Analysis of the Impact of Effective Competition on Supply Security In Energy Market Using Agent-based Modeling

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Sequence of Presentation

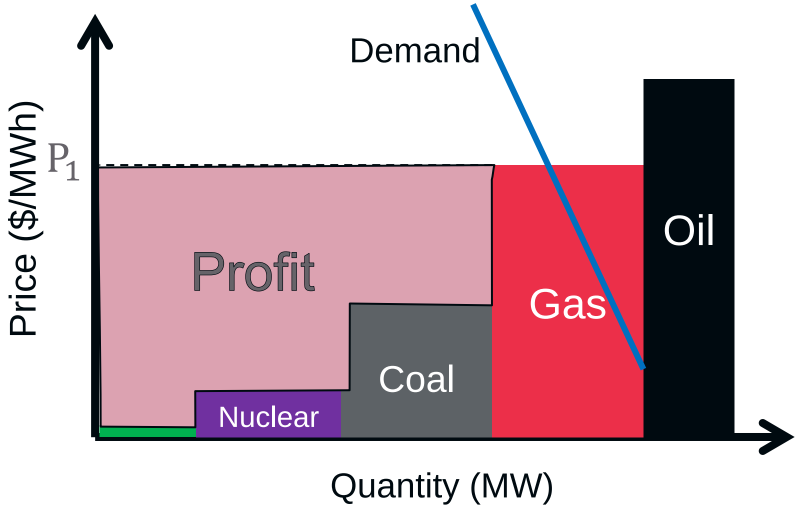
- Introduction
- Problem Statement
- Literature Review
- Research Question
- Methodology
- Case Study
- Conclusion

Introduction

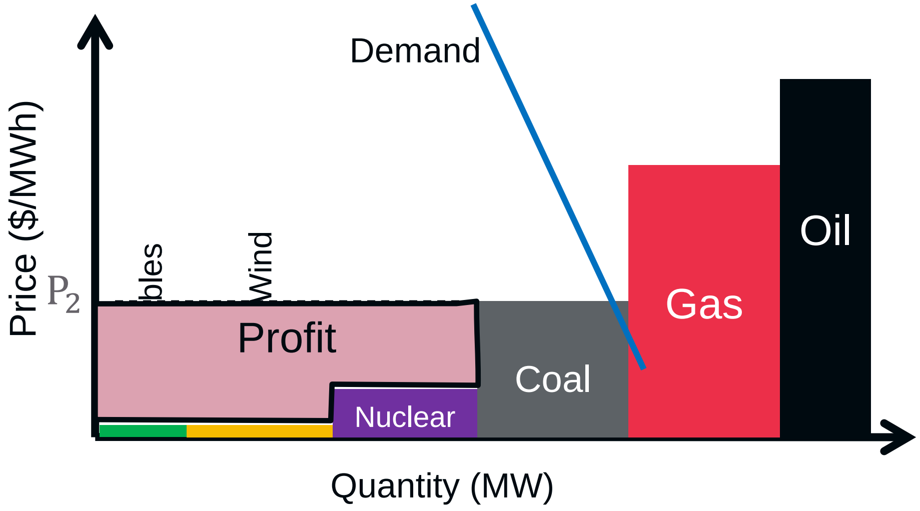
Changing landscape:

- Increasing the share of **Intermittent Renewables** in the electricity generation

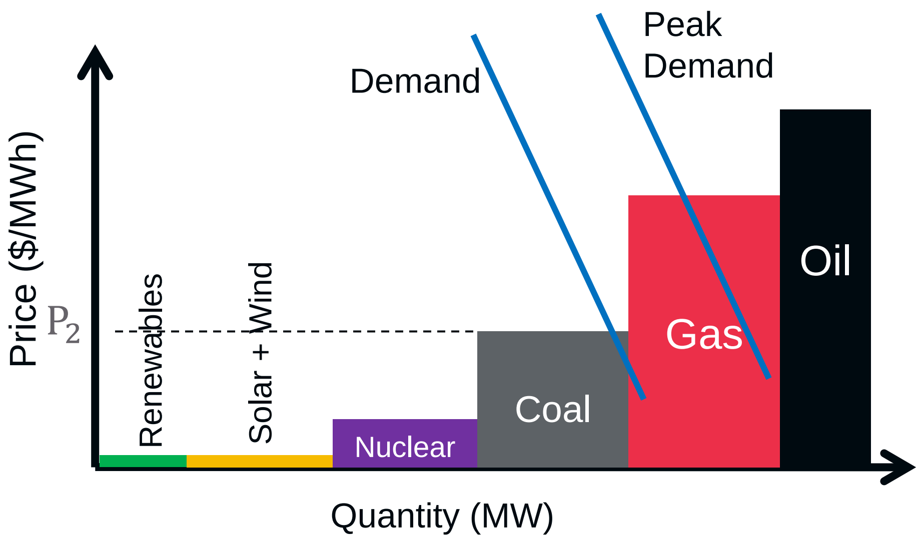
Problem Statement



Problem Statement



Problem Statement



- Electricity produced by renewables
  - is highly fluctuating and intermittent
  - causes less utilization of conventional generators
  - causes lower market prices

Problem Statement

- 1, 2, 3 lead to:
- Less profit (revenue) for conventional generators
- Less incentive to investment in conventional generators
- Less reliable backup in the electricity market

  - **Supply Security Problem**

- Resource Adequacy ~ Revenue Sufficiency ~ Missing Money

- ISO (Independent System Operator) needs a way to repay this “missing money (missing profit)” to conventional generators to keep enough reliable generation on hand

Literature Review

- Solutions are placed in 2 catagories:

- 1) Energy-only market mechansims
  - Effective competition

- 2) Capacity mechanism
  - Capacity payments
  - Strategic reserves
  - Capacity credits
  - Reliabilty options

Market Structure: Effective Competition

- Effective competition in new market design

4 elements

- **1) Effcient Scarcity Prices**

  NOW

  - Scacity situation ocurrs rarely
  - Price cap

  To Do

  - Increase the frequency and duration of scarcity situations
  - High price caps
  - e.g. ERCOT,
    - maintain energy-only market (2012)
    - $4500 per MWh in 2012 to $9000 per MWh in 2015

Market Structure: Effective Competition

- **2) Active demand side participation**
  - Add flexibility to the market
  - e.g. Interruptible loads
  - e.g. PJM market, 2000 MW in 2007 to 16000 MW in 2015 (10% of total capacity cleared in capacity auctions)

- **3) Utilization of storage facilities**
  - Add more flexibility to the market

- **4) Optimized guaranteed policies**
  - Reduce the investment risk
  - e.g. renewables support policies, introducing price caps

Research Question

How an effective competition in energy market can solve resource adequacy problem?

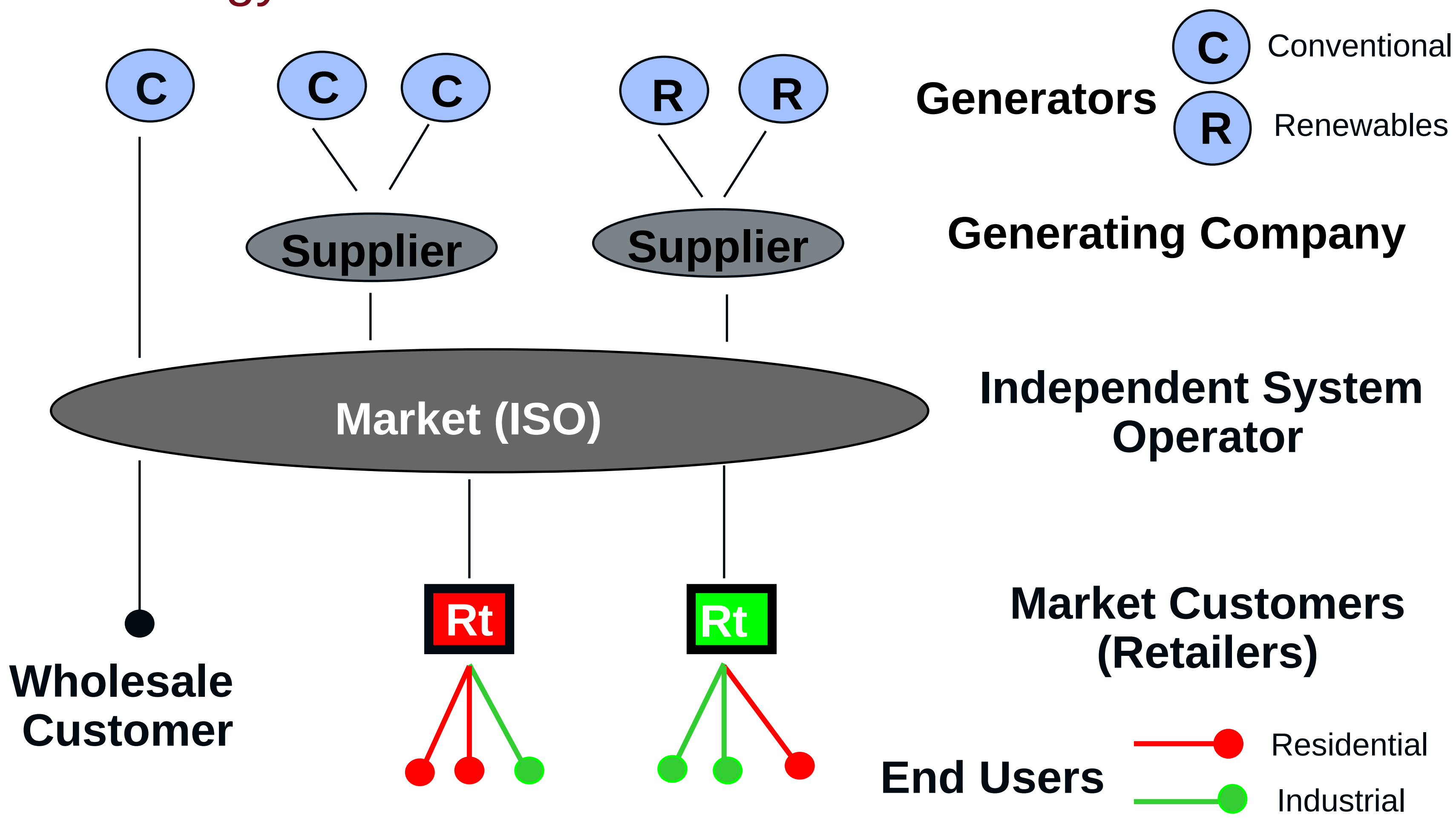
Methodology

- Hybrid Model (Multi Agent Systems + Game Theory)

- Multi-Agent Systems (MAS)
  - Agent: an entity that acts upon the environment it inhabits
    - rationality
    - Autonomy
    - Proactiveness
    - Reactivity
    - Social ability
- Game Theory (GT): analyze the interplay between parties that may have similar, opposed, or mixed interests

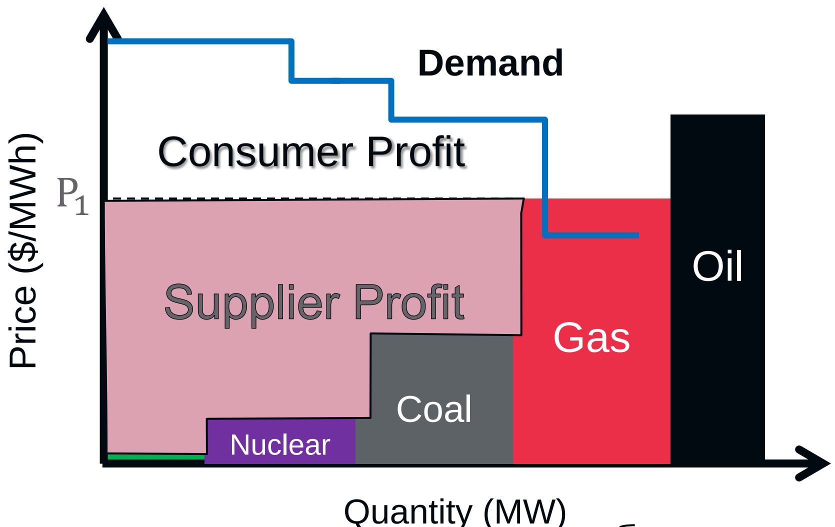
- Difference between GT and MAS : Strategic Decision Making

Methodology: Market Model



Methodology

- Agents‘ strategies (actions): {Bidding price, Bidding quantity}
- Agent‘s goal: maximize its own individual surplus



- Strategy selection: ϵ-Greedy

$$P = \begin{cases} \mathbf{1 - \epsilon + \epsilon/n} & \text{Action with best payoff} \\ \mathbf{\epsilon/n} & \text{Other actions} \end{cases}$$

Methodology

- Reward Function

$$\boldsymbol{R_{a_i} = \left(MCP - c_{a_i}\right) * q_{a_i}} \quad \text{for Generator Agent}$$

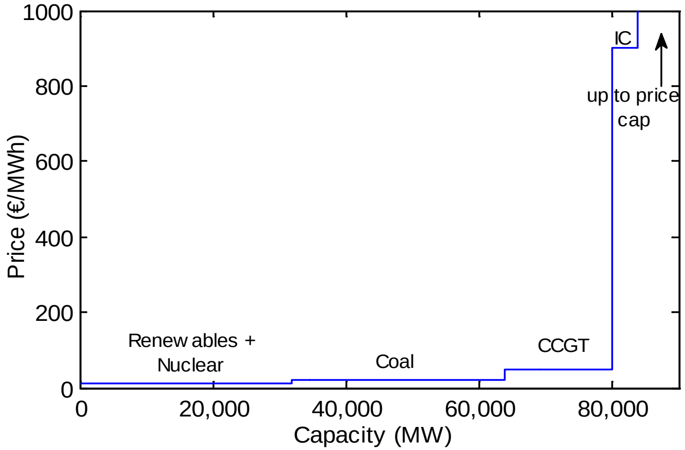
$$\boldsymbol{R_{a_i} = \left(d_{a_i} - MCP\right) * q_{a_i}} \quad \text{for Consumer Agent}$$

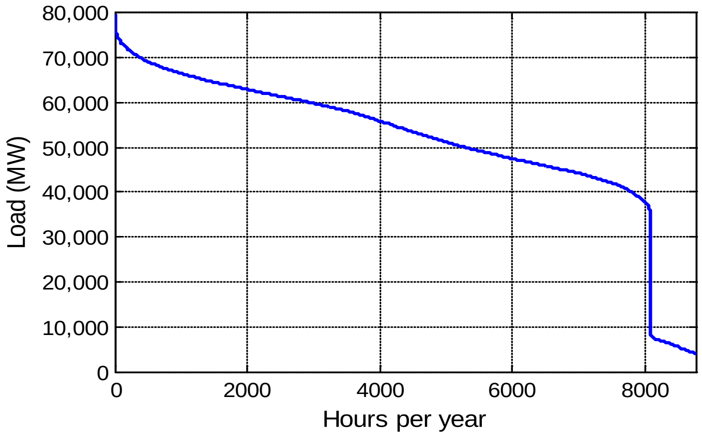
  - $\boldsymbol{MCP}$: Market Clearing Price
  - $\boldsymbol{q_{a_i}}$: Bidding Quantity
  - $\boldsymbol{c_{a_i}}$,$\boldsymbol{d_{a_i}}$: Bidding Prices

- Update Q-values : $Q_{a_i}^{new} = (1 - \alpha) * Q_{a_i}^{old} + \alpha * R_{a_i}$

Case Study

- Supply and Demand





- Price:

$$P(n,t) = \begin{cases} MCP & D(n,t) < G(n,t) \\ IC & G(n,t) < D(n,t) < (1+R).G(n,t) \\ Cap & D(n,t) > (1+R).G(n,t) \end{cases}$$

MCP: Market Clearing Price *IC: Interruptible Contracts*

R: Percentage of demand which is available as interruptible load

Case Study

- Investment

$$\widehat{D}(n+\tau) = (1+r-e)^{\tau}.D(n)$$

$$S(n) = \max\{\widehat{D}(n+\tau) - \widehat{D}(n+\tau-1), 0\}$$

- Profit

$$\pi_j(n,t) = \Big(P(n,t) - B_j(n,t)\Big).Q_j(n,t)$$

$$\sum_{t=1}^{8760}(\pi_{new}(n+\tau,t) - G_{new}(n+\tau,t) * FC_{CCGT}) \geq 0$$

$$\sum_{j=1}^{m}\sum_{t=1}^{8760}(\pi_j(n+\tau,t) - G_j(n+\tau,t) * FC_j) \geq 0$$

Case Study (Results)

Comparison of the Performance of Different Demand-side Participation Scenarios in Two Market Designs

	Energy-only Market		Market with Capacity Payments	
	Interruptible Contracts hours	Outage hours	Interruptible Contracts hours	Outage hours
scenario 1	-	47.9	-	18
scenario 2	38.8	9.1	16.1	1.8
scenario 3	46.6	1.3	18	0.02

Values in the table represent the average number of hours per year for each case

- Scenario 1: No demand-side participation
- Scenario 2: 3% of total demand is interruptible load
- Scenario 3: 6% of total demand is interruptible load

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Case Study (Results)

Comparison of the Performance of Different Price Cap Scenarios in Two Market Designs

	Energy-only market	Market with capacity payments
	Outage hours	Outage hours
Scenario 4	137.1	29
Scenario 5	73.1	22.1
Scenario 6	47.9	18

Values in the table represent the average number of hours per year for each case

- Scenario 4: price cap = 3000 €/MWh (current price cap in German market)
- Scenario 5: price cap = 6000 €/MWh
- Scenario 6: price cap = 9000 €/MWh (Value of Lost Load)

Conclusion

- **Purpose:**
  - Solve supply security problem using characteristics of market competition instead of administratively determined capacity requirements
- **Effective Competition:**
  - Efficient Scarcity Prices
  - Active Demand Side Participation
  - Storage Facilities
  - Optimized Guaranteed Policies
- **Method:**
  - Multi Agent Modeling
    - Adaptive learning
    - Strategic decision making

<u>Thank you</u>