# Capacity Investments and Security of Supply

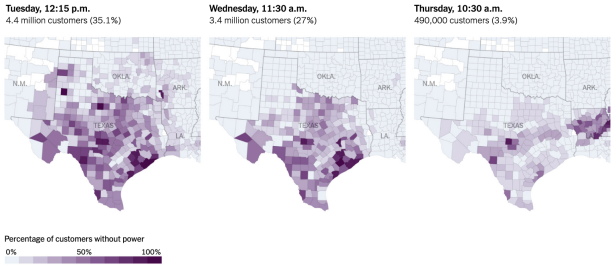
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CEMFI and CEPR

**CEMFI**

# The Texas Blackout (February 2021)

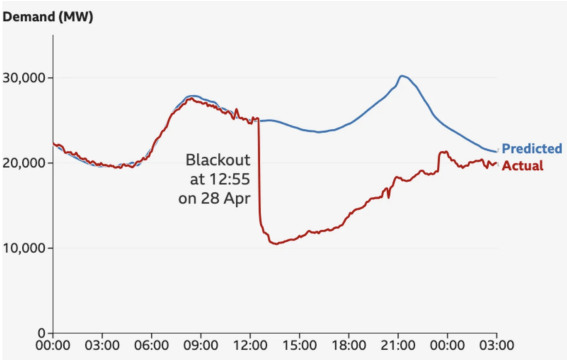
*"Power interruptions began on Sunday night, as Texas' grid operator sought to balance a surge in demand and a* **shortage of supply** *that followed an extreme drop in temperatures. Just as electricity use soared — with Texans looking to beat back the cold by* **turning up their heaters** *— the state lost a portion of its generating capacity. Some of the state's* **natural gas and coal plants were knocked offline** *by the cold, and icy conditions stymied* **wind turbines**, *too."*




Source: NYT

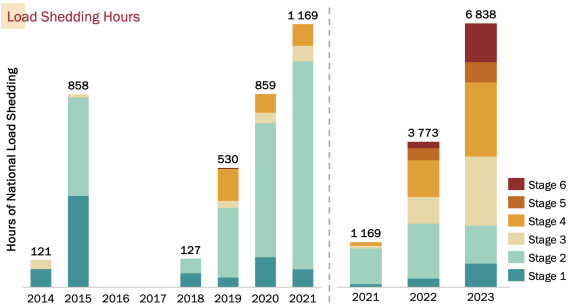
# The Spanish Blackout (April 2025)

*"Buildings were plunged into darkness, while* **mobile phones and traffic lights stopped** *working. Queues snaked around street corners and* **card payments failed**, *forcing people to queue for cash and cram on to buses as other transport systems were not running. Emergency workers were called to 286 buildings to free* **people trapped** *inside elevators in the Madrid region and hospitals implemented* **emergency plans**, *halting routine procedures."*



# Rolling Blackouts in South Africa (since 2017)

**Rolling blackouts in South Africa happen because there's not enough electricity to meet demand.** *A rolling blackout is a planned power outage that happens in specific areas for a set period of time when the demand for electricity exceeds the available supply. Unlike unexpected power failures caused by technical faults or bad weather, rolling blackouts are controlled and scheduled by the electricity provider.*




Source: Wikipedia

# Multiple potential causes of blackouts

- **Generation shortfall**: forced outages, low renewable output during peak demand, aging infrastructure.
- **Transmission issues**: line trips, congestion, interconnector failures...
- **Demand** surges beyond capacity (extreme temperatures, unexpected spikes).
- **System instability**: frequency/voltage collapse, cascading failures.
- **Fuel supply disruptions**: gas pipeline curtailments, coal shortages, low hydro inflows.
- Severe weather, natural hazards
- **Human error**, protection and control misoperations
- **Cyberattacks** or physical sabotage on grid assets.
- **Planned load shedding**/rolling outages to protect the system during shortages.

# With one common consequence: major negative externalities

- **Health and public safety risks** (hospitals, life-support devices, dark traffic signals).
- Disruption of **critical services** (water/wastewater, emergency response).
- **Communication and IT** outages (mobile networks, internet, data centers...).
- **Economic losses** (business downtime, lost production, reputation loss).
- **Transportation** disruptions (rail/air control systems, traffic lights, fuel pumps).
- **Residential impacts** (loss of heating/cooling, lighting, cooking, elevators...)
- **Supply-chain** and payment disruptions...

**Security of Supply is a Public Good**


Capacity Investments
and Security of Supply

# Electricity markets at a crossroads

- Massive deployment of renewables is needed for the low-carbon transition.
- Renewables depress wholesale prices.
- Profitability falls and risk rises for conventional technologies.

**Are the current arrangements well suited to induce adequate investments?**

"There is a need for unprecedented levels of investment to be sustained over many years, in difficult financial conditions and against a background of increased risk and uncertainty. Ofgem does not consider that leaving the current arrangements unaltered is in the interests of consumers." UK energy regulator Ofgem (2010)

# Regulatory Instruments: price versus quantity

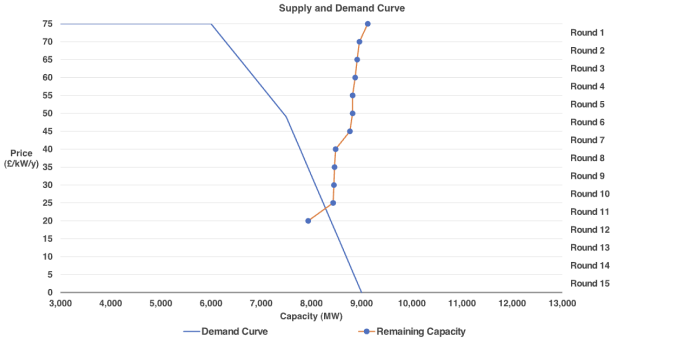
1. **Capacity Payments:** Regulator pays per unit of available capacity to encourage investment and reliability.
2. **Capacity Markets:** Regulator sets a capacity target (reliability standard) and runs auctions for new/existing capacity; demand response may qualify.

**A patchwork of solutions in practice:**

- **UK:** centralized capacity market
- **France:** decentralized capacity market
- **Germany:** strategic reserves
- **Italy & Ireland:** Capacity auctions

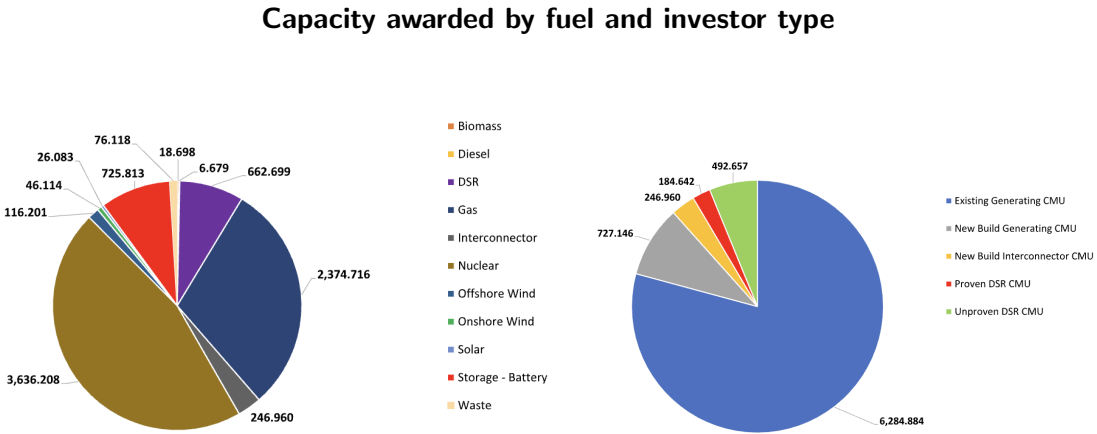
# UK Capacity Market: 2024 auction results

| | |
|---|---|
| Auction and Delivery Year | T-1 DY2025/26 |
| Date and time auction cleared | 05/03/2025 10:00 |
| Clearing Price | £20.00 |
| Aggregate Capacity of CMUs awarded Capacity Agreements | 7,936.289 MW |
| Target Capacity | 7,500 MW |
| Capacity entering auction and proportion awarded an agreement | 9,122.961 MW (86.99% awarded an agreement) |
| Number of CMUs awarded an agreement | 246 |
| Number of Parent companies awarded an agreement | 92 |
| Number of Applicant companies awarded an agreement | 135 |




Source: NESO

# UK Capacity Market: 2024 auction results



# Key research and policy questions

**What is the need, effect, and design of capacity mechanisms?**

- Needed to ensure security of supply?
- What is the impact of capacity payments on energy markets?
- How does market power in the energy market interact with capacity instruments?
- What is the optimal capacity target and policy instrument?
- Who should be paid: all plants or only new ones?
- How do market power concerns in capacity markets affect outcomes?
- What is the role of financial commitments?

# A simple model of capacity investment

Fabra 2018

**Firms, costs, and demand:**

- $n$ firms; zero marginal cost up to capacity $k_i$.
- Unit capacity cost $c > 0$.
- Demand $\theta \sim \text{Uniform}[0, 1]$; price-inelastic; price cap $P$.
- Consumers get gross utility $v \geq P$ per unit of electricity consumed.

**Timing of the game:**

1. Simultaneous capacity choices $(k_1, \ldots, k_n)$.
   - Choices observed; $\theta$ realized.
2. Simultaneous price offers (for entire capacity)
   - The market clears and payoffs are realized.

# First-Best capacity investment

- Total welfare is:

$$W(K) = v\int_0^K \theta \, d\theta + v\int_K^1 K \, d\theta - cK$$

- Taking the FOC of welfare maximization with respect to $K$:

$$\frac{\partial W}{\partial K} = v(1-K) - c = 0 \;\Rightarrow\; K^{FB} = \frac{v-c}{v} \;<\; 1.$$

- The solution strikes a balance: the value of consumption $v$ *vs.* the investment cost $c$
- Some rationing is optimal: $K^{FB} < 1$.

# The energy-only paradigm

**Assumptions:**

- free entry $\Rightarrow$ zero profits
- No market power $\Rightarrow$ prices=MC if excess capacity
- Profits = scarcity rents minus investment costs

$$\pi_i = P \int_{nk}^{1} k \, d\theta - ck$$

- In equilibrium, free entry and zero profits imply:

$$k^* = \frac{1}{n} \frac{P - c}{P} \;\Rightarrow\; K^* = nk^* = \frac{P - c}{P} \leq K^{FB}$$

- Price caps create under-investment.
- Removing price caps allows for efficient investment and maximum $CS$.

# Reasons why removing price caps need not maximize welfare

- **Involuntary rationing (blackout prob. $\gamma$):**

$$W = v\int_0^K \theta\, d\theta + (1-\gamma)\, v\int_K^1 K\, d\theta - cK.$$

$$K^{FB} = \begin{cases} 1, & \gamma \geq 1 - \frac{v-c}{v}, \\ \dfrac{1}{1-2\gamma}\left(\dfrac{v-c}{v} - \gamma\right), & \gamma < 1 - \frac{v-c}{v}. \end{cases}$$

# Other considerations

**Blackout cost $b$:**

$$W = v\int_0^K \theta\, d\theta + (v-b)\int_K^1 K\, d\theta - cK \Rightarrow K^{FB} = \frac{v-b-c}{v-2b} > K^*.$$

**Reputational cost $B$:**

$$W = v\int_0^K \theta\, d\theta + v\int_K^1 K\, d\theta - cK - B(1-K) \Rightarrow K^{FB} = \frac{v+B-c}{v} > K^*.$$

**Negative externality $e$:**

$$W = (v-e)\int_0^K \theta\, d\theta + (v-e)\int_K^1 K\, d\theta - cK \Rightarrow K^{FB} = \frac{v-e-c}{v-e} < K^*.$$

# Adding renewables

## Llobet and Padilla 2018

Available renewables $\alpha R$, $\alpha \sim G$.

$$W = v\int_0^1 \left[\int_0^{K+\alpha R} \theta \, d\theta + \int_{K+\alpha R}^1 (K+\alpha R)\, d\theta\right] dG(\alpha) - cK.$$

FOC:

$$\frac{\partial W}{\partial K} = v(1-K) - v\,\mathbb{E}[\alpha]R - c = 0 \;\Rightarrow\; K^{FB} = \frac{v-c}{v} - \mathbb{E}[\alpha]R.$$

- The more renewables there are, the less the need to invest in conventional capacity.
- If larger demands less likely: the more volatile $R$, the higher $K^{FB}$

$$\frac{\partial W}{\partial K} = v\int_0^1 \left(1 - H\left(K^{FB} + \alpha R\right)\right) dG\left(\alpha\right) - c = 0$$

- Previous result reinforced if negative correlation between $\theta$ and $R$.

# Equilibrium investment under market power

Fabra 2018

**Dominant firm-fringe model:** Fabra, von der Fehr, and Harbord 2006

- Firms $i = 2, .., n$ bid at marginal cost (capacity $k_F$)
- Firm $1$ maximizes profits over residual demand (capacity $k_1$)
- Energy market profits:

$$\pi_f = P \int_{k_F}^{1} k_f d\theta - ck_f, \text{ for } f = 2, ., n$$

$$\pi_1 = P \int_{k_F}^{k_F+k_1} [\theta - k_F] \, d\theta + P \int_{k_F+k_1}^{1} k_1 d\theta - ck_1$$

# Equilibrium investment

- **Dominant firm**: only benefits from capacity expansions when $\theta > K$

$$\frac{\partial \pi_1}{\partial k_1} = P\left[1 - K\right] - c$$

$$K^* = \frac{P - c}{P} \leq K^{FB}$$

- **Fringe firms**: $k_f \uparrow$ has additional effects
  - $(+)$ produces at capacity more often
  - $(-)$ greater incidence of MC pricing
    - In equilibrium, both effects cancel out: symmetric capacities

# Profits, Consumer Surplus and Welfare

- Profits = market power rents (scarcity rents = investment costs)

$$\pi_1^* = P \int_{(n-1)k^*}^{nk^*} [\theta - (n-1)\, k^*]\, d\theta > 0$$

$$\pi_f^* = \int_{(n-1)k^*}^{nk^*} k^* d\theta > 0$$

- Welfare maximized at $P^* = v$ [**caveats*]
- $CS$ maximized at some $P^* \in (0, v)$
  - trade-off greater consumption- higher prices

# Capacity Mechanisms

- Capacity payments: pay $sk$ regardless of firms' production.
  - **price regulation:** regulator sets $s$ and investors choose $K$
  - **quantity regulation:** regulator chooses $K$, and market sets $s$
- Investment cost net of capacity payments becomes $c' = (c - s)$,

$$K^* = \frac{P - (c - s)}{P} \Rightarrow s = c - (1 - K^*)\, P$$

- To induce $K^*$, pay firms investment costs net of scarcity rents
- To induce first-best capacity

$$K^{FB} = \frac{v - c}{v} \Rightarrow s = \frac{v - P}{v} c$$

- $s = 0$ when $P = v$ (i.e., no price cap)
- $s = c$ when $P = 0$ (prices capped at MC)

# The optimal policy: price-caps and capacity payments

- For given $P$, consumer surplus is maximized at

$$s^* = c - P\frac{(2n-1)\,P + cn^2}{(2n-1)\,P + vn^2}.$$

- $s^*$ is lower if market power: decreasing $P$ and increasing in $v$
- $s^*$ is higher if $K^{FB}$ higher: increasing in $v$
- If no price caps ($P = v$), charge an entry free $s^* < 0$
  - the energy-only market paradigm is sub-optimal ($P = v;\ s = 0$)
- **Optimal policy:** $s^* = c$ and $P = 0$ [**caveat: asymmetric info*]
  - But too much capacity $K = 1 > K^{FB}$: pay $s^*$ only up to $K^{FB}$

# Main Take-Aways

- Scarcity pricing is optimal *only* with free entry and no market power.
- Removing price caps empowers market power; externalities and blackout risks matter.
- Consumer surplus maximized via a mix of price caps and capacity payments.
- Demand response may reduce capacity needs—but evidence is evolving.

# References I


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