Power Systems: Basic Principles

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Outline

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

Some Definitions

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

Quality of electricity:

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

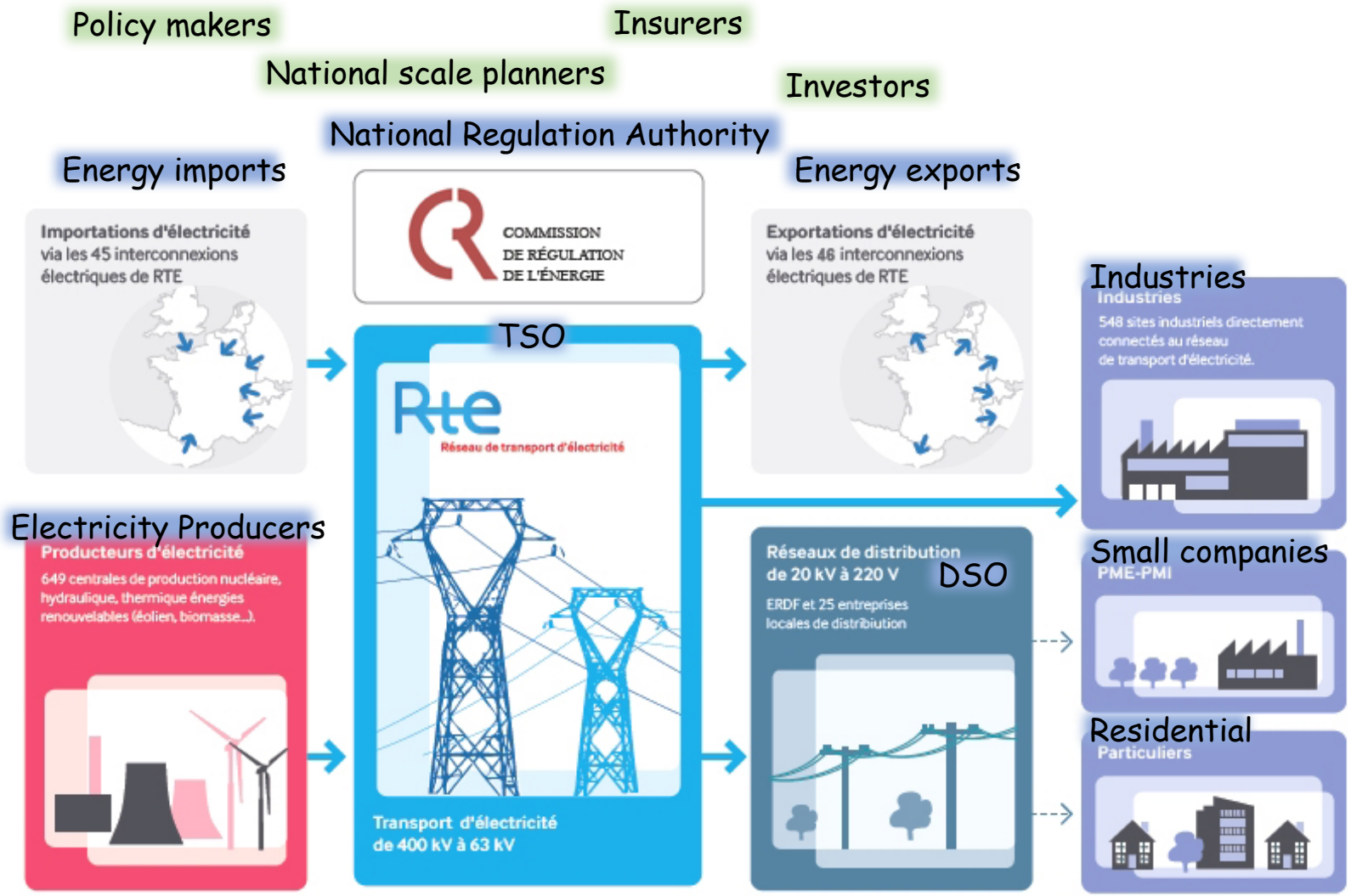
Specificity of Electricity as a Commodity

- 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 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?

Source: EDF

Stakeholders



Source: RTE

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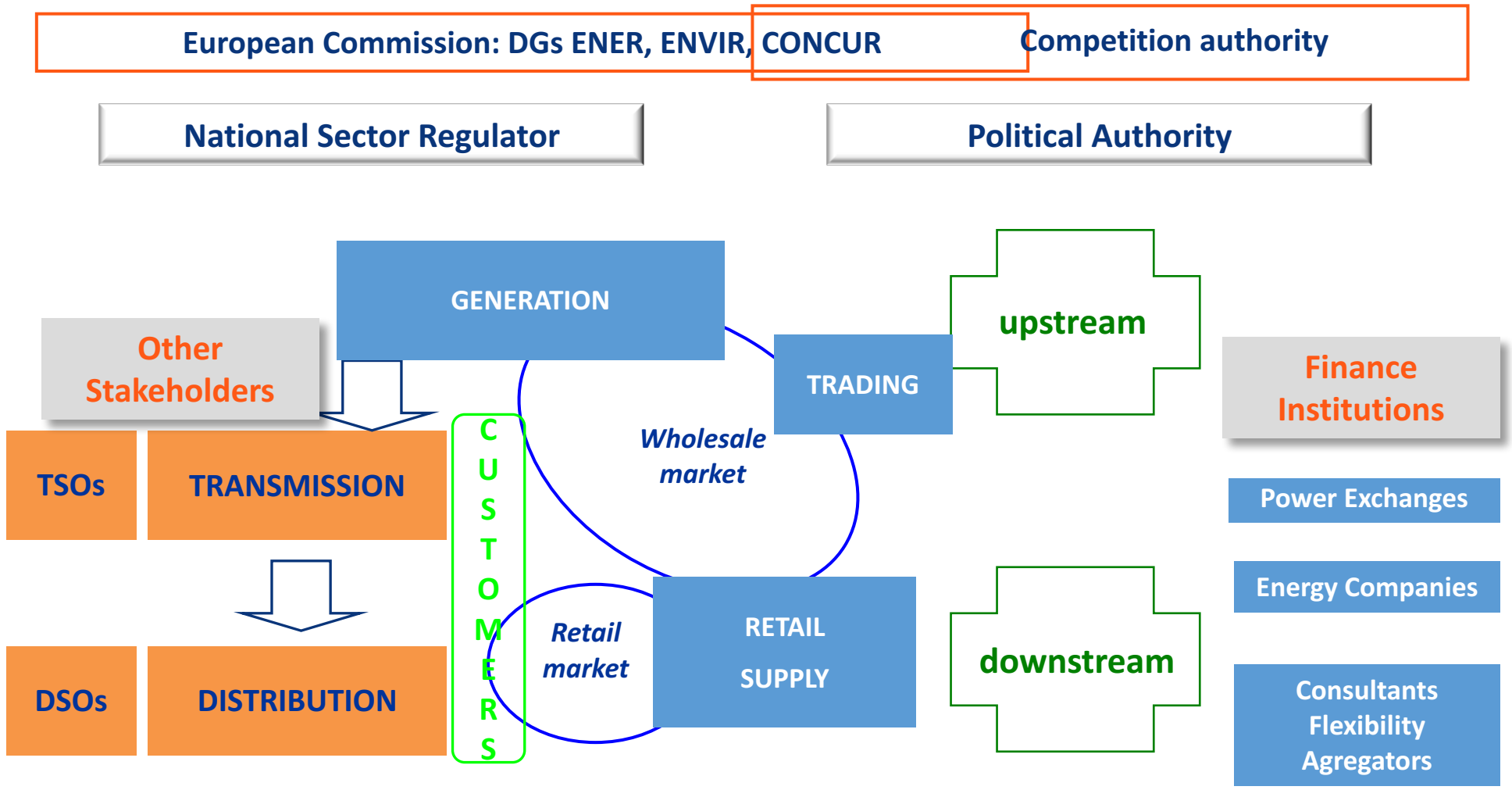
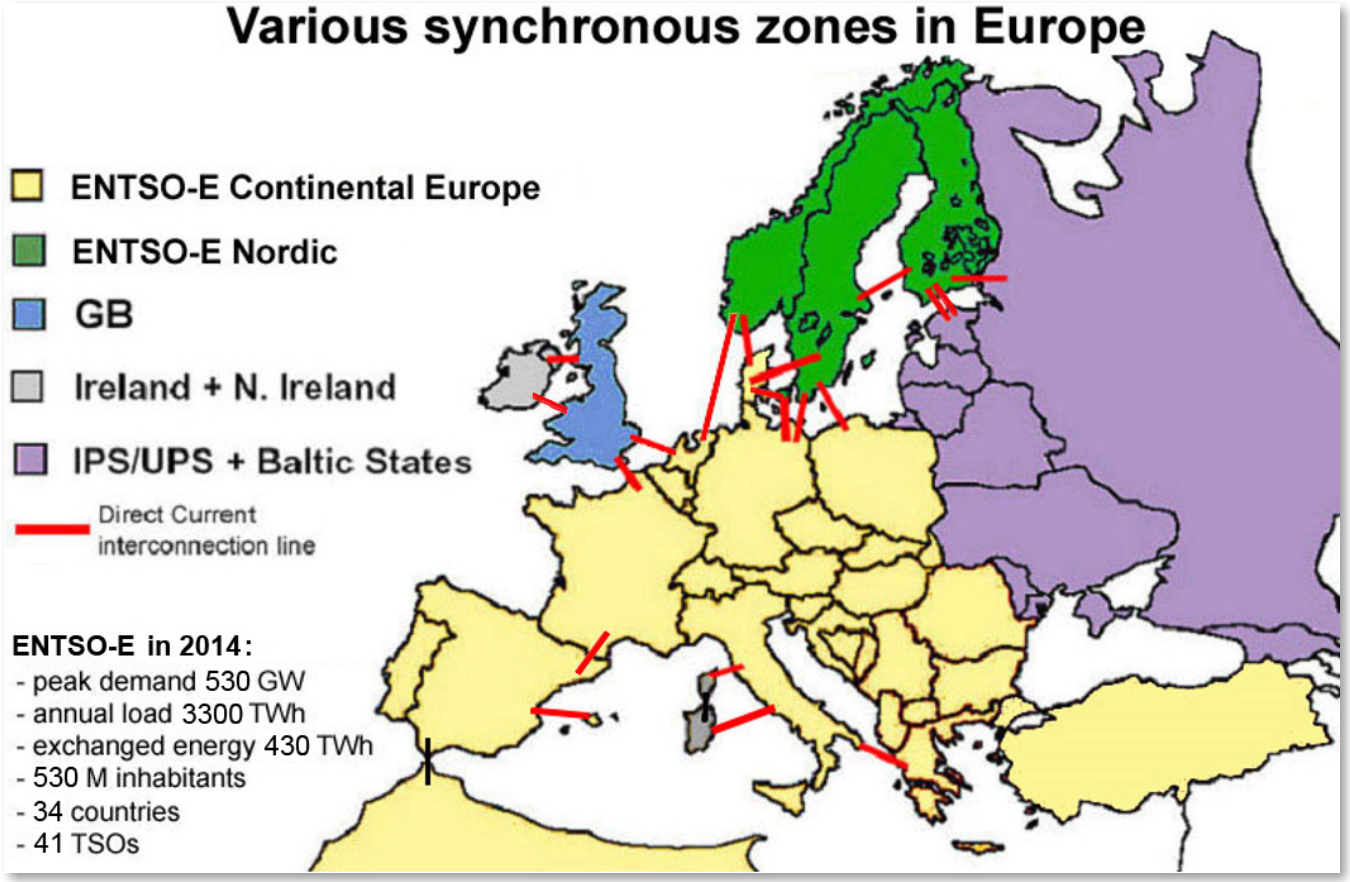
Supply Chain in a Competitive Market



- Networks connection

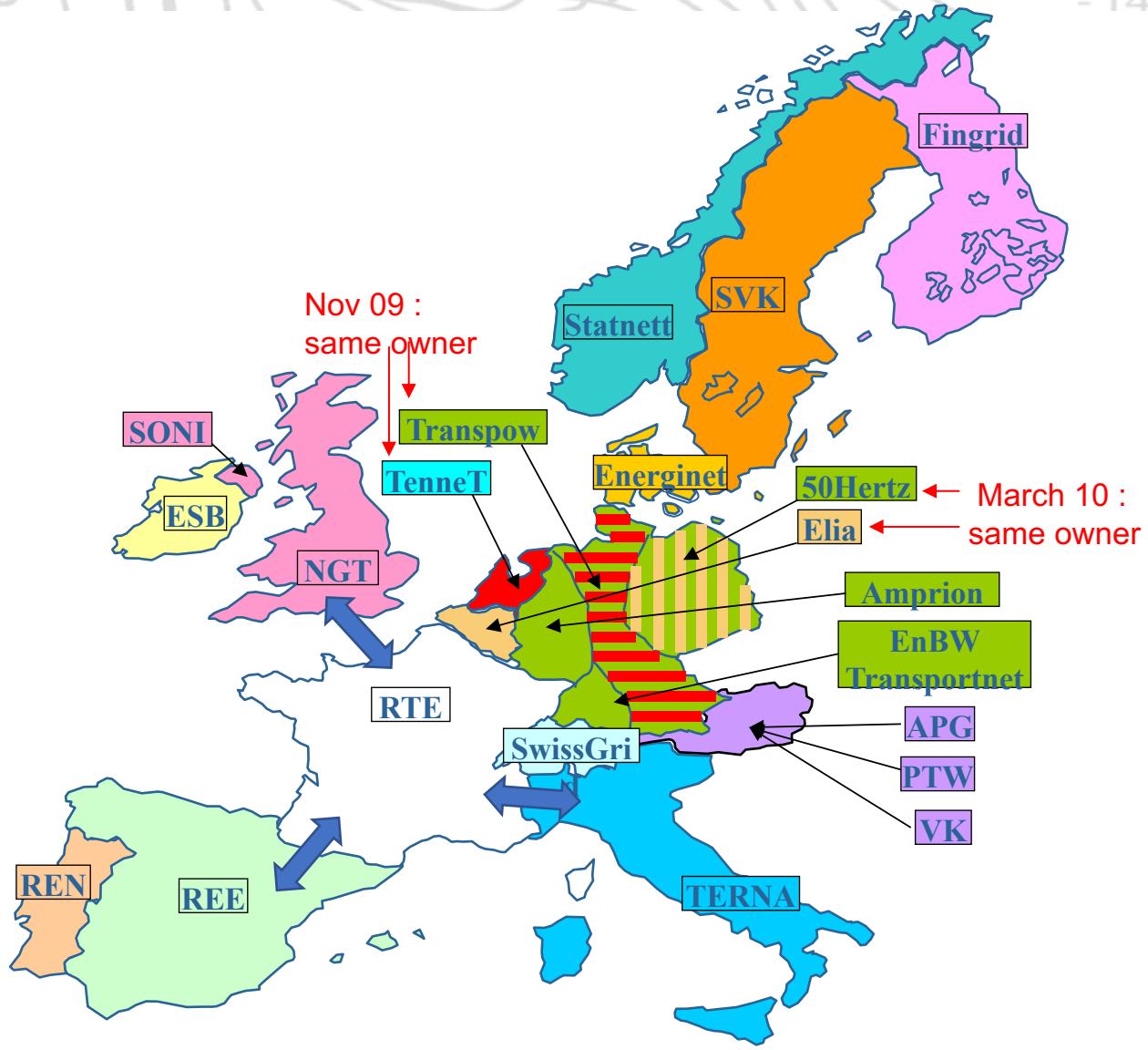
  ➔ pooling and mutual help
- Interconnections

  ➔physical bridges between networks & economic bridges between markets

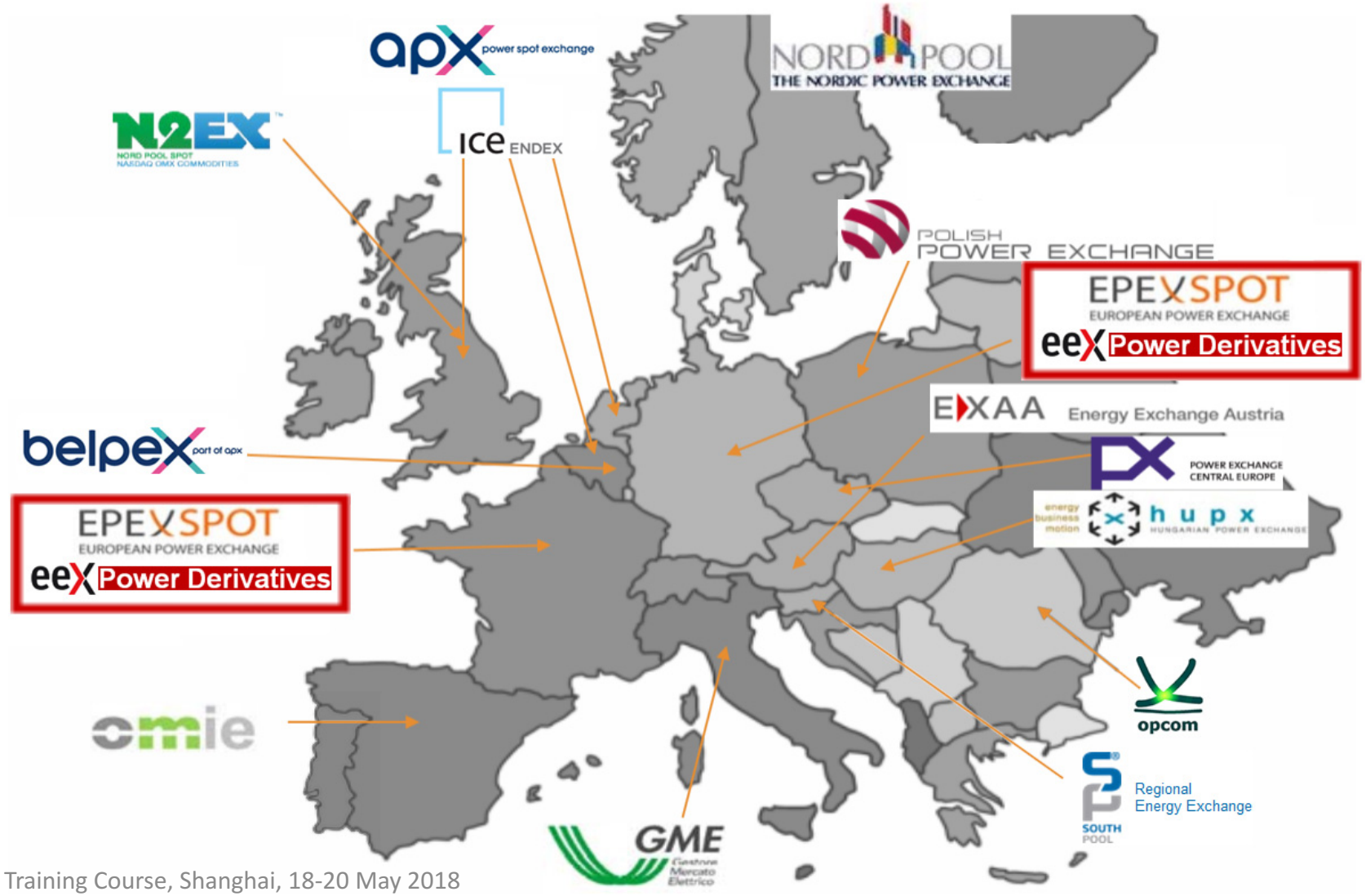


The European System: TSOs

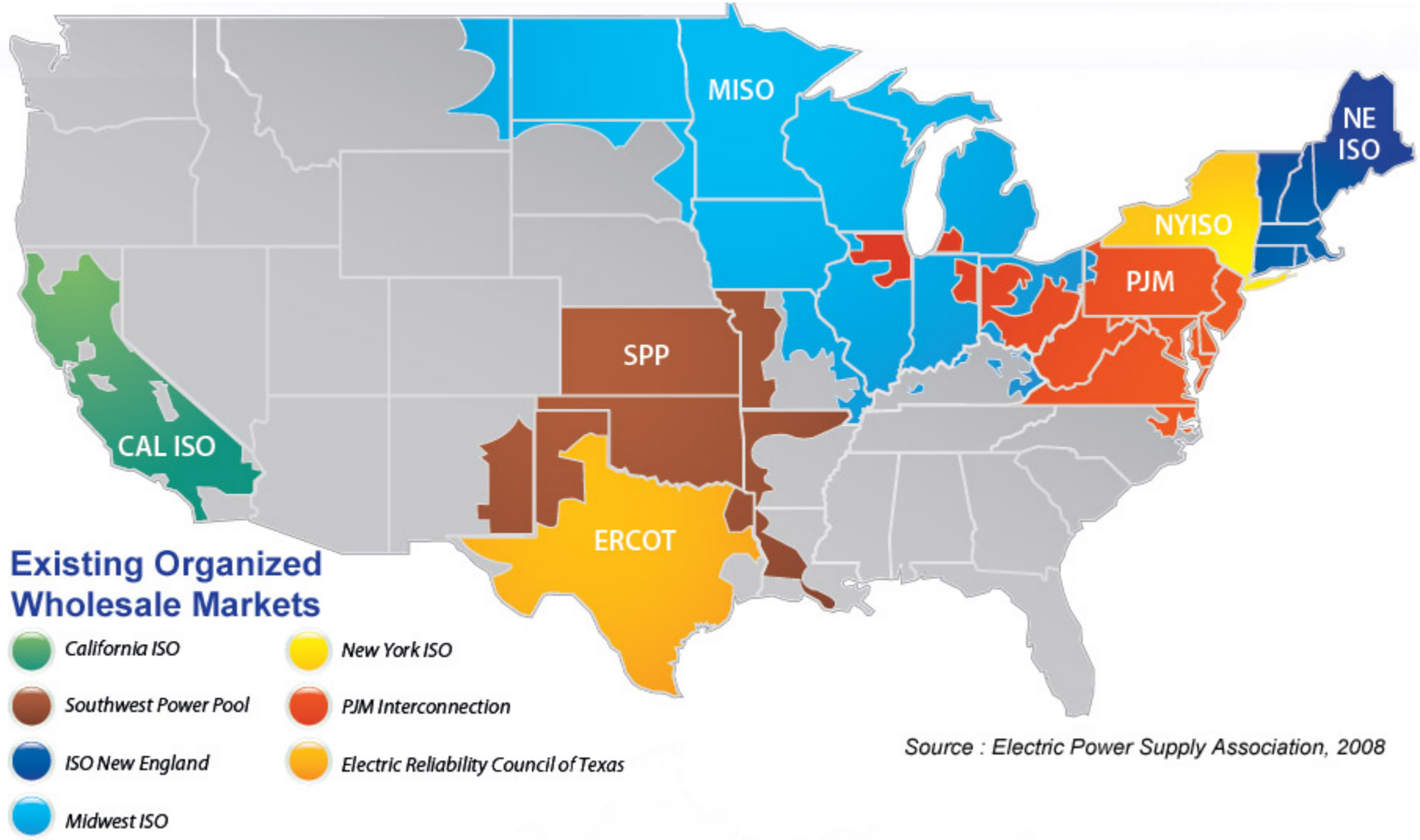
Notice France *is at the* ***heart of the system*** *since it connects 3 electric peninsulas.*



Power Exchanges in Europe

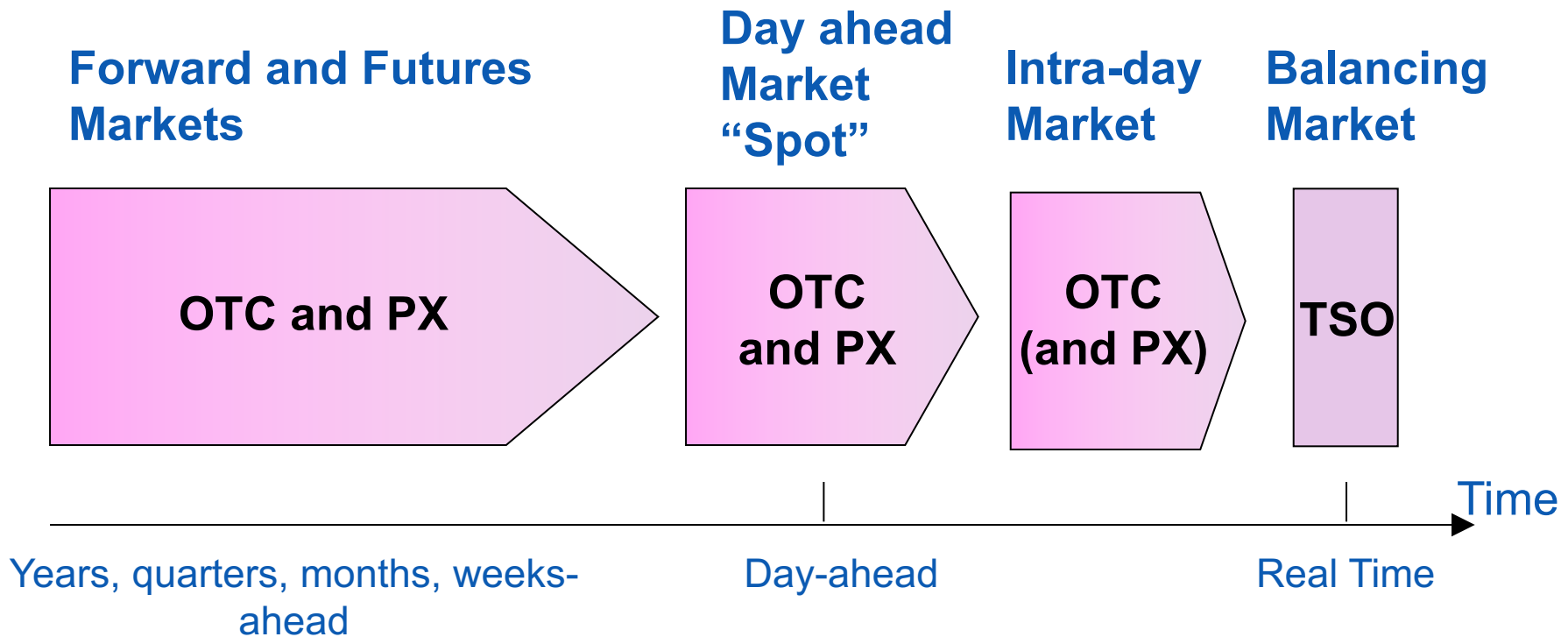


Electricity Markets in the USA



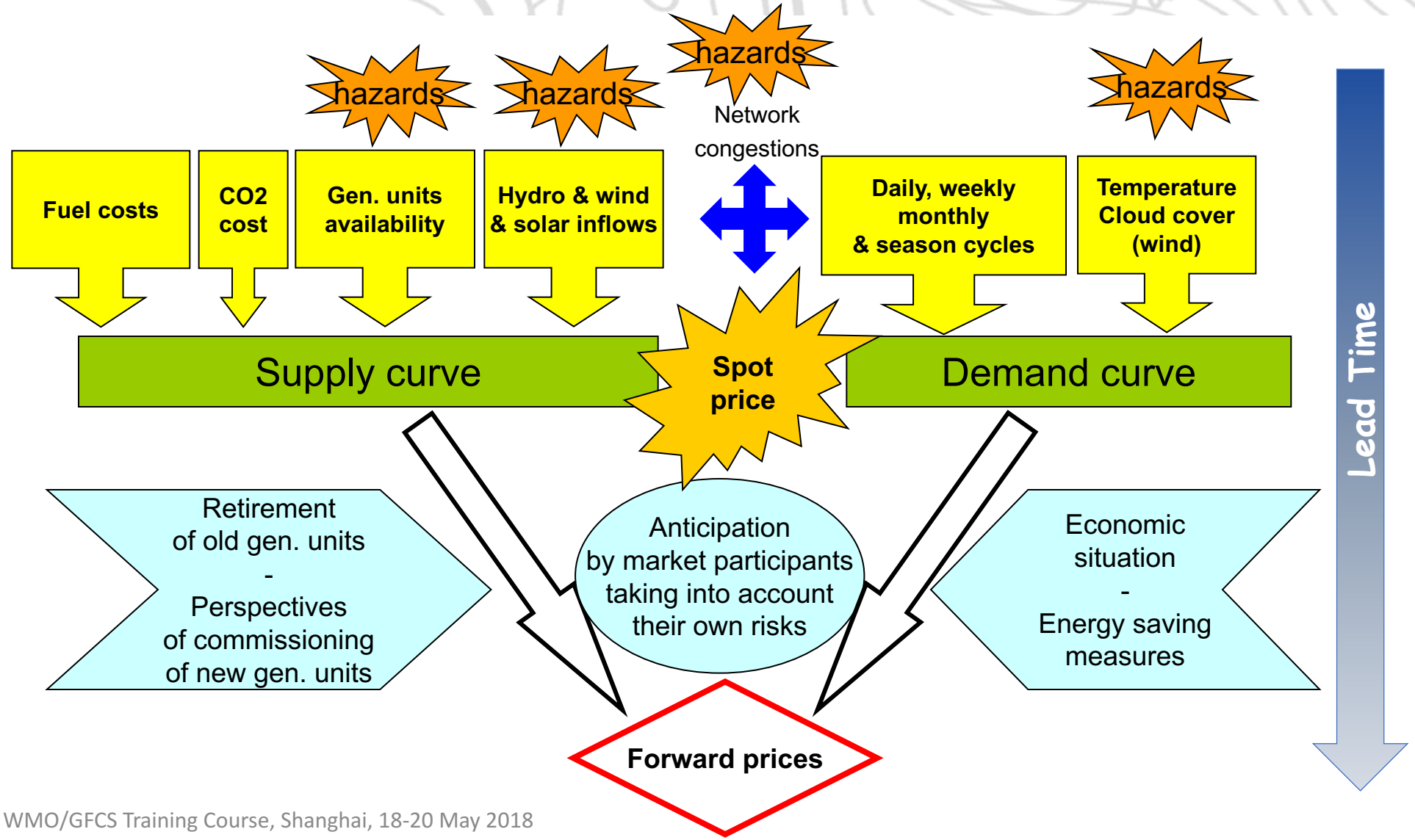
Source : Electric Power Supply Association, 2008

Dominant Market Design in Europe

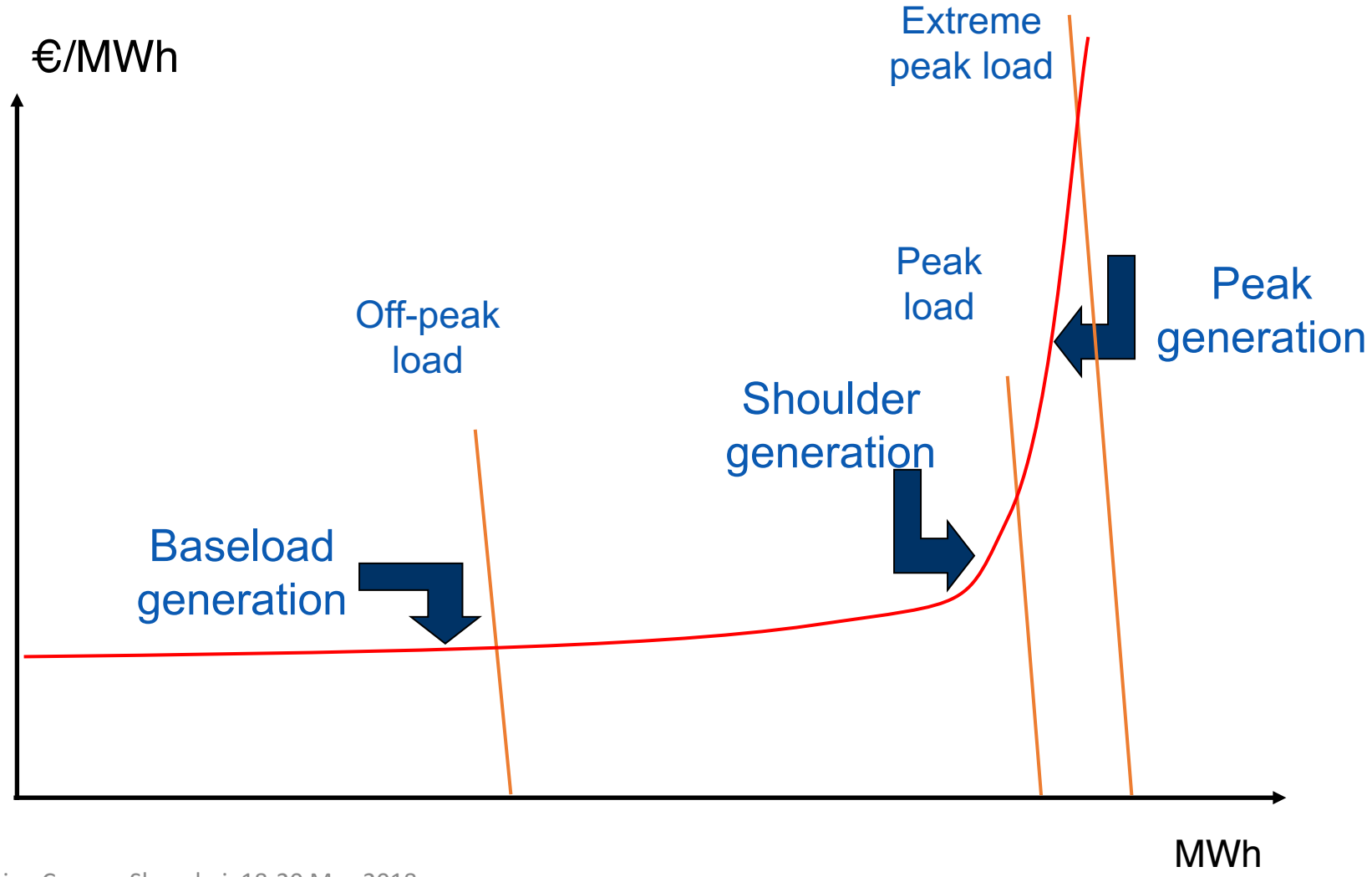


OTC : Over the Counter, bilateral transactions
PX : Voluntary power exchange, trading standard products
TSO : Transmission System Operator

How Prices are Determined on the Wholesale Market



Typical Supply/Demand Curve



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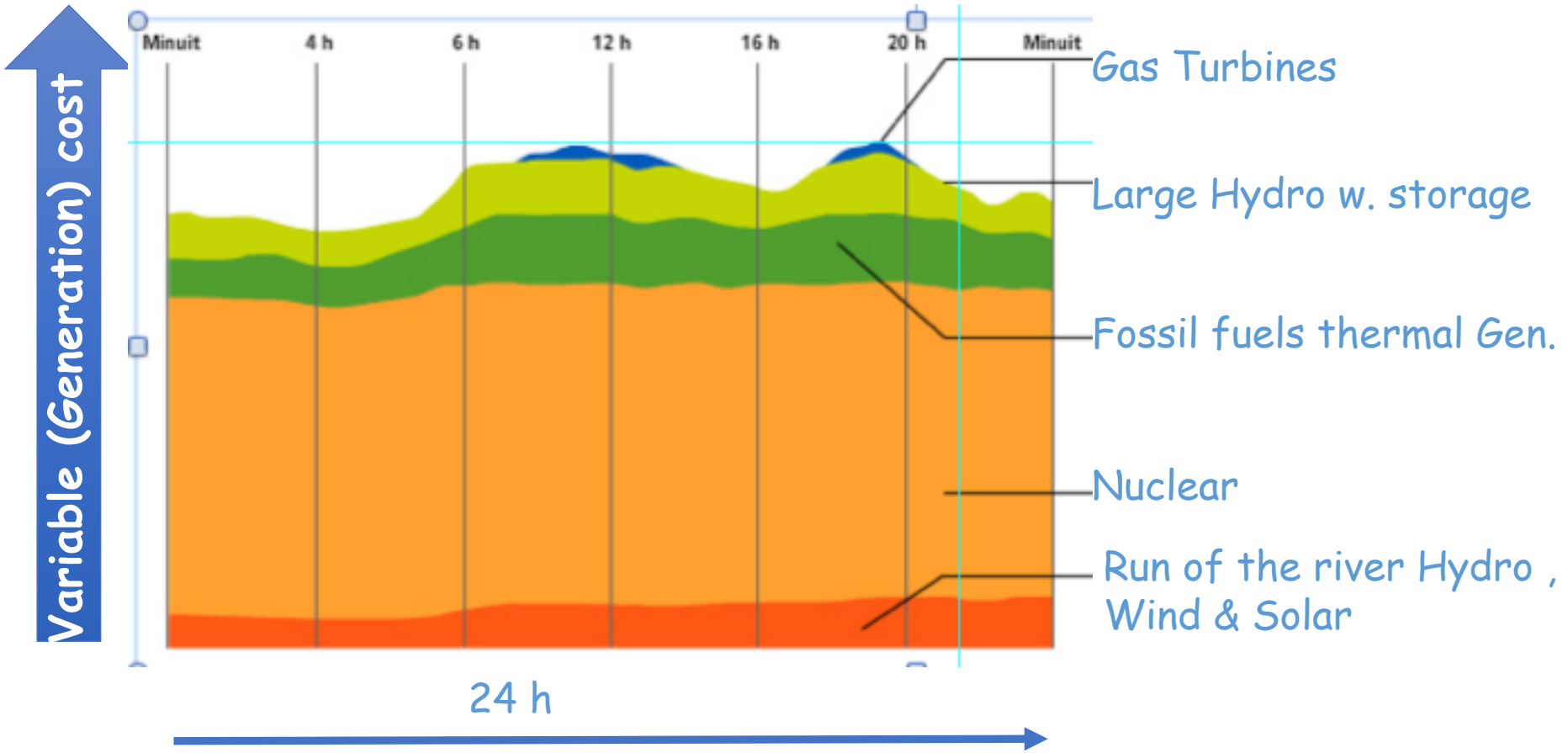
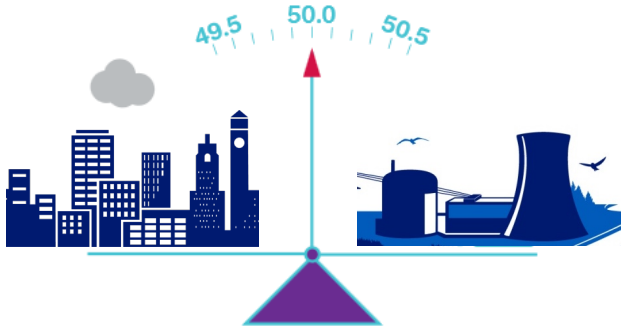
Supply / Demand Balance

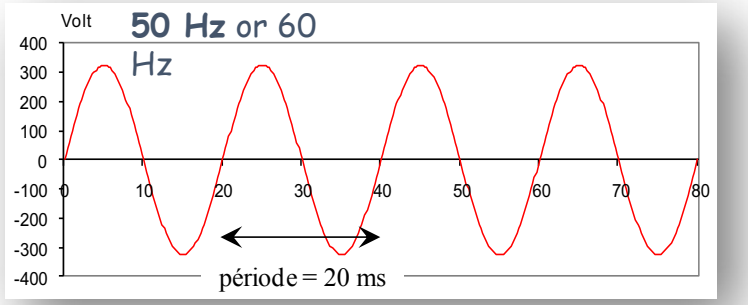
Example: France

Production units called based on increasing marginal cost of generation



Frequency Adjustment





Engine Torque (turbine)

Change in Rotation speed

Resisting torque (network)

$$J_i \frac{d\Omega_i}{dt} = Cm - Ce$$

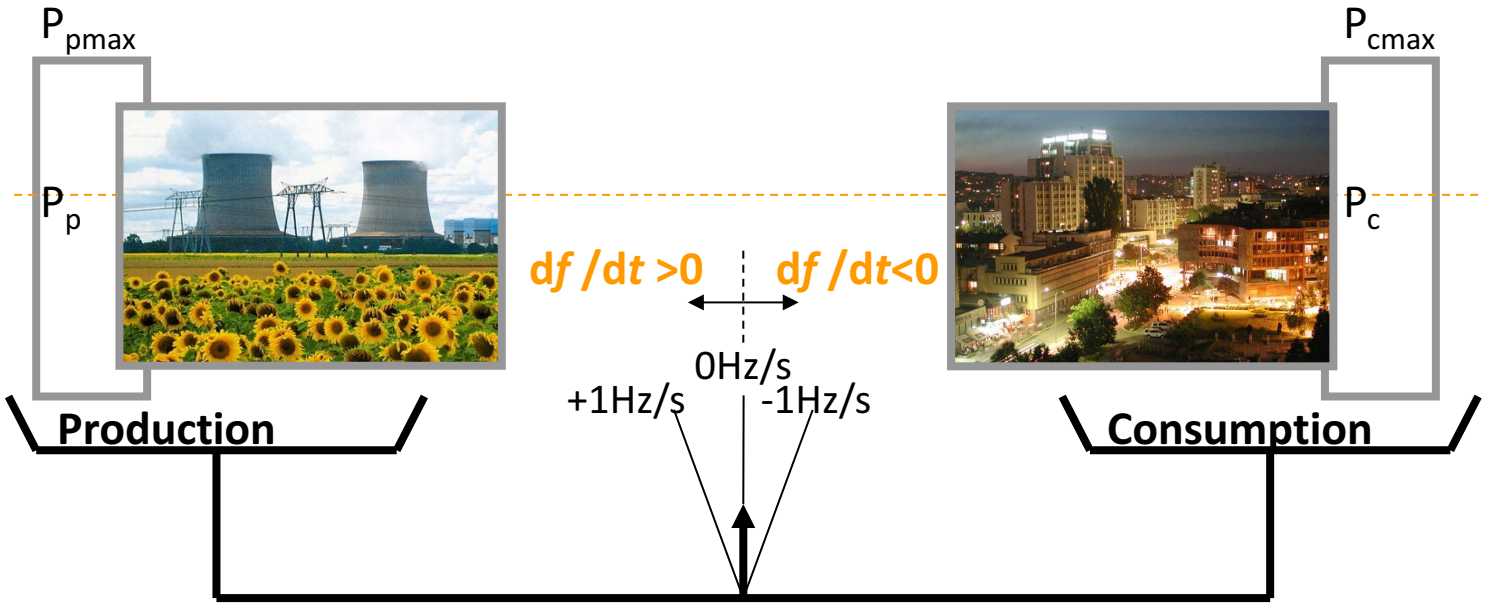
Frequency is the electrical consequence of synchronous alternators' rotation speed

In permanent regimes, alternators run at the same speed

Frequency is uniform on an interconnected network

Frequency Reflects Supply/Demand Balance

$$J_i \frac{d\Omega_i}{dt} = Cm - Ce$$



Cm > Ce, alternators stock kinetic energy : f increases

Ce > Cm, alternators release kinetic energy: **f decreases**

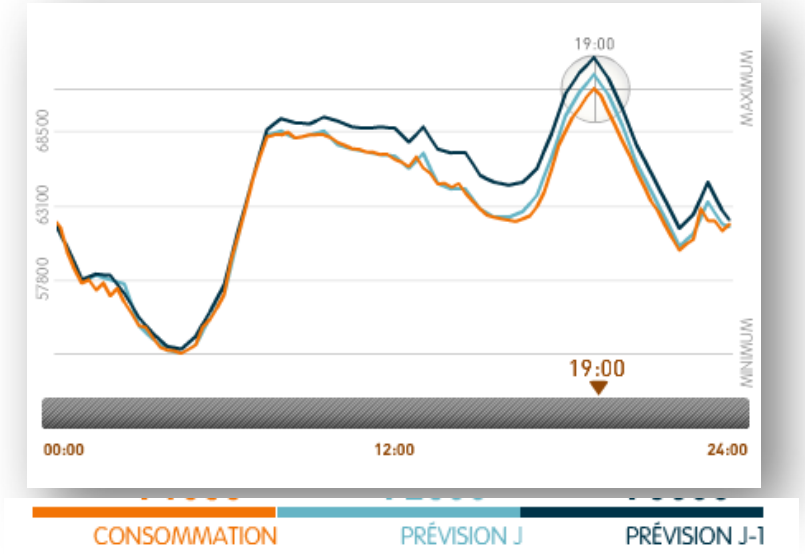
Frequency Perturbation: Several Origins

Small perturbations

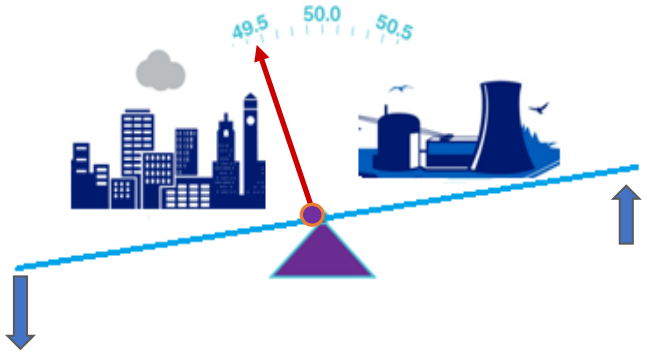
- Fluctuations in demand: imperfect forecast
- Fluctuations in supply:
  - Impossible to control perfectly
  - **VARIABLE GENERATION: WIND & SOLAR**

Large perturbations

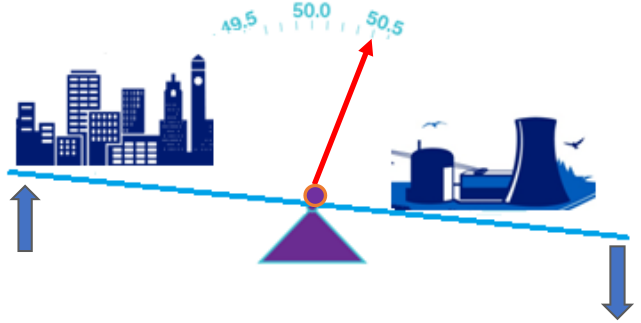
- Loss of production unit
- Loss of interconnection line in peninsulas



Generation unit loss

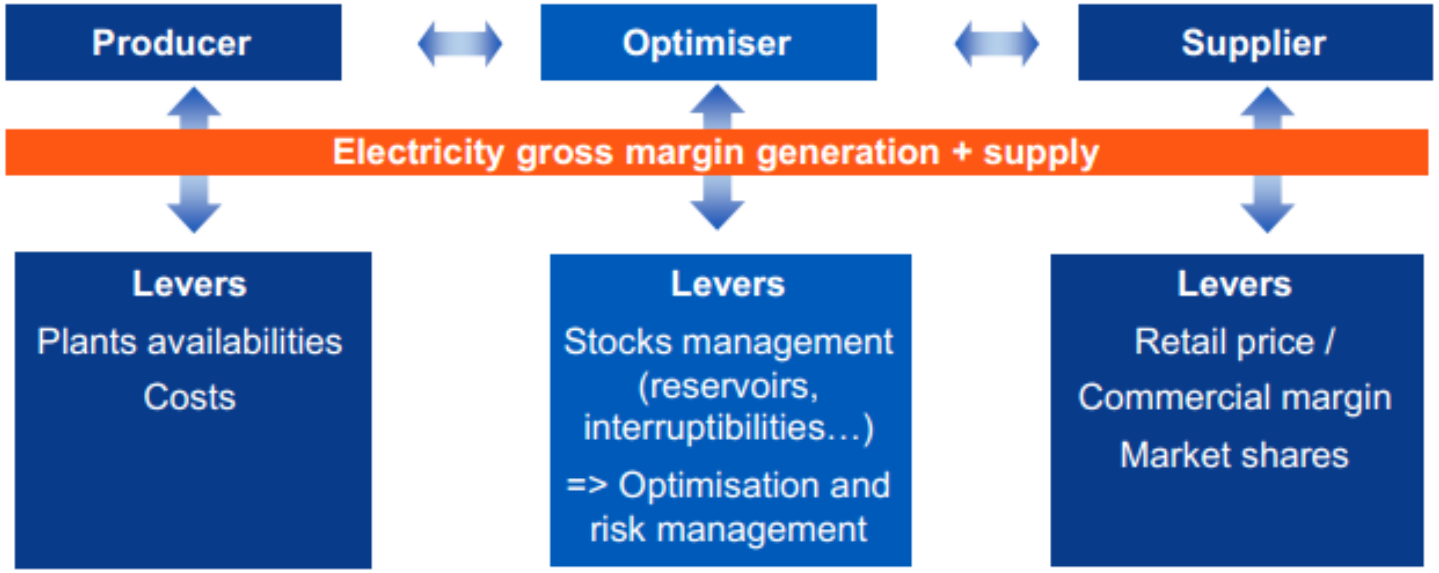


Demand reduction



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

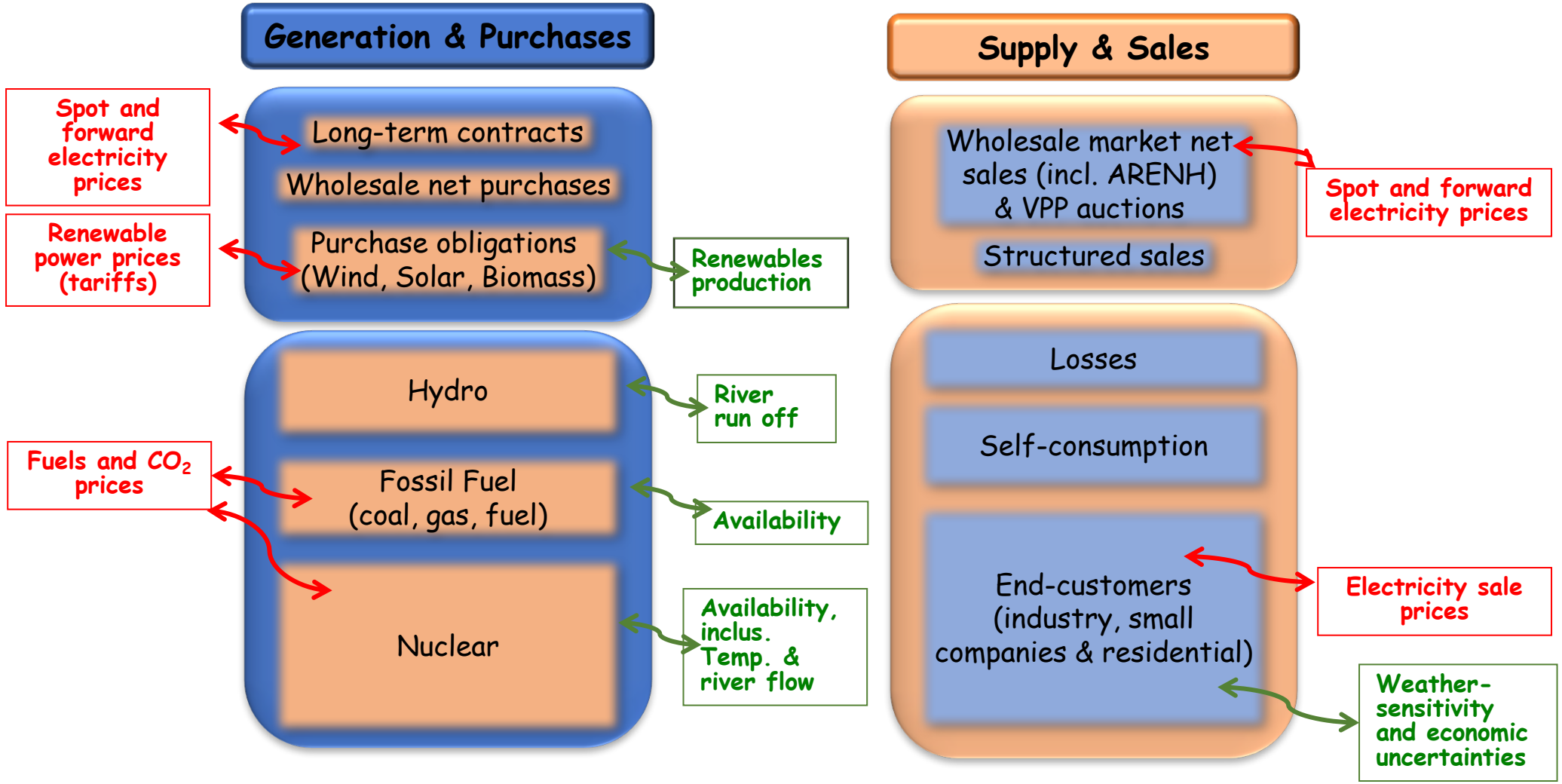
Supply/Demand Balance Optimization



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

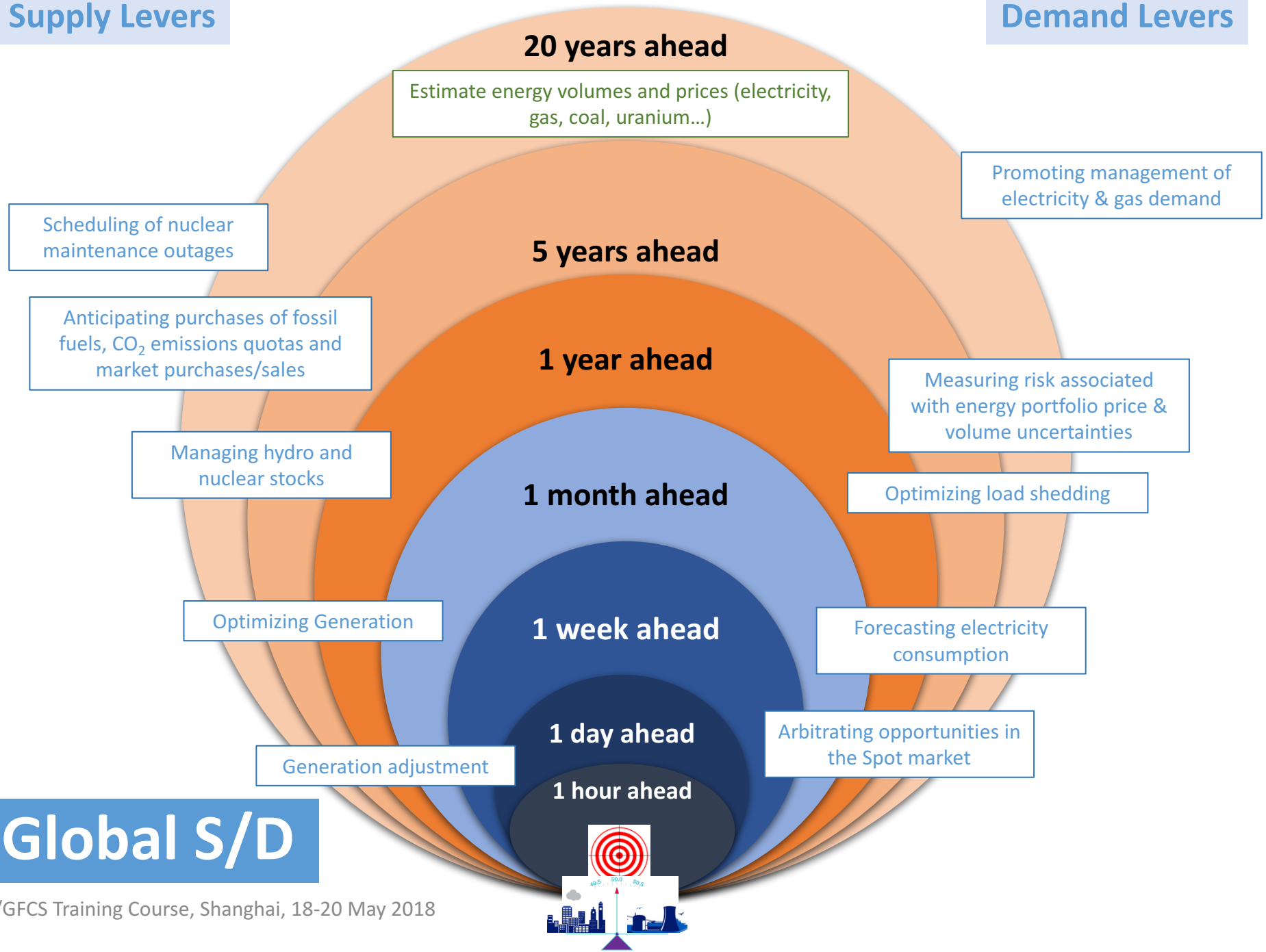
A Portfolio Exposed to Risks in **Volume** and **Price**



Global S/D

Supply Levers

Demand Levers



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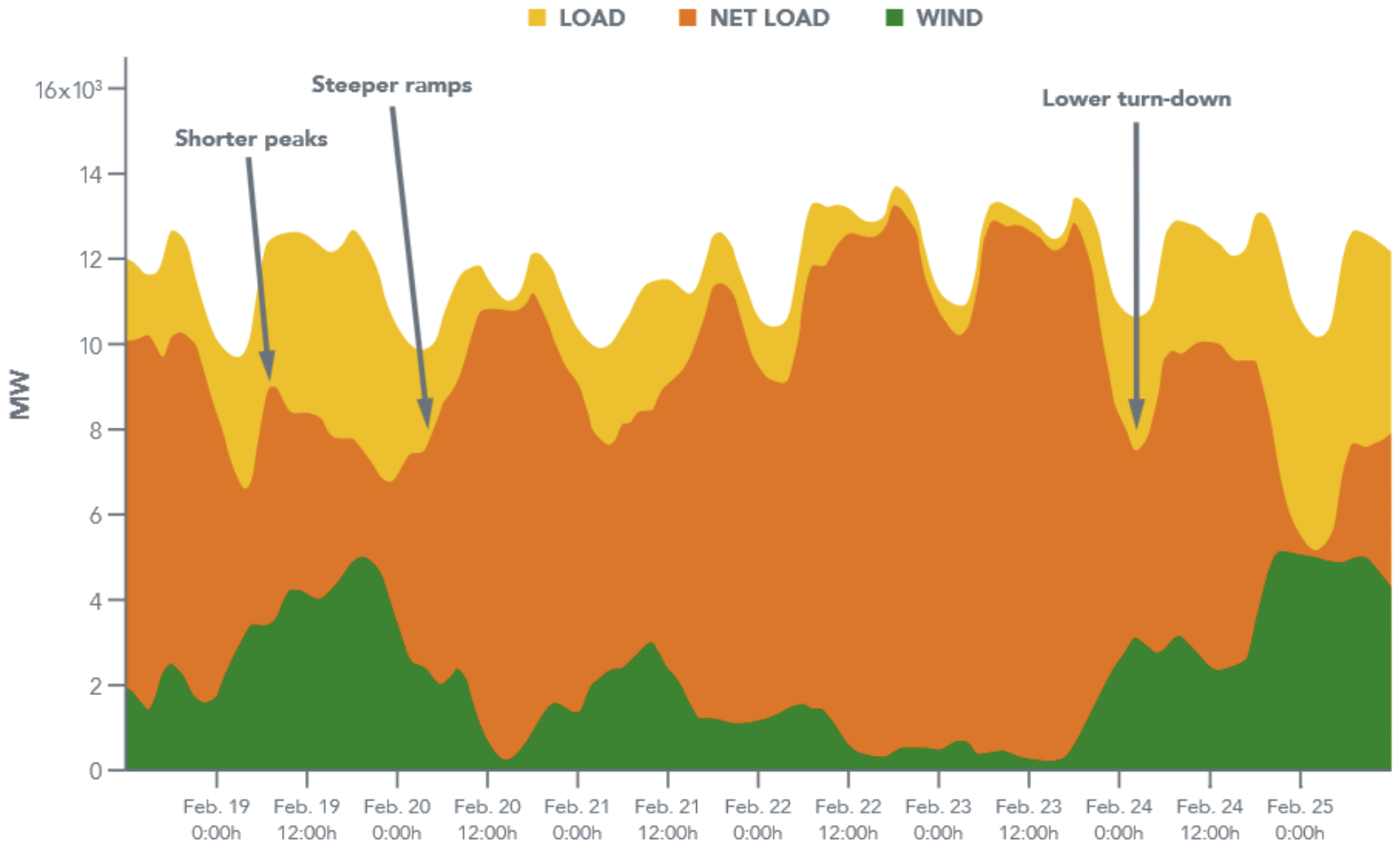
Impact of Increasing Variable Generation



Addding RE Increases Complexity

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

Vera Silva

EDF R&D

London, 28 June 2016

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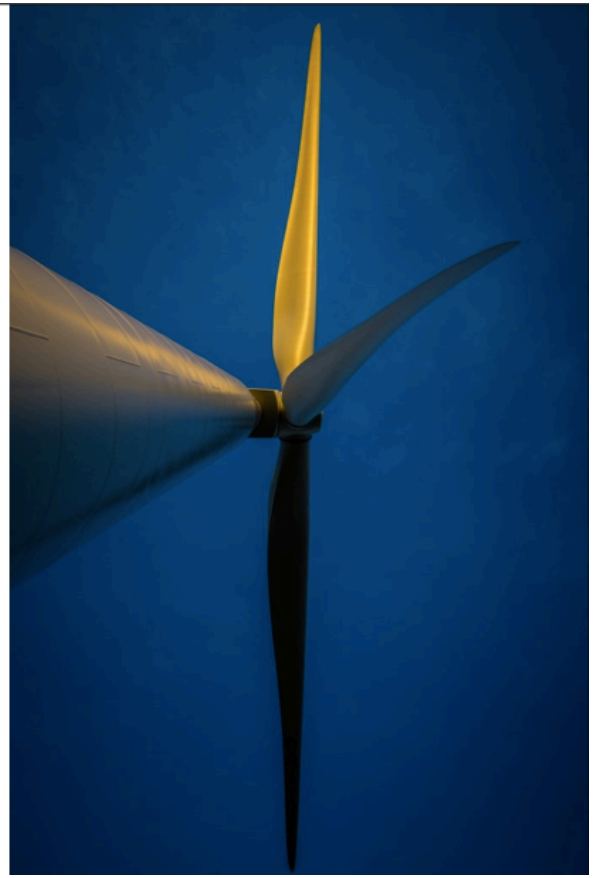
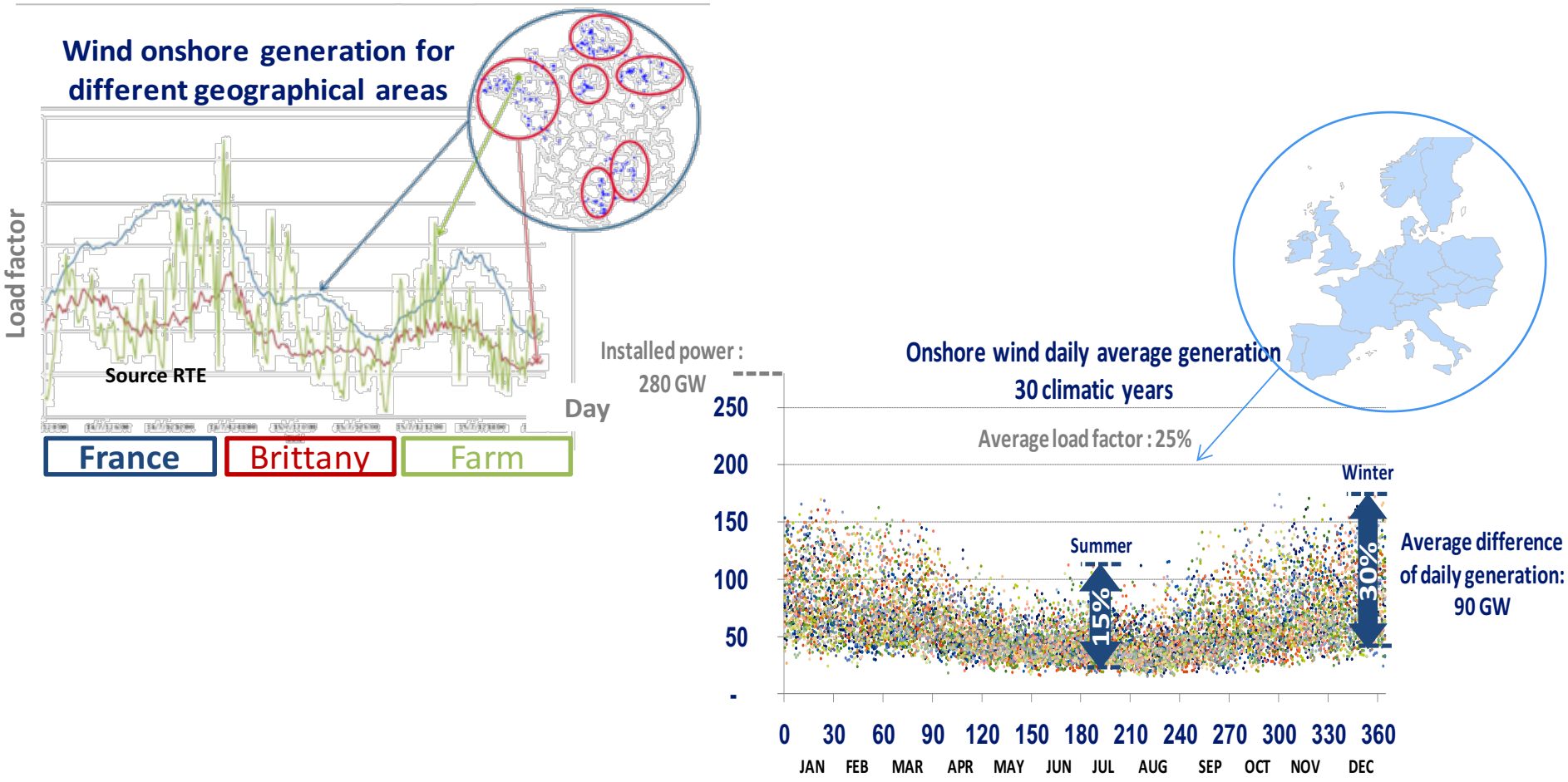


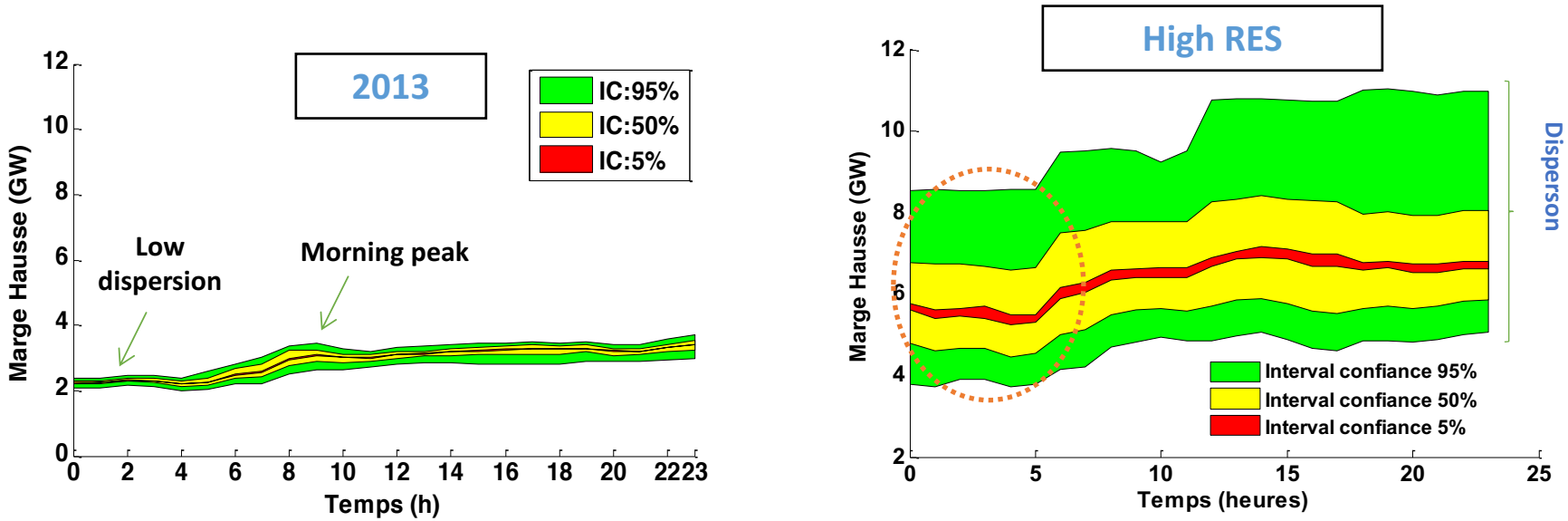
Geographical Diversity Helps, but there is still Significant Variability at the European Level



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 Forecasts 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**

WEMC
World Energy & Meteorology Council

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**
- ✓ **New power systems paradigms are necessary**
- ✓ **Meteorology (Weather & Climate) is key to the energy sector !**

WEMC
World Energy &
Meteorology Council

@WEMCouncil

Thank You

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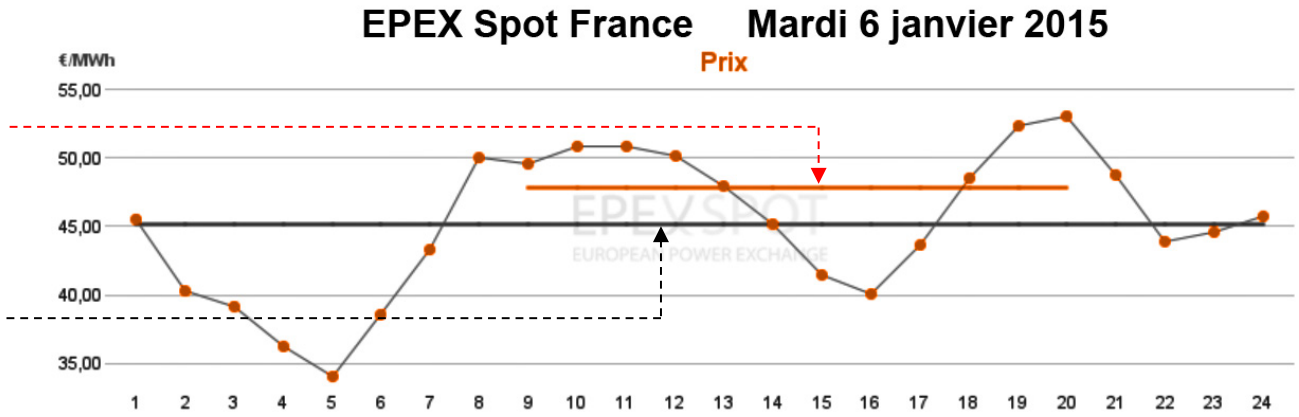
Price Formation

- **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

Average 08-20 :
Peak load price

Average 00-24 :
Baseload price



- 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

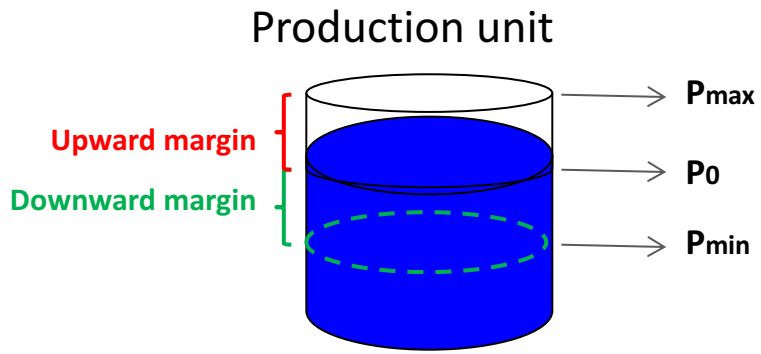
3- Restore primary & secondary reserves by re-optimizing the economic use of the mix

Primary Adjustment

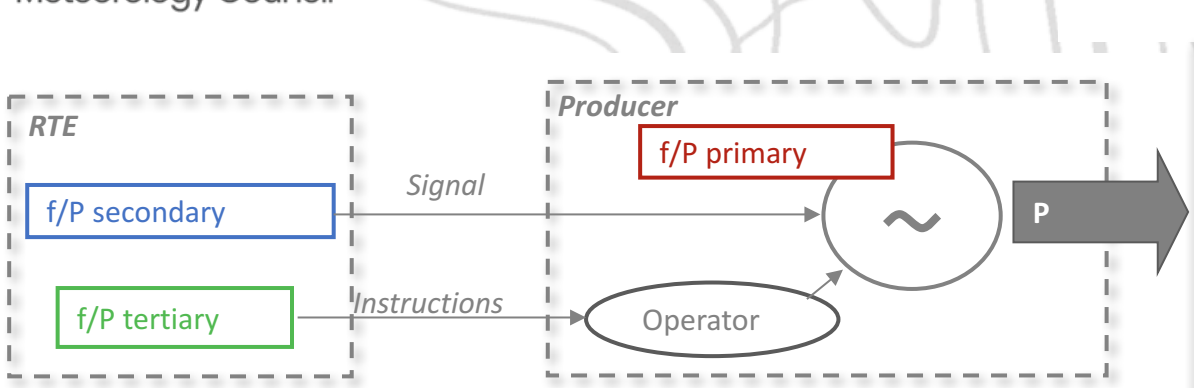
Secondary Adjustment

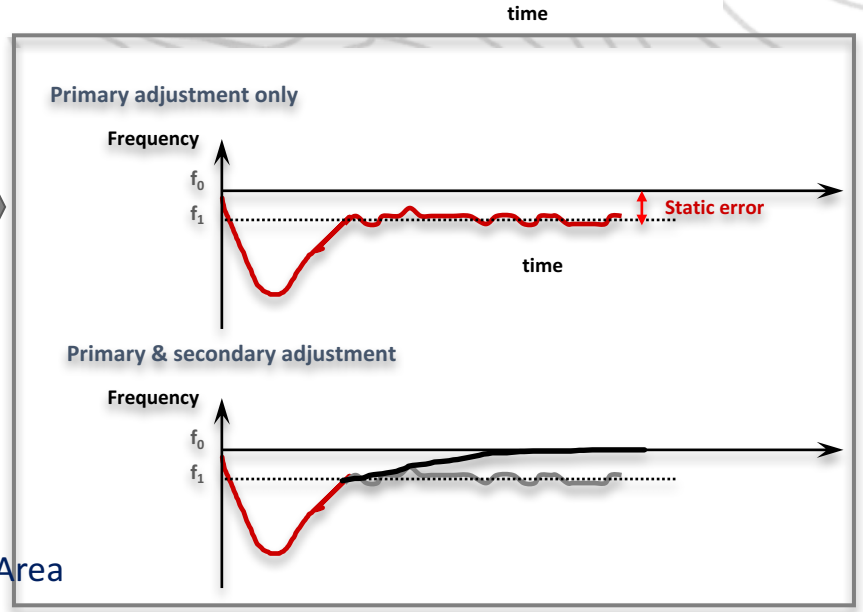
Tertiary Adjustment

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



How it works: France





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

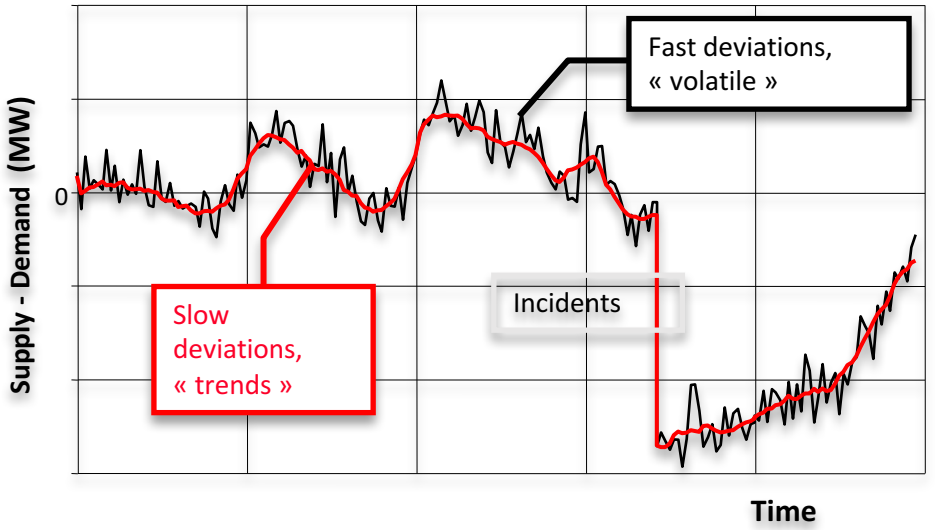
Adequacy & Flexibility

- **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)