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**

- **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**

- **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 depend on storage availability?

Electricity Market
Supply = Demand

Government
Renewable Premium

Conventional Power
Storage
Renewables
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](image-url)
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

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<th>Renewable Target</th>
<th>Market Premium</th>
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<tbody>
<tr>
<td>No</td>
<td>Technology-neutral</td>
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<tr>
<td>No Policy</td>
<td>Neutral subsidy</td>
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<tr>
<td>70%</td>
<td>No Policy</td>
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Exogenously vary storage capacity
Overview

- Motivation

- Numerical Approach

- Results

- Summary and Conclusions
Storage Capacity and Curtailment

<table>
<thead>
<tr>
<th>Storage capacity (GWh)</th>
<th>Solar Generation Share (%)</th>
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<tr>
<td>Neutral</td>
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<td>Existing</td>
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<tr>
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<table>
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<th>Storage capacity (GWh)</th>
<th>Solar Subsidy (% of wind subsidy)</th>
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<tr>
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<td>62</td>
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<tr>
<td>Existing*5</td>
<td>74</td>
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<tr>
<td>Existing*10</td>
<td>84</td>
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<tr>
<td>Unlimited</td>
<td>91</td>
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</table>
Storage Capacity and System Cost

- Differentiated subsidy
- Neutral subsidy
- No policy

Existing storage capacity

Total System Cost [Billion EUR]

Storage Capacity [GWh]
How much Storage is needed?
Overview

- Motivation
- Numerical Approach
- Results

- 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
Overview

- Motivation
- Numerical Approach
- Results
- Summary and Conclusions
- Backup Slides
(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.
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.