Energy Economics: The Case of Renewable Electricity

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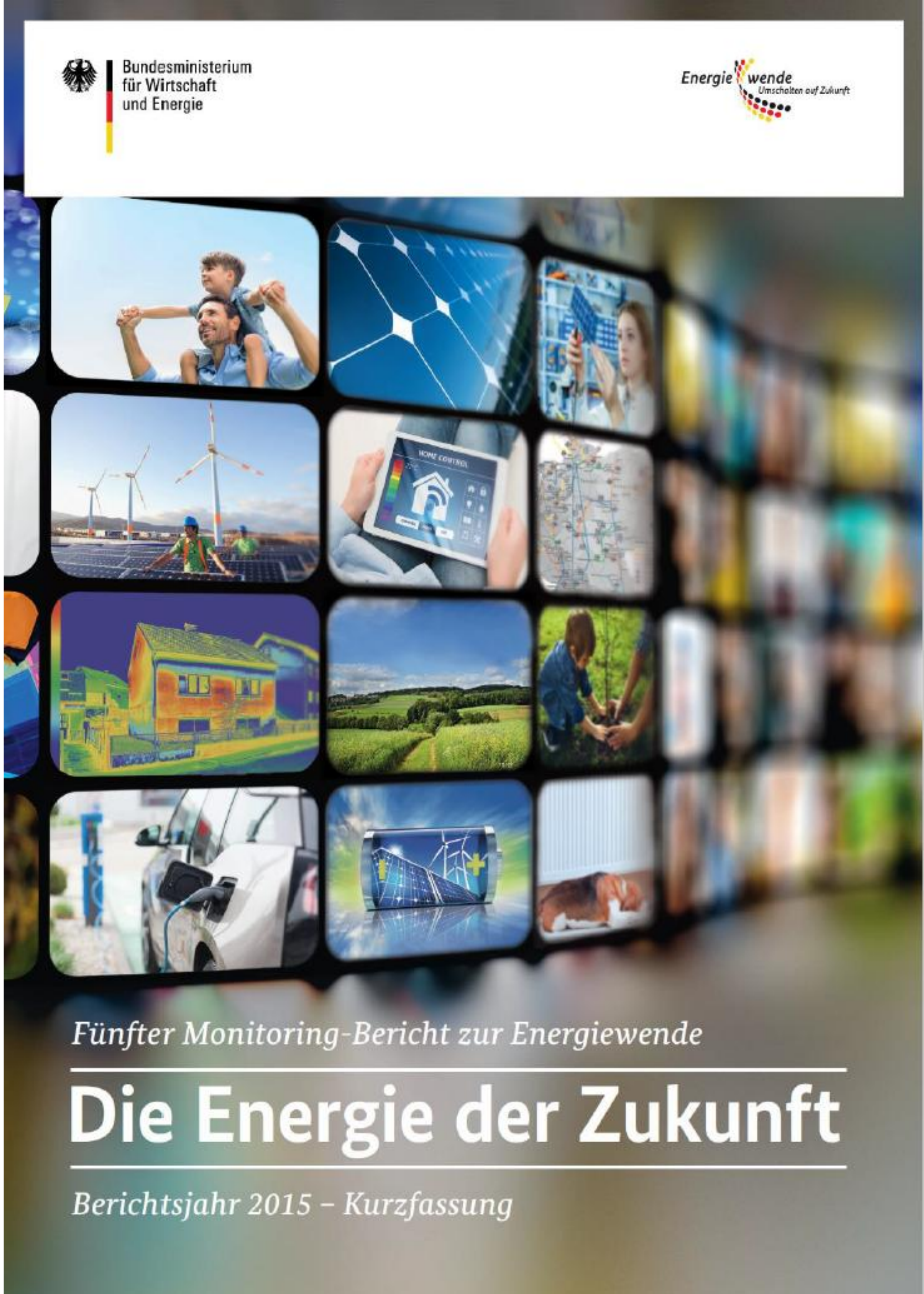

- 5th Monitoring Report of the Federal Ministry of Economics "Energy of the Future"
- Published in December 2016
- Topics:
  - Targets and indicators
  - Renewables
  - Energy demand and efficiency
  - Buildings
  - Transportation
  - Greenhouse gases and environmental impacts
  - Power plants and supply security
  - Affordable energy and competition
  - Grid infrastructure
  - Integration of the energy system
  - International context

Expertenkommission zum Monitoring-Prozess „Energie der Zukunft“

Stellungnahme zum fünften Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2015

Berlin · Münster · Stuttgart, Dezember 2016

- Prof. Dr. Andreas Löschel (Vorsitzender)
- Prof. Dr. Georg Erdmann
- Prof. Dr. Frithjof Staiß
- Dr. Hans-Joachim Ziesing

ENERGIE DER ZUKUNFT
Kommission zum Monitoring-Prozess

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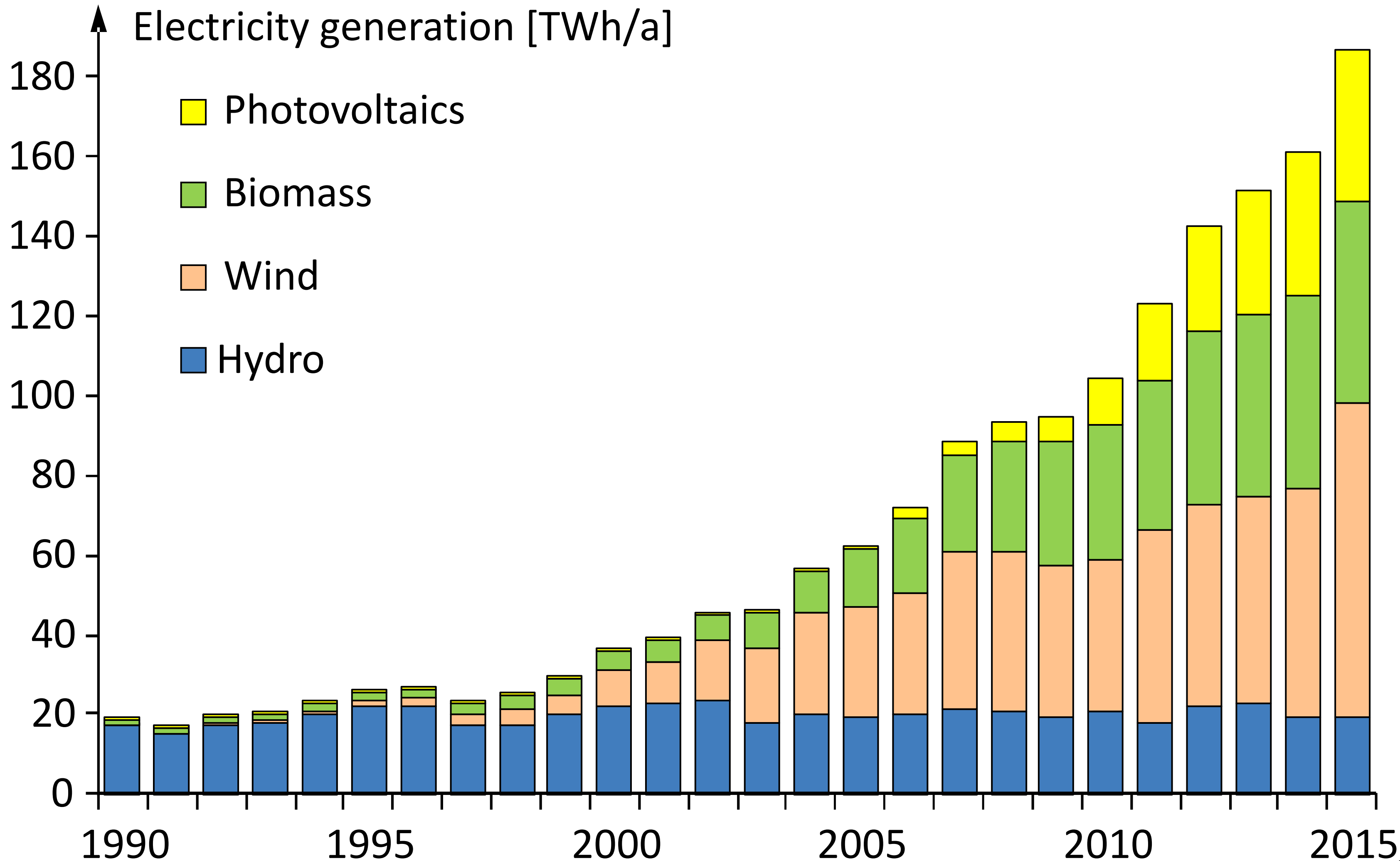
- Assessment of Independent Expert Commission “Energy of the Future” of the 5th Federal Monitoring Report
- Published in December 2016
- Topics:
  - Credibility of the energy transformation
  - Organizing climate protection
  - Improving energy efficiency
  - Broad approach to transportation
  - Strategic REN development
  - Securing electricity infrastructure
  - Affordability of energy
  - Using digitalization

Renewable Electricity Generation in Germany

[Source: Arbeitsgemeinschaft Energiebilanzen AGEB]



Agenda of my Presentation Today

1. Economics of Renewable Energy Investment
2. Renewable Electricity Support Schemes
3. Merit Order Effect of Renewable Electricity
4. The Intermittency Problem
5. Sector Coupling

A Primer on Levelized Cost of Energy (LCOE)

1. Economics of Renewable Energy Investment

- How should an investor of a renewable electricity plant determine whether or not the investment is profitable?
- Solution: Define a time series of the expected cash flows CF_t (t = 1,…,T) over the economic lifetime T of the investment project …
- … and discount the cash flows of different years with an interest rate i in order to make them comparable

Simplified Calculation of the Net Present Value

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+i)^t} = -I_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t}$$ Net Present Value

$$NPV = -I_0 + \sum_{t=1}^{T} \frac{(p_{E,t} - oc_t) \cdot Q_t}{(1+i)^t} = -I_0 + (p_E - oc) \cdot Q \cdot \sum_{t=1}^{T} \frac{1}{(1+i)^t}$$

CF_t	Cash flow in period *t*
I_0	Investment expenditure in period 0
i	Interest rate / discount rate
oc	Operating cost per output unit *Q*
p_E	Revenue per output unit *Q*
T	Economic lifetime

$$RBF_{i,T} = \sum_{t=1}^{T} \frac{1}{(1+i)^t} = \frac{1}{i} - \frac{1}{i \cdot (1+i)^T}$$ Annuity factor

NPV and Break Even Conditions

The economic evaluation of an investment project is positive if the Net Present Value $NPV > 0$

To calculate break even conditions, set $NPV = 0$:

$$NPV = -I_0 + (p_E - oc) \cdot Q \cdot RBF_{i,t} = 0$$

$$I_0 = (p_E - oc) \cdot Q \cdot RBF_{i,T}$$

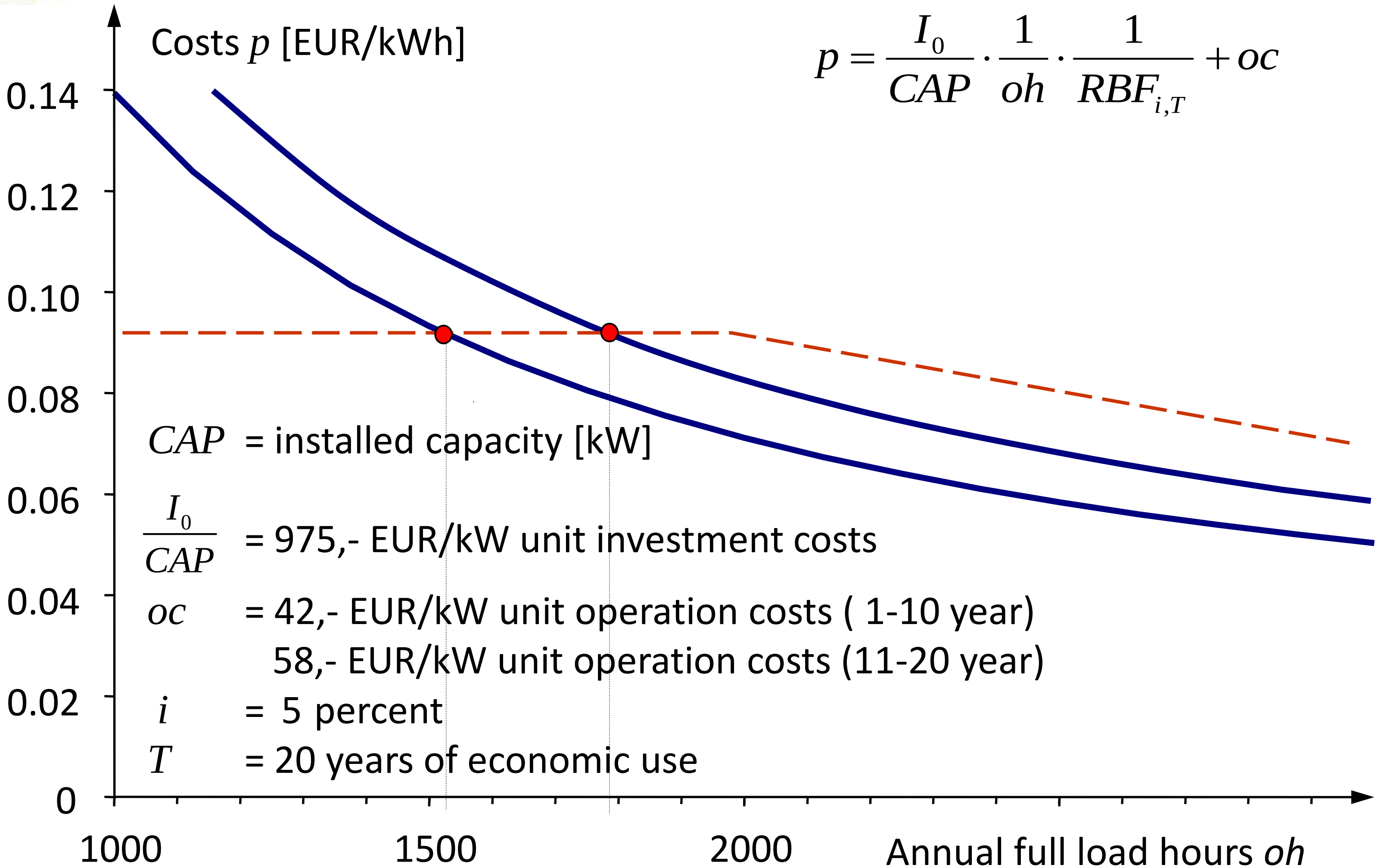
- Solving for p_E gives the $LCOE$ (break-even price)

$$p_E = \frac{I_0}{Q \cdot RBF_{i,T}} + oc$$

- Solving for i gives the Internal Rate of Return IRR, or the profitability of the investment (no closed form solution exists)

Example: Wind Power LCOE

$$p = \frac{I_0}{CAP} \cdot \frac{1}{oh} \cdot \frac{1}{RBF_{i,T}} + oc$$



CAP = installed capacity [kW]

$\frac{I_0}{CAP}$ = 975,- EUR/kW unit investment costs

oc = 42,- EUR/kW unit operation costs (1-10 year)
58,- EUR/kW unit operation costs (11-20 year)

i = 5 percent

T = 20 years of economic use

Interpretation of Wind Power LCOE

- The LCOE varies between 0.05 and 0.15 Ct/kWh or 50.- and 150.- Euro/MWh
- Key determinants are the unit investment cost, the interest rate, and the annual full load hours which strongly depend on the location of the wind turbine
- Land lords with particularly good wind conditions have bargaining power against potential investors
- The same holds for wind turbine manufacturers. The economic calculus of their customers is fully transparent to them once they know the investment location of the wind turbine
- The wind energy investor holds the economically weak position along the value chain

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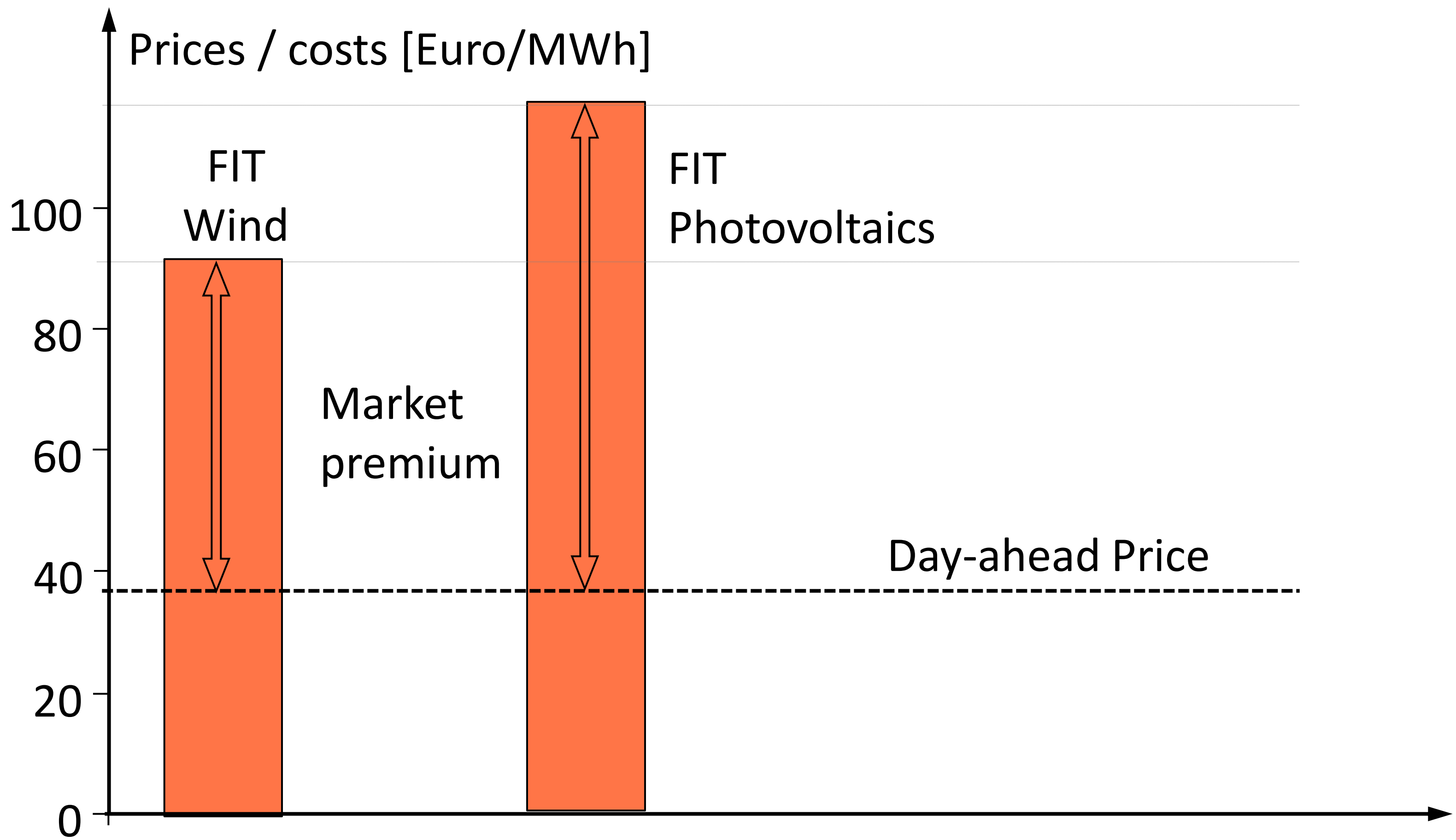
Renewable Electricity Support Schemes

Price control	Obligation of grid operators (or ISO) to purchase all offered renewable electricity at legally defined (and technology specific) fixed feed-in payments	Dominant model but challenged by the EU Commission
	Legally defined and technology specific market premium (on top of the market price) granted to renewable generators that have sold the electricity	Similar to Contract for Differences
Volume control	Obligation of retailers to hold a minimum number of Renewable Electricity Certificates (RECs) issued by registered renewable generators	
	Renewable portfolio standard (retailers must physically purchase a minimum share of renewable electricity)	Do retailers have the capacity to comply?
	Renewable investment tenders (government defines the renewable capacity additions and selects the investors that ask for the lowest market premium)	Model preferred by the EU Commission

FIT, Flexible or Constant Market Premiums

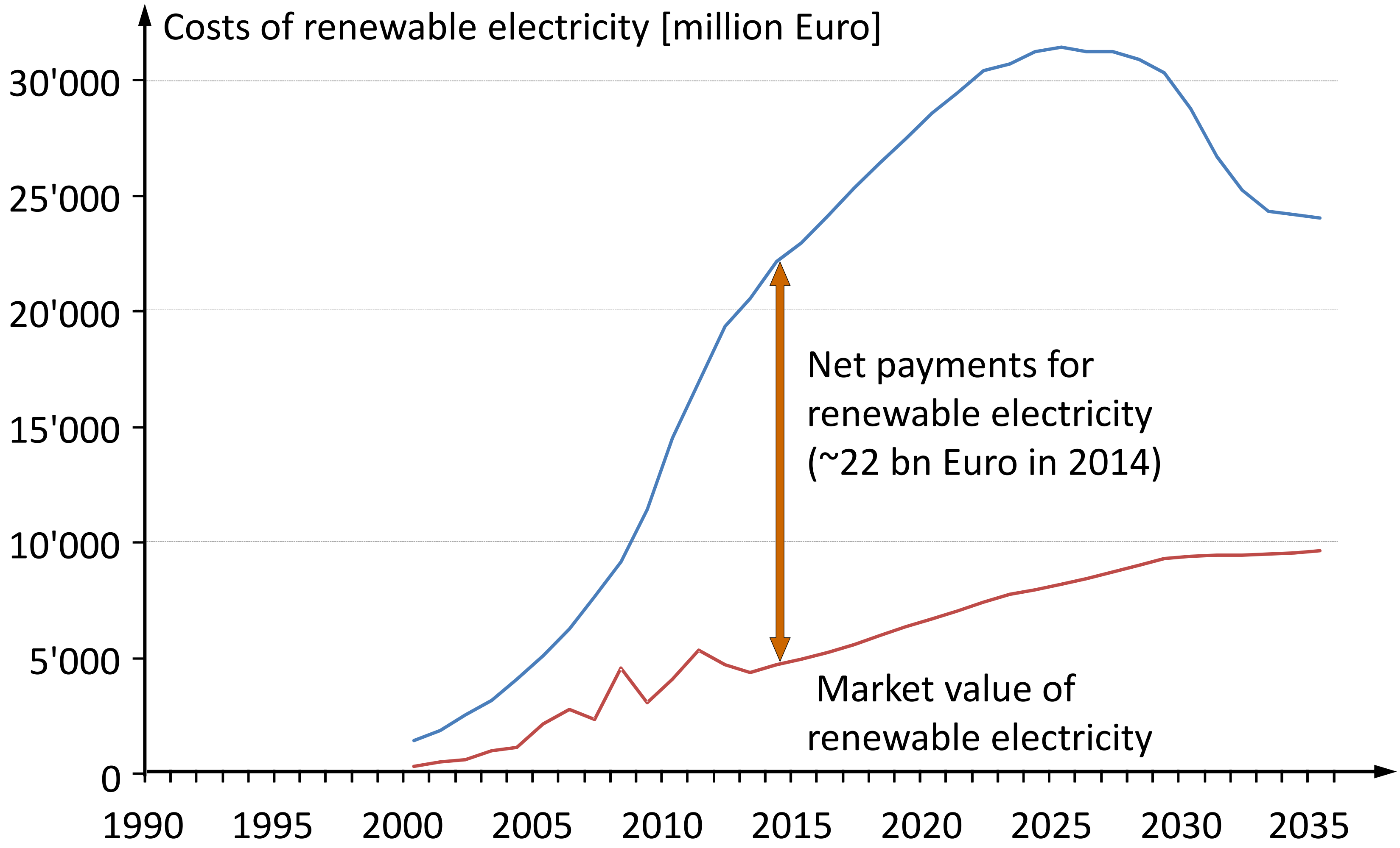


Development of the German REN Legislation

- 1990: Preferred grid access for renewable sources with the obligation of the grid owners to pay the market price (Stromeinspeisegesetz)
- 2000: German Renewable Energy Sources Act (EEG) with 12 paragraphs. Mandatory feed-in tariff (FIT) Grid owners become sellers of renewable electricity
- EEG Amendments of 2004, 2009, 2010, 2012, 2014 and 2016. Replacement of FIT by market premiums. The premium requires renewable electricity generators to sell power to the electricity markets
- Determination of the market premiums by technology specific auctions (experimental since 2014, mandatory after 2017)
- Why so many legal reforms?

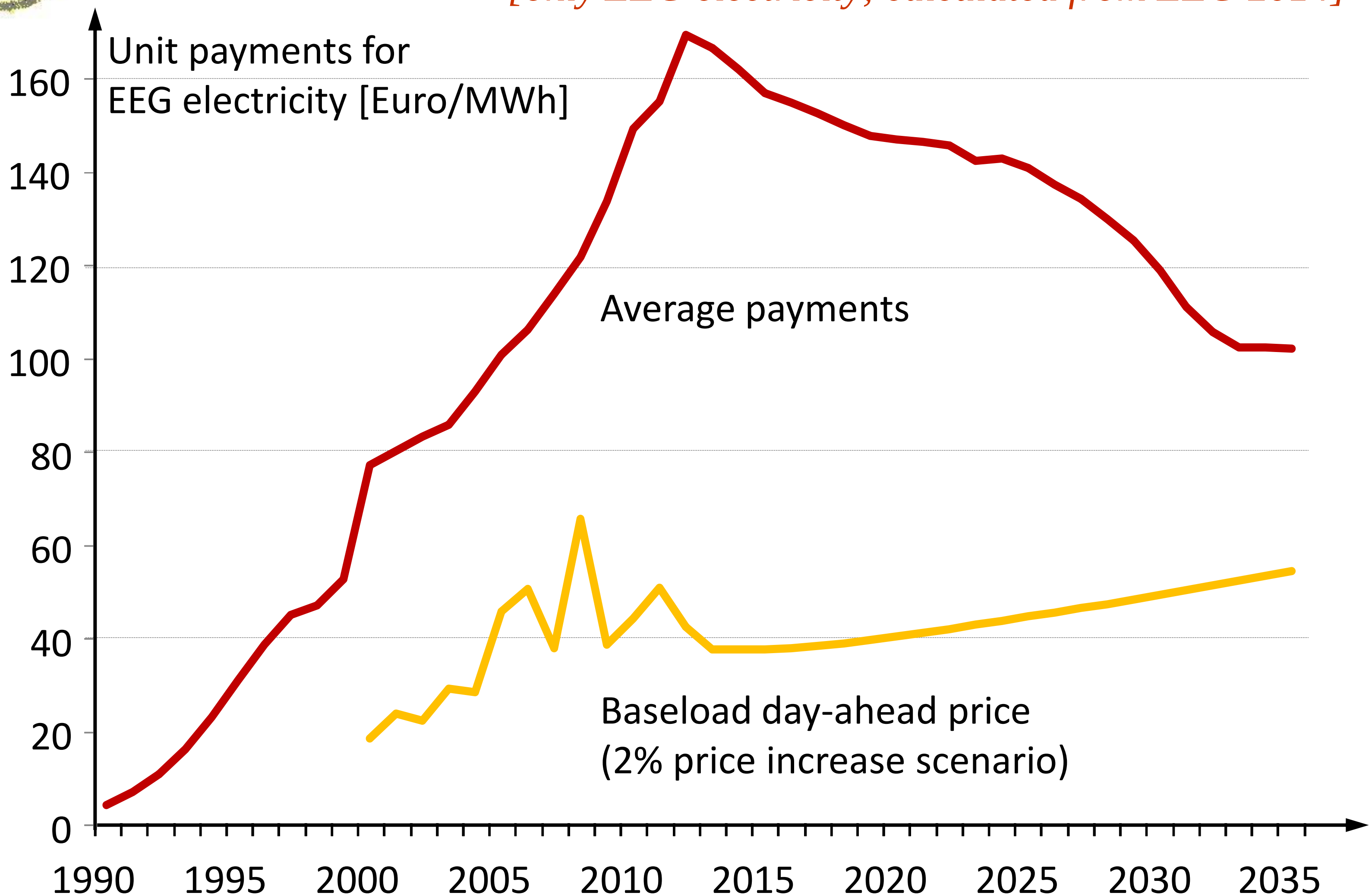
Costs of Renewable Electricity Generation

[My forecast of 2014 calculated from EEG-2014]



Unit Payments for Renewable Electricity

[only EEG electricity; calculated from EEG 2014]



Direct and Indirect REN Costs

[Cost of new REN capacity invested in Germany in January 2012]

Euro/MWh$_{el}$	**Onshore wind**	**Offshore wind**	**PV**	**Bio methane**
Premium above electricity price	55	152	153	182
Integration costs gas grid	-	-	-	22
Transportation costs gas grid	-	-	-	19
Power distribution grid extension	26	-	15	-
Power transmission grid extension	8	8	1	-
Costs offshore grid	-	26	-	-
Risk offshore grid	-	3	-	-
Merit-order effect	-28	-29	-32	-29
Backup capacity	27	22	27	-
Power grid losses	3	12	-	-
Total	**67**	**194**	**164**	**194**

Expenditures for Electricity in Germany

[Assessment Report of the Independent Expert Commission 2016]

Billion Euros p.a.	2010	2011	2012	2013	2014	2015
Total annual expenditures	**60.9**	**63.6**	**64.3**	**71.0**	**70.3**	**69.4**
Expenditures induced by governmt	**17.2**	**23.0**	**23.3**	**30.0**	**32.3**	**31.3**
Electricity taxes	6.4	7.2	7.0	7.0	6.6	6.6
Concession fees	2.1	2.2	2.1	2.1	2.0	2.0
Renewable electricity levy	8.3	13.4	14.0	19.8	22.3	22.0
Combined heat and power Levy	0.4	0.2	0.3	0.4	0.5	0.6
Offshore grid levy (§ 17F ENWG)	-	-	-	0.7	0.8	0.0
Expenditures regulated by the government	**16.9**	**17.6**	**19.0**	**21.2**	**21.4**	**21.4**
Fees for the transmission grid	2.2	2.2	2.6	3.0	3.1	3.5
Fees for the distribution grid	14.7	15.4	16.4	18.2	18.3	17.9
Expenditures driven by the market	**26.8**	**23.1**	**22.0**	**19.8**	**16.6**	**16.8**
Market value of REN electricity	3.5	4.4	4.8	4.2	4.1	4.7
Generation, marketing and sales	23.3	18.6	17.2	15.6	12.6	12.0

Perspectives of the Renewable Support

- The financial support for renewable electricity has passed 22 billion Euros annually – not including the additional grid costs
- The financial support is financed through the renewable electricity levy (REN levy) paid by final electricity customers to the grid operators
- In particular energy intensive companies lobby successfully in favor of a reduction of the REN levy
- The REN levy could be reduced by
  - Cuts of the legally defined market premiums
  - Reduced growth of renewable electricity (as far as it is subject to financial support)
  - Higher wholesale power prices (higher CO_2 prices)

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Pricing on Perfectly Competitive Markets

$$\Pi = p_E \cdot Q - C(Q)$$

Π	Profit (per period)
p_E	Sales price
Q	Output (Quantity)
C	Costs depending on Q

$$\Pi = p_E \cdot Q - c_{var} \cdot Q - C_f$$

c_{var}	variable unit costs
C_f	fixed costs

Profit maximizing output of a "price taker"

$$\frac{d\Pi}{dQ} = \frac{d(p_E \cdot Q)}{dQ} - \frac{dC}{dQ} = 0$$

$$\frac{d\Pi}{dQ} = \underbrace{\frac{dp_E}{dQ}}_{=0} \cdot Q + p_E - \frac{dC}{dQ} = 0$$

$$p_E = \frac{dC}{dQ}$$ "Marginal cost = Price" rule

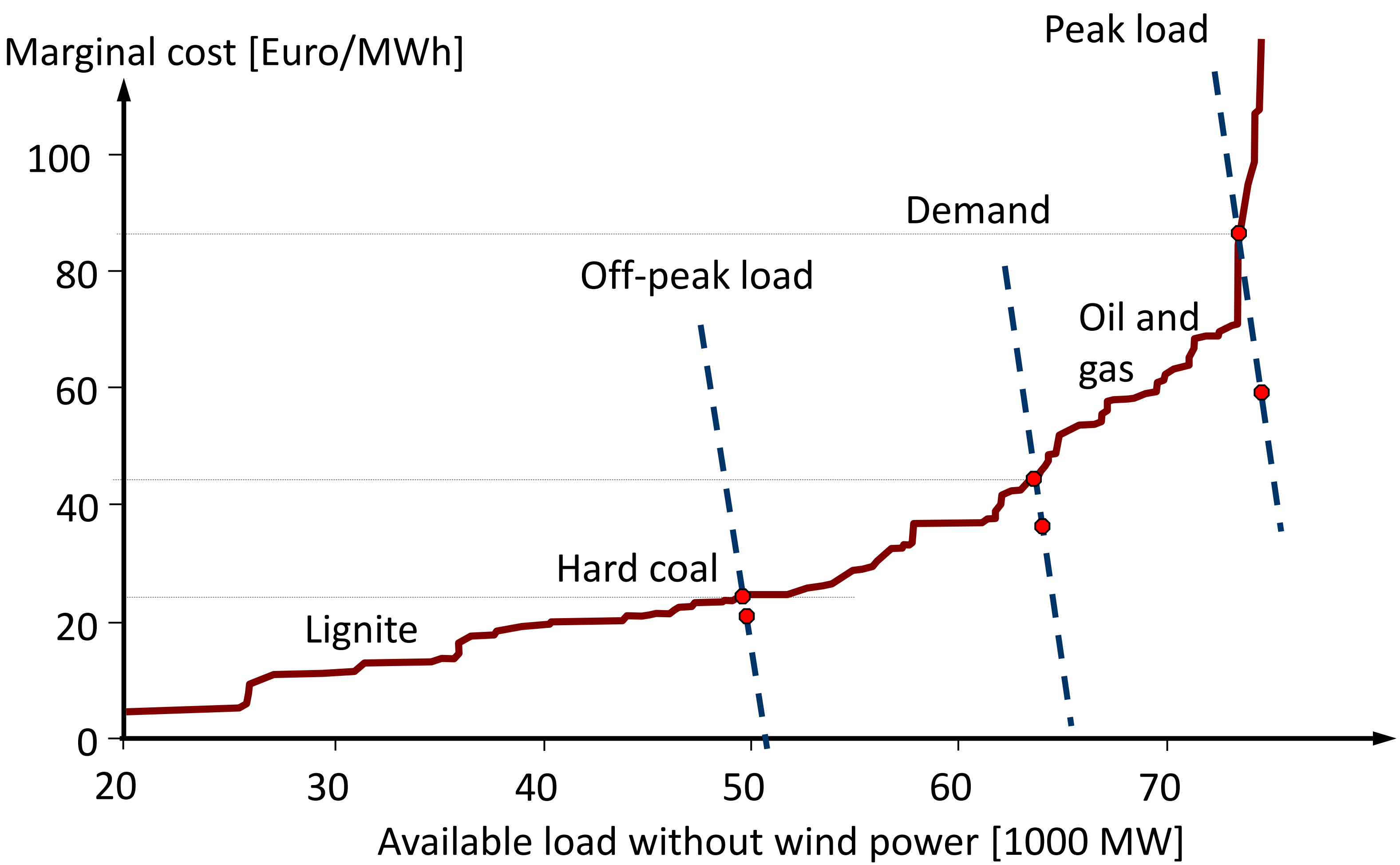
$$p_E = \frac{dC}{dQ} = c_{var}$$

What is the Merit Order of Power Plants?

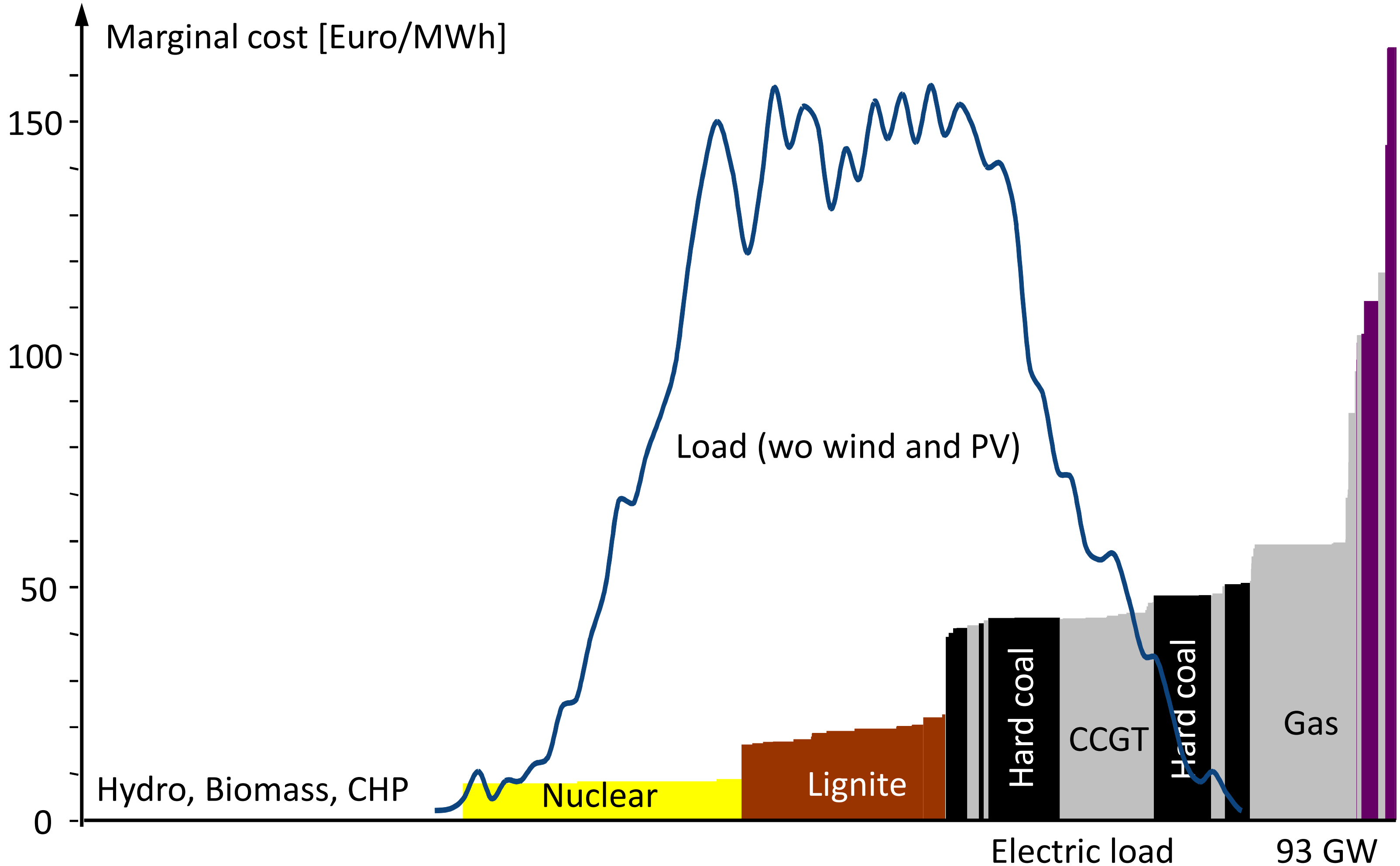
- On perfectly competitive markets each operator of an existing generator reaches the profit maximum if the dispatch of the plant is organized according to its marginal cost
- The marginal cost corresponds to the additional expenditures for fuel and greenhouse gas allowances associated with the generation of one additional electricity Unit [MWh]. In addition, the wear of the equipment might be taken into account
- Allocating all power plants according to their marginal costs gives the merit order
- Compared to fossil fuel plants, wind and photovoltaic generators have rather low marginal costs and therefore stand at the beginning of the merit order

Example: Merit Order Curve for Germany

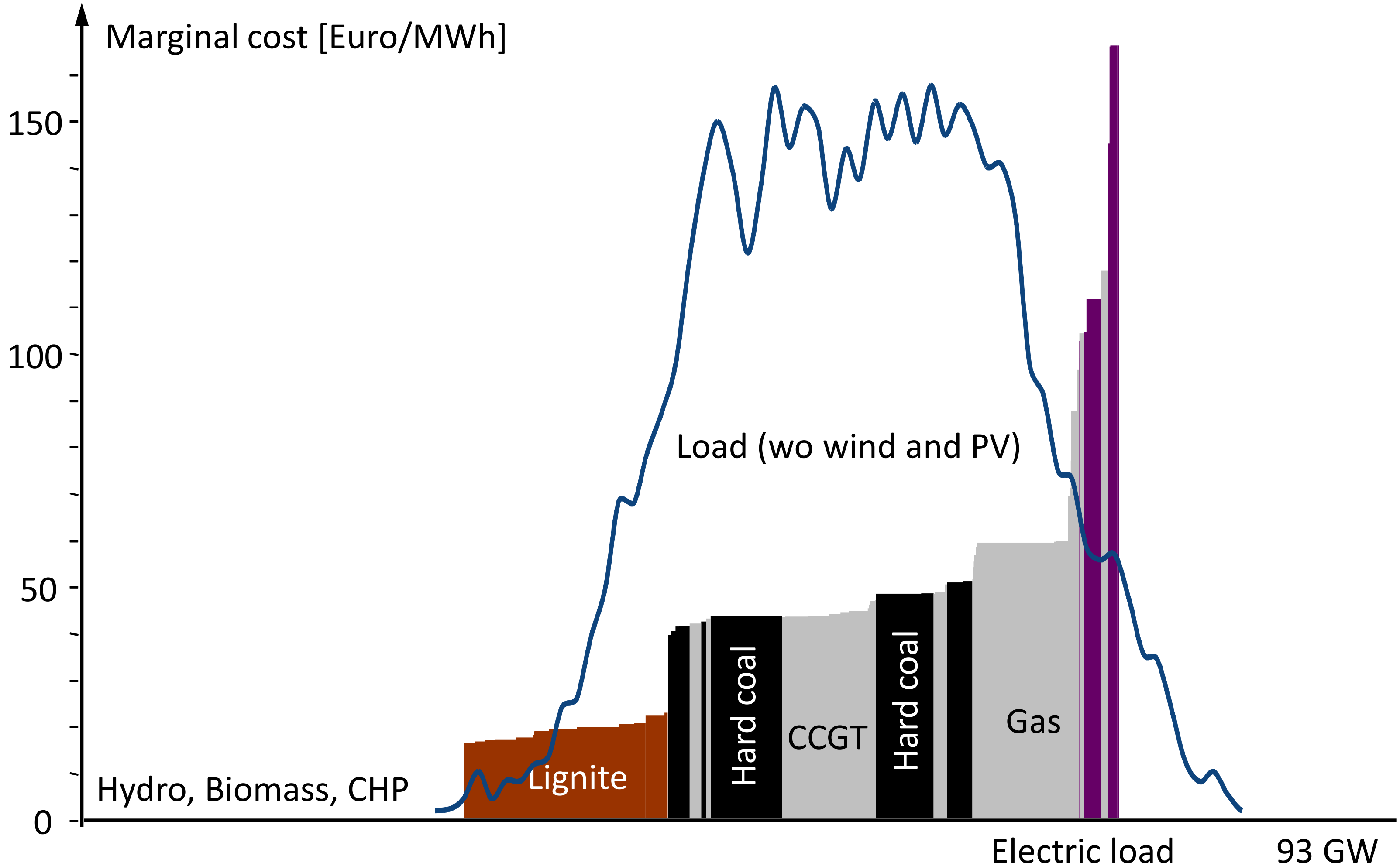
[without CO_2 cost; data source: EU Sector Enquiry 2007, p. 260]



Merit Order of the German Power Plant Portfolio with/without Nuclear



Merit Order of the German Power Plants with Additional Wind and PV Capacities

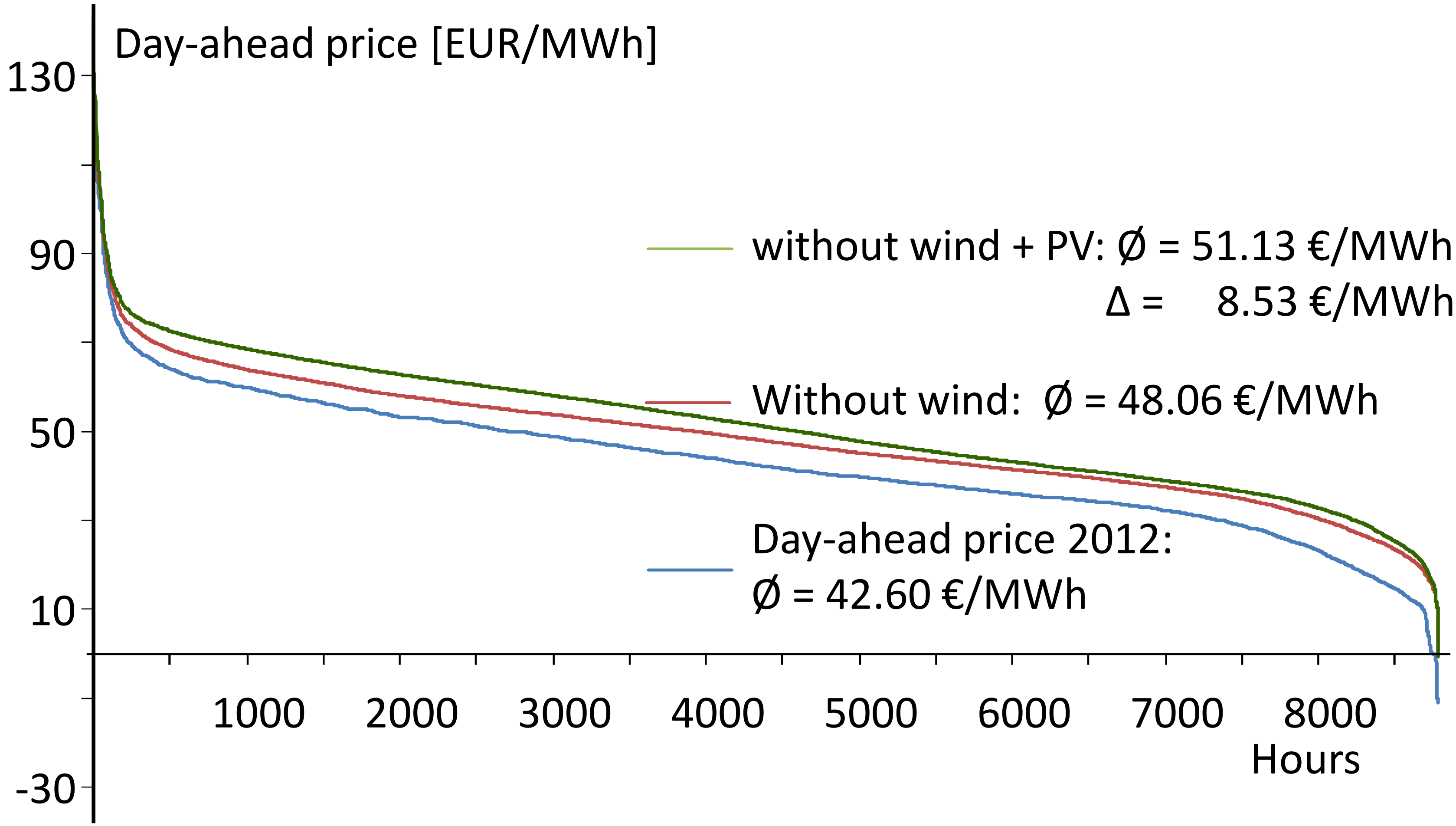


Merit Order Effect of Wind and PV in Germany

Literature review	2006	2007	2008	2009	2010	2011	2012
	Euro/MWh						
Sensfuß et al. (2008)	-7.8						
Weigt (2009)	-6.2	-10.4	-13.0				
vbw (2011)					-8.0		
Sensfuß (2012)		-5.8	-5.3	-6.0	-5.2	-8.7	-8.9
Speth, Stark (2012)					-5.6	-5.6	
Cludius et al. (2013)			-10.8	-7.8	-6.0	-7.7	-10.1

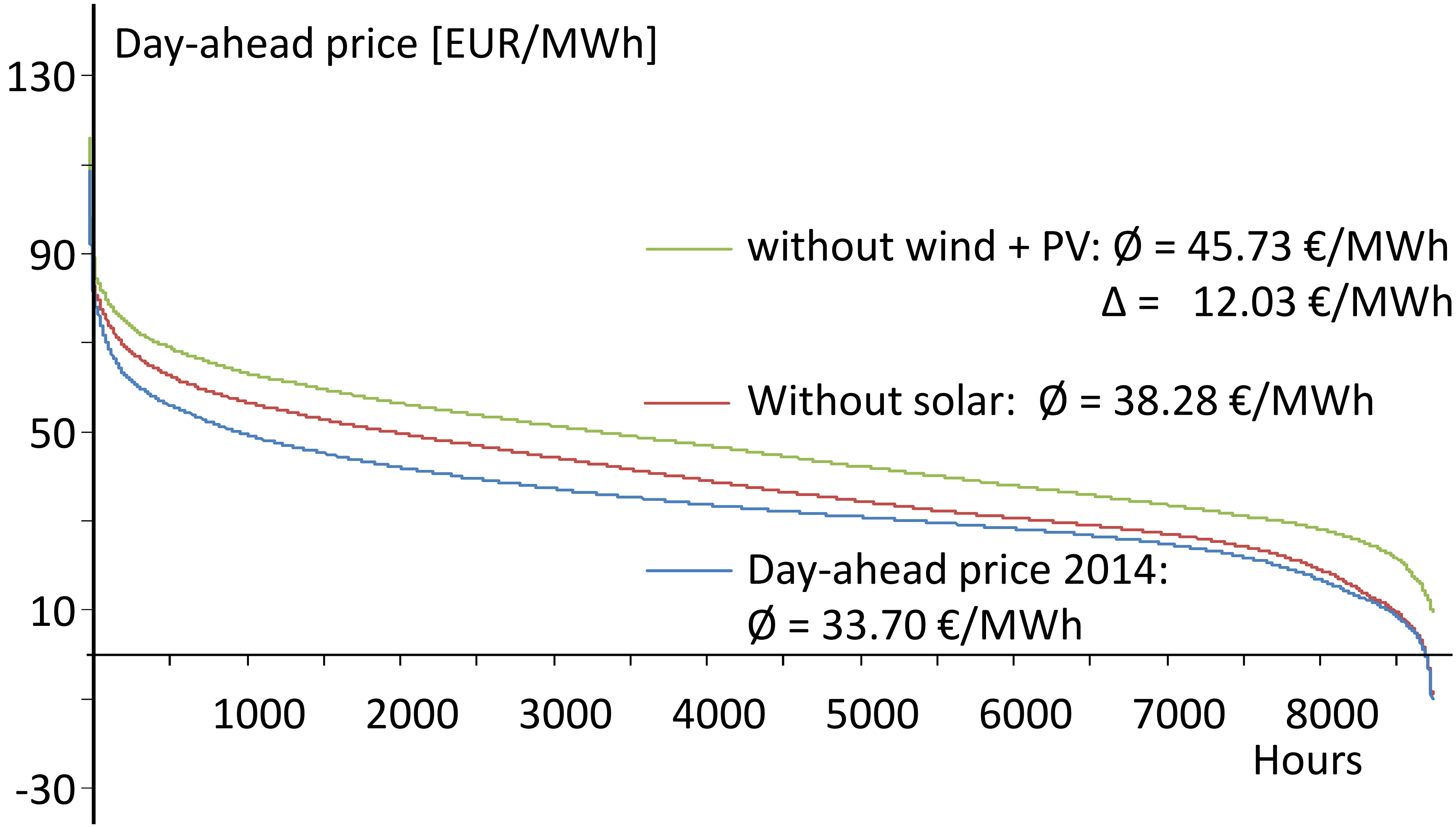
Merit-Order-Effect of Renewable Electricity

[2012; Source: Own calculations from EEX and TSO data]

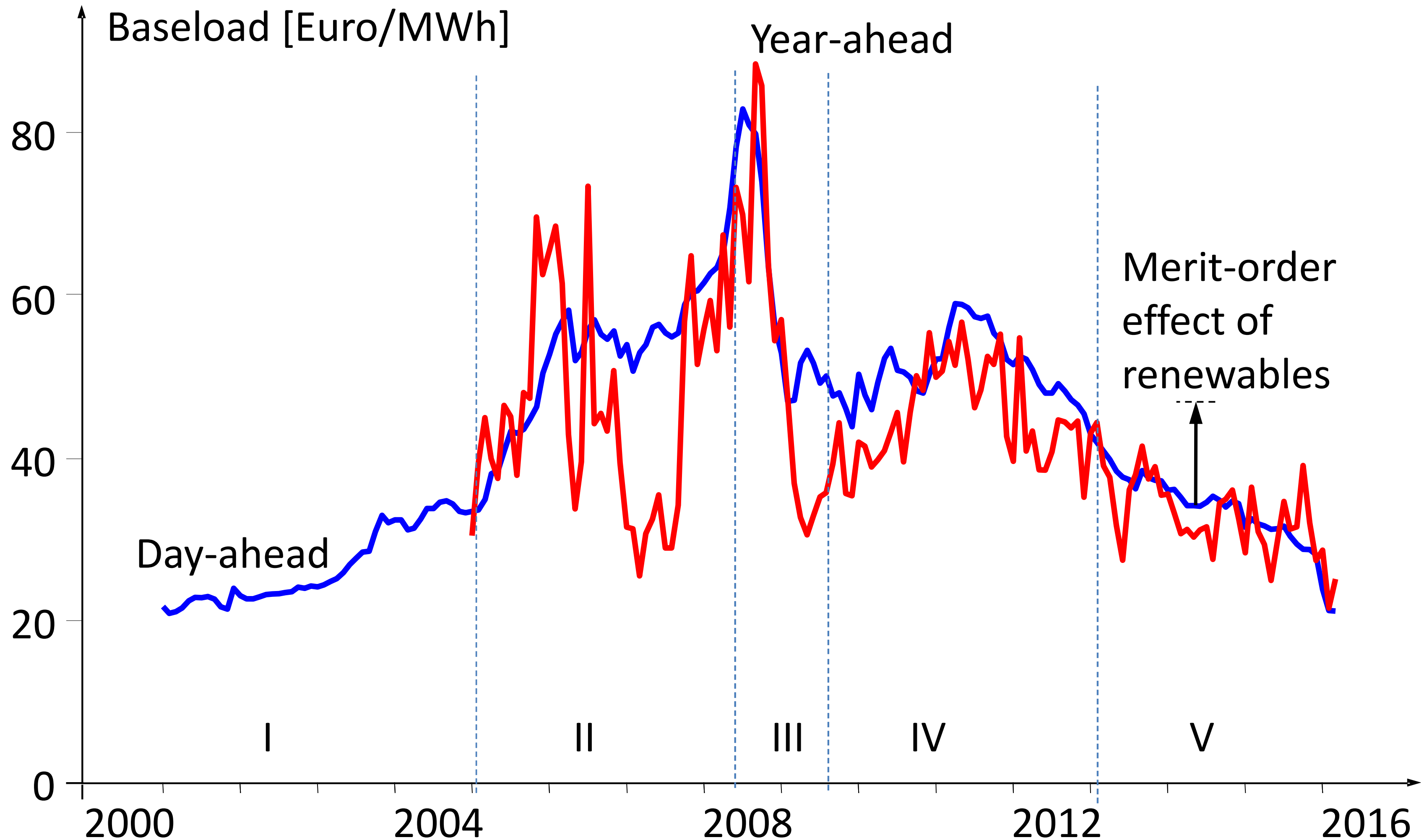


Merit-Order-Effect of Renewable Electricity

[2014; Source: Own calculations from EEX and TSO data]



Wholesale Power Prices [Sources: EEX, EPEX]



Implications of the Merit Order Effect

- The increase in the renewable electricity share has reduced the German wholesale power prices
- The merit order effect of renewable electricity challenges the economics of conventional power generation. In particular new gas fired power stations are not able to cover their investment costs by selling electricity
- Power in Germany becomes attractive for customers in neighboring countries. Therefore the German net electricity exports increased to >50 TWh or >8% of national generation
- The net exports spread the merit order effect to neighboring countries and challenge the economics of gas fired power plants all over Europe

Effect of European Emission Allowances

	Carbon content		Assumed wholesale fuel price	Price markup of 10 EUR/t CO_2
	[kg CO_2 per GJ]	[kg CO_2 per kWh_{th}]	[Ct/kWh_{th}]	[percent]
Lignite	108	0.39	0.6	65
Hard coal	93	0.33	0.8	41
Heavy oil	78	0.28	1.2	23
Fuel oil	74	0.27	1.9	14
Natural gas	55	0.20	2.2	9

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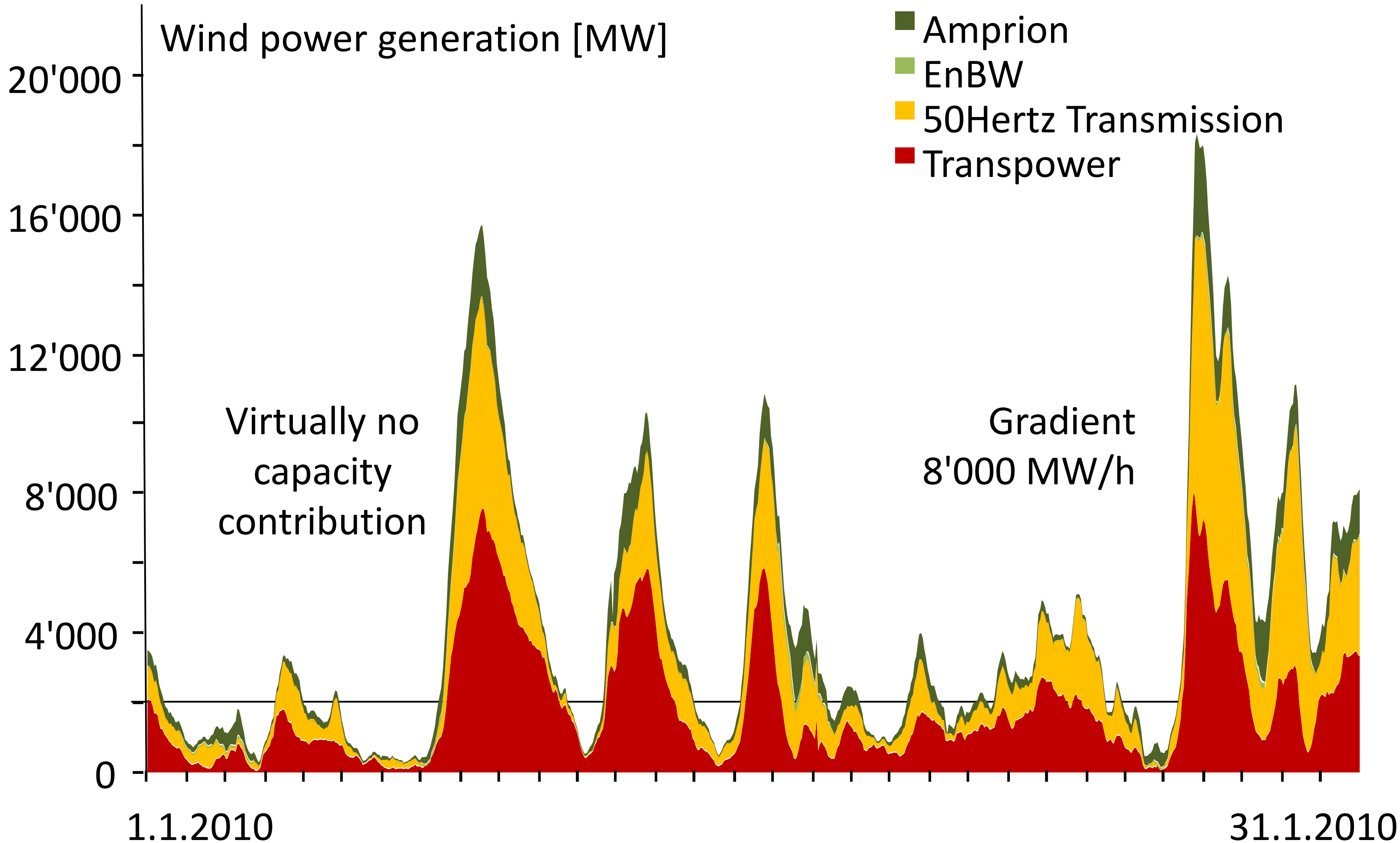
Volatility of Wind Power [Source: Ehlers 2011, p. 100]

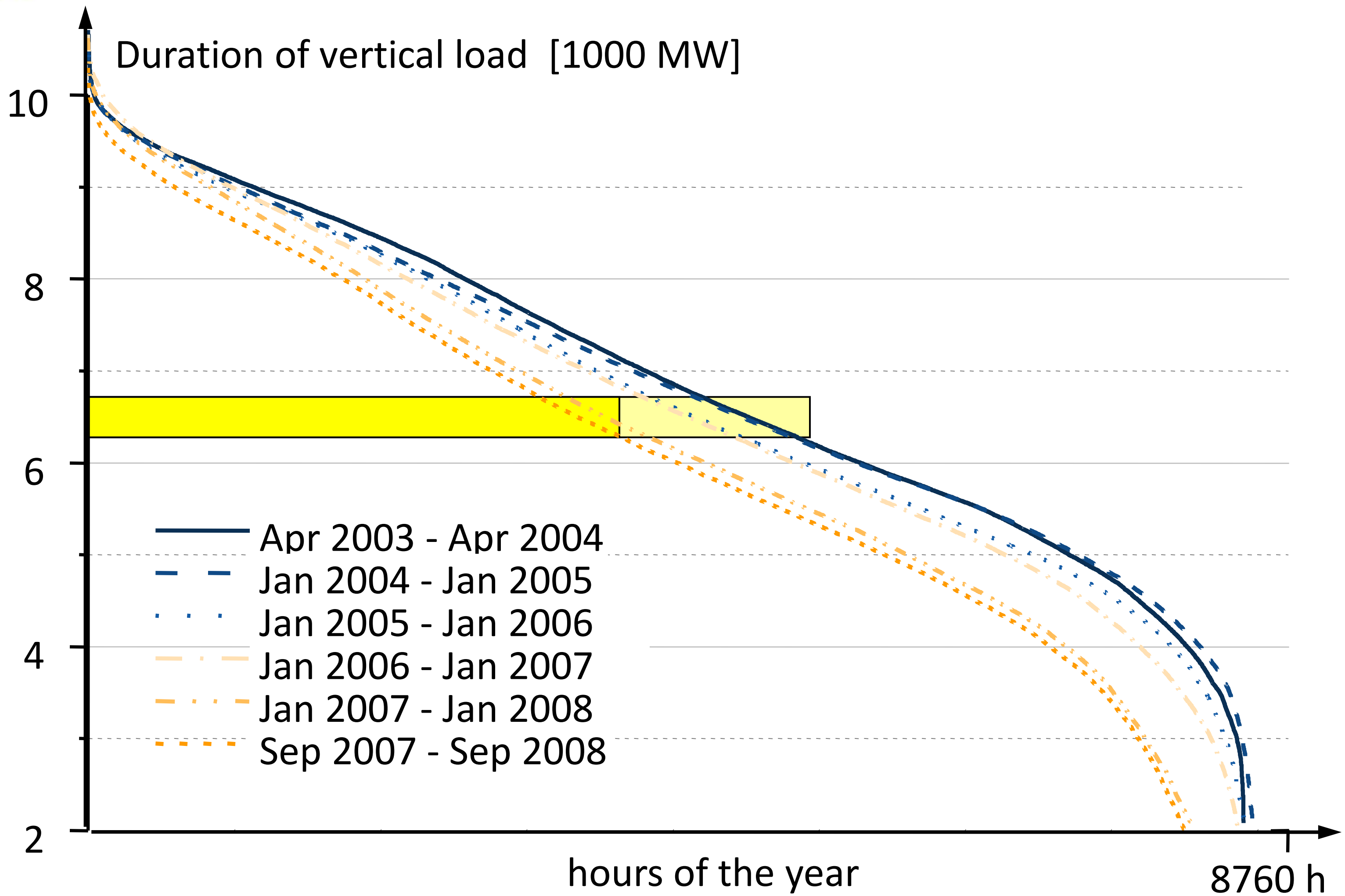


Nature of the Intermittency Problem

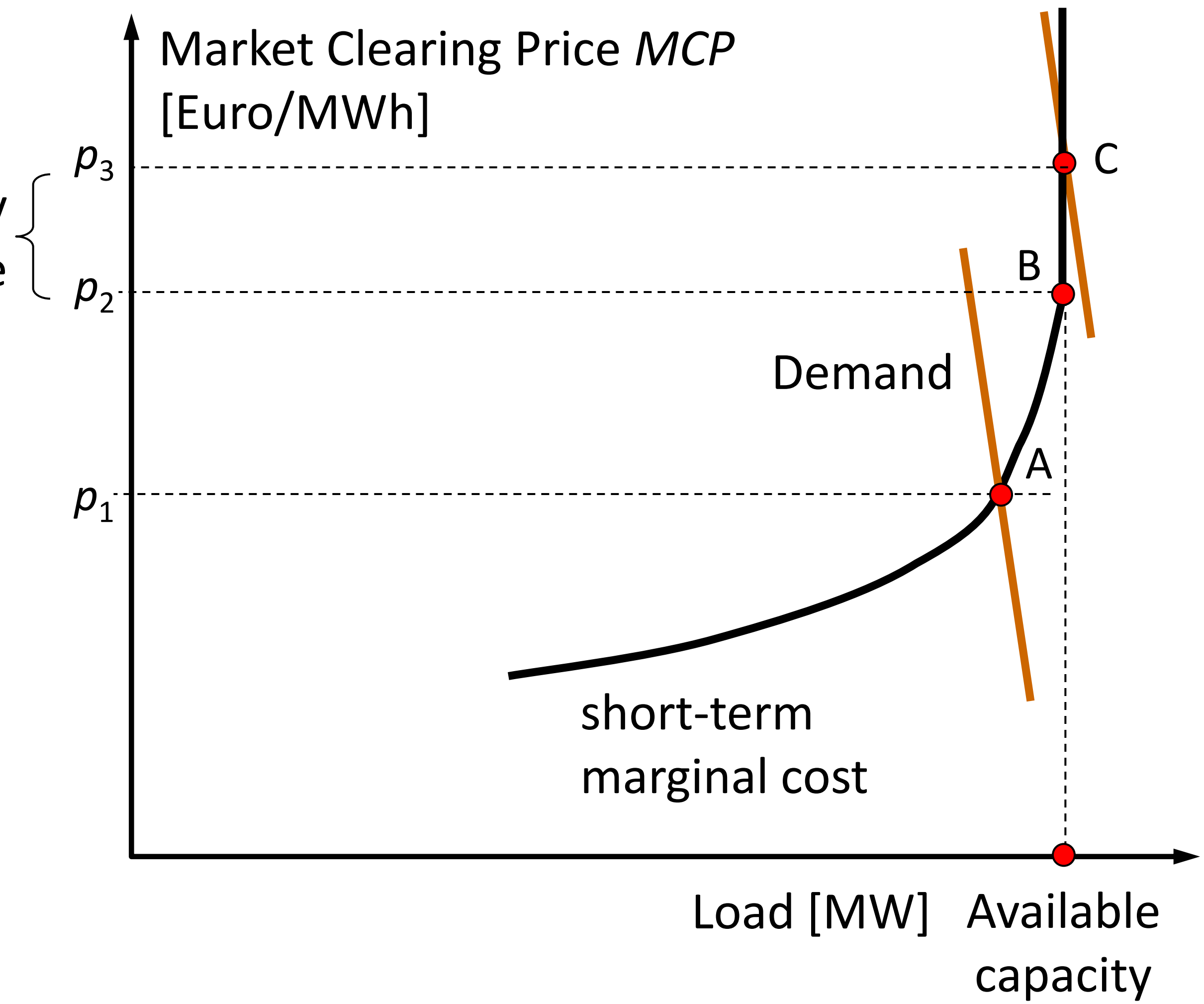
- Electricity cannot be stored in macro-economically relevant volumes. Therefore the electricity generation should follow the demand
- While generation of fossil and hydro power generators can be controlled accordingly, wind an photovoltaic generators cannot
- In the absence of large electricity storage capacities (hydro power storage plants, accumulators, …) and without an effective demand side management, (fossil) backup power generators are necessary to balance supply and demand
- But the merit order effect of renewables hinders such investments. In the future this may lead to electric shortages

Renewables Replacing Thermal Generation

[Data source: 50Hertz GmbH 2009]



Market Clearing Price (MCP) under Capacity Shortages



Missing Money:

For institutional, political or social reasons there is a ceiling on (wholesale) power prices

Possible State Intervention: Capacity Market

- Some (new or old) power plants are eliminated from the normal market supply and scheduled according to the requirements of the regulator. Thus available power capacity shrinks in normal periods and increases in critical periods

- Plants in the strategic reserve are selected through a competitive bidding process organized by the regulator. Successful plants receive a capacity premium financed through the grid fees. If scheduled, the plants become regular market participants

- Alternative: Any market participant that feeds electricity into the grid (takes electricity out of the grid) must hold an equivalent number of capacity guarantees issued by flexible generators or flexible demand (“Decentralized capacity market”)

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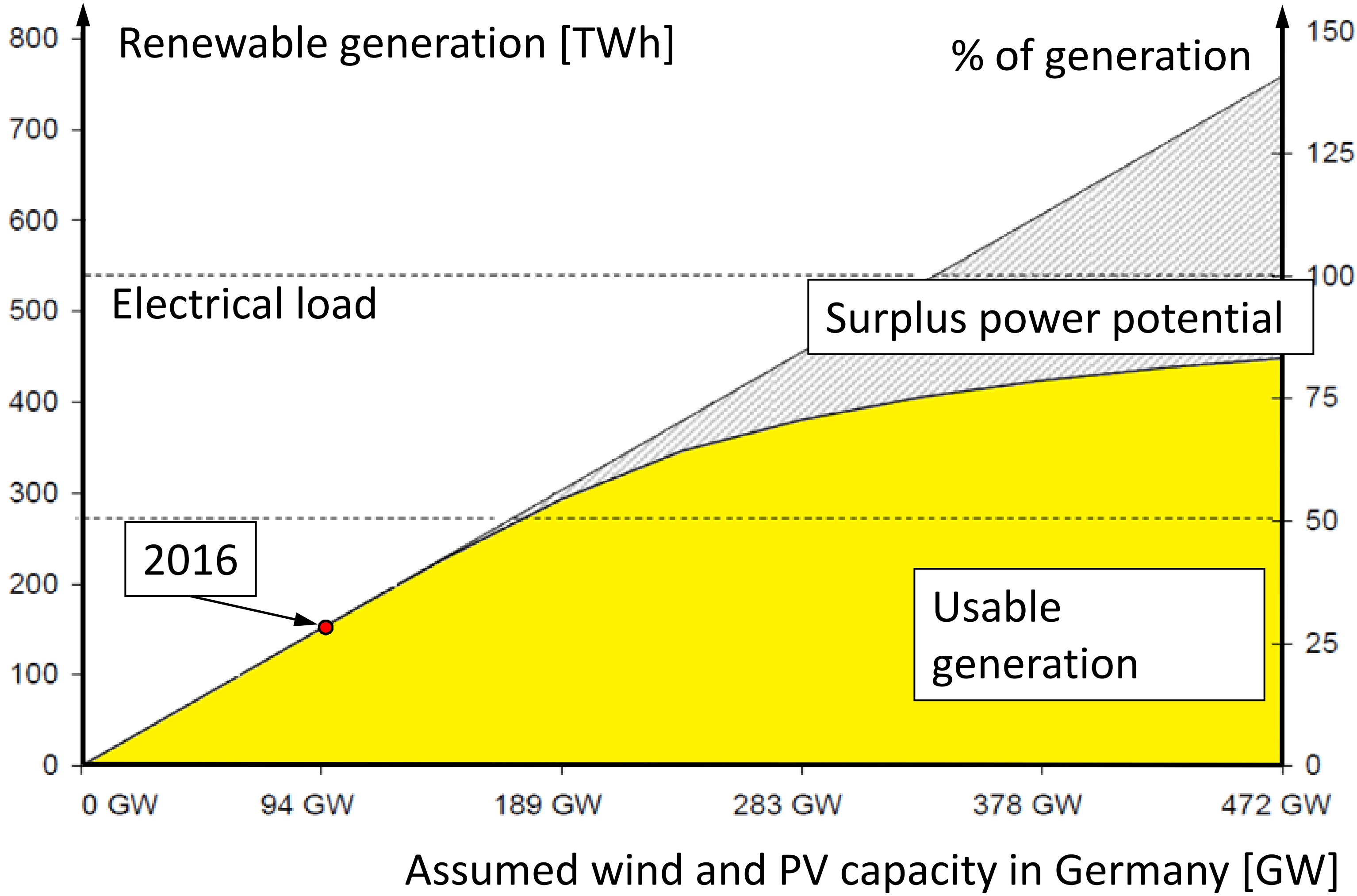
Distributed Generation in Germany

	Generation units	Installed Capacity [MW]	Generation 2014 [GWh]
Nuclear	9	12'068	97'100
Coal, gas, oil	890	84'893	353'700
Wind	26'206	40'456	55'970
Solar	1'547'000	38'236	34'930
Biomass	15'499	6'867	43'000
Hydro	7'513	5'590	20'500
Other renewables	873	1'245	6'210

Power-to-X [Source: from Grosse Böckmann 2010]



Nature of the Problem to be Solved

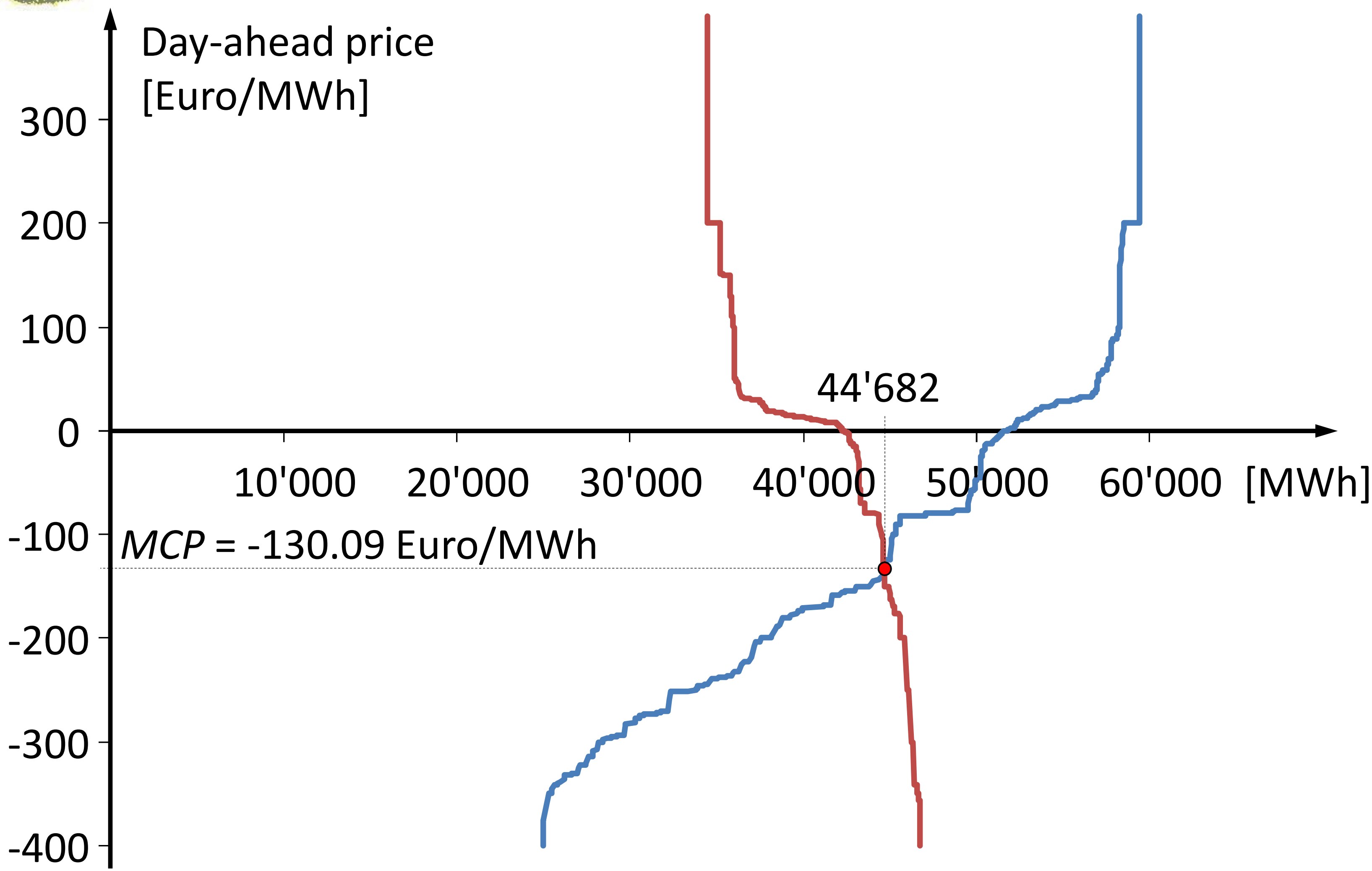
- With growing shares of wind and photovoltaic capacities the number of hours with excess electricity will increase. Without additional electricity demand in these hours the renewable generation potential cannot fully be used
- The curtailment of renewable electricity can also be due to bottlenecks in the electric grid
- Use of the excess renewable electricity in heat and fuel markets where fossil fuels are thereby replaced
- Examples:
  - Transportation market (electric mobility)
  - Heat market (Power-to-Heat, hybrid heating systems)
  - Chemistry, refineries (Power-to-Gas)
  - Chemical energy storage (Power-to-Gas)

Negative Day-ahead Prices in Germany

[Own calculations; data source: EPEX]

Year	Number of hours with day ahead price ≤ 0	Minimal day-ahead price [Euro/MWh]
2010	12	-20.45
2011	16	-38.82
2012	55	-221.99
2013	621	-100.93
2014	61	-65.03
2015	118	-79.94
2016	97	-130.09

What happened on 08.05.2016, 14-15 h?



Electricity Price Components in Germany in the Year 2016

	Power purchase from the grid	Auto generation	Generation in „local context“
		Euro/MWh	
Grid fee	18.00 – 30.00		18.00 – 30.00
REN levy	63.54	22.24	0.00
Electricity tax	20.50	Legally unclear	
Concession fee	1.1 – 23.90		1.1 – 23.90
CHP levy	4.45		4.45
§ 19 StromNEV	3.78		3.78
Offshore levy	0.40		0.40
Total	86.77 – 121.57	22.24 – 42.74	23.73 – 83.03

Challenge of Sector Coupling

- Wholesale electricity is cheap, in particular during hours with excess supply from wind and PV
- Electricity used for substituting fossil fuels should not be more expensive than the price of the substituted fuel (example gas 40 to 90 Euro/MWh)
- In spite of low wholesale prices, electricity end user prices are usually above this benchmark, due to grid access fees, levies and taxes
- What could be the solution?
  - Selective exemptions from certain price components for certain electricity uses …
  - … a modified model for financing grid and levies: Shift from energy pricing to capacity pricing

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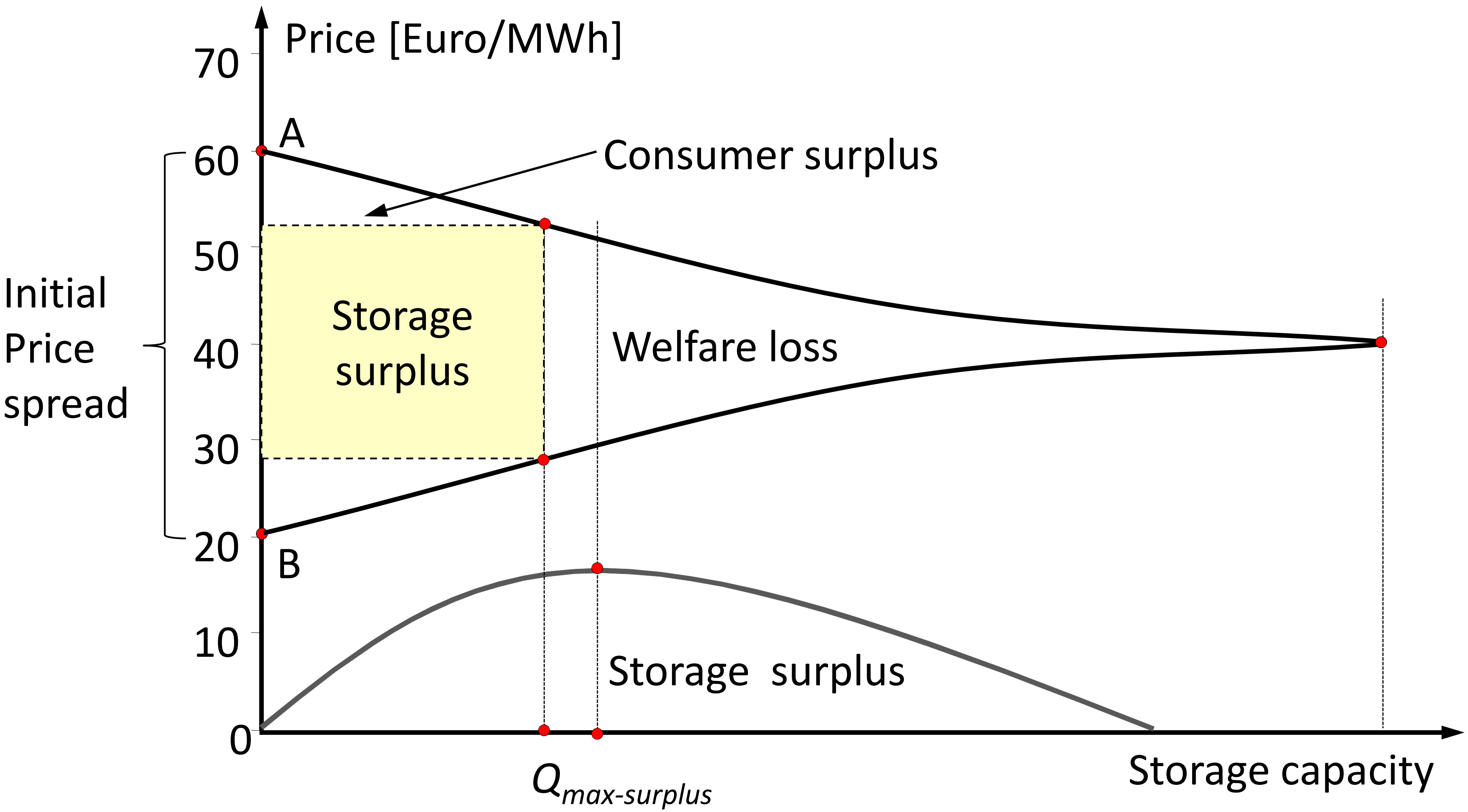
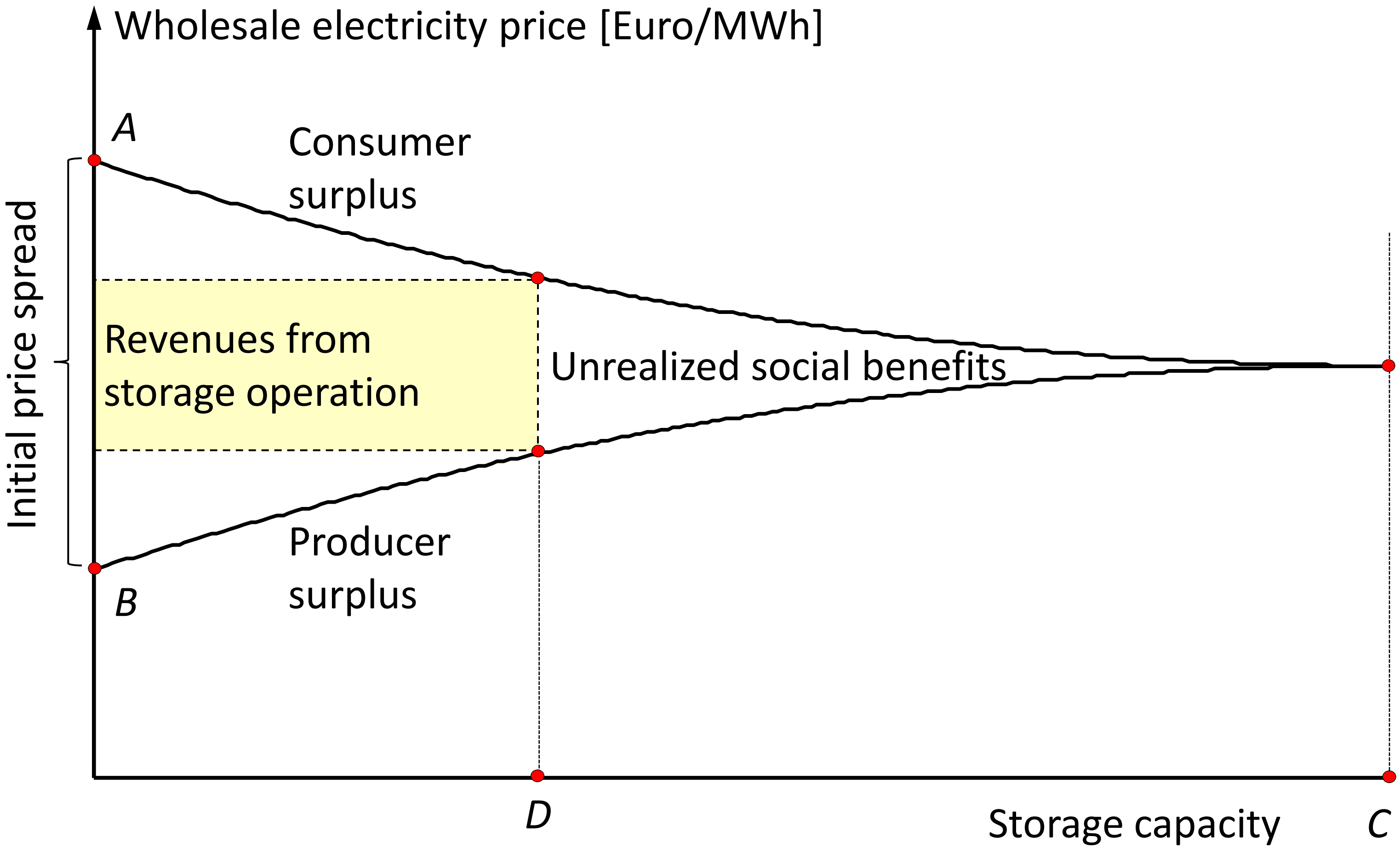
6. **Backup: Economics of Electricity Storage**

Business Case for Storage Capacities



Price Spread and Power Storage Capacities

[Source: Ehlers 2010]



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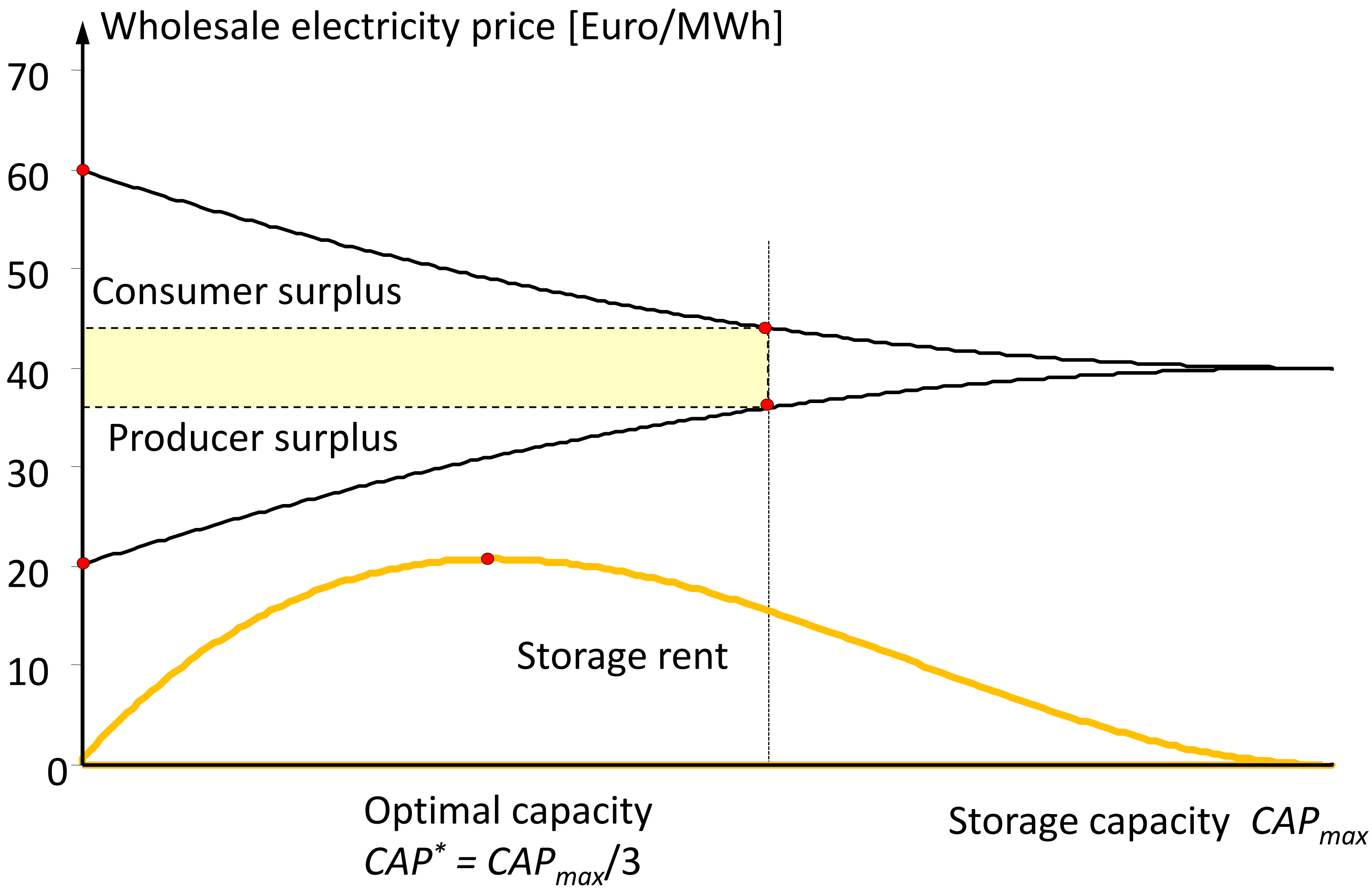
[Source: Ehlers 2010]



Economics of Energy Storage Investments

- Merchant investments into energy storage are economic if the price spread between different time periods is sufficiently large. (Similarly investments into electricity grids are economic if regional price spreads are sufficiently large)
- Cannibalization effect of storage investments: Additions into storage volumes reduce the price spread. This underlines the complexity of competitive markets for electricity storage infrastructures (grid infrastructures)

Grazie!

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