Electricity Markets: Summer Semester 2016, Lecture 13

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The Californian electricity crisis: Abuse of market power

California

The deregulated spot market for electrical energy in California went into operation in April 1998.

Prices started to rise and strong peaks started appearing from May 2000 onwards.

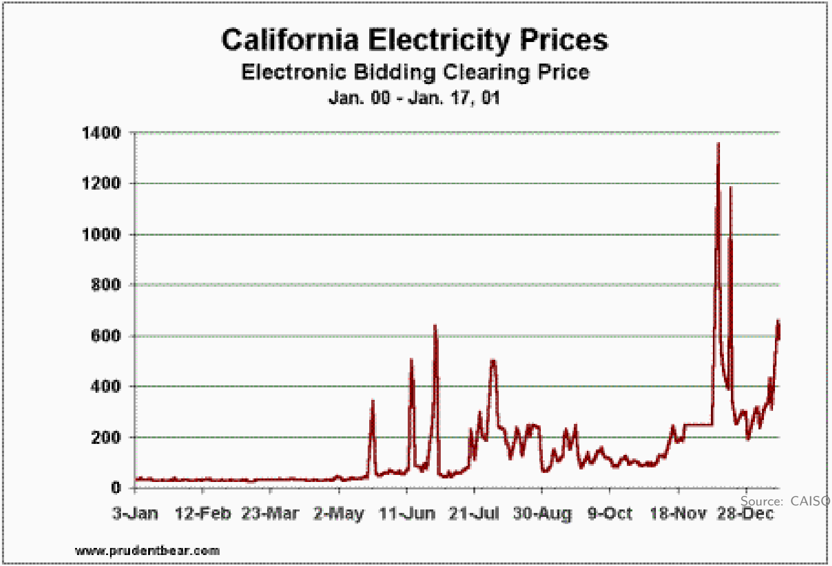
Blackouts followed in 2000-2001, affecting hundreds of thousands of people, culminating in blackouts affecting 1.5 million customers in March 2001.

A shortage of electricity supply had been caused by market manipulations, illegal shutdowns of pipelines by the Texas energy consortium Enron, water shortages and capped retail electricity prices.

Government intervention was required to defuse the crisis.

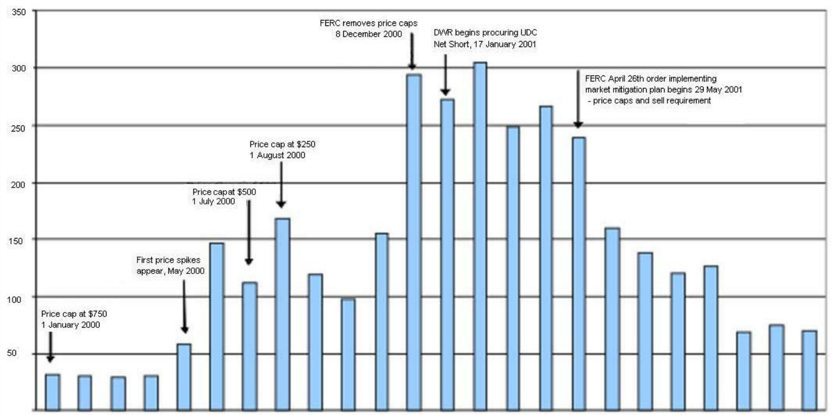
First price spikes

First price spikes started appearing in May 2000



Source: CAISO

Average prices in California in 2000-2001



Date	Jan00	Feb00	Mar00	Apr00	May00	Jun00	Jul00	Aug00	Sep00	Oct00	Nov00	Dec00	Jan01	Feb01	Mar01	Apr01	May01	Jun01	Jul01	Aug01	Sep01	Oct01	Nov01	Dec01
$/MWH	31.63	30.43	29.55	30.78	58.06	146.77	112.06	167.93	118.55	98.02	154.86	294.19	271.98	304.42	248.99	265.89	239.50	159.81	137.83	120.16	126.84	69.37	74.82	69.63

Source: CAISO

Explanations of the crisis

1. Classic case of abuse of market power: artifical shortages were created by taking power plants offline for maintenance at times of peak demand (mainly by Enron)
2. "Overscheduling" of transmission lines - blocking more capacity than was needed, leading to artifical congestion
3. Manipulation of imports and exports from outside the state
4. Delays in approval of new power plants
5. Drought affected hydro and there were fuel price increases
6. Long-term contracts were disallowed by law, forcing all utilities onto the spot market
7. Cap on retail prices squeezed the margins of retailers and dissuaded energy efficiency

Clear-up process

Testimony on crisis in Californian Senate in 2002:

“There is one fundamental lesson we must learn from this experience: electricity is really different from everything else. It cannot be stored, it cannot be seen, and we cannot do without it, which makes opportunities to take advantage of a deregulated market endless. It is a public good that must be protected from private abuse. If Murphy’s Law were written for a market approach to electricity, then the law would state ’any system that can be gamed, will be gamed, and at the worst possible time.’ And a market approach for electricity is inherently gameable. Never again can we allow private interests to create artificial or even real shortages and to be in control.”

The crisis cost tens of billions of dollars.

Source: Wikipedia

Solution to the crisis

Government intervention.

On January 17 2001, Governor Gray Davis declared a state of emergency and bought long-term contracts on the open market at highly unfavorable terms for the utilities, wiping out the state surplus and creating a massive debt. By then, the utilities were in backruptcy and had no buying power. The prices of electricity that the long-term contracts locked in reportedly averaged $69 per megawatt-hour, compared to September 2002 prices of $30 per megawatt-hour.

Retail competition was ended in September 2001.

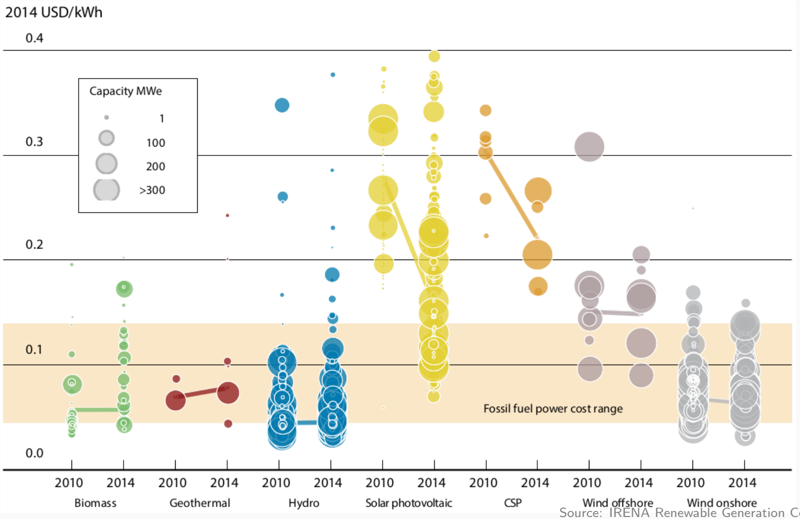
Energy efficiency was also improved.

Integrating Renewables in Power Markets

Characteristics of Renewables

- Variability: Their production depends on weather (wind speeds for wind, insolation for solar and precipitation for hydroelectricity)
- No Upwards Controllability: Variable Renewable Energy (VRE) like wind and solar can only reduce their output; raising is hard
- No Long-Term Forecastability: Although short-term forecasting is improving steadily
- Low Marginal Cost (no fuel costs)
- High Capital Cost
- No Carbon Dioxide Emissions
- Small unit size (wind turbine is 2-3 MW; coal/nuclear is 1000 MW)
- Somewhat Decentralised Distribution for some VRE (e.g. solar panels on household rooves); offshore is however very centralised
- Provision of system services: Increasing

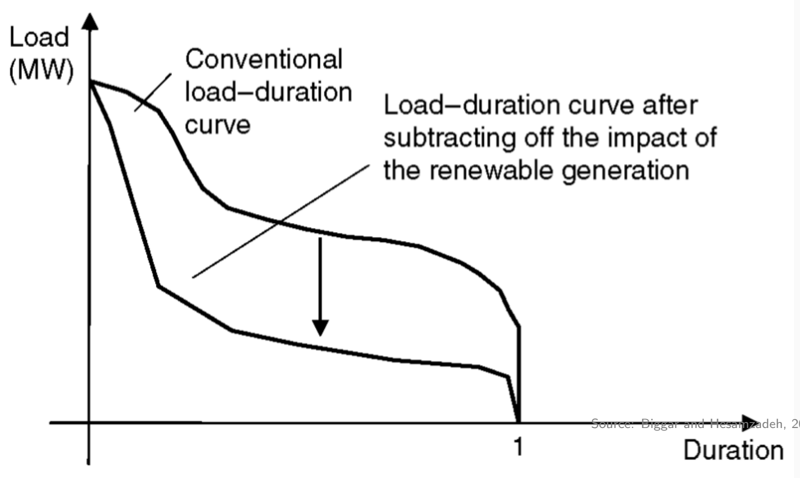
RE Levelised Cost already approaching fossil fuels



Source: IRENA Renewable Generation Costs

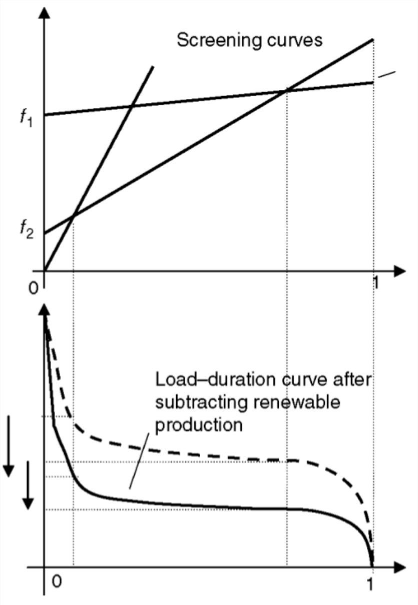
Effect on effective ‘residual’ load curve

Since RE often have priority feed-in (i.e. network operators are obliged to take their power), we often subtract the RE production from the load to get the residual load, plotted here as a demand-duration-curve.



Source: Biggar and Hesamzadeh, 2014

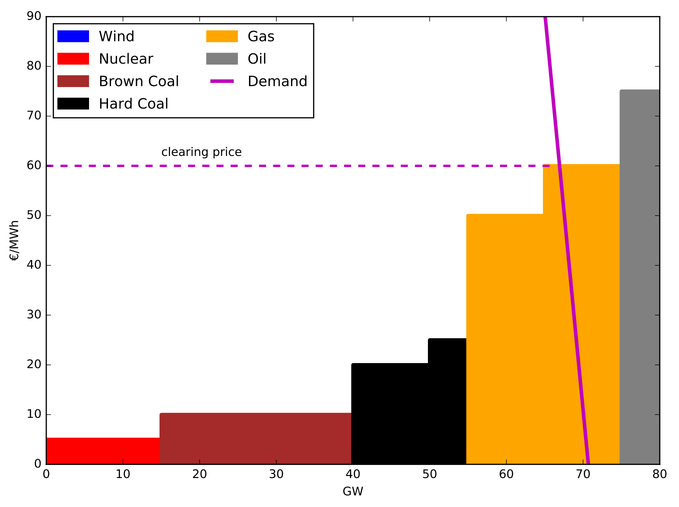
Residual load curve and screening curve



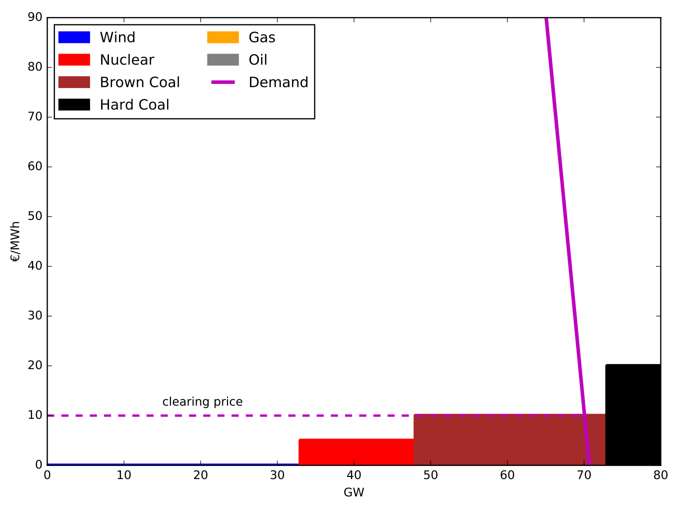
The residual load must be met by conventional generators.
The changed duration curve interacts differently with the screening curve, so that we may require less baseload generation and peaking plant and more load shedding, depending on the shape of the curve.
In some markets, there is increased demand for medium-peaking plant.

Source: Biggar and Hesamzadeh, 2014

Effect of varying renewables: fixed demand, no wind

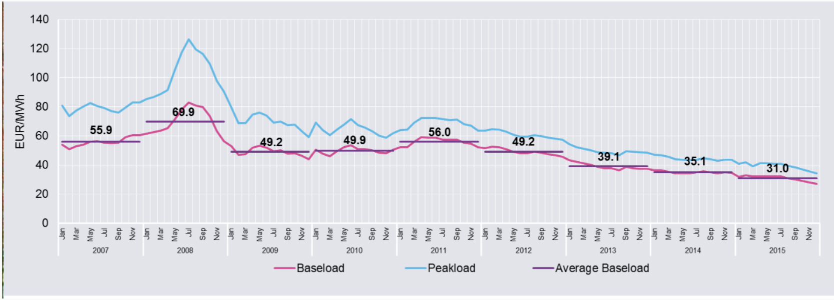


Effect of varying renewables: fixed demand, 35 GW wind



Spot market price development

As a result of so much zero-marginal-cost renewable feed-in, spot market prices have been steadily decreasing:



Source: Agora Energiewende

Merit Order Effect

To summarise:

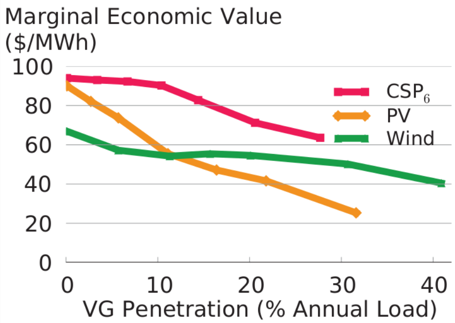
- Renewables have zero marginal cost
- As a result they enter at the bottom of the merit order, reducing the price at which the market clears
- This pushes non-CHP gas and hard coal out of the market
- This is unfortunate, because among the fossil fuels, gas and hard coal are the most flexible and produce the *lowest* CO_2 per MWh
- It also massively reduces the profits that nuclear and brown coal make
- Will there be enough backup power plants for times with no wind/solar?

This has led to lots of political tension...

Market value

VRE have the property that they cannibalise their own market, by pushing down prices when lots of other VRE are producing.

We define the market value of a technology by the average market price it receives when it produces. At low shares of VRE the market value may be higher than the average market price (because for example, PV produces a midday when prices are higher than average), but as VRE share increases the market value goes down.

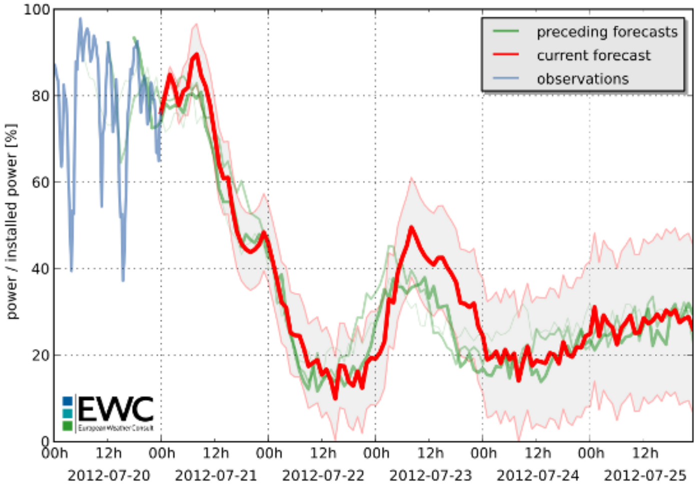


Source: Mills & Wiser, 2014

The effect is particularly severe for PV, since the production is highly correlated; for wind smoothing prevents a steeper drop off. The bigger the catchment area, the longer wind preserves its market value.

RE Forecasting

Just like the weather on which it depends, Variable RE (wind and solar) production can be forecast in advance. (Shaded area is the uncertainty.)



RE Forecasting

Like the weather, the forecast in the short-term (e.g. day ahead) is fairly reliable, particularly for wind, but for several days ahead it is less useful. In addition, it is subject to more uncertainty than the load. For example, fog and mist is very local, hard to predict, and has a big impact on solar power production.

This makes scheduling more challenging and has led to the introduction of more regular auctions in the intraday market.

Forecasting has also become a big business.

Day-ahead, intraday and balancing markets

Introduction

So far we've looked at an ideal system where we know in advance exactly what the load will be. In reality there are many uncertainties:

- Consumer behaviour may make load unpredictable
- Renewable feed-in may differ from forecasts
- Sudden failure of power plants or transmission lines or transformers or substations (e.g. due to weather-related accidents, construction work, or component failure)

The power in the system must be balanced at all times, so system operators need to have reserves in place for these contingencies.

On the other hand, market participants and network/system operators must have partial planning certainty to organise the generation dispatch.

Overview of time scales

The compromise between partial planning certainty and system security is dealt with by having different markets for power at different time scales.

For energy markets we have different time scales:

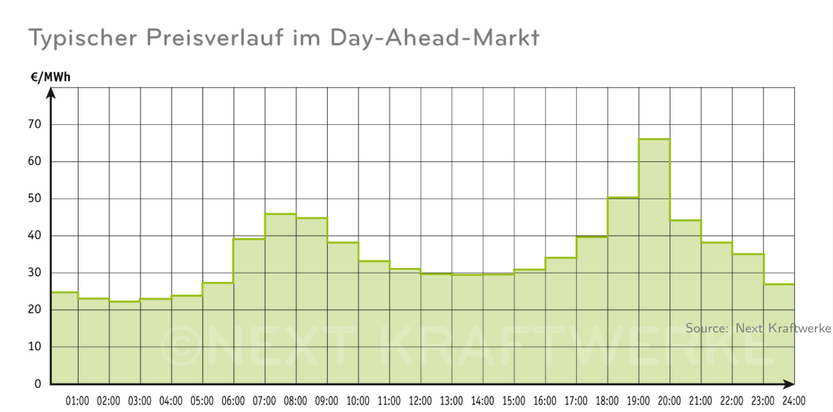
Market	Gate closure	interval
Bilateral Contracts	years-months before	multi-hour
Day Ahead Spot	day before at midday	hourly
Intraday Spot	30 min before	15 mins

In addition there are balancing power markets for capacity to cover very short-term imbalances and emergencies, e.g. due to power plant or transmission outages.

Day-Ahead Market

The Day-Ahead market is where most of the energy is traded. For each day, bids and offers must be submitted to the power exchange for every hour of that day, by midday on the previous day.

Bids/offers must be at least 0.1 MW at a price between -500 €/MWh and 3000 €/MWh. Block bids over multiple hours are also possible.

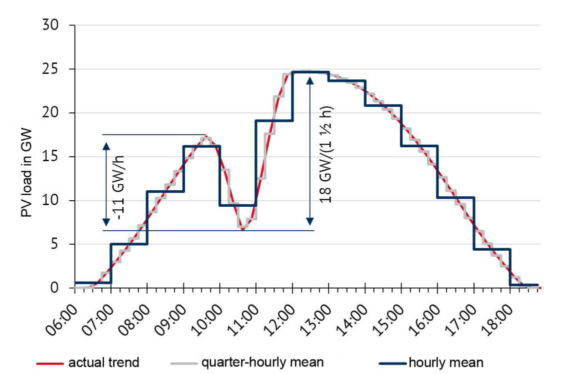


Source: Next Kraftwerke

Intraday Market

Hours are too coarse to capture changes in load / forecast errors for RE, so an Intraday Market fills the gaps from the Day-Ahead market.

The trading is done in a smallest size of 15-minute blocks, and bids must be submitted by 30 minutes before the block.



(This example is actually for PV feed-in during the March 2015 eclipse, when there were worries about high ramp rates.)

Intraday Market

The Intraday Market plays an increasingly important role in balancing the fluctuations from RE. It has been adapted in recent years to accommodate larger shares of RE. For example, in 2011 the block size was reduced from 1 hour to 15 minutes; in July 2015 the gate closure time was reduced from 45 minutes before the block, to 30 minutes before the block.

NB: The Australian NEM operates at 5-min intervals, so things could be tighter still; some people advocate real-time markets, but it is then difficult for network operators to calculate network security, etc.

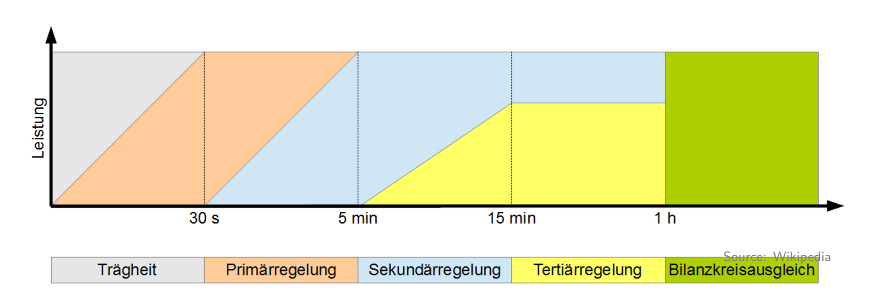
Unlike the Day-Ahead Market, which is Pay-As-Clear, the Intraday Market is Pay-As-Bid (which means each generator is paid what they bid, rather than the market clearing price).

Prices tend not to deviate too far from Day-Ahead prices.

Balancing Power

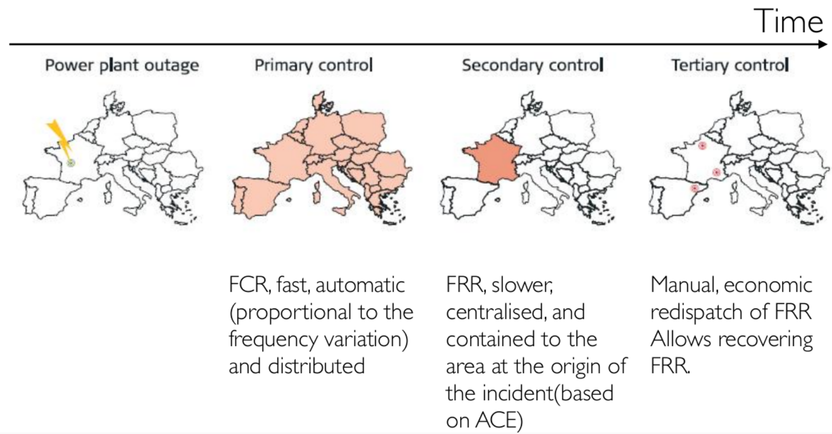
However, we're still not done. Below 15 minutes there may be power fluctuations and there may also be sudden imbalances due to the loss of generators or transmission lines. For these cases, the network operator acts to ensure that demand is equal to supply, in near-real time.

Balancing services are split into three time scales: primary, secondary and tertiary (names differ by region/regulator, etc.), according to how fast they act.



Source: Wikipedia

Balancing Power in Time and Space



ENTSO-E requires 3000 MW primary reserve at all times (equivalent to the failure of a substation where several power plant blocks are attached).

Balancing Markets

Requirements for each category of balancing power are put to tender by the TSOs on balancing markets. Requirements are for capacity, NOT energy, since it's a capacity which is kept in reserve.

In 2015 in Germany primary reserve requirements were around 600 MW (determined by ENTSO-E in cooperation with TSOs), secondary around 2 GW, and tertiary also around 2 GW.

Like the Intraday market, the balancing markets are also pay-as-bid.

Balancing power is split into positive (upward, increased generation) and negative (downward, increased load) balancing.

The overlap between tertiary reserves and the intraday market is becoming ever blurrier. Because the intraday is taking over part of the balancing provision, there has been both a decrease in volume and cost of balancing reserves, even though RE capacity has gone up.

Other ancillary services

Ancillary Services

Other “ancillary” (i.e. non-power-related) services which network operators provide may also be handed over to markets in the future.

- Inertia (very short-term frequency control)
- Coverage of thermal losses in transmission lines
- Black start capability, to restart the grid following a blackout
- Reactive power for voltage regulations
- Short-circuit current
- National and International Redispatch to manage grid bottlenecks

Other Flexibility: Networks, Storage, Demand-Side Management

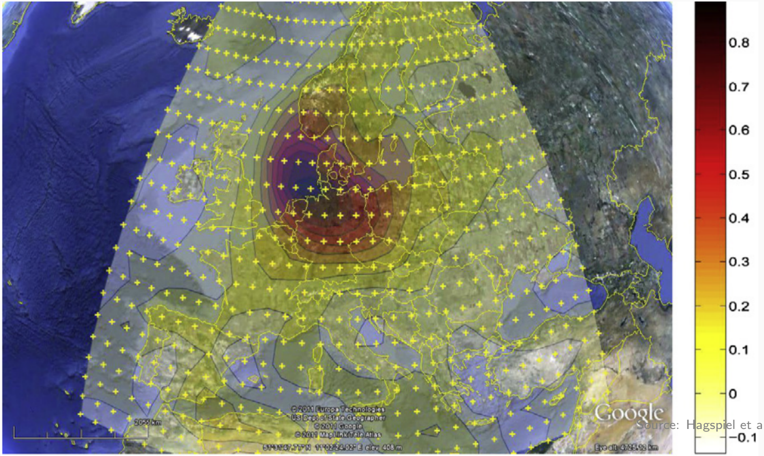
Flexibility to Accommodate Fluctuating Renewables

It is often said that fluctuating renewables require more power system flexibility, since their power output is not controllable like conventional power plants. Flexibility can come from a variety of places:

- More flexible conventional power plants, that can ramp up and down faster without suffering wear-and-tear damage
- More network capacity, so that fluctuations smooth out over larger areas (smoothing in *space*)
- Storage to balance fluctuations over *time*
- More flexible loads, that turn on-and-off according to the price or availability of renewables (like storage, but on the demand side)

Flexibility essentially allows the arbitrage of power and price in space and time; it reduces volatility and spikes in prices.

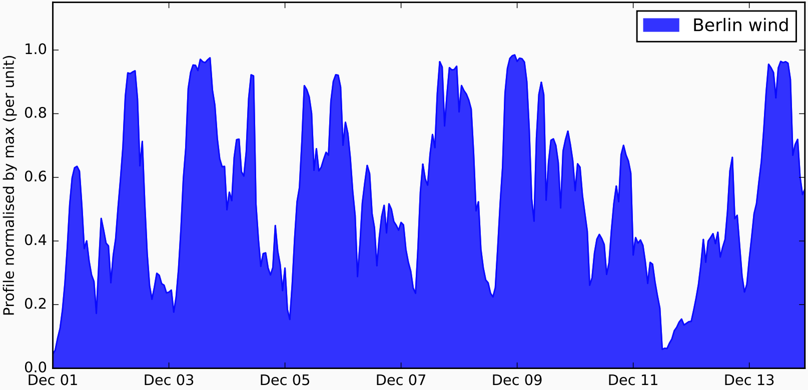
Although VRE may be correlated locally, the correlation drops off, particularly for wind, with distance. Correlation of wind speeds with a point in Germany on a summer day:



Source: Hagspiel et al, 2012

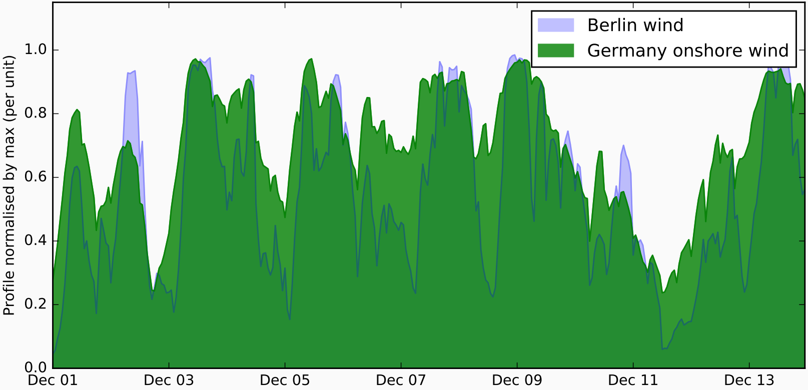
Variability: Single wind site in Berlin

Looking at the wind output of a single wind plant over two weeks, it is highly variable, frequently dropping close to zero and fluctuating strongly.



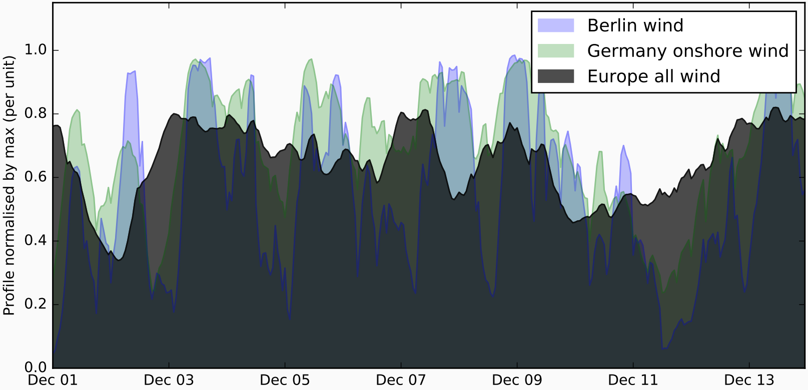
Variability: Single country: Germany

For a whole country like Germany this results in valleys and peaks that are somewhat smoother, but the profile still frequently drops close to zero.



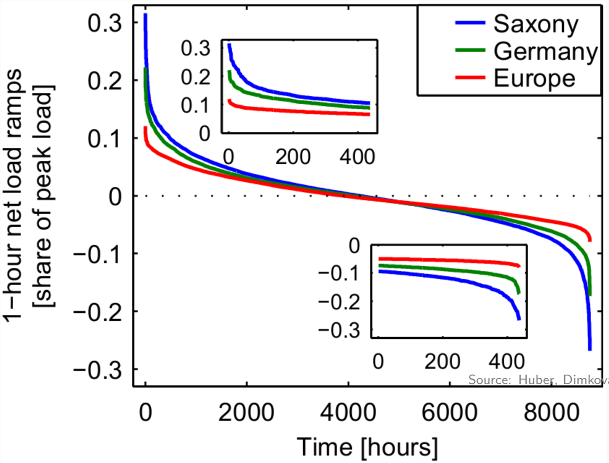
Variability: A continent: Europe

If we can integrate the feed-in of wind turbines across the European continent, the feed-in is considerably smoother: we've eliminated most valleys and peaks.



Networks: reduced ramping

The reduction in ramping can of course be quantified. 1-hour net load ramp duration curves at the regional, country and European spatial scales at 50% share of renewables and 20% PV in the wind/PV mix for the meteorological year 2009:

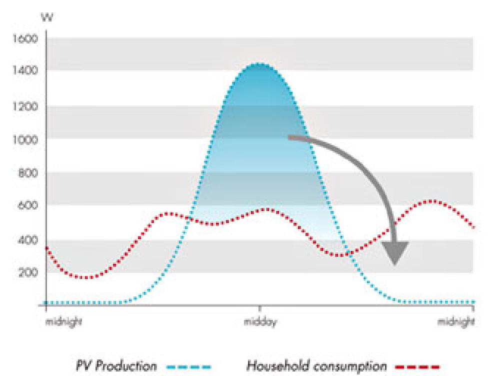


Source: Huber, Dimkova, Hamacher (2014)

Storage

Storage can store energy at times of over-supply (and low prices) and feed it back in at times of under-supply (and high prices). This is a form of arbitrage in time and can be highly profitable.

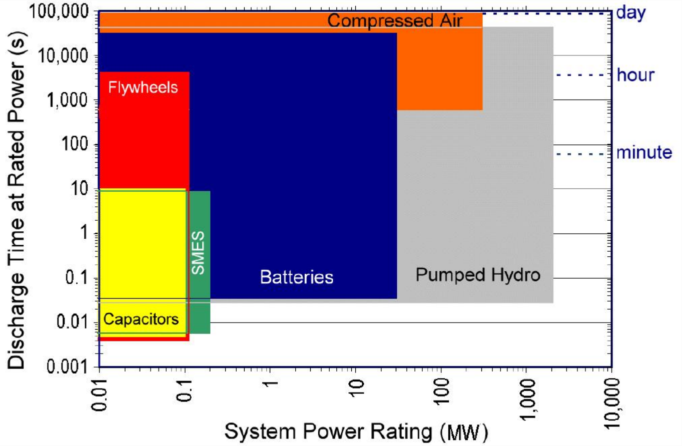
After WWII pumped hydro storage was built in Europe to complement baseload nuclear; water was pumped up at night, when prices were low, and let down through turbines during the day when prices where high.



Today storage complements VRE well, particularly PV whose feed-in is localised during daylight, which may not correspond to the peak load.

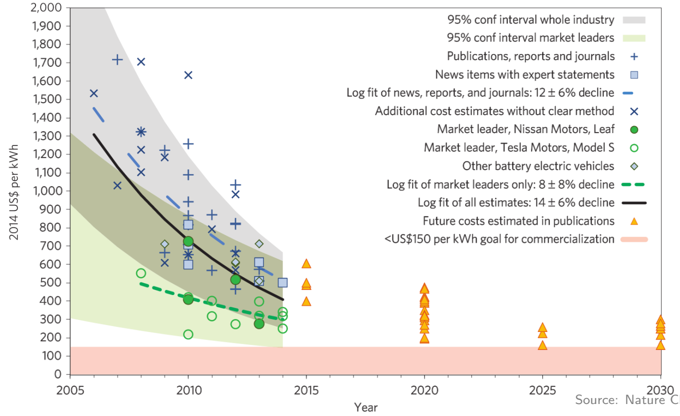
Storage: Classification

There are different technologies for power storage, which can be classified by their different properties: cost [€], energy weight/density [MWh/kg, MWh/m^3], power rating [MW], energy storage capacity [MWh].



Storage: Price development

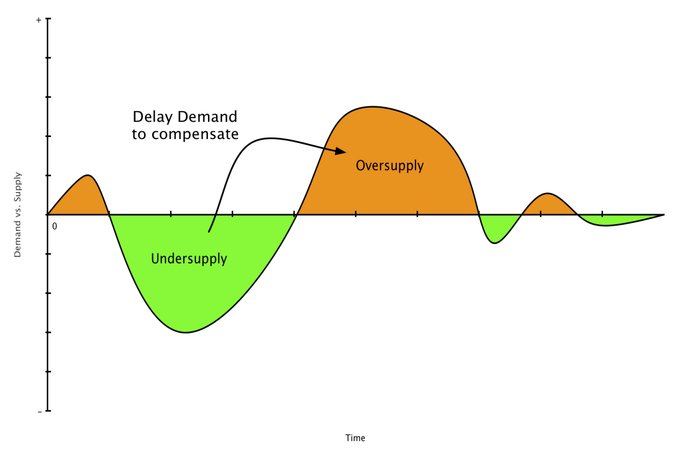
The cost of storage, particularly Lithium Ion batteries, is dropping fast, initially due to requirements for phone/laptop batteries and now increasingly for electric vehicles:



Source: Nature Climate Change

Demand Side Management (DSM)

DSM works similarly to storage, except that it works on the demand side rather than like a generation technology. Loads which may not be time-critical (refridgeration, desalination, washing machines, some industrial processes, electric vehicle charging, etc.) can be delayed:



Flexibilise demand

High price spikes can also be ameliorated by adjust demand, which was here assumed to be fairly inelastic.

Flexibilise demand by making it price-responsive.

The technology required to make a sufficient portion of the demand responsive to short-term price signals is not yet available, although some large loads (cement works, industrial refridgeration, etc.) may already implement demand-side management (DSM).

Widespread load disconnections are extremely unpopular and often have disastrous social consequences (accidents, vandalism). They are also economically very inefficient. Their impact can be estimated using the value of lost load (VOLL), which is several orders of magnitude larger than the cost of the energy not supplied. Consumers are not used to such disruptions and it is unlikely that their political representatives would tolerate them for any length of time.

A Personal Perspective

The electricity market of today is considerably more complicated than even five years ago.

It is also in flux, with dramatic price developments constantly changing the economic calculus.

Wind is already competitive or cheaper than fossil fuels in many markets. In markets with good solar resources, photovoltaics (PV) are also approaching competitiveness.

At the moment, networks and DSM are the cheapest flexibility options, but dramatic price drops in battery storage many alter this assumption.

There is an rough axis of wind-networks-centralisation versus PV-storage-decentralisation. The former is more competitive, but may not meet public acceptance; probably we will end up somewhere in the middle.

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