ETH zürich

Are Wind and Sun the Same? – Cost-effective Renewable Policies for Intermittent Energy Sources

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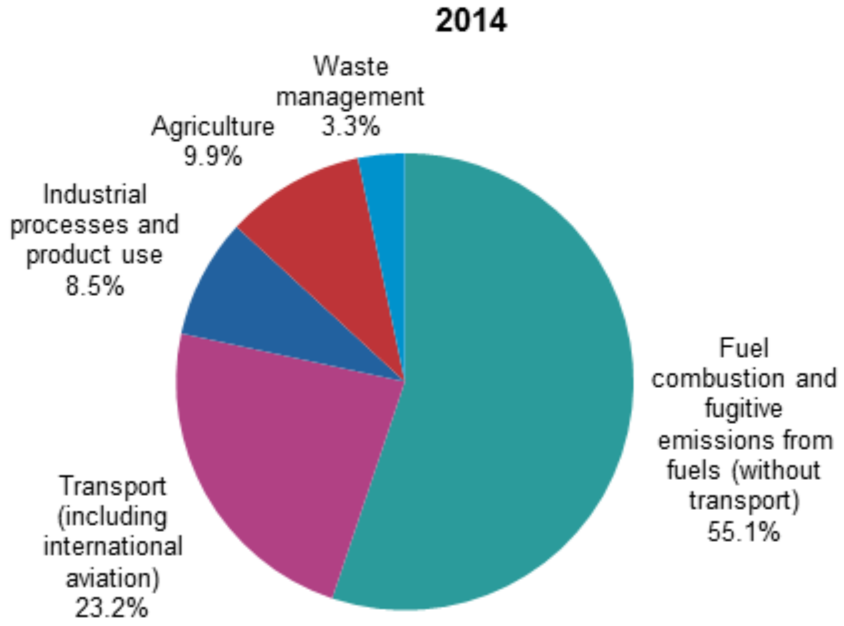
Contents

Introduction: Greenhouse gas emissions and electricity

Greenhouse gas emissions EU 28 (Eurostat)



- Combat climate change ⟶ reduce GHG emissions
- Energy sector (electricity, heat) is one of the biggest emitters
- Potential of high reduction of emissions
- Use new renewables (wind, solar) to produce clean electricity

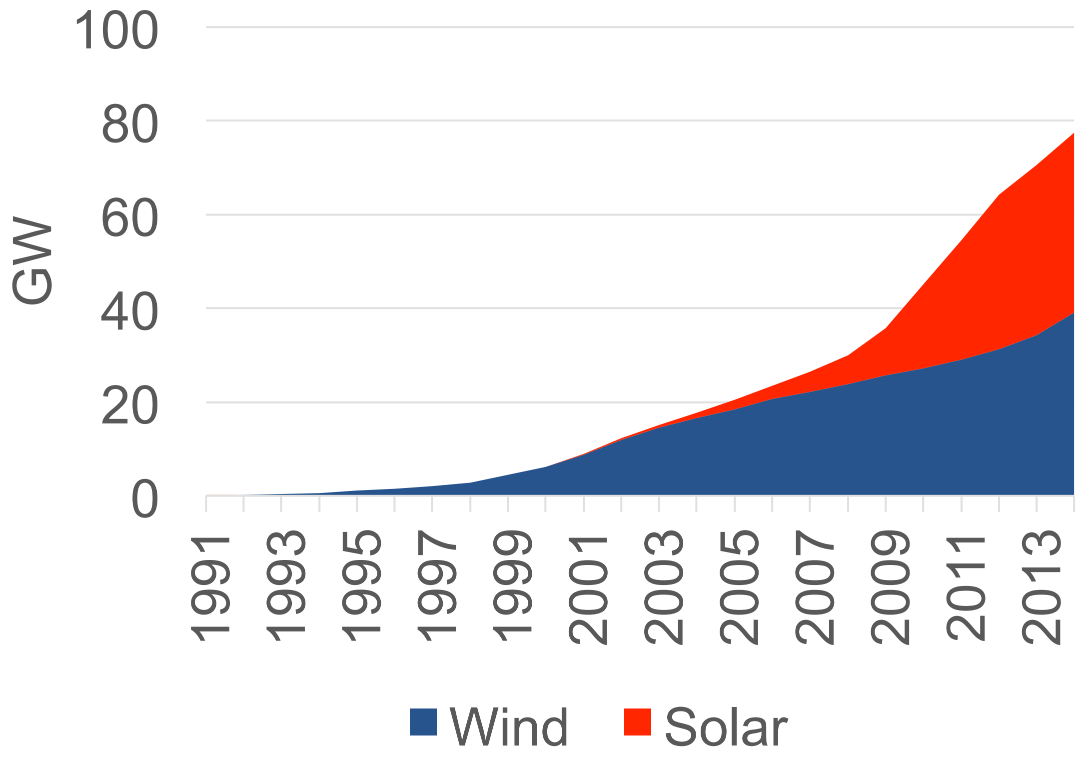
Introduction: Why renewable energy support (RES)?

Need for policy to promote renewables

RES has strong impact on diffusion of technologies

Goal: Carbon abatement

- Short-Term: Substitute carbon intensive production
- Long-Term: Change capacity mix
  Exploit learning effects



Introduction: Policy design?

- Increasing shares of wind and solar energy enter the electricity market
- A new element of intermittency is introduced which interacts with the existing conventional generators
- Wind and solar energy differ greatly in their generation patterns (more later)

Question:

What is a cost-effificient design for a RES support policy given the heterogeneity of intermittent renewables?

Introduction: What types of RES instruments are there?

- Types of RES instruments
  - Feed-in tariff
  - Feed-in premium
  - Renewable quota (green certificates)
  - Tenders
  - Tax incentives
  - Command and control

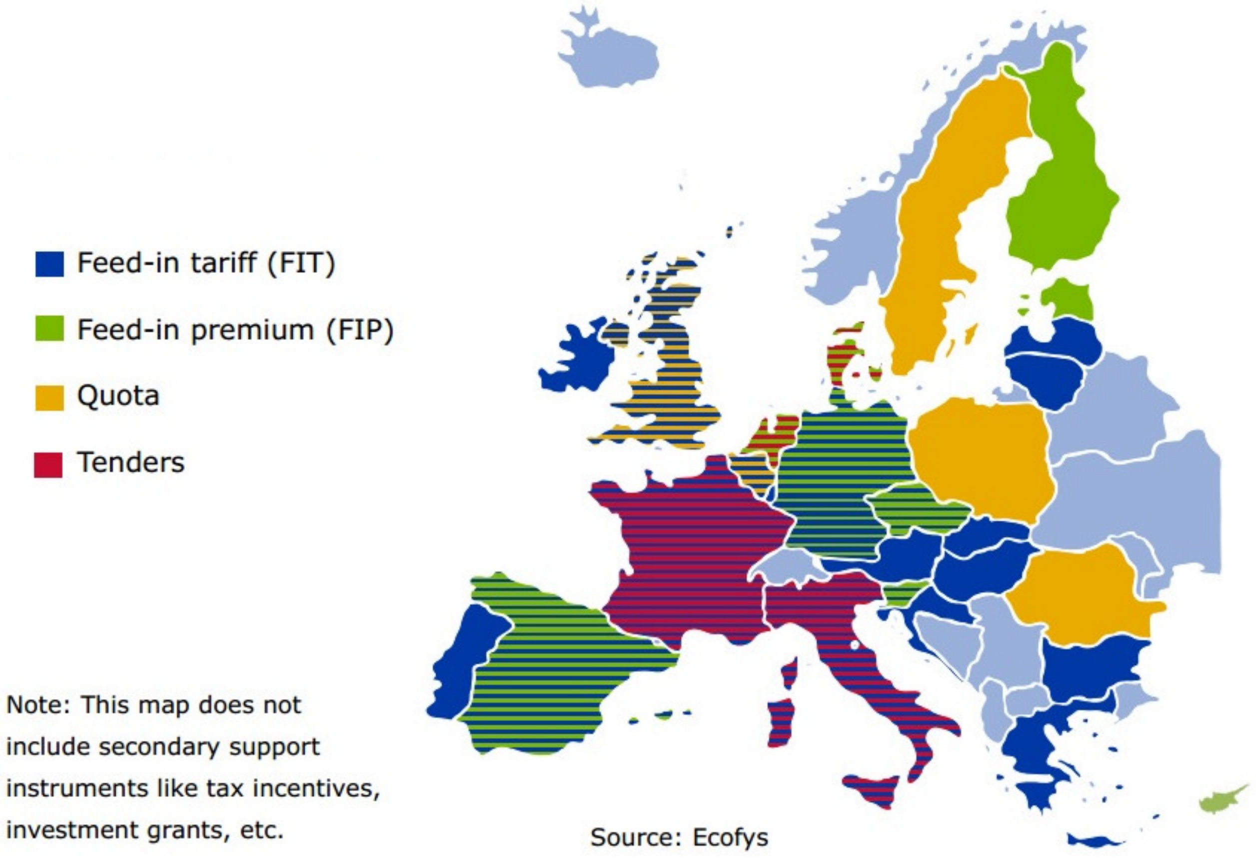
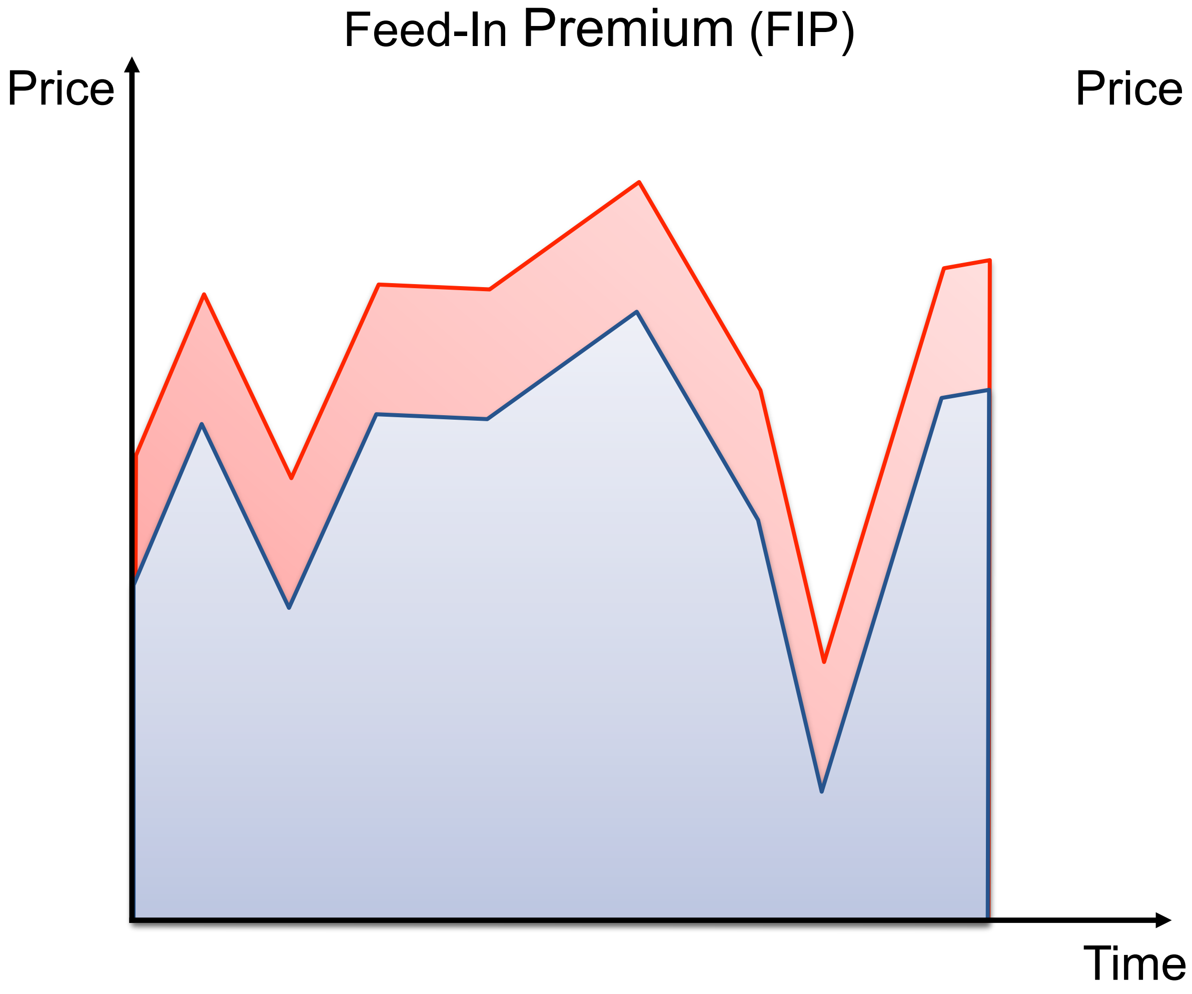
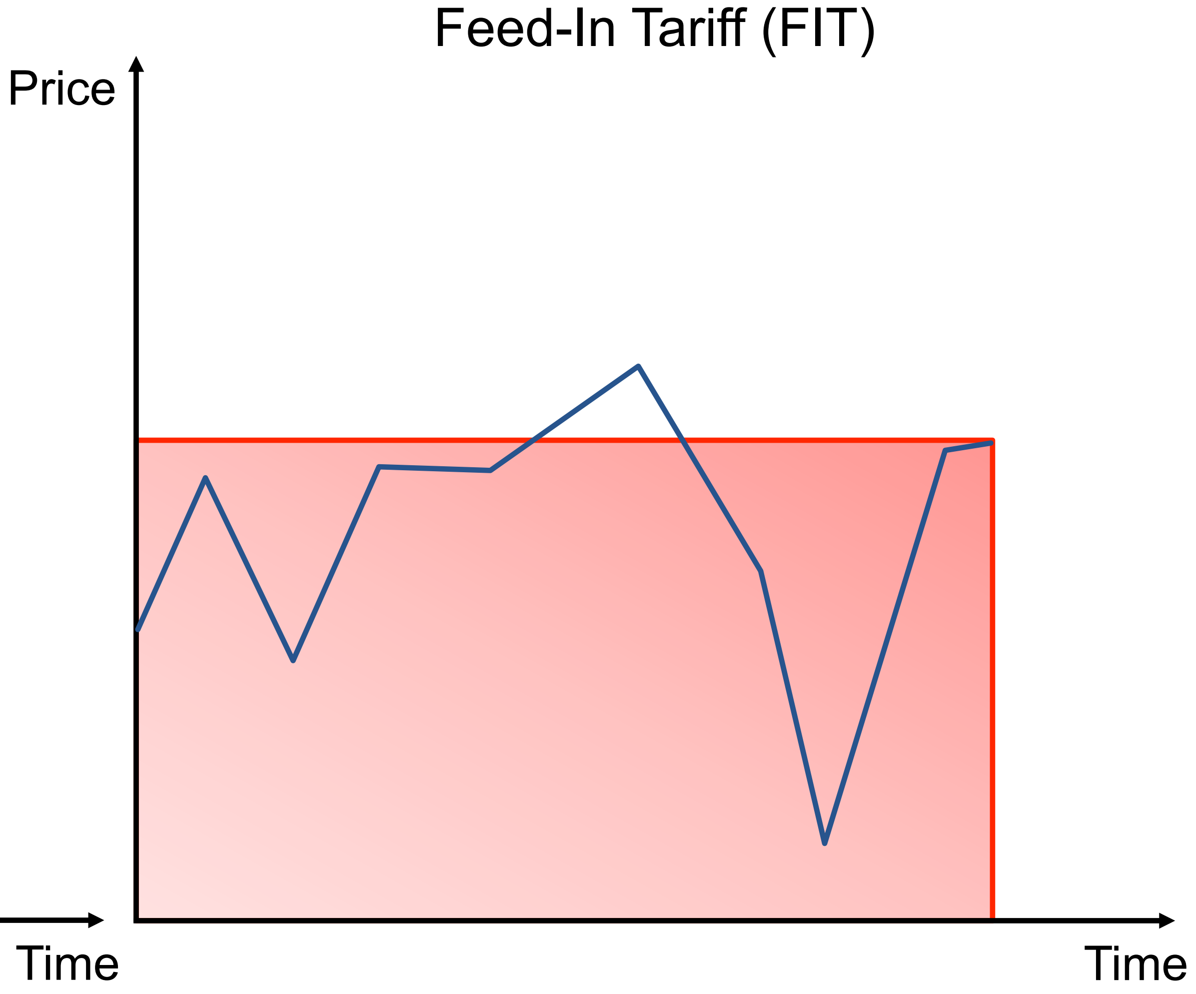


Illustration of selected RES instruments: Price instruments





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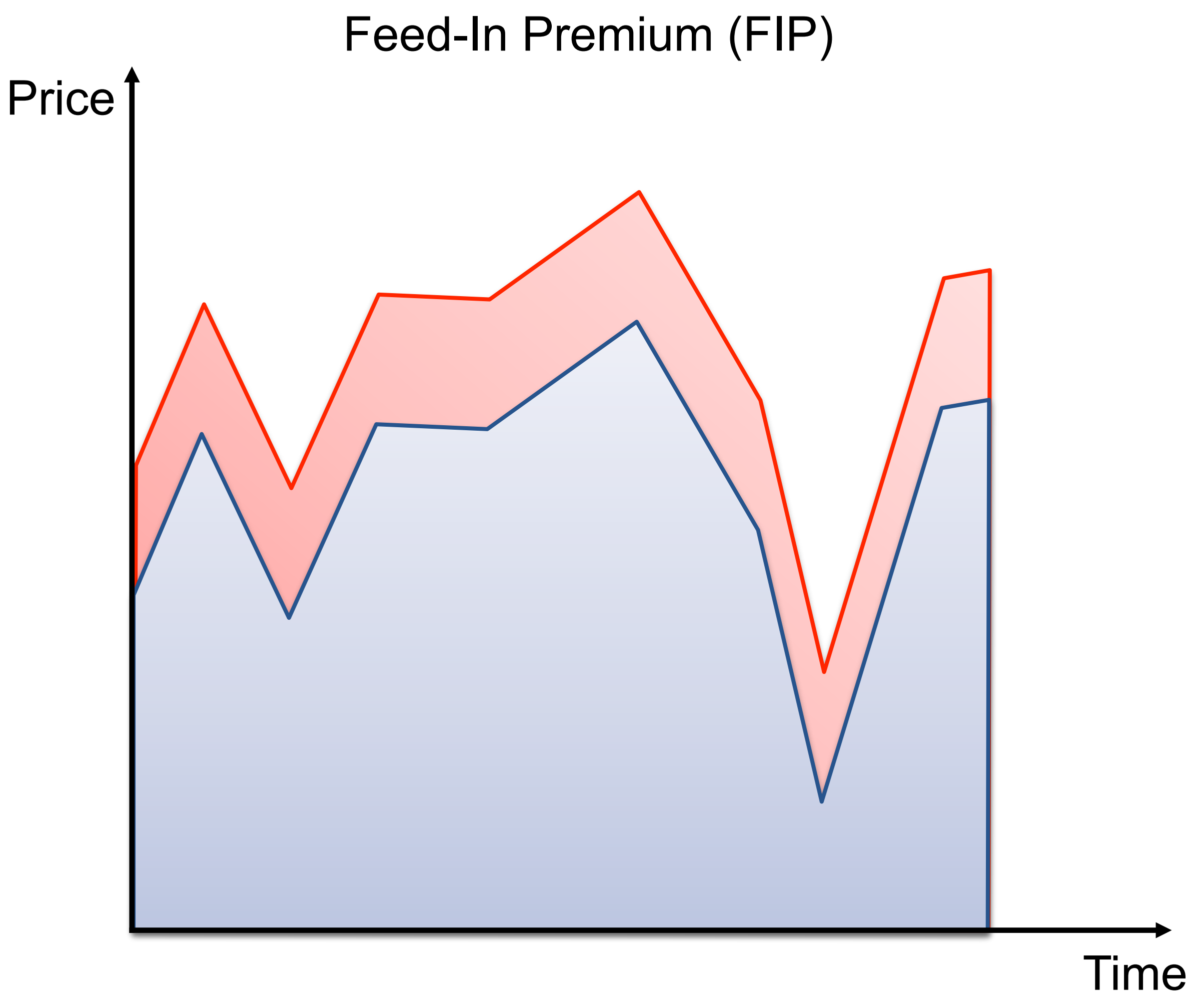


- Fixed premium on top of market price
- For the regulator:

  Uncertainty over RES share →

  What premium achieves X% RES?
- For the generator:

  Falling prices directly affect revenue

  Negative producer prices are possible

Illustration of selected RES instruments: Price instruments

- Fixed price per unit of electricity generated

- For the regulator:
  Uncertainty over RES share →
  What FIT achieves X% RES?

  Might need to implement curtailment

- For the generator:
  No direct risk from market prices
  Steady revenues

Feed-In Tariff (FIT)

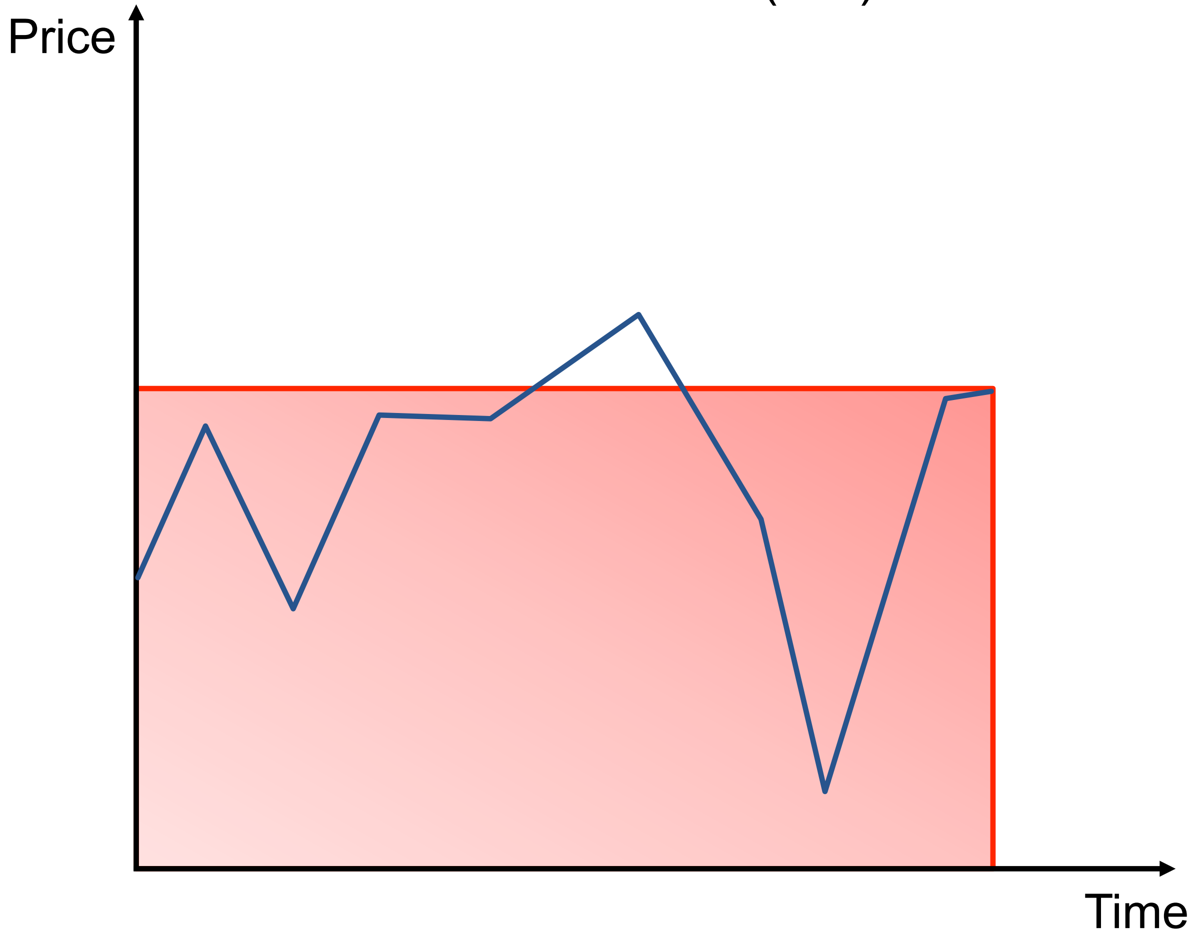
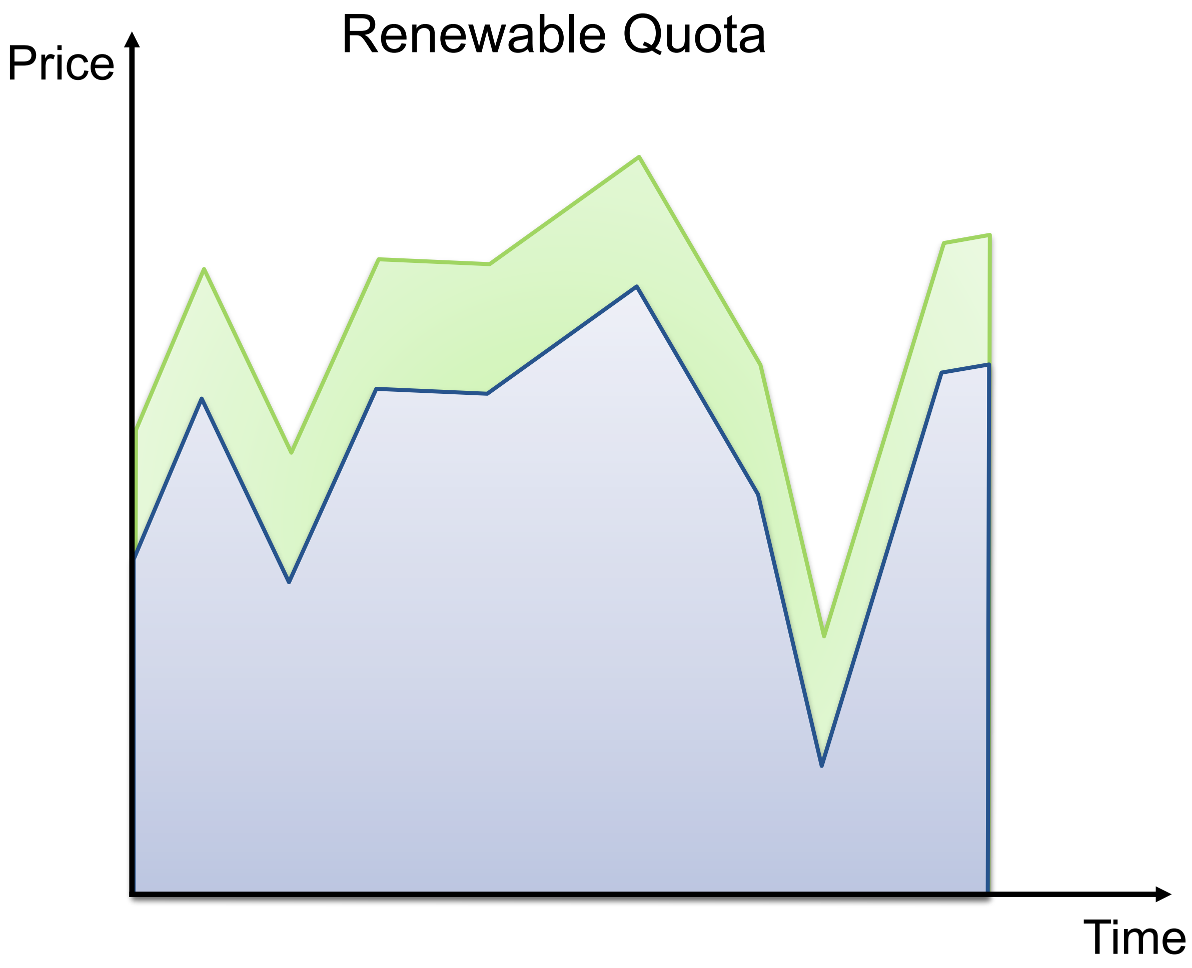
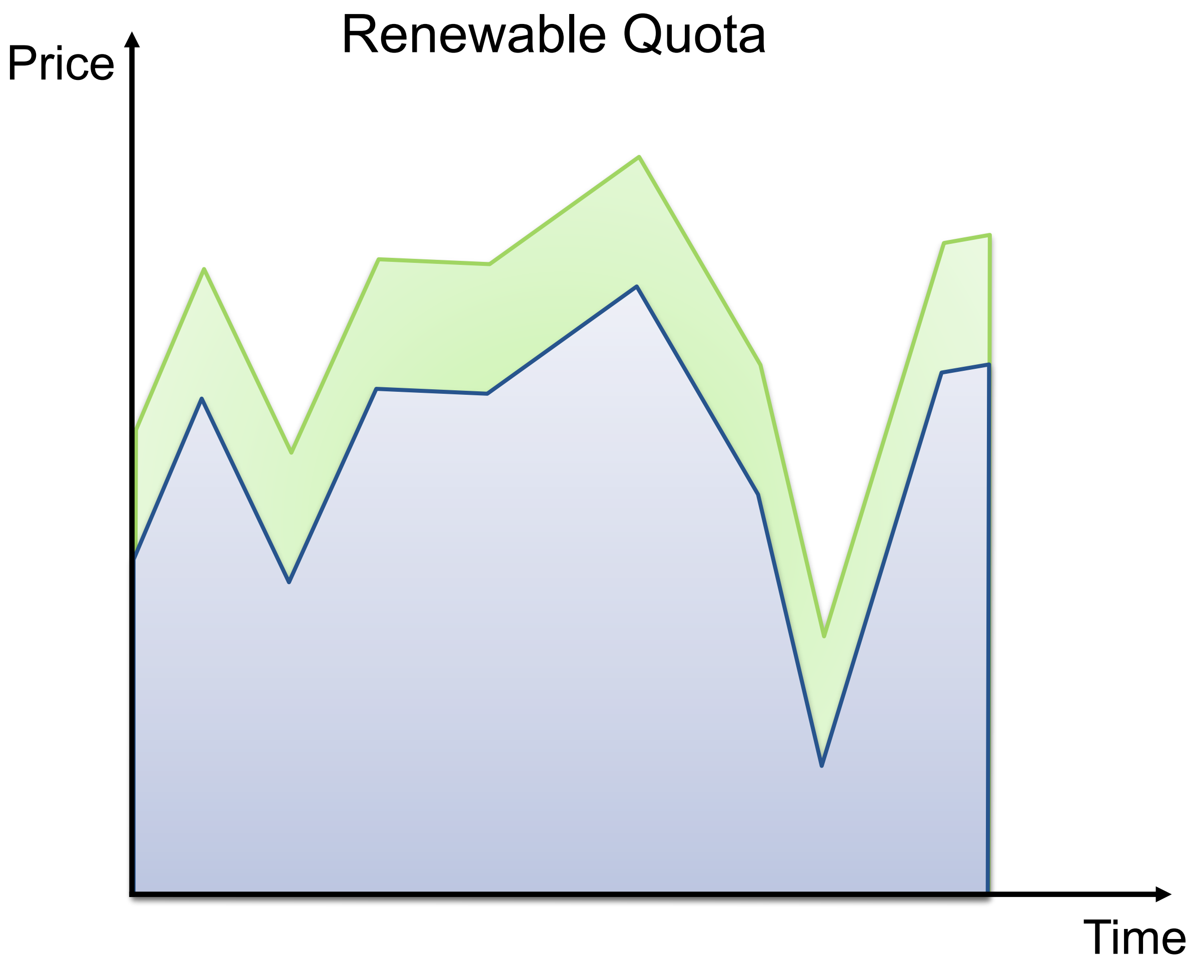


Illustration of selected RES instruments: Quantity instrument



- Renewable generators sell green certificates
- Conventional generators need to purchase a fixed amount of certificates per unit of electricity generated
- Price of certificates determined on a certificate market

Illustration of selected RES instruments: Quantity instrument



- Revenue from certificates on top of market price
- For the regulator:
  Possible to set a fixed share of renewable production
- For the generator:
  Uncertainty over certificate price
  Falling prices directly affect revenue
  Negative producer prices are possible

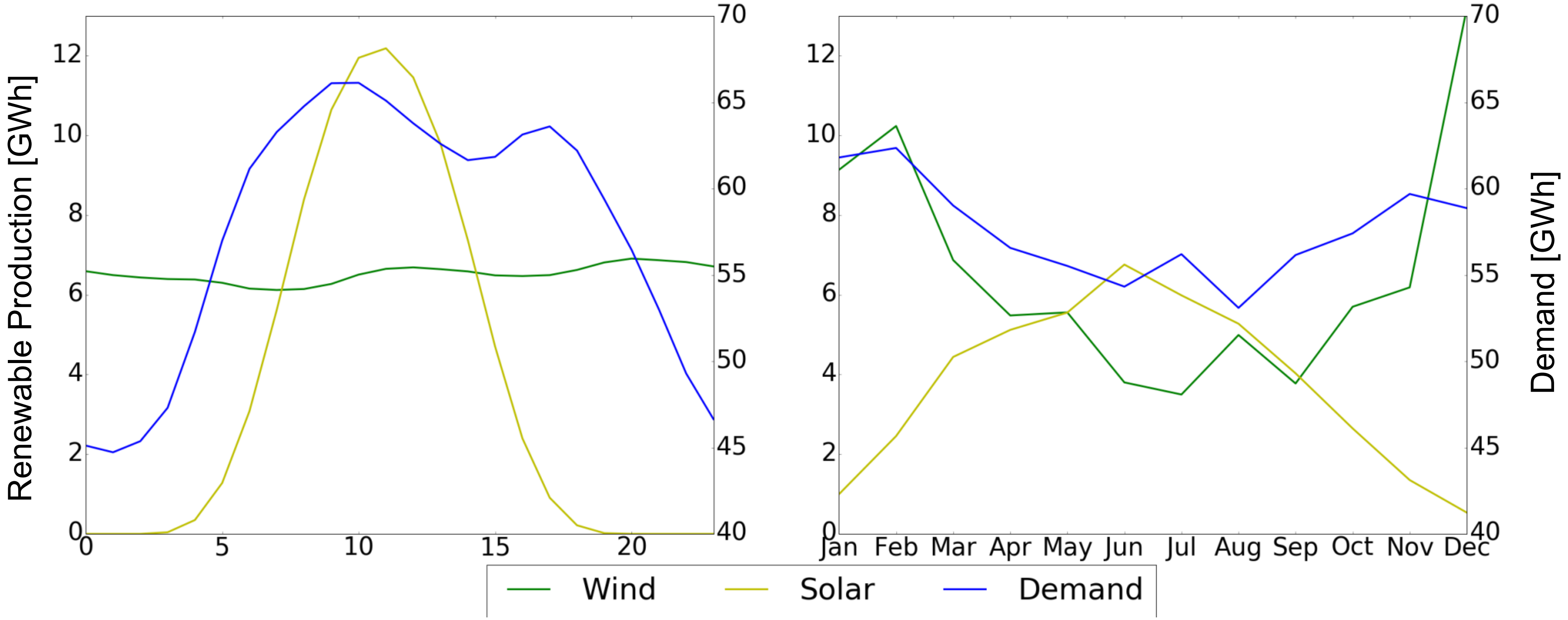
Equivalence of price instruments and quantity instruments

The presented instruments (feed-in tariff, feed-in premium, renewable quota) are theoretically equivalent if:

- There are no negative prices
- There is no interaction with other policies such as a carbon tax or a carbon cap

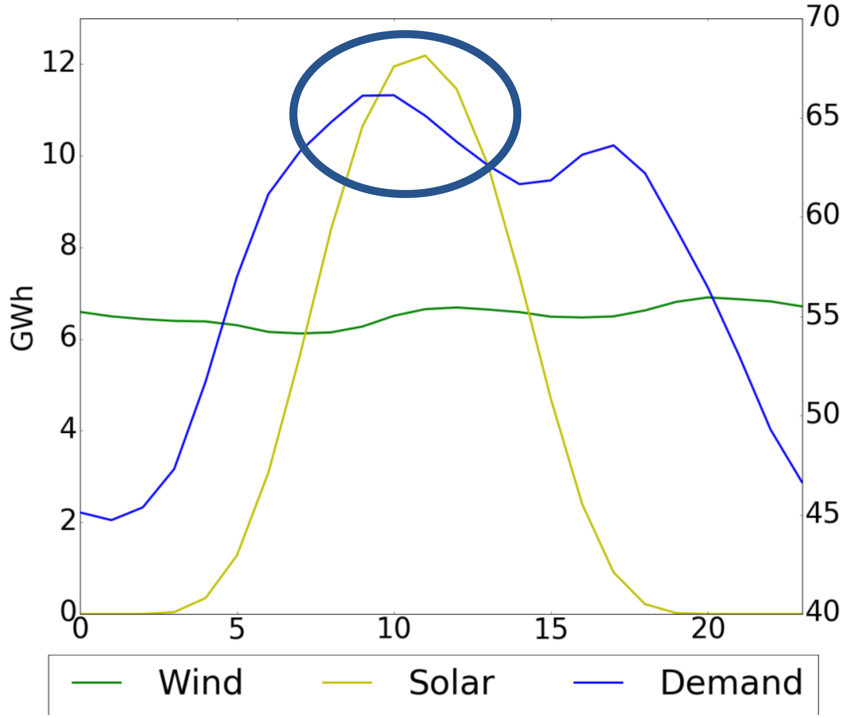
Availability profiles of renewables differ

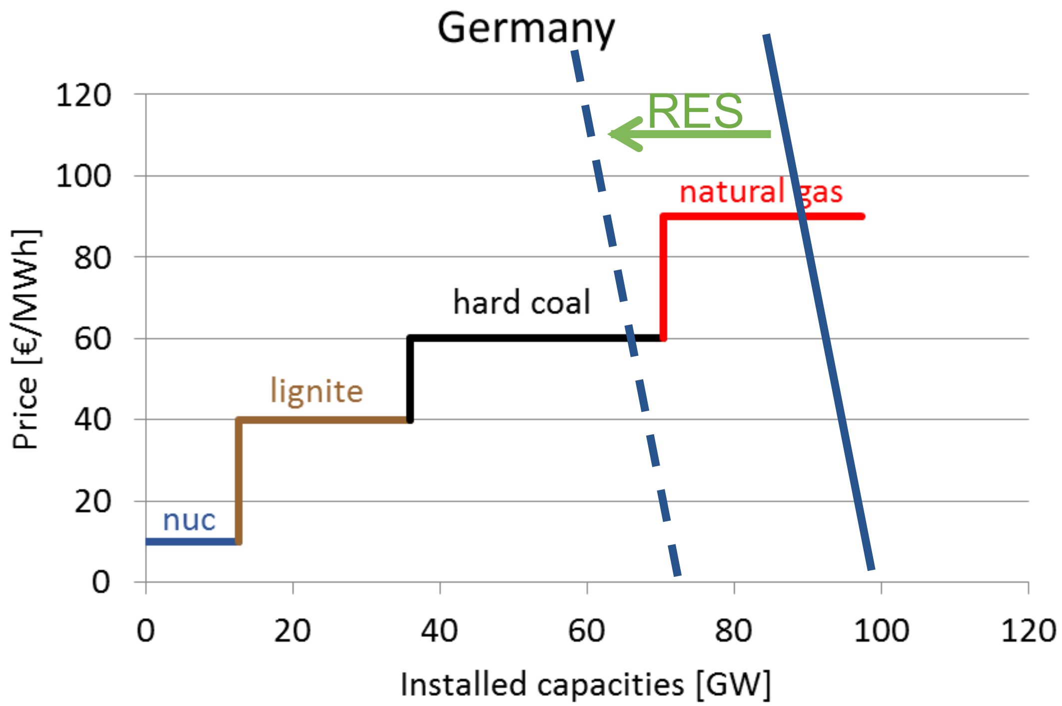
- Generation of solar and wind power varies greatly: yearly and daily
- Electricity is special in time varying demand (hourly scale, difference to other markets, relatively inelastic, non-storable)



Technology Substitution Effect

- Different technology substitution effect of wind and solar (due to different marginal generators)





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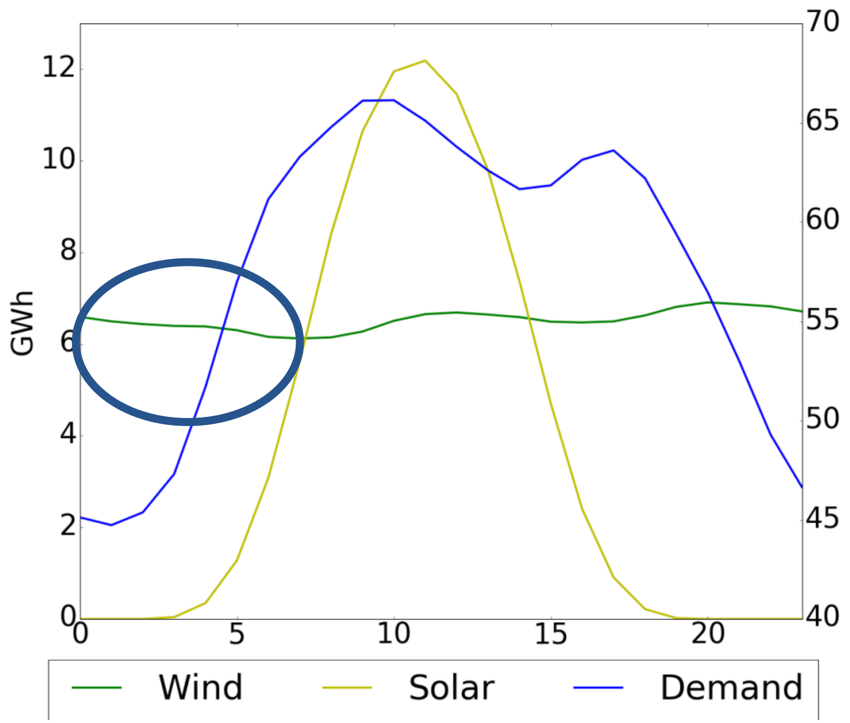
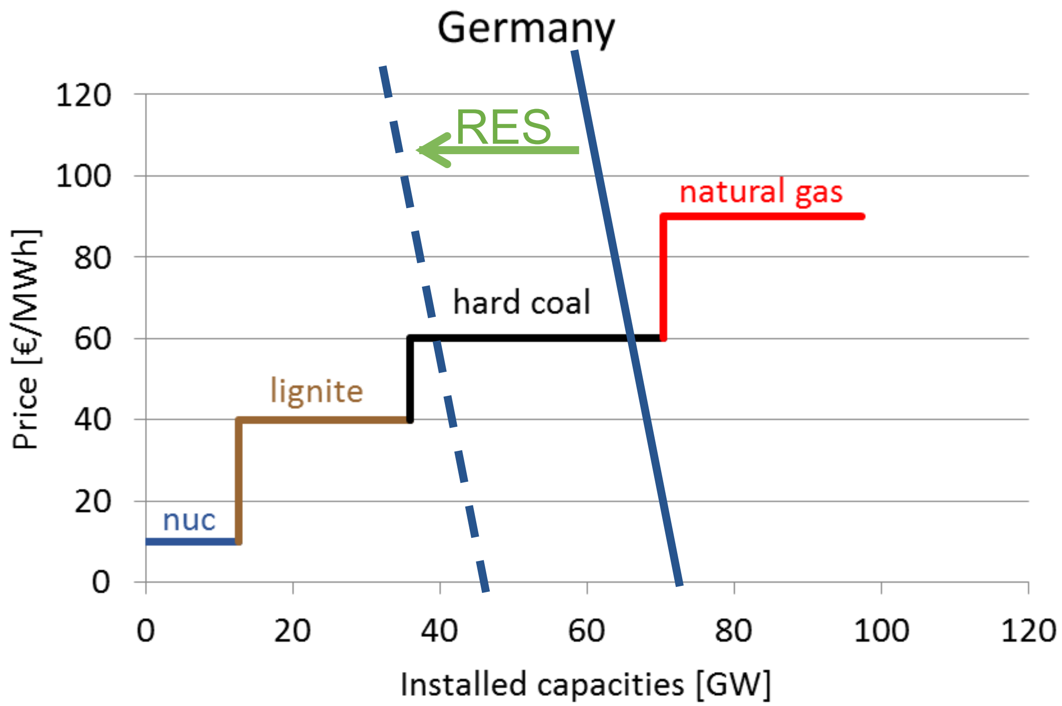
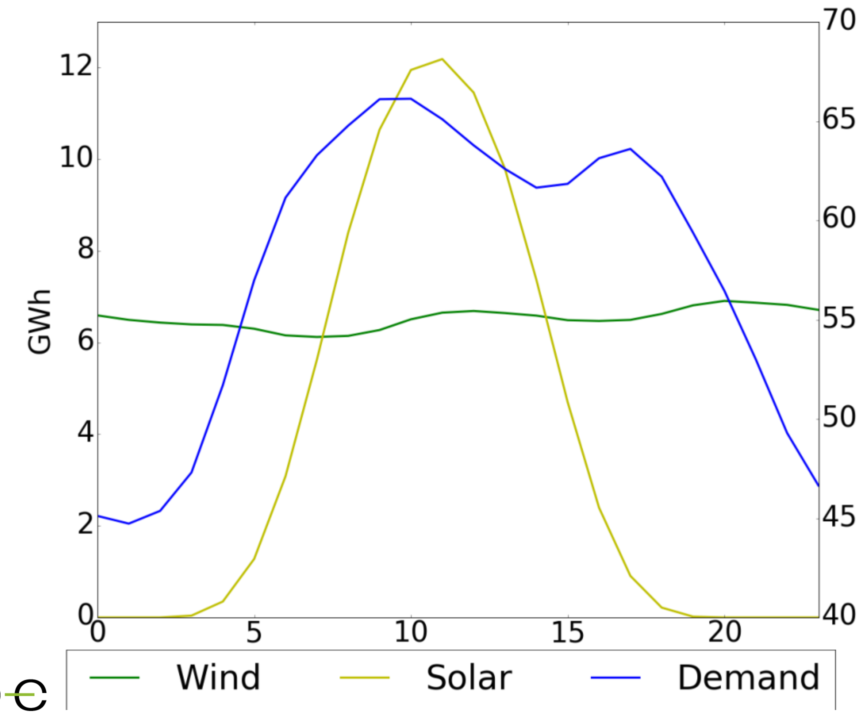
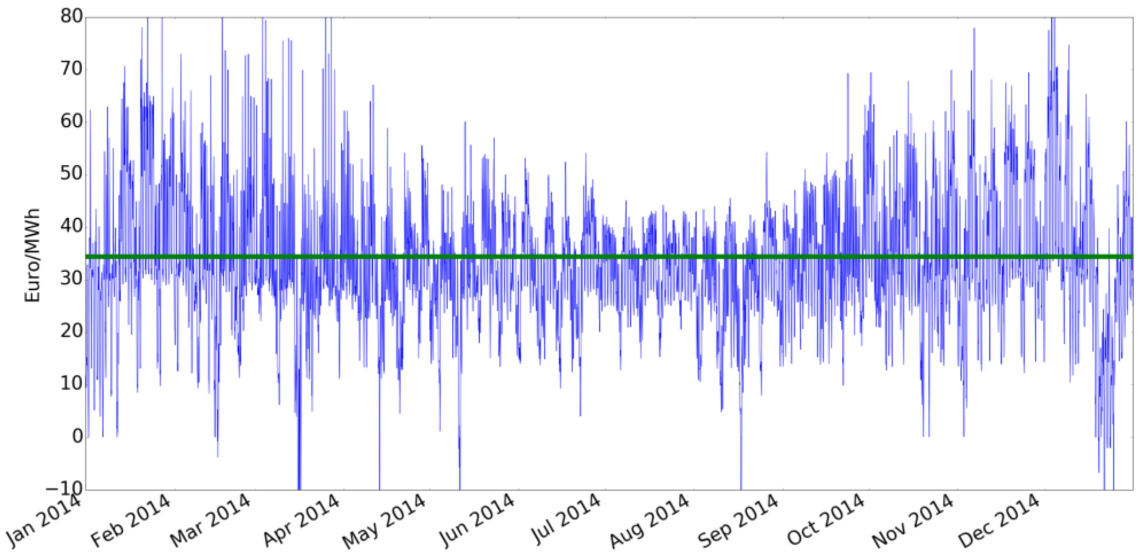




Price Effect

- Average cost pricing vs. marginal cost pricing
- Again: Time varying demand makes the difference, consumers are usually not price responsive on an hourly scale





Research Questions

- Do different availability profiles provide an argument for differentiated renewable promotion due to
  - (a) technology substitution effects?
  - (b) price variation effects?

- What are the optimal (cost-effective) renewable promotion schemes/rates for solar and wind power?
- How does interaction with existing CO_2 policies affect the optimal policy design?

Literature and Contribution

Literature

- Ambec, Crampes 2012: Optimal energy mix with interaction of intermittent sources (availability 0 or 1) with reliable sources
- Helm, Mier 2016: Market diffusion of intermittent renewable technology
- Möbius, Müsgens 2015: Volatility of wholesale prices with one intermittent technology
- Chao 2011: Interaction of the availability of one intermittent technology with conventionals
- Böhringer, Rosendahl 2010: Green promotes the dirtiest
- Wibulpolprasert 2016: Differentiated RES support for wind in Texas

Contribution

- Investigation of the impact of different availability profiles of renewables
- Implications for RES policy design

Contents

Model Overview

- Partial equilibrium model of electricity market
- Generation is aggregated on the technology level
- Agents may invest in new capacity and base their production decision on profit maximization
- Two renewable technologies: Wind and Solar

Electricity Generation

Generator i maximizes their profits given

- hourly electricity prices (P_t)
- the green certificate price (PR)
- emissions price (PE)

$$\max \sum_t \left[\left(P_t - c_{it}^{\text{gen}} - \gamma PR - \varphi_i PE \right) X_{it} - c_i^{\text{r}+} X_{it}^{+} \right] - c_i^{\text{inv}} I_i$$

Choosing

- Generation (X_{it})
- Investment into capacity (I_i)

$$\alpha_{it} \left(\overline{cap}_i + I_i \right) \geq X_{it} \quad \text{Capacity constraint } \forall t$$

$$X_{it}^{+} \geq X_{it} - X_{it-1} \quad \text{Ramping constraint } \forall t$$

$$I_i, X_{it}, X_{it}^{+} \geq 0,$$

Flexibility of generation is restricted using ramping cost (c_i^{r+})

For green technologies additional income from RES needs to be included.

Storage operator

Given the electricity price (P_t) the storage operator maximizes profit choosing

- Amount of storage (S_t)
- Injection into storage (J_t)
- Release from storage (R_t)

Energy losses through pumping are accounted for by an efficiency factor (ψ)

$$\max \sum_t (P_t R_t - P_t J_t)$$

$$S_{t-1} + \psi J_t - R_t = S_t \qquad \forall t$$

$$cap^S \geq S_t \qquad \forall t$$

$$cap^J \geq J_t \qquad \forall t$$

$$cap^R \geq R_t \qquad \forall t$$

$$R_t, J_t, S_t \geq 0$$

Market clearing

Electricity market clears on hourly basis

$$\sum_i X_{it} + R_t - J_t = D_t \quad \perp \; P_t$$

Consumers react to the price in each hour

$$D_t = a_t + b_t P_t$$

Policy instruments

Market for green certificates determines the quota price (PR)

$$\sum_{i \in G,t} X_{it} \geq \gamma \sum_{i,t} X_{it} \quad \perp \; PR \geq 0$$

In case of feed-in tariffs, subsidies are refinanced via a tax on final demand price

Market for emission permits determines the allowances price (PE); alternatively CO_2 tax is possible

$$\bar{e} \geq \sum_{i,t} \varphi_i X_{it} \quad \perp \; PE \geq 0$$

Data

- Hourly demand data for Germany 2014 (entso-e)
- Hourly dayahead prices (EPEXSpot)
- Hourly production (and forecasts) of wind and solar (TSO websites)
- Hourly production of conventional technologies (https://www.energy-charts.de/)
- Installed capacities (BMWi)
- Bottom-up technology data

Contents

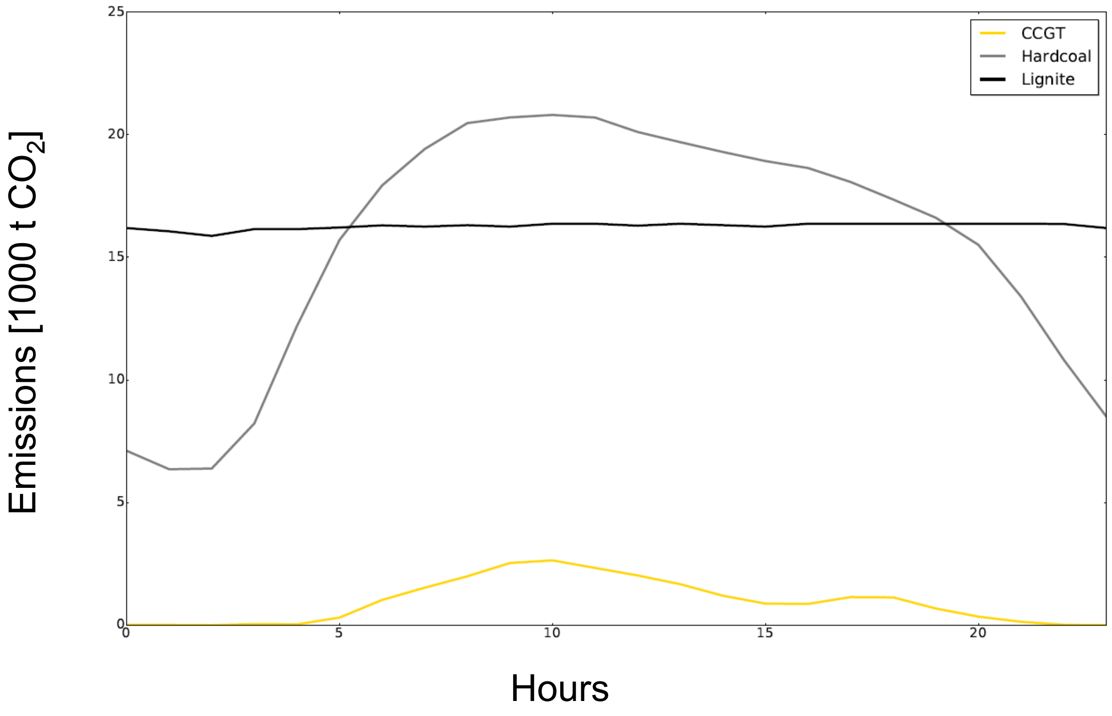
Scenarios

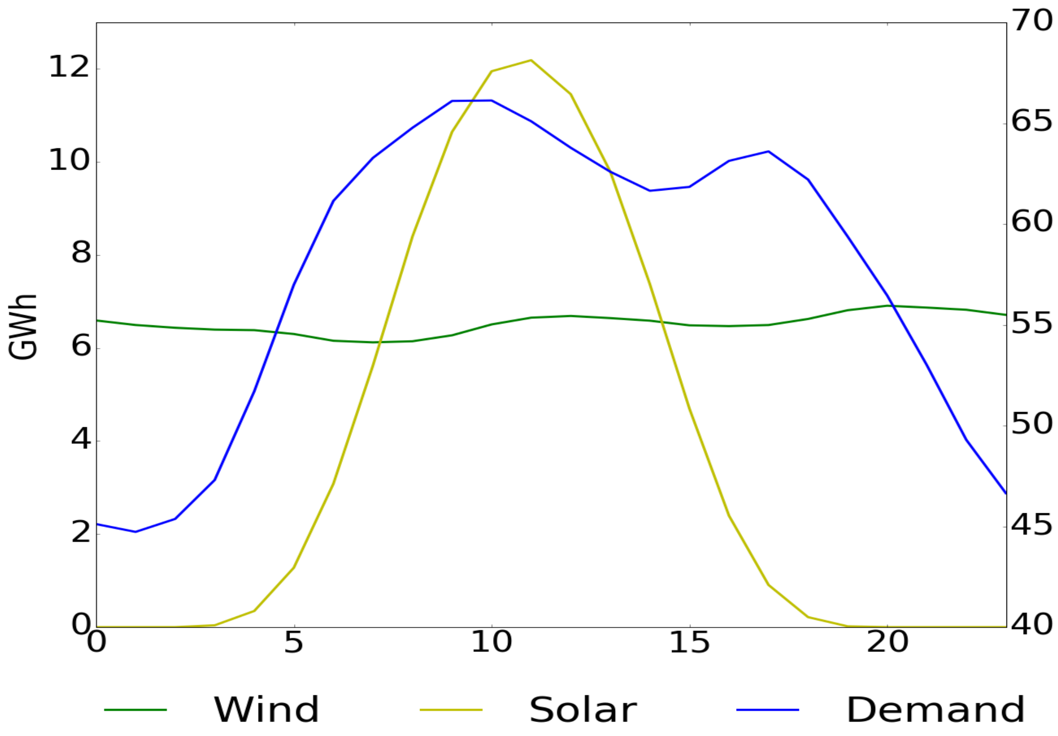
		Renewable Technology		
		None	Solar	Wind
Policy	None	**Base**		
	RES		**Solar**	**Wind**
	Emissions Cap		**Cap_Solar**	**Cap_Wind**

Scenario Description

- Base case: Existing conventional capacity without renewables
- RES target of 10% - 50% wind or solar
- Normalized investment costs for wind and solar

Hourly variation of emissions and renewable generation

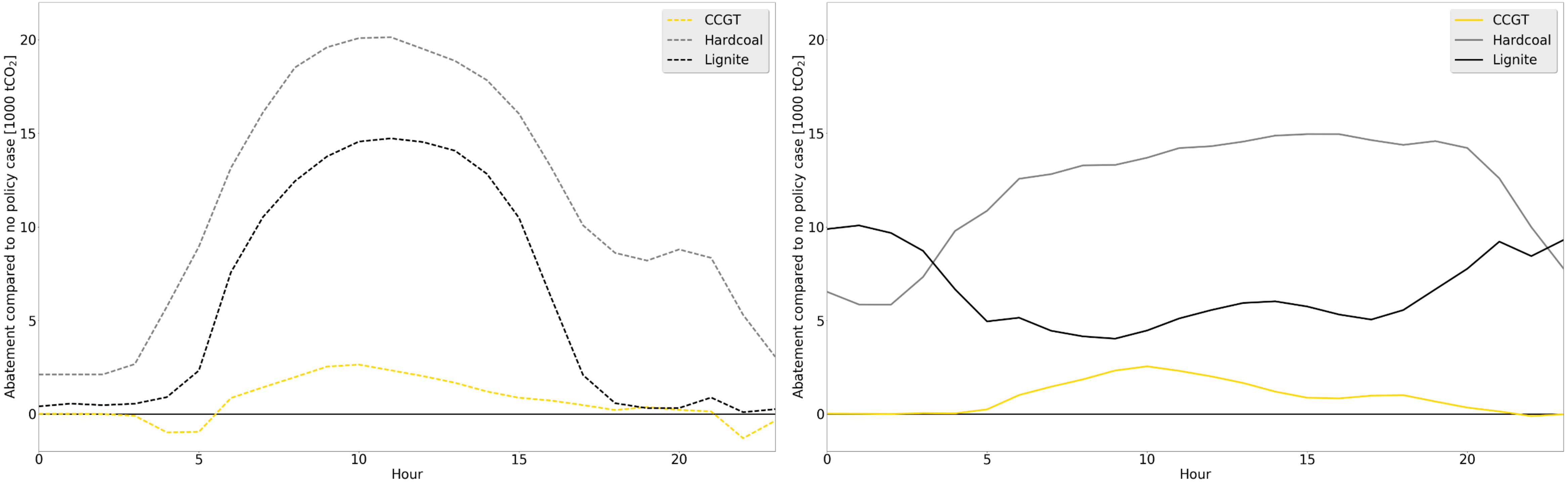




Correlations:

Emissions ⟷ Demand: 0.988 Solar ⟷ Demand: 0.394 Wind ⟷ Demand: 0.114

Hourly abatement due to 40% renewable generation



- Solar energy does not contribute much to abatement during base load hours
- Wind energy reduces emissions more evenly in base load and peak load hours

Comparing 0%, 20%, and 40% RES

TABLE I
GENERATION, EMISSIONS, AND COST-EFFECTIVENESS FOR TECHNOLOGY-SPECIFIC RES SUPPORT FOR EITHER WIND OR SOLAR

	Renewable share (in %)				
		Wind		Solar	
	0	20	40	20	40
Annual generation (TWh)	405.5	390.3	375.0	390.4	376.8
Natural Gas	17.1	2.4	0.8	5.1	5.0
Hardcoal	122.9	62.3	28.0	63.2	34.2
Hydro	15.7	15.7	14.5	15.6	12.7
Lignite	121.5	105.9	72.4	104.0	77.5
Nuclear	70.8	69.1	59.3	68.5	52.2
Others	57.6	56.9	50.4	55.9	44.5
Solar	0.0	0.0	0.0	78.1	150.7
Wind	0.0	78.1	150.0	0.0	0.0
Emissions (million tons of CO_2)	220.1	149.1	89.3	149.2	100.7
Welfare cost relative to 0% RES share (in billion €)	–	-14.1	-30.0	-14.1	-32.3
Cost-effectiveness (€ per ton CO_2 avoided)	–	198.4	229.2	199.4	270.4

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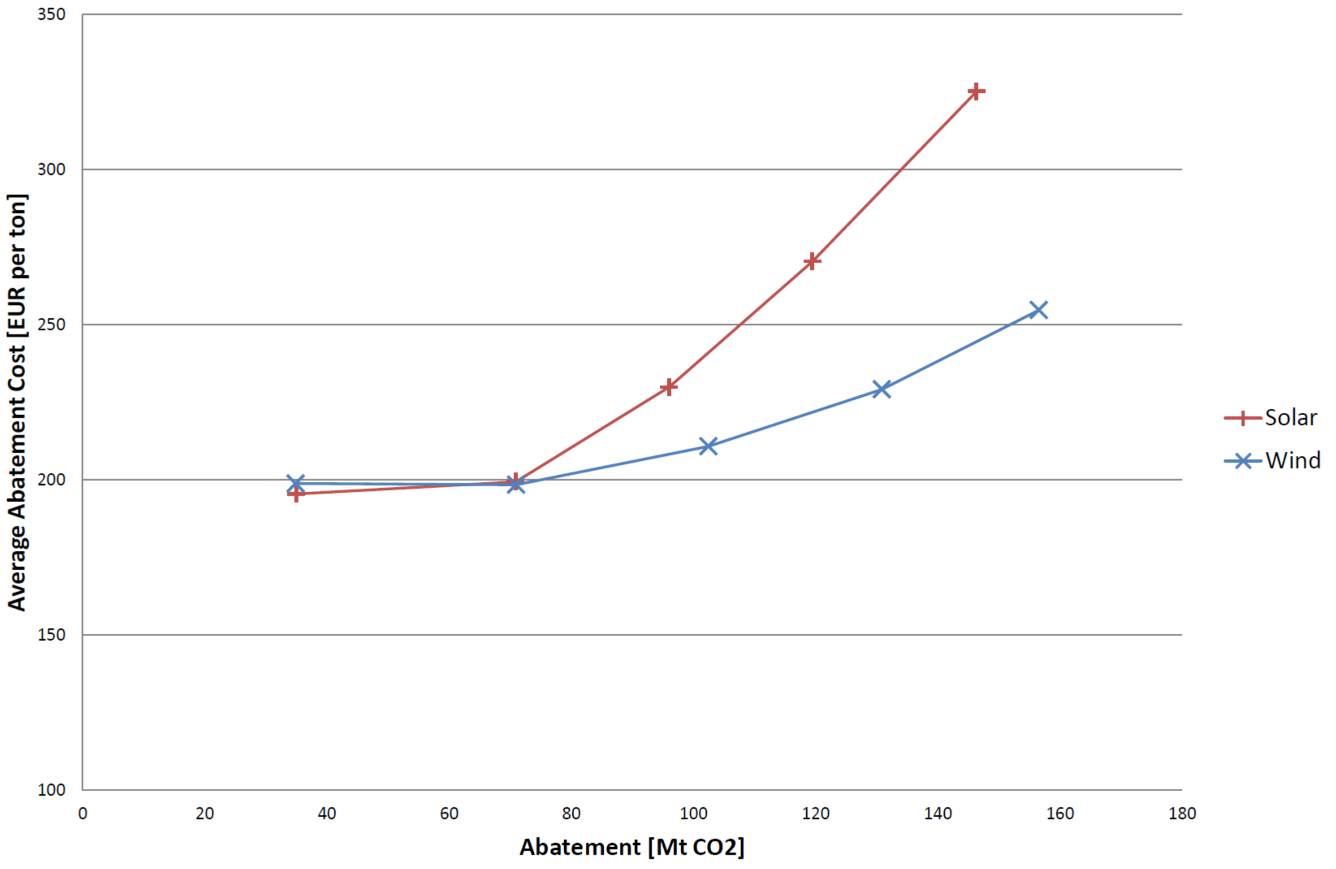
Average abatement costs for rising RES share

- For higher shares of RES average abatement costs per ton of CO2 avoided are higher for solar energy.
- Less carbon abatement with solar for equal share of generation compared to wind ⟶ higher abatement cost



Contents

Conclusions

- There is a difference between wind and solar energy even if their investment costs are normalized.
- Availability patterns are a fundamental property of wind and solar energy
- Solar has a greater inpact on peak load technologies
- Wind substitutes also base load technologies

Conclusions

- For the German conventional electricty mix wind has lower abatement costs per ton CO2 avoided
- Assessment of environmental value of renewables depends crucially on the existing conventional capacity
- A differentiated renewable support might help to achieve abatement goals at lowest cost

Next steps and extensions

- Investigate further the interaction with existing carbon policy
- Find optimal differentiation for RES support for a given abatement goal
- Extend study to countries with a different mix of conventional generation capacity