Making Resource Adequacy a Private Good: *The Good, the Bad and the Ugly*

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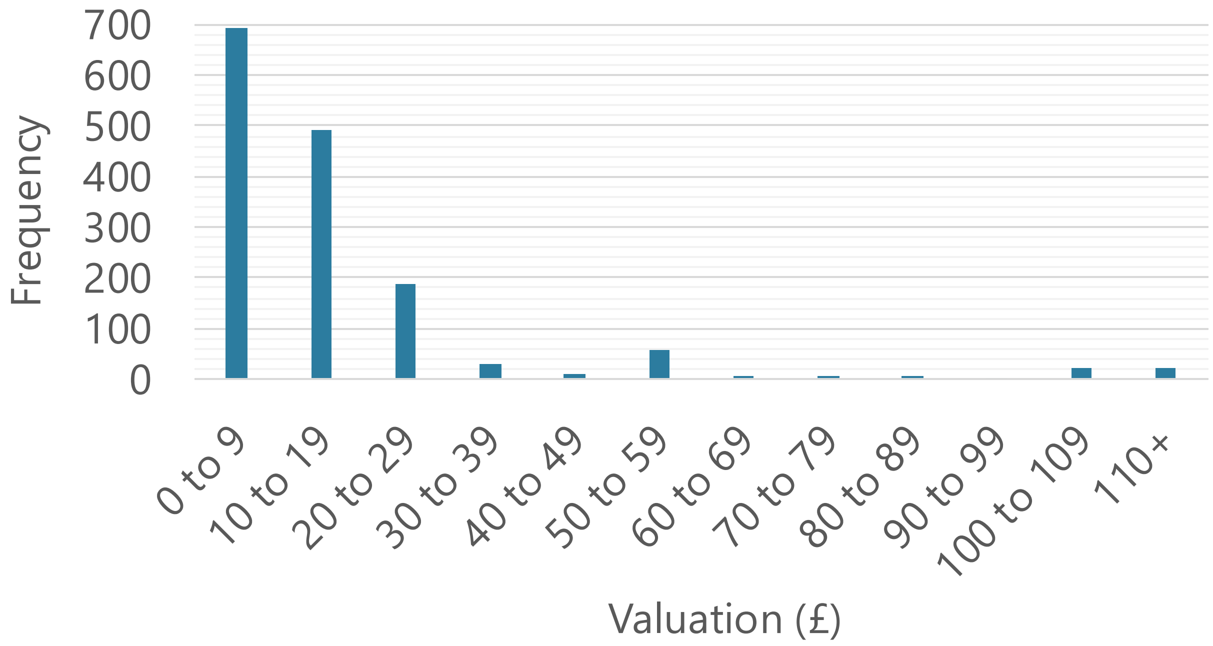
Question

How much would you be willing to pay to avoid a 1-hour blackout in winter?

West London 2015 blackout.
(The Standard, 2015)

Value of Lost Load (VoLL)

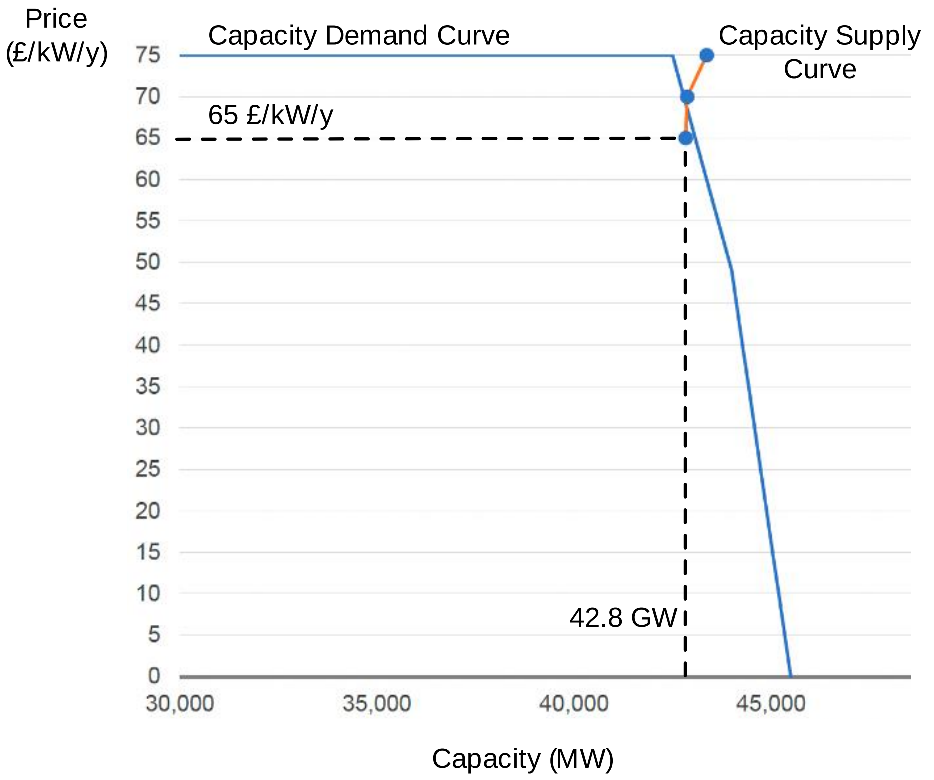
- Value of Lost Load (VoLL) estimates willingness to pay for security of supply
- Overall, average UK VoLL is estimated to be ~£16 per kWh
- Large variation between customers (even for a given outage duration and time of year)
- Example factors:
  - Residential vs. commercial
  - Life support equipment
  - Backup generation
- “Willingness to pay” vs. “ability to pay”



Payment to accept a 1-hour outage during winter from choice experiment with UK residential customers.
(London Economics, 2013)

Resource Adequacy in Great Britain

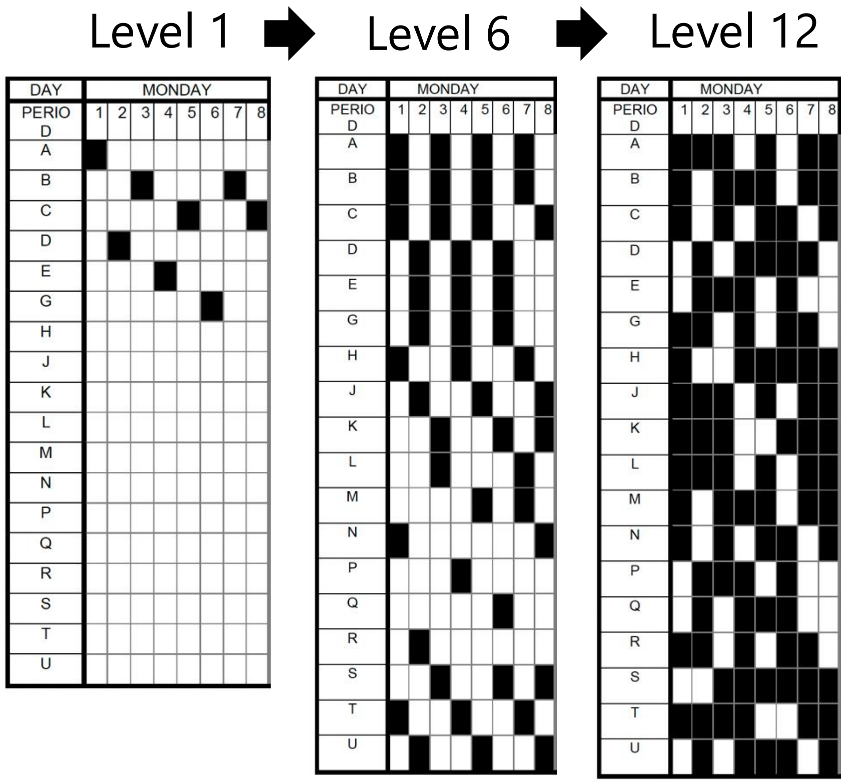
- Resource adequacy:
  - Measured by Loss of Load Expectation (LOLE) (Expected hours/year where Gen. < Dem.)
  - Key for security of supply (but not the whole story)
- VoLL + cost of (de-rated) generation → Target LOLE
- Capacity Market supports GB resource adequacy
  - LOLE target of 3 hours/year (99.97% reliable)
  - LOLE actually ~0.2 hours/year (99.998%)
- Upside: Very reliable system
- Downside: Customers pay for it



2023 4-year ahead capacity auction supply and demand curves. (National Grid ESO, 2024)

Drivers of Capacity Over-Procurement

- Factors contributing to capacity over-procurement:
  - Blackouts are high impact low probability events
  - New generation takes years to build
  - Electricity is used for safety critical systems
  - Asymmetric politics
    - Small upside vs. big downside
  - Demand reduction has traditionally relied on rolling blackouts
    - Blunt and disruptive



UK Electricity Supply Emergency Code Monday disconnection rota plans for 18 x 5% load blocks (3-hour intervals). (DESNZ, 2019).

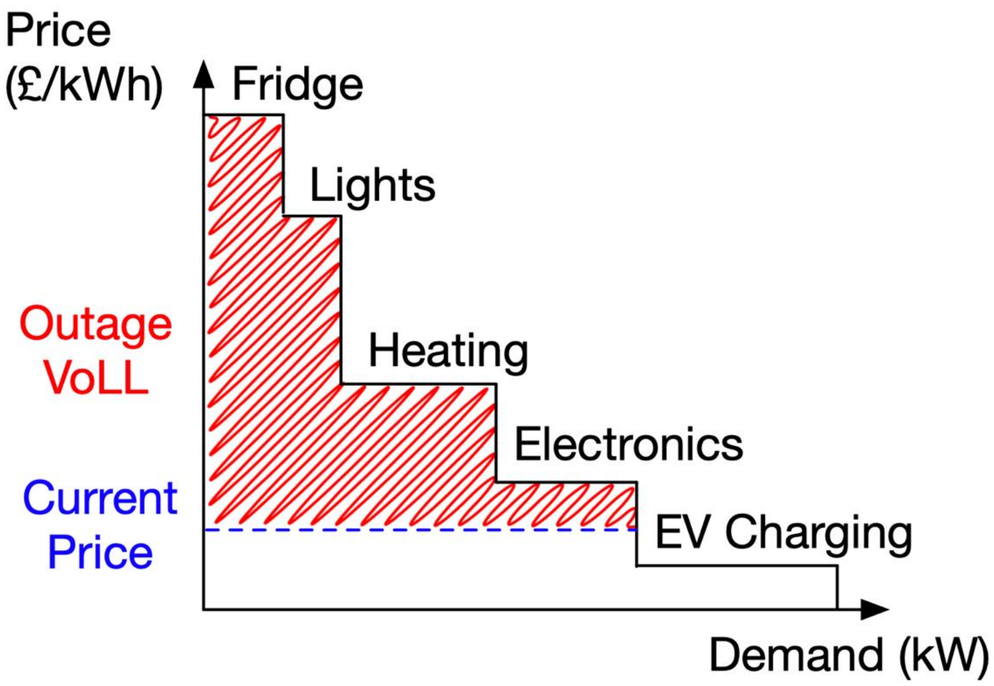
Conceptualising Resource Adequacy as a Common Pool Resource

- Energy traded in electricity markets:
  - Excludable and rivalrous → private good
- However, energy trading relies on grid stability
- If demand > generation capacity, we have grid instability and potentially a blackout
- Resource Adequacy can be considered a common pool resource:
  - Rivalrous since generation capacity is finite
  - Non-excludable since demand is not directly dispatched

	Rivalrous	**Non-Rival**
Excludable	Private Good (e.g. sushi)	Club good (e.g. software)
Non-Excludable	Common Pool Resource (e.g. fish stocks)	Public Good (e.g. national security)

Common-Pool Problems

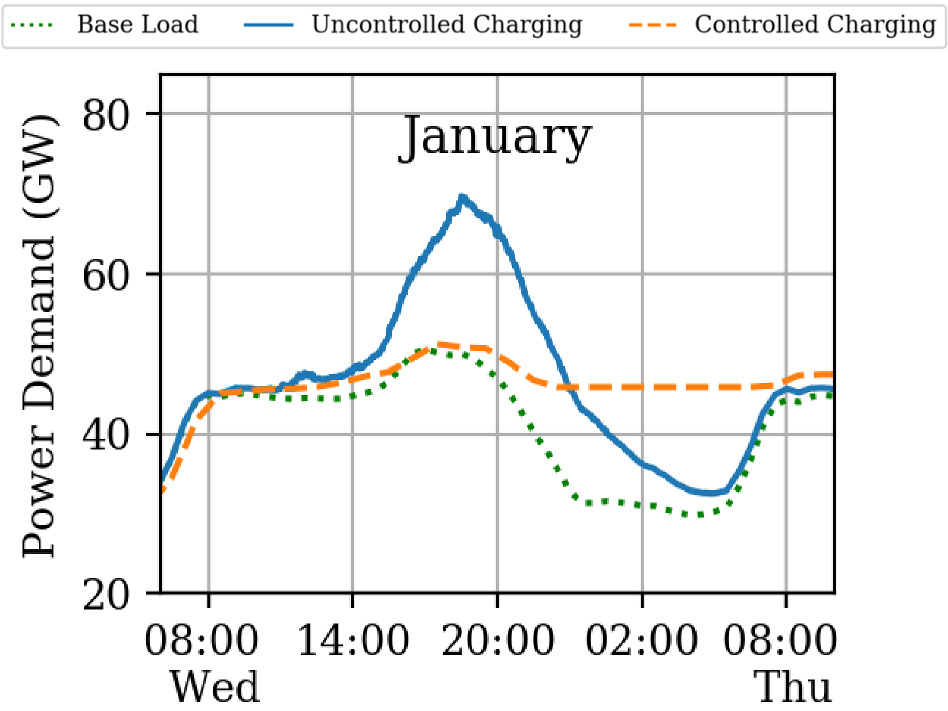
- Misaligned incentives:
  - Lack of incentives to limit demand when supply is constrained
- Single shared level of resource adequacy:
  - Customers with high VoLL have an incentive to defect from the grid
  - Customers with low VoLL pay unnecessarily high bills
- Rolling blackouts are a blunt tool:
  - Can only limit demand by shutting off entire distribution feeders
  - Doesn't account for individual customer demand curve and VoLL



Sketched example demand curve and VoLL for a customer at a particular point in time.

Exacerbated by Net-Zero

- Renewable generation:
  - More variable and less dispatchable
  - Geographically concentrated making network congestion more important
  - Lower average energy price
- Electrification of heating and transport
  - Increases peak demand
  - Potential for significant demand flexibility
- System costs driven by power capacity rather than energy production

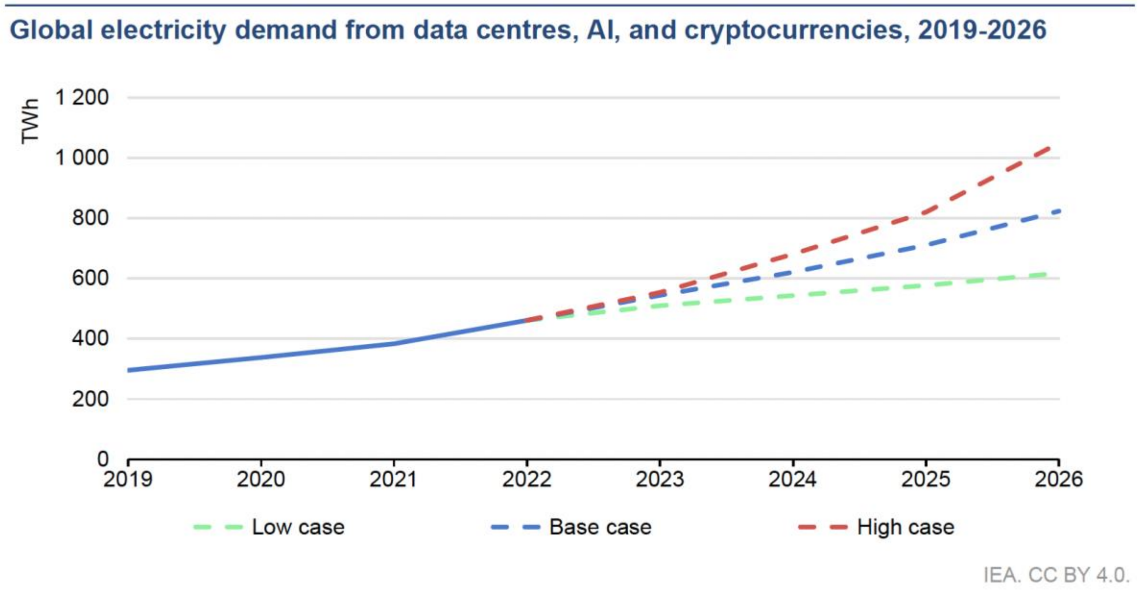


GB winter demand with a fully EV private vehicle fleet with & without controlled charging.

C Crozier, T Morstyn, MD McCulloch, "The opportunity for smart charging to mitigate the impact of electric vehicles on transmission and distribution systems" *Appl. Energy*, 2020

Emerging Challenge: AI Data Centres

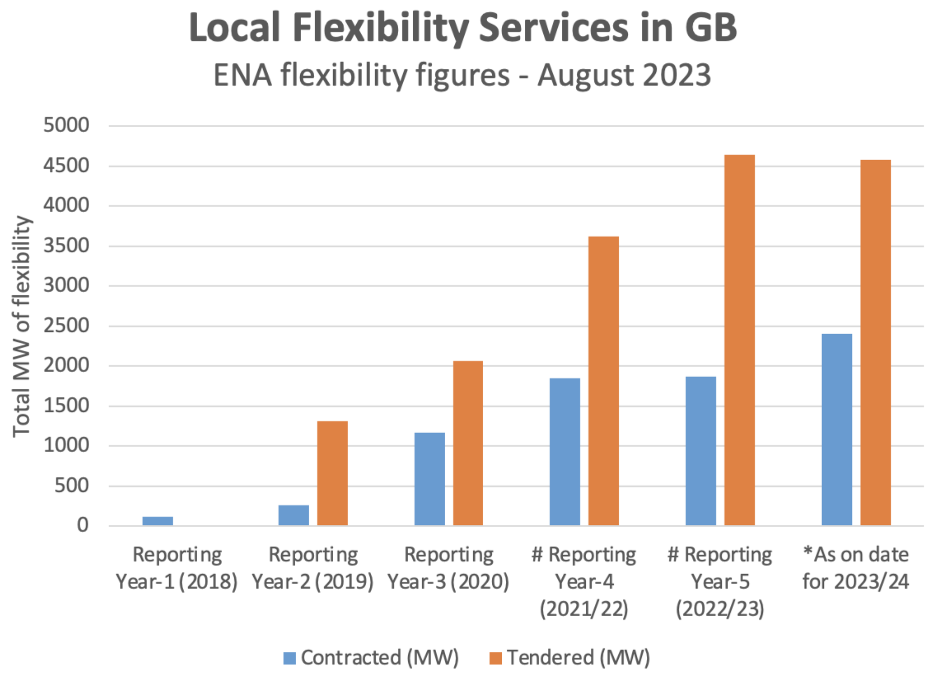
- Highly power intensive:
  - IEA projects data centres to double global electricity demand growth (to 3.4%) by 2026
- Requires high levels of reliability:
  - Tier 4 data centres have 96-hour backup power (battery + generator)
- It doesn't make sense for customers to subsidise data centre resource adequacy
- However, restricting data centre grid connections in the UK is likely to:
  - Reduce growth
  - Increase global emissions

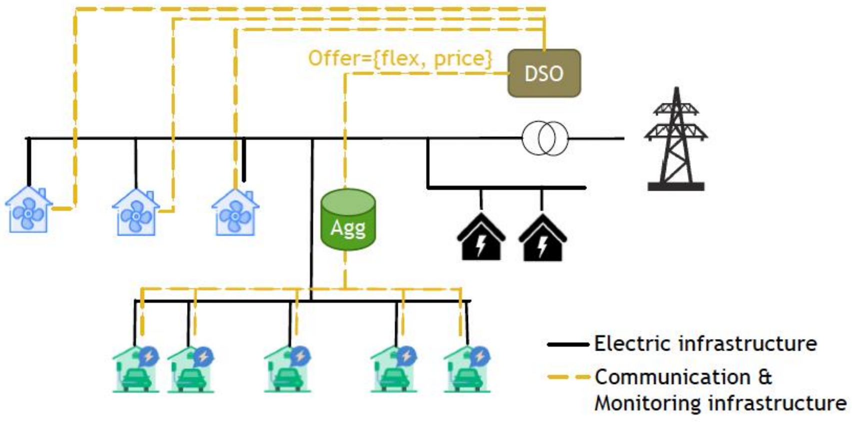


(IEA, 2024)

UK Demand Flexibility

- Developments in demand side flexibility:
  - Local scale: GB DNOs trialling local flexibility markets (2.5 GW contracted in 2023/24)
  - National scale: Demand Flexibility Service (DFS) included 2.2 million homes/ businesses in winter 2023/24 (~400 MW)
- However, these are optional and provide bonus payments on top of the retail market
  - Layered structure creates inefficiency
  - Challenging to accurately baseline demand and disincentivise non-delivery





Making Resource Adequacy a Private Good

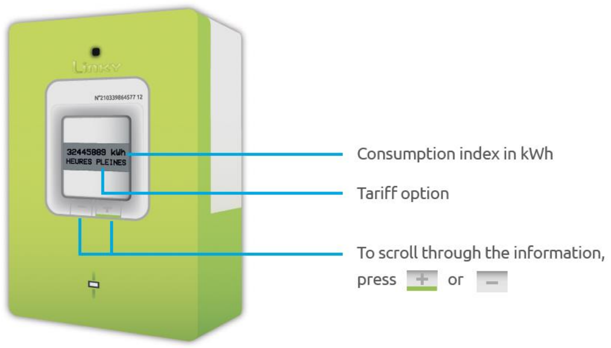
- Previously, resource adequacy was assumed to be non-excludable:
  - Customer demand assumed to be largely inflexible
  - Costly to implement customer-level control
- These assumptions no longer hold:
  - Rollout of grid-edge devices creates demand side flexibility
  - Grid digitalisation reduces implementation costs
  - Greater customer awareness of energy usage and flexibility

	Rivalrous	**Non-Rival**
Excludable	Private Good	Club good
Non-Excludable	Common Pool Resource	Public Good

Case Study: French Linky Meter Power Limit Reduction

- In France, Linky smart meters have a subscribed power limit (3 to 36 kVA) which is remotely adjustable
- A circuit breaker automatically trips above the subscribed power
- Enedis Power Reduction test:
  - 200,000 customers
  - Power limit reduced from 6 kVA to 3kVA for 2 hours during morning and/or evening peaks
  - Sufficient power for lights, refrigerator and computer
  - Reduced peak demand by 20%

Informations that you can directly access via your meter

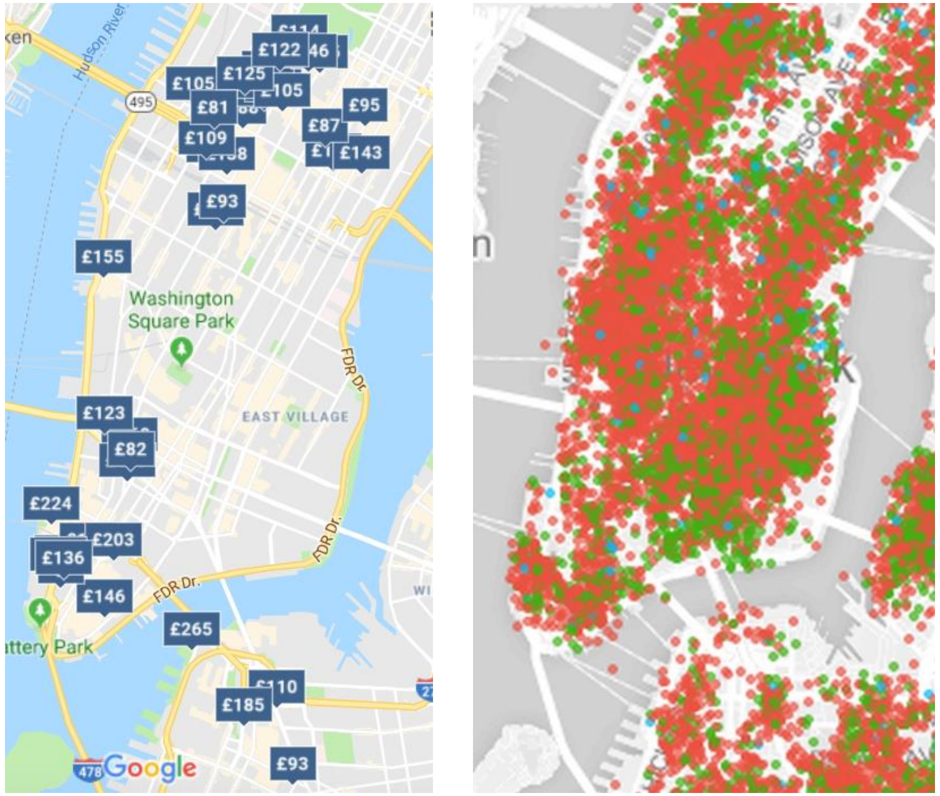


Below are some examples of the meter's dispay screens

BASIC CONTRACT TYPE **Type of contract:** This specifies the tariff option chosen as part ofyour electricity supply contract.	**12 kVA CONTRACTUAL POWER** **Contractual power:** The amount of power that you have subscribed to as part of your contract.
3252 VA APP POWER **Apparent power:** The power used at the time of consultation.	**8647 VA MAX POWER** **The maximum power reached during the day, at the time of the reading** (re-started at midnight each day).

Digitalisation Can Enable Smarter Excludability

- Grid digitalisation includes:
  - Smart meter rollout (35 million)
  - Home energy management systems
  - Flexibility aggregation
  - Automated grid dispatch
- Reduces transaction costs for:
  - Near real-time customer-level monitoring
  - Understanding complicated preferences
  - Contract automation
  - Integration into grid control systems



Manhattan Hotels vs Airbnbs. (insideairbnb.com)

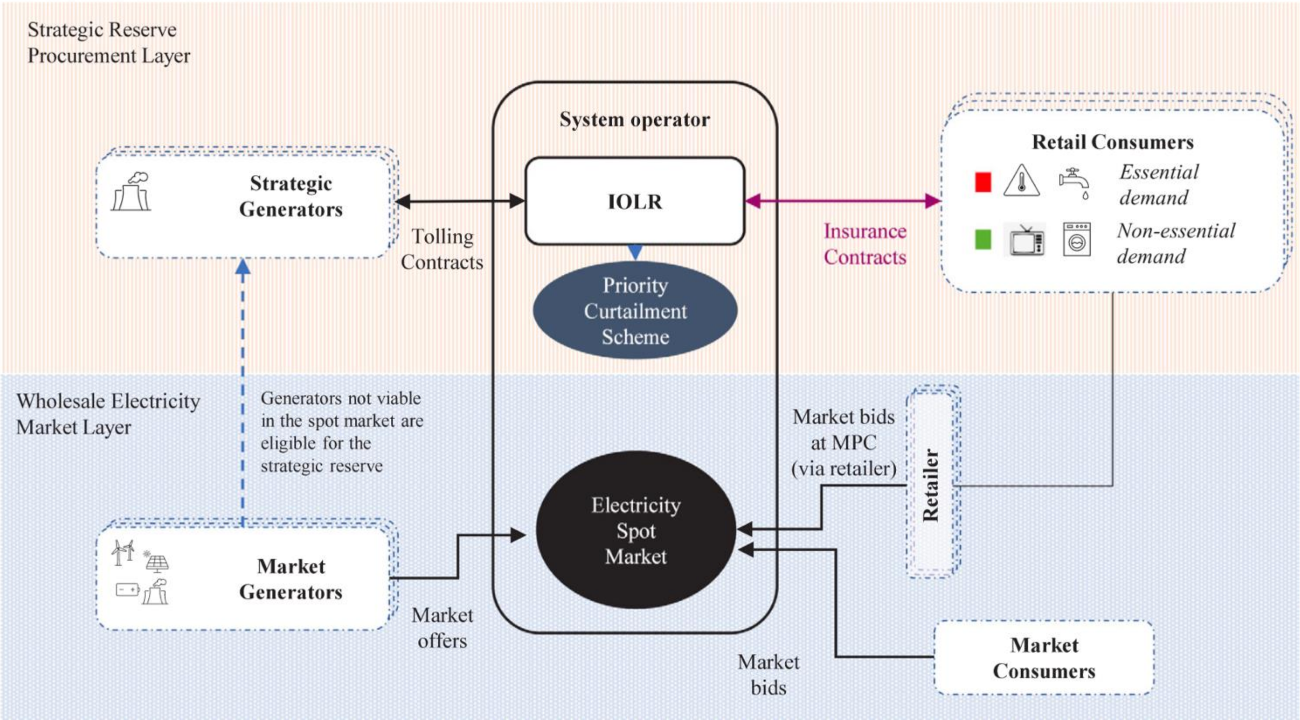
Consensus on “Essential Demand” is Important

- Electricity is considered essential for human wellbeing
- This motivates guaranteed provision of a minimum “essential demand”
- Definitions and targets for “essential demand” vary considerably
- Most definitions focus on energy
- However, for a net-zero system, minimum *power capacity* and *reliability* during peak periods may be more important for cost

Organisation	Concept	Target
International Energy Agency	SDG7 modern energy access (urban) threshold	100 kWh per person per year
Energy for Growth Hub	Modern Energy Minimum	1,000 kWh per person per year (300 kWh household usage)
New Economics Foundation	National Energy Guarantee	2,100 kWh household electricity per year (assuming gas heating)

Market Design: Electricity Reliability Insurance

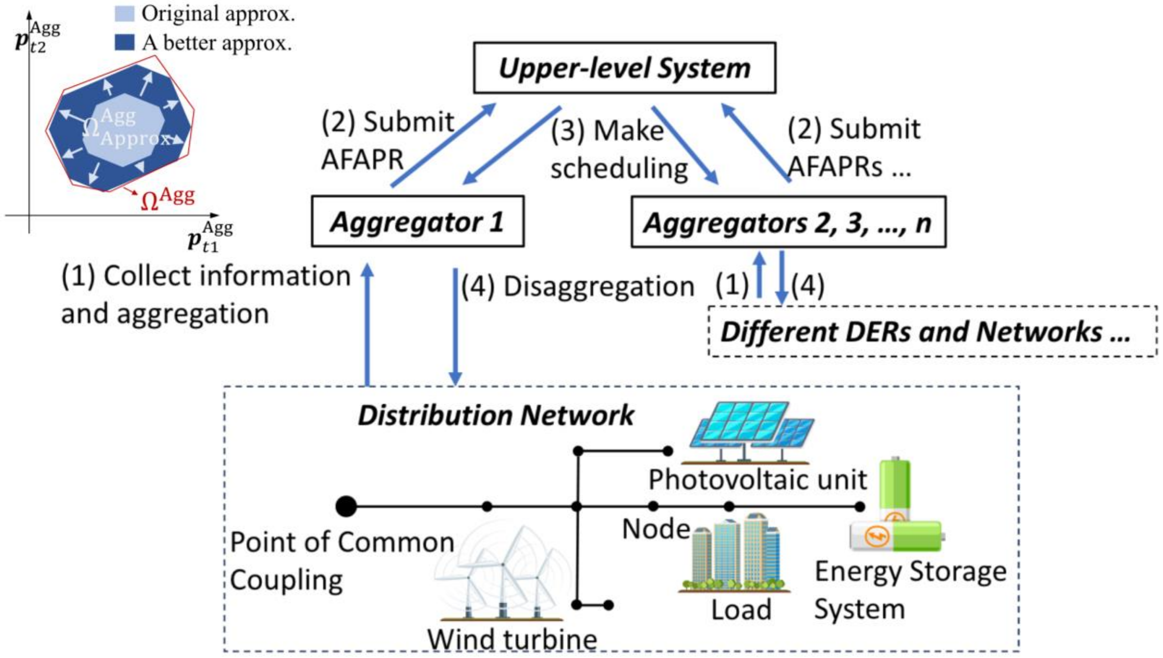
- Energy + Reliability Insurance:
  - Consumers can buy "reliability insurance" with a payout for interruptions
  - Appliance-level contracts can capture detailed demand curves and VoLLs
  - Insurer is incentivised to invest in strategic reserves to reduce outage risk
  - Insurer manages priority load curtailment scheme during emergency conditions



F Billimoria, F Fele, I Savelli, T Morstyn, MD McCulloch, "An insurance mechanism for electricity reliability differentiation under deep decarbonization" *Applied Energy*, 2022.

Robust Aggregation of Demand Side Flexibility

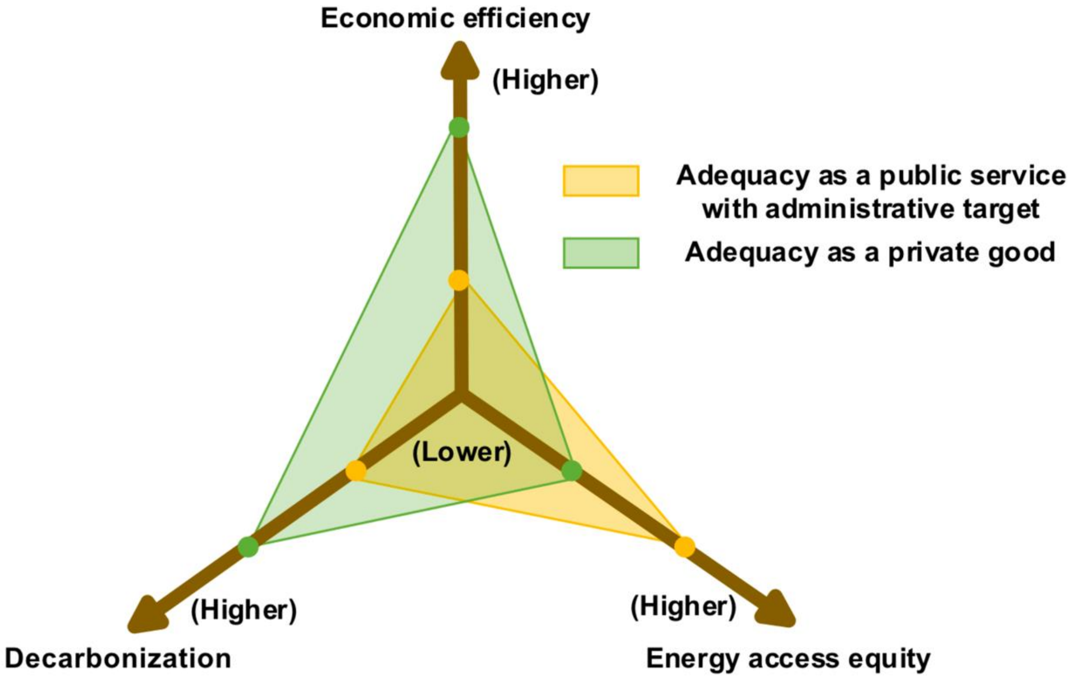
- To contribute to resource adequacy, aggregated flexibility must be dependable
- Available flexibility is time-coupled and has multiple sources of uncertainty:
  - Weather dependence
  - Behaviour dependence
  - Network constraint dependence
- Proposed approach:
  - Data-driven jointly reliable *probabilistic virtual battery* model
  - Can be integrated into chance constrained grid dispatch strategies with probabilistic guarantees



Y Zhou, C Essayeh, T Morstyn, "Aggregated Feasible Active Power Region for Distributed Energy Resources with a Distributionally Robust Joint Probabilistic Guarantee" *IEEE Trans. Power Systems*, 2024

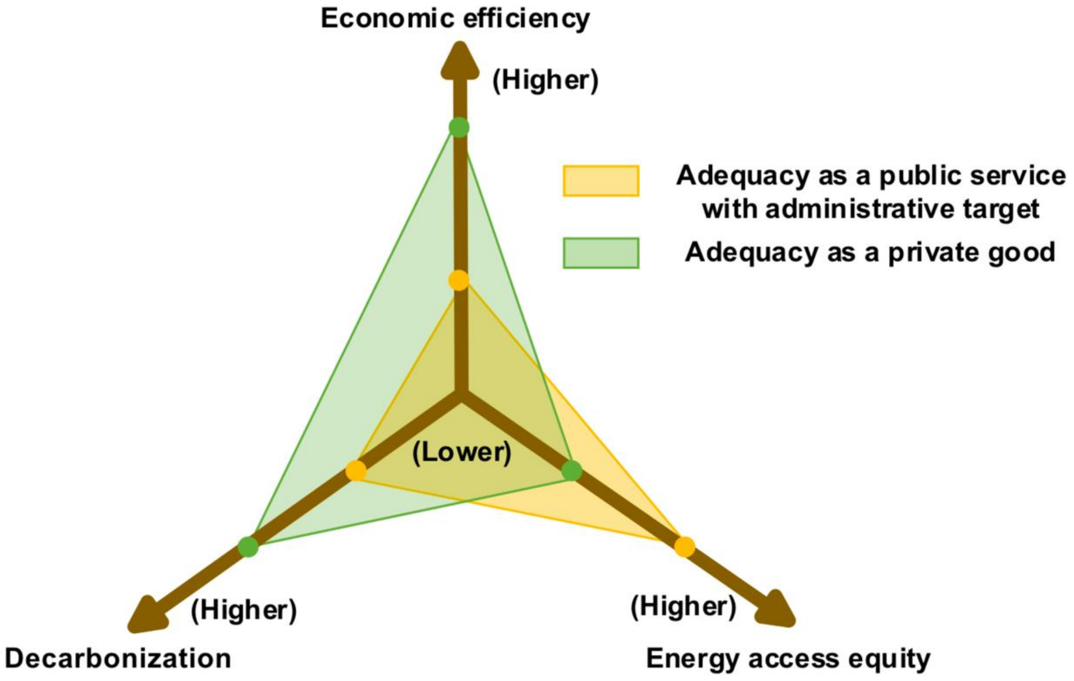
Economic and Net-Zero Benefits

- Economic benefits:
  - Prioritises emergency demand reduction based on value
  - Reduces bias towards over-procurement of capacity
  - Reduces incentive to over-use resource adequacy
- Net-Zero benefits:
  - Incentivises demand flexibility
  - Incentivises demand efficiency



Challenges and Ethical Considerations

- Fair or unfair?
  - Less equitable energy access
  - More cost reflective energy bills
- Defining a socially acceptable level of essential demand:
  - Likely to be contentious
  - Should vary by location, housing etc
- Detailed customer demand curves and VoLLs require privacy safeguards



Conclusions

- Paper: X Ren, I Savelli, T Morstyn, "Making Resource Adequacy a Private Good: The Good, the Bad and the Ugly" *Joule*, 2024.
- Resource adequacy is important for net-zero:
  - System costs increase exponentially towards 100% reliability
  - Costs are increasingly being driven by firm power capacity (instead of energy production)
  - Grid flexibility is moving from supply to demand
- Electricity markets govern the economic flows and technical operation of the power system:
  - Always heavily designed and regulated
  - Digitalisation provides a new toolbox for market design

Thanks!

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