# Introduction to electricity risks, markets and trading

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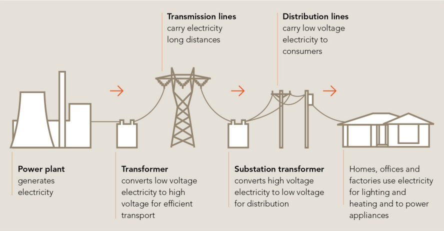
# Overview of the course

1. **The power generation sector; electricity as a commodity**
   Electricity sector in the world, energy transition. Features of electricity, properties of electricity demand, transport networks. Functioning of electric systems and role of system operators. Network stability and frequency control. Specific risks associated to intermittent renewable electricity generation.
2. **Electricity markets and electricity derivatives**
   Ways to sell electricity. Organization of electricity markets: balancing; intraday, day-ahear, forward and capacity markets. Electricity futures and other derivative products.
3. **Modeling electricity prices and trading in electricity markets**
   Stochastic models for intraday, spot and forward prices. Trading strategies for power producers.

# Outline

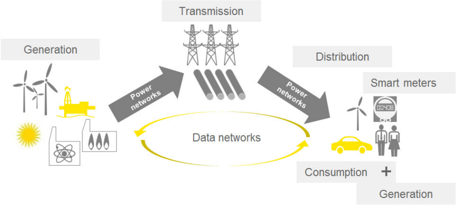
# The electricity supply chain




TRANSPORT OF ELECTRICITY

**Source**: `eex.gov.au`

Historically, energy production and distribution was carried out by integrated energy companies; electricity was produced by steam turbines at large power plants and sold to consumers at regulated tariffs




**Source**: `ey.com`

Nowadays, electricity production is competitive, but transport and distribution continue to be managed by state companies; distributed renewable generation plays an important role and data networks and smart meters are used for load management

# The electricity sector

- In most countries the electricity sector is competitive, generation is separated from transport and distribution.
- The transport (high voltage grid) is a natural monopoly and usually managed by Transportation Service Operator (TSO), a state company (in Russia, Федеральная Сетевая Компания, in France RTE), who is also responsible for real time operation and equilibrium of the energy system.
- The distribution and generation companies are independent competing entities from public or private sector.

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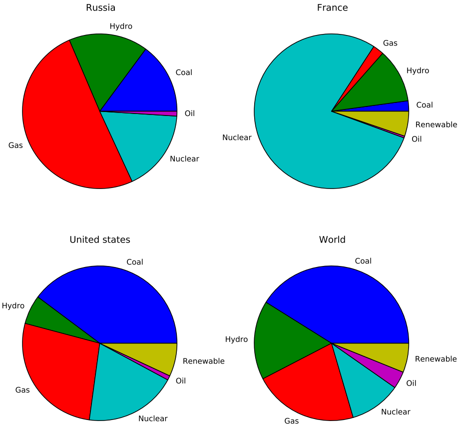
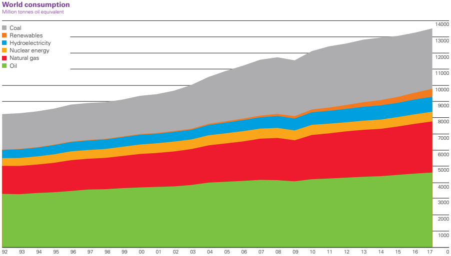
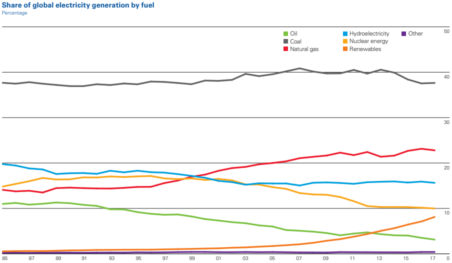



Energy mix in selected countries and the world

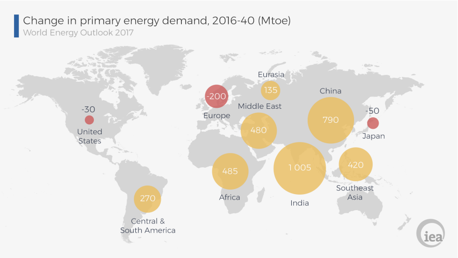
# The energy mix

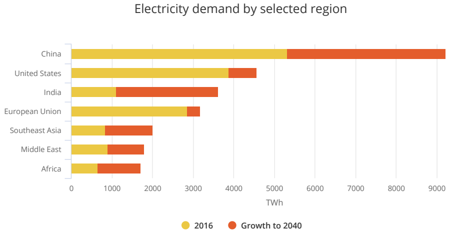


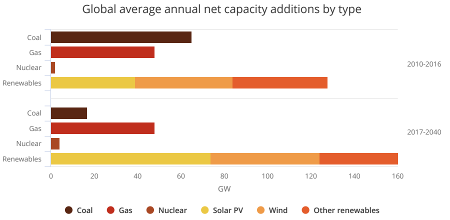




Left: global energy consumption. Right: global electricity generation. Source: BP Statistical Report on World Energy 2018.

# Future evolution of the world energy production




World Energy Outlook 2017, IEA

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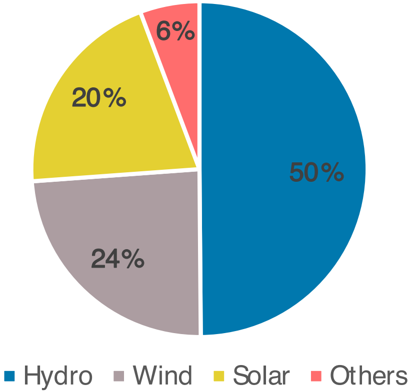
# Renewable energy




| Installed capacity | GW |
|---|---|
| Hydro | 1172 |
| Wind | 564 |
| Solar | 486 |
| Bioenergy | 115 |
| Geothermal | 13 |
| Marine | 0.5 |

**Source: IRENA**

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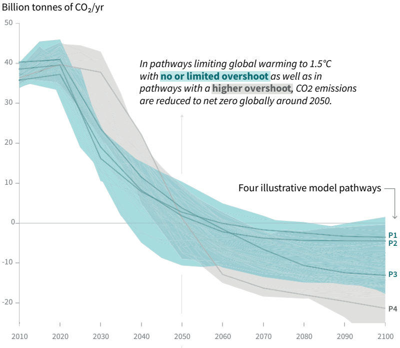
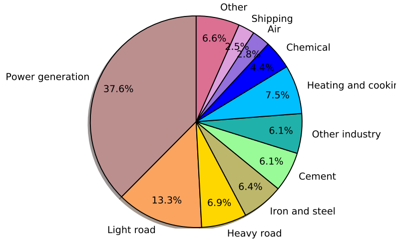
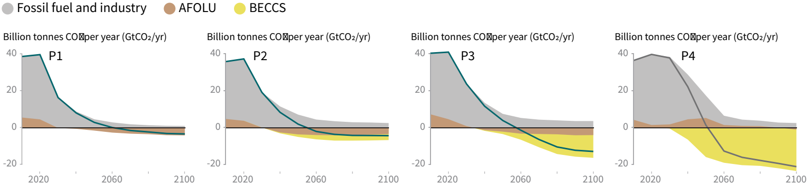
- Do you agree that large-scale efforts are necessary to control global warming?
- Which industry makes the largest contribution to GHG emissions?

# The energy transition

Global total net $CO_2$ emissions

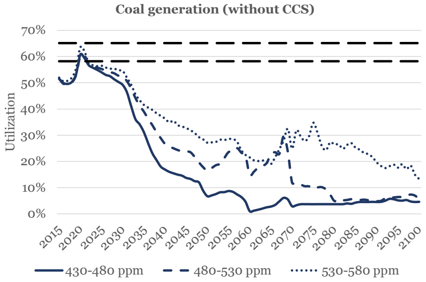


# Asset stranding in the energy industry

- To stop climate warming below 1.5 degrees, carbon neutrality must be achieved before 2050.
- Since fossil-fuel power generators have long lifetimes (35-40 years), committed emissions from existing and planned generators are uncompatible with emission pathways towards decarbonized energy sector.
- This creates a risk of asset stranding, i.e., early retirement or underutilisation.



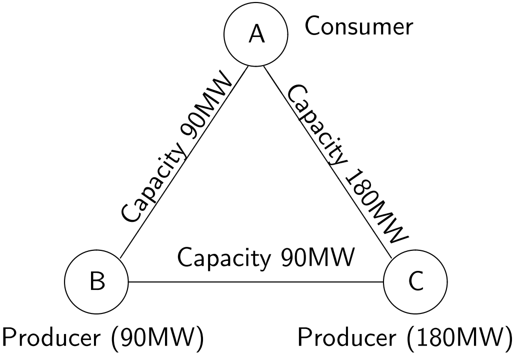

Source: A. Pfeifer et al., "Dead on arrival: Implicit stranded assets in leading IAM scenarios"

# Outline

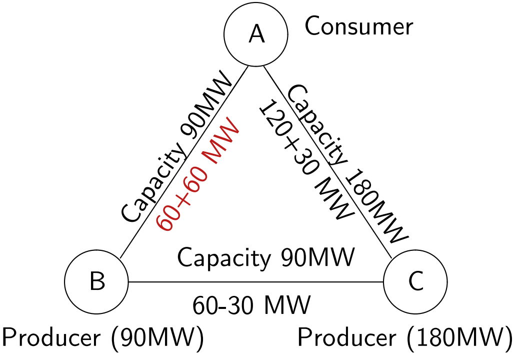
# Features of electricity as a commodity

- Electricity (almost) cannot be stored;
- Electricity is a *local* commodity: cross-border capacity is limited, market structure is different in different states
- Electricity network is subdivided into multiple energy systems (frequency control zones), encompassing multiple countries
- Demand must equal supply at all times within each frequency control zone
- Sum of currents flowing in and out of each node is zero
- Sum of voltages around each loop is zero
- Electricity flows through all available paths

# Example

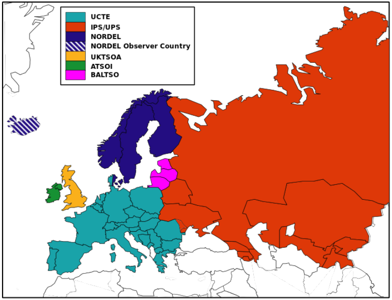

A
Consumer
Capacity 90MW
Capacity 180MW
Capacity 90MW
B
C
Producer (90MW)
Producer (180MW)

# Example


A
Consumer
Capacity 90MW
60+60 MW
Capacity 180MW
120+30 MW
B
C
Capacity 90MW
60-30 MW
Producer (90MW)
Producer (180MW)

# Features of electricity as a commodity

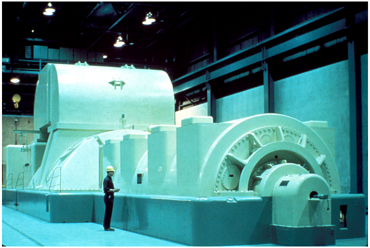
- The electric grid is separated into very large synchronous regions (frequency control zones)
- Complex wholesale market and physical mechanisms are in place to guarantee equilibrium within each zone.



# Supply/demand balance and frequency control

- Balancing over very time horizons (seconds) is ensured by frequency control.

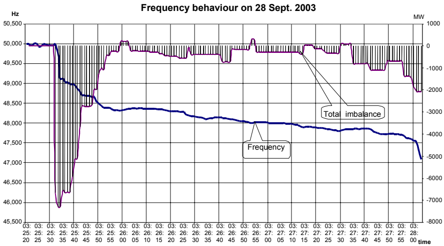
- Due to inertia of conventional generators, after a sudden load increase (power plant failure), frequecy of the AC system goes down progressively, allowing the automatic frequency control systems to ramp up production.



- Renewable generators have no spinning reserve: increased renewable penetration makes frequency control more difficult.

# Frequncy control

- Frequency is a global charactereistic of power networks
- Frequency stability expresses the balance between generation and load: if load exceeds generation, the speed of turbines starts to drop and the frequency goes down
- In France, admissible frequency range is 50 Hz $\pm 0.5$ Hz. Automatic load shedding starts at 49 Hz.

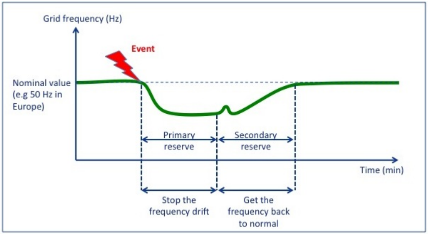



Frequency collapse during the 2003 blackout in Italy.

**Source: UCTE report on the 28 September 2003 blackout in Italy**

# Defense against frequency collapse

- Primary reserve: automatic turbine valve controllers restore supply demand balance at a lower frequency level by increasing output;
- Secondary reserve: capacity of generator units is increased (by the national dispatch center) to bring frequency back to normal.




**Source**: `cleanhorizon.com`

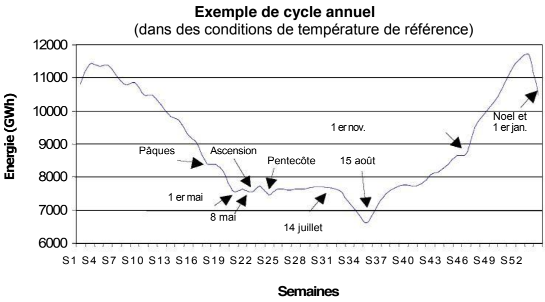
- Tertiary reserve: balancing bids are activated to reconstitute primary / secondary reserve.

In a competitive market, primary/secondary/tertiary reserves must be procured in advance via market mechanisms.

# Electricity demand: seasonal trends

Electricity consumption is strongly seasonal with pronounced yearly, weekly and seasonal cycle

- In France, maximal consumption is observed in December and minimal around August 15



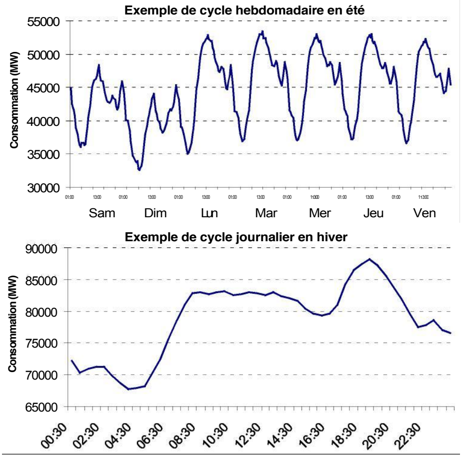

**Source: RTE, Consommation française d'électricité, Nov 2014**

- The consumption is lower during the week-end and especially on Sunday due to reduced economic activity
- The daily maximum is attained around 1PM in summer and 7PM in winter; the minimal consumption is observed during the night.

# Electricity demand: meteorological effects

Electrical consumption is strongly correlated with meteorological conditions.

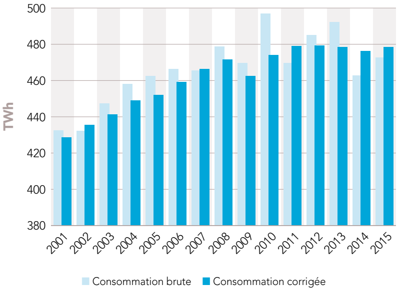
- Temperature: in France, in winter, a variation of $1^\circ C$ corresponds to an variation of consumption of 2500 MW. In summer, the variation is about 400 MW due to air conditioning.
- Cloud cover: measured on the scale from 0 to 8. A variation of 1 unit corresponds to a variation of consumption of about 800 MW.




Source: RTE, Consommation française d'électricité, Nov 2014

# Electricity demand: non stationarity

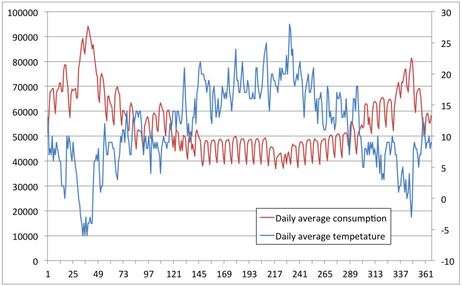
- Electrical consumption is not stationary: average annual consumption has been rising throughout the 20th century, but has stabilized recently in France and has even fallen slightly in the EU over the last 10 years.
- It is expected to rise in future due to electrification of transport and other industries to reduce $CO2$ emissions.




**Source: RTE, Bilan previsionnel 2016**

# Electricity demand: consumption spikes

- The main risk for power systems comes from *consumption spikes* during the cold season, which are caused by cold waves.




**Data source: RTE web site and** `www.wunderground.com`

**(temperature at Paris Orly)**

# Electricity demand: risks for TSO

- The risks of electricity consumption are related to ensuring supply-demand balance and preventing blackouts.
- In the long term, network structure must be adapted to new consumption patterns, new plants and interconnections must be built.
- In the medium term, sufficient supply margin must be ensured for the cold season, taking into account the possibility of extreme tempetatures.
- In the short term (1-2 days), sufficient production units must be affected to meet demand.
- Following the liberalization of electricity markets, the supply-demand balance is managed through market mechanisms in a (partially) decentralized manner.
- Specific market tools used by TSO to ensure supply-demand balancing are: capacity market, balancing market and system services market (рынок мощности, балансирующий рынок, рынок системных услуг).

# Load management

- Individual customers may be encouraged to disconnect loads via specific tariffs (EJP - effacement jour de pointe in France).
- Industrial customers may post load shedding offers on the adjustment markets.
- Utility companies may disconnect certain loads (heating, air conditioning, electric car chargers) directly via smart meters.

# Demand response

- Contract between a consumer and a producer (or a retailer)
- The consumer pays a lower fare for power all the days of the year except on a certain days (or periods) decided by the retailer.
- The number of days of price events is determined at inception.
- This form of demand-response contract is named dynamic Time-Of-Use (dToU).

Example: Low Carbon London Pricing trial experiment 2012-2013

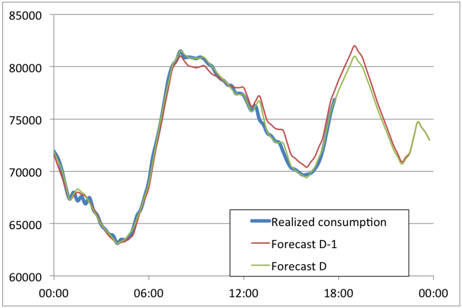
- 5,567 London households with consumption measured at an half hourly time-step on the period from February, 2012 to February, 2014.
- Standard tariff was 14 p/kWh.
- Consumer enrolled in the dToU tariff would pay their power:
  - 11.76 p/kWh on Normal days,
  - 67.2 p/kWh on High price days,
  - 3.99 p/kWh on Low price days.

# Demand dispatch

- Demand dispatch refers to direct control of loads by the system operator to optimize network operations.
- The controllable load must be able to shift their consumption in time without affecting the end users. Examples are : water heaters, heating, ventilation, and air conditioning (HVAC), electric vehicle chargers, pool pumps etc.
- Mechanisms for remotely controlling the loads and incentivizing the consumers are presently being developed.

# Load forecasting and scenario generation

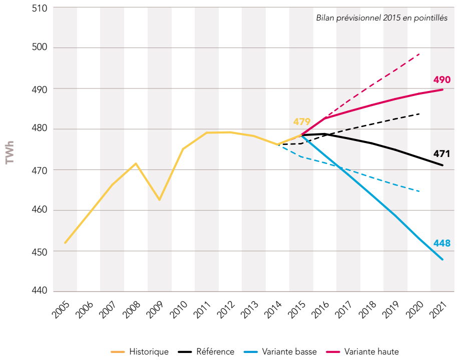
- Short-term forecasting demand (up to 1 week) is based on meteorological forecasts and on historical consumption data.
- Seasonal forecasts are produced with reference meteorological data. Historical simulations may be used for scenario analysis.




Data source: RTE web site

# Load forecasting and scenario generation

- Long-term consumption scenarios are produced by RTE based on plausible scenarios of economic activity in different sectors and the evolution of consumption patterns.

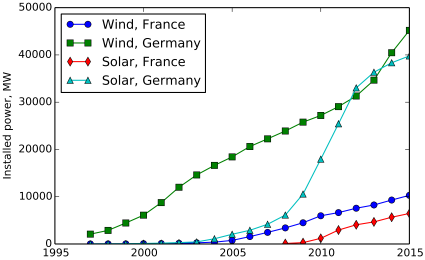



**Source: Bilan previsionnel RTE 2016**

# Outline

# Intermittent renewable production penetration

- European Union targets 20% from renewable energy by 2020 then 27% by 2030 and in some regions renewable penetration is already beyond this target

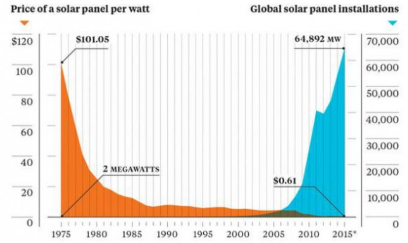


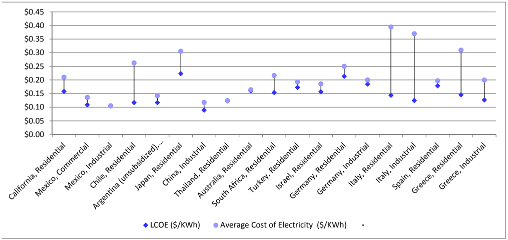

Wind and solar power in France and in Germany. Data source: Wikipedia.

| Country | 2014 Share | Target |
|---|---|---|
| France | 18.3% | 40% by 2030<br>27% by 2020 |
| Germany | 28.2% | 40-45% by 2025<br>55-60% by 2035<br>80% by 2050 |
| Denmark | 48.5% | 50% by 2020<br>100% by 2050 |
| Italy | 33.4% | 26% by 2020 |

Renewable shares and targets in selected EU countries. **Source: REN21 2016 report.**

# Solar power economics




Left: cost of solar panels vs. global installed solar power. Source: `cleantechnica.com`. Right: markets at grid parity, Jan 2014 data. Source: Deutsche bank.

To promote renewable electricity, various support mechanisms are used:

- Feed-in tariffs: used in 19 EU countries

  - in France a wind energy producer sells the generated output to EDF at a fixed price of 8.2 cents per KWh for 15 years (obligation d'achat)

  - The European commission recommends to phase out feed-in tariffs in favor of more market oriented mechanisms

- Feed-in premiums (10 EU countries): the producers sell their output in the market but receive a premium if the market price is below production costs.

  - In France, a 2016 law introduces feed-in premiums for certain renewables (complément de rémunération)

- Quota obligations (green certificates) (6 EU countries): obligation for energy suppliers to purchase a certain percentage of green energy

- Investment support (grants or preferential loans) : 19 EU countries

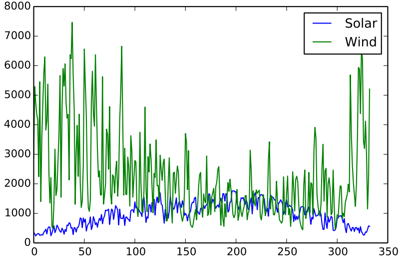
- Tax exemptions – often at the household level: 12 EU countries

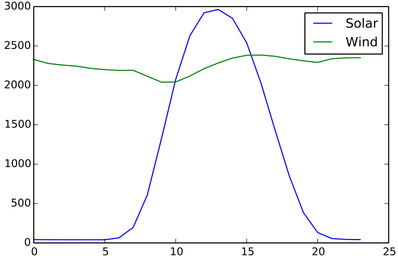
# Economic framework of renewable energy production

- To encorage the producers to reveal their true costs, support mechanisms are sometimes allocated on a competitive basis (tenders)
- Excessive or poorly implemented support mechanisms drive conventional flexible producers out of the market, reducing spare capacity and system stability
- This has led to the understanding that spare capacity is a commodity and should be financially compensated
- In France spare capacity of producers is certified by RTE and can be bought by suppliers who have the obligation to possess spare capacity matching the peak load of their clients (capacity mechanism)
- An organized capacity market has been launched by EPEX Spot in December 2016

# Risks of intermittent renewable production: contingencies

- Production from renewable sources is intermittent and possesses strong daily and annual seasonality creating new constraints on storage capacities in the network to balance supply and demand

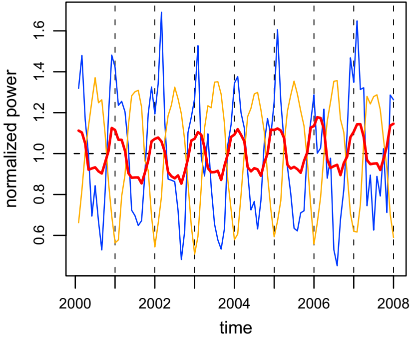



Left: average daily wind and solar power production in France in 2016, MW. Right: daily pattern of wind and solar production, 2016 average, MW. Data source: RTE.

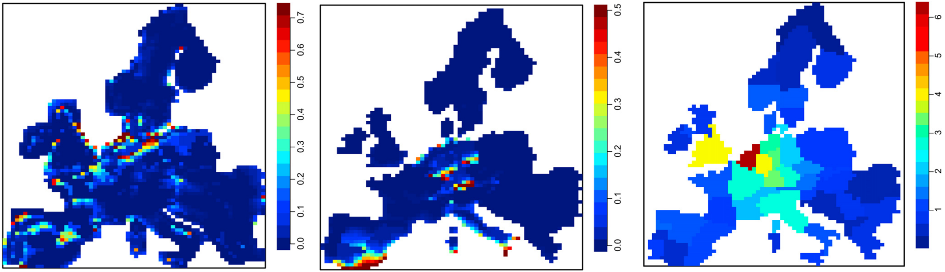
# Risks of intermittent renewable production: contingencies

Normalized monthly wind power generation (blue), solar power generation (orange) and load (red) aggregated over Europe. Source: Heide et al. (2010)



# Risks of intermittent renewable production: contingencies

- Production from renewable sources is spatially distributed in a non-uniform manner, creating new constraints on transmission capacities in the network to balance supply and demand

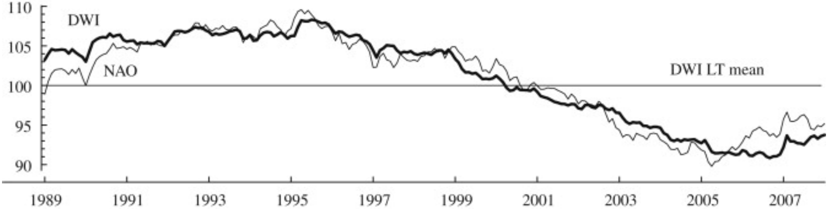



From left to right: expected wind power capacity in 2020, expected solar power capacity in 2020, average annual load.

Source: Heide et al., Seasonal optimal mix of wind and solar power in a future, highly renewable

# Risks of intermittent renewable production: contingencies

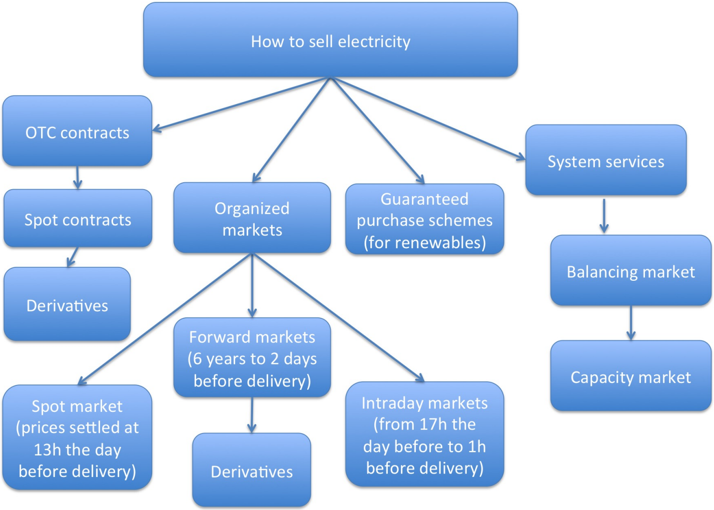
Non-stationarity: due to decadal variations of wind and climate change effects, wind potential may be over-estimated leading to lower than expected profitability of wind farms.




Danish wind index vs. the North Atlantic Oscillation index (difference in pressure between Açores and Iceland). Source: N. Boccard, Capacity factor of wind power: realized values vs. estimates. Energy Policy, 2009

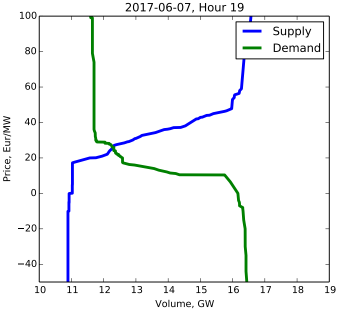
# Outline

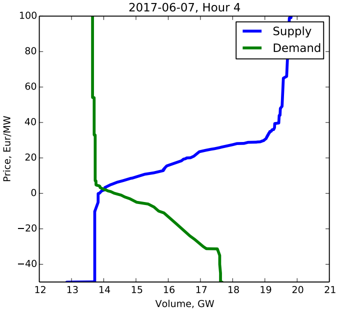
# How to sell electricity



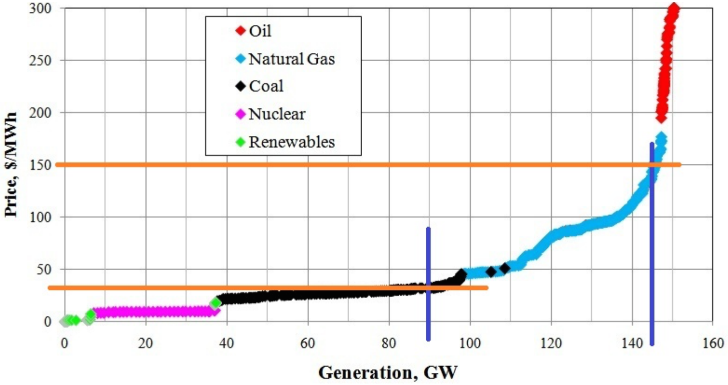
# The spot (day-ahead) market (рынок на сутки вперед)

- One of the main trading venues for electricity is the day-ahead market (EPEX Spot in France/Germany).
- In this market trading happens only once: participants submit bids for specific hours of blocks of the next day until 12:00, then at 12:55 the price is fixed and market clears.



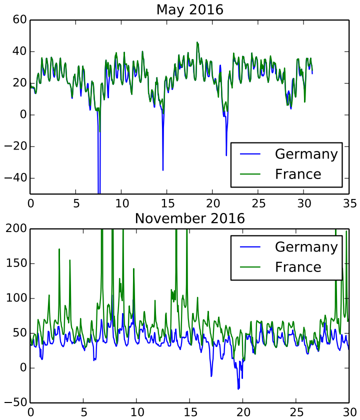



# Generation stack (PJM)



# Market coupling mechanism

- Each country has its own day-ahead market, but due to market coupling prices in different countries coincide in absence of binding transport constraints
- As long as interconnection capacity permits, demand in one market may be matched by supply in any other market
- If the transport constraints become binding, the prices decouple

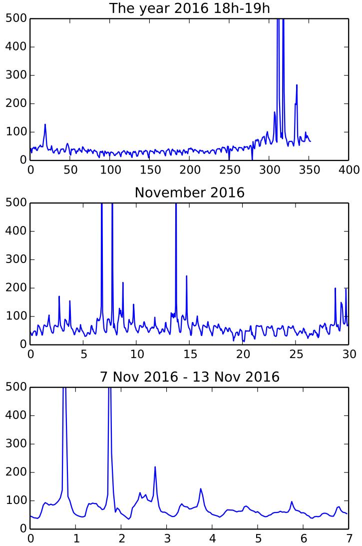



Day-ahead prices in France and Germany. In May, prices are coupled almost all the time, except during negative spikes in Germany. In November, prices are decoupled. Data source: `transparency.entsoe.eu`

# Features of spot electricity prices

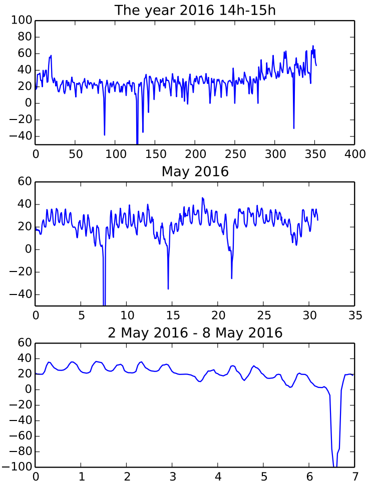
- Spot electricity prices possess daily, weekly and annual seasonality
- Prices are highly correlated with consumption and in countries where electricity is used for heating / air conditioning, with the temperature
- Due to non-storability, prices exhibit spikes which occur, e.g., in case of plant outage, especially in winter

Day-ahead prices in France. Data source: `transparency.entsoe.eu`



# Features of spot electricity prices

- Negative prices: since it is costly to shut down coal-fired and nuclear plants, producers are ready to pay to keep the plant running
- This phenomenon is particularly important in Germany due to the large-scale production from renewable sources (at zero marginal cost)



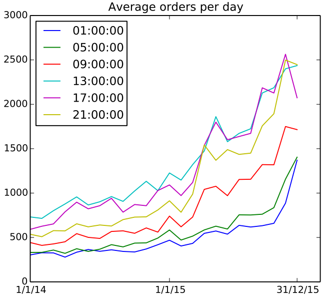

Day-ahead prices in Germany. Data source: `transparency.entsoe.eu`

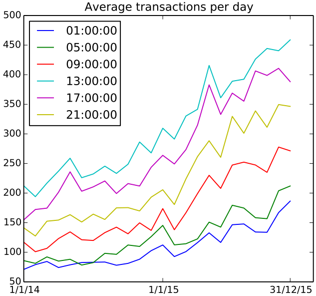
# The intraday market

The intraday market opens at 15h and allows continuous trading for each hour/quarter-hour of the next day, up to 30 minutes before delivery.

Every delivery hour of every day corresponds to a different product: the life time of a single product is from 9 to 32 hours.

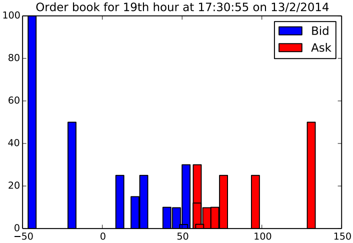
Market liquidity is improving but remains relatively low.



# The intraday market

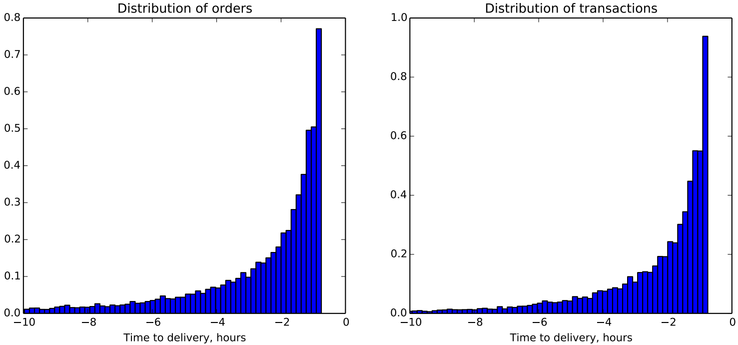
- Trading in intraday markets is order book-based, with a separate order book for each delivery hour.
- Each country has a separate intraday market, but the markets are coupled: if transmission capacity exists, traders in any market see the orders from other markets in their order books.




Intraday electricity markets are gradually acquiring the characteristics of other high-frequency markets with automated trading, optimal execution algorithms, presence of arbitrageurs, price manipulation attempts etc.

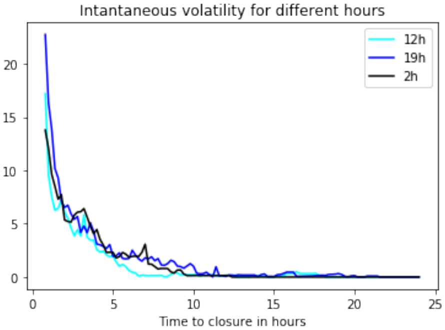
# Intraday market liquidity patterns

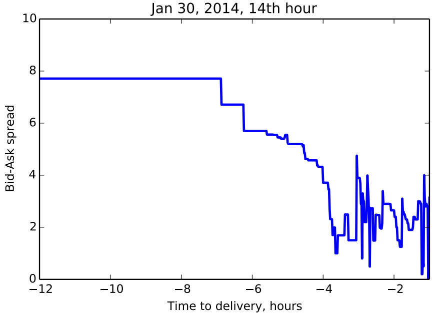
Liquidity only appears a few hours before delivery.




Distribution of orders/transactions as function of time to delivery for all contracts expiring in February 2015.

# Bid-ask spread and volatility

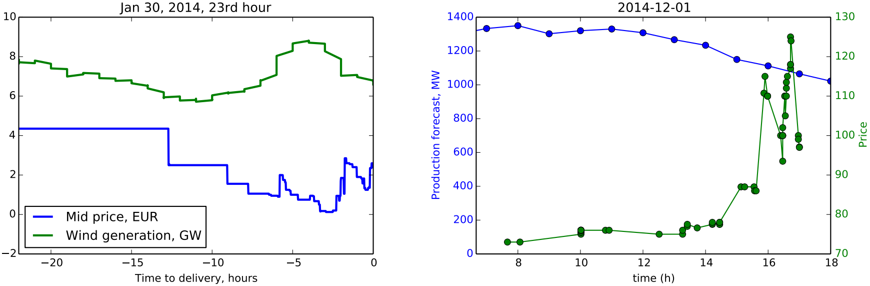



Left: (Normal) volatility averaged over all days of February 2014 (kernel estimator, source: L. Tinsi). Right: bid-ask spread evolution on a typical day.

# The intraday market

The development of intraday markets has been fueled by the expansion of intermittent renewables: prices are correlated with renewable production forecasts.




Left: dynamics of intraday price vs. wind production in Germany. Right: dynamics of intraday price for the 19th hour of 12 Dec 2014 vs. the forecast of wind power production in France. Data source: EDF and RTE