CENTRE FOR RESEARCH INTO
ENERGY DEMAND SOLUTIONS

Energy demand and its temporal flexibility: A cross disciplinary approach

Waseda University
Energy Policy Workshop
10th June 2022

Samuele Lo Piano

International Energy Policy Workshop

2017.01.24

AOYAMA GAKUIN

WASEDA UNIVERSITY

A Multi-Scale Integrated Assessment of the energy metabolism of society

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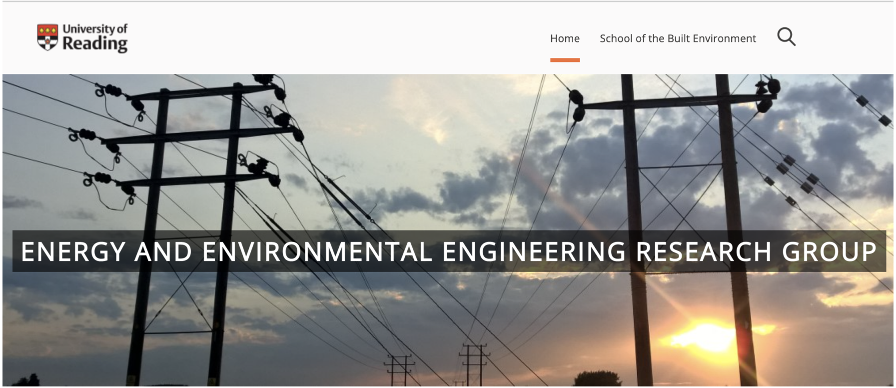
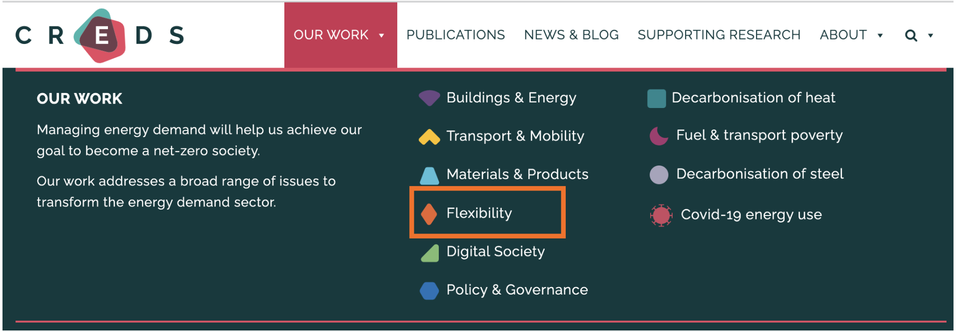


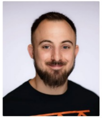


19M £ Research Centre, 20 universities, > 200 researchers

Flexibility


Jacopo Torriti


Osaru Agbonaye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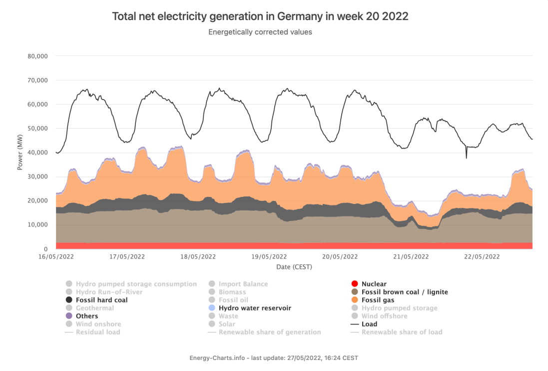
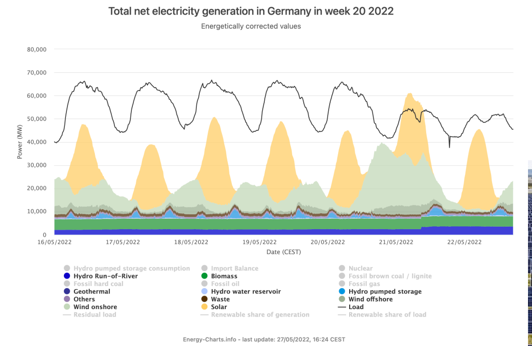
Current generation - Germany, May 2022



Current generation - Germany, May 2022 (renewable to increase)



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Why focussing on energy demand

- Increasing penetration of temporally (day, season) and spatially variable (to an extent unpredictable) intermittent primary energy sources
- Which raises the need to influence/control the temporal and spatial pattern of energy demand
- As a social, technological and economic (geopolitical) challenge

If you want to know more

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Energy demand and its temporal flexibility: Approaches, criticalities and ways forward

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ARTICLE INFO

Keywords:
Flexibility
Energy demand
Social practice theory
Demand response
Demand management
Temporality

ABSTRACT

This contribution reviews the options proposed to reduce and/or act on the temporal profile of energy demand (flexibility), mainly at the residential level. Automated technology-driven options and/or monetary incentives towards behaviour shifting from end users are firstly examined. A relevant finding is the existing potential points of frictions between options aimed to reduce energy demand and those acting on its temporality.

The identified socio-economic drivers of residential energy demand patterns and temporality are discussed through the application of analytical frameworks for the coupling of energy and social systems, with the overall aim to gather a thorough understanding of energy demand and its temporality for more aware options for the control of energy demand and its temporal flexibility. A particular focus is dedicated to the perspective of social-practice theory for its capability of capturing relations between users and material artefacts, with a discussion of its theoretical principles and of its application in practical examples. Through examination of the dialogue between technological and social dimensions of energy demand and its temporality in the literature, assumption and epistemic uncertainty exploration lead to more aware energy demand options. Despite its significance, this research avenue remains largely unexplored. We suggest critical areas for development of this dialogue are: (i) the translation of meaning of demand in relation to concepts of non-negotiable energy end use effects associated with technology efficacy/efficiency, (ii) issues of new fixities resulting from intended technological demand flexibility, (iii) addressing issues of determinism in accounts of new technology impacts, (iv) implementation of demand side management and response technology with respect to social accounts of demand temporality.

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Research Questions

- What approaches have been proposed in the literature to curtail energy demand and/or enact energy-demand temporal shifts?
- What are the differences between the social and technical framings of approaches?
- What are the levels of separation between the technological modelling and the theoretical frameworks from the domain of social science/humanities?

Literature review search criteria

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Search on technological aspects of energy demand	#
TITLE-ABS-KEY	
((‘energy demand technologies ‘) OR	(12)
(‘demand side technologies’) OR	(47)
(‘technologies’ AND ‘demand flexibility’))	(76)

Search on social aspects of energy demand	#
TITLE-ABS-KEY	
((‘flexibility’ AND ‘energy demand’ AND ‘habits’) OR	(3)
(‘flexibility’ AND ‘energy demand’ AND ‘behaviour’) OR	(63)
(‘flexibility’ AND ‘energy demand’ AND ‘practices’) OR	(27)
(‘flexibility’ AND ‘energy demand’ AND ‘rhythms’) OR	(5)
(‘flexibility’ AND ‘social activities’) OR	(82)
(‘flexibility’ AND ‘time allocation’)) OR	(71)
(‘flexibility’ AND ‘energy demand’ AND ‘social practices’) OR	(4)
(‘flexibility’ AND ‘energy demand’ AND ‘activities’) OR	(51)
(‘practice shifting’) OR	(74)
(‘energy demand’ AND ‘social practices’)	(39)
(‘energy demand’ AND ‘social activities’)	(9)
(‘energy demand’ AND ‘rhythm’)	(107)
(‘energy demand’ AND ‘habits’)	(116)
(‘energy demand’ AND ‘time allocation’)	(8)

Manual search

Additional references cited or citing the selected documents (found upon Scopus search alert)

(40)

794 documents (779 + 15 duplicates)

Screening upon more in-depth analysis → 569 documents

210 documents

250 documents

Article yearly trends

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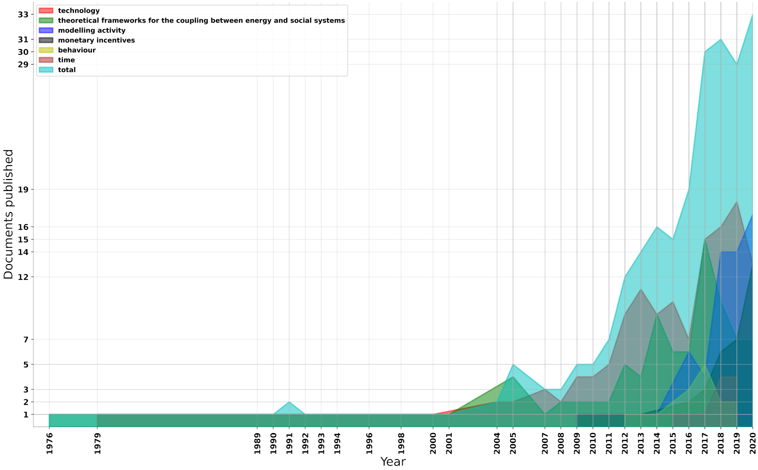

Literature search quantitative outcomes

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- Technology (145)
- Theoretical frameworks for the coupling between energy and social systems (87)
- Modelling activity (61)
- Monetary incentives (36)
- User behaviour (19)
- Time (15)
- 153 papers on one dimension, 78 two dimensions, 18 three dimensions, 1 paper covered four.

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Demand-side technologies

- *Particular subset of artefacts of energy systems able to directly affect energy demand and/or shift the spatial and/or temporal pattern of demand.*

- Acting upon (or within) energy distribution networks.

- 'Close to' or at the point where energy is used.

Demand-side technologies: not that new...

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ELECTRIC-UTILITY DEMAND-SIDE PROGRAMS:

RESOURCES FOR THE 1990s*

CONF-890425--2

DE89 011581

Eric Hirst
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Oak Ridge, Tennessee 37831

April 1989

ABSTRACT

The primary purpose of this paper is to suggest much larger and more active roles for electric utilities in acquiring energy-efficiency and load-management resources. Valuable utility actions include increased efforts to assess existing and new demand-side technologies; to test alternative ways to implement demand-side programs; to aggressively acquire energy and capacity resources through efficiency and load-management programs; to develop innovative pricing mechanisms to modify load shapes and levels and to encourage participation in utility programs; to work with governments to support efficiency standards for new buildings, appliances, and other energy-using equipment; to integrate their planning for demand-side programs with planning for supply resources; and to incorporate the risk-reduction benefits of demand-side programs into their resource planning.

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Demand-side technologies

Demand-side technologies overview: approaches, targets and purpose.

Approach	Target	Purpose
Energy storage	Overall electricity and thermal demand	Permitted increase in use of intermittent renewable\locally generated energy when higher than demand
Building thermal mass, thermal insulation	Heating and cooling system	Reducing thermal energy demand
Shading panels, green façades, adiabatic cooling	Cooling system	Reducing cooling energy demand
Domestic-hot-water connection for appliances	Wet appliances	Reduce electricity demand from wet appliances upon more efficient building design
More efficient appliances	All appliances types	Reduce electricity demand from appliances under the same usage pattern
Context aware energy management systems	Lighting appliance, HVAC system	Reduce electricity demand from lower\less-intensive temporal use

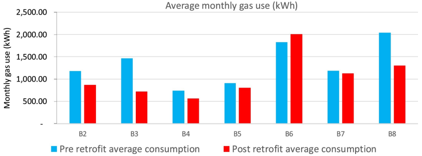
Reduction in thermal energy demand from buildings

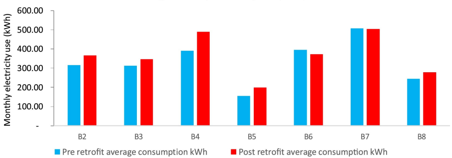
Plenty of factors affecting the effectiveness of thermal insulation:

- Local climate
- Pattern of heating demand (continuous - households vs. discontinuous - shops/schools)
- Presence of windows
- Relative orientation with respect to cardinal points
- Presence of unoccupied properties in multi-residential buildings

Demand-side technologies: retrofit effectiveness

Reduction in gas consumption up to 24% for a sample of eight buildings retrofitted. However, reduction partially compensated by increase in electricity consumption 12%





Papadopoulos et al. *Actual energy and environmental savings on energy retrofit works at the Lakes Estate, Milton Keynes*. Sustain Cities Soc 2018;41:611–24.

Demand-side technologies: controllers

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- Dimmer and timer controls, photo and occupancy sensors
- Machine-learning based occupant location prediction (Neural Networks, Decision trees and Random Forest, Support Vector Machines, Hidden Markov Models)

Figure 2. (a) Rotary Dimmer (b)Slider Dimmer (c)Touch Dimmer.

Ayan Turkay. *Comparison of lighting technologies in residential area for energy conservation. In: 2017 2nd International conference sustainable and renewable energy engineering.* ICSREE, 2017, p. 116–20.
Shaptala Kyselova. *Location prediction approach for context-aware energy management system. In: 2016 IEEE 36th international conference on electronics and nanotechnology.* ELNANO, 2016, p. 333–6.

Flexibility in energy demand

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- Flexibility: *The measure of how rhythms of demand change in time*
- Recent increased emphasis over energy demand reduction due to:
  - The expected increase in electrification of mobility (electric vehicles) and heating (heat pumps)
  - The possible exacerbation of peak phenomena (magnitude and frequency) on the meso-temporal scale (daily to seasonal) with all the related grid stability risks
  - The increasing reliance on variable/intermittent primary energy sources
  - The stringent goals in terms of CO_{2eq} reduction

Approaches for flexibility

- Demand-side Management (DSM): switchable loads (to less critical times) and storage
  - Top-down, utility driven
  - Pessimistic, automated
  - *Passive*
- Demand-side Response (DSR): household and users shifting their loads upon monetary compensation
  - Bottom-up
  - Optimistic, user-based
  - *Active*

Flexibility strategies

- *Exploring demand side management to cope with variable generation from RES, seeks to make the most out of each and every piece of possible flexibility that might be achievable in displacing load along the time line. This postponed (or anticipated) consumption should be allowed to surface as this variable primary energy from RES powers their respective converters. Thus, as an essential amount of load is displaced along the timeline it may gain a higher priority making the respective market agent bid higher to place it within the assembled curve of the total power expected from the resources foreseen to be available at each moment.* ***Ultimately a quasi-real time market will be needed to fulfill the new paradigm in which it is the load that follows generation instead of the other way around.***

  Ósorio Estanqueiro *Exploring demand side management to cope with variable generation from renewable energy sources. In: Symposium Lisbon - 2013. Vol. 2. Lisbon: Cigré; 2013, p. 1–8.*

Flexibility strategies

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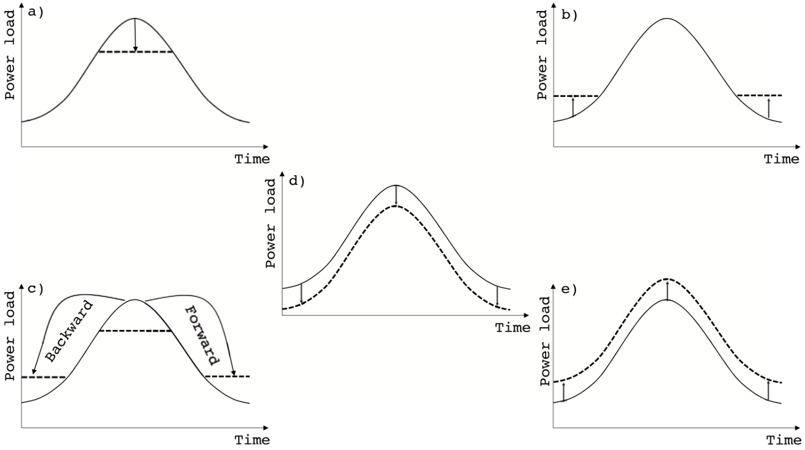

Strategies for the temporal shift of peak demand. (a) Peak clipping; (b) Valley filling; (c) Load shifting; (d) Strategic conservation; (e) Strategic load growth.

Sallam Malik *Electric distribution systems.* 2019

Flexibility strategies

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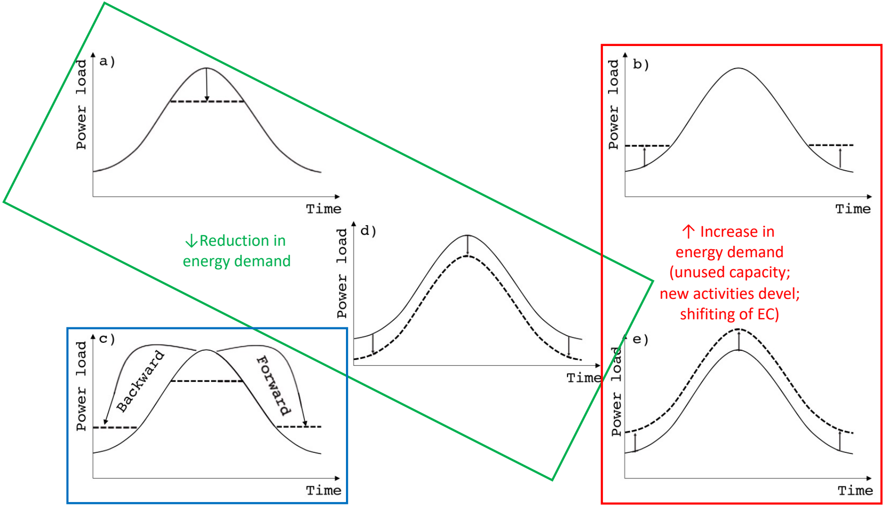

Strategies for the temporal shift of peak demand. (a) Peak clipping; (b) Valley filling; (c) Load shifting; (d) Strategic conservation; (e) Strategic load growth.

Flexibility level attainable with appliances

Table 2
Demand-side management overview: targets, level of flexibility, temporal features and strategies.

Target	Level of flexibility	Temporal flexibility	Enacting options
Electrical-based heating, cooling appliance, integrated-battery devices	High	Sub-hour flexibility	Internet of things, smart home
Electric vehicles, thermal loadings	High	Hour flexibility and beyond	Internet of things, virtual power plant voltage control reserve
Wet appliances, iron, (and vacuum cleaner)	Medium	Hour flexibility and beyond	Internet of things, smart home
Lighting, cooking appliances and microwave oven, hairdryer, (and vacuum cleaner)	Low	Sub-hour/ Hour flexibility and beyond	Internet of things, smart home
Entertainment devices	None	None	Not defined

Flexibility through technological DSM: passive and algorithmic control

- DSM algorithms to switch off (supply lower than demand), or switch on appliances (supply higher than demand)
- Supply lower than demand: prioritise highly-flexible appliances; supply higher than demand: prioritise less-flexible appliances (mitigate inertia).
- Two properties are acted upon: the duration and the power level of the load.
  - HVAC appliances: Summer pre-cooling (and night ventilation)/winter pre-heating. The environment is cooled (heated) at a slightly lower (higher) temperature hours before peak demand to shift energy consumption and reduce peak load

DSM for EV

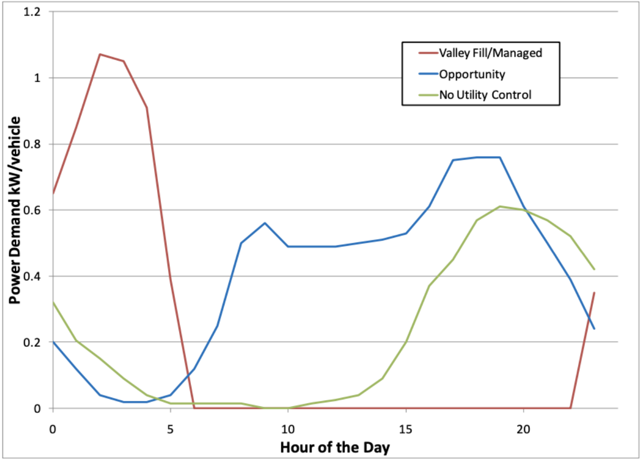

Figure 5: Three PEV fleet charging profiles based on 227 driving profile vehicle simulation results

Markel et al. *Transportation electrification load development for a renewable future analysis: preprint.* Tech. rep. NREL/CP- 5400-49181, National Renewable Energy Lab. (NREL), Golden, CO (United States); 2010

Obstacles to deployment of DSMs (frequent, but not ubiquitous)

- Privacy concerns (data leakage)
- Lack of financial advantages (if not additional cost, e.g. due to rebound in consumption)
- Lack of confidence in the technology (technology anxiety) and in the operator (giving away control to an external source)
- Lack of information

Li et al. *Motivations, barriers and risks of smart home adoption: From systematic literature review to conceptual framework*. Energy Res Soc Sci 2021;80:102211.

DSM for industry

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Options tailored to the industrial process, potentially interwoven with the generation available on site

Storage technology	General principle	Advantages	Disadvantages
embodied energy in products	Store energy in embodied energy of products by shifting production demand	no additional converting cycle needed	requires flexibility of production system; might affect technical and operational indicators
supercapacitor	energy storage in electric field	very fast response time; high cycle stability	low volumetric energy density
battery storage	energy storage in electro-chemical reactions	fast response time; high energy density	limited cycle times; environmental concerns
compressed air generation (CA)	shift CA production to times with high energy availability	infrastructure already present; fast response time	limited by total CA demand and storage size

Schulze et al. *Energy storage technologies to foster energy flexibility in learning factories. In: Research. experience. education.* 9th conference on learning factories 2019 (CLF 2019), Braunschweig, Germany. Vol. 31. Procedia Manuf 2019;330–6.

Flexibility through DSR: monetary leverage

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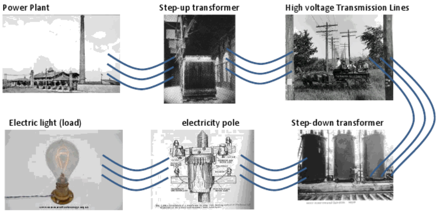


Time-of-day pricing in the U.S. electric power industry at the turn of the century

William J. Hausman*

and

John L. Neufeld**

Around the turn of the century, a debate occurred within the infant U.S. electric power industry on the issue of electricity rate structures. We describe those discussions and consider the views of some of the economists who first addressed the issue. Although they were ultimately unsuccessful, there were sophisticated advocates of time-of-day rates among the first engineers, utility executives, and economists to study electricity rates.

Hausman Neufeld. Time-of-day pricing in the U.S. electric power industry at the turn of the century. RAND J Econ 1984;15(1):116–26.

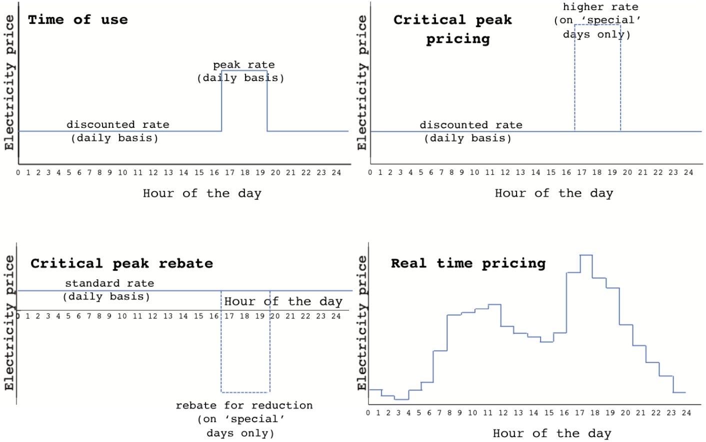
Flexibility through DSR

Strategy	Temporal flexibility requested	Target	
Incentive-based demand-side response	Variable, typical hour flexibility and beyond	Large costumers (industry, commercial, hotels, etc.)	Direct, system-led, emergency approach
Time-of-use tariffs	Hour flexibility and beyond	Residential (all types of appliances) and medium (industry and commercial) costumers	Indirect, market-led, economic approach
Critical peak pricing tariffs	Sub-hour, hour flexibility and beyond	Residential, medium and large costumers	
Extreme day pricing tariffs	Daily flexibility	Medium and large consumers	
Critical peak rebate tariffs	Sub-hour, hour flexibility and beyond	Mostly residential	
Real time prices	Sub-hour flexibility	Residential (highly flexible appliance, see details in Table 2), medium and large costumers	

Flexibility through DSR: incentive-based

- Encompasses
  - Direct load control from system operators
  - Curtailable load
  - Demand-side bidding from customers
  - Capacity market, ancillary and emergency services (upon load-reduction signal, e.g. to prevent violation of grid network operation constraints, or help reducing costs of network augmentation)

Flexibility through DSR: price-based tariffs



Critical peaks and 'extreme day' pricing more effective due to limited time commit from end users

DSR limitations

- No clear trends/correlation in country-wise cross comparisons in time consumptions vs. prices

- Counter-peaks after the end of DSR events, highly-priced peak hours

- Rise in futile energy demand (due to less attentive use) within cheap hours

Faruqui A, Sergici S. *Arcturus: International evidence on dynamic pricing.* Electr J 2013;26(7):55–65

DSM-DSR Joint approaches

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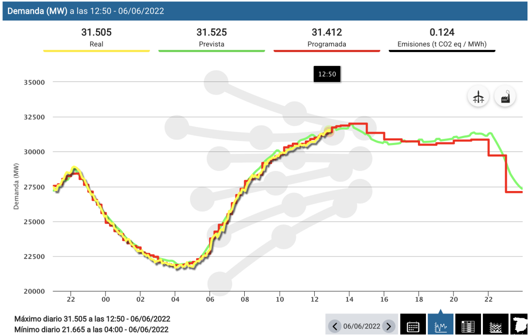
- Six variable-temporal-scale strategies for energy-demand management: (i) Continuous energy consumption minimisation (through so-called energy efficiency measures); (ii) monthly peak demand management; (iii) daily time-of-use management; (iv) day-ahead response; (v) day-off response; and, (vi) fast-demand response (automated, manual in demand response programmes)

- Semi-automated demand responses: centralised control system for some types of appliances (typically HVAC systems), and manual control for others.

Kiliccote et al. *15 - Improved energy demand man- agement in buildings for smart grids: The US experience.* In: Bessède J-L, editor. Eco-friendly innovation in electricity transmission and distribution networks. Oxford: Woodhead Publishing; 2015, p. 315–38

Drivers of users energy demand



- Yet socio-demographic factors do play a role (e.g. gender, age, etc.): *A combination of quantitative measurements and qualitative interviews has shown how different user behaviour in identical houses may result in a three times higher energy consumption for heating.*

Gram-Hanssen K. *Residential heat comfort practices: understanding users.* Build Res Inf 2010;38(2):175–86.

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Drivers of users energy demand: a matter of scale

Energy Vol. 4, pp. 911 to 918
Pergamon Press Ltd., 1979. Printed in Great Britain

CHALLENGES IN THE IMPLEMENTATION OF ENERGY CONSERVATION†

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(*Received 9 January* 1979)

Abstract—Penetration of energy-conservation devices during the last few years has led to progressive reductions in estimated total energy demands for the U.S. and other countries. Relatively rapid reductions have been implemented in areas dominated by social habits. Significant gains are noted in the transportation and space-conditioning sectors.

Drivers of users energy demand

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Building Serv. Eng. Res. Technol. 28,3 (2007) pp. 223–235

Measured and predicted energy demand of a low energy building: important aspects when using Building Energy Simulation

F Karlsson[a] MSc PhD, **P Rohdin**[a] MSc PhD-student and **M-L Persson**[b] MSc PhD
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[b]The Ångström Laboratory, Department of Engineering Sciences, Uppsala University, P.O. Box 534, SE-751 21 Uppsala, Sweden

Practical application: Building energy simulation software is often used to make predictions of how different construction materials, design principles and operation influence the energy balance and indoor thermal comfort. It is therefore important that the output of these software tools is trustworthy and accurate. This paper discusses the importance of accurate input data during the design process in order to achieve a valid prediction of energy use with emphasis on tenants' behaviour. It was shown that the deviations in a parametric study were larger than the deviations in the comparison between the results from the three simulation tools. This indicates a need for more accurate models for modelling tenant behaviour and habits rather than more accurate building component models.

The Swedish low-energy house used as a case for this study

Drivers of users energy demand: coupling of energy and social systems

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	Organisation of system	*Construction of demand*	*Model of systemic change*
[1] Human-ecological systems	Closed-loop flow of materials and resources	Driven by industries, consumers, markets	Life-cycle approach, improve efficiency of throughput
[2] Systems of provision	Dual configuration of agency and structure	Co-produced by consumers and providers	Greening of socio-collective material systems
[3] Socio-technical systems	Path-dependent socio-technical systems	Institutionally and technically structured, historically grounded	Co-evolution through multiple macro, meso, micro levels
[4] Systems of practice	Practices nested in systems of systems	Socially and culturally embedded expectations of need or service	Redefining expectations and conventions held in emergent sub-systems

These idealised modes of systems thinking further reveal different dimensions that might be incorporated in attempts to define more systematically sustainable energy management possibilities. Insights from industrial ecology help to identify the multiple points at which

Chappells H. *Systematically sustainable provision? The premises and promises of 'joined-up' energy demand management.* Int J Environ Technol Manag 2008;9(2/3):259.

The reading of energy demand from the social-practice theory (SPT) perspective

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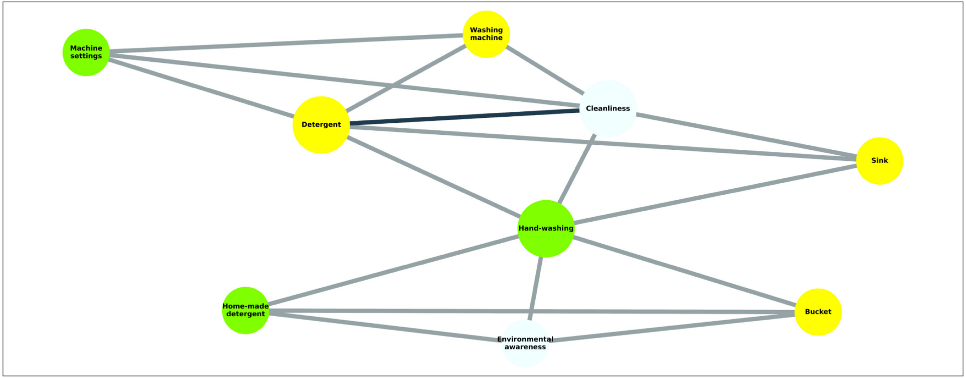
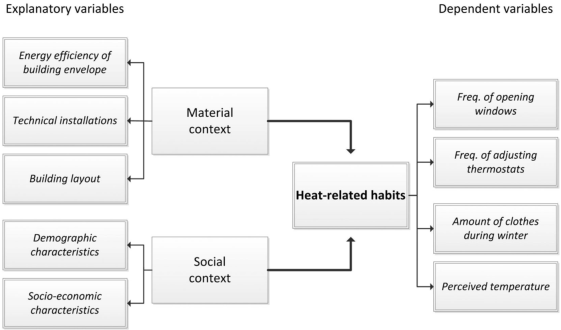
- Interconnection of three elements: knowledge (competence), things (material artefacts), their use (conventions/meanings).



Higginson S. et al. *Diagramming social practice theory: An interdisciplinary experiment exploring practices as networks*. Indoor Built Environ 2015;24(7):950–69.

SPT: Residential energy demand for heating

- Heating practices of the occupants, heating technology, expectations of indoor temperature.



- Denmark: wear warmer clothes in winter in less thermally energy efficient houses; set higher thermostat temperatures in more efficient houses.

Hansen AR et al. *How building design and technologies influence heat-related habits*. Build Res Inf 2018;46(1):83–98

SPT: Residential energy demand for lighting

- Shifting from single-light ceilings to multiple lights (in the corner of the rooms) for all purposes (dining, reading, crafting)

Jensen CL. *Understanding energy efficient lighting as an outcome of dynamics of social practices.* J Clean Prod 2017;165:1097–106.

SPT: Other practices

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- Reflection practices, e-practice: alignment with energy consumption expectations, activism, participation in energy storage/generation.

Verkade N., Höffken J. *Is the resource man coming home? Engaging with an energy monitoring platform to foster flexible energy consumption in the Netherlands.* Energy Res Soc Sci 2017;27:36–44.

SPT essence on energy demand

- Energy demand not for its own sake, it is for doing something through a specific practice, influenced by institutional, political, cultural, social and historical factors.

- These practices define what energy is used for and overall trends.

Shove E, Walker G. *What is energy for? Social practice and energy demand.* Theory Cult Soc 2014;31(5):41–58.
Yamaguchi Y. *A practice-theory-based analysis of historical changes in house- hold practices and energy demand: A case study from Japan.* Technol Forecast Soc Change 2019;145:207–18.

SPT: Residential energy demand for heating, historical perspective

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- Changing heating practices between 1920 and 1970 in a Northern English town due to:
  - the materialisations of ideals for separating domestic activities
  - the emergence of new uses for heat following from a shift towards more sedentary, indoor activities.

Kuijer L, Watson M. *'That's when we started using the living room': Lessons from a local history of domestic heating in the United Kingdom.* Energy Res Soc Sci 2017;28:77–85.

SPT: Residential energy demand for heating, historical perspective

University of Reading

- With practices contributing and being shaped by:
  - the room configurations in the dwelling
  - the uptake of given types of appliances
  - the technology used for heating these environments

Kuijer L, Watson M. *'That's when we started using the living room': Lessons from a local history of domestic heating in the United Kingdom.* Energy Res Soc Sci 2017;28:77–85.

SPT: Cooling demand and institutional factors

- For our discussion: Could you please tell me if and how you have been affected by the *Cool Biz* campaign? How did it change your practices?

Source: *KyodoNews.*

The reading of the temporality of energy demand from the social-practice theory perspective

- Practices occur in accordance with temporalities, which are in turn defined by the rhythms of these practices

- Change, rhythm and synchronicity of energy demand and social practices (at variable temporal scales)

- Societal collective and temporal rhythms: activity rushed *hot spots* in order to have chill times *cold spots* (e.g. resorting to multitasking b/c of child care).

Southerton D. *Habits, routines and temporalities of consumption: From in- dividual behaviours to the reproduction of everyday practices.* Time Soc 2013;22(3):335–55.
Walker G. *The dynamics of energy demand: Change, rhythm and synchronicity.* Energy Res Soc Sci 2014.
Southerton D. *'Squeezing time': Allocating practices, coordinating networks and scheduling society.* Time Soc 2003;12(1):5–25,

Temporality of energy demand, rhythms and the SPT triad

- Competence-convenience-material artefacts affect also the temporality of energy demand (e.g. manual workers showering after work unlike office workers, with the same purpose of being clean before socialising)

- Rhythms of practices affected by one owns' compromise between e.g. care and convenience, affecting the seek for cold spots

Gram-Hanssen K, et al. *Sequence of practices in personal and societal rhythms – showering as a case*. Time Soc 2020;29(1):256–81
Southerton D. *'Squeezing time': Allocating practices, coordinating networks and scheduling society.* Time Soc 2003;12(1):5–25,

Temporality of energy demand and synchronicity/changes of practices

- Day-light saving schemes as well as DSR create fixity in determining synchronicity of practices (and the entailed energy demand)

- Change: owning a pet (and turning the heating/cooling system on for it while away) as well as the recent massive working from remote caused by CoVid measures lead to more regular residential demand patterns throughout the day

Durand Daublin M. *Time Use policies, energy demand and seasonal rythms: daylight saving time.* Lancaster, United Kingdom; 2019, p. 130–5

Strengers Y et al. *Smart energy futures and social practice imaginaries: Forecasting scenarios for pet care in Australian homes.* Energy Res Soc Sci 2019;48:108–15

Activities and time of use surveys

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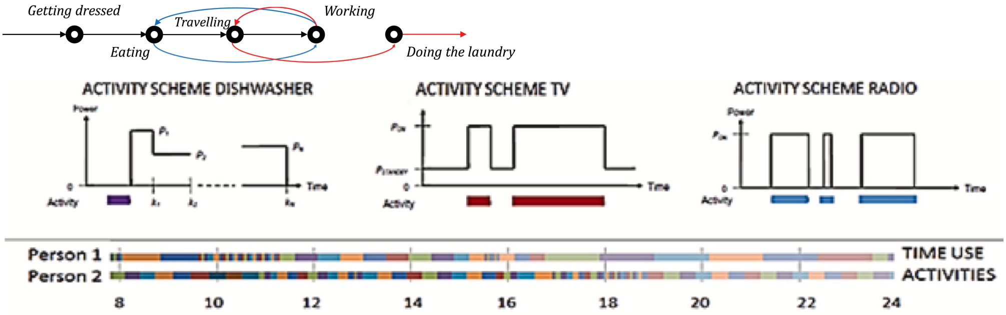
Weekday				
00:00	01:00	Washing	Bathroom	General lighting, hot water
01:00	06:30	Sleeping, dressing	Master bedroom	General lighting, night lighting
06:30	07:30	Washing	Bathroom	General lighting, hot water
07:30	10:00	Eating, sitting, cooking	Living room, kitchen	Gas stove, general lighting
10:00	12:00	Travel		
12:00	13:30	Sitting relaxed	Living room	Mobile phone
13:30	17:30	Travel		
17:30	18:45	Eating	Dining room	General lighting
18:45	19:15	Sleeping	Master bedroom	General lighting
19:15	20:30	Washing	Bathroom	General lighting, hot water
20:30	22:45	Eating, sitting	Living room	General lighting
22:45	01:00	Sitting relaxed	Living room	General lighting
Friday				
00:00	01:00	Watching television	Living room	Television
01:00	07:45	Sleeping, dressing	Master bedroom	General lighting, night lighting
07:45	08:15	Washing	Bathroom	General lighting, hot water
08:15	10:00	Eating, sitting, cooking	Living room, kitchen	Gas stove, general lighting
10:00	12:00	Sleeping	Master bedroom	
12:00	13:30	Sitting relaxed	Living room	Mobile phone
13:30	17:30	Travel		
17:30	18:00	Eating	Dining room	General lighting
21:00	22:00	Watching television	Living room	Television, general lighting
22:00	23:00	Washing	Bathroom	General lighting, hot water
23:00	00:00	Sleeping	Bedroom	Night lighting
Weekend				

Sari DP, Chiou YS *Do Energy Conservation Strategies Limit the Freedom of Architecture Design? A Case Study of Minsheng Community, Taipei, Taiwan.* Sustainability 2019;11(7):2003.

Time of use surveys: understand sequence of activities



- Highlight activities at peak time, identify activities at fixed (washing, cooking) and flexible hours (computer use).

Mckenna E, et al. *Exploratory analysis of time-use activity data using network theory.* Lancaster, United Kingdom; 2016, p. 1–20.
Torriti J. *Temporal aggregation: Time use methodologies applied to residential electricity demand.* Util Policy 2020;64:101039.

Time of use surveys: understand sequence of activities and fixities

- Fixed commuting times even when flexible working hours available (constrained on school time, sport and leisure hours)

- Food preparation and child-caring informed and informing the schedule of other activities

Burkinshaw J. *The tenuous and complex relationship between flexible working practices and travel demand reduction*. In: Hui A, Day R, Walker G, editors. Demanding energy: space, time and change. Cham: Springer International Publishing; 2018, p. 165–81..
Hoolohan C et al. *Food related routines and energy policy: A focus group study examining potential for change in the United Kingdom.* Energy Res Soc Sci 2018;39:93–102..
Torriti J et al. *Peak residential electricity demand and social practices: Deriving flexibility and greenhouse gas intensities from time use and locational data.* Indoor Built Environ 2015.

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Teleworking and flexibility in sequence of activities

- Foster flexible allocation of time amidst house chores and working activity

- More constant residential demand patterns documented throughout the day, however primarily driven by needs of self-organisation rather than an energy demand perspective

Sullivan C, Lewis S. *Home-based telework, gender, and the synchronization of work and family: perspectives of teleworkers and their co-residents.* Vol. 8. No. 2. Gender Work Organization; 2001, p. 123–45.
Hampton S. *An ethnography of energy demand and working from home: Exploring the affective dimensions of social practice in the United Kingdom.* Energy Res Soc Sci 2017;28:1–10.

Time of use surveys and DSM/DSR options

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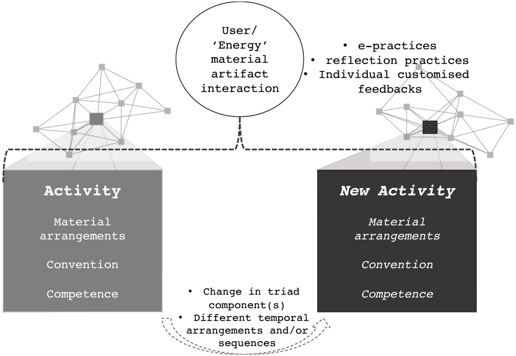

- Introducing a new material artefact can profoundly affect the temporal sequence and the network of activities.
- Knowing what people are doing at a given point in time can foster technological options towards adjusting their residential energy demand.

Powells G et al. *Peak electricity demand and the flexibility of everyday life.* Geoforum 2014;55:43–52.

Time of use surveys and DSM/DSR options

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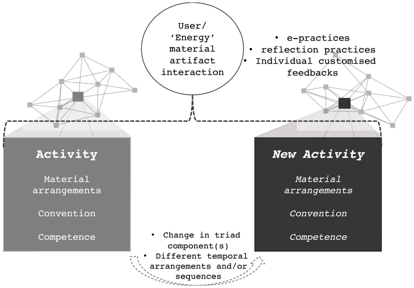

- These interventions along with DSR may introduce elements of arrhythmia in daily routines and rhythms (being back the coupling with rhythms of nature - e.g. wind and solar energy).

- No difficulties in charging EV at night, less likely to unload wet appliances in the morning (sacrifice *cold spot* breakfast with hotspot)

Friis F, Haunstrup Christensen T. *The challenge of time shifting energy demand practices: Insights from Denmark.* Energy Res Soc Sci 2016;19:124–33

Conclusions

- **What approaches have been proposed in the literature to curtail energy demand and/or enact energy-demand temporal shifts?**
- Technologies for reduction in energy demand: more efficient appliances, thermal insulation, etc.
- Technologies for flexibility in energy demand: communication devices to switch on appliances and tune their demand.
- However, borderline: switches also used in context-aware energy management, storage (overall level and temporality of demand).
- *Level of separation:* flexibility -> raise energy demand when generation is available.

Conclusions

- **What are the differences between the social and technical framings of approaches?**
- **What are the levels of separation between the technological modelling and the theoretical frameworks from the domain of social science/humanities?**
- What energy is for and in doing so questioning the non-negotiability of comfort standards (e.g. upon variable practices)
- How measures aimed at shifting the temporal pattern of energy demand may result in producing new fixities caused by specific dimensions and acting at multiple scales
- How energy consumption may backfire upon the adoption of more efficient appliance due to changing practices/comfort standards and/or the addition of new functionalities (complexification of social meanings)

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Conclusions

- **What are the differences between the social and technical framings of approaches?**
- **What are the levels of separation between the technological modelling and the theoretical frameworks from the domain of social science/humanities?**
- The overall effect of societal complexification on societal energy consumption
- How DSM and DSR should be implemented by taking into account how demand temporality emerges from rhythm, synchronisation and sequences of users' practices

Conclusions - what ways forward?

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- A structured dialogue between technical and socio(-)technical perspectives to help each discipline become more informed on the impact of its epistemic positioning

- Collaboration between energy system modellers and social-theory practitioners (or scholars working on the coupling of energy and social systems)

- Working on iterative rounds of (socio-)technical modelling and social practice theory practitioners joint assessments of DSM/DSR options

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Let's stay in touch

Thank you for your kind attention

I am looking forward to your questions

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