THEME 4: FLEXIBILITY (TORRITI, READING)

We take 'flexibility' to refer to the capacity to use energy in different locations at different times of day or year (via storage or by changing the timing of activity including whether it takes place at all); to switch fuels; to smooth or create peaks in demand or, in the case of mobility, to re-arrange destinations and journeys in ways that reduce energy demand and/or congestion. We contend that flexibility is constituted and limited by the interaction of social and technological/infrastructural arrangements including systems of storage and generation alongside social and institutional rhythms. These are critical for the fast changing relation between the timing and extent of energy demand, on the one hand, and the provision and consumption of energy services on the other. Identifying the scale of future flexibility and where and when it lies is a central priority for UKCRED, along with the task of anticipating and addressing 'flexibility gaps' of different forms. The research will be organised under two sub-themes: (4.1) Defining, conceptualising and measuring flexibility; and (4.2) Intervening to enhance flexibility. Individual projects are designed to investigate different aspects of 'flexibility' and situate the topic as a cross cutting concern within the centre as a whole.

Co-Is in this Theme include:

Prof Elizabeth Shove, Professor of Sociology at Lancaster University. Elizabeth is also PI of the DEMAND centre and has written extensively on questions of energy demand, infrastructures, institutions and social practices.

Stanley Blue, Lecturer in Sociology at Lancaster University. He is a sociologist with interests in the temporal organisation of institutions. He has written on institutional rhythms and how they matter for energy and travel demand management in the National Health Service.

Greg Marsden, Professor of Transport Governance at the University of Leeds. Greg is a CoI of the DEMAND centre and has led research on understanding disruptions and on how travel demand flexibility is understood in practice.

Stefan Thor Smith, Lecturer in Energy Systems and the Built Environment, University of Reading. Integrating energy system models with urban and regional scale meteorology, his research addresses questions on energy system dynamics, demand, and associated environmental impacts

Sub-theme 4.1 Defining, conceptualising and measuring flexibility

This sub-theme will develop research on flexibility on the basis of a thorough understanding of the contemporary timing of energy demand (domestic, non-domestic and in relation to the mobility of things and people). The projects are designed to understand how energy demand is bound up with the temporal rhythm of society and with what people do. Future projects in this area may include: 'Flexibility and cities: urban metabolism'.

Project 4.1.1 Flexibility: past, present and future (Shove, Lancaster)

Context and background: Looking to the future, there are major uncertainties about how social and institutional rhythms might fit with decarbonised and renewable energy systems (Labanca 2017). Energy systems (gas, oil, electricity and related demands) have always had a degree of flexibility in how demand meets supply and *vice versa.*

Aim: This project develops methods of conceptualising and evaluating actual and potential flexibility within and between energy systems over time and at different scales.

Questions and methods: *How has flexibility been managed in the past?* Historians of infrastructures and energy will synthesise evidence of flexibility gaps and crises in transport, gas and electricity systems and draw lessons for the future (8 commissioned studies/literature reviews/industry feedback). *How flexible is the energy system today?* We will develop methods of mapping energy-system flexibility at national and city scale. We will use data on pinch points, and 'reserves' (e.g. National Grid data on STOR events; the BEIS sub-national road transport consumption data) to develop methods of representing the changing relation between supply, demand and service provision for gas, electricity and vehicle fuel in space and time (Shove et al. 2009). *How are future flexibilities envisioned and established?* We need to know what visions of demand adaptability and timing are inscribed in present and future infrastructure plans, and how institutional arrangements 'block' or facilitate demand-side flexibility at different scales (see 6.3.1). Turning the problem around, we explore plausible patterns of time-use consistent with significant decarbonisation of energy supply and much greater reliance on renewables (secondary data analysis/interviews with national organisations (National Grid, Ofgem, DfT, NIC); and city authorities/interactive feedback/time use and practice scenarios/international workshop).

Outputs: a single flexibility 'map' of gas, electricity and vehicle fuel showing headroom over time, identifying thresholds/critical points relating to increased and decreased demand and showing when and where these occur + workshop; commissioned analyses of flexibility in the past; review of current thinking about the future timing of demand and flexibility and analysis of proposed plans; time-energy scenarios + international workshop. 3 Journal articles; 1 special issue.

Start date: October 2018 End date: September 2020. Resource: ES 2 months; SB 3 months; JT 2 months; GM 1 month; PDRA 24 months Lancaster; PDRA 6 months Reading.

Project 4.1.2 Measuring flexibility in the timing of electricity demand

Context and background: Model-based assessments of electricity demand vary in their estimates of the costs and benefits of flexibility. Unlike physical assets, which can be subjected to a test procedure in isolation to collect all relevant parameters to characterise their flexibility, measuring demand side flexibility poses challenges in terms of counterfactual demand and value over different time scales.

Aim: This work will produce innovative ways of measuring demand side flexibility and its value.

Questions and methods: *How can demand side flexibility be measured in practice? Which data are available and what missing data need to be captured?* This project will review flexibility metrics; analyse baseline methodologies; and develop flexibility assessment frameworks. Novel statistical and probabilistic methods will be developed to assess the impact and efficacy of interventions. Data comprising household composition, occupancy and activity patterns (e.g. METER and SMRP) will capture the diversity of electricity services provided and their temporal dependencies.

Outputs: Working paper on flexibility metrics, statistical toolkit (flexibility index).

Start date: April 2020. End date: March 2021. Resource: PDRA 12 months unallocated, JT 1 month.

Project 4.1.3 Conceptualising flexibility (Shove, Lancaster)

Context and background: Flexibility is not only about adapting supply to demand or switching fuel to match or meet existing temporal patterns. It is also about recognising that temporal patterns are not fixed: they vary and are in part shaped by technologies and systems of provision.

Aim: The work will conceptualise whole system 'flexibility' to better understand how forms of synchronisation, periodicity and duration structure mobility and other forms of energy demand. This project is a 'theoretical engine room' that will inform and influence research across the whole centre.

Questions and methods: Articulating the time-related implications of present energy policies and related research in science and engineering depends on integrating and mobilising concepts developed across the social sciences (Blue 2017). This foundational work is in three phases: a) *critically reviewing methods of conceptualising and measuring flexibility across disciplines and research fields, and between supply, demand, and the provision of energy services*; b) f*ocussing on how forms of spatial and temporal flexibility are structured and conceptualised in relation to transport (see 2.2.2), and domestic and non-domestic energy demand, and analysing assumptions about flexibility embedded in energy research and policy*; and c) *drawing on international experience and expertise, including hosting a major conference on flexibility and energy demand*.

Outputs: 2 articles, 2 interactive workshops involving UK energy researchers and social scientists, and 1 international conference.

Start date: October 2018. End date: March 2023 Resource: ES 2 months; SB 3 months; JT 2 months; GM 2 months.

Sub-theme 4.2 Intervening to enhance flexibility:

This sub-theme assesses the impacts of interventions aimed at mitigating peaks and increasing flexibility in the timing of energy demand. The focus is on technologies, pricing mechanisms and shifts in institutional timings and understanding the extent to which these shape the temporalities of daily social life and generate new challenges for demand-side flexibility. Future projects in the area may include: 'Flexibility and working arrangements' and 'Flexibility and segments of population: older people, solo living, night shifts'.

Project 4.2.1 Flexible demand-side technologies and temporalities (Smith, Reading)

Context and background: Storage and control technologies such as household batteries, vehicle- to-grid electric vehicles, and system network platforms for metering and actuation are expected to enable a more flexible management of demand. The operational constraints of individual and combined technologies need to be understood in relation to flexibility of how, where, and when people demand energy and what this means to demand profiles across distribution networks.

Aim: This project will analyse how existing demand-side technologies (DST) can change patterns of demand at different scales by modelling technology functionality and the implications on the temporality of practices.

Questions and methods: Activity profiles and demand flexibility will be modelled using statistical methods to capture variation under different levels of DST adoption. Modelling inputs will be based on a combination of data from case-study interviews, monitoring campaigns, and time-use diaries (both primary and secondary data). Analysis will be undertaken to address a) *whether existing technologies require changes in social practices in order to offer effective demand side management*; and b) *if technologies that enable flexibility actually change temporalities in what people do*. Flexible demand estimates will be integrated into an existing energy system model that also incorporates models of demand-side technology operation and control. Simulations for different levels of technology adoption will be undertaken to see: c) *on what spatial scales do changing practices impact flexibility*; d) *what the operational limits of flexibility are for the studied technologies under identified social practices*; and e) *the significance of different scenarios of technology adoption to flexible demand at different spatial scales on distribution networks*.

Outputs: 3 research articles covering: modelling approach and data integration; technological limitations to flexibility; and grid-spatial patterns of flexibility under technology adoption scenarios. Computational models of demand-side technology operation; demand related activity profiles integrated into energy system models; network maps of technology adoption and demand flexibility; data on demand practices of early adopters; case study data on demand practices of adopters (interviews and energy monitoring); 1 workshop on technology adoption and demand flexibility.

Start date: October 2019. End date: September 2022. Resource: PDRA1 36 months Reading; PDRA2 6 months Reading; STS 9 months; JT 3 months.

Project 4.2.2 Price and time elasticity (Torriti, Reading)

Context and background: In the energy economics literature price elasticity is the main proxy for calculating the average change in demand by (groups of) end-users following variations in prices (Torriti, 2014). This does not reflect how people's flexibility varies based on the time of the day, location, work and social commitments.

Aim: This project will move thinking beyond average price elasticities by critically engaging with existing work on price elasticity, focusing on time-of-day fixities, considering wider societal impacts of dynamic pricing, comparing elasticities across different types of derived demand, estimating how price elasticities vary according to the time of the day, weather and occupancy levels.

Questions and methods: This project will address key questions on how does price elasticity change based on the time of the day. It will explore the relationships between elasticity and flexibility. By doing so, it will examine how elasticity is dependent by variables other than prices, such as fixities around routines and schedules. This work will require critical engagement with energy elasticity literature and scholars. It will inform work which makes use of elasticity (e.g. energy and transport regulators introducing time-of-day pricing) for dynamic tariff planning. The project will: a) *critically review existing work and projects on short-term price elasticity;* b) *derive fixities in what people do from UK time use data;* c) *assess wider impacts of dynamic pricing;* d) *compare dynamic pricing of household electricity, transport and other sectors;* e) *measure time-of-day price elasticity; and* f) *create new metrics based on non-price elasticities*. Methods will involve meta-analysis of price elasticity; analysis of time use data; econometric analysis of distributional effects of ToU tariffs; cross-sectoral comparative analysis of price elasticity; analysis of price signals at different scales; new elasticity metrics.

Outputs: 1 review paper of existing elasticity estimates; 2 research articles on energy economics journal; 1 research article on different elasticity metrics; 1 conference paper on time use data analysis; 4-5 blog articles; 1 workshop on derived elasticity; 1 impact event (Ofgem and BEIS); exchange with UKCRED visitors.

Start date: April 2021. End date: March 2023. Resource: PDRA 36 months Reading; JT 2 months.

Project 4.2.3 Time dependence and institutional flexibility (Blue, Lancaster)

Context and background: Institutions already intervene to shape patterns of energy demand. But current demand-side management (DSM) strategies tend to work in the background with the aim of minimising disruption to services. A more significant challenge is to exploit opportunities for adapting socio-temporal rhythms to better match peaks and troughs of renewable supply.

Aim: This project analyses DSM interventions in practice, doing so as a means of identifying institutional flexibilities and new opportunities for more extensive demand side response.

Questions and methods: a) *How can demand be managed flexibly within institutions?* We will examine the impact of existing DSM strategies, focusing on their limits and possibilities, and how they shape and reflect the institutional timing and organisation of services. We will select 5 example case study institutions (e.g. hospitals, hotels, retail, transport networks) and analyse energy/travel data and local building management systems data alongside interview data (n.15) with key stakeholders. The aim is to analyse critical peaks and patterns in energy use as a way of identifying potential institutional rhythms that might be shifted as a method of demand-side response. b) *What forms of time dependence hold institutional rhythms in place?* We will disaggregate practices and sequences at peak and high-price times and separate 'background' energy use (e.g. heating, cooling, lighting) to isolate different forms of demand and develop a typology of temporal dependencies (that include periodicity, tempo, duration, synchronisation, and coordination). This will involve interviews (n.30) with people who have influence over the time-dependency of activities. c) *Can institutional rhythms be modified to change the timing of demand?* We will revisit institutions and managers interviewed to discuss revealed dependencies and opportunities for reconfiguring services to improve demand management. We will focus on institutional configurations that demonstrate the maximum potential of institutional practice-energy-time mapping. The potential for developing a new style of demand side management will be disseminated to DSM and energy suppliers as well to a broad range of institutions through case study reports and national dissemination events.

Outputs: new methods of institutional practice-energy-time profile mapping, 10 practice-energy-time profiles, 2 journal articles, reports for case study institutions, 2 dissemination events.

Start date: July 2020. End date: June 2022. Resource: SB 4 months; ES 2 months; PDRA 24 months Lancaster.