


Global grid

Elia grid
Impact of renewable energies
Global grid
Energy future

ULg 01/12/2023 Jean-Jacques Lambin

elia

Contents

Le Groupe Elia

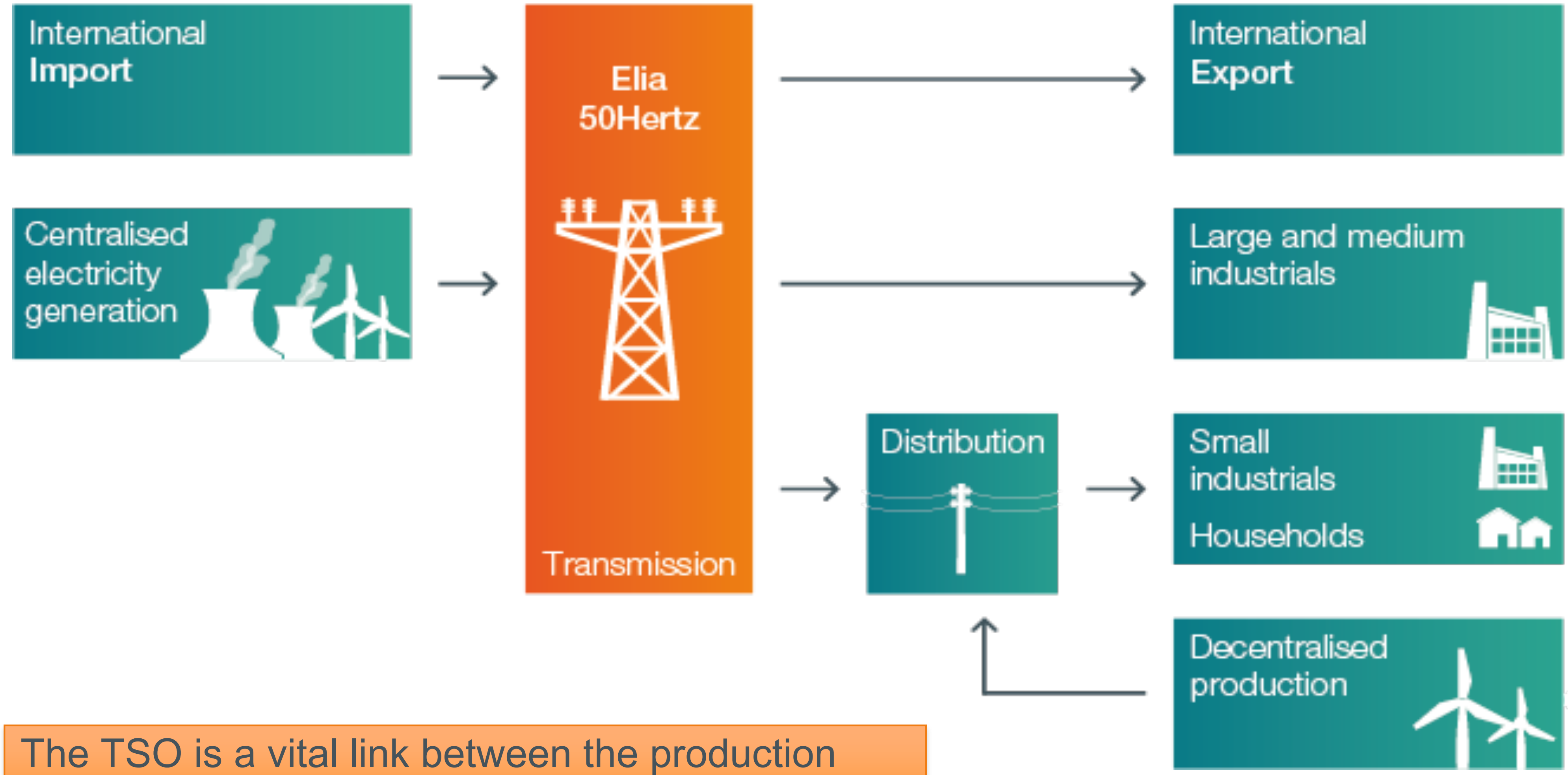
Le groupe Elia, une position unique au coeur de l'Europe

Le groupe Elia s'articule autour de 2 gestionnaires de réseau de transport haute tension (GRT),

Elia en Belgique,

50Hertz en Allemagne

Role of ELIA



The TSO is a vital link between the production and the industrial or private consumers

Medium-Term / Short-Term / Real-Time management of the grid

Permanent monitoring of all equipment

Any component, even the largest (1,000 MW power plant, international line), can be tripped

- *Always check that the N-1 is covered. If NOK, look for a solution as quickly as possible.*

Importance of preparation outage planning and control reserve volumes (Prim R, Sec R, Tert R)

Main controls

- **N-1 rule respected**

- **Primary reserve (R1)**: 3000 MW in ENTSO-E. Enough for facing the loss of 2 of the biggest nuclear plants within 15'
  Frequency deviations and involuntary power exchanges on borders occur

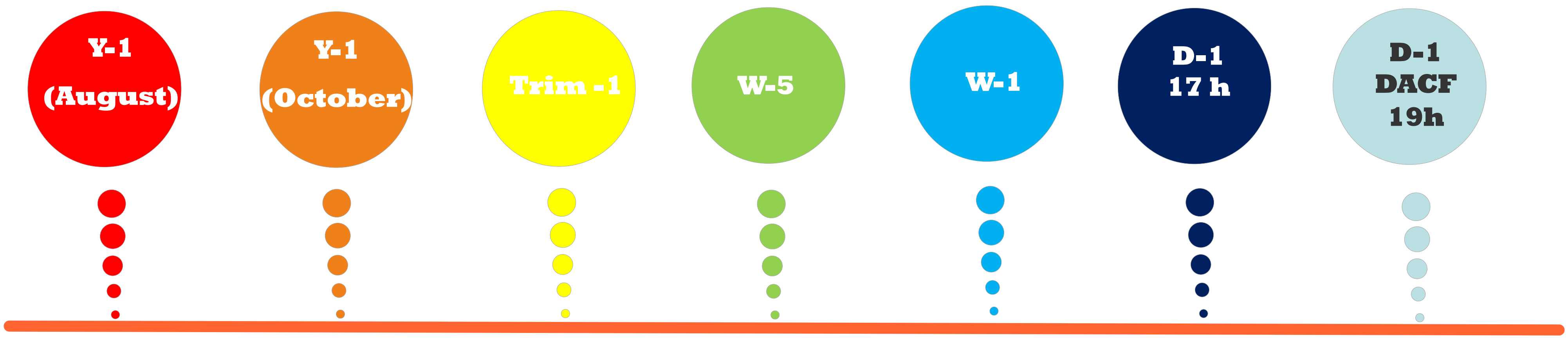
- **Secondary reserve (automatic)**: Used in order to restore the initial balance between generation and consumption and thus restore frequency and cross border power exchanges.

- **Tertiary reserve (manuel)**: In case of larger imbalances in the control area.

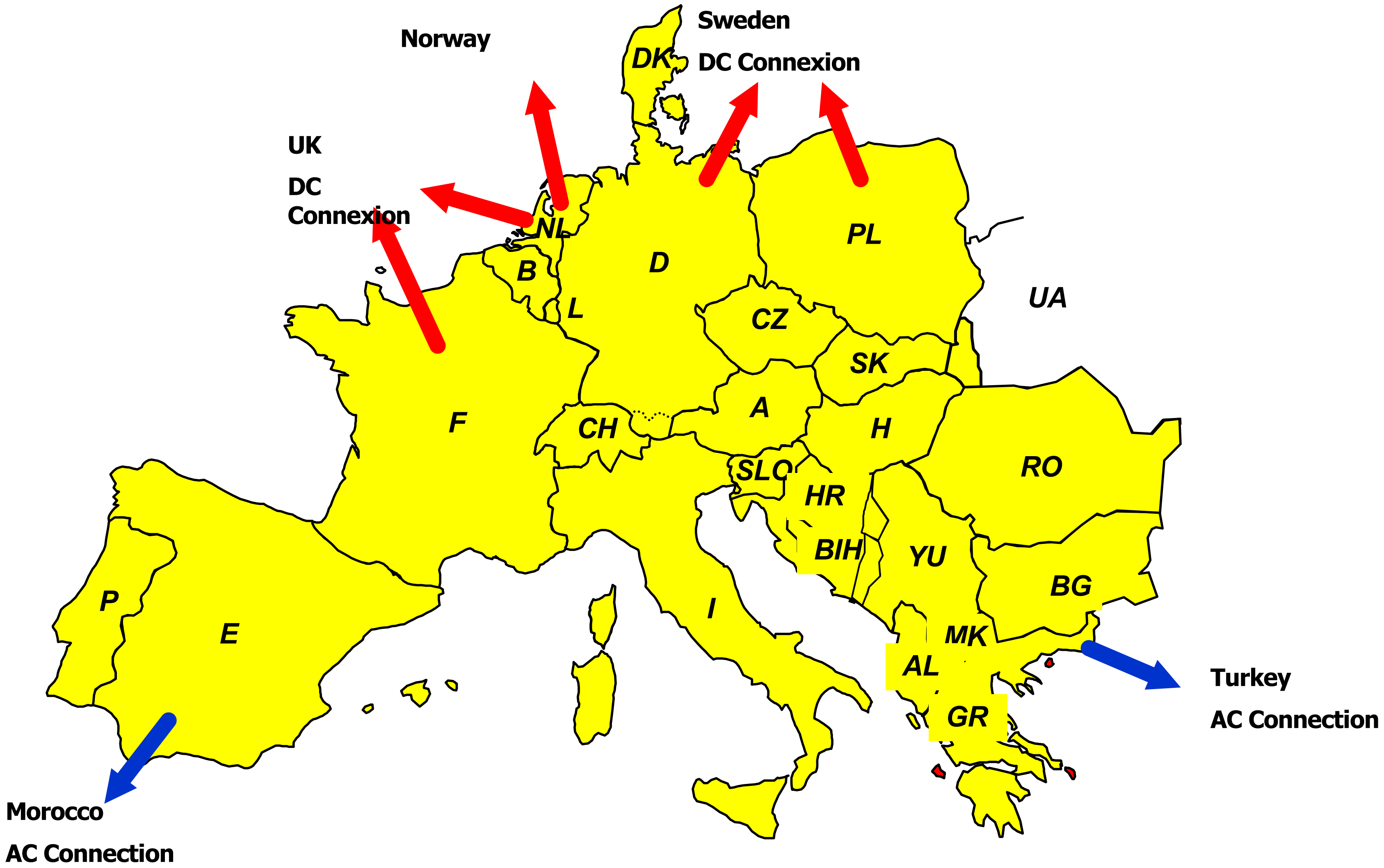
Process schedule

The process is iterative and each day is analysed at least seven times.

The closer day D, the more accurate the data and hypotheses.

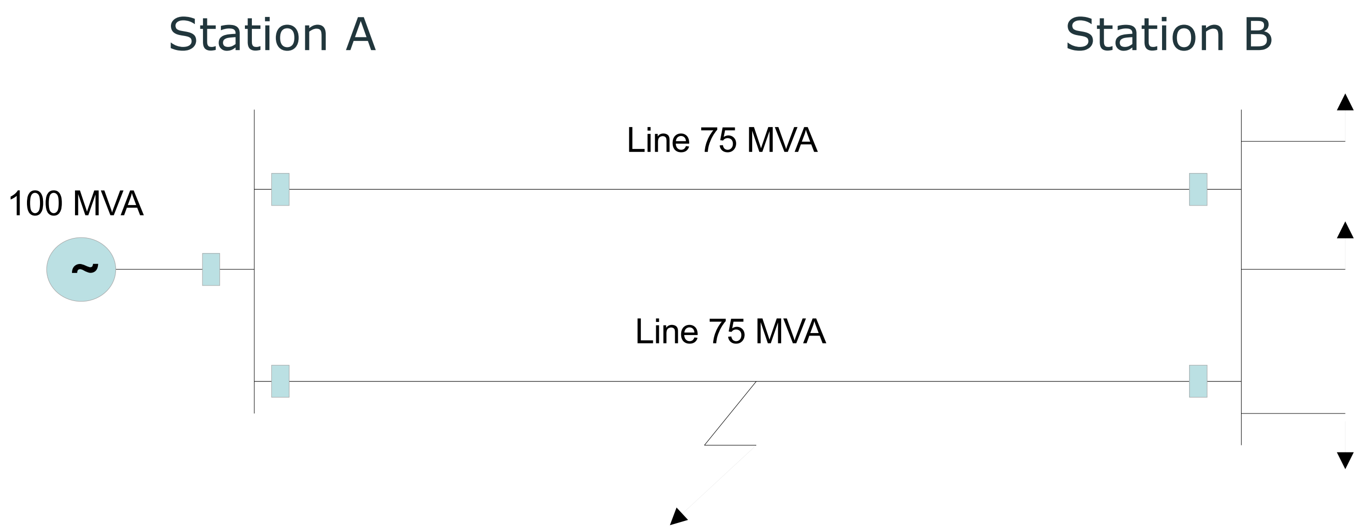


Day Ahead Congestion Forecast: 25 countries



N-1 concept

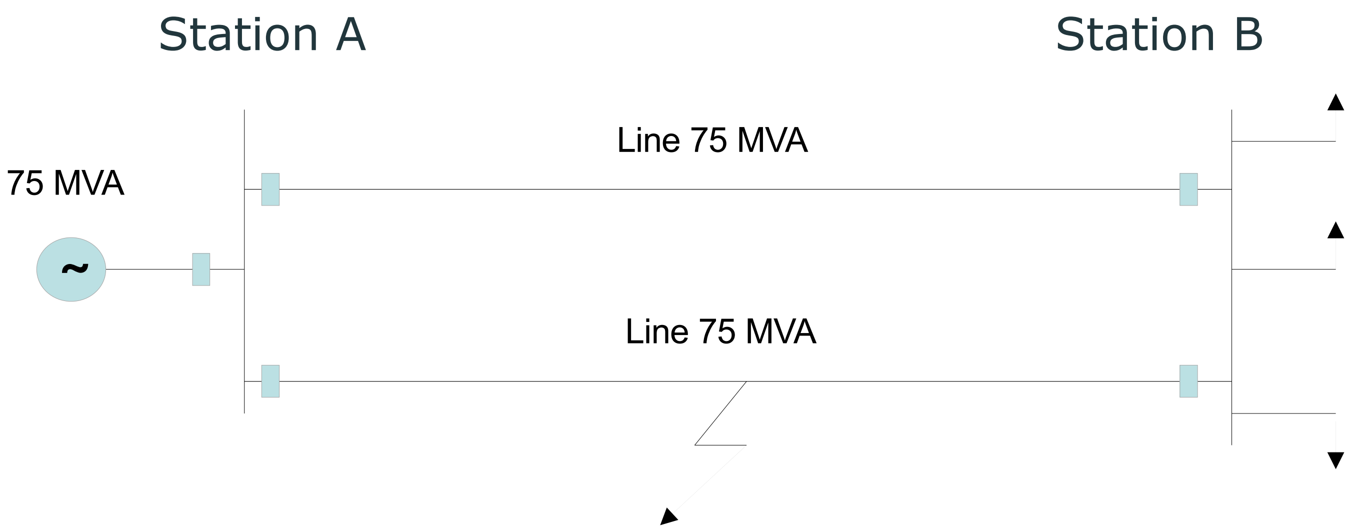
Example 1



N-1 **NOK**

N-1 concept

Example 2



N-1 **OK**

Italy, black-out on 28 September 2003

N-1 rule not respected

Overhead lines <> Underground cables

Heating of electrical connections

– cooling underground cables is more difficult than cooling overhead lines

→ **Larger cable section for the same current to limit heating.**

Capacitive generation for lines & cables

$\omega C\, U^2$

Voltage	Line capacitive generation	Cable capacitive generation
380 kV	± 0,55 Mvar/km	± 20 Mvar/km
220 kv	± 0,15 Mvar/km	± 7,5 Mvar/km
150 kV	± 0,06 Mvar/km	± 3,5 Mvar/km

Impact reactive power on voltage

Impact energizing circuit (line/cable) on voltage

S_{CC} (short circuit power)

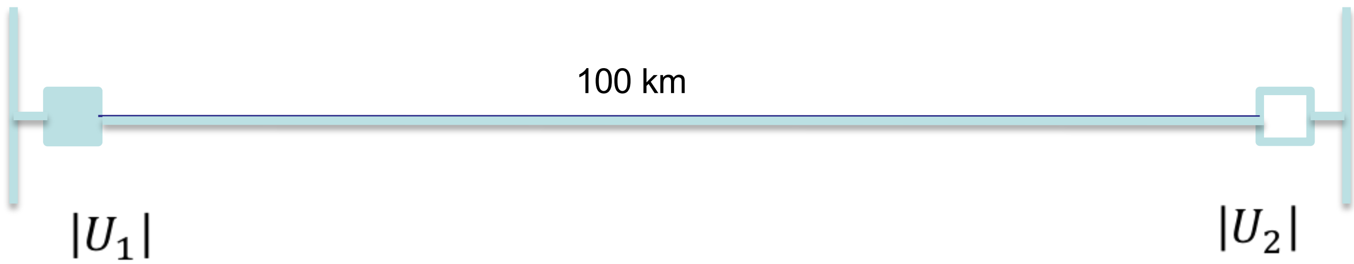
$$\Delta U(p.u.) \approx \frac{reactive\ generation\ circuit\ (rgc)}{S_{CC}}$$

Ferranti effect for circuit (line/cable)

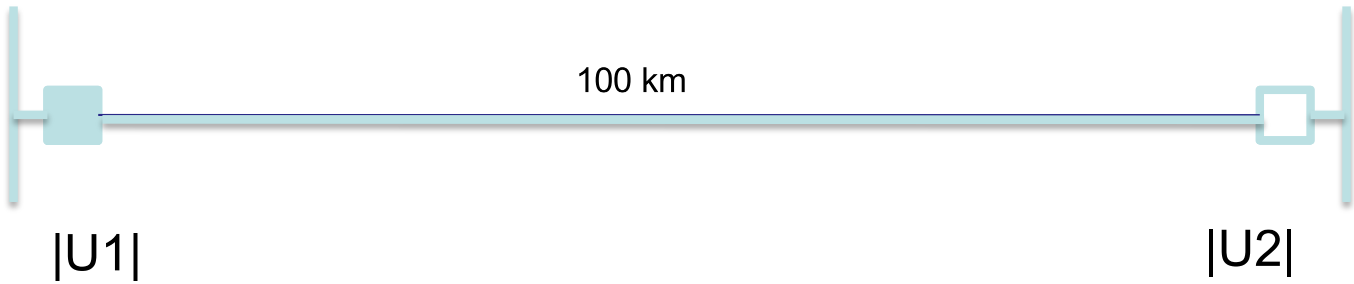
$|U|$ = substation voltage before energizing circuit

$$|U_1| \approx |U| + \frac{rgc}{S_{CC}} \quad \text{after energizing circuit}$$

$$|U_2| \approx |U| + \frac{rgc}{S_{CC}} + \frac{rgc}{2} X$$



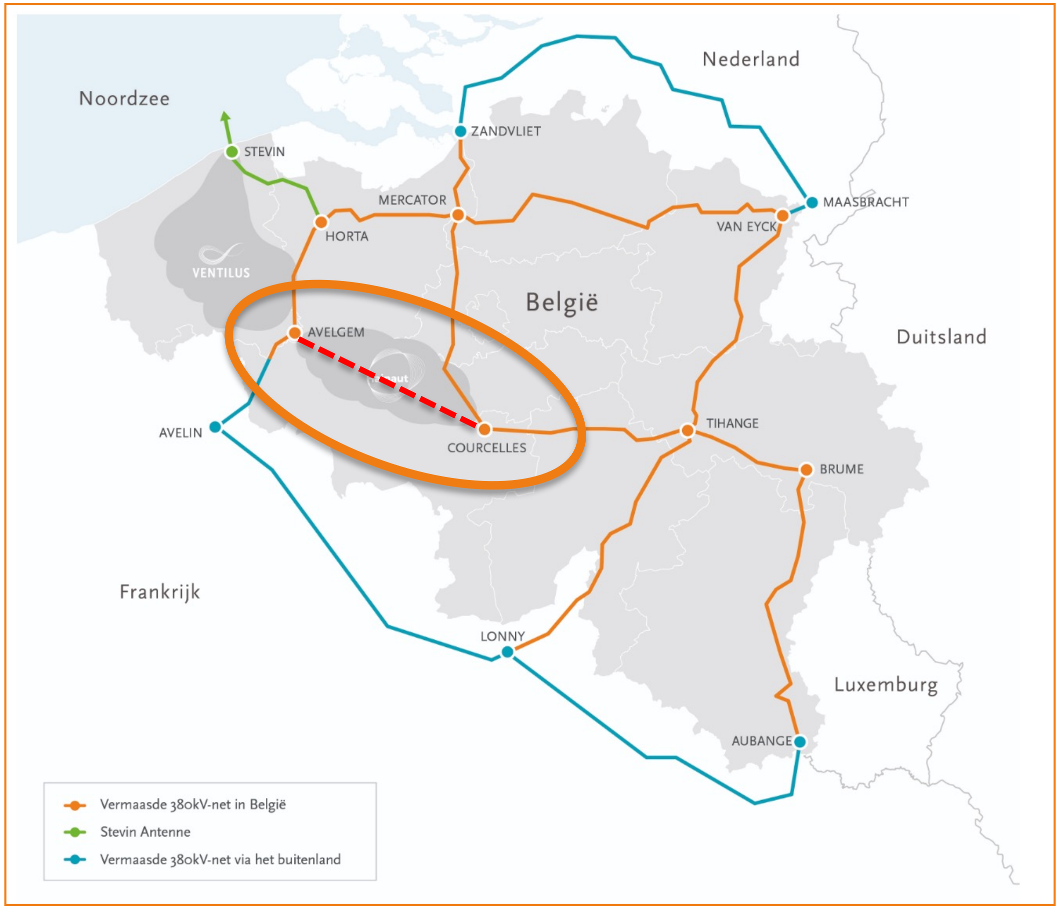
Ferranti effect for circuit (line/cable)



$|U|$ = substation voltage before energizing circuit

	|U|	|U1|	|U2|
line (100 km)	380 kV	|U| + 0,2%	|U| + 0,8%
cable (100 km)	380 kV	|U| + 8%	|U| + 20%

Connection 380 kV :
« Boucle du Hainaut »



Import/export capacities / Market coupling

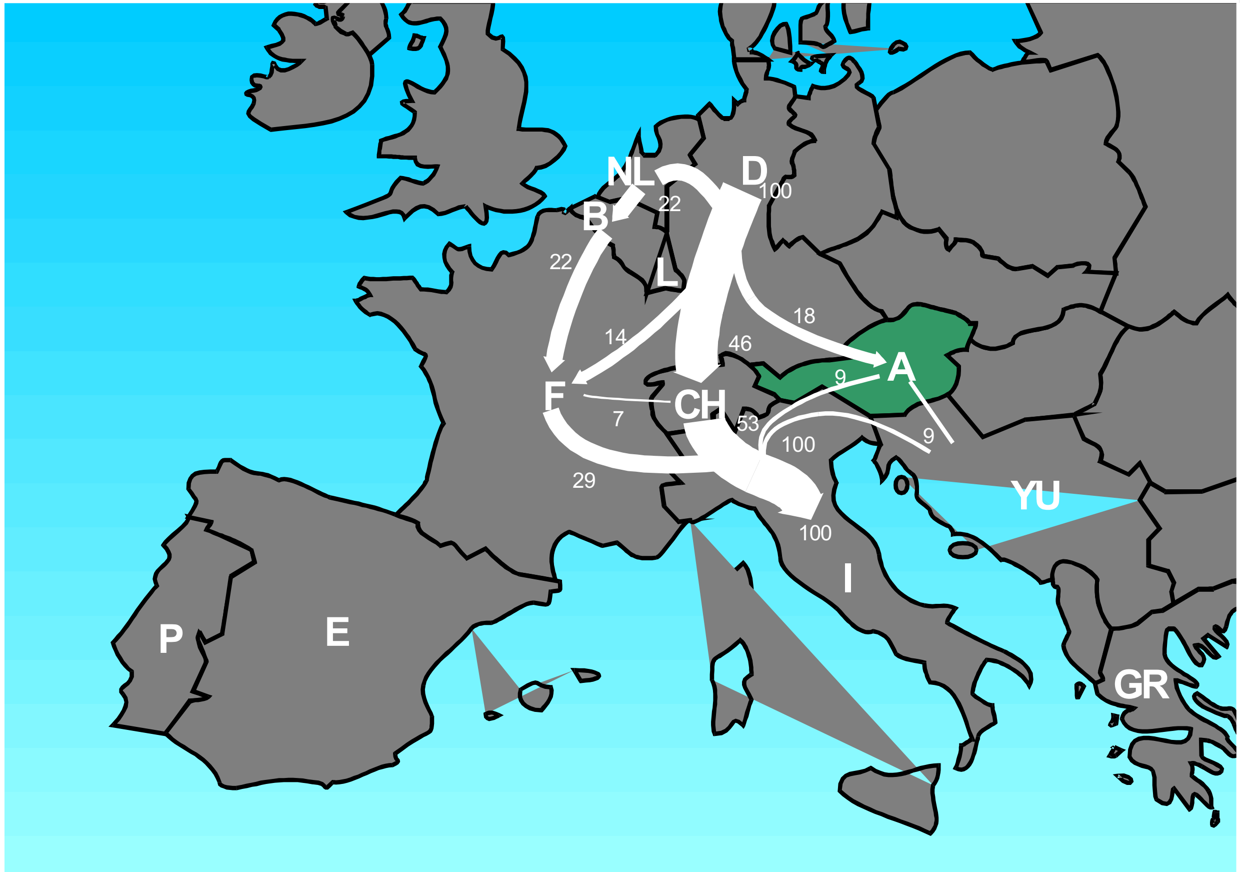
Import/export capacities

Import/export generates Loop flows

Potential import/export capacities

Problem of loop flows

Controlling loop flows
Electricity follows the laws of physics:
path of least resistance



Impact of wind generation in Germany on the Elia grid

- Unscheduled flows:
  - Caused by wind farms located in neighbouring countries (north of Germany)
  - Variations between -2,000 and 2,000 MW on the Belgian grid

Figure 23: Main corridors of electrical power transmission in the Base Case

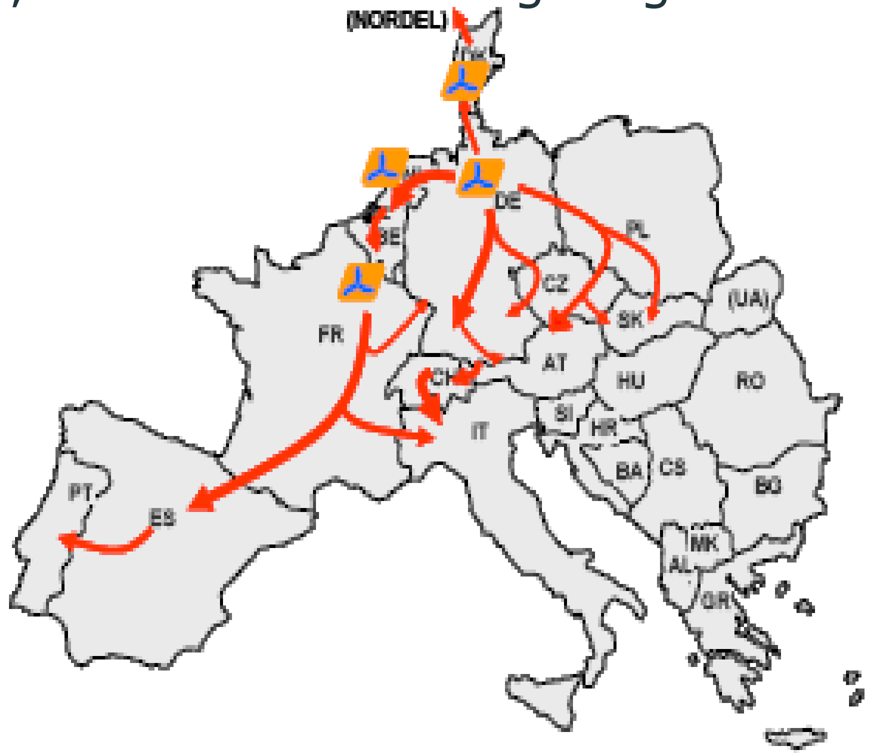
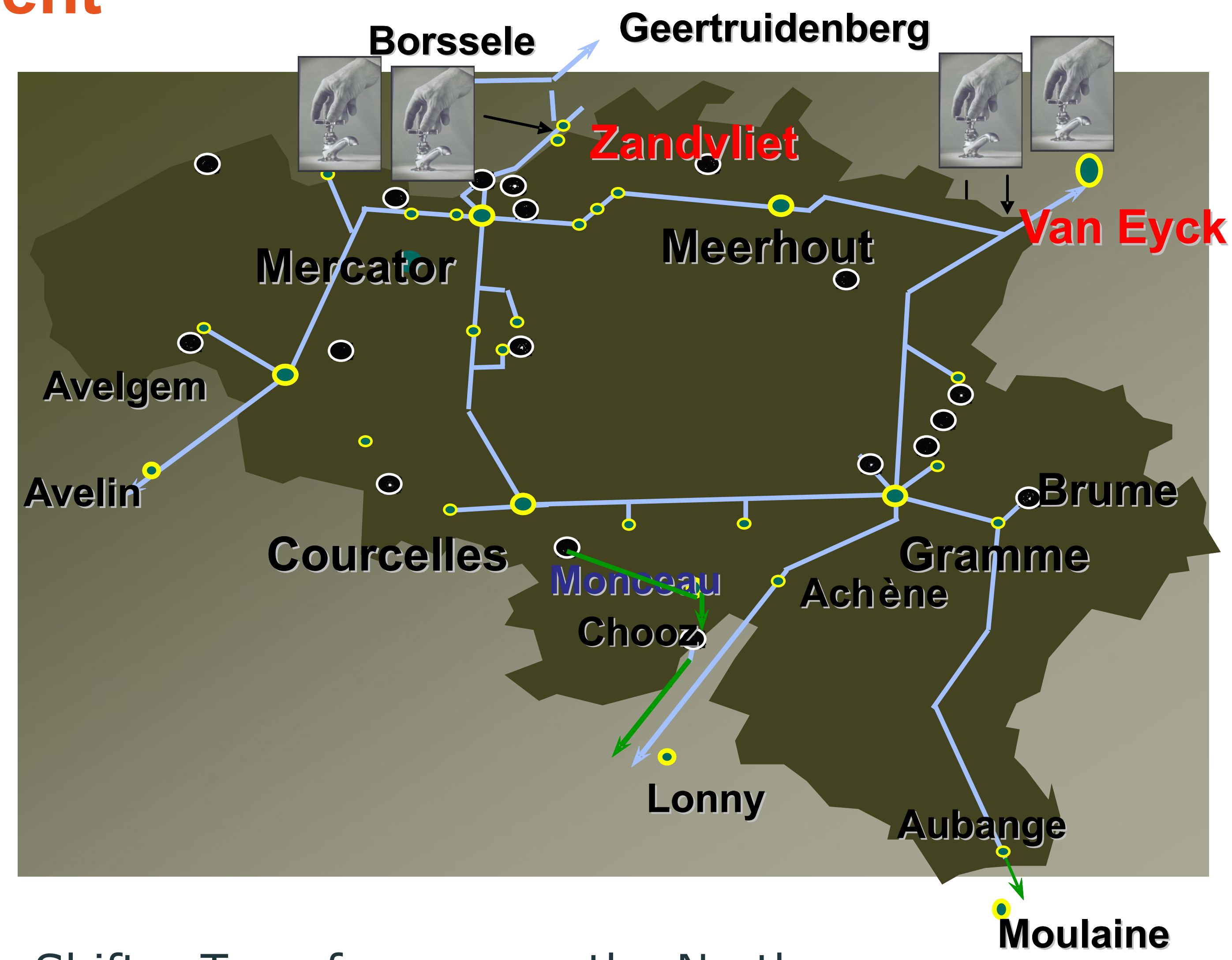


Figure 24: Changes of electrical power transmission in UCTE Scenario North

Flow management



Installation of Phase Shifter Transformers on the Northern border for managing increasing Loop flows

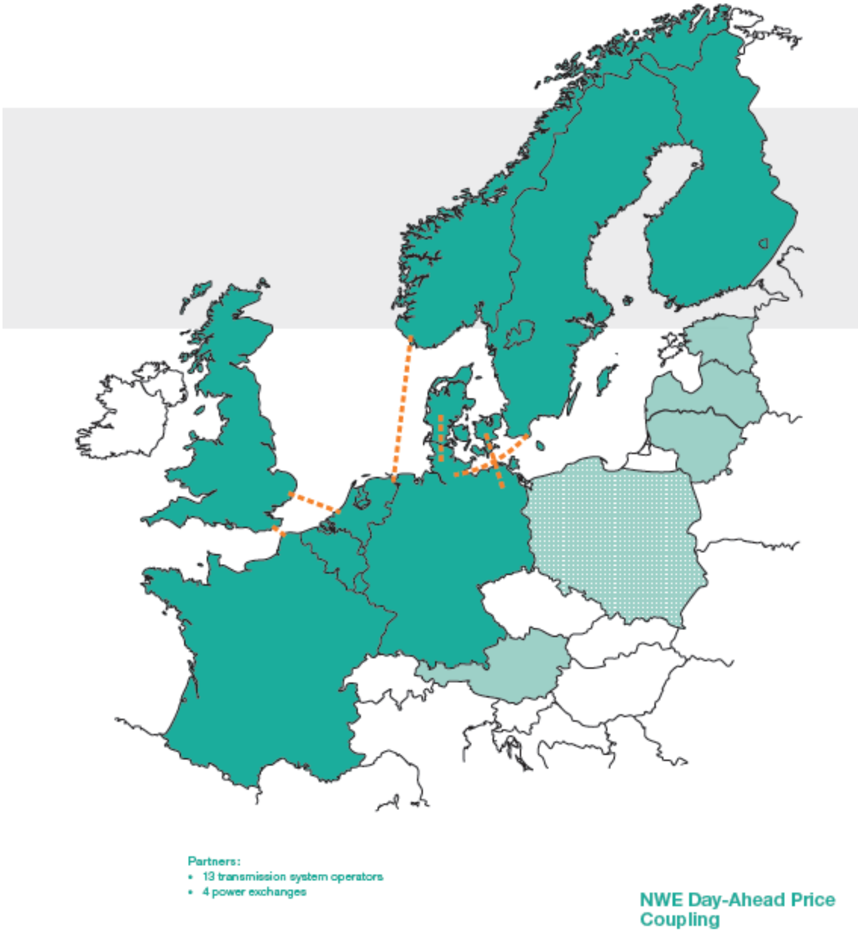
Coreso: centralised coordination between TSOs

- The first Regional Technical Coordination Service Centre
- Independent company (SA) with its own employees
- Created December 2008 in Brussels
- Operational since 16 February 7d/7 (afternoon shift)
- Round-the-clock operations since 29 June 2009
- Employs 25 engineers (18 are on shift)

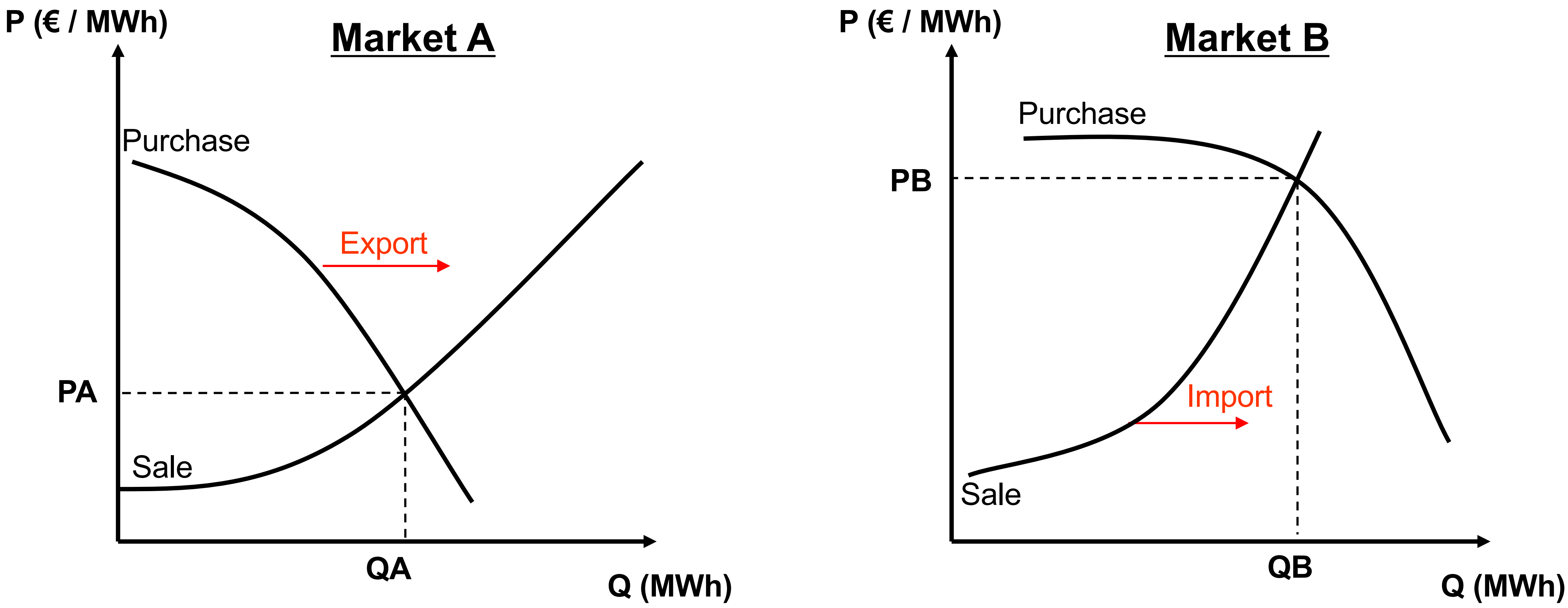
Impact of import/export capacities on the markets

Market Coupling

Market Coupling



Market Coupling (basic concept)



- **Isolated price Market A < isolated Price Market B**
- **Market A can export to market B (purchase- and sale curve shift)**

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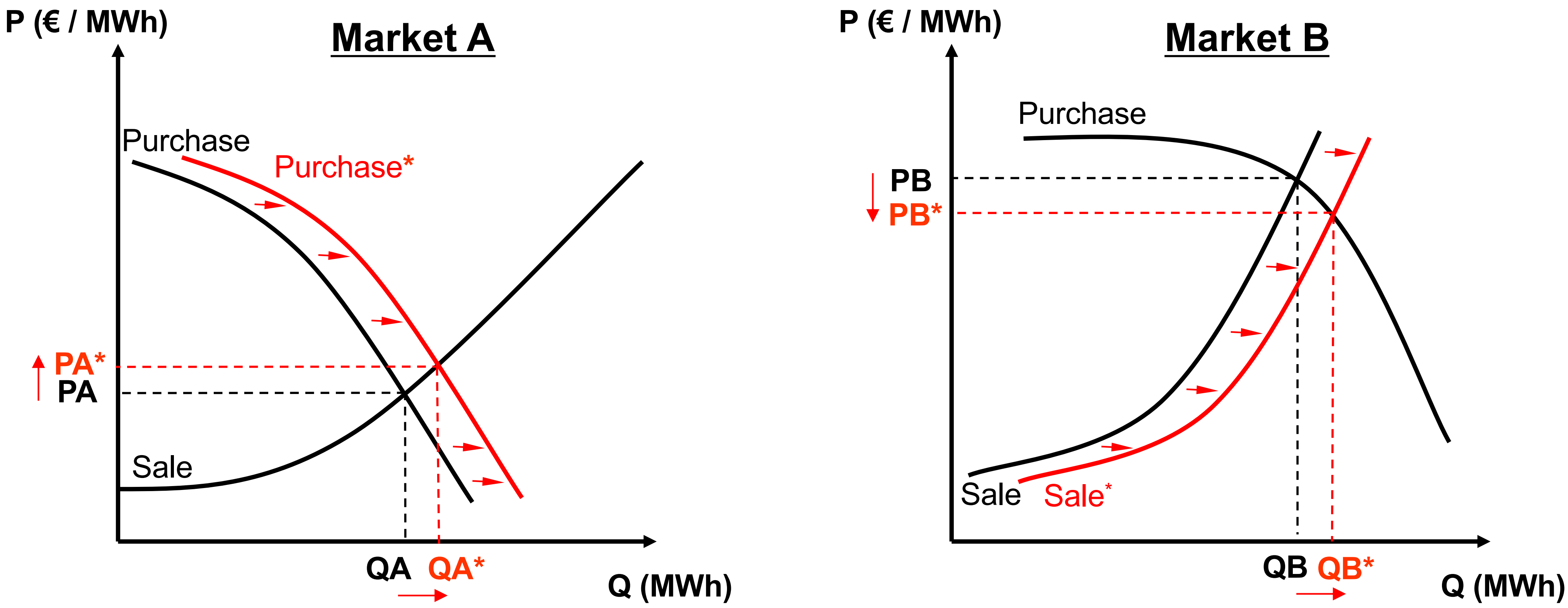

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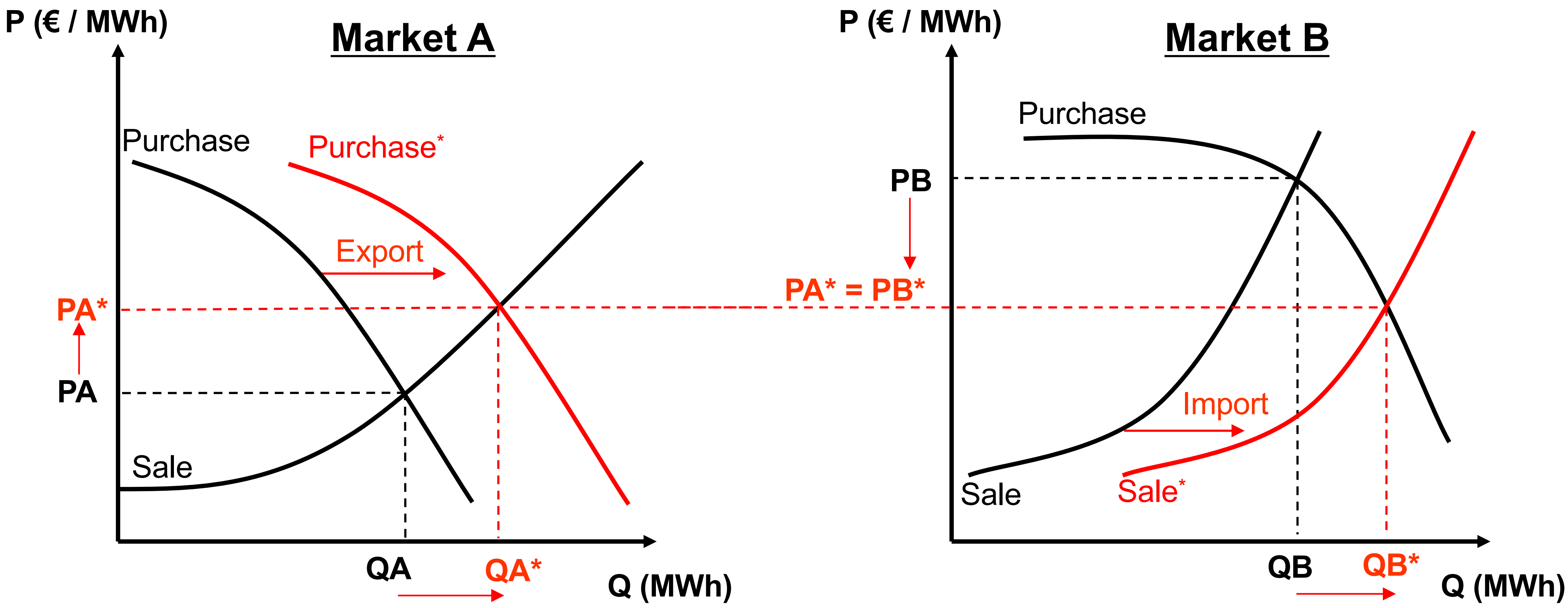

- **Isolated price Market A < isolated Price Market B**
- **Market A can export to market B (purchase- and sale curve shift)**
- **Prices market A and B converge till price market A = price market B**

Impact of renewable energies on grid management

Germany, incident on 4 Novembre 2006

Le Norwegian Pearl

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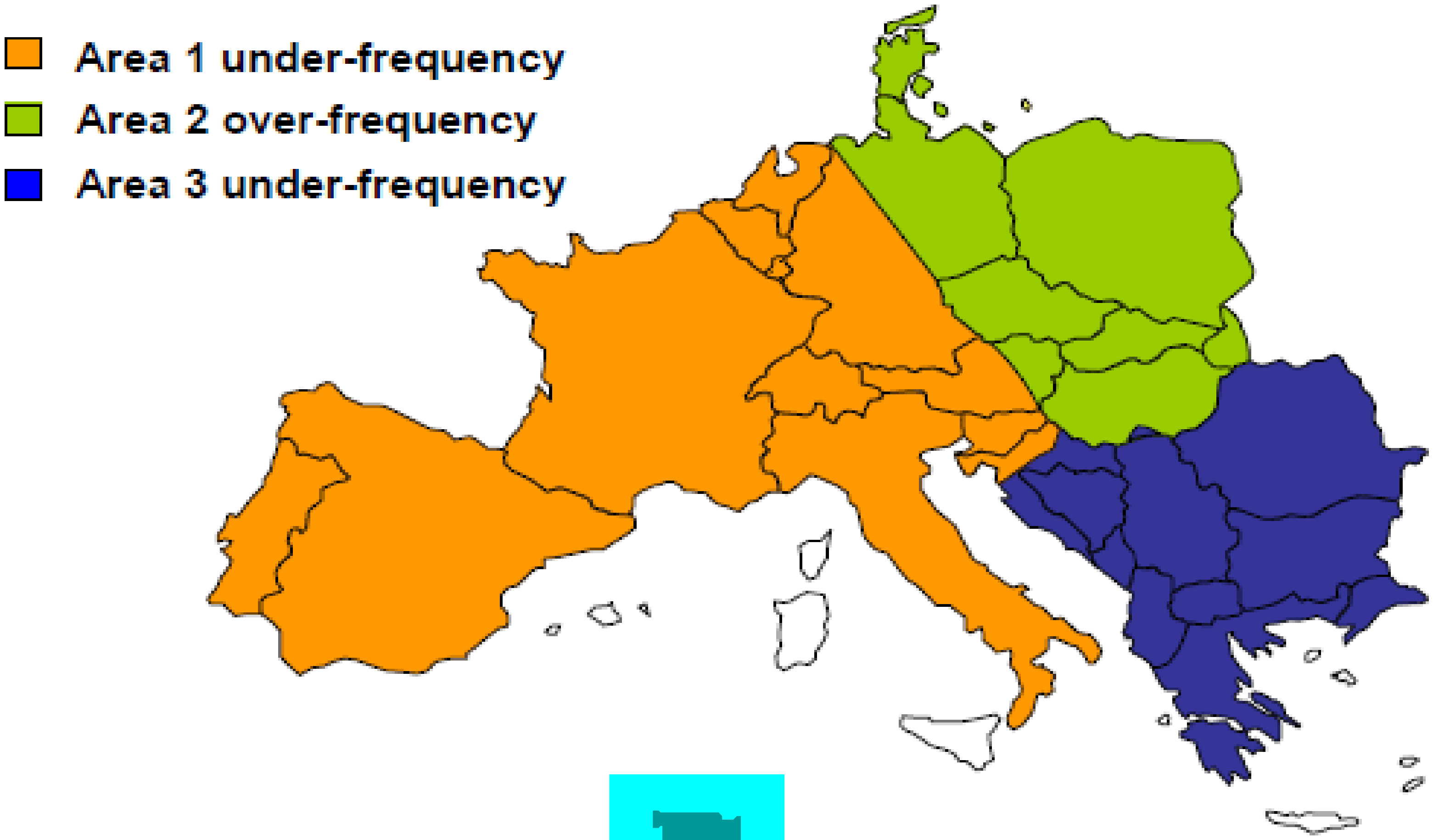
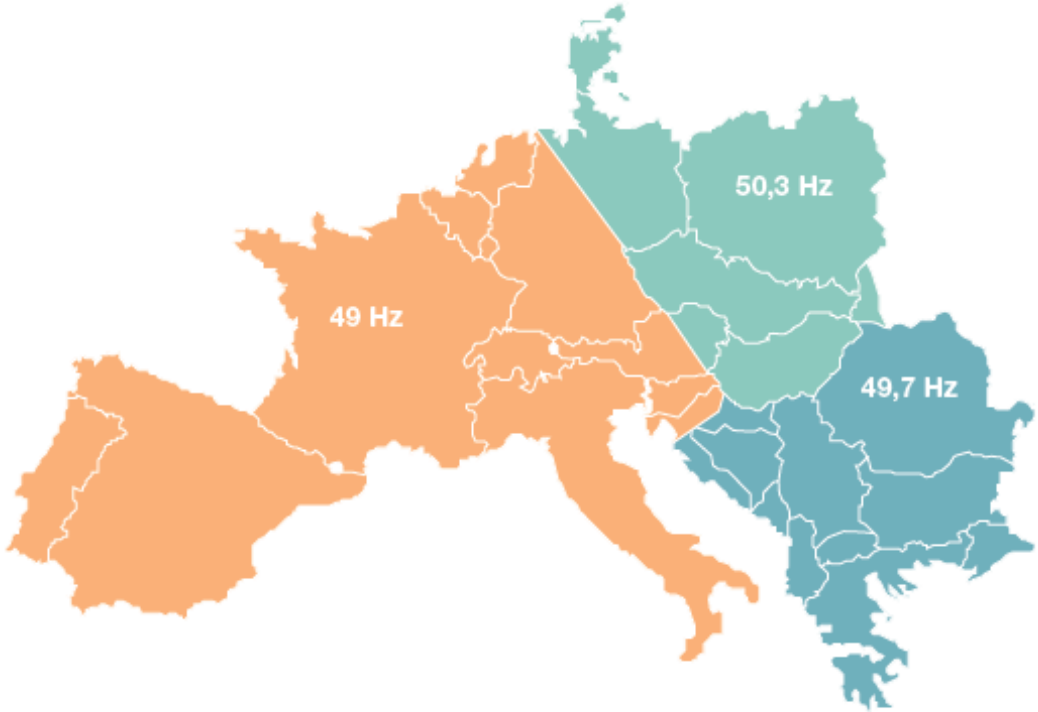
Incident on 4 November 2006



Incident on 4 November 2006

Europe is divided into 3 electric zones



Impact of decentralised generation on GRT activities

- Although decentralised generation units are connected to DSOs' grids, as the volume of these units is growing significantly, it affects the overall management of the electricity grid in Belgium.

1. Management of the electricity grid in Belgium

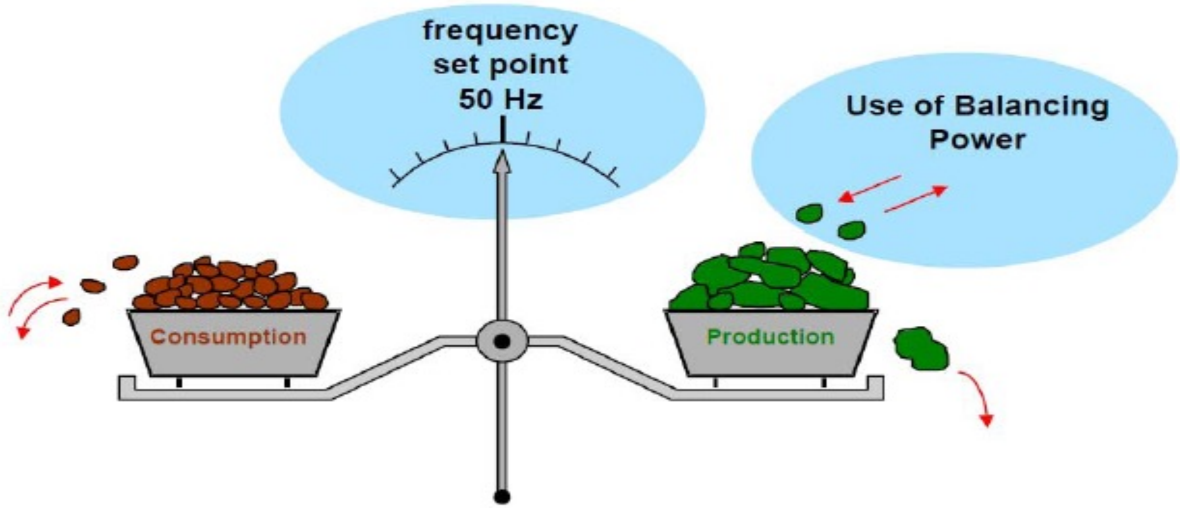
1. Balance between generation ←→ load
2. Management of system services: Prim R, Sec R, Tert R, voltage control
3. Management of flows, import/export, Must Run
4. System security, safeguard plan

Grid stability

The increase in power electronic based energy feed-in impacts grid stability which is mainly ensured by synchronous generators today.

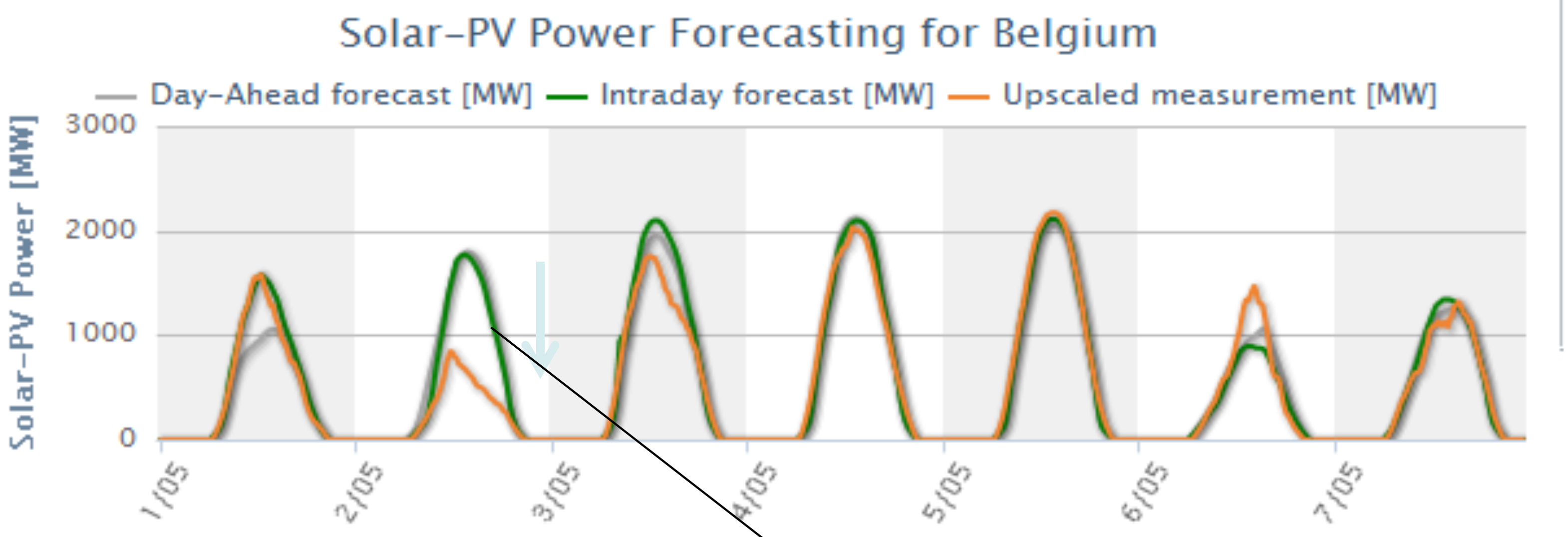
Management of the electricity grid

- **Balance between generation ←→ consumption**
- AC electricity is not stored, generation and consumption must always be balanced

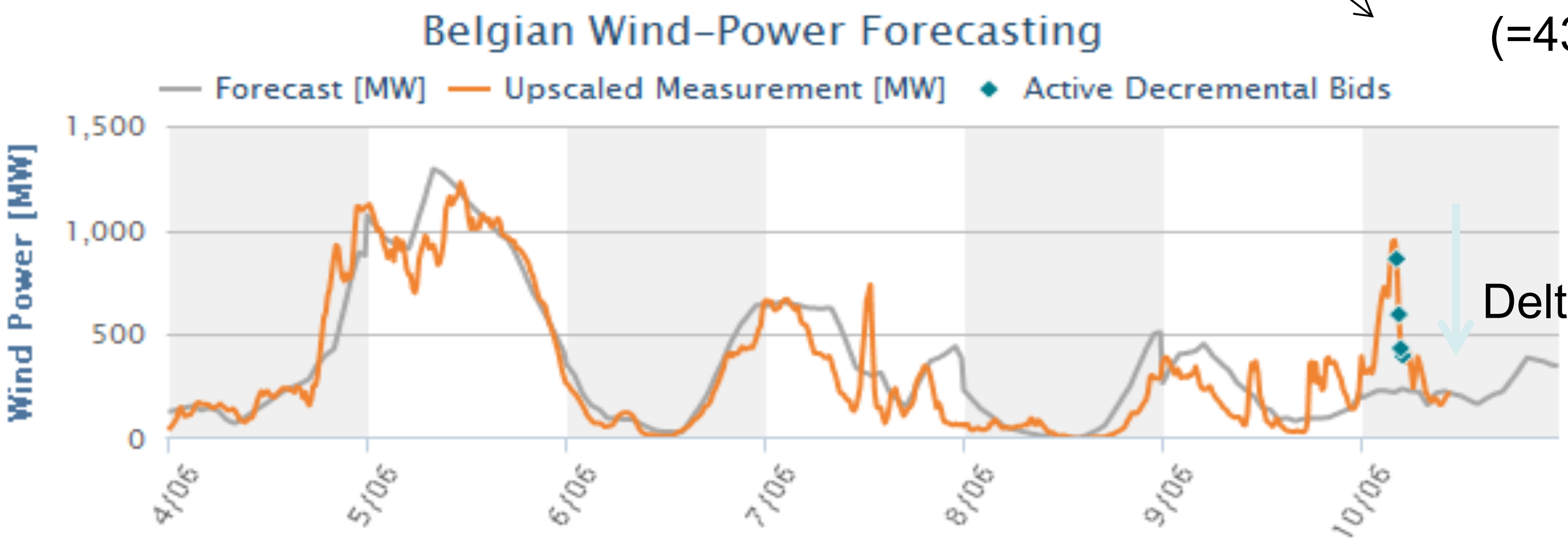


* Source: Elia Communication

Impact of forecasting errors



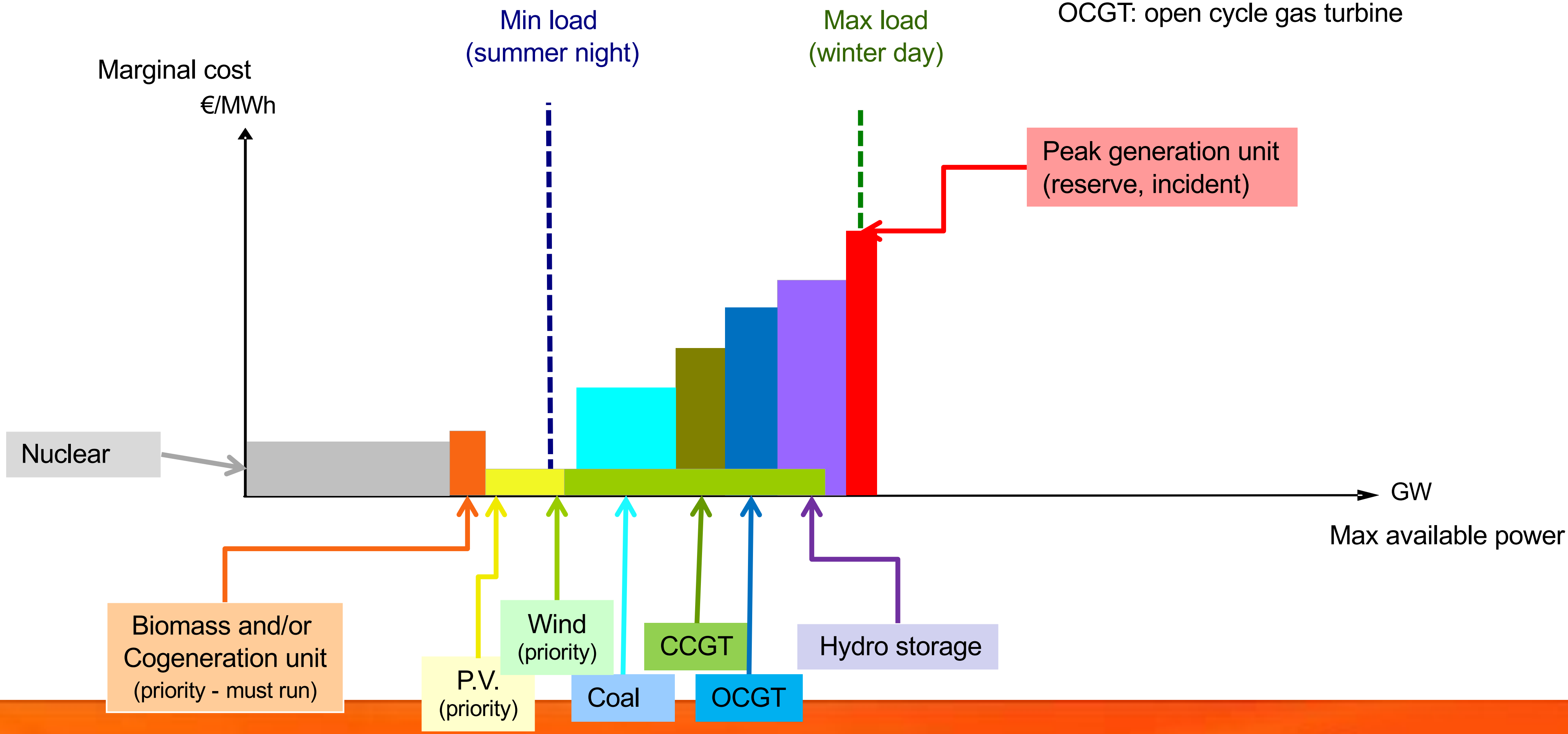
Delta P = 1211 MW
(=43% of $P_{installed}$)



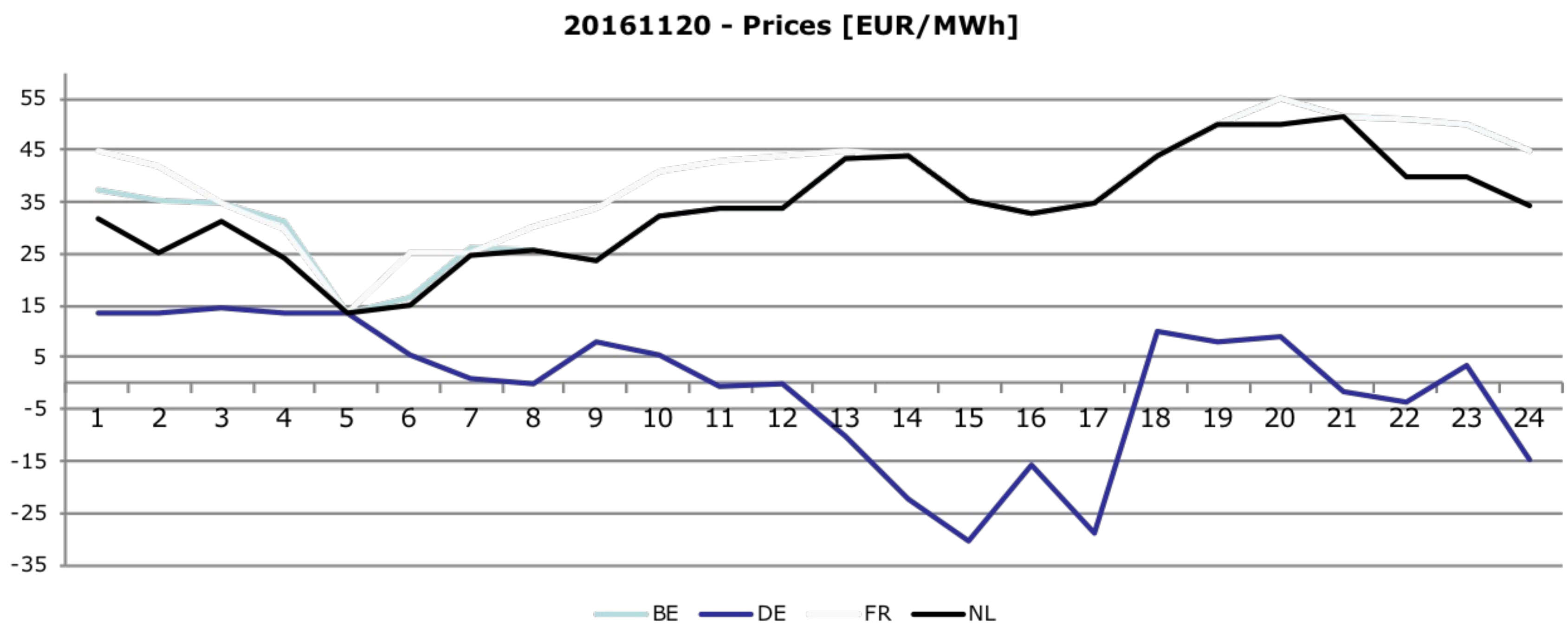
Delta P = 729 MW
(=41% of $P_{installed}$)

Impact on CWE merit order

PV: photovoltaic
CCGT: combined cycle gas turbine
OCGT: open cycle gas turbine



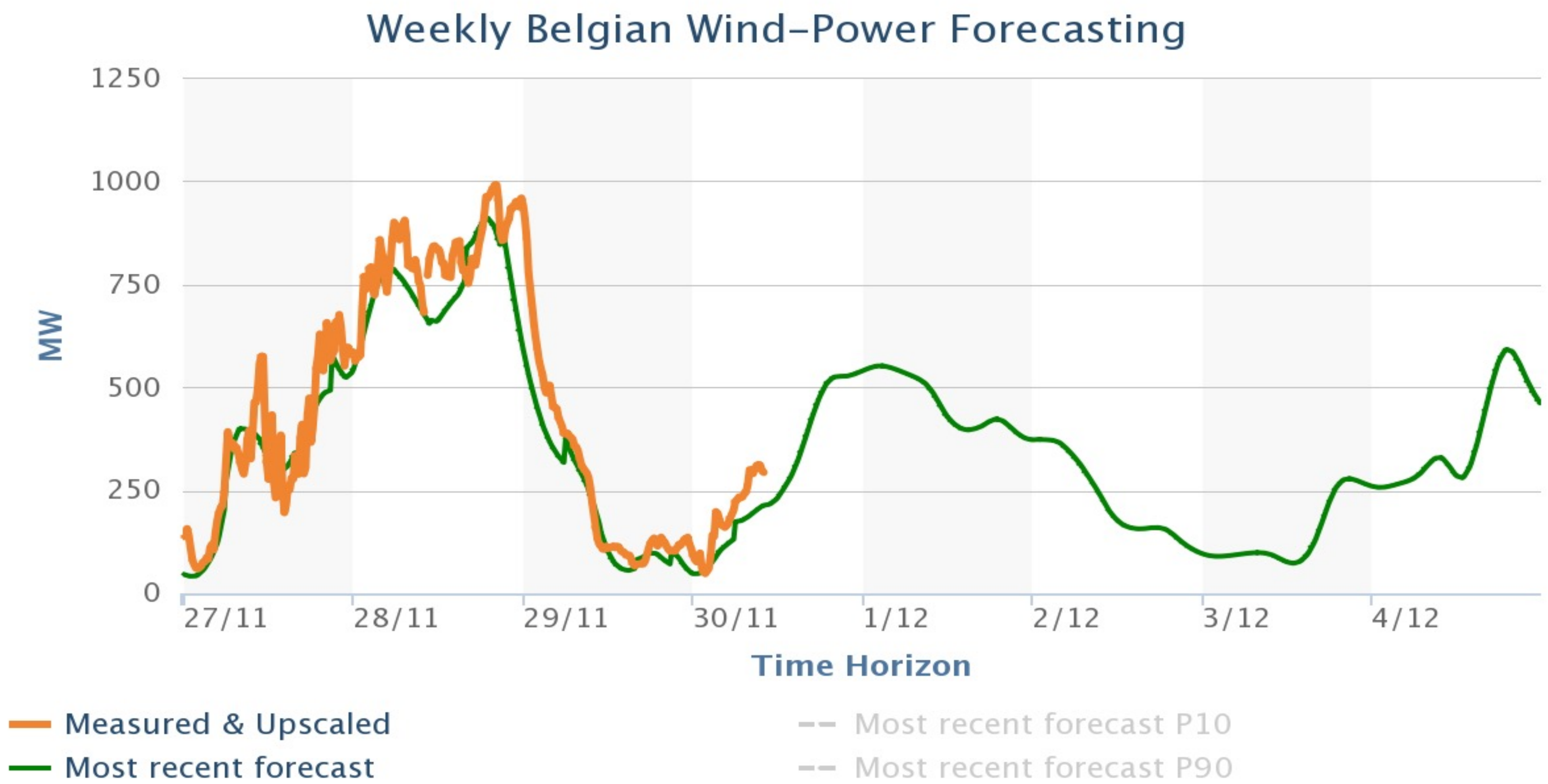
CWE price on a windy Sunday in Germany



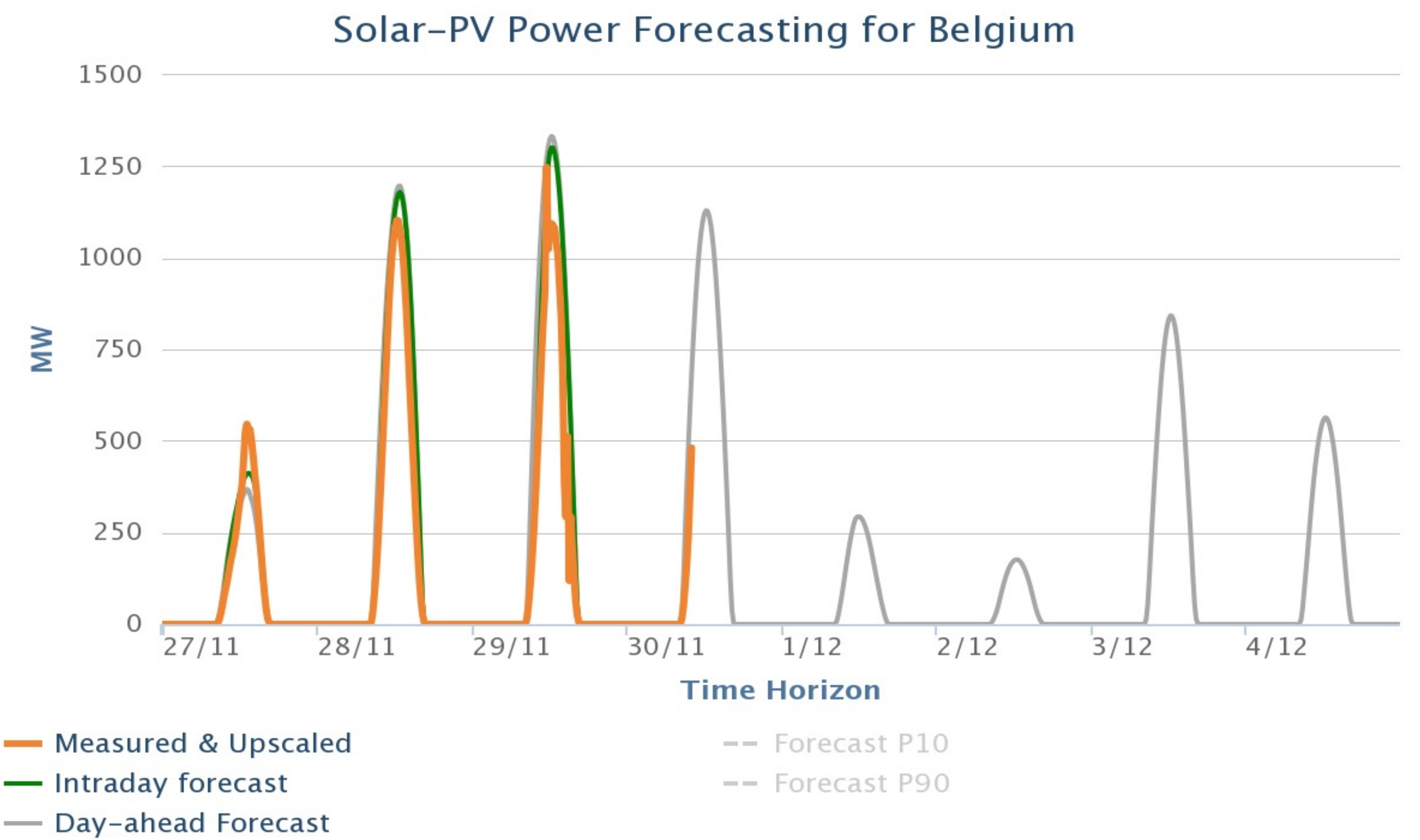
New needs to be taken into account

- **Balance between generation ←→ load**
  - Good overview of decentralised generation units per domain of activity and substation
  - Wind/solar/temperature forecasting tools
  - System service management: takes into account the intermittent nature of renewable energies as regards the volume of reserves
    - ✓ Prim R, Sec R, Tert R

Wind Forecasting



Solar Forecasting



Wind power

Available theoretical power

The available wind power P_{vent} is equal to:

$$P_{vent} = \frac{1}{2}\rho A. v_{vent}{}^{3} \quad [W]$$

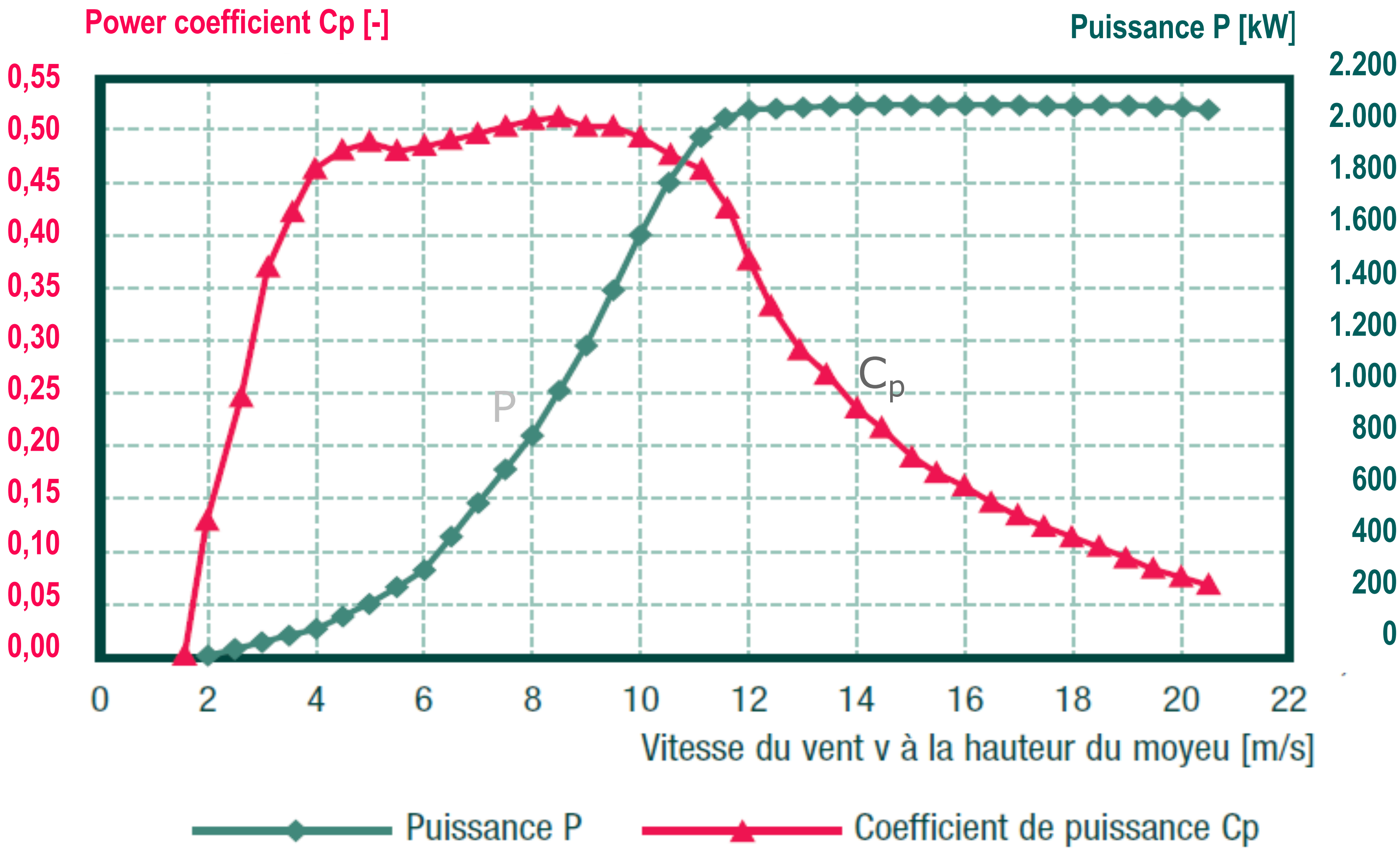
- ρ = Air density (kg/m^3)
- A = Area swept by the blades (m^2)
- v_{vent} = Wind speed [m/s]

Example :
Wind speed: 10 m/s, Rotor diameter: 82 m

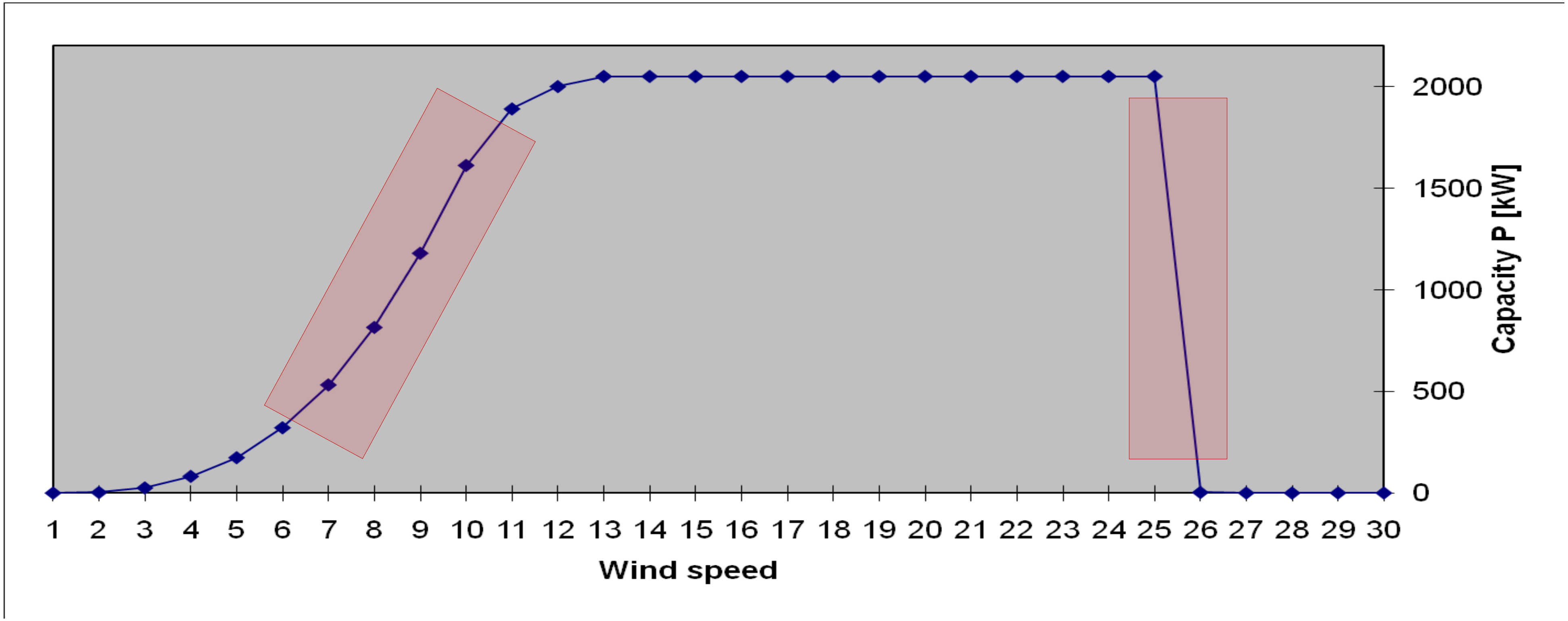
Wind power: 1/2 x 1,225 x 5.281 x 10^3 = 3.235 x 10^3 W ou 3.235 kW

Captured power by the wind turbine = Wind power x **cp**
Cp : performance coefficient, theoretical maximum = 0,59

Power curve= f(wind speed)

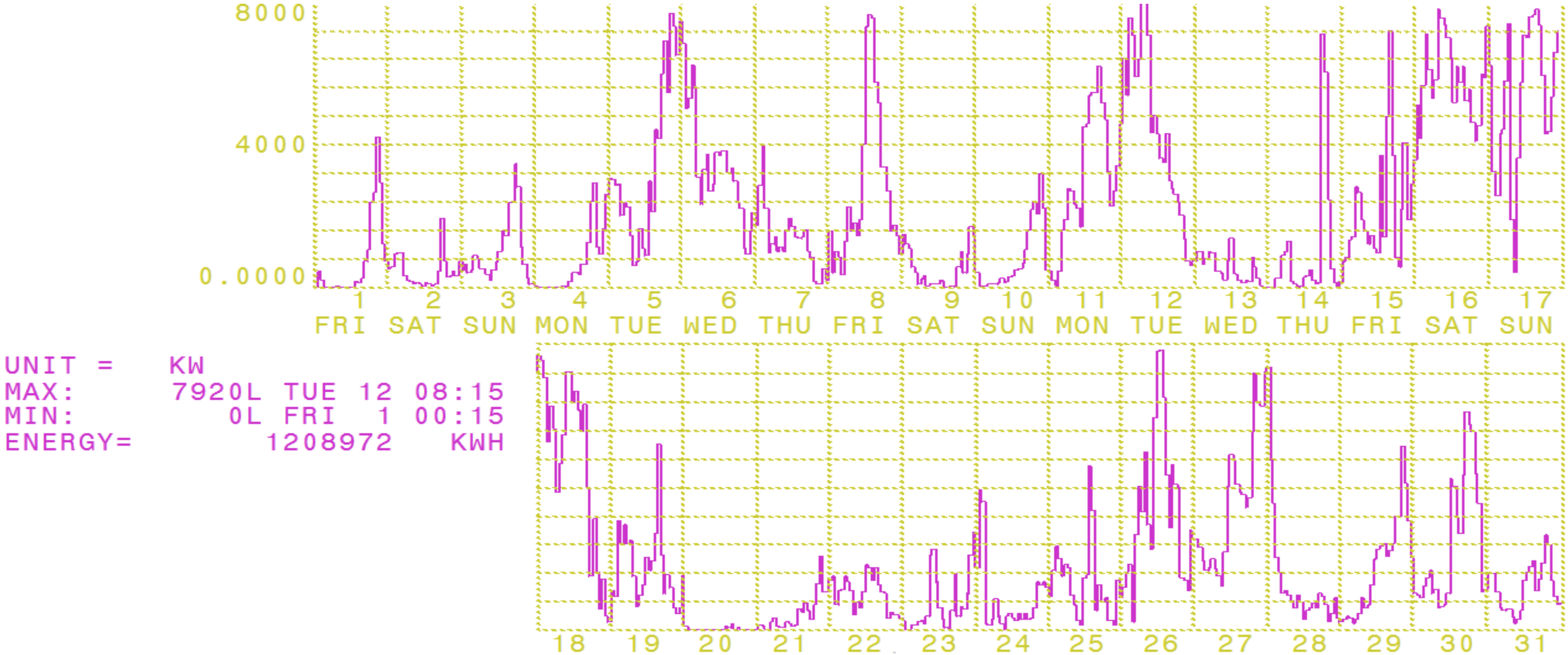


Restrictive areas in wind turbine operation



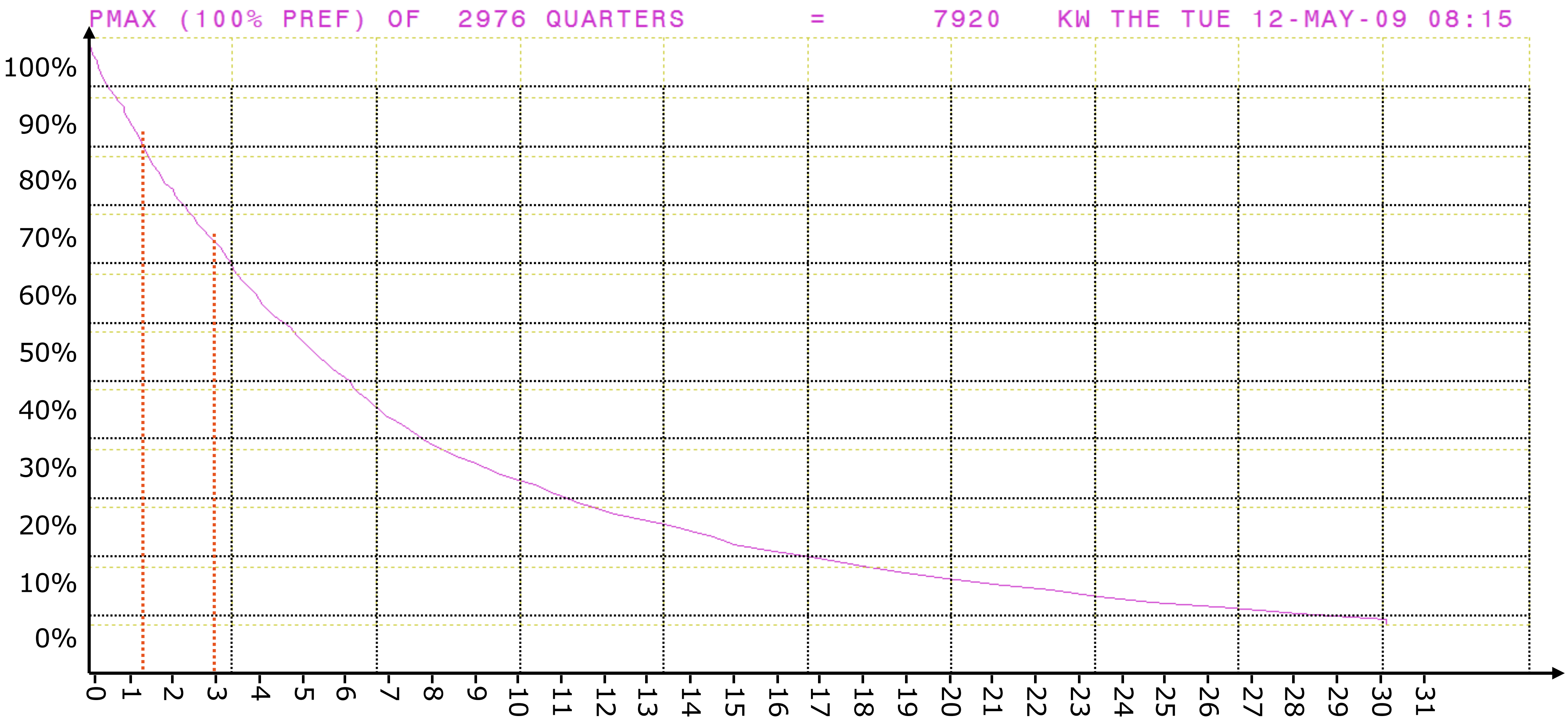
Onshore farms

Monthly generation of a farm



Onshore farm

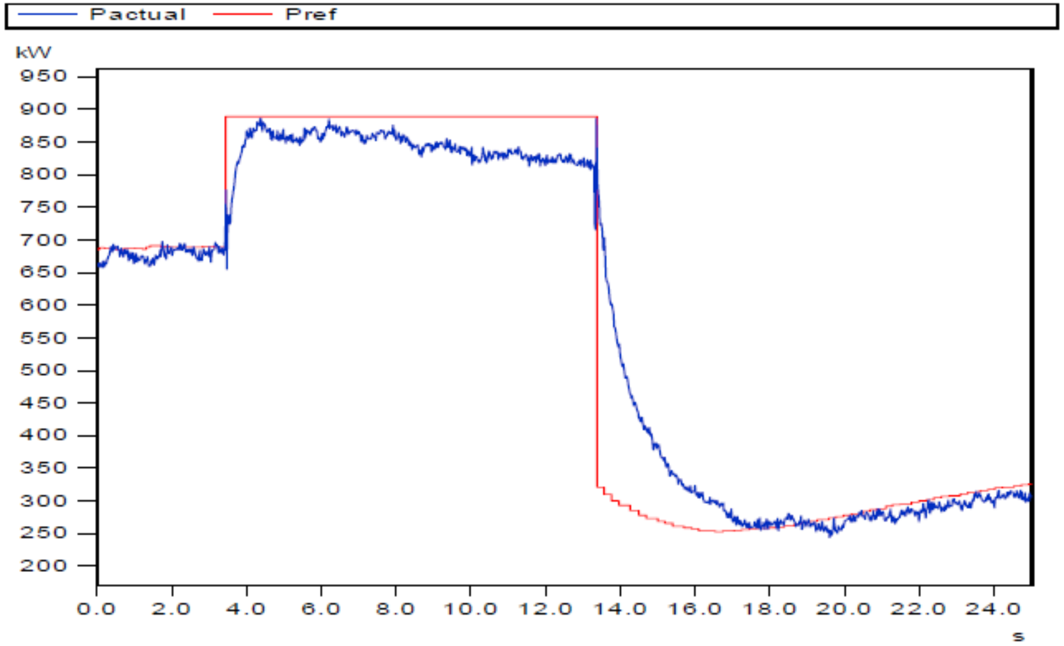
Monthly monotonic curve for the same farm



2. Underfrequency:

Optional active power boost, using the inertia of the rotor.

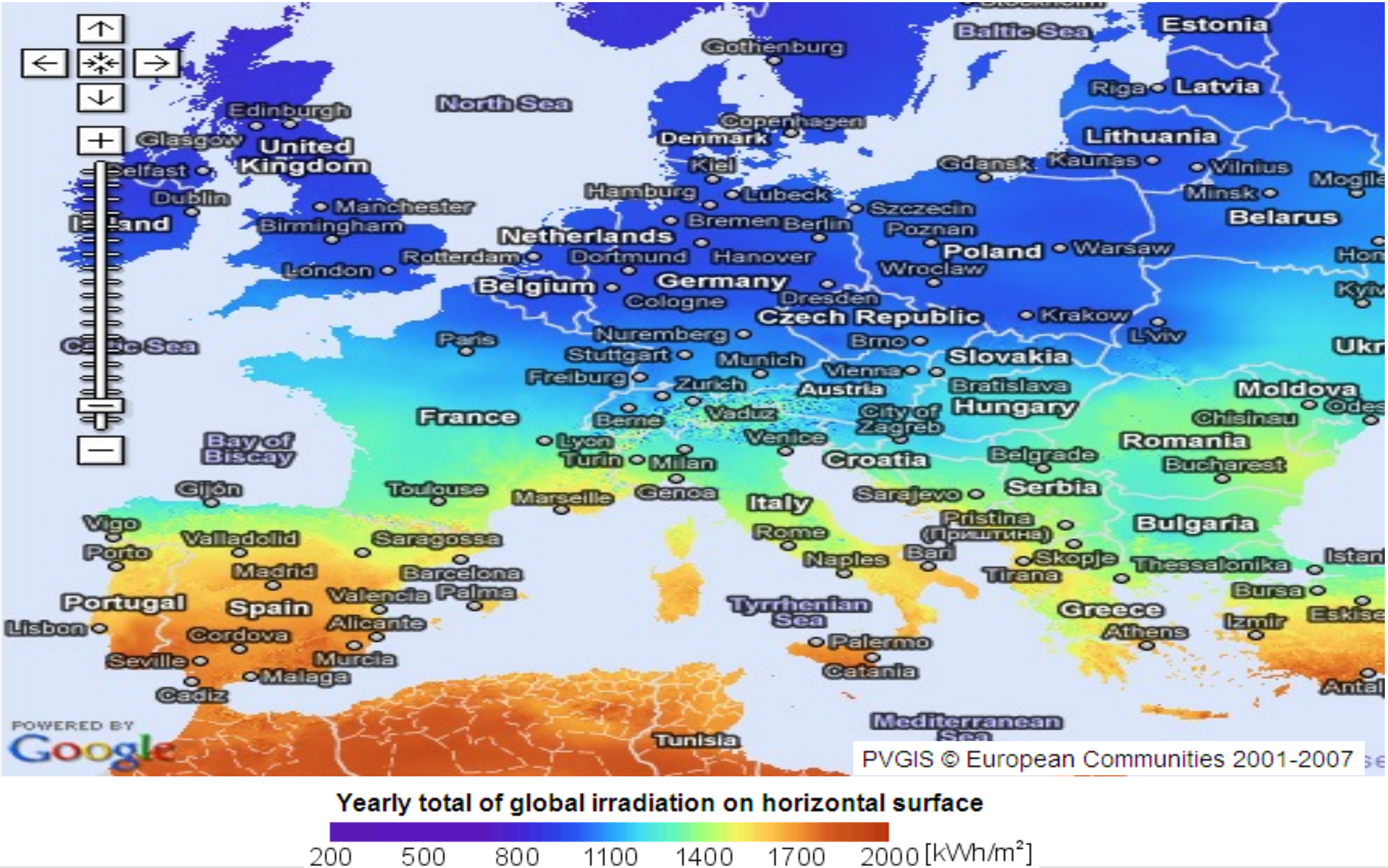
- ✓ $P_{boost} = 10\%P_{rated}$
- ✓ Available as soon as $P_{actual} \geq 4\%P_{rated}$
- ✓ P_{boost} fully available within 800ms
- ✓ Boost for max. 10 seconds
- ✓ Recovery time after boost = 2 x T_{boost}



- **Performance achieved by changing excitation, using rotor inertia.**
- **Activated based on local frequency measurement.**
- **Additional investment in WF necessary.**
- **Cost relevant => Economical value for the power system?**
- **Impact to the max. installable wind power?**

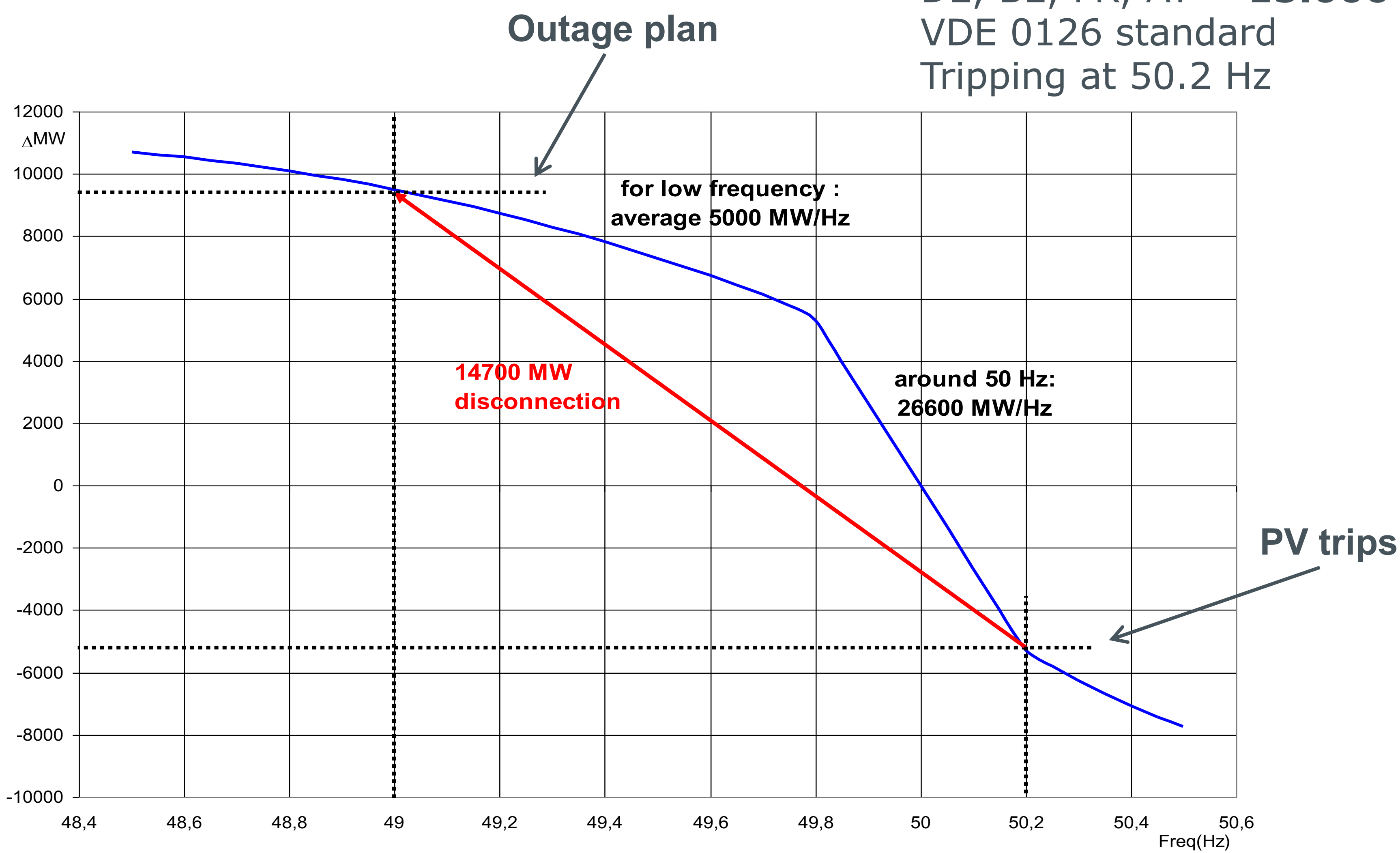
Photovoltaic

Potential in Europe



Risk of disconnection at 50.2 Hz

DE, BE, FR, AT = **15.000 MWp**
VDE 0126 standard
Tripping at 50.2 Hz

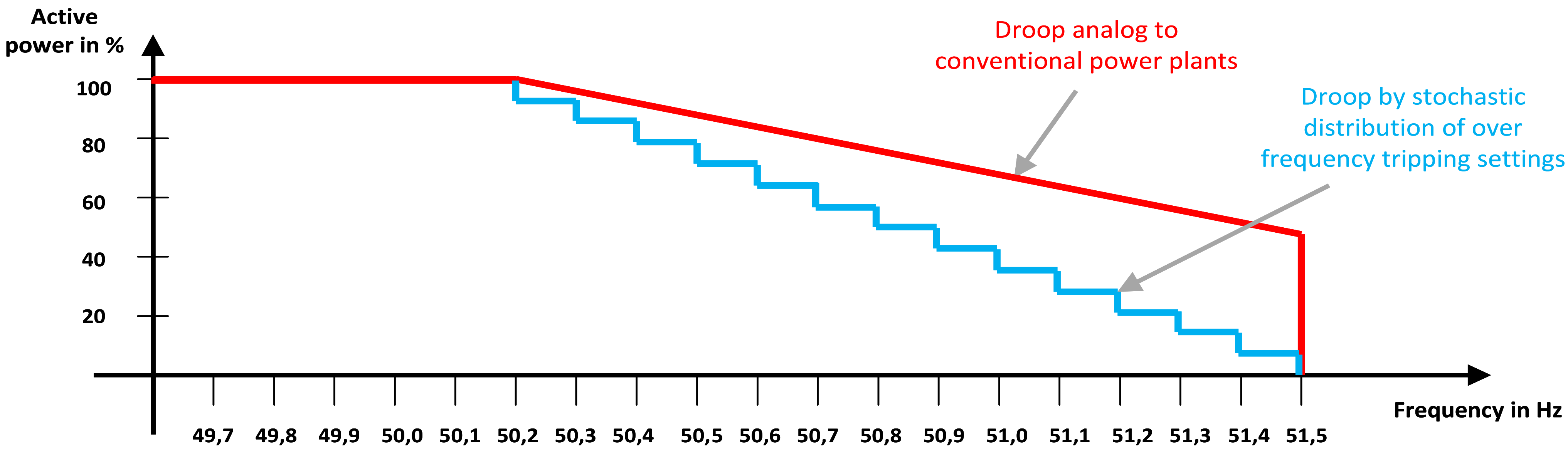


➔ **Risk of increasing uncontrolled frequency fluctuations**

taking into account the f-sensitivity of generation (primary reserve + self-regulation) and load

Modification of the standard: gradual reduction of generation

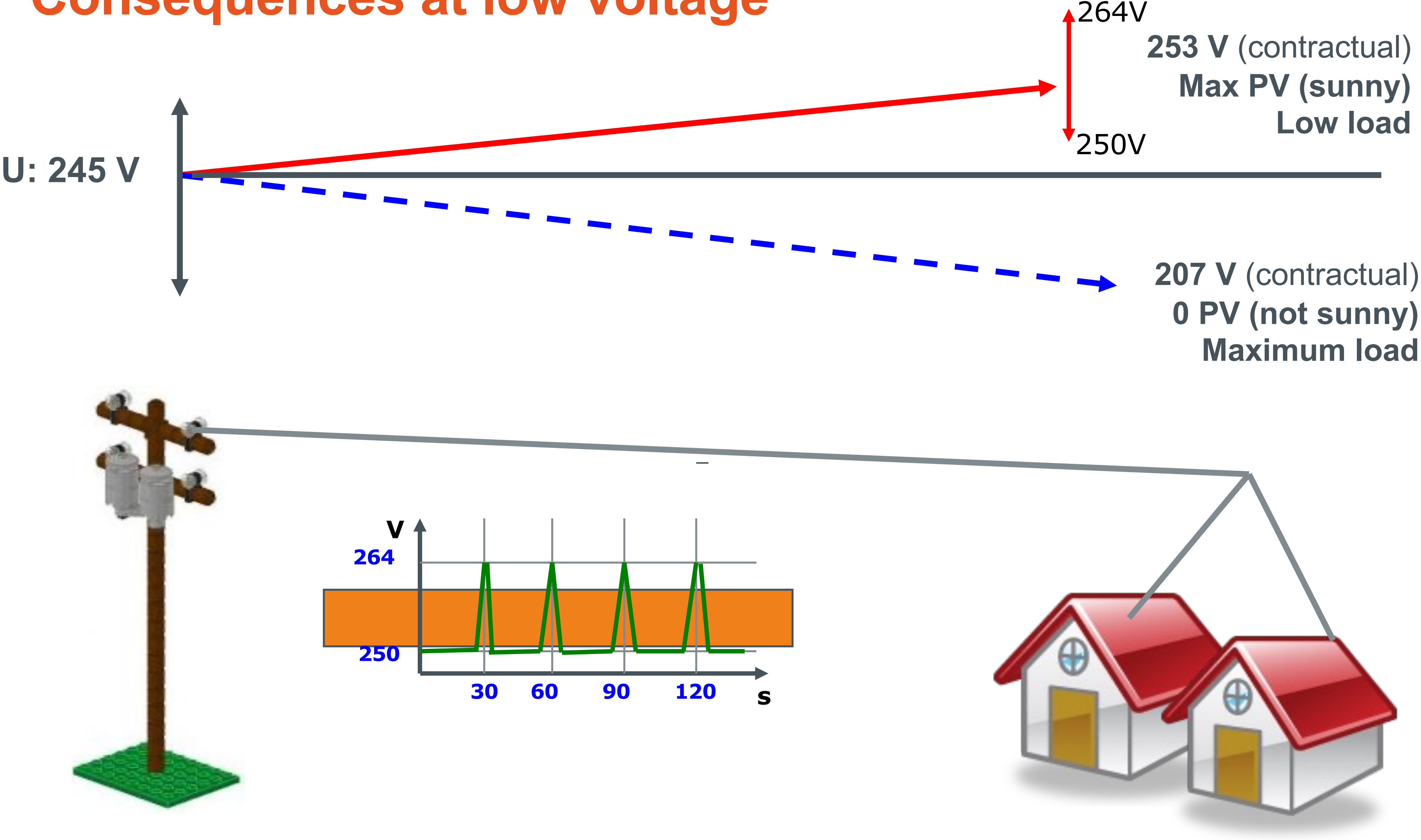
- New units (from 2012 onwards)
  - Gradual reduction of generation
- Existing units
  - Coordinated retrofitting



Voltage problems
Standard DIN VDE 0126-1-1

- Maximum instantaneous voltage: **264.5 V** (115%)
- Maximum average voltage over 10 minutes: **253.0 V** (110%)
- Former instantaneous limit: **243.8 V** (106%)
- Reconnection after **30 seconds**

Consequences at low voltage



PV Germany: SMA solution

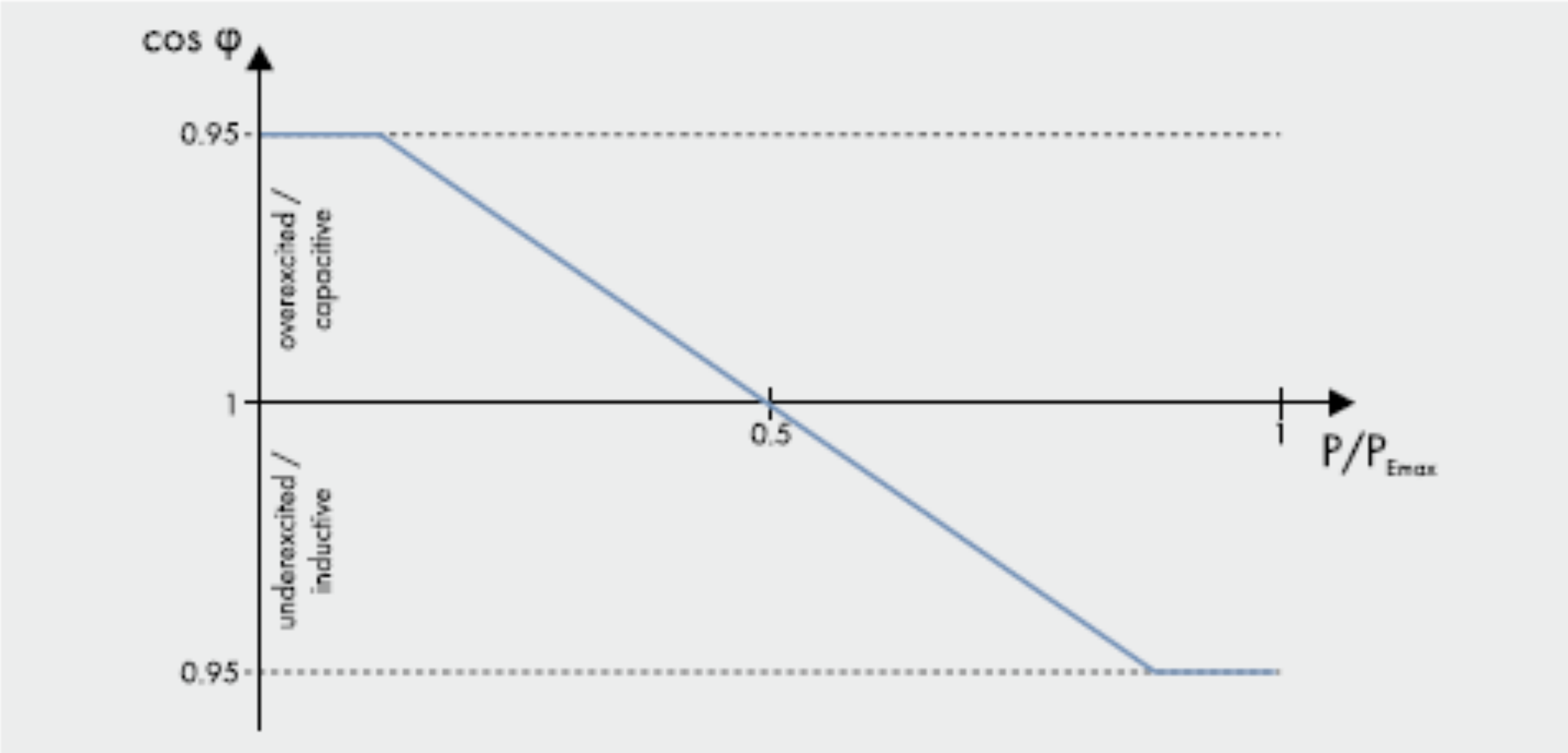


Fig. 4: Among others, the reactive power may be regulated as a function of the supplied active power

Impact on a supplier of the meter running backwards

Year 2021

Average electricity price in July 2021	74.42 €/MWh
Average electricity price in December 2021	245.44 €/MWh

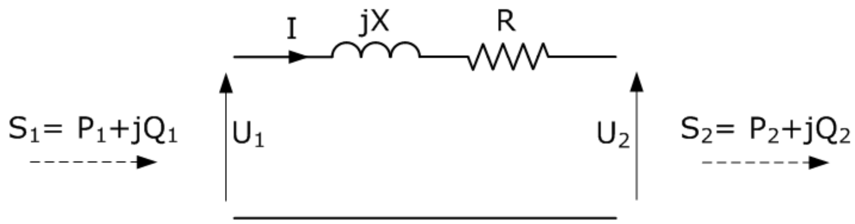
The supplier of the prosumer who received **kWh** in July that were worth **74.42 €/MWh** must return them to this prosumer in December when they are worth **245.44 €/MWh**

This supplier loses 171.02 €/MWh with this prosumer.

For a large installation, we can talk about 3 or 4 MWh
To compensate for the losses with the prosumers, the supplier has to increase the prices with his other customers accordingly.

Theoretical concept : Transmittable power

Transmittable power



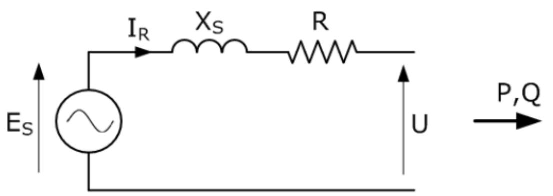
$$P_1 \approx \frac{|U_1||U_2|}{X} \sin \delta$$

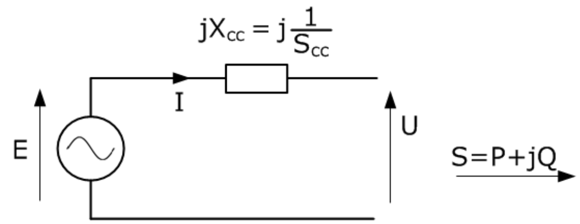
At very high voltage, R negligible compared to X

Theoretical concept : Scc

Scc ≈ strength of the grid
Scc ≈ 1/(electrical distance with the grid)
generators.

Thevenin



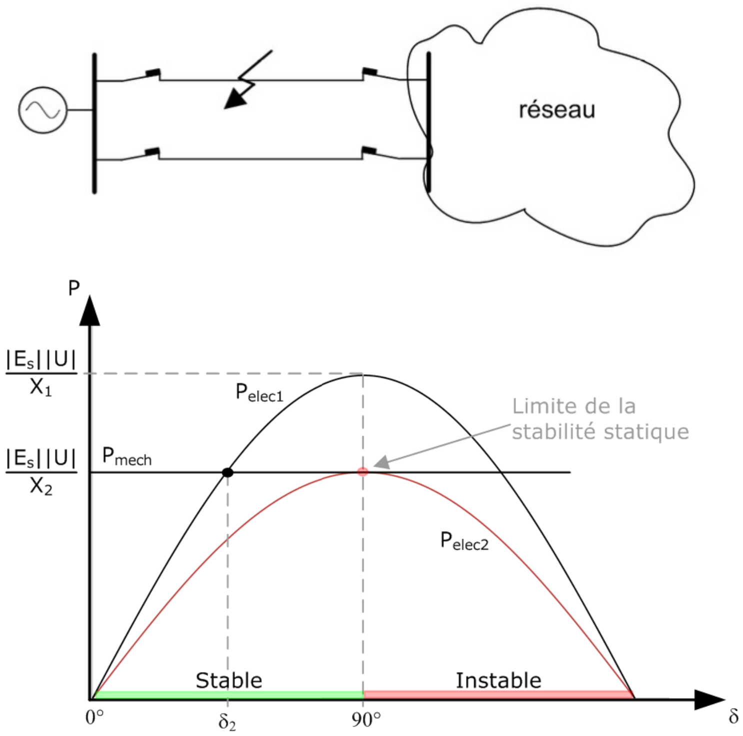


En per unit $X \approx \frac{1}{|S_{CC}|}$

<u>Scc contribution</u>
Synchronous generators = 4*Pnom
Power electronics = 1*Pnom

Impact of renewable energy on stability

Generator stability



Renewable energies ⇑ => Synchronous generators ⇓

=> Scc ⇓ => risks of instability especially at weekends when the load is low

Impact of renewable energy on stability

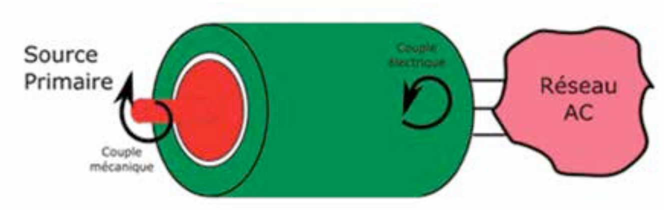
Network inertia

Mechanical function of inertia

The lower the inertia, the faster the frequency changes due to an imbalance.
If the frequency deviates from its stability range (48.5 Hz to 51.5 Hz), the network runs a high risk of blackout.

Inertia is provided by synchronous rotating machines.

The replacement of synchronous rotating machines by renewable energy, usually connected by power electronics decreases the total inertia of the grid.



$$\frac{Jd\Omega}{dt} = C_m - C_e$$

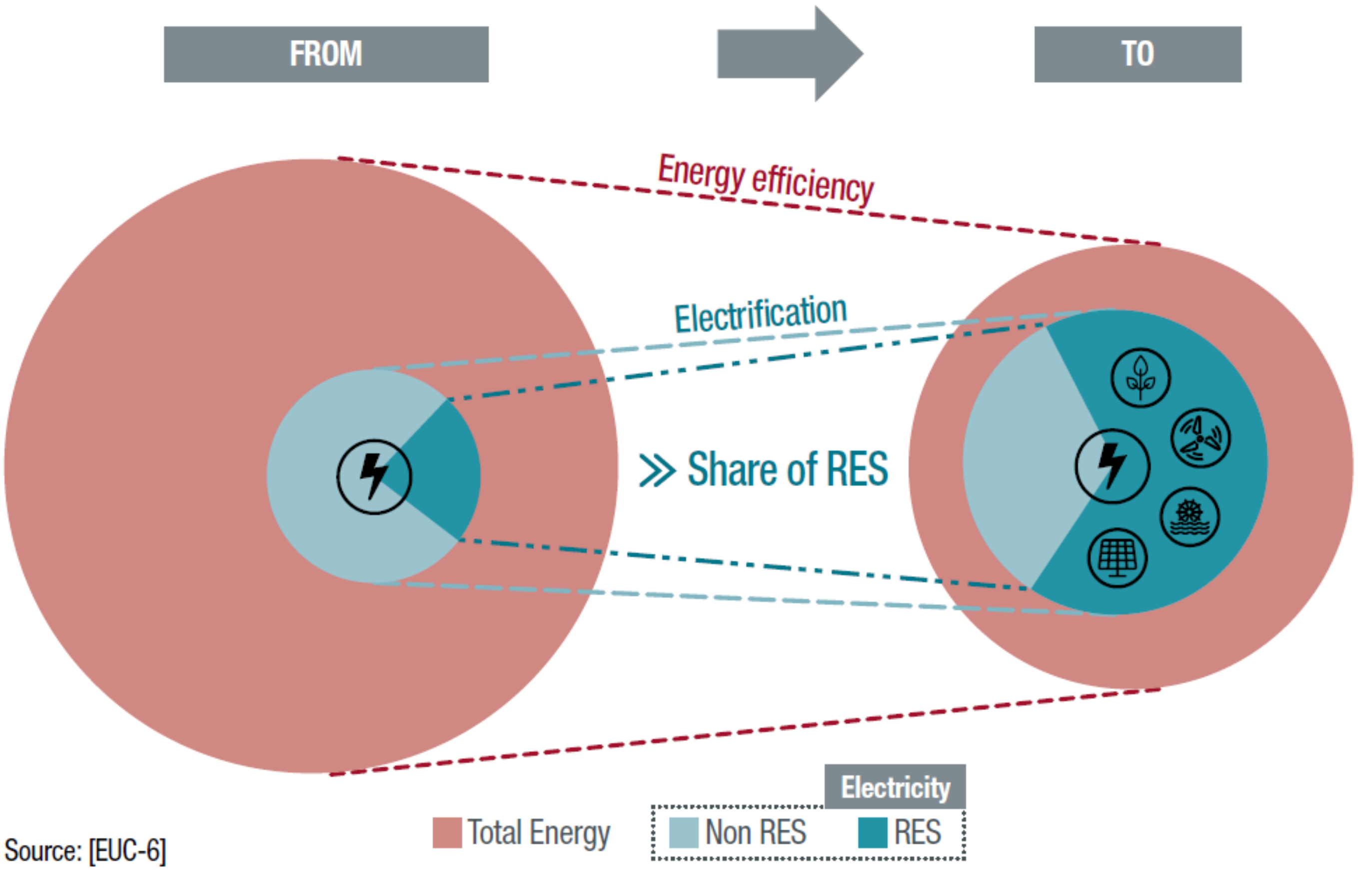
J, inertia of synchronous machine
Ω, rotation speed of synchronous machine
Cm, mechanical torque provided on the alternator shaft
Ce, electrical torque called by the network.
Source RTE

Environmental Objectives

European Objectives

	2008-2012	2020	2030	2050
Europe	GES : -8%/1990	GES : -20% /1990	GES : - 40%/1990 = -43%/2005 (ETS) Et -30%/2005 (non-ETS)	GES :- 80 à - 95% /1990
		EnR : 20% consommation finale brute d'énergie	EnR : 32% consommation finale brute d'énergie	
		EE : -20% consommation énergie primaire	EE : 32.5% d'efficacité énergétique (consommation primaire et/ou finale)	

European Objectives 2040-2050



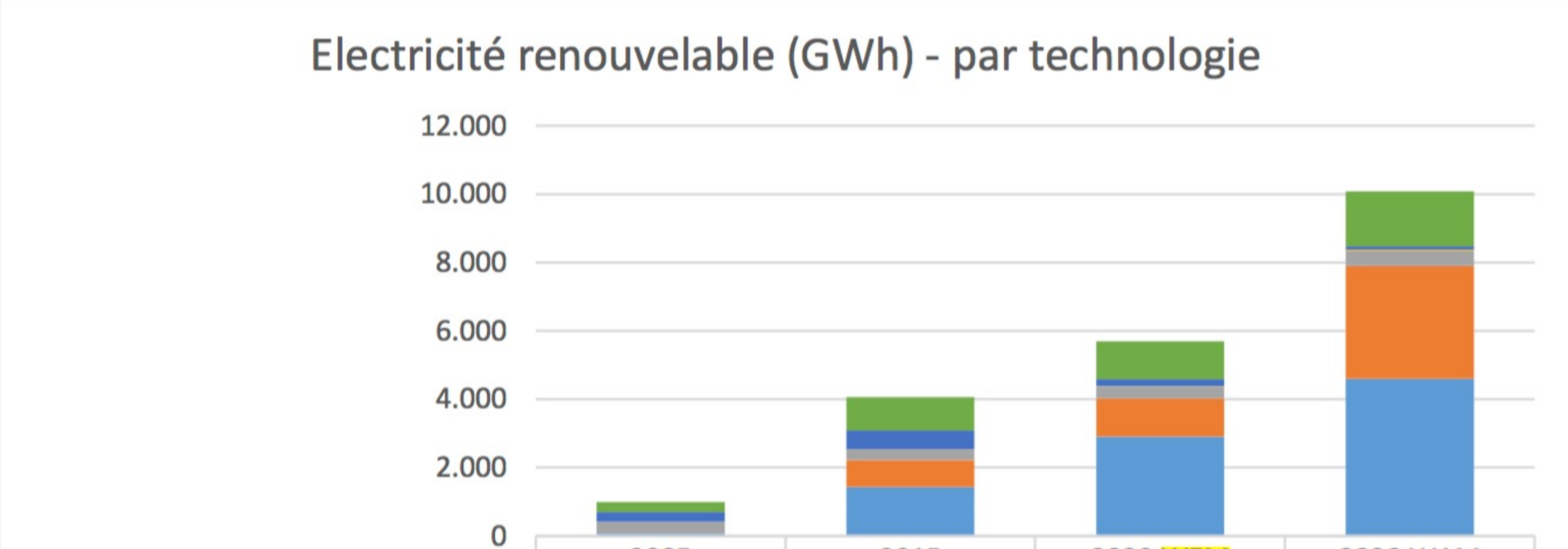
Source: [EUC-6]

The total energy consumed will be reduced with additional energy efficiency measures

The electricity share in the final energy consumption will increase with additional electrification

The increase of renewables in the energy mix and particularly in the electricity sector will increase

Belgian Objectives 2030 (Walloon region)

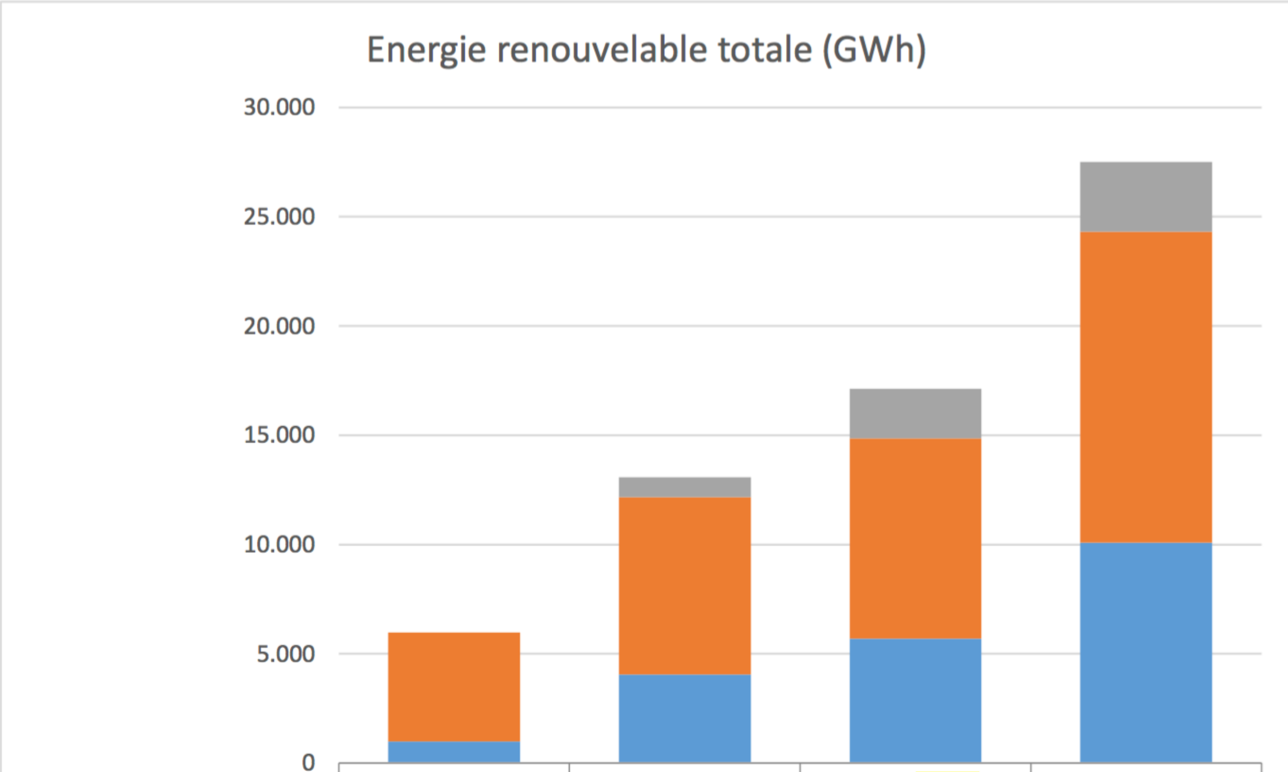


	2005	2015	2030 WEM	2030 WAM
Biomasse - cogénération	282	975	1.104	1.611
Biomasse - électricité uniquement	280	543	208	90
Géothermie	0	0	11	40
Hydraulique	352	314	342	440
Photovoltaique	0	792	1.120	3.300
Eolien on shore	75	1.437	2.907	4.600

WEM : With Existing Measures

WAM : With Additional Measures

Belgian Objectives 2030 (Walloon region)



	2005	2015	2030 WEM	2030 WAM
Transport (biofuel)	0	906	2.263	3.187
Chaleur	4.985	8.108	9.170	14.233
Electricité	988	4.060	5.691	10.081

■ Electricité ■ Chaleur ■ Transport (biofuel)

Figure 39 : Evolution de l'énergie renouvelable en Wallonie

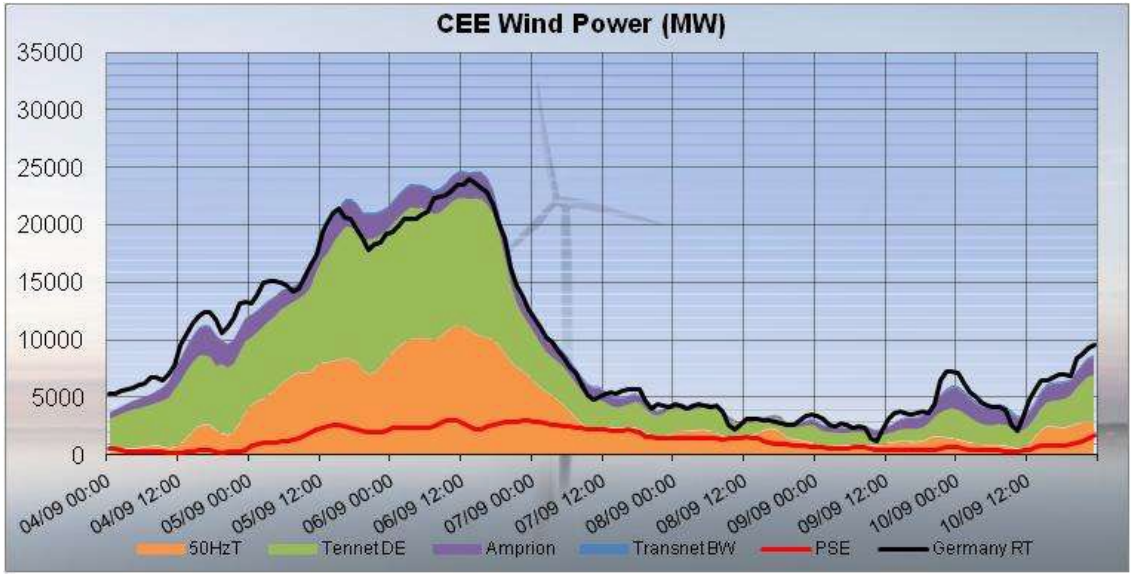
Belgian Objectives 2030 (Walloon region)

Consommation finale (GWh)	2005	*2030 WEM*	2020 WAM	2030 WAM	Ecart 2030 WAM-WEM	Ecart 30-05 WAM %	Ecart 30-20 WAM %
Résidentiel	37 585	*30 018*	29 524	26 141	-12.92%	-30.45%	-11.46%
Tertiaire	12 249	*13 800*	12 813	12 146	-11.99%	-0.84%	-5.21%
Industrie	61 793	*41 375*	39 408	40 272	-2.67%	-34.83%	2.19%
Agriculture	1 289	*1 289*	1 289	1 289	0.00%	0.00%	0.00%
Transport	36 305	*43 916*	35 265	35 619	-18.89%	-1.89%	1%
TOTAL Consommation finale énergétique	**149 221**	**130 398**	**118 300**	**115 467**	***-11.45%***	***-22.62%***	***-2.39%***

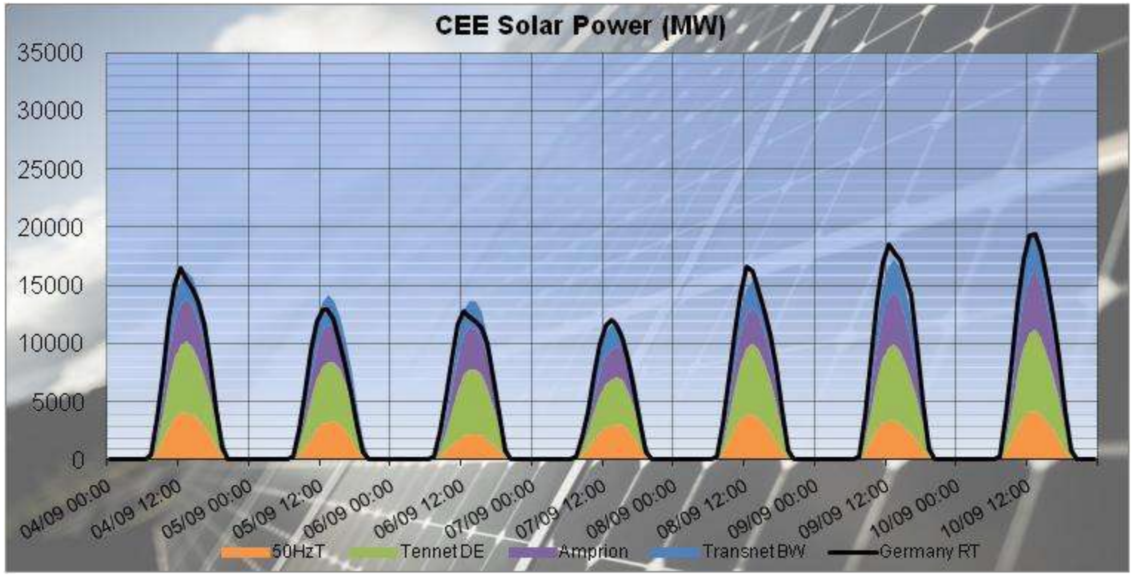
Tableau 12 : Consommation finale WAM

Renewable Energy in Germany (during one week)

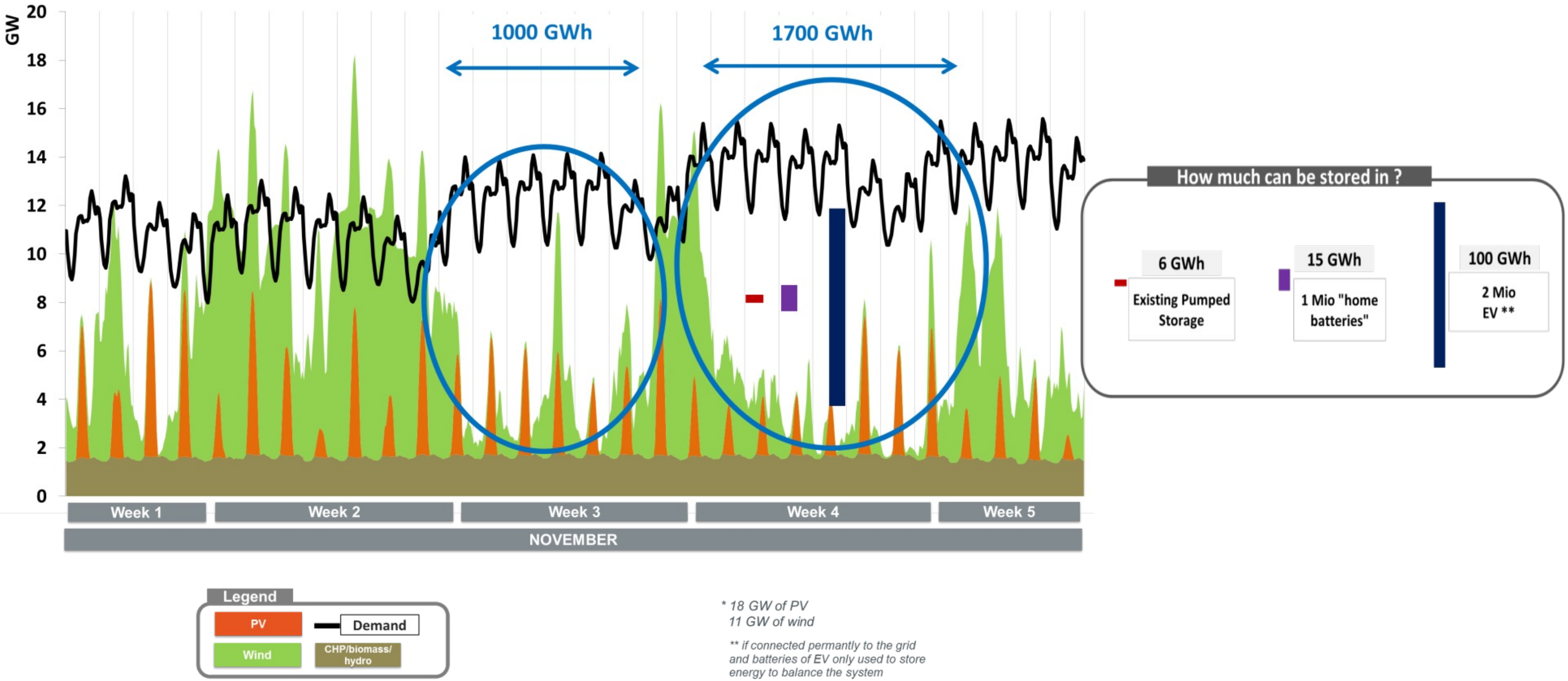
- **WIND**



- **SOLAR**



2040, need storage and flexible demand during periods with no wind and no sun



* 18 GW of PV
11 GW of wind

** if connected permantly to the grid and batteries of EV only used to store energy to balance the system

Hydraulic storage

Exemple :

available power and energy from a waterfall

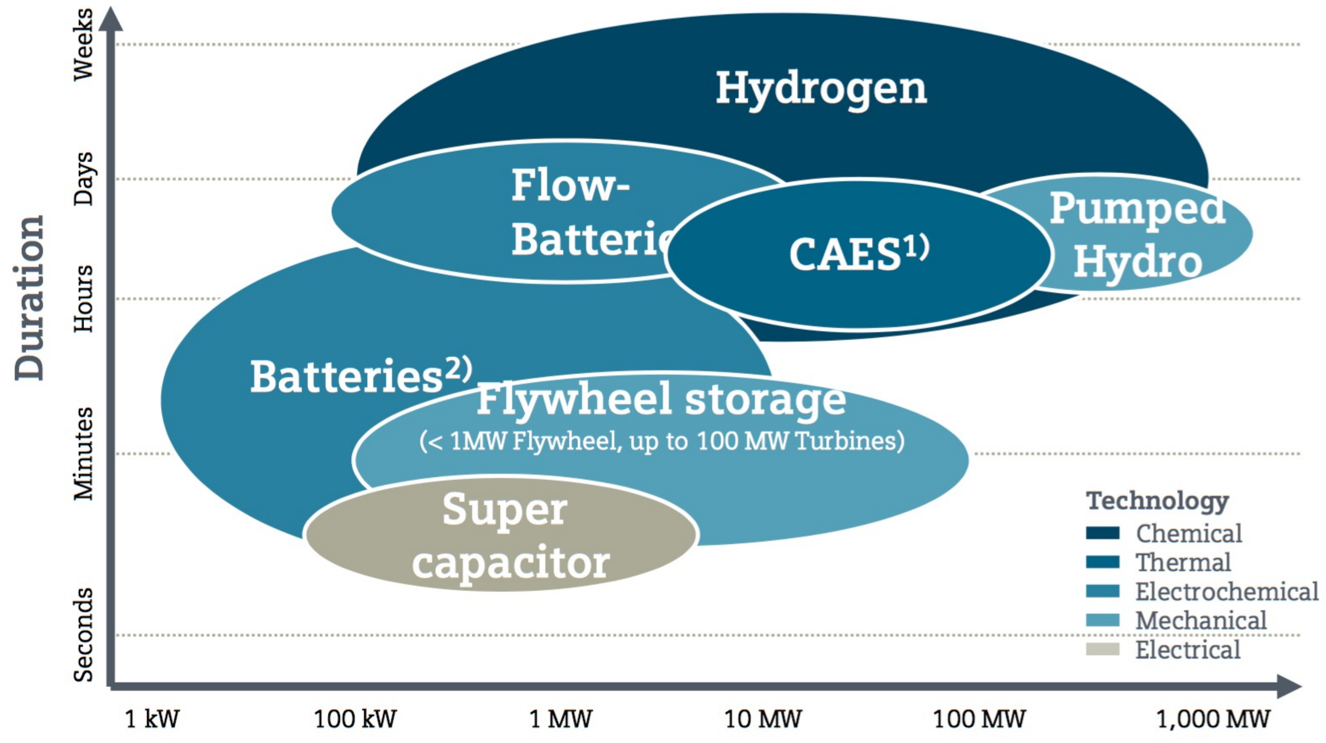
Types of storage

- Hydraulic : pumped storage
- Lithium ion batteries
- Biomass
- Power to Gas : H_2 or CH_4
- CAES (crompressed air energy storage)
- Kinetic energy
- Sensitive or latent heat
- Etc.

Types of storage and potential

Ragone Diagram

SIEMENS



Hydrogen can be stored cost-effectively and in large scale.

1) Compressed Air Energy Storage; 2) Li-Ion, NaS, Lead Acid, etc.

Hydrogen production

Silyzer 300
Large scale PEM electrolyzer

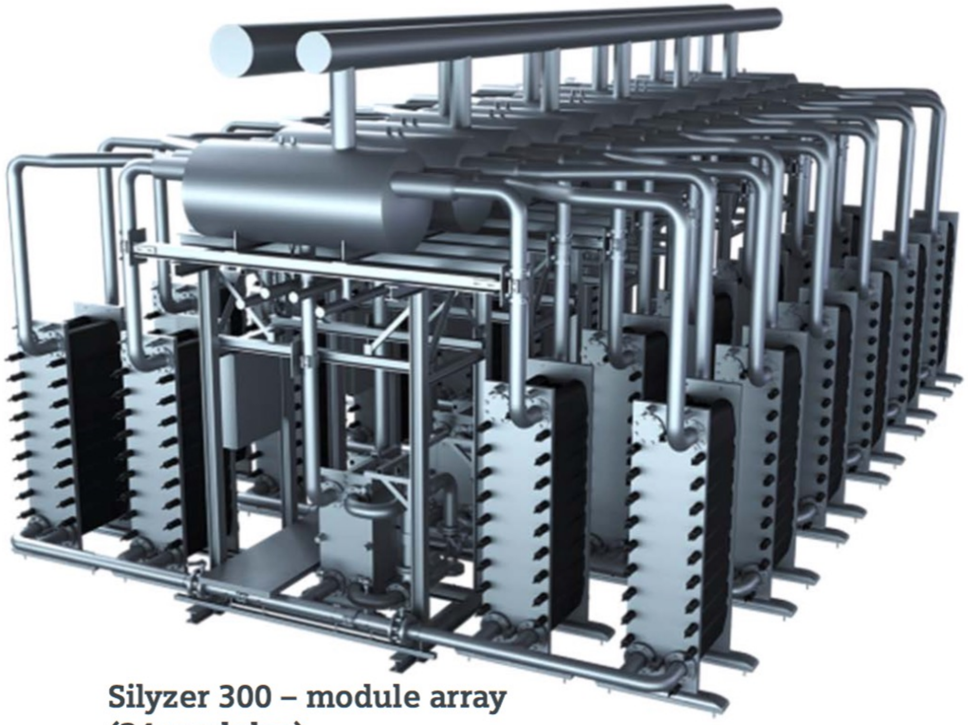
SIEMENS

17.5 MW
per full module array
(24 modules)

75%
System efficiency
(higher heating value)

24 modules
to build a
module array

340 kg
hydrogen per hour
per module array
(24 modules)



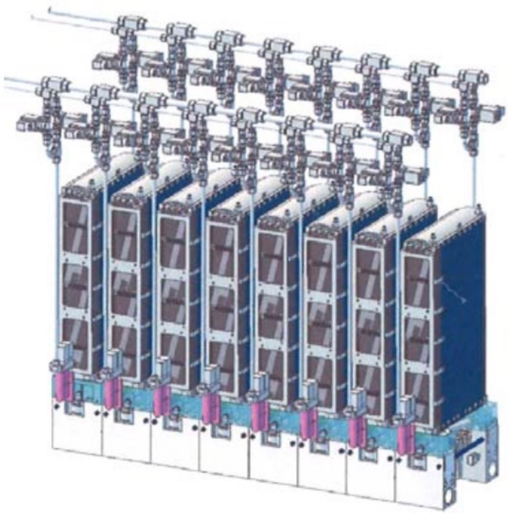
Silyzer 300 – module array
(24 modules)

H2 to electricity

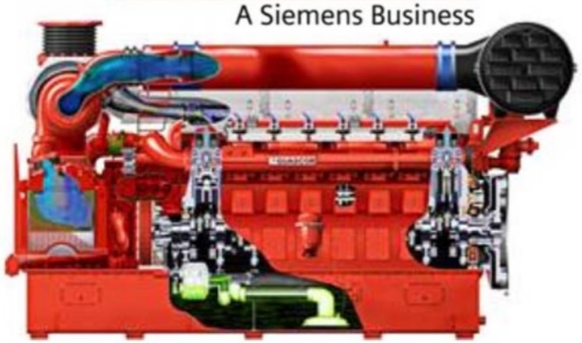
Power to Gas (Hydrogen), how it looks like

Reconversion of H_2 to electricity & heat, kW to MW

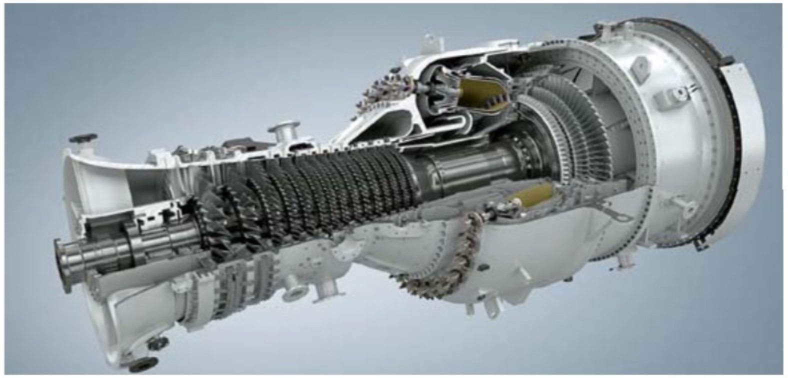
SIEMENS



DRESSER-RAND
A Siemens Business



		Cyl	Displac.	Power (kW)
SFGLD	240	8L	24	250
SFGLD	480	16V	48	500



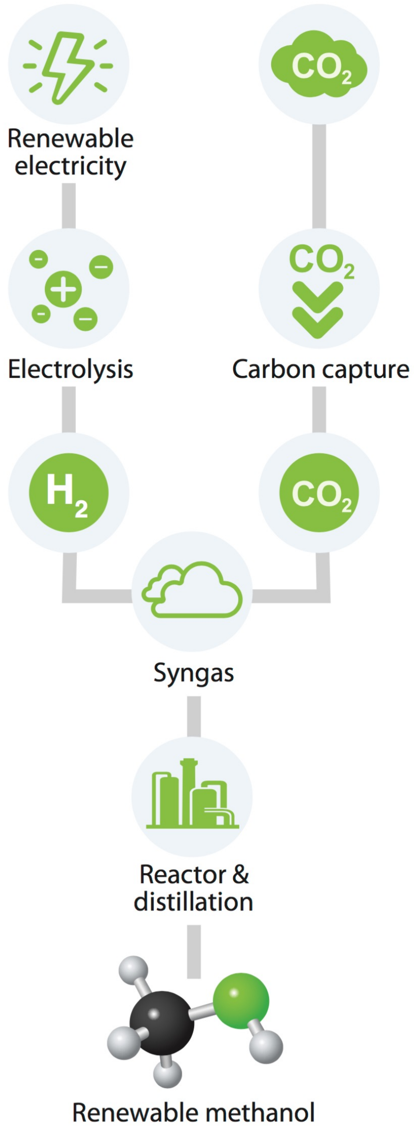
Fuel Cell
kW – MW, η≈ 58%

Gas Motor
kW – MW, η≈ 35%

Gas Turbine
25 – 50 MW, η≈ 35% - 57%

Methanol production

	Net heating value (kWh/l)
Diesel fuel	9,96
Methanol	4,37



Global Grid

Global Grid

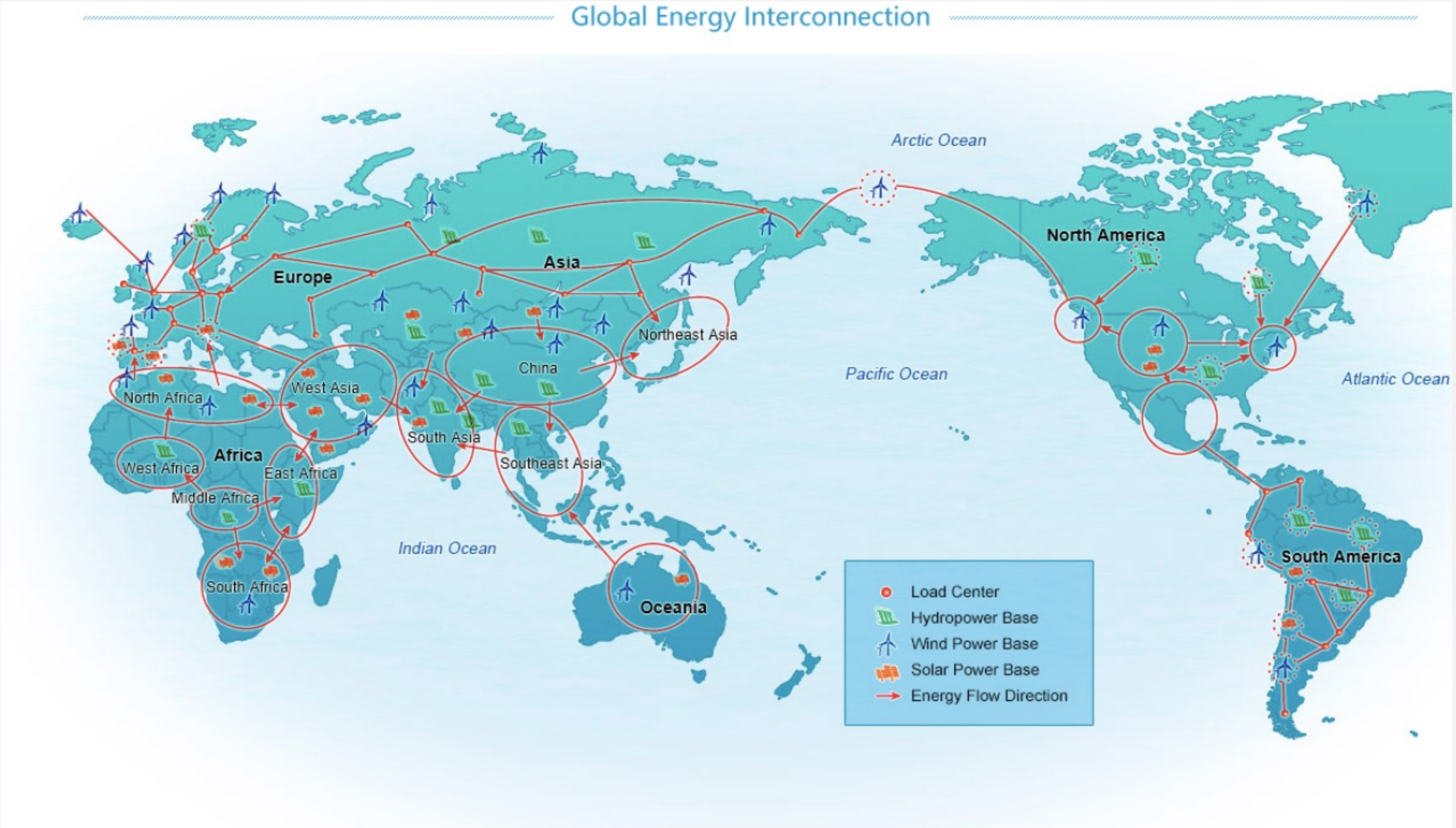


IMAGE @GEIDCO

Technical characteristics of the global grid

Need:

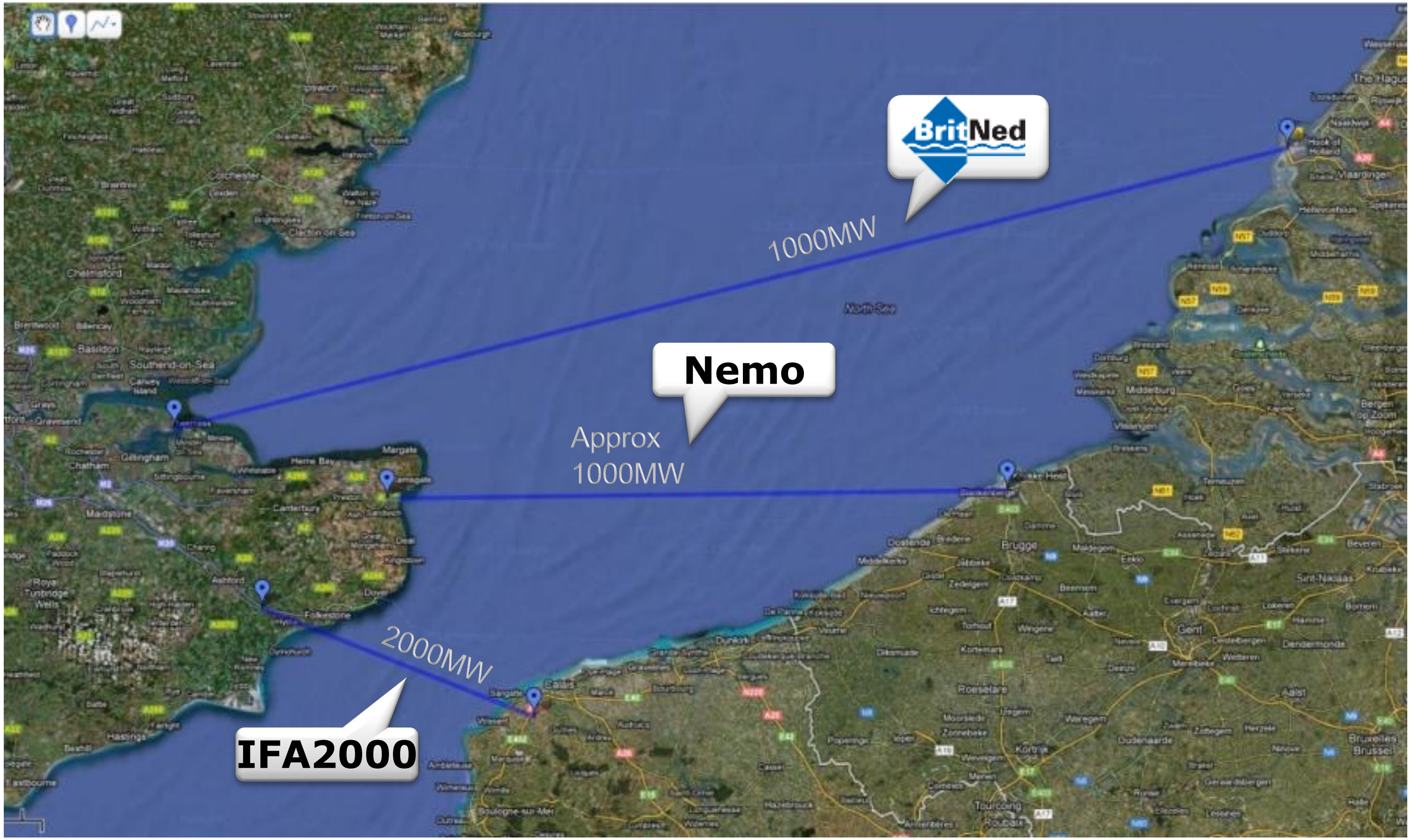
Transport of very large power over long distances

Adapted technology:

Direct curent links

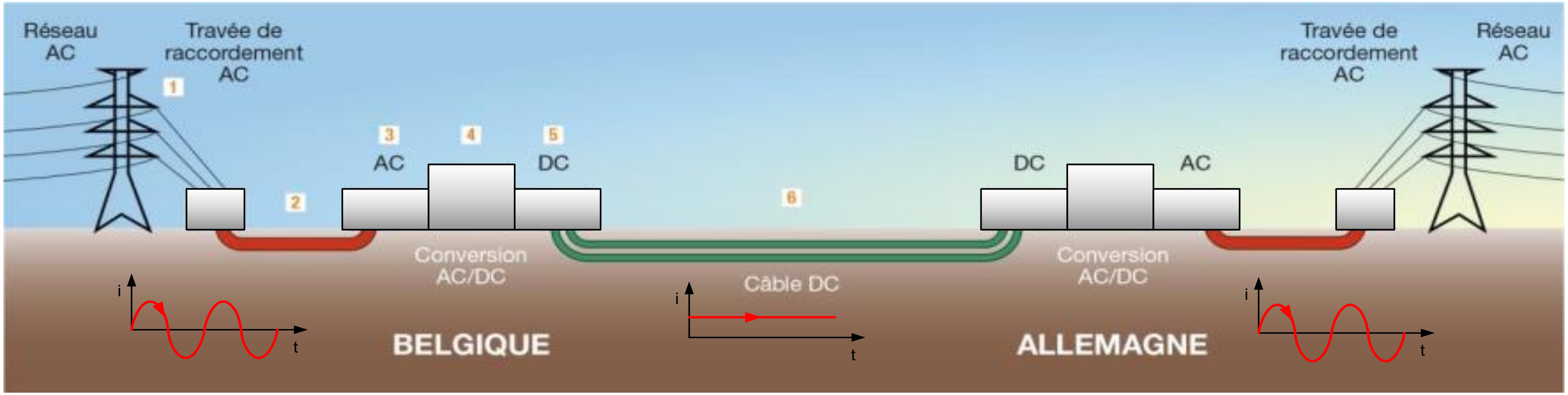
- Low losses
- Easy flow modulation
- Participation in system services

Nemo Link :new electricity interconnector between UK and the continent



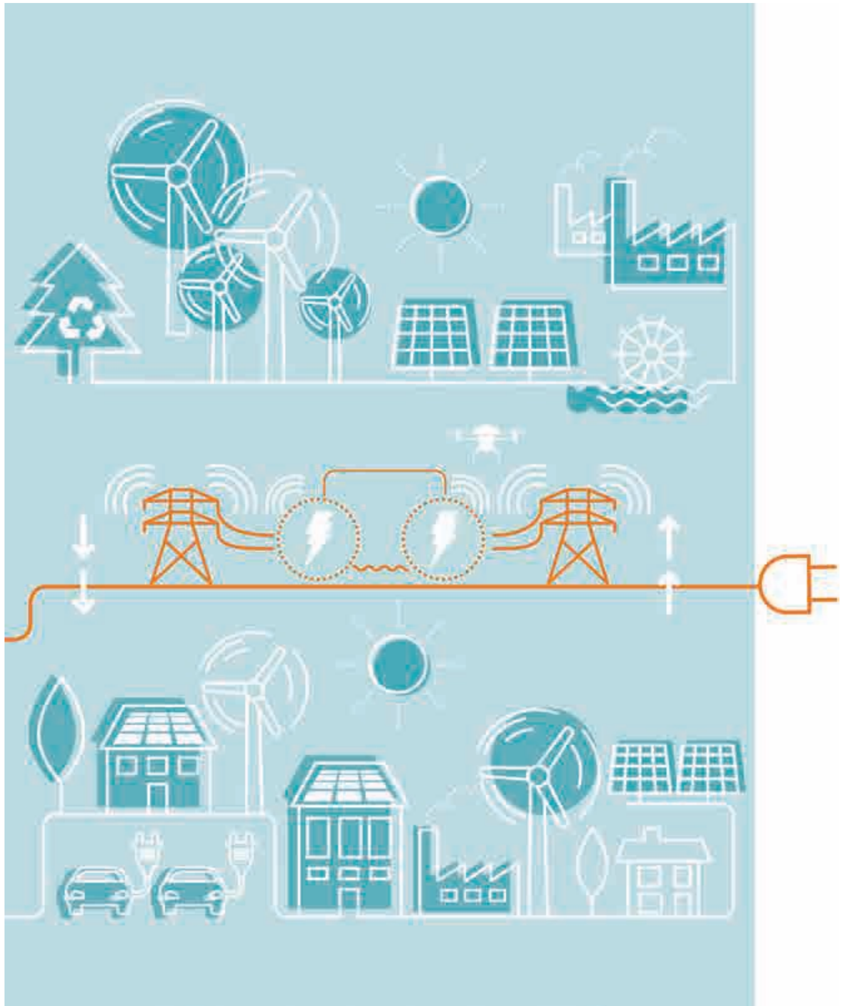
The ALEGrO interconnector

Converter station technology	HVDC VSC multilevel Symmetrical Monopole	
Bi-directional capacity	~ 1000 MW	
Cable technology	HVDC XLPE	
Applied DC voltage	320 kV	
New interconnection	Belgium	Germany
TSO	Elia	Amprion
Region	Liège	Aachen
Converter station location	Visé	Oberzier
Route length	49 km	45 km



Energy future

Energy future



Energy future

Technical problem

- Intermittence of renewable energies
- Variability of renewable energies

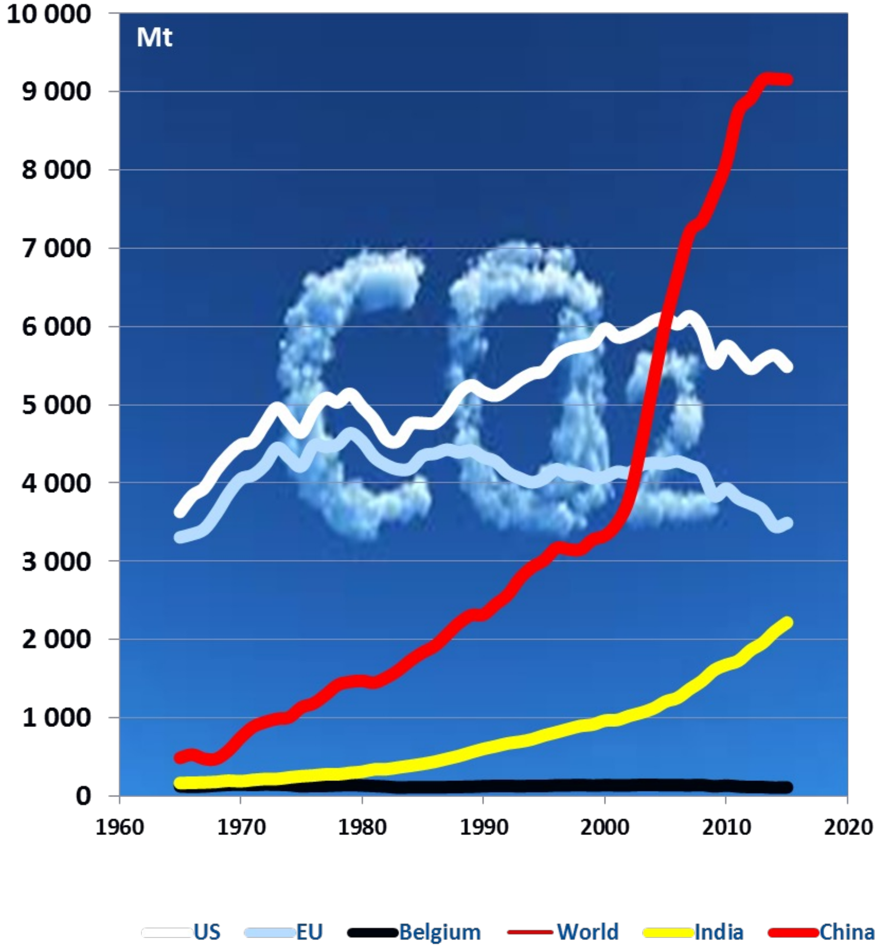
Problems to be solved locally with storage, micro grid,DSM, and at European and Global level with global grid

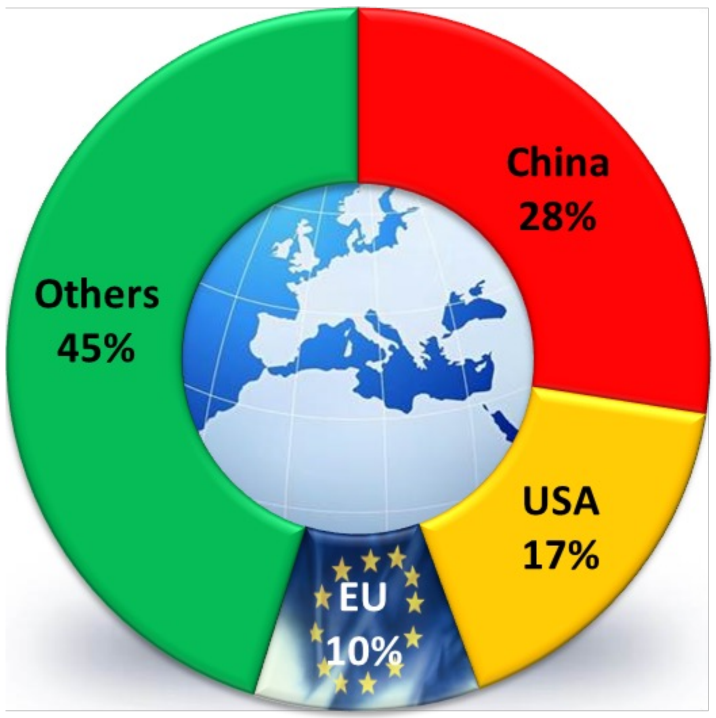
Political issue

- Nuclear shutdown
- Réduction of CO2 emissions

Global problem to solve at planet level

Energy future





Samuele Furfari Data : BP 2016

Many thanks for your attention!

Jean-Jacques Lambin