Zurich University
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Buffering Volatility: Storage Investments and Technology-Specific Renewable Energy Support

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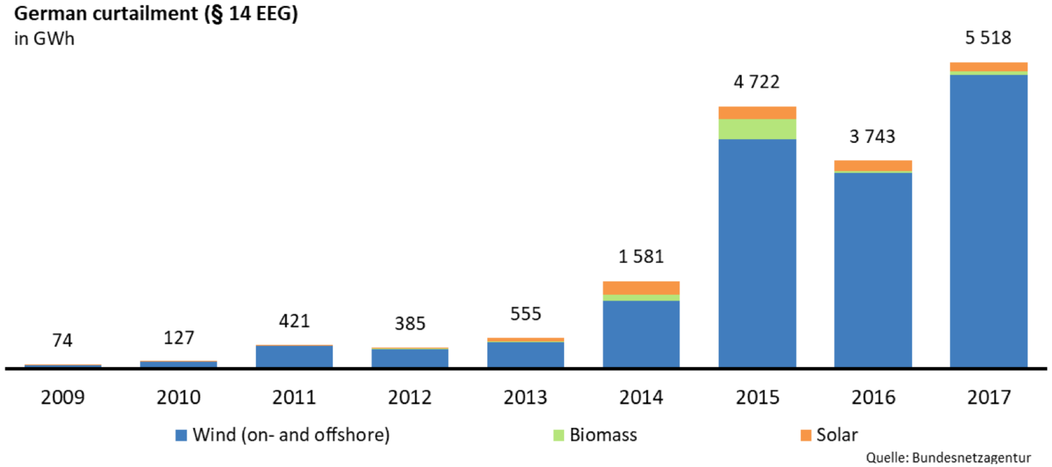
Background

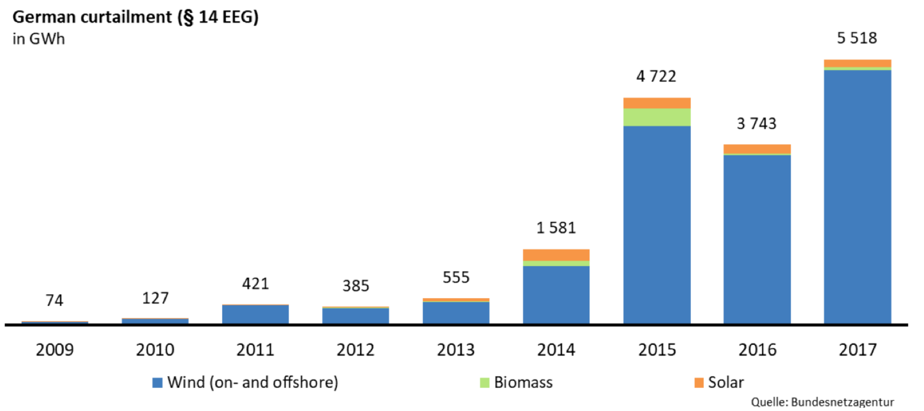
- Carbon mitigation in the electricity sector is a major concern of climate change regulation
- Renewable energy (RE) support led to large increase in wind and solar capacities
- EU Energy Roadmap 2050 foresees RE share of 64 to 97%

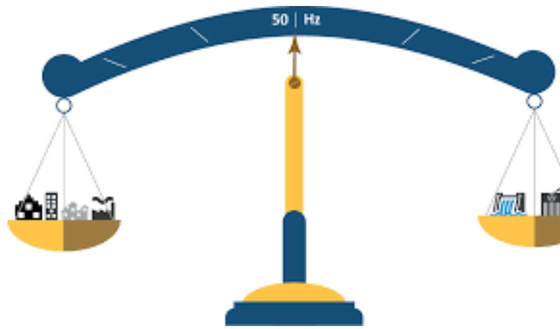
How to integrate such high amounts of RE into the electricity system?

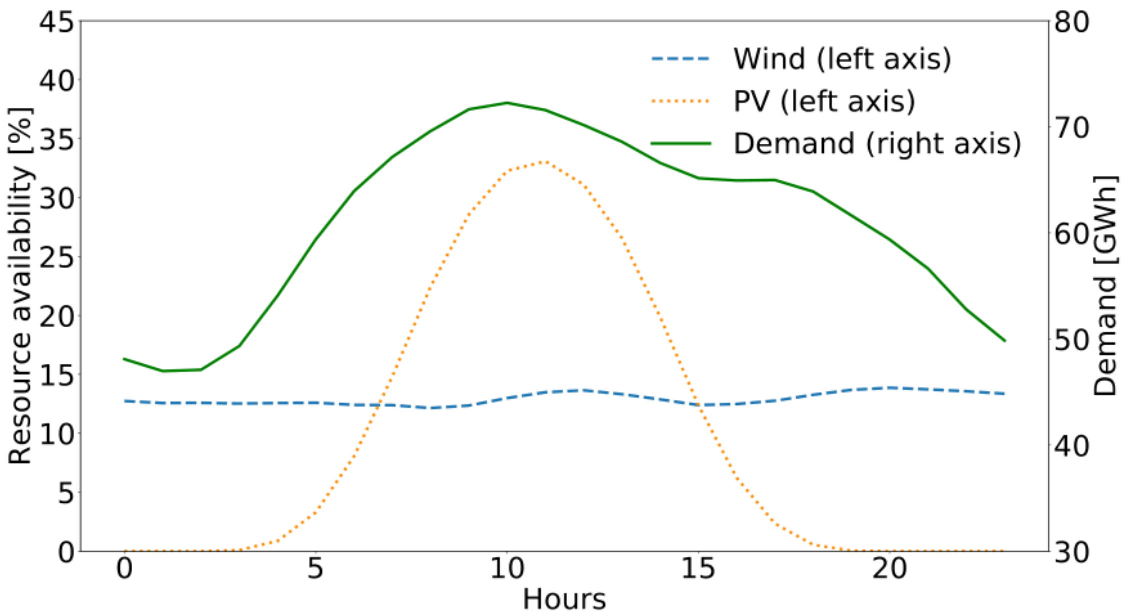


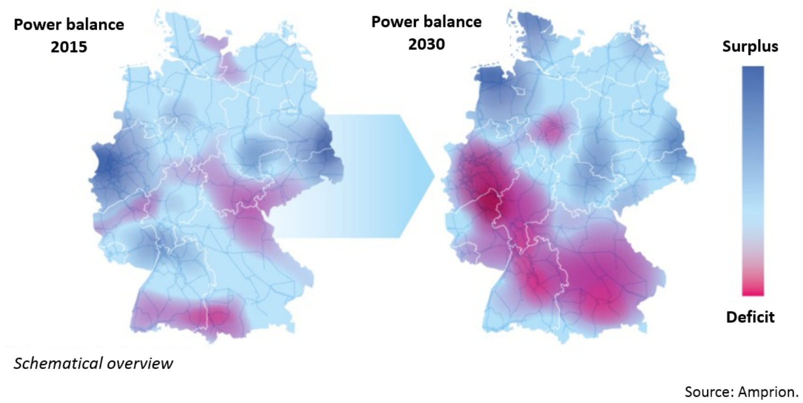
Renewable Energy (RE) and Integration Cost

- Renewable energies are
  - variable
    ➔ Profile cost
  - uncertain
    ➔ Balancing cost
  - location specific
    ➔ Congestion cost





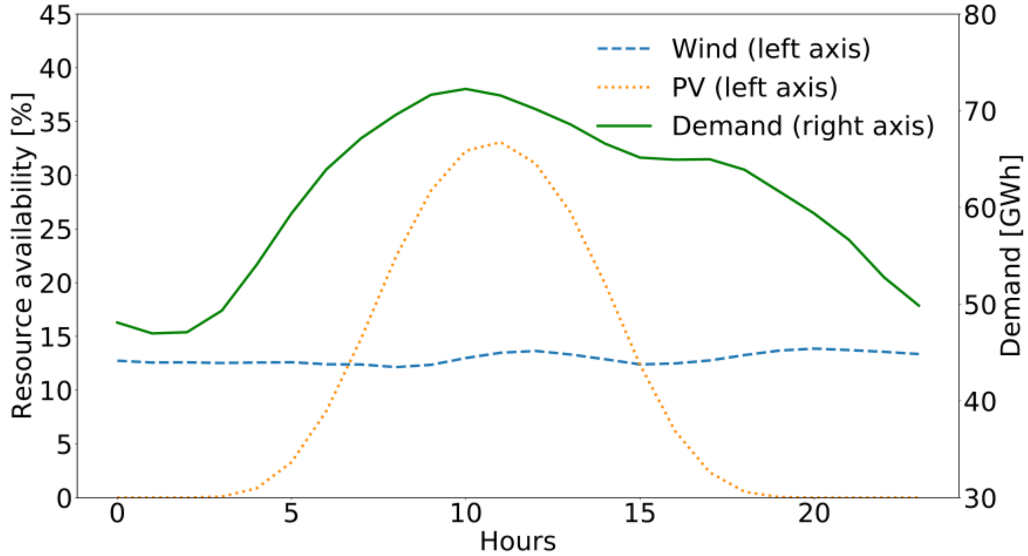




Research Question: How to deal with profile cost?

- Two major options to match RE supply and demand profile
  - Storage facilities
  - Optimize RE mix

- Numerical model of German electricity market to answer the question



To what extent integration cost can be reduced modifying the design of RE support?

Related Literature and Contribution

- Renewable support policy
  Abrell et al. (2019), Wibulpolprasert (2016), Fell & Linn (2013)

- Storage and renewable energies
  Zerrahn et al. (2018), Sinn (2017)

- Integration cost of renewables
  Gorwrinsankaran et al. (2016) , Hirth et al. (2015)

- Storage and emissions
  Helm & Mier (2018), Carson & Novan (2013), Crampes & Moreaux (2010)

- **This paper**
  Technology differentiated renewable support to avoid costly storage investments

Overview

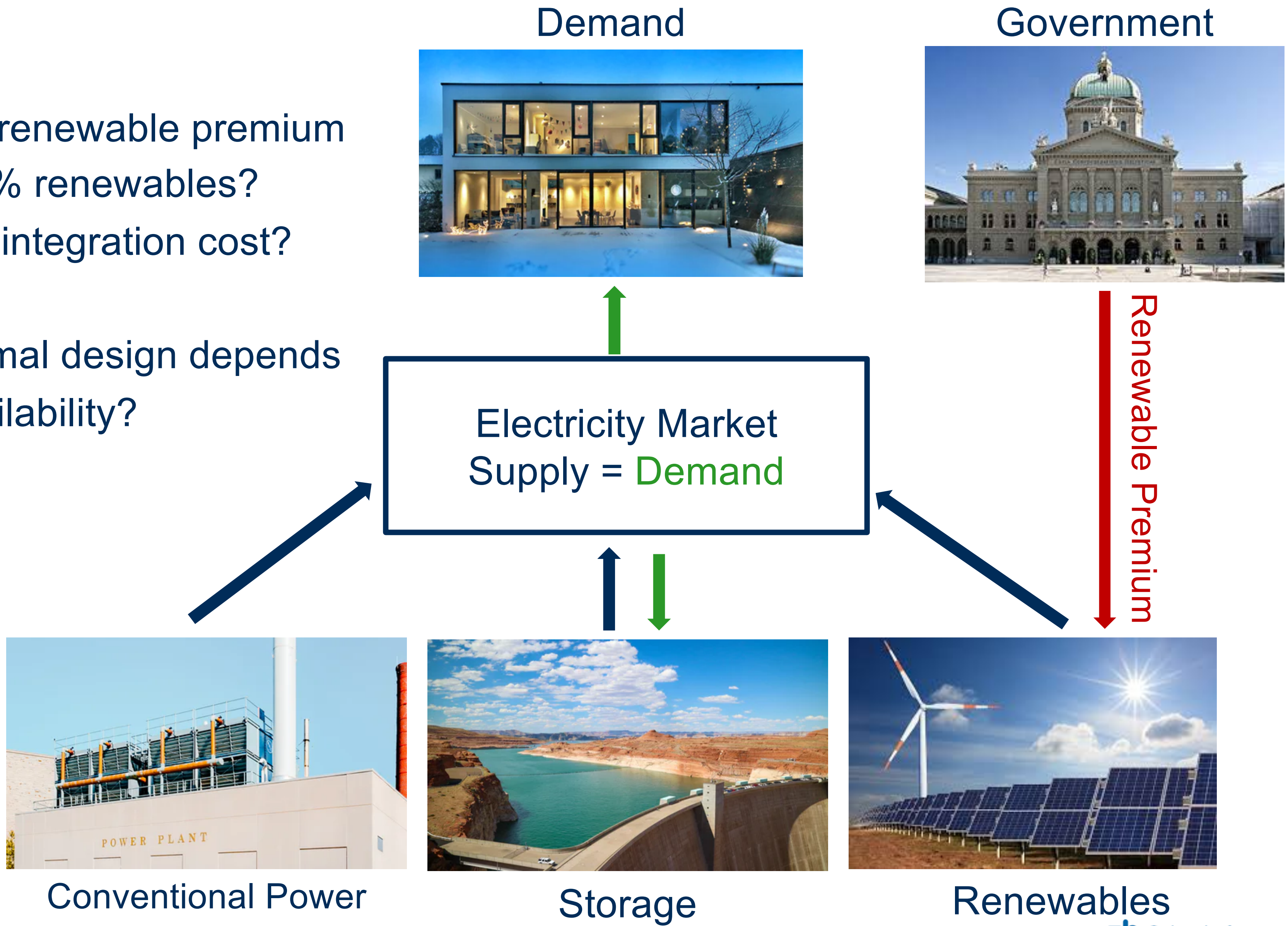
- Motivation
- Numerical Approach
- Results
- Summary and Conclusions

Numerical Electricity Market Model: Overview

How to design renewable premium

- to reach 70% renewables?
- to minimize integration cost?

How does optimal design depends on storage availability?

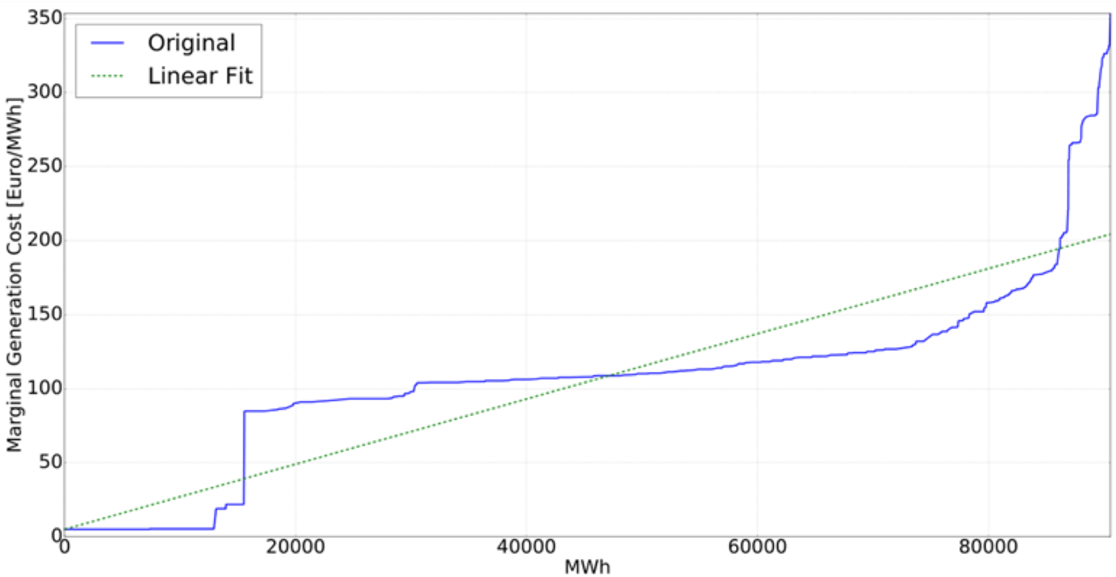


Model Assumptions: Demand and Conventionals

- General assumptions
  - German electricity market 2014
  - Hourly resolution with two weeks per season
- Inelastic **demand**

- One **conventional technology**
  - Increasing production cost
  - Constraint by capacity
  - No investments

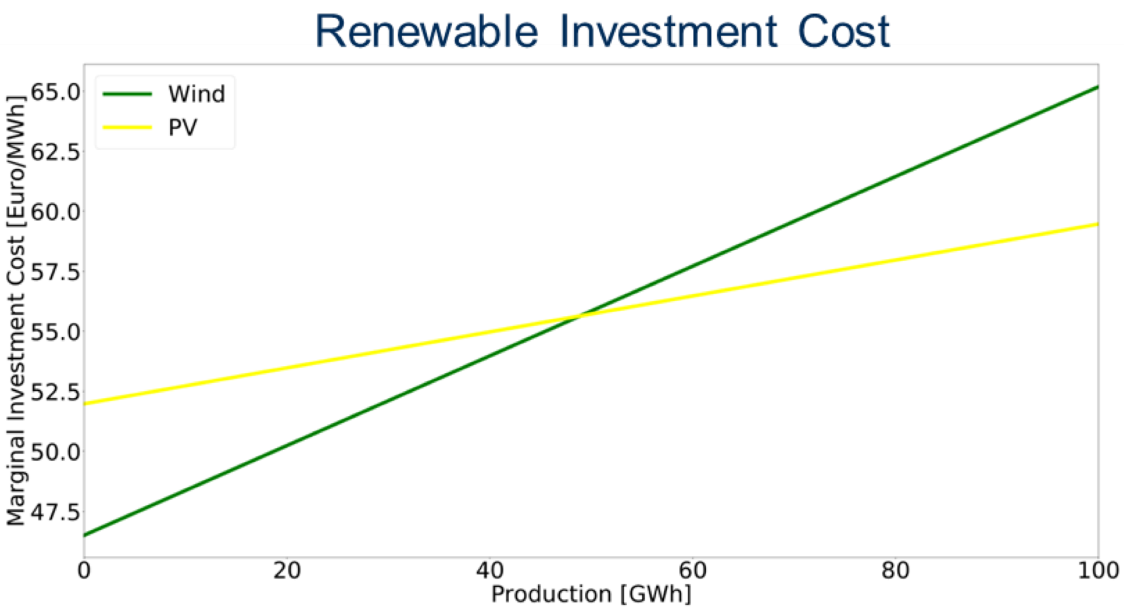
Conventional Supply Curve



Model Assumptions: Storage and Renewables

- **Storage**
  - Constraint by
    - storage capacity
    - turbine capacity
  - Efficiency: 75%

- **Renewable Energies**
  - Wind and solar power
  - Zero production but investment cost
  - Exogenous profiles



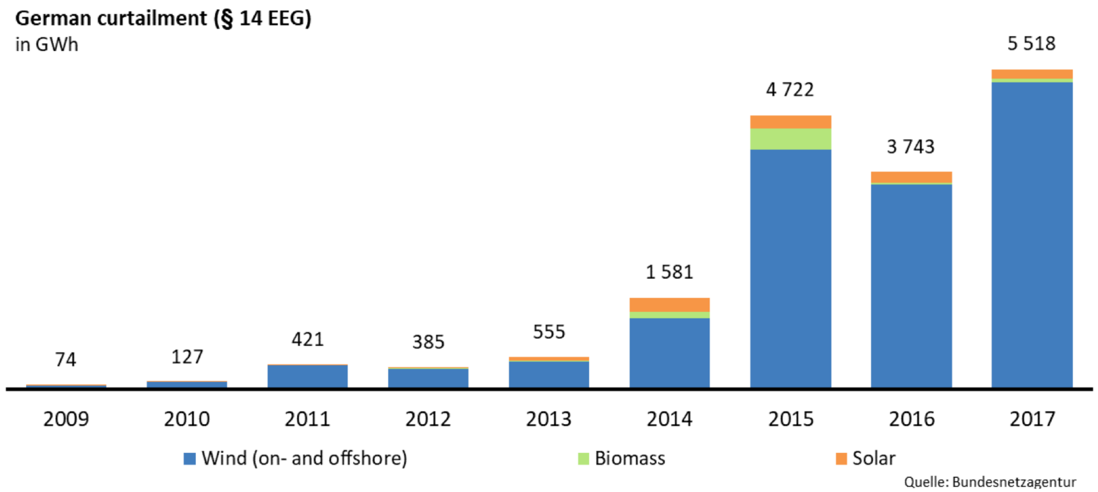
Model Assumptions and Calibration: Government

- **Government** implements renewable premium

- Renewable generation receive premium and market price

- **Integration cost**
  - System operator allowed to curtail renewable energies
  - Premium always paid to investor
  - ➔ Unused generation potential = additional cost

- Finding optimal premium MPEC solved using grid search

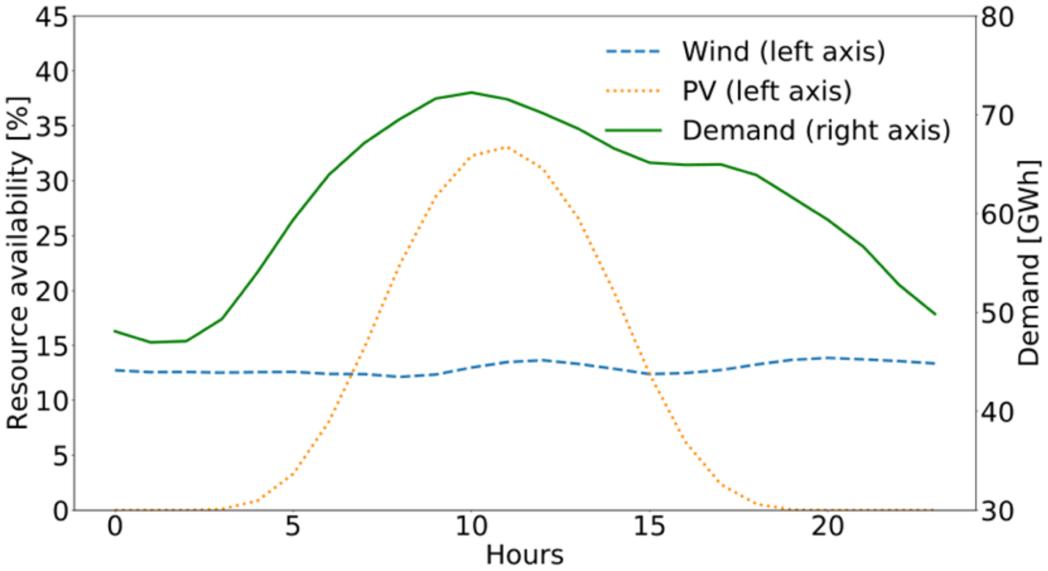


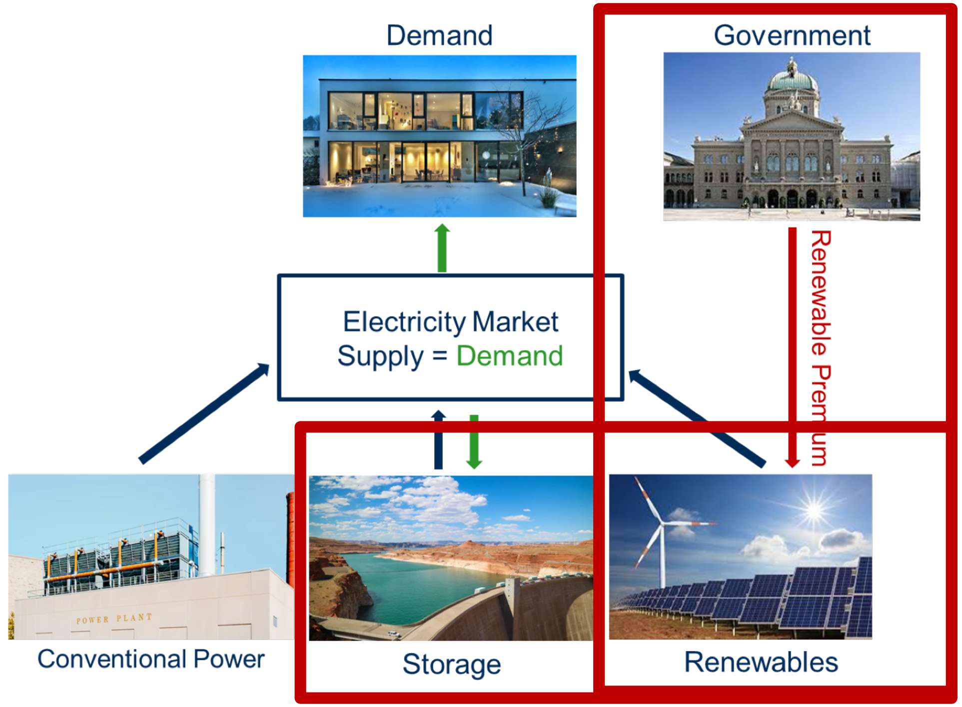
Scenarios

- How to design renewable premium
  - to reach **70% renewables**?
  - to minimize integration cost, i.e., curtailment?

- Should premium be differentiated?

- How does optimal design depends





		Market Premium		
		No	Technology-neutral	Technology-differentiated
Renewable Target	No	No Policy		
	70%		Neutral subsidy	Differentiated subsidy

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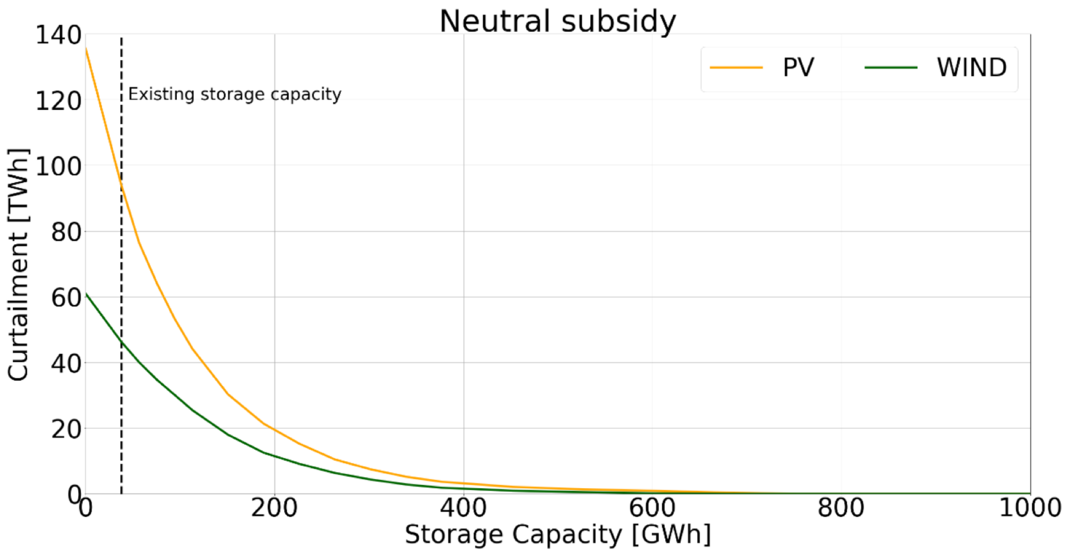
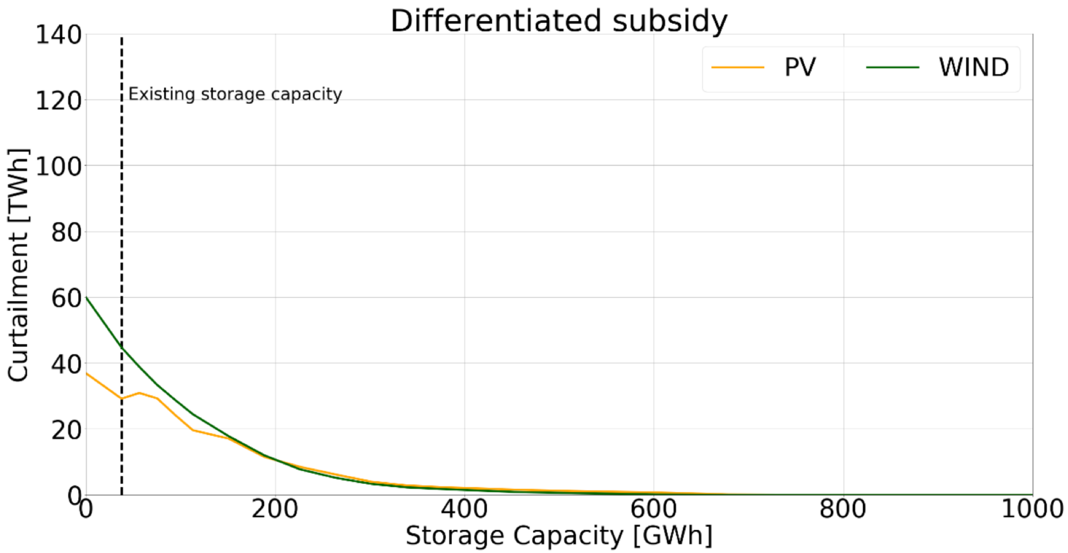
Storage Capacity and Curtailment

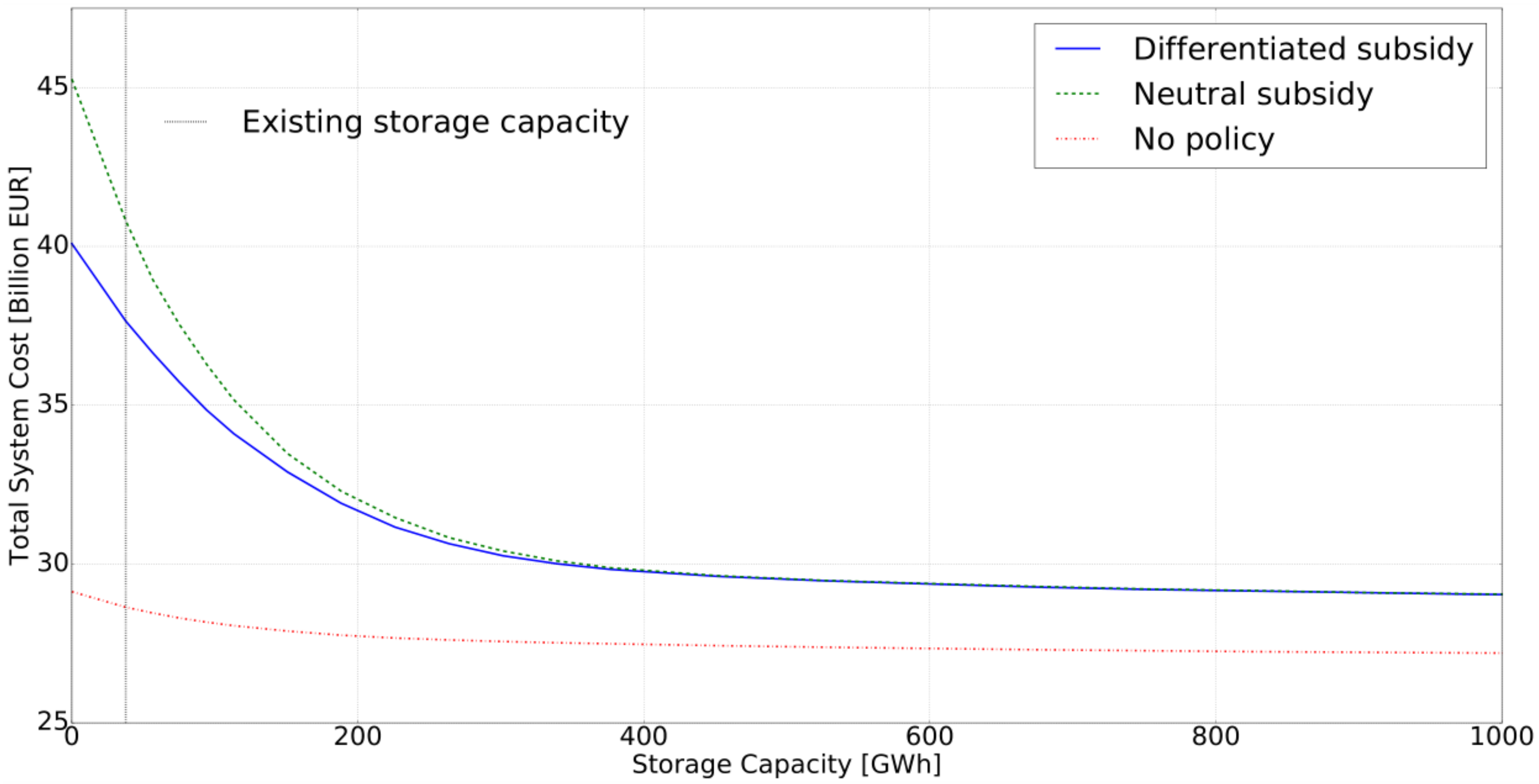




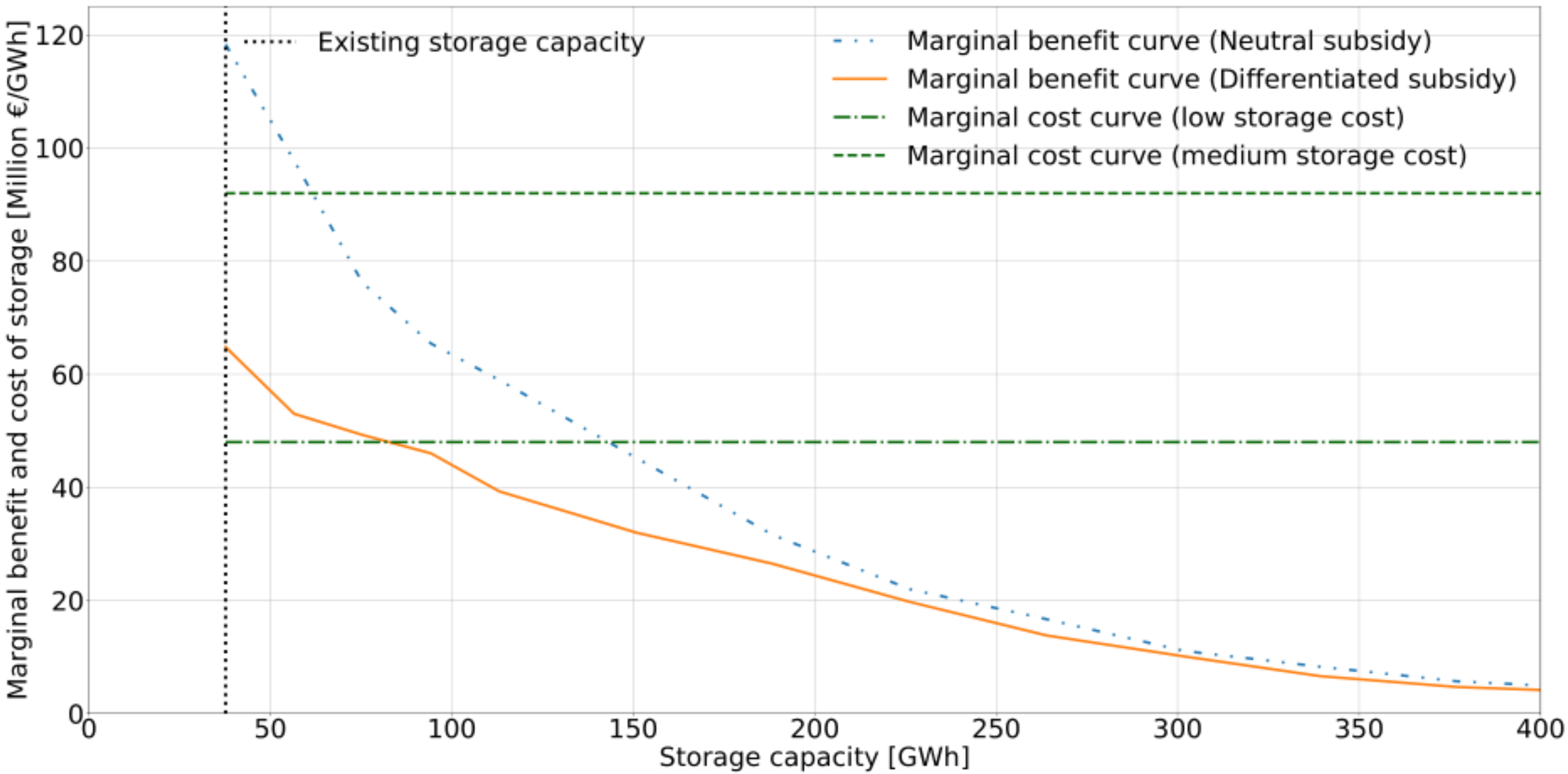
Storage capacity (GWh)	Solar Generation Share (%)	
	Neutral	
Existing	39.5	
Existing*5	42.6	
Existing*10	45.4	
Unlimited	49.9	

Storage capacity (GWh)	Solar Subsidy (% of wind subsidy)
Existing	62
Existing*5	74
Existing*10	84
Unlimited	91

Storage Capacity and System Cost



How much Storage is needed?



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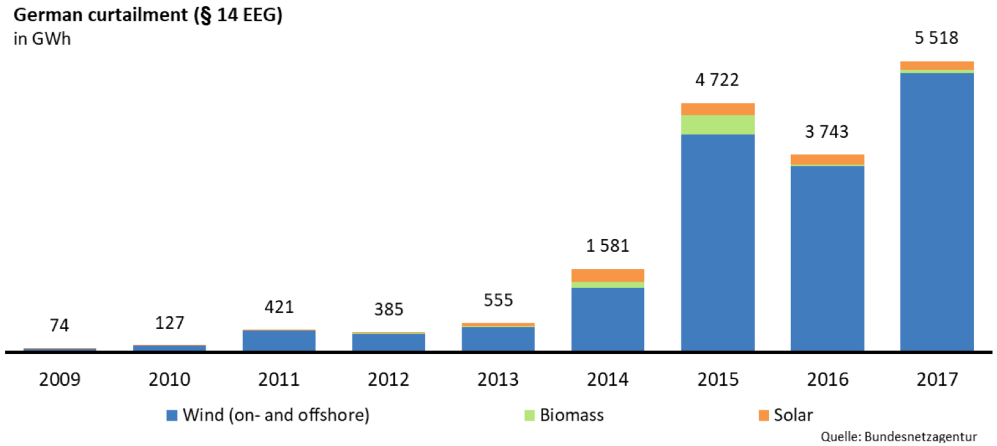
Summary and Conclusions

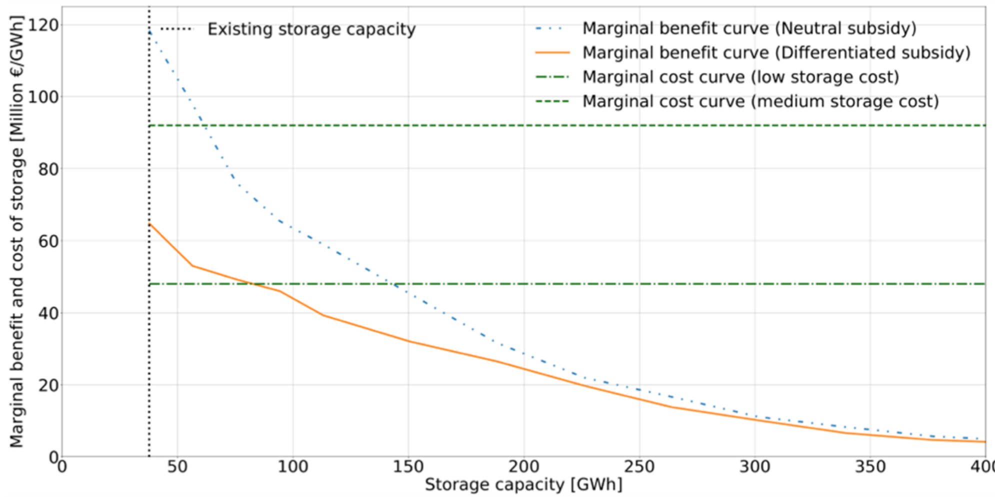
– To what extent integration cost can be reduced modifying the design of RE support?

– Storage requirement to achieve 70% of RE in Germany is rather modest

– Technology-differentiation of RE support helps to avoid costly storage investments

➔ Policy design should reflect system integration cost





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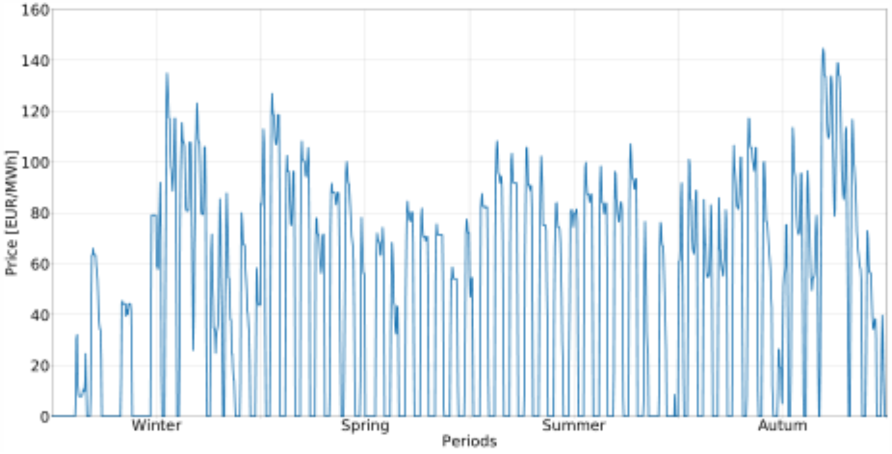
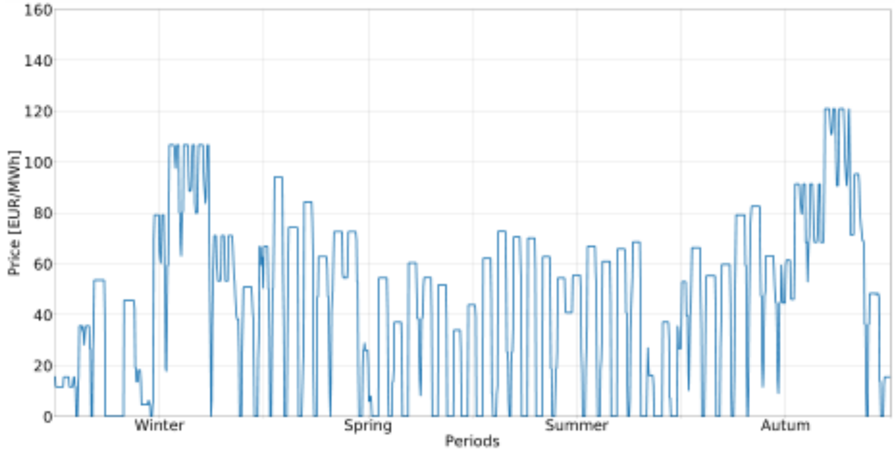
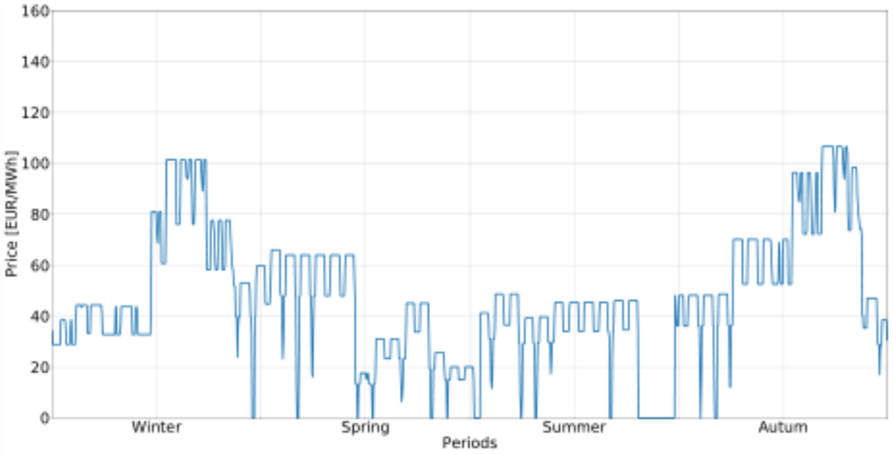
Price Development



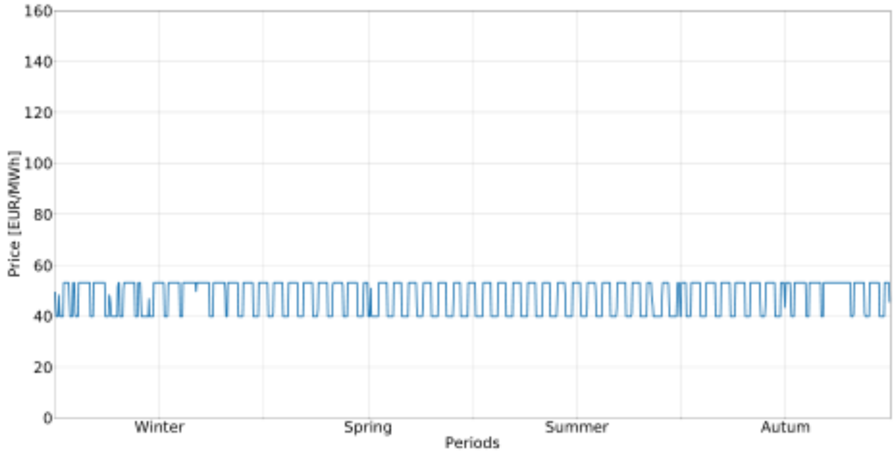
(a) Storage level 1 (37.7 GWh).



(b) Storage level 5 (188.5 GWh).



(c) Storage level 10 (377 GWh).



(d) Unlimited storage.

Figure 5: Hourly electricity price for a 70% RE target with a technology-neutral RE subsidy and increasing storage capacity measured in multiples of the currently (i.e., year 2014) installed level.

Stored Energy

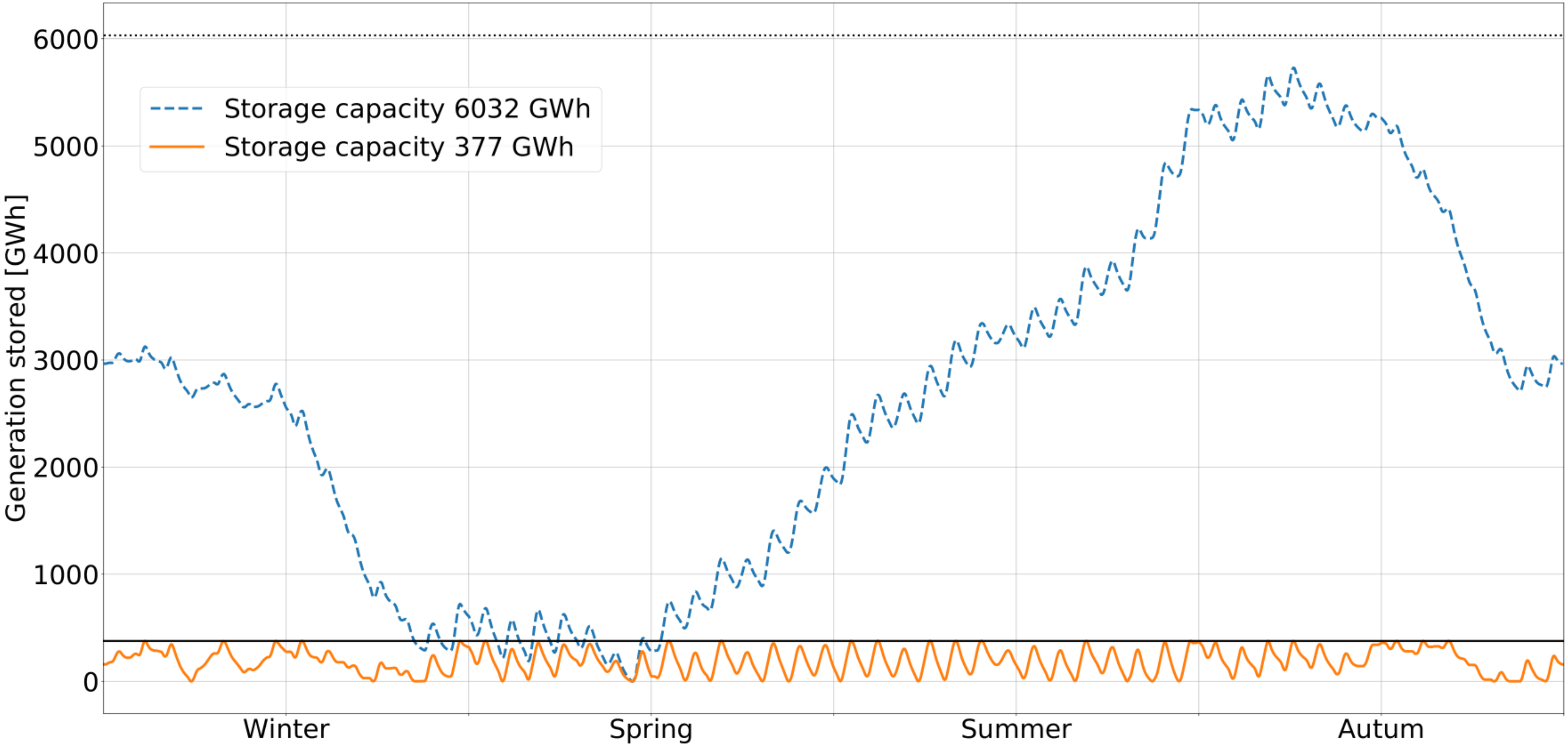


Figure 6: Electricity generation stored over the course of a year. The horizontal lines indicate the maximum storage capacity available in the two cases of constrained (377 GWh) and unlimited storage capacity. Under unlimited storage, the capacity of 6032 GWh is never exhausted.