How Green Are Wind and Sun?
European Renewable Energy Policies and Carbon Abatement

A Toxa - June, 25 2016

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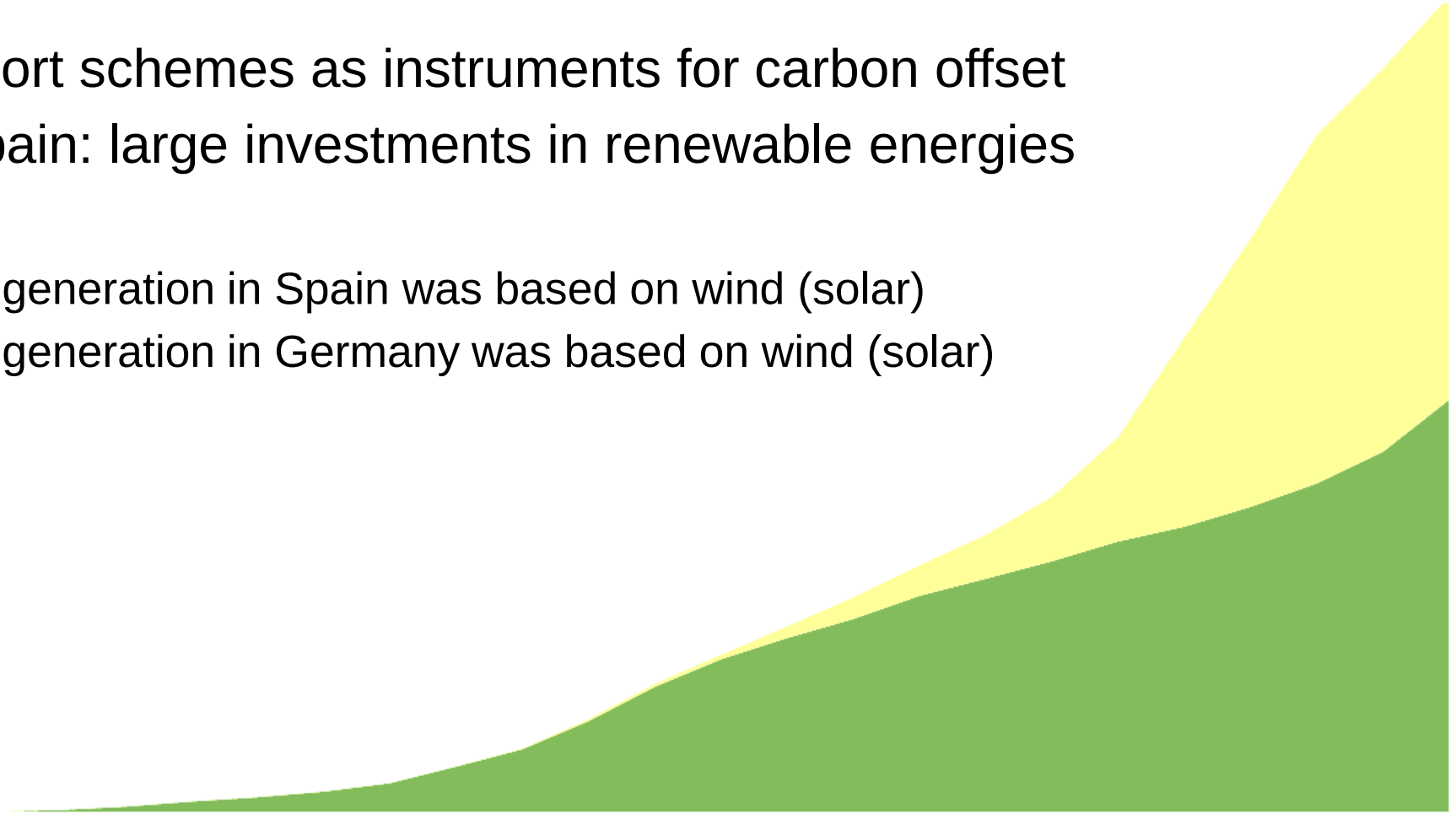
Motivation

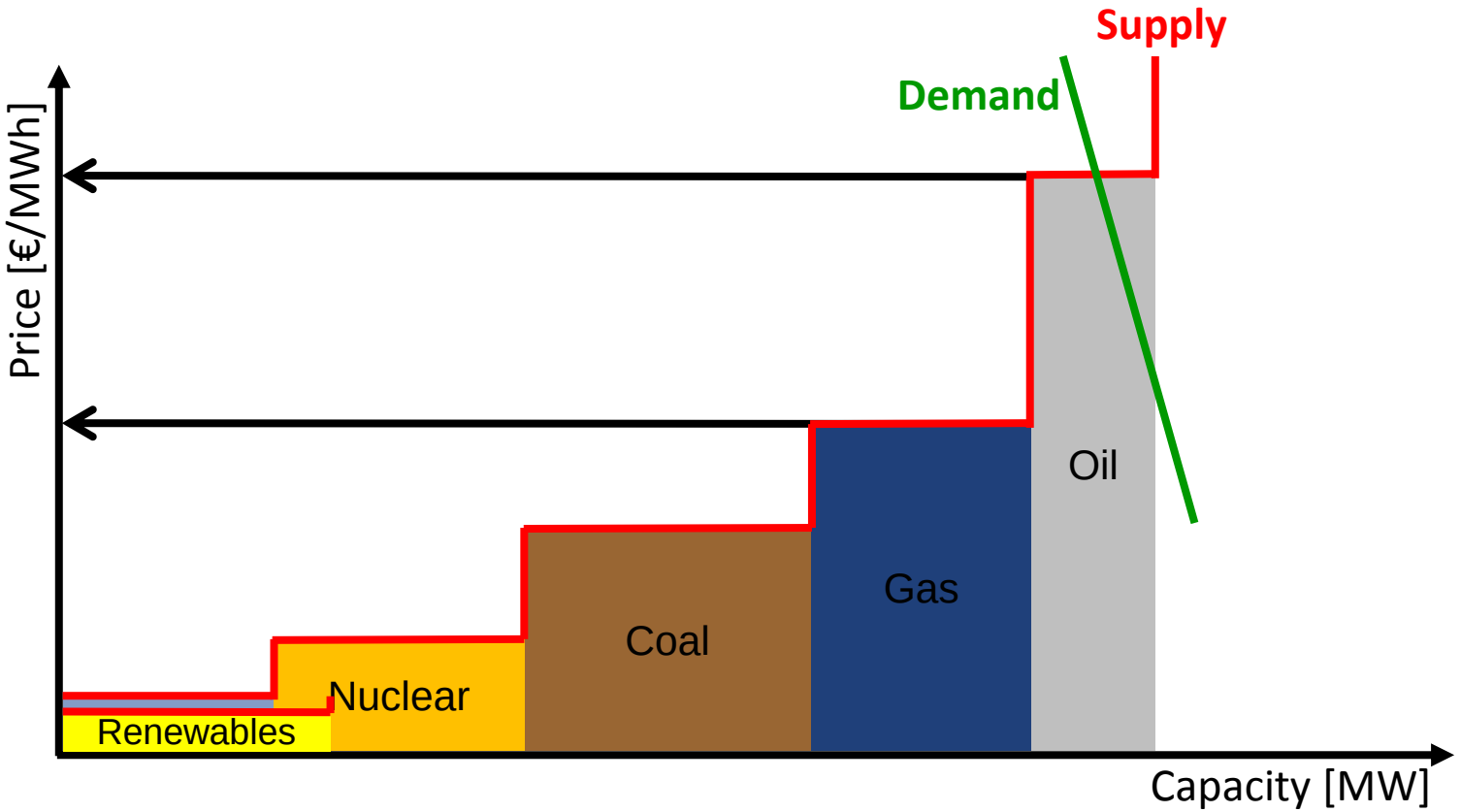
- Renewable support schemes as instruments for carbon offset
- Germany and Spain: large investments in renewable energies
- 2015
  - 19% (5%) of total generation in Spain was based on wind (solar)
  - 13% (6%) of total generation in Germany was based on wind (solar)



Research Question: How green are the wind and the sun?

- How «good» are wind and sun in replacing fossil fuels and offsetting carbon emissions?
- What are the factors that drive the replacement?
- What are the implicit costs of carbon abatement through renewable promotion?

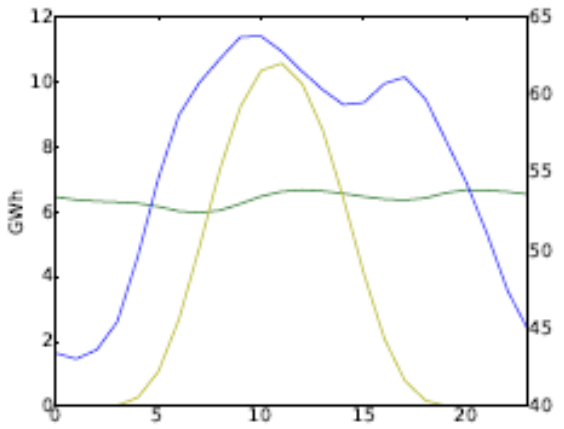
Background: Merit order effect

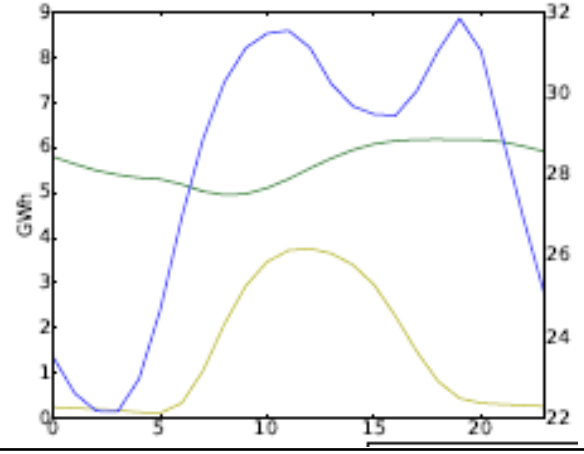


- Price decreases because of changing marginal generator (price effect)
- Marginal generator has lower production levels (replacement effect)

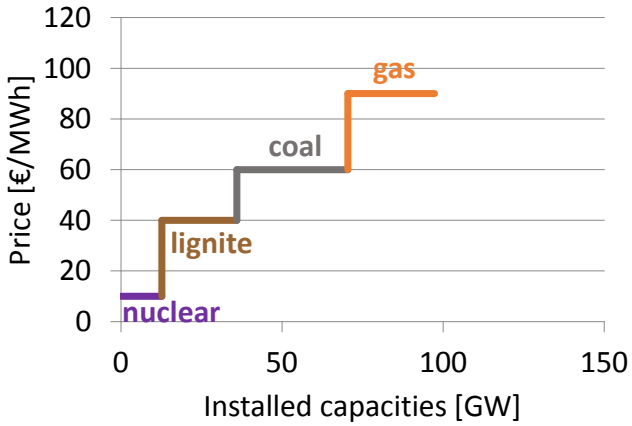
What are the factors that drive the fossil fuel replacement?

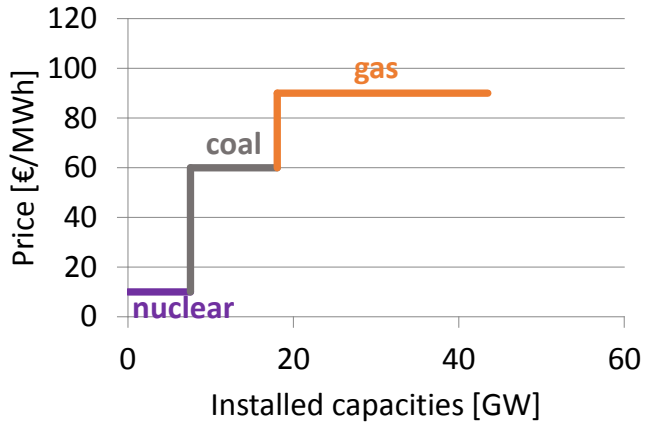
- correlation of renewable generation and demand





- pre-installed generation capacity





- export possibilities

NTC ~ 15 GW

NTC ~ 2.2 GW

Method and Data

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Method & Data Overview

Method

- Estimation of short-term impact of wind and solar power on output of conventional technologies and imports
- Determine emission offset and implicit abatement cost

Data

- Houry wholesale market prices, generation per technology, demand, net-import
- Daily mean temperature per country
- Country specific IEA historical emission coefficients
- Country specific data on renewable support (feed-in tariffs)

Estimation: Econometric specification

Autoregressive distributed lag (ARDL) model:

$$q_{it} = \beta_{i0} + \beta_{i1} W_t + \beta_{i2} W_t^2 + \beta_{i3} W_t D_t + \beta_{i1} S_t + \beta_{i2} S_t^2 + \beta_{i3} S_t D_t + \boldsymbol{Z}_t \boldsymbol{\gamma}_i + \boldsymbol{V}_t \boldsymbol{\omega}_i + \boldsymbol{D}_t \boldsymbol{\delta}_i + \epsilon_{it}$$

q_{it}	output of conventional technology i in hour t
W_t, S_t, D_t	wind/solar generation and demand in hour t
Z_t	contemporaneous controls: demand, temperature with squared terms
V_t	lagged controls: contemporaneous controls & output of all conventional technologies lagged over 24 hours
D_t	daily date dummies

- Randomness and exogeneity of wind and solar power

Results

How «good» are wind and sun in replacing fossil fuels?

Table 1: Replacement effect by technology

	Germany		Spain	
	Wind	Solar	Wind	Solar
Coal	-0.13	-0.18	-0.16	-0.09
	(-)	(-)	(0.00)	(0.00)
Lignite	-0.05	-0.05		
	(-)	(-)		
Gas	-0.06	-0.08	-0.26	-0.25
	(-)	(-)	(0.00)	(0.00)
Nuclear	-0.01	-0.02	0.00	0.00
	(-)	(-)	(0.00)	(0.00)
Hydro	-0.03	-0.02	-0.31	-0.27
	(-)	(-)	(0.00)	(0.00)
PSP	-0.11	-0.05	-0.23	-0.25
	(-)	(-)	(0.00)	(0.00)
Other	-0.02	-0.02	0.00	-0.01
	(-)	(-)	(0.00)	(0.00)
Import	-0.31	-0.39	-0.08	-0.18
	(-)	(-)	(0.00)	(0.00)
Total	-0.73*)	-0.80	-1.04	-1.05

Note: Standard errors in parenthesis.

- Germany
  - More than one third of renewable generation is exported to neighbouring countries
  - Wind and solar have higher impact on coal than on gas
  - Base load almost not affected
- Spain
  - Wind and solar have higher impact on gas than on coal
  - Wind has higher impact on coal than solar
  - Solar has higher impact on net imports than wind
  - Base load almost not affected

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*) Germany: Generation data used for the regression correspond to only ~80% of real generation.

What are the factors that drive the replacement?

- Germany exhibits a higher increase in exports.

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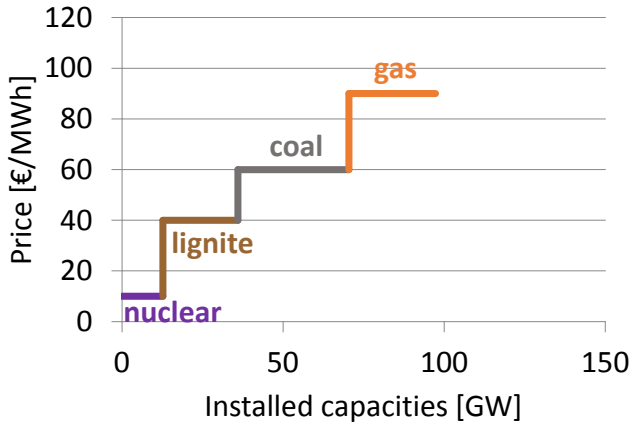
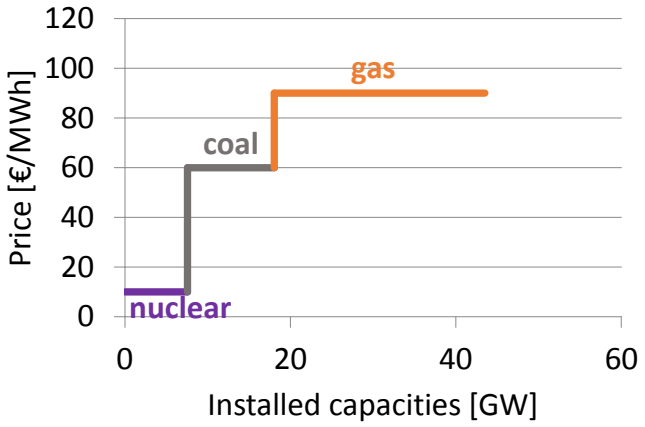
NTC ~ 2.2 GW

- German coal power shows the highest reaction among the fossil-fuel powered plants.
- In Spain mostly gas-fired plants are pushed out of the market.





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How «good» are wind and sun in offsetting emissions?

	Germany		Spain	
	Wind	Solar	Wind	Solar
Average marginal carbon offset (domestic) [t/MWh$_r$]	-177.2	-225.6	-244.1	-176.5
Total annual carbon offset (domestic) [Mio. t CO_2]	10.7	5.5	11.2	2.4

- Using historical carbon coefficients we calculate carbon offset

- Average marginal offset in Germany higher for solar, in Spain higher for wind
- Total annual carbon offset in both countries higher for wind
- Wind and solar offset 21% of total electricity sector emissions in Spain
- Wind and solar offset 5% of total electricity sector emissions in Germany

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What are the implicit costs of carbon abatement?

	Germany		Spain	
	Wind	Solar	Wind	Solar
Net financial support [€/MWh]	41.6	292.7	-1.7	330.5
Paid renewable energy support [€/MWh]	*75*	*331*	*39*	*380*
Per-unit revenue [€/MWh]	*33.4*	*38.3*	*40.7*	*49.6*
Average marginal carbon offset (domestic) [t/MWh$_r$]	-177.2	-225.6	-244.1	-176.5
Implicit carbon cost [€/t CO_2]	**234**	**1298**	**-7**	**1872**

- High cost for solar, lower (or even negative) cost for wind
- Two main drivers:
  - Marginal abatement per MWh$_r$: DE (ES) higher abatement of solar (wind)
  - Financial support per MWh$_r$: much higher for solar

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Conclusions

How green are wind and sun?

It depends…

- …on export possibilities
- …on the pre-existing plant portfolio
- …on correlation of renewable production with carbon-intensive generators being marginal producers

Implicit costs of carbon abatement through renewable promotion are generally high for wind and very high for solar.

Questions?

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