The Market Value of Wind and Solar Power: an Analytical Approach

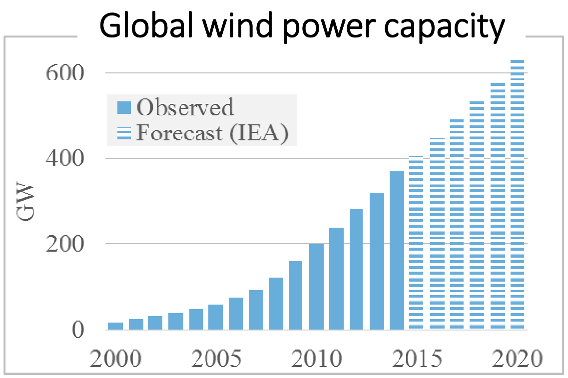
Lion Hirth & Alexander Radebach

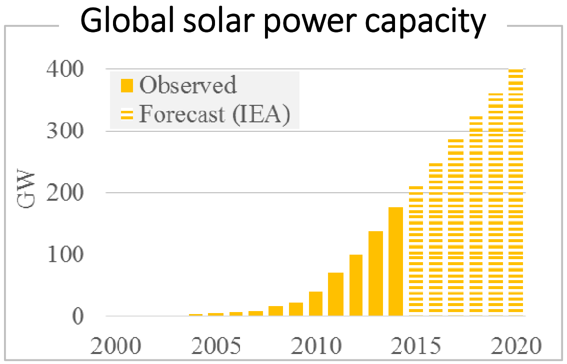
Strommarkttreffen | 27 November 2015 | hirth@neon-energie.de

neon neue energieökonomik

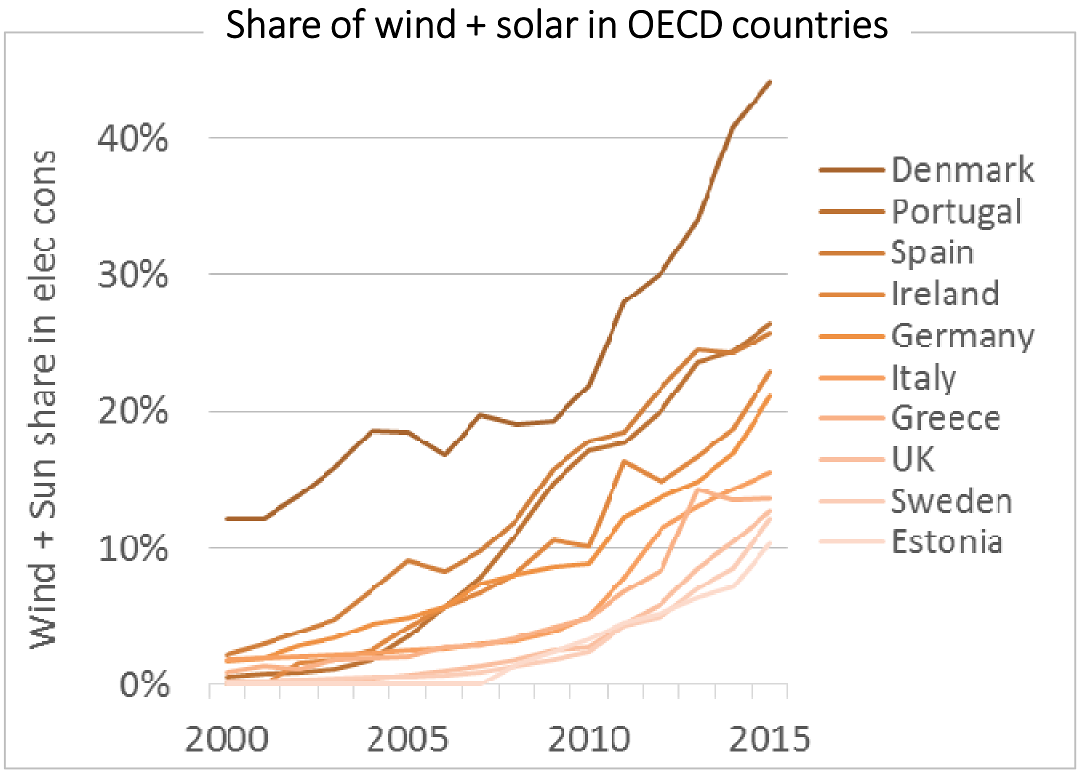
This is work in progress

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





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

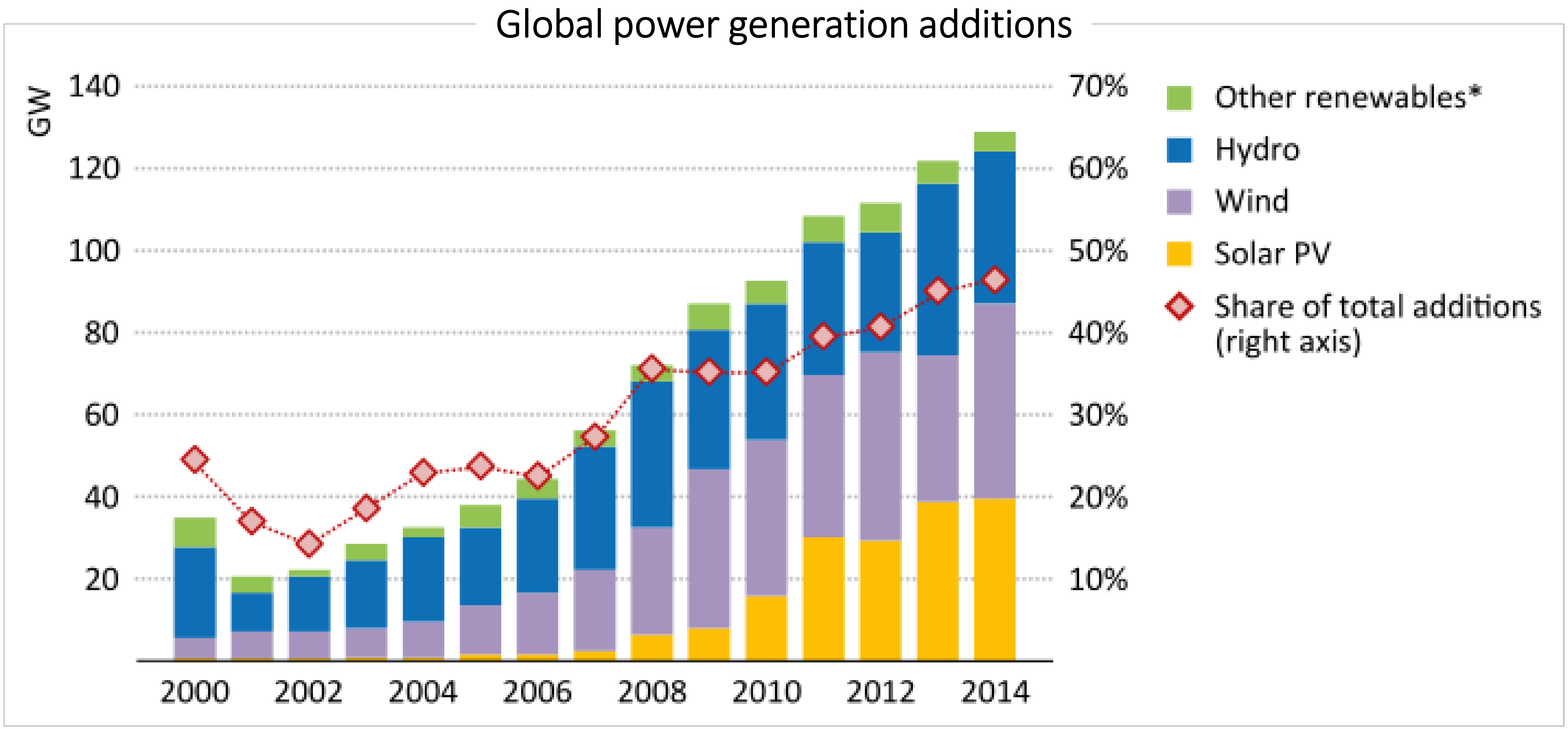


Data source: IEA (2015

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.

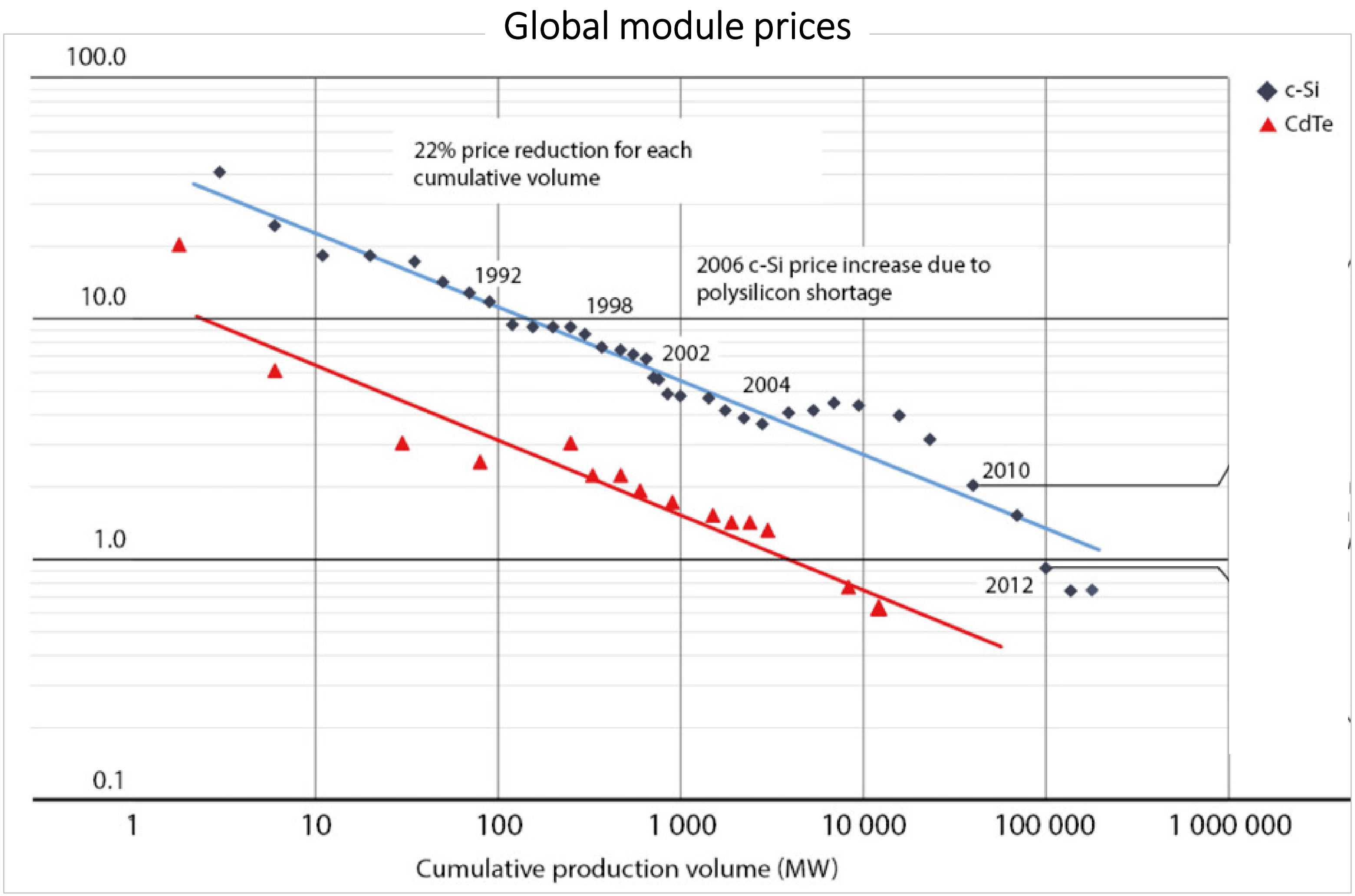
50% of globally added capacity is renewable



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%.

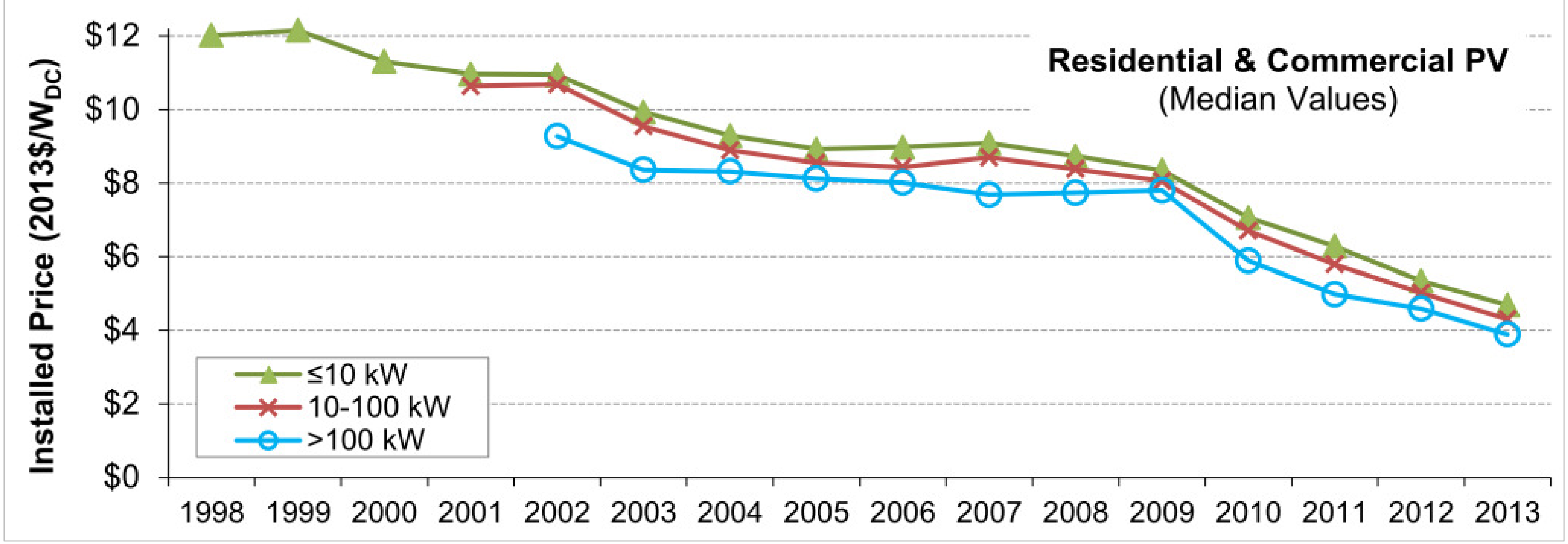
Renewables are becoming cheaper and cheaper ...



LBNL (2014): Tracking the Sun VII

Renewables are becoming cheaper and cheaper ...

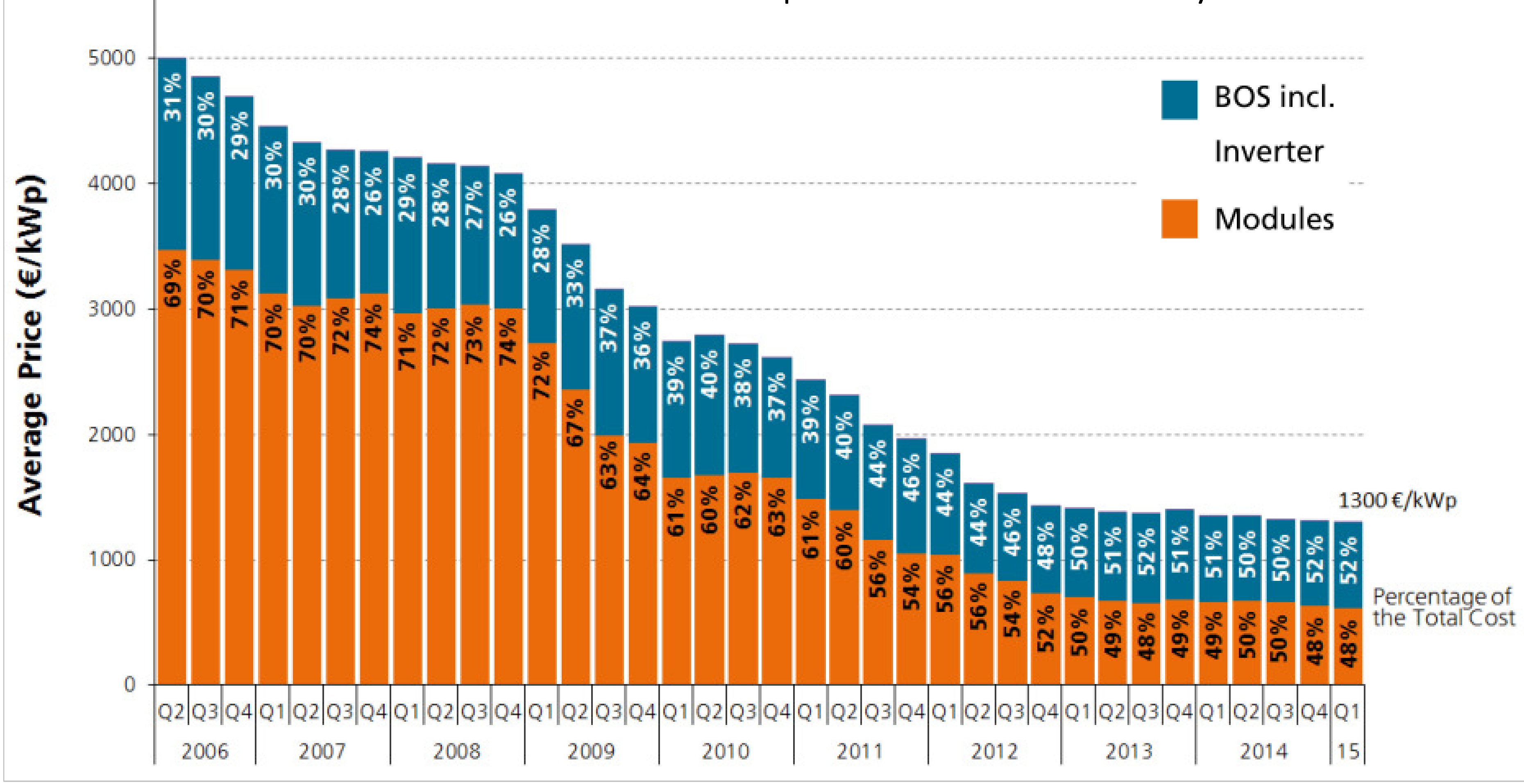
Solar PV costs in the U.S.



LBNL (2014): Tracking the Sun VII

Renewables are becoming cheaper and cheaper ...

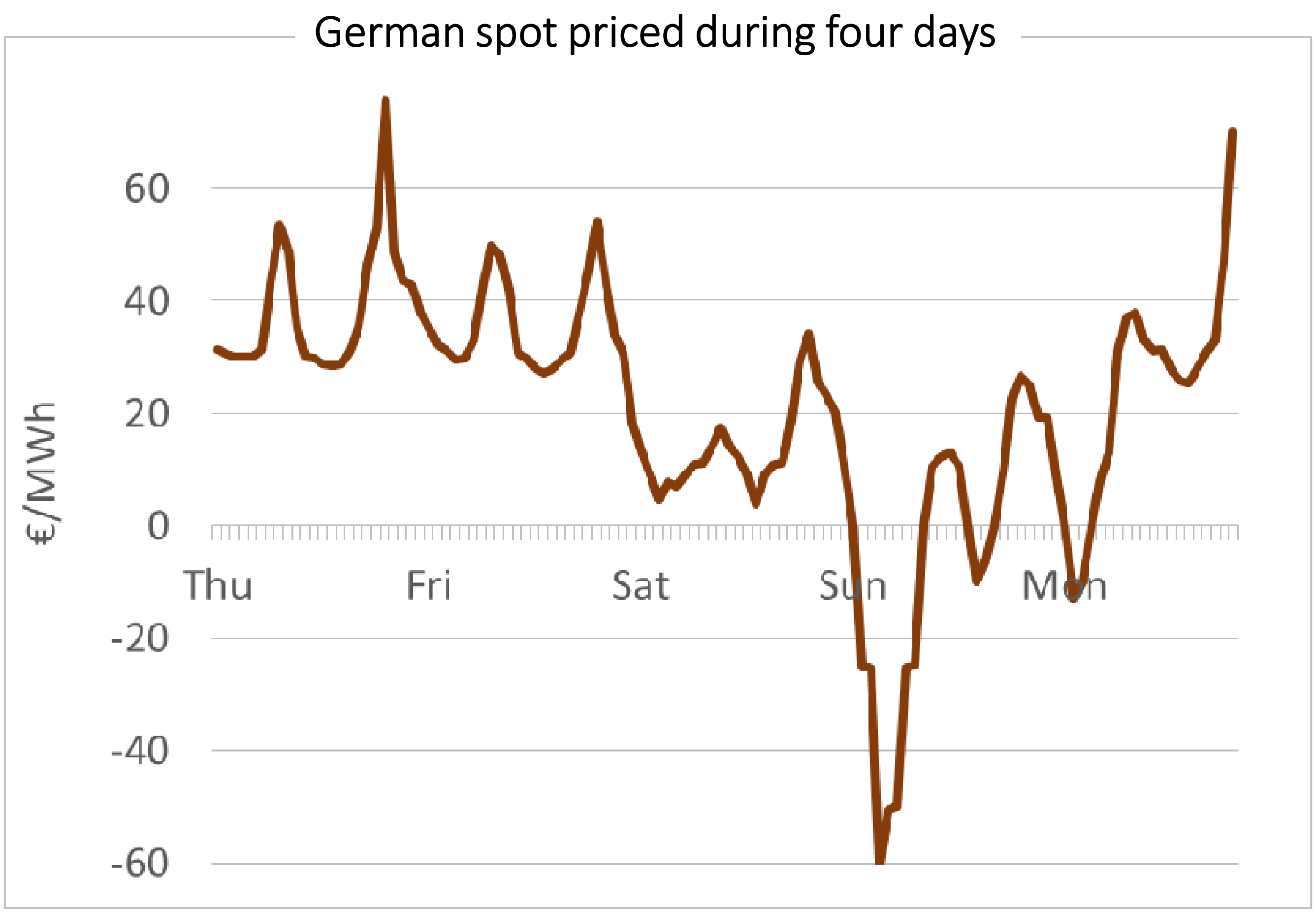
Residential small-scale rooftop solar PV costs in Germany



Source: Fraunhofer ISE (2015): Photovoltaics Report

Economics has two sides: costs and *value*

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

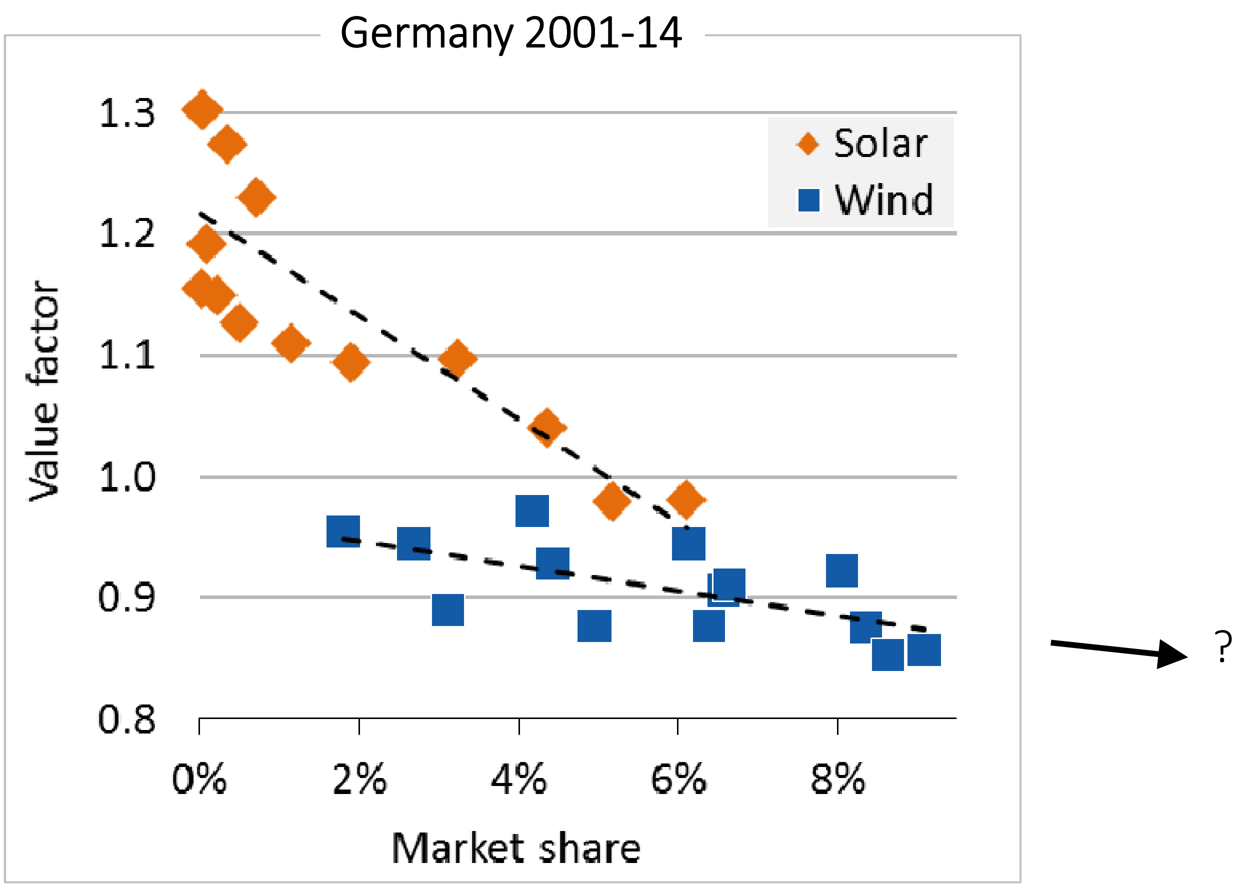
↑ Simple average of all hours of the year

↑ Wind-weighted average

↑ Ratio of these two

The wind and solar value drop

market data



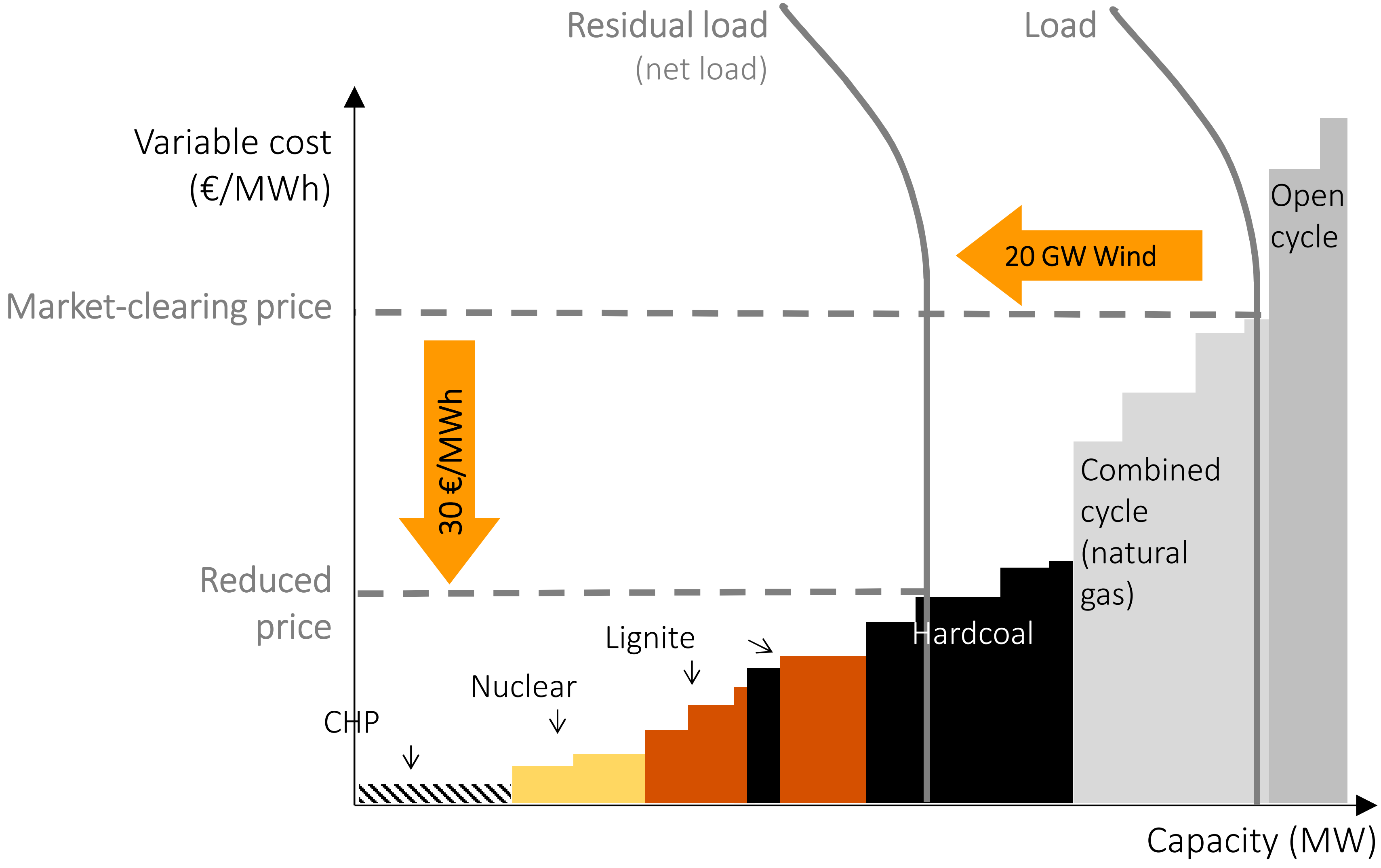
Value Factor = Market value / base price

Each dot represents one year

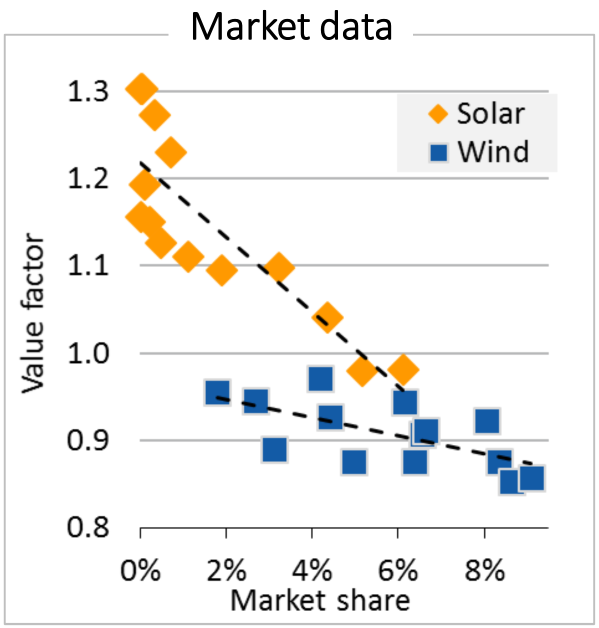
Updated from Hirth (2013).: Market value

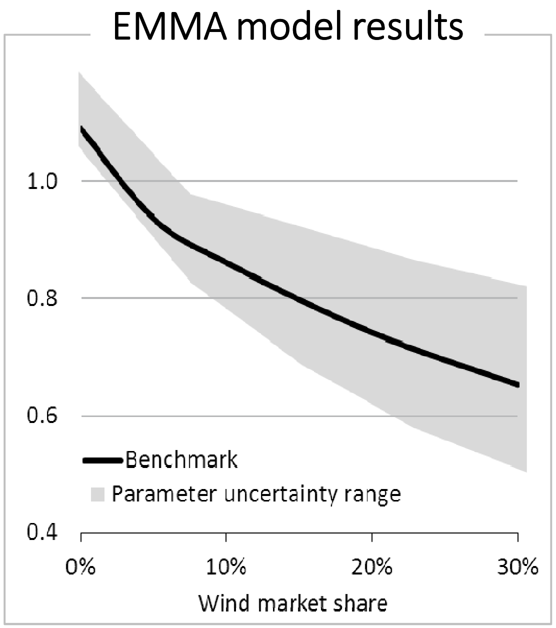
The relative value of electricity from wind and solar power is reduced as their market share grows. This has been called the "cannibalization effect", but in fact it is simply diminishing returns. For solar power, the value drop is more pronounced.

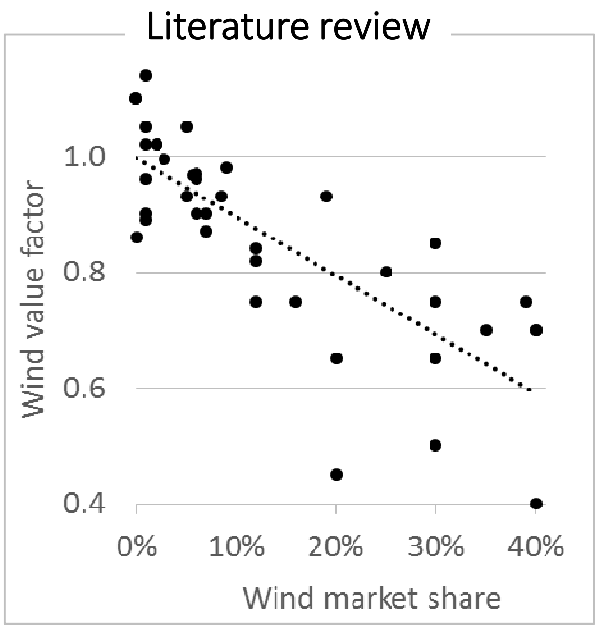
The mechanics behind the value drop



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.

Market value research

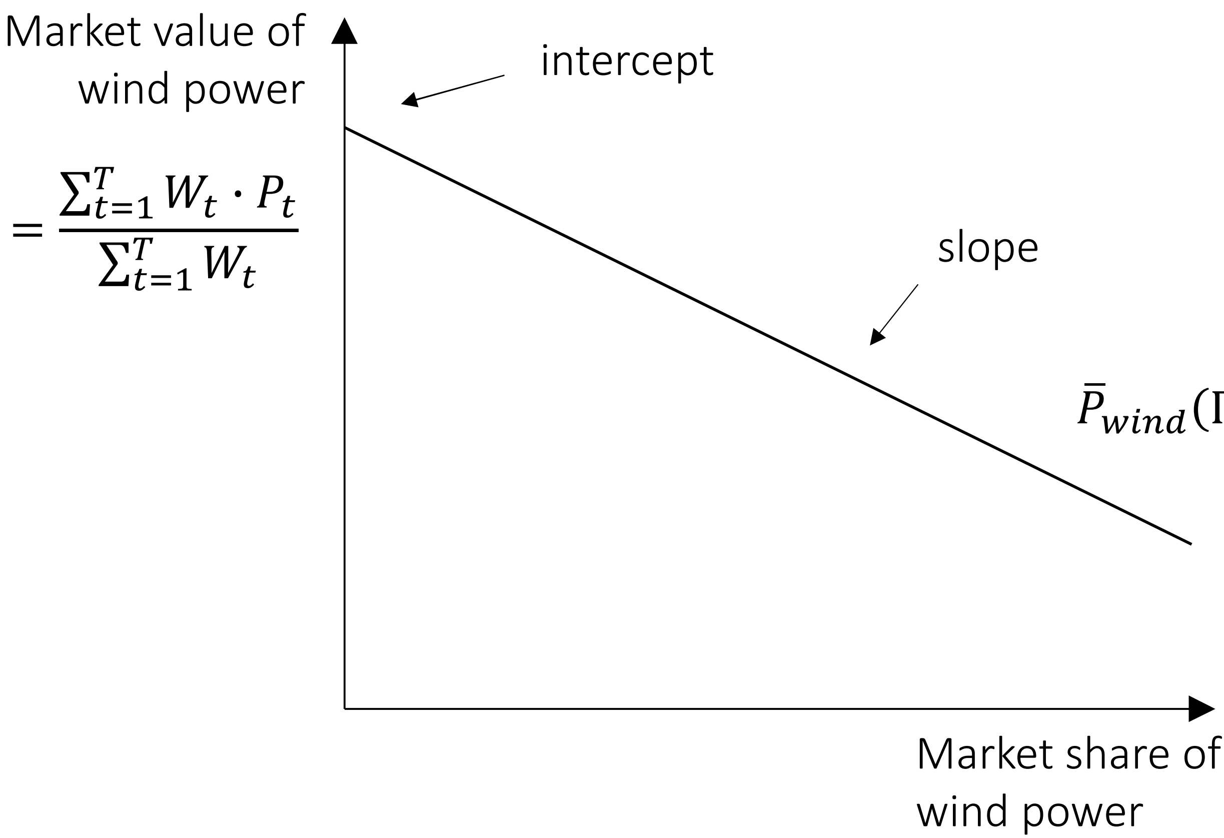
Status quo of the literature

- Many quantitative studies based on numerical modelling
- Scatter literature, lack of synthesis
- Little theoretical understanding, in fact, Lamont (2008) might be the only one

Our contributions to the literature

1. Empirical: new data, new econometrics, better synthesis
2. Theoretical: an analytical expression for the value drop

A (linear) approximation of the value drop



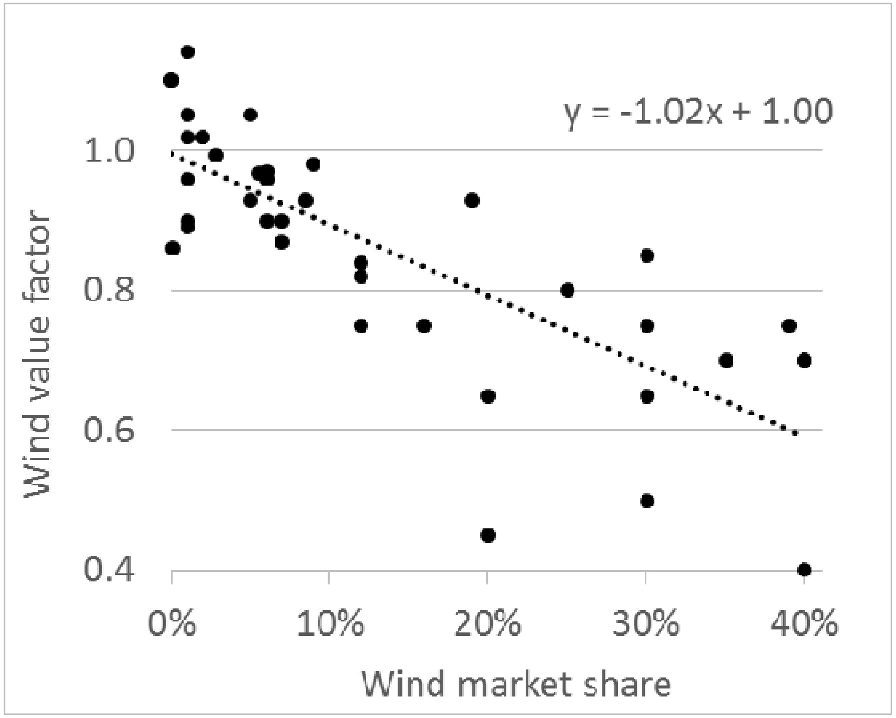
$$\bar{P}_{wind} = \frac{\sum_{t=1}^{T} W_t \cdot P_t}{\sum_{t=1}^{T} W_t}$$

$$\bar{P}_{wind}(\Pi) = \beta_0 - \Pi \cdot \beta_1$$

$$\Pi = \frac{\sum_{t=1}^{T} W_t}{\sum_{t=1}^{T} L_t}.$$

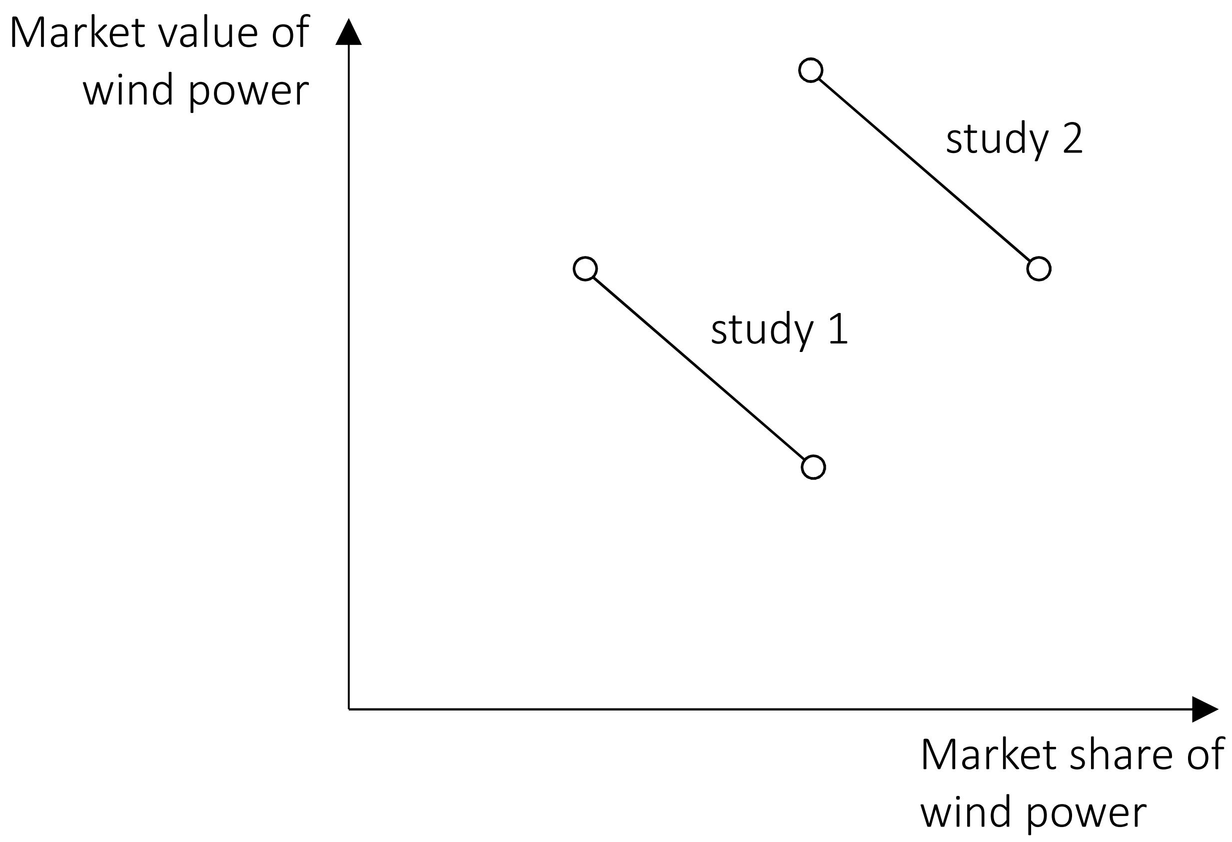
1. Econometrics

Quantitative Literature: overview

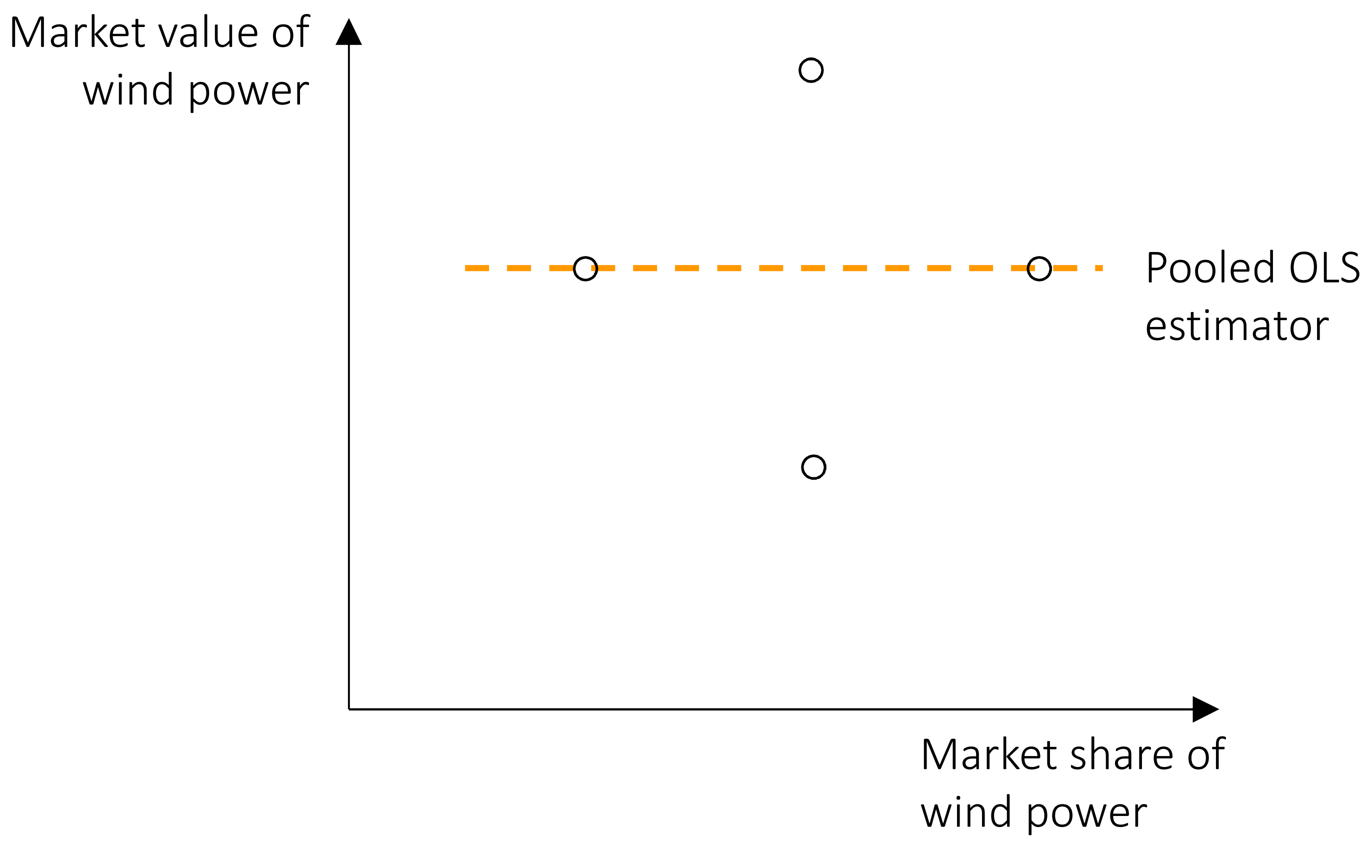


	# of studies
Observed (realized) prices ("market data")	4
Numerical dispatch model ("short-term model")	8
Numerical investment and dispatch model ("long-term model")	6
Total	18

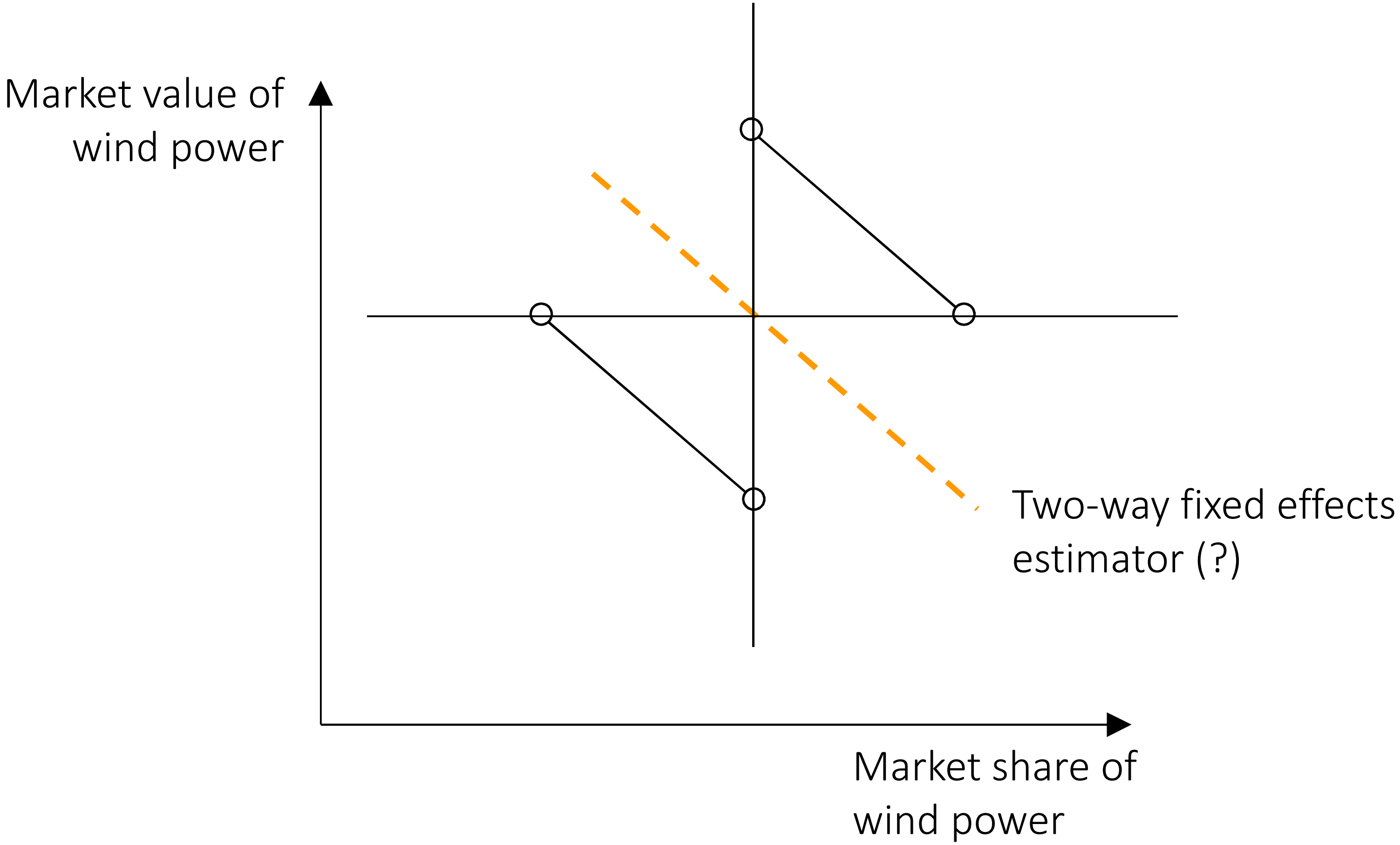
Within- and between study variation



Within- and between study variation



Within- and between study variation

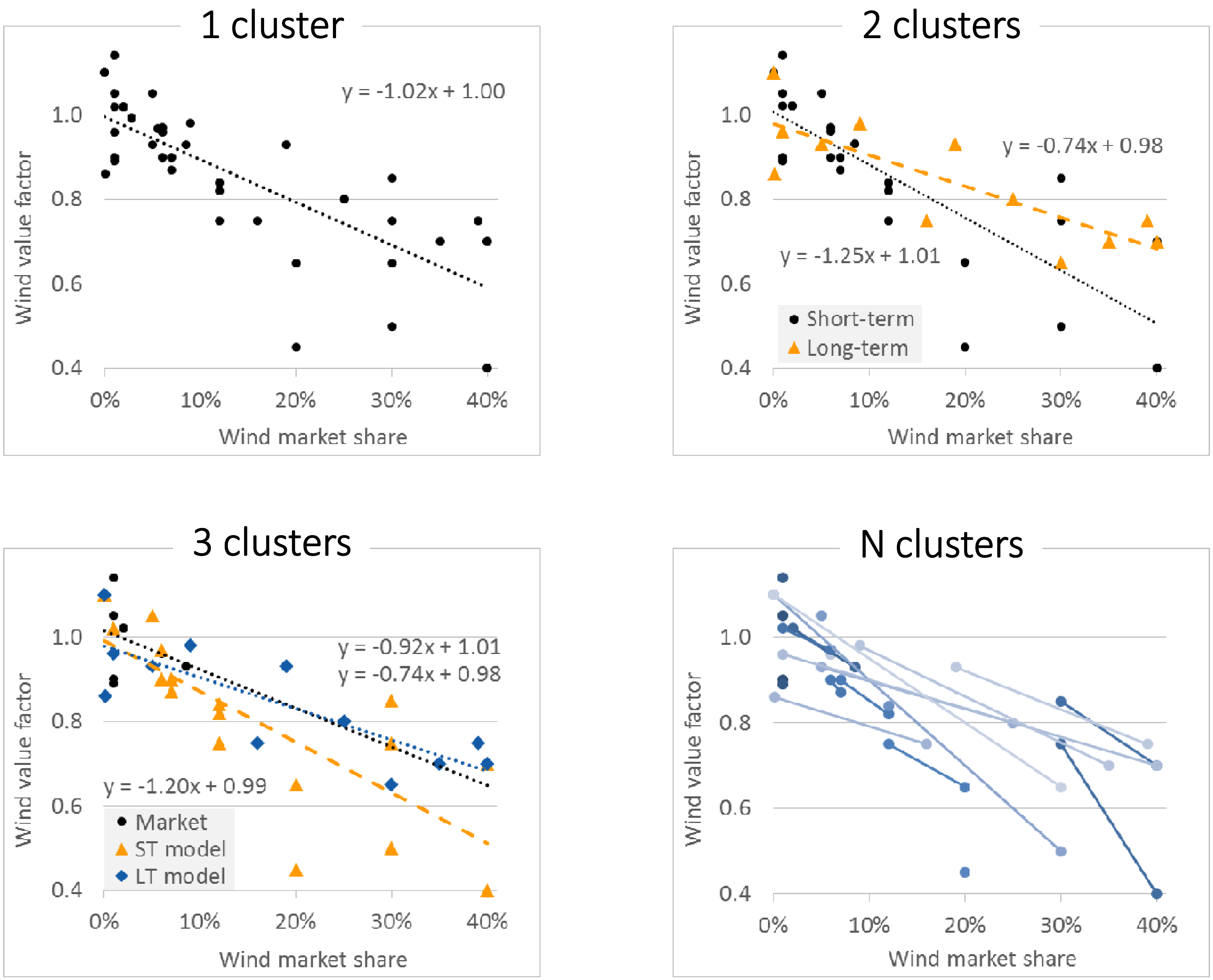


Clustering based on exogenous information

- We know not only results, also methodology of studies
- We can cluster studies into two groups
  - short-term approaches (ST)
  - long-term approaches (LT)
  - expectation: slope should be smaller in LT models, as they account for capital adjustments
- We can also cluster studies into three groups
  - short-term approaches based on numerical modelling (ST models)
  - econometric estimates based on observed market data (market)
  - long-term approaches based on numerical modelling (LT models)

Clustering estimates

# of subsamples	1	2	3	N
	Pooled data; Within and between variance = OLS	ST & LT	ST, LT and market estimates	Within variance only = two-way fixed effects


1 cluster
y = -1.02x + 1.00
Wind value factor
Wind market share
2 clusters
y = -0.74x + 0.98
y = -1.25x + 1.01
Short-term
Long-term
Wind value factor
Wind market share
3 clusters
y = -0.92x + 1.01
y = -0.74x + 0.98
y = -1.20x + 0.99
Market
ST model
LT model
Wind value factor
Wind market share
N clusters
Wind value factor
Wind market share

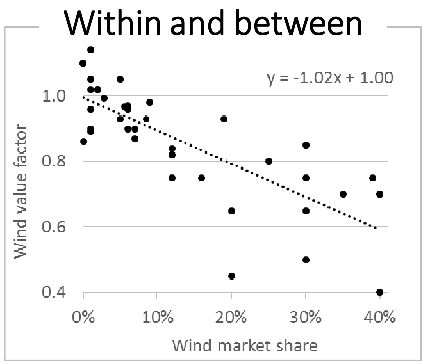
Clustering and pooling

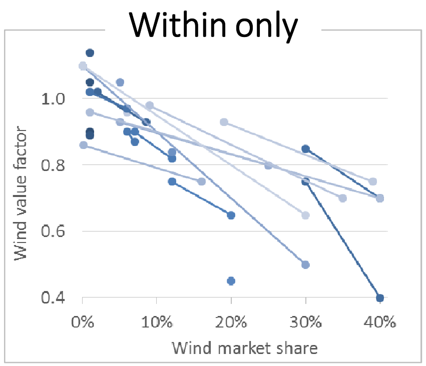
	1 cluster	2 clusters	3 clusters	N clusters
Pooled (OLS)	x	x	x	x
Separated (2-way fixed effects)	x	x	x	-

For separate model, we report mean coefficient estimates (model democracy, or rather: "study democracy").

Results: different estimates

Slope estimate	# of studies	OLS (within & between)	FE (within only)
Pooled	18	-1.0	-1.5
Short-term	12	-1.3	-1.9
Long-term	16	-0.7	-0.9
Market data	4	-0.9	-1.4
Short-term model	8	-1.2	-2.0
Long-term model	6	-0.7	-0.9





- Short-term numerical models estimate steeper slope than market data suggests
- Studies Individually show steeper slope than pooled sample.

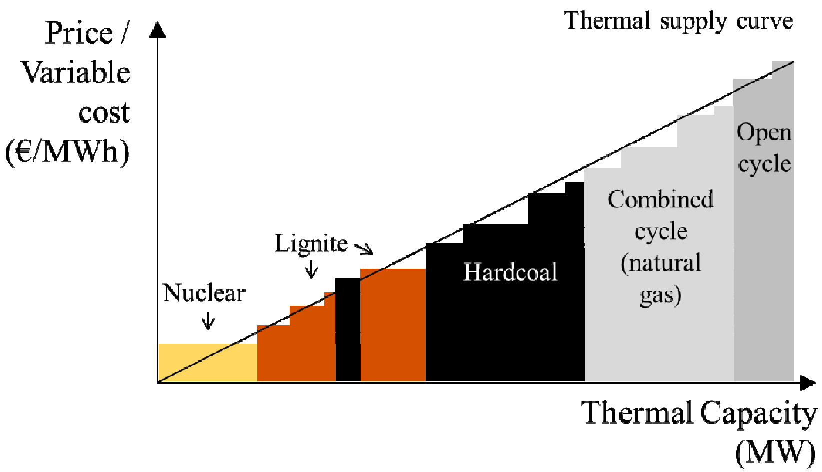
Conclusions and next steps

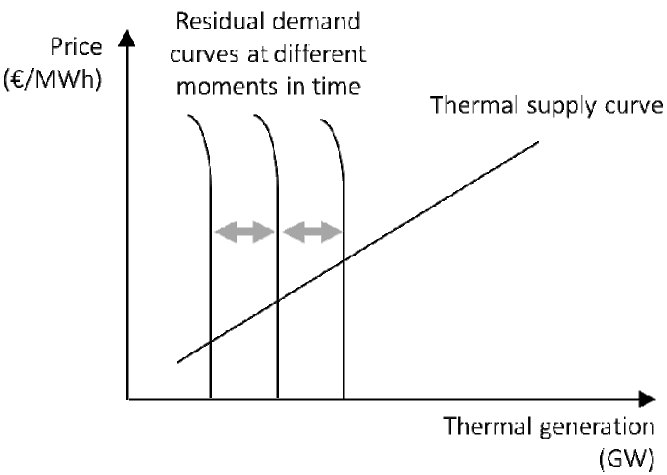
- New studies and more diverse econometric approaches confirm the established result: the value factor (relative price) of wind power drops as its market share increases
- Long-term models (accounting for changes in the capacity mix): drop of 0.7 – 0.9 percentage points per percentage point increase in market share
- Short-term models and market data estimates: 0.9 – 2.0

- What is the information value of between-model variation?
- Apply panel data techniques more rigorously?

2. Theory

A linearized supply curve (merit-order curve)





$$P_t = \alpha \cdot \frac{R_t}{L_{max}} \qquad R_t = L_t - W_t$$

The market value of wind power: analytically

- $P_t = \alpha \cdot \frac{R_t}{L_{max}}$ (price, as above)
- $\lambda_t = \frac{L_t}{L_{max}}$ (normalized load time series)
- $\omega_t = \frac{W_t}{C}$ (normalized wind in-feed time series)
- $\bar{P}_{wind} = \frac{\alpha}{L_{max}} \cdot \frac{\sum_{t=1}^{T} W_t \cdot R_t}{\sum_{t=1}^{T} W_t}$ (market value definition, as above)
- $\bar{P}_{wind} = \frac{\alpha}{L_{max}} \cdot \left\{ L_{max} \cdot \frac{\sum_{t=1}^{T} \omega_t \cdot \lambda_t}{\sum_{t=1}^{T} \omega_t} - C \cdot \frac{\sum_{t=1}^{T} \omega_t^2}{\sum_{t=1}^{T} \omega_t} \right\}$
- $C = \Pi \frac{\bar{L}}{\bar{\omega}} = \Pi \frac{\bar{\lambda} \cdot L_{max}}{\bar{\omega}}$
- $\bar{P}_{wind} = \alpha \cdot \left\{ \frac{\sum_{t=1}^{T} \omega_t \cdot \lambda_t}{\sum_{t=1}^{T} \omega_t} - \Pi \cdot \frac{\bar{\lambda}}{\bar{\omega}} \cdot \frac{\sum_{t=1}^{T} \omega_t^2}{\sum_{t=1}^{T} \omega_t} \right\}$

Market value in terms of (co-) variances

Using the fact that:

- $cov(\omega_t, \lambda_t) = \frac{1}{T}\sum_{t=1}^{T} \omega_t \cdot \lambda_t - \bar{\omega}\bar{\lambda}$ (definition of covariance)
- $var(\omega_t) = \frac{1}{T}\sum_{t=1}^{T} \omega_t^2 - \bar{\omega}^2$ (definition of variance)
- $c_v(\omega_t) = \frac{\sqrt{var(\omega_t)}}{\bar{\omega}}$ (def. of coefficient of variation)

We derive:

- $\bar{P}_{wind} = \alpha \cdot \bar{\lambda} \cdot \left\{\left(1 + \frac{cov(\omega_t,\lambda_t)}{\bar{\lambda}\bar{\omega}}\right) - \Pi \cdot \left(1 + \frac{var(\omega_t)}{\bar{\omega}^2}\right)\right\}$
- $\bar{P}_{wind} = \alpha \cdot \bar{\lambda} \cdot \left\{\left(1 + \frac{cov(\omega_t,\lambda_t)}{\bar{\lambda}\bar{\omega}}\right) - \Pi \cdot (1 + c_v(\omega_t)^2)\right\}$

Interpreting: intercept and slope

$$\bar{P}_{wind} = \alpha \cdot \bar{\lambda} \cdot \left\{ \left(1 + \frac{cov(\omega_t, \lambda_t)}{\bar{\lambda}\bar{\omega}} \right) - \Pi \cdot (1 + c_v(\omega_t)^2) \right\}$$

Intercept: a function of ...

$$\lim_{\Pi \to 0} \bar{P}_{wind} = \bar{P} \cdot \left(1 + \frac{cov(\omega_t, \lambda_t)}{\bar{\lambda}\bar{\omega}} \right)$$

- ... the covariance btw load & wind
- ... the "capacity factors " of both time series

Wind	Solar
1.02	1.05

Slope: a function of ...

$$\frac{\partial \bar{P}_{wind}}{\partial \Pi} = -\alpha \cdot \bar{\lambda} \cdot (1 + c_v(\omega_t)^2)$$

- ... the capacity factor of load
- ... the variance of wind generation, expressed as it's coefficient of variation

Wind	Solar
-1.25	-2.47

Conclusions and next steps

- To the best of our knowledge, this is the first expression of the market value of wind power as a function of its statistical properties and those of load
- Lamont (2008) provides the only other expression, but assumes prices to be given
- It is the covariance between load and wind that determines the wind value initially
- *It is the variance of wind that determines the value drop* – independent of the correlation with load
- Constant wind generation would also lead to dropping value, but the slowest drop possible
- "More constant" wind generation is more robust against value loss: wind turbines with a higher capacity factor and lower coefficient of variation
→ Hirth & Müller (forthcoming)

The Market Value of Wind and Solar Power: an Analytical Approach

hirth@neon-energie.de