Integration of High Penetration of Solar and Wind Power in Power Systems: Experiences and Challenges
Lecture 10: Markets

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Future power system

System	Regulation	Operation	Planning	Investments
Aviation	technical function of aircraft and ground control	emergency plans, keeping schedules, economical flying	air routes, maintenance, pricing	new aircraft
Papermill	machine function	economical operation, varying raw material, optimal quality	submitting offers, pricing, maintenance	new machines
Office	the individual task of each co-worker	coordination, deadlines	submitting offers, estimating costs, education	new staff, new equipment, new premises
Power system	primary control, secondary control	coordination of power plants, economical operation	pricing, maintenance	new power plants, grid expansion, long-term contracts

seconds → years
technology → economy
security → uncertainty

Electricity as a commodity

A commodity is produced

A commodity is consumed

A commodity is traded

The quantity of a commodity is measured

What about electricity as a commodity?

Electricity as a commodity

Specific electricity characteristics:

Continuous flow (also valid for gas)

Instant generation and consumption

Not easily stored

Consumption variability

Non-traceability

Essential to the community

Breakdown possibility

Vertical Integrated vs. Deregulated Market

Vertical Integrated:

Electricity Price = Cost + Profit (regulated**)**

Deregulated Market:

Profit = Electricity Price (set by “Market”**) - Cost**

What is a “good” market? - 1

Static allocation efficiency (=are available resources used as efficient as possible? E.g. in deficit situations)

Management efficiency (= is the administrative organization efficient?)

Plant operation efficiency (= is each plant operated in an efficient and reliable manner?)

Production optimization (= correct merit order = is cheapest possible operation, including externalities, applied?)

What is a “good” market? - 2

Transaction cost efficiency (= the amount of transactions costs, as measurements, spread of information and contracts)

Dynamic investment efficiency (= are the correct investments done at the right time?)

Risk management efficiency (= are risks and uncertainties handled in an efficient way?)

System reliability (= is it on a correct level?)

Electricity Markets

- An electricity market is an arrangement to transfer electric energy from producers to consumers.

- Transmission of electric energy requires a special infrastructure: a power system.

Organisation of the Power System

- **Transmission.** National or international grid—long distance, high wattage
- **Sub-transmission.**

  Regional grid
- **Distribution.** Connects the majority of the consumers

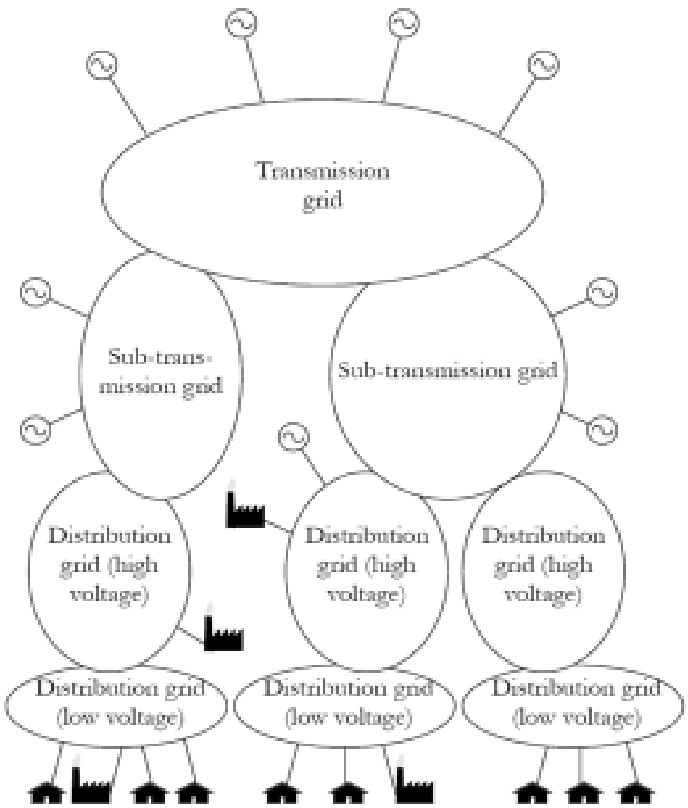
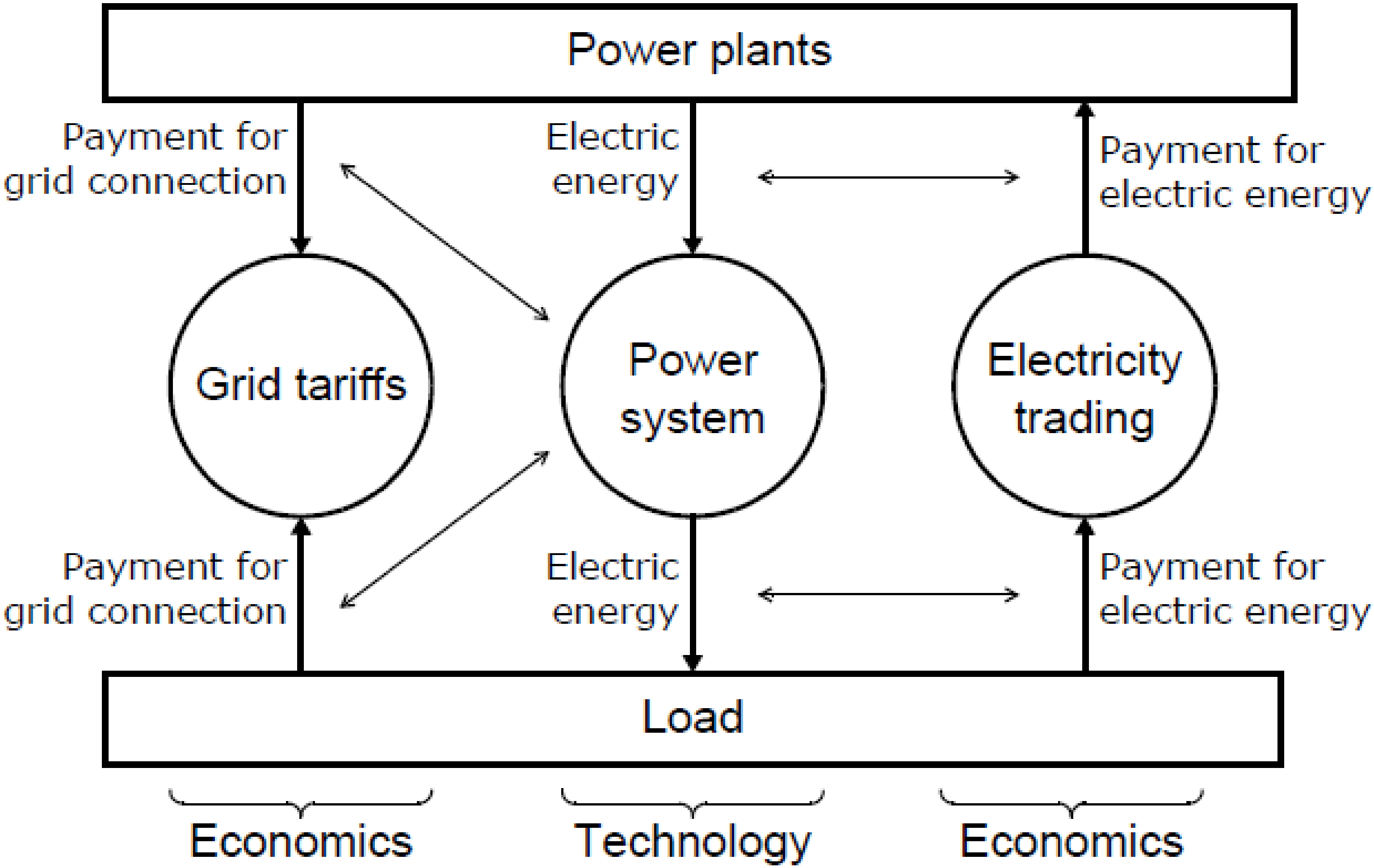


Figure 1.1 The structure of a larger power system.

The Electricity Market



Functions in an Electricity Market

- Producers
- Consumers
- Retailers and traders
- Grid owners
- System operator
- Balance responsible players

Notice that the same player may have several functions in the electricity market!

Markets for
Power system operation

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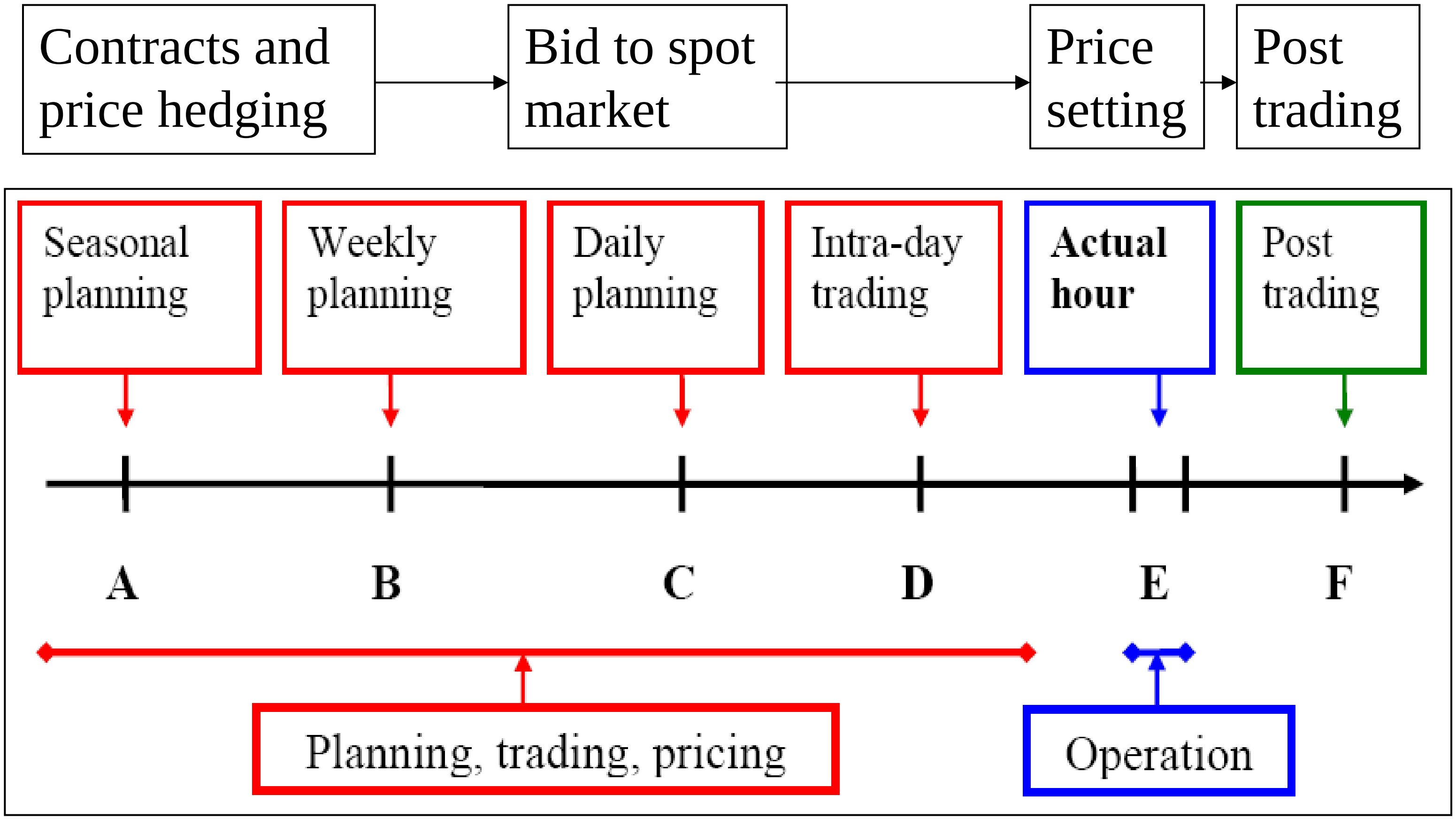
Trading/planning overview



Power trading overview - 1

“Physical” trading:

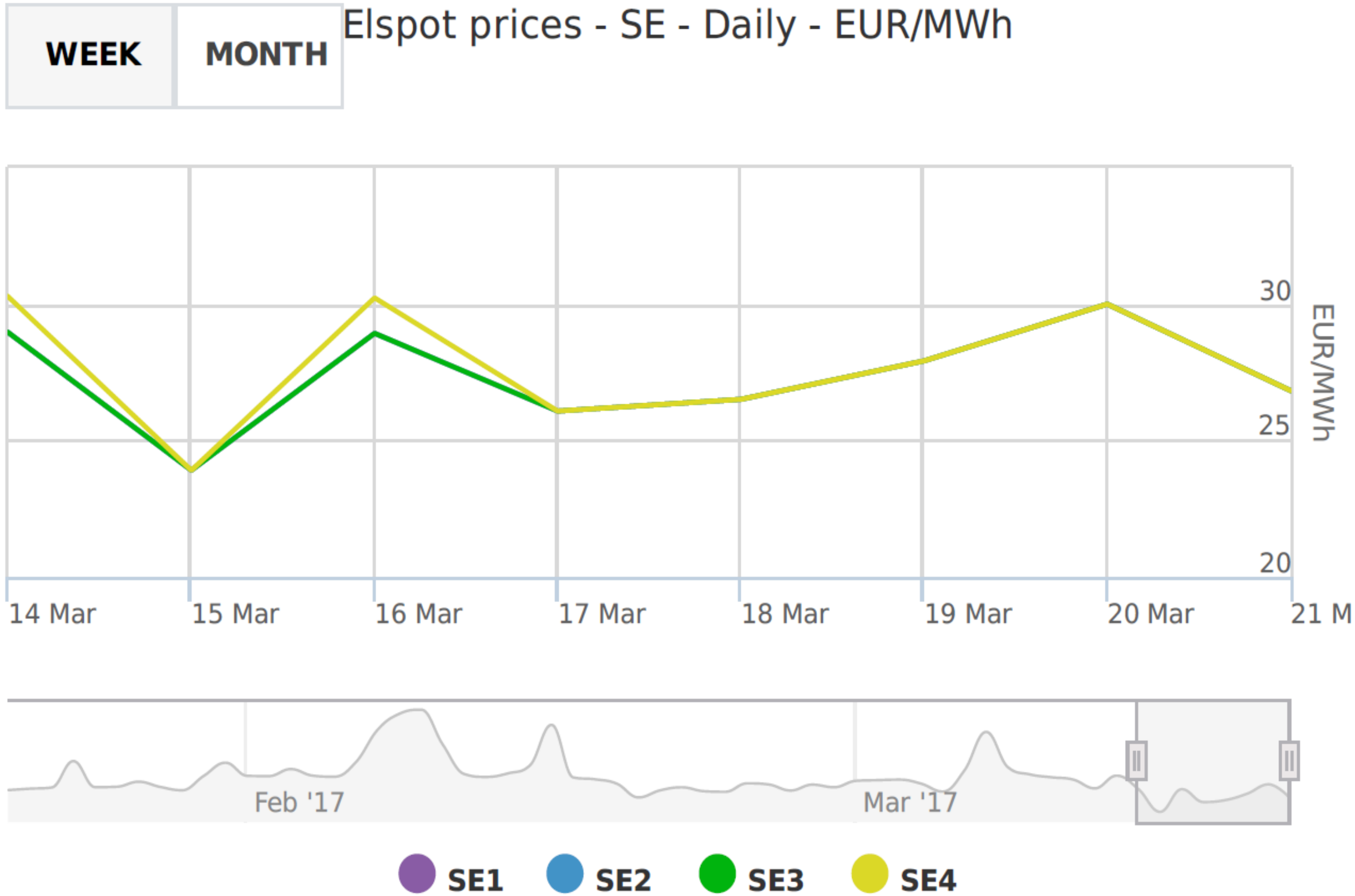
Ahead market. This means that you sell power for a certain period (e.g. a certain hour) before the actual period. Based on a forecast.

Real-time balancing market. The “system responsible”, keeps the physical balance between all producers and all consumers.

Post trading. Imbalances caused by imperfect forecasts are traded between surplus and deficit players.

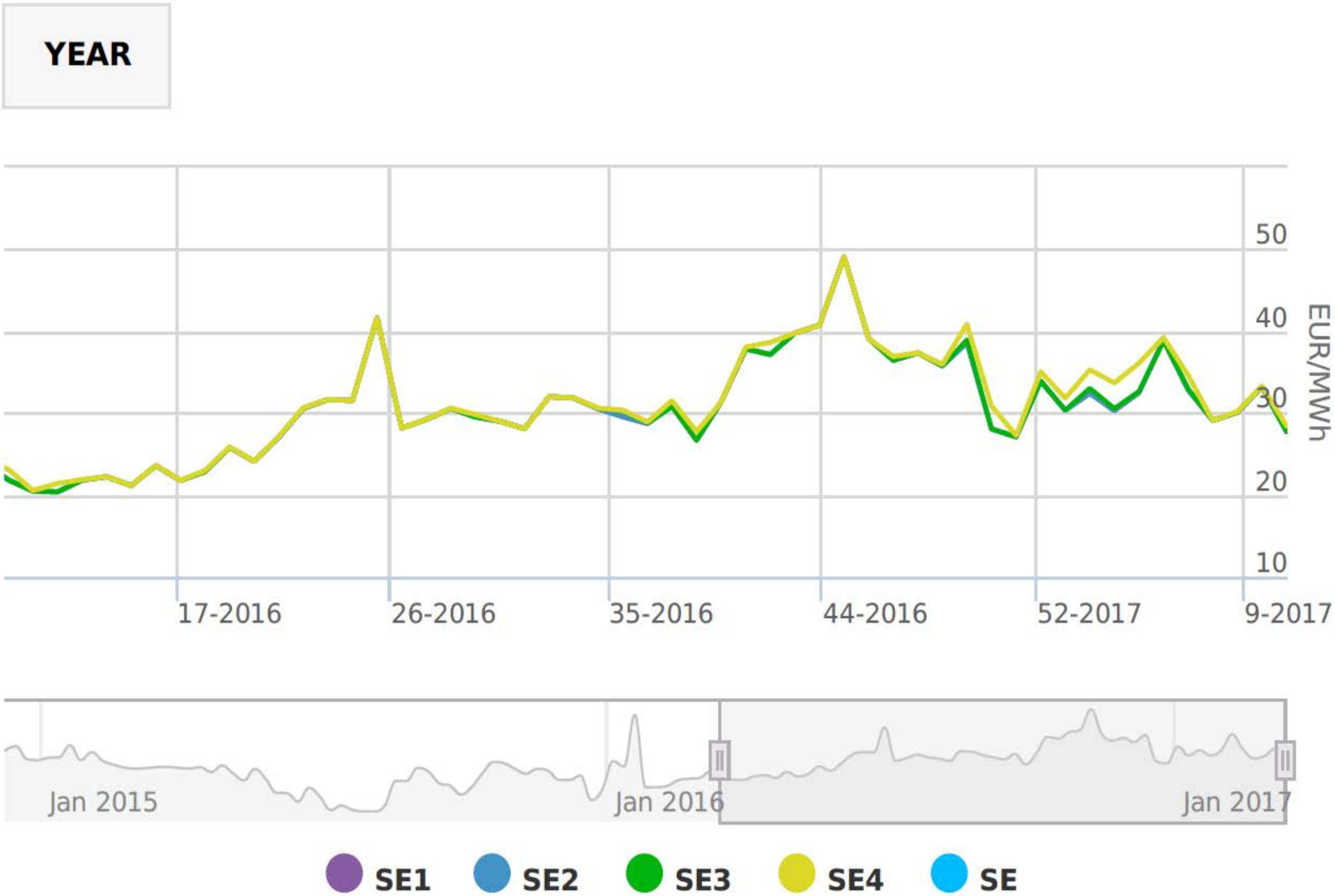
Nordpool prices, area Sweden, March 14 – 21, 2017

www.nordpoolspot.com



Nordpool prices, area Sweden, March 2016 – March 2017

www.nordpoolspot.com



Nordpool prices and price areas March 21, 2017

System price: 28,76 Eur/MWh

November 15, 2017

System price: 31,63 Eur/MWh

Ahead market (spot market) - 1

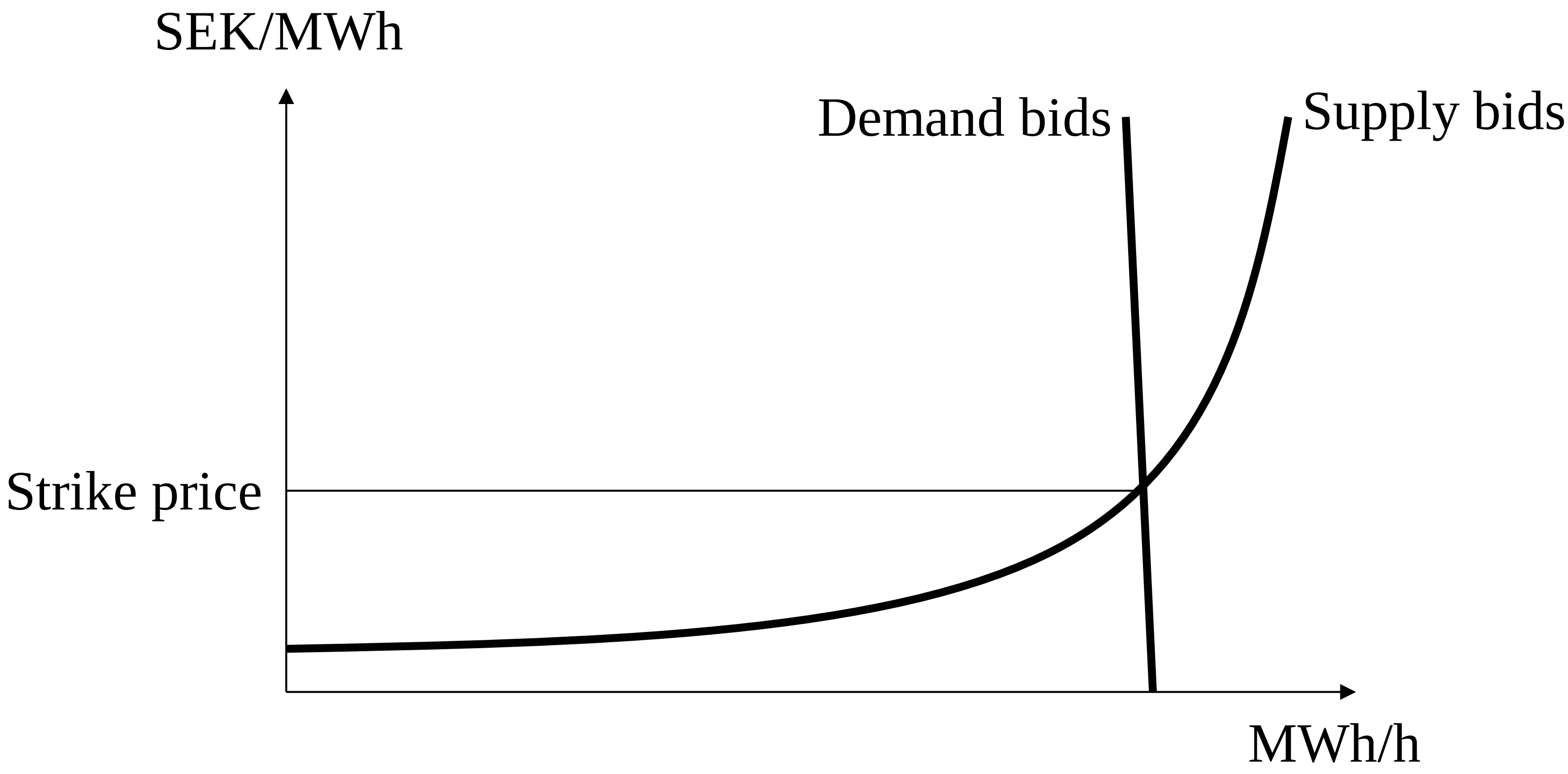
Nordic market:

Bids. Purchase (and sell) bids (MWh/h, price in Euro/MWh) to the spot market for a certain hour has to be delivered not later than 12.00 the day before.

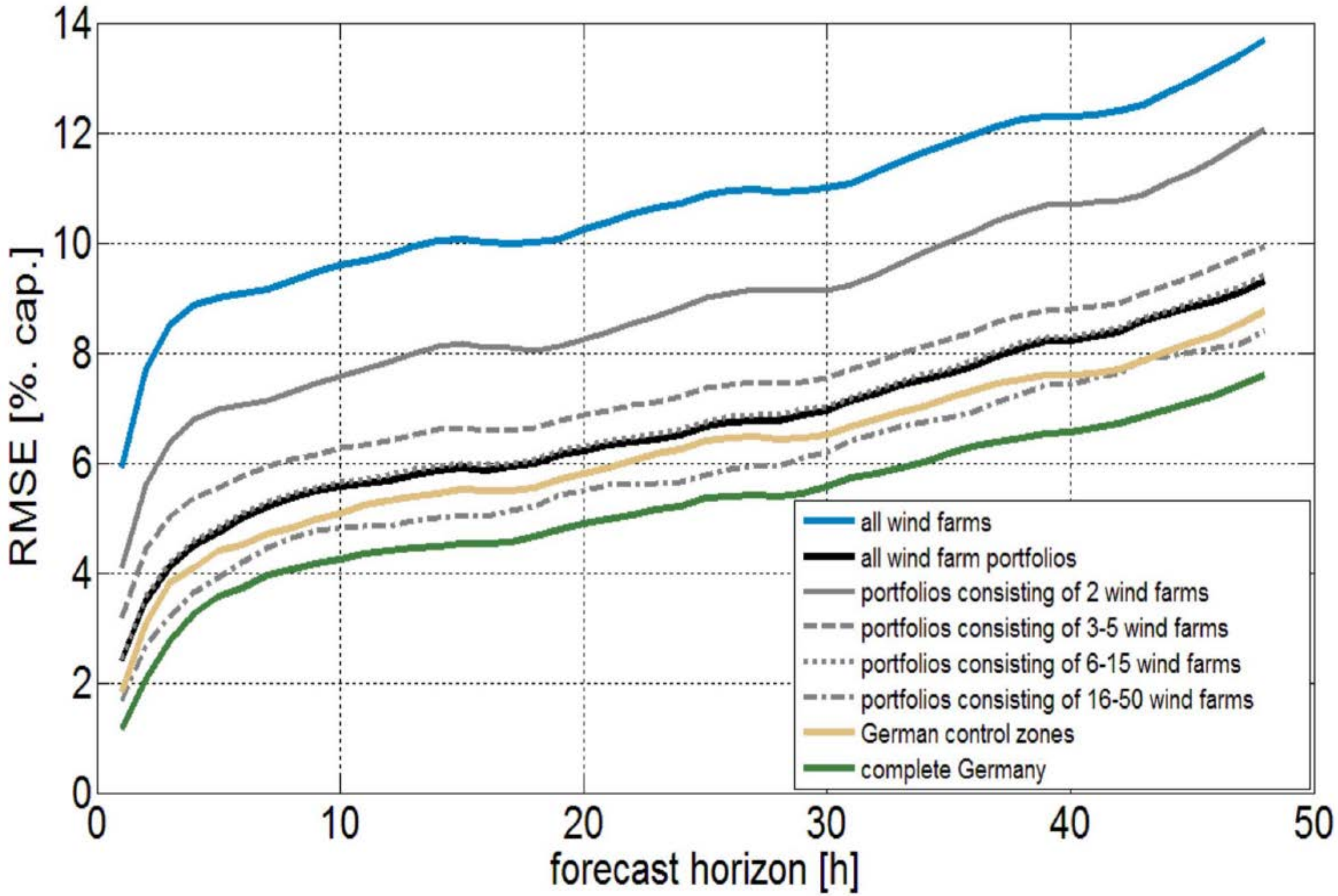
Price setting. The price is set by the *strike price*, so you have to bid lower than this price to get your bid. All Nordic bids together results in the *system price*

Price areas. When there are congestions in the Nordic system then the price becomes different in different areas. Spot market is based on *area prices*

Ahead market (spot market) - 2



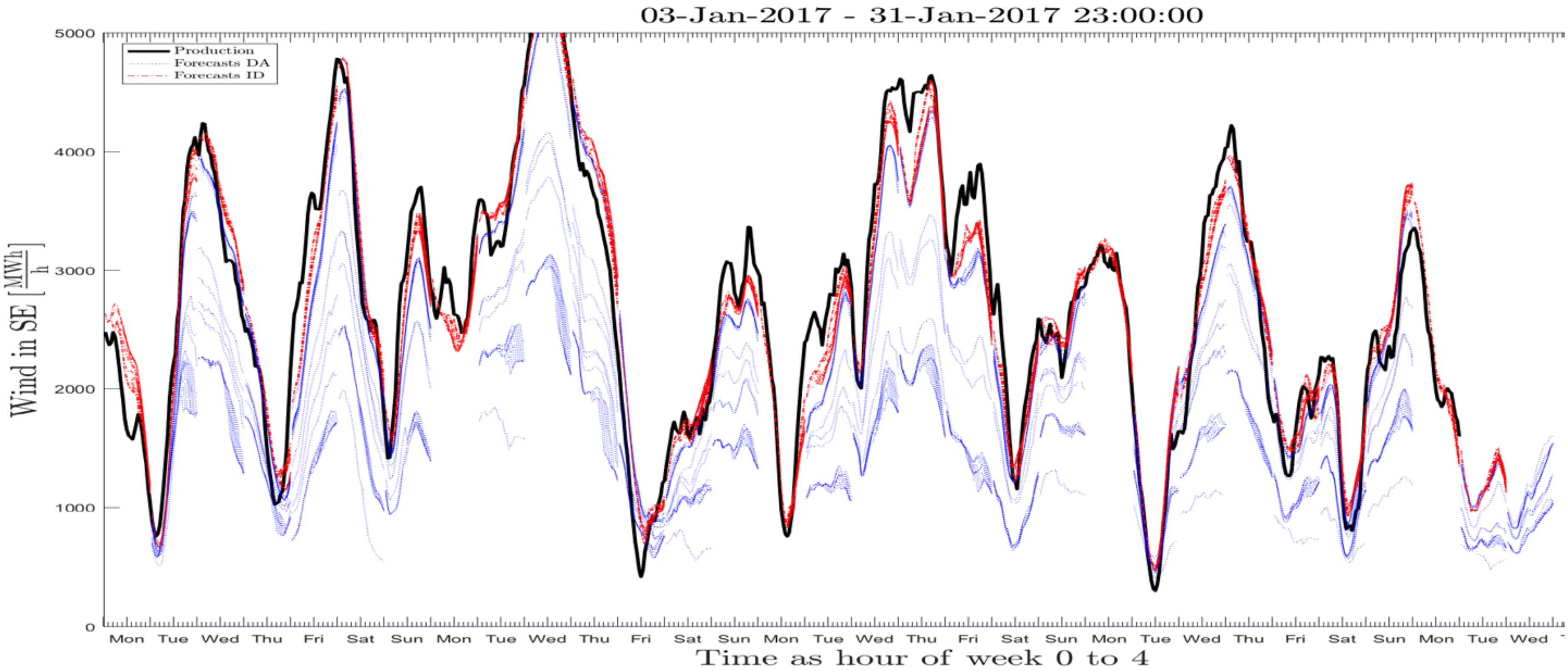
Wind power forecasts in Germany



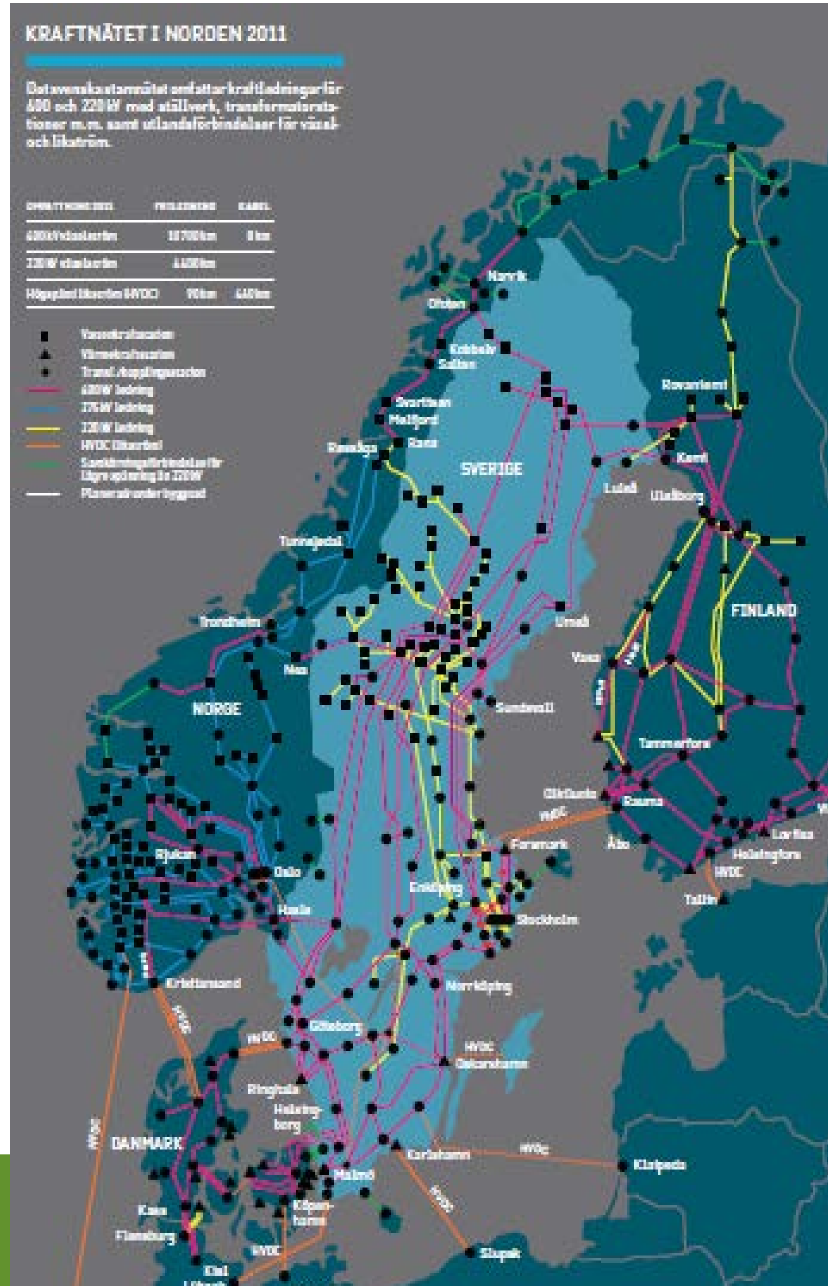
Jan Dobschinski, *How good is my forecast? Comparability of wind power forecast errors*, 13th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Power Plants, Berlin, Germany; 11/2014 (2014)

Wind power forecasts in Sweden

Black = "**real**". Updated every hour



The Nordic transmission grid



Sweden is divided into four price areas

Real time balancing market

Nordic market:

Bids. *Upward* and *downward regulation* bids (MW, price in Euro/MWh) for a certain hour has to be delivered not later than 10 minutes before each hour. The cheapest bids are called by the *system operator* during the hour to keep system physical balance.

Price setting. The *price* for upward and downward regulation is set by the price of the last accepted bid. The price can be different for different areas.

Price for imbalances - 1

Nordic market:

Imbalance calculation: All ahead bids are registered and the consumption of all consumers is measured (or estimated) on hourly basis. The difference is denoted *imbalance*. *Positive imbalance* means that you have bought more than your consumers consumed. The opposite is *negative imbalance.*

Price setting. The *imbalance price* is set by the prices on the *regulating market* and on the *spot market* for the actual hour.

Price for imbalances - 2

Nordic market concerning Sweden:

The imbalance prices are different depending on if your imbalance is in the same direction as total system imbalance or not.

	Up-regulation hour	Down-regulation hour
You did not produce as much wind power as you have sold.	*P* = *up-regulation price* *P* > *spot price*	*P* = *spot price*
You produced more wind power than you have sold.	*P* = *spot price*	*P* = *down-regulation price* *P* < *spot price*

Markets for
Power system design

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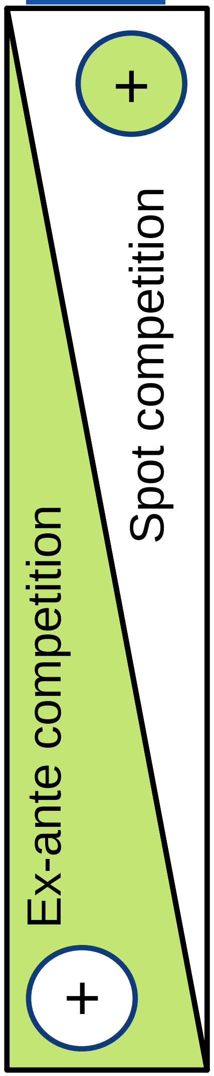
Aim of future power system:

- **Competitive prices**
- **Sustainable**
- **Reliable**
  - Efficient regulation
  - Efficient operation
  - Efficient planning

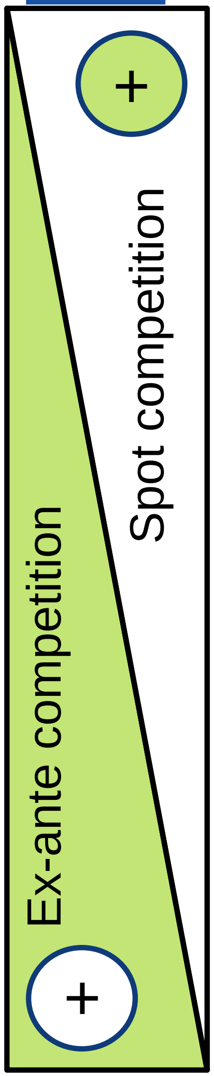
Set-up to achieve ”competition”

Four different market designs studied within Eurelectric



Market	Renewables	Capacity
1) Energy-only market	• No support for mature technology	• Energy-only market for existing and new capacity
2) Decentraliz-ed certificate	• Certificates that retailers have to purchase	• Capacity certificate that the retailers have to purchase
3) Central auctions	• Central auctions of renewables with additionsl income from the market	• Central capacity auctions with additional income from the market
4) Full payment auctions	• Central auctions of full payment (Some CfD models) • No market price risk	• Central auctions with full payment (Some CfD models) • No market price risk

Energy- only market

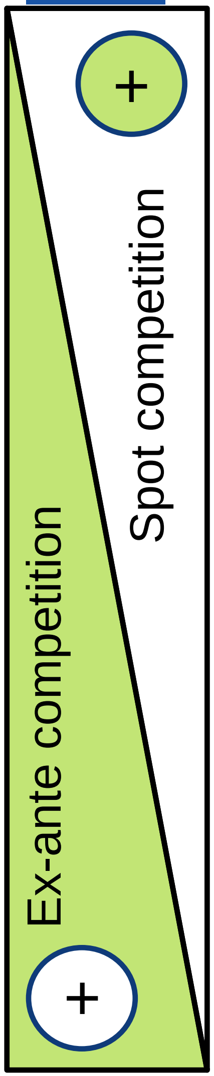


Market	Renewables	Capacity
1) Energy-only market	• No support for mature technology	• Energy-only market for existing and new capacity

Many countries have reduced their subsidies, e.g. Spain, Portugal, Italy and Bulgaria

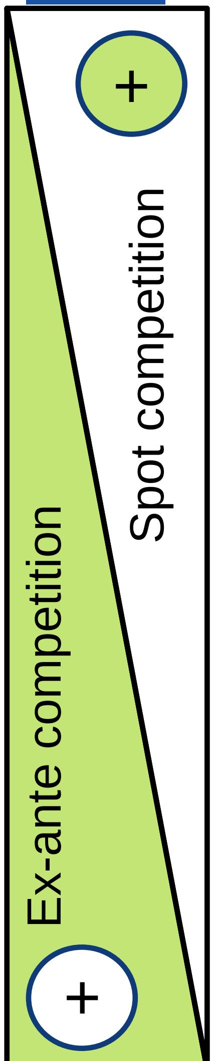
Does not exist in any EU country in a ”pure” form, but in combination with a strategic reserve

Decentalized certificates



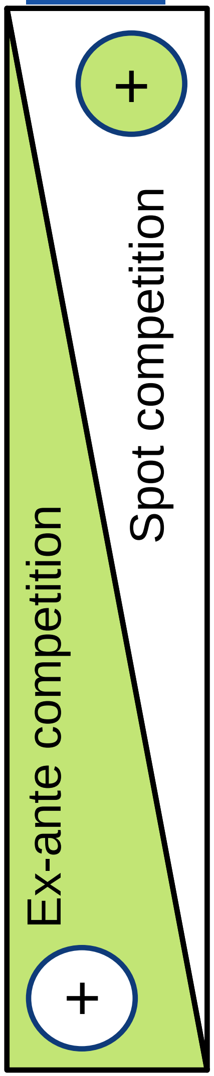
Market	Renewables	Capacity
2) Decentraliz-ed certificate	• Certificates that retailers have to purchase	• Capacity certificate that the retailers have to purchase
	Exists in Sweden, Norway, Rumania, Poland, Belgium and Great Britain	**In France**

Central auctions



Market	Renewables	Capacity
	In Spain	**In Great Britain and Italy**
3) Central auctions	• Central auctions of renewables with additionsl income from the market	• Central capacity auctions with additional income from the market

Full payment auctions



Market	Renewables	Capacity
	Exists in Great Britain and Germany	**In large parts of South America and Asia**
4) Full payment auctions	• Central auctions of full payment (Some CfD models) • No market price risk	• Central auctions with full payment (Some CfD models) • No market price risk

Future power system

System	Regulation	Operation	Planning	Investments
Aviation	technical function of aircraft and ground control	emergency plans, keeping schedules, economical flying	air routes, maintenance, pricing	new aircraft
Papermill	machine function	economical opera-tion, varying raw material, optimal quality	submitting offers, pricing, maintenance	new machines
Office	the individual task of each co-worker	coordination, deadlines	submitting offers, estimating costs, education	new staff, new equipment, new premises
Power system	primary control, secondary control	coordination of power plants, eco-nomical operation	pricing, maintenance	new power plants, grid expansion, long-term contracts

seconds → years

technology → economy

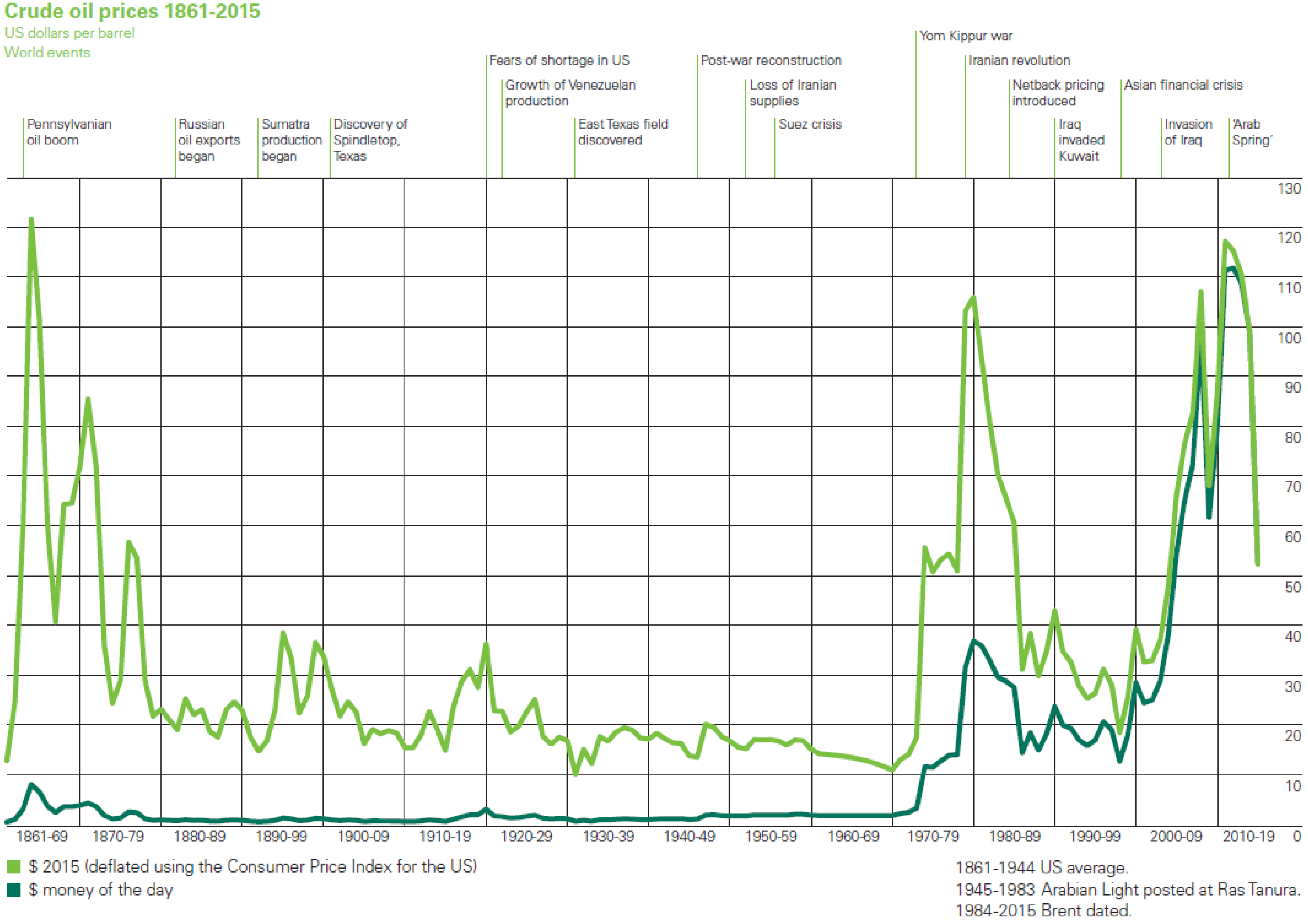
security → uncertainty

Future power system <u>uncertainties</u> include:

1) Uncertain **fuel prices**
2) Uncertain **interest rates**
3) Uncertain **investment costs**
4) Uncertain **construction time**
5) Uncertain amount of **demand**
6) Uncertain impact from climate change (amount of **yearly energy from solar, wind, hydro, waves**)
7) Uncertain **life length of current power plants**
8) Uncertain **policy** concerning
   - **Reliability**
   - **Sustainability**
   - **Market / taxes /subsidies**

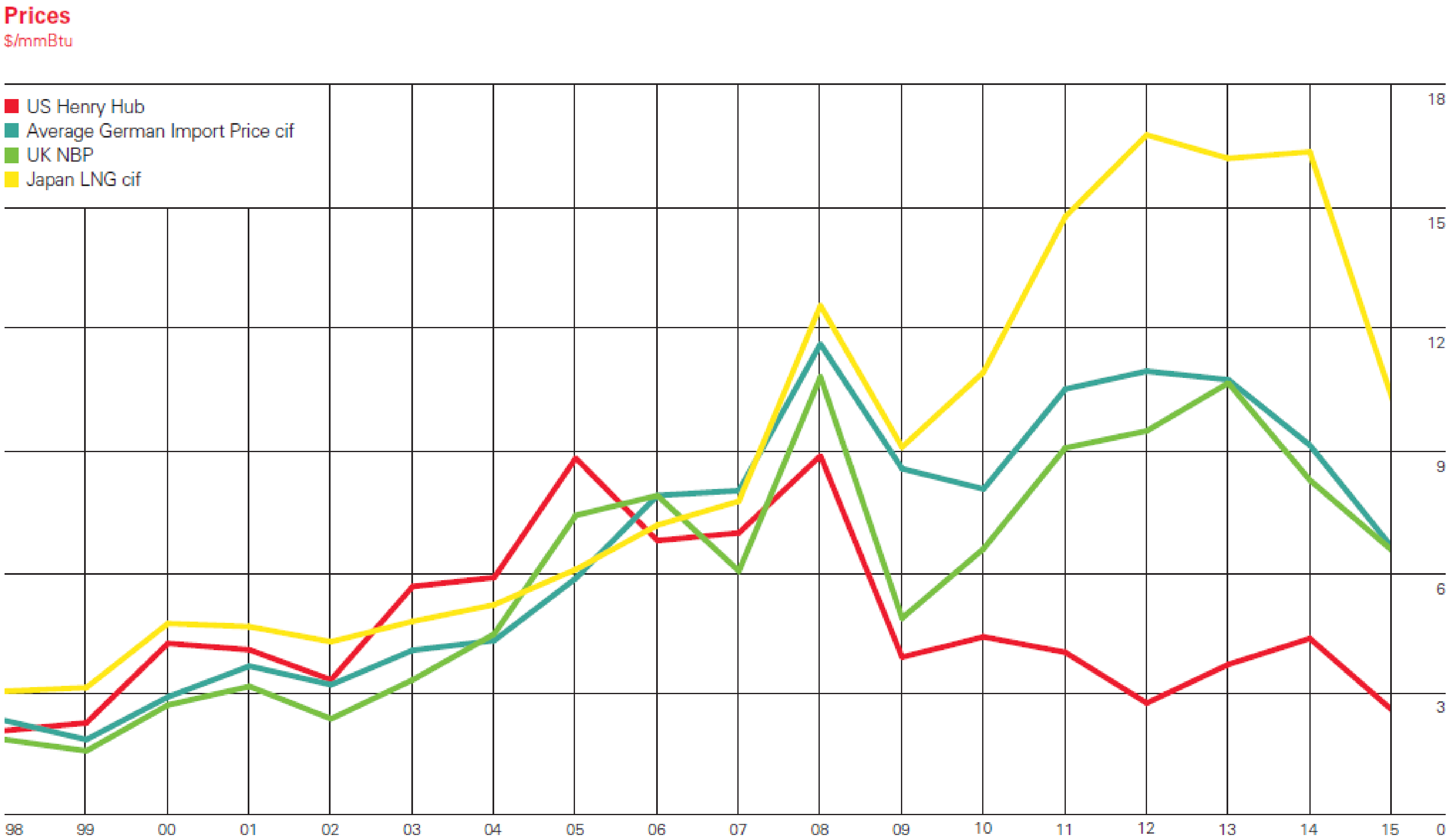
1) Uncertain fuel prices

Development of oil prices



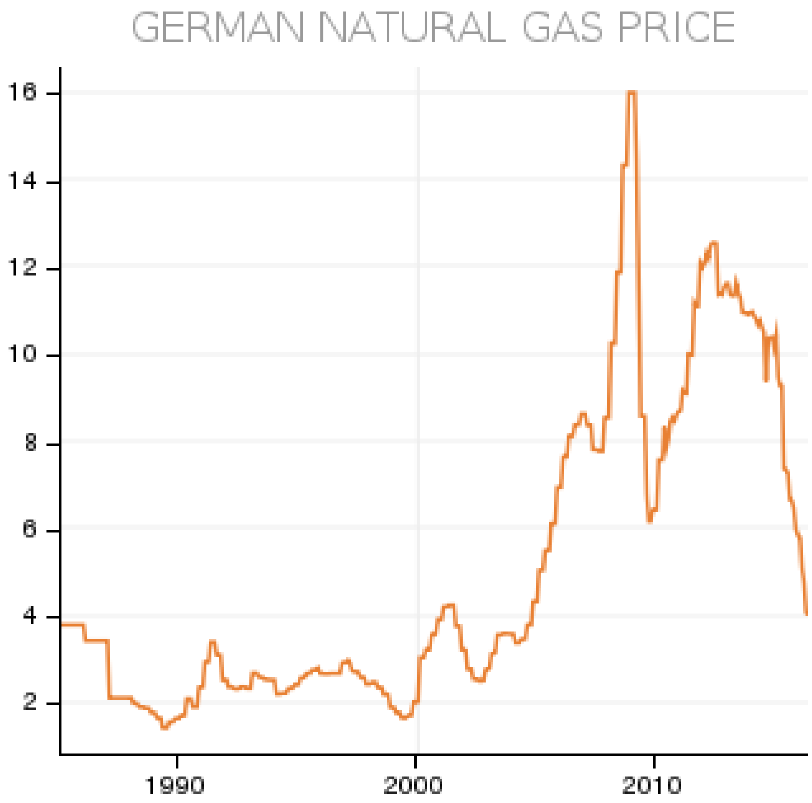
http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

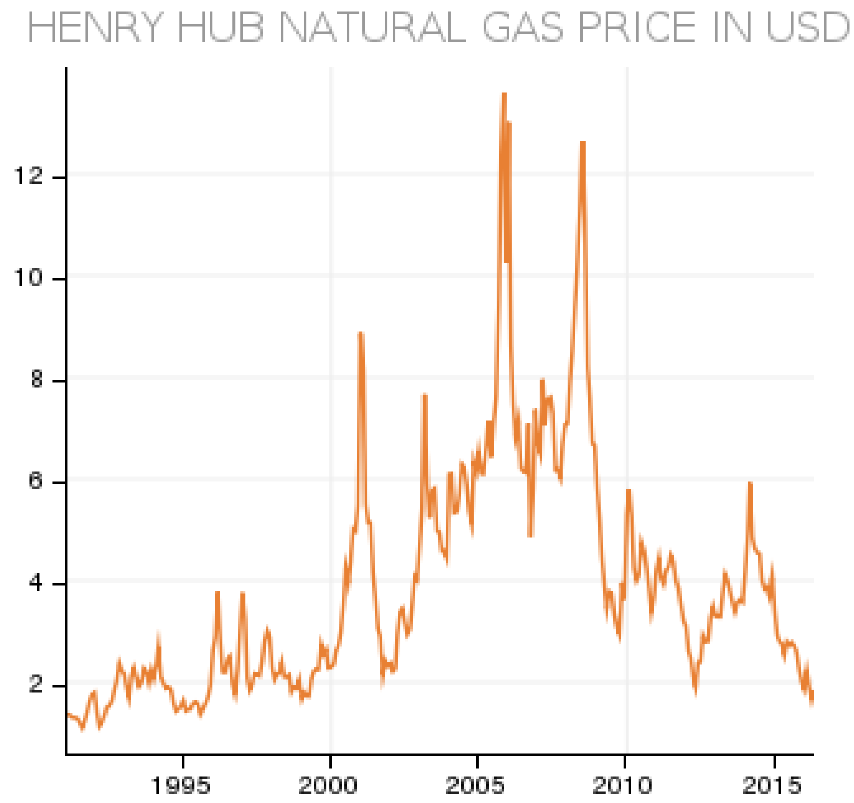
Development of gas prices



http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Development of gas prices (up to May 2016)



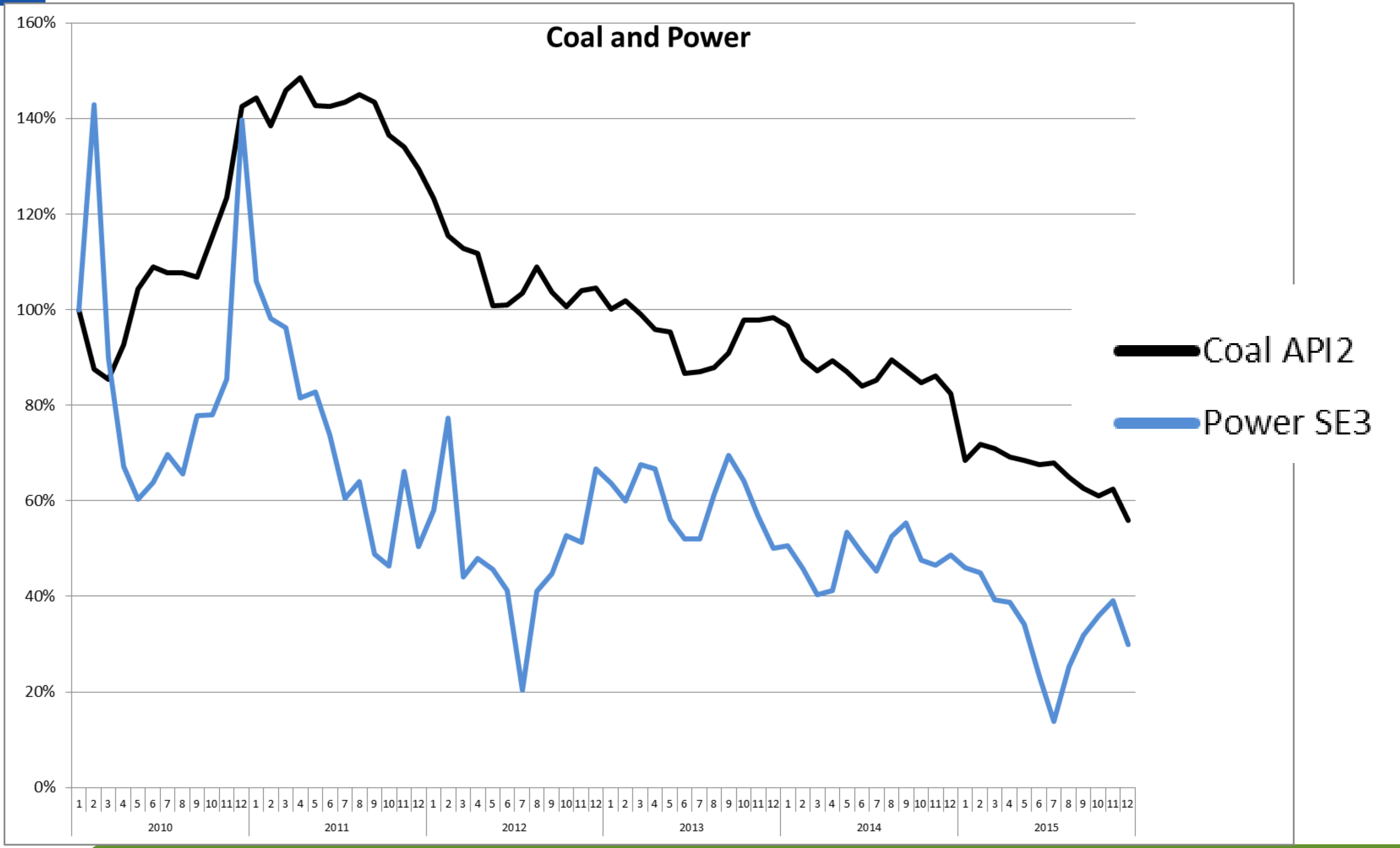


https://www.quandl.com/collections/markets/natural-gas

Development of coal prices

http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Price development for coal and Swedish Electricity Price.



|2010 | 2011 | 2012 | 2013 | 2014 | 2015 |

Uncertainty: Risk example:

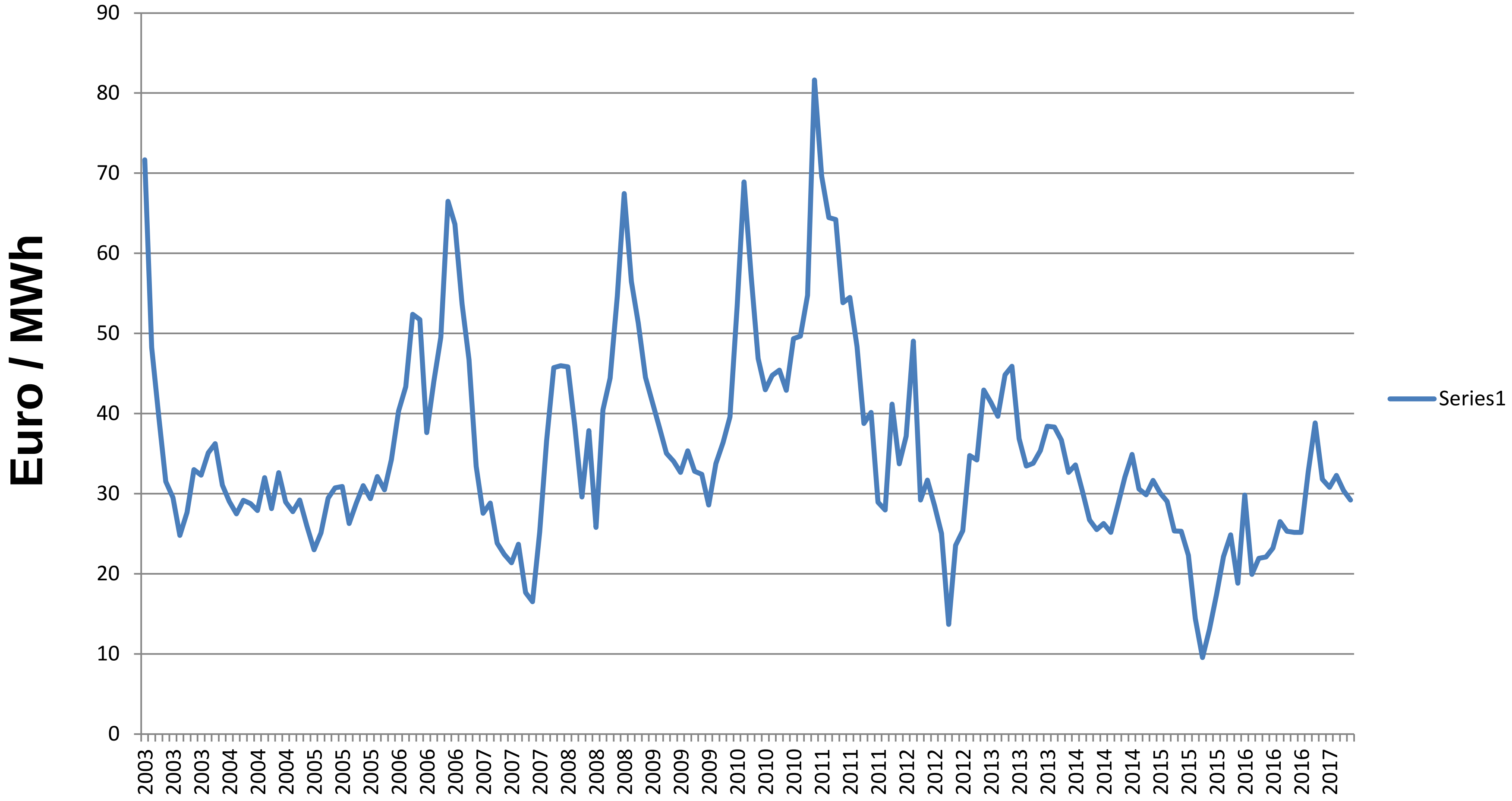
In 1965, a Frenchman named André-François Raffray thought that he had found a great deal: “He would pay a 90-year-old woman $500 a month until she died, then move into her grand apartment in a town Vincent van Gogh one roamed. But [on 25 December 1995] Raffray died at age 77, having forked over 184,000$ for an apartment he never got to live in.

On the same day, Jeanne Clement, now the world’s oldest person at 120, dined on foi gras, duch thighs, cheese, and chocolate cake at her nursing home near the sought-after apartment” (Trenton Times 1995)

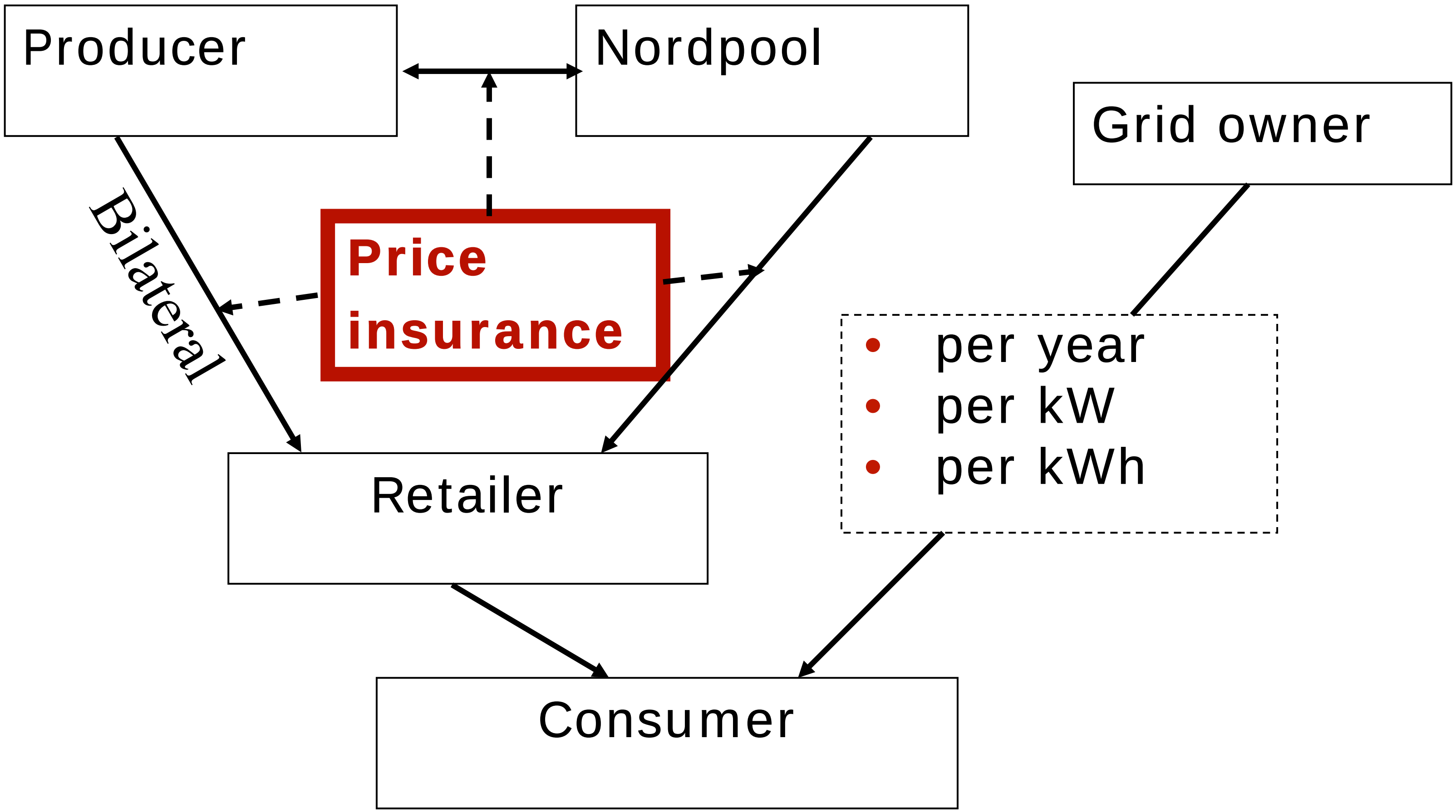
Risks in electricity markets

- Fuel costs
- Currencies
- Power prices
  - Spot market prices
  - Regulating market prices
  - Imbalance prices
- Area price differences
- Consumption level
- Generator availability
- Emission rights prices
- Green certificate prices

Nordpool system spot prices: 2003-2017



Trading in Nordpool



Risk hedging

A common way of *handling risks* problem is to *hedge against the risks* with ***financial derivatives.***

A ***derivative*** is any financial instrument (such as futures or option contracts) and is so called because it derives its value from a related or ***underlying asset***.

In electricity markets it is common that the underlying asset is the electricity spot market price. But there are also financial derivatives available on e.g. crude oil, interest rates, currencies etc.

Financial contracts = derivative instruments

The basic types are denoted ***plain vanilla***.

They are

– ***forwards,***

– ***futures,***

– ***options***

More “exotic” derivatives can be formed as combinations of vanilla derivatives.

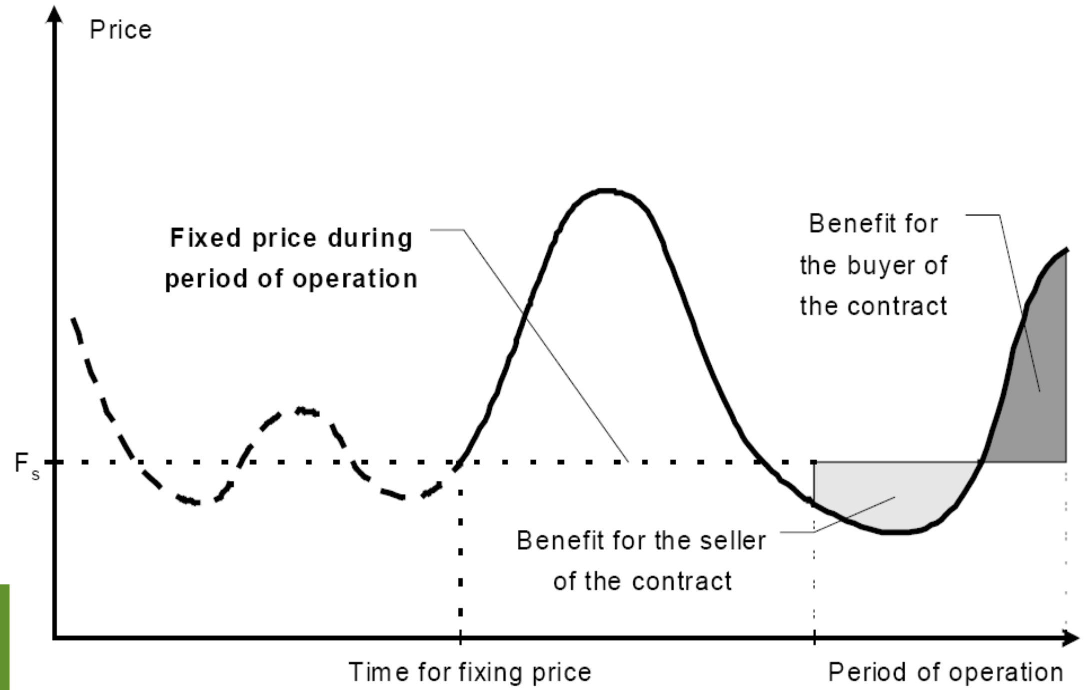
Examples below will use **electricity price** as the **underlying asset**.

Forward contract - 1

- A forward contract is an agreement between two parties to buy or sell electric power at a certain future time for a specific price.
- The forward price can be different for different periods in the future.
- There are, for example, one-month or three-month forwards.

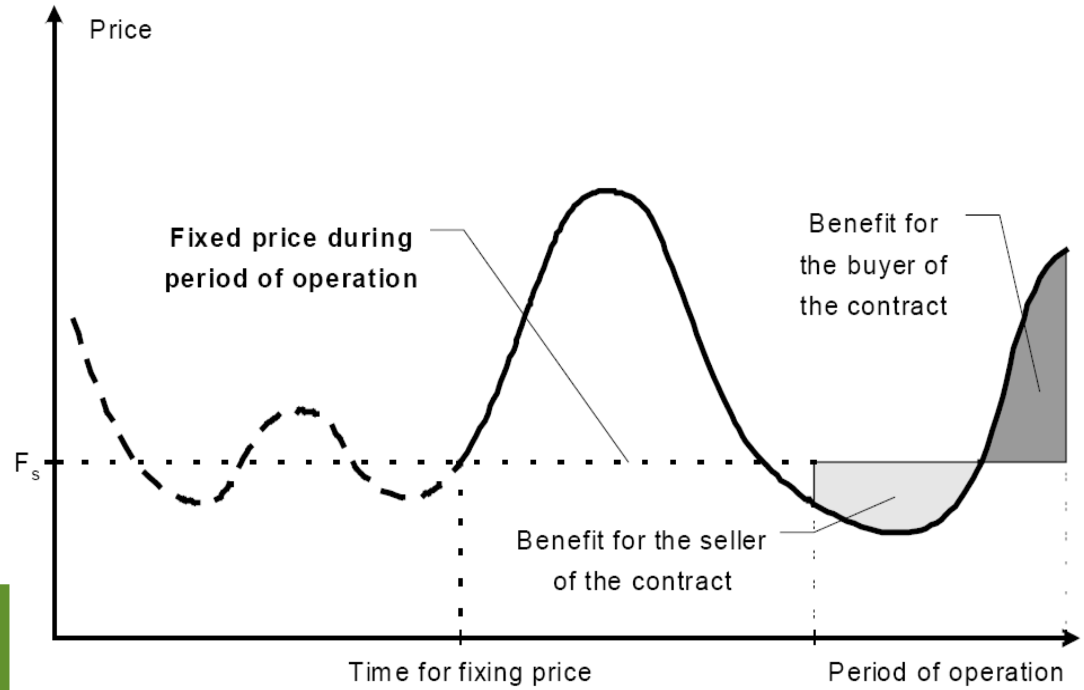
Forward contract - 2

- A **forward contract** means that the company writes a contract with e.g. a financial actor. The contract includes a defined forward price, Fs, for the sold power.
- The forward contract means that the power selling company will get a known price = Fs, for the sold power, while the financial actor will take the risk since the price in reality is not known.



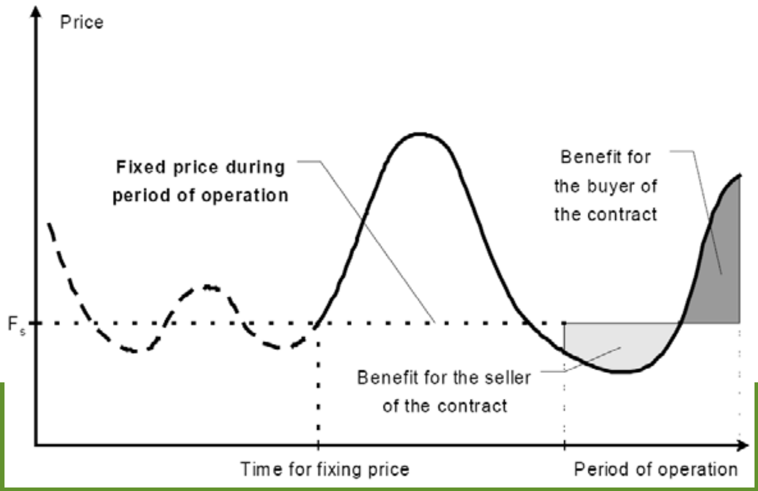
Forward contract - 3

- If the market price becomes higher than Fs, then the financial actor makes a profit.
- But if the market price becomes lower than Fs, then the selling company made a profit on the contract, since the contract means that power was sold to the price Fs.



Forward contract - 4

- The price of the forward contract will approach the estimated mean price for the considered period of the contract.
- The expected profit of the contract must be positive for both parties, which can be the case due to the following:
  - The view of the mean future price is different for the two parties.
  - The possibility or willingness of taking risks is different for the two parties.
  - The two actors have opposite matching needs of hedging.
- It can be noted that an estimation of future price levels, or to be more specific, the markets view of future prices, is to study the price levels offered in forward contracts.



Future contract - 1

- A futures contract has the same structure as a forward contract. The aim of the contract is to obtain a constant price for sold or purchased power in the future.
- The risk with the uncertain price is in reality moved from the power trader to the hedger.
- The difference between a forward and a futures contract is that the **futures are standardized** and **traded on exchanges**. Being traded at an exchange they provide a guarantee of contract performance, as the exchange is the counterpart.
- The exchange specifies certain **standardized features** of the contract: the product price, the delivery quantity and the location. As the product is standardized and traded on an exchange it will **attract more liquidity**.
- A higher liquidity should lead to **more accurate prices** due to the shorter spread between best demand prices and best offer prices, and the market is generally easier to analyze due to the higher level of transparency.

Summary about futures and forwards

The result is that futures and forwards provides estimations on different actors view on the prices in the future.

One example of exchanges is Nasdaq

http://www.nasdaqomx.com/transactions/markets/commodities

There one can find future price estimations of

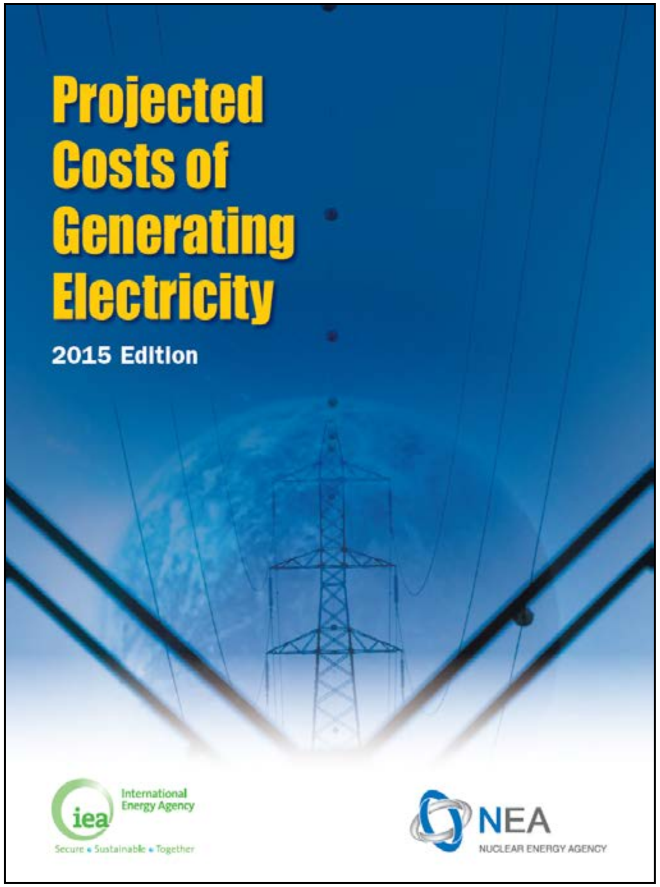
Electricity, Natural gas, Certificates, CO2 Allowances, Oil, Seafood (!)

There are many other estimations: Google on “oil markets futures” etc to get estimations.

2) Uncertain interest rates

Interest rates estimations: IEA

https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf



Page 137:

” Part I uses three costs of capital: **3%, 7% and 10%.** This differs from previous editions; see Chapter 5 comparing the assumptions and results of the earlier editions. In particular, the 2010 update used two costs of capital, **5% and 10%,** under the assumption that the cost of capital for a particular electricity provider would be bracketed by these values.

However, recently, the cost of some government bonds (debt) has been hovering around 0% (currently at 0.02% in the United States on 90-day bonds; see US Department of the Treasury, 2015). In fact, in some countries, the rate has dropped below zero on short-term borrowing. The discount factor is equal to the inverse of one plus the discount rate: 1/[1+r]; so the discount rate has dropped below one when the cost of capital drops below zero. This section first defines the cost of capital, and then examines the components in the cost of capital.

Interest rate comments: Swedish Energy Inspectorate (in Swedish):

http://ei.se/Documents/Publikationer/rapporter_och_pm/Rapporter%202016/Ei_R2016_14.pdf


Energimarknadsinspektionen
Swedish Energy Markets Inspectorate

Ei R2016:14

Ökad andel variabel elproduktion

Effekter på priser och producenters investeringsincitament

p70: Annuity method was used to calculate capital cost and the real cost of interest was assumed to **4%** during the construction period and **6%** during the depreciation period.

p76: “Different actors use different interest rates”:

- Communities: **4-5%**
- Industries: **4-8%**
- Institutional investors: **5-7%**
- Traditional power companies: **6-8%**
- Independent power producers: **7-9%**

3) Uncertain investment costs

Cost Estimations:
Power from new and future plants 2014
Swedish with English summary

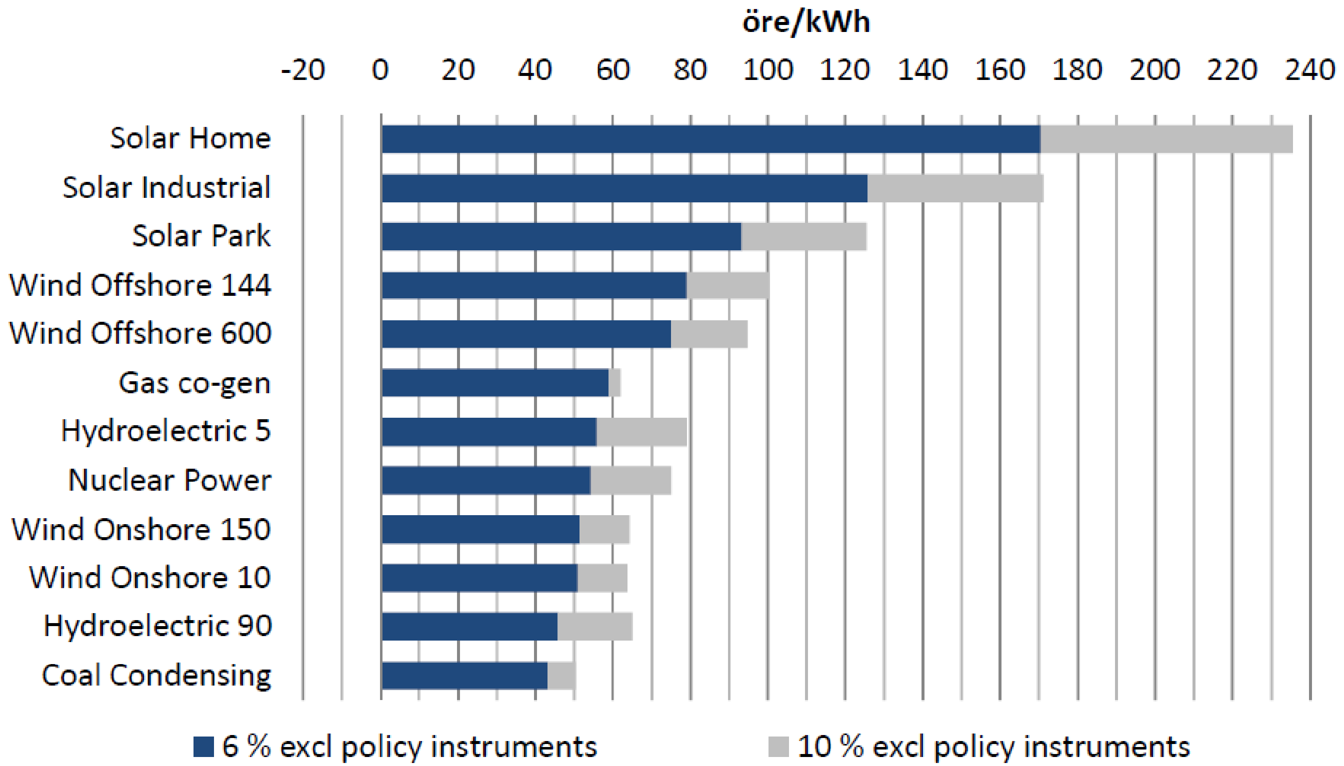


Figure II. The cost of electricity generation for commercial technologies that only generate electricity, excluding policy instruments with 6 and 10% cost of capital respectively.

http://www.elforsk.se/Rapporter/?rid=14_40_

Cost estimations: IEA

https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

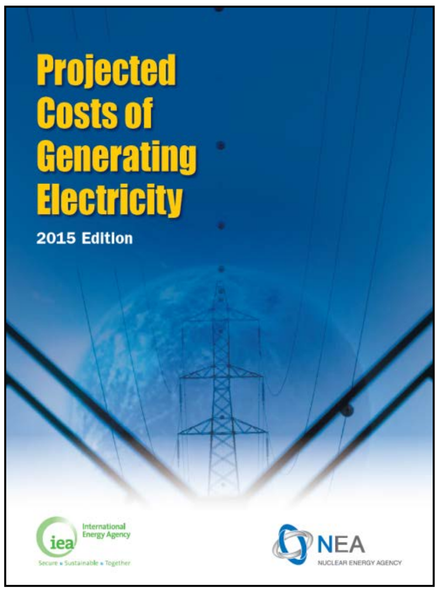
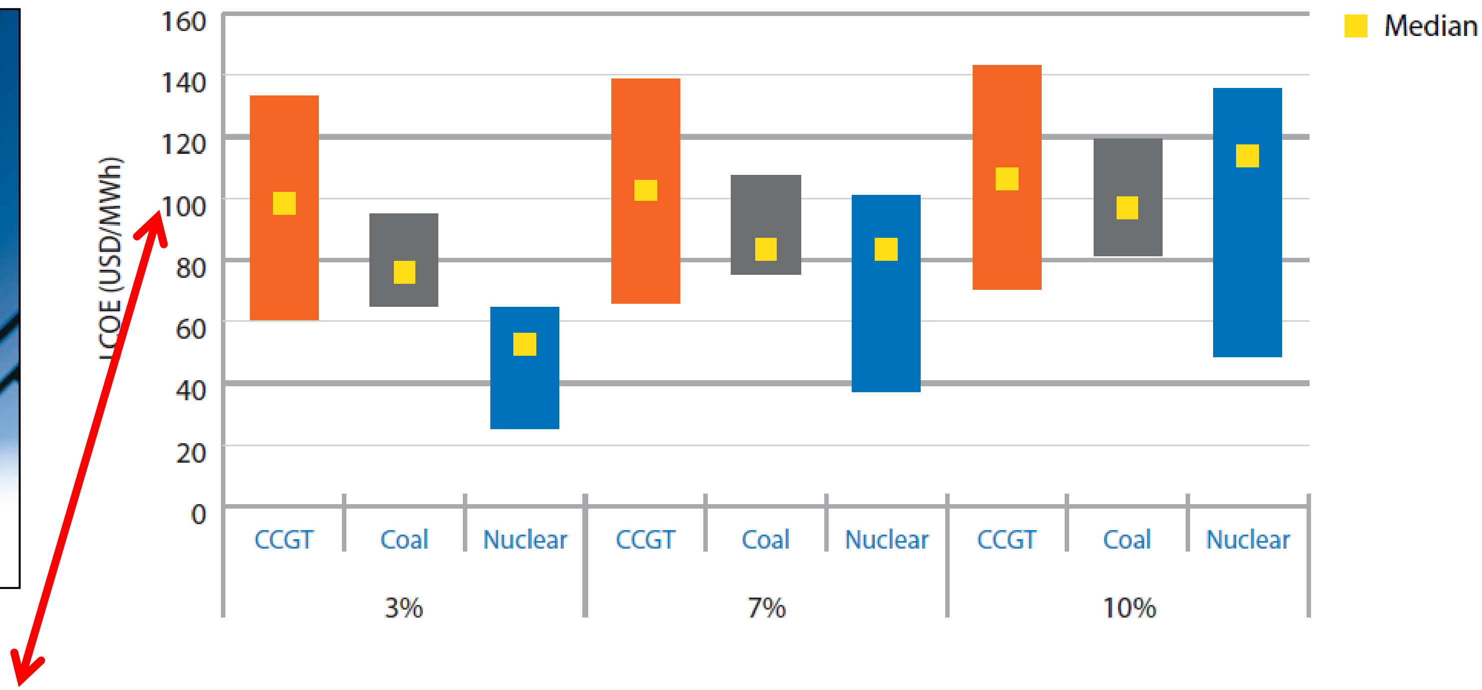


Figure ES.1: LCOE ranges for baseload technologies (at each discount rate)



100 USD/MWh + [1 USD= 8.8 SEK] ➔ 88 öre/kWh.

Cost estimations: IEA

https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf

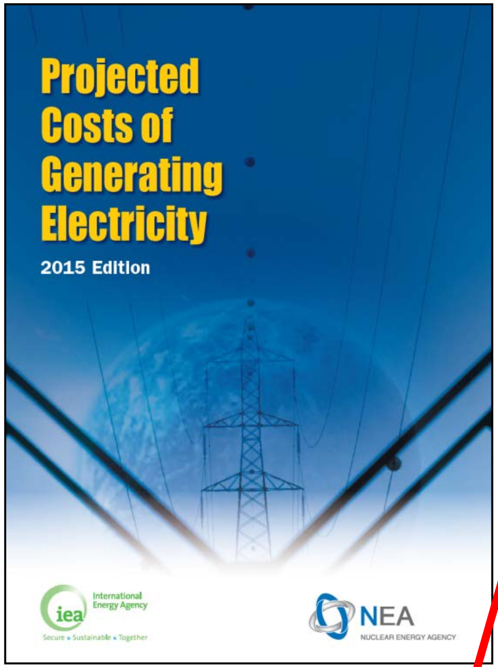
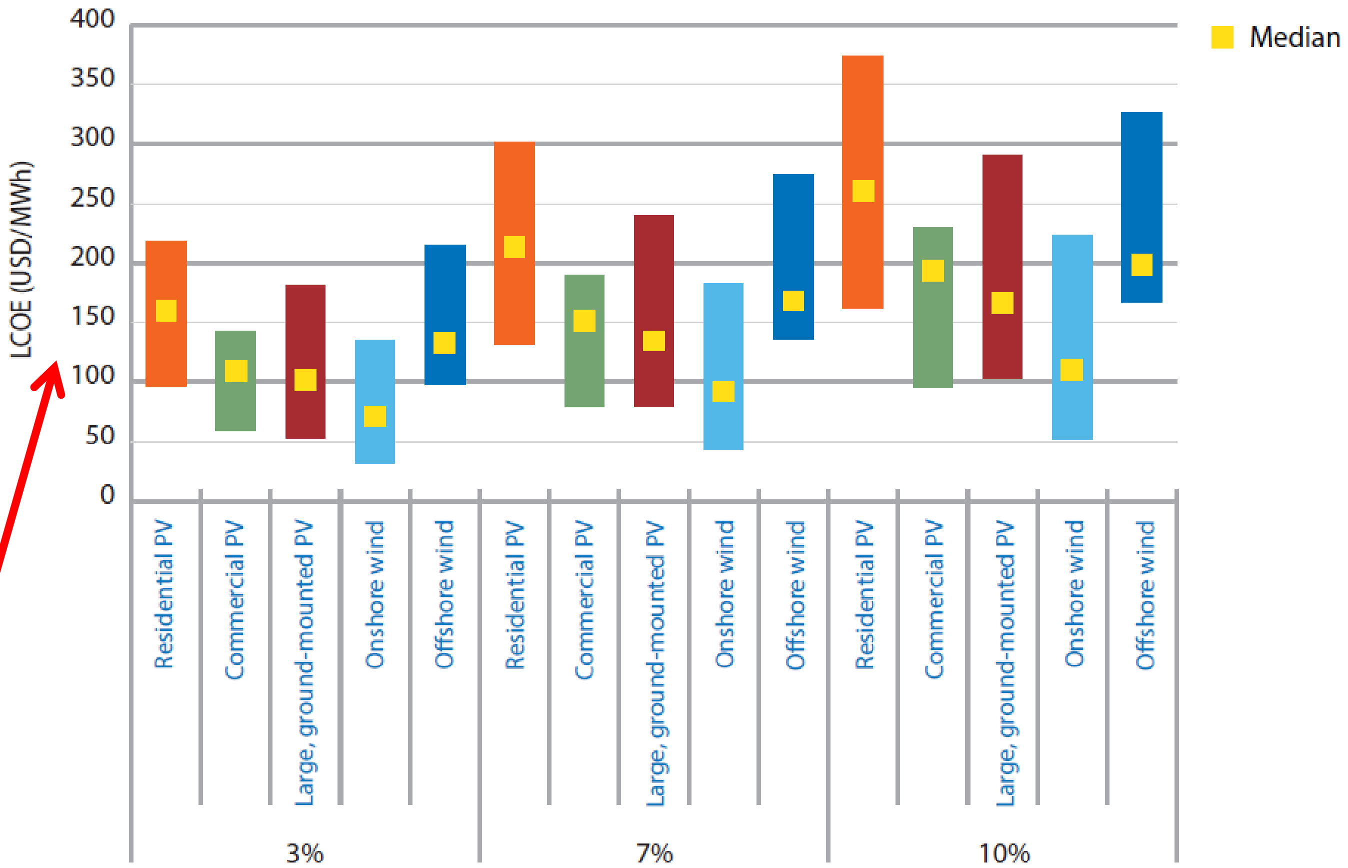


Figure ES.2: LCOE ranges for solar PV and wind technologies (at each discount rate)

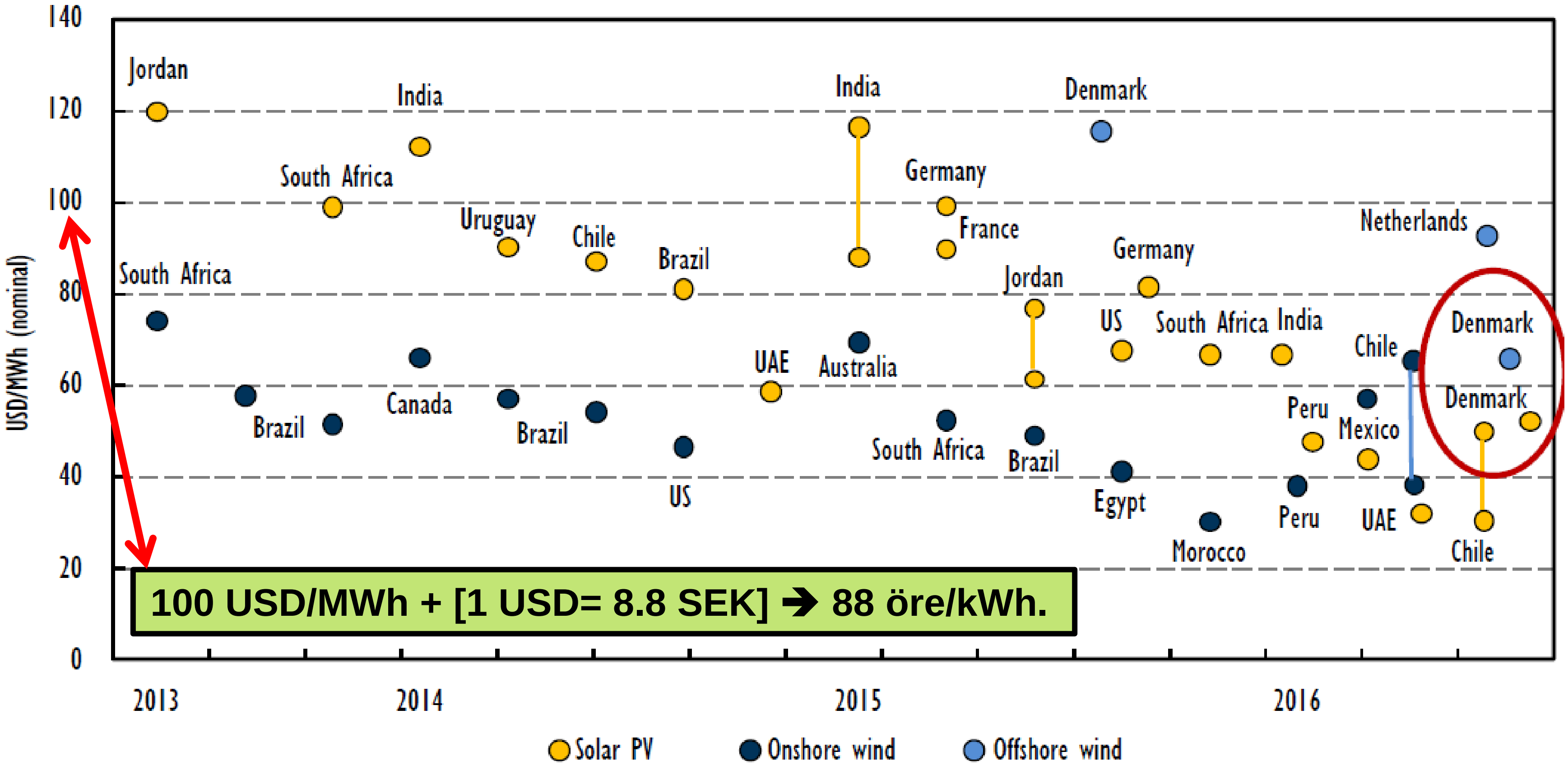


100 USD/MWh + [1 USD= 8.8 SEK] ➔ 88 öre/kWh.

Policy transition from government-set tariffs to policy-driven auctions/tenders

RENEWABLE ENERGY
Medium-Term Market Report 2016

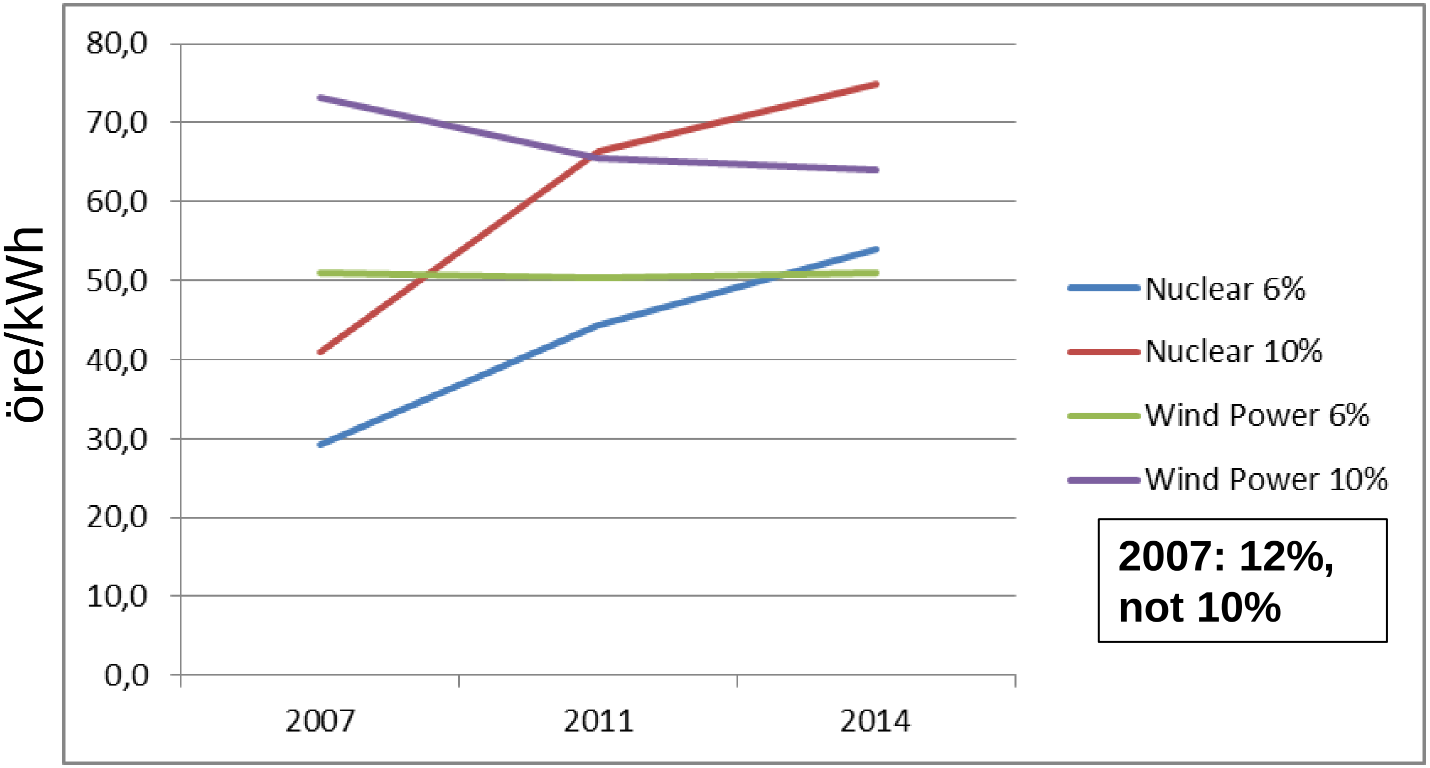
Recent announced long-term contract prices for new renewable power to be commissioned over 2016-2019



Best results occur where price competition, long-term contracts and good resource availability are combined

Cost Estimations:
Power from new and future plants 2007-2014
Cost development (2014 prices)

and earlier versions from 2007-2014



3) Uncertain construction time

Costs during construction time - 1

2.1 Costs during the construction time

It can take several years to construct some types of power plants. This then means that the owner has to spend money before there is some kind of income, which causes costs depending on the amount and interest rate . This then increases the cost, especially at high interest rates and long construction times. To estimate the total cost one takes the investment for each year and add the costs of the interest rate up to the actual start of the unit:

$$C_k = \sum_{i=1}^{I_k} C_{ki} \cdot (1 + r_{yc})^i \qquad (2)$$

I_k = Number of construction years for power plant k

C_{ki} = Investment cost i years before real start for power plant k

r_{yc} = Interest rate during the construction time.

Costs during construction time – 1

Compendium example 2.1

In this example we will start to show the calculation of the total cost of a nuclear power plant. The investment cost i 40000 SEK/kW. Using 9.5 Euro/SEK this results in 4211 Euro/kW.

- The construction is performed during six years with 10% at year -6, 15% at year -5, 15% at year -4, 20% at year -3, 20% at year -2 and 20% at year -1.
- The interest rate during the construction phase is 4%. Calculate the investment cost per kW. Also calculate an equivalent construction time assuming that the investments is spread out equally over a certain time and an interest rate of 4%.

Result:

The cost **increases with** (4774/4211-1)= **+13,4%** because of the construction time up to 6 years.

7) Uncertain life length of current power plants

Swedish situation 2013-2017:

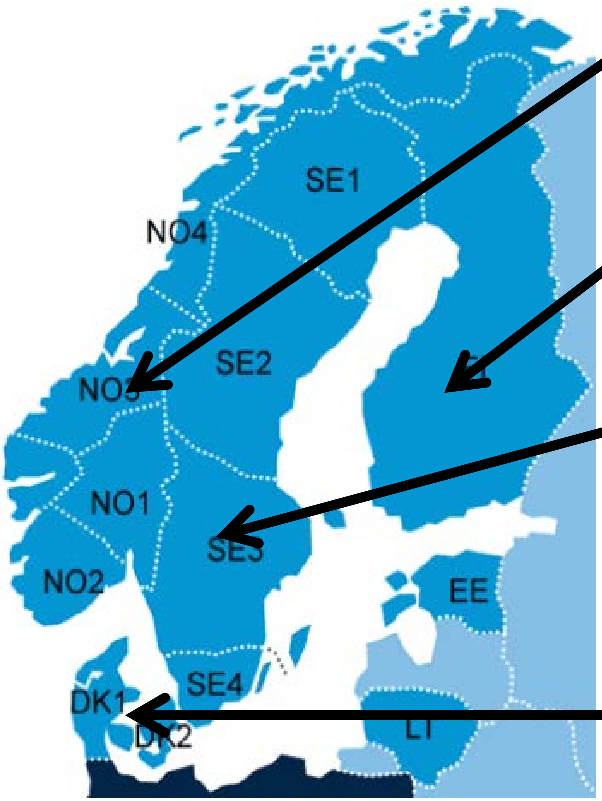
- **February-2013**: State Energy Agency made a forecast for the future: ”All nuclear stations will survive for **50-60 years** each”
- Election discussions during **summer 2014**: ”How can the green party assume that the Social Democrats will accept dismantling of **any** nuclear stations?”
- **Autumn-2015**: Owning Power Companies decides, by **economic reasons**, to close down the 4 oldest nuclear reactors. R1-R2 closed after **45 years**, O2 after **41 years** and O1 after **46 years**.

8) Uncertain policy concerning

Reliability, Sustainability, Market / taxes /subsidies

Reliability: Different current Nordic rules:

Peak capacity responsibilities



Norway: TSO-Statnet is responsible for “enough capacity”

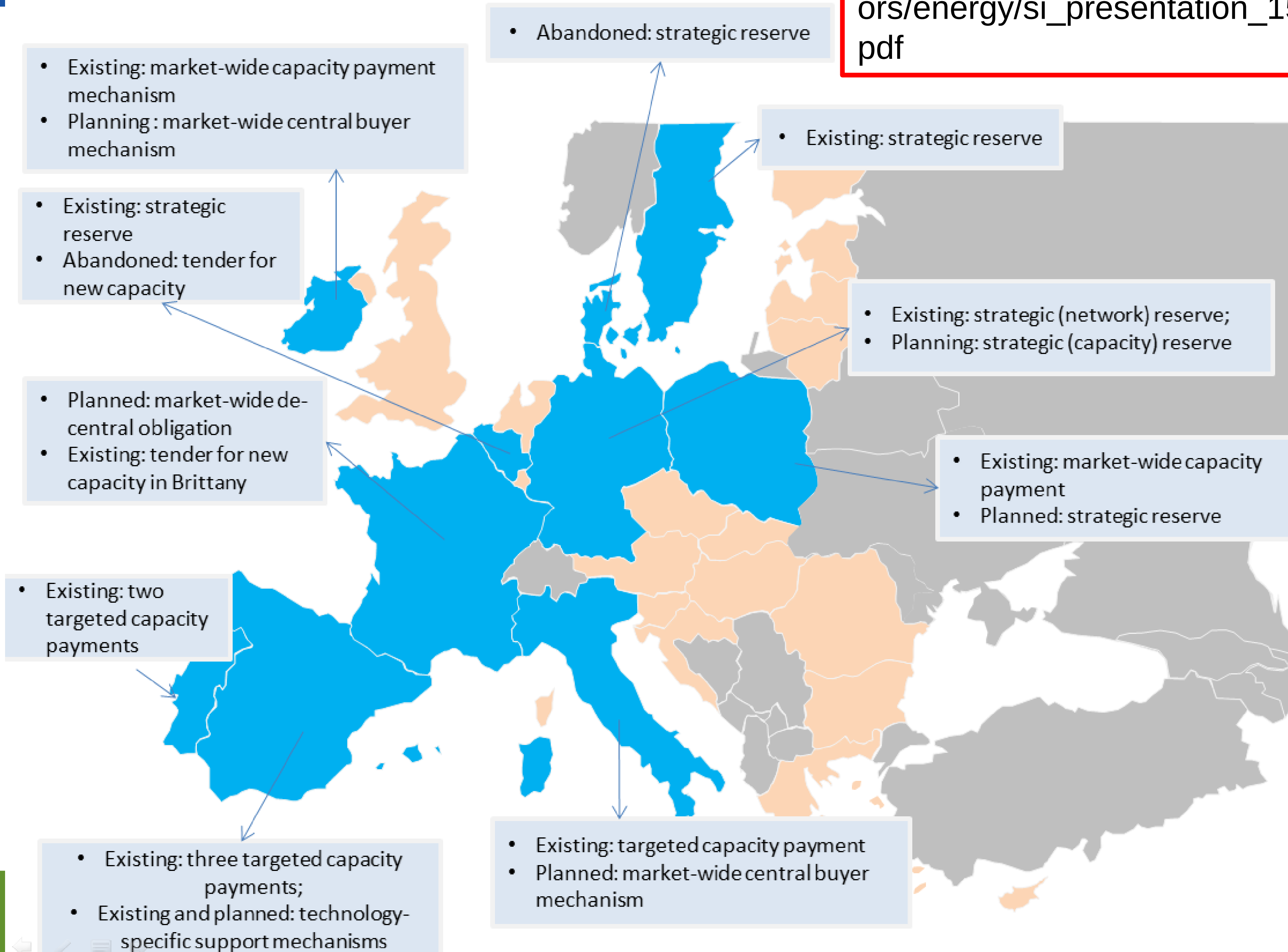
Finland: TSO-Fingrid is NOT responsible for “enough capacity”

Sweden: TSO-Svenska Kraftnät is NOT responsible for “enough capacity”. But: “up to 2000 MW”

Denmark: TSO-Energinet.dk is responsible for “enough capacity”

Some European strategies to get a reliable power system (2015)

http://ec.europa.eu/competition/sectors/energy/si_presentation_15_06.pdf



Swedish 5 party agreement on policy on taxes and renewables:

Announced June 6, 2016

Ramöverenskommelse mellan Socialdemokraterna, Moderaterna, Miljöpartiet de gröna, Centerpartiet och Kristdemokraterna

Grundpelare

Den svenska energipolitiken ska bygga på samma tre grundpelare som energisamarbetet i EU. Politiken syftar alltså till att förena:

- Ekologisk hållbarhet
- Konkurrenskraft
- Försörjningstrygghet

Sverige ska ha ett robust elsystem med en hög leveranssäkerhet, en låg miljöpåverkan och el till konkurrenskraftiga priser. Det skapar långsiktighet och tydlighet för marknadens aktörer och bidrar till nya jobb och investeringar i Sverige. Energipolitiken tar sin utgångspunkt i att Sverige är tätt sammankopplat med sina grannländer i norra Europa och syftar till att hitta gemensamma lösningar på utmaningar på den gemensamma elmarknaden.

Mål

Senast år 2045 ska Sverige inte ha några nettoutsläpp av växthusgaser till atmosfären, för att därefter uppnå negativa utsläpp.

Målet år 2040 är 100% förnybar elproduktion. Detta är ett mål, inte ett stoppdatum som förbjuder kärnkraft och innebär inte heller en stängning av kärnkraft med politiska beslut.

Ett mål för energieffektivisering för perioden 2020 till 2030 ska tas fram och beslutas senast 2017.

Förutsättningar på den svenska elmarknaden

Det behövs bättre förutsättningar för investeringar i förnybar energi, energiteknik och energieffektiviseringar. Utvecklingen av energisystemet ska utgå från en mångfald av storskalig och småskalig förnybar produktion som är anpassad till lokala och industriella behov.

En stor utmaning är att förändra energipolitiken från att nästan enbart fokusera på levererad mängd energi (TWh) till att även se till att det finns tillräckligt med effekt (MW). Ett viktigt steg bör vara att se över regelverk på energiområdet och

- S(31%)+M(23%)+MP(7%)+C(6%)+KD(5%)=**72%**
- Lower nuclear and hydro tax
- +18 TWh new renewable energy (certificate system) 2020-2030
- A goal is set up for ”100% renewable electricity production year 2040”
- This is a goal but not a ”stop date” for nuclear power.
- A goal for ”energy efficiency” will be decided during 2017.

Current (2016) challenges in Sweden and many other countries

1. Low Power Prices
2. Depends to high extent on low costs on fossil fuels
3. Difficulties to fund existing power plants, e.g., nuclear and other