Complex Renewable Energy Networks
Summer Semester 2017, Lecture 11

Dr. Tom Brown

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Frankfurt Institute for Advanced Studies (FIAS), Goethe-Universität Frankfurt
FIAS Renewable Energy System and Network Analysis (FRESNA)

brown@fias.uni-frankfurt.de

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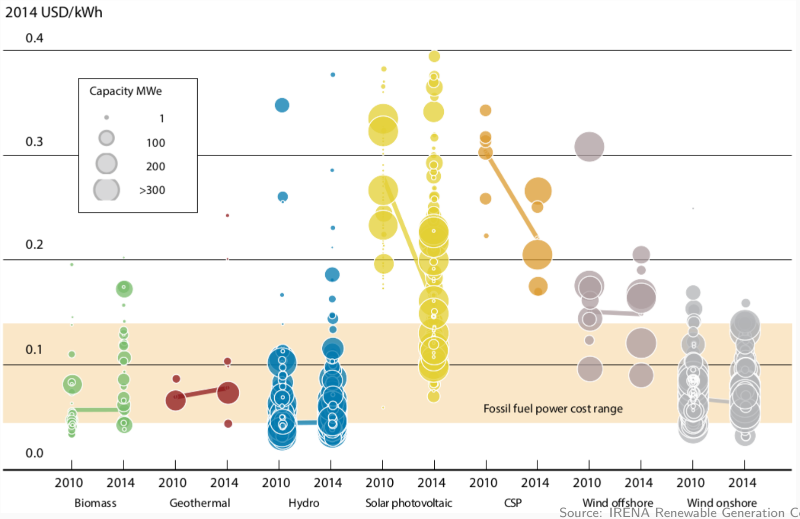
Integrating Renewables in Power Markets

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

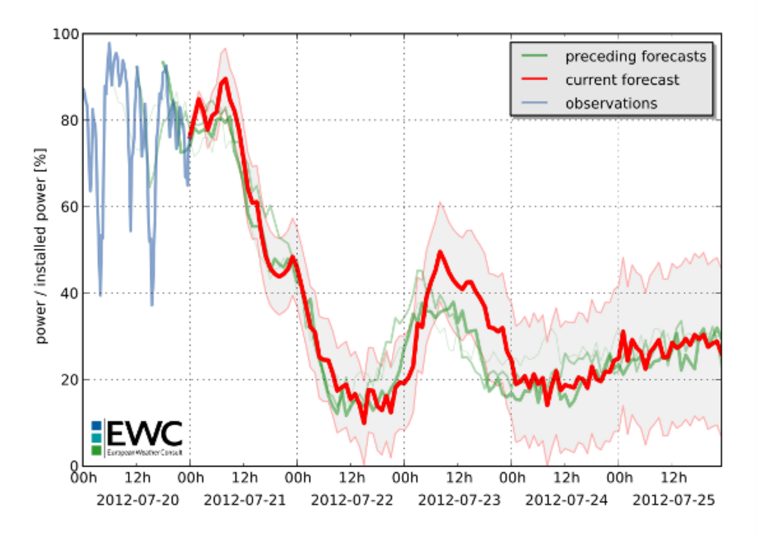
RE Levelised Cost already approaching fossil fuels



Source: IRENA Renewable Generation Costs

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

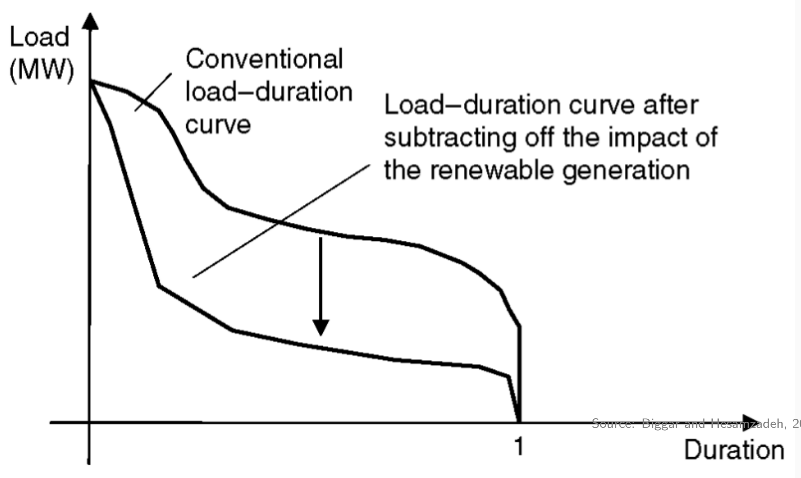
Like the weather, the forecast in the short-term (e.g. day ahead) is fairly reliable, particularly for wind, but for several days ahead it is less useful. In addition, it is subject to more uncertainty than the load. For example, fog and mist is very local, hard to predict, and has a big impact on solar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

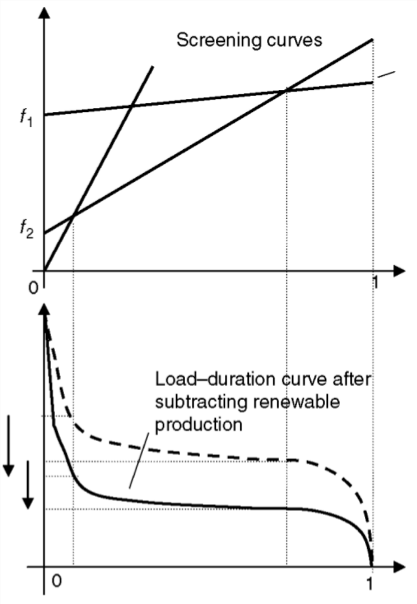
Effect on effective ‘residual’ load curve

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

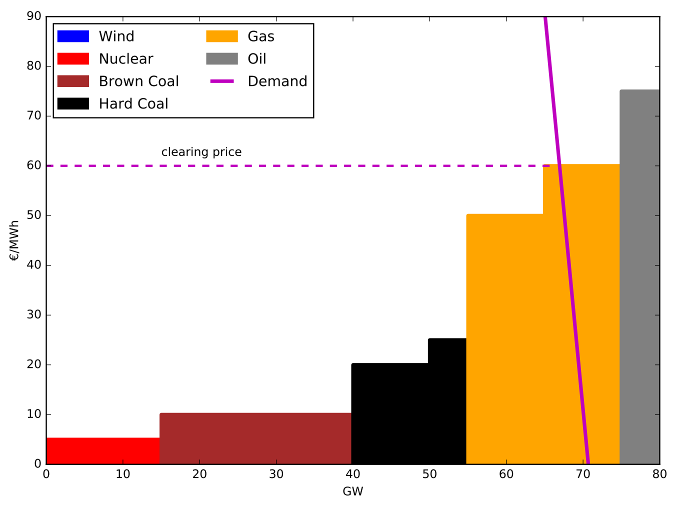
Residual load curve and screening curve



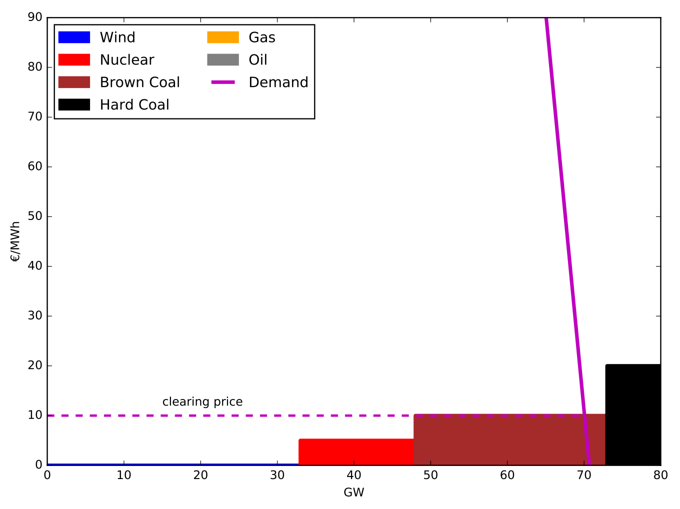
The residual load must be met by conventional generators.
The changed duration curve interacts differently with the screening curve, so that we may require less baseload generation and peaking plant and more load shedding, depending on the shape of the curve.
In some markets, there is increased demand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

Source: Biggar and Hesamzadeh, 2014

Effect of varying renewables: fixed demand, no wind

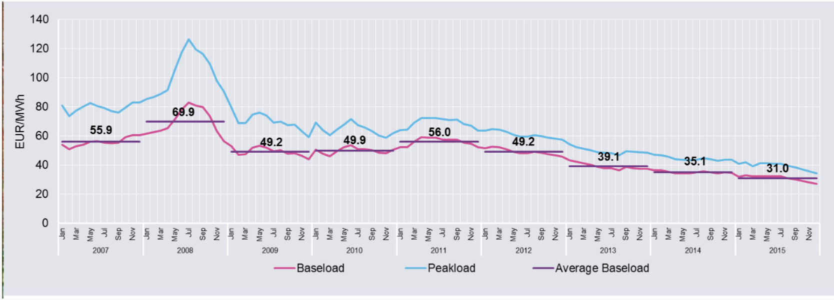


Effect of varying renewables: fixed demand, 35 GW wind



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, i.e.

$$MV_s = \frac{\sum_t \lambda_t^* g_{s,t}}{\sum_t g_{s,t}}$$

We can compare this to the average market price, defined either as the simple average $\frac{1}{T}\sum_t \lambda_t^*$ or the demand-weighted average $\frac{\sum_t \lambda_t^* d_t}{\sum_t d_t}$.

Historic market values in Germany

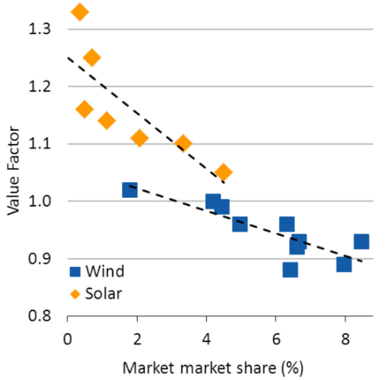


Figure 6. Historical wind and solar value factors in Germany (as reported numerically in Table 3).

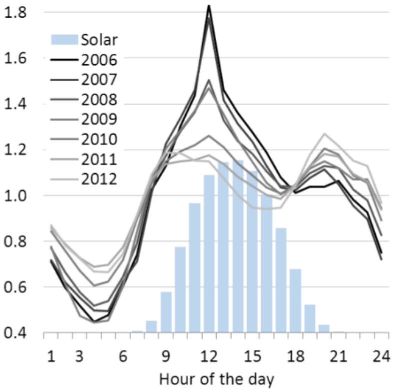
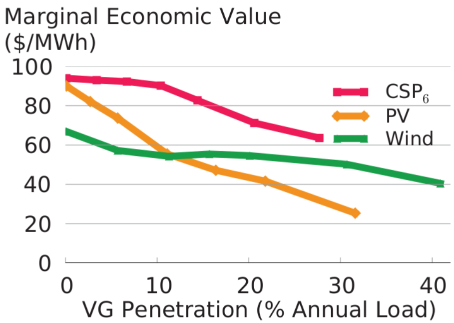


Figure 7. The daily price structure in Germany during summers from 2006 – 2012. The bars display the distribution of solar generation over the day.

Source: Lion Hirth, 2013

Market value at higher shares

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.

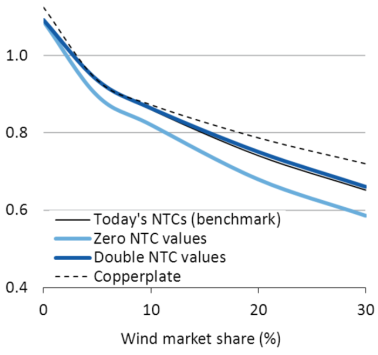


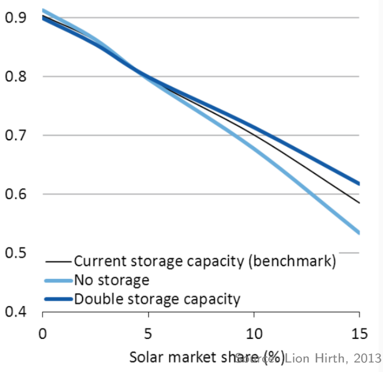
The effect is particularly severe for PV, since the production is highly correlated; for wind smoothing prevents a steeper drop off. The bigger the catchment area, the longer wind preserves its market value.

Source: Mills & Wiser, 2014

Market value mitigation

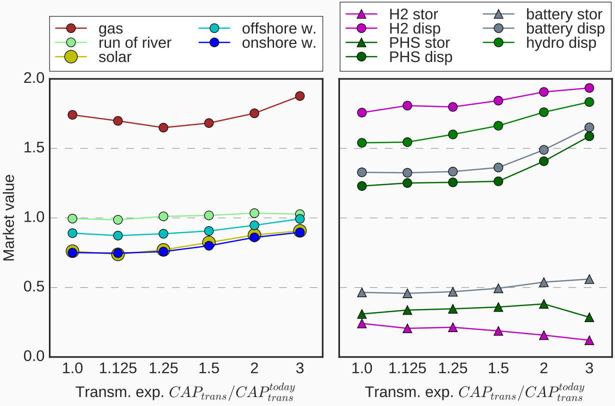
To halt the drop in market value (and hence revenue for wind and solar) we can use networks to do price arbitrage in space, storage to do arbitrage in time, or introduce CO2 prices that push up the prices in times when fossil fuel plants are running.





Source: Lion Hirth, 2013

Market value from FIAS highly renewable simulations



- Storage charges at low market prices and dispatches at high prices.
- Dispatchable power sources take advantage of high prices.
- Variable renewables get lower prices, but saved by storage, networks and high CO2 price.

Course evaluation

Course evaluation

Course evaluation: please log in on the following website:

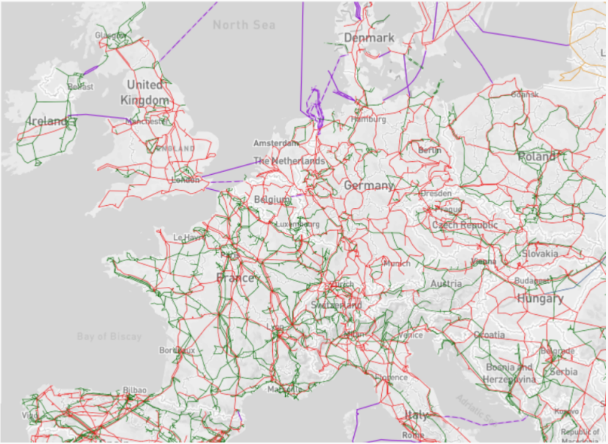
`http://r.sd.uni-frankfurt.de/25212e8a`

This site is open 28.06.2017, 14:00 - 16:00 Uhr

Effect of spatial scale on results of energy system optimisations

Motivation: Transmission bottlenecks

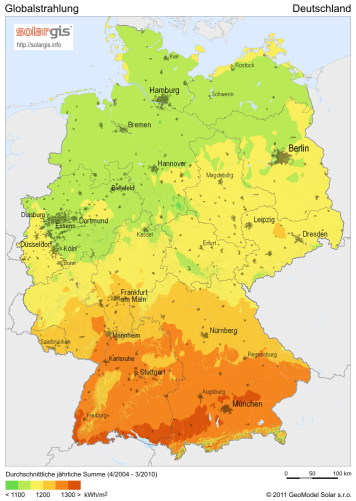
Many of the results we've examined so far have aggregated countries to a single node. However, there are also transmission network bottlenecks within countries (e.g. North to South Germany).

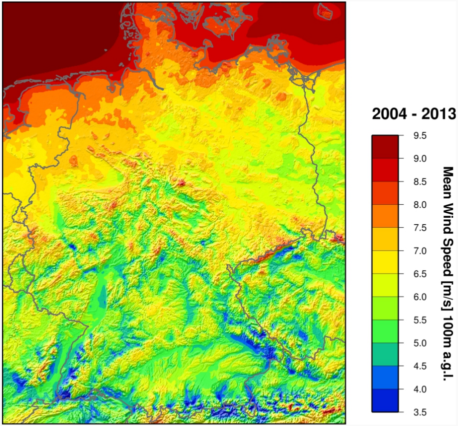


Source: ENTSO-E

Motivation: Wind and solar resource variation

There is also considerable variation in wind and solar resources...





Spatial Scale in System Optimisations

See presentation:

`https://nworbmot.org/energy/brown-champery.pdf`