Role of Flexible Consumers in a Future Renewable Power System

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Overview

Technical

Requirement

Capability

Consumer Side

Data Analytics

System Side

Optimization

Social Science

Economical

Market

Willingness

Behavioral Economics

Optimization

Policy
Key questions:

1. Are consumers **capable** of being flexible?  
   Engineering

2. Is it **profitable** for consumers to provide flexibility?  
   Economics and Operations Research

3. Are consumers **willing** to be flexible?  
   Game Theory and Behavioral Economics
Overview

1. Motivation - Wind Power Forecasts
2. System Balance – An Analogy
3. Flexible Consumers – 3 examples
4. Recent Paper - Flexibility Gap
1. Wind Power Forecasts

1. Wind Power Forecasts

- Intermittent Renewables
- Uncertain forecasts
1. Wind Power Forecasts

2. Balance: Production = Consumption
2. Keeping the balance - An Analogy

Normal Operation

No Inertia

Blackout
2. Rowing Boat

- Technically Superior
- Physically Superior
- "Engine Room"
- Coxswain
- Power
- \( f = 0.5 \text{ Hz} \)
2. Sweden Today

Production

Peak Power

Base Power

Flexible

Operator

f = 50 Hz
2. Sweden Target

Need for Flexibility

Production

Peak Power
Variable & Uncertain
Flexible

Need for Flexibility
3. Flexible Consumers

Energy Flexibility
1. Valley filling
2. Peak Shaving
   • Energy Efficiency

Power Flexibility
3. Balancing: FCR-N/-D
   • Strategic Reserve
3. Flexible Consumers

**Electric Heating/Cooling**
7.4 GW Flexibility in Sweden

**Electric Vehicles**
Cost savings:
50% (NO)  50-100% (SE)

**Pulp and Paper Mill**
15% of SE el. consumption
Cost savings: 2.3-7.4%
Recent Paper: Flexibility Gap


Table 1: Parameters impacting the responsiveness of consumers [53]

<table>
<thead>
<tr>
<th>More Responsive</th>
<th>Less Responsive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price Exposure</td>
<td>Volatile RTP</td>
</tr>
<tr>
<td>Cost [% O&amp;M]</td>
<td>High</td>
</tr>
<tr>
<td>Equipment</td>
<td>Auto DR</td>
</tr>
<tr>
<td>Normal Load</td>
<td>High</td>
</tr>
<tr>
<td>Load urgency</td>
<td>Time-) critical</td>
</tr>
<tr>
<td>Lead Time</td>
<td>??</td>
</tr>
</tbody>
</table>

Abstract

Power systems with large shares of renewable energy generation require flexibility from both producers and consumers. Demand side management enables flexible electricity consumers to participate in system services that contribute to enhanced integration of renewable energy sources. The specific market timing, pricing scheme and demand response program dictate in which way consumers react and trade in services. Aside from pricing, several other parameters were found to greatly influence consumer behavior. Here, the impact of market timing on the flexibility of consumers is investigated and its impact on social welfare is estimated. The price elasticity of consumers can vary in different ways regarding the lead time. Consequently, the time when the price is forward-looking would affect the response and the social welfare. We simulate projects and focus on consumer choice and conduct a simulation study, where the aggregated demand is updated with statistically improved forecasts at several instants. The results show the importance of lead time for demand side management. We find that the difference between stated and measured elasticity results in a demand flexibility gap and quantify this in terms of social welfare. We conclude that lead time should be considered in electricity market design, e.g., in commodity futures markets in order to tap the full potential of flexibility from the demand side.

Keywords: load time, price elasticity, flexible consumers, demand response, wind power integration, electricity market design
Definition: Lead Time Window

<table>
<thead>
<tr>
<th>DR program</th>
<th>TOU</th>
<th>DB, RTP</th>
<th>CPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>lead time</td>
<td>Static</td>
<td>Day-ahead</td>
<td>Intra-day</td>
</tr>
<tr>
<td>mean</td>
<td>108 h</td>
<td>36 h</td>
<td>12 h</td>
</tr>
<tr>
<td>window</td>
<td>168 ... 48 h</td>
<td>48 ... 24 h</td>
<td>24 ... 1 h</td>
</tr>
</tbody>
</table>
Stated Sensitivity: Pilot Project Review

\[ \sigma_w = \frac{PAI_w}{P_w - C_w} \]

- projects with 3 lead time windows \((\sigma^M)\)
- projects with 2 and more lead time windows
- projects with 1 and more lead time windows

Possible Explanation

- When **costs are immediate**, you tend to **procrastinate**; if you are aware you will procrastinate in the future, that makes you perceive it as more costly to procrastinate now.

- When **rewards are immediate**, you tend to **preproperate**; if you are aware you will preproperate in the future, that makes you perceive it as less costly to preproperate now.

O’Donoughe and Rabin, “Doing It Now or Later”, 1999
Measured Response: Survey Data

• 400 respondents
• Mälarenergi (DSO) customers

Table 5: price sensitivity obtained from the survey

<table>
<thead>
<tr>
<th>Lead Time</th>
<th>24 h</th>
<th>6 h</th>
<th>2 h</th>
<th>1 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elasticity</td>
<td>-0.0462</td>
<td>-0.0670</td>
<td>-0.0576</td>
<td>-0.1272</td>
</tr>
</tbody>
</table>

Stated and Measured Price Sensitivity

Questions and Discussion

- What is the reason for the difference between stated and measured price sensitivity?
- How will this difference affect consumers in practise?
- How is consumer flexibility used today?
- How does the uncertainty in price sensitivity affect energy companies?
