



Conceptualising Spatial Flexibility

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ECEEE Summer Study

Jose Ramirez-Mendiola
University of Reading



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Energy Demand Research Centre



- 5-year research centre
- Team of ~100 people from 12 UK universities
- 5 core research teams:

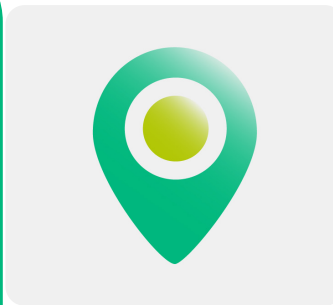


Futures

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Flexibility



Place



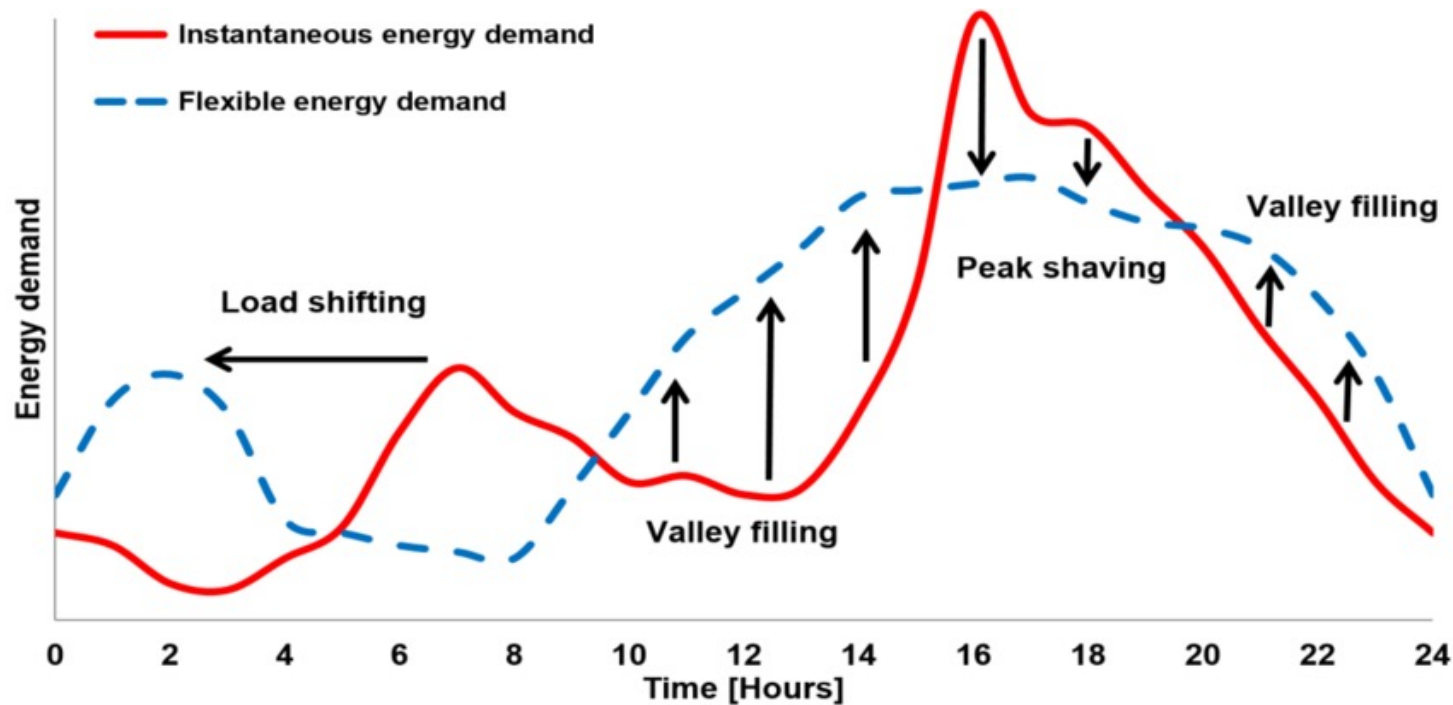
Governance



Equity

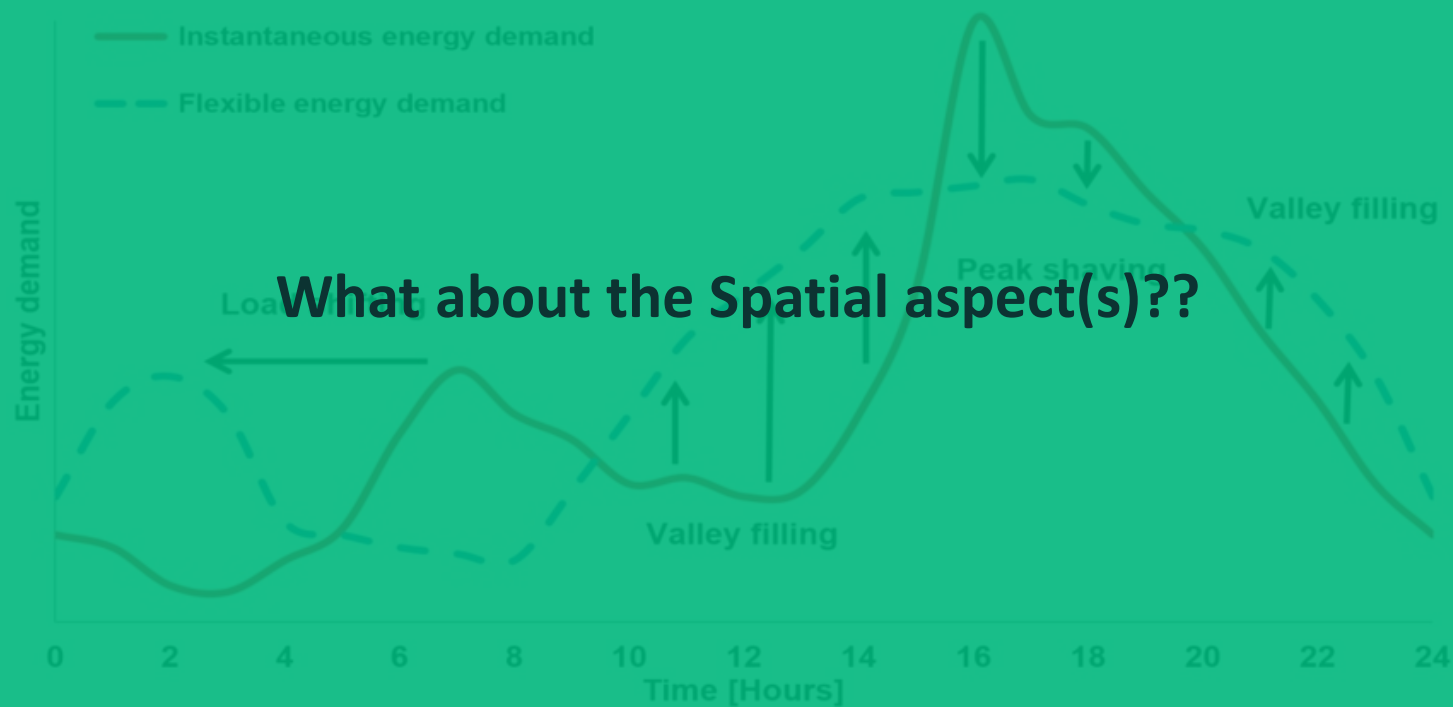
Energy demand flexibility...

what's the first thing that comes to mind?



Energy demand flexibility...

what's the first thing that comes to mind?



What about the Spatial aspect(s)??

Once upon a meeting...



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Dear Aruna,

First of all, thank you for hosting us at Imperial. I have been amazing. Secondly, I would like to share some of the things that Meysam and I discussed during our Hyde park excursion, regarding Spatial Flexibility, the Financial value, and the financing of it. In terms of spatial flexibility, we both agreed in that it is necessary to make a distinction between locally available and required flexibility, and on the other hand, the flexibility in terms of shifting demand to different regions or parts of the network. An obvious area to explore in this regard is the potential for the use of data centre coordination to distribute the load across a region, nation, or even beyond. Another one is a tighter integration of the Power-to-Gas plant across the network so that we are able to address not only the spatial flexibility issues raised, but also the temporal flexibility across longer timescales such as weekly, monthly and seasonal flexibility. Regarding the financial value, we also recognised that there is lots to do in terms of understanding the valuation procedures for demand reductions, as well as the valuation of additional benefits of flexibility such as reduced need for reinforcements and new infrastructure.

In terms of attention to infrastructure through energy services, previous times. For capital on and

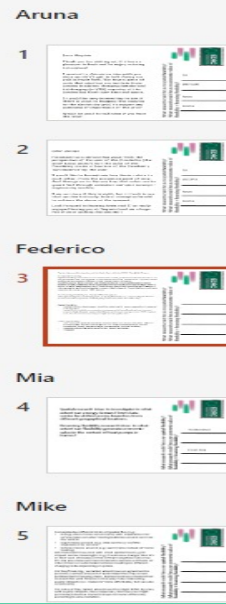
What research could focus on spatial flexibility?
What research could focus on economic value of flexibility + financing flexibility?

To: Aruna

Imperial College

From: Jose

University of Reading



Spatial flexibility

Thoughts on a possible concept paper

Work on demand flex tends to focus on temporal aspect – when electricity is used

Changing place of interaction with electricity system can have similar benefits for system management, but is under-conceptualised

What are the different ways in what spatial flexibility can be enacted? And what are the implications of enacting it in these different ways?

A helpful way to begin to break this down is to think about what changes spatially for (a) interaction with the grid, and (b) delivery of service.

For example

- Service/interaction concentration: Instead of heating many separate spaces (e.g. houses), people come together at times to a shared space (e.g. warm hub) and share in the energy service provided. The elec use is also shifted accordingly from the individual dwellings to the shared space.
- Service stays in same place, interaction point differs: A car parked in the same driveway could conceivably charge at different places without moving, with different consequences for grid interaction. E.g. at their own chargepoint, at a neighbour with solar panels' chargepoint, at an on-street charging point.
 - A subcategory of above – it would also be possible to move storage around spatially, e.g. delivering charged battery to the EV on the drive
- Service moves around, interaction moves around: An EV charging at home or at work.

A collective effort

The team:

- Mike Fell (UCL)
- Jacopo Torriti (Reading)
- Jacek Pawlak (Imperial)
- Shahab Dehghan (Newcastle)
- Hui Yan (Birmingham)
- Han Wang (Imperial)
- Ren Kang (Reading)
- Maria Wood (UCL)
- Yuerong Zhang (UCL)
- Meysam Qadrdan (Cardiff)
- Aruna Sivakumar (Imperial)

OUTLINE

- Rationale for conceptualising spatial flexibility
- What do we mean by spatial flexibility?
- Typology: breaking down spatial flexibility
- Scales of spatial flexibility
- Potential value of spatial flexibility & opportunities
- Barriers to spatial flexibility
- Policy implications

Rationale: Conceptualising spatial flexibility



- Most academic research, policy, and industry focus on temporal aspects of flex – shifting grid interaction in time
- Spatial flexibility – shifting the **location** of grid interactions – either implicit or simply ignored
- There are important conceptual considerations within spatial flexibility that have not been clearly expressed – e.g. difference between an EV charging in different locations, and running a digital process at different data centres
- Spatial flexibility can increase the overall cost-effectiveness of demand flexibility by providing options when temporal flexibility is unavailable, or when it is more effective/efficient/cheaper than temporal alternatives

What do we mean by Spatial Demand Flexibility?



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- **A definition:** Spatial flexibility is the **intentional adjustment of the geographical location of electricity consumption** to resolve localised grid issues, enhance system resilience, and improve overall energy system efficiency and equity.



While traditional flexibility focuses on the temporal aspect (*when* electricity is used), spatial flexibility addresses the **geographical dimension** (*where* users engage with the electricity system)

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- **Conceptual Shift:** It requires viewing energy demand not as a fixed, local burden tied to a specific meter, but as a **mobile, system-wide resource**.

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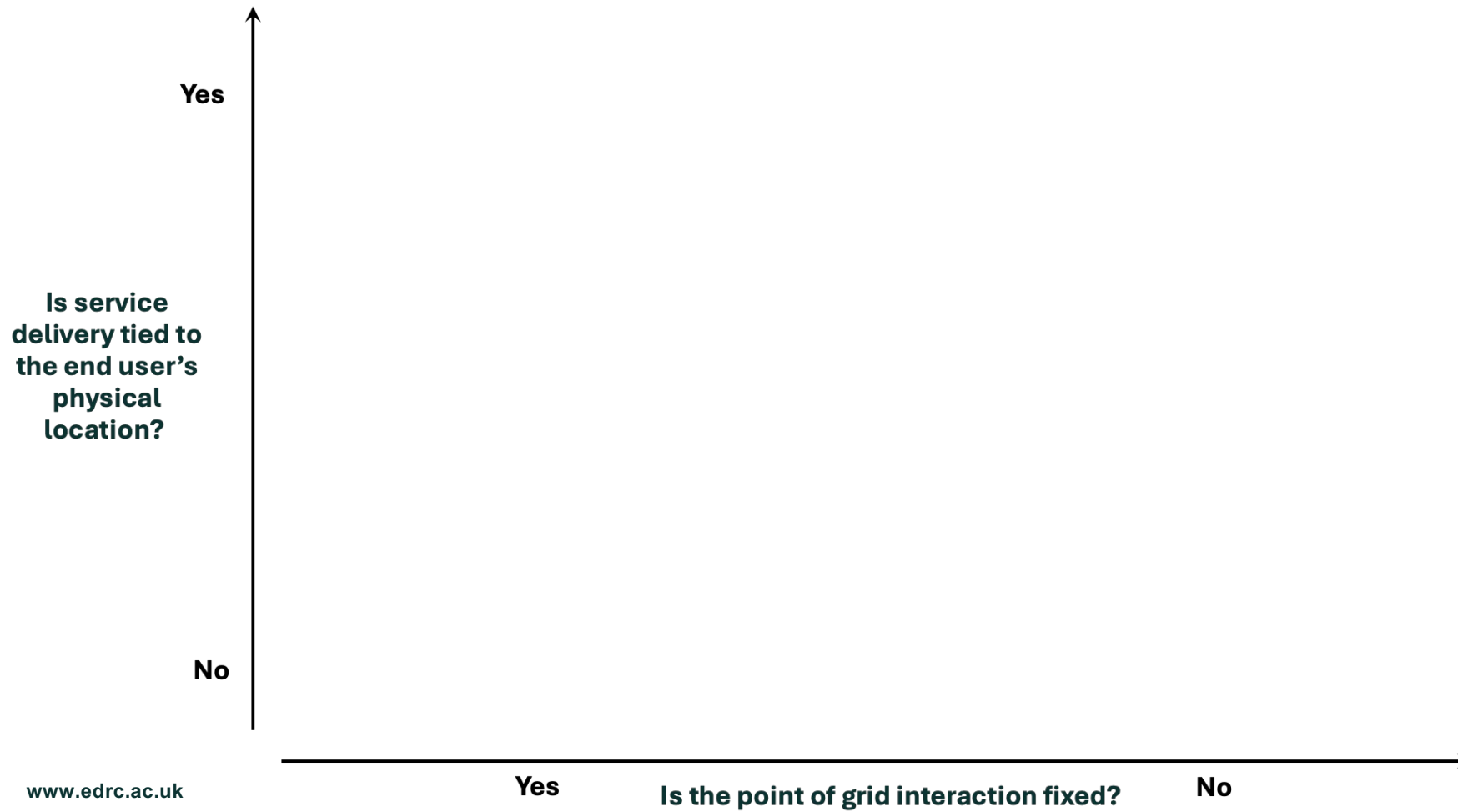
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- **Decoupling Service from Location:** It seeks to decouple the energy service delivered to the end-user (such as thermal comfort, mobility, or data processing) from the specific physical location of its consumption.

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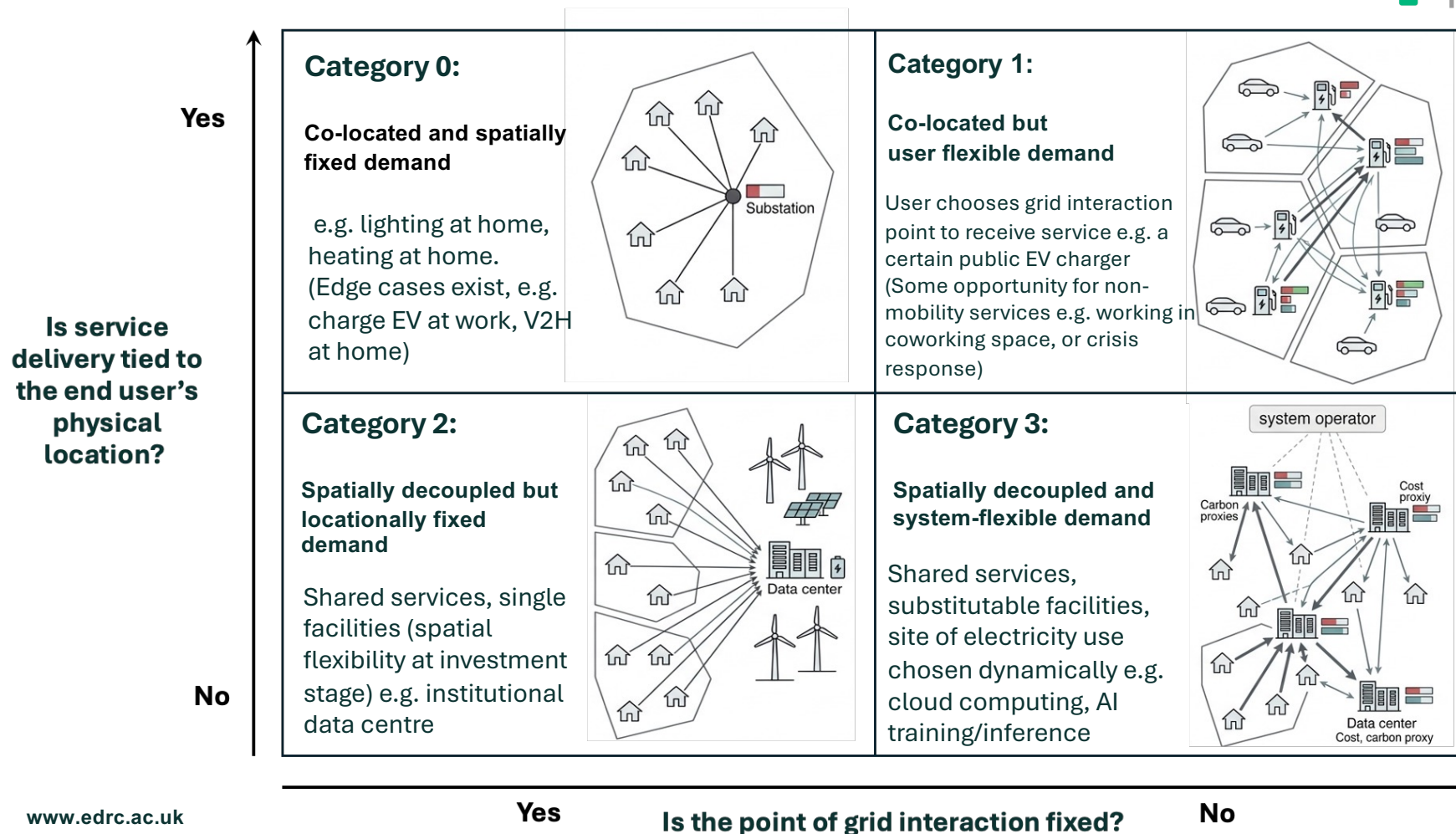


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- **Conceptual Shift:** It requires viewing energy demand not as a fixed, local burden tied to a specific meter, but as a **mobile, systemic resource**.
- **Decoupling Service from Location:** It seeks to decouple the energy service delivered to the end-user (such as thermal comfort, mobility, or data processing) from the specific physical location of its consumption.
- **Main goal:** to capitalise on the **heterogeneity of energy imbalances** across different areas to **avoid or defer costly physical infrastructure upgrades** while ensuring the grid remains resilient and fair

Breaking down spatial flexibility



Breaking down spatial flexibility



Scales of spatial flexibility (1)

1. Local and Regional Scales

- At this level, spatial flexibility is primarily concerned with addressing **bottlenecks at the distribution network level**.
- **Stakeholders:** DNOs are the primary stakeholders as they manage local network assets.
- **Mechanisms:** Impact manifests as "postcode-level" flexibility, where groups of users shift demand within and across adjacent neighbourhoods.
- **Key Challenges:** A major concern at this scale is ensuring that relocating demand does not simply "move the problem" by overloading a neighbouring area.

Scales of spatial flexibility (2)

2. National and Large Regional Scales

- At this scale, spatial flexibility addresses **broader distributional imbalances** and involves relocating demand loads across major transmission boundaries.
- **Stakeholders:** Close coordination between **DNOs and TNOs** is essential to manage capacity.
- **Mechanisms:** Large-scale energy users, like data centres, play a critical role here. For example, shifting computing workloads from a data centre in a congested area to one in a region with surplus generation (e.g., routing tasks from the South to the North of England) can alleviate national transmission constraints.
- **Infrastructure:** Realising this potential may require "grid-aware" operational strategies, such as a **nationwide computing market platform** that reflects the benefits of shifting demand between facilities in the price of computing tasks

Scales of spatial flexibility (3)

3. Transnational Scale

- At the highest level, spatial flexibility is facilitated by **interconnectors between different countries**.
- **Stakeholders:** National governments and international energy bodies are the primary stakeholders, as this scale involves **energy security and geopolitical considerations**.
- **Value:** Transnational flexibility acts as a critical "safety net" during emergency events. A notable example is the early 2025 power outage in the Iberian Peninsula, where France and Morocco provided immediate support through existing interconnectors.
- **Strategic Balance:** While providing resilience, this scale requires striking a balance between system safety and avoiding overreliance on foreign energy supplies.

Potential value of spatial flexibility

The fundamental value of spatial flexibility is in reframing demand as a mobile, system-wide resource rather than a fixed local burden

- **Enhancing system resilience and reliability:** managing emergencies such as localised blackouts or extreme events such as heatwaves, and ensuring consistent service quality
- **Market stimulation and economic value:** cost-effective alternative to expensive physical grid reinforcements, especially when a service cannot be delayed; allow price and emissions arbitrage; maintain stable market prices
- **Social and environmental value:** can improve energy equity if measures are properly designed (e.g. warm hubs), reducing adoption friction (e.g. V2G – EVs), or improving delivery of energy services across geographies

Barriers & risks to unlocking Spatial Flexibility



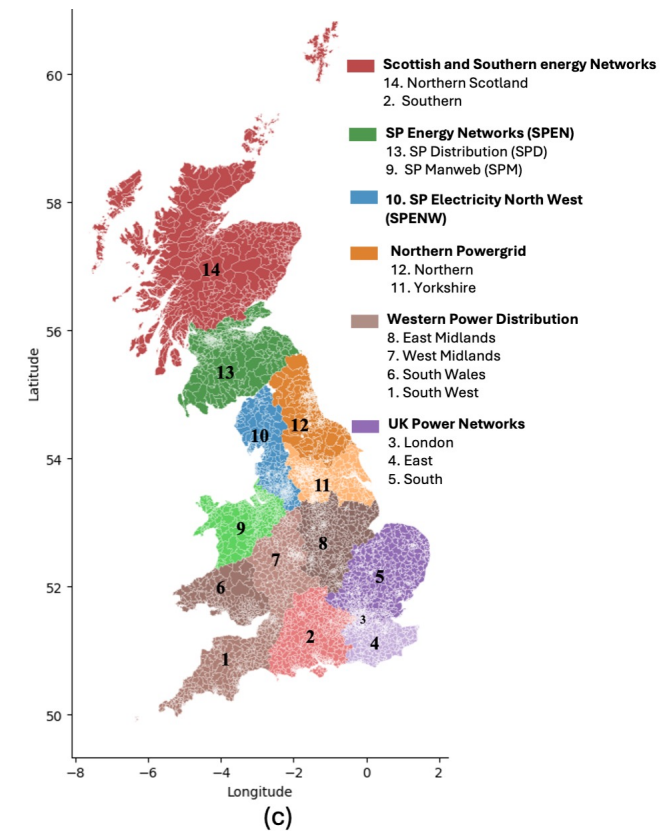
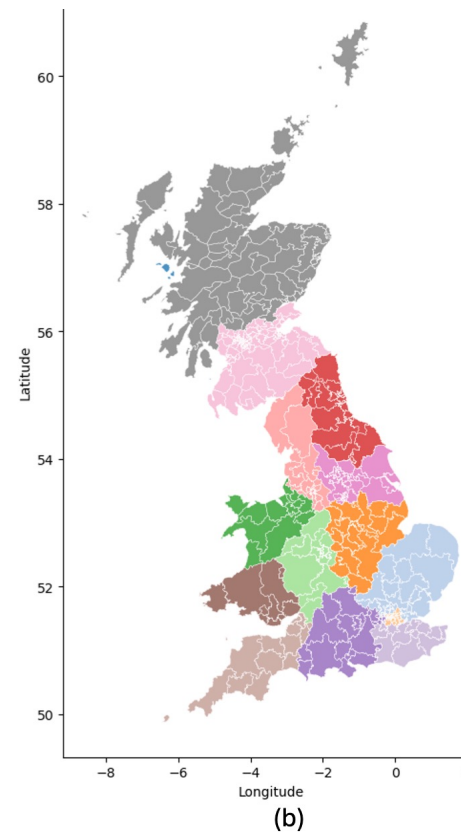
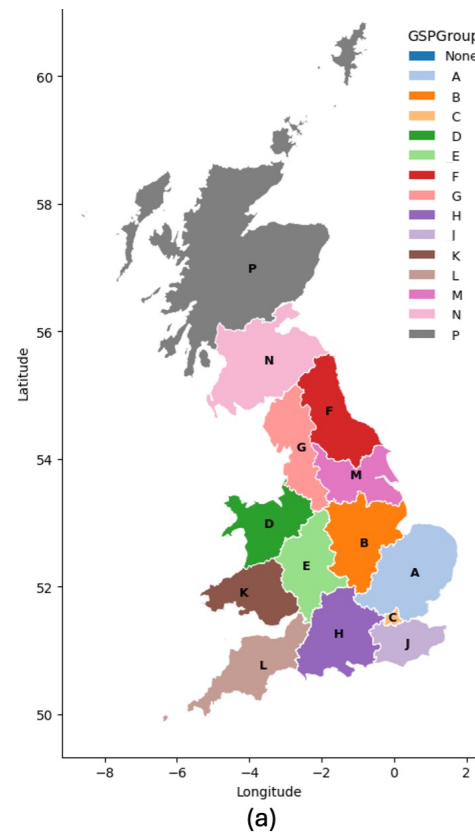
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Barriers & risks to unlocking Spatial Flexibility

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- UK example:

Spatial misalignment of primary substation service areas with administrative and statistical boundaries

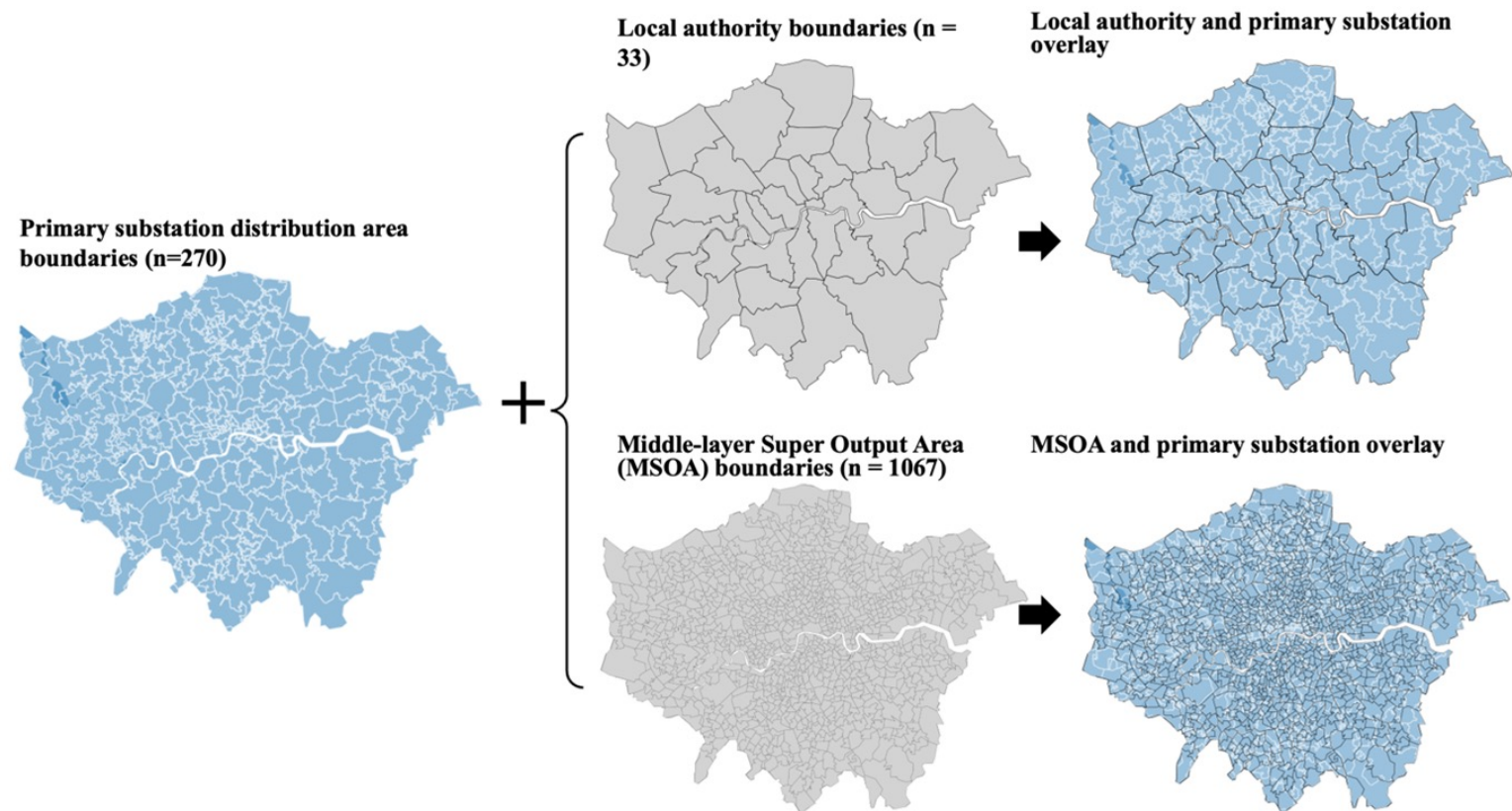
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Local authority and primary substation overlay



Barriers & risks to unlocking Spatial Flexibility

Other barriers and risks:

- 4 main categories:

Social equity and consumer welfare

- Risk of societal divides: 'flex elite', postcode lotteries
- Choice of flex vs. enforced flex (or both)
- Equity and fairness: domestic but also non-domestic (businesses)

Operational feasibility and synergies across sectors

- Technological readiness: transmission capacity, communications
- Data availability (e.g. forecast, readiness)
- Asset controllability
- Synergies across sectors

Economic and financial

- Infrastructure redundancy
- Competitive against other flexibility measures (RoI)
- Cost to the business
- Incentives

Environmental

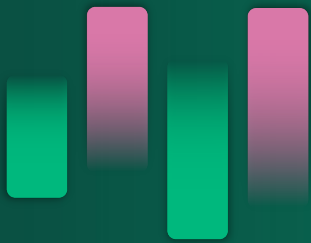
- Infrastructure cost
- Unintended consequences of incentives:
 - induced demand
 - perverse outcomes
 - avalanche effects
 - congestion (EV)

Policy implications

- The spatial lens is crucial for building resilient, efficient, and equitable infrastructure networks that maximise **local** economic utility
- Embrace spatial flexibility concepts ensures that we turn geographical energy imbalances into new opportunities for strategic and coordinated developments
- Integrating spatial flexibility concepts directly supports drive towards decentralised grid architectures and local energy planning
- UK context:
 - Regional Strategic Energy Plans (RESPs)
- EU context:
 - Distribution Network Development Plans (DNDPs)

Questions:

- What are your views on the premise/rationale for the paper?
- Do you have any cases/examples you think we should be looking into?
- Do you have any other suggestions?



Thank you!

J.ramirez-mendiola@reading.ac.uk