



World Energy &  
Meteorology Council

EUPORIAS

# POWER SYSTEMS: BASIC PRINCIPLES

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# OVERVIEW

1. Some definitions
2. Energy Markets
3. Supply / Demand Balance
4. Impacts of Renewables
5. Summary

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# SOME DEFINITIONS

|               |                            |                    |
|---------------|----------------------------|--------------------|
| Voltage (U)   | Analog to pressure         | Volt               |
| Current (I)   | Analog to flow             | Ampère             |
| Power (P)     | $P = U \times I$           | Watt               |
| Energy (E)    | $E = P \times \text{time}$ | Watt h (Wh)        |
| Frequency (f) | For alternating            | Hertz ( $s^{-1}$ ) |

## Quality of electricity:

- Continuity (no short/long power cuts)
- Voltage (level, flickering, brownouts, transient overvoltage, harmonics, imbalance between phases, frequency)

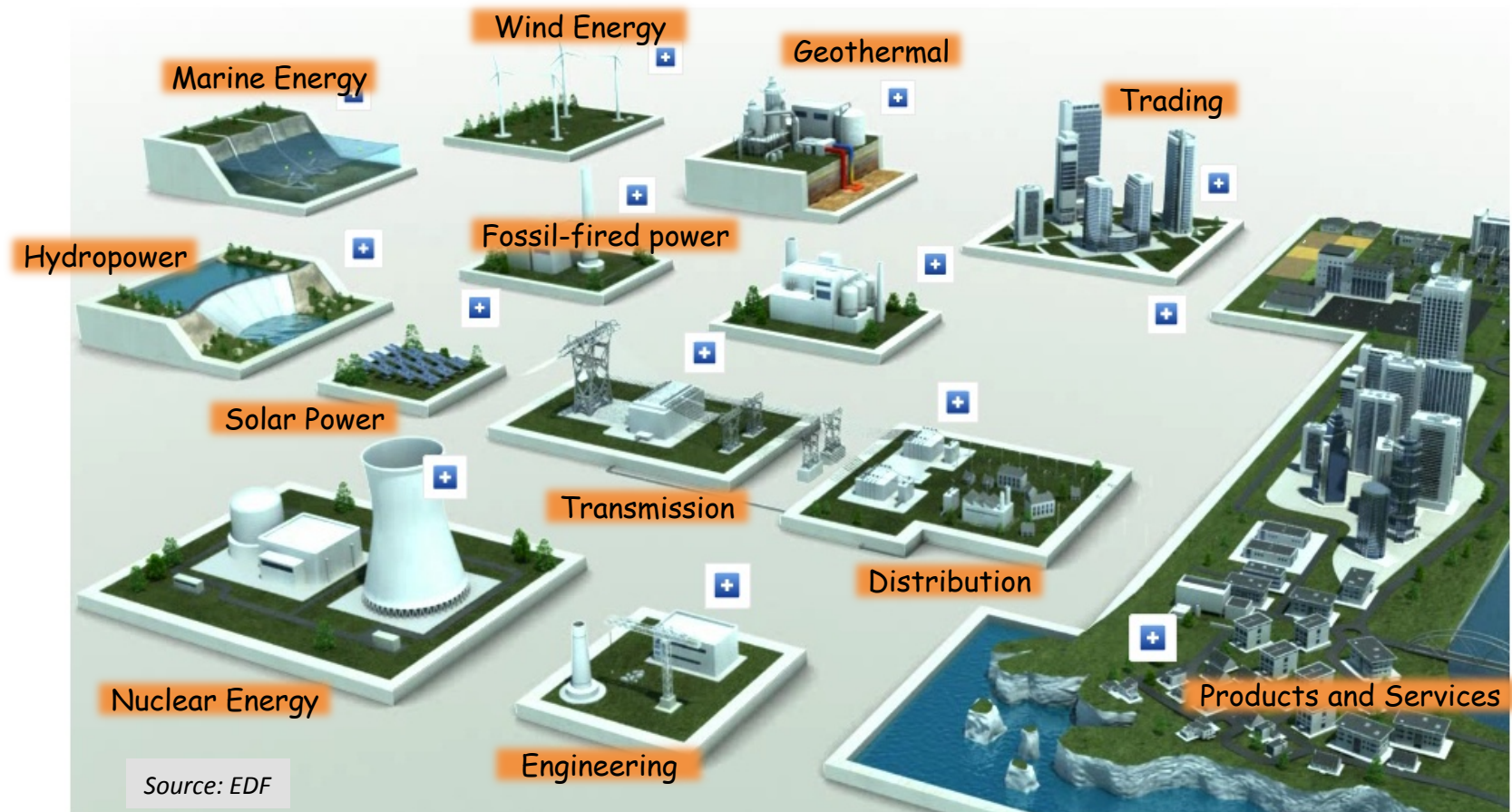
# SPECIFICITY OF ELECTRICITY AS A COMMODITY

- Electricity cannot be stored / Real Time generation / storage capacity limited and/or very expensive
- Demand: variable
- Prices: Volatile
- Natural monopolies (e.g. networks)
- Many technical complexities : difficulties to control load flows, interactions generation/transmission (network congestions, blackout risks)
- Economic dispatch of production means based on increasing variable costs
- Marginal production cost of electricity INCREASES with volume
- A KWh is more expensive during a peak in load

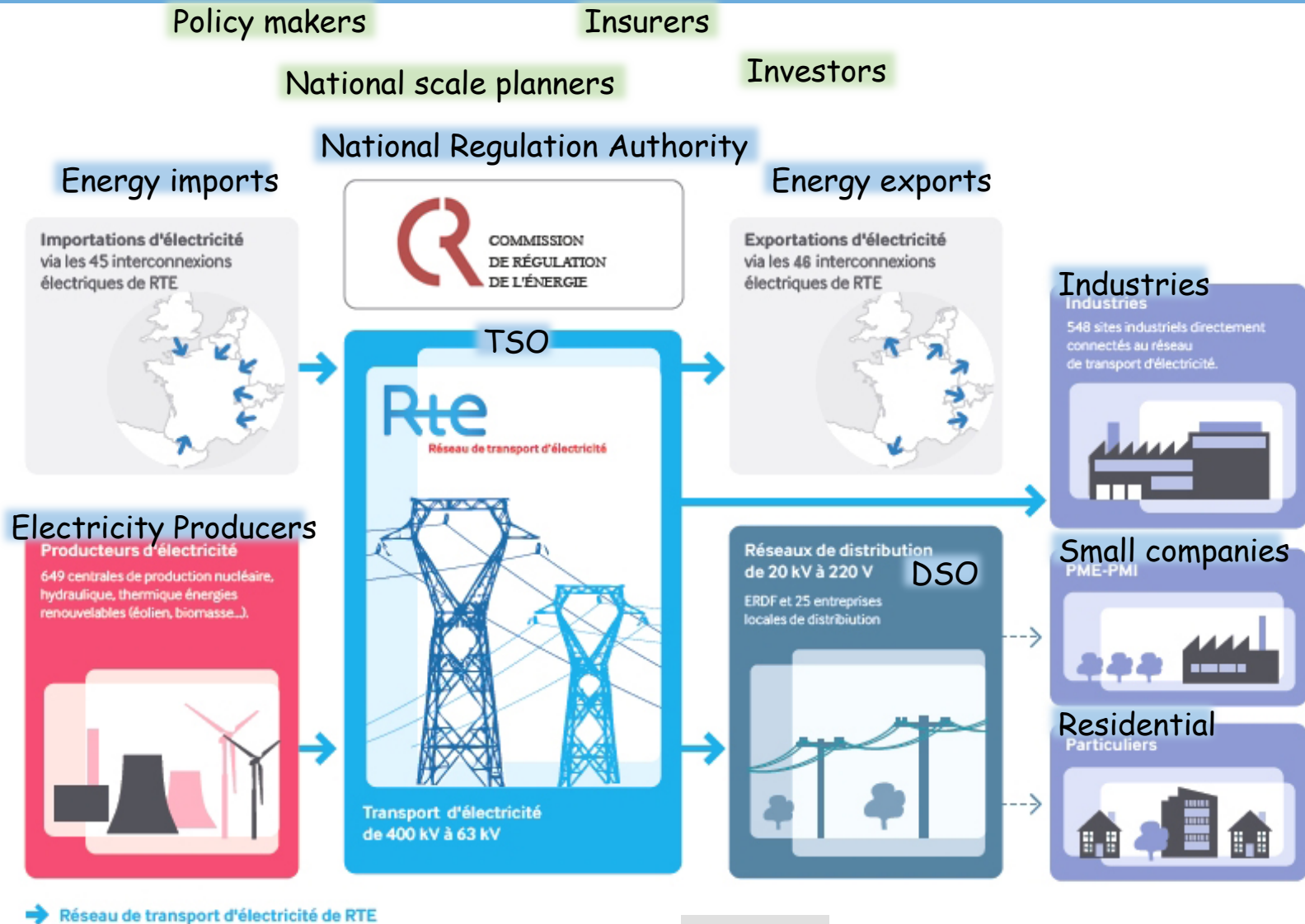
# WHAT IS A POWER SYSTEM ?

[ABOUT US](#)[BUSINESSES](#)[RESEARCH AND INNOVATION](#)[PRESS](#)[SHAREHOLDERS AND INVESTORS](#)[CAREERS](#)

## ACTIVITIES



# STAKEHOLDERS



Source: RTE

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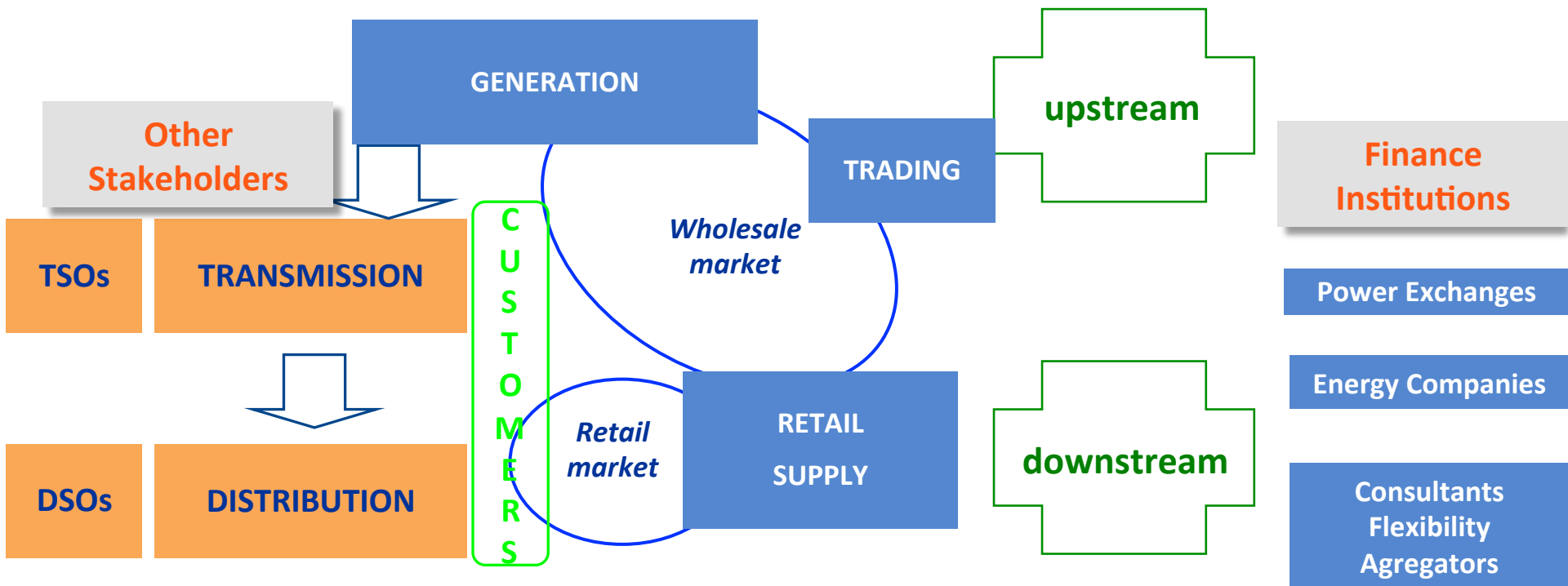
# SUPPLY CHAIN IN A COMPETITIVE MARKET

European Commission: DGs ENER, ENVIR, CONCUR

Competition authority

National Sector Regulator

Political Authority



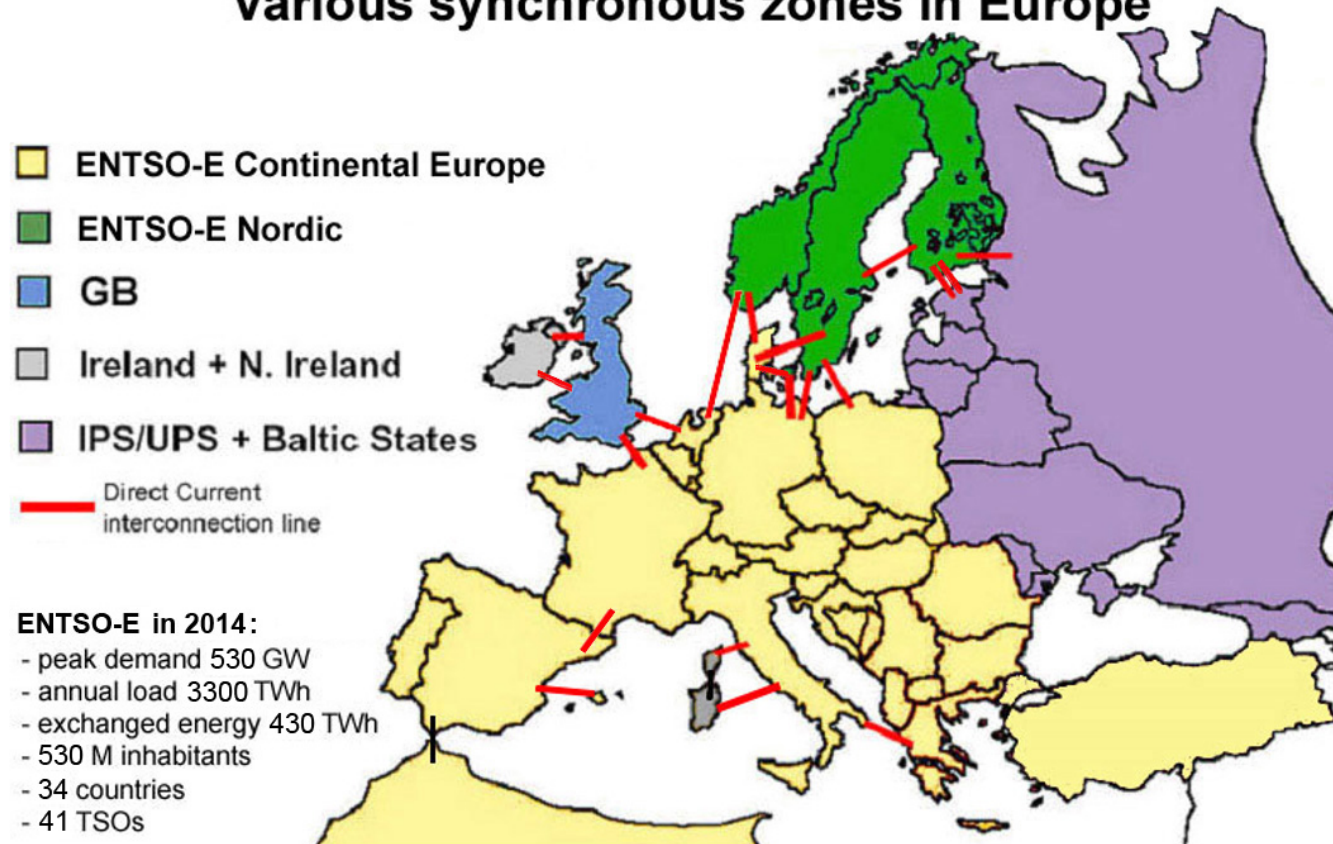
*Network activities, run under regulated monopoly regime*

*Activities open to competition*

# THE EUROPEAN SYSTEM: SYNCHRONOUS ZONES

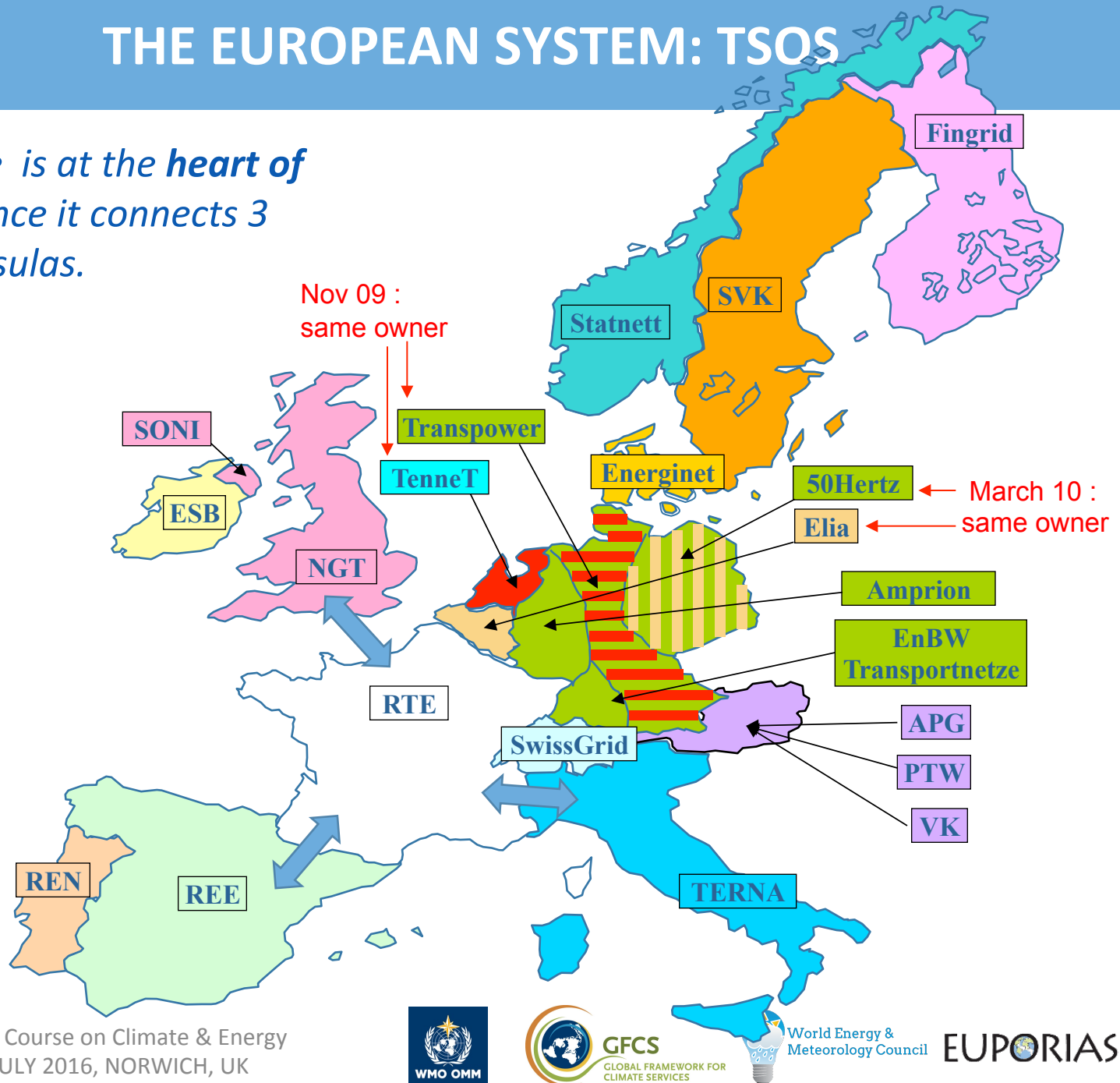
- Networks connection → pooling and mutual help
- Interconnections → physical bridges between networks & economic bridges between markets

## Various synchronous zones in Europe



# THE EUROPEAN SYSTEM: TSOS

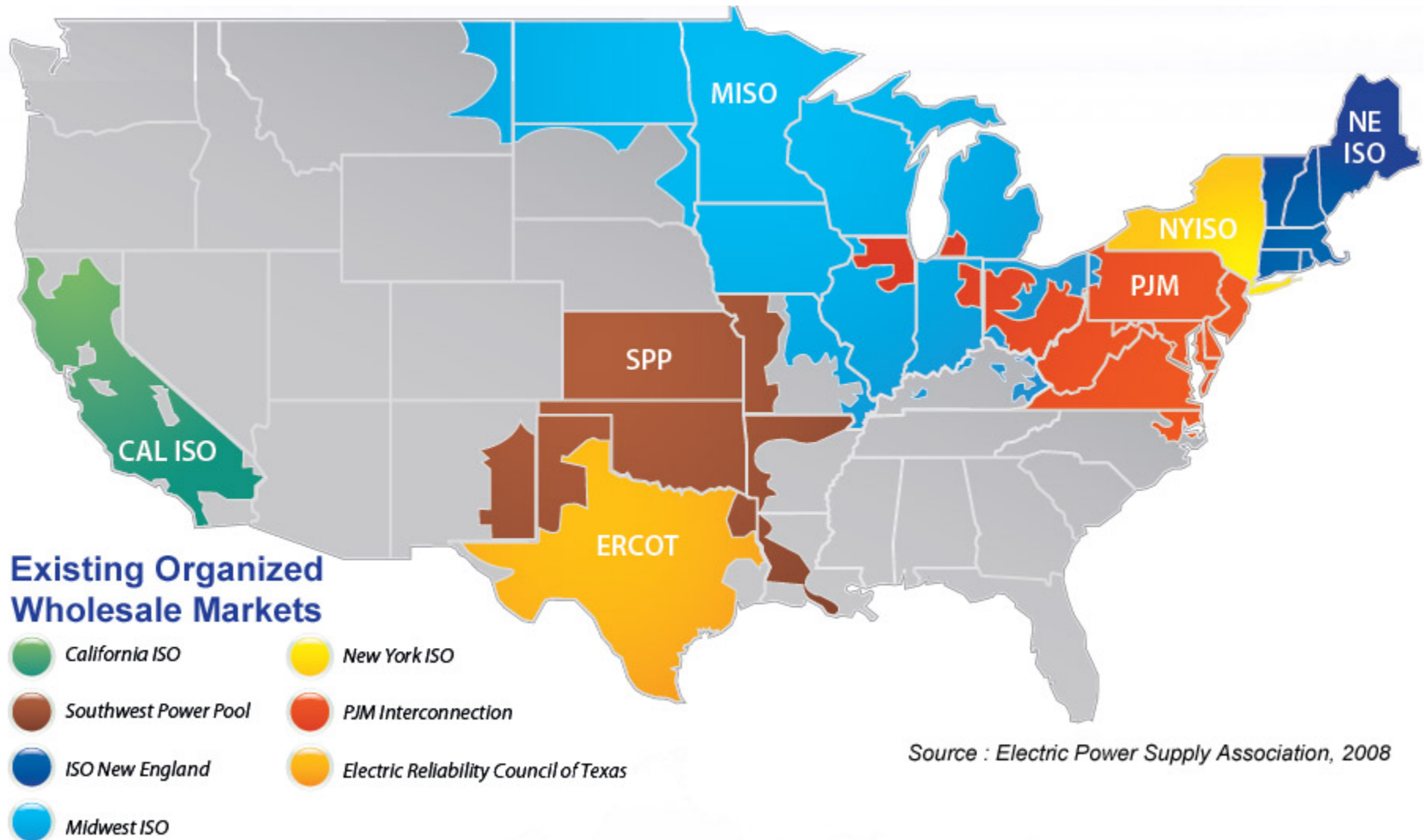
*Notice France is at the heart of the system since it connects 3 electric peninsulas.*



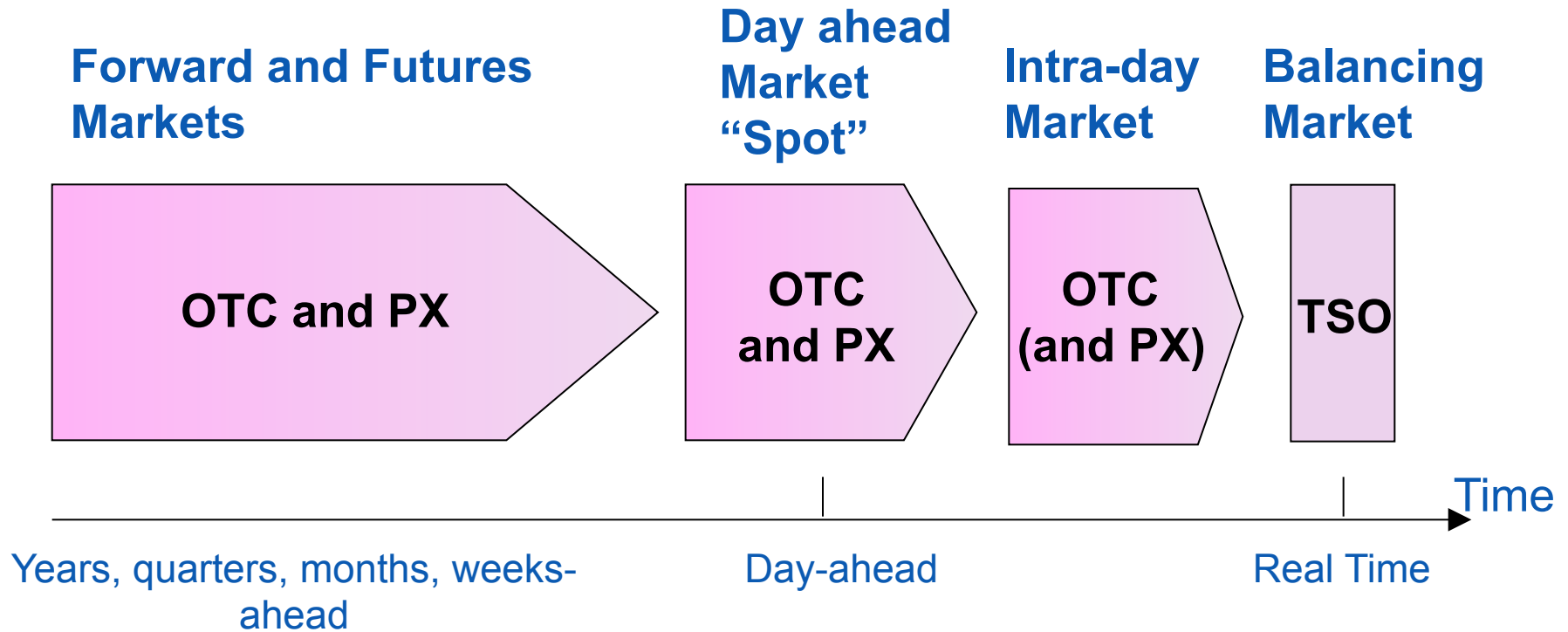
# POWER EXCHANGES IN EUROPE



# ELECTRICITY MARKETS IN THE USA



# DOMINANT MARKET DESIGN IN EUROPE

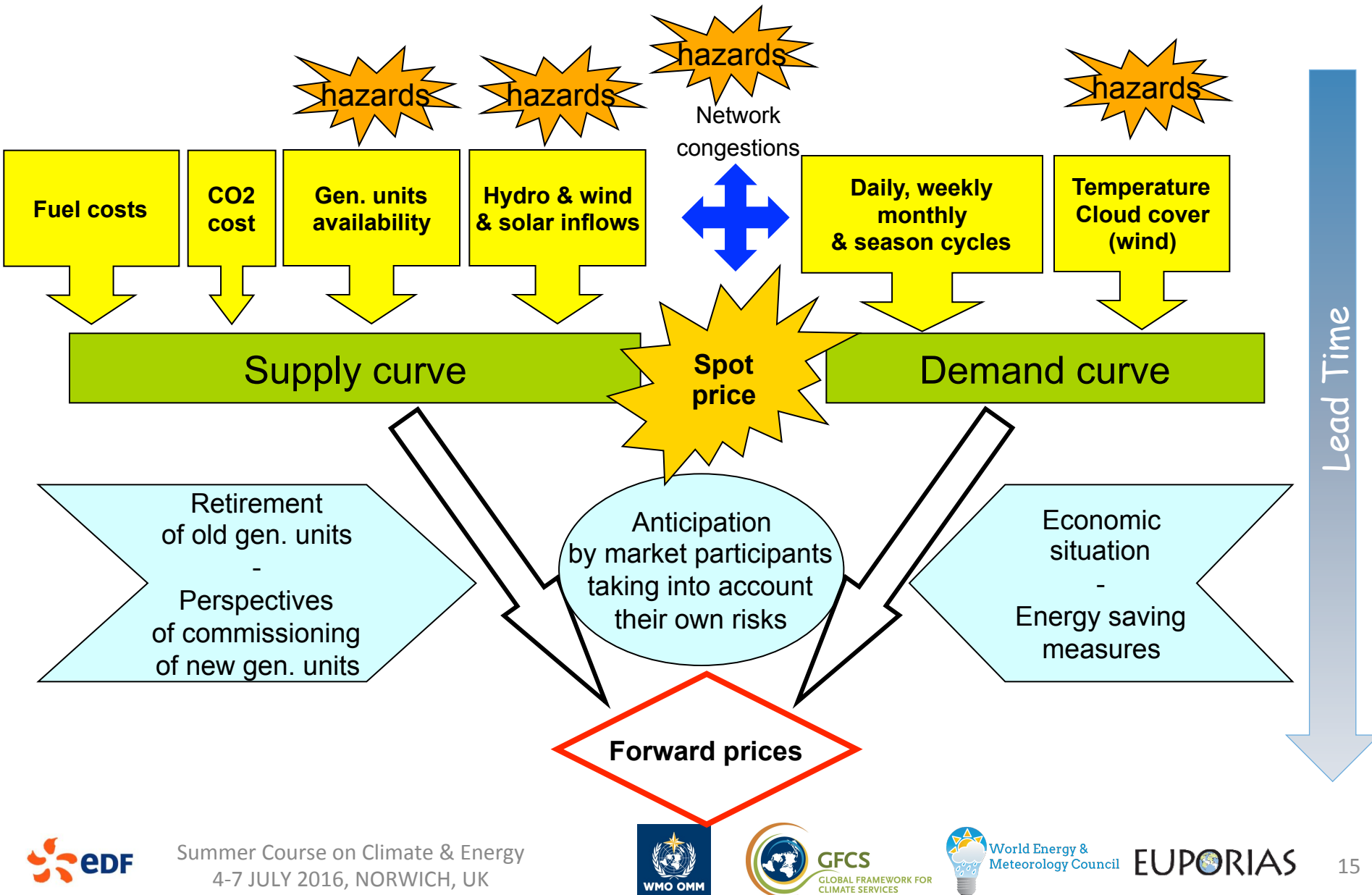


**OTC** : Over the Counter, bilateral transactions

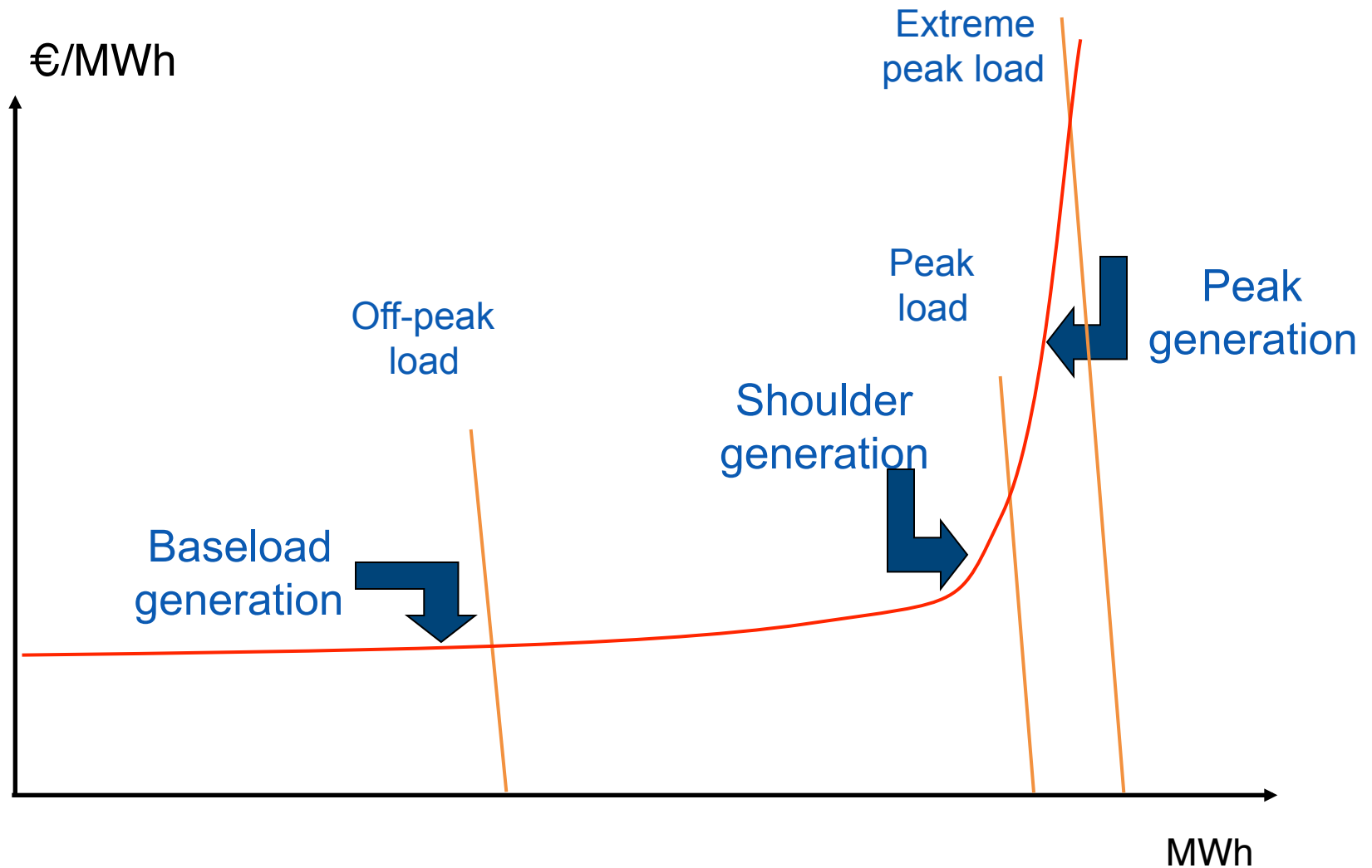
**PX** : Voluntary power exchange, trading standard products

**TSO** : Transmission System Operator

# HOW PRICES ARE DETERMINED ON THE WHOLESALE MARKET



# TYPICAL SUPPLY / DEMAND CURVE

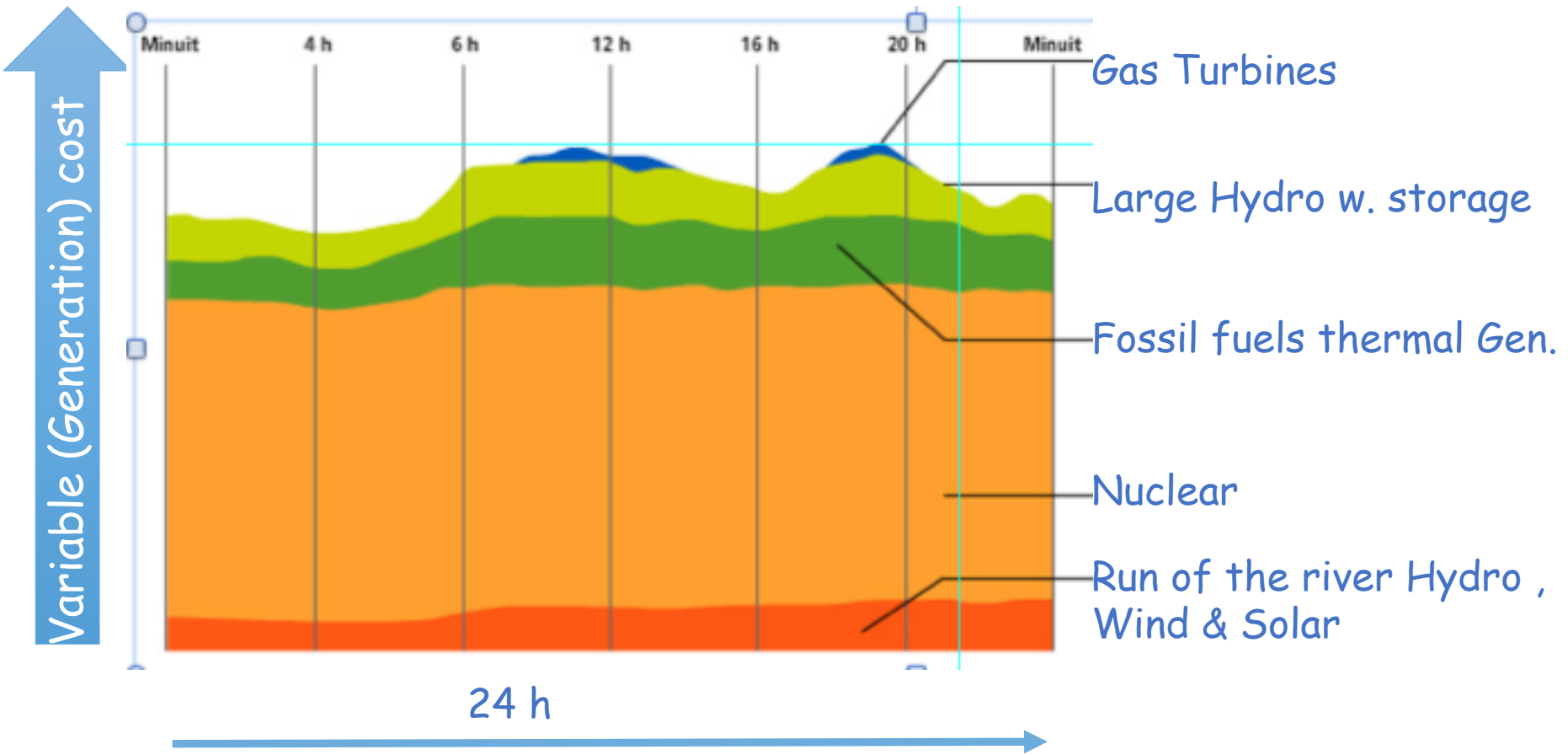


# OVERVIEW

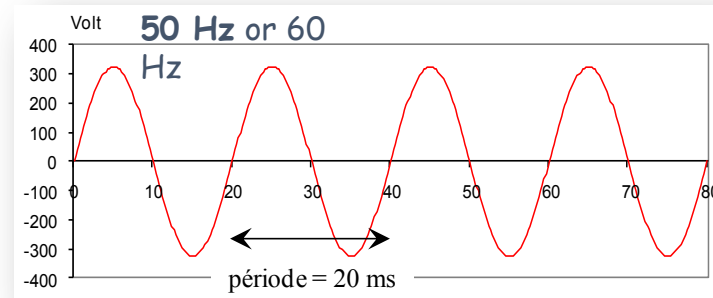
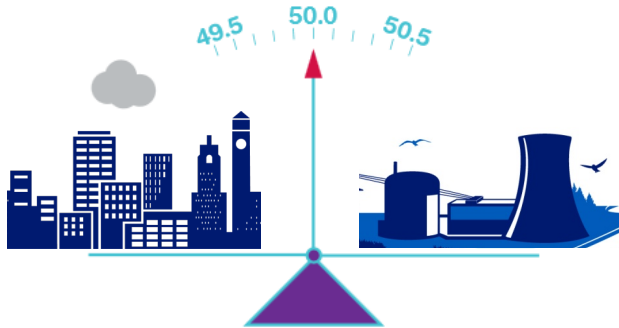
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# SUPPLY / DEMAND BALANCE

Example: France



# FREQUENCY ADJUSTMENT



**Frequency is the electrical consequence of synchronous alternators' rotation speed**

Change in Rotation speed  
Engine Torque (turbine)  
Resisting torque (network)

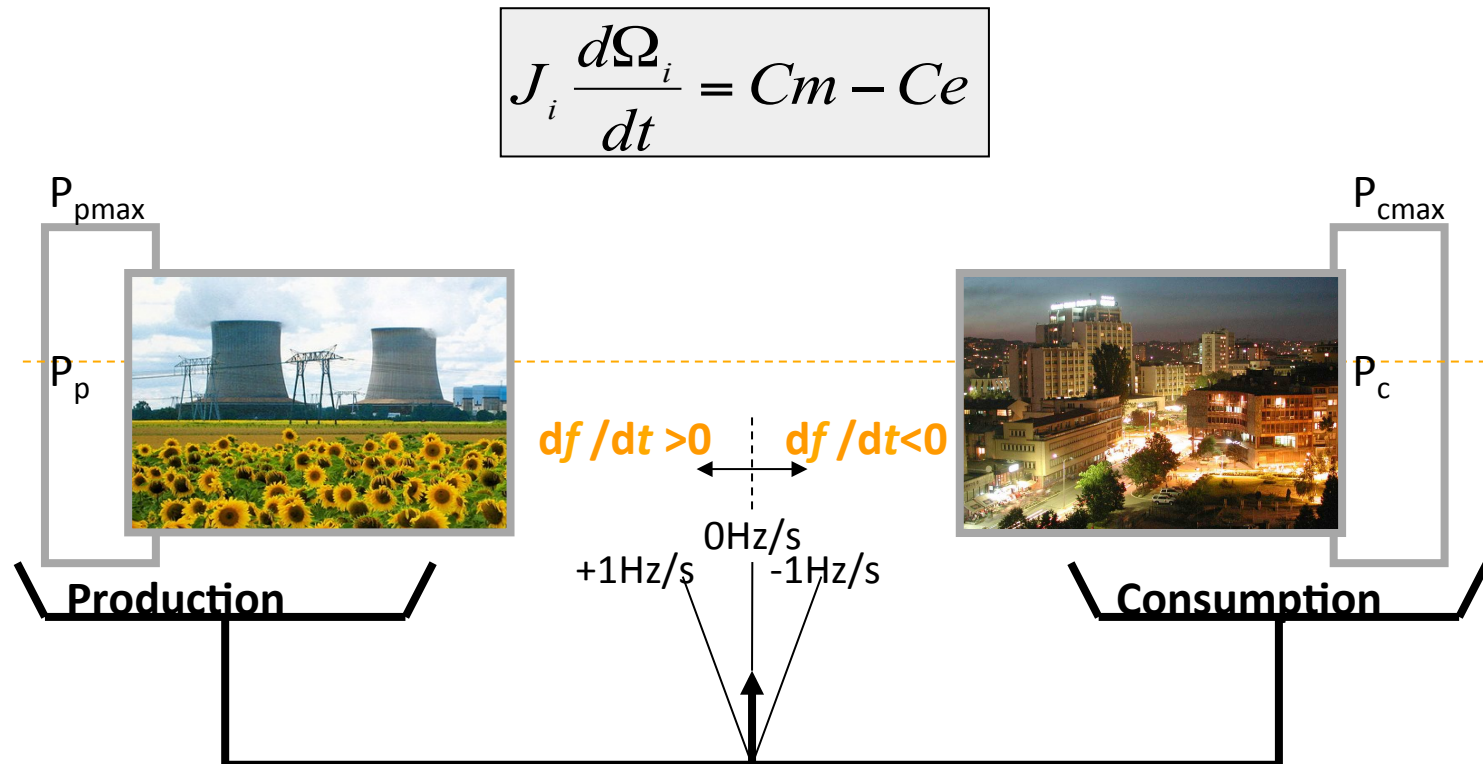
$$J_i \frac{d\Omega_i}{dt} = C_m - C_e$$

In permanent regimes, alternators run at the same speed



**Frequency is uniform on an interconnected network**

# FREQUENCY REFLECTS SUPPLY/DEMAND BALANCE



$C_m > C_e$ , alternators stock kinetic energy :  $f$  increases

$C_e > C_m$ , alternators release kinetic energy:  $f$  decreases

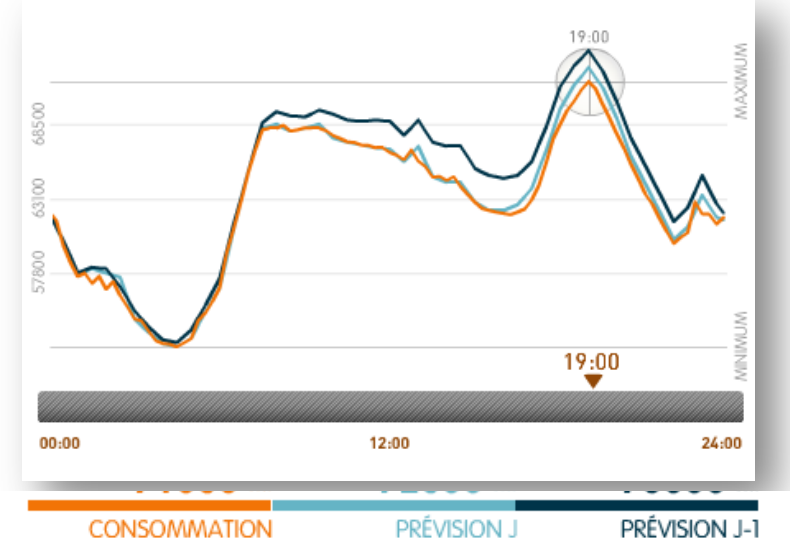
# FREQUENCY PERTURBATION: SEVERAL ORIGINS

## Small perturbations

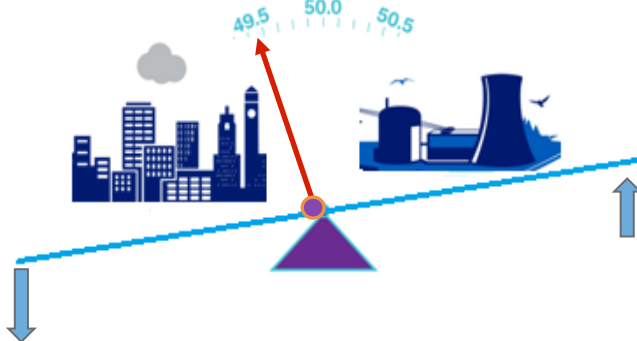
- Fluctuations in demand: imperfect forecast
- Fluctuations in supply:
  - Impossible to control perfectly
  - **VARIABLE GENERATION: WIND & SOLAR**

## Large perturbations

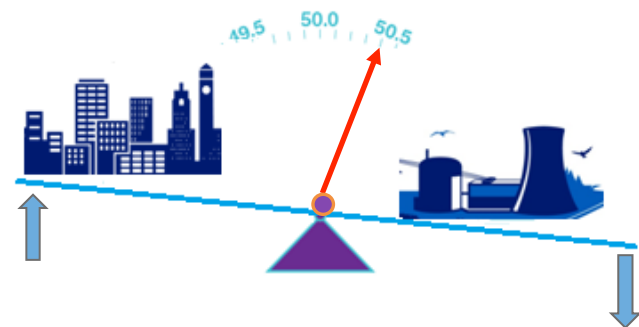
- Loss of production unit
- Loss of interconnection line in peninsulas



### Generation unit loss

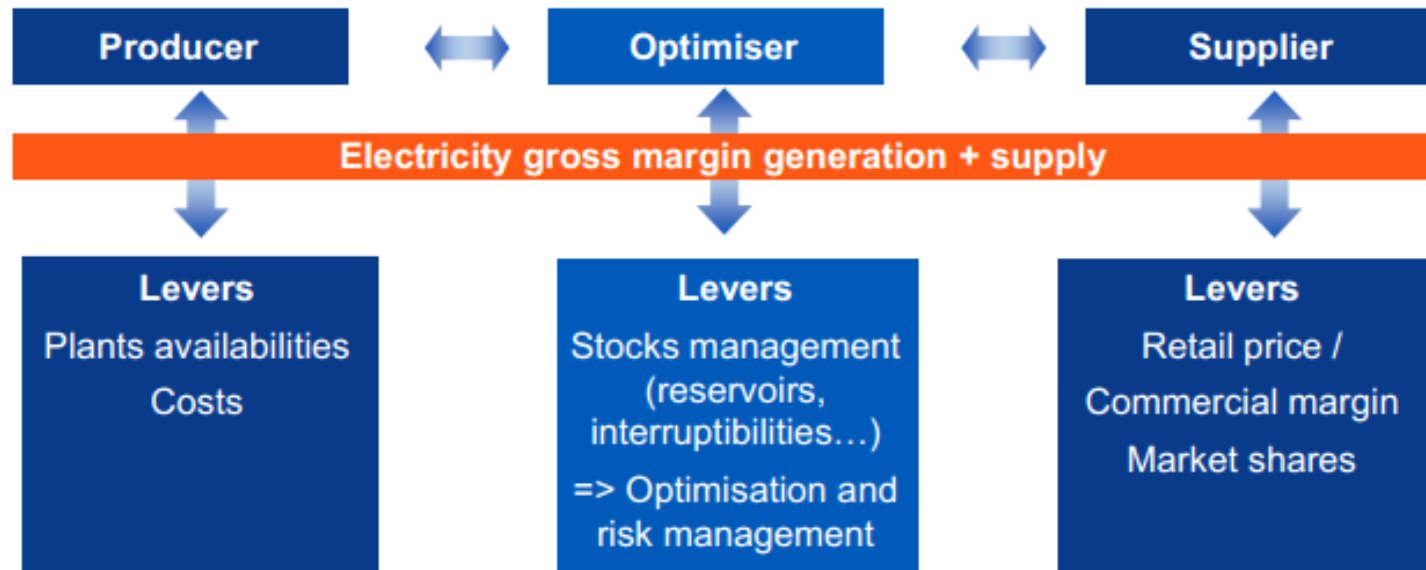


### Demand reduction



➔ Need **RESERVES** in generation and **FLEXIBILITY** in demand

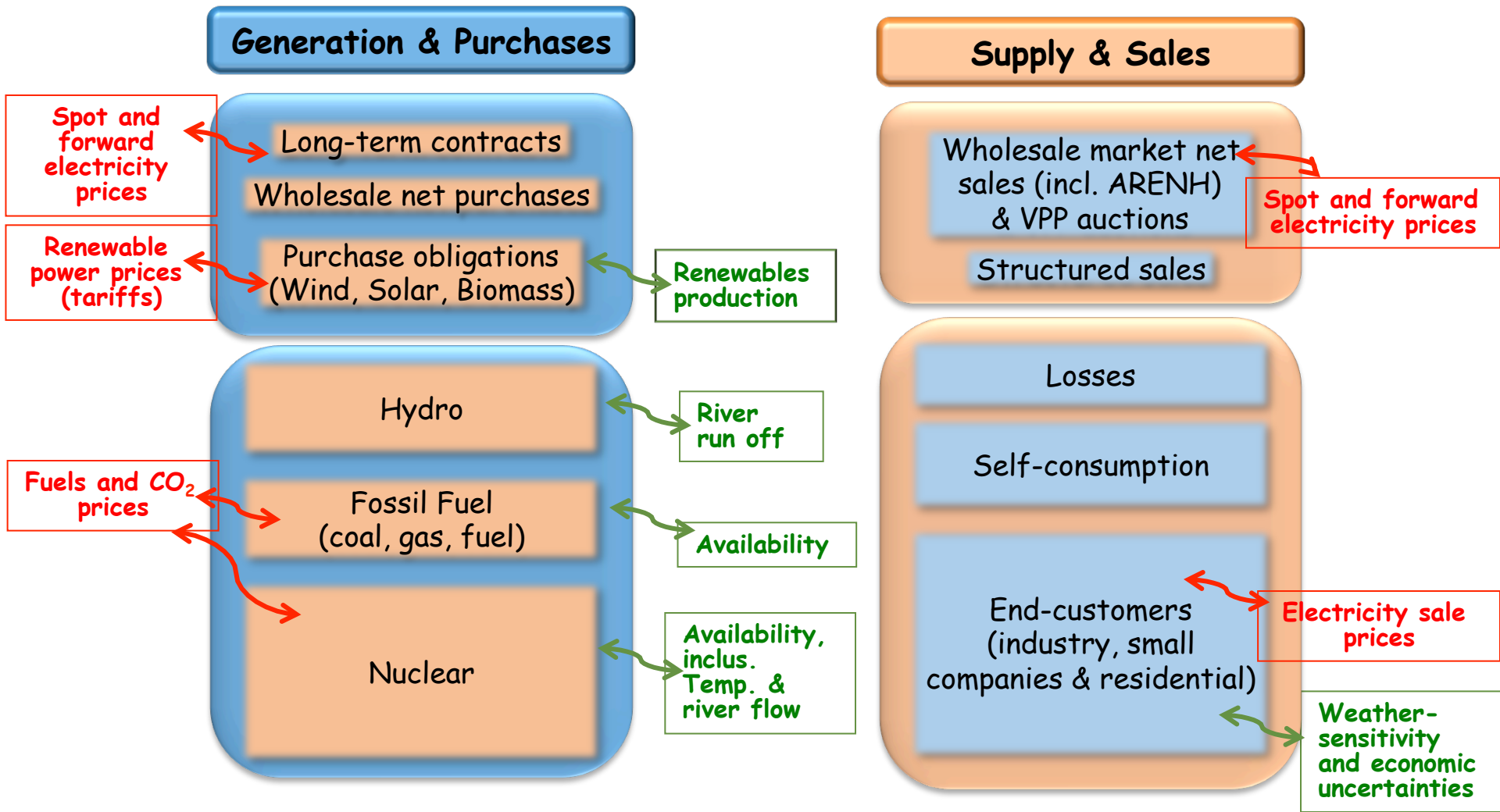
# SUPPLY/DEMAND BALANCE OPTIMIZATION



Optimisation with the market means:

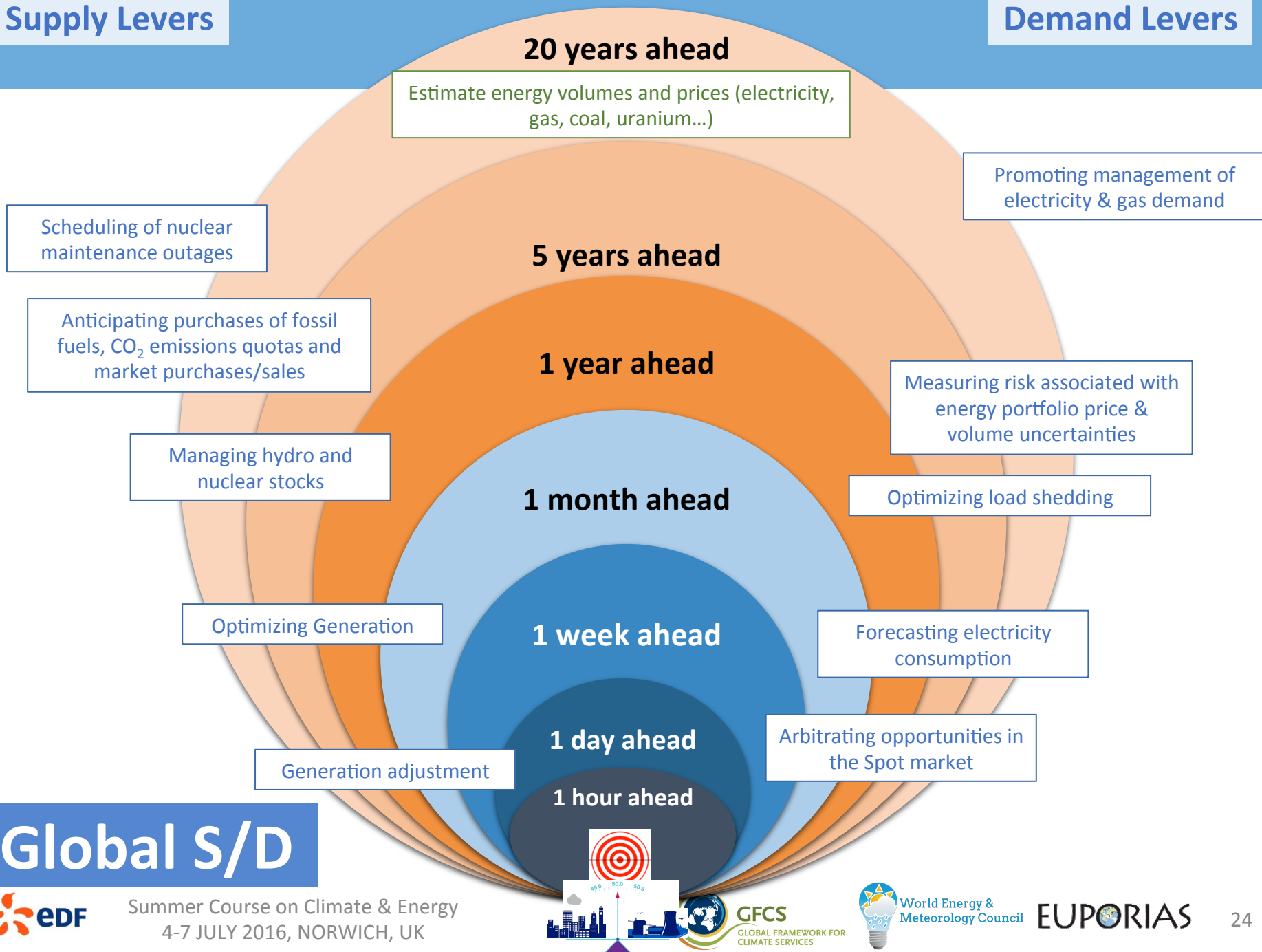
- decision-making to optimise the balance between supply and demand...
- ... maximising the global supply/demand gross profit
- ... using a risk management policy to guarantee this gross profit (price/volume arbitration, hedging...) and the (physical) balance of the perimeter

# A PORTFOLIO EXPOSED TO RISK IN **VOLUME** AND **PRICE**



## Supply Levers

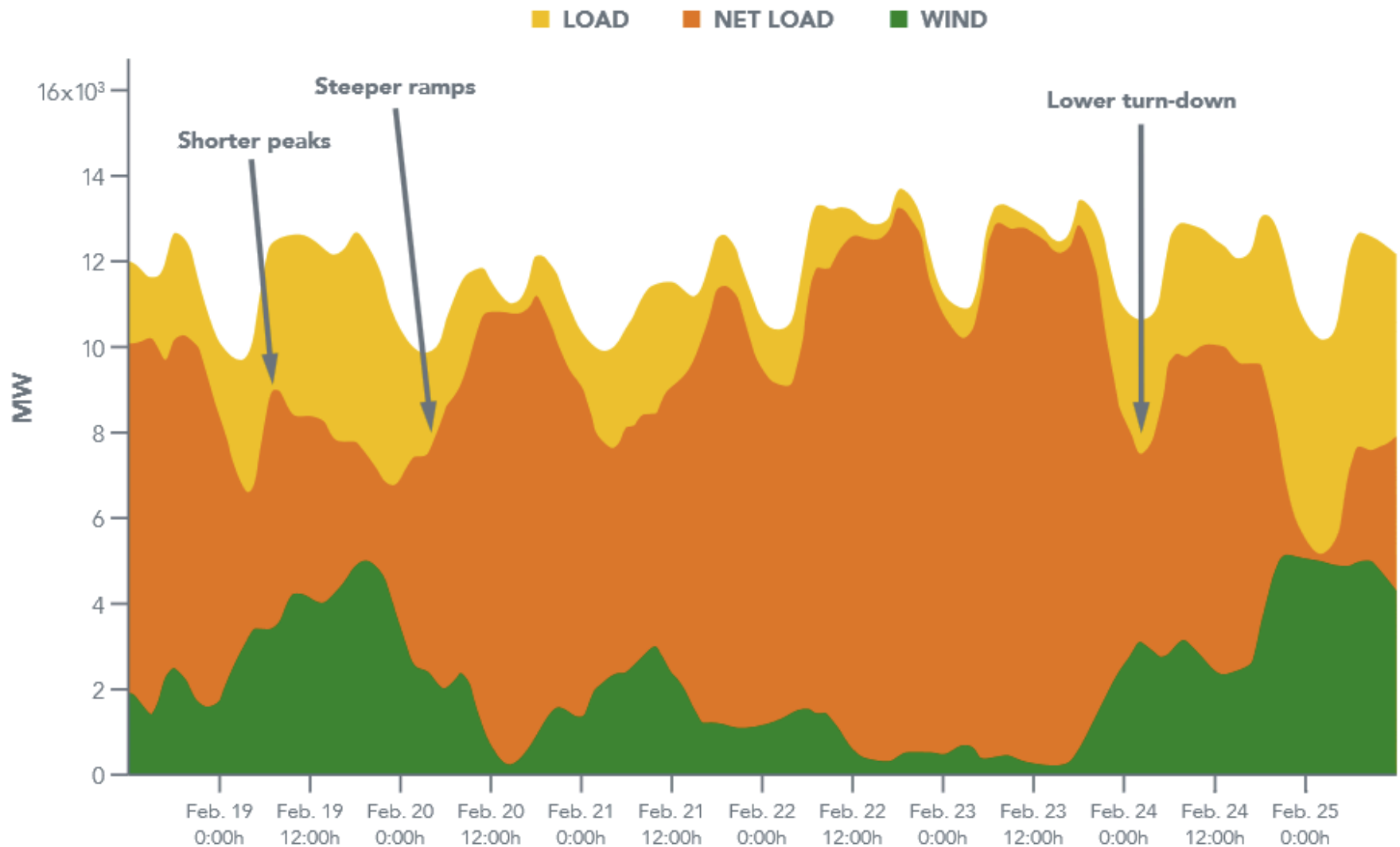
## Demand Levers



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# IMPACTS OF INCREASING VARIABLE GENERATION



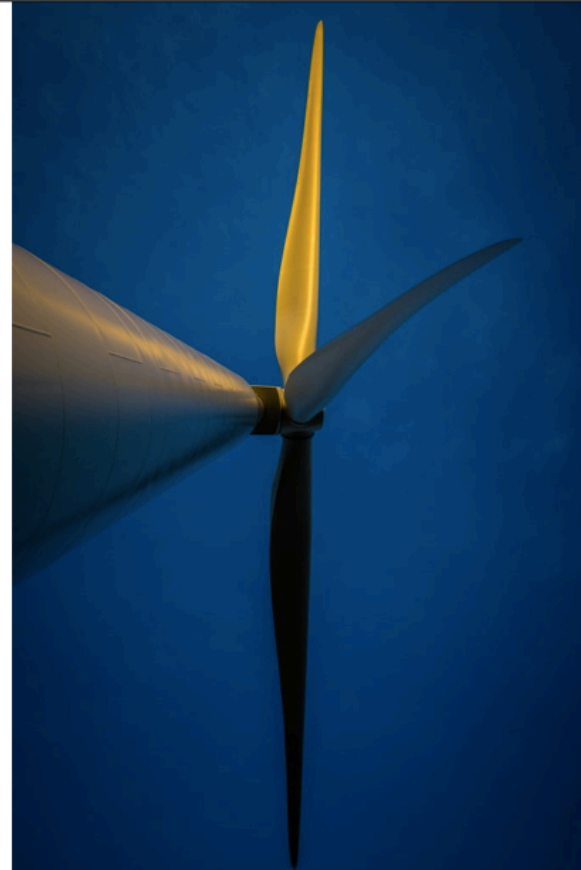
# ADDING A LOT OF RE INCREASES THE COMPLEXITY

## TECHNICAL AND ECONOMIC ANALYSIS OF THE EUROPEAN ELECTRICITY SYSTEM WITH 60% RES

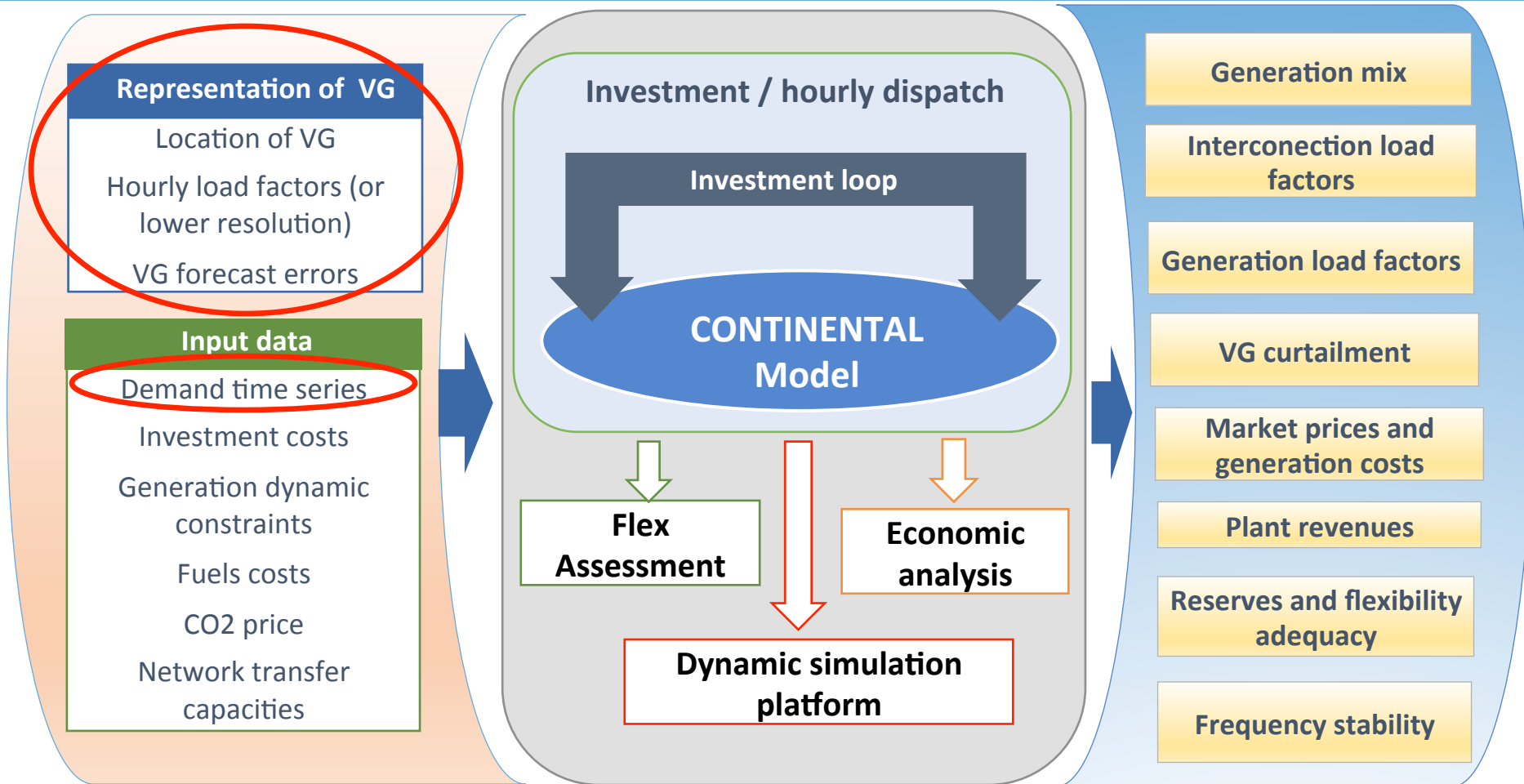
Vera Silva

EDF R&D

London, 28 June 2016



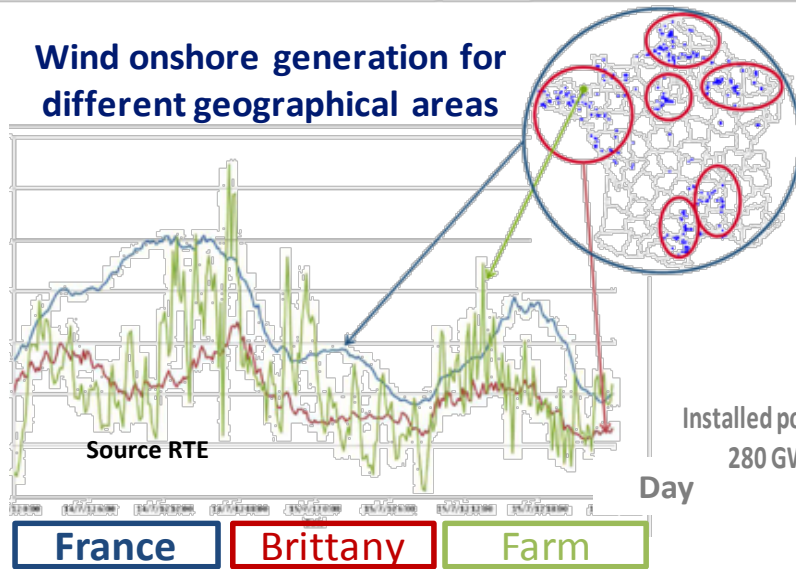
# INTEGRATED APPROACH FOR THE TECHNICAL & ECONOMICAL ANALYSIS OF HIGH RES SCENARIOS IN EUROPE



**Reference :** M. Lopez-Botet, et all, *'Methodology for the economic and technical analysis of the European power system with a large share of variable renewable generation'*, presented at **IEEE PES General Meeting**, Washington, USA, 27-31 July, 2014.

# GEOGRAPHICAL DIVERSITY DOES HELP, BUT THERE IS STILL SIGNIFICANT VARIABILITY AT EUROPEAN LEVEL

Wind onshore generation for different geographical areas

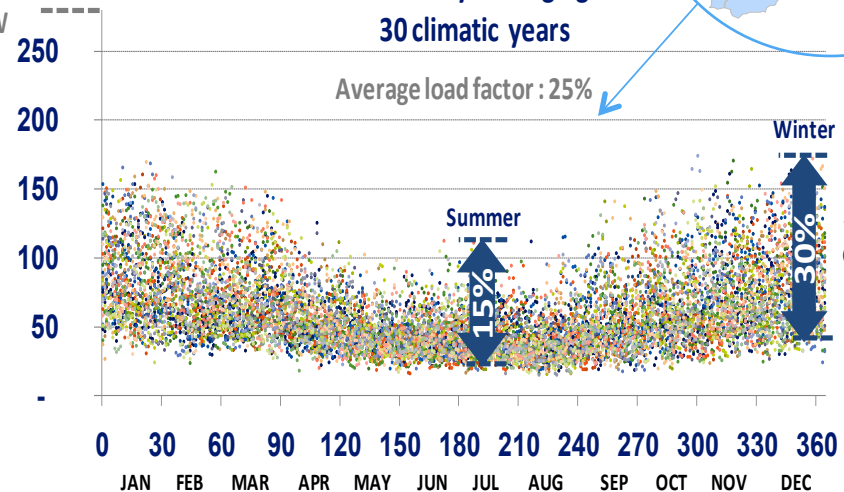


Installed power :

280 GW

Onshore wind daily average generation  
30 climatic years

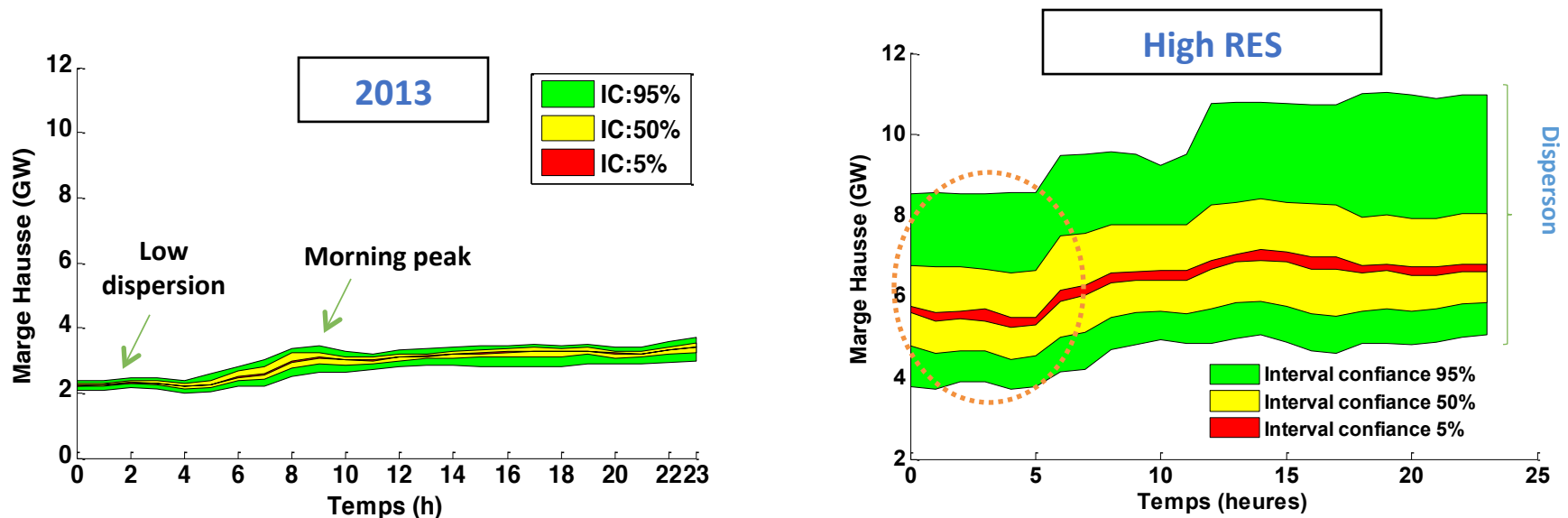
Average load factor : 25%



You can reduce the variability of wind and PV at local level but the correlation in wind regimes acts as a limit at continental level

# FLEXIBILITY MARGINS NEED TO INCREASE DUE TO VARIABLE GENERATION (AND ITS FORECAST ERRORS)

Profile of day-ahead upward operation margin required to cover a 1% risk level



The operation margin profile changes and in the future critical periods are no longer driven by demand patterns => need for dynamic calculation of flexibility margins and reserve requirements

➔ For large penetration of wind and PV generation:

- **variability and uncertainty** have significant impact
- **short term operation** needs to be considered at **planning stage**

# SUMMARY

- ✓ **Power systems: Complex & Interconnected**
- ✓ **Long-term to Real-Time chain of Processes and Decision Makings**
- ✓ **Variable Generation large scale integration increases need for flexibility, and improved meteorological information**
- ✓ **New power systems paradigms are necessary**
- ✓ **Meteorology (Weather & Climate) is key to the energy sector !**

# *Thank you for your attention*

## *Questions ?*

*Contact:*

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*Expert Researcher*

*Fluid Dynamics, Energies and Environment Department*

*Applied Meteorology and Atmospheric Environment Group*

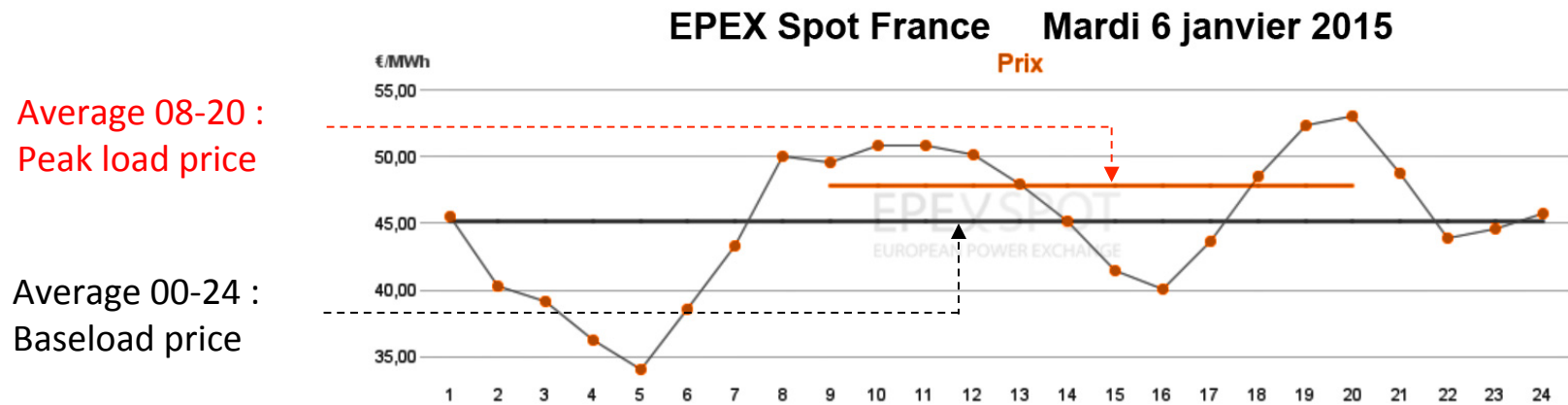
*6 Quai Watier - BP 49*

*78401 CHATOU CEDEX*

*FRANCE*

# Price formation

- Prices are based on the offer/demand law
- Daily market: auction organized by the power exchange to set the price of each of the 24 hours of the next day



- Forward market: continuous quotation analog to stock market
  - Year-ahead products on 16/6/2015 :
    - year 2016 base 38,20 €/MWh, peak 46,38 €/MWh
    - year 2017 base 38,37 €/MWh, peak 46,25 €/MWh
    - year 2018 base 38,52 €/MWh, peak 46,50 €/MWh

# 3 types of frequency adjustment

1- Ensure supply/demand balance and frequency around 50 Hz

2- Manage exchanges with neighboring countries et bring frequency to 50 Hz

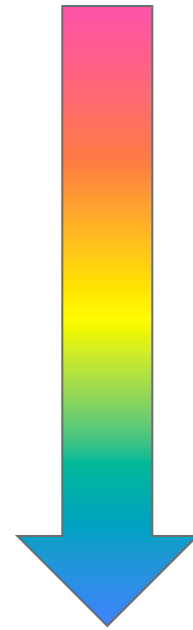
3- Restore primary & secondary reserves by re-optimizing the economic use of the mix

Production units that contribute to adjustments modify their production to adjust the frequency and the global (national) supply/demand balance

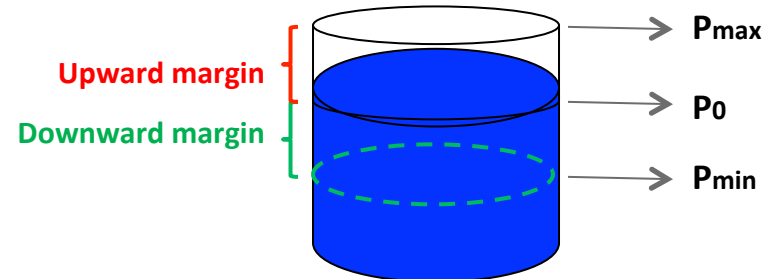
Primary Adjustment

Secondary Adjustment

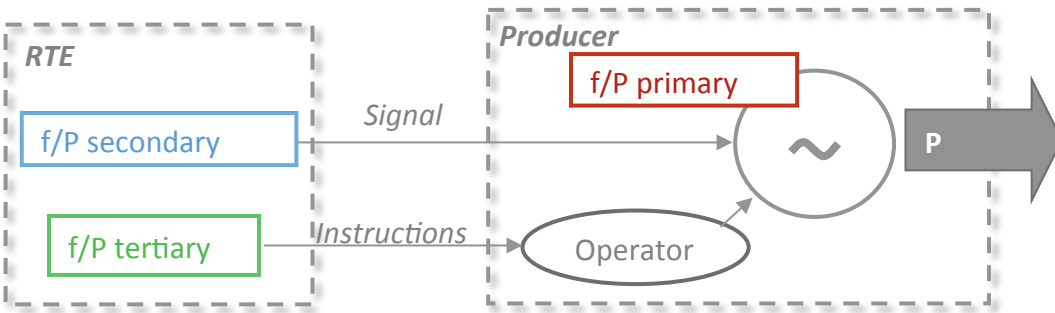
Tertiary Adjustment



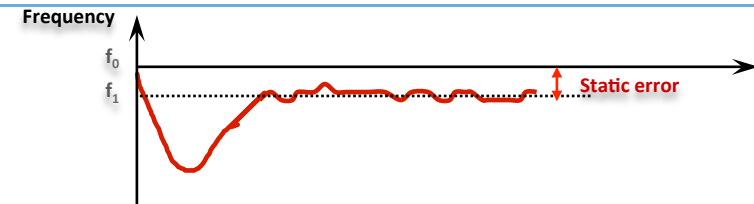
Production unit



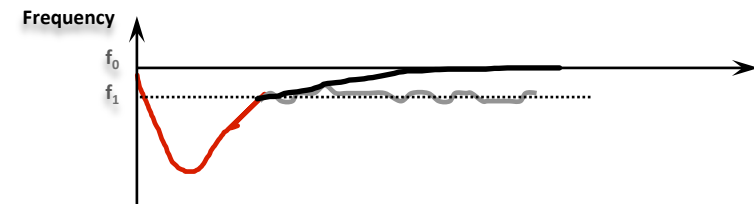
# How it works: France



Primary adjustment only



Primary & secondary adjustment



| Primary                      | Secondary  | Tertiary   |                 |
|------------------------------|--|--|-----------------|
| UCTE, global, mutual         | National mutual level                                  | National level                                     | Area            |
| Maintain frequency stability | Back to $f=50$ Hz and restore interconnexion exchanges | Restore Primary & secondary reserves & re-optimize | Function        |
| Automatic                    | Automatic  | Manual   | Activation mode |
| ~ 660 MW                     | [500-1100] MW  | [500-...] 1000 MW                                  | Volume          |
| 50% in 15 s<br>100% in 30 s  | Fast 2 min<br>normal 13 min                            | 1500 MW in 30 min<br>~2000 MW                      | Dynamics        |

# Adequacy & Flexibility

- **Adequacy** is connected with the issues of investment decisions and is used as a measure of long term ability of a system to match demand and supply with an accepted level of risk. This is a measure that internalizes the stochastic fluctuations of demand and supply and their correlations.
- **Flexibility** is mostly connected with operation decisions and represents the ability of a system to adapt itself to both predictable and unpredictable fluctuating conditions, either on the demand or generation side, at different time scales, within economical boundaries.

# System services

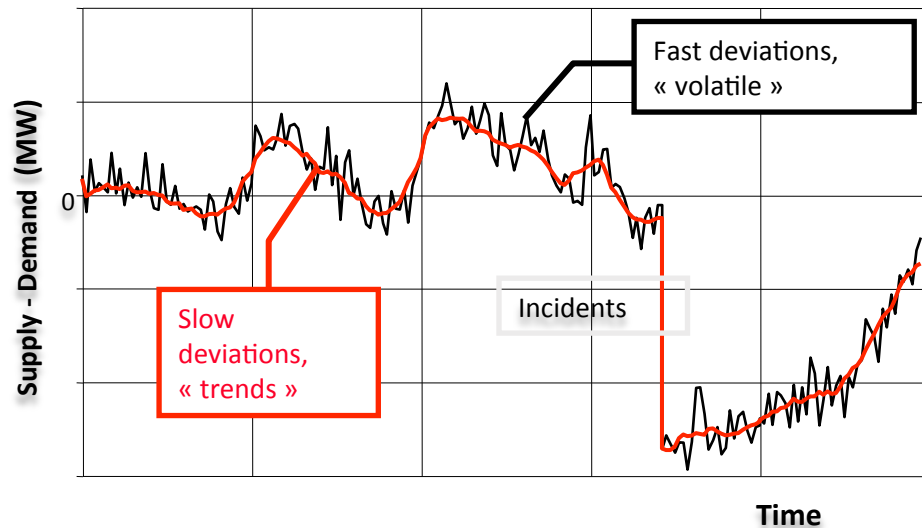
Frequency primary  
adjustment

Voltage primary  
adjustment

Frequency secondary  
adjustment

Voltage secondary  
adjustment

Network restoration  
after incident



Services provided by generation units and network components

Necessary for TSOs to ensure supply/demand balance, fulfilling network safety, security and availability

Mix of compulsory and competitive services (market)

