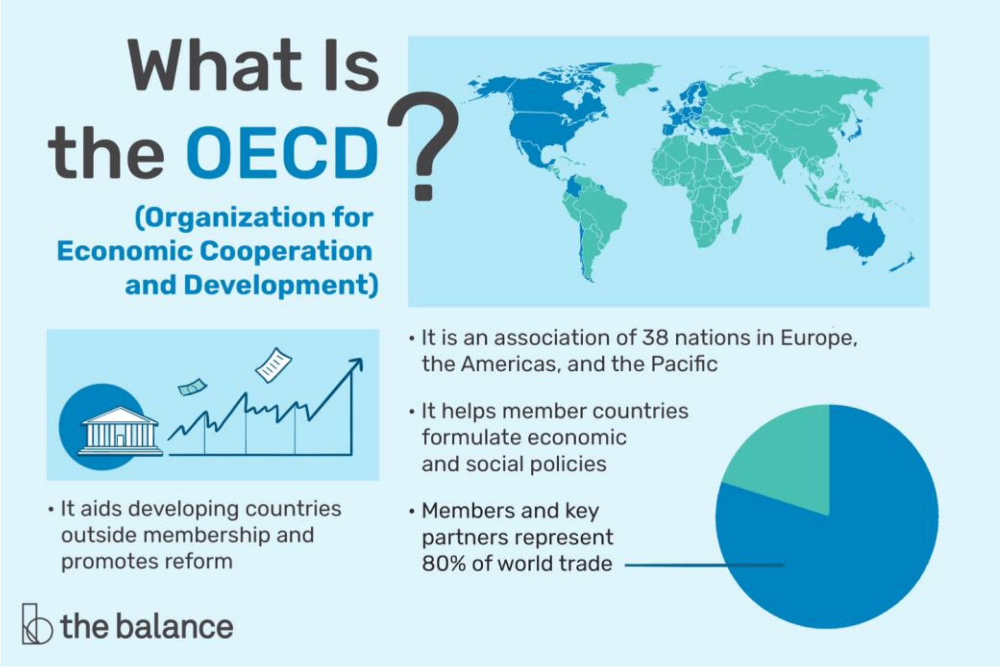
Global demand for electricity



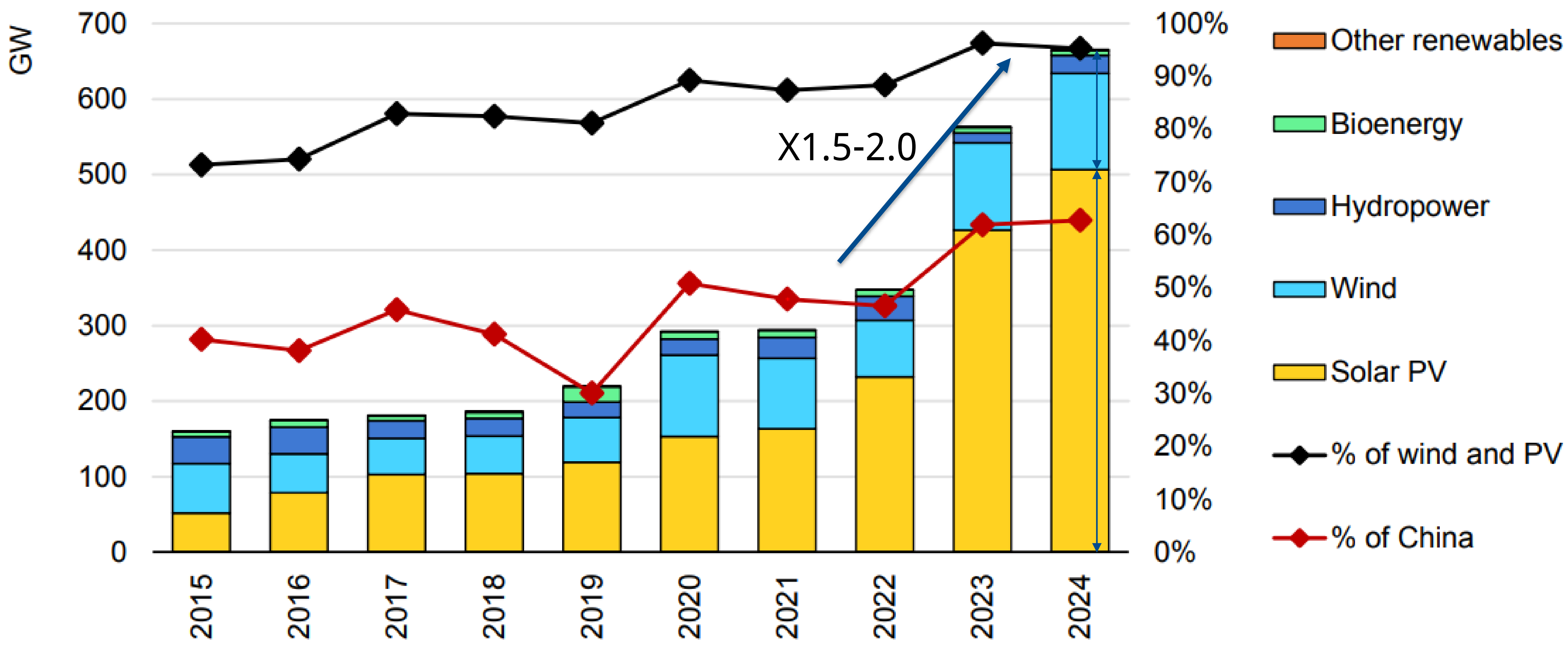
Global demand for electricity



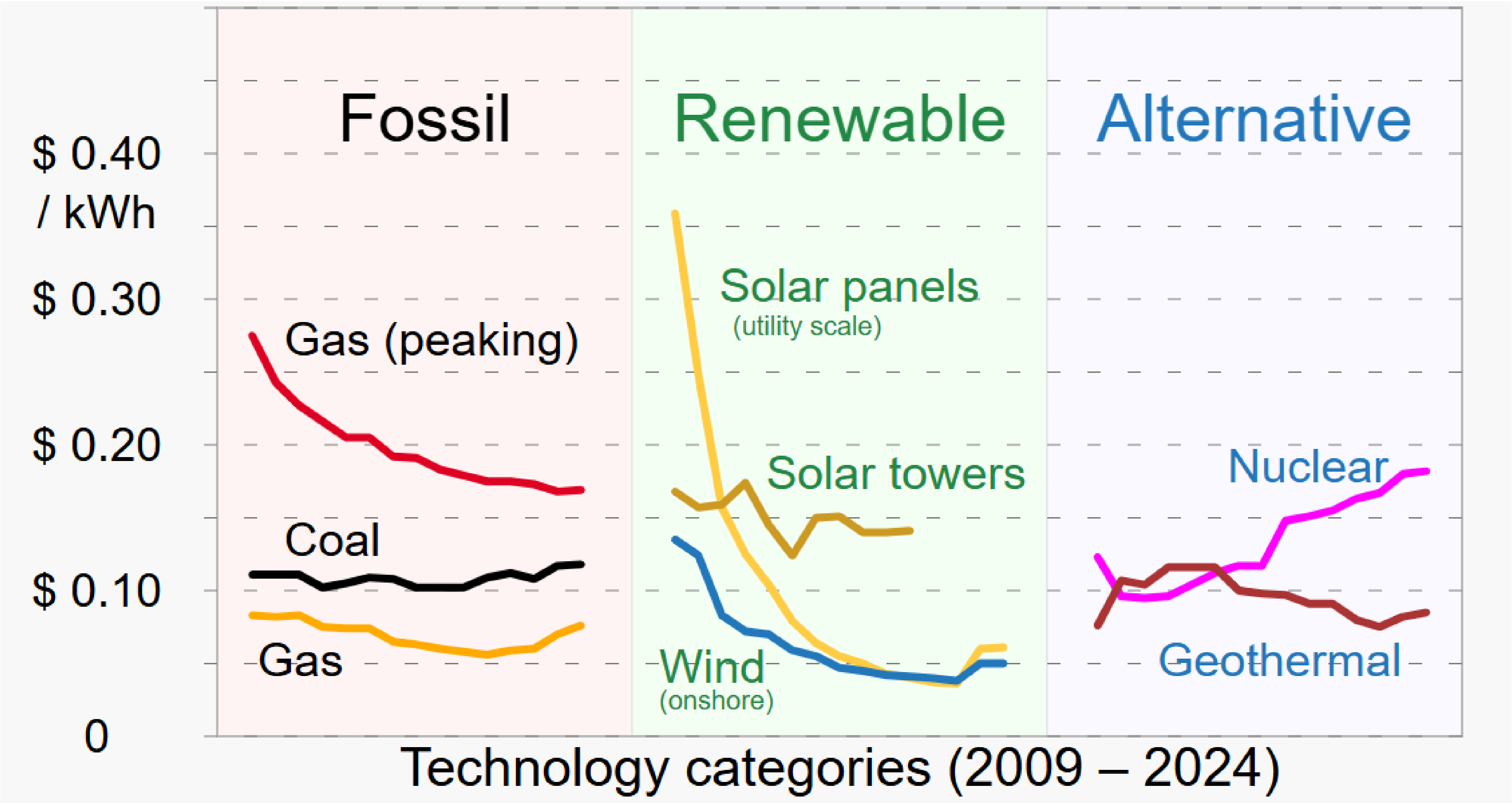




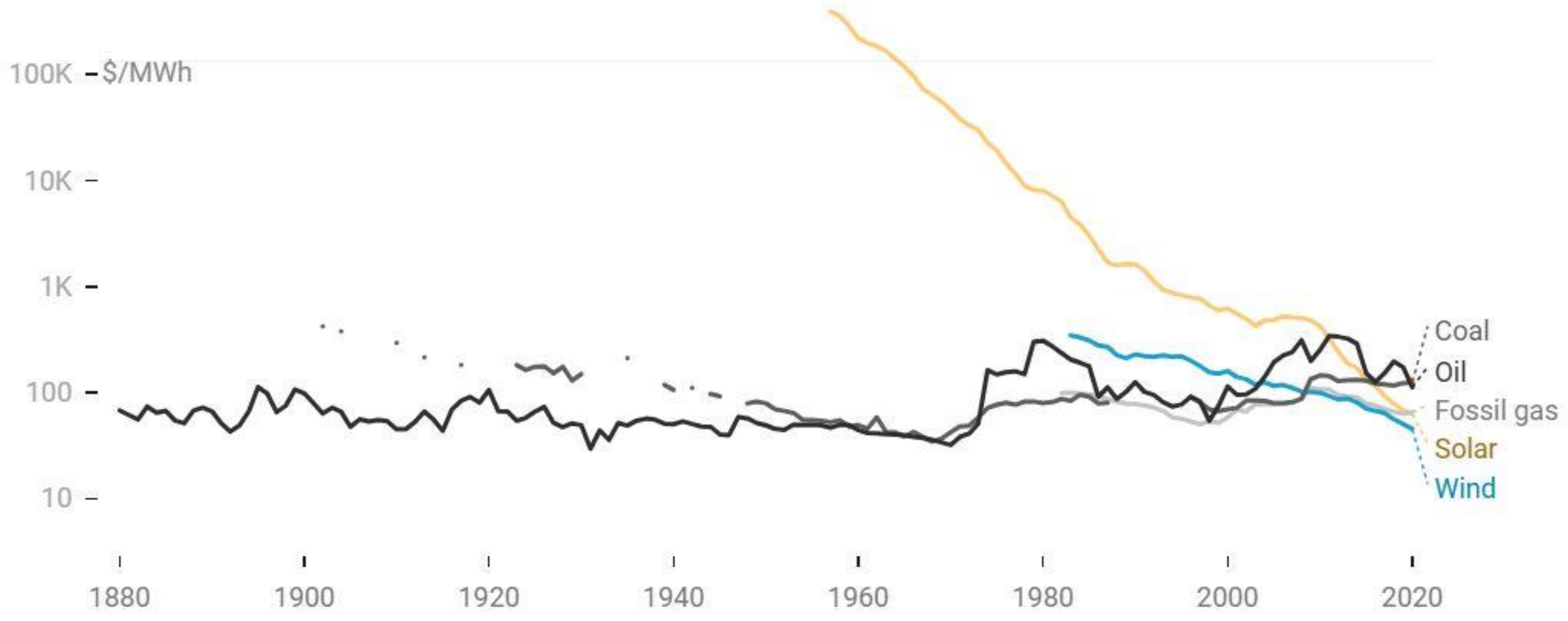
Renewable electricity capacity additions by technology, and China's share



Levelized cost of energy (LCOE)

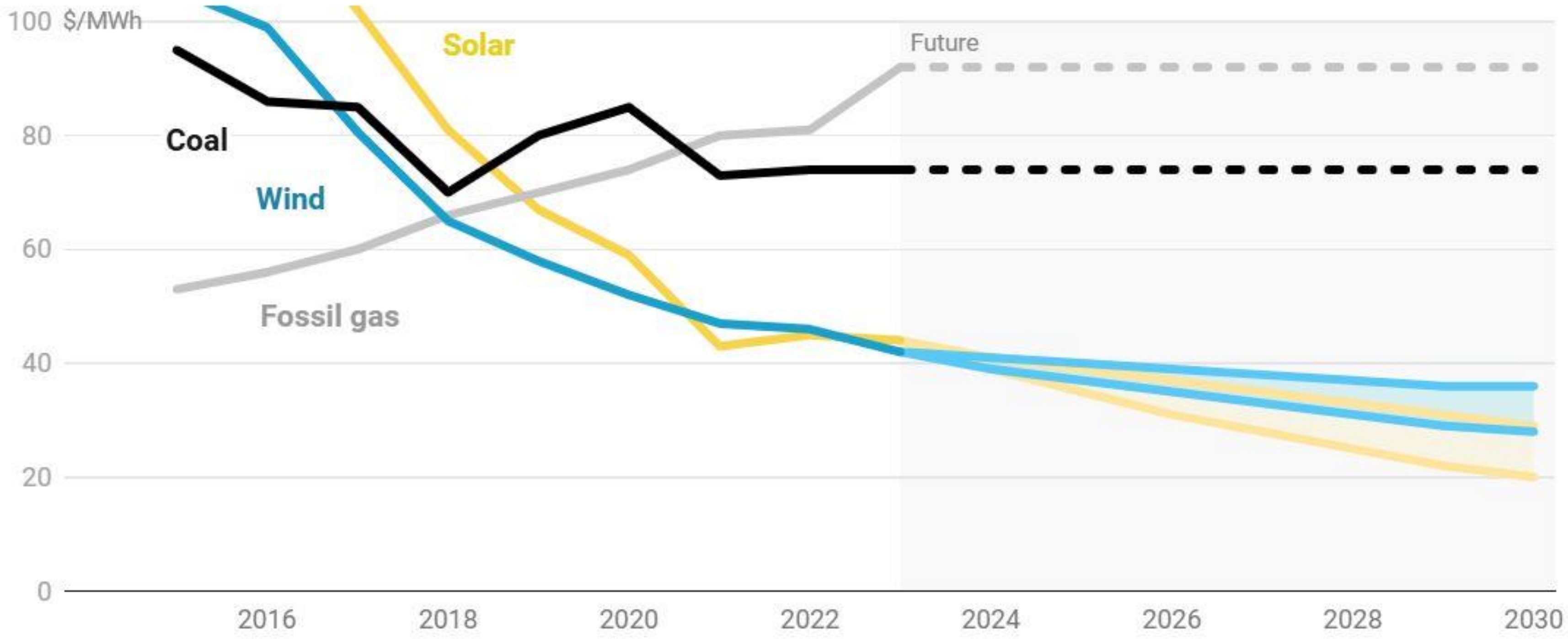


Fossil fuels haven't gotten cheaper with time



Renewables will keep beating fossil fuels on cost

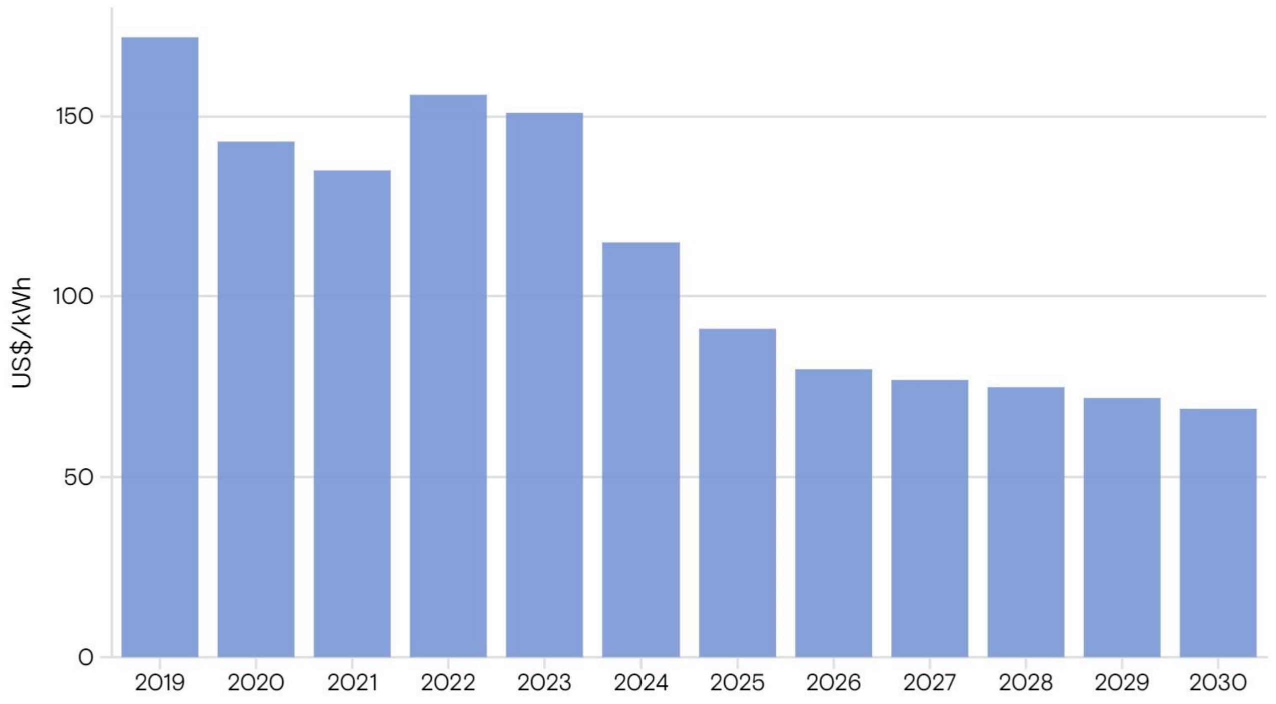
The cost of solar power and battery storage continue to fall, which makes such a technologies more affordable thus decarbonization process speeds up



Battery prices

Battery prices are forecast to fall

Global average battery pack prices



Source: Company data, Wood Mackenzie, SNE Research, BNEF, Goldman Sachs Research
2023-2030 are estimates

Goldman Sachs

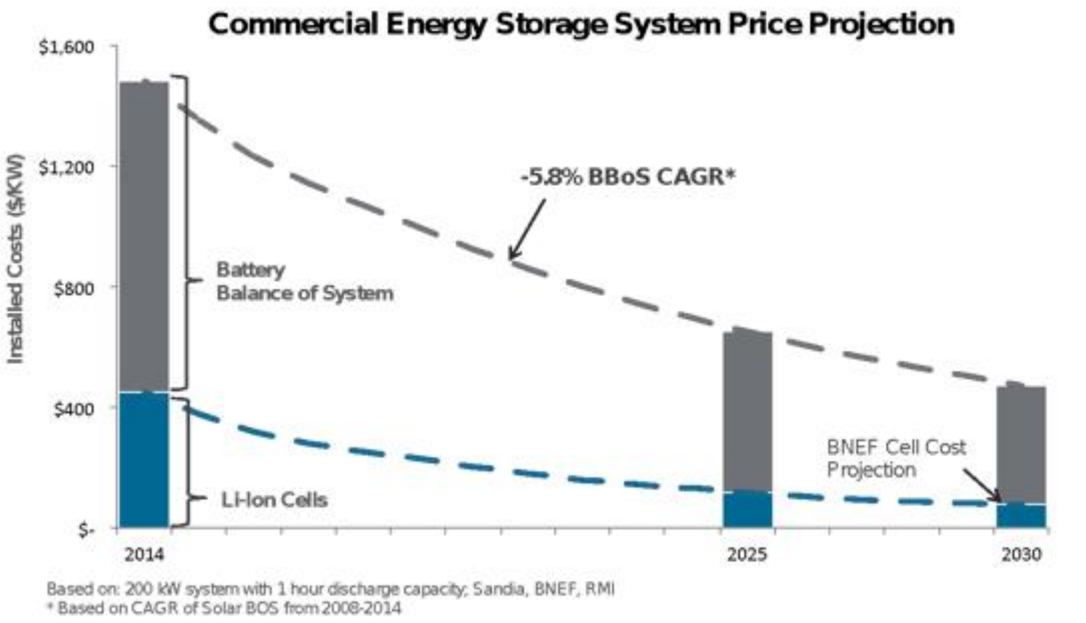
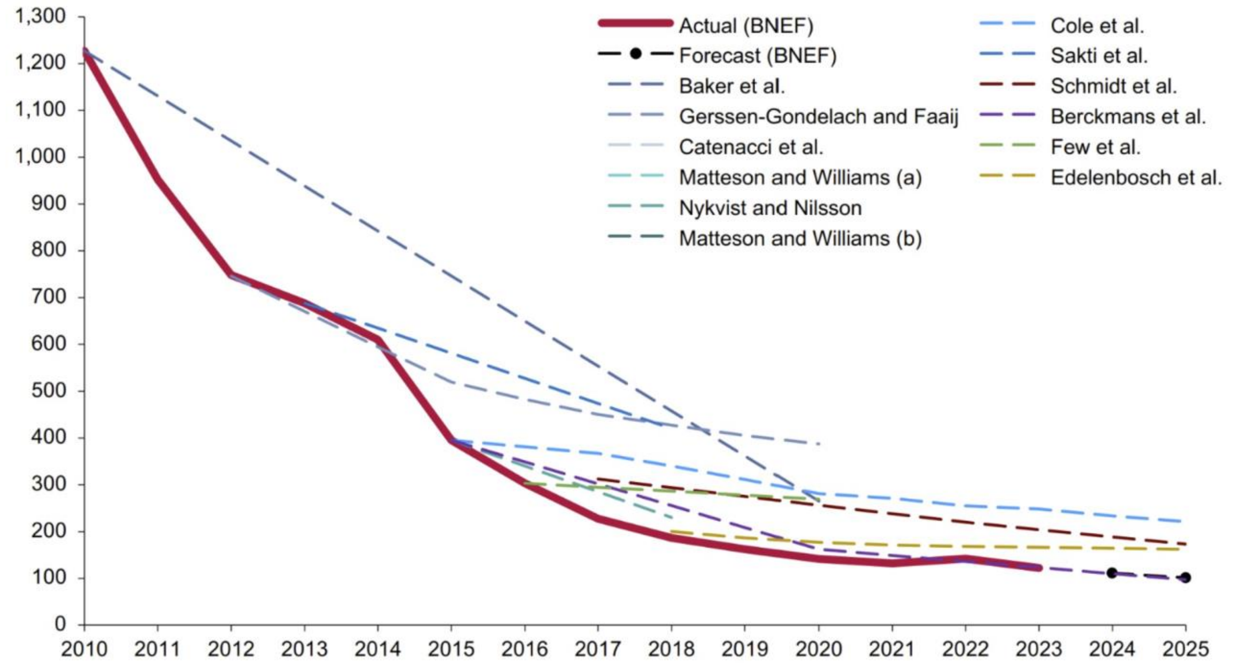
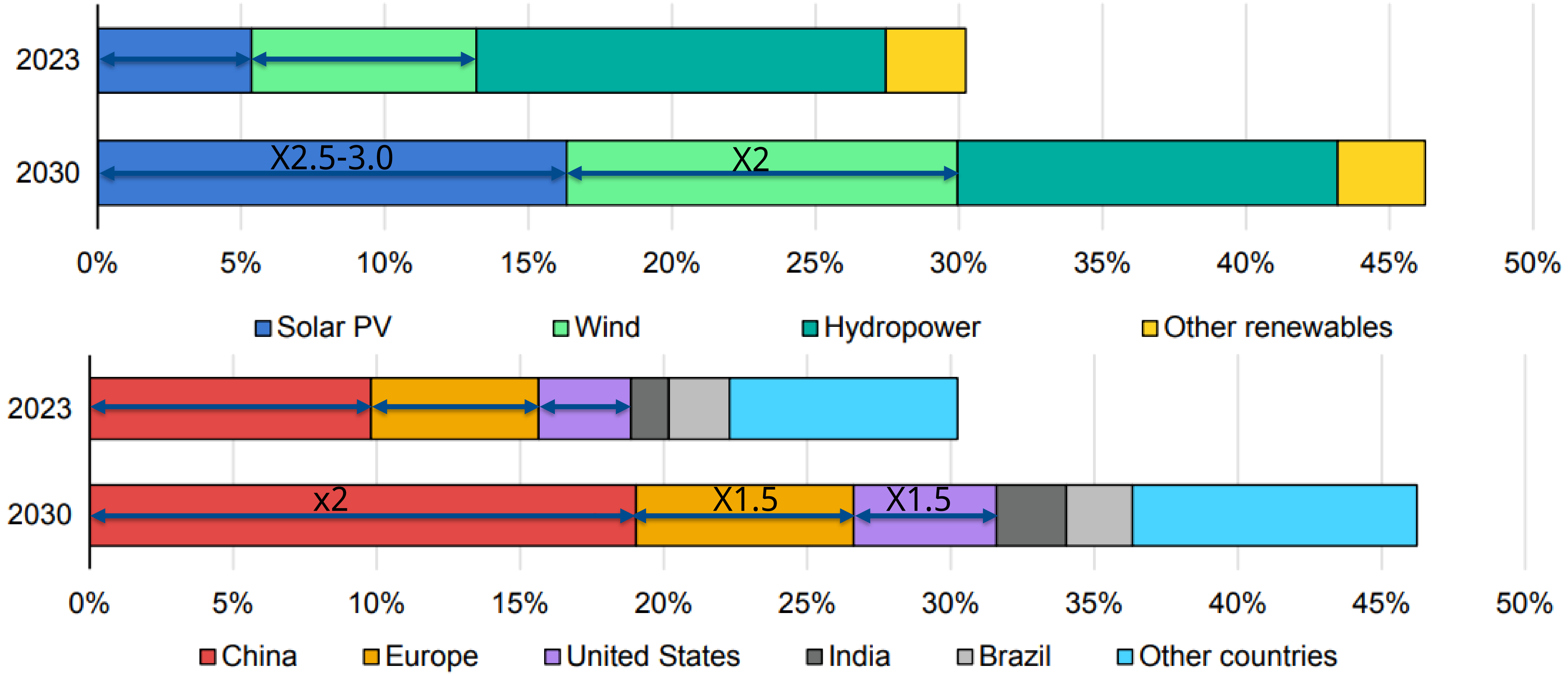


Figure 13: Battery cell costs, expert forecasts vs. actuals, $/kWh

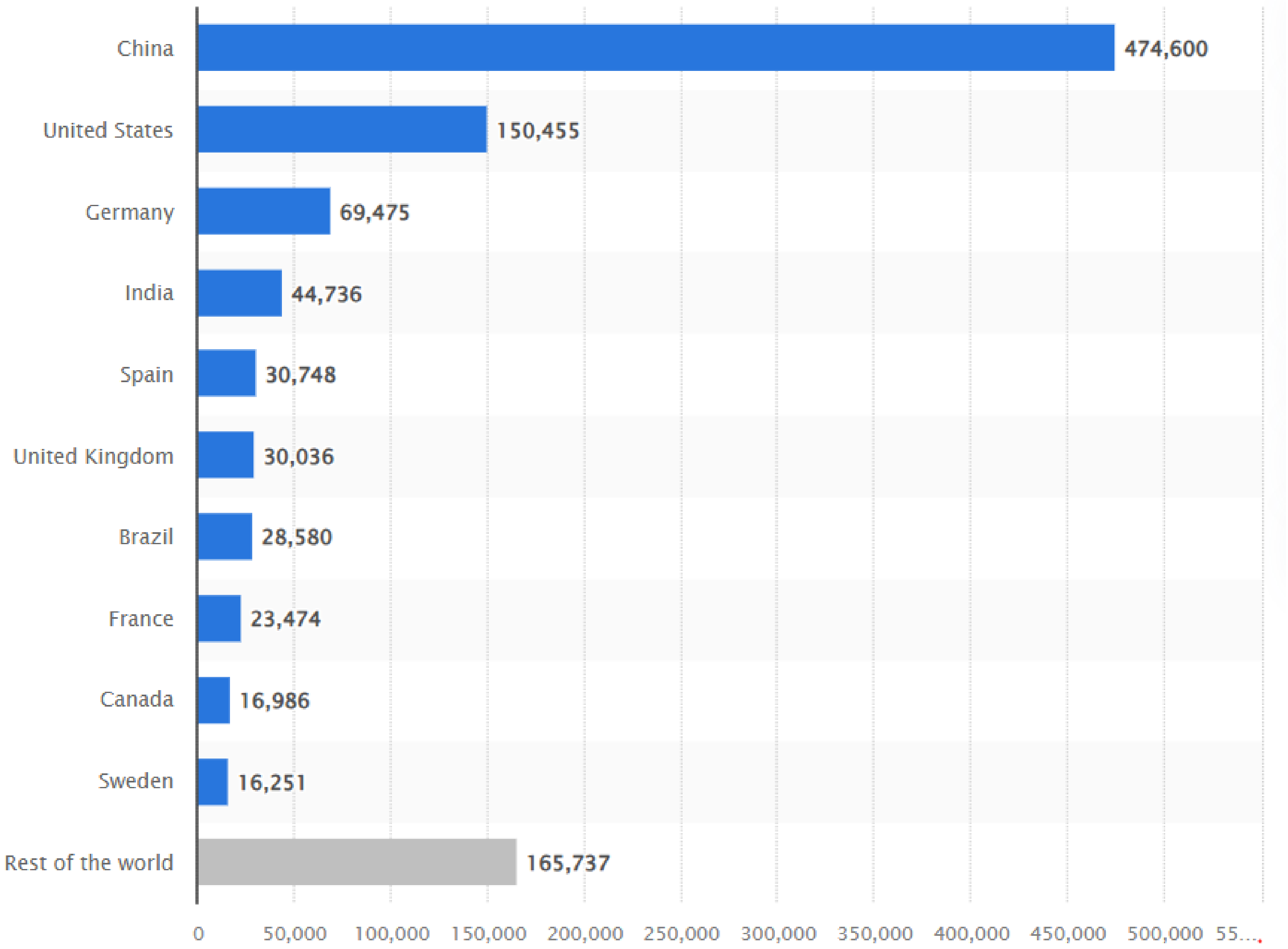


Source: Mauler et al. (2021)[64] for expert forecasts of 2010-2018, BNEF Lithium-Ion Battery Price Survey (2023)[65] for actuals and most recent forecasts.

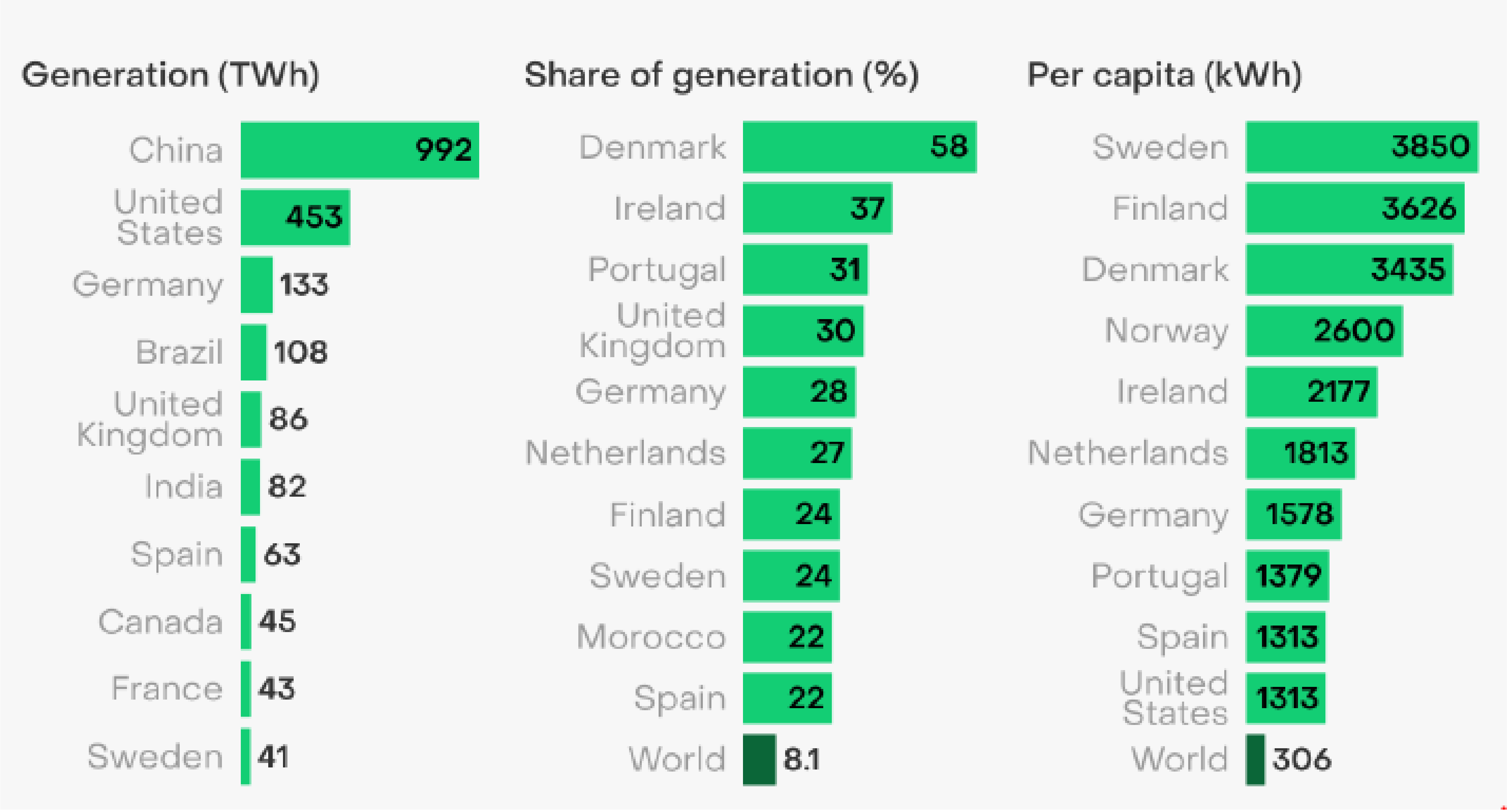
Global electricity generation by renewable energy technology and country/region, main case, 2023 and 2030



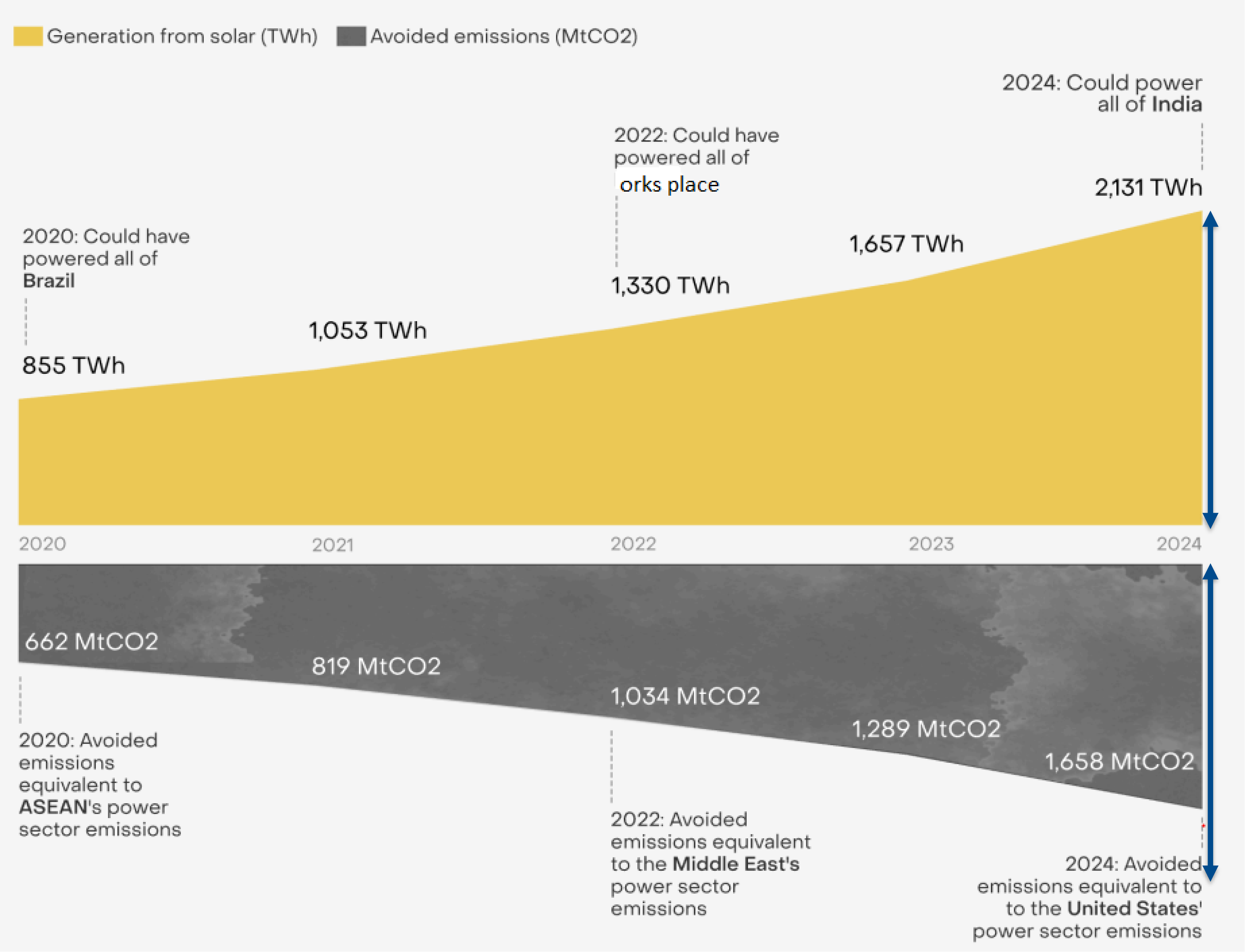
Cumulative installed capacity of wind power worldwide in 2023, by country



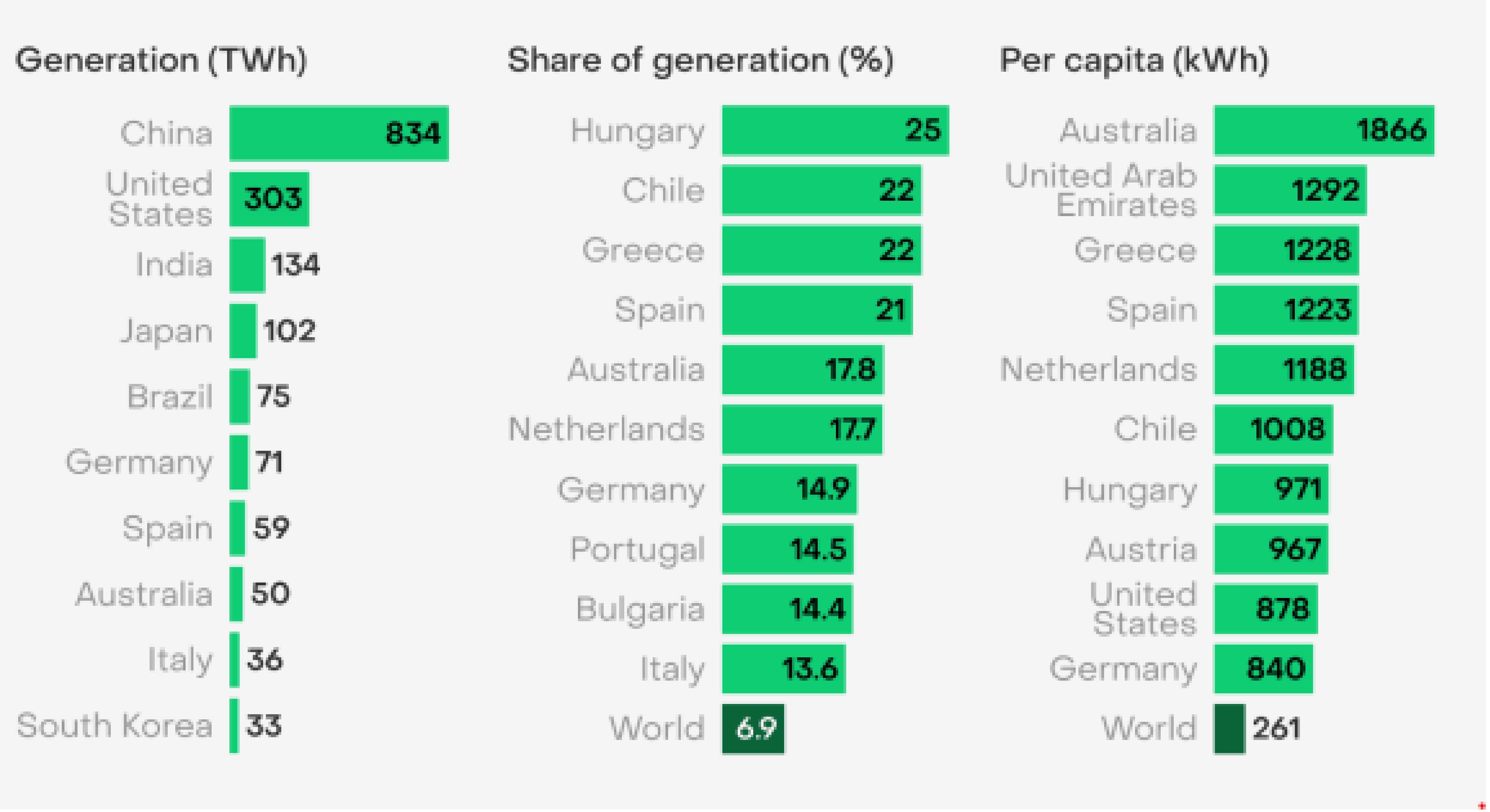
Wind: 2024 global electricity rankings



Global solar generation is now equivalent to the entire electricity demand of India, avoiding significant emissions



Solar: 2024 global electricity rankings



The biggest wind turbines in the world

Commercially deployed:

- Siemens Gamesa SG 14-222 DD
- Power – 14.7 MW
- Rotor diameter – 222 m
- Farm – Moray West
- Country – Spain-German

Prototype:

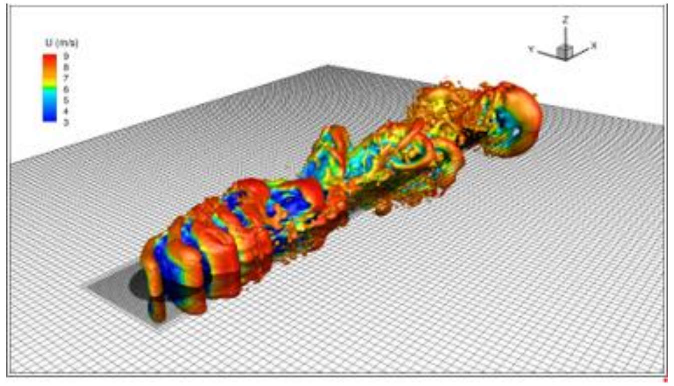
- Siemens Gamesa SG DD-276
- Power – 21.5 MW
- Rotor diameter – 276 m
- Test field – Osterild
- Country – Spain-German

Concept:

- Dongfang Electric DEW-26 MW-310
- Power – 26 MW
- Rotor diameter – 310 m
- Farm – Fuzhou, Fujian Province.
- Country - China

The larger the WTs are the bigger issues come along the way

Transportation/infrastructure issues:



Large territories are needed and advanced modelling of the flows:

Possibilities: new roads, more jobs

Possibilities: from ground to offshore, more jobs

The biggest wind solar hybrid plant in the world

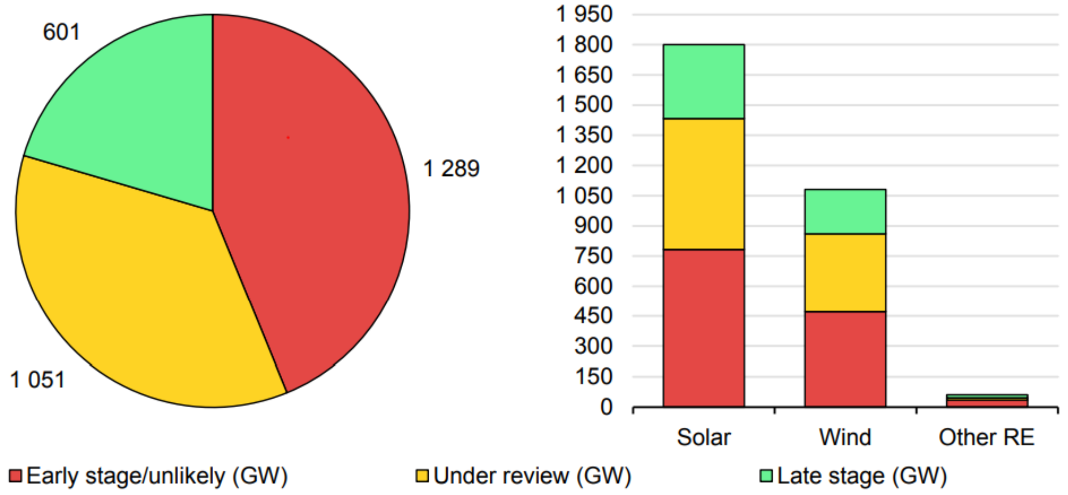
- Owners – Adani Group, India
- Installed capacity – 30 GW
- Number of PV panels – 60 000 000
- Number of wind turbines - 770
- Area – 538 км^2

Adani is a global leader balancing two worlds — dominating **renewable energy projects** while remaining deeply entrenched in **coal, mining, and heavy industry**

Bottlenecks in the development of new power generation plants

- Bureaucracy when using large territories for the plants
- Old grid infrastructure to be redesigned – more powerful transformers, more robust power lines and substations
- Increasing wind and solar PV generation is leading to higher curtailment, underlining the growing need for flexibility
- Grid connection queues have become show stoppers for renewable power plants. 1650GW of installed power plants are waiting for their turn (based on the July 2024)
- Sophisticated algorithms of control dur varying nature of renewables (rapid clouds, wind gusts, etc.)
- Harsh grid compliance requirements
- Energy traders making the control even more advanced
- Negative prices for the generated power from VRE

Renewable energy capacity in connection queues by project stage



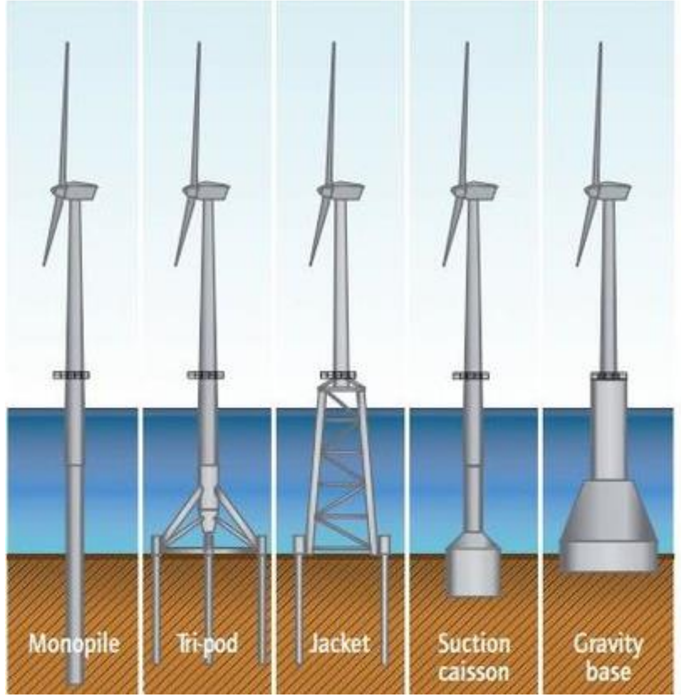
Horizontal axis wind turbines (HAWT)

Types

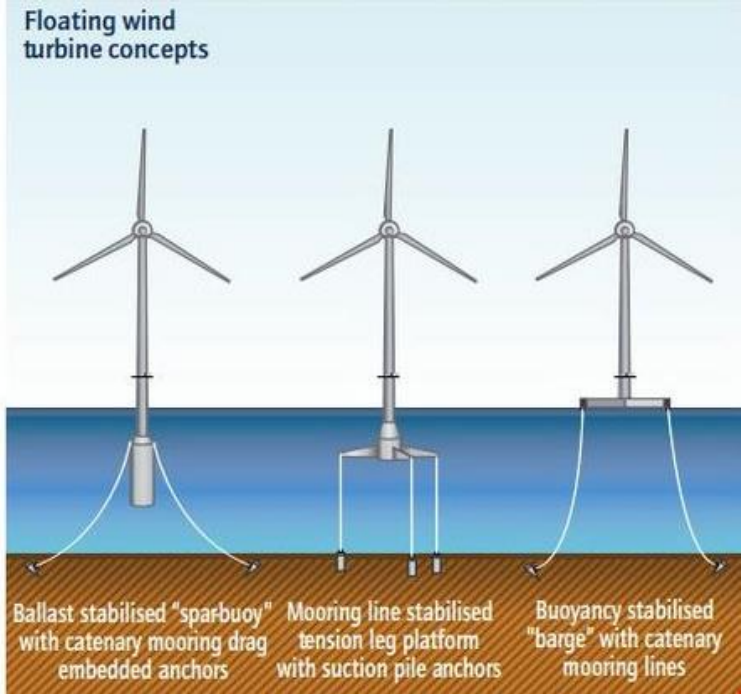
Onshore

Offshore

Offshore - fixed



Offshore - floating



Vertical axis wind turbines (VAWTs)

Types by rotor

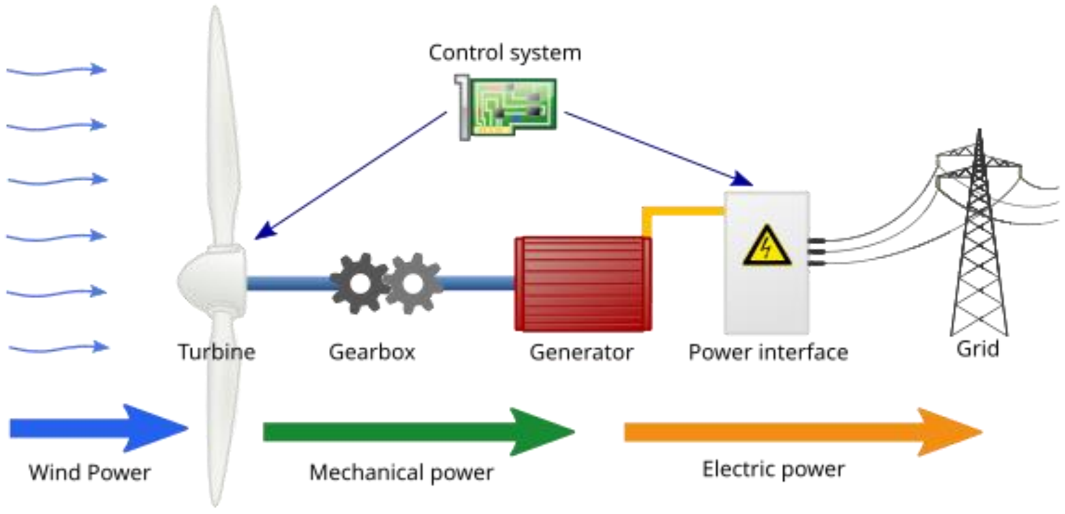
Savonius

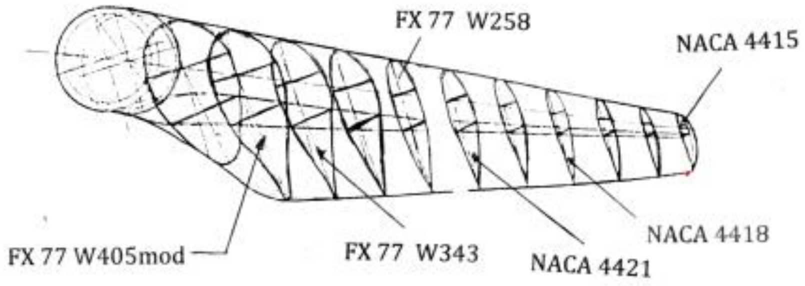
Darrius

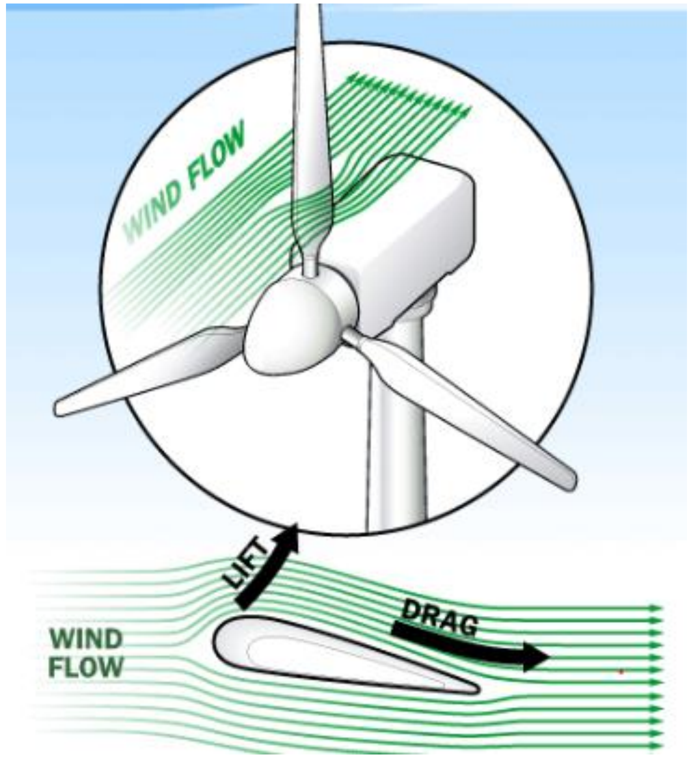
H-rotor

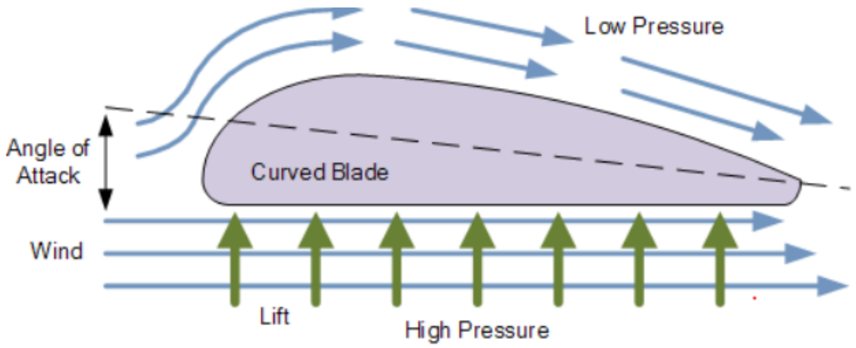
VAWT with concentrator

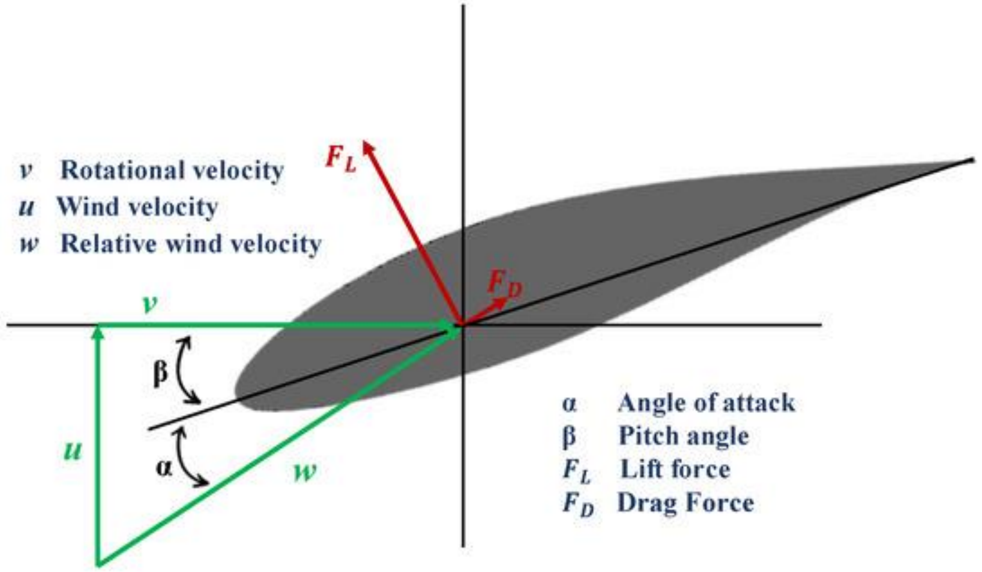
General scheme of transforming wind energy into the electrical energy – part 1



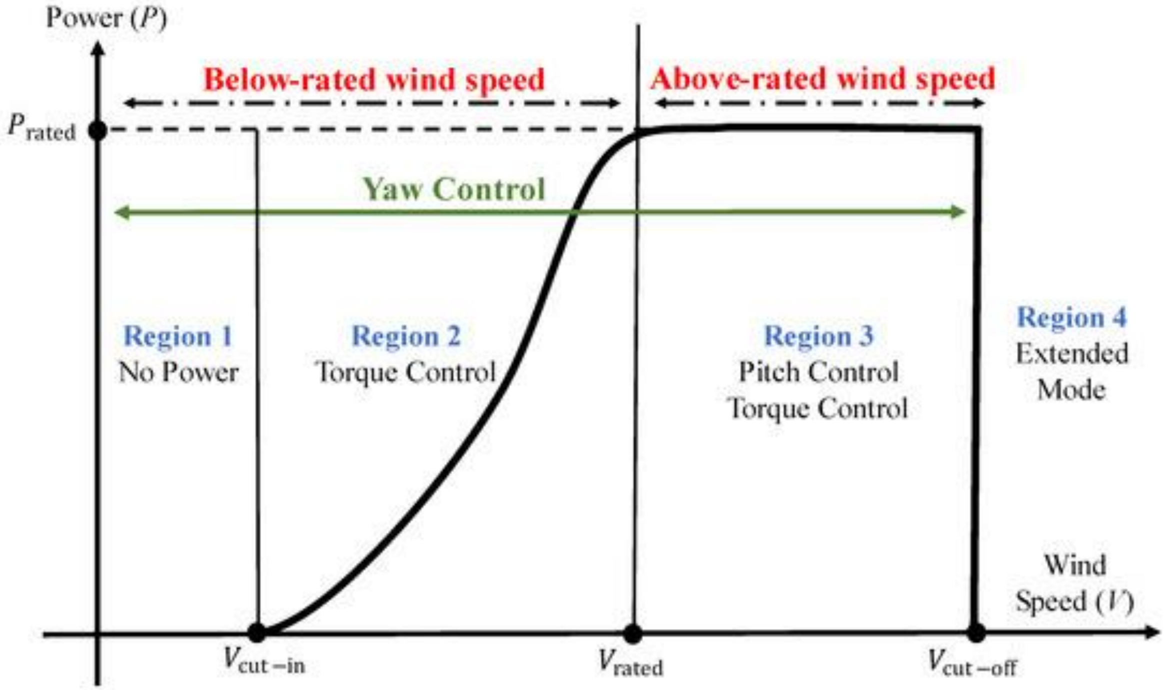


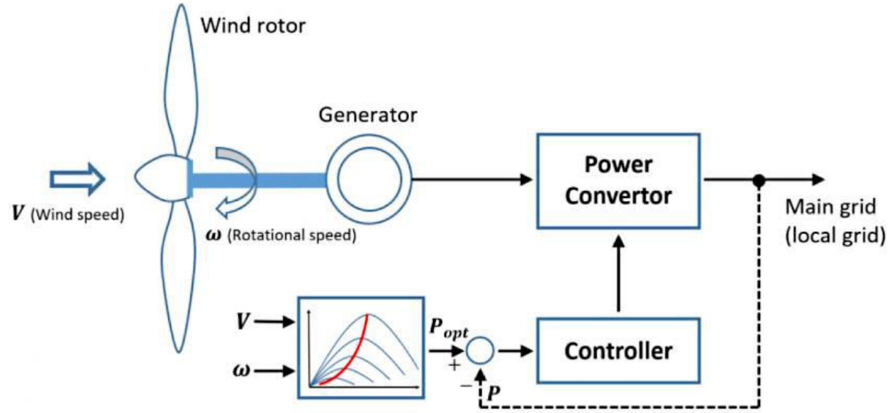


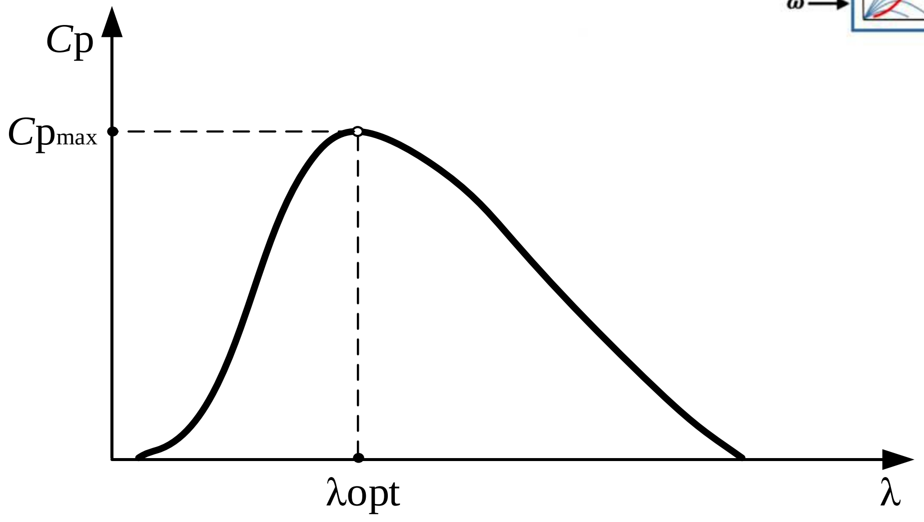




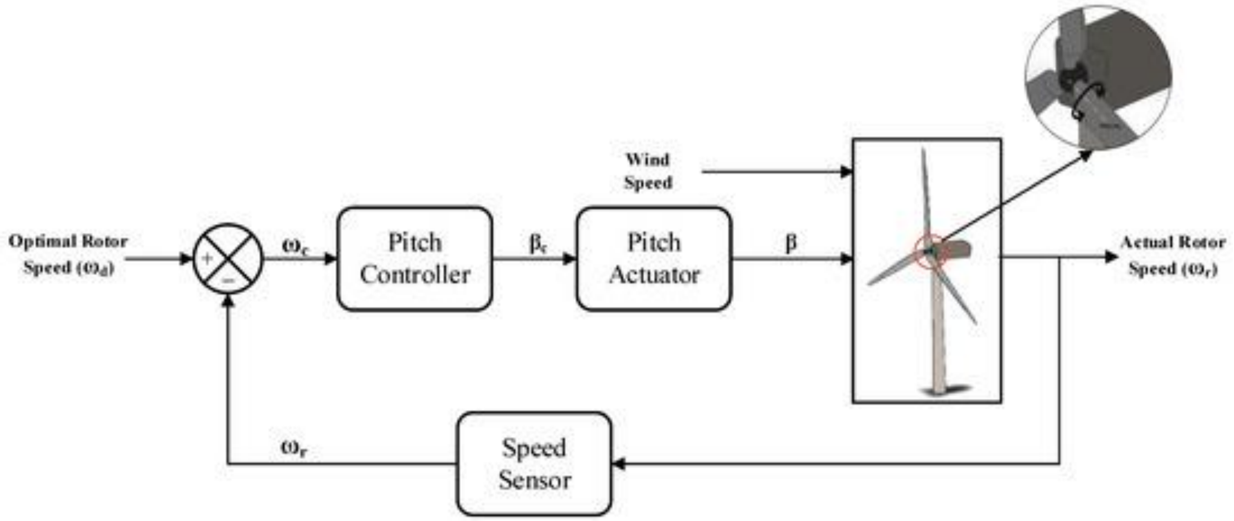
General scheme of transforming wind energy into the electrical energy – part 2







$C_P = 0.593,$
Bet′z limit



$$P_w = 0{,}5\ \rho_a\ A\ C_P(\lambda)\ V_w^3$$

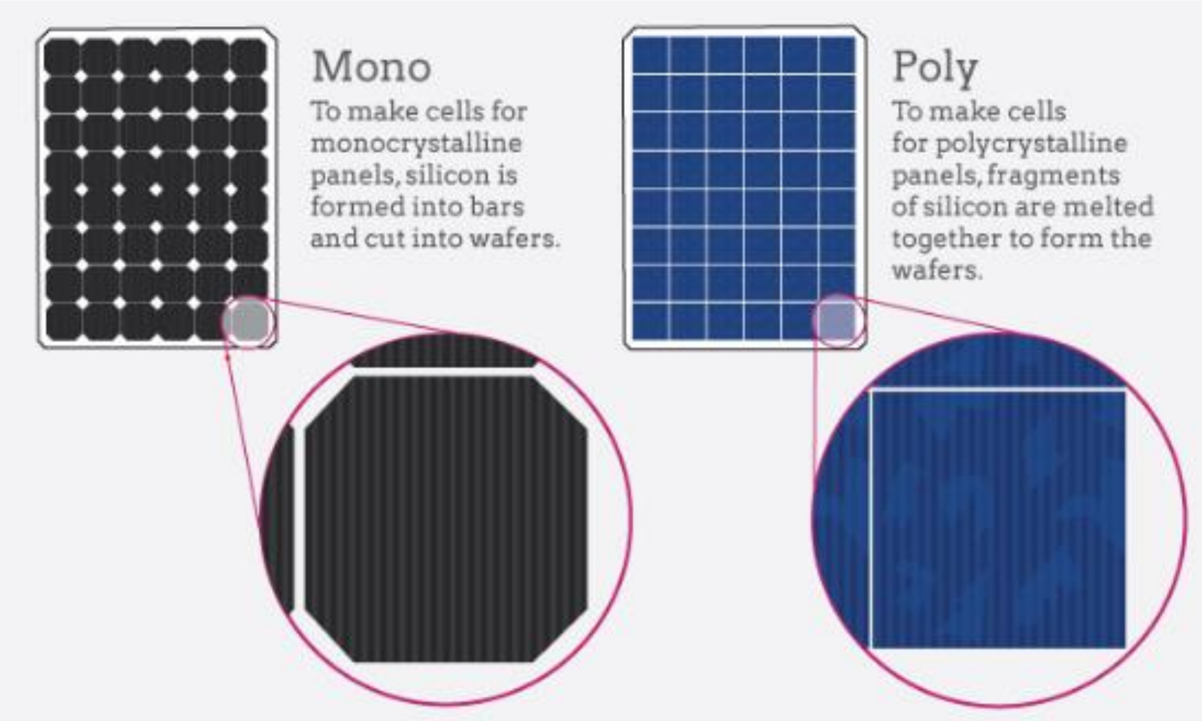
$$\lambda = \frac{\omega\ R}{V_w}$$

ρ_a – density of the fluid

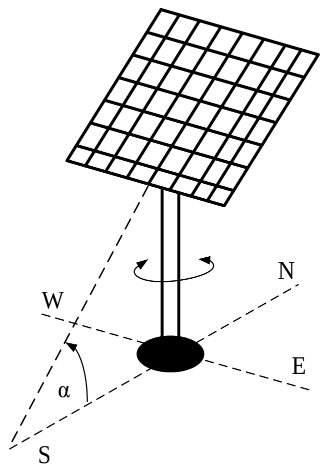
$A = \pi r^2$

V_w – wind speed, m/s

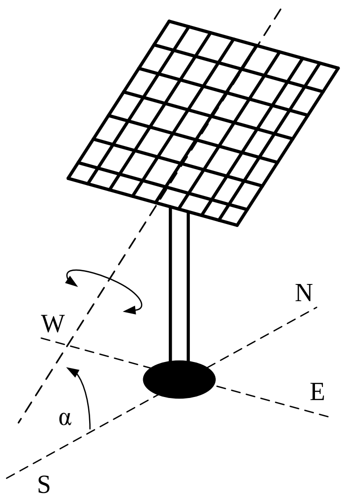
Photovoltaic panels & inverters



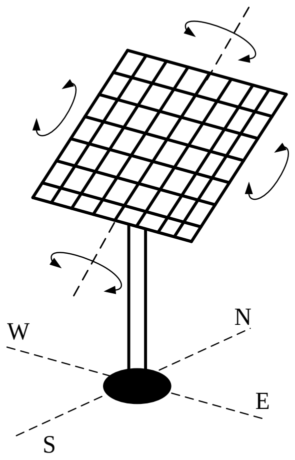
String inverter



Single coordinate azimuthal orientation (single axis tracker)

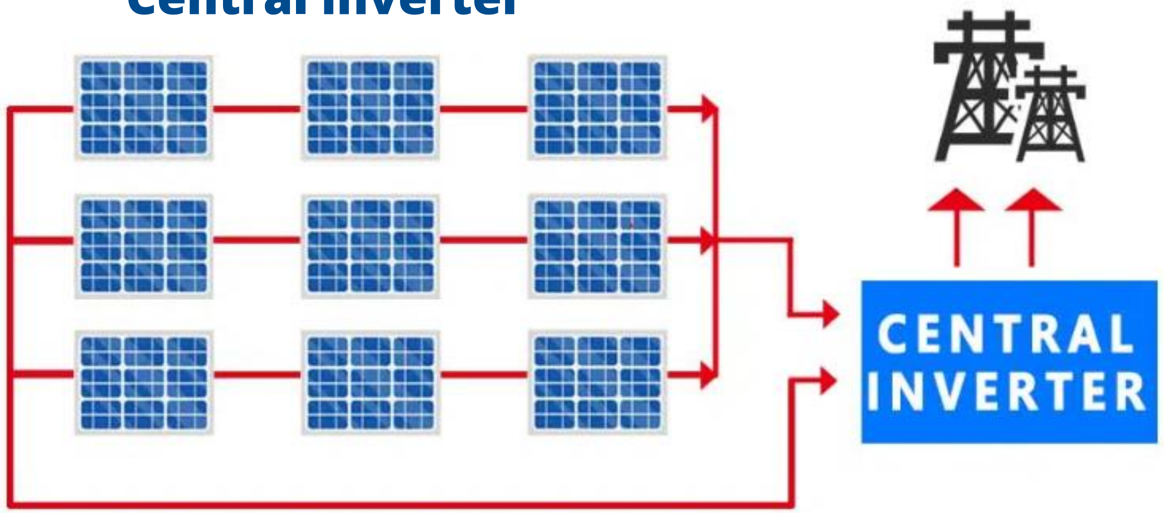


Single coordinate meridional orientation (single axis (tilted) tracker)

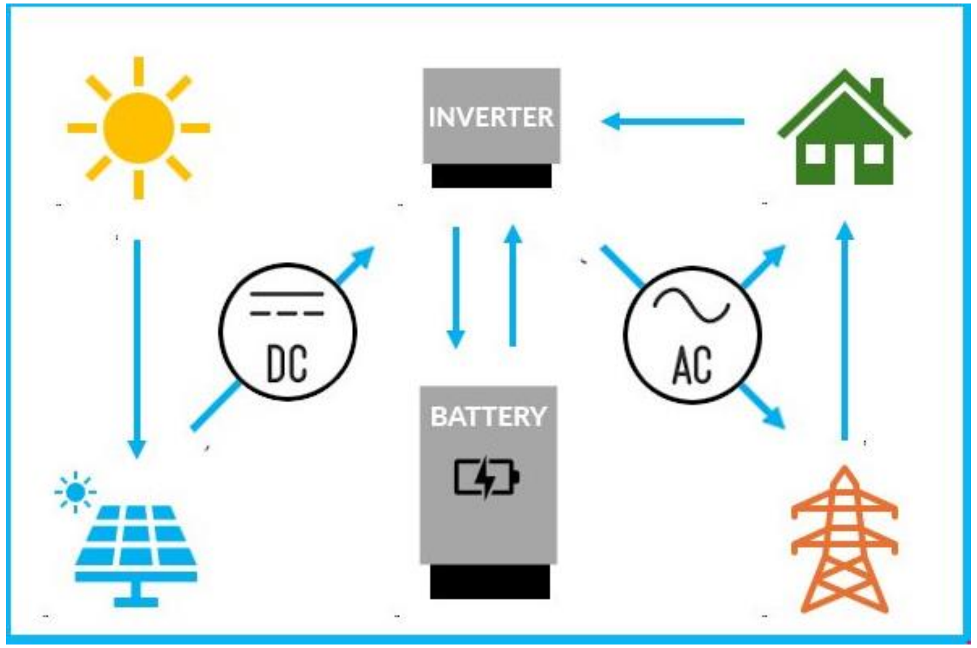


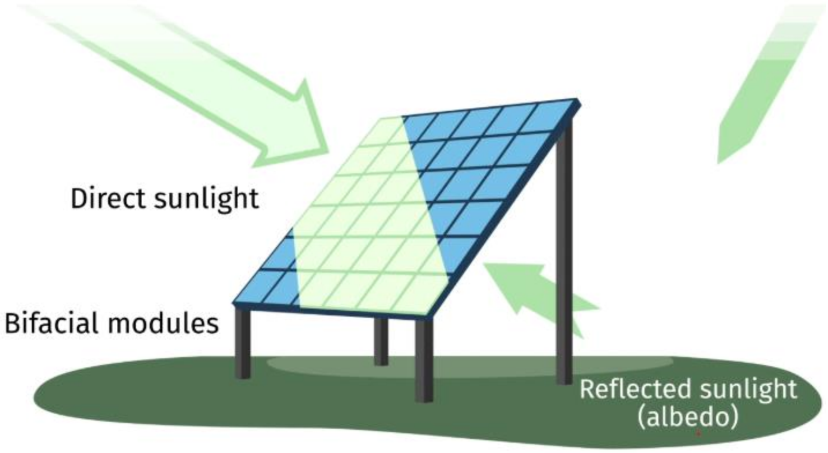
Double coordinate Orientation (dual axis tracker)

Central inverter



General scheme of transforming solar energy into the electrical energy – part 1



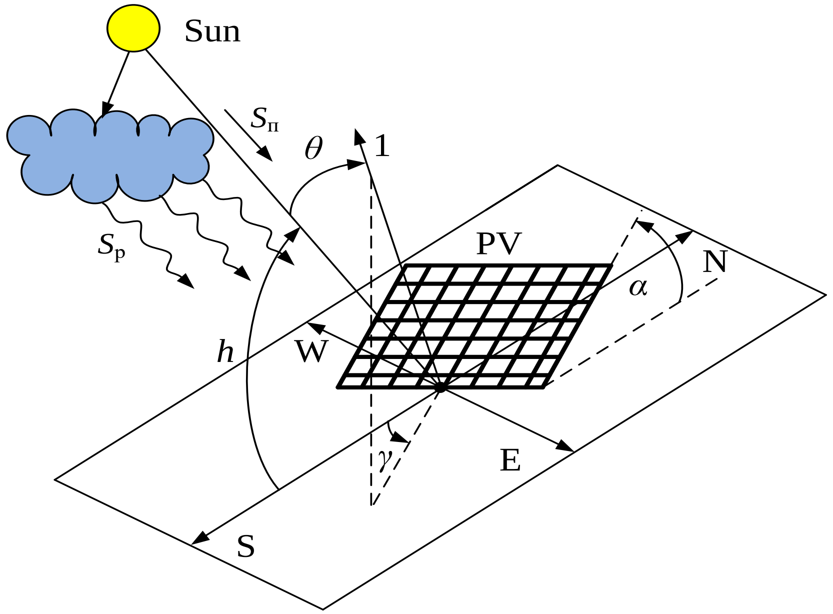


$$P_{total} = P_{front} + P_{rear}$$

$$P_{front} = POA * A * Efficiency,$$

POA – plane of array irradiance, $\frac{\text{W}}{\text{m\^{}2}}$

A – area, m^2



$$S_п = S_м \cos\theta$$

$$S_м = 1085{,}46 - 194{,}1(\sin h)^{-1} + 11{,}36(\sin h)^{-2}$$

$$\cos\theta = \sin\varphi\ \cos\alpha\ \sin\delta - \cos\varphi\ \sin\alpha\ \cos\gamma\ \sin\delta + \sin\alpha\ \sin\gamma\ \sin t_г\ \cos\delta + \cos\varphi\ \cos\alpha\ \cos t_г\ \cos\delta + \sin\varphi\ \sin\alpha\ \cos\gamma\ \cos t_г\ \cos\delta$$

$$S_р = 137{,}1 - 28{,}82(\sin h)^{-1} + 2{,}27(\sin h)^{-2}$$

$$P_{rear} = GHI * Albedo * View\ Factor,$$

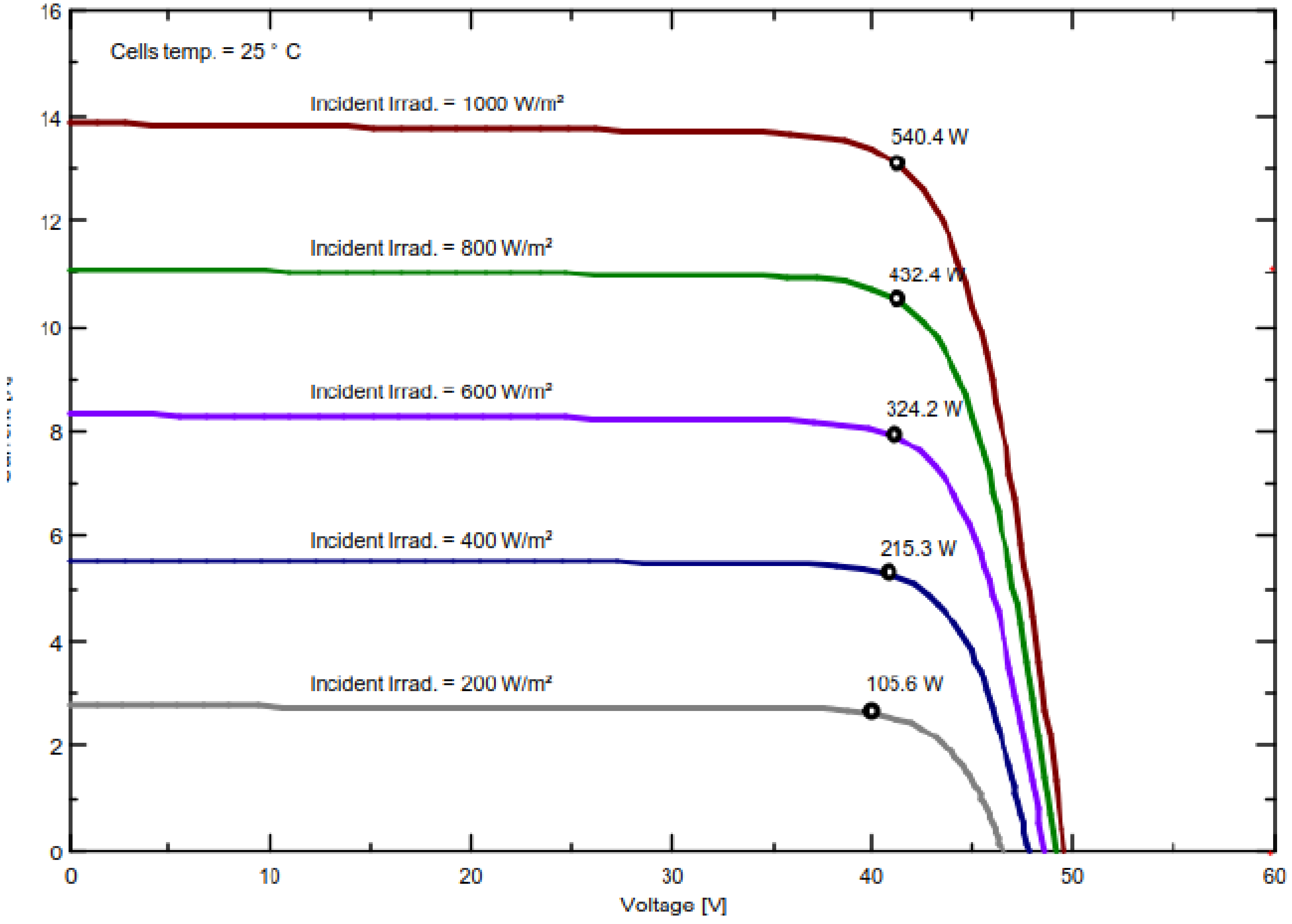
POA – global horizontal irradiance, $\frac{\text{W}}{\text{m\^{}2}}$

$Albedo$ – ground reflectivity

View factor – bifacial gain

General scheme of transforming solar energy into the electrical energy – part 1

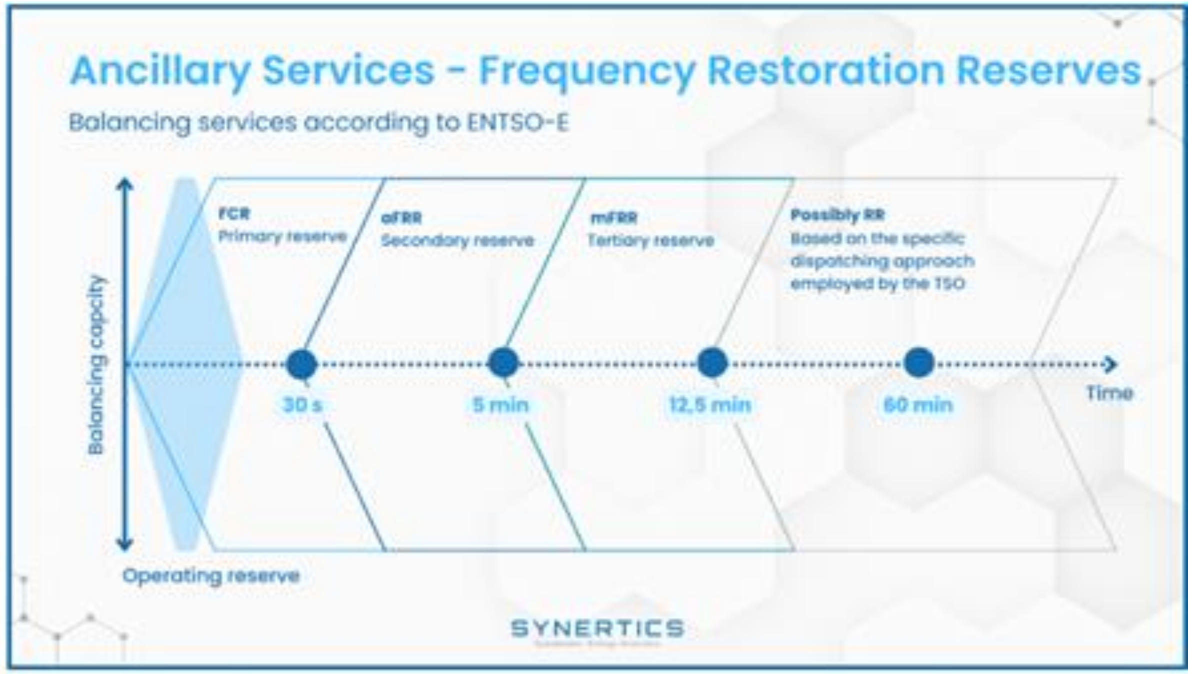
Power curve of the PV module: Longi Solar, LR5-72HPH-540M

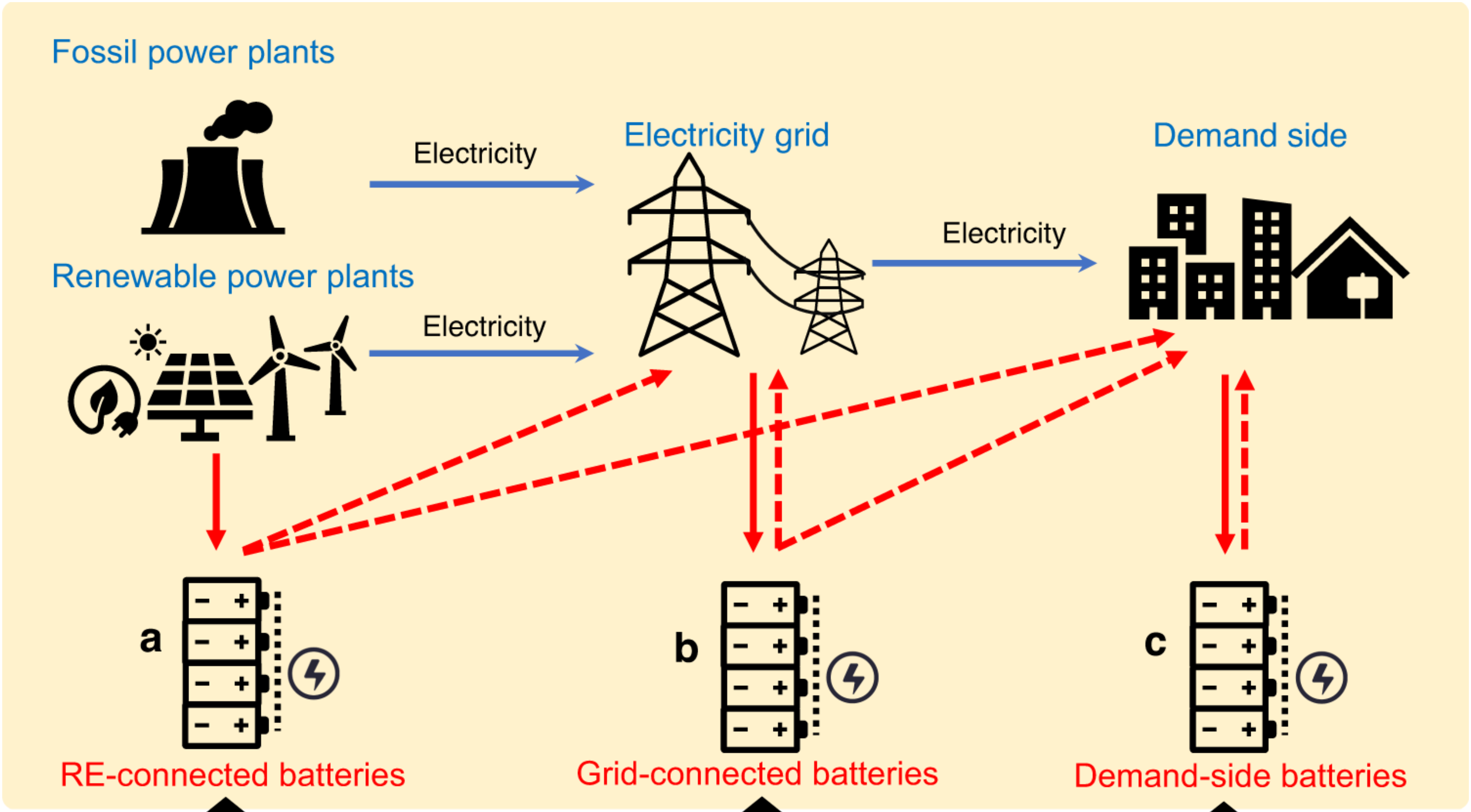


Corrections by temperature PV module: Longi Solar, LR5-72HPH-540M

Average Pmax [W] Results Acquired over Multiple Irradiances per Temperature				
Irradiance [W/m²]	Module Temperature			
	15 °C	25 °C	50 °C	75 °C
100	53.028	51.203	-	-
200	108.540	104.701	-	-
400	220.413	212.811	195.466	-
600	332.473	321.054	295.510	266.880
800	443.603	428.739	395.174	357.287
1000	553.631	535.000	492.285	445.672
1100	-	587.307	539.709	487.047

Batteries

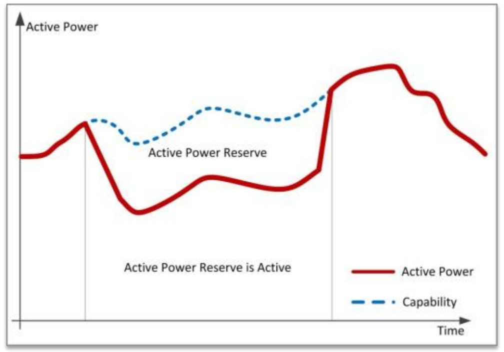




Constraint: Batteries charged only with co-located REs in each province

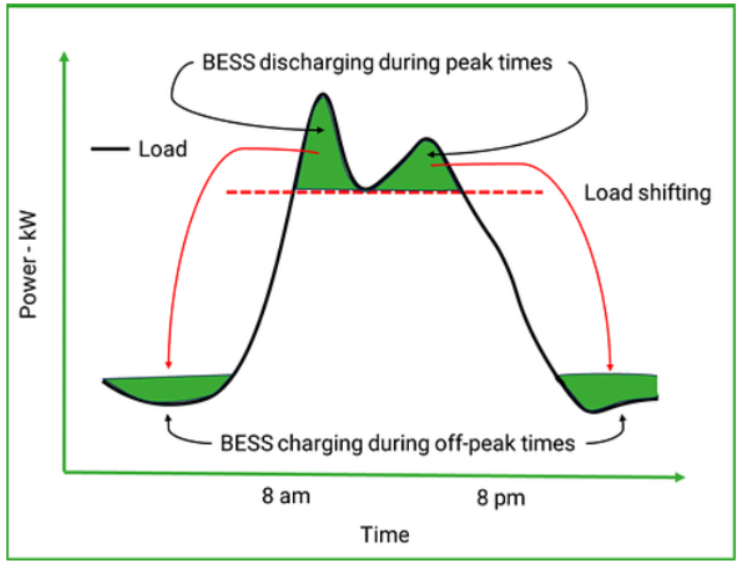
No Constraint

Constraint: Batteries are only discharged to the local distribution grid



Batteries: main functions

Load shifting



Generation smoothing

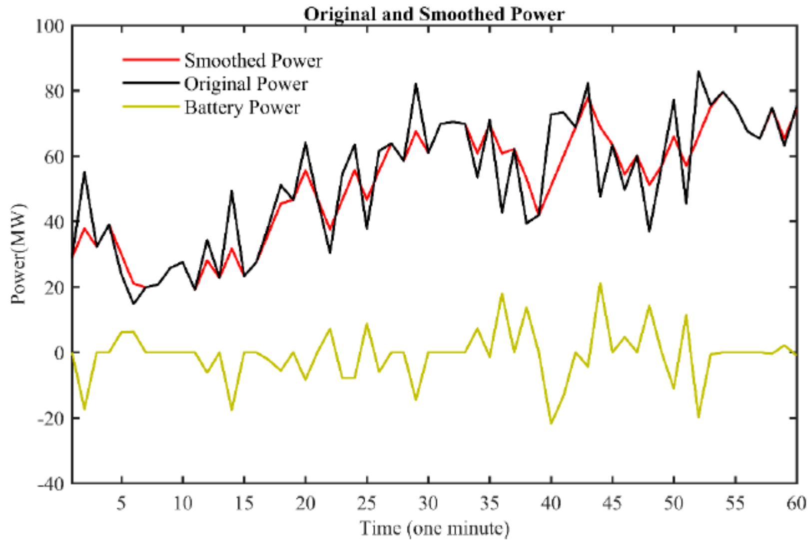


Figure 4. Sample DST-based battery power determination.

Ancillary services

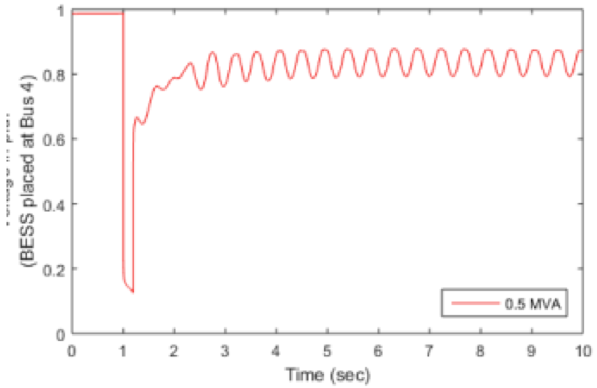
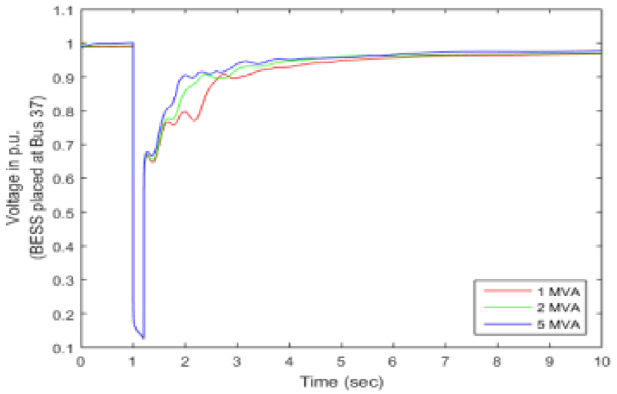
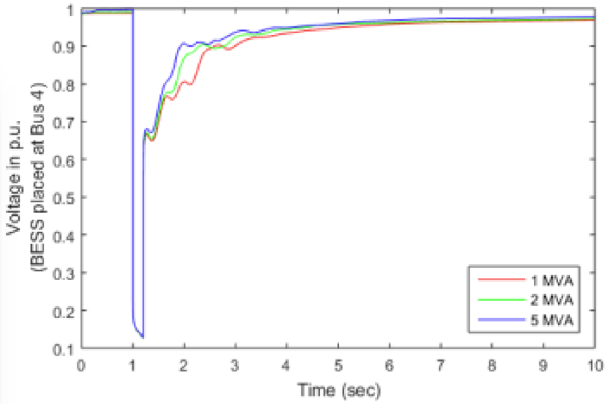


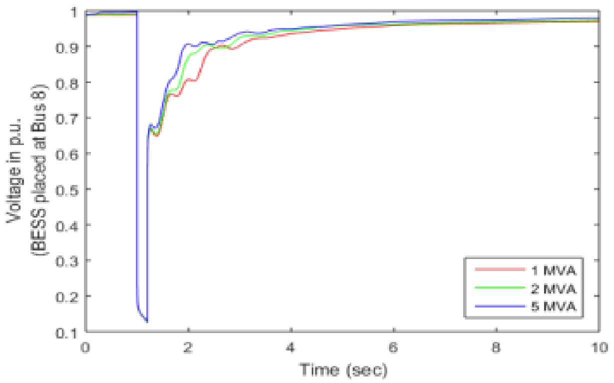
Fig. 5. Response of post-fault voltage at bus 4 with BESS of 0.5 MVA.



(d) Response of post-fault voltage at bus 4 when BESS is placed at bus 37.



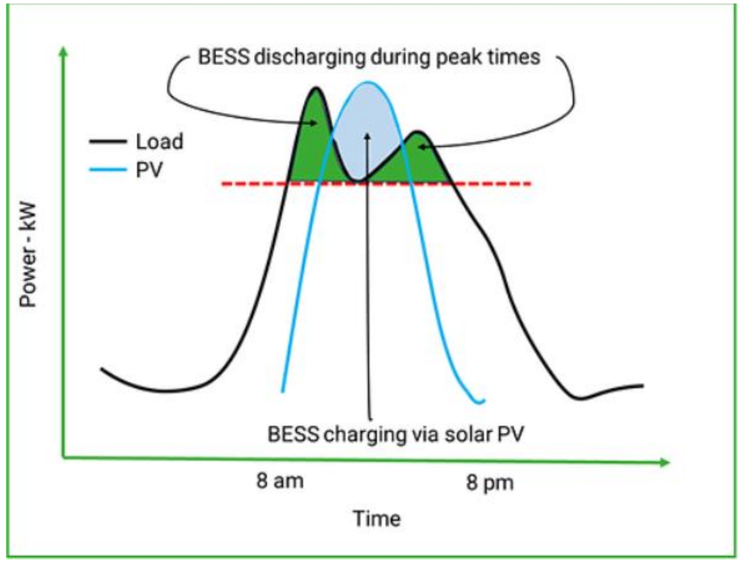
(a) Response of post-fault voltage at bus 4 when BESS is placed at bus 4.



(e) Response of post-fault voltage at bus 4 when BESS is placed at bus 8.

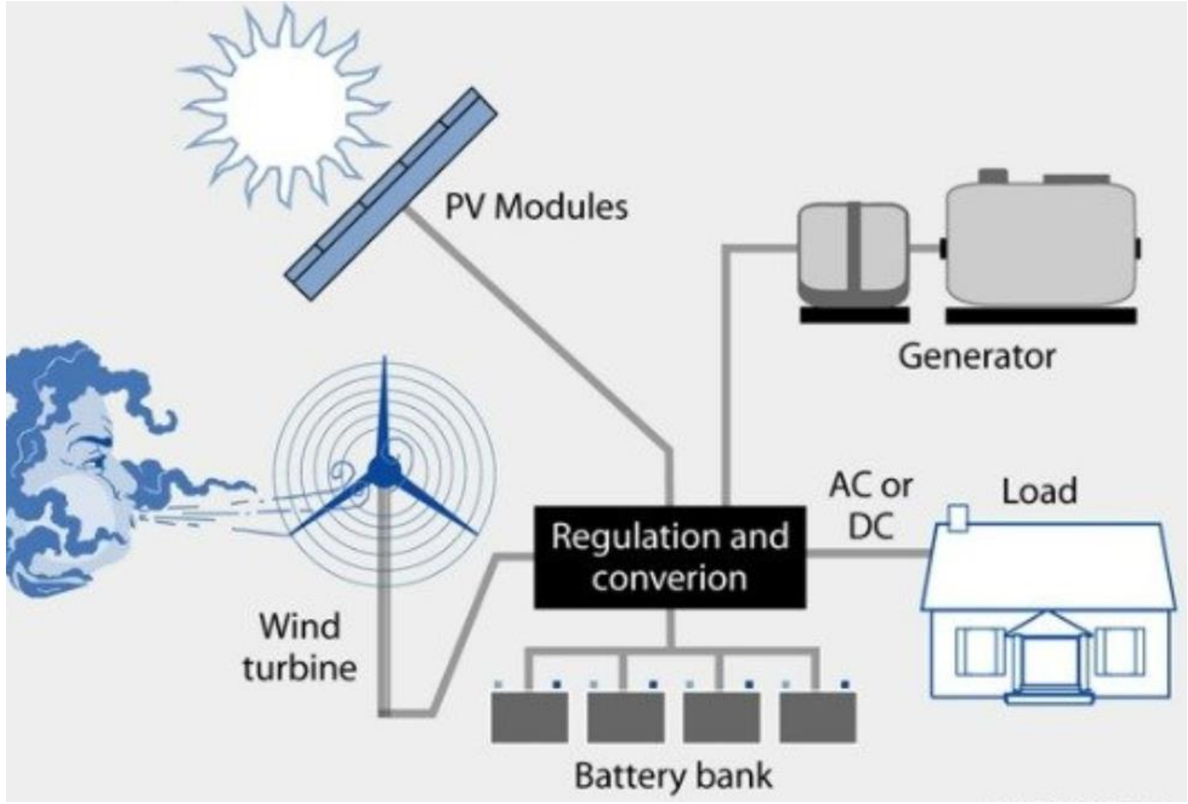
Fig. 6. Responses of post-fault voltage at selected locations with BESS of 1 MVA, 2 MVA and 5 MVA.

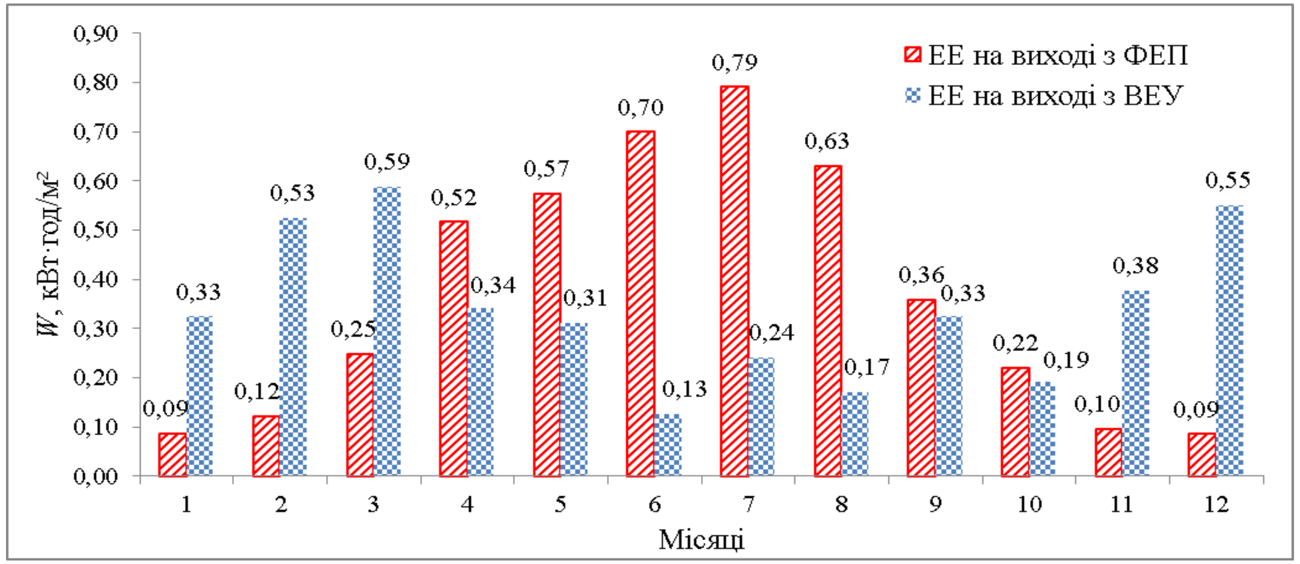
Peak shaving

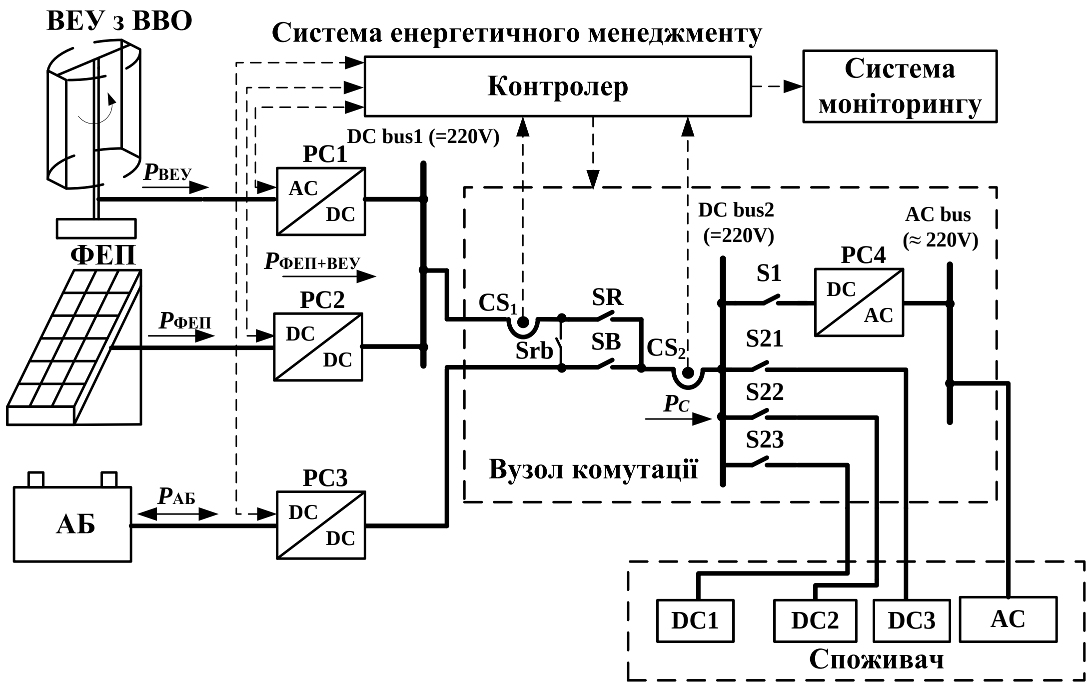


Energy trading support

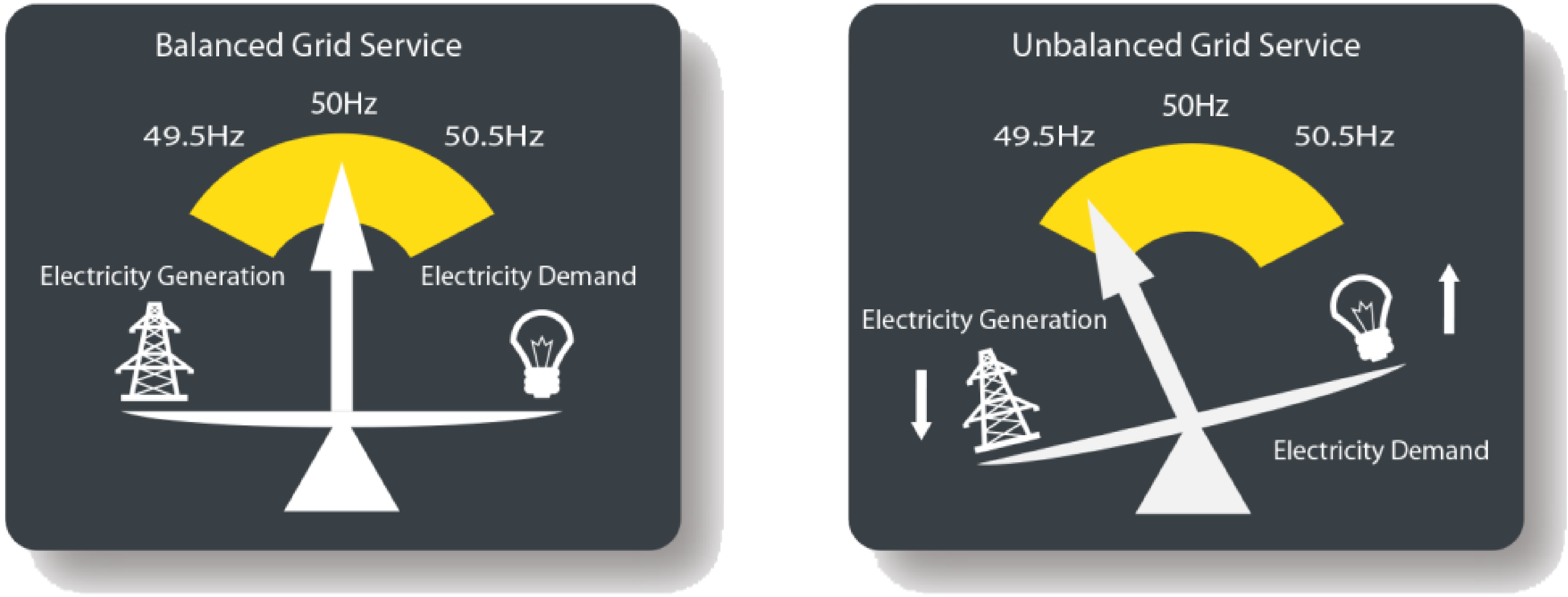
Hybrid plants

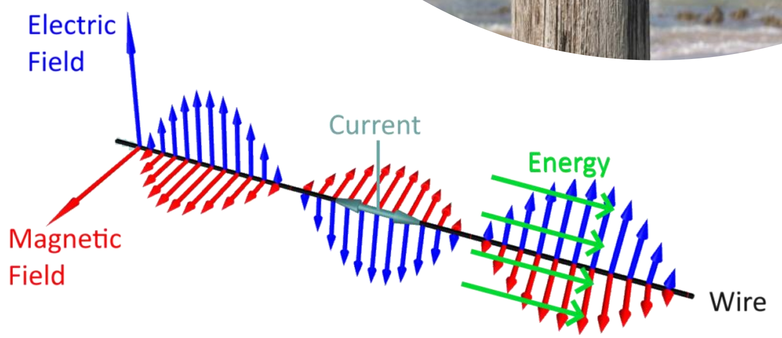


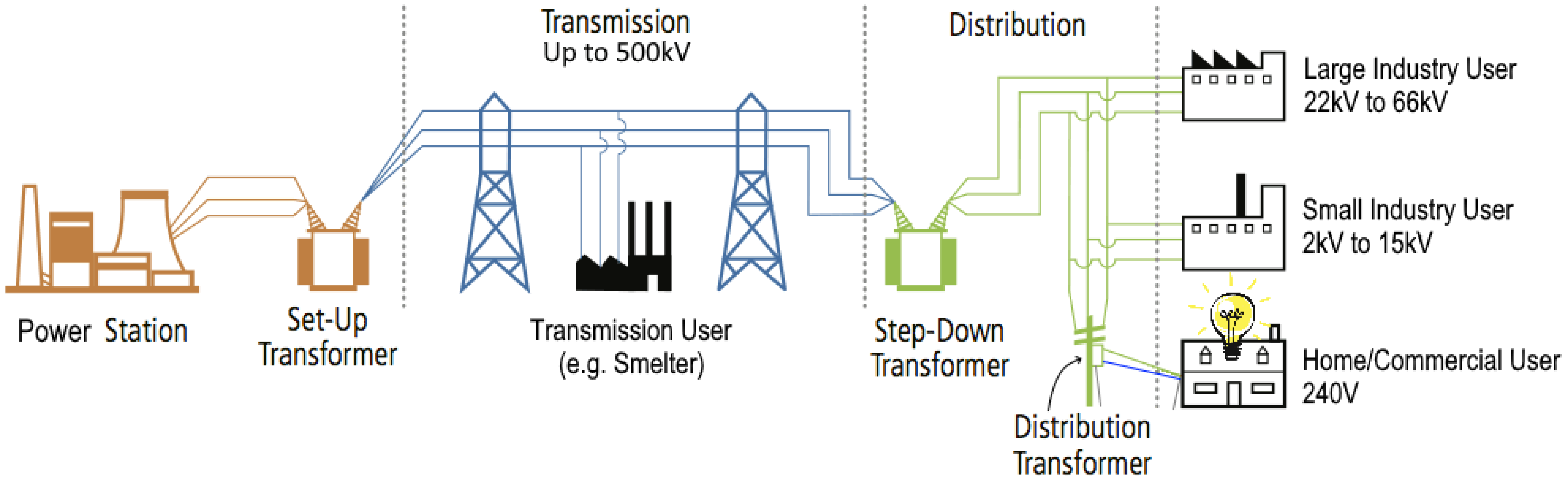


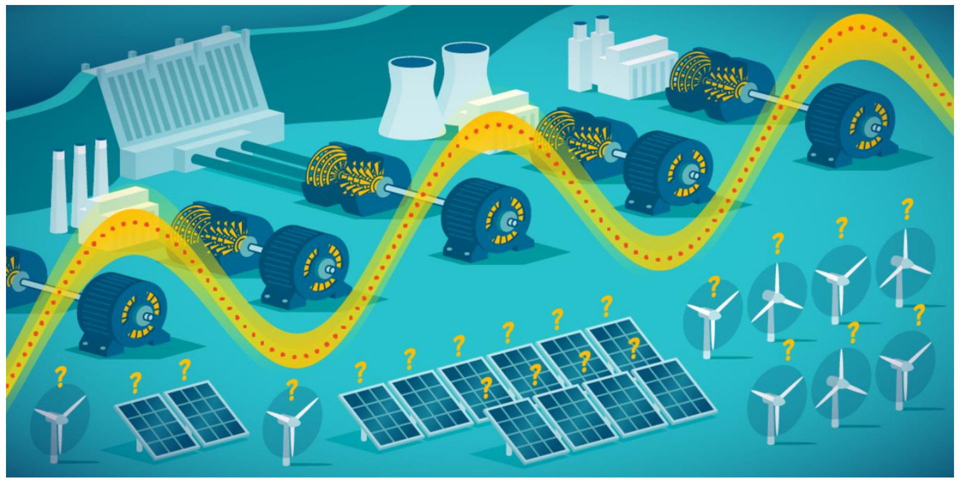


Challenges in balancing power in the grid

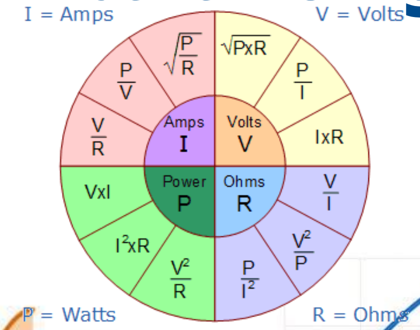


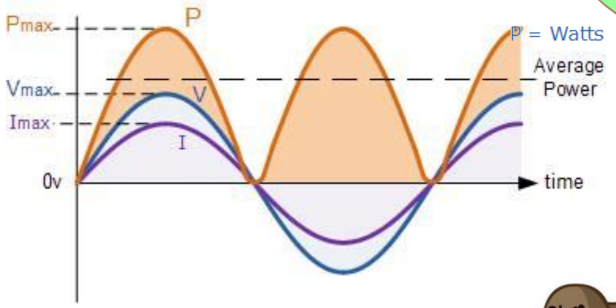


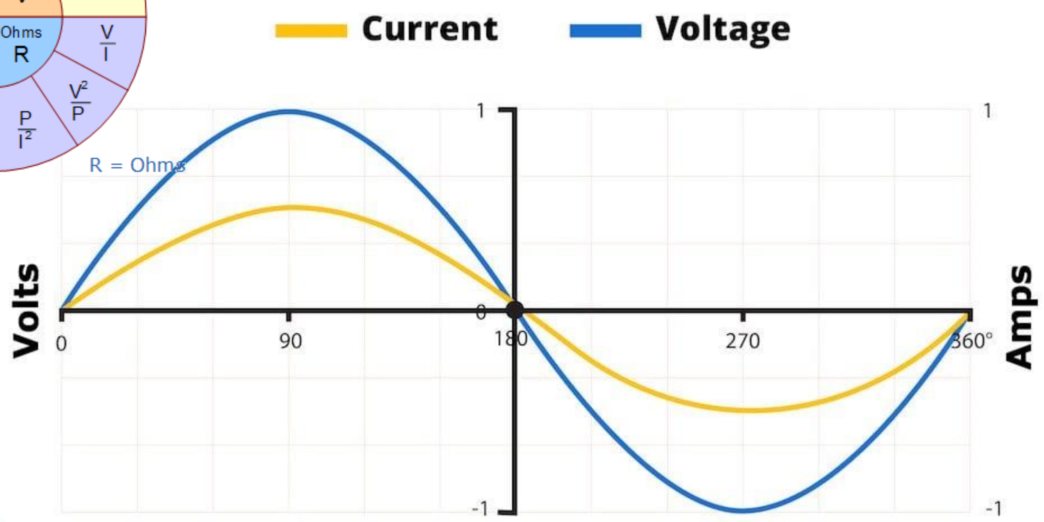


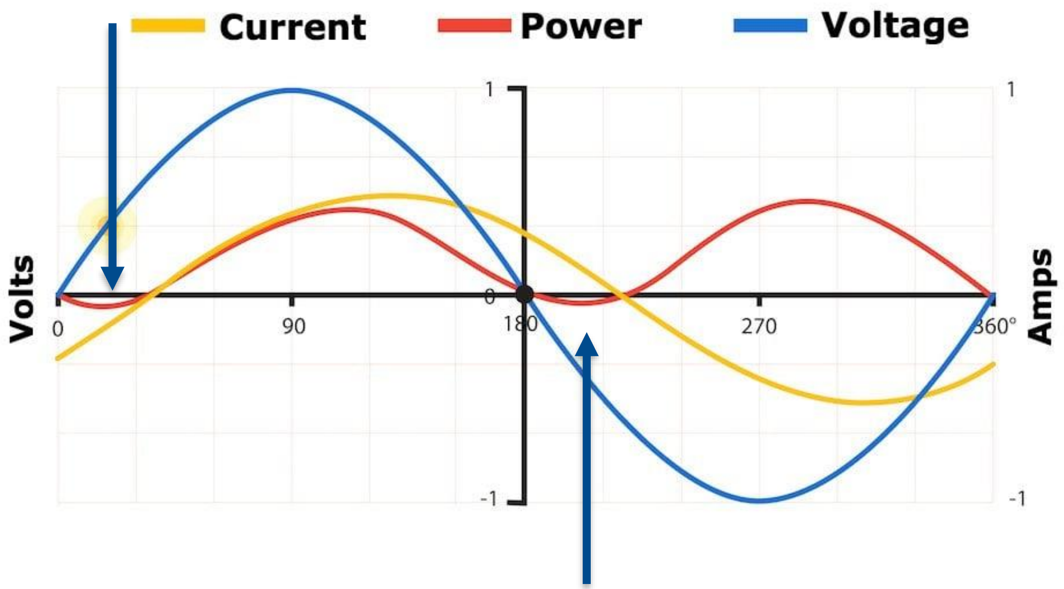


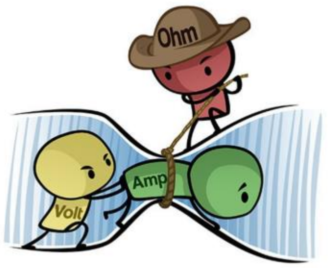
Challenges in balancing power in the grid

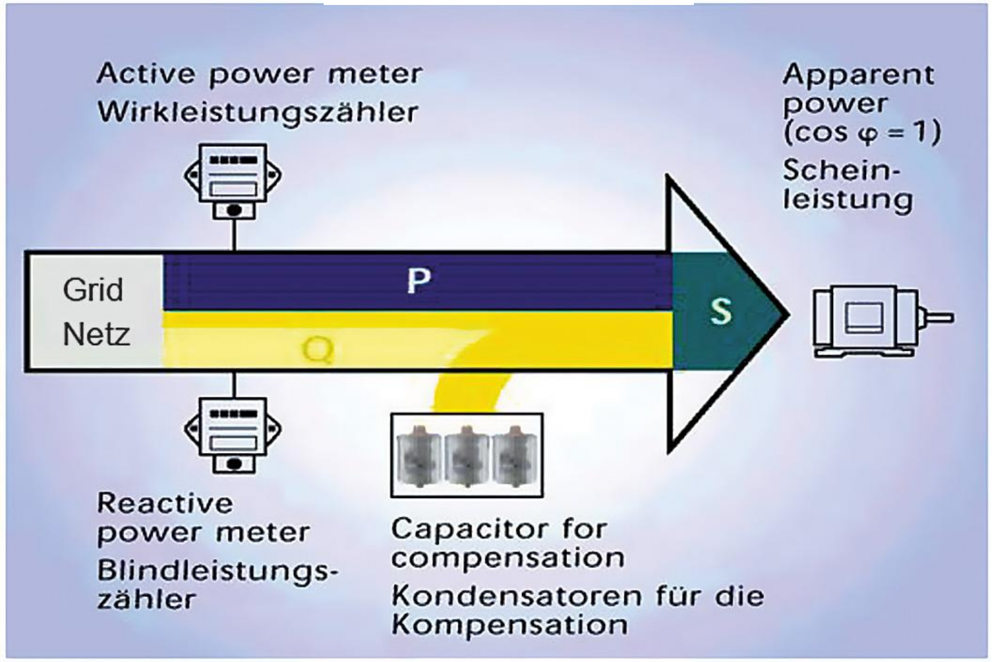








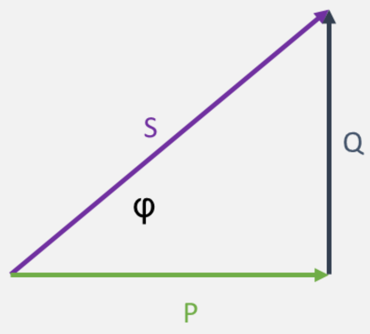




Active Power	P	[W]
Reactive Power (total)	Q_{total}	[var]
Effective Power-Factor	$\cos(\varphi) = \frac{P}{S}$	

$$sin(\varphi) = \frac{Q}{S} \qquad tan(\varphi) = \frac{Q}{P}$$

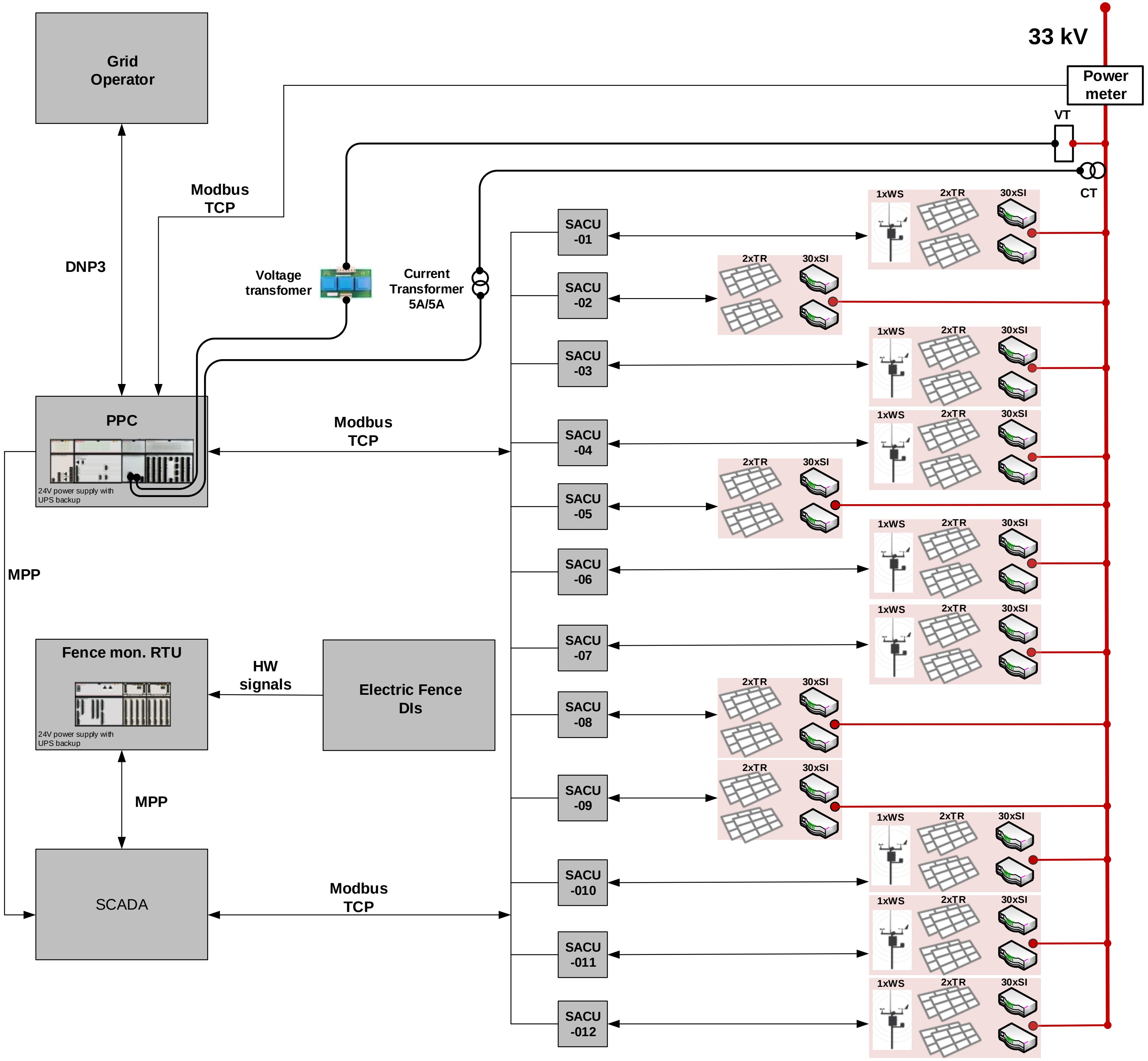
Fundamental View (50Hz/60Hz)



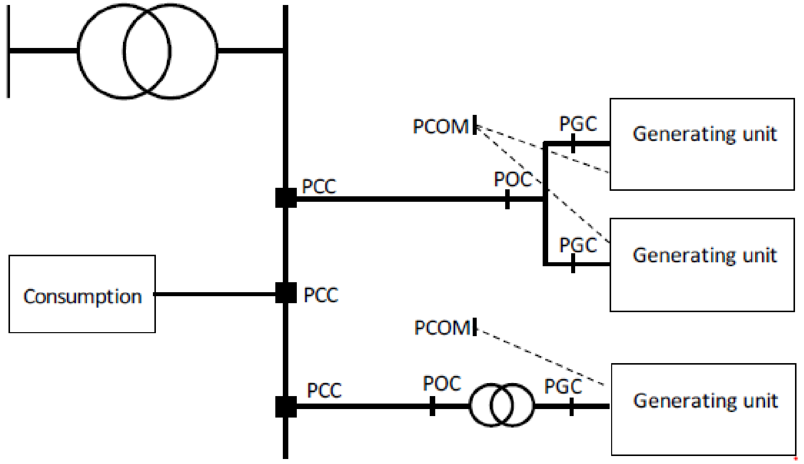
$$S = \sqrt{P^2 + Q^2}$$

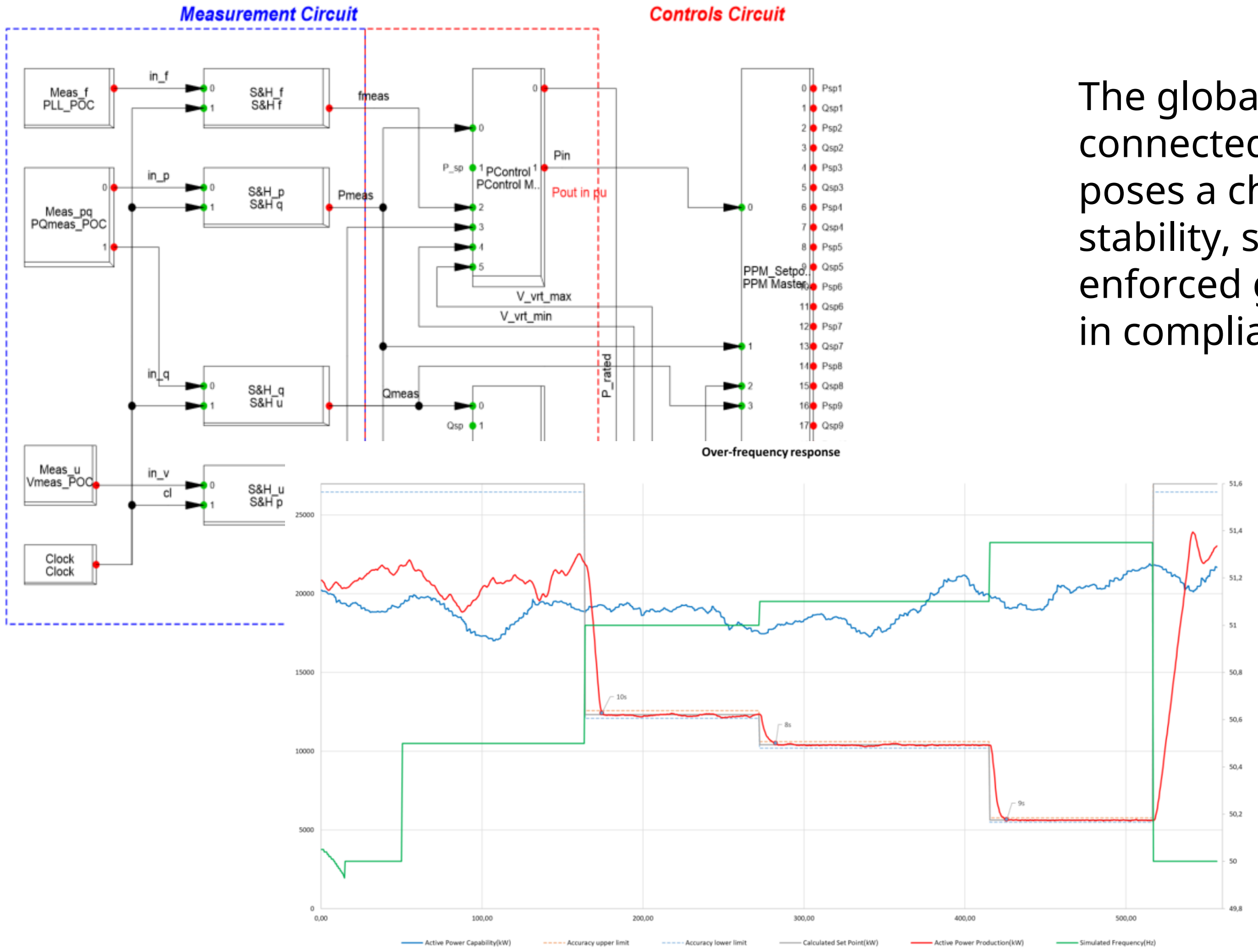
Apparent Power	S	[VA]

Solar plant control system



Grid Compliance



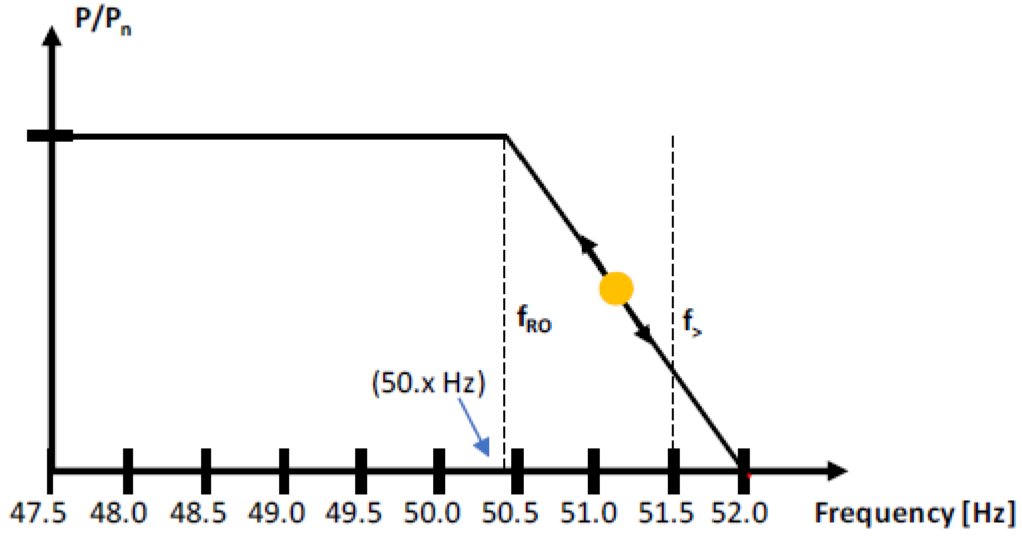


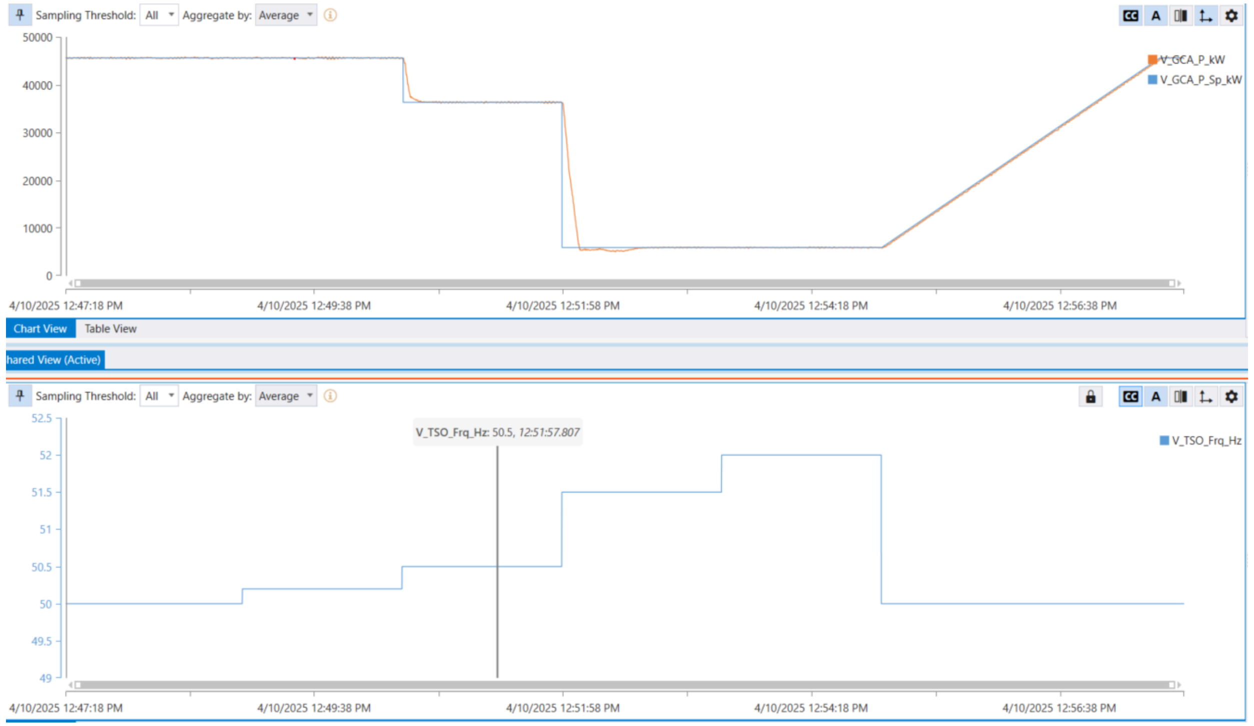
The global expansion of fluctuating renewable energy connected to the public transmission and distribution grids poses a challenge for grid stability. To enable robust grid stability, standards and national grid codes has been enforced globally. Our solutions ensures that your asset is in compliance with the national grid requirements.

- Grid Code Compliance off-the-shelf
- Verified simulation models in **DIgSILENT PowerFactory** and **PSCAD.**
- Grid Compliant with national Grid Codes:
- Hybrid PPC fulfills the recommendations and guidelines of **Entso-E**

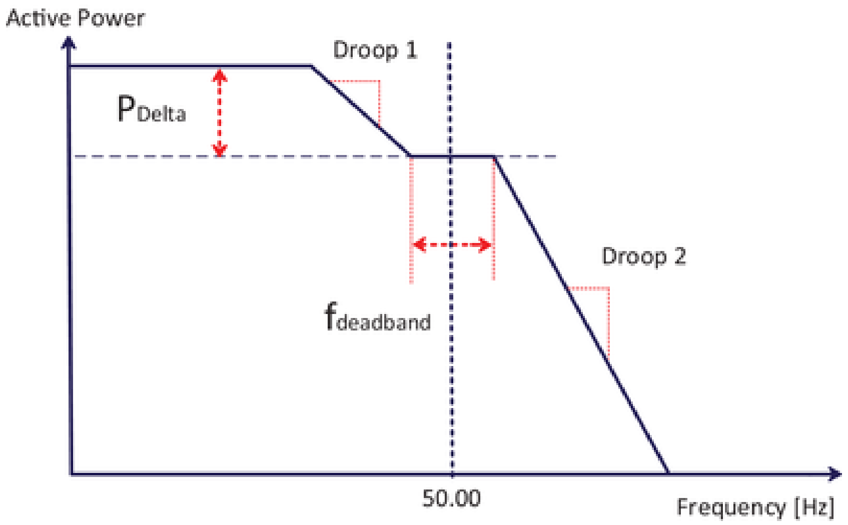
Preparing the plant for the grid compliance

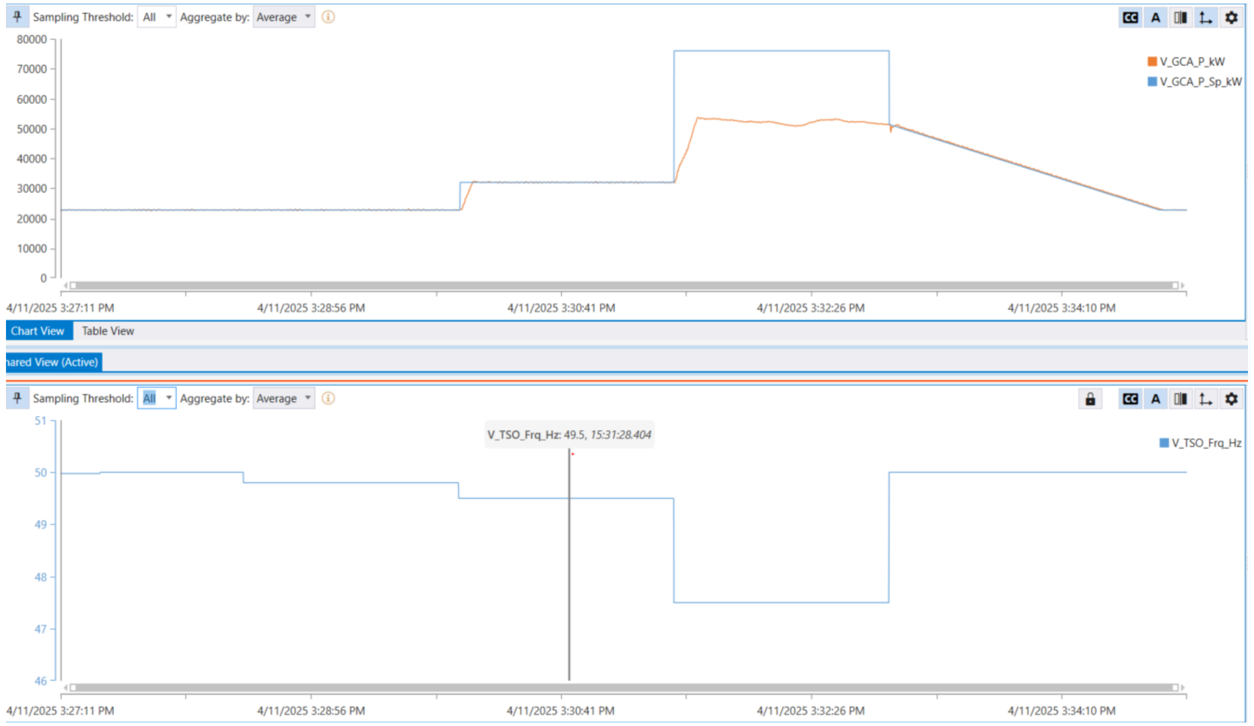
Active power constraint regulation



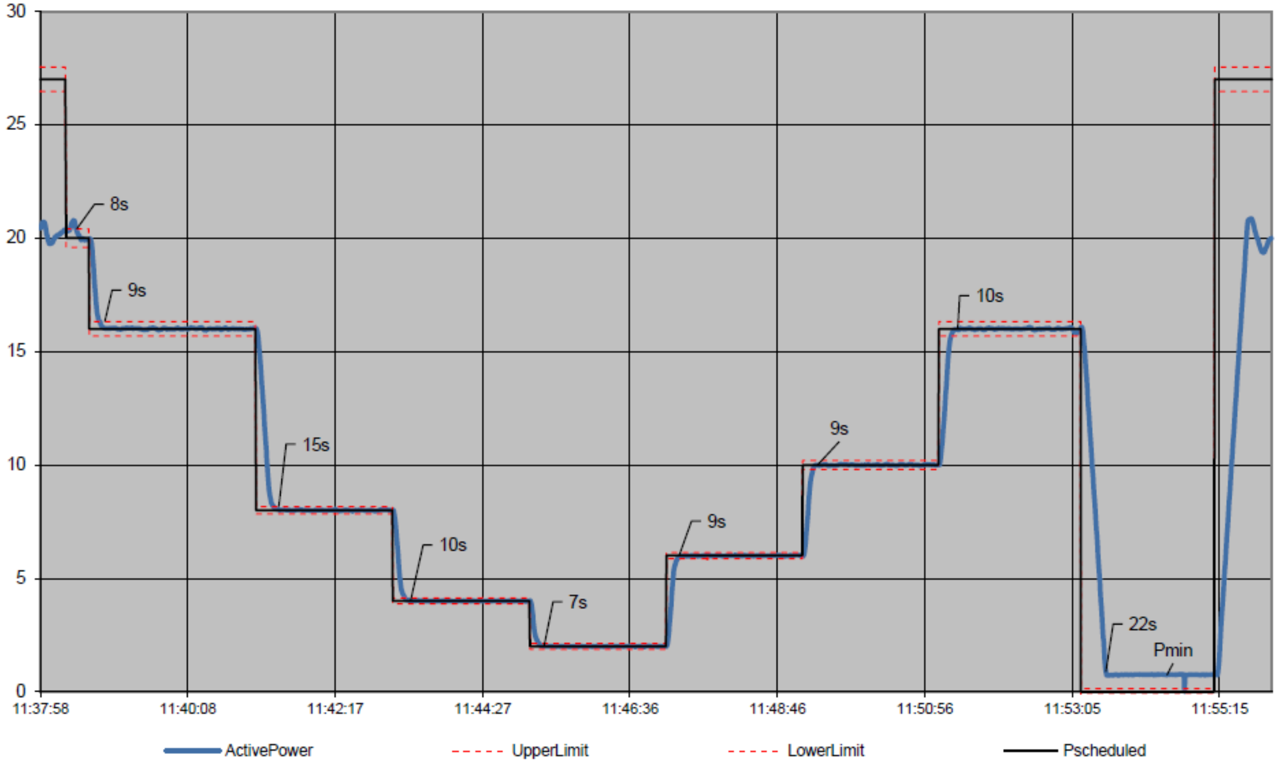


LFSM-O and LFSM-U regulation

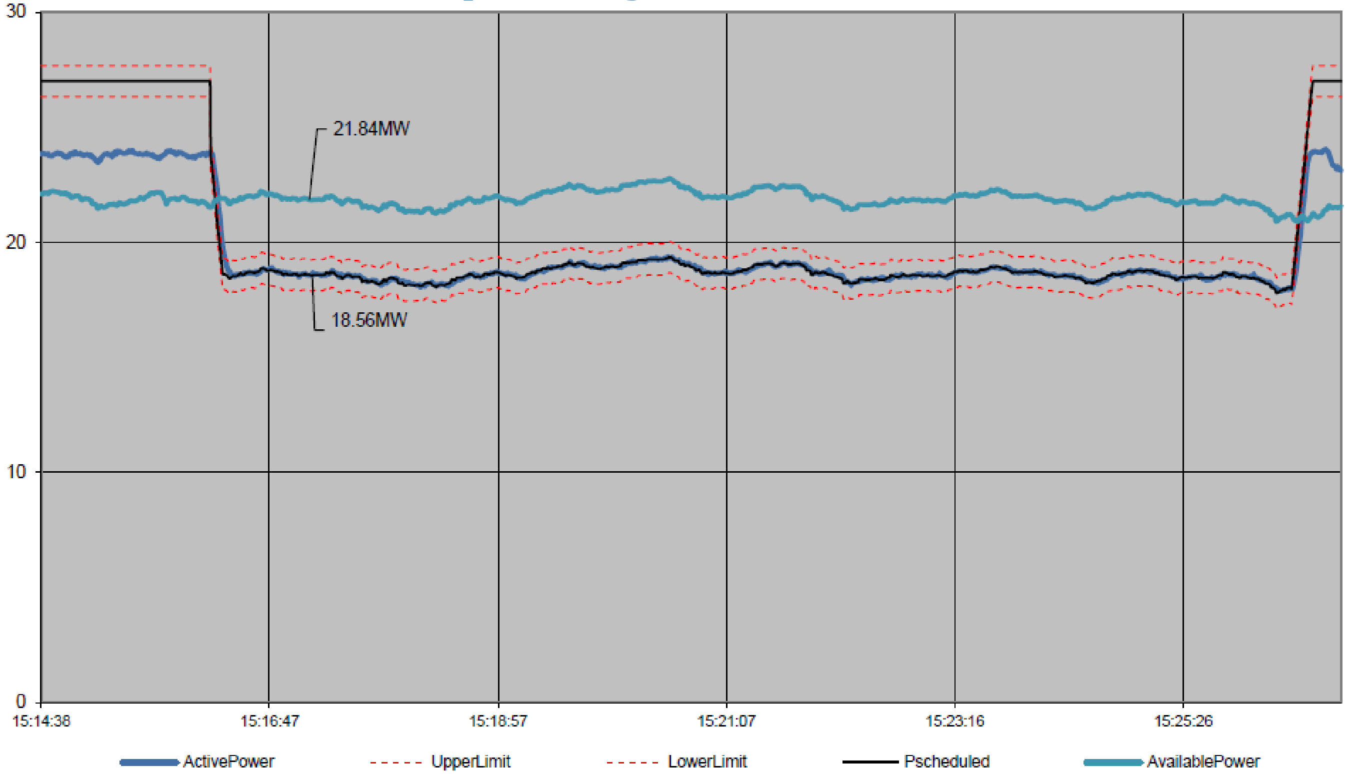




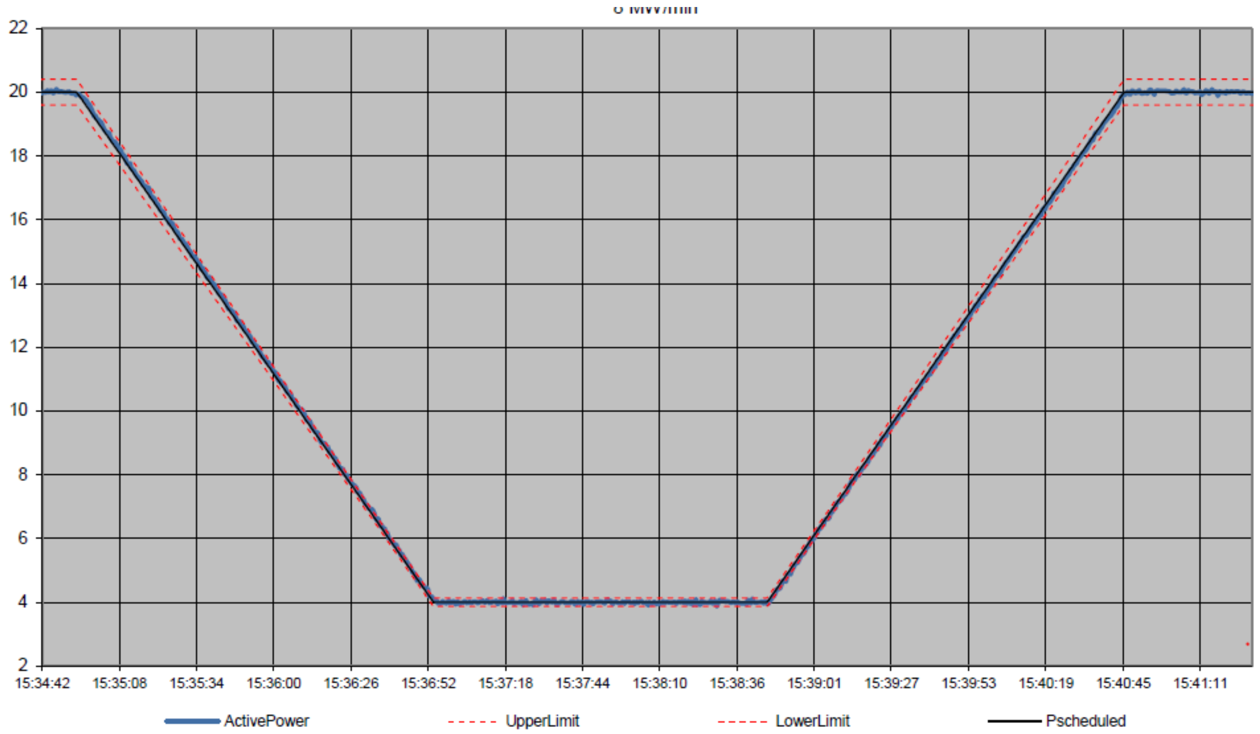
Absolute active power constraint



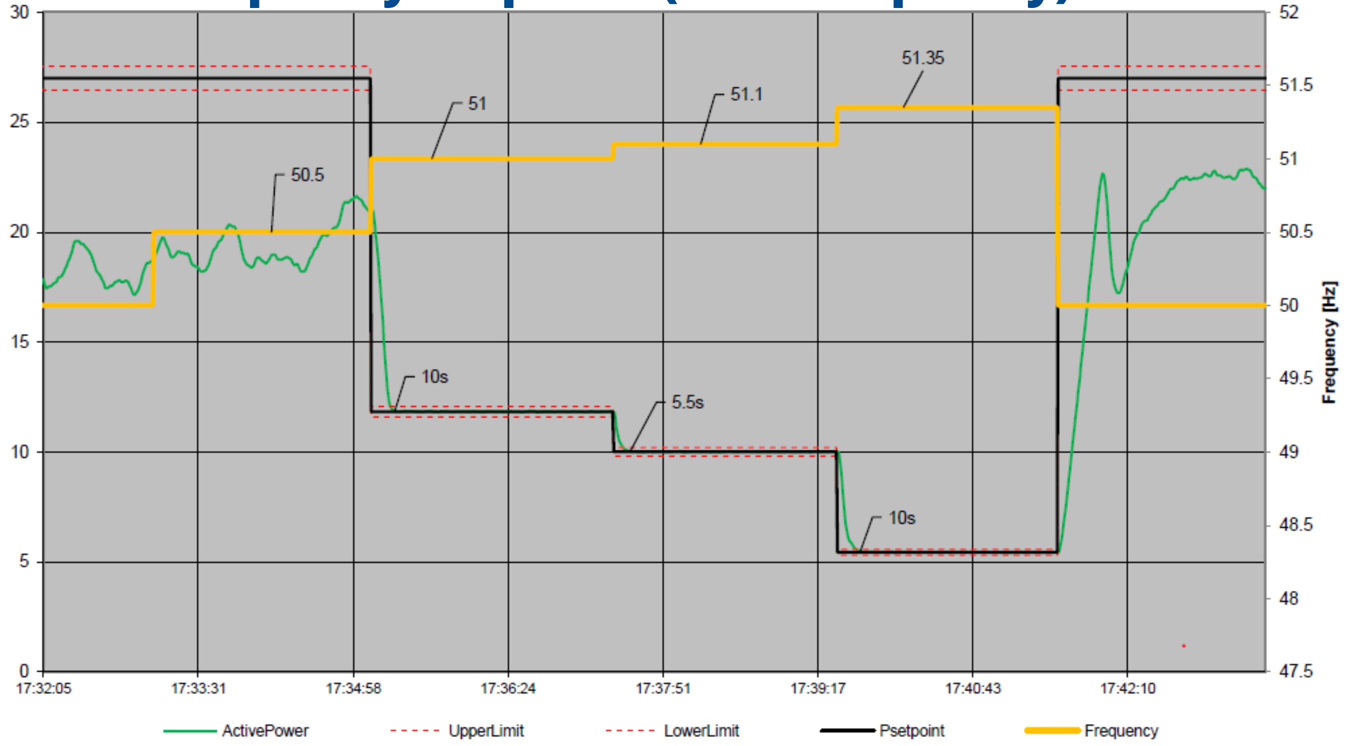
Pdelta (spinning reserve)



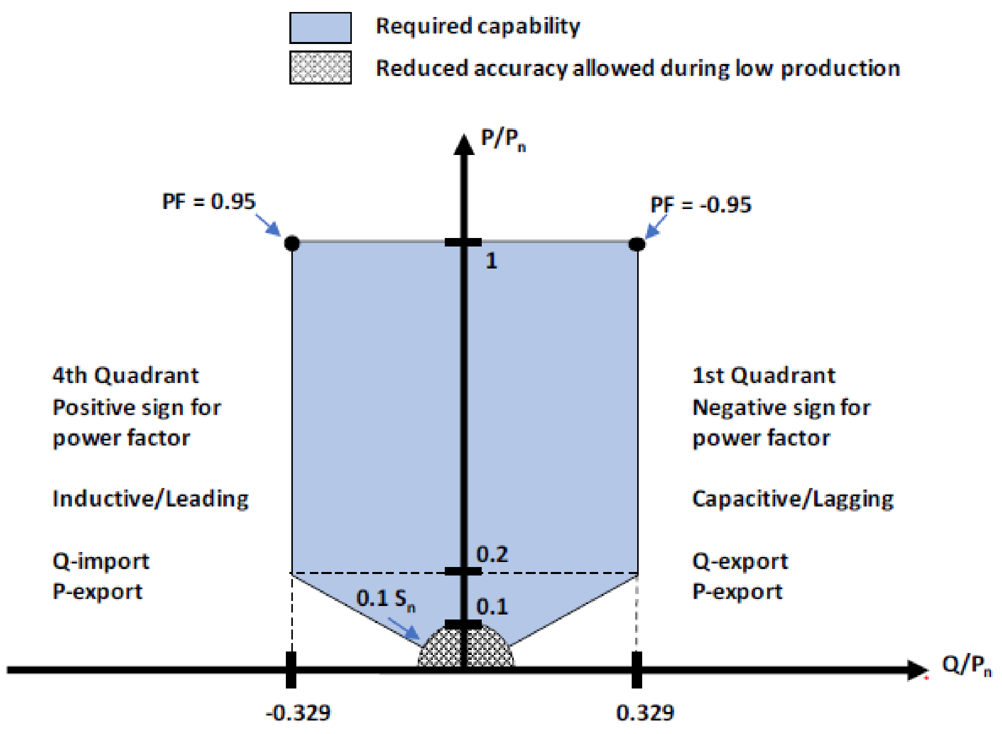
Active power gradient constraint

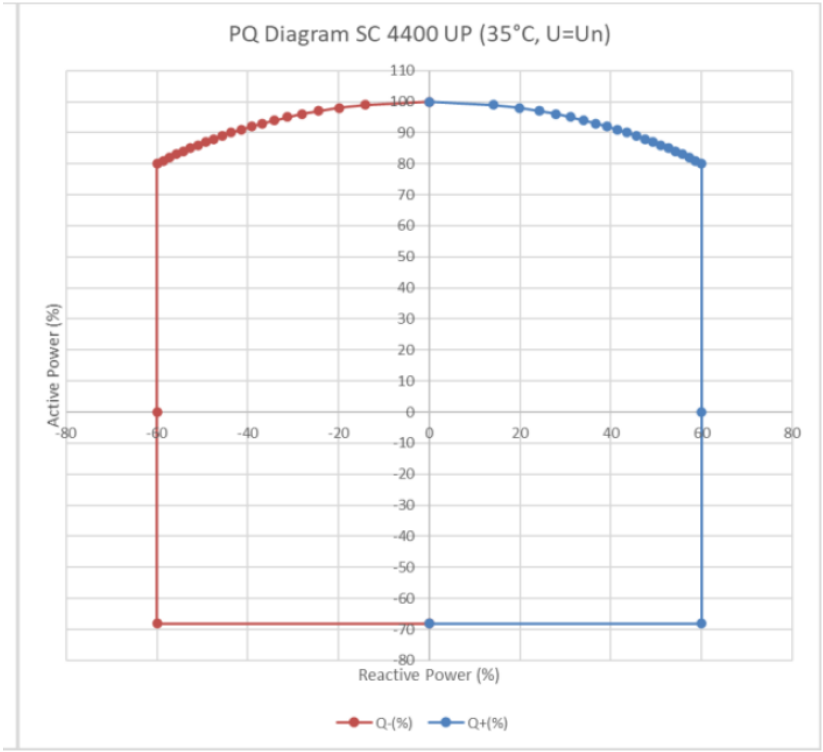


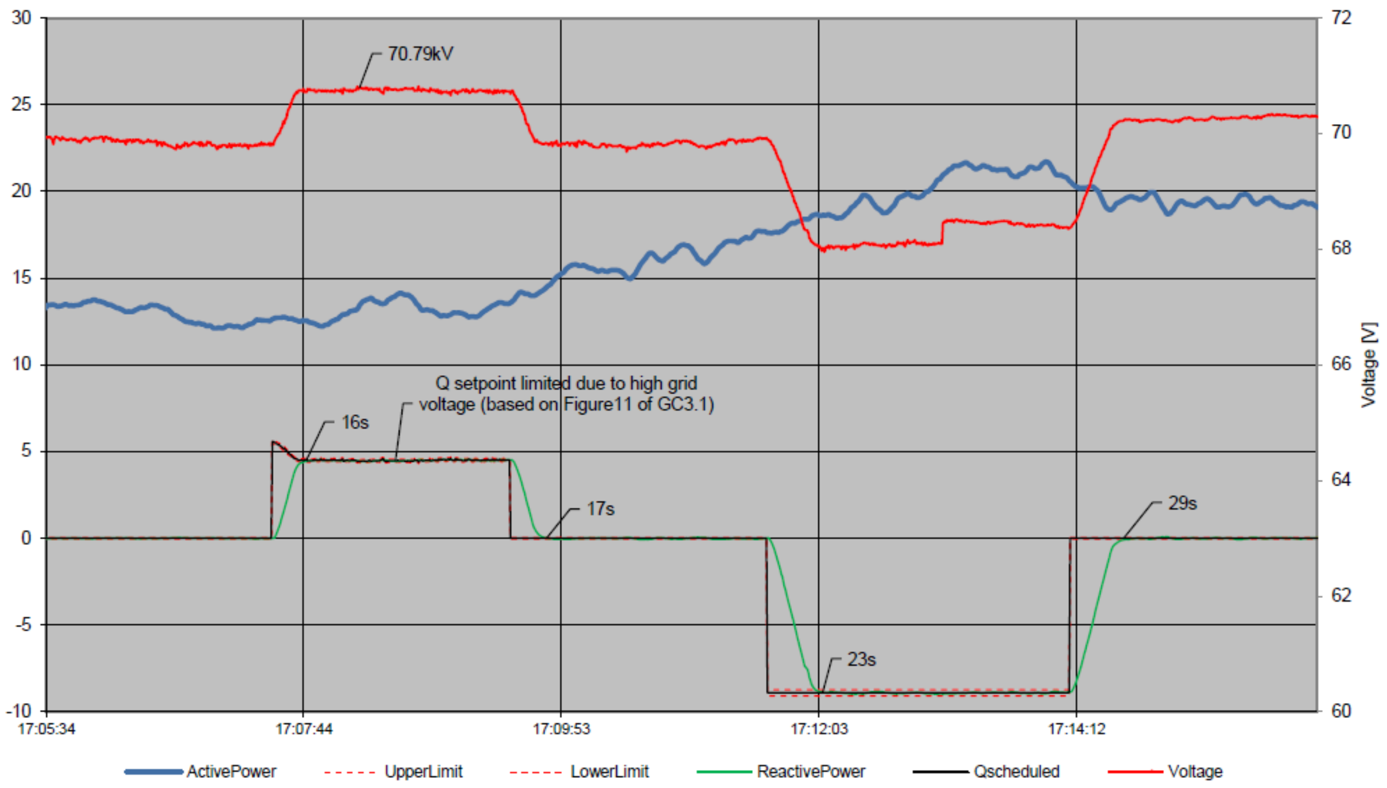
Frequency response (over frequency)

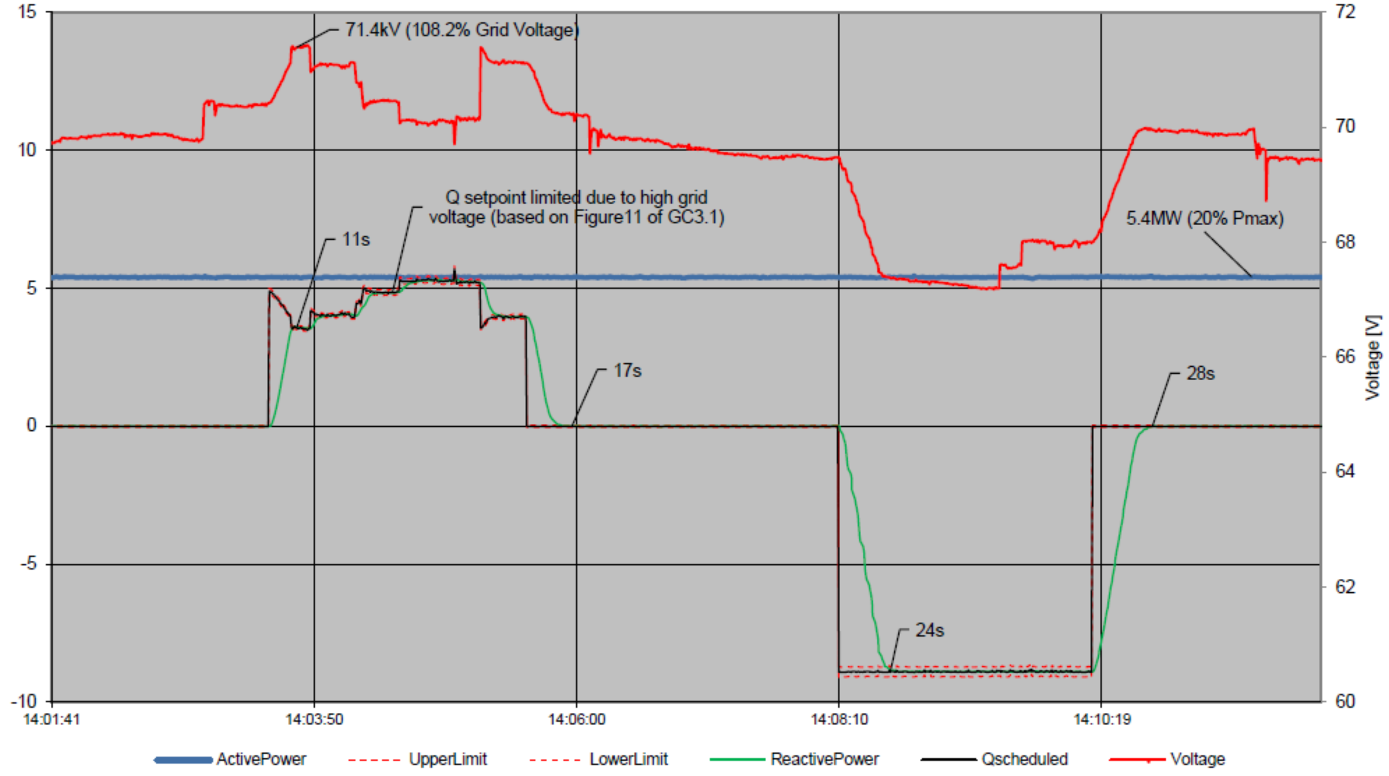


Reactive power control

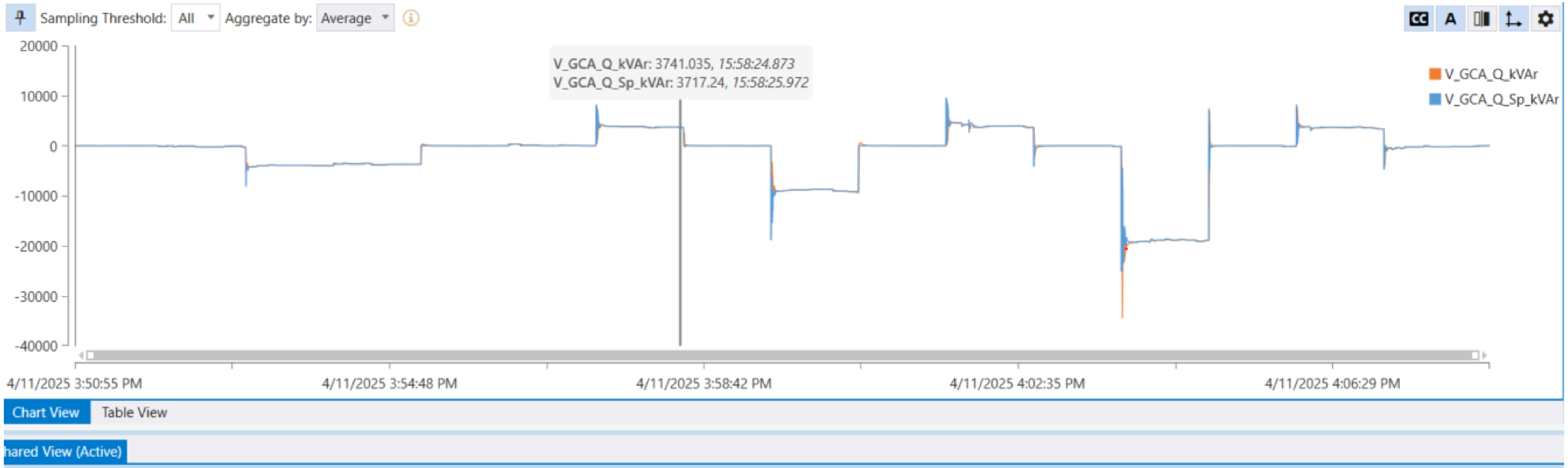


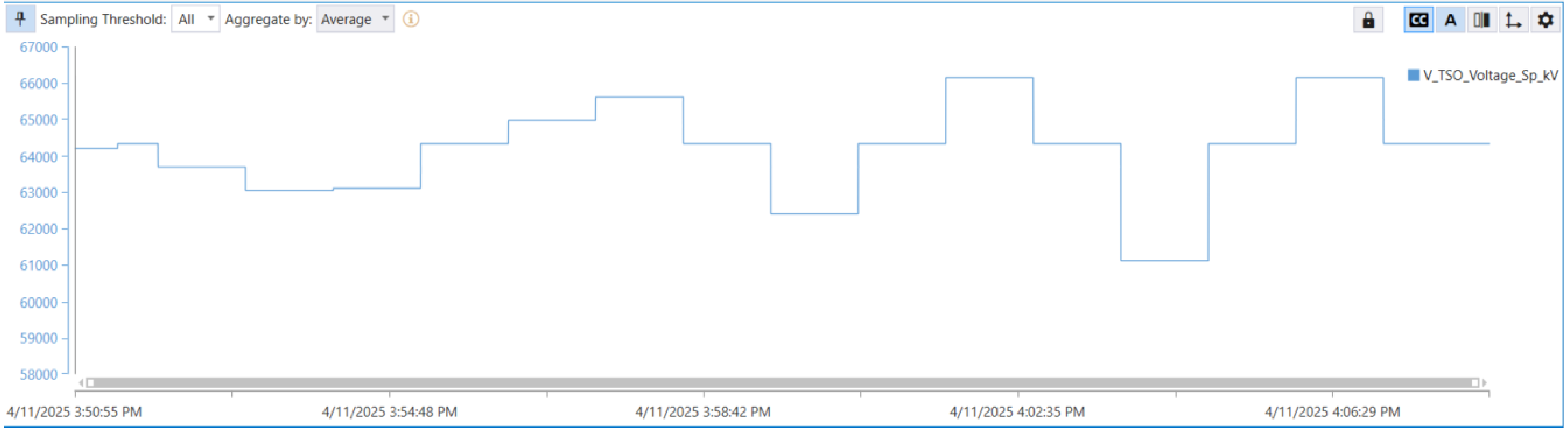




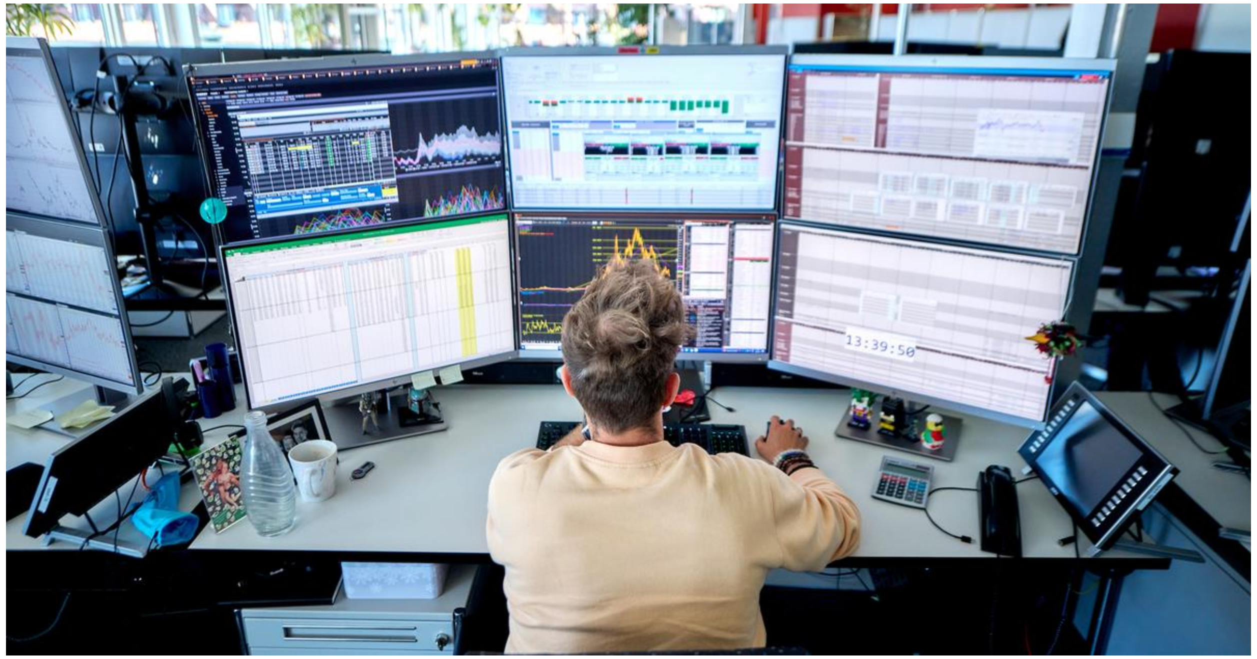


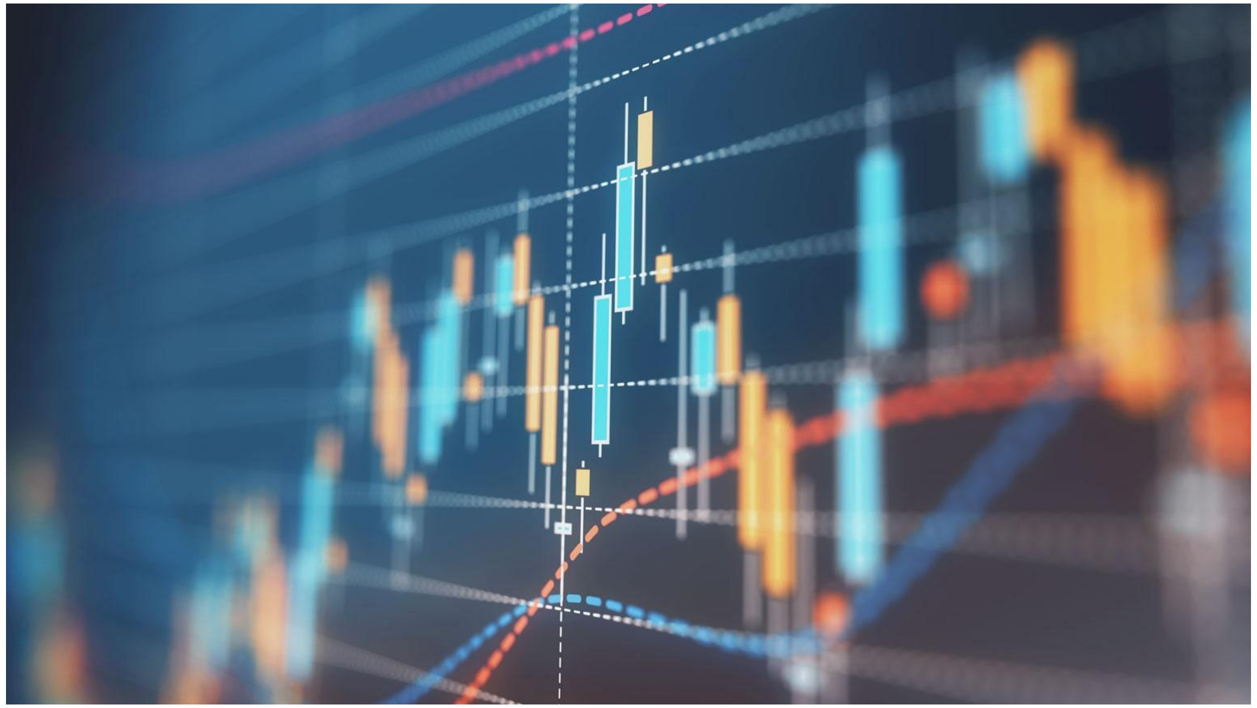
Voltage control

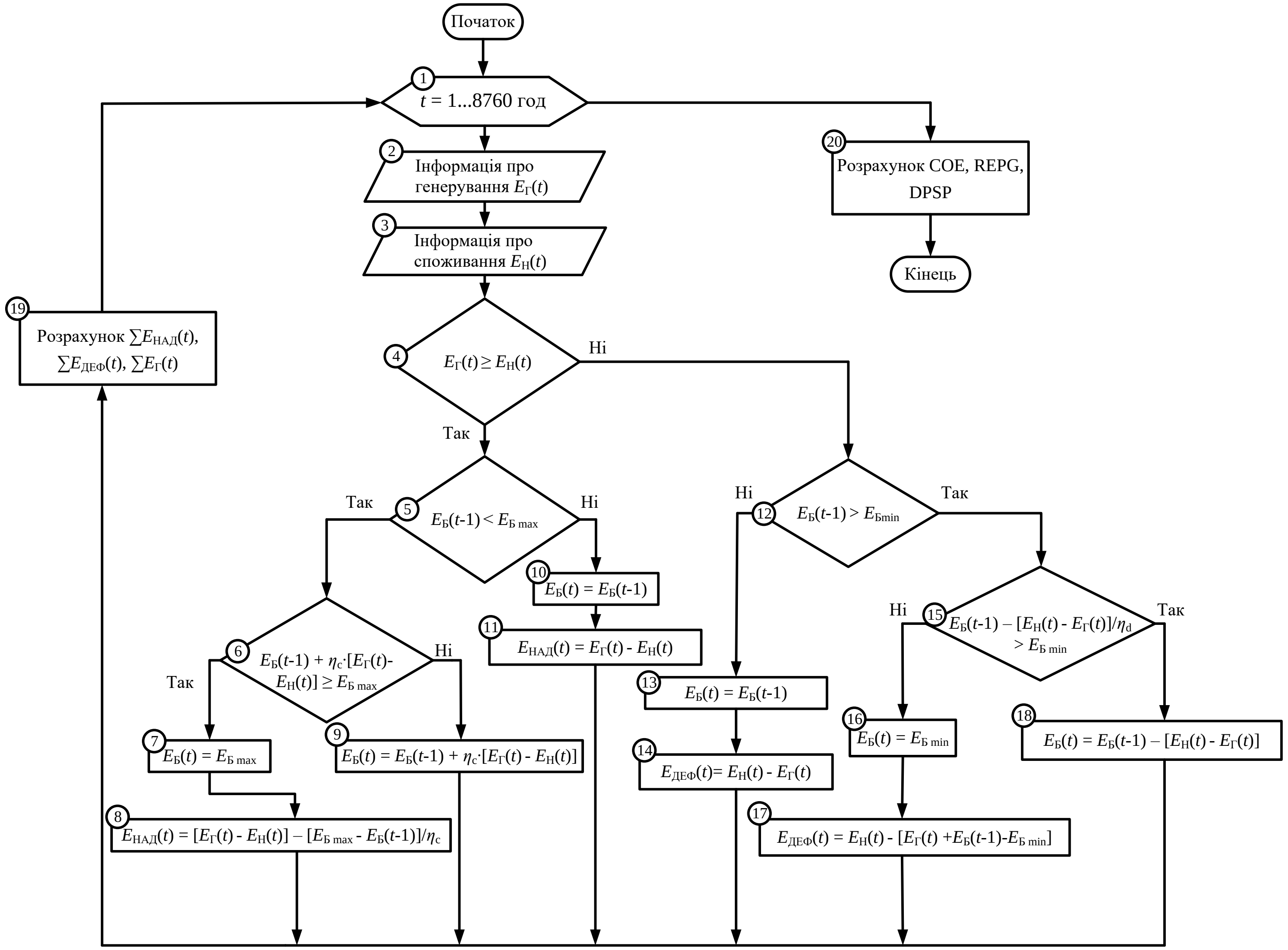




Energy trading








MAIN MENU
Unit Info
User Accounts
OS
System
Shutdown
Mita-Teknik Control
Modbus Master
Saitec MM82 Floater
Saitec MM82 WT
Modbus Slave
MTC STATE
MTC State Req.
Normal stop
MTC State
Stopped
Production Control State
Blade 1 SP
Blade 2 SP
Blade 3 SP
Power Limit
Actual Power SP
STERN
BOW
WTG
CONVERTER
MAIN LV CABINET
DIESEL GENERATOR
Recursos
ASUS


saitec


SINOVEL
华锐风电

Thank you for your attention!

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