Market value and the future of renewables

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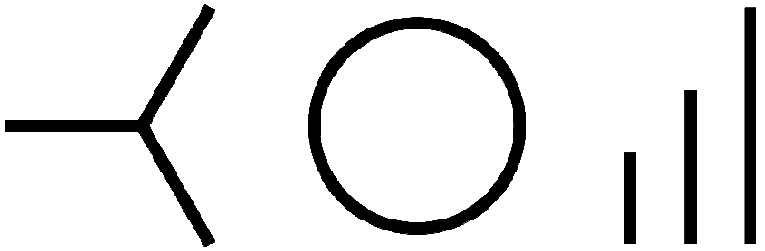
EFORIS Stockholm | 24 November 2015 | hirth@neon-energie.de

neon neue energieökonomik



Seeking advice on power markets? Neon Neue Energieökonomik is a Berlin-based boutique consulting firm for energy economics. Neon conducts model-based studies of power markets, provides electricity price forecasts, and organizes workshops. www.neon-energie.com

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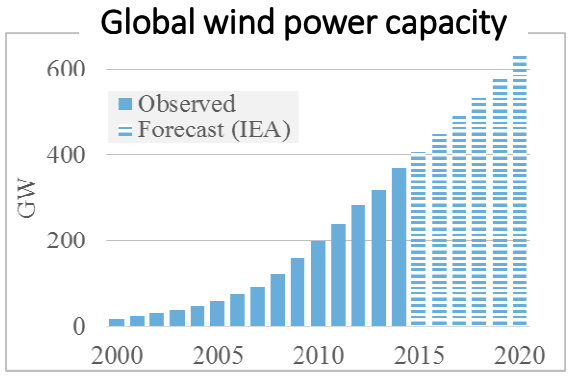
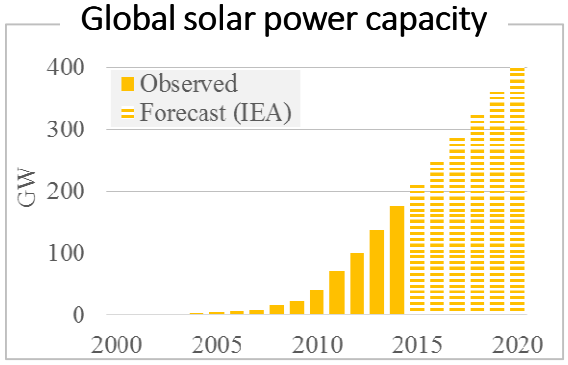
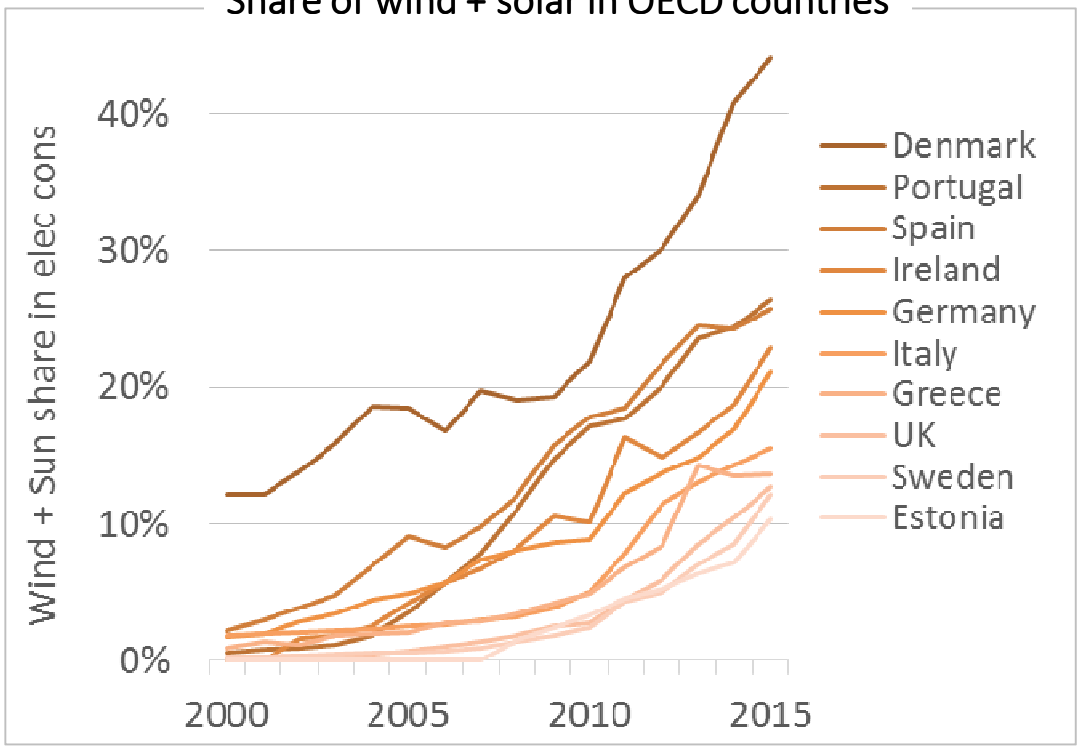
Wind & sun deliver 15+% of electricity in some regions





Data source: REN21 (2015), IEA (2014)

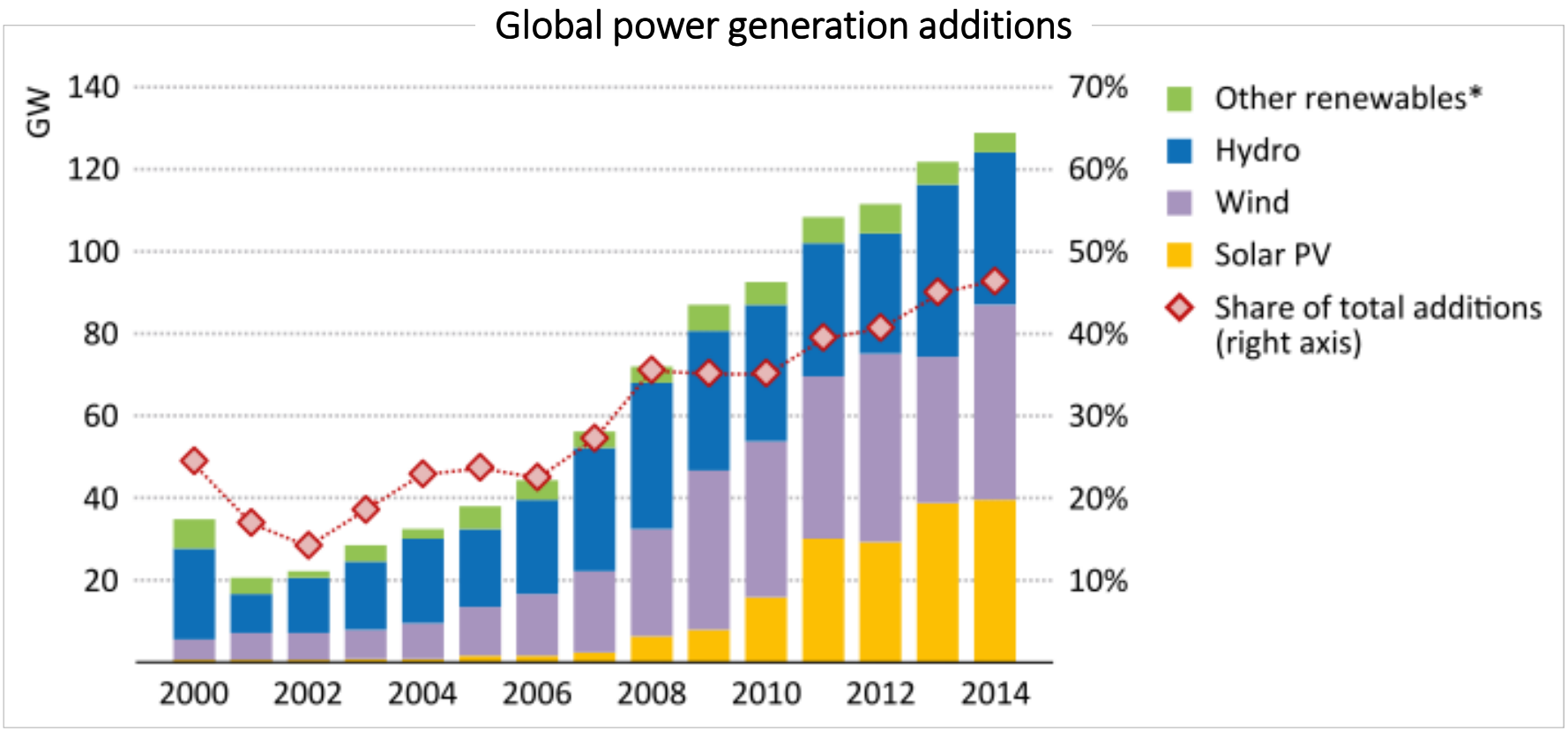


Data source: IEA (2015

Wind and solar power have been growing strongly, and are expected to continue to grow.

Wind and solar power combined now supply more than 10% of electricity in several power systems (and more than 20% in some) – they have become mainstream technologies.

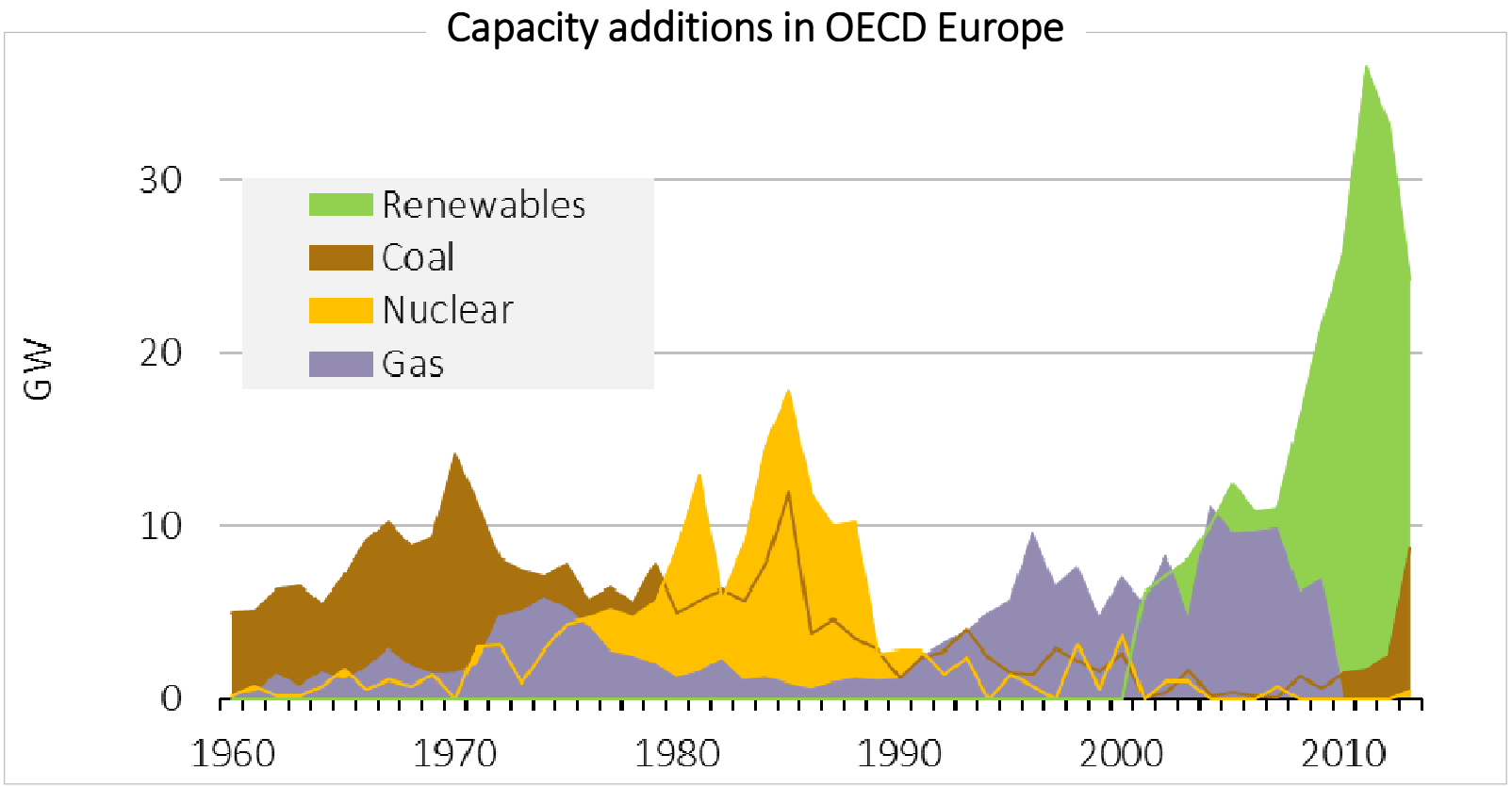
50% of globally added capacity is renewable



Source: IEA (2015): WEO special report

In 2014, almost half of all new power generation capacity globally was based on renewables – of which wind and solar power captured the lion's share of 70%.

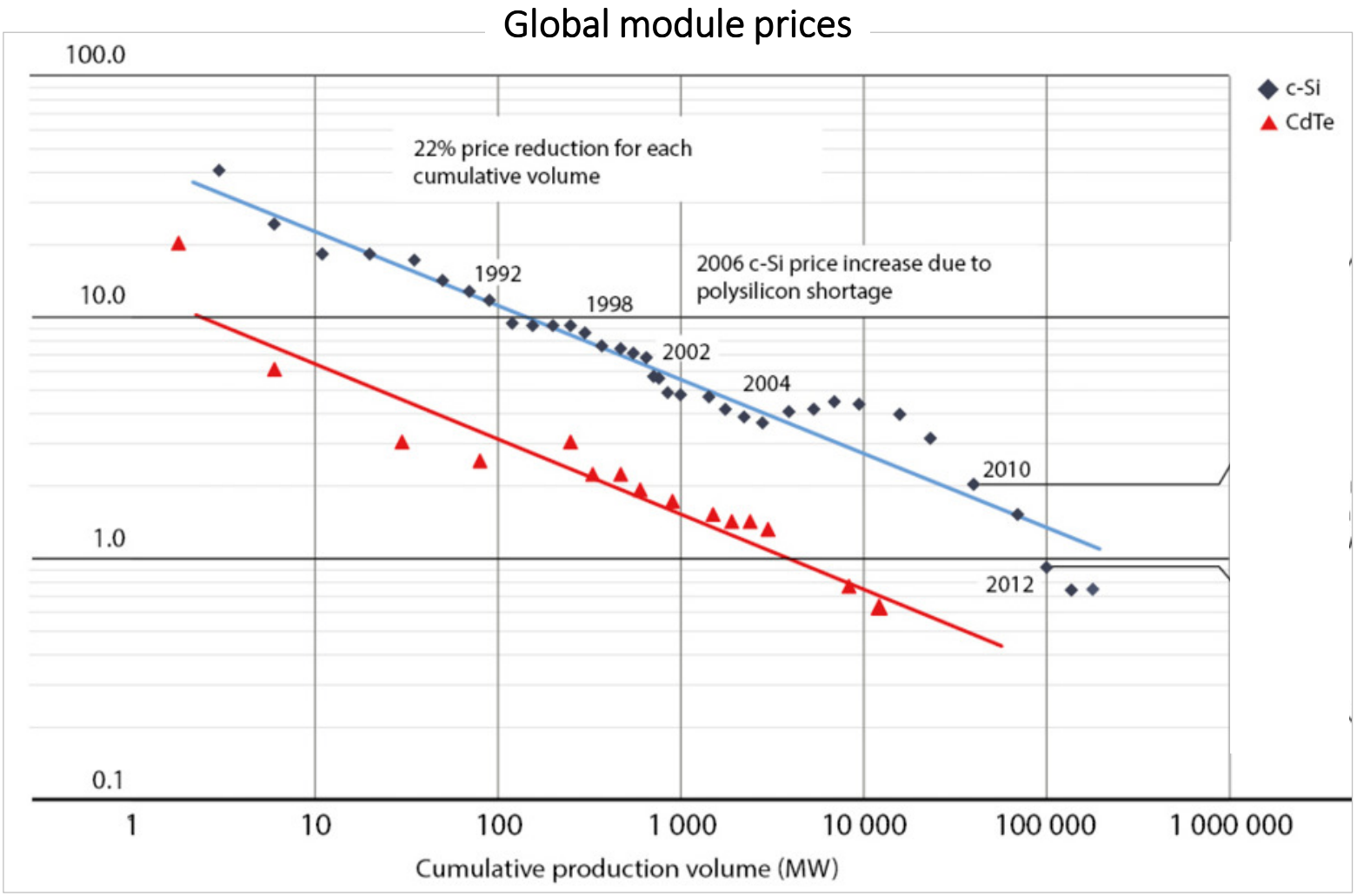
Technologies come and go



Source: Own figures, based on IEA data

In historical perspective, the rise of renewables is impressive. Also the renaissance of coal is visible (much more in other regions of the world).

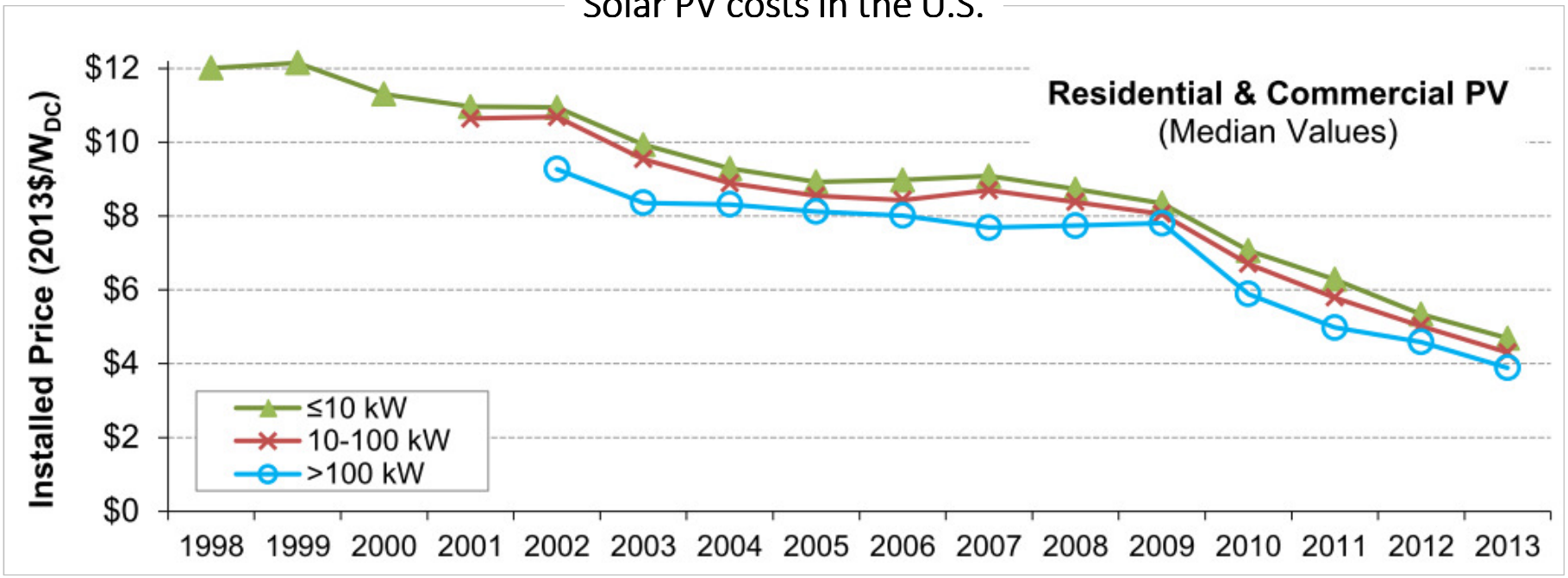
Renewables are becoming cheaper and cheaper ...



LBNL (2014): Tracking the Sun VII

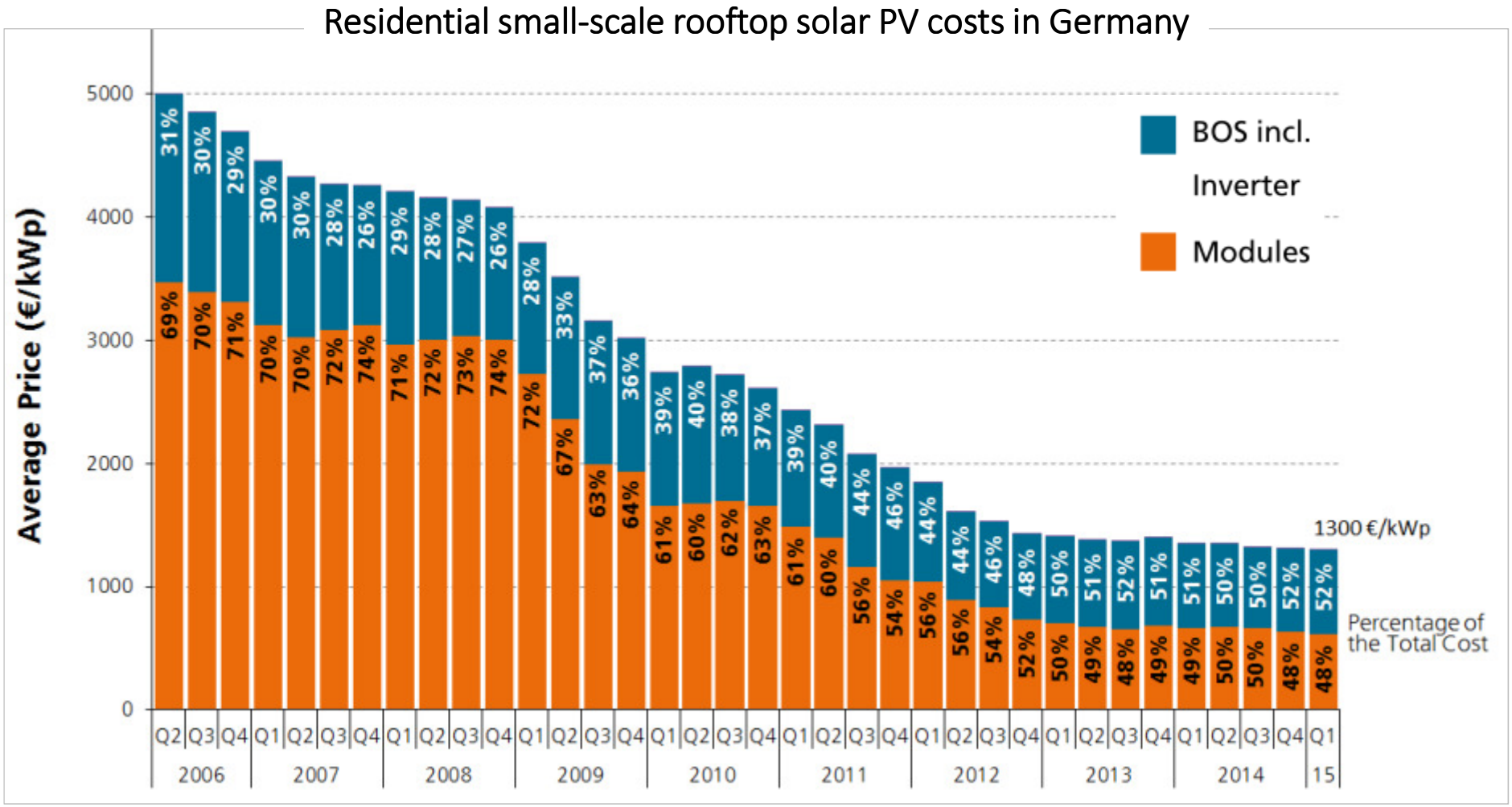
Renewables are becoming cheaper and cheaper ...

Solar PV costs in the U.S.



LBNL (2014): Tracking the Sun VII

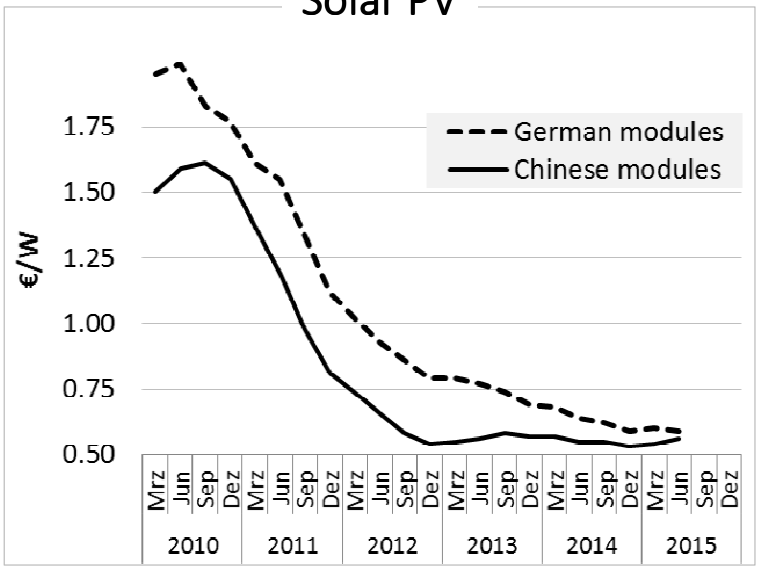
Renewables are becoming cheaper and cheaper ...



Source: Fraunhofer ISE (2015): Photovoltaics Report

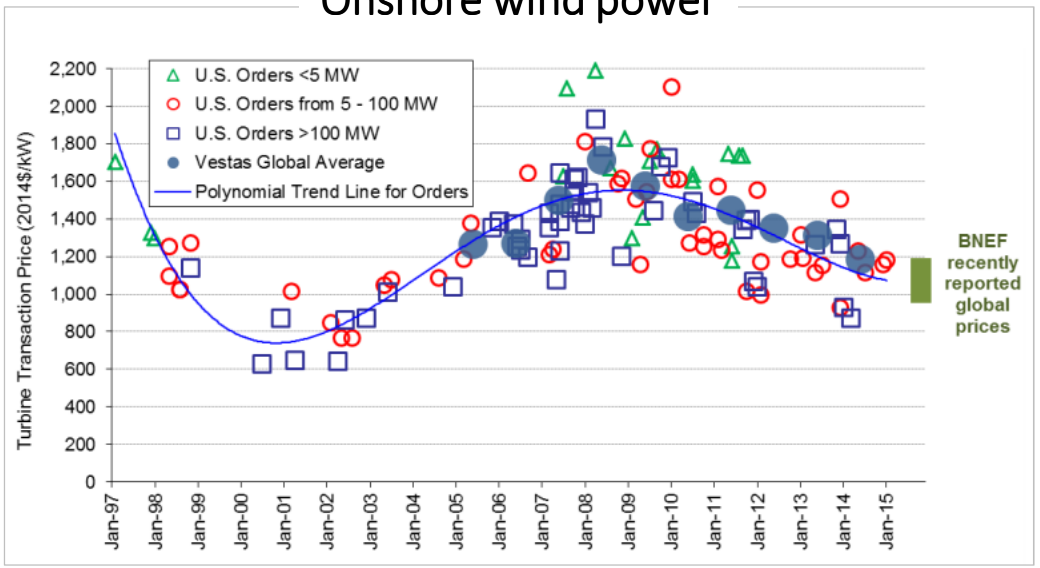
Renewables are becoming cheaper and cheaper ...

Solar PV



Data source: pvxchange.org (2015)

Onshore wind power

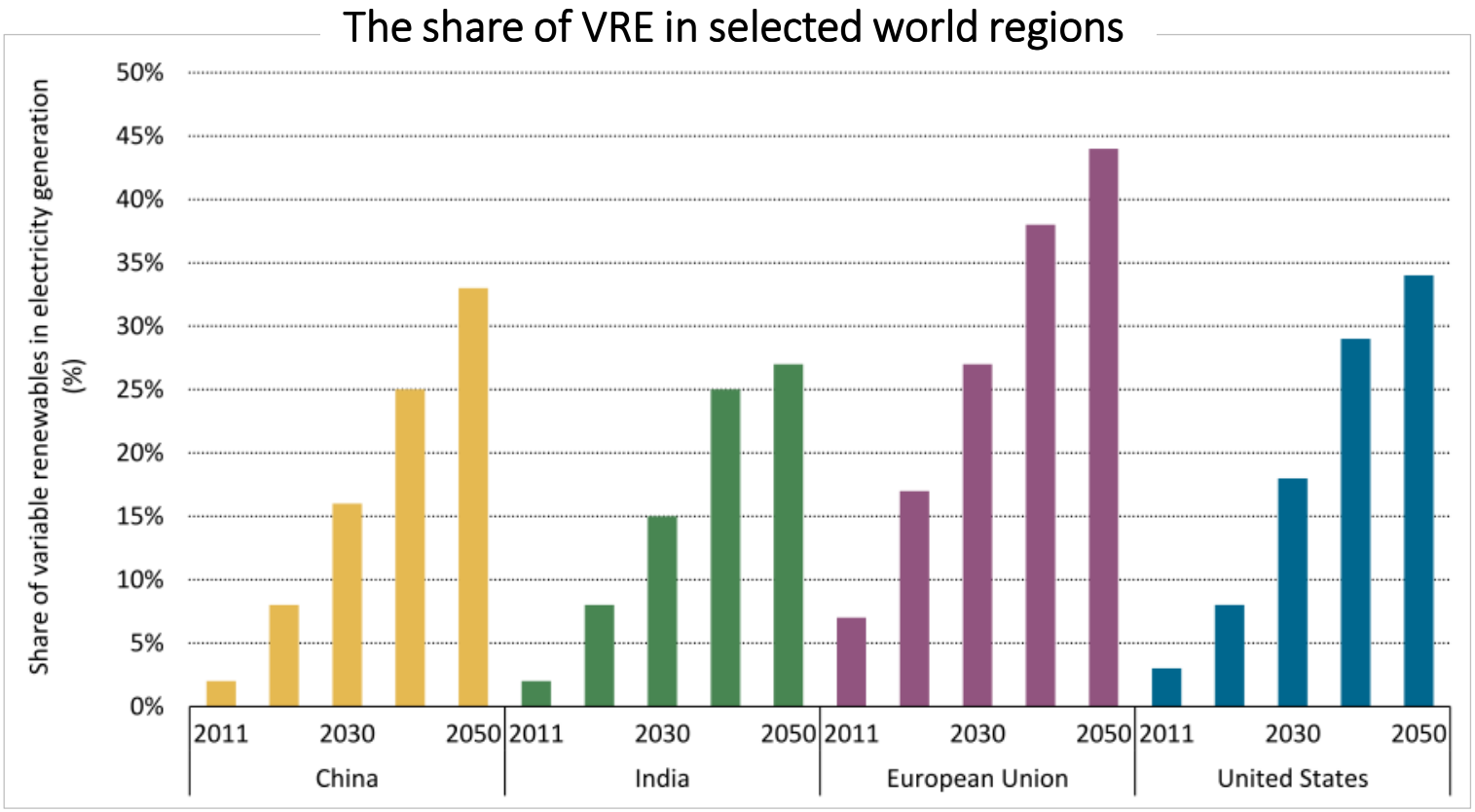


Source: LBNL (2015): Wind power market report

Solar PV module price stagnate since 2012 – after a hefty price drop 2012-12.

During the 2000s, wind turbine prices were on the rise for as long as a decade, driven by robust demand material prices.

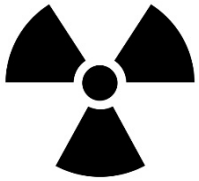
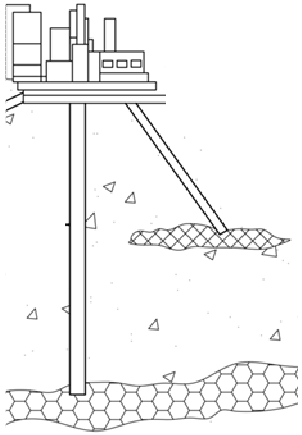
Variable renewables will supply a large share of power

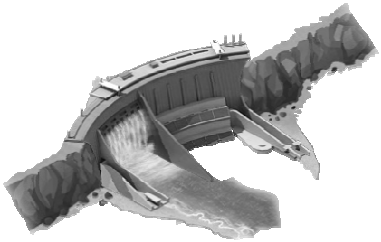
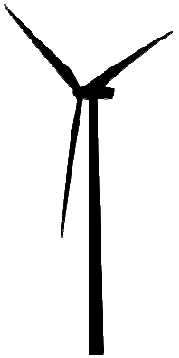


IEA (2014): Energy technology perspectives

IEA's *Energy Technology Perspectives* projects that in most major world regions, variable renewables will capture at least 25% market share in energy terms by the mid of this century – up from single digit numbers today.

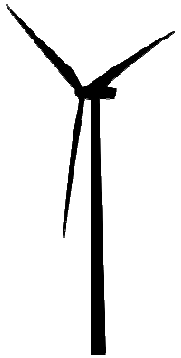
Six options for low-carbon electricity generation


“the *Energiewende* is all about wind and solar power”

(Agora Energiewende 2013)

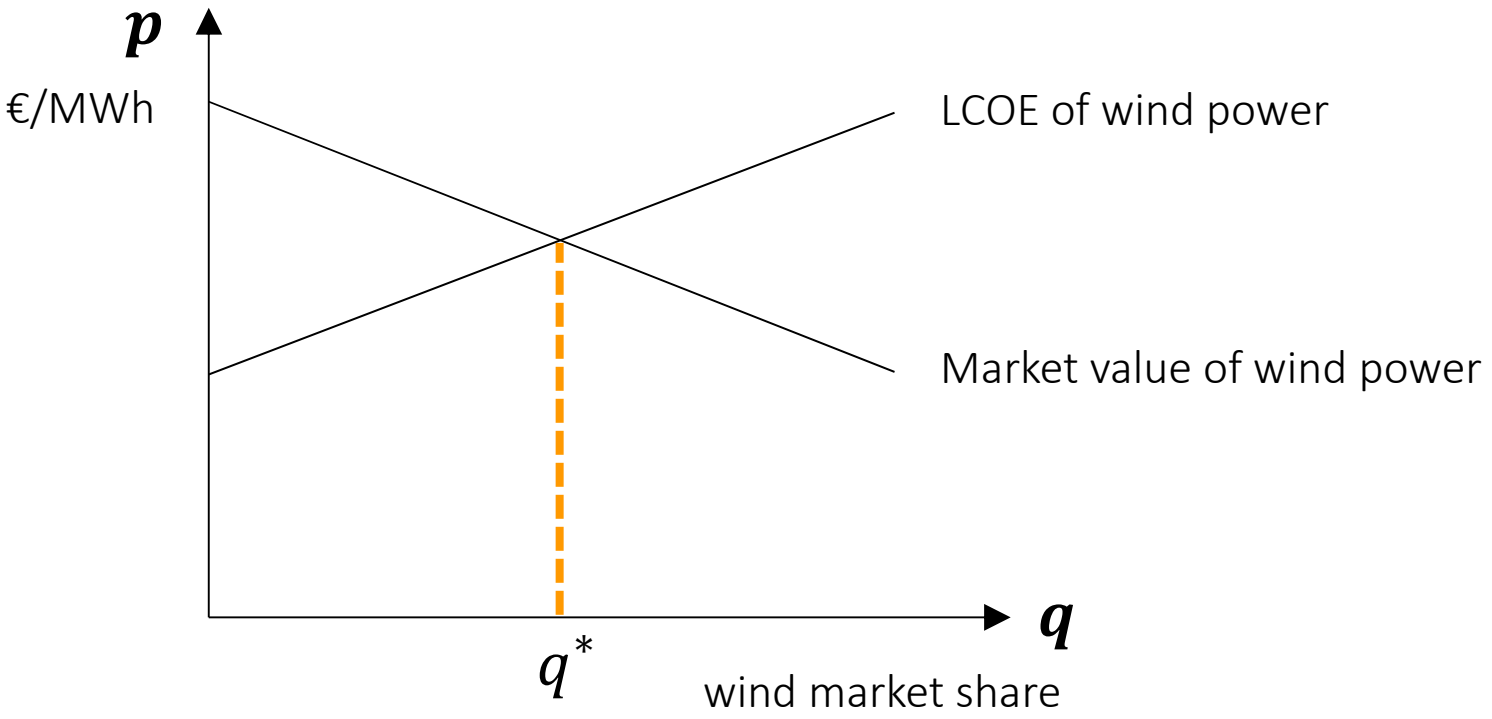


Economics has two sides: costs and *value*

The value of wind power

Why Wind is not Coal: On the Economics of Electricity, *The Energy Journal* (forthcoming).

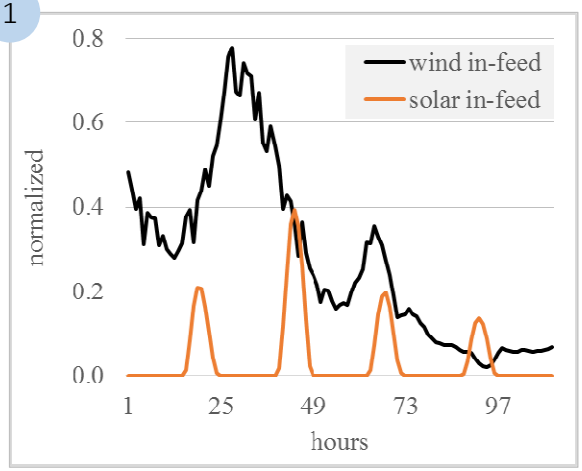
Long-term market equilibrium



The intersection of LCOE (long-term marginal costs) and market value (long-term marginal value) defines the long-term equilibrium (optimum).

Wind and sun: “intermittent” or “variable” sources

1



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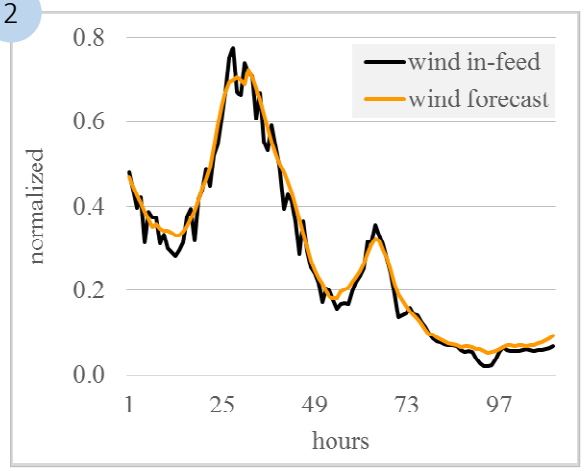

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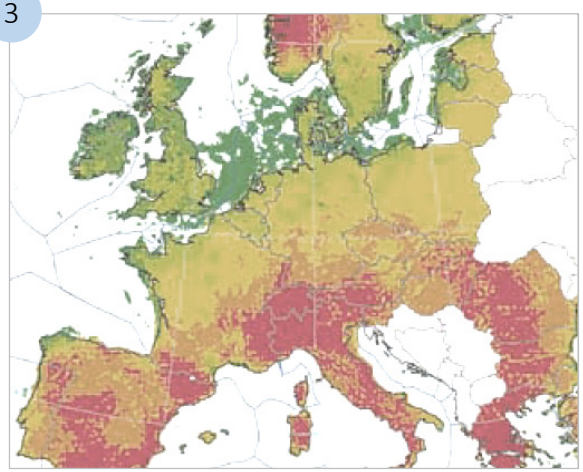


Updated from Hirth et al. (2016): Why wind is not coal

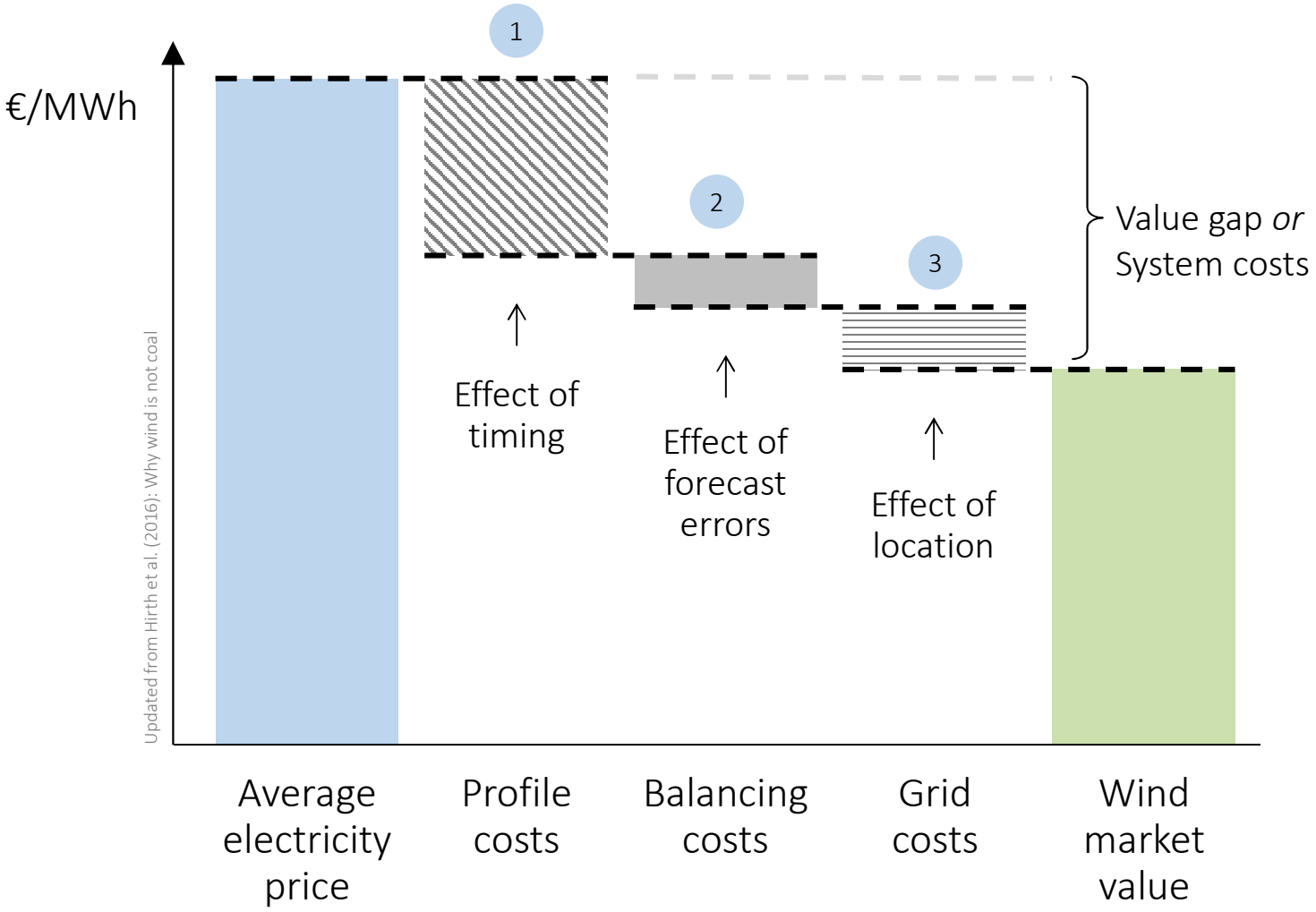
Wind does not always blow

Difficult to predict

Good sites are distant from load centers

“Variable“ renewable energy source (VRE)

The market value of wind power

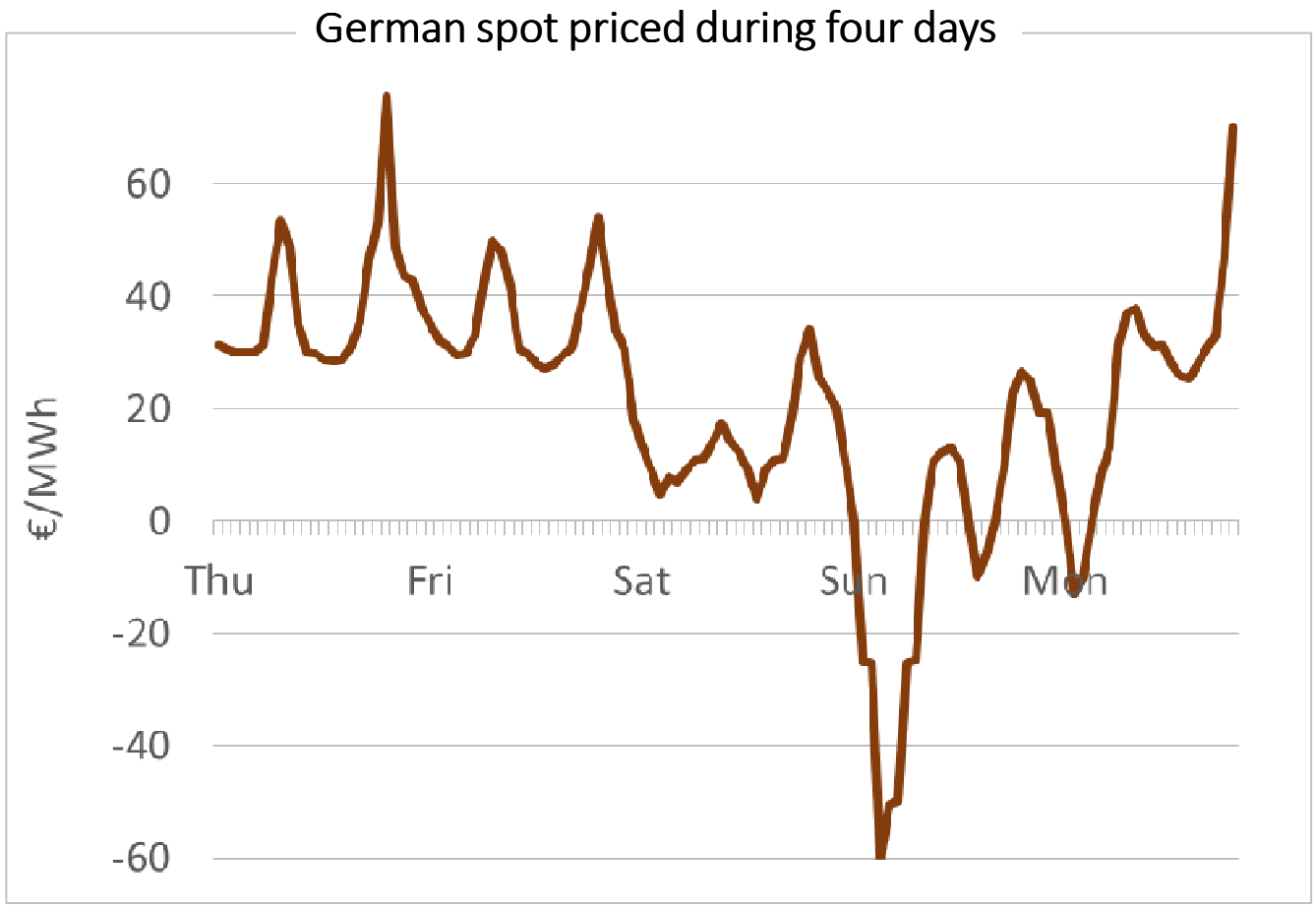


The wind and solar power value drop: market data

The Market Value of Variable Renewables, *Energy Economics*, 2013.

The Market Value of Solar Photovoltaics: Is solar power cost-competitive?, *IET Renewable Power Generation,* 2015.

For economics, it matters *when* electricity is produced



German day-ahead spot price. 13-17 March 2014. On Sunday morning, the instantaneous wind penetration rate exceeded 50%.

Value factor: the relative price of wind power

market data

Wind in Germany			
	Base price (€/MWh)	Wind Revenue (€/MWh)	Value Factor (1)
2001	23.1	22.7	0.96
…	…	…	…
2014	35	30	.86

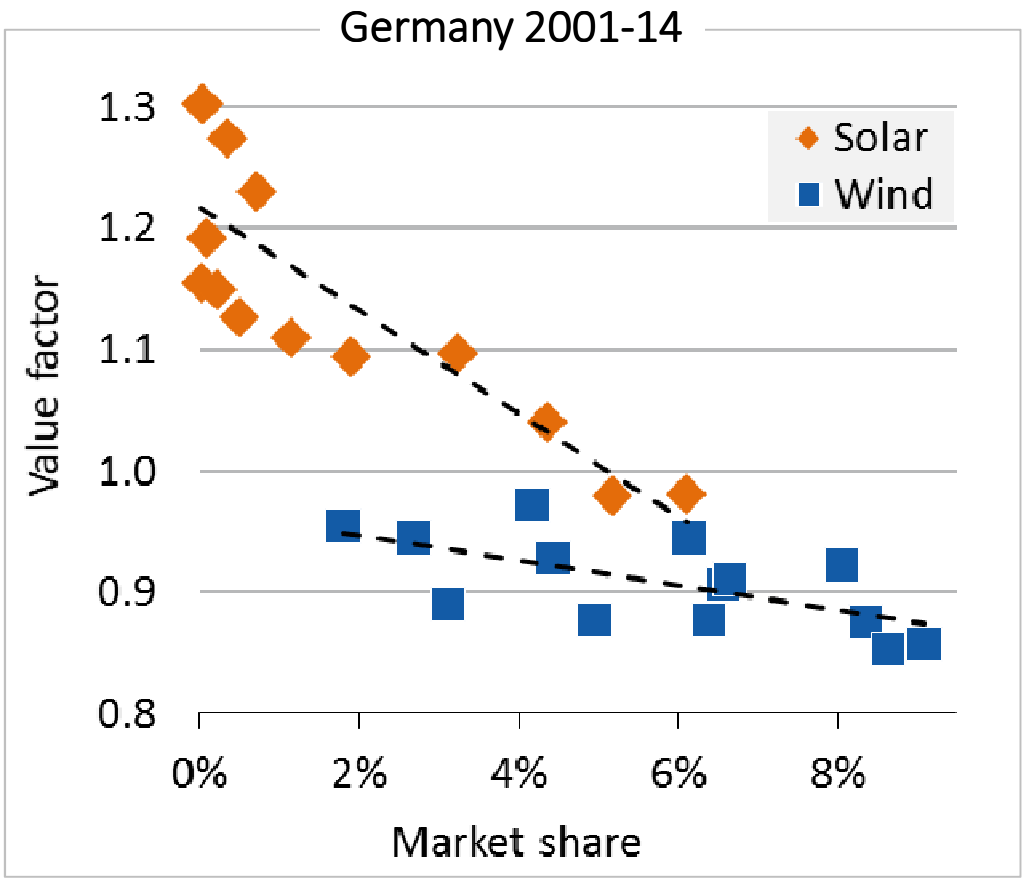
↑ Simple average of all hours of the year

↑ Wind-weighted average

↑ Ratio of these two

market data

The wind and solar value drop



Updated from Hirth (2013).: Market value

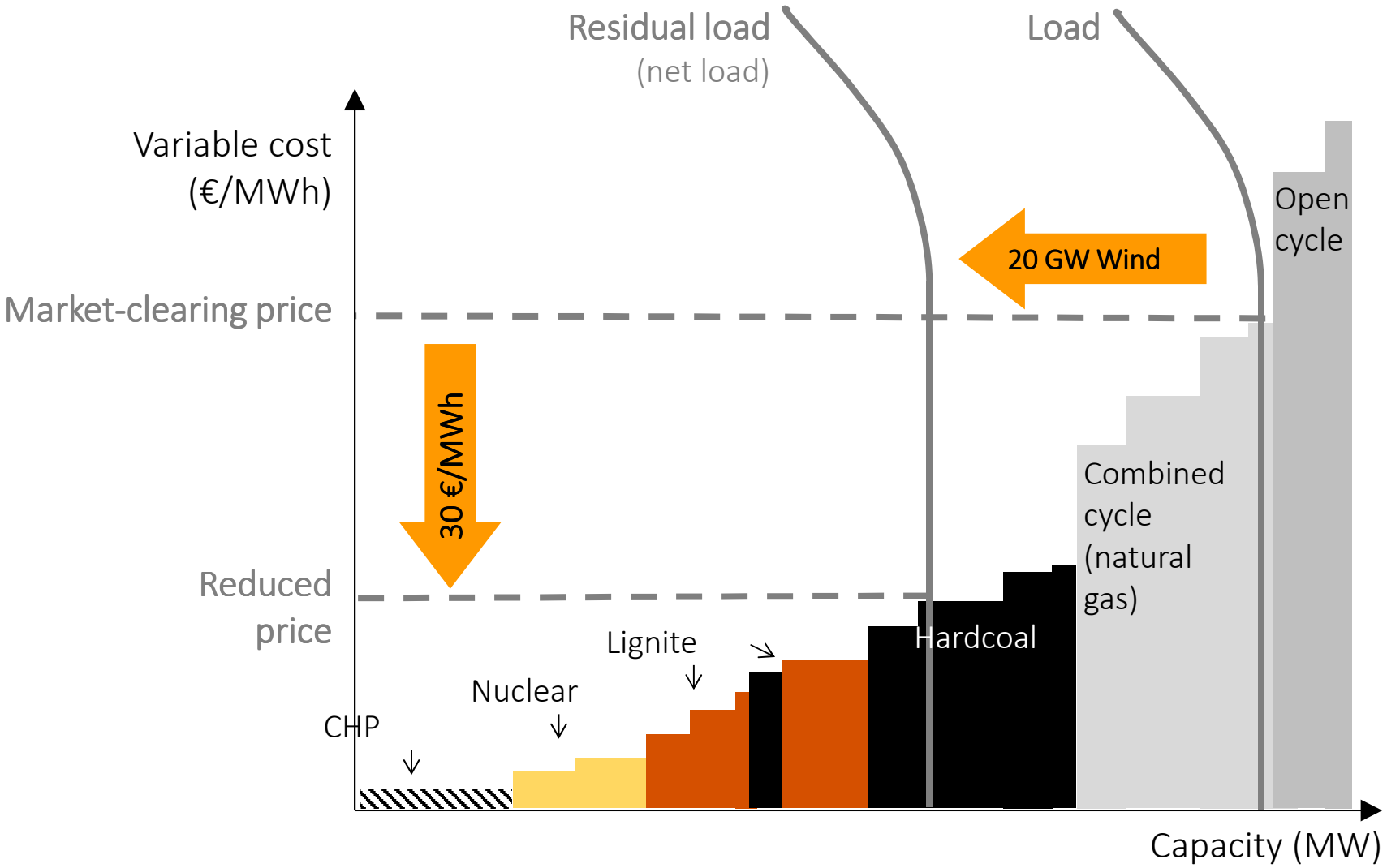
Value Factor = Market value / base price

Each dot represents one year

→ ?

The relative value of electricity from wind and solar power is reduced as their market share grows. This has been called the "cannibalization effect", but in fact it is simply diminishing returns. For solar power, the value drop is more pronounced.

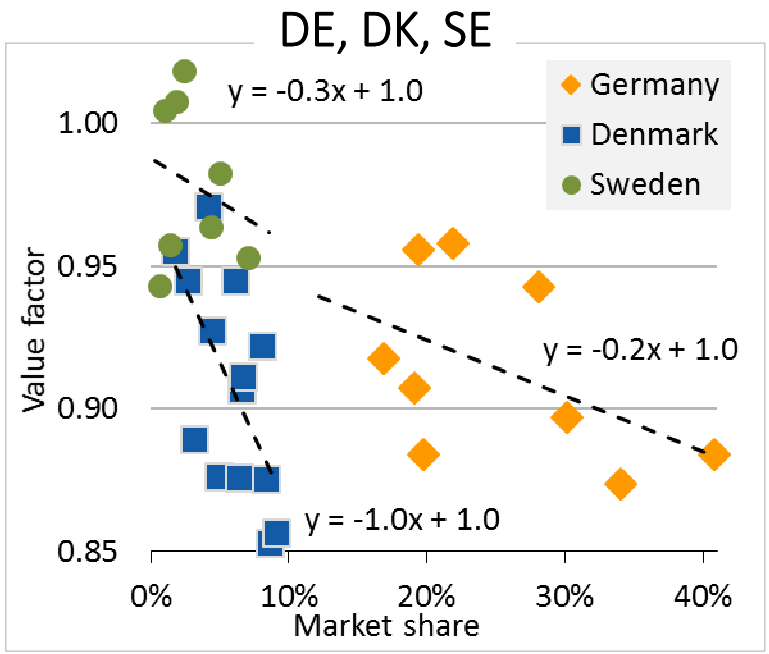
The mechanics behind the value drop

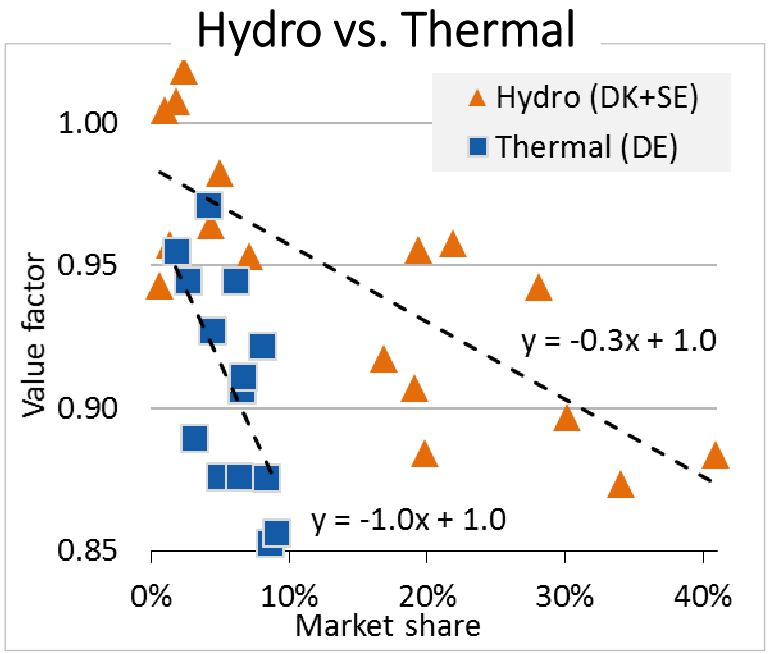


preliminary

market data

The value drop in hydro systems





In Germany, the value of wind power drops much more rapidly than in Sweden and Denmark.

Germany (thermal system): 1% per 1%
SE+DK (hydro system): 0.3% per 1%

Model results

The Market Value of Variable Renewables, *Energy Economics*, 2013.

The Market Value of Solar Photovoltaics: Is solar power cost-competitive?, *IET Renewable Power Generation,* 2015.

The Electricity Market Model EMMA

Numerical partial-equilibrium model of the European interconnected power market

Objective: minimize system costs

- Capital costs
- Fuel and CO2 costs
- Fixed and variable O&M costs
- ... of power plants, storage, interconnectors

Decision variables

- Hourly dispatch
- Yearly investment
- ... of plants, storage, interco's

Constraints

- Energy balance
- Capacity constraints
- Volume constraints of storage
- Balancing reserve requirement
- CHP generation
- (No unit commitment, no load flow)

Resolution

- Temporal: hours
- Spatial: bidding areas (countries)
- Technologies: eleven plant types

Input data

- Wind, solar and load data of the same year
- Existing plant stack

Equilibrium

- Short-/mid-/long-term model (= dispatch / capacity expansion / greenfield)
- Equilibrium ("one year") rather than a transition path ("up to 2030")

Economic assumptions

- Price-inelastic demand
- No market power
- Carbon price

Implementation

- Linear program
- GAMS / cplex

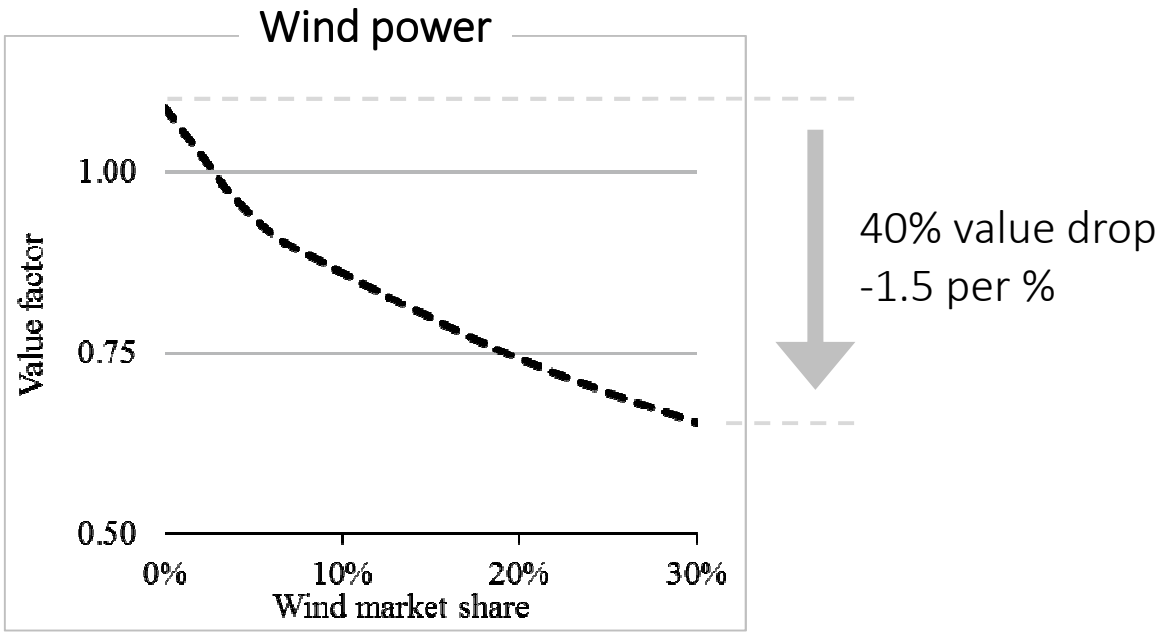
Applications

- Four peer-reviewer articles
- Various consulting projects
- Copenhagen Economics

Open source

$$P^*(Q,\cdot)$$

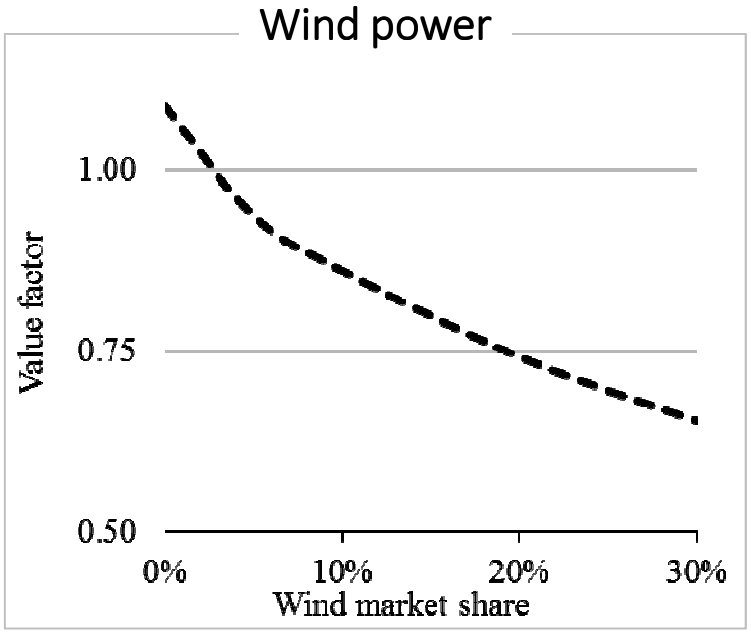
The value drop continues: model results



Updated from Hirth (2013): Market value

The value factor of wind power decreases from ~1.1 at low penetration to ~0.65 at 30% market share (1.5 points per point market share).

The value drop continues: model results



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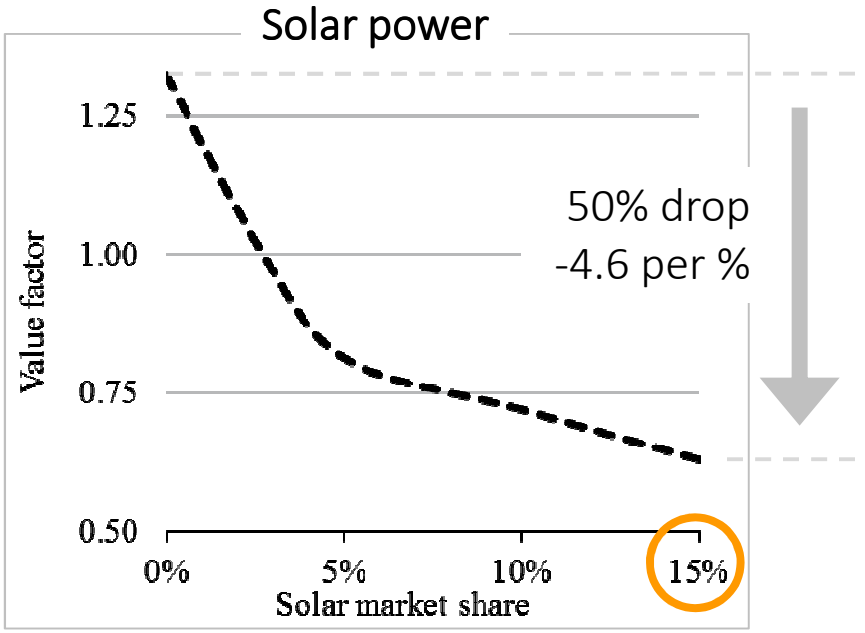


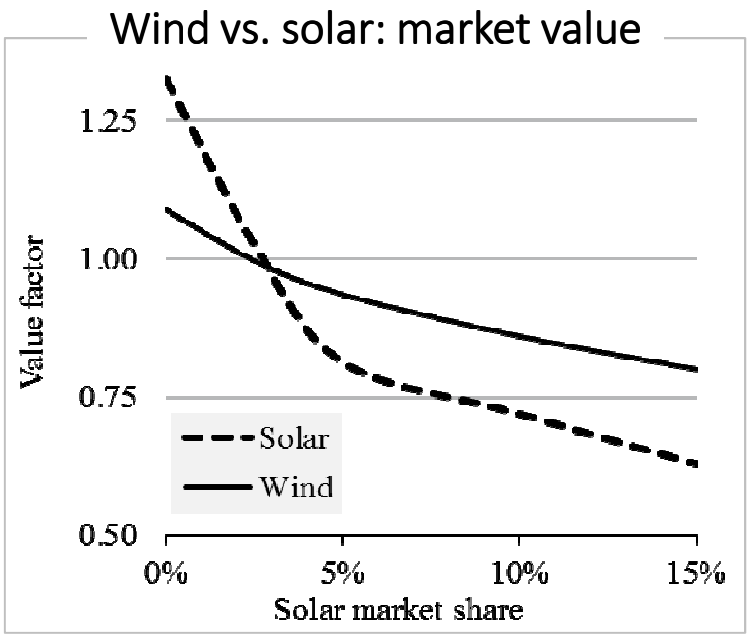
Updated from Hirth (2013): Market value

The value factor of wind power decreases from ~1.1 at low penetration to ~0.65 at 30% market share (1.5 points per point market share).

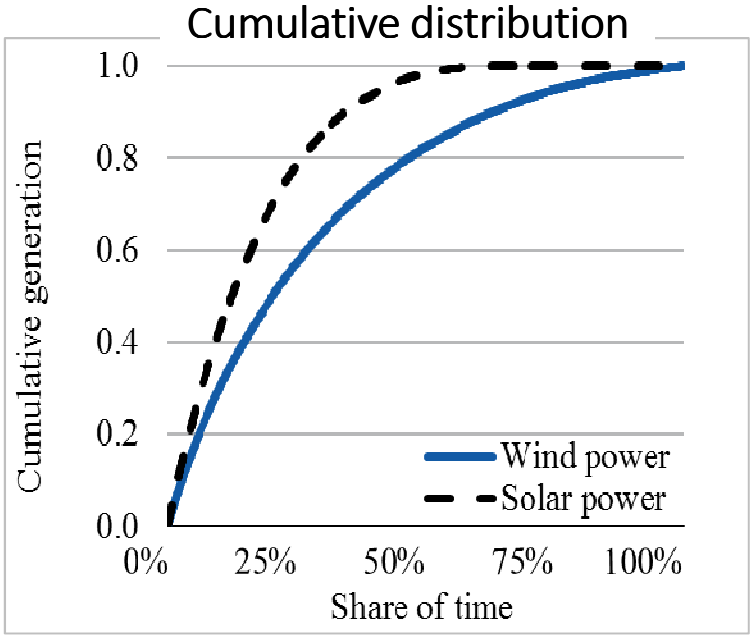
The value factor of solar power decreases from ~ 1.3 at low penetration to ~ 0.6 at 15% market share: (4.6 points per point market share).

model results

Solar generation is concentrated in very few hours



Updated from Hirth (2015): Market value solar



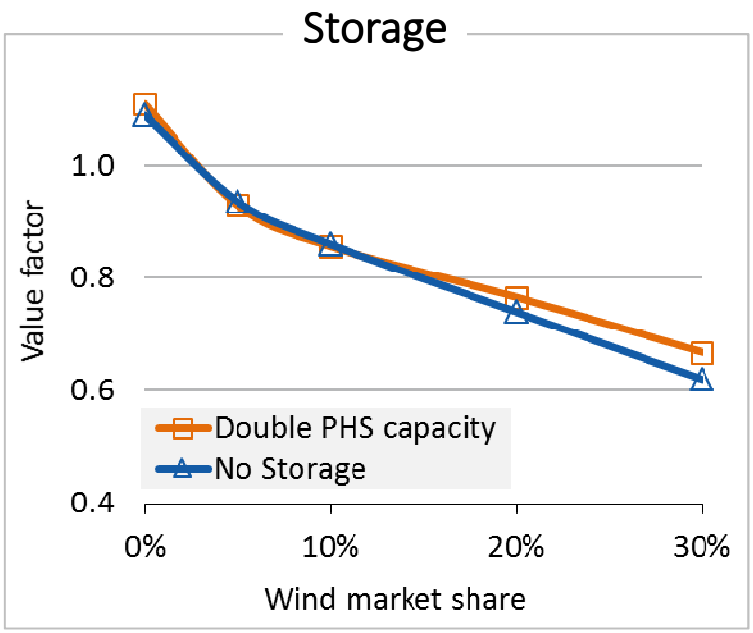
Updated from Hirth (2015): Market value solar

Solar power's market value is higher than wind power's at low penetration, but drops quicker.

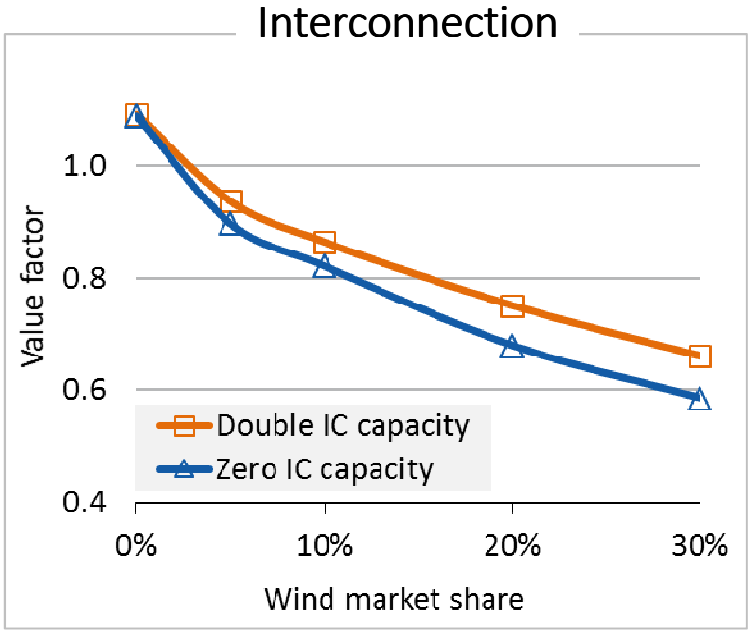
Solar generation is concentrated in fewer hours than wind power. The fundamental reason is earth's rotation: at night, the sun never shines.

model results

Storage and transmission help ... but not much



Updated from Hirth (2013): Market value

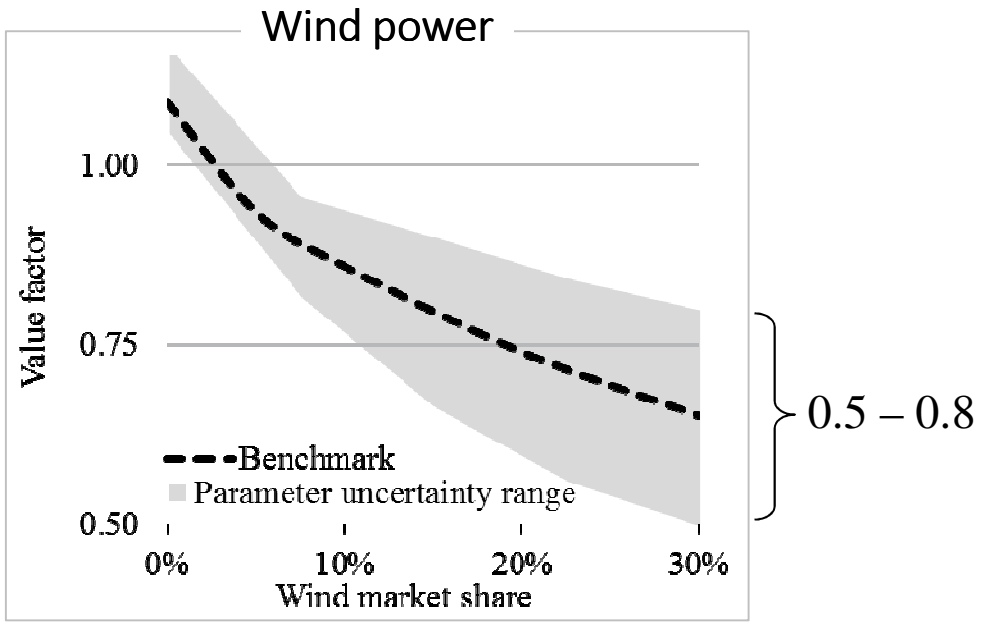


Updated from Hirth (2013): Market value

Doubling existing pump hydro storage capacity has a positive, but minor, impact on the value of wind power. The impact is larger for solar.

Doubling European interconnector capacity has a moderate positive.

The value drop continues: model results



Updated from Hirth (2013): Market value

The wind value factor falls to 0.5 to 0.8 at 30% penetration.

CO2 price between 0 – 100 €/t, Flexible ancillary services provision, Zero / double interconnector capacity, Flexible CHP plants, Zero / double storage capacity, Double fuel price, …

The value drop jeopardized…

… profitability

… phase-out of support schemes

… decarbonization of the power system

… renewables targets

… which is bad news for …

… investors in renewables

… finance ministers

… the climate

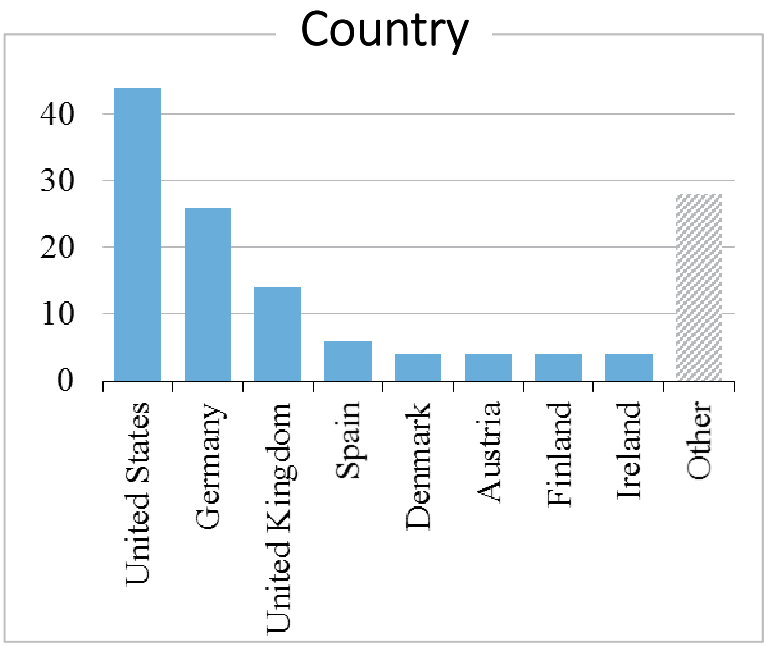
… the renewable industry

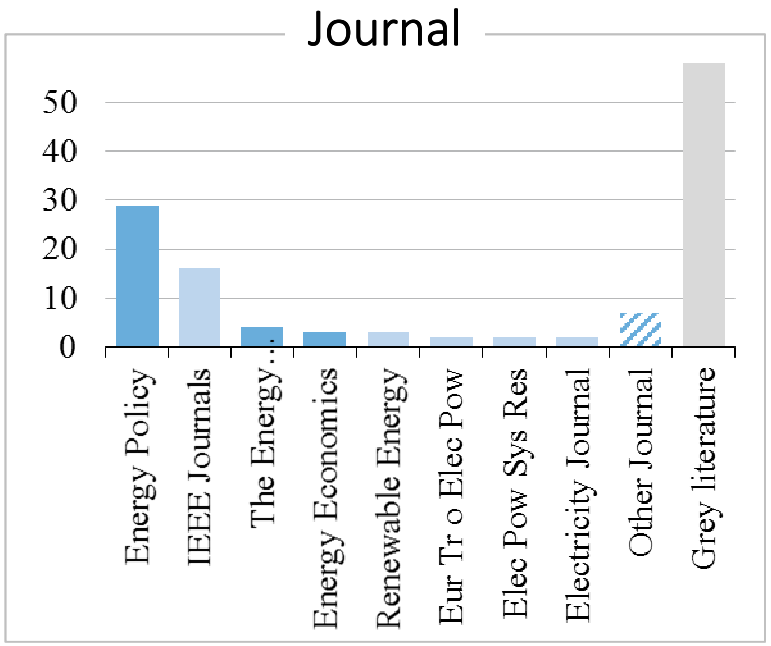
Literature review

The Market Value of Variable Renewables, *Energy Economics*, 2013.

The Market Value of Solar Photovoltaics: Is solar power cost-competitive?, *IET Renewable Power Generation,* 2015.

We reviewed 100+ studies

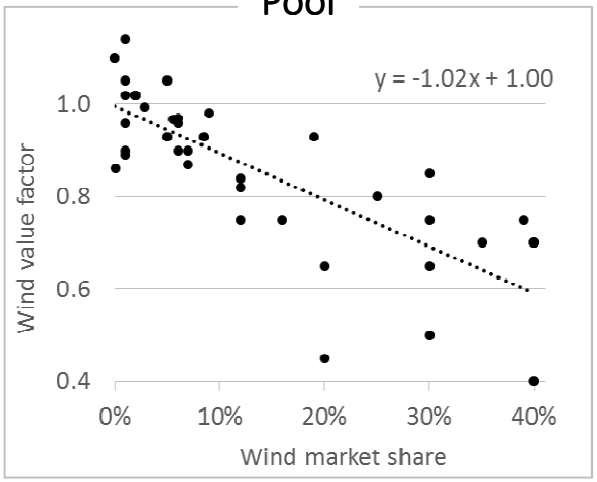




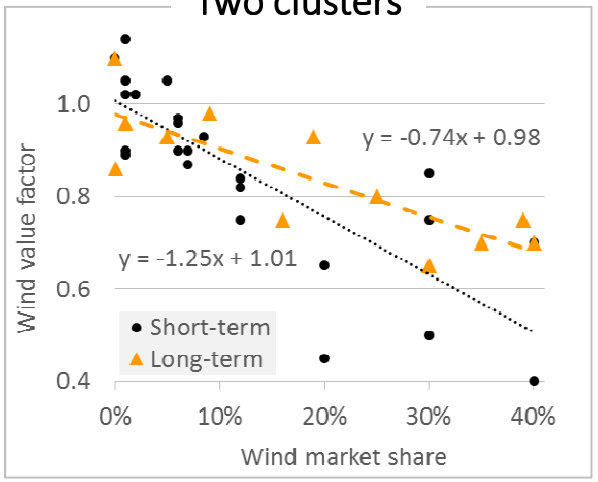
lit review

Three ways to look at the literature

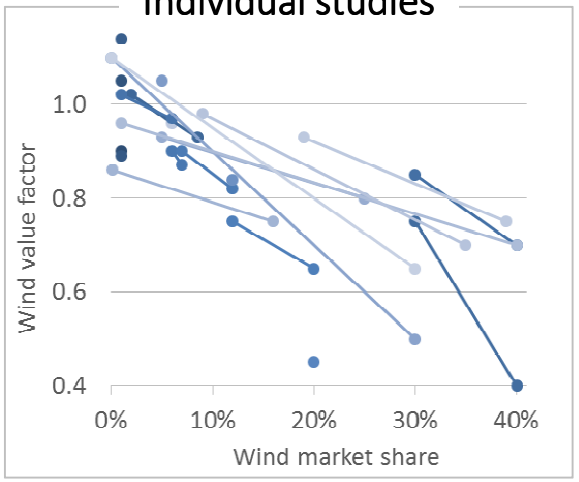
Pool



Two clusters



Individual studies



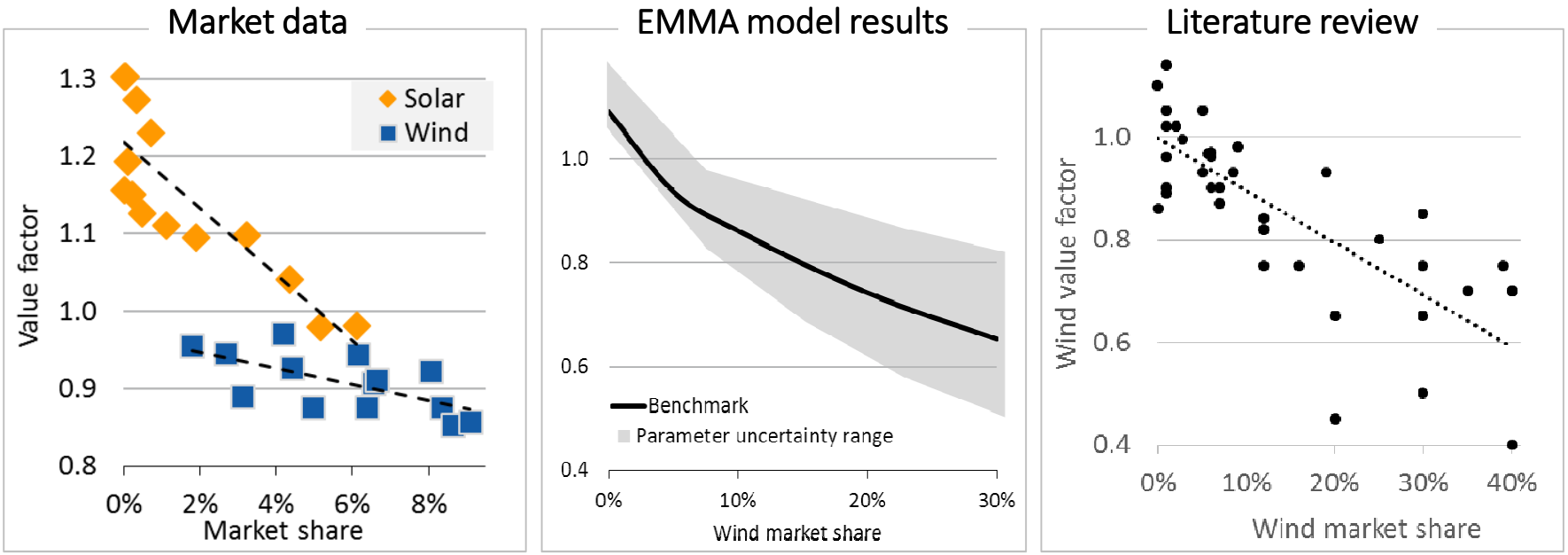
Hirth & Radebach (forthcoming)

All observations (pooled).

Two subsamples (short-term and long-term models).

Study by study (fixed effects estimator).

Different methodologies – robust finding: value drops



Updated from Hirth (2013): Market value and Hirth (2015): Market value solar

At 30% penetration, the value factor of wind falls to 0.5 – 0.8 of the base price. In Germany, it has already fallen from 0.96 to 0.86 as penetration increased from 2% to 8%. The value drop jeopardizes power system decarbonization and transformation.

Summing up: Market value

Low value of wind and solar power at high penetration

- Compared to value of other generators
- Compared to today‘s value of wind and solar power

Value drop is large

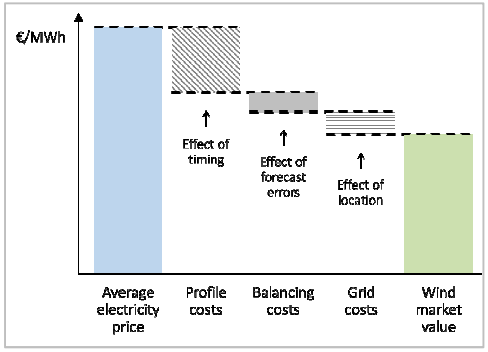
- ~40% value drop for wind
- In other words: a massive shift in relative prices
- Drop is at least twice as steep for solar as for wind

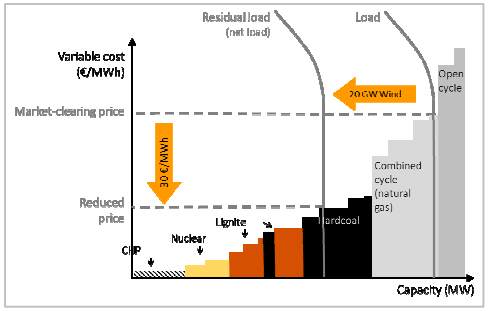
Robust results

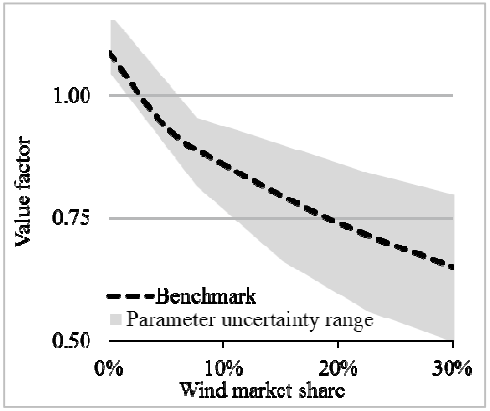
- w.r.t. parameter uncertainty
- w.r.t. model uncertainty

Profitability in questions

- Difficult to archive profitability at high penetration rate
- Puts into question ambitious renewables targets without subsidies







System-friendly wind power

System-friendly wind power, *Energy Economics*, forthcoming.

Mitigating the value drop: integration options

There exist a wide range of options to integrated VRE into power systems that help mitigating the value drop ("integration options" or "mitigation measures").

VRE-friendly system

- Demand response / price elasticity
- Electricity storage
- Long-distance interconnection
- Reservoir hydro power
- Reduce thermal must-run (CHP, ancillary services)
- Shifting the thermal generation mix from capital-intensive base load towards low-capex mid and peak load plants
- Spot and balancing market design

System-friendly VRE

- Optimized geographic allocation of VRE generators
- Diversification of VRE mix
- Low wind speed turbines with higher capacity factors
- East-west oriented solar modules with higher capacity factors

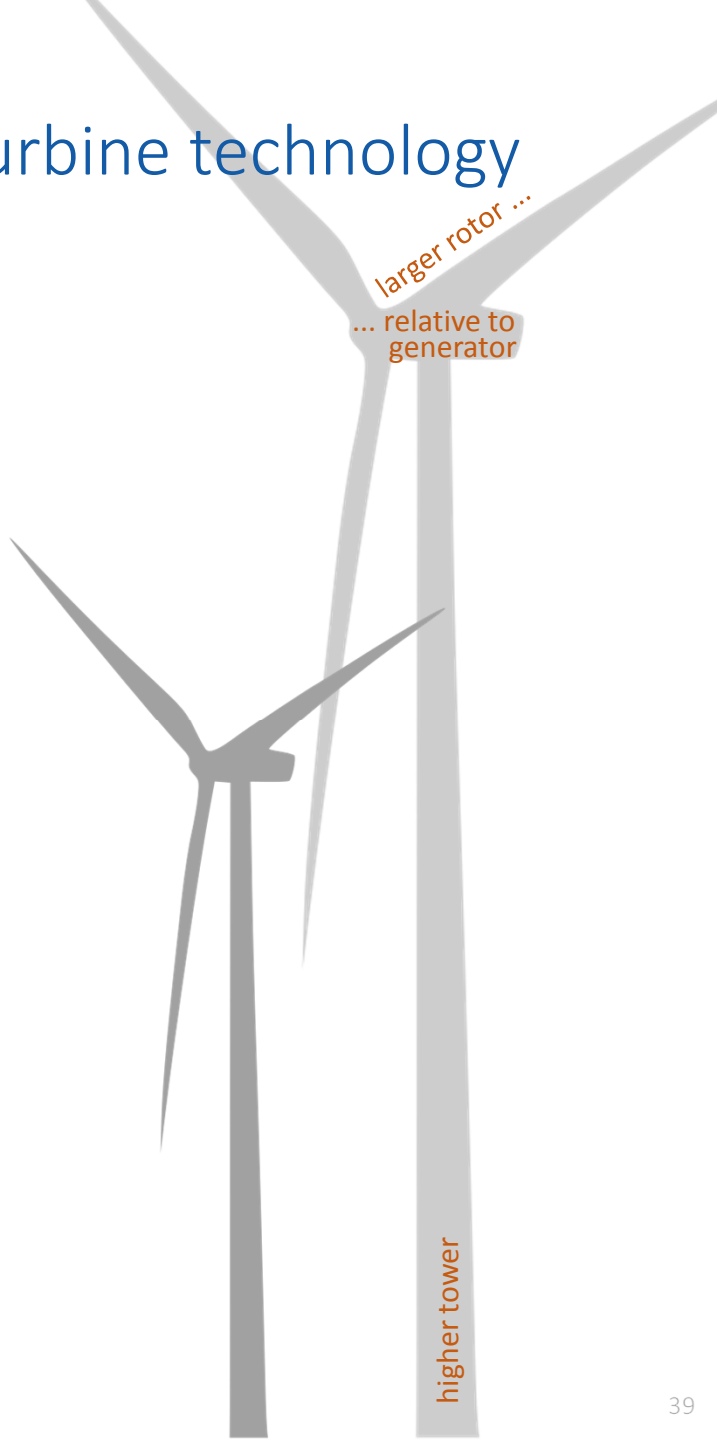
The *silent revolution*: new wind turbine technology

Wind turbine technology has changed dramatically during the past years…

- higher towers
- lower specific rating (W/m²)
- → increased capacity factors
- "advanced wind turbines"

… with potentially large effect on power systems and markets.

- higher capacity credit
- reduced grid expansion requirements
- impact on optimal thermal mix
- reduced storage & flexibility requirements
- less forecast errors
- *higher market value*



market data

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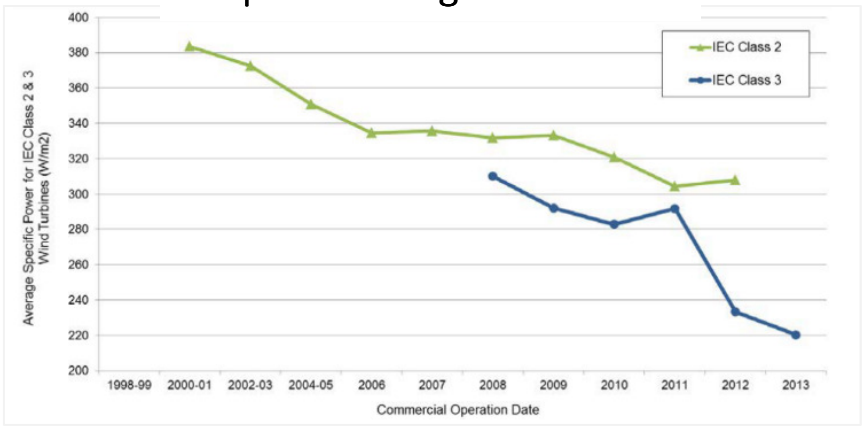
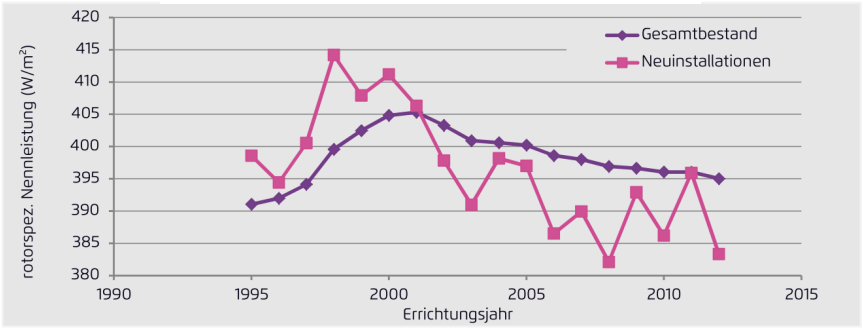
Specific rating in the U.S.



Wiser & Bolinger (2014)

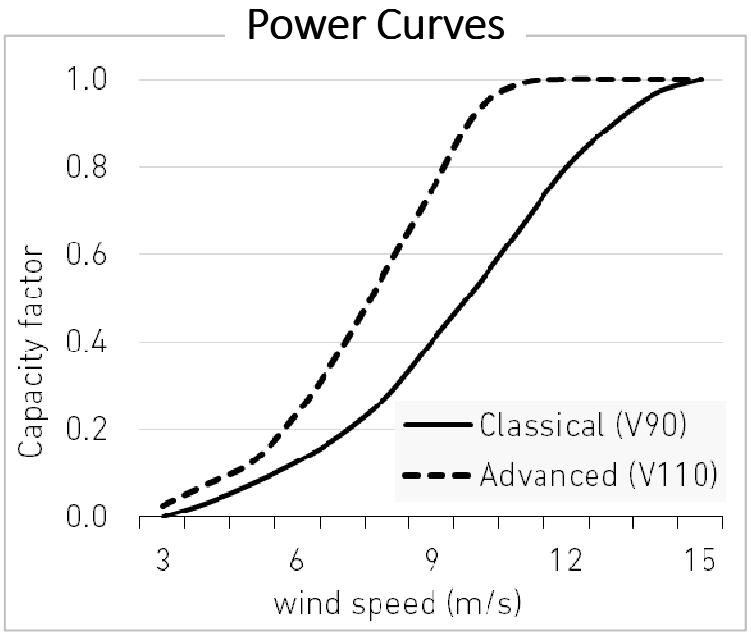
Specific rating in Germany



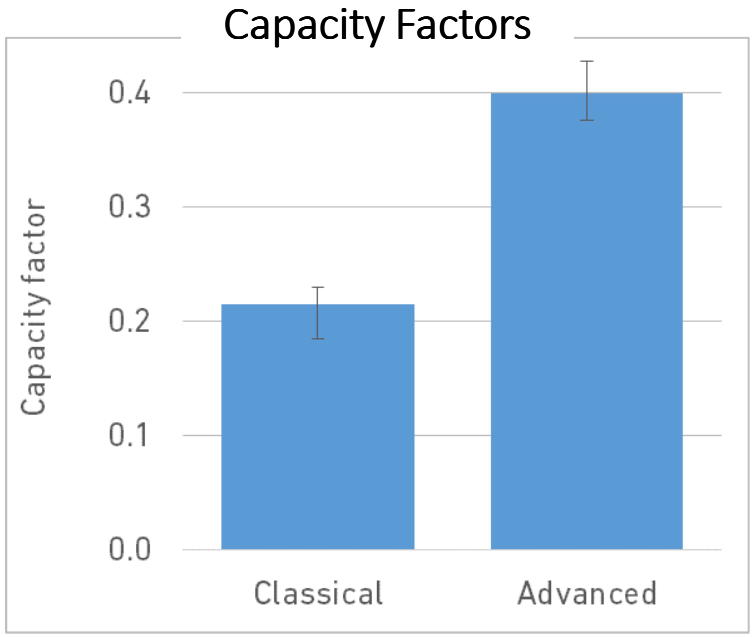
Fraunhofer IWES (2013)

model result

Advanced wind turbines are *very* different



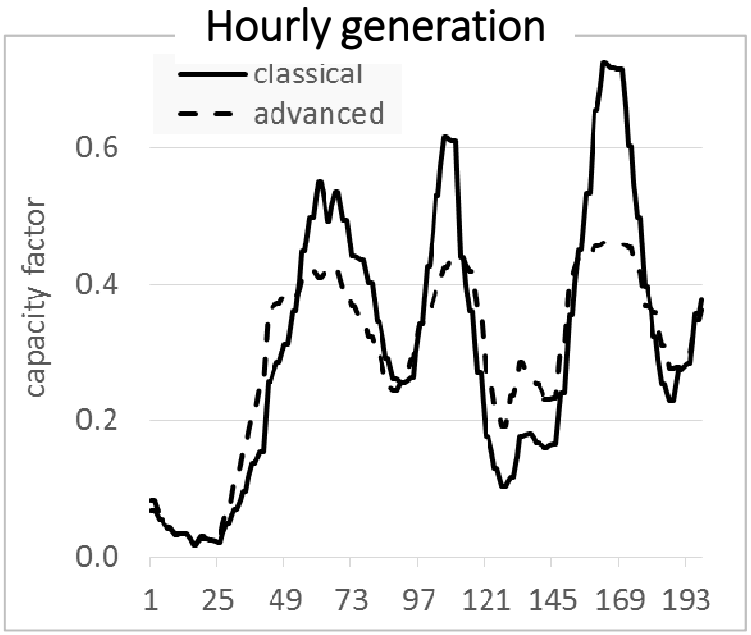
At intermediate wind speeds (8-10 m/s), advanced turbines generate much more electricity than classical turbines.

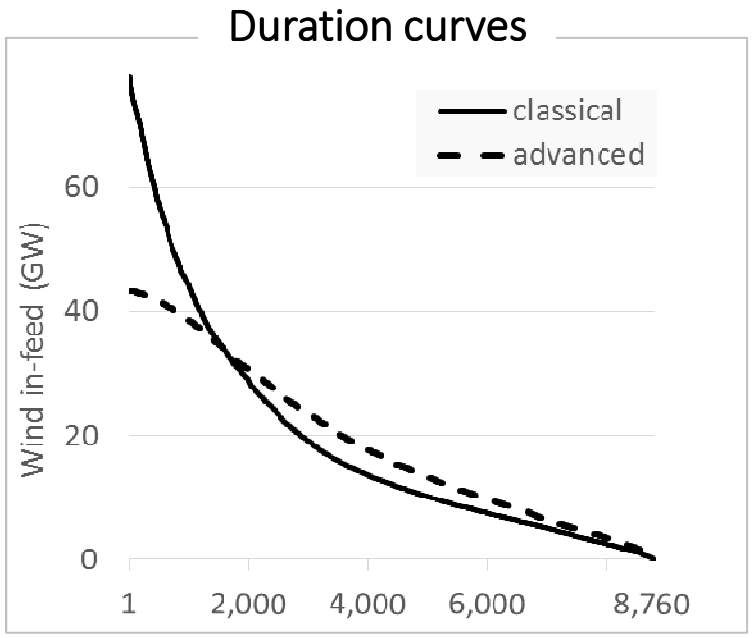


Advanced turbines can have twice the capacity factor of classical turbines.

model result

Much *smoother* generation profile





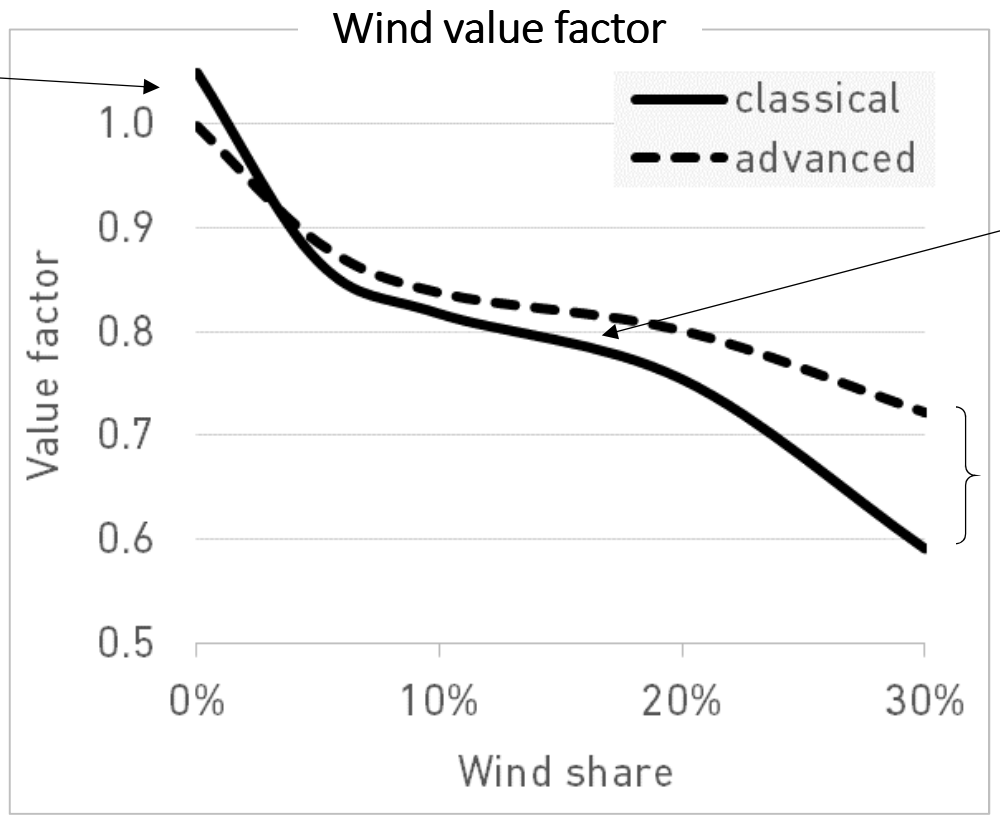
Less fluctuations of output...

... and more evenly distribution. (Both figures assume the yearly amount of electricity generated.)

model result

Major result: market value strongly increases

Classical turbines: stronger seasonal correlation with load



Delta becomes significant at 15% penetration

13 percentage-points (22%): large delta at high penetration

Penetration (always) in energy terms

Land-based wind power from system-friendly turbines is 22% more valuable than wind power from classical turbines (at 30% penetration).

Summing up: System-friendly wind power

Wind turbines are changing ...

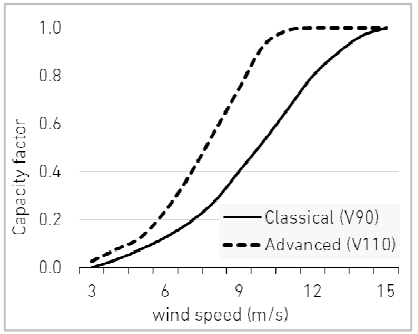
- higher towers
- lower specific rating
- → more constant power generation

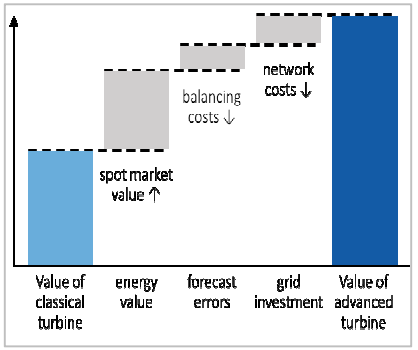
... improving the economics of wind power (€/MWh)

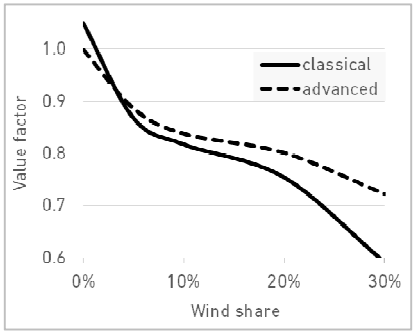
- higher spot market value
- reduced balancing costs
- reduced grid costs

~22% spot market value increase at 30% market share

- benefit increases with penetration
- large relative to other integration options
- robust with respect to parameter assumptions







Conclusions

1. Methodological conclusions

- Value differences among generators matter (not only for renewables) – comparing costs is misleading
- Wind and solar power variability matters – ignoring it can lead to large bias
- Surprising results – use models, and model capital adjustments

2. Technology conclusions

- The largest economic impact of wind and solar is to reduce the utilization of other plants, not forecast errors or grid costs
- Wind and solar require low-capex mid and peak load plants as counterparts – not base load technologies (nuclear, CCS)
- Reason is not inflexibility, but capital-intensity
- Flexible (reservoir) hydro power can be a crucial enabler

Conclusions

3. Economic conclusions

- Variability has major economic costs at high penetration rate
- This materializes in different ways, mostly as a loss of spot market value
- The value loss is *not* caused by a "flawed" design of power markets, but a fundamental economic effect

4. Policy conclusions

- A smaller role for VRE than some hope, even at a high CO_2 price ...
- ... but (much) larger than today
- Many options to mitigate the value drop: flexible plants, reservoir hydro power, system-friendly wind turbines are among the most promising
- Design markets and policies properly: let prices signal scarcity!

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Integration Costs	Hirth, Lion, Falko Ueckerdt & Ottmar Edenhofer (2015): "Integration Costs Revisited – An economic framework of wind and solar variability", *Renewable Energy* 74, 925–939. http://dx.doi.org/10.1016/j.renene.2014.08.065
Market Value	Hirth, Lion (2013): "The Market Value of Variable Renewables", *Energy Economics* 38, 218-236. http://dx.doi.org/10.1016/j.eneco.2013.02.004
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System LCOE	Ueckerdt, Falko, Lion Hirth, Gunnar Luderer & Ottmar Edenhofer (2013): "System LCOE: What are the costs of variable renewables?", *Energy* 63, 61-75. http://dx.doi.org/10.1016/j.energy.2013.10.072
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Balancing Power	Hirth, Lion & Inka Ziegenhagen (2015): "Balancing power and variable renewables: Three links", *Renewable & Sustainable Energy Reviews* 50, 1035-1051. http://dx.doi.org/10.1016/j.rser.2015.04.180
open access:	www.neon-energie.de/publications/

Neon project references

Neon is a Berlin-based boutique consulting firm for energy economics. We combine expertise on economic theory with advanced modelling capabilities and extensive industry experience. Neon specializes in five areas:

1. Market value of wind power
2. Design of spot and balancing power markets
3. System costs / integration costs
4. Open-source power market modeling

System-friendly wind and solar power (IEA). Model-based study for the International Energy Agency, Paris. Neon assessed the market and system benefits of low-wind speed wind turbines and east- and west-oriented PV based on its power market model EMMA. The study has been published by the IEA. More

Integration costs (Agora Energiewende). Literature-based study for Agora Energiewende, Berlin. Neon advised Agora and helped implementing workshops in Berlin and Paris. The report has been published by Agora. More

Open Power System Data (BMWi). Construction of an open platform for European power system data for the German Ministry of Economic Affairs an Energy. Neon coordinates a team of three research institutes. The project runs 2015-17. More

Electricity market design (IEA-RETD). Project on power market design under very high shares of variable renewables. Wholesale, balancing, and retail markets are covered in different markets, ranging from liberalized to vertically integrated. Neon is conducting the project in cooperation with FTI CompassLexecon Energy. More

Model support (Vattenfall). Neon supported Vattenfall in power market modeling.

Power market trainings. Neon trained staff at IRENA, ERRA, Vattenfall, JRC, UFZ, Swedenergy, Clean Air Task Force, IG Windkraft in topics such as power markets, energy economics, and electricity policy. More

Market value and the future of renewables

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