European University Institute
ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES
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The Cost of Abating CO2 Emissions by Renewable Energy Incentives in Germany

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Outline

I. Introduction

II. The Relevant Costs

III. Methodology

IV. Results

Scope of the research

- Treat renewable energy as a climate instrument to reduce CO2 emissions
- Ignore energy security, green growth, jobs, other rationales

- The question we try to answer is:

How much did it cost to reduce CO2 emissions using renewable energy incentives?

We analyse…

- What: *wind* and *solar* energy
- Where: *Germany*
  - Germany has a leading role in renewable expansion (wind capacity from 6GW in 2000 to 27GW in 2010; solar capacity from 6MW in 2000 to 17GW in 2010)
  - Very successful system of feed-in tariff (FIT) since 2000
- When: years *2006-2010*
  - *Ex-post* analysis
  - Annual CO2 abatement cost
- How:

$$\text{CO2 abatement cost} = \frac{\text{Total cost of renewable}}{\text{CO2 emission reduction}}$$

- We do not consider costs of transmission and distribution.

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Costs of renewable energy (1)

- *Remuneration* : Start with payments to RE generators
  - No interest in engineering cost of production, profits, etc.
  - Generators receive real claims on resources
  - May be fixed feed-in tariff, premium + electricity price, with or w/o tax other benefits

- *Fuel Cost Savings*: Must deduct cost of electricity for fixed feed-in tariff, as in Germany
  - Generators receive remuneration for a joint product: electricity and CO2 abatement
  - These cost savings are cost of the fossil fuel not used for generation
  - For our purposes, quantities shown by the model times appropriate fuel price

- Also a *carbon cost savings*
  - CO2 emissions reduced times EUA price
  - No attempt to take price interaction effect into account

Costs of renewable energy (2)

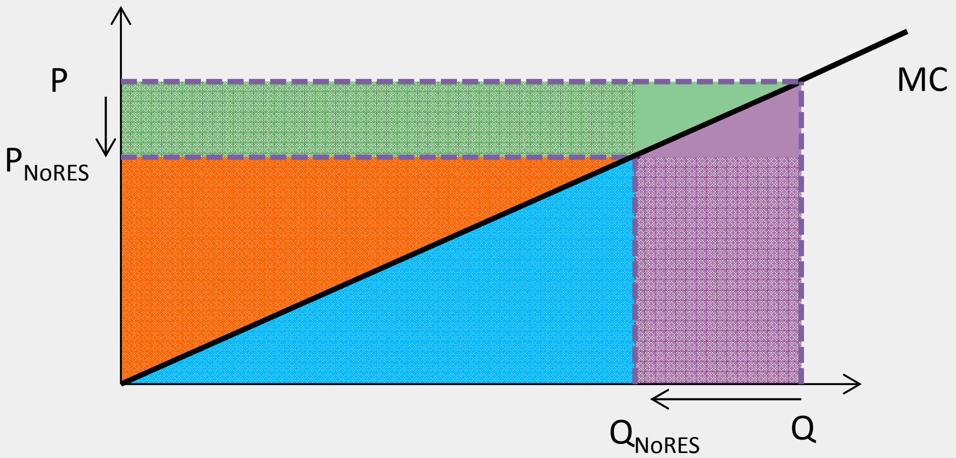
- Additional cost of the power system: *balancing cost*
  - Costs due to short term intermittency of renewable energy
  - Short-term fluctuations need additional system balancing reserves with respect to conventional generations with an increase of cost for consumers

- Additional cost of conventional generations: *cycling cost*
  - Costs due to intermittency of renewable generation
  - Increasing start-up cost
  - More inefficiency in convention power production because generations tend to work at lower capacity factor than what was designed for maximum efficiency
  - Higher maintenance costs

- Additional savings in reduced capacity need: *Capacity credit*
  - Amount of conventional capacity that can be replaced by wind capacity (expressed as a % of the installed capacity), either existing or future
  - The inverse of 'back-up capacity'…what will *not* be needed

The merit order effect is mostly a transfer

Refers to reduction in wholesale electricity price resulting from RE injection



P = price w/ RES
P_{NoRES} = price w/o RES
Q = fossil fuel generation w/ RES
Q_{NoRES} = fossil fuel generation w/o RES
MC = marginal cost of fossil fuel generation

<u>Consumer savings?</u>

- Whether passed through to consumer depends on regulation
- Also, expectation effects in liberalized markets

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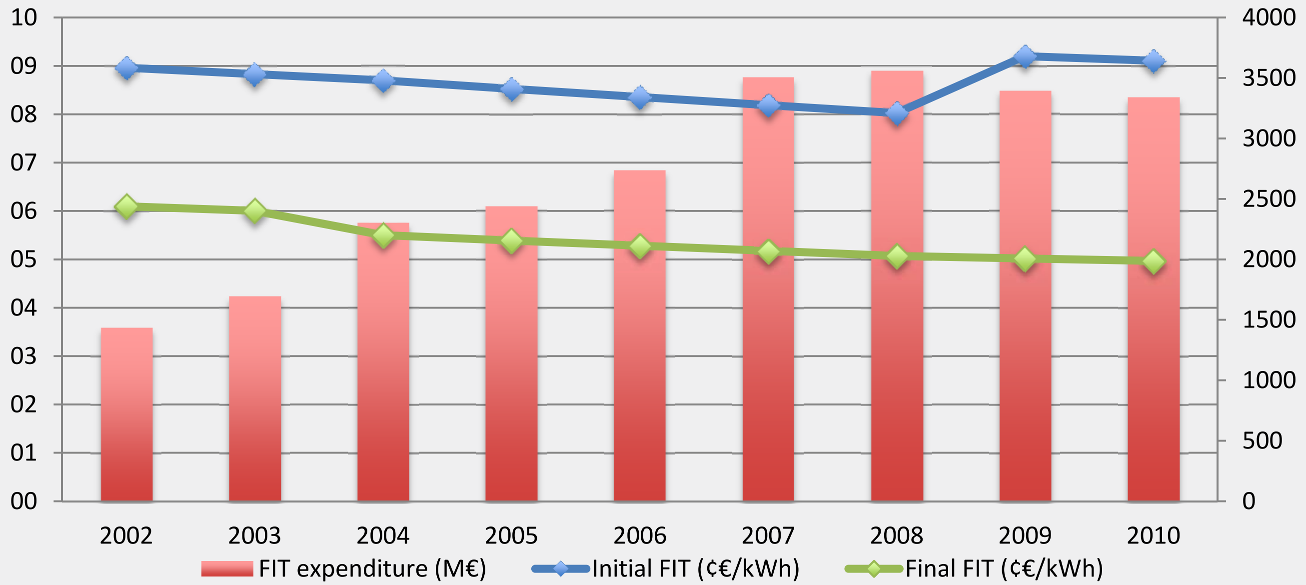
Remuneration to Wind

- In Germany, renewable energy receives a guaranteed feed-in tariff (FIT) for 20 years
- The level of FIT can be reduced after 5 years depending on the characteristics of the power plants
- More than half power plants receive the initial tariff payment over 20 years and more than three-quarters at least for 15 years
- All the FIT are nominal



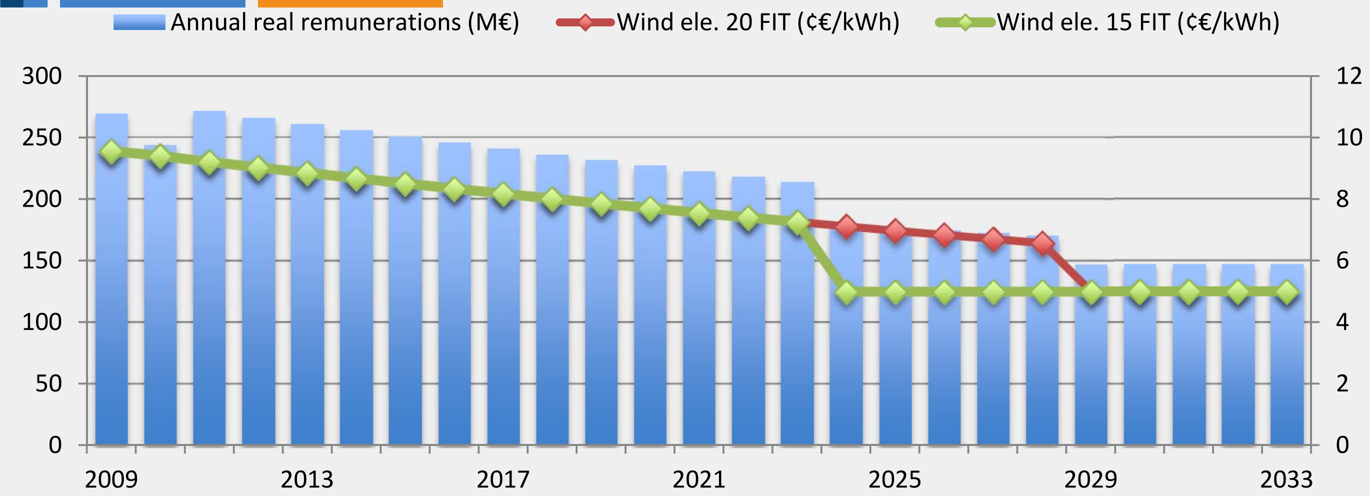
Annualized Economic Cost

- Actual FIT payments overstate cost in early years and understate it in later years
  - FIT diminishes in value over time both in nominal and real terms
  - FIT lasts for 20 years but average life-time of power plant is longer

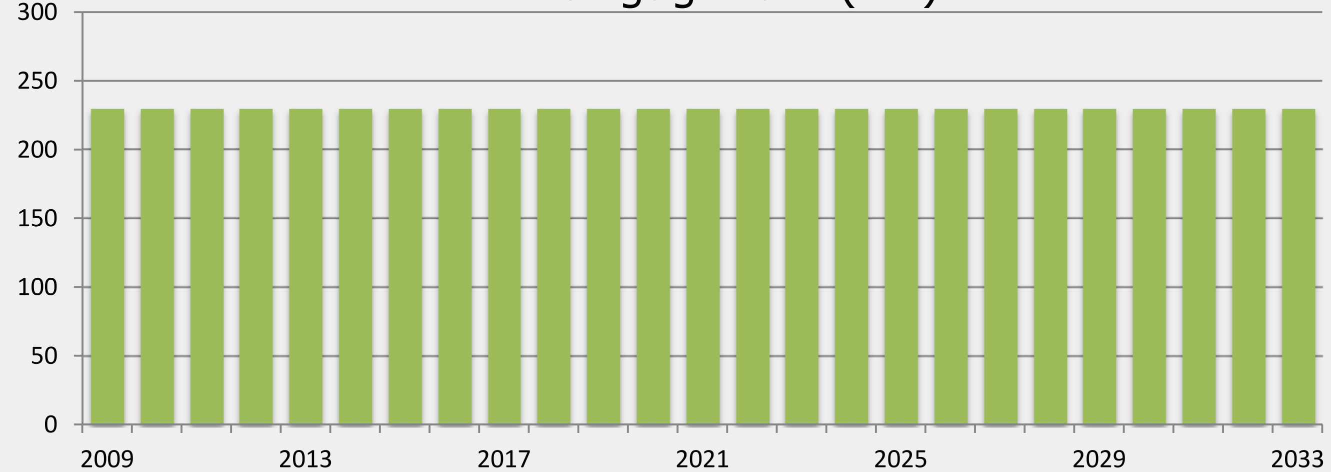
- We estimate an equal annualized 'mortgage' cost:

1. Determine the real annual remuneration of the installed capacity year by year for the life-time of the RE generating plants
   - 25 years life-time
   - 2% inflation
   - Same annual capacity factors for all wind power plants (18%)
   - 50% power plants receive the initial tariff for 20 years and 50% for 15 years
   - €50/MWh electricity price after expiration of FIT
2. Discount the annual remunerations and sum them to get an initial NPV and redistribute that sum over a 25-year mortgage using the same interest rate
   - fixed cost of capital of 7%
3. The total annualized economic cost is the sum of the mortgage payments for each in-service capacity cohort

Example for capacity installed in 2009 (1.7GW)



Mortgage rate (M€)



Comparison with Actual FIT

- Annualized wind economic cost

Wind		2006	2007	2008	2009	2010
Expenditure for FIT	[M€]	2988	3718	3731	3524	3412
Annualized economic cost	[M€]	2663	2851	3033	3268	3463
%		89%	77%	81%	93%	101%

- Annualized solar economic cost

Solar		2006	2007	2008	2009	2010
Expenditure for FIT	[M€]	1304	1746	2351	3307	5284
Annualized economic cost	[M€]	895	1247	1740	2633	4087
%		69%	71%	74%	80%	77%

Fuel cost saving

- Estimated fuel cost saving are based on the model developed by Weigt et al.
- The model is a deterministic unit commitment model of the German electricity market calibrated to simulate the years 2006-2010 (actual prices, load, injections)
- The model calculates fuel cost in the *OBS* scenario, which corresponds to the actual observation, and in the *No Wind* (*No Solar*) scenarios at actual prices
- Fuel cost saving are given by the difference between the fuel costs in the *No Wind* (*No Solar*) and the *OBS* scenario

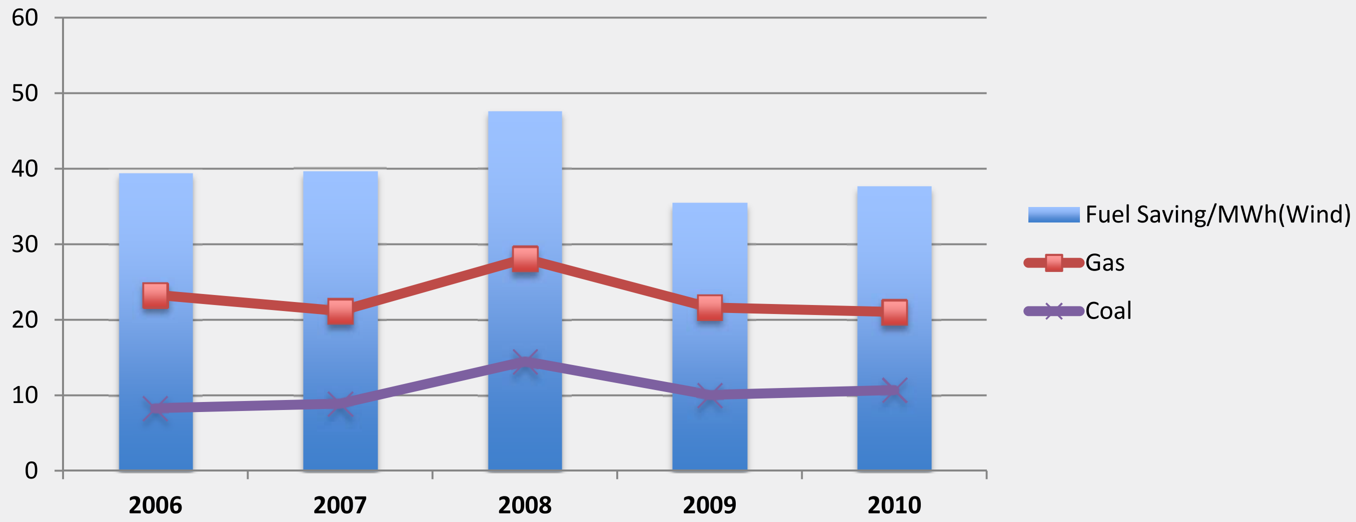
WIND			2006	2007	2008	2009	2010
Fuel cost	No Wind	[M€]	11726	12104	15718	11705	12433
	OBS	[M€]	10621	10622	13875	10423	11111
Fuel cost saving		**[M€]**	**1207**	**1570**	**1931**	**1330**	**1350**

SOLAR			2006	2007	2008	2009	2010
Fuel cost	No Solar	[M€]	10719	10739	14080	10649	11519
	OBS	[M€]	10621	10622	13875	10423	11111
Fuel cost saving		**[M€]**	**107**	**124**	**214**	**234**	**416**

Fuel cost saving

- Fuel cost saving depends on the price of fossil fuels

Wind fuel cost saving and fossil fuel prices (€/MWh)



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Additional start-up cost

- They are calculated similarly to the fuel cost using the model by Weigt et al.
- Start up cost does not take into account all cycling costs

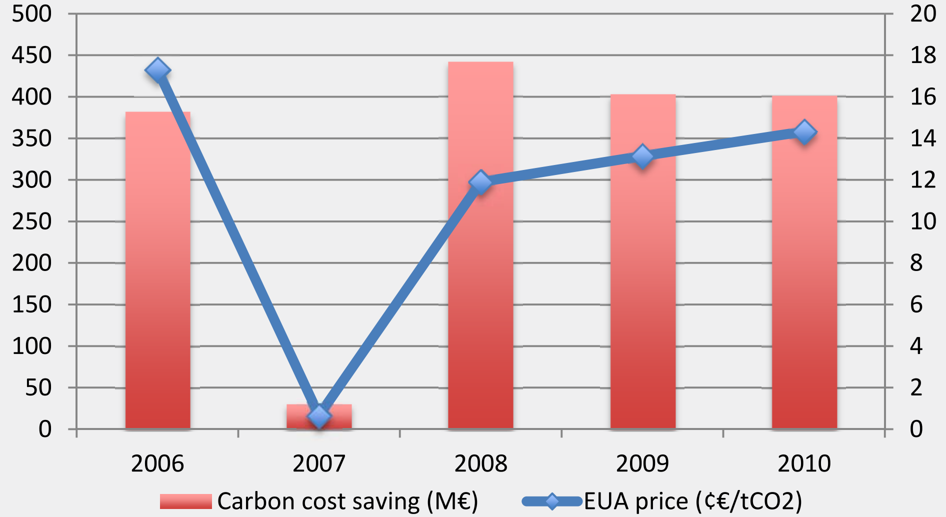
WIND			2006	2007	2008	2009	2010
Start up cost	No Wind	[M€]	178	169	217	197	203
	OBS	[M€]	173	156	212	199	207
Additional start up cost		**[M€]**	**-6**	**-14**	**-5**	**2**	**4**

SOLAR			2006	2007	2008	2009	2010
Start up cost	No Solar	[M€]	175	159	213	209	207
	OBS	[M€]	173	156	212	199	207
Additional start up cost		**[M€]**	**-2**	**-3**	**-1**	**-10**	**0**

Carbon cost saving

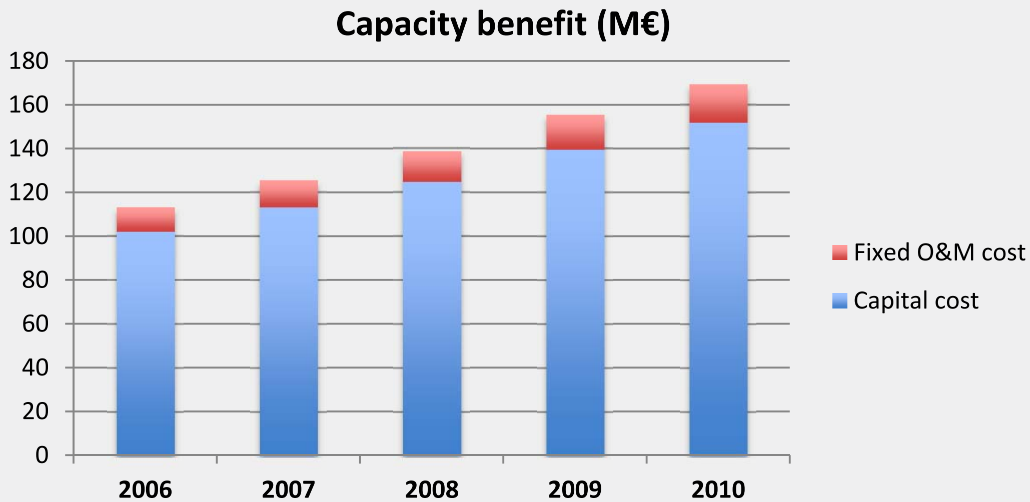
- They are calculated similarly to the fuel cost using the model by Weigt et al.
- In all scenarios the EU ETS carbon price is exogenous and equal to the historical values
- The model does not take into consideration interactions between renewable policy support and the EU ETS.

WIND			2006	2007	2008	2009	2010
CO_2 emissions	No Wind	[MtCO2]	329	344	329	312	314
	OBS	[MtCO2]	307	318	297	282	287
CO_2 emission reduction		**[MtCO2]**	**22**	**26**	**32**	**30**	**27**



Wind capacity benefit

- 100 MW wind ≠ 100 MW dispatchable capacity, nor 0 MW!
- There is <u>some</u> savings in capital cost plus the savings in fixed O&M cost of the conventional capacity that will not be built (or maintained) because of the increased wind capacity.
- We assume a capacity credit of 7%
- We assume that the savings are 70% coal and 30% gas for new capacity
- We suppose that capacity credit that comes from all wind capacity built before 2010 is realized in 2015.
- We redistribute these savings along the lifetime of the wind plants on-line in 2006-10



Additional wind balancing cost

- We assume €2 per MWh for the additional balancing cost due to wind penetration

		2006	2007	2008	2009	2010
Balancing cost per MWh of wind energy	[€/MWh]	2	2	2	2	2
Wind energy generated	[TWh]	30.6	39.6	40.5	37.5	35.8
Additional balancing cost	**[M€]**	**61**	**79**	**81**	**75**	**72**

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Abatement cost

Wind		2006	2007	2008	2009	2010	Average
Annualized economic cost	[M€]	2663	2851	3033	3268	3463	
Additional start up cost	[M€]	-6	-14	-5	2	4	
Additional balancing cost	[M€]	61	79	81	77	76	
Fuel cost saving	[M€]	-1207	-1570	-1931	-1330	-1350	
Carbon cost saving	[M€]	-382	-31	-443	-403	-401	
Capacity benefit	[M€]	-113	-125	-139	-155	-196	
Total cost	[M€]	1081	877	648	1416	1536	
CO2 emission reduction	[MtCO2]	22	26	32	30	27	
Abatement cost	**[€/tCO2]**	**45**	**46**	**19**	**49**	**61**	**43**

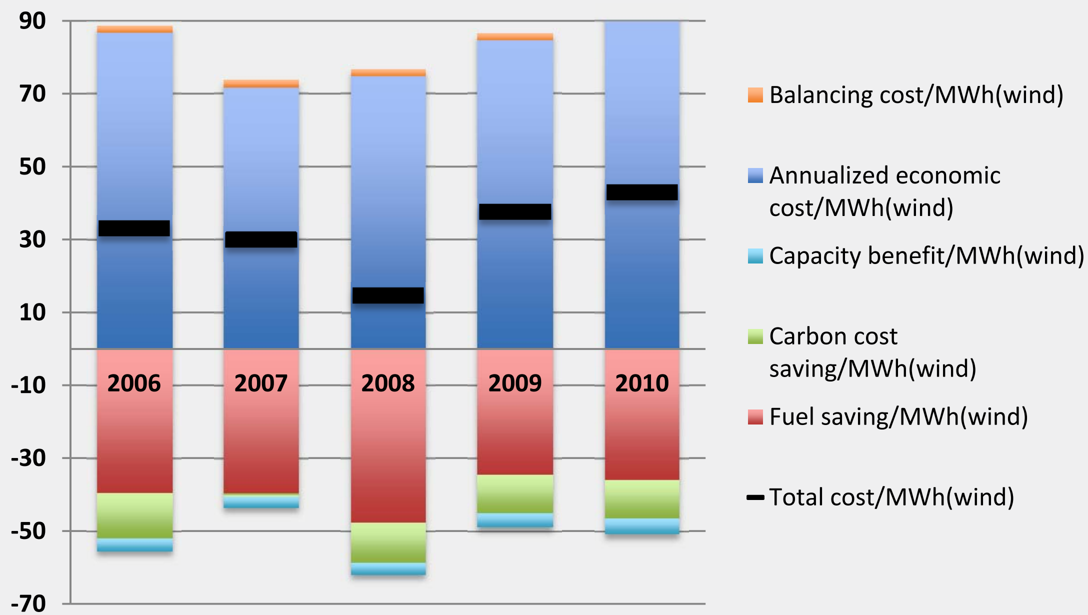
Solar		2006	2007	2008	2009	2010	Average
Annualized economic cost	[M€]	929	1294	1806	2731	4236	
Additional start up cost	[M€]	-2.4	-2.9	-0.7	-9.7	0.0	
Fuel cost saving	[M€]	-107	-124	-214	-234	-416	
Carbon cost saving	[M€]	-28	-1	-82	-65	-113	
Total cost	[M€]	791	1167	1509	2422	3707	
CO2 emission reduction	[MtCO2]	1.5	2	3.6	4.6	7.3	
Abatement cost	**[€/tCO2]**	**527**	**598**	**414**	**524**	**510**	**505**

Abatement cost

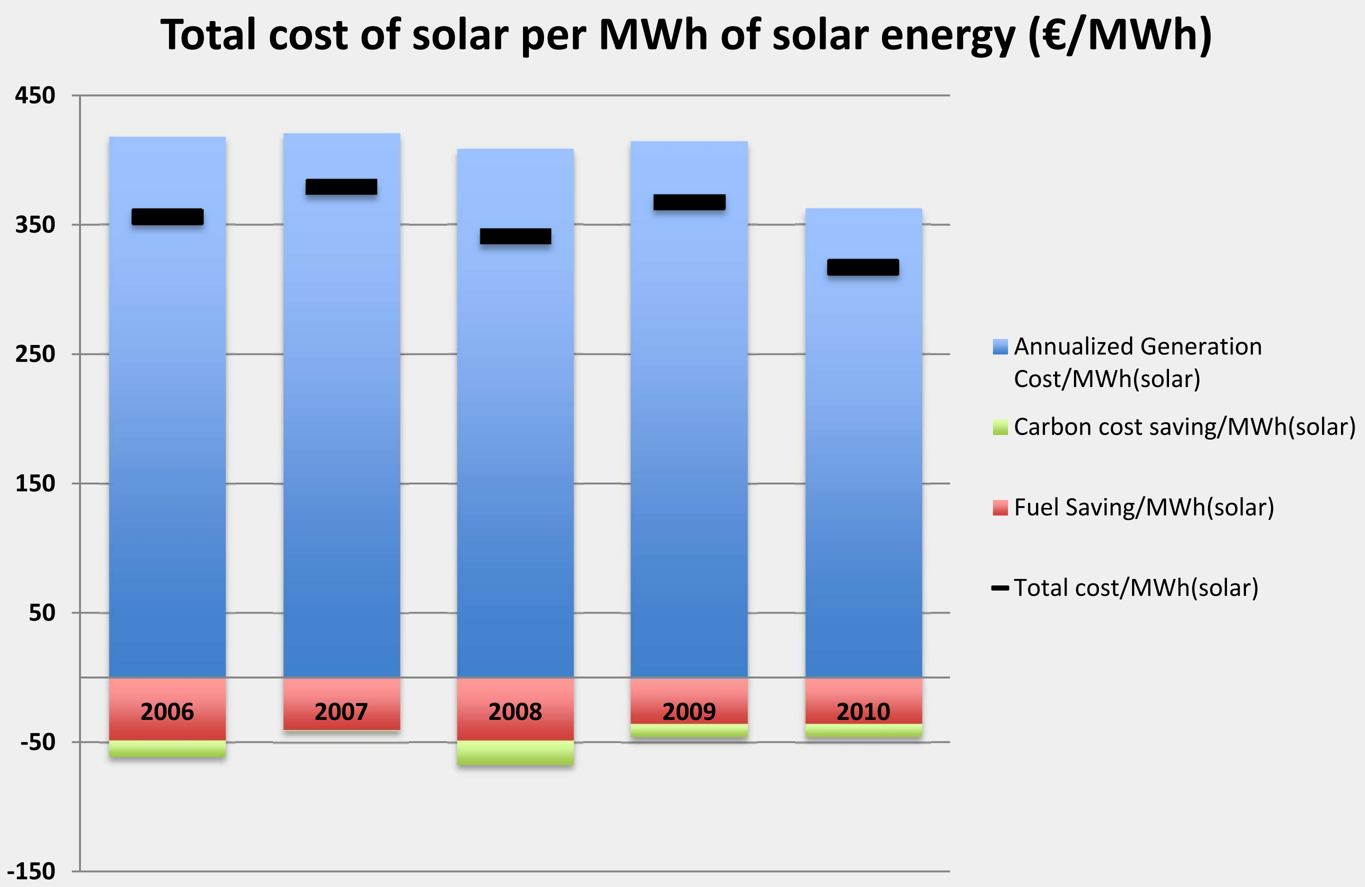
- There is one main cost: *remuneration to RE generators*. Additional start up cost and balancing cost, are insignificant in comparison

- There is one main cost saving: *fuel costs*. Carbon cost saving and capacity benefit are much lower than fuel cost saving, although not irrelevant

Total cost of wind per MWh of wind energy (€/MWh)



Abatement cost



Conclusions

- CO_2 abatement costs of *wind* are relatively low (average 2006-2010 40€/tCO_2)

- CO_2 abatement costs of *solar* are very high (average 2006-2010 505€/tCO_2)

- The cost of CO_2 abated is almost entirely determined by the remuneration to RE generators less the fuel cost savings of the displaced generation.

- CO_2 abatement cost can vary considerably from year to year due to variation of fossil fuels prices assuming constant remuneration

- In Germany, low abatement cost in 2008 due to high fuel prices; higher in 2009-10 due to higher remuneration and lower fuel prices.