Power Markets in Transition: Decarbonization, Energy Efficiency, and Short-Term Demand Response

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Increasing Attention Towards Demand Side

- Since the *Paris Agreement*, among others, more ambitious decarbonization goals are envisaged
- Regulator's decarbonization efforts were mainly characterized by supply side measures
- Already implemented policies show limited impact on CO_2 emissions
- As a consequence, regulators also announced targets that aim at adopting the demand side (e.g., European Commission's *Energy Efficiency Directive* with 20% reduction in energy demand by 2020 and a 30% reduction by 2030)
- There exist little analyses on the optimal level of demand side adjustment and its general role

Concept

- *Responsive Demand* comprises long-term demand response and short-term demand response
- *Long-term demand response* is understood as energy efficiency (EE) improvements
- *Short-term demand response* is demand shedding and shifting

Research Questions

- What is the optimal energy efficiency level in response to a climate policy and the resulting electricity demand?
- What's the impact of a responsive demand side for the decarbonization of power markets?
- How does the demand side interact with the supply side of power markets?

- Perfectly competitive firms decide on production and capacity investments
- Central planner maximizes welfare by investing in EE
- Performance parameter $\gamma(t)$, technological progress, depreciation
- Consumer behavior reflected by a downward sloping inverse demand function

$$\max_{\mathbf{q},\mathbf{y}} W = \sum_t \left(\sum_s CS(s,t) - C^{ee}(\cdot) - C^{tr}(\cdot) \right) \tag{1}$$

$$\text{s.t. } 0 = \sum_j y(s,t) + TR(s,t) - d(s,t), \tag{2}$$

$$d(s,t) \geq x(s,t) - \gamma(t) Q^{ee}(t), \tag{3}$$

$$x(s,t) = x_0(s,t) + \epsilon_i^s \frac{x_0(s,t)}{p_0(s,t)} \left(p(s,t) - p_0(s,t)\right) + \sum_{s' \neq s} \epsilon_i^{s,s'} \frac{\bar{x}_0(s,s',t)}{\bar{p}_0(s,s',t)} \left(p(s,t) - p(s',t)\right). \tag{4}$$

Implement Framework in EU-REGEN Model

- Implement framework in the EU-REGEN model for EU power market to find the welfare maximizing technology mix under responsive demand
    - *Type*: Partial equilibrium and perfect-foresight model
    - *Geographic resolution*: EU28 plus Switzerland & Norway grouped into 13 model regions
    - *Temporal resolution*: base year 2015 with 5-year time steps, model horizon 2050, 121 intra-annual time segments
    - *Technology*: 25 generation technologies, distinguished into 73 generation blocks by region
    - *Demand sectors*: industry, residential, commercial, and transport
- Carbon constraint of 80% emission reduction in the period 1990–2050 to account for European decarbonization goals

Moderate Role of Energy Efficiency

- EE capacity gradually increases until 2035 and then remains constant until 2050
  - 2030: 41.8 GW, equals 394 TWh (11%) demand reduction
  - 2050: 42.3 GW, equals 429 TWh (10%) demand reduction
- In relation to the already existing level, this represents a further 69% increase in 2030 and 2050
- EE has a role in the European power market, especially, in the short- and medium-run

Robust Optimal EE Level

- *Depreciation rate*: EE constantly leads to a reduction in electricity demand of around 10%
- *Performance parameter*: Threshold 0.35 required for significant investment in EE
- *Technological progress*: Little impact on optimal EE level

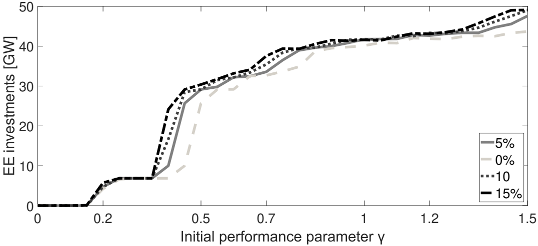

Figure 1: Energy efficiency investments for varying performance and technological progress in 2030 (default: 5%)

Moderate Rebound Effect

- *Rebound effect*: Loss in EE savings due to economic response by consumers
- Aggregate rebound effect is captured by framework
- Default market outcome: 9% rebound effect
- Its magnitude changes with the abilities to shed and shift

Table 1: Sensitivity of rebound effect in 2050

Ability levels	1×	2×	3×	4×	5×
Rebound from EE investments [TWh]	37	81	104	115	125
Rebound effect from EE investments [%]	9	19	24	27	29

Generation Path for 80% Target

- Responsive demand increases contribution from renewables
- Variable RES generation share of 35% in 2030 and 51% in 2050
- Use of CCS technologies not welfare maximizing

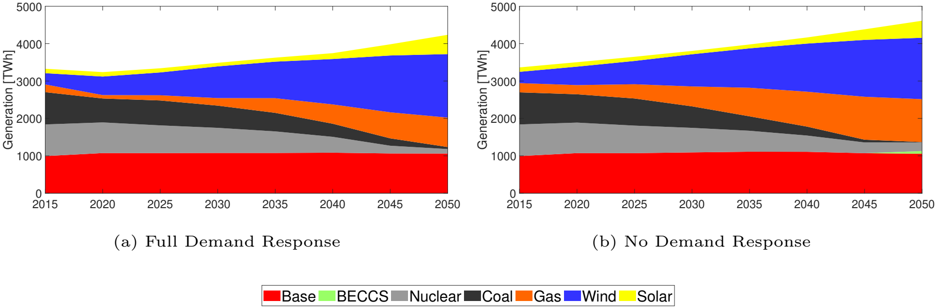

Figure 2: Long-run generation path with and without demand response

Minor Role of EE for Decarbonization

- Comparison of market outcomes under 80% climate policy and under the absence of a climate policy
- Dominated by intermittent renewables (53% in 2050) and fuel switching (36%)
- Minor role of energy efficiency with an 11% contribution
- IEA predicts that EE improvements provide 44% of abatement to meet *Paris Agreement*

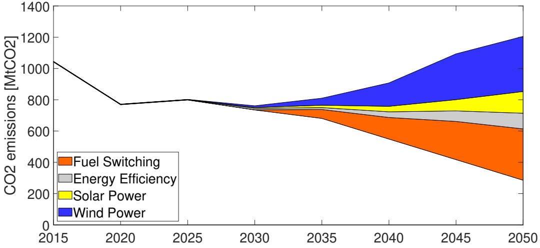

Figure 3: Contribution of different abatement channels to climate policy

Main Findings

- Rebound effect of 9% from EE so that electricity demand is finally reduced by only 10%.
- Short-term demand response and EE enhance role of renewables and reduced need for base load generators
- EE contributes 11% toward meeting the 80% emission reduction target

Implications

- EE is rather required for the mid-run transition
- Incentivizing short-term demand response is crucial for efficient implementation of long-run decarbonization path
- Policies heavily promoting gas power should be chosen with caution