Energy storage and demand-side scheduling coordination in electricity markets

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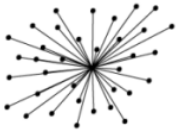
Energy storage

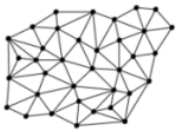
- Growing family of technologies
- Could provide numerous electricity system services to different agents
- Arbitrage could reduce electricity price peaks
- Recognised as one of ‘Eight great technologies’ by the UK
- EES is a net consumer of electricity

Who should control storage?

As consumer generation and storage capacity increases, demand-side coordination can have profound impacts on electricity prices



Centralized: The SO controls consumers' storage



Distributed: Private users control their own devices

Previous work & gaps

Electricity system value of storage

- Carbon Trust (2012, 2016)
- Pudijanto et al. (2014)

Consideration of **consumer types** – load profiles have crucial impact on demand; thermal storage is the most abundant form of ES

Scheduling coordination > electricity prices

- Jia and Tong (2016)
- He at el. (2012)

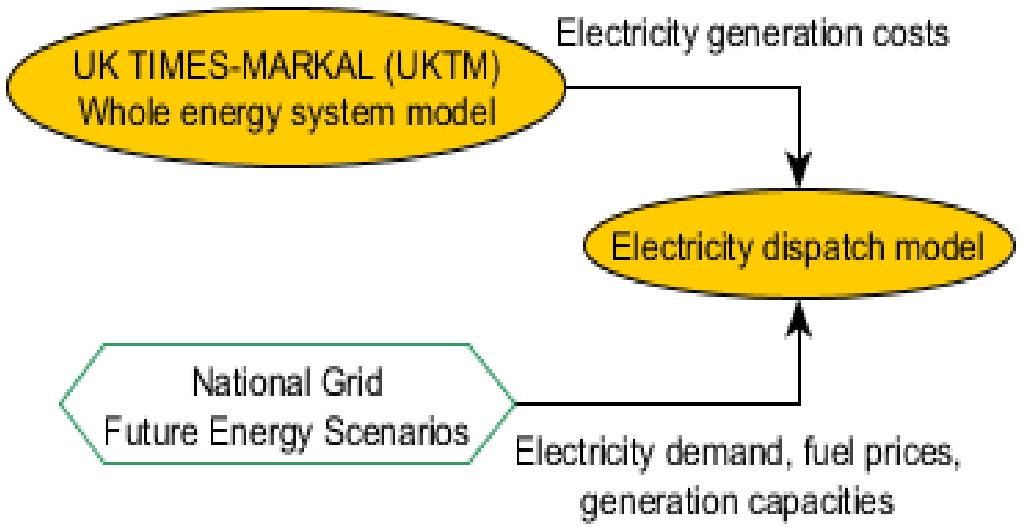
Whole-systems view – impact on electricity prices must be based on holistic framework

Research questions

- What is the impact on wholesale electricity prices of **centralized/distributed demand-side coordination**?

- How do different **consumer types** (commercial, domestic, industrial) affect savings from storage in these coordination regimes?

Methods



Time period: 2015-2040, UK

National scenarios

Prosperity (+ / −)

Consumer Power

Economic – moderate economic growth

Political – government policies focus on indigenous security of supply and carbon reduction

Technological – high innovation focused on market and consumer needs. High levels of local generation and a mixture of generation types at national level

Social – consumerism and quality of life drives behaviour and desire for 'going green', not a conscious decision

Environmental – Long-term UK carbon and renewable ambition becomes more relaxed

Gone Green

Economic – moderate economic growth

Political – European harmonisation and long-term environmental energy policy certainty

Technological – renewable and low carbon generation is high. Increased focus on green innovation

Social – society actively engaged in 'going green'

Environmental – new policy intervention ensuring all carbon and renewable targets are achieved

No Progression

Economic – slower economic growth

Political – inconsistent political statements and a lack of focus on environmental energy policies

Technological – little innovation occurs in the energy sector with gas as the preferred choice for generation over low carbon

Social – society is cost conscious and focused on the here and now

Environmental – reduced low carbon policy support and limited new interventions

Slow Progression

Economic – slower economic growth

Political – European harmonisation, focus on low cost environmental energy policies

Technological – medium levels of innovation lead to a focus on a mixture of renewable and low carbon technologies

Social – society is engaged in 'going green' but choices are limited by cost

Environmental – new policy interventions are constrained by affordability

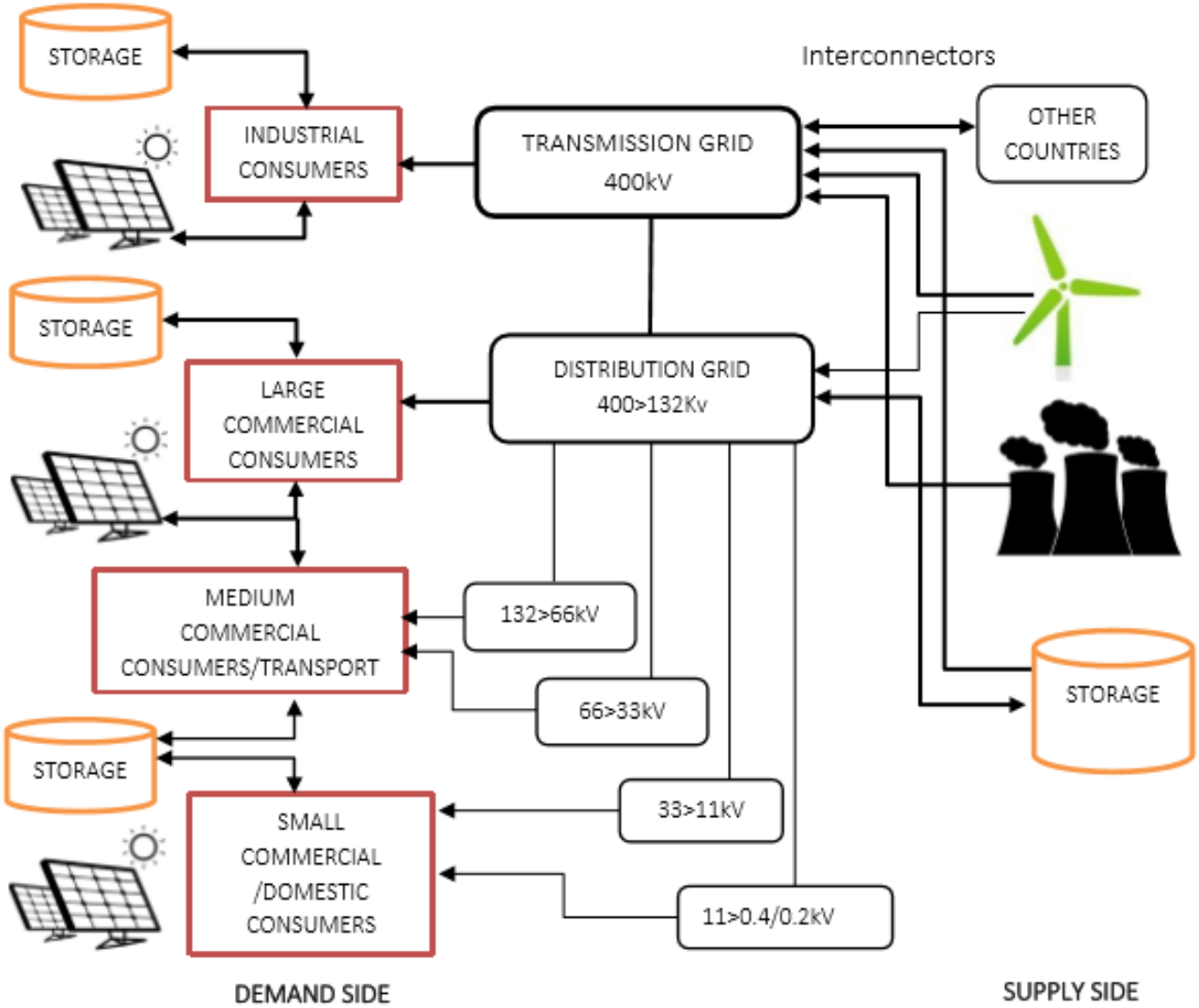
Green ambition (− / +)

Methods

- Consumers have access to flexible demand resources (incl. EES, heat pumps, thermal stores)

- We also model transport

Methods


STORAGE
INDUSTRIAL CONSUMERS
STORAGE
LARGE COMMERCIAL CONSUMERS
MEDIUM COMMERCIAL CONSUMERS/TRANSPORT
STORAGE
SMALL COMMERCIAL /DOMESTIC CONSUMERS
TRANSMISSION GRID 400kV
Interconnectors
OTHER COUNTRIES
DISTRIBUTION GRID 400>132Kv
132>66kV
66>33kV
33>11kV
11>0.4/0.2kV
STORAGE
DEMAND SIDE
SUPPLY SIDE

Coordination

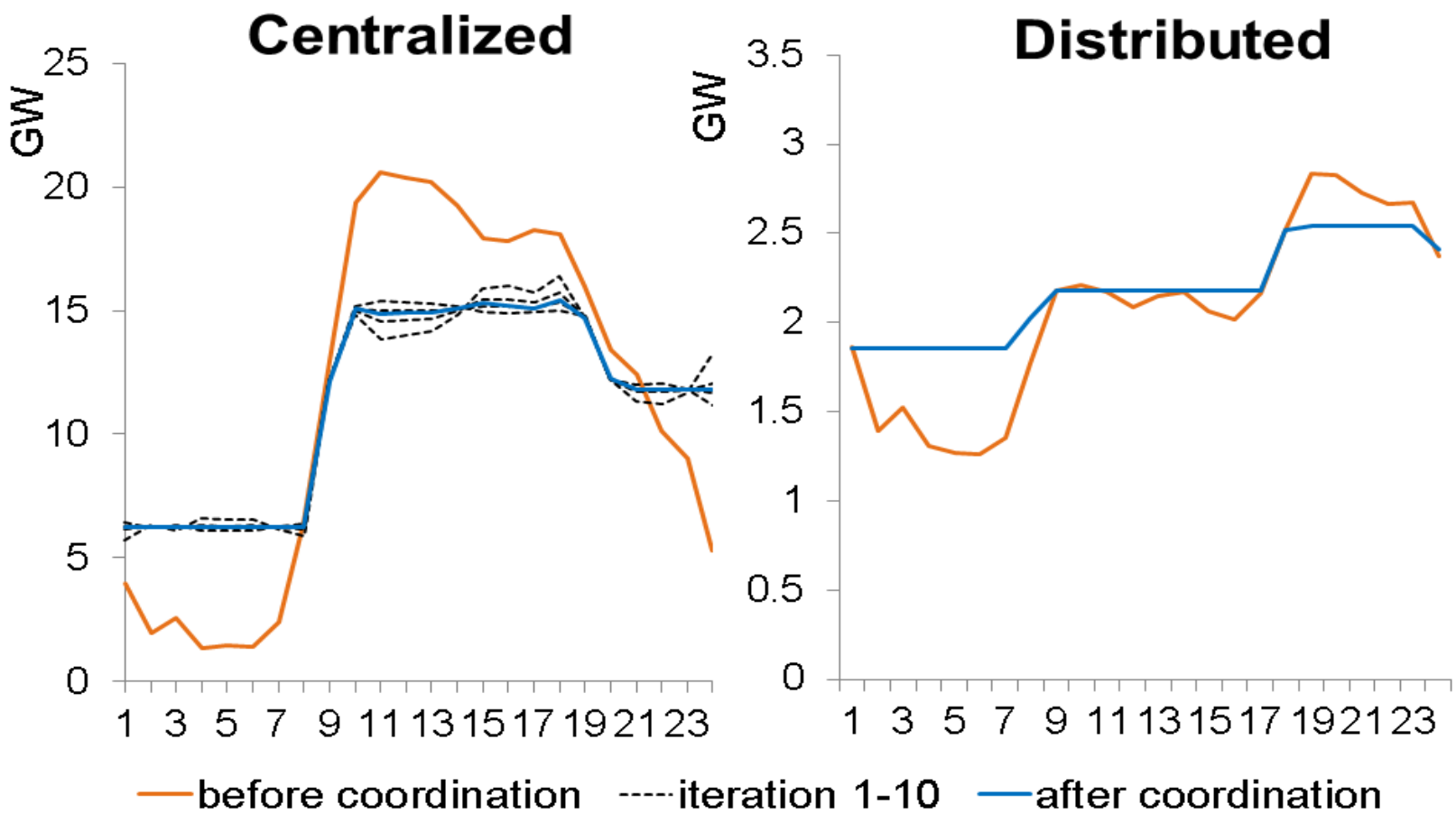
Centralized – *the SO uses consumer storage to smooth system demand*

$$\min \sum_{t=1}^{T} L_{net}(t,d) \cdot p(t,d)$$

Distributed – *consumer storage is operated individualistically to smooth own demand*

$$\min \frac{1}{T} \sum_{t=1}^{T} \left(l_{net}^{a}(t,d) - \frac{1}{T} \sum_{\tau=1}^{T} l_{net}^{a}(t,d) \right)^2$$

Electricity demand & coordination



Paying consumers to control their storage devices

We aim to find the SO's maximum willingness to pay domestic, commercial, and industrial consumers for controlling their storage device.

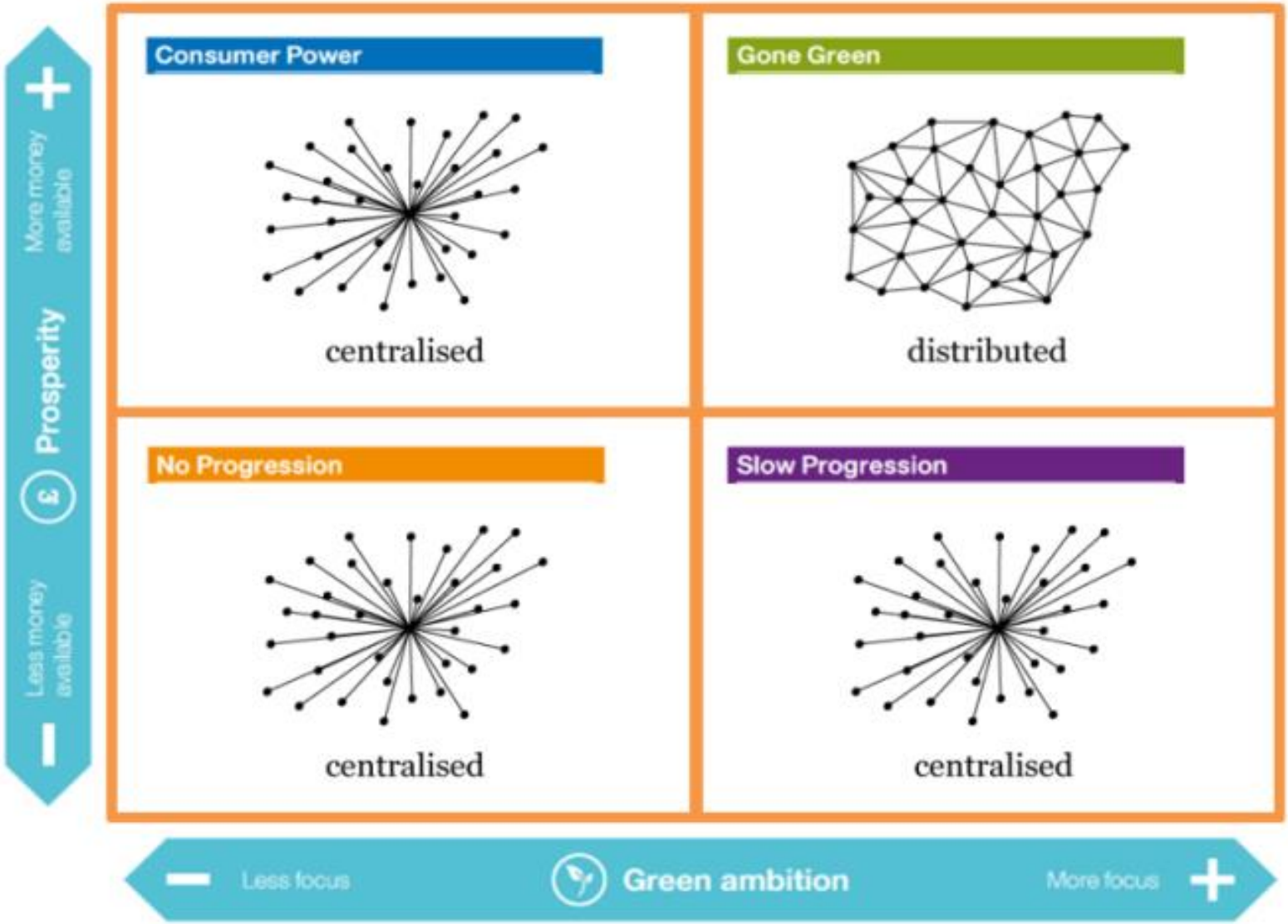
$$\omega_t(i) = \lambda_t^c(i) - \lambda_t^d(i)$$

$$\Gamma_t(i) = \frac{\omega_t(i)}{S_t(i)}.$$

This will depend on the difference between savings under each coordination regime and the ability of each consumer to store electricity.

Results

Savings per unit of storage capacity



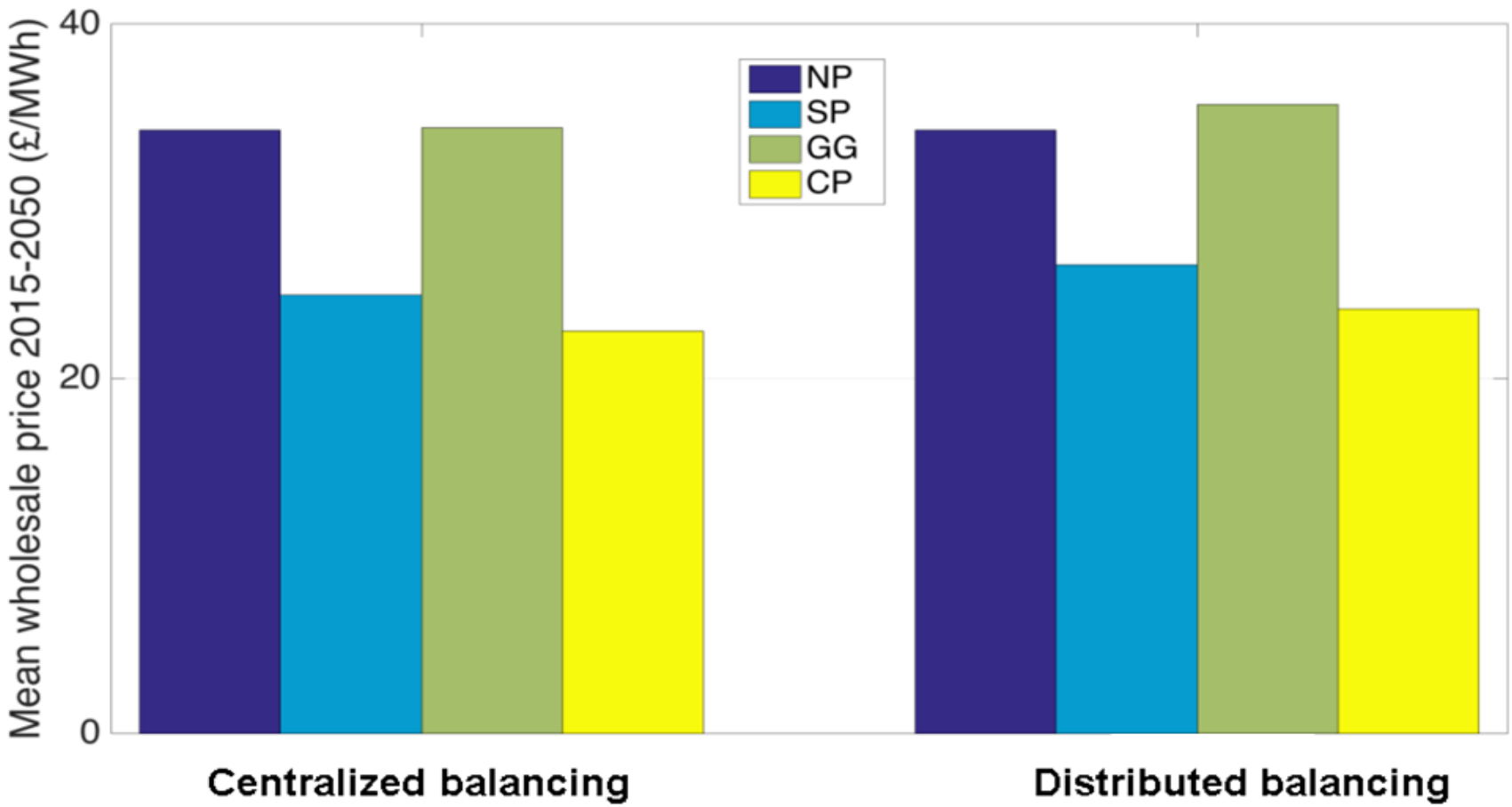
Savings per unit of storage capacity

Coordination	Gone Green (GG)	Slow Progression (SP)	Consumer Power (CP)
Storage savings in distributed relative to centralized case (%)	59	-102	-82

Wholesale prices

Balancing coordination	Mean electricity price (£/MWh)			
	NP	GG	SP	CP
Centralized	34	24.7	34.2	22.7
Distributed		26.4	35.5	23.9

Wholesale prices



Max control payment (£/MWhs)

Based on excess system savings in centralised over distributed scenario

Consumer type	GG	SP	CP	Mean
Domestic	20.4	311.4	30.7	**120.8**
Commercial	13.6	15.5	11.2	**13.4**
Industrial	8.4	5.7	6.8	**6.9**

Domestic users require a larger payment to give away control of their technology compared to others because they display the largest savings in the centralised over the distributed case per unit of storage.

Discussion

- Cost of electricity decreases with coordination
- But coordination means lower private utility from a unit of storage
- Consumers' storage benefits the system differently
- The SO should be willing to pay different consumers differently to control their technology
- Smart meters and new aggregation algorithms could enable scheduling algorithms that jointly minimise private and public electricity costs
- Limitations and future work

Conclusions

- **Electricity prices** are considerably higher under distributed coordination
- Distributed coordination provides higher electricity system **savings** only under high economic prosperity and green ambition
- **SO should pay consumers for using their devices** in a way that benefits the entire system because it reduces their private savings potential
- **SO should be prepared to pay** domestic users the most because they produce largest system savings/MWs if their storage is centrally operated

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