# THE IMPACT OF CARBON PRICES ON OPTIMAL RENEWABLE SUPPORT

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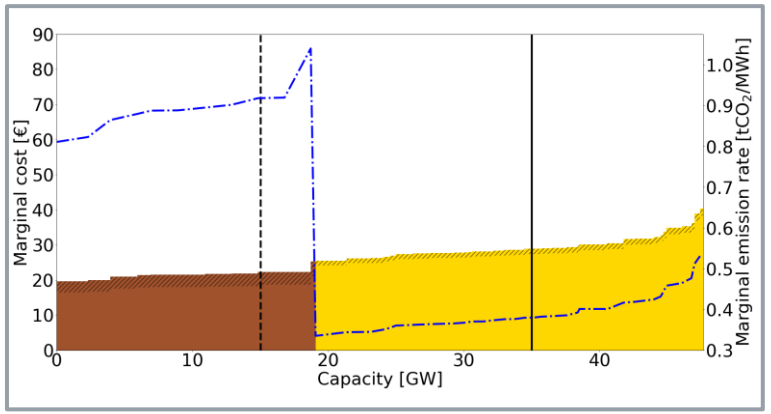
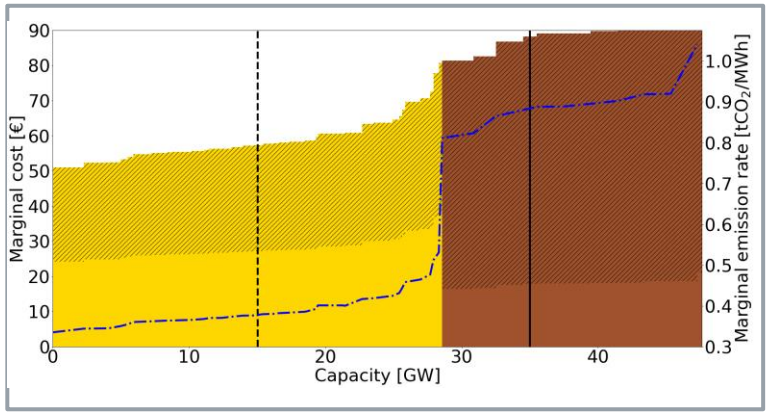
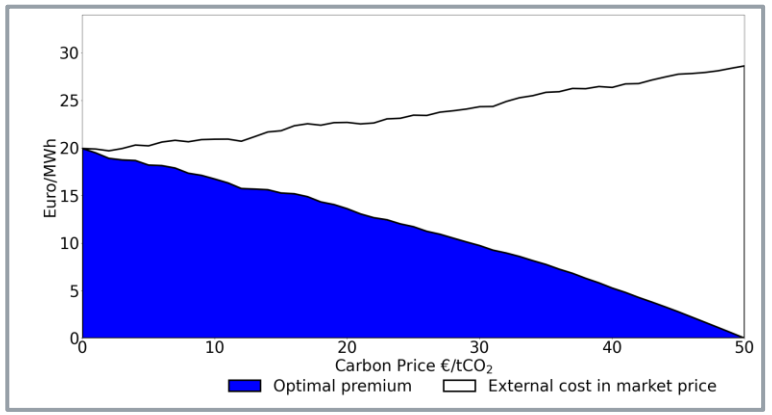
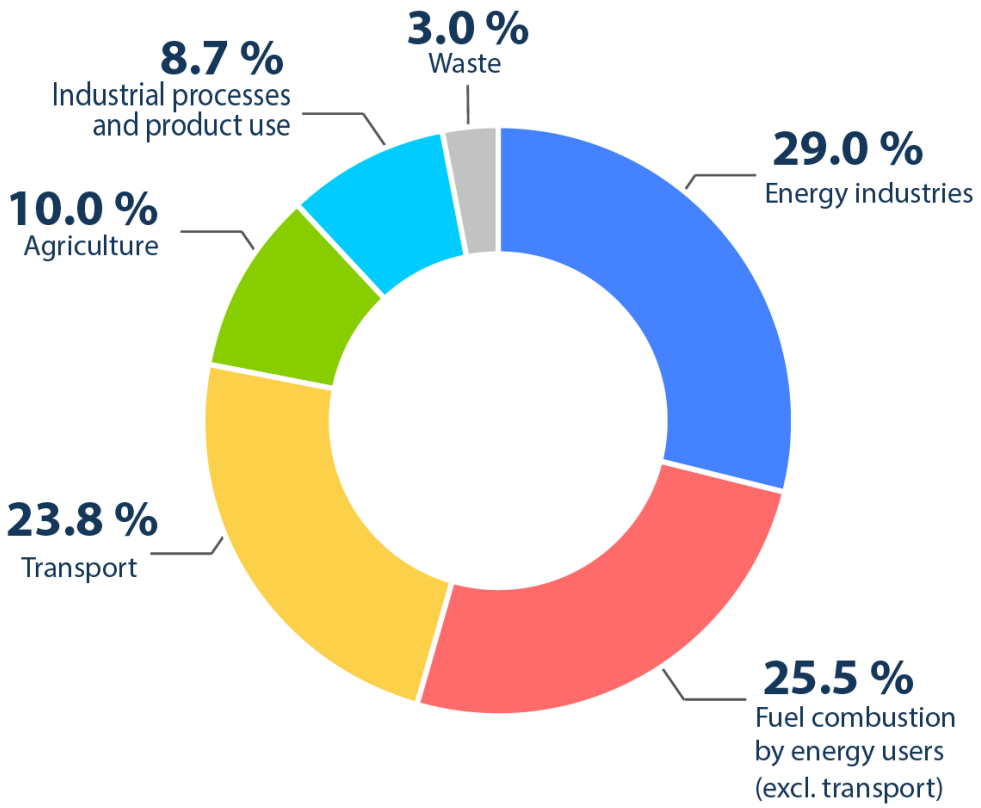


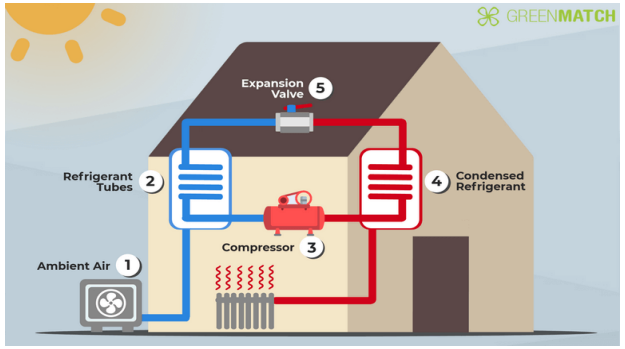



# ELECTRICITY GENERATION


**Share of EU greenhouse gas emission by source, 2017**




Quelle EEA (2020): EU carbon emissions by source 2017

# MAJOR CLIMATE REGULATION IN THE ELECTRICITY SECTOR

## Carbon Price: EU Emission Trading System


## Production Subsidies: Renewable Promotion

# RESEARCH QUESTION

*How should optimal renewable promotion respond to carbon pricing?*

- Optimal renewable promotion
  Callaway et al. (2018); Abrell et al. (2019); Lamp and Samano (2020)
  ➔ Extended for carbon prices
- Interaction emissions trading and renewable promotion
  Gonzalez (2007); Böhringer and Rosendahl (2010); Böhringer and Behrens (2015)
  ➔ Consider constant carbon taxes and how renewable promotion should react
- Empirical
  Holladay and LaRiviere (2017); Cullen and Mansur (2017); Kaffin et al. (2013); Novan (2015); Abrell et al. (2019)
  ➔ Estimation of optimal subsidies depending on carbon and fuel price regime using empirical and numerical methods

# OVERVIEW

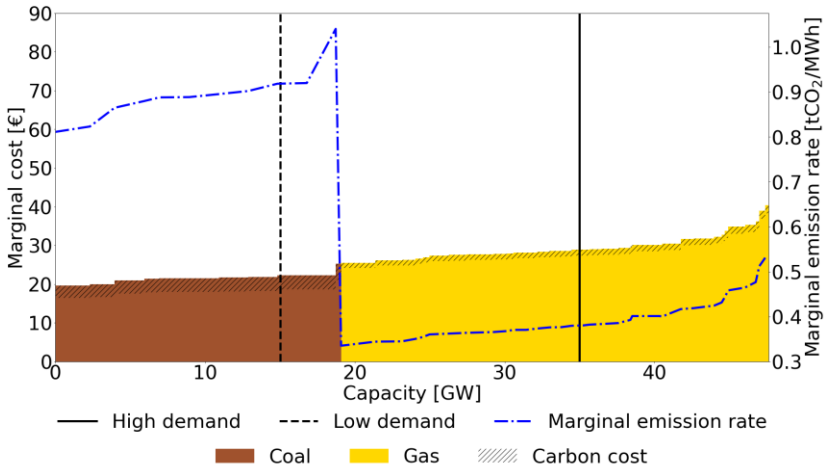
- Motivation
- The impact of carbon prices on optimal renewable promotion
- Empirical results
- Summary and conclusions

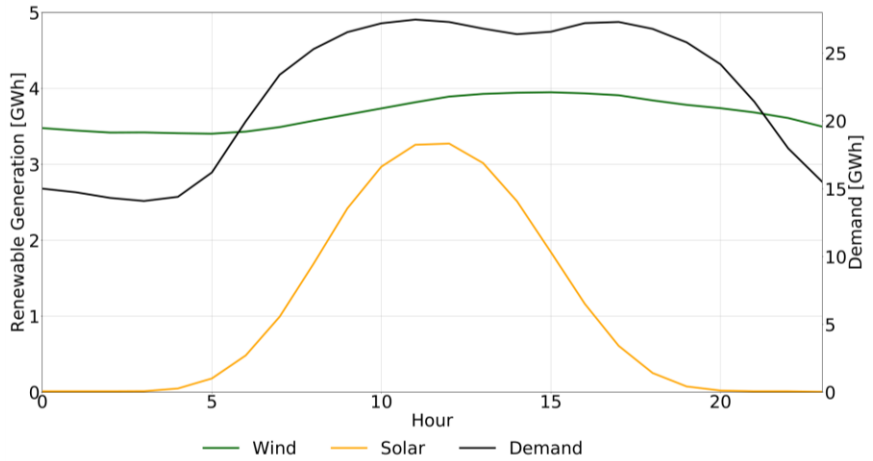
# MARGINAL ECONOMIC VALUE OF RENEWABLE PROMOTION

- Optimal renewable promotion:
  marginal economic value = marginal income

- Marginal economic value (MEV) of renewable generation reflects
  - Marginal external benefit
  - Avoided operating cost (c)
  - Other cost avoided

- Marginal external benefit determined by emissions avoided
  - $MER_t$: Marginal emissions rate
  - $\omega_{rt}$: Production profile of renewable source
  - SCC: Social cost of carbon



# OPTIMAL RENEWABLE PREMIUM

marginal economic value = marginal income

$$\sum_t \omega_{rt} \left[ c_t + SCC \cdot MER_t \right] \stackrel{!}{=} \sum_t \omega_{rt} P_t + s_r^*$$

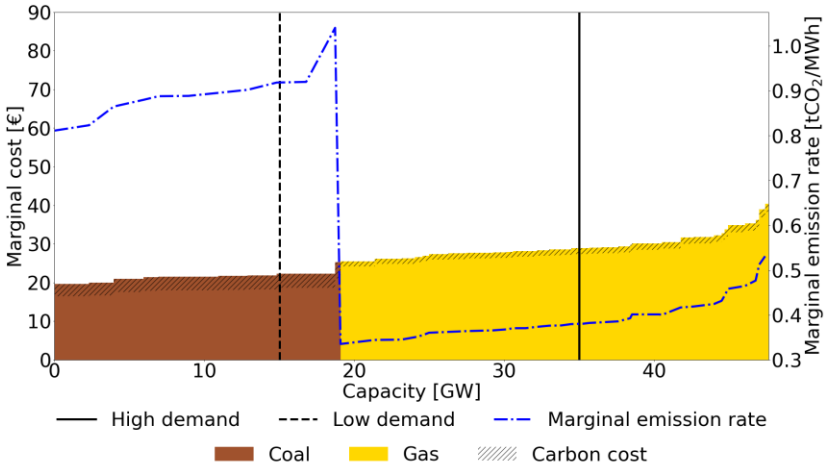
- Price includes a carbon rent determined by the carbon price ($\tau$) and the marginal emission rate (MER)

$$P_t = c_t + \tau MER_t$$

- Optimal premium reflects
  - marginal external benefit (production profile)
  - carbon rent embedded in market price
  - production profiles

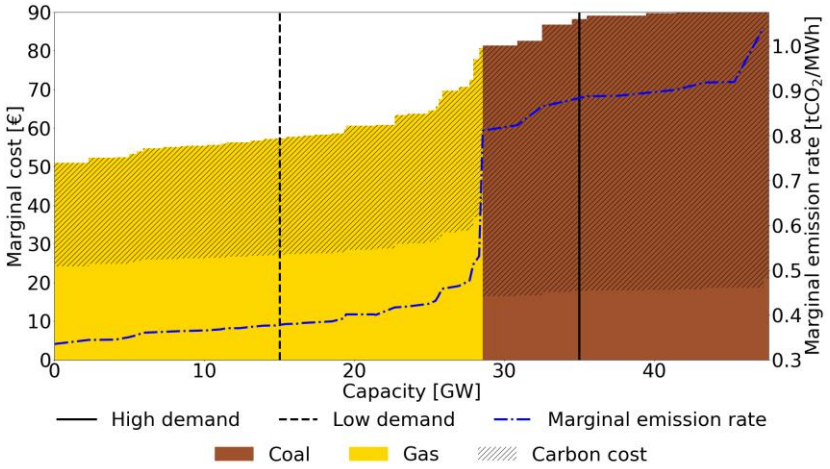
$$\boxed{s_r^* = (SCC - \tau) \cdot \sum_t \omega_{rt} MER_t}$$

# OPTIMAL RENEWABLE PREMIUM AND CARBON PRICES




$$s_r^* = (SCC - \tau) \cdot \sum_t \omega_{rt} MER_t$$

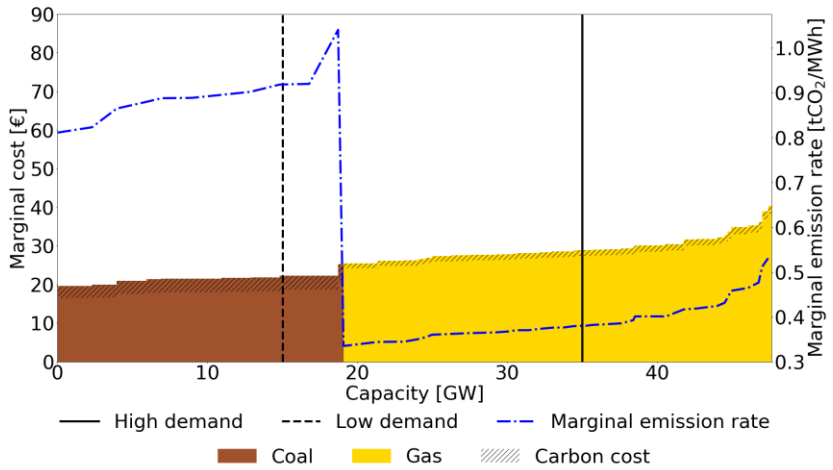
Increase carbon price



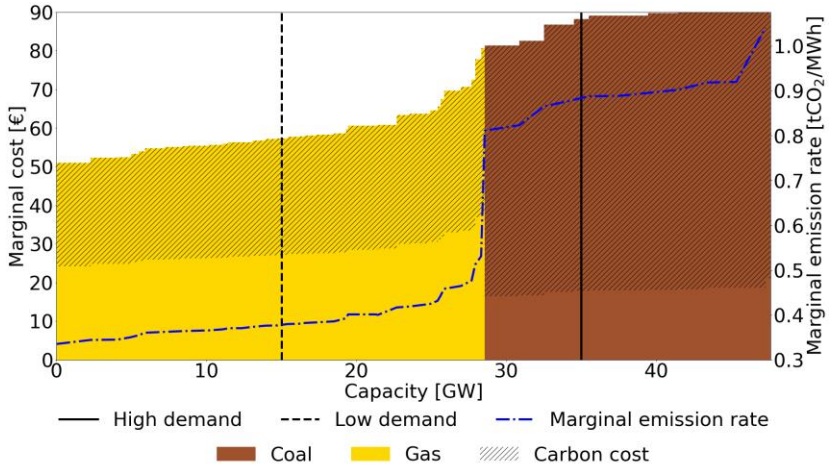

- Increasing the carbon price
  - carbon rent increases
  - marginal emission rate changes

$$\frac{\partial s_r^*}{\partial \tau} = -\sum_t \omega_{rt} MER_t + (SCC - \tau) \sum_t \omega_{rt} \frac{\partial MER_t}{\partial \tau}$$

# PREMIUM ADJUSTMENT DEPENDS ON PRODUCTION PROFILE

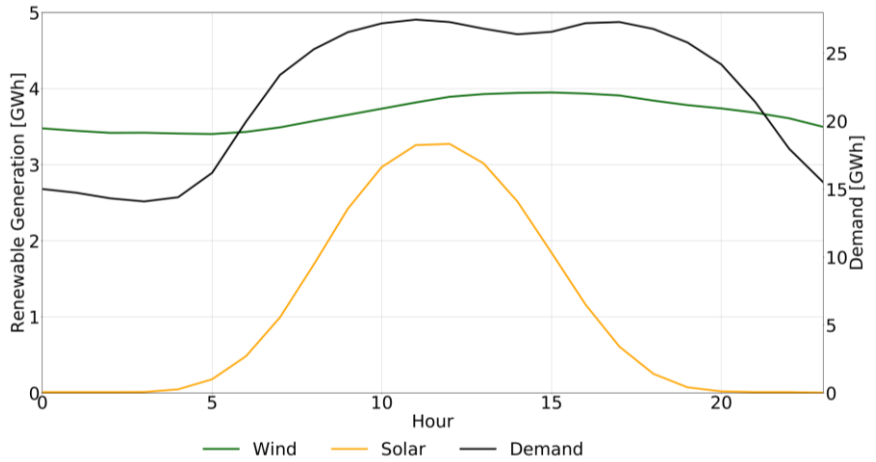



Increase carbon price




- Under complete fuel switch
  Marginal emissions rate is increasing in demand

- Solar: Likely increase subsidy
- Wind: Likely smaller impact on subsidy



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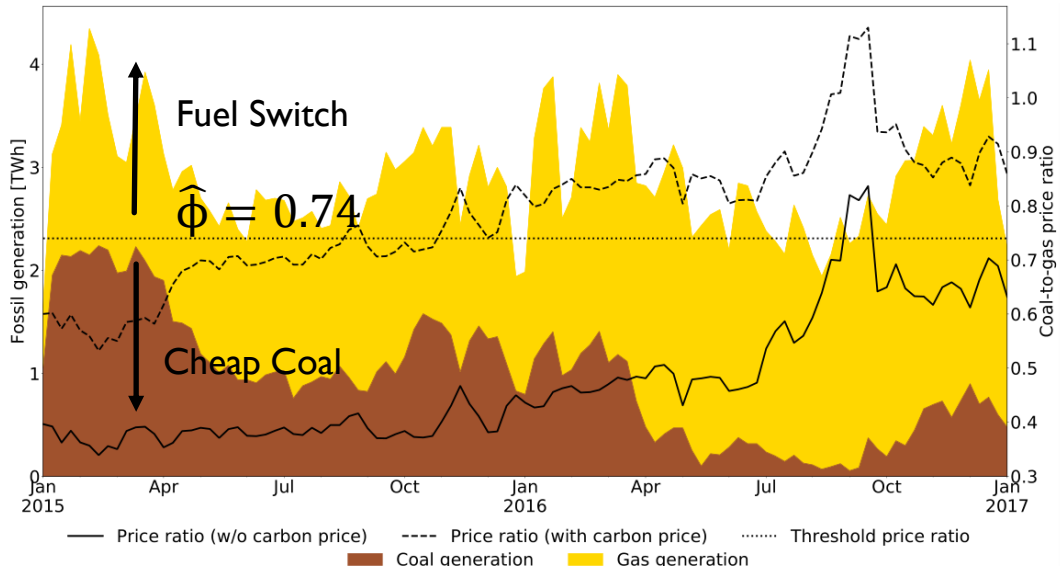
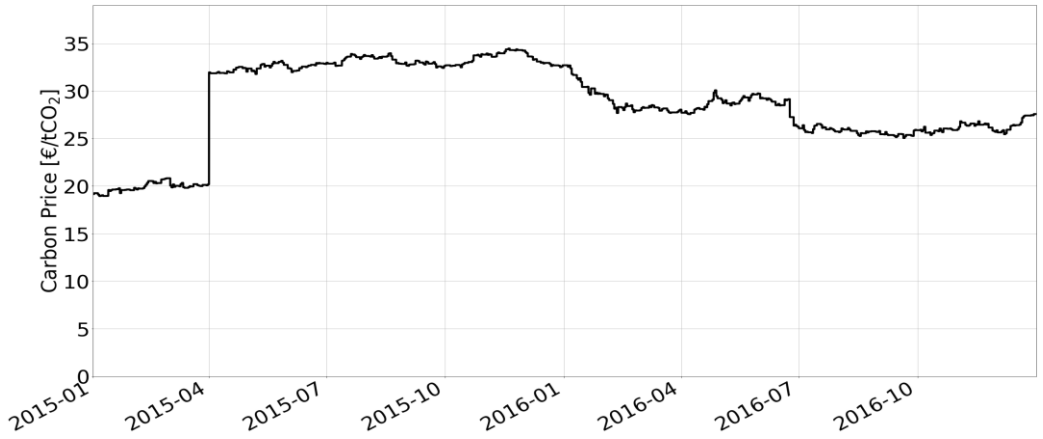
# EMPIRICAL APPROACHES

- UK electricity system in 2015/2016
- Distinguish two different price regimes depending on fuel price ratio ($\phi$)
  - Cheap coal
  - Fuel switch
- Two approaches to calculate optimal subsidies:
  - Econometric estimation of marginal external benefit
  - Numerical model of UK electricity market based on plants' average heat efficiencies



# EMPIRICAL APPROACH

- Estimate the impact of renewables on conventional generation depending on fuel price regime ($\tilde{\phi}$)

$$q_{it} = \sum_{\tilde{\phi}} (\alpha_{\tilde{\phi}} + \beta_{1wi\tilde{\phi}} w_t + \beta_{1wi\tilde{\phi}} w_t^2 + \beta_{3wi\tilde{\phi}} w_t d_t + \beta_{1si\tilde{\phi}} s_t + \beta_{2si\tilde{\phi}} s_t^2 + \beta_{3si\tilde{\phi}} s_t d_t +$$
$$\beta_{4i\tilde{\phi}} d_t + \beta_{5i\tilde{\phi}} d_t^2 + \beta_{6i\tilde{\phi}} \phi_t + \beta_{7i\tilde{\phi}} temp_t + \boldsymbol{\gamma_i k_t}) I_{t\tilde{\phi}} + \boldsymbol{\delta_i D_t} + \epsilon_{it}$$

- Calculate marginal emission rate by regime using average emission intensity: $MER_{\tilde{\phi}r}$

- Social cost of carbon: 50€/tCO$_2$

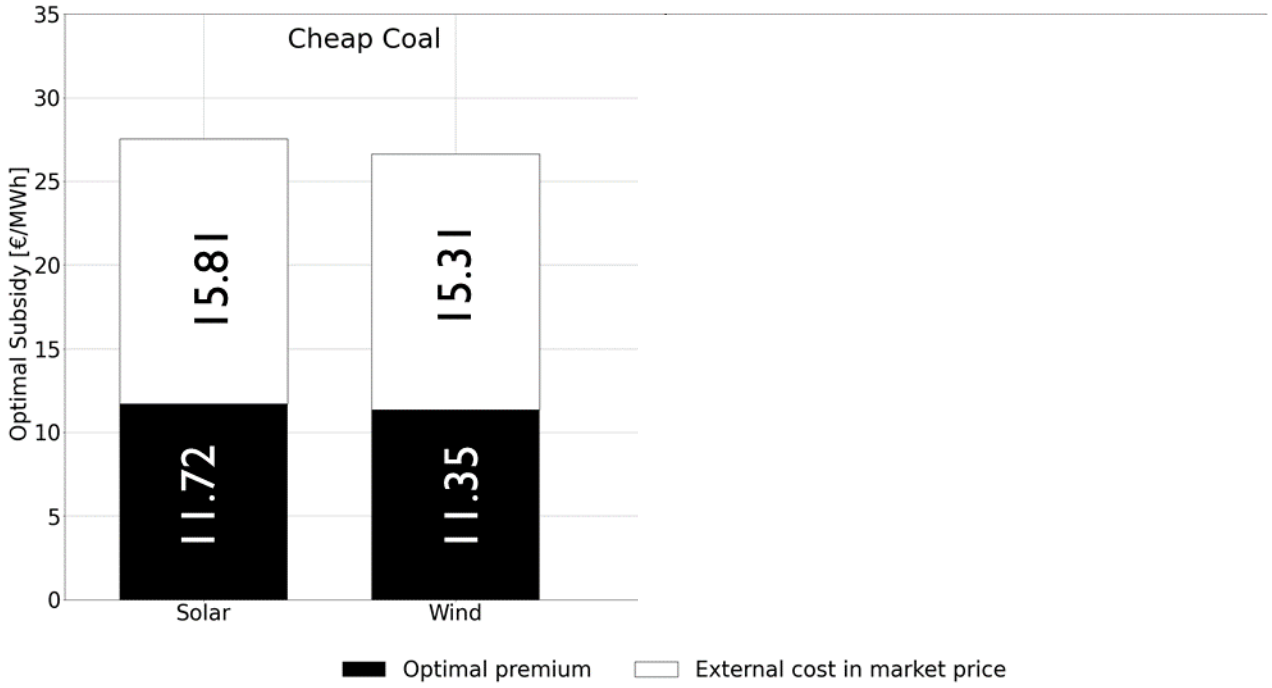
- Optimal subsidy: $s_r^* = (SCC - \tau)\, MER_{\tilde{\phi}r}$

| Variable | Description |
|---|---|
| Generation | |
| $q_{it}$ | Hourly generation of technology $i$ [MWh] |
| $w_t$ | Hourly wind generation [MWh] |
| $s_t$ | Hourly solar generation [MWh] |
| Demand | |
| $d_t$ | Hourly electricity demand [MWh] |
| Weather data | |
| $temp_t$ | Daily mean temperature [°C] |
| Prices | |
| $\phi_t$ | Daily coal-to-gas price ratio |
| Capacities | |
| $k_{it}$ | Hourly available capacity of technology $i$ [MW] |

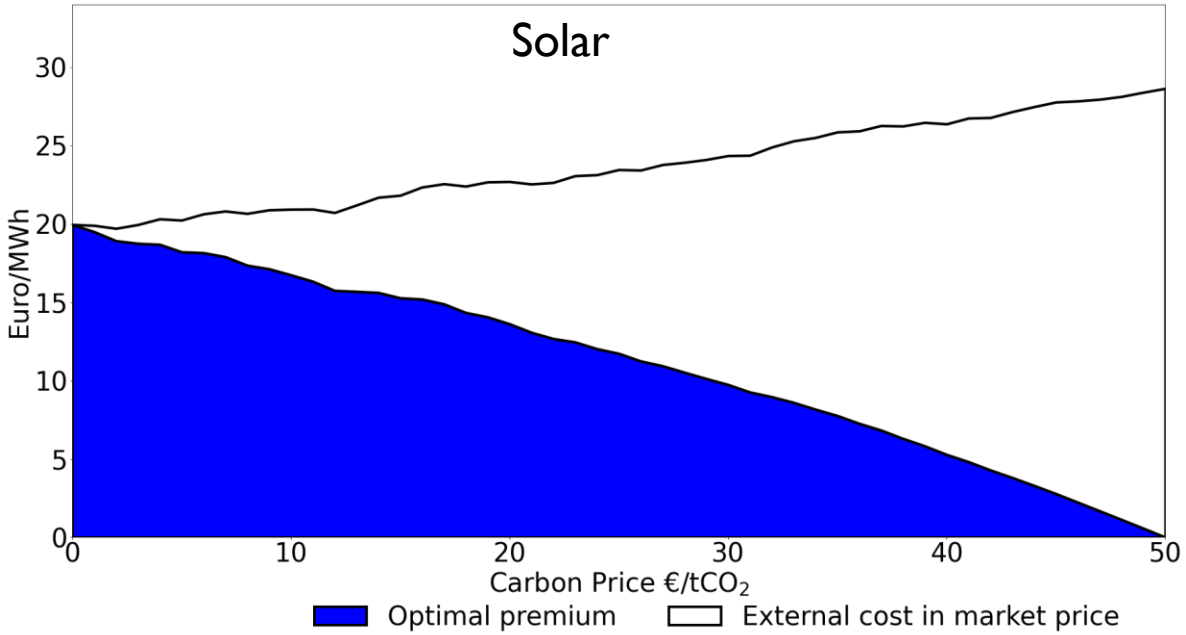
# OPTIMAL PREMIUM AND FUEL SWITCH

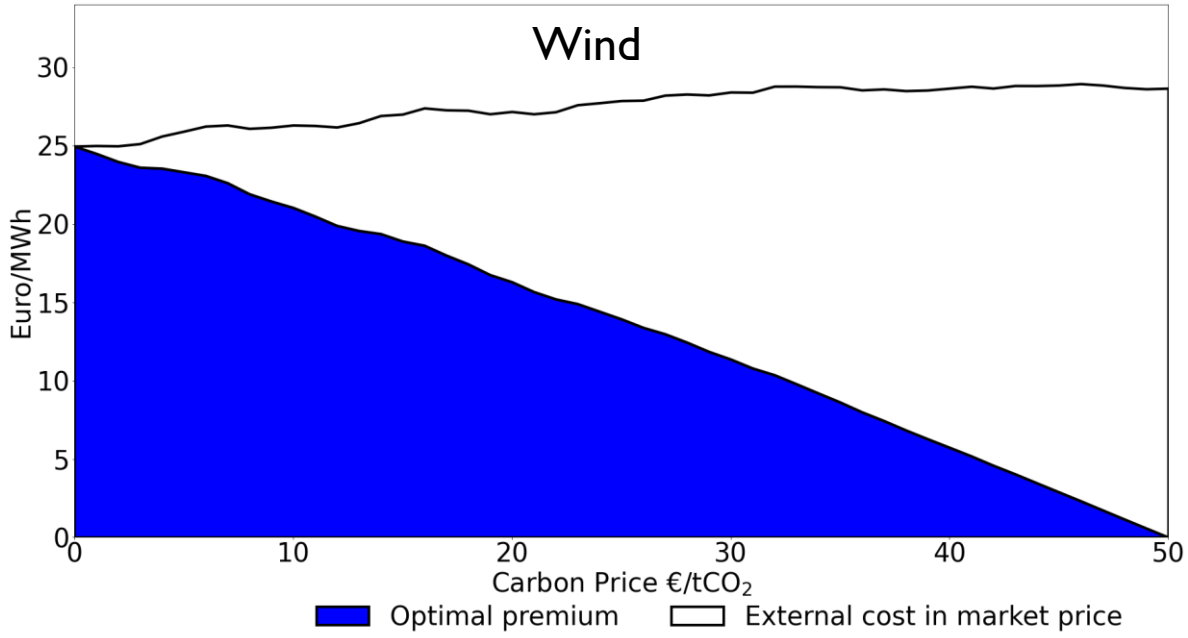
- Cheap coal
  Wind and solar premium rather similar

- Fuel switch
  - Solar premium increases
  - Wind premium slightly decreases
  - Modest differentiation of premiums



# OPTIMAL PREMIUM AND CARBON PRICES




- Use numerical model to examine the impact of varying carbon prices
- Partial equilibrium model minimizing system cost under perfect competition assumption
- Increase carbon price ➔ Decrease optimal premium

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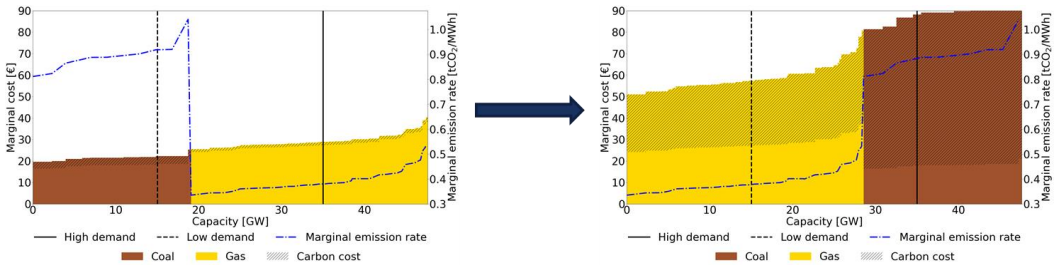
# SUMMARY

*How should optimal renewable promotion respond to carbon pricing?*

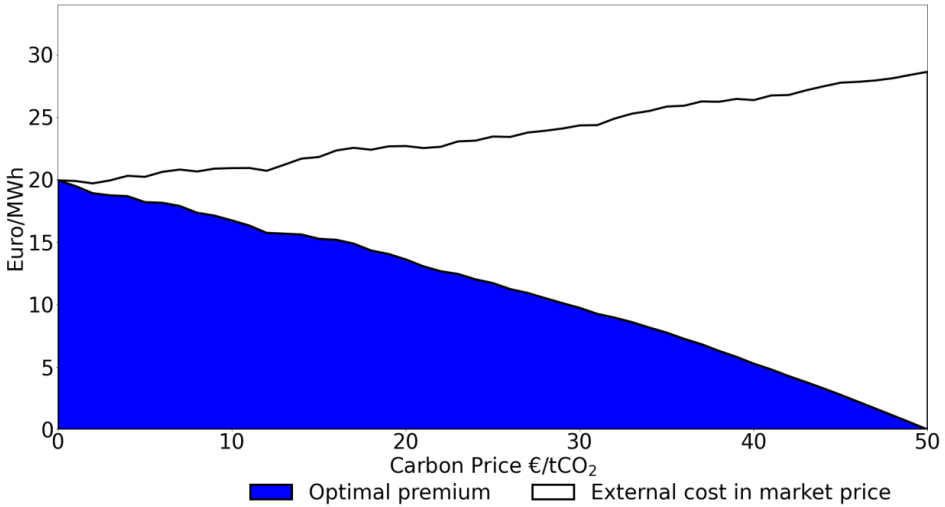
Carbon prices impact optimal premium in two ways

(1) Change in merit order changes marginal emission rates (only in systems with decreasing marginal emission rates)
➔ Premium adjustments rather small




(2) Higher carbon rent transported through the market price

➔ Phase out renewable promotion



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- Backup Slides