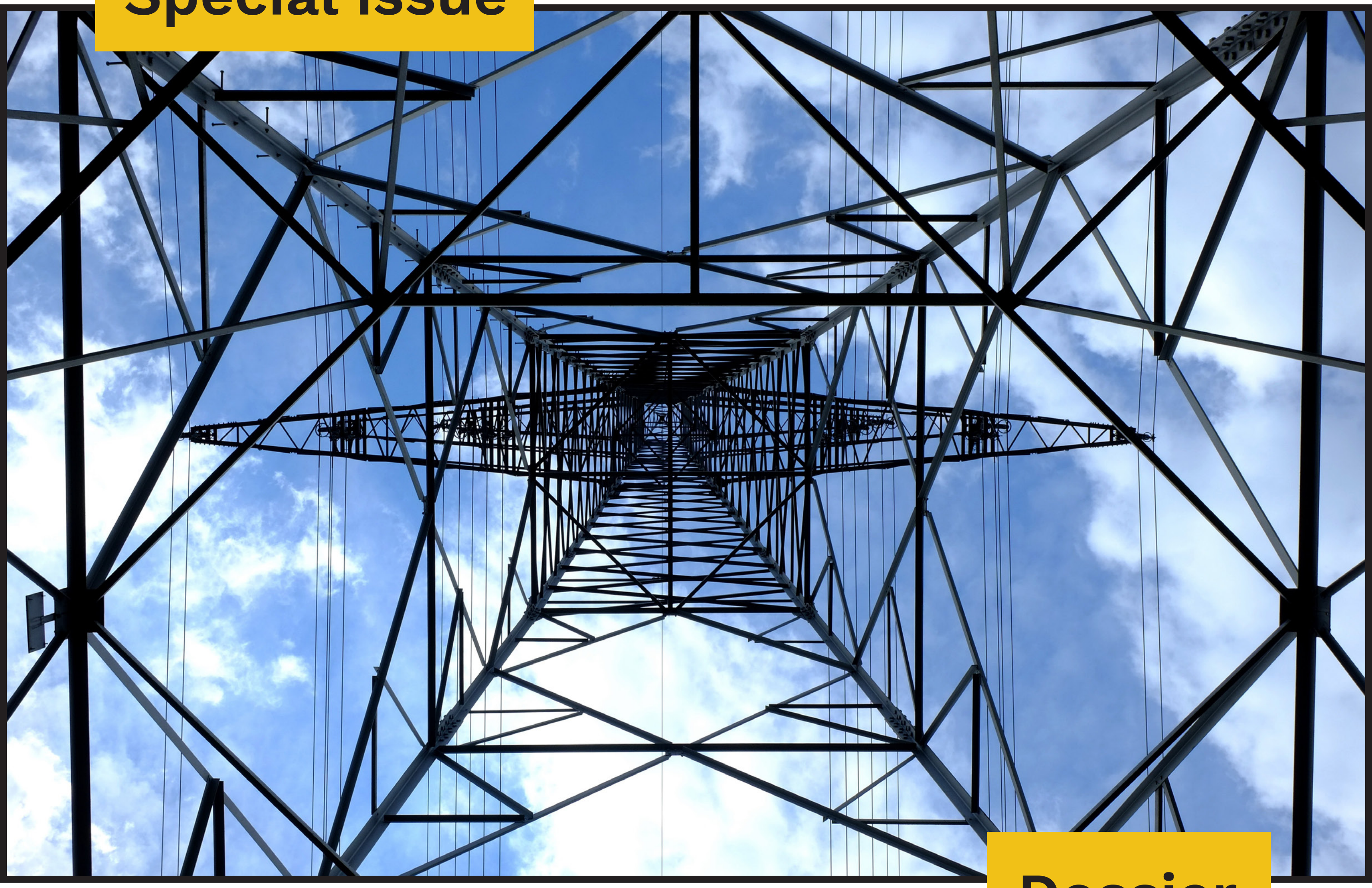
JEH RHE
Journal of Energy History
Revue d'Histoire de l'Énergie

#5

Special issue

Historicising Flexibility



Dossier

Historiciser la flexibilité

NUMBER 5 - DECEMBER 2020

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

Summary

SPECIAL ISSUE

REVIEWS

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

SPECIAL ISSUE

Historicising Flexibility

ISSN 2649-3055

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

Flexibilities in Energy Supply and Demand: Legacies and Lessons from the Past

AUTHOR

Stanley Blue
Sociology, Lancaster University,
@stanleybluephd
Peter Forman
Geography and Environmental Science, Northumbria University,
@PeterJForman1
Elizabeth Shove
Sociology, Lancaster University,
@ElizabethShove

POST DATE
05/05/2021
ISSUE NUMBER
JEHRHE #5
SECTION
Special issue
THEME OF THE SPECIAL ISSUE
Historicising Flexibility
KEYWORDS
Network, Distribution, Consumption, Gas, Electricity
DOI
in progress

TO CITE THIS ARTICLE
Stanley Blue, Peter Forman, Elizabeth Shove, "Flexibilities in Energy Supply and Demand: Legacies and Lessons from the Past", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 05 May 2021, URL: energyhistory.eu/en/node/249.

Abstract
The goal of maintaining current levels of energy supply and demand whilst reducing their carbon intensity will require greater use of renewables. As a result, new forms of flexibility will be needed. While the emerging "flexibility industry" promises solutions based on current configurations, this collection shows that the problem of managing fluctuations in the relation between supply demand is not new. The papers included in this special issue work with different approaches and scales of analysis, but all show that lessons for balancing energy supply and demand today can be drawn from the past. Just as important, they show that the legacies of past practices and infrastructures live on and have effect in contemporary energy systems.

Acknowledgements
This work was funded by UK Research and Innovation (grant agreement number EP/R035288/1) as part of the Centre for Research into Energy Demand Solutions (CREDS). Thanks to Jacopo Torriti and the Flexibility Theme; to everyone who contributed papers to this special issue and to the workshop discussion, and special thanks to Léonard Laborie and to the mentors and referees who have helped along the way.

Plan of the article

INTRODUCTION

1 Flexibility has emerged as a central concern and as an increasingly important concept for governments and institutions committed to the project of rapidly decarbonising energy systems.[1] This makes sense: if the goal is to reduce the carbon intensity of energy networks while maintaining present levels of energy supply and demand, there is no option but to make much greater use of more renewable sources of energy (e.g. wind, solar, tidal power). Since patterns of generation are intermittent (following seasonal or diurnal cycles, including tidal flow), new forms of flexibility are needed to keep supply and demand in balance.

2 These challenges have created opportunities for what is known as the "flexibility industry", and for organisations promising to help utilities "... respond rapidly to large fluctuations in demand and supply, both scheduled and unforeseen variations and events, ramping down production when demand decreases, and upwards when it increases."[2] Decarbonisation implies greater flexibility across the energy system as a whole, and a range of interventions and solutions are proposed, some of which are more relevant to gas (which is easier to store) than to electricity. These include commodifying non-consumption, paying businesses and organisations to shed or reduce consumption when demand is high, and/or encouraging fuel switching to balance loads. In the residential sector, tariffs, price signals, and other sorts of information, including data on carbon emissions are designed to encourage consumers to change the timing of what they do and to use electricity during off-peak hours. On the supply side, various strategies are adopted including "packing" gas into the network and ramping up electricity supply to cope with peaks in demand.

As one might expect there are different ways of conceptualising flexibility.[3] Is it a feature of "whole" energy systems? Is it a commodity (being bought and sold as a means of balancing supply and demand)? Is it a term that describes strategies for demand side management? Does it refer to an individual or organisational capacity to "flex"? Or is it best understood as a feature of how social relations and rhythms of production and consumption are entangled? Whatever the response, there is a tendency to think of flexibility as a new problem. Rather than tracing the history of the concept of flexibility, and rather than supposing that there could be one such narrative, the papers in this collection show that the problem of balancing supply and demand has been formulated, understood, and acted on in different ways and at different scales in particular times and places. 3

In putting this special issue together one aim is to draw lessons from the past and to enrich and inform the ways in which flexibility is understood today. In taking this agenda forward, contributors bring the insights of historical research to bear on contemporary social, technical, economic, and political questions about energy supply and demand. In doing so they make use of concepts from social theory – for example, emphasising the layering of infrastructural and institutional relations; the recursive dynamics of supply and demand, and the salience of "scale" for the analysis of more and less flexible configurations. This combination of approaches is consistent with our second aim which is to foster interdisciplinary exchange between historians and social scientists as a means of revealing the legacies of 4

1 See, for example, Ofgem, "Upgrading our Energy System: Smart Systems and Flexibility Plan" (HM Government, UK, 2017). **https://www.ofgem.gov.uk/publications-and-updates/upgrading-our-energy-system-smart-systems-and-flexibility-plan**. Stéphane Goutte, Philippe Vassilopoulos, "The Value of Flexibility in Power Markets", *Energy Policy,* vol. 125, 2019, 347-357. Eric Martinot, "Grid Integration of Renewable Energy: Flexibility, Innovation, and Experience", *Annual Review of Environment and Resources*, vol. 41, 2016.

2 International Energy Agency, *Empowering Variable Renewables: Options for Flexible Electricity Systems* (Paris: IEA, 2008), 14. **https://www.iea.org/publications/freepublications/publication/Empowering_Variable_Renewables.pdf**

3 Stanley Blue, Elizabeth Shove, Peter Forman, "Conceptualising Flexibility: Challenging Representations of Time and Society in the Energy Sector", *Time & Society*, vol. 29 n° 4, 2020.

previous policies, strategies, and practices for present systems and infrastructures of provision.

5 Although some authors are historians by training, others have backgrounds in sociology, engineering, geography, and science and technology studies. This is relevant for how contributors approach, conceptualise, and make use of historical material. Other differences have to do with the spatial scale of analysis. For example, Shaw, Moss and Sareen, and Hatton-Proulx describe infrastructural relations within cities. By contrast, Silvast and Abram report on the details of network management as that is enacted in gas and electricity control rooms. There are also differences in the time scales across which these studies extend. For example, some contributions describe the development of infrastructures (and related patterns of demand) over several decades (Hatton-Proux; Moss and Sareen); others select a series of revealing turning points (Shaw) and phases (Forman), or zoom in on one moment in time (Fell). In their different ways, all these strategies shed light on the challenges of managing supply and demand, and on how these have been understood and handled in different settings.

6 The result is a collection that reveals the multiple and layered socio-material-political geographies of energy systems and the various flexibilities that they afford and enable. It shows how material legacies (in the form of infrastructures and networks) are intertwined with ideological legacies; with embedded assumptions and interpretations of consumers, markets and control, and with the fluctuating sociotemporal rhythms of both supply and demand. More specifically this special issue shows how the balance and the mix of consumption and provision has been thought about and how these schools of thought persist and change.

7 The rest of this introduction maps out the themes that link these papers together, and highlights the conclusions and insights arising from this novel conjunction of methods, sites, and units of analysis and enquiry.

FLEXIBILITY IS MULTIPLE, DISPERSED AND EMERGENT

Rob Shaw's paper on "polyflexibility" introduces a range of ideas that also frame the collection as a whole. Inspired by Lefebvre's rhythmanalysis, Shaw writes about how different kinds of flexibilities constructively and destructively interact with one another. In taking this approach he suggests that what constitutes flexibility at a given time, and in a particular place, is an outcome of how financial, political, technological, social, and legal assemblages combine. 8

These effects and processes are revealed via a careful analysis of public lighting in Newcastle-upon-Tyne in the UK. In detail, Shaw describes the "modalities" (of governance, infrastructure, finance) that characterise the gradual introduction of electric lighting; the management of lighting during the Second World War, and the phasing in of LED (responsive) lighting (today). 9

Drawing on documents and reports produced by the Eastern Electricity Supply company, the Newcastle Lighting Committee, the City Police, and local newspapers, Shaw describes how the interests of various parties not only matter in moments of transition, but have effect on and shape the future capacities of each other all the time. As this study shows, and as other contributors demonstrate, the possibilities of the present (in this case, the scope for adopting smart, agile, and responsive LED public lighting) are defined by the material, ideological, and institutional "legacies" of previous configurations. 10

More importantly, the notion of polyflexibility recognises that flexibility is not singular, and not a property of a given service, system, or person. Rather, it is dispersed and emergent, dependent on and contributing to the unfolding of possible historical interactions and, the capabilities of related modalities. The articles included in the rest of the special issue explore different aspects of this multiplicity, starting with a discussion of how changes in the domestic use of gas matter for the timing of demand and the development of gas networks in the UK. 11

FLEXIBILITY IS A PRODUCT OF INTERCONNECTED ENERGY SYSTEMS AND THEIR HISTORIES

12 The fact that gas can be stored does not undermine the importance of balancing supply and demand in real time. Forman works with selected material from the UK's National Gas Archives to show that the practicalities of managing this relation depend on what gas is used for, and as a result, when demand occurs. When gas was mostly used for lighting, peaks occurred at night and during the winter. When it was used not only for lighting, but for cooking and/or for industrial manufacturing new rhythms of demand came into play that required different networks and arrangements of provision. Now that gas is predominantly used for heating, seasonal fluctuations are much more important than variation through the day. The first point that this paper makes is that these changes depend on a two-way street. This is obvious in Forman's description of how utilities have responded, and in how changing patterns and temporalities of demand figure in the design and management of the gas network as a whole. A second insight is that the material and institutional organisation of gas cannot be seen in isolation: the shift from one dominant end use to another relates to the positioning of gas alongside other fuels, including electricity. These conclusions underline the point that the flexibility of a given fuel is a relational and not an essential property. More specifically, it depends on what any one energy source is used for not in the abstract, but alongside coexisting fuels, technologies, and everyday practices.

13 Contemporary debates about flexibility and decarbonisation tend to focus on when and how the timing of electricity demand might need to "flex" in order to accommodate more renewable but intermittent supply. The place of gas, and indeed other fuels, is missing from this debate, as is an understanding of the historical legacy of different systems and scales of provision – all of which are, in turn, related to changing patterns of end use and thus demand. Recognising these complexities takes us deeper into themes of modality and assemblage, as introduced by Shaw. The next two papers also consider the effects and legacies of different modalities within an energy system or assemblage, but do so by focusing specifically on different spatial scales: an energy utility and a city respectively.

FLEXIBILITY IS POSITIONED AT THE INTERSECTION OF SUPPLY AND DEMAND

Hatton-Proulx's history of Montréal Light, Heat and Power shows how the ebb and flow of demand and supply in Montréal have been managed by just one monopoly supplier in the time between the First World War and the Great Depression. This work complicates more familiar narratives of endless growth, revealing significant fluctuations within energy systems, including moves back and forth between fuels and between "modern" (networked) and "traditional" systems like heating with wood. In characterising these "stop-go" patterns, this paper distinguishes between fluctuations that are, at different times, primarily associated with provision on the one hand, or consumption on the other. 14

By zooming in on a particular location and utility, Hatton-Proulx reveals the detail of changes and fluctuations in the balancing of energy supply and demand, and their volatility, including the effects of major changes in demand associated with the First World War and the Great Depression. As represented here, different forms of flexibility arise as a consequence of the asymmetric and contingent relationship between supply and demand. Although aspects of this case are specific to the location, this paper points to the fact that the challenge of handling intermittency, gaps, and major fluctuations is an unavoidable aspect of making and managing networked infrastructures. 15

FLEXIBILITY IS AN OUTCOME OF POLITICAL AND INSTITUTIONAL ARRANGEMENTS

Moss and Sareen also write about the reconfiguring of supply and demand, this time focusing on developments in one city (Berlin) over a hundred year period. These authors use archival 16 material and secondary literature to identify and describe the social, political, and economic events that have shaped Berlin's energy systems since 1920.

17 Much of their description has to do with the spatial organisation of supply and the impact this has on methods adopted to balance loads "locally". More specifically, Moss and Sareen describe the gradual erosion of material arrangements born of an "insistence" on the local production of town gas and electricity. As they explain, the details of infrastructural systems – their size, siting, and capacity – are products of a complex history of political decisions and circumstances, including sometimes spectacular dips in the demand for different fuels. These legacies, inseparable from dramatic upheavals in East and West Berlin, and in the city's unification, have a tangible impact on present patterns of provision.

18 The point is not simply that current possibilities, and current flexibilities (or inflexibilities) are outcomes of the social, political, and material "layering" of infrastructures. While this is one important conclusion, the study of Berlin underlines the extent to which systems of provision in any one location are (and are not) entangled with networks that extend across much larger spatial scales. Given that the interweaving of urban and extra-urban relations is inseparable from the histories of the places involved, flexibility is, in this account, a product of the intersection of quite specific material, institutional, and ideological legacies.

FLEXIBILITY IS A FEATURE OF SERVICE PROVISION

19 The prospect of selling heat-as-a-service (that is, selling certain levels of domestic heating for a fixed price, rather than selling gas or electricity) is currently discussed as a potential solution that allows energy suppliers to meet heating requirements in the most cost effective and carbon efficient way possible. This is not a new idea and in his paper Fell revisits "Budget Warmth", a heat-as-a service, commercial tariff introduced in the UK during the 1980s.

20 Fell's review of industry journals and government reports, alongside an interview with a key informant formerly working at the Electricity Council, reveals some of the tensions that prevented widespread uptake of this scheme. These included consumers' sense of being "out of control", combined with a reluctance to sign up to long term contracts of the kind that providers needed if they were to recoup their costs. To complicate matters, methods of measuring domestic energy use (in the form of heat) were not precise enough at the time to enable providers to modify the timing of provision and thereby benefit financially from the capacity to control domestic load.

21 This one case reveals the importance of an historical understanding of previous "successes" and "failures" but not in the way that one might expect. As Fell describes, the specificities of context and setting are massively important for the fate of schemes like "Budget Warmth". This makes sense, but it also confounds attempts to extract and apply lessons from the experiences of the 1980s to the present day. Instead, the more important point is that consumers' expectations (for example of controllable, instantly adjustable temperatures) are not separable from prevalent systems of provision, including the sizing and design of energy supplies and heating technologies. In other words, interventions such as Budget Warmth have effect (or not) within and as part of a system of expectations and technologies that is constantly in motion.

22 The contributions from Forman, Hatton-Proulx, Moss and Sareen, and Fell shed light on aspects of what Shaw conceptualises as polyflexible socio-material assemblages. Despite taking different angles, and despite working across different historical periods and with diverse materials, these authors describe flexibilities as these are constituted at the intersection of multiple modalities - of governance, infrastructure, and finance. In bringing these threads together,

the final paper in the collection takes a closer look at how contemporary methods of handling fluctuations in the supply-demand relation are shaped by material and ideological legacies, and by networks that have been built, adapted and repurposed over the years.

FLEXIBILITY IS A FEATURE OF HOW ENERGY IS DISTRIBUTED IN SPACE AND TIME

23 Silvast and Abram's ethnographic study of what engineers and control room operators do and how their work is organised shows how multiple histories of the sort explored in the other papers in this special issue intersect and combine. This study, which involved observations of gas and electricity control rooms in the North of England (in 2019), oral histories, and an analysis of trade and technical journals, provides a compelling account of the layering of sociotechnical systems of mixed vintage, and of how past infrastructures define the limits and possibilities of flexibility today. In addition, and as Silvast and Abram explain, methods of network management have histories of their own. These are reproduced in the embodied knowledge of engineers, in the experiences they accumulate, and in the changing challenges of balancing supply and demand in real time.

24 These come together in the control room, and in the training and "culture" of the various occupational groups involved in maintaining networks and in managing the energy that flows through them. None of these aspects is stable. For example, as new equipment is installed and as skills in predicting and forecasting demand become more important, other forms of expertise (including that of managing so-called "legacy" assets) becomes redundant. Similarly, as the features of the network change, the function of the control room, and the scope for making adjustments to accommodate fluctuations in supply and demand, change as well.

25 When viewed in this way, the work of control room operators provides unrivalled insight into how technologies and skills shape each other, and into how these relations unfold over time. Just as important, it shows how past rationales and the forms of infrastructural investment associated with them inform current ambitions and programmes of reinforcement and renewal.

LEGACIES AND LESSONS

There is some truth to the claim that patterns of flexibility are defined by the historical development of infrastructures and by related patterns of demand. Existing energy systems have features (size, capacity, interdependence) that are important for how they are managed and controlled, and for how easy they are to "flex" and adapt. This is something that policy makers would do well to remember. 26

That is one interpretation, and that is one way of reading the papers we have gathered here. However, there are other ways of thinking about the contemporary relevance of the past. In treating energy systems as entangled and dynamic combinations of physical, ideological, and institutional arrangements, contributors to this collection treat them as "assemblages" that are continually in motion. From this perspective it is impossible to pin down or systematically trace the origins or "sources" of contemporary flexibility. Flexibility is, instead, conceptualised as an outcome of the changing *relation* between supply and demand, and of intersecting formations of legal, financial, social, governmental, and technical modalities. 27

That is to say that past modalities live on, and have effect in, present arrangements. This is in keeping with Schatzki's conclusion that past everyday practices and the infrastructural arrangements of which they are a part do not just prefigure but continue to exert their presence on current configurations: 28

> "...the past is present in pushing or carrying across the alleged gap or boundary between it and the present, present events dropping "like ... over-ripe fruit[s]" as the past presses into the future. These conceptions thus hold that the gap between past and present is an illusion. The past is *in* the present. It has not

> fallen away behind the present, consigned to inertness, irrelevance, or inexistence."[4]

29 The suggestion that past configurations have effect *within* and as part of contemporary conventions and understandings of normal practice has implications for the status of historical analysis. From this point of view, the legacy of historical arrangements is reproduced in the present, and in how layers of infrastructure and expectation prefigure and restrict future interpretations of limits and possibilities in supply as well as in demand.

30 This argues for a distinctive role for historical research. When faced with the need to rapidly decarbonise and thus increase the flexibility of the energy system as a whole, policy makers would do well to take note of the *dynamic* processes in play and of the longer and shorter-term "trends" of which present configurations are made. In this context, the contribution is not so much that of explaining how existing infrastructures come to be as they are. Rather it is a matter of better understanding the sorts of relations and tensions that animate ebbs and flows in supply and demand. As the articles in this collection demonstrate, the flexibility of a given service, source, system, or demand is never absolute. Instead it is always extended, relational, and multiply interwoven.

31 Capturing these connections calls for combinations of theory and method and for styles of enquiry that are not the province of sociology, or of history alone. This collection gives a taste of what such hybrid studies have to offer.

4 Theodore R Schatzki, *The Timespace of Human Activity: On Performance, Society, and History as Indeterminate Teleological Events* (Plymouth, UK., Lexington Books, 2020).

Bibliography

Blue Stanley, Shove Elizabeth, Forman Peter
"Conceptualising Flexibility: Challenging Representations of Time and Society in the Energy Sector", Time & Society, vol. 29, n° 4, 2020, 923-944.

International Energy Agency
Empowering Variable Renewables: Options for Flexible Electricity Systems (Paris: IEA, 2008). **https://www.iea.org/reports/empowering-variable-renewables-options-for-flexible-electricity-systems**

Goutte Stéphane, Vassilopoulos Philippe
"The Value of Flexibility in Power Markets", *Energy Policy*, vol. 125, 2019, 347-357.

Martinot Eric
"Grid Integration of Renewable Energy: Flexibility, Innovation, and Experience", *Annual Review of Environment and Resources*, vol. 41, 2016, 223-251.

Ofgem
"Upgrading our Energy System: Smart Systems and Flexibility Plan" (London: HM Government, UK, 2017). **https://www.ofgem.gov.uk/publications-and-updates/upgrading-our-energy-system-smart-systems-and-flexibility-plan**

Schatzki Theodore R.
The Timespace of Human Activity: On Performance, Society, and History as Indeterminate Teleological Events (Plymouth, UK: Lexington Books, 2020).

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR
Peter J. Forman
University of Northumbria (UK)
peter.forman@northumbria.ac.uk

POST DATE
18/12/2020
ISSUE NUMBER
JEHRHE #5
SECTION
Special issue
THEME OF THE SPECIAL ISSUE
Historicising Flexibility
KEYWORDS
gas, consumption, heat, light, town
DOI
in progress

TO CITE THIS ARTICLE
Peter J. Forman, "Histories of Balancing Demand and Supply in the UK's Gas Networks, 1795 – Present", *Journal of Energy History/ Revue d'Histoire de l'Énergie* [Online], n°5, published 18 December 2020, URL: energyhistory.eu/en/node/232.

Histories of Balancing Demand and Supply in the UK's Gas Networks, 1795 – Present

Abstract
This paper provides an account of how past changes in energy demand have affected the balancing of the UK's gas systems between the introduction of gaslight in 1795 and the present day. Four periods are examined in which the principal uses of gas have broadly differed: periods in which the dominant uses of gas were respectively for lighting, cooking, industrial manufacture, and central heating. For each period, the paper describes how changes in the ways gas was used influenced patterns of demand and introduced opportunities and challenges for processes of balancing. Also described are how systems of gas provision were widely restructured in response to these shifts in patterns of gas demand. Three key observations are developed: that issues with balancing demand and supply are not limited to electricity networks but have been, and continue to be, critical to the organisation of gas systems; that the ways in which energy is used influence the timings (durations, frequencies, regularities), intensities, and geographies of demand and condition the balancing strategies that are possible within given contexts; and that how energy is used, and thus the composition of demand and its relationship to patterns of supply, is dynamic.

Acknowledgements
My sincere thanks go to the editors and reviewers of this special issue for their comments throughout the development of this article. Thanks also go to Jean-Pierre Williot at Sorbonne University, to the team at the National Gas Archives, and to Tony Coles. Your knowledge, insights and assistance all helped to make this paper possible.

Plan of the article

INTRODUCTION

1 In the fields of energy provision, policy, and research, discussions over the 'flexibility' of contemporary energy systems have centred around the challenges involved in balancing dissonant patterns of supply and demand within electricity systems.[1,2,3,4] These challenges have emerged as renewable energies have progressively displaced fossil fuels within processes of electricity generation. Material differences in the ease and rapidity with which fossil fuels can be stored, transported or made to produce electricity, compared with renewable resources such as the sun, wind, and tides, have resulted in a growing disconnect between the times when electricity is most available and the times when it is most 'needed'.[5] Flexibility has consequently been considered primarily in relation to electricity systems and attention has been focused on understanding how changes in the material compositions of supply can affect processes of balancing.

2 This paper instead focuses on how changes in the composition of energy demand can influence processes of balancing. This relationship is examined through a historical case study of demand and supply within the UK's gas systems between the years 1795 (the year of coal gas's first UK commercialisation) and the present day. Like today's electricity systems, the UK's gas networks have historically experienced significant fluctuations in patterns of demand and supply and these fluctuations have created distinct challenges for processes of balancing, often bearing striking similarities with contemporary 'flexibility' concerns. As former gas engineers such as Le Fevre have, for example, noted:

> "[t]he provision of an adequate and consistent supply of gas [...] would be a comparatively simple problem if the public demand for gas were itself consistent. But unfortunately, it is far from being consistent. Like all other public requirements, it is subject to rush-hours (periods of peak demand), while being equally prone to slack or off-peak periods".[6] 3

Moreover, 'flexibility' has itself often been explicitly invoked as a potential solution to these issues. Smith, for example, writing: 4

> "So we come to the second fundamental of gas distribution – the fact that the system must be sufficiently flexible to meet the many and varied demands likely to be made upon it".[7] 5

Today, gas is primarily used in the UK for domestic cooking and heating (32.07%), electricity generation (28.31%), and in industrial and commercial applications (20.76%).[8] In the past, however, it was used in a much wider range of activities, including lighting, transport, refrigeration, ironing, hair drying, image projection, and even powering radios.[9] In this paper, I suggest that there have been four periods since 1795 in which the consumption of gas became particularly closely associated with specific activities. These involved periods of prominence for gaslight (1795-1877); gas cooking (1878-1938); 6

1 David Sanders, Alex Hart, Manu Ravishankar, Joshua Brunert, *An Analysis of Electricity System Flexibility for Great Britain* (London: Carbon Trust/Imperial College, 2016).
2 Department for Business, Energy and Industrial Strategy (BEIS), *Upgrading Our Energy System: Smart Systems and Flexibility Plan* (London: BEIS, 2018).
3 International Energy Agency (IEA), *Energy Transitions in G20 Countries: Energy Transitions Towards Cleaner, More Flexible, and Transparent Systems* (2018). URL: https://webstore.iea.org/energy-transitions-in-g20-countries-energy-transitions-towards-cleaner-more-flexible-and-transparent-systems (accessed 22/6/20).
4 Antony Froggatt, Daniel Quiggin, *The Power of Flexibility: The Survival of Utilities During the Transformations of the Power Sector* (London: Royal Institute of International Affairs, Chatham House, 2018).
5 Philip Grunewald and Marina Diakonova, "Flexibility, Dynamism and Diversity in Energy Supply and Demand", *Energy Research and Social Science*, n°38, 2018, 58-66.
6 R. Le Fevre, *Gas Distribution Engineering: The Principles for Students* (London: Walter King Ltd., 1948), 2.
7 Norman Smith, *Gas Manufacture and Utilization* (London: The British Gas Council, 1945), 85.
8 Department for Business, Energy and Industrial Strategy (BEIS) *Digest of UK Energy Statistics (DUKES): Natural Gas* (London: BEIS, 2019). URL: https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes (accessed 06/07/20).
9 Examples of these devices can be viewed at the National Gas Museum in Leicester.

industrial manufacture (1939-1959); and gas-fired domestic central heating (1960-present). Whilst none of these periods involved a totalising shift towards a single application, each reflects a trend towards a dominant way of using gas. I show how these shifting trends have resulted in major alterations to the temporal and spatial characteristics of gas demand and have thereby introduced new opportunities and challenges for processes of balancing; opportunities and challenges that have often been associated with repeated and dramatic reconfigurations of gas's systems of provision.

7 In documenting these historic patterns of demand and supply, the paper draws on written evidence from the UK's National Gas Archives. This material includes articles from industry journals, internal company documents (annual reports, company procedures, operational manuals, archived correspondence), historic legislation, and published secondary histories. Three observations are developed from analysing this material: 1) that issues concerning the balancing of demand and supply are not limited to electricity systems but have been, and continue to be, critical to the organisation of gas systems (albeit often for different reasons and involving different timescales); 2) that how energy is used influences the timings (durations, frequencies, regularities), intensities, and geographies of peaks and troughs in energy demand and can introduce new opportunities and challenges for processes of balancing; and 3) that the composition of energy demand is dynamic: its timings, intensities and geographies shift as the uses of energy change.

8 The paper proceeds as follows. Section 2 describes the period between 1795 and 1877 when gas was primarily used for artificial lighting. Section 3 focuses on the years between 1878 and 1938, when gas was mainly used for cooking. Section 4 examines the period between 1939 and 1959, when gas was predominantly used within industrial processes. And section 5 describes the increase in domestic central heating that took place from the 1960s. The paper concludes with a reflection on the consequences of these examples for conceptualising processes of balancing.

GASLIGHT (1795 – 1877)

The first instance of a methane-based gas being used within commercial applications in the UK was in 1795, when industrial gas-lighting systems were commissioned at Neath Abbey ironworks (South Wales) and at a factory in Old Cunnock, Ayreshire (Scotland).[10] Known as 'coal gas', this fuel was produced by baking coal in retorts that isolated it from oxygen,[11] and it was initially used principally for lighting mills and factories. Coal gas offered significant advantages over candles, producing a stronger light that was less susceptible to starting fires.[12] The consequent reduction in fire risk lowered insurance premiums and helped to offset the high cost of gaslighting equipment.[13] 9

It was these costs that meant that, apart from one or two affluent enthusiasts, the initial producers and consumers of coal gas were almost exclusively mills and factories. This began to change in 1814 with the opening of the first public gasworks in London, the purpose of which was to produce and distribute gas to private consumers for the purposes of lighting.[14] At first, these consumers were limited to affluent individuals and local councils, the latter using it to deliver the new public service of streetlighting.[15] However, as 10

10 Experiments using gases for energy services began much earlier, in locations other than the UK. 1795 only marks the commissioning of the first gaslight system for commercial use. The more concerted marketing of gaslight took place from 1802 onward, mainly through the campaigning of Frederick Winsor. For more information, see: Everard Stirling, *The History of the Gas Light and Coke Company 1812-1949* (London: A&C Publishers Ltd., 1992 [1949]).

11 Samuel Hughes, *A Treatise on Gas-Works and the Practices of Manufacturing and Distributing Coal Gas* (London: Lockwood & Company, 2010 [1871]).

12 John Maiben, *A statement of the advantages to be derived from the introduction of coal gas into factories and dwelling houses, as a substitute for the lights now in use: together with observations on the method of making and using it* (Perth: John Maiben & Company, 1813).

13 Malcom Falkus, "The Early Development of the British Gas Industry, 1795-1815", *Economic History Review*, vol. 35, nº 2, 1982, 217-234.

14 Stirling, *The History* (cf. note 10).

15 John Wilson, *Lighting the Town: A Study of Management in the North West Gas Industry 1805-1880* (London: Paul Chapman Publishing Ltd, 1991).

further gasworks opened and expanded, the price of coal gas fell and domestic gaslighting became increasingly widespread.[16] The manufacturing and distribution systems for coal gas subsequently became known as 'town gas networks', each typically serving a single town or district and consisting of an array of buried pipes that connected dispersed consumers to a central gasworks. By 1819, town gas networks had been established in the cities of Bath, Birmingham, Bristol, Cheltenham, Edinburgh, Exeter, Glasgow, Leeds, Liverpool, London, Preston, and Manchester.[17] By 1882, this number had risen to over 500.[18]

11 Even before the debut of town gas networks however, challenges had emerged concerning the balancing of demand and supply for gas. In mills and factories (as within town networks from 1814 onward), artificial light was generally required only during the hours of darkness and daily demand was characterised by a pronounced evening peak.[19] Conversely, patterns of production required consistency across the day. Manufacturing processes were often slow to start, with retorts taking time to heat up. These devices also did not react well to rapid alterations in operating procedures and gas workers therefore had to gradually heat their retorts and produce gas over extended periods.[20] This resulted in a diurnal disconnect between the timings of peak gas demand and the timings of supply.

12 In 1805, gasholders were developed in response to this tension.[21] Gasholders were a simple form of gas storage that consisted of gas-tight containers. Their deployment enabled gas to be produced at a constant rate (gas being stored across the day) and then rapidly withdrawn as peaks in demand developed. Their deployment marked a notable shift in operational approach. Previously, manufacturing plant had been sized around a maximum level of *momentary demand,*[22] but now the scaling of these facilities became framed around a calculated level of maximum *daily demand.*[23] Gasholders were therefore built to be of "sufficient capacity to contain the maximum quantity of gas produced in twenty-four hours".[24]

Yet, whilst this new scaling helped to balance the diurnal disconnect between the timings of demand and production, it also introduced a problem. As the principal use of gaslight shifted from mills and factories to houses and streets, demand for gas grew rapidly. However, because gas systems had been sized around a static calculation of maximum daily demand, the scale of gasholders, pipes and workforces became increasingly inadequate for balancing gas supplies with the growing intensities of demand. Almost everything about town gas networks consequently had to be resized once demand reached a certain level. Necessary alterations were often extensive, including enlargements to the diameters of distribution pipes, increases in the number and size of gasholders and retorts, and the recruitment of larger workforces.[25] 13

Moreover, during this period, town gas networks began to experience issues with seasonal fluctuations in demand. Hours of darkness in the UK vary across the year, with summers being 14

16 Stirling, *The History* (cf. note 10).
17 British Gas, *Gas Chronology: The Development of the British Gas Industry* (London: British Gas, 1980).
18 Malcolm Peebles, *Evolution of the Gas Industry* (New York & London: New York University Press, 1980).
19 Smith, *Gas Manufacture and Utilization* (cf. note 7).
20 Douglas Copp, *Gas Transmission and Distribution* (London: Walter King Ltd, 1967).
21 Leslie Tomory, "Fostering a new industry in the Industrial Revolution: Boulton & Watt and gaslight 1800–1812", *The British Journal for the History of Science*, vol. 46, n°2, 2013, 199-229.
22 Momentary demand' is an engineering term that refers to the volume of gas exiting a gasworks in a given moment, as a result of its consumption or release across the network. See, for example, Le Fevre, *Gas Distribution Engineering* (cf. note 6). However, this figure rarely reflects the total demand occurring across the network in a given instant. Due to the slow movement of gas, and because a surplus of gas is stored gas within pipes, there is often a significant lag between when gas is consumed and when it leaves a gasworks.
23 Despite this, the size of gas distribution equipment still had to be "sufficient to cope with the maximum momentary demand" - Le Fevre, *Gas Distribution Engineering* (cf. note 6).
24 Hughes, *A Treatise on Gas Works* (cf. note 11), 195.
25 *Id.*

characterised by longer periods of daylight than winters. As a result, demand for gaslight assumed a strongly seasonal character, peaking in midwinter and declining to almost nothing during summer months.[26] Whilst similar fluctuations had affected mills and factories before, the increasing scale of town gas networks rendered seasonality a more pressing issue. Having invested heavily in higher-capacity plant and larger workforces, town gas networks were faced with regular forms of infrastructural and labour redundancies, as levels of gas demand dramatically declined during the summer.[27] Gasholders had limited value in managing these fluctuations because they had been scaled around demand fluctuations over the timescales of days, not around longer durations such as weeks and months. Gas companies therefore had to develop alternative approaches to balancing, the most common involving operating existing plant at reduced loads during the summer (at the expense of efficiency), and/or relying upon seasonal workforces.[28] Indeed, until at least 1911, many gas workers were only employed during winter months.[29,30,31]

COOKING (1878 – 1938)

15 Between 1878 and 1938, the dominant use of gas broadly shifted from lighting to cooking. This was closely associated with the introduction of electric light, which despite experiments with arc lighting during the early 1800s, only became commercially viable with the invention of the incandescent lightbulb in 1878. Electric light first entered the UK's lighting markets in 1879,[32] but it didn't become widely available until the metal filament had been invented (1911) and after that, when the UK's Electricity (Supply) Act had been passed (1926). Despite this slow start, it was clear by 1878 that the brighter, cleaner light promised by electric lighting would present gaslight with significant competition.[33]

By 1878, a mature, nationally regulated coal gas industry had developed, consisting of a multitude of organisations involved in manufacturing and distributing coal gas, developing appliances, and maintaining consumer installations. This industry responded to the emerging competition from electricity in two ways. First, it took efforts to improve gaslight's competitiveness relative to electric light, culminating in the UK launch of the first Welsbach incandescent mantles in 1887.[34] These devices fitted over existing gas lamps and produced a comparable light to electric bulbs. They were comparatively inexpensive and easy to install, and they required no new wiring or appliances. As such, they offered a compelling alternative to electric light and they have since been credited with slowing the rate of gaslight's demise.[35] 16

The gas industry's second response was to diversify the markets for coal gas. Attempts at this had begun in 1824 with the release of the first gas cookers, followed by a series of high-profile demonstrations in the following years.[36,37] Diversification was only really pursued in earnest after 1900 however, as competition from the nascent electricity industry began to develop. Efforts to facilitate this included the formation of the Society of British Gas Industries in 1905 (which supported the interests of appliance developers), the creation of 17

26 Smith, *Gas Manufacture and Utilization* (cf. note 7).
27 *Id.*
28 Leslie Tomory, "Building the First Gas Network, 1812—1820", *Technology and Culture*, vol.52, nº1, 2011, 75-102.
29 Zerah Colburn, *The Gasworks of London* (London: Bucklersbury, 1865).
30 Frederick Dolman, "Municipalities at Work", *The New Review,* vol.11, nº62, 1894, 74-86.
31 Frank Popplewell, "Seasonal Fluctuations in Employment in the Gas Industry", *Journal of the Royal Statistical Society,* vol. 74, nº7, 1911, 693-754.
32 First in Liverpool in 1879, then nationally in 1882. See: UK Government, *Liverpool (Corporation) Electric Lighting Act* (London: UK Government, 1879); UK Government, *Electric Lighting Act* (London: UK Government, 1882).
33 Peebles, *Evolution of the Gas Industry* (cf. note 18).
34 Named after Carl Auer von Welsbach who had patented the first incandescent gas mantle in Paris in 1885. See: John Stock, "Carl Auer von Welsbach and the Development of Incandescent Gas Lighting", *Journal of Chemical Education,* vol. 68. nº10, 1991, 801-803.
35 J. Terrace, *Terrace's Notebook for Gas Engineers and Students* (London: Ernest Benn Ltd, 1948).
36 British Gas, *Gas Chronology* (cf. note 17).
37 Sara Pennell, *The Birth of the English Kitchen, 1600-1850* (London: Bloomsbury, 2016).

the Gas Heating Research Committee in 1907, and the establishment of the British Commercial Gas Association in 1911.[38] This latter entity served as a centralised publicity agency for the British gas industry, promoting the benefits of new gas appliances.[39]

18 Two shifts in patterns of gas demand occurred in conjunction with these developments. First, the use of gaslight declined dramatically, accounting for just 5% of the UK's total gas sales by 1939.[40] Second, the use of gas for cooking and water heating dramatically increased. Such was the strength of this growth that overall demand for gas grew and cooking became the new principal use of gas. Demand for gas-fired space heating remained limited during this period due to gas's high price relative to other solid heating fuels such as coke and coal[41] (Robinson, 1956). Figures 1 to 4 represent these shifts in demand patterns, each depicting an average daily demand profile for a typical London town gas network between 1899 and 1927.[42]

19 These changes in gas demand introduced new opportunities for balancing gas networks. The shift to gas cooking brought about a decline in seasonal swings in gas demand (the result of cooking practices being performed relatively consistently across the year).[43] This reduced the need for

Figure 1: In 1899, gas was principally used for lighting and daily demand reflected periods of daylight. Peak demand occurred in the early evening (~7pm), tailing off towards midnight, as people went to bed. A baseload demand remained overnight due to gas being used for streetlighting. Source: R. Le Fevre, *Gas Distribution Engineering: The Principles for Students* (London: Walter King Ltd, 1948, 4-5. All rights reserved).

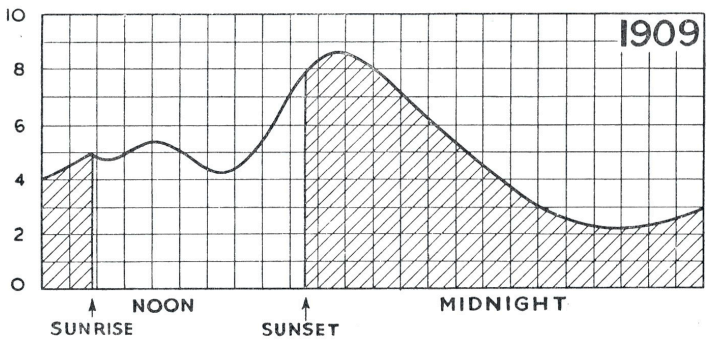


Figure 2: By 1909, gas cooking had become more common, but lighting remained the principal use of gas. The largest peaks were defined by the hours of day and night, but demand was now consistently higher across the day due to gas being used in food preparation. A small midday peak emerged as gas became used for lunchtime cooking. At night, demand levels remained roughly the same, with gas being used for streetlight. Source: R. Le Fevre, *Gas Distribution Engineering: The Principles for Students* (London: Walter King Ltd, 1948, 4-5. All rights reserved).

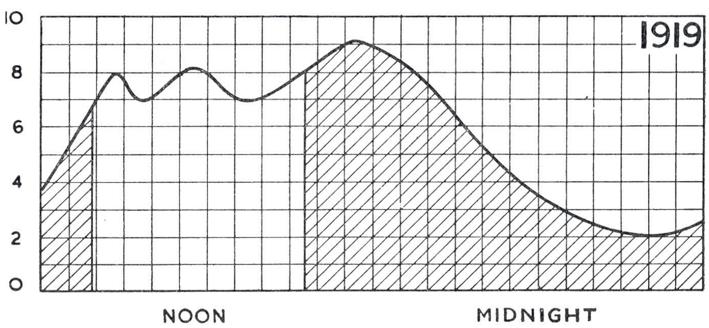


Figure 3: By 1919, overall gas demand had risen as a result of the growth of gas cooking. Gas was used more consistently across the day, but three peaks had also begun to develop around the morning, lunchtime, and evening mealtimes. The evening peak was more pronounced than others due to the continued use of gaslight. Source: R. Le Fevre, *Gas Distribution Engineering: The Principles for Students* (London: Walter King Ltd, 1948, 4-5. All rights reserved).

38 British Gas, *Gas Chronology* (cf. note 17).
39 Charles Hastings, "British Commercial Gas Association", *The Gas Engineer's Magazine*, vol.29, n°441, 1913, 277-278.
40 Hugh Barty-King, *New Flame: How Gas Changed the Commercial, Domestic and Industrial Life of Britain Between 1813 and 1984* (Tavistock: Graphmitre Ltd, 1984).
41 H. Robinson, "Radiant Heating – Past, Present and Future" *British Junior Gas Associations Joint Proceedings 1955-56*, vol. XXXIX, 1956, 720-724.
42 These images have been reproduced from: R. Le Fevre, *Gas Distribution Engineering: The Principles for Students* (London: Walter King Ltd, 1948, 4-5. All rights reserved). Several identical images also appeared in the earlier text: Norman Smith, *Gas Manufacture and Utilization* (London: The British Gas Council, 1945, 86-87. All rights reserved). I have been unable to identify the original source.
43 Gas networks would often still experience some, minor, seasonal fluctuations in load due to the continuation of some gaslight and heating activities.

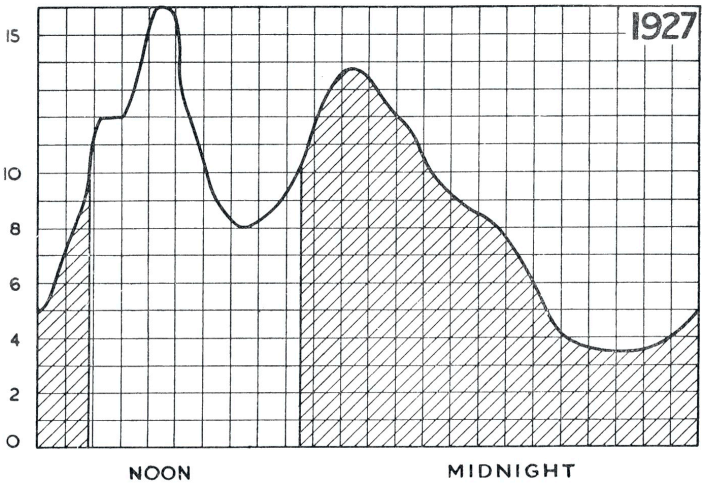


Figure 4: By 1927, gas cooking had exceeded gaslight as the main use of gas and overall gas demand had risen significantly. Daily demand peaks reflected mealtime conventions, but the most pronounced peak now occurred at noon, coinciding with the then-traditional timing of the main daily cooked meal[44]. Gaslight continued to be used at night. Source: R. Le Fevre, *Gas Distribution Engineering: The Principles for Students* (London: Walter King Ltd, 1948, 4-5. All rights reserved).

seasonal labour[45] and brought about a shift in how coal gas was both valued and made.[46] Coal gas had previously been sold for its illuminating power (a measure of the amount of light that its combustion would produce), but the shift to gas cooking, in combination with the turn to using incandescent mantles,[47] resulted in gas instead being valued for the amount of heat that its combustion produced (measured in terms of its 'calorific value').[48] This was significant for processes of balancing because it removed earlier limitations to processes of gas-making. Previously, the production of highly luminescent gas had "dictate[d] the type of gas-making plant employed, the kind of coal used, and the conditions of operation".[49] Indeed, it required highly specific raw materials[50] and had placed restrictions on the kinds of production methods that could be employed. The requirements for producing gas with a high thermal output were much less stringent, allowing for a wider range of coal types to be used and vertical, rather than horizontal, retorts to be employed. These latter devices allowed gas to made continuously, rather than production being regularly interrupted as spent coal was removed and fresh coal was introduced.[51]

Perhaps most significantly however, the shift to 20
manufacturing gas for its calorific value permitted the deployment of a new strategy known as 'peak shaving'. This involved the rapid production of large volumes of gas with a low calorific value (gas that produced less heat when burnt). This could then be enriched with small quantities of a higher-calorie supplement, such as gasified oil or butane, which would boost the calorific value of the overall gaseous mixture and thereby enable larger volumes of gas with a similar-to-normal calorific value to be quickly produced.[52] Peak shaving meant that gas production could be rapidly ramped up during periods of peak demand, albeit at a cost to efficiency. It subsequently became a routine part of balancing town gas networks, with most gasworks installing new plant that was dedicated to producing high volumes of lower-calorie gases that could then be enriched. Two methods became common: the production of 'producer gases' and the manufacture of 'water gases. Although resulting in gases with different qualities and characteristics, both involved the introduction of steam to heated coke and involved harnessing of the

44 Today, it is more common for main meals to be eaten in the evening. See: Alan Warde and Luke Yates, "Understanding Eating Events: Snacks and Meal Patterns in Great Britain", *Food, Culture & Society,* vol. 20, n°1, 2017, 15-36.
45 Seasonal employment was still in use in 1911 but at a reduced level. It also continued to decline over this period. Retort workers were the worst affected by seasonal demand patterns. See: Popplewell, *Seasonal Fluctuations* (cf. note 31).
46 Smith, *Gas Manufacture and Utilization* (cf. note 7).
47 Incandescent mantles worked by their materials emitting light when heated. This meant that they relied on gas for the heat it produced, not its light output. See: Terrace, *Terrace's Notebook* (cf. note 35).
48 See: UK Government, *Gas (Standard of Calorific Power) Act* (London: UK Government, 1916); UK Government, *Gas Regulation Act* (London: UK Government, 1920).
49 Terrace, *Terrace's Notebook* (cf. note 35), 52.
50 This had become an issue during the first world war (1914-18), as the availability of these specific coals declined. See: Terrace, *Terrace's Notebook* (cf. note 35).
51 *Id.*
52 E. Ward, *Gasmaking* (London: The British Petroleum Company Ltd, 1959).

subsequent reaction to produce large volumes of gas quickly.[53]

21 Yet, the turn to gas cooking also created challenges for balancing, however. In particular, it resulted in particularly intense but infrequent peaks in demand on Sundays and on special days, such as Christmas and Easter.[54] During this period, it was traditional to prepare roast dinners on these occasions and the associated increase in gas consumption could create intense, but infrequent, demand peaks. These peaks presented balancing challenges concerning infrastructural redundancy, typically described in terms of 'network load factors': calculations of the disparity between the average and maximum rates of gas demand.[55,56] If a network was designed to accommodate high rates of momentary demand that only occurred infrequently, much of the added capacity would prove redundant during more ubiquitous periods of lower demand, resulting in a poor load factor.[57,58] Poor load factors could affect gas prices and depress overall demand.

22 Load factor issues manifested in two ways during this period. First, Sunday demand could exceed the total volume of gas supply available, and whilst this could technically be solved by investing in extra peak-load plant or more storage capacity, the infrequency of peaks meant that these infrastructures "would be used only for a few hours weekly, and for the remainder of the week would remain idle".[59] This could make such investments uneconomical. A second problem then related to how distribution systems were not always sufficiently sized to deliver gas in the necessary volumes to all consumers during peak periods.[60] Friction from the pipe walls could limit the amount of gas reaching properties at a given moment, resulting in gas pressures "too low to give the requisite heat input into the ovens of the cookers".[61] Customers worst affected were often those located at the extremities of gas networks and, as a result, balancing challenges began to assume a distinctly geographical dimension. Whilst this issue could be solved by increasing pipe diameters (reducing friction relative to gas volume), it would often be detrimental to load factors because of the cost of replacing pipework.[62] Two alternative strategies developed during this period were to install booster equipment to raise gas's pressure (and speed) across networks,[63] and to build cheaper 'static' gasholders near to network extremities. These devices made it possible to store gas close to locations of demand so that it did not have as far to travel to reach consumers in time. They would typically be filled up during mid-week demand troughs.[64]

A final geographical complication that emerged during this period concerned the greater geographical variability of gas cooking demand compared to the earlier demand for gaslight. Networks that supplied seaside resorts were especially affected, these locations often experiencing seasonal peaks during the summer, as large numbers of caterers used gas to prepare food for holidaymakers. These geographically specific peaks in demand rarely caused issues for balancing however, for they often 'evened out' disparities between winter and summer gas loads, helping to reduce seasonal load factors. As Coe writes: 23

53 Alexander Humboldt-Sexton, *Producer Gas: A sketch of the properties, manufacture, and uses of gaseous fuel* (Manchester: Scientific Publication Company, 1905). A. Parker, "The Manufacture of Blue Water Gas", *Nature*, vol.115, 1925, 501–502. Ward, *Gasmaking* (cf. note 51).

54 Sunday roasts have since declined in popularity but remain a widespread UK tradition. See: Nestle Family Monitor (NFM), *Eating and Today's Lifestyle* (London: Carried out by MORI on behalf of Nestle UK, 2001); Mintel, *Changing British Diet – UK –May 2003* (London: Mintel International Group, 2003); Andy Gatley, Martin Caraher, Tim Lang, "A qualitative, cross cultural examination of attitudes and behaviour in relation to cooking habits in France and Britain", *Appetite*, vol.75, 2014, 71-81.

55 Le Fevre, *Gas Distribution Engineering* (cf. note 6).

56 Smith, *Gas Manufacture and Utilization* (cf. note 7).

57 *Id.*

58 Copp, *Gas Transmission and Distribution* (cf. note 20).

59 Smith, *Gas Manufacture and Utilization* (cf. note 7), 105.

60 *Id.*

61 *Id.*

62 *Id.*

63 A. Langford, "Methods for Reducing District Complaints", *British Junior Gas Associations Joint Proceedings 1933-34*, vol. XXIV, 1933, 283-288.

64 Smith, *Gas Manufacture and Utilization* (cf. note 7), 105.

24 "At seaside resorts both the maximum daily load, and the maximum hourly peak load occur in summer, so that heating of every kind of premises, and in fact all purely winter loads, do not increase either of these demands, and public lighting has but a negligible effect upon the maximum daily load".[65]

INDUSTRIAL MANUFACTURE (1939 – 1959)

25 With the commencement of the second world war, overall demand for gas fell. National air raid blackouts reduced the demand for gaslight and demand for gas-based cooking and heating activities similarly declined as the price of gas rose in response to wartime coal shortages.[66] These trends also continued after the war. Damaged gaslight infrastructures were widely replaced with electric lights and gas became increasingly perceived as old fashioned, dirty and poisonous.[67,68] Moreover, the price of gas remained high relative to other fuels, increasing on average by 67% between 1950 and 1959[69] as a result of the continuing high cost of coal, the extent of post-war infrastructural repairs, and the fact that many gasworks had been left only with gas-making plant that had been designed for peak shaving. Indeed, peak load plant became widely used in manufacturing gas for base loads, reducing the efficiency of production and increasing gas prices. Domestic demand continued to stagnate as a result.[70,71]

At the same time, however, the war stimulated growth in industrial gas demand.[72] Industrial gas consumption was not new to this period. Gas had first become widely used in manufacturing processes during the 1930s, following the shift to high thermal output gases that were better suited to industrial applications.[73,74,75] However, the production of wartime apparatus stimulated major growth in this form of gas usage however, to the extent that industrial demand quickly exceeded the falling levels of domestic gas consumption.[76] Combined with the sale of by-products for military applications, this increase enabled many gas companies to stay afloat during this period. Strategies employed for balancing varied dependent upon individual network loads, but they typically involved a combination of storage, variable production and peak shaving.[77] 26

With the close of the war, wartime production then ceased, and industrial gas demand went into sudden decline.[78] Gas cooking consequently resurfaced as the dominant use of gas and demand again assumed its previous daily and weekly peaks. Balancing was performed using the same strategies as had been employed during the 1930s, but the combination of lower levels of domestic demand, reduced industrial demand, and the need for urgent widespread infrastructural repairs resulted in many gas networks facing collapse by 1948. In response to this crisis, the gas 27

65 Arthur Coe, *The Science and Practice of Gas Supply Volume III, Including the Economics of Gas Supply* (London: The British Commercial Gas Association, 1939), 1376.

66 E. Brooks, "Thermal Environment and Comfort in the Home: Progress, Procrastination, and Probable Trends", *Institution of Gas Engineers Journal*, vol.10, 1970, 523-537.

67 Town gas often had a high carbon monoxide content and its inhalation could prove fatal. It consequently became a common method of suicide. See: Wolfgang Schivelbusch, *Disenchanted Night: The Industrialisation of Light in the Nineteenth Century* (California: University of California Press, 1983).

68 Barty-King, *New Flame* (cf. note 40).

69 J. Ellis, "Industrial Gas in Birmingham", *British Junior Gas Associations Joint Proceedings*, 1959-1960, pp.689-720.

70 Ward, *Gasmaking* (cf. note 51).

71 R. Deans, "The Value of the Space Heating Load", *British Junior Gas Associations Joint Proceedings 1952-53*, vol. XXXVI, 1952, 861-875.

72 J. Oates, "Presidential Address, Manchester Association General Meeting, 17th October 1953", *British Junior Gas Associations Joint Proceedings 1953-54*, vol. XXXVII, 1953, 261-270.

73 P. Lloyd, "Industrial Gas Heating", *British Junior Gas Associations Joint Proceedings 1933-34*, vol. XXIV, 1933, 218-239.

74 K. Langford, "Economics of Gas in Industry", *British Junior Gas Associations Joint Proceedings 1933-34*, vol. XXIV, 1933, 425-434.

75 G. Windiate, E. Craddock, "The Application of Town Gas to Industrial Heating Problems", *British Junior Gas Associations Joint Proceedings 1934-35*, vol. XXV, 1934, 110-113.

76 Oates, *Presidential Address* (cf. note 72).

77 *Id.*

78 *Id.*

Figure 5: Map of the UK's gas boards following nationalisation. Source: K. Hutchinson, "The Future of the Gas Industry in Great Britain", *Institution of Gas Engineers Journal,* vol. 6, 1966, 538. Image reproduced with permission from IGEM.

industry was nationalised in 1949.[79,80] The large number of privately and municipally owned town gas networks were consolidated into 12 new area boards and these were overseen by a national Gas Council (Figure 5). Under this arrangement, much of the damaged gas infrastructure was repaired and local gas networks were linked together to form 12 regional gas 'grids'.[81]

79 K. Hutchinson, "The Future of the Gas Industry in Great Britain", *Institution of Gas Engineers Journal,* vol. 6, 1966, 537-552. The coal and electricity industries were also nationalized in 1946 and 1947, respectively.

80 UK Government, *Gas Act* (London: UK Government, 1948).

81 Hutchinson, *The Future of the Gas Industry* (cf. note 79).

28 These changes introduced the possibility of new strategies for balancing demand and supply in real time. Integrating town gas networks allowed gas boards to share production and storage capacity across regional grids, improving the efficiency with which demand and supply could be balanced. This reduced manufacturing costs significantly.[82] Rather than individual gasworks varying their outputs to meet localised demands, select sites could provide gas only for regional base loads, producing larger volumes of gas more efficiently.[83,84] Other sites could be used to produce gas for peak load requirements.[85] In combination, this resulted in a significant decline in the number of gasworks required across the UK. Between 1948 and 1965, the number of UK gasworks fell from 1050 to just 246, resulting in significant savings in the costs of manufacture.[86] Many former gasworks were converted into gasholder stations, allowing area boards to retain their gasholder storage for the purposes of diurnal balancing.[87]

29 Whilst this arrangement enabled more effective load management and reductions in operating costs, it also required careful planning for balancing to be effective. The integration of multiple town gas networks with varying consumers and loads caused the geographical distribution of demand to become increasingly complex across regional grids. In the process, issues with the sizing of distribution pipes and their abilities to satisfy geographically specific peaks in demand re-emerged. In the process, the location of sites of gas production (in particular, peak load plants), became increasingly significant to balancing processes.[88]

Furthermore, despite these new forms of efficiency, poor load factors continued to present challenges for balancing. Distribution systems still had to be sized to meet the intense but infrequent Sunday peaks in demand. Combined with high levels of infrastructural investment and stagnating gas sales, this meant that gas prices remained high, further supressing overall demand for gas and preventing it from being competitive in the fast-growing post-war market for domestic central heating.[89,90] 30

During this period, gas boards consequently attempted to improve their network load factors by attracting new industrial and commercial consumers who promised loads that effectively 'filled in' troughs in demand.[91,92] This involved gas boards offering gas at cheaper rates, often to companies who only used gas during weekdays. Indeed, between 1950 and 1959, this initiative stimulated significant growth in industrial gas demand.[93,94,95,96,97,98] In conjunction, many gas networks experienced an inversion 31

82 K. Summersgill, "Some Aspects of Grid Interlinkage", *British Junior Gas Associations Joint Proceedings 1953-54*, vol. XXXVII, 1954, 365-385.
83 R. Jones, "The Chemical Control of Modern Base Load Works", *British Junior Gas Associations Joint Proceedings 1956-57*, vol. XXXX, 1956, 810-811.
84 A. Yeaman, "Carbonisation on Base Load Works", *British Junior Gas Associations Joint Proceedings 1957-58*, vol. XLI, 1957, 834-854.
85 Summersgill, *Some Aspects* (cf. note 82).
86 Hutchinson, *The Future of the Gas Industry* (cf. note 79).
87 R. Langford, "Planning Small Holder Stations to Reduce Operation and Maintenance Costs to a Minimum", *British Junior Gas Associations Joint Proceedings 1960-1961*, vol. XLIII, 1961, 42-52.
88 Summersgill, *Some Aspects* (cf. note 82).
89 W. Moxley, "Peak Load Medium Pressure Distribution Systems", *British Junior Gas Associations Joint Proceedings 1956-1957*, vol. XL, 1956, 754-765.
90 D. Adam, "The Load Factor", *British Junior Gas Associations Joint Proceedings 1956-57*, vol. XXXX, 1957, 644-651.
91 G. Johnson, C. Taylor, "A Review of Post-War Domestic Gas Water Heating", *British Junior Gas Associations Joint Proceedings 1955-56*, vol. XXXIX, 1956, 131-166.
92 Oates, *Presidential Address* (cf. note 72).
93 *Id.*
94 J. Stretton, "The Development of Industrial Gas Sales in North Wales", *British Junior Gas Associations Joint Proceedings 1960-1961*, vol. XLIII, 1960, 473-478.
95 D. Murray, "Industrial Gas in the Central Division", *British Junior Gas Associations Joint Proceedings 1960-1961*, vol. XLIII, 1961, pp.387-390.
96 A. Higgs, "Gas is Competitive", *British Junior Gas Associations Joint Proceedings 1956-57*, vol. XXXX, 1956, 456-486.
97 K. Edwards, "The Requirements of Base Load Operation", *British Junior Gas Associations Joint Proceedings 1957-1958*, vol. XLI, 1957, 701-715.
98 R. Currie, "Selling Industrial Gas", *British Junior Gas Associations Joint Proceedings 1957-1958*, vol. XLI, 1958, 660-673.

in demand profiles such that "the gas demand on one day at the weekend [constituted] about half of the demand on one day during the working week".[99]

CENTRAL HEATING (1960 – PRESENT)

32 In contrast to the 1950s, the period between 1960 and 2020 has been broadly characterised by a marked increase in domestic gas demand, centred around the use of gas for central heating. Demand for gas-fired central heating had previously been limited due to gas's high cost relative to oil and electricity, and by 1957, it accounted for just 5-10% of domestic gas demand.[100] However, by 1965, this pattern had dramatically shifted. Knights and Allen announced that:

33 > "[t]he fantastic sales of domestic space heating appliances that have occurred over the past few years, and are expected to continue for some years to come, have drastically increased the load on gas distribution systems in this country".[101]

34 Such was this growth that demand profiles once again changed, with domestic demand making up 64% of total gas sales by 1970, compared to 21% for industrial uses.[102] Of this, 75% was for space heating.[103]

35 The reasons for this transformation have been widely attributed to the combination of a highly successful marketing campaign that presented gas as a clean, efficient, convenient, and modern space heating fuel, alongside a dramatic change in the raw materials that were used to make gas: production shifting from using coal to oil.[104] As Lawton described over a decade earlier, around this time:

36 > "the price of coal [had] risen steadily, and [...] oil refineries, faced with an increased demand for lighter products, [had] been forced to crack their raw materials to a greater extent, with a consequent detrimental effect on the market value of residua. The nett effect [was] that the price per therm of certain heavier grades of oil [had] not risen so sharply as the price per therm of coal".[105]

37 Shifting from coal to oil both reduced the cost of raw materials and enabled more efficient production methods, reducing the overall price of gas and rendering it more attractive to consumers.[106]

38 Sales for industrial and commercial gas consumption also remained strong during this period, and gas continued to be used for cooking.[107] The result was typical daily demand patterns that were more even than those of previous decades (Figure 6). Demand rose in the morning, with central heating systems automatically turning on before people awoke and remained consistent throughout the day. At night, it dropped off as people retired to bed. These patterns eliminated the previously problematic daily peaks in cooking demand and resulted in more efficient diurnal load factors.[108] They also enabled operators to shift to a daily rhythm of gas storage, with gas being stored overnight (as demand dropped) and it being consumed during the day[109].

99 A. Pratt, E. Johnson, "Storage", *Institution of Gas Engineers Journal,* vol. 7, 1967, 603-620.
100 A. Burrell, G. Fudge, "Domestic Space Heating by Gas", *British Junior Gas Associations Joint Proceedings 1956-1957*, vol. XL, 1957, 132-149.
101 I. Knights, J. Allen, "High Speed Gas Networks", *Institution of Gas Engineers Journal*, vol. 6, 1965, 75.
102 A. Adam, G. Vasey, "Evolution of the Modern Gas Fire", *Institution of Gas Engineers Journal,* vol. 10, 1970, 797-816.
103 D. Heslop, "Central Heating: Where from – where to? Some personal reflections 1958-1978 – Part 1", *Institution of Gas Engineers Journal,* vol. 20, 1980, 99-108.
104 Hutchinson, *The Future of the Gas Industry* (cf. note 79).
105 E. Lawton, "The Manufacture of Gas from Oil: A General Review with Detailed Consideration of the 'Semet-Solvay' and 'Segas' Processes", *British Junior Gas Associations Joint Proceedings 1952-53*, vol. XXXVI, 1952, 644.
106 Hutchinson, *The Future of the Gas Industry* (cf. note 79).
107 F. Giddings, "Gas Sets the Pace" *Institution of Gas Engineers Journal*, vol. 6, 1966, 377.
108 Pratt and Johnson, *Storage* (cf. note 100).
109 R. Langford, P. Wood, "Meeting the Storage Requirements within an Area Board", *Institution of Gas Engineers Journal,* vol. 13. 1973, 129-140.

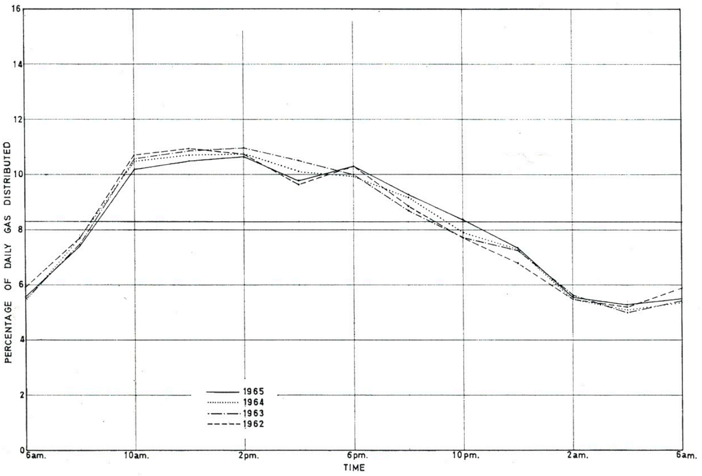


FIGURE 2.—*Variation in output, Northern Region, at 36°F.*

Figure 6: Typical daily demand profile for the Northern Region at 36 degrees Fahrenheit (1962 – 1965). Source: A. Pratt, E. Johnson, "Storage", *Institution of Gas Engineers Journal,* vol. 7, 1967, 605. Image reproduced with permission from IGEM.

39 Indeed, because gas continues to be used in broadly similar ways today, patterns of gas consumption, and the diurnal balancing strategies employed in relation to them, remain similar. The main difference today concerns the form of diurnal storage that is used to balance gas networks.[110] From 1960 onwards, the UK's 12 area grids became increasingly interconnected via high-pressure transmission pipes, allowing for gas supplies to be shared between them.[111] Unlike their lower-pressure counterparts, these new pipes could hold more gas, allowing for a surplus to be stored across gas networks. Known as 'line pack', this new form of storage grew dramatically over following decades, to the point that it eventually rendered gasholders redundant in 2014.[112] Gas continues to be stored as line pack overnight and used during the day.[113]

The growth in demand around gas-fired central heating developed geographically unevenly however, creating new balancing challenges for balancing. As Edwards, an engineer from the north Thames gas board, described: "[the] increase [was] not spread uniformly throughout the Board. It [was] concentrated in the residential areas at the periphery where annual increases of up to 30% [were] being experienced".[114] Because gas networks had not been sized to deliver enough gas to their peripheries to meet these new peaks, many gas boards resorted to locating new sites of production near to areas of demand, in addition to installing static gasholders near these locations. As Edwards continues, 40

> "whereas originally it was always possible to locate the production to suit the supplies of raw materials for gas manufacture, it [therefore became] both necessary and practicable to so locate them to assist the distribution system to the maximum possible extent".[115] 41

Moreover, the use of gas for space heating also brought about the return of strong seasonal demand variations that were characterised by enduring winter peaks and summer lulls. Rather than directly reflecting rhythms of daylight however, these new patterns were more closely associated with outside temperatures and meteorological conditions, rendering them more variable over the timescales of hours, days and weeks than had previously been the case with gaslight.[116,117] These seasonal rhythms, combined with the strong overall growth in gas demand experienced during this period, encouraged investment in new forms of seasonal storage, including facilities such as underground aquifers, gas wells, mines and salt caverns, as well as vessels for the storage 42

110 Katie Boxall, "Improving Short Term Gas Demand Forecasting", *Gas International,* November 2015, 37-39.
111 Stathis Arapostathis, *Natural Gas Network Development in the UK (1960-2010): Coping with Transitional Uncertainties and Uncertain Transitions* (Cardiff: Low Carbon Research Institute, 2011). URL: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.645.6520&rep=rep1&type=pdf (accessed 21/10/20).
112 Institute of Gas Engineers and Managers (IGEM), *Gasholders: Recording an End of an Era* (London: The British Library, 2014).
113 National Grid, *Physical Operations of the NTS and Winter Forecasting* (Webinar: National Grid, 11th September 2014).

114 E. Edwards, "Gas Supplies for the North Thames Area", *Institution of Gas Engineers Journal,* vol. 6, 1966, 633-657.
115 *Ibid.*, 634.
116 A. Buckley, "Gas Load Forecasting – A Marketing Contribution", *Institution of Gas Engineers Journal,* vol. 6, 1966, 169-181.
117 W. Roger, "What's in a Peak Day? – Alternative Uses of the Planning Model", *Gas Engineering and Management: Journal of the Institution of Gas Engineers,* July/August 1984, 269-281.

of high-calorie distillates and liquefied natural gas (LNG) for peak shaving.[118,119] Indeed, LNG storage subsequently came to play a particularly significant role in the balancing of the UK's gas networks. Major advancements were made concerning its transport, storage, and regasification, and reception terminals were built to facilitate its delivery by boat from countries such as Algeria and the United States.[120] Its increasing use for peak shaving became a major driver for the interconnection of regional grids, allowing for stored LNG to be shared between regions.[121,122]

43 Despite these measures, seasonal demand variations continued to introduce issues around seasonal load factors, with much of the capacity of gas grids becoming redundant over summer months. Gas boards therefore again sought to acquire new loads, this time aiming to fill summertime troughs in demand. As Emerson and Roberts wrote in 1968, "the industry is faced with an accentuated seasonal difference between the Winter and Summer loads [...] The acquisition of even a partial balancing load is thus a matter of urgency".[123] New loads that were pursued included hot water loads (encouraged by building boiler systems into new central heating unit, thereby promoting the simultaneous uptake of gas-fired water heating)[124], and industrial loads that had low seasonal variations. The latter were solicited by offering more favourable gas rates to eligible consumers.[125] 'Interruptible' industrial loads were also pursued during this period, in efforts to reduce the intensity of seasonal demand peaks.[126] This involved signing contracts with large consumers that had year-round demands for gas and that could switch to alternative forms of energy at short notice, if needed. Eligible companies could then purchase gas at discounted rates, knowing that their supply could be interrupted.[127,128]

Many of these strategies remain in use today, albeit adjusted to accommodate two changes in the structure of the British gas industry. The first change involved the conversion of the UK's gas systems to natural gas in the late 1970s. This resulted in the creation of an interconnected, national gas infrastructure comprised of a high-pressure national transmission system (NTS) and 6 regional distribution networks (an amalgam of the earlier gas boards).[129] 44

With the abundance of cheap domestic natural gas supplies and the higher calorific value of natural gas compared to coal or oil gas,[130] gas quickly became used in a variety of new industrial applications, most notably within electricity generation. Whilst power station loads have had a nett positive effect on the load factors of gas systems (gas typically being used during the summer, when gas prices are lower), their consumption patterns are highly dependent upon how energy is used within other energy systems. As such, the intensity of power station demand varies considerably, and this presents potential challenges for balancing gas systems. A major shift in approach to balancing since the 1970s has therefore been the increased prominence of demand forecasting. National Grid (the NTS operator) now attempts to anticipate changes in 45

118 Hutchinson, *The Future of the Gas Industry* (cf. note 79).
119 Langford and Wood, *Meeting Storage Requirements* (cf. note 110).
120 British Gas, *Gas Chronology* (cf. note 17).
121 Edwards, *Gas Supplies for the North Thames Area* (cf. note 115).
122 Hutchinson, *The Future of the Gas Industry* (cf. note 79).
123 J. Emerson, J. Roberts, "Summer Hot Water from Central Heating Boilers", *Institution of Gas Engineers Journal*, vol. 8, 1968, 365.
124 R. Holden, "Central Heating in Existing and New Property", *Institution of Gas Engineers Journal,* vol. 6, 1966, 628-629.
125 G. Thomas, "Factors Associated with and Influencing the Growth of the Industrial Gas Load in East Anglia", *Institution of Gas Engineers Journal,* vol. 6, 1966, 772-776.
126 Interruptible contracts continue to be used within both the UK's electricity and gas industries.
127 N. Bryant, "The Practical Handling of Interruptible Loads", *Institution of Gas Engineers Journal,* vol. 13, 1973, 317-324.
128 W. Howell, G. Robertshaw, "Natural Gas and the Industrial Market", *Institution of Gas Engineers Journal,* vol. 8, 1968, 780-801.
129 Charles Elliott, *The History of Natural Gas Conversion in Great Britain* (Royston: Cambridge Information and Research Services Ltd., 1980).
130 Ward, *Gasmaking* (cf. note 51).

demand within other energy systems that may affect power station loads. Analysed factors including the behaviours of electricity markets and of meteorological systems.[131]

46 Forecasting is now also the main method for managing the fluctuations in demand that result from the interconnection of the UK's gas networks with other countries' gas systems. Today, interconnector pipelines link the NTS to gas systems in Belgium, the Netherlands, Norway, Northern Ireland, and the Republic of Ireland, and these pipes allow gas to be moved between these systems more-or-less instantly.[132] This can result in sudden large fluctuations in available gas supplies that can potentially threaten the successful balancing of UK demand and supply. A key aspect of the routine day-to-day management of the NTS has therefore become the forecasting of international gas market behaviours.[133]

47 Finally, peak shaving has fallen out of use as a routine balancing strategy. The most significant reason for this is that LNG (which, since the 1960s, had become the main fuel used for peak shaving), is chemically the same as natural gas and does not have a markedly higher calorific value. As such, it cannot be used to enrich existing gas supplies. Despite this, LNG continues to play an important role in the balancing of the UK's gas system, being used more-or-less interchangeably with other natural gas supplies.[134]

48 The second major change in the structure of the British gas industry involved its return to private ownership in 1987.[135] Today, the NTS is operated by National Grid; the 6 distribution networks are overseen by multiple companies; numerous shippers purchase and sell gas supplies; storage facilities are independently operated; and different producers extract and process gas (domestic and imported natural gas, as well as domestic biomethane).[136] The whole system is regulated by Ofgem, the independent market regulator.

This arrangement has resulted in responsibility for balancing broadly shifting to the market. 49
National Grid supervises the process, but its control is limited to ensure fair market competition. It consequently has no powers over when or where gas enters the NTS, how much gas is put into it at any one time, when or where gas is put into or taken out of storage, or when and in what volumes gas is exchanged over interconnectors.[137] This marks a stark change from prior arrangements where both the production and distribution of gas was overseen by central network operators. This has also brought about several key changes in how balancing is approached.

On the one hand, diurnal demand fluctuations 50
currently present few issues for balancing. This is due to line pack allowing for peaks and troughs in demand over minutes and hours to be managed more-or-less automatically. Minor issues can still arise from dissonances in the geographical distribution of demand and supply over these timescales though, due to National Grid's commitment to permitting shippers to deliver gas into the NTS at any entry point around the country, at any time. As a result, gas demand could theoretically peak in locations where relatively small quantities of gas are stored as line pack. One of National Grid's main responsibilities is

131 Boxall, *Improving Short Term Gas Demand Forecasting* (cf. note 111).
132 House of Lords European Union Committee, *Brexit: Energy Security. 10th Report of Session 2017–2019*. (London: House of Lords European Union Committee, HL Paper 63, 2018).
133 Boxall, *Improving Short Term Gas Demand Forecasting* (cf. note 111).
134 National Grid, *Physical Operations of the NTS* (cf. note 114). The calorific value of LNG can fluctuate, dependent upon its source and the distance it must travel. Richer LNG is chemically altered to lower its calorific value in line with UK specifications. See also: D. Chrétien, "Process for the Adjustment of the HHV in the LNG Plants" (Amsterdam: 23rd World Gas Conference, 2006) URL: http://members.igu.org/html/wgc2006/pdf/paper/add10492.pdf (accessed 22/6/20).

135 Jonathan Stern, "The British Gas market 10 years after privatisation: A model or a warning for the rest of Europe?", *Energy Policy,* vol. 25, n°4, 1997, 387-392.
136 Biomethane is produced onshore using organic materials. It currently constitutes only 0.3% of UK gas supply. See: BEIS, *Digest* (cf. note 8).
137 National Grid, *Physical Operations of the NTS* (cf. note 114).

therefore to transport gas around the NTS using compressors, delivering it to areas of anticipated demand. This requires shippers declaring ahead of time when, where and in what volumes they will deliver gas into the NTS, and National Grid then forecasting the geographical distribution of demand a day ahead. This enables National Grid to anticipate patterns of future demand and supply and to move gas supplies around the country accordingly.[138]

51 On the other hand, more problematic demand fluctuations commonly manifest over longer timescales, either in relation to unexpectedly intense peaks in seasonal demand (and the associated physical unavailability of sufficient gas supplies), or market challenges that render bringing additional supplies online less profitable. One recent example of such a challenge involved successive mild winters reducing the profitability of seasonal storage, with many storage operators consequently attempting to generate smaller, faster, profits by trading gas based on day-to-day (rather than seasonal) fluctuations in gas price. This resulted in a marked reduction in the availability of winter supply reserves and fears for the security of the UK's gas supplies.[139]

52 National Grid's main approach to mitigating against these kinds of challenges is to forecast demand at different intervals (day ahead, week ahead, long term). This gives market actors the time to respond to fluctuations in demand and make additional supplies of gas available.[140] In more extreme scenarios where supply deficits look likely, National Grid can also undertake additional actions. These include providing temporary market incentives to encourage the delivery of further supplies; suspending normal market trading; and shedding interruptible loads.[141] Domestic demand-side response is reserved to only the very worst-case scenarios, taking the form of longer-term rationing (this differs from electricity rationing initiatives, which seek to shift the timings of consumption activities). Rationing is possible because, unlike electricity systems, the line pack within gas systems reduces the need to respond to short-term fluctuations in demand.[142]

BALANCING THE DEMAND/SUPPLY RELATION

In tracing these different ways in which fluctuations in demand have presented challenges for balancing within the UK's gas systems between 1795 and the present day, it is possible to draw out three observations that may inform how we understand processes of balancing dissonant patterns of demand and supply. 53

1) Issues with balancing dissonant patterns of demand and supply are critical to gas systems, not just present-day electricity networks. Within present-day discussions of 'flexibility' in the energy sector, balancing issues have been widely represented as exclusively affecting electricity systems. In this paper, I have instead described how balancing issues have repeatedly surfaced within the UK's gas networks across a 225-year period. Examining these issues reveals a series of similarities and differences in the approaches employed within past gas systems, compared to those found within present-day electricity systems. Examples such as the manifestation of peaks and troughs in demand over the timescales of weeks, months, and seasons, rather than the seconds, minutes and hours more commonly discussed in the electricity sector, reveal how different kinds of balancing issue can have major implications for the ways in which energy systems are configured. Studying how these issues manifest, and the ways in which they have historically been responded to, has value for understanding opportunities and challenges relating to balancing that may affect future electricity systems and may also have value for coming to terms with potential issues that could affect the balancing of other kinds of energy systems. 54

138 *Id.*
139 Boxall, *Improving Short Term Gas Demand Forecasting* (cf. note 111).
140 *Id.*
141 National Grid, "National Grid Emergency Operations" (Webinar, National Grid, 4th September, 2014).
142 *Id.*

55 2) Patterns of demand are affected by how energy is used and play a major role in how balancing is approached and how energy systems are organised. To date, discussions of 'flexibility' have primarily focused on the importance of the composition of energy supply for the balancing of energy systems, including how easily energy supplies can be stored, transported, or made to produce electricity. This paper has instead focused primarily upon the significance of the composition of energy demand for processes of balancing. A key finding is that how energy is used dramatically influences patterns of energy demand and can have major implications for how balancing is achieved. The paper has shown how changes in the dominant uses of gas across four time periods have influenced patterns of demand and have conditioned the kinds of balancing processes possible at different moments. With each change in gas usage, the organisation of the UK's gas systems has been shown to have undergone successive alterations.

56 More specifically, the paper has also documented how changes in the ways in which energy was used influenced the composition of demand across three dimensions: its timings, intensities and geographies. Each of these dimensions (which are described in more detail below) have been shown to have had consequences for how balancing could be approached, and for how energy systems were organised.

57 Timings. Different types of energy use influence the timings of energy demand in terms of the durations of demand peaks and troughs (seconds, minutes, days, weeks, months, seasons, years); their frequencies (daily, weekly, seasonal); and their regularities (here, daily vs. occasional). For instance, gaslighting introduced seasonal peaks in demand that endured over weeks and months, whereas the use of gas for cooking resulted in less seasonal demand patterns as well as multiple peaks within days and on Sunday afternoons and special occasions. These variations necessitated different balancing methods, from the duration of demand peaks influencing the kinds of storage that could be utilised, to the frequencies of peaks affecting the sizing of gas systems and their load factors.

Intensities. How energy is used also influences the intensities of energy demand. Issues concerning demand intensity have manifested in two ways in this paper: as forms of consistent increases in the volume of demand, and as forms of temporally or spatially inconsistent demand growth. In cases where demand grew consistently (such as during the early 1800s when demand for gaslight was burgeoning), widespread alterations to the sizing of gas networks were often required. This involved pipes and storage facilities being enlarged, new forms of infrastructure being developed for the production, transport and storage of gas, and larger workforces being recruited. In cases where growth in intensity was less spatially and temporally consistent, however, further issues often emerged, most commonly in relation to network load factors. At different times and in different ways, the UK's gas systems experienced pronounced differences in the intensities of peaks and troughs in demand over different timescales (hours, days, weeks, months/seasons) and across different locations (seaside areas, network peripheries). These differences could similarly create problems around the (in)adequate sizing of gas networks and the (in)abilities of networks to transport sufficient supplies of gas to locations of demand, but they also raised concerns around the cost of necessary measures for balancing, relative to the frequency and distribution of these peaks. Various strategies were consequently developed to try to balance gas networks whilst avoiding poor network load factors. 58

Geographies. The geographies of peaks and troughs in energy demand are affected by the ways in which energy is used. Since 1795, certain kinds of gas usage have proved more geographically variable than others. Whereas lighting loads were relatively consistent across town gas networks, cooking loads displayed greater geographical variance. For instance, particularly intense loads were often experienced during summer months in areas that served large numbers of seasonal caterers. As gas became 59 used for central heating, demand growth also occurred primarily within residential areas, often resulting in peaks in demand at network peripheries. Such spatially uneven demand patterns had implications for the organisation of the UK's gas systems, involving extensive infrastructural adjustments that could include the installation of gasworks and sites of gas production near to locations of demand; the use of booster stations; and the deployment of static gasholders close to residential areas. As the uses and users of gas multiplied; as gas networks became larger and increasingly interconnected; and as the UK's gas systems became further liberalised, issues with geographical demand variation also increased in scale and complexity, necessitating the emergence of demand forecasting as a routine aspect of the day-to-day balancing of gas networks.

60 These three qualities of energy demand (timings, intensities and geographies) are each dependent upon how energy is used and have implications for the balancing methods that are possible in a given moment. In the current context, this relationship could be particularly significant for thinking through attempts to pursue decarbonisation by shifting specific activities (in particular, transport and heating) off their reliance upon fossil fuels and onto electricity.[143,144] As electricity becomes used within different applications, it is highly likely that the timings, intensities and geographies of electricity demand will shift in ways that create new opportunities and challenges for balancing.

61 Moreover, beyond these qualities, the example of the UK's gas systems demonstrates the value of better understanding how energy demand is composed, including the ways in which it relates to different forms of energy use and what its implications are for processes of balancing. Furthering our understanding of this relationship will likely require studying how current electricity demand profiles relate to contemporary forms of electricity use but may also require further investigation of how forms of energy use within other kinds of energy systems in both the past and the present relate to patterns of demand.

3) The ways in which energy is used, and therefore the compositions of energy demand, are dynamic. As has been argued elsewhere,[145] current discussions of flexibility within the energy sector have been widely underpinned by assumptions that take the composition of demand to be static. The examples described in this paper testify to demand's constantly dynamic nature and its always-shifting relationships with patterns of energy supply. The examples described here speak of the changing ways in which people use energy, and of how these patterns of usage will likely continue to change in the future. The composition of energy demand (including its timings, intensities and geographies) will therefore also almost certainly change as a result. The examples described in this paper serve as a warning of the potential dangers of designing energy systems around these fixed understandings of demand. Across the history of the UK's gas networks, the infrastructures of gas provision have been repeatedly resized and reconfigured around new and emerging patterns of demand that have been characterised by different timings, intensities and geographies, and these alterations have often proved extensive and costly. 62

CONCLUSION

Current discussions of flexibility within the fields of energy provision, policy and research have centred around contemporary challenges concerning the balancing of fluctuating patterns of energy demand and supply. These discussions have overwhelmingly focused on present-day electricity systems and have been predominantly supply-oriented, attending to the consequences of material changes in the composition of energy supplies, such as the ease with which different forms of energy can be stored, transported or made to produce electricity, for processes of balancing. 63

143 BEIS, *Upgrading* (cf. note 2).
144 Centre for Research into Energy Demand Solutions (CREDS), *Shifting the focus: energy demand in a net-zero carbon UK* (Oxford: CREDS, 2019).

145 Stanley Blue, Elizabeth Shove, Peter Forman, "Conceptualising flexibility: Challenging representations of time and society in the energy sector", *Time and Society,* (Early access), 2020, https://doi.org/10.1177/0961463X20905479.

64 I have taken a different approach in this paper, instead studying the consequences of the shifting composition of energy demand for balancing the UK's gas networks across a 225-year timeframe. I have described four periods in which gas was predominantly used within different applications (gaslight, cooking, manufacture, central heating), and I have shown how the composition of demand, and the procedures employed to balance gas networks, changed as a result. In the process, I have demonstrated how issues relating to balancing fluctuations in demand and supply are not exclusive to electricity systems, nor are they limited to the present context. The historical study of gas systems reveals a plurality of moments in which tensions between patterns of gas demand and supply have emerged over time. These tensions have taken quite different forms: the timings, intensities and geographies of peaks and troughs in demand shifting in relation to how gas was predominantly used. I have also shown how these changing demand patterns were responded to via a variety of balancing strategies, many of which proved both extensive and costly. The longitudinal perspective provided by this account therefore serves as a reminder of the constant dynamism of energy demand and of the potential dangers of calibrating energy systems around fixed understandings of it.

65 However, looking beyond gas networks, the composition of energy demand, including what constitutes it, how and why it changes, and what opportunities and challenges for balancing it introduces, clearly requires further analysis. Indeed, understanding this relationship is important both for looking beyond the immediate balancing challenges facing decarbonising electricity networks, and also for understanding the longer-term consequences of the methods of balancing proposed in relation to these challenges. As this paper has shown, history can play a valuable role in coming to terms with this processes. Turning to examples from other energy systems in the past can help us to grasp the dynamism of the demand/supply relationship in ways that are often not possible through studies of the present, nor through projections of future patterns of consumption.

Bibliography

Adam A., Vasey G.
"Evolution of the Modern Gas Fire", *Institution of Gas Engineers Journal*, vol. 10, 1970, 797-816.

Adam D.
"The Load Factor", *British Junior Gas Associations Joint Proceedings 1956-57*, vol. XXXX, 1957, 644-651.

Arapostathis Stathis
Natural Gas Network Development in the UK (1960-2010): Coping with Transitional Uncertainties and Uncertain Transitions (Cardiff: Low Carbon Research Institute, 2011). URL: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.645.6520&rep=rep1&type=pdf (accessed 21/10/20).

Barty-King Hugh
New Flame: How Gas Changed the Commercial, Domestic and Industrial Life of Britain Between 1813 and 1984 (Tavistock: Graphmitre Ltd, 1984).

Blue Stanley, Shove Elizabeth, Forman Peter
"Conceptualising flexibility: Challenging representations of time and society in the energy sector", *Time and Society,* (Early access), 2020, https://doi.org/10.1177/0961463X20905479.

Boxall Katie
"Improving Short Term Gas Demand Forecasting", *Gas International,* November 2015, 37-39.

British Gas
Gas Chronology: The Development of the British Gas Industry (London: British Gas, 1980).

Brooks E.
"Thermal Environment and Comfort in the Home: Progress, Procrastination, and Probable Trends", *Institution of Gas Engineers Journal,* vol.10, 1970, 523-537.

Bryant N.
"The Practical Handling of Interruptible Loads", *Institution of Gas Engineers Journal,* vol. 13, 1973, 317-324.

Buckley A.
"Gas Load Forecasting – A Marketing Contribution", *Institution of Gas Engineers Journal,* vol. 6, 1966, 169-181.

Burrell A., Fudge G.
"Domestic Space Heating by Gas", *British Junior Gas Associations Joint Proceedings 1956-1957*, vol XL, 1957, 132-149.

Centre for Research into Energy Demand Solutions (CREDS)
Shifting the focus: energy demand in a net-zero carbon UK (Oxford: CREDS, 2019).

Chrétien D.
Process for the Adjustment of the HHV in the LNG Plants (Amsterdam: 23rd World Gas Conference, 2006). URL: http://members.igu.org/html/wgc2006/pdf/paper/add10492.pdf (accessed 22/6/20).

Coe Arthur
The Science and Practice of Gas Supply Volume III, Including the Economics of Gas Supply (London: The British Commercial Gas Association, 1939).

Colburn Zerah
The Gasworks of London (London: Bucklersbury, 1865).

Copp Douglas
Gas Transmission and Distribution (London: Walter King Ltd, 1967).

Currie R.
"Selling Industrial Gas", *British Junior Gas Associations Joint Proceedings 1957-1958*, vol. XLI, 1958, 660-673.

Deans R.
"The Value of the Space Heating Load", *British Junior Gas Associations Joint Proceedings 1952-53,* vol. XXXVI, 1952, 861-875.

Department for Business, Energy and Industrial Strategy (BEIS)
Upgrading Our Energy System: Smart Systems and Flexibility Plan (London: BEIS, 2018).

Digest of UK Energy Statistics (DUKES): Natural Gas (London: BEIS, 2019). URL: https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes (accessed 06/07/20).

Dolman Frederick
"Municipalities at Work", *The New Review,* vol.11, n°62, 1894, 74-86.

Edwards E.
"Gas Supplies for the North Thames Area", *Institution of Gas Engineers Journal,* vol. 6, 1966, 633-657.

Edwards K.
"The Requirements of Base Load Operation", *British Junior Gas Associations Joint Proceedings 1957-1958*, vol. XLI, 1957, 701-715.

Elliott Charles
The History of Natural Gas Conversion in Great Britain (Royston: Cambridge Information and Research Services Ltd., 1980).

Ellis J.
"Industrial Gas in Birmingham", *British Junior Gas Associations Joint Proceedings 1959-1960*, 689-720.

Emerson J., Roberts J.
"Summer Hot Water from Central Heating Boilers", *Institution of Gas Engineers Journal,* vol. 8, 1968, 364-384.

Stirling Everard
The History of the Gas Light and Coke Company 1812-1949 (London: A&C Publishers Ltd., 1992 [1949]).

Falkus M.
"The Early Development of the British Gas Industry, 1795-1815", *Economic History Review,* vol. 35, n° 2, 1982, 217-234.

Froggatt Antony, Quiggin Daniel
The Power of Flexibility: The Survival of Utilities During the Transformations of the Power Sector (London: Royal Institute of International Affairs, Chatham House, 2018).

Gatley Andy, Caraher Martin, Lang Tim
"A qualitative, cross cultural examination of attitudes and behaviour in relation to cooking habits in France and Britain", *Appetite,* vol.75, 2014, 71-81.

Giddings F.
"Gas Sets the Pace", *Institution of Gas Engineers Journal,* vol. 6, 1966, 377.

Grunewald Philip, Diakonova Marina
"Flexibility, Dynamism and Diversity in Energy Supply and Demand", *Energy Research and Social Science,* n°38, 2018, 58-66.

Hastings Charles
"British Commercial Gas Association", *The Gas Engineer's Magazine*, vol.29, n°441, 1913, 277-278.

Heslop D.
"Central Heating: Where from – where to? Some personal reflections 1958-1978 – Part 1", *Institution of Gas Engineers Journal,* vol. 20, 1980, 99-108.

Higgs A.
"Gas is Competitive", *British Junior Gas Associations Joint Proceedings 1956-57*, vol. XXXX, 1956, 456-486.

Holden R.
"Central Heating in Existing and New Property", *Institution of Gas Engineers Journal,* vol. 6, 1966, 628-629.

House of Lords European Union Committee
Brexit: Energy Security. 10th Report of Session 2017–2019 (London: House of Lords European Union Committee, HL Paper 63, 2018).

Howell W., Robertshaw G.
"Natural Gas and the Industrial Market", *Institution of Gas Engineers Journal,* vol. 8, 1968, 780-801.

Hughes S.
A Treatise on Gas-Works and the Practices of Manufacturing and Distributing Coal Gas (London: Lockwood & Company, 2010 [1871]).

Humboldt-Sexton Alexander
Producer Gas: A sketch of the properties, manufacture, and uses of gaseous fuel (Manchester: Scientific Publication Company, 1905).

Hutchinson K.
"The Future of the Gas Industry in Great Britain", *Institution of Gas Engineers Journal,* vol. 6, 1966, 537-552.

Institute of Gas Engineers and Managers (IGEM)
Gasholders: Recording an End of an Era (London: The British Library, 2014).

International Energy Agency (IEA)
Energy Transitions in G20 Countries: Energy Transitions Towards Cleaner, More Flexible, and Transparent Systems (Online: IEA, 2018). URL: https://webstore.iea.org/energy-transitions-in-g20-countries-energy-transitions-towards-cleaner-more-flexible-and-transparent-systems (accessed 22/6/20).

Johnson G., Taylor C.
"A Review of Post-War Domestic Gas Water Heating", *British Junior Gas Associations Joint Proceedings 1955-56*, vol. XXXIX, 1956, 131-166.

Jones R.
"The Chemical Control of Modern Base Load Works", *British Junior Gas Associations Joint Proceedings 1956-57*, vol. XXXX, 1956, 810-811.

Knights I., Allen J.
"High Speed Gas Networks", *Institution of Gas Engineers Journal,* vol. 6, 1965, 75-79.

Langford A.
"Methods for Reducing District Complaints", *British Junior Gas Associations Joint Proceedings 1933-34*, vol. XXIV, 1933, 283-288.

Langford K.
"Economics of Gas in Industry", *British Junior Gas Associations Joint Proceedings 1933-34*, vol. XXIV, 1933, 425-434.

Langford R.
"Planning Small Holder Stations to Reduce Operation and Maintenance Costs to a Minimum", *British Junior Gas Associations Joint Proceedings 1960-1961*, vol XLIII, 1961, 42-52.

Langford R., Wood P.
"Meeting the Storage Requirements within an Area Board", *Institution of Gas Engineers Journal,* vol. 13, 1973, 129-140.

Lawton E.
"The Manufacture of Gas from Oil: A General Review with Detailed Consideration of the 'Semet-Solvay' and 'Segas' Processes", *British Junior Gas Associations Joint Proceedings 1952-53*, vol. XXXVI, 1952, 644.

Le Fevre R.
Gas Distribution Engineering: The Principles for Students (London: Walter King Ltd., 1948).

Lloyd P.
"Industrial Gas Heating", *British Junior Gas Associations Joint Proceedings 1933-34*, vol. XXIV, 1933, 218-239.

Maiben J.
A statement of the advantages to be derived from the introduction of coal gas into factories and dwelling houses, as a substitute for the lights now in use: together with observations on the method of making and using it (Perth: John Maiben & Company, 1813).

Mintel
Changing British Diet – UK –May 2003 (London: Mintel International Group, 2003).

Moxley W.
"Peak Load Medium Pressure Distribution Systems", *British Junior Gas Associations Joint Proceedings 1956-1957*, vol. XL, 1956, 754-765.

Murray D.
"Industrial Gas in the Central Division", *British Junior Gas Associations Joint Proceedings 1960-1961*, vol XLIII, 1961, pp.387-390.

National Grid
National Grid Emergency Operations (Webinar, National Grid, 4th September 2014).

Physical Operations of the NTS and Winter Forecasting (Webinar: National Grid, 11th September 2014).

Nestle Family Monitor (NFM)
Eating and Today's Lifestyle (London: Carried out by MORI on behalf of Nestle UK, 2001).

Oates J.
"Presidential Address, Manchester Association General Meeting, 17th October 1953", *British Junior Gas Associations Joint Proceedings 1953-54*, vol. XXXVII, 1953, 261-270.

Parker A.
"The Manufacture of Blue Water Gas", *Nature,* vol.115, 1925, 501–502.

Peebles Malcolm
Evolution of the Gas Industry (New York & London: New York University Press, 1980).

Pennell Sara
The Birth of the English Kitchen, 1600-1850 (London: Bloomsbury, 2016).

Popplewell Frank
"Seasonal Fluctuations in Employment in the Gas Industry", *Journal of the Royal Statistical Society,* vol.74, nº7, 1911, 693-754.

Pratt A., Johnson E.
"Storage", *Institution of Gas Engineers Journal,* vol. 7, 1967, 603-620.

Robinson H.
"Radiant Heating – Past, Present and Future", *British Junior Gas Associations Joint Proceedings 1955-56*, vol. XXXIX. 1956, 720-724.

Roger W.
"What's in a Peak Day? – Alternative Uses of the Planning Model", *Gas Engineering and Management: Journal of the Institution of Gas Engineers,* July/August, 1984, 269-281.

Sanders D., Hart A., Ravishankar M., Brunert J.
An Analysis of Electricity System Flexibility for Great Britain (London: Carbon Trust/Imperial College, 2016).

Schivelbusch Wolfgang
Disenchanted Night: The Industrialization of Light in the Nineteenth Century (California: California University Press, 1983).

Smith N.
Gas Manufacture and Utilization (London: The British Gas Council, 1945).

Stern Jonathan
"The British Gas market 10 years after privatisation: A model or a warning for the rest of Europe?", *Energy Policy,* vol. 25, nº4, 1997, 387-392.

Stock John
"Carl Auer von Welsbach and the Development of Incandescent Gas Lighting", *Journal of Chemical Education,* vol. 68, nº10, 1991, 801-803.

Stretton J.
"The Development of Industrial Gas Sales in North Wales", *British Junior Gas Associations Joint Proceedings 1960-1961*, vol. XLIII, 1960, 473-478.

Summersgill K.
"Some Aspects of Grid Interlinkage", *British Junior Gas Associations Joint Proceedings 1953-54*, vol. XXXVII, 1954, 365-385.

Terrace J.
Terrace's Notebook for Gas Engineers and Students (London: Ernest Benn Ltd, 1948).

Thomas G.
"Factors Associated with and Influencing the Growth of the Industrial Gas Load in East Anglia", *Institution of Gas Engineers Journal,* vol. 6, 1966, 772-776.

Tomory Leslie
"Building the First Gas Network, 1812—1820", *Technology and Culture,* vol. 52, nº1, 2011, 75-102.

Tomory Leslie
"Fostering a new industry in the Industrial Revolution: Boulton & Watt and gaslight 1800–1812", *The British Journal for the History of Science,* vol. 46, nº2, 2013, 199-229.

UK Government
Liverpool (Corporation) Electric Lighting Act (London: UK Government, 1879).

Electric Lighting Act (London: UK Government, 1882).

Gas (Standard of Calorific Power) Act (London: UK Government, 1916).

Gas Regulation Act (London: UK Government, 1920).

Gas Act (London: UK Government, 1948).

Ward E.
Gasmaking (London: The British Petroleum Company Ltd, 1959).

Warde Alan, Yates Luke
"Understanding Eating Events: Snacks and Meal Patterns in Great Britain", *Food, Culture & Society,* vol. 20, n°1, 2017, 15-36.

Wilson John
Lighting the Town: A Study of Management in the North West Gas Industry 1805-1880 (London: Paul Chapman Publishing Ltd, 1991).

Windiate G., Craddock E.
"The Application of Town Gas to Industrial Heating Problems", *British Junior Gas Associations Joint Proceedings 1934-35*, vol. XXV, 1934, 110-113.

Yeaman A.
"Carbonisation on Base Load Works", *British Junior Gas Associations Joint Proceedings 1957-58,* vol. XLI, 1957, 834-854.

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR

Robert Shaw
Newcastle University
robert.shaw2@ncl.ac.uk
Twitter: @WhatIsRobShaw

POST DATE
09/01/2021

ISSUE NUMBER
JEHRHE #5

SECTION
Special issue

THEME OF THE SPECIAL ISSUE
Historicising Flexibility

KEYWORDS
Light, Gas, Electricity, Town

DOI
in progress

TO CITE THIS ARTICLE
Robert Shaw, "Polyflexibility in Public Lighting", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 09 January 2021, URL: energyhistory.eu/en/node/234.

Polyflexibility in Public Lighting

Abstract

This article introduces the concept of 'Polyflexibility' as a way of expressing the complexity of interacting forms of flexibility. The term, deriving from Henri Lefebvre's concept of polyrhythmia, is used in contrast to conceptualizations of flexibility in energy studies which rest primarily on locating flexibility in either supply or demand. By focusing on the Polyflexibility of an energy system as a whole, we can better identify when, how and why certain systems have been flexible or inflexible. This is illustrated through a study of the different relationships between financial, political, technological, social, legal and other modalities at three moments of transition with public light in Newcastle-upon-Tyne, UK: the start of the transition from gas to electric lighting (1890-1907); the blackout period of World War Two (1938-1946); and the contemporary transition from sodium-vapour to LED (2012-).

Plan of the article

1 In the realm of public lighting, a promise has emerged since the early 2010s. This promise is that new, smart lighting systems drawing from LED lighting technology will be able to respond in real-time to the demands of the users of public spaces. The reward, we are told, is reduced energy use which in turn translates into: lower carbon emissions; reduced light pollution; and less public expenditure on lighting. The confidence in this future, for example, can be seen in the engineering, planning and design firm Arup's 2015 publication *Cities Alive: Rethinking Shapes of Night* in which "Rapid advances in lighting, information technology and intelligent systems offer immense opportunities for radical new approaches to urban night-times".[1] This vision of smart and LED lighting offers the *capacity* for significant changes in public lighting regimes, most centrally surrounding the flexibility of public lighting infrastructure. The smartest of such smart lighting systems are currently confined to experiments, pilots and showcase installations, offering developer-curated insights into possible future urban nightscapes. In wider cities, the implementation of smart lighting is underway but is more tentative. Local authorities introduce technologies into already-operating infrastructures, legal frameworks, political contexts and budgetary restraints, all of which shape the reality of technological change. In other words, "technologies and their institutional and social settings co-evolve"[2], as path-dependent moments in which existing social, economic and governmental-institutional settings intersect with the materiality of both existing and new technologies.

2 In this paper, I want to historicize the contemporary transition in public lighting with reference to some of its predecessors, using the city of Newcastle-upon-Tyne in the UK for my case study. Newcastle is of interest as a notable city in the history of lighting: the first public display of an incandescent lightbulb occurred on 3rd February 1879 in Newcastle, produced by local engineer Joseph Swan;[3] subsequently, Swan created the first – experimental – public electric lighting in the world on Moseley Street, and lit the first known private home to have full electric lighting installed, Cragside, the rural mansion of local businessman William Armstrong.[4] As well as the contemporary transition towards greater use of LED and smart lighting technologies (focusing on the period since 2012), two further moments of transition in Newcastle's lighting history are chosen. The first covers the period of experimentation associated with the first widespread use of electric public electric lights (1890-1907); and the second covers the rapid transition into and out of the World War Two blackout restrictions (1938-1946). The paper draws from archival material held by the Tyne and Wear Archives & Museums (TWAM) for the first two periods, and from qualitative interviews and the analysis of contemporary policy documents for the latter period.

3 In looking at these moments, I want to show how flexibility – and fixity – have been dependent upon the particular relationship between technology, institution and investment. In other words, what is fixed and what is flexible have not been consistent, but have been dependent upon the public lighting assemblage at the time and place of transition. In so doing, I present flexibility not as a characteristic of either demand-side usage or supply-side provision, but as an emergent characteristic of the energy assemblage as a whole. To make this argument, I use the term *polyflexibility* to draw attention to this conceptualization of flexibility as emergent from the intersection of the flexibility of multiple different actors, rather than as a single characteristic. Polyflexibility is a way of describing a relational flexibility, that is, a flexibility which is dependent upon how different actors relate. The term is lifted from Lefebvre's description of

1 Arup, *Cities Alive: Rethinking the Shades of Night* (London: Arup, 2015), 65

2 Charlie Wilson and Arnulf Grubler, "Lessons from the History of Technological Change for Clean Energy Scenarios and Policies", *Natural Resources Forum,* vol. 35, n° 1, 2011, 165.

3 Ralph Clark Chirnside, "Sir Joseph Swan and the Invention of the Electric Lamp", *Electronics and Power*, vol. 25, n° 2, 1979, 98.

4 *Ibid.*, 100.

polyrhythms in his book *Rhythmanalysis,*[5] which explores what he sees as the dialectic relationship between ever-expanding capitalism, and everyday embodied temporalities. This helps express the way in which flexibility is a result of changing, evolving and contextual power relations between distinct actors.

THE PROMISE OF TRANSITION IN SMART LIGHTING SYSTEMS

4 Street-lighting management has, since it evolved as a city-wide process toward the end of the eighteenth century, involved a certain amount of temporal planning and organisation. In a well-known account, Schivelbusch describes a lighting schedule for early nineteenth century Paris, revealing a detailed plan for lighting shaped by the diurnal cycle of light and dark, as well as public rhythms: for example, no public lighting was to be provided on Christmas Day.[6] Similar levels of this planning and management occurred in the UK: in 1896, the 'Newcastle-upon-Tyne Corporation Street-Light Sub-Committee' (hereafter: Newcastle Lighting Committee) researched the different times at which British cities operated their street-lights on a month-by-month basis. Their research revealed wide variation in hours of lighting from 3408 hours a year in Leicester and 4313 hours a year in Newcastle. The differences could not be explained by latitude: at mid-summer, Newcastle provided more public lighting than many cities to its south. They also discovered complex local lighting practices; in Edinburgh, it was reported that "care has been taken to put alternate lamps on separate circuits in all streets… [this] allows half the lamps to be switched off at or about midnight, still leaving the streets well lighted"[7]. Here in the late nineteenth century we see practices which attempted to offer something similar to the new promises of smart lighting, namely, varied lighting levels according to predicted demand, at the most efficient cost. Temporal coordination has thus long been part of street-lighting, and the idea of coordinating with both natural lighting levels and anticipated demand is not new.

What is potentially new with smart lighting is the 5
extent, depth and sophistication of this planning and coordination. Smart lighting draws on three primary technologies. The first is LED lighting, which while not inherently smart, is the form of public lighting most suitable for integrating into smart systems. LED lighting can be switched on and off quickly, and can be set to different levels of brightness. Furthermore, it produces a more condensed and focused light than the diffuse lighting of the most common pre-existing public lighting source, electric sodium lamps. All of these mean that in designing a smart lighting system, which gains its potential efficiency from this technological flexibility, LED lighting is necessary.[8] Second (and third) are the two technologies used to make this LED lighting 'smart'. Smart lighting can operate either, or both, through the forecasting of demand, or through real-time responses to demand, that is, through sensors which identify users of cities being present. Smart technology which uses forecasting and sensors together is the most powerful, allowing lighting to be programmed in anticipation of demand created by particular events, traffic conditions and the weather, and integrating this with real-time data about the city. Researchers anticipate possible savings of 30-50% of energy if neural networks are used to predict demand, in comparison to lighting provided without any anticipatory procedure.[9],[10] Using only sensor-technology is a simpler but cheaper approach, with lighting either off or at lower levels, until sensors identify that lighting is required. Such systems will switch on according

5 Henri Lefebvre, *Rhythmanalysis: Space, Time and Everyday Life* (London: Continuum, 2004 [1992]).

6 Wolfgang Schivelbusch, *Disenchanted Night* (Oxford: Berg Publishers, 1988), 91

7 Report to Newcastle Lighting Committee, 7 December 1896. Tyne and Wear Museums and Archives (TWAM).

8 Miguel Castro et al., "Smart Lighting Solutions for Smart Cities", in *Proceedings of the 27th International Conference on Advanced Information Networking and Applications Workshops* (Institute of Electrical and Electronics Engineers, 2013), 1374-1379.

9 Stefano Pizzuti *et al.*, "Smart Street Lighting Management", *Energy Efficiency*, vol. 6, n° 1, 2013, 614.

10 Francesco Marino *et al.*, "Adaptive Street Lighting Predictive Control", *Energy Procedia*, vol. 111, n° 1, 2017, 798.

to the speed of traffic or pedestrians, providing light when users require it and less light when there is no demand.

6 As part of the emergence of studies of night, artificial light, and darkness across multiple disciplines,[11],[12] studies of the history of public lighting technologies and practices have been one of the most prevalent areas of attention. This is undoubtedly connected to the promises that smart-lighting systems contain for the future, but also because public lighting has been taken as a somewhat exemplary case within the study of the history of socio-technical systems and energy use more broadly.[13],[14],[15],[16],[17] Across these (and many other) accounts both lighting and electricity are exemplars of a historically and socioculturally contingent infrastructure, whereby the implementation of technological innovation is shaped by but also produces social contexts. Hughes argues that these technologies need to be understood as systems, the growth of which can be explained exclusively by its contingency, rather than requiring any additional explanatory tools.[18] In an editorial to a recent special issue of this journal on histories of light and darkness, Le Gallic and Pritchard argue that "The history of public lighting offers a classic illustration of infrastructure: extensive, often invisible, technological systems that are taken for granted—at least until they fail".[19] Within that special issue, Dunn's paper on the history of lighting in Manchester provides a good counterpoint to this article, focusing as it does on a broad-brush history of lighting in that city from the early nineteenth century to the LED-era.[20] Dunn's story of Manchester offers many similarities to the history of lighting in Newcastle, but where his article covers an extended period of time, this one dives into moments of transition between the different lighting systems.

7 Despite this wealth of study, the research on historical transitions in public lighting has not been extensively applied to understandings of the contemporary transition. Work in energy studies has contrasted transitions with notions of path-dependency: Nordensvärd and Urban, for example, define path-dependency as "a form of lock-in",[21] while Mori contrasts path-dependent energy systems with transitions driven by niche innovators.[22] I argue that this opposition between path-dependency and transition is misleading; transitions are path-dependent, playing-out in the contextual settings into which they are inserted. This is somewhat akin to what Strambach calls 'path-plasticity', which "describes a broad range of possibilities for the creation of innovation within a dominant path of innovation systems".[23] In other words, it is not necessary to break with path-dependency in order to innovate; rather, the capacity of innovation is dependent upon the elasticity of institutions and the "interpretative flexibility"

11 Christopher Kyba *et al.*, "Night Matters—Why the Interdisciplinary Field of "Night Studies" Is Needed", *J—Multidisciplinary Scientific Journal*, vol. 3, n° 1, 2020. Url: https://www.mdpi.com/2571-8800/3/1/1/htm (accessed 07/12/2020).

12 Michele Acuto, "We Need a Science of the Night", *Nature*, vol. 576, 2019, 339.

13 Schivelbusch, "Disenchanted Night" (cf. note 6).

14 David Nye, *When the Lights Went Out: A History of Blackouts in America* (Cambridge, MA: MIT Press, 2010).

15 Joachim Schlör, *Nights in the Big City: Paris, Berlin, London 1840-1930* (London: Reaktion, 1998).

16 Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: John Hopkins Press, 1983).

17 Sandy Isenstadt *et al.* (eds.), *Cities of Light: Two Centuries of Urban Illumination* (London: Routledge, 2015).

18 Hughes, *Networks of Power*, 2-5 (cf. note 16).

19 Stéphanie Le Gallic and Sara B.Pritchard, "Light(s) and darkness(es): Looking back, looking forward", *Journal of Energy History/Revue d'Histoire de l'Énergie,* vol. 2, 2019. Url: energyhistory.eu/en/node/137.

20 Nick Dunn. "Dark Futures: the Loss of Night in the Contemporary City?" *Journal of Energy History/Revue d'Histoire de l'Énergie,* vol. 2, 2019. Url: energyhistory.eu/en/node/108 (accessed 07/12/2020).

21 Johan Nordensvärd and Frauke Urban, "The Stuttering Energy Transition in Germany: Wind Energy Policy and Feed-In Tariff Lock-In", *Energy Policy,* vol. 82, n° 1, 2015, 15.

22 Akihisa Mori, "Socio-technical and Political Economy Perspectives in the Chinese Energy Transition", *Energy Research and Social Science*, vol. 35, n° 1, 2018, 28-30.

23 Simone Strambach, "Path Dependency and Path Plasticity: the Coevolution of Institutions and Innovation - the German Customized Business Software Industry", *Working Papers on Innovation and Space,* Philipps-University Marburg, Department of Geography, n° 02.08, 2008, 4. Url: www.econstor.eu/handle/10419/111860, (accessed 07/12/2020).

of actors.[24] Transitions are not externally driven moments of change, but dependent upon the flexibility or plasticity of the pre-existing paths. This aligns with Hägerstrand's time-geography, which emphasizes the intersection "trajectories" of actors which result in "processes which cannot unfold freely as in a shielded laboratory but have to accommodate themselves under the pressures and opportunities which follow from their common coexistence in terrestrial space and time".[25] Moments of transition in lighting show these trajectories or paths as intertwining and interlinked, rather than as ruptures of breaks. Describing early twentieth century American city streets, Baldwin says that there was "a crazy quilt of different forms of illumination: arc light towers, arc light gloves near street level, incandescent lights, gaslights with and without mantles, lamps burning gasoline or kerosene".[26] Despite the eventual dominance of the orangey-yellow electric sodium-gas based lights through the twentieth century, all cities retained and retain something of a patchwork of different lighting technologies.[27] Moments of technological transition highlight diversity in technological provision, as the 'old' technologies find new ways of persisting alongside newer developments.[28] Thus in understanding the promises of LED lighting systems, we need to understand both the paths with which these technologies intertwine, and the new trajectories that emerge out of the transition.

FLEXIBILITY AS POLYFLEXIBILITY

8 It is helpful to distinguish flexibility from dynamism. If flexibility is understood as the capacity for variation within a system, dynamism should be understood as the specific capacity of the system to change. It is thus possible to imagine an energy system which is quite flexible, but not particularly dynamic. For example, in their research into domestic use of energy, Powells et. al., argue that peaks in energy demand can be conceptualized as the result of the configurations of differing social practices.[29] Similarly, Shove et. al. argue that the persistence of car-dependency in society is a result of the obduracy of "infrastructural arrangements and... the spatial and temporal connections between practices that these enable".[30] In both cases, there is a relatively high-level of everyday flexibility experienced by the user, who can drive their car or use their washing machine when they want. Yet the lock-in of practices and infrastructures means that both systems lack dynamism. Conversely, Hirsch argues that very finely tuned systems can reach a state of 'technological stasis', in which "technical, managerial and "social" forces reach a stalemate characterized by unimproved technological performance".[31] While this stasis might seem to be lacking in dynamism, it can in fact lead to very dynamic and unstable systems, as the absence of flexibility in a system means that small changes can lead it to collapse (Hirsh calls this an "unstable equilibrium"). In other words, while dynamism is related to flexibility, this relationship is a complex one.

These arguments also show the need to study infrastructure and practice together. Infrastructures facilitate some practices over others, and in turn people adapt to enact certain social practices while rejecting others. Habits, desires and imaginations form, and flexibility is reduced. Policymakers and energy-system oriented academic research has only lately started to pay attention to this relationship between practice and infrastructure[32],[33]; too often, infrastructural changes are proposed with a 9

24 *Ibid*.
25 Torsten Hägerstrand, "Geography and the Study of Interaction between Nature and Society", *Geoforum*, vol. 7, n° 5-6, 1976, 332.
26 Peter C. Baldwin, *In the Watches of the Night* (Chicago: University of Chicago Press, 2012), 159.
27 Arup, *Cities Alive,* 39 (cf. note 1).
28 David Edgerton, *The Shock of the Old : Technology and Global History since 1900* (London: Profile, 2008), 11.
29 Gareth Powells *et al., "*Peak Electricity Demand and the Flexibility of Everyday Life", *Geoforum,* vol. 55., n° 1, 2014, 44.
30 Elizabeth Shove *et al., "*Conceptualising Connections: Energy Demand, Infrastructures and Social Practices", *European Journal of Social Theory,* vol. 18, n° 1, 2015, 276.
31 Richard F. Hirsh, *Technology and Transformation in the Electric Utility Industry* (Cambridge: Cambridge University Press, 1989), 191.
32 *Ibid*., 283-285.
33 Powells, "Peak Electricity", 50 (cf. note 29).

presumed direct causal impact on social practices, whereas research shows that to enact change, both infrastructure and the practices themselves require attention.[34] Research driven by theories of social practice has more recently done the job of showing the need to open up the range of actors involved in energy systems,[35] but the relative newness of this area of research, means that there are several actors whose impact has received less attention. Of note, the relationships between technological transition and legal, financial and governance frameworks have received less attention. However, when dealing with energy systems, we often find that change is shaped by the complexities of such frameworks, particularly as many systems incorporate a mixture of public, collective private and individual private actors (with some actors falling into more than one of these categories).

10 In other words, there are many different actors to yet consider when exploring polyflexbilty as opposed to flexibility. The term Polyflexibility draws directly from Lefebvre's 'polyrhythmia', where it appears alongside two companions, 'eurhythmia' and 'arrhythmia'. [36] Lefebvre describes a dialectic, in which eurhythmia are the merged rhythms of normed everydayness, while arrhythmia are the discordant, pathological rhythms of suffering and hurt. The synthesis of these is the polyrhythmia, the rhythms of everyday life. Crucially for Lefebvre, analysis of polyrhythmia "simultaneously discovers the multiplicity of rhythms and the uniqueness of particular rhythms".[37] Polyrhythmia contain both eurhythmia and arrhythmia; as Blue puts it:

> "within a given polyrhythmia there exists bundles or collections of rhythms that are in sync, healthy, and 'normed'. Lefebvre describes these rhythms as eurhythmia. In that same polyrhythmia there are rhythms that are desynchronising, pathological, and different. He describes these as arrhythmia".[38]

In other words, independent and unique rhythms coordinate in complex ways, not simply facilitating each other but also sometimes operating against dominant rhythms. We can see here an analysis which shares many concerns with the approach taken in practice theories, arguing that practices and infrastructures are simultaneously unique and interdependent, although Lefebvre attributes change largely to class intervention, [39] rather than the coevolution of materials and practices. Still, his ethnographic approach and focus on everyday life have led to Lefebvre's work being explored alongside practice theories. Returning to Blue, he argues that Lefebvre helps provide a framework to "describe the emergence and entrenchment of connections between practices",[40] as well as offering an approach which emphasises the variety of contradictions between practices. 11

In adapting the term polyrhythmia to the term polyflexibility, I seek to highlight how flexibility exists both at the level of an assemblage as a whole, and at the level of the individual practices and actors which constitute that assemblage. This speaks to the previously cited work that conceptualizes transitions as dependent upon and part of a trajectory with existing paths,[41] rather than as externally triggered ruptures. Even rather rigid and fixed systems are thus likely to contain some flexibility; this relational flexibility is neither fully flexible nor fixed. As with Lefebvre's polyrhythmia, polyflexibility is composed of both forms of flexibility, and forms of stasis. As an emergent characteristic, polyflexibility is always relational and contingent. Within practice theories, flexibility is understood as a feature of both practices and actors; or as Powells *et al.* write, "flexibility varies between 12

34 Elizabeth Shove, "Beyond the ABC: Climate Change Policy and Theories of Social Change", *Environment and Planning A: Economy and Space*, vol. 42, n° 6, 2010, 1274.
35 Powells, "Peak electricity", 44 (cf. note 29).
36 Lefebvre, *Rhythmanalysis*, 16 (cf. note 5).
37 *Ibid.*, 17.
38 Stanley Blue, "Institutional Rhythms: Combining Practice Theory and Rhythmanalysis to Conceptualise Processes of Institutionalization", *Time & Society*, vol. 28, n° 3, 2019, 940.
39 Lefebvre, "Rhythmanalysis", 14 (cf. note 6).
40 Blue, "Institutional Rhythms", 925 (cf. note 38).
41 Strambach,"Path Plasticity", (cf. note 23).

practice entities and also between performances of particular practices".[42] However, such research has tended to retain a binary division between supply-side and demand-side, even where it has argued that these must be understood relationally. As Rinkinen and Shove note, this has also tended to focus on future trajectories of transitions, with much less attention on the historical paths on which these trajectories depend.[43] Working with Polyflexibility helps move beyond analysing through this binary, instead attuning to different 'modalities' which intersect in an energy system and which have differing levels of flexibility. I introduce modalities primarily as analytical, which are unique to a particular assemblage. In public-lighting, for example, we can identify a technological and infrastructural modality composed of the energy sources used, their capacities, and their transmission; a governmental-bureaucratic modality, composed of both the bodies involved in the governance of lighting, and the legislation to which they are bound; an experiential modality, composed of the modes of engagement that the public have with public-lighting; and a financial modality, composed of both the broad socio-economic system within which lighting is provided, and the specific finances of the bodies responsible for lighting in any given location. Different energy systems would have different modalities, but in this paper I show that flexibility – and stasis – at any one moment comes from both the characteristics of these different modalities, and how they intersect.

13 The difference which this conceptualization makes is to argue that Polyflexibility is flexibility as understood as the result of multiple intersecting actors, practices, technologies and institutions which themselves have their own flexibility. In turn, energy transitions are emergent from this Polyflexibility, rather than externally driven ruptures. This goes beyond widening the net for which actors and practices we consider as part of an energy system. Rather, the concept of Polyflexibility indicates, first, that all forms of flexibility consist of forms of flexibility and inflexibility. The result is that we cannot find an ultimately inflexible or unmoving modality within an energy assemblage. Second, there is also no pure flexibility either: there is nothing which if shifted or moved will somehow entirely unchanged. Third, when describing Polyflexibility, we should describe not just the variety of actors or practices which are flexible, but the *variety of ways in which* those actors and practices can be (in)flexible. These ways of being flexible shift over time as the relationship between different actors, practices and modalities change, and as such both the flexibility of a socio-technical system and the source of this flexibility change over time. A historical understanding of how polyflexibility has operated at different transition moments, in the same place, should help in revealing this.

METHODS

As outlined in the introduction, Newcastle-upon-Tyne is an appealing case study, as the location where early innovations in electric lighting and public lighting took place. Most of the archives consulted were housed by TWAM. Within their archives, three sets of documents proved most useful. The first was the archives of the North Eastern Electric Supply Company (NESCO). Minutes of directors' meetings, alongside copies of correspondence with local authorities and miscellaneous promotional documents were all consulted, covering the period of 1888-1908 and 1936-1948, this latter period of archives ending with the nationalization of energy suppliers in the UK. The second were the archives of the Newcastle-upon-Tyne Corporation, and specifically the minutes of the Newcastle Lighting Committee, which were reviewed from 1883-1908 and 1936-1946. The third set of archives were the records of the Newcastle-upon-Tyne City police, with their documents on lighting regulations and applications for exemptions from 1938-1948 being available. In addition to TWAM's collection, I used the British Library newspaper archives for historical reporting. Between them, 14

42 Powells *et al.*, "Peak electricity", 50 (cf. note 29).
43 Jenny Rinkinen and Elizabeth Shove, "Energy Demand", *in* Jenny Rinkinen, Elizabeth Shove and Jacopo Torriti (eds.), *Energy Fables. Challenging Ideas in the Energy Sector* (Abingdon: Earthscan, 2019), 9.

these three sets of archives offered a comprehensive overview of the planning and management of changes at the two historical moments.

15 Documents for the contemporary era were much more difficult to track down, despite having located similar documents for a neighbouring local authority in research on an associated project.[44] In the case of Newcastle, the terms of its Public Finance Initiative (PFI) mean that many of the relevant policy documents are redacted and unavailable. I therefore had to piece together data from different sources. The first were semi-structured interviews carried out in 2013 for an earlier project on street-lighting decision making, one with an official from Newcastle-upon-Tyne and the second with officials from North Tyneside, a neighbouring local authority with which Newcastle shares a Public Finance Initiative contract with SSE Lighting.[45] The second source is the *Newcastle Evening Chronicle*, the city's largest newspaper which has reported on the transition. Beyond this, the available documents were the minutes of the Newcastle and North Tyneside Join Street Lighting Committee, consulted from 2015-2019, and the PFI performance reports submitted to that committee. Nevertheless, some redacted material means that these sources are not as full as they might be.

16 All three data sources – archival material, policy documents and qualitative interviews, are understood in similar ways as partial, reflecting a distilled and curated selection of broader debates.[46],[47] The approach to all the material consulted drew from a broadly constructionist framework, in which the data was considered to be a partial representation of the ways in which different actors have constructed their social world, with the researcher's job being to try and untangle that process of construction.[48] All documents, including the interview transcripts, were coded directly or, in the case of archival material, had coded notes made about them. All documents in the archives were consulted between June-August 2019. The three sections below outline different how flexibility has varied, across the three case study moments.

VARIATIONS IN INSTITUTIONAL FLEXIBILITY

> "If the electric lighting is to be done cheaply, as large a portion of the City as possible should be covered, and not in the isolated manner it is now carried out in Newcastle"[49]

Despite its reputation as a city of lighting innovation, Newcastle ended up falling behind many other British cities in its introduction of electric lighting. By 1897, the city's lighting committee was sending a delegation to South Shields, a much smaller town ten miles to the east of Newcastle at the mouth of the River Tyne, to look at the electric lights that had been introduced there.[50] Indeed through the period 1896-1902, the minutes of the lighting committee reveal a repeated series of reports, visits and localized experiments which saw a range of different proposals and costings produced by the city's lighting officer. This stands in contrast to the quick development of the electric network as a whole within the city, which was used as an exemplar in within the UK and operated at a more complex and higher capacity than London.[51] The extract opening this section is from one of the lighting officer's many reports, perhaps indicating a frustration with the lack of decision-making and change on behalf of the committee. The major 17

44 Ankit Kumar and Robert Shaw, "Transforming Rural Light and Dark under Planetary Urbanisation: Comparing Ordinary Countrysides in India and the UK", *Transactions of the Institute of British Geographers,* vol. 45, nº 1, 2020, 155.
45 Robert Shaw, "Streetlighting in England and Wales: New Technologies and Uncertainty in the Assemblage of Streetlighting Infrastructure", *Environment and Planning A,* vol. 46, nº 9 , 2014, 2228.
46 Annulla Linders, "Documents, Texts and Archives in Constructionist Research" *in* James Holstein and Jaber Gubrium (eds.), *Handbook of Constructionist Research* (London: The Guildford Press, 2008), 469.
47 Robyn Longhurst, "Semi-Structured Interviews and Focus Groups" *in* Nicholas Clifford *et al.* (eds), *Key Methods in Geography* (London: Sage, 3rd ed., 2016), 153.
48 Linders. "Documents, Texts and Archives", 469 (cf. note 46).
49 Minutes of the Newcastle Lighting Committee, 12/01/1893, TWAM.
50 Minutes of the Newcastle Lighting Committee, 09/07/1897, TWAM.
51 Hughes, *Networks of Power,* 228 (cf. note 16).

barriers to change, in this case, seemed to be threefold. The first was financial. An initial installation of arc electric lighting in central streets of Newcastle in 1890 appeared to offer significant savings over existing gas lighting. Enthusiasm at this point was high: the lighting officer's report on the first electric lights stated that:

> "the lamps have given great satisfaction and I have no hesitation in saying that the lighting committee art to be congratulated upon the result of the experiment, and that the problems of satisfactorily lighting our main street with the electric light has been brought considerably nearer by the action of your committee".[52]

18 Progress soon stalled, however. In particular and despite satisfaction with the lighting, the committee seemed to be unable to make the finances of the installation across the city of the necessary infrastructure for lighting work. Several letters between the lighting committee and NESCO seemed to reach a standstill on the issue of the cost of installing the necessary wires. Looking at NESCO's own archives, agreements with suburban authorities such as the 1901 agreement with Fenham Urban District Council, covering an area to the west of Newcastle city center, seem to have been reached more quickly.[53] Here, the added cost of installing new infrastructure alongside rapidly growing suburbs was lower than digging into Newcastle's already-densely developed city center, with overlapping medieval, eighteenth century and nineteenth century urban infrastructure.

19 Second, the introduction of electric lighting was more complicated because of the existing relationship between the local authority and the gas supply company. Almost immediately, the lighting committee showed concern about this relationship, but in the first instance the gas company wrote with their approval of small scale experiments with electric lighting. However as the first set of proposals were developed, the gas company responded more aggressively, by threatening to raise prices.[54] The lighting committee responded by reducing the number of hours' lighting being provided, in order to offset the increased cost of gas.[55] In this instance, the inflexibility of the gas company was offset by increasing flexibility in terms of the hours of lighting provided; this reemphasizes the insights that the transition is path-dependent, with existing technologies shaping the introduction of the new. Third, the introduction of electricity was also held-back by a lack of political power and will. At this time, British local governance was relatively weak.[56] With infrastructure provided entirely by private companies, the Newcastle Lighting Committee only had power as the *buyer* of electricity or gas. As such they were unable to prevent the emergence of a duopoly of electrical provision in Newcastle among two companies, NESCO and the Newcastle and District Electric Lighting Company (NDELC). These companies agreed that rather than compete by price, NESCO would supply the west of the city and NDELC the east.[57] In November 1891 the committee reacted angrily to the refusal of these companies to break this agreement, expressing their belief that they had "a right to request supply from whichever provider the committee desires".[58] By mid-1892, however, the committee relented, powerless in the face of the institutional inflexibility of the two companies.[59] Hughes shows how in Newcastle, the local electricity supply companies – particularly NESCO – prioritized the overall network supply rather than just lighting.[60] While this meant Newcastle became a higher consumer of electricity than other British

52 Minutes of the Newcastle Lighting Committee 16/07/1890, TWAM.

53 Agreement between Fenham and Benwell Urban District Council and North Eastern Electric Supply Company. 09/03/1904, TWAM.

54 Minutes of the Newcastle Lighting Committee 12/03/1890, TWAM.

55 *Ibid.*

56 Hughes, *Networks of Power*, 229 (cf. note 16).

57 NESCO, "Division of Electricity Supply with Newcastle and District Electric Supply Company", 17/03/1890, TWAM.

58 Minutes of the Newcastle Lighting Committee, 17/02/1891, TWAM.

59 Minutes of the Newcastle Lighting Committee, 17/05/1892, TWAM.

60 Hughes, *Networks of Power*, 251 (cf. note 16).

cities,[61] the lighting committee faced a difficult task in engaging businesses that had priorities elsewhere.

20 Commercial agreements have also led to inflexibility in Newcastle in recent times. As noted in the methodology, Newcastle City Council, North Tyneside Council and SSE operate lighting together under a PFI agreement, lasting 25 years from 2004. In interviews in 2013, staff at both councils said to me that at the time, LED lighting was not being installed as costs had already been incurred under that PFI agreement to replace orange 'SOX' street-lighting with white 'SON' street-lighting: "We've gone through an expensive PFI in whichever way you look at it, cheap or expensive which every way you look at it but there's a lot of cost involved so if we are going to fund the next stage 1) the money's got to be sought from somewhere 2) it's got to have a good payback… something like an LED – stop me if I'm wrong here but – are good units but they're quite expensive".[62] Here, the institutional inflexibly was created by the PFI award, which restricted the room for maneuver of Newcastle and North Tyneside councils. As in the late 1890s, Newcastle found itself falling behind neighbours such as Gateshead, which started the process of introducing LED in 2012.[63] By contrast, it was only in 2017 when the widespread introduction of LED lighting was approved by Newcastle City Council; I infer that this reflects the reduced cost of LED lighting by that time, although the discussion of this introduction is redacted in council minutes.[64] The replacement scheme has only just begun at the time of writing, while many other cities have been operating LED lighting for several years.

Institutional flexibility was at its lowest during the wartime Blackout period (1939-1946). The archives at this time reveal numerous letters requesting permission for extra lighting, all of which were subject to police inspections and many of which were rejected. Chief Constable Crawley of the Newcastle City Police, who appears to have personally adjudicated on all requests for exemptions, rejected the majority of requests made to him between 1939 and 1944. Restrictions in Newcastle-upon-Tyne were harsher than in many other cities because of its location near the east coast of England.[65] Sill there, were some exceptions. A request came through in September 1939, shortly after the introduction of lighting restrictions, from the city's head postmaster:

> "I would like to bring to your notice the need for some lighting in the archways leading from Neville Street to Orchard Street and Westgate Road to Calvering Place. We have a considerable number of officers leaving and commencing work round about 10.00pm daily and the absence of light of any kind has already lead to at least one of my staff being injured. Members of the female staff have also complained of molestation".[66]

Permission was granted for a small light to be hung under the archways, but this was one of few exemptions granted. 21

Newcastle at all three moments has had lower levels of flexibility than many other British local authorities, though for contrasting reasons. In the 1890s-1900s, local authorities in the UK had relatively little capacity to combat powerful 22

61 Ibid., suggests ten times higher than in London.

62 Interview with author, 2013.

63 Gateshead Borough Council. "Street Lighting Tender Gateshead: Supply of Luminaires for Phase 3 of the Street Lighting Carbon Reduction Project" 02/07/2012. Url: https://www.government-online.net/street-lighting-tender-gateshead/ (accessed 26/05/2020).

64 Approved Cabinet Minutes, 20/07/2017, Newcastle City Council. Url: https://democracy.newcastle.gov.uk/documents/b25988/Approved%20Public%20Minutes%2020th-Nov-2017%2016.30%20Cabinet.pdf?T=9 (accessed 26/05/2020)

65 The specific case of extra restrictions on public lighting in Newcastle was raised in the House of Commons by David Adams in ministerial questions to the Home Secretary, John Anderson, in August 1940. The Home Secretary strongly defended these extra restrictions in Parliament: "In a place so near the coast as Newcastle defence considerations make it impossible to allow street lighting of any kind". Hansard, *House of Commons, Oral Answers to Questions*, vol. 360, col. 1444. Url: https://hansard.parliament.uk/commons/1940-08-22/debates/e10540a8-2aec-46b4-b344-d6ad09c0421d/CommonsChamber (accessed 26/05/2020).

66 Letter to Chief Constable Crawley, 15/09/39, TWAM.

capital, albeit they had significantly more than 50 years previously,[67] and as such they were weak in the face of the objection to change that came from local energy companies. Newcastle seemed in this matter to have a particularly reticent local council, operating more slowly than both similarly sized cities in northern England and central Scotland, and smaller towns within Tyne and Wear. By contrast in the Blackout period, flexibility was constrained by very strong governmental control; the absolute and moral authority of the state-war machine combined with geography to restrict even very small forms of public lighting. Here, this authority facilitated dynamism where the state required it – both the start and end of blackout restrictions were relatively swift – but was otherwise very inflexible. In contemporary Newcastle, flexibility has once again been constrained by commercial relations, but this time round the capacity to make profit has broken through more quickly than in the 1890s. To understand the relative speed of action in the 2010s compared to the 1890s-1900s, we need to understand polyflexibility: ultimately, it is the intersection of relatively high flexibility in the financial modality with low flexibility in the governmental modality which led to change in Newcastle in the contemporary era, whereas both were equally inflexible in the 1890s-1900s. In other words, institutional flexibility is itself multiple, dependent upon organizational structure, legal power, moral/authoritative power, financial resources, and the capacities of individuals within the institution.

MEASURING AND PRESENTING DATA TO FACILITATE FLEXIBILITY

23 As previously described, Newcastle-upon-Tyne city council agreed a deal for an LED lighting replacement scheme, which began in the spring of 2019. Commercial restrictions have resulted in limited availability of information about the LED replacement programme. Nonetheless, the minutes of the Joint Street Lighting Committee held between Newcastle and North Tyneside do reveal some of the motivations. In the meeting of August 2016, it is noted that reports on the PFI should include "a section on electricity consumption, which was not previously included".[68] The introduction of this data in 2016 – and indeed its absence in previous reports – is revealing of the emergence of the importance of energy consumption in the management of lighting through the 2010s. This reflects in part that LED technologies suddenly created the opportunity to both save money and reduce energy use. This provides an example of the role of data in facilitating forms of flexibility.

North Tyneside council were more confident in the new technologies than Newcastle, and started a programme of dimming, trimming and part night switch off in 2014, followed by a transfer to LED lighting in 2017. As part of the 6 monthly PFI reports to the two local authorities, the differences between the originally projected and actual energy consumption for the previous twelve months is reported, and the evolution of this since North Tyneside began its lighting reduction plan is shown in figure 1. 24

Year	Newcastle	North Tyneside
2013	98.86	99.25
2014	98.81	89.70
2015	98.10	80.54
2016	97.85	78.65
2017	91.41	75.08
2018	89.51	65.40

Figure 1: Percentage of projected energy consumption actually used per year. Source: Author.[69]

67 Jan Palmowski, "Liberalism and Local Government in Late Nineteenth Century England and Germany", *The Historical Journal,* vol 45, n°2, 2002, 382.

68 Minutes of the Joint-Street Lighting Committee, 10/08/2016, North Tyneside Council. Url: http://ntc-web-democratic-archive-public.s3-website.eu-west-2.amazonaws.com/Files/JSL/JSL-2016-08-10_Joint_Street_Lighting_Committee_10-08-2016_-_Minutes.pdf (accessed 07/12/2020).

69 Table compiled from several editions of the Minutes of Joint-Street Lighting Committee, 2013-2019, Newcastle City Council and North Tyneside Council. Url: http://ntc-web-democratic-archive-public.s3-website.eu-west-2.amazonaws.com/JSL.html, (accessed 07/12/2020). Url: https://democracy.newcastle.gov.uk/ieListMeetings.aspx?CId=500&Year=0, (accessed 07/12/2020).

25 While both local authorities saw efficiencies due to general improvements by the PFI partner SSE, the savings gained by North Tyneside first by dimming in 2014 and moving to LEDs from 2017 are clearly shown in this table, such that North Tyneside was in 2018 saving £508,000 a year more than Newcastle, in comparison to projected energy use.[70] That these figures are also reported on in terms of saved expenditure suggests that a major driver behind these changes was the opportunity to save money. What we see in this reporting is that an energy assemblage which was apparently inflexible when my qualitative interviews took place in 2013, became flexible when, first, reliable data could be produced which showed the value of change; and second, as the cost implications of being inflexible continued to rise. As such, the financial modality and overall flexibility were reliable on availability of data.

26 Data was also important in the move between gas and electric lighting in the 1890s and 1900s. In this period, the main push for flexibility came through reports of Newcastle's lighting inspector, and visits by the committee members to other cities. In addition to the visit mentioned to nearby South Shields previously, in 1896-1897 visits were made to Sunderland, Edinburgh, Bolton and Southport.[71] These visits were used alongside data on the practices of other local authorities, obtained through written requests.[72] Technical reports on different technologies were provided by the (ever-patient) lighting inspector on different technologies and approaches to electric lighting are provided in July 1897, March 1898 and February 1900. It was this final report that contributed to the authorization of a fresh round of trials of electric lighting, which in turn led to the eventual approval of the installation of a greater number of electric lights in 1902.[73] Here, we can see that what was required for flexibility on behalf of the bureaucracy of the lighting committee and the local authority, was for electric lighting to be presented in terms with which bureaucracy could cope. As has been the case in the 2010s, flexibility was only possible once electric lighting had been transformed into the sort of known, reported upon and authorized data that bureaucracy recognizes. As well as being dependent upon the intersection of multiple modalities, polyflexibility is also about the translation of information into data that is recognizable to different modalities within an assemblage.

While Newcastle's PFI agreement in the 2010s was initially slow to change compared to other contemporary local authorities,[74] it has proved to be the flexible once a particular path was agreed upon. After agreeing on the transition to LEDs, barriers to flexibility were quickly removed, and resources allocated to the new installation programme. We can contrast the two periods by looking at the speed of change. In the contemporary era, LED lighting was approved in November 2017, with installations currently taking place and a projected point of conclusion in September 2021. By contrast, despite the first trial of permanent electric lighting taking place in Newcastle in 1890,[75] the decision to have a widespread programme of electric lighting installation was not taken until 1902, and only around 800 new electric lights had been installed by 1910.[76] In both cases, what was important in producing flexibility was the presentation of data in a form that could be recognised across the assemblage. Polyflexilbity, as a concept, highlights to us that flexibility is a result not just of interacting flexibilities, but also how this flexibility is communicated. This raises the role of measurement and presentation of data as central to understanding the flexibility of an assemblage. 27

70 *Ibid.*
71 Minutes of Street Lighting Committee, 1896-1898, TWAM.
72 Minutes of the Street Lighting Committee 14/12/1896, TWAM.
73 Minutes of the Street Lighting Committee 25/02/1902, TWAM.
74 Shaw, "Streetlighting", 2235 (cf. note 45).
75 Minutes of the Street Lighting Committee 16/07/1890, TWAM,.
76 Minutes of the Street Lighting Committee 20/12/1910, TWAM.

TECHNOLOGICAL PROMISES AND LIMITATIONS

28 The Blackout in World War 2 was managed and facilitated by a series of more or less innovative technologies.[77] Its management was the responsibility of local police, but its efficacy was also monitored by the RAF. In the early months of the Blackout, regular reports from RAF planes were sent to the Newcastle police, reporting mainly on the failure of Blackout measures to conceal the city. For example, a report from September 1939 states that "all towns in the Tyne and Tees area have odd lights visible and Newcastle is clearly recognizable as a town area".[78] By October 1939, these reports had become much more positive, and reports of visible breaches of the Blackout almost disappear from the archives.[79] New technologies started to emerge, providing businesses alternatives to forms of lighting that were visible from the sky. In Newcastle, however, very few of these were applied. As noted previously, Newcastle's location and arms industry made it a primary target, and Chief Constable Crawley was unmoved by technological innovation. For example, in November 1939, W.M. Storey of the Imperial Tobacco Company requested permission to install internal illumination of cigarette machines "with one low wattage blue lamp (5 watts)", noting that "permission has been granted by certain local authorities throughout the country".[80] Crawley wrote back, denying the request, on the grounds that lighting from automated machines was not covered in any listed exemptions.[81] By 1943, in a request from central government for a list of exemptions granted, only 11 were listed, almost all concerning the ability of shipyards to use lighting at night when emergency repairs were required, although this list excluded the centrally managed exemptions given to railway companies for repairs.[82] The Blackout period thus saw technological innovation, but this innovation was in the case of Newcastle unable to produce flexibility due to the strong state.

29 Technological innovations also helped bring about the end of the Blackout period. On the 15th November 1943, the Newcastle Lighting Committee were informed that a complete blackout was no longer necessary, and that 'starlighting' – the restricted form of street-lighting that had been provided in cities away from the east coast – could now be used in Newcastle as well.[83] However, this lighting only provided any value in mid-Winter, and six weeks-notice was required to manufacture the fittings that would be applied to street-lights to allow this. Combined with labour shortages, this meant that there was very little opportunity to introduce starlighting into Newcastle before April 1944, at which point summer brightness meant that all streetlighting was discontinued until August for fuel efficiency reasons.[84] Anticipating further relaxations on restrictions during 1944, the city council set-about repairing as many street-lights as possible. On the 9th September 1944, permitted lighting was increased to 'moonlighting', and "steps were immediately taken to have the streets of the City illuminated as quickly as possible".[85] Here, planning in the form of repairs through the summer of 1944 allowed for this measure to be taken up more quickly. Labour shortages were initially a major limitation, although the gradual reduction in the number of soldiers required on the fronts from late 1944 onwards allowed redeployment to increase the speed of infrastructural repair. By November 1944, 500 lanterns a week were being switched back on in Newcastle.[86] In April 1945 the lighting

77 James Robinson, "'Darkened surfaces': Camouflage and the Nocturnal Observation of Britain, 1941–45", *Environment and Planning A*, vol. 45, n° 5, 2013, 1053.
78 Report to Chief Constable Crowley, 04/09/39, TWAM.
79 Various, Newcastle City Police Archives, 1939-1940, TWAM.
80 Letter to Chief Constable Crowley, 29/11/1939, TWAM.
81 Letter from Chief Constable Crowley, 30/11/1939, TWAM.
82 Letter from Assistant Chief Constable, 12/05/43, TWAM.
83 Minutes of the Street Lighting Committee, 15/11/1943, TWAM.
84 Minutes of the Street Lighting Committee, 05/05/1944, TWAM.
85 Minutes of the Street Lighting Committee, 06/10/1944, TWAM.
86 Minutes of the Street Lighting Committee, 03/11/1944, TWAM.

committee heard that "no further intermediate standards of lighting is contemplated, and the next step at the appropriate time will accordingly be the removal of all restrictions and the restoration of unscreened lighting."[87] Factors other than the danger of enemy bombardment were barriers to the ability to return to more available lighting. Specifically, there were continued fuel shortages which meant that lighting was restricted through the summer months, such that lanterns were switched off between May 1945 and the end of August 1945. Similar restrictions were in place during the summer of 1946 and it was only after this time that the return to 'normal' lighting conditions was made.[88]

30 The technological modality was therefore a relatively weak part of the flexibility of Blackout-era public lighting. Both the contemporary installation of LED lighting and the slow move towards gas lighting in the 1890s-1900s show periods at which technological and infrastructural capacities were more important. In both instances, a source of difficulty was the conflict between the technological and the infrastructural. Specifically, the difficulty of installing new infrastructure into an already densely built-upon city was a major factor restricting flexibility in early 1900s Newcastle, and 2010s Newcastle. In the contemporary case, existing columns have proved unsuitable in many cases for the specific lighting capacities of LEDs, with their height and spacing designed for the intensity and diffusion of sodium-based light bulbs. In an interview prior to the decision to transition to LED lighting, an official one of the councils involved in the joint North Tyneside/Newcastle scheme said:

> "One of the issues that we have is that because we've got new lampposts if we were going to do lighting changes to try and reduce the energy we're not going to reposition lampposts, we want to use the existing lampposts and some LEDs can't quite achieve the performance standards based on what we currently have."[89]

In other words, the different technological capacities of LEDs compared to sodium-based lights mean that different infrastructure is required to implement them. 31

While these two transitions show similar infrastructural inflexibilities, in both cases there is little evidence of public opinion creating inflexibility. When the installation of the first permanent electric lighting occurred in 1890, the *Newcastle Courant* proudly asserted that "each lamp has a light of 1500 actual candle power, and is most brilliant and effective",[90] although the same paper had as early as 1881 proclaimed, based on Swan's experiment in Mosely Street, that "the adoption of the electric light for street lighting purposes is only a matter of time".[91] The relatively slow adoption of electric lighting in Newcastle does not appear to have been commented on in the paper at that time. In the contemporary transition, there is little evidence for strong public opinion on the matter, reflecting research that suggests the issue of LED street-lighting transition generally of low concern, and that many people barely notice where changes have happened.[92] In particular, that Newcastle's transition has come after neighbouring boroughs may have dampened interest. The *Newcastle Evening Chronicle* in the 2010s reported on the transitions to LED lighting in nearby County Durham[93] and North Tyneside, [94] whereas recent reporting on Newcastle's scheme is embedded within wider discussion of the 32

87 Minutes of the Street Lighting Committee, 26/04/1945, TWAM.

88 Minutes of the Street Lighting Committee, 06/09/1946, TWAM.

89 Interview with author, 2013.

90 "North of England News*", Newcastle Courant*, Newcastle-upon-Tyne, issue 11233 03/05/1890, The British Newspaper Archive (BNA).

91 "Local Notes", *Newcastle Courant*, Newcastle-upon-Tyne, issue 10792 04/11/1881, BNA

92 Judith Green *et. al.,* Reduced Street Lighting at Night and Health: A Rapid Appraisal of Public Views in England and Wales, *Health and Place,* vol. 34, n° 1, 2015, 178.

93 "Bright sparks light up lives", *Newcastle Evening Chronicle*, Newcastle-upon-Tyne, 15/10/2015, Nexis Archives.

94 Tony Henderson and Sonia Sharma, "'Trim and Dim' Plan to Cut Street Lighting Bills", *Newcastle Evening Chronicle*, Newcastle-upon-Tyne, 13/11/2013, Nexis Archives.

local authority's response to climate change.[95] In these contemporary cases, the major question is about the financial demand of transition, rather than the experiential qualities of lighting.

33 In both the historical and the contemporary cases, new, brighter, cheaper public lighting was promised, but the existing infrastructural forms were sufficiently inflexible to delay the installation of these new technologies. In both cases public opinion has been relatively neutral to or mildly in favour of transition, with questions of financial value at the forefront of local newspaper reporting. This fits with the outcome that in both cases, technological changes were able to cut through and drive transitions when it became clear that the financial savings of the new technologies outweighed the initial cost of infrastructural change.

DISCUSSION

34 These three cases show a polyflexibility in which transitions emerge from the relative flexibilities and fixities of different actors who make up the energy assemblage. The three cases show contrasting systems of governance: a bureaucratic state in the 1890s-1900s; a strong militarized operation through World War Two; and a PFI in the 2010s. Across the three cases, flexibility is not the same as dynamism. Arguably, the blackout period was the most *dynamic*, in terms of having the fastest pace of change and the ability to quickly redeploy resources and people in order to change the lighting regime. However, this system was also the least *flexible*: there were essentially no mechanisms for inserting flexibility in face of a strong state. Polyflexibility is not simply therefore a sum of the flexibility of different parts of an assemblage, but also an effect of the relations between these parts and the how they can communicate.

35 As such, thinking about flexibility in singular ways has the consequence of embedding fixed patterns within our reading of energy systems.[96] As the three moments in Newcastle's public lighting history show, there have been both different levels of polyflexibility, and different sources of (in)flexibility. In both the 1890s-1900s transition from gas to electric lighting and the contemporary transition, infrastructure was a source significant inflexibility, and smaller suburbs or surrounding towns started energy transitions before the city itself. The two cases differ in the power of the financial modality; by contrast to the 1890s-1900s, the increased power of finance in the 2010s meant that once change was decided upon, the system was highly dynamic: there is perhaps now low flexibility but high dynamism. By contrast, the blackout era was dynamic insofar as a strong state was able to quickly enact change, but to a very inflexible regime. While technological changes were attempted to provide more lighting, the state was largely able to use its power to prevent them from being implemented. In the most recent transition, we see something of a hybrid between the two historical cases.

The concept of Polyflexibility has helped me open up an analysis of flexibility which does not use the analytical tool of supply and demand as the main framing device. While often useful, these concepts offer less when considering public lighting, where the demand can be understood either as demand from the state for energy or from the public for lighting, and the supply can be understood as supply by the state of infrastructure, or from energy suppliers for the energy itself. Thinking in terms of Polyflexibility encourages a conceptualization of a relational flexibility which changes over both time and space as different practices and infrastructures mutually produce one-another. It helps conceptualized energy transitions as path-dependent, but not as externally produced interruptions; rather they appear as moments on trajectories. 36

95 Dan Holland, "Climate Change Row: Council Clash Over Spending on Eco Action", *Newcastle Evening Chronicle*, Newcastle-upon-Tyne, 26/12/2019, Nexis Archives

96 Elizabeth Shove, "Beware a Fixed Approach to Flexibility", *New Power*, 16/10/2019. Url: https://www.new-power.info/2019/10/beware-a-fixed-approach-to-flexibility/, (accessed 26/05/2020).

Bibliography

Acuto Michele
"We Need a Science of the Night", *Nature*, n° 576, 2019, 339.

Arup
Cities Alive: Rethinking the Shades of Night (London: Arup, 2015).

Baldwin Peter C.
In the Watches of the Night (Chicago: Unviersity of Chicago Press, 2012).

Blue Stanley
"Institutional rhythms: Combining practice theory and rhythmanalysis to conceptualise processes of institutionalisation", *Time & Society*, vol. 28, n°3, 2019, 922-950.

Castro Miguel, Antonio Jara and Antonio Skarmeta
"Smart Lighting Solutions for Smart Cities", in *Proceedings of the 27th International Conference on Advanced Information Networking and Applications Workshops* (Institute of Electrical and Electronics Engineers, 2013), 1374-1379.

Chirnside Raplh Clark
"Sir Joseph Swan and the Invention of the Electric Lamp", *Electronics and Power*, 1979, vol. 25, n°2, 96-100.

Dunn Nick S.
"Dark Futures: the Loss of Night in the Contemporary City?", *Journal of Energy History/Revue d'Histoire de l'Énergie*, 2019, vol. 2. Url: energy-history.eu/en/node/108.

Edgerton David
The Shock of the Old : Technology and Global History since 1900 (London: Profile, 2008).

Le Gallic Stéphanie and Pritchard Sara B.
"Light(s) and Darkness(es): Looking back, Looking Forward", *Journal of Energy History/Revue d'Histoire de l'Énergie,* vol. 2, 2019. Url: energy-history.eu/en/node/137.

Green Judith, *et. al.*
"Reduced Street Lighting at Night and Health: A Rapid Appraisal of Public Views in England and Wales", *Health and Place*, vol. 34, n° 1, 2015, 171-180.

Hägerstrand Torsten
"Geography and the Study of Interaction between Nature and Society", *Geoforum*, vol. 7, n° 5-6, 1976, 329-334.

Hughes Thomas Parker
Networks of Power: Electrification in Western Society, 1880-1930 (Baltimore: John Hopkins Press,1983).

Isenstadt Sandy, Maile-Petty Margaret and Neumann Dietrich (eds.)
Cities of Light: Two Centuries of Uurban Illumination (London: Routledge, 2014).

Kumar Ankit and Shaw Robert
"Transforming Rural Light and Dark under Planetary Urbanisation: Comparing Ordinary Countrysides in India and the UK", *Transactions of the Institute of British Geographers,* vol. 45, n°1, 2020, 155-167.

Kyba Christopher, Pritchard Sara B, Ekirch A. Roger, *et al*.
"Night Matters—Why the Interdisciplinary Field of "Night Studies" Is Needed", *J—Multidisciplinary Scientific Journal*, vol 3, n°1, 2020, 1-6. Url: https://www.mdpi.com/2571-8800/3/1/1/html.

Lefebvre Henri
Rhythmanalysis: Space, Time and Everyday Life (London: Continuum, 2004).

Marino Francesco, Leccese Fabio and Pizzuti Stefano
"Adaptive street lighting predictive control", *Energy Procedia,* vol. 111, n°1, 2017, 790-799.

Mori Akihisa
"Socio-Technical and Political Economy Perspectives in the Chinese Energy Transition", *Energy Research and Social Science*, vol. 35, n°1, 2018, 28-36.

Nordensvärd Johan and Urban Franke
"The Stuttering Energy Transition in Germany: Wind Energy Policy and Feed-In Tariff Lock-In", *Energy Policy*, vol, 82, n°1, 2015, 156-165.

Nye David
When the Lights Went Out: A History of Blackouts in America (Cambridge, MA: MIT Press, 2010).

Palmowski Jan
"Liberalism and Local Government in Late Nineteenth Century England and Germany", *The Historical Journal,* vol. 45, n°2, 2002, 381-409.

Pizzuti Stefano, Annunziato Mauro and Moretti Fabio
"Smart street lighting management", *Energy Efficiency,* vol. 6, n°1, 2013, 607-616.

Powells Gareth, Bulkeley Harriet, Bell Sandra and Judson Ellis
"Peak Electricity Demand and the Flexibility of Everyday Life", *Geoforum,* vol. 55, n°1, 2014, 43-52.

Rinkinen Jenny and Shove Elizabeth
"Energy Demand", *in* Rinkinen Jenny, Shove Elizabeth and Torriti Jacopo (Eds.), *Energy Fables. Challenging Ideas in the Energy Sector,* (Abingdon: Earthscan, 2019), 7-14.

Robinson James
"'Darkened surfaces': Camouflage and the Nocturnal Observation of Britain, 1941–45", *Environment and Planning A*, vol. 45, n° 5, 2013, 1053-1069.

Schivelbusch Wolfgang
Disenchanted Night (Oxford: Berg Publishers, 1988).

Schlör Joachim
Nights in the Big City: Paris, Berlin, London 1840-1930 (London: Reaktion, 1998).

Shaw Robert
"Streetlighting in England and Wales: New Technologies and Uncertainty in the Assemblage of Streetlighting Infrastructure", *Environment and Planning A,* vol. 46, n°9 , 2014, 2228-2242.

Shove Elizabeth
"Beware a Fixed Approach to Flexibility", *New Power*, 16/10/2019. Url: https://www.newpower.info/2019/10/beware-a-fixed-approach-to-flexibility/.

Shove Elizabeth, Watson Matt and Spurling Nicola
"Conceptualising Connections: Energy Demand, Infrastructures and Social Practices", *European Journal of Social Theory,* vol. 18, n°1, 2015, 274-287.

Strambach Simone
"Path Dependency and Path Plasticity: the Coevolution of Institutions and Innovation - the German Customized Business Software Industry", *Working Papers on Innovation and Space,* Philipps-University Marburg, Department of Geography, n° 02.08, 2008, 4. url: www.econstor.eu/handle/10419/111860.

Wilson Charlie and Grubler Arnulf
"Lessons from the History of Technological cCange for Clean Energy Scenarios and Policies", *Natural Resources Forum,* vol. 35, n°1, 2011, 165-184.

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR
Clarence Hatton-Proulx
PhD candidate, Institut national de la recherche scientifique, Centre Urbanisation Culture Société (Québec) & Sorbonne Université, UMR Sirice (Paris)
clarencehatton@gmail.com
Twitter : @clarence_hp

POST DATE
02/09/2020
ISSUE NUMBER
JEHRHE #5
SECTION
Special issue
THEME OF THE SPECIAL ISSUE
Historicising Flexibility
KEYWORDS
hydroelectricity, gas, production, consumption, business
DOI
in progress

TO CITE THIS ARTICLE
Clarence Hatton-Proulx, "Creating Supply, Creating Demand: Gas and Electricity in Montréal from the First World War to the Great Depression", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 02 September 2020, URL: energyhistory.eu/node/222.

Creating Supply, Creating Demand: Gas and Electricity in Montréal from the First World War to the Great Depression

Abstract
Reducing energy use is a key imperative for Western societies. However, it is hard to envision how this might come about and what changes are entailed. This article proposes that studying energy history helps understand flexibility in energy systems. It uses the case of Montréal to analyze the fluctuation of electricity and gas supply and demand during an eventful historical period that stretches from the First World War to the Great Depression, marked both by capacity expansion and stagnation. By studying the activities of the city's monopolistic energy utility and the practices of energy consumers, this article proposes a typology of four different kinds of energy flexibility: upwards supplier-led flexibility, downwards supplier-led flexibility, upwards consumer-led flexibility, and downwards consumer-led flexibility. This analysis has important implications for future energy megaprojects and the shaping of energy consumption. It also shows how energy history can reveal the implications of past patterns for future decisions.

Acknowledgements
My sincerest gratitude goes to Jan Hadlaw, who supervised the M.A. thesis upon which this paper is based and taught me so much ; to Sean Kheraj, Claire Poitras, Alain Beltran, and Jessica Zaphiropoulo for their insightful comments on previous versions of this paper ; to participants at the Doctoriales de l'énergie, ICOHTEC, Histories of Urban Knowledge workshop and Histories of Flexibility workshop for their excellent feedback ; to the coordinators of this special issue, Elizabeth Shove in particular ; to the journal editor, and to two anonymous reviewers. Funding for this research was provided by York University and the Comité d'histoire de l'électricité et de l'énergie.

Plan of the article

INTRODUCTION: THE FAULT LINES OF GROWTH

1 Looking at a chart illustrating the evolution of global energy consumption since the 19th C. tells a pretty straightforward story (fig. 1). Slow growth during the 19th C. was superseded by an exponential increase in the 20th C., in particular from the 1950s onwards. Historian Steve Penfold has recently, and provocatively, argued that “you could reduce the entire history of Canadian gasoline to a single keyword: *more*.”[1] Claims like these reinforce the impression that the history of modern energy consumption is one of growth and acceleration. However, by zooming in on the chart we discover a different story that is both geographically and historically situated. At various points over the last two centuries there have been phases of *reduced* energy consumption (fig. 2). For example, wars and economic recessions have sometimes caused people to use less energy than they had done before.[2]

2 These episodes are tremendously revealing in that they allow historians to examine past forms of flexibility. Anthropogenic climate change, carbon emissions from fossil fuels, and resource scarcity compel industrialized nations to reduce energy consumption and in response, policymakers and scholars argue for greater energy flexibility. There are different interpretations of what this actually means. Some argue that energy flexibility must come from the supply side: in other words, the energy sector needs to promote the development of renewable energy sources and the reduction of energy intensity through technological improvement.[3] Others contend that energy flexibility must come from the demand side: for them, individuals need to change their energy-intensive lifestyles and pivot towards more sustainable ways of living.[4] This article argues that these two positions are reconcilable: going further, it suggests that supply and demand within energy systems are inextricably linked, both when energy systems expand and when they contract.

The story it tells takes place in Montréal during the first half of the 20th C., a period during which the city was Canada’s economic, industrial, and cultural capital.[5] The First World War is its starting point: during this period, energy entrepreneurs built additional gas and electricity capacity to help meet the requirements of energy-intensive wartime production. Once the war ended, the monopolistic gas and electricity utility controlling the city of Montréal generated more energy than its home market could immediately absorb. For this reason, the utility actively sought to create markets by encouraging the adoption of energy consuming appliances, and by promoting conventions of cleanliness and comfort as a means of fostering the normalization of lifestyles dependent upon limitless and invisible forms of energy. But these plans were severely checked by the Great Depression of the 1930s. Economic hardship and massive unemployment in Montréal led to a reduction in energy consumption, and to something of a reversal in energy-intensive lifestyles: a historically significant moment. The last part of the paper reviews these trends and proposes a typology of flexibility, based on experiences in Montréal from the 1910s to the 1930s. Based on municipal, provincial, and business archives, the paper provides new 3

1 Steve Penfold, “Petroleum Liquids”, *in* Ruth W. Sandwell (ed.), *Powering up Canada: A History of Power, Fuel, and Energy from 1600*, (Montréal & Kingston: McGill-Queen’s University Press, 2016), 277. Italics in the original.

2 Jean-Baptiste Fressoz, “Pour une histoire désorientée de l’énergie”, *in* Daniel Thevenot (ed.), *25èmes Journées Scientifiques de l’Environnement - L’économie Verte En Question*, Journées scientifiques de l’environnement (Créteil, France, 2014).

3 See for example: Eric Martinot, “Grid Integration of Renewable Energy: Flexibility, Innovation, and Experience”, *Annual Review of Environment and Resources*, vol. 41, 2016, 223–51.

4 See for example: Clare Hocking and Ulla Kroksmark, “Sustainable Occupational Responses to Climate Change through Lifestyle Choices”, *Scandinavian Journal of Occupational Therapy*, vol. 20, no° 2, 2013, 111–17.

5 This changed after the Second World War, when Toronto took the crown. For more discussion on this topic, see: Jane Jacobs, *The Question of Separatism: Quebec and the Struggle over Sovereignty*, 2nd ed. (Montréal: Baraka Books, 2011); Mario Polèse, “Montréal économique : de 1930 à nos jours,” *in* Dany Fougères (dir.), *Histoire de Montréal et de sa région, t. II* (Québec: Presses de l’Université Laval, 2012), 959–1004.

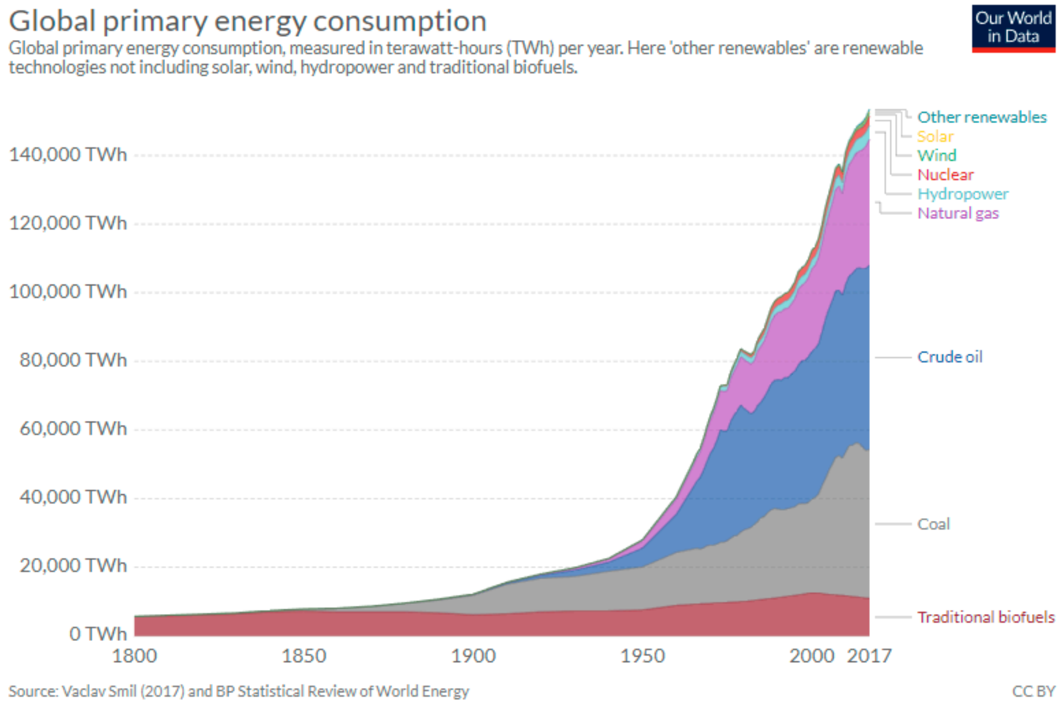


Figure 1: Global energy consumption. Source: Ritchie and Roser, 2018.[6]

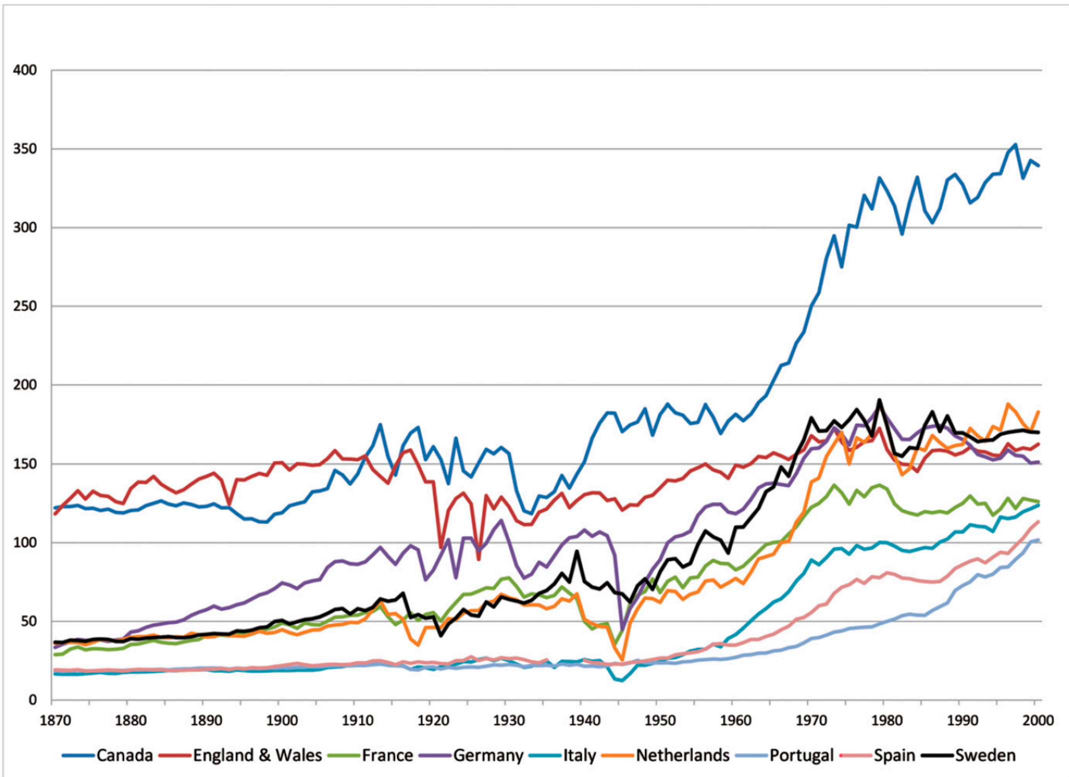


Figure 2: Energy consumption per capita in different Western countries. Source: Unger, 2018.[7]

6 Hannah Ritchie and Max Roser, "Energy Production & Changing Energy Sources", *Our World in Data*, 2018, https://ourworldindata.org/energy-production-and-changing-energy-sources.

7 Richard W. Unger, "Shifting Energy Sources in Canada: An International Comparison, 1870–2001", *Canadian Journal of History*, vol. 53, n° 3, 2018, 489.

insights into present and future energy transitions, arguing that supply and demand cannot be treated separately and that if decarbonization is to happen, both supply- and demand-side solutions need to be considered simultaneously.[8]

GREAT WAR, GREAT BUSINESS

4 At the dawn of the First World War, Montréal was Canada's major metropolis, and home to around 500,000 inhabitants.[9] After the development of thermoelectricity — generated from the combustion of coal — in the last two decades of the 19th C., Anglo-Canadian businessmen with experience in running urban utilities started to construct hydroelectricity schemes in the late 1890s, building run-of-the-river generating stations at Lachine in 1897 (fig. 3) and Chambly in 1899. Montréal's unique situation meant that the city had access to a variety of energy sources: it is nestled within a particularly rich hydrographic basin (fig. 4) and relatively close to the coal deposits needed to produce manufactured gas.[10] In that sense, this case study documents the energy history of a city in which there was an abundance of energy supply, an oddity compared to cities like Berlin.[11]

The city's local entrepreneurs could also count on both British and American capital to help them finance the construction of large infrastructure. All three levels of government — municipal, 5

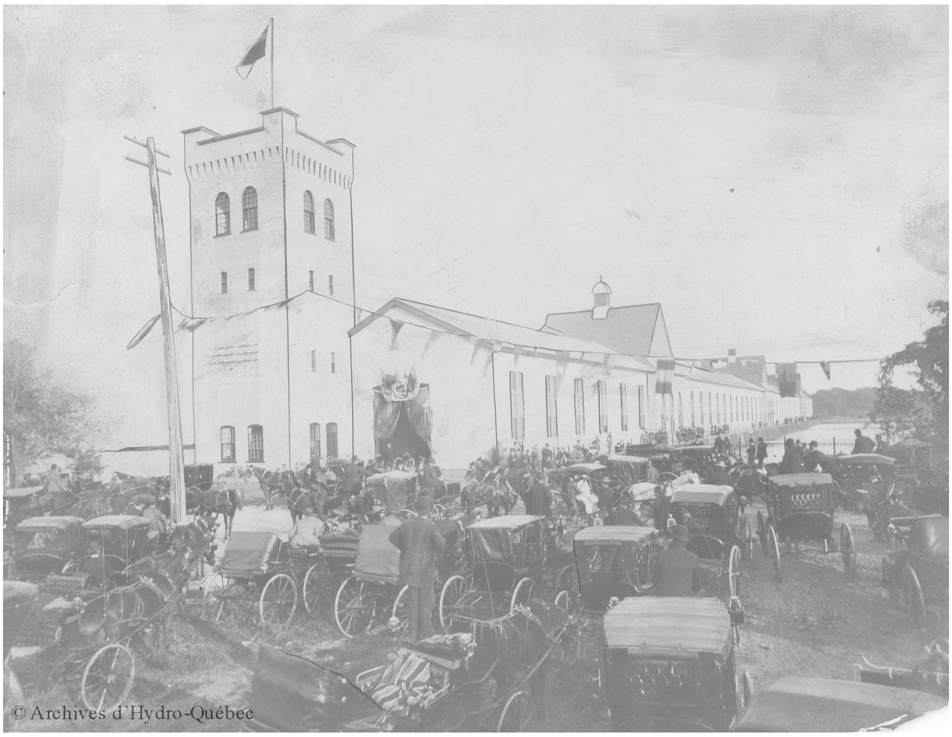


Figure 3: Opening day at Lachine, 1897. Source: Hydro-Québec Archives

8 This article is based upon the author's master's thesis. See: Clarence Hatton-Proulx, "A Lust for Power. Electrifying Montréal's Streets and Homes, 1884-1939" (M.A. Thesis, Toronto, York University, 2019).

9 Ville de Montréal, "Population Totale et Variation de La Population, Agglomération de Montréal," *Ville de Montréal* (blog), 2016, http://ville.montreal.qc.ca/portal/page?_pageid=6897,67887840&_dad=portal&_schema=PORTAL.

10 On Montréal's water history, see : Michèle Dagenais, *Montréal et l'eau. Une histoire environnementale* (Montréal: Boréal, 2011); Dany Fougères, *L'approvisionnement en eau à Montréal. Du privé au public, 1796-1865* (Québec: Septentrion, 2004); Robert Gagnon, *Questions d'égouts. Santé publique, infrastructures et urbanisation à Montréal au XIXe siècle* (Montréal: Boréal, 2006).

11 See this article in the special issue: Timothy Moss and Siddharth Sareen, "Demanding Demand: Political Configurations of Energy Flexibility in Berlin, 1920-2020", *Journal of Energy History / Revue d'Histoire de l'Énergie [Online]*, n°5, 2020.

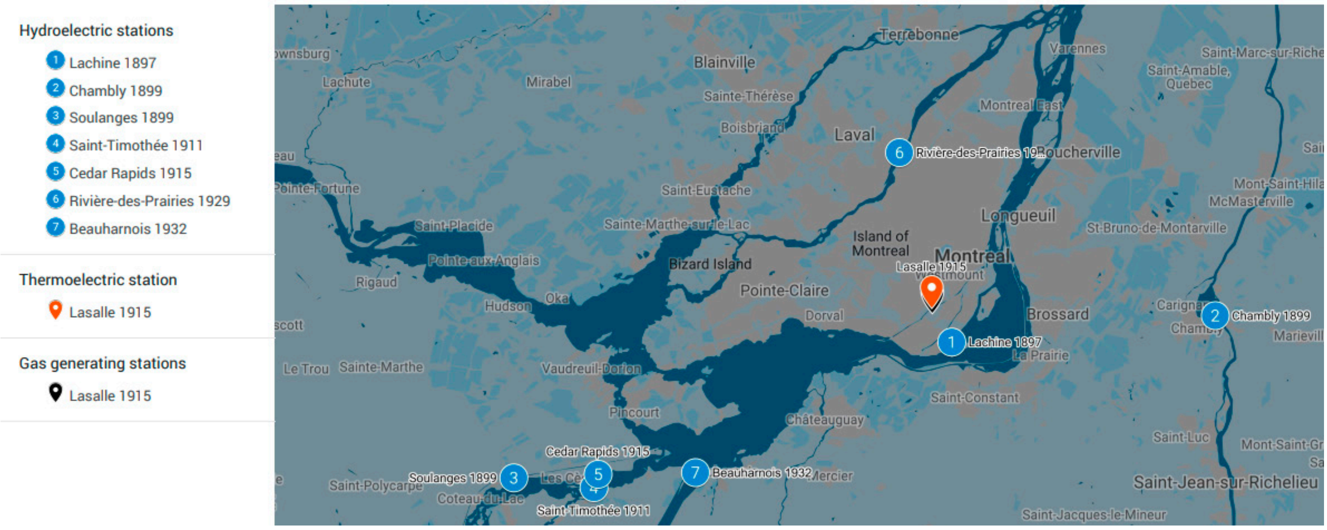


Figure 4: MLHP's main gas and electricity stations. Made by the author using Google Maps.

provincial, and federal — were favourable to big business.[12] Despite vigorous public opposition, the state didn't prevent the creation of a gas and electricity monopoly that reigned over the island of Montréal. The Montreal Light, Heat & Power Company (MLHP) was formed in 1901 after the merger of the Royal Electric Company, the Saint Lawrence Company, and the Montreal Gas Company.[13] Cartel arrangements were reached in subsequent years with the Shawinigan Water & Power Company (SWP), a strong industrial conglomerate operating from the city of Shawinigan.[14] So, from the 1900s until its expropriation by the Québec provincial government in 1944, MLHP operated a virtual monopoly over the distribution of gas and electricity in Montréal.[15]

In practice, this means that the firm's history can be taken as a history of the gas and electricity sectors in Montréal during the first half of the 20th C. In this instance, business history becomes a proxy for understanding urban energy history.

Once MLHP took control of the domestic market, 6
it looked to slowly increase the supply of energy but without flooding the market with low-cost power. Different locations had been identified by engineers as potentially interesting sites for hydroelectric schemes, attesting to the richness of Montréal's hydrographic basin. However, the utility company wasn't interested in exploiting them all at the same time. After the fusions and acquisitions of 1901 and 1903, it had to stabilize its activities and wasn't in an expansionist mode, having seen its fixed charges increase by 99% between 1902 and 1903, and by 153% between 1903 and 1904 — a complete anomaly in the firm's history.[16] It is improbable that the state would have granted emphyteutic leases for multiple locations simultaneously since this could have disrupted water circulation around Montréal. In any case, the market for additional electricity

12 See for example the parallel case of neighbouring Ontario: Henry Vivian Nelles, *The Politics of Development: Forests, Mines, and Hydro-Electric Power in Ontario, 1849-1941* (Montréal & Kingston: McGill-Queen's University Press, 2005).

13 Monopolistic control was furthered in 1903, when MLHP acquired Lachine Rapids Company and its subsidiaries.

14 For an exhaustive account of SWP's history, see: Claude Bellavance, *Shawinigan Water and Power, 1898-1963. Naissance et déclin d'un groupe industriel au Québec* (Montréal: Boréal, 1994).

15 Except for a few municipal systems in suburbs like Westmount and occasional competition from smaller ventures that were eventually bought out by the monopolistic company, like the Quebec New England Hydro-Electric Corporation acquired by United Securities Ltd. On behalf of SWP, MLHP, and Montreal Tramways. Engineering Department, *Montreal Light, Heat & Power Cons. Valuation of Electric Property. General Report*, Archives d'Hydro-Québec (later referred to as AHQ) F9/3458/13549 loc. 3930 (Montréal: Montreal Light, Heat & Power Consolidated, 1943), 7.

16 Montreal Light, Heat & Power Consolidated, *A Statistical Analysis of Montreal Light, Heat & Power Consolidated*, AHQ F9/3413/12350 loc. 3121 (Montréal: Montreal Light, Heat & Power Consolidated, 1931), 8.

was not yet formed, meaning that the city could not have absorbed the additional energy produced. According to the city of Montréal's boiler inspector, in 1911 "steam was by far the main source of power in the city's plants."[17] Less than half of the city's households were connected to the electricity distribution network, and those that were mainly used electricity to power a few lightbulbs.[18] Hydroelectric capacity had to be developed selectively and patiently. An engineering report on the potential for capturing power from the Back River published in 1914 confirms this interpretation.[19] Water and ice conditions were deemed to be favourable for the construction of a hydroelectric plant. However, the authors stated that "the market for power is well supplied as there are two large developments [...] that have large quantities of power yet unsold. The Shawinigan Company too can send more power to Montreal than they now send, so that for some time at least the market for a new large development would not be favourable."[20] As a result, the proposed development on the Back River was shelved until the end of the 1920s.[21]

7 One of two developments mentioned in the report was the Cedar Rapids station. In 1912, MLHP and SWP acquired control of the Cedar Rapids Manufacturing & Power Company, incorporated in 1904, which had obtained permission from the federal and provincial governments to build a power station on the Saint-Lawrence River south-west of Montréal. MLHP and SWP immediately concluded supply contracts with the Aluminum Company of America (Alcoa) in 1913 for the delivery of 60,000 horsepower (HP) starting in 1915.[22] The development of additional electrical capacity was justified by this new industrial activity located in Massena, NY, without which it is probable that Cedar Rapids wouldn't have been developed at that time. The outbreak of the First World War proved a great business opportunity for both MLHP and Alcoa. Canada, as a British Dominion, entered the conflict from the start and produced important wartime goods such as aluminum. Smelting aluminum through electrolysis requires large amounts of energy. This energy-intensive activity fitted well with the huge hydroelectric capacity found in the province of Québec and some of SWP's most important customers were aluminum companies like Alcan, the Canadian subsidiary of Alcoa.[23] During the First World War, a major outlet was found for aluminum: airframes. As military aviation kicked off during the conflict, warring sides started mass producing military aircrafts.[24] MLHP, through the Cedar Rapids station, took part in this impressive war effort.

Cedar Rapids started operating in January 1915. 8
Nine units of 10,800 HP were built, bringing the station's installed capacity to 97,200 HP. A tenth unit was added a year later, and two more were

17 Cited in Alain Gelly, "A Precipitous Decline, Steam as Motive Power in Montreal: A Case Study of the Lachine Canal Industries", *IA. The Journal of the Society for Industrial Archeology*, vol. 29, n° 1, 2003, 65.

18 It is estimated that the 50% threshold for houses with electricity was reached between 1916 and 1921. Claude Bellavance and Paul-André Linteau, "La diffusion de l'électricité à Montréal au début du XXe siècle", *in* Paul-André Linteau et Horacio Capel (dir.), *Barcelona-Montréal: Desarrollo Urbano Comparado / Développement Urbain Comparé* (Barcelone: Publicacions de la Universitat de Barcelona, 1998), 249.

19 The Back River is now commonly known as the Rivière-des-Prairies and separates the island of Montréal from the Île Jésus, where Montréal's biggest suburb, Laval, is now situated.

20 Montreal Light, Heat & Power Company, *Engineer's Report. Sault Au Recollet*, AHQ F9/3425 13028 loc. 3942 (Montréal: Montreal Light, Heat & Power Company, 1914), 7.

21 For more information on the "industrialization" of the Rivière-des-Prairies, see: Dagenais, ch. 5.

22 The Cedar Rapids Manufacturing and Power Company, *Memorandum on the Cedar Rapids Manufacturing & Power Company and the Cedar Rapids Transmission Company*, AHQ F9/3409/12156 loc. 3960 (Montréal, 1944), 2.

23 The aluminum sector played an important role in the industrialization of the province of Québec and Canada. See: David Massell, *Quebec Hydropolitics: The Peribonka Concessions of the Second World War* (Montréal & Kingston: McGill-Queen's University Press, 2011); Matthew Evenden, *Allied Power: Mobilizing Hydro-Electricity during Canada's Second World War* (Toronto: University of Toronto Press, 2015).

24 At that time, the United States were responsible for 73% of all the aluminum produced globally, which necessitated huge amounts of electrical energy. Marco Bertilorenzi, *The International Aluminium Cartel: The Business and Politics of a Cooperative Industrial Institution* (New York: Routledge, 2015), 104.

contracted for in 1917.[25] Some have argued that Cedar Rapids was built to address the accelerated uptake of electricity in Montréal across all sectors.[26] However, historical records show that its existence was first justified by industrial and wartime demand. Between July 1915 and January 1916, 232,705 kWh were produced at Cedar Rapids.[27] Out of this total, 198,701 kWh were bought by Alcoa, and just 34,004 kWh by MLHP.[28] In other words, less than 15% of the power produced in the early history of Cedar Rapids supplied the Montréal market, the rest helping Alcoa accelerate wartime production. For the following years, it seems clear that most of the energy generated at Cedar Rapids was exported to Massena: in 1918, about 75% of the electrical energy produced went to Alcoa while 25% went to Montréal.[29]

9 During the conflict, Montréal's industry, while mostly dependent upon steam engines and independently produced thermoelectricity, also purchased some of the energy sold by MLHP. Munitions, weapons, ships, and military uniforms were all produced in the metropolis' factories, notably by the women replacing men gone to fight in Europe.[30] In 1915, the utility company finished the construction of a steam reserve plant and of a manufactured gas plant in the then suburb of Lasalle. The steam reserve plant, of an installed capacity of 25,000 HP, was designed to help the company meet peaks in electricity demand when its hydroelectricity wasn't sufficient, notably when climatic conditions, such as ice accumulation, disturbed the normal flow of water. The manufactured gas plant, of a capacity of 4,000,000 cubic feet per day, supplemented the company's existing gas infrastructure which provided gas for heating and cooking to the factories, shops, and dwellings connected to its network.[31]

POST-WAR BLUES IN THE JAZZ AGE

After important hydroelectric, thermoelectric, and manufactured gas expansion during the First World War, the transition to peacetime was difficult to negotiate for MLHP. The company's supply capacity had been massively extended thanks to industrial clients looking to profit from exceptional wartime production. However, once the war ended, many of these industrial firms slowed down their activities, and the demand for energy dropped. Alcoa, for instance, purchased less electrical energy from MLHP in 1919 than in 1918.[32] Up to this point, the utility company had managed to increase its supply capacity gradually by anticipating and meeting potential demand. Now, the company was faced with the problem of excess supply. The distinctive features of hydroelectricity made that a problem. Water flows around the clock through the turbines that produce electricity, and this is not 10

25 The Cedar Rapids Manufacturing and Power Company, *Memorandum on the Cedar Rapids Manufacturing & Power Company and the Cedar Rapids Transmission Company*; Engineering Department, *Montreal Light, Heat & Power Cons. Appraisal of Electric Property. Subsidiary Report No. 1. Cedars Rapids Mfg. & Power Co.*, AHQ F9/3458/13544 loc. 3930 (Montréal: Montreal Light, Heat & Power Consolidated, 1942).

26 See: Jacques Lecours and Raymonde Lavoie, *L'électrification de la région de Montréal. Synthèse historique* (Montréal: Hydro-Québec, 1991), 74–76.

27 I refrain from converting the measuring units and stick to the ones used in the sources.

28 Montreal Light, Heat & Power Company, *Statement Showing Comparison Between Power Generated and Power Sold Between July 1st 1915 & Jan. 1st 1916 at Cedar Rapids*, AHQ F9/3469/14235 loc. 3913 (Montréal: Montreal Light, Heat & Power Company, 1916).

29 Leo G. Denis, *Electric Generation and Distribution in Canada* (Ottawa: Commission of Conservation, 1918), 56.

30 Paul-André Linteau, *Une histoire de Montréal* (Montréal: Boréal, 2017), chap. 11. For an excellent account of the conflicts involved in the entry of women into munition production, see: Susan Pedersen, *Family, Dependence, and the Origins of the Welfare State: Britain and France, 1914-1945* (Cambridge: Cambridge University Press, 1993), chap. 2.

31 Montreal Light, Heat & Power Company, *Annual Report 1914*, AHQ F9/3413/12296 loc. 3121 (Montréal: Montreal Light, Heat & Power Company, 1914); Montreal Light, Heat & Power Company, *Annual Report 1915*, AHQ F9/3413/12297 loc. 3121 (Montréal: Montreal Light, Heat & Power Company, 1915).

32 In 1918, the American company purchased 390,000,000 kWh from MLHP. In 1919, that number fell to 321,000,000 kWh. Montreal Light, Heat & Power Consolidated, *Cedar Rapids - Alcoa Contracts and Correspondance*, AHQ F9/3470 #1 loc. 13322 (Montréal: Montreal Light, Heat & Power Consolidated, 1941).

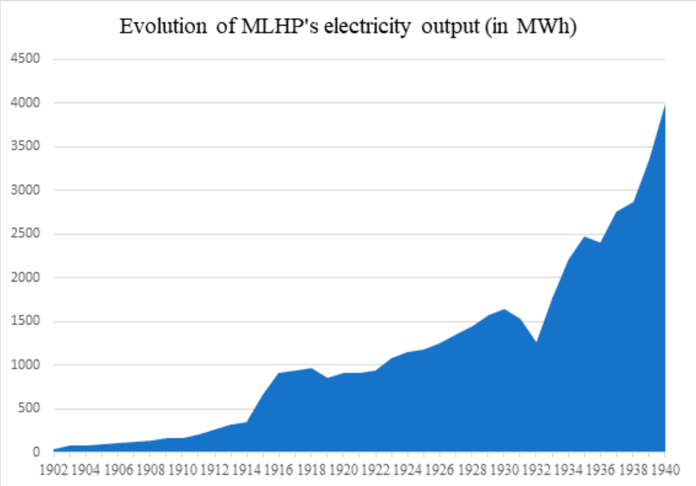


Figure 5: *Evolution of MLHP's electricity output measured in MWh. Sources:* A Statistical Analysis of Montreal Light, Heat & Power Consolidated *for years 1902-1930,* Cedar Rapids - Alcoa Contracts and Correspondence *for years 1931-1940.*

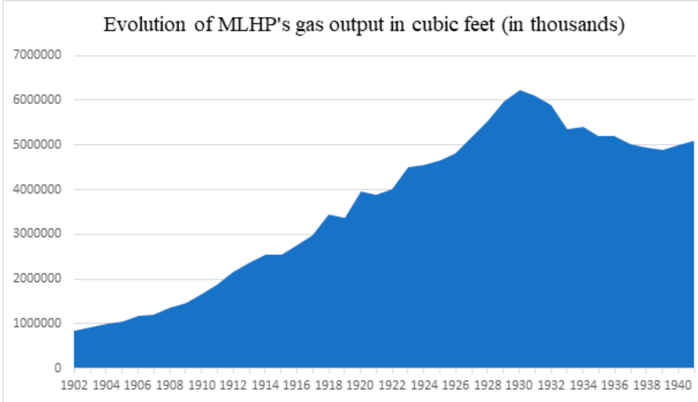


Figure 6: *Evolution of MLHP's gas output in thousands. Sources:* A Statistical Analysis of Montreal Light, Heat & Power Consolidated *for years 1902-1930,* Entre-Nous 1938 *for years 1933 and 1937,* A Record of Expansion and Improvement 1925-1943 *for years 1931-1932, 1934-1936, and 1938-1941*

something that can be stopped quickly or at will. A lot of the energy produced was 'lost' in the sense that it didn't find any users. This ran counter to the need to optimize the efficiency of costly equipment. One response was to slow down production. In 1919, MLHP reduced its electricity output over the previous year by 13% (fig. 5).[33] To do so, the company closed down some of its generating stations, or at least units, for parts of the day.[34] The gas division also witnessed a curtailment of production. In 1919, gas output diminished by 2% over the previous year (fig. 6).[35] Less coal was burned at the company's gas plants at a time when post-war coal shortages led prices in Montréal to increase rapidly. But these measures were only temporary. A strike in 1919 revealed the fragility of MLHP's post-war situation.[36]

Meanwhile, more structural shifts were under 11
way in Montréal's energy markets as MLHP's executives turned their attention to the domestic sector. Utility companies courted households in the hope that this would help them diversify their load factor, an important concept in the history of electrification. Since operating costs and fixed expenses remained almost identical whether electricity was being used 18 hours per day or just a few hours every night, firms had a strong incentive to encourage the use of electrical energy over 24 hours per day, seven days per week, and 365 days per year.[37] This meant pushing uses beyond the usual peak demand,

33 In 1918, its total output was 967,462,529 kWh. In 1919, it was 852,680,550. Montreal Light, Heat & Power Consolidated, *A Statistical Analysis of Montreal Light, Heat & Power Consolidated*, 42.

34 For example, on June 30th, 1921, Chambly generating station was closed down at 12:05AM, and Soulanges at 7:55PM. Montreal Light, Heat & Power Consolidated, *Extracts from P.H. and Station Reports. June 1921*, AHQ F9/3427 13059 loc. 3941 (Montréal: Montreal Light, Heat & Power Consolidated, 1921). Montreal Light, Heat & Power Consolidated, *Cedar Rapids Production Journal*, AHQ F9/3427 #202 loc. 2140 (Montréal: Montreal Light, Heat & Power Consolidated, 1925).

35 In 1918, gas output was of 3,441,329,000 cubic feet. In 1919, it was of 3,375,125,000. Montreal Light, Heat & Power Consolidated, *A Statistical Analysis of Montreal Light, Heat & Power Consolidated*, 46.

36 Civic Investment and Industrial Company, *Meeting Minutes*, AHQ F9/3410/12062 loc. 4198 (Montréal: Civic Investment and Industrial Company, 1917).

37 Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983), 463. The load factor is obtained by dividing the average load by the peak load over a certain time period. It is also important to note that the electricity sector is highly capital-intensive: operating electric networks involves acquiring prime real estate near rivers, building generating stations, installing heavy and expensive machinery like water turbines and generators, erecting the poles and wires making up the transmission and distribution networks, adding substations to step-down the voltage for end use, and paying interest on borrowed capital meant.

typically occurring in early evenings when electric lights and appliances were simultaneously turned on, especially in the winter.[38] As in other countries, night-time storage radiators were seen as a good way of selling electricity off-peak.[39]

12 Extending the domestic market and encouraging the use of electricity at times of the day, week, and year when industrial demand was low made good commercial sense. Promoting diversified uses of electricity around the clock would lower unit costs by maximizing the constant output of hydroelectric stations. The more electrical energy that could be sold without extending the existing transmission and distribution networks, the smaller the proportion of total expense per kWh, meaning that lower rates could be charged to end consumers.[40] The hope was that potential customers would be attracted by a cheaper rate and that those who were already connected would use more. This vision was consistent with the so-called rebound effect — according to which a drop in the cost of an energy service leads to an increase in demand. Manufactured gas is different in that it can be stored, but there are still economies of scale. Furthermore, since coal and oil were expensive in the aftermath of the war, MLHP risked having to increase the price of gas instead of being able to absorb the costs.[41] In this context, escalating consumption, an eternal mantra of gas and electricity utility companies, was critical to survival and success.

MLHP consequently invested in public relations and promotion, putting more emphasis on its public image and on advertising. While the former was tarnished by constant cries for public ownership from municipal and provincial politicians — the case of neighbouring Ontario was always cited by MLHP's foes — the latter attempted to convince potential domestic consumers to connect to gas and electricity systems and to persuade existing customers to use more.[42] At the end of the 1910s, around half of all Montréal's dwellings were wired to the electricity distribution network, a little less in the case of gas but at this point, consumption was minimal.[43] The use of electricity was by and large limited to a few lightbulbs turned on at night, and gas to a stove operated only a few times a week. To change that, MLHP employed a panoply of tactics to promote a new, modern moral economy based on invisible, effortless, and seemingly boundless forms of energy.[44] 13

Historical records reveal some of the strategies involved, from two-tiered rate systems to the integration of energy infrastructure into plans 14

38 Montreal Light, Heat & Power Consolidated, *Schedule of Rates and Some Information Regarding the Sale and Measurement of Electric Current*, AHQ F9/3469/14279 loc. 3912 (Montréal, 1909), 18.

39 "Fuel-Power Problem of Canada", *Journal of the Engineering Institute of Canada*, n° 1, May 1918, 52–53. On storage water heaters and their importance for load balancing, see: Nina Lorkowski, "Managing Energy Consumption. The Rental Business for Storage Water Heaters of Berlin's Electricity Company from the Late 1920s to the Early 1960s", *in* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies: How Energy Connects Politics, Technologies and Cultures* (Bielefeld: Transcript Verlag, 2012), 137–62.

40 Montreal Light, Heat & Power Consolidated, *Entre-Nous. 1938*, AHQ F9/3423/13000 loc. 3943 (Montréal: Montreal Light, Heat & Power Consolidated, 1938), 6 (April Edition).

41 Montreal Light, Heat & Power Consolidated, *Annual Report 1918*, AHQ F9/3413/12299 loc. 3121 (Montréal: Montreal Light, Heat & Power Consolidated, 1918).

42 The publicly owned Hydro-Electric Power Commission of Ontario was created in 1906 and bought up most of its competitors in the 1910s and 1920s until it achieved a public monopoly over the electricity sector in that province. See: Keith Robson Fleming, *Power at Cost: Ontario Hydro and Rural Electrification, 1911-1958* (Montréal & Kingston: McGill-Queen's University Press, 1992); Christopher Armstrong and H. V. Nelles, "Contrasting Development of the Hydro-Electric Industry in the Montreal and Toronto Regions, 1900-1930", *Journal of Canadian Studies/Revue d'Études* Canadiennes, vol. 18, no° 1, 1983, 5–27.

43 Data for electricity was calculated in Bellavance & Linteau, *op. cit.* For gas, I estimate that this proportion was a little bit lower, but not significantly. In 1921, MLHP counted 118,542 registered gas customers and 140,445 electricity customers.

44 See Joy Parr's superb case study on the competition between the wringer washing machine and the automatic one in Canada in which she argues whether some machines get domesticated — and energy systems more broadly in my view — depends on the moral economy of householders, particularly women. Joy Parr, *Domestic Goods: The Material, the Moral, and the Economic in the Postwar Years* (Toronto: University of Toronto Press, 1999), chap. 10.

for new construction and housing.[45] Alongside these, the method of associating high-energy living with material comfort, convenience, and cleanliness proved to be especially effective. According to a MLHP company document, "Every householder wants the comfort and convenience electrification brings; every company wants the higher load factor and lower unit costs such increased consumption ensures."[46] As it turns out, the householder in question was often a woman. Following the Victorian ideal of separate spheres, men were conceptualised as producers and women as consumers.[47] Thus, women first and foremost had to be convinced of the 'need' for gas and electricity. There was initially some resistance, after all, other energy sources, like wood and coal, had been integrated into daily routines for decades. In addition, the experience of power shortages, common in the early decades of the 20th C., meant that some were wary of relying on utility companies for the energy needed to complete daily chores reliably and to the expected standard.[48]

15 In response the utilities employed other women to speak to these reluctant housewives and went to considerable lengths to promote and sell household appliances.[49] In 1918, MLHP opened its first store outside of its headquarters. The showroom exhibited an array of gas and electric appliances. Public demonstrations were conducted, often by women, who were employed as salesladies and cashiers by the company in 1919.[50] MLHP managers hoped that women would speak more convincingly to other upper class women, and that these strategies would be more effective than having salesmen demonstrate the practical value of domestic appliances, most designed by men.[51] Home economists promised that appliances would liberate housewives by substantially reducing the time and effort spent on household chores. However, as Ruth Schwartz Cowan famously showed, the time and labour saved by the use of domestic appliances were soon filled by new activities and higher standards of efficiency, cleanliness, comfort, and normality.[52]

45 For the two-tiered rate system, which rewarded high consumers with lower rates per unit consumed, see: Harold L. Platt, *The Electric City: Energy and the Growth of the Chicago Area, 1880-1930* (Chicago: University of Chicago Press, 1991), 85. For the integration of different energy sources in council housing, see: Frank Trentmann and Anna Carlsson-Hyslop, "The Evolution of Energy Demand in Britain: Politics, Daily Life, and Public Housing, 1920s-1970s", *The Historical Journal*, vol. 61, n° 3, 2018, 807–39.

46 G.R. Whatley, *A Brief Submitted by Montreal Light Heat & Power Consolidated in Support of Revised Tariff for Residential Electricity Service*, AHQ F9/3413 loc. 3121 #15 (Montréal: Quebec Public Service Commission, 1934), 16.

47 This is an obviously flawed dichotomy. Even if most women didn't participate in the labor market to the same extent as men, they were still working, although their labor wasn't monetized and recognized as official labor by statistical offices and general popular representations. See: Ruth Schwartz Cowan, "The 'Industrial Revolution' in the Home: Household Technology and Social Change in the 20th Century", *Technology and Culture*, vol. 17, n° 1, 1976, 1–23. See also: Ruth Schwartz Cowan, "The Consumption Junction: A Proposal for Research Strategies in the Sociology of Technology", *in* Wiebe E. Bijker, Thomas Parke Hughes and Trevor Pinch (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge: MIT Press, 1987), 261–80.

48 Ruth W. Sandwell, "Pedagogies of the Unimpressed: Re-Educating Ontario Women for the Modern Energy Regime, 1900-1940", *Ontario History*, vol. 107, n° 1, 2015, 53.

49 Carolyn M. Goldstein, "From Service to Sales: Home Economics in Light and Power, 1920-1940", *Technology and Culture*, vol. 38, no° 1, 1997, 128. However, women weren't encouraged to train as electrical engineers as that would turn them away from their purported true vocation: housekeeping. Montreal Light, Heat & Power Consolidated, *Dual Service. 1927*, 15 (July Edition).

50 Montreal Light, Heat & Power Company, *Report on Strike*, AHQ F9/3412/12904 loc. 1992 (Montréal: Montreal Light, Heat & Power Company, 1919). In general, however, the electric and gas sectors overwhelmingly employed men, usually associated with technical trades. This is consistent with most infrastructure sectors. See: Matti Siemiatycki, Theresa Enright, and Mariana Valverde, "The Gendered Production of Infrastructure", *Progress in Human Geography*, vol. 44, no° 2, 297-134.

51 Joy Parr has shown how the appliance sales floor wasn't welcoming to women purchasers: stoves couldn't be tried, manufacturers designed them without consulting women — for example, they wanted stoves to be raised above waist level, which rarely was the case — and salesmen weren't experts in their use. See: Joy Parr, "Shopping for a Good Stove: A Parable about Gender, Design, and the Market", *in* Joy Parr (ed.), *A Diversity of Women: Ontario, 1945-1980* (Toronto: University of Toronto Press, 1995), 206–7.

52 Cowan, "The 'Industrial Revolution' in the Home: Household Technology and Social Change in the 20th Century," 15.

16 Even so, there was a definite shift of emphasis. Throughout the 1920s, MLHP acted as a comfort vendor, or what Elizabeth Shove *et al.* define as a profit-making enterprise with an interest in creating and inflating need and demand.[53] Often invoking medical discourses, MLHP's advertising department highlighted the importance of cleanliness for household health.[54] According to one such narrative, a respectable and responsible housewife had to keep her house perfectly clean and the best way of doing so was within an electric vacuum cleaner.[55] Another refers to new forms of domestic science in making the case for precision cooking.[56]

17 Technologies and norms of cleanliness and efficiency co-evolved[57] through the 1920s, along with and as part of MLHP's strategy for finding outlets for the excess electricity and gas capacity added during the First World War. Contrary to popular opinion, appliances, from the gas water heater to the electric washing machine, were not introduced to satiate an existing need for cleaner and more comfortable dwellings. Rather, their introduction and popularization boosted standards of normality, and transformed meanings and expectations of convenience.[58]

THE GREAT DEPRESSION

At the end of the 1920s, MLHP embarked on a new expansionist drive. After having shelved the project in 1914, MLHP allied with a subsidiary, the Montreal Island Power Company, to open the Rivière-des-Prairies hydroelectric station in 1929. The same year, work started at Beauharnois to construct a large hydroelectric facility at a site considered in the early 1900s but not developed at the time. MLHP, at first a simple customer of the Beauharnois Light, Heat & Power Company — a contract had been signed for the purchase of 150,000 HP — became majority shareholder soon after, strongly reinforcing its monopolistic situation.[59] Beauharnois started operating in 1932. These investment decisions were justified in the following manner: "It has always been our policy to keep well ahead of the market for power [...] notwithstanding the large quantity of unsold power at present available."[60] Archival documents indicate that this phase of increasing capacity was partly justified by the belief that Montréal's population would continue to grow at an impressive pace.[61] To meet the anticipated demand, MLHP also built a coke oven plant adjacent to its Lasalle gas generating station in 1927, in association with the Montreal Coke and Manufacturing Company. The 18

53 Elizabeth Shove et al., "Comfort in a Lower Carbon Society", *Building Research & Information*, vol. 36, no° 4, 2008, 309.

54 See for example: Montreal Light, Heat & Power Consolidated, *Dual Service. 1929*, AHQ F9/3423/12993 loc. 3944 (Montréal: Montreal Light, Heat & Power Consolidated, 1929), 13 (June Edition).

55 According to this article, housekeepers needed to be extremely careful when purchasing electric appliances for the efficiency and comfort of their home depended on them. "The Kitchen: 1933 Model", *Canadian Homes and Gardens,* vol. 10, no° 6, 1933, 44.

56 See for example: Montreal Light, Heat & Power Consolidated, *The Household Book. Le Livre Ménager* (Montréal: Montreal Light, Heat & Power Consolidated, n.d.). The nascent science of nutrition, learned by home economists, also fostered greater standards of cleanliness and efficiency. See: Caroline Durand, *Nourrir la machine humaine: Nutrition et alimentation au Québec, 1860-1945* (Montréal & Kingston: McGill-Queen's University Press, 2016), 15–16.

57 Elizabeth Shove, *Comfort, Cleanliness and Convenience: The Social Organization of Normality* (Oxford: Berg, 2003), 76. Magazines and the media in general also acted as comfort vendors. This is particularly clear in the *Canadian Homes and Gardens*: "There is no end, in these fast-moving days, to the business of making a house more comfortable and convenient." Ethel Craigie, "New Gadgets for the Modern House", *Canadian Homes and Gardens*, vol. 8, no° 1, 1931, 34. One writer in particular, Eustella Burke, penned many articles inflating norms of normality. The motivations of such women journalists in early 20th C. Canada should merit further study.

58 Shove, *Comfort, Cleanliness and Convenience*.

59 Montreal Light, Heat & Power Consolidated, *Montreal Light Heat and Power Consolidated and Operating Subsidiaries*, AHQ F9/3409/12338 loc. 3960 (Montréal: Montreal Light, Heat & Power Consolidated, 1933).

60 Montreal Light, Heat & Power Consolidated, *Annual Report 1927*, AHQ F9/3413/12308 loc. 3121 (Montréal: Montreal Light, Heat & Power Consolidated, 1927).

61 "There is not a single city in the same stage of development in North America, which shows such a steady high rate of growth as Montreal with the exception of a few communities of mushroom growth type such, for instance, as Los Angeles and Detroit." Montreal Light, Heat & Power Consolidated, *A Statistical Analysis of Montreal Light, Heat & Power Consolidated*, 13.

coke produced from the destructive distillation of coal was primarily destined for the domestic market as heating and cooking fuel.

19 But the Great Depression of the 1930s cut the grass under MLHP's feet. After a stock market crash in the neighbouring United States in October 1929, Canada faced reduced trade with its main economic partner, a harsh economic downturn, massive unemployment, and a fall in personal incomes and living conditions in general.[62] Between a fourth and a third of the labor force was unemployed during the worst years of the Great Depression in Montréal.[63] Economists, following the energy ladder model, assume that as incomes rise consumers switch to more modern fuels, going from biomass to coal, from coal to natural gas, and so on. Complicating this linear model, others have put forward the concept of energy stacking, according to which consumers use multiple fuel sources simultaneously, occasionally going back down the ladder to use more traditional sources of energy.[64] The case of Montréal during the Great Depression, a rare historical moment in which energy demand decreased significantly, offers empirical evidence in favor of the energy stacking model. Additionally, it demonstrates the flexibility of demand, as households adapted.

20 In its August 3rd, 1933 edition, the daily newspaper *Le Devoir*'s front page announced that the days when wood was used for heating were over. Interviewed by the Montréal paper, an experienced fuel dealer predicted the imminent demise of this traditional energy source, as urban dwellers turned towards anthracite coal. Lower on the same page, a classified ad targeted the unemployed, offering maple and wild cherry wood specifically for home heating.[65] Beyond reflecting a clash between elitist discourse and working-class realities, this anecdotal evidence shows that households switched between different energy sources during the 1930s. This is confirmed by two surveys conducted by the state in the second half of the 1930s. Out of 211 Francophone families surveyed in Montréal and Québec city by the Dominion Bureau of Statistics, 96% reported buying electricity, 74% wood, 55% coal, 51% gas, 16% fuel oil, 6% kerosene, 5% gasoline, and 12% other sources of energy.[66] Out of 4,216 working-class dwellings surveyed, the main fuel used for cooking was wood (3,039), followed by gas (1,412), coal (697), fuel oil (209), and electricity (83).[67] The capacity to switch fuels was inscribed in the design of combination stoves, allowing the user to employ both wood and coal, coal and gas, or gas and electricity. To be sure, this wasn't a break with previous decades, since relying on multiple forms of energy was already a characteristic of most Canadian households.[68] But economic hardship intensified the need to find innovative ways to get fuel by any means necessary, as this informant reminiscing about her husband's creativity told Denyse Baillargeon:

62 For the effects of the Great Depression in Canada, see: James Struthers, *No Fault of Their Own: Unemployment and the Canadian Welfare State, 1914-1941* (Toronto: University of Toronto Press, 1983).

63 Nadia Atallah, "Les quartiers ouvriers de Montréal pendant la Grande Dépression", *Bulletin de l'Institut Pierre Renouvin*, vol. 27, no° 1, 2008, 122.

64 For a discussion of the energy ladder model, see: Bianca van der Kroon, Roy Brouwer, and Pieter J.H. van Beukering, "The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta-Analysis", *Renewable and Sustainable Energy Reviews*, vol. 20, 2013, 504–13.

65 Émile Benoist, "L'âge du chauffage au bois serait bel et bien passé," *Le Devoir*, August 3, 1933.

66 It is important to note that this survey is characterized by an important selection bias. All the families surveyed had to be of wage-earner type, with husband and wife living together as joint heads. All families had to have a maximum of one lodger or domestic. Earnings were to range from $450 to $2,500 and all families had to be self-supporting during this period. Finally, no family shared any living amenities with other families. All these factors point towards a class bias towards richer and more conventional households. Were the study to be truly representative of working-class families in Canada, it is probable that the percentage of households purchasing wood, for instance, would be higher. Dominion Bureau of Statistics, *Family Income and Expenditure in Canada. 1937-1938* (Ottawa: Edmond Cloutier, 1941).

67 Réal Bélanger, George S. Mooney, and Pierre Boucher, *Les vieux logements de Montréal. Rapport d'une étude Faite pendant l'été 1937*, Archives de la ville de Montréal (AVM) 001 XCD00-P7450 (Montréal: Commission métropolitaine de Montréal. Département d'urbanisme et de recherche, 1938), 11.

68 See Ruth W. Sandwell (ed.), *Powering Up Canada: The History of Power, Fuel, and Energy from 1600* (Montréal & Kingston: McGill-Queen's University Press, 2016).

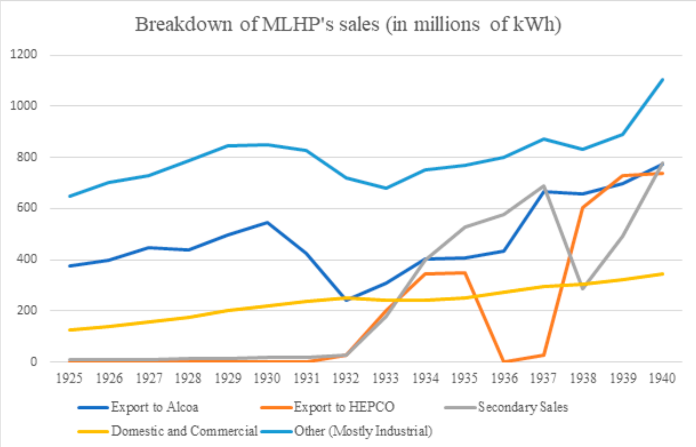


Figure 7: *Breakdown of MLHP's sales in millions of kWh, 1925-1940. Secondary sales correspond to surplus electrical energy sold under certain conditions when available. Source: Cedar Rapids - Alcoa Contracts and Correspondence.*

21 "He'd go out in the morning to look for wood in Saint Lambert (…). After that, he'd go to the store so he'd have some cardboard. He'd take the cardboard cartons apart, roll them up, and tie them with wire and stack them in the shed to make wood for next winter. Then (…) he'd soak newspapers in water in a basin (…) and make them into balls (…) and then let them dry. There, that was our coal for the winter. (E25)"[69]

22 Beyond switching between different fuels, domestic consumers in Montréal probably reduced the amount of energy they used, although hard evidence is tricky to amass. MLHP's electricity output decreased in 1931, 1932, and again in 1936 (fig. 5). At some point during this decade, production slowed at Chambly, Saint-Timothée, Cedar Rapids, Rivière-des-Prairies, and Beauharnois, while purchases from SWP were also stepped back.[70] Whereas in 1932 MLHP sold 250,000,000 kWh of electricity to its domestic and commercial customers, this amount decreased to 240,000,000 kWh the following year (fig. 7).[71] MLHP's gas output decreased even more severely and declined spectacularly between 1930 and 1939 (fig. 6).[72] Some customers unsubscribed from both services during the 1930s, in all likelihood because they could no longer afford them: even if they reduced their use to a minimum, the company still charged its clients a fixed monthly rate. In 1933, 264,351 households were paying MLHP for electricity. Four years later, despite demographic growth in the city, the firm lost around 2,000 paying customers — although the evidence is somewhat conflicting.[73] Important discrepancies separated working class districts — such as Verdun, where domestic consumption averaged 41 kWh per month — and wealthier ones — like Outremont, averaging 84.3 kWh per month for the year 1937.[74] The decline in gas consumption was starker. Between 1933 and 1937, the firm's gas customer base went down from 194,813 to

69 Denyse Baillargeon, *Making Do: Women, Family and Home in Montreal during the Great Depression* (Waterloo: Wilfrid Laurier University Press, 1999), 138.

70 Montreal Light, Heat & Power Consolidated, *Extracts from P.H. & Station Reports. June 1932*, AHQ F9 3427 13073 loc. 3941 (Montréal: Montreal Light, Heat & Power Consolidated, 1932).

71 Montreal Light, Heat & Power Consolidated, *Cedar Rapids - Alcoa Contracts and Correspondance*.

72 Exact statistical data for gas is somewhat lacking after 1930. However, multiple documents attest to a decrease in output in the 1930s. Montreal Light, Heat & Power Consolidated, *A Record of Expansion & Improvement 1925-1943*, AHQ F9/3409/12161 loc. 3960 (Montréal: Montreal Light, Heat & Power Consolidated, 1943).

73 The number of subscribers comes from the firm's internal journal, but the counting method seems to have changed between 1933 and 1937, the former number being calculated from total installations and the latter from average years billed. It is likely that the first method of calculation inflated the actual number of paying customers since it probably included dwellings that were wired to the distribution network but didn't use MLHP's services. Another document — produced to show the company's historical progress — doesn't provide exact numbers but presents a graph that seems to indicate an increase in the customer base from 1925 to 1932, then stagnation until 1936, after which point growth picks up. This isn't to say that disconnections were improbable: internal documents do attest to the existence of this phenomenon in the 1930s. Montreal Light, Heat & Power Consolidated, *Entre-Nous. 1938*; Montreal Light, Heat & Power Consolidated, *A Record of Expansion & Improvement 1925-1943*.

74 Montreal Light, Heat & Power Consolidated, *Electricity and Gas Sales, 1937*, AHQ F9/3469/14322 loc. 3686 (Montréal: Montreal Light, Heat & Power Consolidated, 1945). Unfortunately, no such precise figures exist before that year, which would've facilitated a comparison of consumption before and after the Great Depression.

174,909.[75] Reasons cited for this included change in habits (people eating away from home and buying cooked food), the use of small electric appliances to prepare breakfast, the use of oil burners in coal stoves, more efficient gas appliances, and competition from electricity.[76] Although we lack conclusive evidence, these elements put together likely signal reduced per capita gas and electricity consumption amongst Montréal's households. If industrial demand diminished drastically — in particular exports to Alcoa — domestic and commercial customers also reduced their use between 1932 and 1933, and for the rest of the decade sales were pretty much stagnant for this class of customer (fig. 7).

23 These quantitative indications — reduced output and sales, clients disconnecting — point towards qualitative changes in people's lifestyles. To cope with the Great Depression, some consumers resorted to various forms of illegal connection.[77] Some of these bootleg modifications were made by amateur technicians, acting at night — meaning that some energy services were pushed until the end of the day — and sometimes undertaken with the help of MLHP employees.[78] Others focused on manipulating electricity and gas meters. More fundamentally, as the women interviewed by Denyse Baillargeon showed, the recession prompted consumers to reorganise everyday routines — like cooking and heating — that depended upon energy.[79] The uptake of installment plans, introduced in the 1920s to boost the sales of appliances was limited, and many consumers defaulted on their payments.[80] Indeed, Robert Rumilly estimates that more than 20,000 families were deprived of electricity in Montréal in the 1930s for this reason.[81] All in all, customers stuck to their wood, coal, or combination stoves, which provided the majority of their energy services, and many postponed the purchase of expensive electric refrigerators and "modern" gas ranges.

24 MLHP blamed French Canadian thrift for the slow uptake of appliances and weak energy consumption. It was, for example, critical of those who only used the kitchen stove for heat and who turned off the lights when leaving a room — acceptable in the 1910s, but no more in 1934, according to MLHP's company journal.[82] Even when households acquired appliances like a gas water heater, these were often used sparingly, for occasional baths and weekly laundry.[83] Everyday activities, like washing dishes and cooking, still

75 Montreal Light, Heat & Power Consolidated, *Entre-Nous. 1938*.
76 D.D. Barnum, *Report on Ways and Means of Promoting Gas Sales in Montreal*, AHQ F9/3413/12352 loc. 3121 (Montréal: Montreal Light, Heat & Power Consolidated, 1937).
77 It is hard to find traces of these practices in the archives, but many of the documents consulted elliptically allude to it. Montreal Light, Heat & Power Consolidated, *Facture*, AHQ H2/1800-00 1444 loc. 211 (Montréal: Montreal Light, Heat & Power Consolidated, 1941). In one instance, a customer's electricity service was cut by MLHP after he was allegedly caught stealing gas. Régie des services publics, *Routine des dossiers de requêtes provinciale de l'électricité - Nos 1100 à 1500* (dossier 1216), BANQ Montréal, fonds Régie de l'énergie 1909-2012 (E175 1993-11-001\8) (Québec: Régie des services publics, 1940).
78 Denyse Baillargeon, *Ménagères au temps de la Crise* (Montréal: Remue-ménage, 1993), 175. This is an example of temporal variation in energy use, although it didn't have to see with considerations about load factors and peak demand. For more information on the temporal variation of energy demand, see: Jacopo Torriti, "Understanding the Timing of Energy Demand through Time Use Data: Time of the Day Dependence of Social Practices", *Energy Research & Social Science*, vol. 25, 2017, 37–47. Montreal Light, Heat & Power Company, *Bulletins to Employees*, AHQ F9/3423/12986 loc. 13404 (Montréal: Montreal Light, Heat & Power Company, 1911).
79 Baillargeon, *Ménagères au temps de la crise*, 175. See also: Harold Wilhite and Loren Lutzenhiser, "Social Loading and Sustainable Consumption", *NA - Advances in Consumer Research*, vol. 26, 1999, 281–87.
80 Montreal Light, Heat & Power Consolidated, *Dual Service 1933*, AHQ F9/3423/12998 loc. 3944 (Montréal: Montreal Light, Heat & Power Consolidated, 1933). On forms of credit in Montréal during this period, see: Sylvie Taschereau and Yvan Rousseau, "The Hidden Face of Consumption: Extending Credit to the Urban Masses in Montreal (1920s–40s)", *Canadian Historical Review*, vol. 100, no° 4, 2019, 509–39.
81 Cited in Baillargeon.
82 Montreal Light, Heat & Power Consolidated, *Dual Service 1934*, AHQ F9/3423/12999 loc. 3944 (Montréal: Montreal Light, Heat & Power Consolidated, 1934). John H. Dales, author of the most famous monograph on the energy sector in Québec, repeated the same questionable assumption: "In Quebec, no doubt, the power companies have been faced with stubborn cultural barriers to an expansion of the per-household consumption of electricity." John Harkness Dales, *Hydroelectricity and Industrial Development: Quebec, 1898-1940* (Cambridge: Harvard University Press, 1957), 192.
83 Baillargeon, *Ménagères au temps de la Crise*, 165.

Types of flexibility displayed in Montréal (1910s-1930s)	**Description**
Upwards supplier-led flexibility	-Construction of extra energy capacity in anticipation of potential demand -Marketing and advertising to sell more energy services
Downwards supplier-led flexibility	-Shelving of potential expansion projects in unfavorable business contexts -Reduction of output by switching off units or entire power stations, or by producing less gas
Upwards consumer-led flexibility	-Increased demand from industrial, commercial, and domestic consumers for energy services -Energy ladder model -Upwards revision of standards of cleanliness and comfort
Downwards consumer-led flexibility	-Reduction of gas and electricity use -Switching back to less “modern” fuel sources (wood, coal) -Downwards revision of standards of cleanliness and comfort

Figure 8: Typology of energy flexibility in Montréal, 1910-1930s

depended on water heated on the stovetop, fuelled by wood or coal. Most dwellings were heated by a central stove, which kept the central room warm but left distant rooms in the cold.[84] Different conventions of warmth and comfort coexisted. For instance, letting a child sleep all winter in a non-heated room — albeit with good blankets — was deemed better than potentially exposing them to noxious gases from a gas fire. At the same time, in richer neighbourhoods, bungalows were being built with central heating, electric refrigerators, and air conditioning.[85] Multiple standards of normality existed in parallel through the 1930s and it was only after the Second World War that networked energy services were the norm in Montréal, escalating domestic energy demand in the process.

84 Peter Ward, *A History of Domestic Space: Privacy and the Canadian Home* (UBC Press, 1999), 49–51; Bettina Bradbury, *Working Families: Age, Gender, and Daily Survival in Industrializing Montreal* (Toronto: McClelland & Stewart, 1993), 154–58.

85 Air conditioning as it was conceived in the 1930s was akin to today’s humidifiers. See: “Air Conditioning. From the Woman’s Point of View”, *Canadian Homes and Gardens*, vol. 10, no° 10, 1933, 22. For a critical perspective on the popularization of AC, see: Elizabeth Shove, Gordon Walker, and Sam Brown, “Transnational Transitions: The Diffusion and Integration of Mechanical Cooling”, *Urban Studies*, vol. 51, no° 7, 2014, 1506–19.

CONCLUSION: THE FLEXIBILITY OF FIXITY

25 The story sketched in this paper presents different interpretations of energy flexibility that need to be unpacked (fig. 8). The first part described multiple examples of supplier-led flexibility. This process starts by anticipating energy demand. As potential customers are enrolled and markets are imagined, utilities create and expand infrastructures and systems of energy provision. Decisions are taken on the basis of anticipation: purported needs are constructed, to which solutions are offered.[86] Using projections of demographic and economic growth, executives rationalize their investment decision to shareholders. It was on this basis that MLHP built the Cedar Rapids hydroelectric station and the Lasalle gas plant, both inaugurated in 1915, in a display of upwards supplier-led flexibility. Wartime production enabled both plants to run at full speed. However, once the First World War ended, industrial demand slowed down. The gas and electricity capacity that had been added

86 Engineering is in essence a future-oriented activity, part physical and part social engineering. See: Frédéric Graber, “Inventing Needs: Expertise and Water Supply in Late Eighteenth- and Early Nineteenth-Century Paris”, *The British Journal for the History of Science*, vol. 40, n° 3, 2007, 315–32.

was being wasted and to correct this financially damaging situation, MLHP tried to develop new markets. The company focused on the domestic sector, under-exploited at the end of the 1910s yet coveted for its role in diversifying the load factor and its capacity to absorb intensive energy services. The monopolistic utility branched out into public relations and devised an impressive arsenal of promotional tactics to enroll new customers and persuade others to adopt a more energy-intensive lifestyle. Throughout the 1920s, the firm hiked up notions of cleanliness and comfort, arguing that modern ways of living could only be achieved with the help of energy demanding domestic appliances. For that, it targeted women specifically, employing home economists and strongly gendered discourses of home and care. This move into the realm of promotion and advertising is another example of upwards supplier-led flexibility, albeit targeting end use.

26 MLHP — like industry in general — benefitted tremendously from the two global conflicts of the 20th C., adding capacity and finding energy-thirsty outlets in the extraordinary context of wartime production. This is also true of the Second World War, which allowed MLHP to increase Beauharnois' capacity and step up its coke production, all to the benefit of industry. The company recognized that it would take years to build anything like the same demand under peacetime conditions.[87] This adds evidence to the thesis according to which wars and conflicts are major accelerators of environmental degradation and materialization. As others have argued, military demand fosters the development of goods and services for which civil uses must be found and invented once arms are laid-down.[88]

27 On other occasions, MLHP demonstrated that it could revise energy supply downwards.[89] It did so by stepping down its production on various occasions when it understood that demand was decreasing. In practice, this involved temporarily switching off units or whole power stations for hours or days, or reducing the amount of coal — and thus of gas produced — burned at the generating plant. More substantially, MLHP also shelved projects when its executives felt that the added power wouldn't be absorbed by the firm's customer base. What was supposed to become a hydroelectric station at Sainte-Thérèse ended up being used for storage purposes and to mitigate against frazil ice reaching the existing Chambly station.[90] Possible sites like Rivière-des-Prairies and Beauharnois were identified early in the 20th C. but only developed at the end of the 1920s. Other potential locations, were singled out in technical reports but never developed during MLHP's reign.[91] Often these were business decisions motivated by the necessity of maintaining manufactured energy scarcity in Montréal to keep prices relatively high. A public relations document advised executives on how to defend this policy: "Correct erroneous impression that superabundant water powers necessarily permit

87 Montreal Light, Heat & Power Consolidated, *Annual Report 1941*, AHQ F9/3413/12322 loc. 3121 (Montréal: Montreal Light, Heat & Power Consolidated, 1941), 6.

88 François Jarrige and Thomas Le Roux, *La contamination du monde. Une histoire des pollutions à l'âge industriel* (Paris: Le Seuil, 2017), chap. 7. Christophe Bonneuil and Jean-Baptiste Fressoz, *L'événement anthropocène. La Terre, l'Histoire et nous* (Paris: Seuil, 2016), chap. 6.

89 For cases of electric utilities encouraging its users to step down their consumption, see: Matthew Evenden, "Lights Out: Conserving Electricity for War in the Canadian City, 1939-1945", *Urban History Review / Revue d'histoire urbaine*, vol. 34, n° 1, 2005, 88–99; Yves Bouvier, "Observer, mesurer, maîtriser. Les entreprises du secteur de l'énergie et les consommateurs individuels (France, années 1950-1980), " *in* Geneviève Massard-Guilbaud and Charles-François Mathis (dir.), *Sous le soleil. Systèmes et transitions énergétiques du Moyen Âge à nos jours* (Paris: Éditions de la Sorbonne, 2019).

90 Montreal Light, Heat & Power Company, *Annual Report 1907*, AHQ F9/3413/12289 loc. 3121 (Montréal: Montreal Light, Heat & Power Company, 1907), 4.

91 For example, the potential of the Carillon site was spotted early on. But when the American firm International Paper courted the site, SWP and MLHP objected, illustrating in passing the cartel that the two companies had carved up for their province: "It is not desirable that any large block of power so geographically situated as that Carillon, should get into the hands of a Company, which through competition would interfere with the M.L.H&P. and S.W.&P. Co's plan of development of the Province of Quebec." Cited in Bellavance, *Shawinigan Water And Power, 1898-1963. Naissance et déclin d'un groupe industriel au Québec*, 111. Hydro-Québec finally opened a hydroelectric station at Carillon in 1962.

low rates. [...] Demonstrate that falling water is not in itself a dynamic asset."[92] These are all examples of downwards supplier-led flexibility, whereby the energy company diminished its output and capacity. However, it is important to stress that this type of flexibility was always temporary and often cosmetic. What really mattered for the company and for its shareholders was financial growth based on increasing output.

28 This article has also provided evidence of consumer-led flexibility. Instances of upwards oriented consumer-led flexibility are easy to document: in the 20th C. overall, more people used more energy for more services and uses, and Montréal is no exception. It is harder to find archival evidence of reductions in demand, but they do exist. In coping with economic hardship associated with the Great Depression Montreal's residents reduced demand and juggled between different sources of fuel. Wood, considered *passé* by some experts, appears to be one of the dominant fuels during this period.[93] Gas and electricity, which were both relatively expensive, were used sparingly by users trying to make ends meet. Quantitative data point to qualitative lifestyle changes, like dusting off the good old oil lamp to save on the electricity bill or putting away the electric iron and toaster.[94] These either involved reducing standards of cleanliness and comfort — fewer baths, un-ironed clothes, colder dwellings — or additional labour on the part of housewives — fewer clothes that had to be washed more frequently, say. Some users simply unsubscribed from MLHP's services, estimating that they could live without modern forms of energy. Others already embedded in the modern energy regime found ways to obtain the service illegally, whether by surreptitiously connecting to the company's distribution grid or by hacking its meters. More common was the delayed purchase of expensive domestic appliances, widespread adoption of which mostly came after the Second World War.

These are not the only scenarios of energy degrowth. Looking ahead, societies will either decarbonize, dematerialize, and reduce their energy consumption, or face environmental degradation. Montréal is unusual in having access to an abundance of energy supply but it is precisely this that allows us to see the modulation of supply and demand over time.[95] First and foremost, supply and demand were inextricably linked by feedback loops.[96] Utilities imagined markets, convinced investors, and built supply infrastructure to 'harvest' these resources. They employed numerous tactics to enroll consumers into their energy provision network. Doing so lowered the unit cost for companies who benefitted from economies of scale and the advantages of natural monopolies. Rate decreases followed, along with increases in consumption.[97] Additional production projects were justified on the assumption that demand would grow. As such, there is a certain performativity inscribed in energy infrastructure: if demand isn't directly there, it will be manufactured and invented.[98] 29

92 J.R. MacMillan, *Discussion and Summary of a Public Relations Campaign Designed to Promote Informed Public Opinion of and Favourable Reaction to the Proposed Revision of Electric Rates and to Gain Public Acceptance of New Rate Schedule*, AHQ F9/3469/14309 loc. 3912 (Montréal: Montreal Light, Heat & Power Consolidated, 1934), 7.

93 An argument needs to be made in energy history for energies-in-use, similar to David Edgerton's technologies-in-use. See: David Edgerton, "From Innovation to Use. Ten Eclectic Theses on the Historiography of Technology", *History and Technology*, vol. 16, 1999, 111–36.

94 Denyse Baillargeon, "La crise ordinaire : les ménagères montréalaises et la crise des années trente," *Labour / Le Travail*, vol. 30, 1992, 154.

95 Comparisons with similar contexts would be extremely insightful. Cities with similar conditions as Montréal — rich energy supply, cold climate, industrial city — could include Russian cities like Saint Petersburg, Scandinavian cities like Oslo, West Coast American cities like San Francisco, and more.

96 See: Christopher F. Jones, *Routes of Power: Energy and Modern America* (Cambridge: Harvard University Press, 2016).

97 Despite multiple rate decreases along its decades of operation, MLHP offered relatively high rates compared to neighboring cities — Toronto being the usual yardstick brandished by local elites and politicians. Public anger accelerated in the 1930s and led to more public scrutiny from the provincial administration which felt that unjust rates were caused by the greed of the company's Anglophone owners.

98 Olivier Coutard and Elizabeth Shove, "Infrastructures, Practices and the Dynamics of Demand", *in* Elizabeth Shove and Frank Trentmann (eds.), *Infrastructures in Practice:*

30 The value of future energy megaprojects has to be interpreted in this light: reduced energy consumption must be encouraged by reduced supply. This is particularly important in the Québec context today. Hydro-Québec, the province-owned monopolistic electric company created after MLHP was expropriated in 1944, is said to have a 'beaver complex' meaning that its legitimacy rests upon the realization of megaprojects. These are strongly associated with the emancipation of the Franco-Québécois nation and economic sovereignty since the so-called Quiet Revolution of the 1960s that saw Francophones reclaim power from an Anglo-Canadian minority in Québec. In practice, these megaprojects have always been problematic in that they implied the appropriation of traditional Indigenous land and the damaging of ecosystems. The cultural association between energy megaprojects, modernity, sovereignty, and technological prowess remains strong but in Quebec as elsewhere, the consequences are incompatible with demand reduction.[99]

31 Focusing only on supply-side flexibility obscures the changes that need to happen in what energy is used for and how and at what rate it is consumed. Historical research is powerful when it shows that what we find perfectly normal today is highly contingent and that what appear to be fixed demands are more flexible than they seem.[100] In 1930s households in urban Montréal, switched between fuels, prioritizing that which was cheaper over that which was cleaner and more efficient. Others revisited what seemed to be established conventions, opening up the possibility of re-negotiating meanings of normality, and the energy demands associated with them. These examples are born of economic hardship. As this and other historical evidence shows, energy degrowth is often associated with recession and times of social unrest.[101] The question for the future is whether economic prosperity and stability can stimulate decarbonization, dematerialization, and reduced energy production and consumption.

The Dynamics of Demand in Networked Societies (London: Routledge, 2018), 14.

99 On the links between Québec nationalism and hydroelectricity, plus its complex relationship with Indigenous populations, see: Caroline Desbiens, *Power from the North: Territory, Identity, and the Culture of Hydroelectricity in Quebec* (Vancouver: UBC Press, 2014); Stéphane Savard, "Les communautés autochtones du Québec et le développement hydroélectrique: Un rapport de force avec l'État, de 1944 à aujourd'hui", *Recherches amérindiennes au Québec*, vol. 39, no° 1–2, 2010, 47–60. On hydro-imperialism, see: Daniel Macfarlane and Andrew Watson, "Hydro Democracy: Water Power and Political Power in Ontario", *Scientia Canadensis: Canadian Journal of the History of Science, Technology and Medicine*, vol. 40, no° 1, 2018, 1-18. On Hydro-Québec's culture of mega projects, see: James Maxwell et al., "Locked on Course: Hydro-Québec's Commitment to Mega-Projects", *Environmental Impact Assessment Review*, vol. 17, 1997, 19–38.

100 On the fixity of flexibility as a concept used in energy research, see: Peter J. Forman and Elizabeth Shove, "The Fixity of Flexibility", *Center for Research into Energy Demand Solutions* (blog), 2019, https://www.creds.ac.uk/the-fixity-of-flexibility/.

101 See for example: Evenden, "Lights Out"; Meg Jacobs, *Panic at the Pump: The Energy Crisis and the Transformation of American Politics in the 1970s* (New York: Hill and Wang, 2016).

DATA

Year	Electricity output in kWh	Percentage change over previous year
1902	42980260	N/A
1903	79457180	85%
1904	85608160	8%
1905	93453141	9%
1906	116714695	25%
1907	130959031	12%
1908	135416358	3%
1909	164351087	21%
1910	167457418	2%
1911	211370008	26%
1912	269340961	27%
1913	323762843	20%
1914	352087460	9%
1915	656504088	86%
1916	920203324	40%
1917	946832817	3%
1918	976462529	3%
1919	852680550	-13%
1920	908658857	7%
1921	907231573	0%
1922	945200656	4%
1923	1089099507	15%
1924	1157648660	6%
1925	1175430650	2%
1926	1251502612	6%
1927	1354895244	8%
1928	1450484998	7%
1929	1568864226	8%
1930	1650636536	5%
1931	1539000000	-7%
1932	1270000000	-17%
1933	1768000000	39%
1934	2215000000	25%
1935	2482000000	12%
1936	2408000000	-3%
1937	2755000000	14%
1938	2865000000	4%
1939	3362000000	17%
1940	3994000000	19%

Evolution of MLHP's electricity output, 1902-1940
Sources: *A Statistical Analysis of Montreal Light, Heat & Power Consolidated* for years 1902-1930, *Cedar Rapids - Alcoa Contracts and Correspondence* for years 1931-1940

Year	Gas output in cubic feet	Percentage change over previous year
1902	848593000	N/A
1903	930470000	10%
1904	998286000	7%
1905	1046442000	5%
1906	1165748000	11%
1907	1192704000	2%
1908	1357681000	14%
1909	1456507000	7%
1910	1657426000	14%
1911	1874116000	13%
1912	2159445000	15%
1913	2373674000	10%
1914	2536688000	7%
1915	2539010000	0%
1916	2737456000	8%
1917	2989564000	9%
1918	3441329000	15%
1919	3375125000	-2%
1920	3951134000	17%
1921	3873797000	-2%
1922	4001525000	3%
1923	4504122000	13%
1924	4546422000	1%
1925	4660532000	3%
1926	4812848000	3%
1927	5172916000	7%
1928	5523937000	7%
1929	5969800000	8%
1930	6241947000	5%
1931	6100000000	-2%
1932	5900000000	-3%
1933	5346126000	-9%
1934	5400000000	1%
1935	5200000000	-4%
1936	5200000000	0%
1937	5008147000	-4%
1938	4950000000	-1%
1939	4900000000	-1%
1940	5000000000	2%
1941	5100000000	2%

Evolution of MLHP's gas output, 1902-1937
Sources: *A Statistical Analysis of Montreal Light, Heat & Power Consolidated* for years 1902-1930, *Entre-Nous 1938* for years 1933 and 1937, *A Record of Expansion and Improvement 1925-1943* for years 1931-1932, 1934-1936, and 1938-1941

Bibliography

"Air Conditioning. From the Woman's Point of View", *Canadian Homes and Gardens*, vol. 10, no° 10, 1933, 22.

Armstrong, Christopher, and H. V. Nelles
"Contrasting Development of the Hydro-Electric Industry in the Montreal and Toronto Regions, 1900-1930", *Journal of Canadian Studies/Revue d'Études* Canadiennes, vol. 18, n° 1, 1983, 5–27.

Atallah, Nadia
"Les quartiers ouvriers de Montréal pendant la Grande dépression", *Bulletin de l'Institut Pierre Renouvin*, vol. 27, no° 1, 2008, 117–28.

Baillargeon, Denyse
"La Crise ordinaire: Les ménagères montréalaises et la crise des années trente", *Labour / Le Travail*, vol. 30, 1992, 135-162.

Making Do: Women, Family and Home in Montreal during the Great Depression. Waterloo: Wilfrid Laurier University Press, 1999.

Ménagères au temps de la Crise. Montréal: Remue-ménage, 1993.

Barnum D.D.
Report on Ways and Means of Promoting Gas Sales in Montreal. AHQ F9/3413/12352 loc. 3121. Montréal: Montreal Light, Heat & Power Consolidated, 1937.

Bélanger, Réal, George S. Mooney, and Pierre Boucher
Les vieux logements de Montréal. Rapport d'une étude faite pendant l'été 1937. AVM 001 XCD00-P7450. Montréal: Commission métropolitaine de Montréal. Département d'urbanisme et de recherche, 1938.

Bellavance, Claude
Shawinigan Water And Power, 1898-1963. Naissance et déclin d'un groupe industriel au Québec. Montréal: Boréal, 1994.

Bellavance, Claude, and Paul-André Linteau
"La diffusion de l'électricité à Montréal au début du XXe siècle." *In* Horacio Capel et Paul-André Linteau (dir.), *Barcelona-Montréal: Desarrollo urbano comparado / Développement urbain comparé*, 239–58. Barcelone: Publicacions de la Universitat de Barcelona, 1998.

Benoist, Émile
"L'âge du chauffage au bois serait bel et bien passé", *Le Devoir*, March 8, 1933.

Bertilorenzi, Marco
The International Aluminium Cartel: The Business and Politics of a Cooperative Industrial Institution. New York: Routledge, 2015.

Bonneuil, Christophe, and Jean-Baptiste Fressoz
L'événement anthropocène. La Terre, l'Histoire et nous. Paris: Seuil, 2016.

Bouvier, Yves
"Observer, mesurer, maîtriser. Les entreprises du secteur de l'énergie et les consommateurs individuels (France, années 1950-1980)", *In* Geneviève Massard-Guilbaud et Charles-François Mathis (dir.), *Sous le soleil. Systèmes et transitions énergétiques du Moyen-Âge à nos jours*. Paris: Éditions de la Sorbonne, 2019.

Bradbury, Bettina
Working Families: Age, Gender, and Daily Survival in Industrializing Montreal. Toronto: McClelland & Stewart, 1993.

Civic Investment and Industrial Company
Meeting Minutes. AHQ F9/3410/12062 loc. 4198. Montréal: Civic Investment and Industrial Company, 1917.

Coutard, Olivier, and Elizabeth Shove
"Infrastructures, Practices and the Dynamics of Demand", *In* Elizabeth Shove and Frank Trentmann (eds.), *Infrastructures in Practice: The Dynamics of Demand in Networked Societies*, 10–22. London: Routledge, 2018.

Cowan, Ruth Schwartz
"The Consumption Junction: A Proposal for Research Strategies in the Sociology of Technology", In Wiebe E. Bijker, Thomas Parke Hughes and Trevor Pinch (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, 261–80. Cambridge: MIT Press, 1987.

"The 'Industrial Revolution' in the Home: Household Technology and Social Change in the 20th Century", *Technology and Culture*, vol. 17, n° 1, 1976, 1–23.

Craigie, Ethel
"New Gadgets for the Modern House", *Canadian Homes and Gardens*, vol. 8, n° 1, 1931, 34–35.

Dagenais, Michèle
Montréal et l'eau. Une histoire environnementale. Montréal: Boréal, 2011.

Dales, John Harkness
Hydroelectricity and Industrial Development: Quebec, 1898-1940. Cambridge: Harvard University Press, 1957.

Denis, Leo G
Electric Generation and Distribution in Canada. Ottawa: Commission of Conservation, 1918.

Desbiens, Caroline
Power from the North: Territory, Identity, and the Culture of Hydroelectricity in Quebec. Vancouver: UBC Press, 2014.

Dominion Bureau of Statistics
Family Income and Expenditure in Canada. 1937-1938. Ottawa: Edmond Cloutier, 1941.

Durand, Caroline
Nourrir la machine humaine: Nutrition et alimentation au Québec, 1860-1945. Montréal & Kingston: McGill-Queen's University Press, 2016.

Edgerton, David
"From Innovation to Use. Ten Eclectic Theses on the Historiography of Technology", *History and Technology*, vol. 16, 1999, 111–36.

Engineering Department
Montreal Light, Heat & Power Cons. Appraisal of Electric Property. Subsidiary Report No. 1. Cedars Rapids Mfg. & Power Co. AHQ F9/3458/13544 loc. 3930. Montréal: Montreal Light, Heat & Power Consolidated, 1942.

Montreal Light, Heat & Power Cons. Valuation of Electric Property. General Report. AHQ F9/3458/13549 loc. 3930. Montréal: Montreal Light, Heat & Power Consolidated, 1943.

Evenden, Matthew
Allied Power: Mobilizing Hydro-Electricity during Canada's Second World War. Toronto: University of Toronto Press, 2015.

"Lights Out: Conserving Electricity for War in the Canadian City, 1939-1945", *Urban History Review / Revue d'histoire urbaine*, vol. 34, n° 1, 2005, 88–99.

Fleming, Keith Robson
Power at Cost: Ontario Hydro and Rural Electrification, 1911-1958. Montréal & Kingston: McGill-Queen's University Press, 1992.

Forman, Peter J., and Elizabeth Shove
"The Fixity of Flexibility". *Center for Research into Energy Demand Solutions* (blog), 2019. https://www.creds.ac.uk/the-fixity-of-flexibility/.

Fougères, Dany
L'approvisionnement en eau à Montréal. Du privé au public, 1796-1865. Québec: Septentrion, 2004.

Fressoz, Jean-Baptiste
"Pour une histoire désorientée de l'énergie." *In* Daniel Thevenot (dir.), *25èmes journées scientifiques de l'environnement. L'économie verte en question*. Journées Scientifiques de l'Environnement. Créteil, France, 2014.

"Fuel-Power Problem of Canada", *Journal of the Engineering Institute of Canada*, vol. 1, n° 1, 1918, 1–58.

Gagnon, Robert
Questions d'égouts. Santé publique, infrastructures et urbanisation à Montréal au XIXe siècle. Montréal: Boréal, 2006.

Gelly, Alain
"A Precipitous Decline, Steam as Motive Power in Montreal: A Case Study of the Lachine Canal Industries", *IA. The Journal of the Society for Industrial Archeology*, vol. 29, n° 1, 2003, 65–85.

Goldstein, Carolyn M
"From Service to Sales: Home Economics in Light and Power, 1920-1940", *Technology and Culture*, vol. 38, n° 1, 1997, 121–52.

Graber, Frédéric
"Inventing Needs: Expertise and Water Supply in Late Eighteenth- and Early Nineteenth-Century Paris", *The British Journal for the History of Science*, vol. 40, n° 3, 2007, 315–32.

Hatton-Proulx, Clarence
"A Lust for Power. Electrifying Montréal's Streets and Homes, 1884-1939", M.A. Thesis, York University, 2019.

Hocking, Clare, and Ulla Kroksmark
"Sustainable Occupational Responses to Climate Change through Lifestyle Choices", *Scandinavian Journal of Occupational Therapy*, vol. 20, n° 2, 2013, 111–17.

Hughes, Thomas Parke
Networks of Power: Electrification in Western Society, 1880-1930. Baltimore: Johns Hopkins University Press, 1983.

Jacobs, Jane
The Question of Separatism: Quebec and the Struggle over Sovereignty. 2nd ed. Montréal: Baraka Books, 2011.

Jacobs, Meg
Panic at the Pump: The Energy Crisis and the Transformation of American Politics in the 1970s. New York: Hill and Wang, 2016.

Jarrige, François, and Thomas Le Roux
La contamination du monde. Une histoire des pollutions à l'âge industriel. Paris: Seuil, 2017.

Jones, Christopher F
Routes of Power: Energy and Modern America. Cambridge: Harvard University Press, 2016.

Kroon, Bianca van der, Roy Brouwer, and Pieter J.H. van Beukering
"The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta-Analysis", *Renewable and Sustainable Energy Reviews*, vol. 20, 2013, 504–13.

Lecours, Jacques, and Raymonde Lavoie
L'électrification de la région de Montréal. Synthèse historique. Montréal: Hydro-Québec, 1991.

Linteau, Paul-André
Une histoire de Montréal. Montréal: Boréal, 2017.

Lorkowski, Nina
"Managing Energy Consumption. The Rental Business for Storage Water Heaters of Berlin's Electricity Company from the Late 1920s to the Early 1960s", *In* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies: How Energy Connects Politics, Technologies and Cultures*, 137–62. Bielefeld: Transcript Verlag, 2012.

Macfarlane, Daniel, and Andrew Watson
"Hydro Democracy: Water Power and Political Power in Ontario", *Scientia Canadensis: Canadian Journal of the History of Science, Technology and Medicine*, vol. 40, no° 1, 2018, 1-18.

MacMillan, J.R.
Discussion and Summary of a Public Relations Campaign Designed to Promote Informed Public Opinion of and Favourable Reaction to the Proposed Revision of Electric Rates and to Gain Public Acceptance of New Rate Schedule. AHQ F9/3469/14309 loc. 3912. Montréal: Montreal Light, Heat & Power Consolidated, 1934.

Martinot, Eric
"Grid Integration of Renewable Energy: Flexibility, Innovation, and Experience", *Annual Review of Environment and Resources*, vol. 41, 2016, 223–51. https://doi.org/10.1146/annurev-environ-110615-085725.

Massell, David
Quebec Hydropolitics: The Peribonka Concessions of the Second World War. Montréal & Kingston: McGill-Queen's University Press, 2011.

Maxwell, James, Jennifer Lee, Forrest Briscoe, Ann Stewart, and Tatsujiro Suzuki
"Locked on Course: Hydro-Québec's Commitment to Mega-Projects", *Environmental Impact Assessment Review*, vol. 17, 1997, 19–38.

Montreal Light, Heat & Power Company
Annual Report 1907. AHQ F9/3413/12289 loc. 3121. Montréal: Montreal Light, Heat & Power Company, 1907.

Annual Report 1914. AHQ F9/3413/12296 loc. 3121. Montréal: Montreal Light, Heat & Power Company, 1914.

Annual Report 1915. AHQ F9/3413/12297 loc. 3121. Montréal: Montreal Light, Heat & Power Company, 1915.

Bulletins to Employees. AHQ F9/3423/12986 loc. 13404. Montréal: Montreal Light, Heat & Power Company, 1911.

Engineer's Report. Sault Au Recollet. AHQ F9/3425 13028 loc. 3942. Montréal: Montreal Light, Heat & Power Company, 1914.

Report on Strike. AHQ F9/3412/12904 loc. 1992. Montréal: Montreal Light, Heat & Power Company, 1919.

Statement Showing Comparison Between Power Generated and Power Sold Between July 1st 1915 & Jan. 1st 1916 at Cedar Rapids. AHQ F9/3469/14235 loc. 3913. Montréal: Montreal Light, Heat & Power Company, 1916.

Montreal Light
Heat & Power Consolidated. *A Record of Expansion & Improvement 1925-1943*. AHQ F9/3409/12161 loc. 3960. Montréal: Montreal Light, Heat & Power Consolidated, 1943.

A Statistical Analysis of Montreal Light, Heat & Power Consolidated. AHQ F9/3413/12350 loc. 3121. Montréal: Montreal Light, Heat & Power Consolidated, 1931.

Annual Report 1918. AHQ F9/3413/12299 loc. 3121. Montréal: Montreal Light, Heat & Power Consolidated, 1918.

Annual Report 1927. AHQ F9/3413/12308 loc. 3121. Montréal: Montreal Light, Heat & Power Consolidated, 1927.

Annual Report 1941. AHQ F9/3413/12322 loc. 3121. Montréal: Montreal Light, Heat & Power Consolidated, 1941.

Cedar Rapids - Alcoa Contracts and Correspondance. AHQ F9/3470 #1 loc. 13322. Montréal: Montreal Light, Heat & Power Consolidated, 1941.

Cedar Rapids Production Journal. AHQ F9/3427 #202 loc. 2140. Montréal: Montreal Light, Heat & Power Consolidated, 1925.

Dual Service. 1927. AHQ F9/3423/12992 loc. 3944. Montréal: Montreal Light, Heat & Power Consolidated, 1927.

Dual Service. 1929. AHQ F9/3423/12993 loc. 3944. Montréal: Montreal Light, Heat & Power Consolidated, 1929.

Dual Service 1933. AHQ F9/3423/12998 loc. 3944. Montréal: Montreal Light, Heat & Power Consolidated, 1933.

Dual Service 1934. AHQ F9/3423/12999 loc. 3944. Montréal: Montreal Light, Heat & Power Consolidated, 1934.

Electricity and Gas Sales, 1937. AHQ F9/3469/14322 loc. 3686. Montréal: Montreal Light, Heat & Power Consolidated, 1945.

Entre-Nous. 1938. AHQ F9/3423/13000 loc. 3943. Montréal: Montreal Light, Heat & Power Consolidated, 1938.

Extracts from P.H. & Station Reports. June 1932. AHQ F9 3427 13073 loc. 3941. Montréal: Montreal Light, Heat & Power Consolidated, 1932.

Extracts from P.H. and Station Reports. June 1921. AHQ F9/3427 13059 loc. 3941. Montréal: Montreal Light, Heat & Power Consolidated, 1921.

Facture. AHQ H2/1800-00 1444 loc. 211. Montréal: Montreal Light, Heat & Power Consolidated, 1941.

Montreal Light Heat and Power Consolidated and Operating Subsidiaries. AHQ F9/3409/12338 loc. 3960. Montréal: Montreal Light, Heat & Power Consolidated, 1933.

Schedule of Rates and Some Information Regarding the Sale and Measurement of Electric Current. AHQ F9/3469/14279 loc. 3912. Montréal, 1909.

The Household Book. Le Livre Ménager. Montréal: Montreal Light, Heat & Power Consolidated, n.d.

Moss, Timothy, and Siddharth Sareen
"Demanding Demand: Political Configurations of Energy Flexibility in Berlin, 1920-2020", *Journal of Energy History / Revue d'Histoire de l'Énergie [Online]*, n°5, 2020.

Nelles, Henry Vivian
The Politics of Development: Forests, Mines, and Hydro-Electric Power in Ontario, 1849-1941. Montréal & Kingston: McGill-Queen's University Press, 2005.

Parr, Joy
Domestic Goods: The Material, the Moral, and the Economic in the Postwar Years. Toronto: University of Toronto Press, 1999.

"Shopping for a Good Stove: A Parable about Gender, Design, and the Market." *In* Joy Parr (ed.), *A Diversity of Women: Ontario, 1945-1980*, 75–97. Toronto: University of Toronto Press, 1995.

Pedersen, Susan
Family, Dependence, and the Origins of the Welfare State: Britain and France, 1914-1945. Cambridge: Cambridge University Press, 1993.

Penfold, Steve
"Petroleum Liquids", *In* Ruth W. Sandwell (ed.), *Powering up Canada: A History of Power, Fuel, and Energy from 1600*, 274–99. Montréal & Kingston: McGill-Queen's University Press, 2016.

Platt, Harold L.
The Electric City: Energy and the Growth of the Chicago Area, 1880-1930. Chicago: University of Chicago Press, 1991.

Polèse, Mario
"Montréal économique : de 1930 à nos jours", *In* Dany Fougères (dir.), *Histoire de Montréal et de sa région, t. II*, 959–1004. Québec: Presses de l'Université Laval, 2012.

Régie des services publics
Routine Des Dossiers de Requêtes Provinciale de l'électricité - Nos 1100 à 1500. BANQ Montréal, Fonds Régie de l'énergie 1909-2012 (E175 1993-11-001\8). Québec: Régie des services publics, 1940.

Ritchie, Hannah, and Max Roser
"Energy Production & Changing Energy Sources", *Our World in Data*, 2018. https://ourworldindata.org/energy-production-and-changing-energy-sources.

Sandwell, Ruth W.
"Pedagogies of the Unimpressed: Re-Educating Ontario Women for the Modern Energy Regime, 1900-1940", *Ontario History*, vol. 107, n° 1, 2015, 36–59.

Sandwell, Ruth W., ed.
Powering Up Canada: The History of Power, Fuel, and Energy from 1600. Montréal & Kingston: McGill-Queen's University Press, 2016.

Savard, Stéphane
"Les communautés autochtones du Québec et le développement hydroélectrique: Un rapport de force avec l'État, de 1944 à aujourd'hui", *Recherches amérindiennes au Québec*, vol. 39, n° 1–2, 2010, 47–60.

Shove, Elizabeth
Comfort, Cleanliness and Convenience: The Social Organization of Normality. Oxford: Berg, 2003.

Shove, Elizabeth, Heather Chappells, Loren Lutzenhiser, and Bruce Hackett
"Comfort in a Lower Carbon Society", *Building Research & Information*, vol. 36, n° 4, 2008, 307–11.

Shove, Elizabeth, Gordon Walker, and Sam Brown
"Transnational Transitions: The Diffusion and Integration of Mechanical Cooling", *Urban Studies*, vol. 51, n° 7, 2014, 1506–19.

Siemiatycki, Matti, Theresa Enright, and Mariana Valverde
"The Gendered Production of Infrastructure", *Progress in Human Geography*, vol. 44, n° 2, 297-134.

Struthers, James
No Fault of Their Own: Unemployment and the Canadian Welfare State, 1914-1941. Toronto: University of Toronto Press, 1983.

Taschereau, Sylvie, and Yvan Rousseau
"The Hidden Face of Consumption: Extending Credit to the Urban Masses in Montreal (1920s–40s)", *Canadian Historical Review*, vol. 100, n° 4, 2019, 509–39.

The Cedar Rapids Manufacturing and Power Company
Memorandum on the Cedar Rapids Manufacturing & Power Company and the Cedar Rapids Transmission Company. AHQ F9/3409/12156 loc. 3960. Montréal, 1944.

"The Kitchen: 1933 Model"
Canadian Homes and Gardens, vol. 10, n° 6, 1933, 20–21.

Torriti, Jacopo
"Understanding the Timing of Energy Demand through Time Use Data: Time of the Day Dependence of Social Practices", *Energy Research & Social Science*, vol. 25, 2017, 37–47.

Trentmann, Frank, and Anna Carlsson-Hyslop
"The Evolution of Energy Demand in Britain: Politics, Daily Life, and Public Housing, 1920s-1970s", *The Historical Journal*, vol. 61, n° 3, 2018, 807–39.

Unger, Richard W.
"Shifting Energy Sources in Canada: An International Comparison, 1870–2001", *Canadian Journal of History*, vol. 53, n° 3, 2018, 480–514.

Ville de Montréal
"Population Totale et Variation de La Population, Agglomération de Montréal." *Ville de Montréal* (blog), 2016. http://ville.montreal.qc.ca/portal/page?_pageid=6897,67887840&_dad=portal&_schema=PORTAL.

Ward, Peter
A History of Domestic Space: Privacy and the Canadian Home. UBC Press, 1999.

Whatley, G.R.
A Brief Submitted by Montreal Light Heat & Power Consolidated in Support of Revised Tariff for Residential Electricity Service. AHQ F9/3413 loc. 3121 #15. Montréal: Quebec Public Service Commission, 1934.

Wilhite, Harold, and Loren Lutzenhiser
"Social Loading and Sustainable Consumption", *NA - Advances in Consumer Research*, vol. 26, 1999, 281–87.

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR

Timothy Moss
Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt University of Berlin, Germany
mosstimo@hu-berlin.de

Siddharth Sareen
Department of Geography, Centre for Climate and Energy Transformation (CET), University of Bergen, Norway / Department of Media and Social Sciences, University of Stavanger, Norway
Siddharth.Sareen@uis.no
Twitter: @sidsareen

POST DATE
22/10/2020

ISSUE NUMBER
JEHRHE #5

SECTION
Special issue

THEME OF THE SPECIAL ISSUE
Historicising Flexibility

KEYWORDS
Electricity, gas, storage, network, politics

DOI
in progress

TO CITE THIS ARTICLE
Timothy Moss, Siddharth Sareen, "Demanding demand: Political configurations of energy flexibility in Berlin, 1920-2020", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 22 October 2020, URL: energyhistory.eu/en/node/230.

Demanding demand: Political configurations of energy flexibility in Berlin, 1920-2020

Abstract

Berlin's modern history provides an instructive window on the evolution of energy flexibility in an urban context. Since being enlarged to its current territory in 1920, it has encountered a huge variety of political regimes and disruptive socio-economic events that have substantially impacted energy use and supply. This paper explores and assesses a century of responses to fluctuations in energy demand and supply in Berlin, revealing their relevance to contemporary challenges of flexibility in urban energy systems. Drawing on insight from energy studies, energy history and urban studies, it highlights how flexibility options have been – and still are – shaped by a degree of local energy production and an 'energy urbanism' agenda.

Acknowledgements

The authors acknowledge generous support from the Gerda Henkel Foundation, Trond Mohn Foundation and the Akademia Agreement between the University of Bergen and Equinor. We are grateful to an anonymous reviewer and the journal editor for helpful suggestions and to the special issue editors for organising a workshop funded by the Centre for Research into Energy Demand Solutions in January 2020, which gave us a valuable opportunity to receive timely feedback from workshop participants.

Plan of the article

INTRODUCTION

1 Berlin has a vast underground gas storage facility that has lost its original purpose and is looking for a new one. Planned during the Cold War to enable the insular West Berlin to store up to a whole year's supply of imported natural gas, it went operational in September 1992, after the Berlin Wall fell. It was put to use in the reunified city, primarily to offset seasonal variations in gas prices, but this function has since been eroded by a glut in gas supplies and less volatile prices. There is hope that the plant may in the future support geothermal or power-to-gas technologies, providing storage to help balance peak inputs from nearby wind and solar farms. But until these technologies become marketable the storage facility has no viable purpose and, in 2020, is being dismantled. Historically speaking, it came too late to assuage West Berlin's gas security concerns and too early to be an integral part of flexibility options in Berlin's current energy transition.

2 This vignette from Berlin's recent history of energy provision highlights the huge significance of spatial-temporal contexts for flexibility responses to fluctuating or volatile levels of supply and demand. This paper uses a 100-year perspective on Berlin's electricity and gas provision to reveal a rich variety of flexibility challenges and responses, their embeddedness in (urban) political agendas and their relevance for energy transitions today. Taking a century-long view of a single city enables us to look beyond moments of transition or evidence of path dependence and attend to empirical examples of energy flexibility as and when they emerged (and disappeared). This analysis demonstrates not only that energy flexibility has an established history, but also how this history can uncover socio-technical phenomena pertinent to contemporary energy transitions yet often overlooked in 'presentist' takes on flexibility issues. At the same time, the paper engages with debates on energy flexibility today in order to point energy history towards promising research topics of relevance to ongoing processes of transformation. This dual purpose is central to our venture. Spatially, the paper targets flexibility challenges and options in cities, by virtue of their concentration of energy use, their capacity to enact local responses and their potential for social and technical innovation. As scholarly interest in 'energy urbanism' grows, we draw attention to the histories of energy flexibility within cities. Taking the case of a city with a strong tradition of locally organised and produced energy services, we explore the significance of the 'urban' as a site for capturing enactments of energy flexibility over a long time period.

Berlin's recent history offers a rich tableau of energy flexibility needs and responses. It faced multiple challenges to managing demand and supply as a result of socio-economic disruption, wartime damage and hardship, political division and reunification. Its responses to these challenges were heavily informed by the highly diverse political regimes the city experienced during the 20th C., ranging from fascism and state-socialism to various incarnations of capitalist democracy. The paper's title – "Demanding Demand" – is indicative of the twin types of flexibility challenges faced. On the one hand, energy demand in Berlin has often proven demanding to manage, as when generation capacity failed to keep up with demand or when consumers deviated from the utilities' script. On the other hand, energy demand has been actively promoted at times for political and technical reasons, whether to bolster the local economy, take up slack in generating capacity or demonstrate system superiority during the Cold War. From each of these perspectives, the Berlin experience reveals how energy demand issues were inextricably linked with supply management. Indeed, Berlin's energy utilities and regulators routinely preferred adaptations to supply as a response to shifts in demand, real or imagined. 3

Consequently, this paper will address both sides of the energy flexibility coin: supply and demand. In dealing with demand, it will encompass seasonal and daily variations, as well as changes caused by political interventions, physical destruction and economic dislocation or restructuring. We thus understand 4 energy flexibility in a broad sense as the balancing of supply and demand, situated within a socio-technically contingent configuration that can vary over time.

5 Three questions guide our research for this paper: 1) What kinds of energy flexibility challenges did Berlin experience over the past 100 years and how were they constructed? 2) How did urban and infrastructure managers respond to these challenges and in what ways did these responses reflect the shifting political leadership of the city? 3) What lessons can be drawn from the Berlin case for scholarship on energy flexibility in cities today?

6 To answer these questions, the paper analyses empirical data drawn from specialist publications, grey literature and archival material on Berlin's energy systems covering the entire period of study. The principal source was articles in energy engineering journals and books published by professionals responsible for Berlin's electricity and gas services. This was supplemented by utility strategy documents, municipal publications and correspondence between utilities and city authorities housed in the city-state archive (Landesarchiv Berlin) and library. This data, together with the available secondary literature on Berlin's energy systems, is interpreted with recourse to debates on energy flexibility in the social sciences today. The methodological approach thus combines historical empiricism with conceptual insight from contemporary energy studies.

7 The argument is advanced in four sections. First, we review the literature on flexibility as addressed by energy historians and energy geographers, mapping out the need for a spatially and temporally sensitive approach to energy flexibility. Second, we present the historical evidence of flexibility in Berlin's electricity and gas systems according to four generic responses. Third, we explore the legacies and lessons of this urban energy history for the city's contemporary challenges of energy flexibility. Finally, we draw conclusions in response to the research questions above.

SPATIAL-TEMPORAL CONTEXTS OF ENERGY FLEXIBILITY

Within social science energy research, flexibility has received limited attention until recently.[1] In the wake of growing interest in energy transitions and the uptake of renewable energy sources during the 2010s, scholars have begun to unpack energy flexibility issues.[2] However, scholarship suffers from some simplistic and problematic assumptions or 'energy fables': that energy is demanded (rather, energy services are demanded); that energy flexibility is a new concern (rather, it has deep historical roots pertinent to the present); that energy flexibility is a technical matter (rather, it is also socio-cultural); and that it is only influenced by energy policies (rather, numerous drivers – the built environment, behavioural patterns, public perception – recursively shape energy flexibility).[3] This suggests that energy flexibility must be broached in a more open-ended manner, as a dynamic property of the spatial-temporal configuration of evolving energy systems. There is thus a need to move beyond ahistorical approaches and spatial blindness in social science energy research towards a broader understanding of energy flexibility. We argue that this requires greater historical and spatial contextualisation. Below, we provide an overview of extant work upon which such richer contextualisation can be built. 8

Energy historians have mapped temporal trajectories of flexibility. This literature construes the contemporary juncture as but one in a series of manifestations of the socio-political dynamics of sectoral reconfiguration that inevitably accompany techno-economic evolution in energy 9

1 Lea Schick and Christopher Gad, "Flexible and Inflexible Energy Engagements: A Study of the Danish Smart Grid Strategy", *Energy Research & Social Science*, vol. 9, 2015, 51-59.

2 Roger Fouquet, "Historical Energy Transitions: Speed, Prices and System Transformation", *Energy Research & Social Science*, vol. 22, 2016, 7-12.

3 Jenny Rinkinen, Elizabeth Shove and Jacopo Torriti (eds.), *Energy Fables. Challenging Ideas in the Energy Sector* (Abingdon: Earthscan, 2019).

sources and energy infrastructure.[4] From such a perspective, 'energy flexibility' – albeit under different names – evokes familiar concerns and tensions with a seasoned history.[5] Examples include: expanding systems to cope with variations in energy demand for lighting and heating at different times of the day and the year; changing energy sources to enable a more flexible response to demand variation (e.g., from coal to oil); upgrading infrastructure to meet demand for heat as well as power (e.g., district heating); and incentivising energy demand at times when base load generation exceeds consumption (e.g., cheap night-time tariffs).[6] Flexibility covers a temporal range from a few seconds (ramping up gas plants to meet sudden demand peaks), to intra-day (powering industrial activity and domestic demand) and annual cycles (ensuring sufficient winter lighting and heating capacity while maintaining a lean system for lower summertime demand). Its configuration is contextually dependent on societal and technical aspects that vary as well.

10 Mobilising historians' temporal insights can enhance contextualisation and inform analyses of novel present-day challenges, such as the prospective contraction of fossil fuel energy sources as cost-competitive renewables proliferate[7] and the integration of intermittent energy sources into existing energy infrastructural logics[8] and techno-economic logics to expand grid flexibility.[9] It can advance understanding of how spatial distributions and temporal rhythms of the electricity supply mix co-evolve, and how this impacts energy system flexibility[10] and citizens. For instance, even in the 'predict and provide' era, demand was flexible and recognised as such, through a wide range of flexibility modes beyond demand-response.[11] Yet, energy historians seldom address contemporary challenges, thus limiting insights from temporal perspectives on current developments.[12]

11 At the same time, Rinkinen and Shove underscore a persistent ahistorical tendency in social science energy research, pointing out that despite energy services being closely linked to dynamics of social practice, demand forecasts remain focused on economic and consumption factors and are "quite unrelated to past and present technologies and infrastructures of provision".[13] Instead, social science research discusses flexibility in terms of modern-day energy source coordination, supply options and demand-side responses. It considers multi-stakeholder roles in a changing field of demand management options due to market

4 Andreas Malm, "Long Waves of Fossil Development: Periodizing Energy and Capital", *Mediations*, vol. 32.1, 2018, 17-40.

5 Cara New Daggett, *The Birth of Energy: Fossil Fuels, Thermodynamics, and the Politics of Work* (Durham: Duke University Press, 2019). Wolfgang Schivelbusch, *Disenchanted Night: The Industrialization of Light in the Nineteenth Century* (Berkeley: University of California Press, 1995).

6 Nina Lorkowski, "Managing Energy Consumption: The Rental Business for Storage Water Heaters of Berlin's Electricity Company from the Late 1920s to the Early 1960s", *in* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies* (Bielefeld: Transcript, 2014), 137-162.

7 Aubrey Meyer, Contraction & Convergence: The Global Solution to Climate Change (Green Books, 2000). Also see Richard York and Elizabeth Bell Shannon, "Energy Transitions or Additions? Why a Transition from Fossil Fuels Requires more than the Growth of Renewable Energy", *Energy Research & Social Science*, vol. 51, 2019, 40-43.

8 Georgios Papaefthymiou and Ken Dragoon, "Towards 100% Renewable Energy Systems: Uncapping Power System Flexibility", *Energy Policy*, vol. 92, 2016, 69-82.

9 Siddharth Sareen and Kjetil Rommetveit, "Smart Gridlock? Challenging Hegemonic Framings of Mitigation Solutions and Scalability", *Environmental Research Letters*, vol. 14, 2019.

10 Wim Zeiler *et al.*, "Flexergy: An Ontology to Couple Decentralised Sustainable Comfort Systems with Centralized Energy Infrastructure", in *Proceedings of 3rd International Conference on Smart and Sustainable Built Environments*, 2009.

11 Jacopo Torriti, "Flexibility" *in* Jenny Rinkinen, Elizabeth Shove and Jacopo Torriti (eds.), *Energy Fables. Challenging Ideas in the Energy Sector* (Abingdon: Earthscan, 2019), 104-107.

12 For an exception, see: Timothy Moss, *Remaking Berlin. A History of the City through Infrastructure, 1920-2020* (Cambridge, MA: The MIT Press, 2020).

13 Jenny Rinkinen and Elizabeth Shove, "Energy Demand" *in* Jenny Rinkinen, Elizabeth Shove and Jacopo Torriti (eds.), *Energy Fables. Challenging Ideas in the Energy Sector* (Abingdon: Earthscan, 2019), 9.

evolution (e.g., dynamic tariffs) and technological innovation (e.g., smart grids).[14]

12 Energy geographers have begun to examine the socio-spatial implications of these trends, in terms of how demand management is being modulated, by whom and to what end.[15] For instance, harnessing energy flexibility at local, disaggregated scales can enlarge users' roles from being consumers to prosumers.[16] Urban geographers assert that cities can be key to such demand reconfiguration,[17] as sites of concentrated energy demand and innovative energy demand patterns with significant decision-making powers. They are ideal locales for exploring how *non*-energy policies can engender wide-ranging, effective forms of demand reduction.[18] Urban energy managers not only need to enrol diverse policy fields in reconfiguring energy systems, but also face the structural and material constraints of institutional inertia and built environments.[19] Normative analyses of these socio-spatial dynamics have given rise to a promising direction of enquiry on energy justice, with a recent focus specifically on flexibility justice.[20] Flexibility justice foregrounds the political-economic tensions and power play that embed specific energy flexibility characteristics in energy infrastructures, and evaluates how energy flexibility *should* be rolled out.[21] Yet, despite the systematisation of energy research in relation to ethical principles,[22] this recent body of work currently lacks insight on how justice issues are mobilised in specific spatial-temporal contexts of energy flexibility reconfigurations.

Such conceptual prowess notwithstanding, 13
a mode of presentism is predominant in the energy geography literature on flexibility. Given the "complicated and contested histories"[23] that condition social, infrastructural and institutional orders, we perceive a need to empirically consolidate this incipient recognition of the socio-spatial factors that significantly shape energy flexibility in energy geographies, explicitly complemented by a temporal perspective. Following the assertion by Rinkinen and Shove that "energy demand has a history (in fact, multiple histories) and is constantly changing in line with the practices on which it depends"[24], we detect scope for rich energy histories of flexibility at the urban scale. It is in urban contexts that the relationship between demand and supply is most intense, owing to the sheer density of energy demand, distributive infrastructures and end-use appliances there. It is also where energy policy is particularly prone to contestation, reflecting the greater variety of political-cultural worldviews and opportunities for collective action generally prevalent in cities. Thus, the urban scale provides a window onto the granular patterns, contestations, adjustments and justifications of decisions and acts that have shaped energy

14 Brian Vad Mathiesen *et al.*, "Smart Energy Systems for Coherent 100% Renewable Energy and Transport Solutions", *Applied Energy*, vol. 145, 2015, 139-154. Larissa Nicholls and Yolande Strengers, "Peak Demand and the 'Family Peak' Period in Australia: Understanding Practice (in)Flexibility in Households with Children", *Energy Research & Social Science*, vol. 9, 2015, 116-124.

15 Stefan Bouzarovski and Neil Simcock, "Spatializing Energy Justice", *Energy Policy*, vol. 107, 2017, 640-648.

16 Siddharth Sareen and Håvard Haarstad, "Bridging Socio-Technical and Justice Aspects of Sustainable Energy Transitions", *Applied Energy*, vol. 228, 2018, 624-632.

17 Gareth Powells, Harriet Bulkeley, and Anthony McLean, "Geographies of Smart Urban Power", *in* Simon Marvin, Andrés Luque-Ayala, Colin McFarlane (eds.), *Smart Urbanism* (Abingdon: Routledge, 2015), 141-160. Vanesa Castan Broto and Harriet Bulkeley, "A Survey of Urban Climate Change Experiments in 100 Cities", *Global Environmental Change*, vol. 23.1, 2013, 92-102.

18 Harriet Bulkeley, Pauline McGuirk, and Robyn Dowling, "Making a Smart City for the Smart Grid? The Urban Material Politics of Actualising Smart Electricity Networks", *Environment and Planning A: Economy and Space*, vol. 48.9, 2016, 1709-1726.

19 Håvard Haarstad, "Where are Urban Energy Transitions Governed? Conceptualizing the Complex Governance Arrangements for Low-Carbon Mobility in Europe", *Cities*, vol. 54, 2016, 4-10.

20 For a reflective overview, see Nathan Wood and Katy Roelich, "Substantiating Energy Justice: Creating a Space to Understand Energy Dilemmas", *Sustainability*, vol. 12.5, 2020, 1917.

21 Gareth Powells and Michael Fell, "Flexibility Capital and Flexibility Justice in Smart Energy Systems", *Energy Research & Social Science*, vol. 54, 2019, 56-59.

22 Benjamin Sovacool and Michael Dworkin, *Global Energy Justice* (Cambridge: Cambridge University Press, 2014).

23 Jenny Rinkinen and Elizabeth Shove. "Energy Demand", 11 (cf. note 13).

24 Idem.

flexibility at the sites where they often first emerged or attracted attention.

14 Here lies the overarching contribution of this paper to social science and historical research on energy flexibility: it reveals the socio-political dynamics of spatial-temporal configurations of fluctuating energy demand and provision,[25] using the city of Berlin as a showcase. By locating energy flexibility transitions within a long-term analysis of 100 years, the paper raises our understanding of the dynamics that constitute the configuration of energy flexibility. For the social sciences we demonstrate the value of setting the societal conditions and socio-spatial effects of energy flexibility in an historical context. For energy historians we provide robust insight into the socio-spatial dynamics of energy flexibility in an urban setting. In contrast to much energy history research, we extend analysis up to the contemporary moment as a continuum of socio-politically contingent junctures. In keeping with the socio-spatial focus in energy geographies research, but enriched with historical empirical data, we demonstrate the relevance of a study of the urban as a site of special enactments of energy flexibility transitions (and continuities) over time.

HISTORIES OF FLEXIBILITY IN BERLIN'S ELECTRICITY AND GAS SYSTEMS

Peaks and troughs of Berlin's energy demand

15 The city of Berlin lends itself admirably to a historical study of energy flexibility. Since Berlin was substantially enlarged to its current territory in 1920, the city has experienced a panoply of economic crises, political extremes, military destruction and physical division that have each left their mark on energy provision and use. Instances of socio-economic disruption – such as the hyper-inflation of 1923, the Depression of the early 1930s or the immediate aftermath of the Second World War – prompted dramatic drops in demand for electricity and gas. Boosts to energy demand came from political aspirations to militarise the urban economy under the Nazi regime or to showcase West Berlin as a bastion of consumerism in the 1950s and 1960s. Meanwhile, the city's energy infrastructures have endured numerous physical disruptions, notably the destruction of power plants during the war and the truncation of electricity and gas networks between East and West during the Cold War. Even reunification in 1990 did not end the volatility of urban energy provision, as Berlin failed to live up to expectations of rapid growth and struggled to adapt to changing energy markets in Europe.

Alongside these contingent factors particular to the city, Berlin has experienced the seasonal and daily variations in energy demand familiar to many other industrialised cities. These have distinct drivers, such as seasonal variance in energy demand for thermal comfort and intra-day energy needs linked with industrial and domestic activities. The value of the Berlin case lies in exploring the interplay between these regular (and familiar) shifts in energy demand and the singular (and distinctive) shifts prompted by forces of political and economic disruption. Looking across 100 years, the resulting supply-demand imbalances are revealed to be influenced strongly by context-specific conditions that problematise an understanding of energy flexibility restricted to regular rhythms. Demand for gas, for instance, was seasonally well-balanced so long as it was used primarily for street-lighting, cooking and industrial production. Only when it became used for home heating, from the 1960s onwards, did a serious seasonal difference emerge. Similarly, the growing use of electricity for cooking and home heating after the war created peak loads in the early evening that had not existed before. A long-term historical analysis of Berlin's energy provision and use can thus reveal valuable insight not only about extreme situations, but also everyday experiences and, above all, how the two interacted. The Berlin experience may be unusually volatile, but it demonstrates in sharp relief the significance of spatial and temporal contextualisation to energy flexibility applicable to any city. 16

25 Gavin Bridge *et al.*, *Energy and Society: A critical perspective* (Abingdon: Routledge, 2018).

17 What responses to these radical shifts and persistent disparities in the relationship between demand and supply of energy can be detected in Berlin across the past 100 years? How did the city's electricity and gas utilities, energy regulators and consumers react to the difficulties these phenomena generated? We focus on the strategies adopted by those responsible for providing energy and how these reflect planners', policymakers' and practitioners' perceptions of energy use and supply. Four strategic responses were pursued, in different guises and to differing degrees, across the period of study. These are: 1) maximising energy reserves and storage, 2) exploring alternative and complementary energy sources, 3) engaging with the energy consumer and 4) accessing external energy sources. The remainder of this section addresses these strategies in turn, analysing what each says about the ways energy flexibility challenges were constructed and flexibility responses reflected the shifting political leadership of the city.

Maximising energy reserves and storage

18 Berlin's energy flexibility challenges are inextricably bound up with the ambition of the city's administration and utilities, for most of the past 100 years, to maximise production of electricity and gas within the territory of the city. Building up local capacity for generating electricity and producing town gas has been a central component of urban energy policy across diverse political regimes, partly as an expression of municipal self-government and partly as a protective strategy against intervention. The consequence has always been that Berlin has had to manage fluctuations in demand and supply itself, with often only limited recourse to the wider power grid or gas network.

19 In the 1920s, when electricity provision was still in its infancy, Berlin experienced rapid growth in demand in line with the electrification of households and businesses.[26] During the period of relative prosperity between the hyper-inflation of 1923 and the Depression of 1929/31, electricity consumption trebled in Berlin, surpassing one billion kilowatt hours (kWh) during 1928-29.[27] Eyeing much higher levels of electrification in the USA, Canada and Switzerland, the city's power utility Bewag, with cross-party support in the city council, enacted a massive investment programme to expand its own electricity generation capacity. In a series of reports produced between 1925 and 1928 it argued that Berlin needed to build its own power stations, rather than rely on imported electricity, to meet the sharp increase in peak loads as well as growing demand for power (fig. 1).[28] Two huge power stations were built within the city limits in the following years, with the Klingenberg and Westkraftwerk plants designed to deliver the base load and old power plants to cover peak demand.

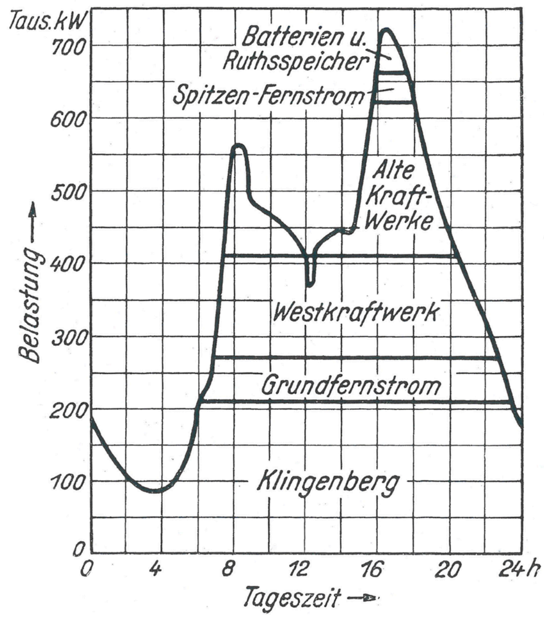


Figure 1: Electricity demand in Berlin in 1928, illustrating how the base load was covered primarily by the city's own power plants (Klingenberg, Westkraftwerk) and the peak load by older power plants and storage facilities, with minimal imports (Fernstrom) in both cases. Source: Martin Rehmer, "Die Stromversorgung der Reichshauptstadt Berlin", *Elektrizitätswirtschaft*, vol. 27/460, 1928, 280.

26 Beate Binder, *Elektrifizierung als Vision. Zur Symbolgeschichte einer Technik im Alltag* (Tübingen: Tübinger Vereinigung für Volkskunde e.V., 1999).

27 Conrad Matschoß *et al.*, *50 Jahre Berliner Elektrizitätswerke 1884-1934* (Berlin: VDI-Verlag, 1934); Otto Büsch, *Geschichte der Berliner Kommunalwirtschaft in der Weimarer Epoche* (Berlin: Walter de Gruyter, 1960), 112.

28 Berliner Städtische Elektrizitätswerke Akt.-Ges.: *Zur Zukunft der Berliner Elektrizitäts-Versorgung. Veröffentlichungen der BEWAG, Reihe II, Band 6*, 1928. The original reports can be found in the Landesarchiv Berlin (LAB), A Rep. 256, Nos. 247 & 250.

20 To optimise flexibility to sharp variations in demand and prevent power outages, electricity from the city's nine power stations and external sources was managed via a load distribution system of parallel grids – the first of its kind in Europe – that enabled any part of the city to be supplied by two independent sources.[29] In addition, a Ruths steam storage facility was built in 1929 to cover for short-term peaks in morning and evening demand by powering turbines with steam (fig. 2). Within 30 seconds this plant could be feeding electricity into the grid, providing up to 50 MW for a maximum of three hours.[30] Ten times larger than any existing steam storage facility in the world, it attracted huge attention at the World Electricity Conference in 1930.[31] By 1932 Berlin was well able to manage peak electricity loads. Indeed, a massive increase in generating capacity and a severe drop in demand during the Depression combined to create new problems of over-capacity and the perceived need to encourage demand, as discussed below.

21 The decline in electricity consumption during the Depression and again during the war did nothing to challenge the meme of constantly rising electricity demand in the post-war era. On the contrary, meeting anticipated growth in energy demand became a symbol of overcoming the tribulations of the war years. By 1949, Berlin was a divided city in the grip of Cold War geopolitics. Each side trusted in the prediction that electricity demand would double every ten years.[32] The East German government set an even higher growth target – at 8.2% per annum – to demonstrate superiority over its rival in the West.[33]

Figure 2: The Ruths steam storage facility, built in 1929 (pictured in 1952 and 2018). Sources: Landesarchiv Berlin (LAB) F Rep. 290 (07), no. 0019330, photo by Willi Nitschke, 8 April 1952. Photo by Timothy Moss, 2018.

While East Berlin was in the advantageous position of having access to electricity and gas from the surrounding German Democratic Republic (GDR), West Berlin became geopolitically isolated following the blockade and division of the city in 1948-49. Cut off from national energy supplies, suffering from the requisition of power 22

29 W. Fleischer, "Lastverteilung bei der Berliner Städtische Elektrizitätswerke Akt.-Ges..", *Elektrizitätswirtschaft*, vol. 28.493, 1929, 502-507.

30 Martin Rehmer, "Der Ausbau und die Betriebsführung der Bewag seit dem Jahre 1924", Sonderabdruck aus der *Zeitschrift des Vereins deutscher Ingenieure*, vol. 78.18, 1934, 2.

31 Hilmar Bärthel, "Anlagen und Bauten der Elektrizitätserzeugung", in Architekten- und Ingenieur-Verein zu Berlin (ed.), *Berlin und seine Bauten. Teil X, Band A (2) Stadttechnik* (Petersberg: Michael Imhof Verlag, 2006), 214.

32 Presse- und Informationsamt des Landes Berlin (ed.): *Perspektiven der Stadtentwicklung* (Berlin: Haupt & Kosta, 1974), 150.

33 E.M.K. Sommer, "Die Öffentliche Stromversorgung in der DDR seit 1945 und Tendenzen ihrer weiteren Entwicklung", *Energietechnik*, vol. 11.3, 1961, 100.

generation plant by the Soviet occupying forces and unwilling to supplicate to the East, West Berlin strove to maximise local generation of electricity and gas.[34] Apart from the loss of significant generation capacity in the East of the city, the island status of West Berlin made it particularly vulnerable to huge variations in demand for electricity, which in 1953 ranged between 30,000 and 330,000 kWh.[35] Massive expansion of electricity generation capacity enabled West Berlin to become fully self-sufficient in electricity provision by 1957 and to cover all demand peaks in the following decades.[36]

23 Essential to the city's electricity autarky, apart from unwavering political and financial support, was a high level of reserve and storage capacity that was integrated in a system of supply back-ups. To ensure security of supply, the Allied powers and the Berlin city government insisted on a permanent minimum reserve of 17%, large enough to cover for a failure to the city's largest generation block.[37] In the event of a power outage or drop in frequency, the steam storage plant (referred to above) would cover the immediate shortfall, followed by gas turbines operational within 30 minutes. In 1986, this back-up system was front-ended with a battery storage facility that could feed 17 megawatts into the urban grid within just 10 seconds. The electricity battery, occupying a three-story building, was the largest of its kind at the time. This high-security, low-risk strategy ensured that West Berlin experienced no significant power cuts throughout its period of geopolitical isolation.

24 This achievement, however, built huge redundancies into the system that ran up against growing criticism from the 1970s onwards. As Bewag demanded ever more power plants to meet growing demand and provide the stipulated reserves, environmentalists and residents questioned the assumptions underpinning the expansionist plans and successfully blocked one major investment in 1977.[38] After reunification, the built-in reserves represented surplus capacity and were decommissioned, along with several inner-city power plants. This reduced over-capacity but deprived the city of its unique system of localised load management.

For gas, the unwillingness of West Berlin to 25
contemplate imports of manufactured or natural gas similarly required massive expansion of local production capacity. During the 1950s and 1960s, when gas consumption rose only modestly, the city was able to meet demand with new, coal-fired gas works. However, once gas became the energy of choice for home heating in the 1970s, the city's gas utility Gasag had to deal with demand that was not only growing sharply, but also highly variable. The load ratio between summer and winter demand for gas increased dramatically, from 1:2.4 in 1960 to 1:8.2 in 1977.[39] Similar to electricity, storage was an option pursued to minimise system shortfalls. A major breakthrough came in the mid-1980s, when drilling revealed a favourable geological structure capable of storing approximately one billion cubic metres of gas: enough to supply West Berlin for a whole year.[40] This discovery – and the security of supply it promised – facilitated an agreement to import natural gas from the Soviet Union and store it underground. This increased the city's capacity to deal with seasonal fluctuations in demand and heralded the end of locally produced town gas – far later than in most other European cities.

34 On the following, see Timothy Moss, "Divided City, Divided Infrastructures: Securing Energy and Water Services in Postwar Berlin", *Journal of Urban History*, vol. 35.7, 2009, 923-942.

35 Senat von Berlin, *Berlin 1953. Jahresbericht des Senats* (Berlin: Kulturbuch-Verlag, 1954), 148.

36 Heinrich Tepasse, *Stadttechnik im Städtebau Berlins. 20. Jahrhundert* (Berlin: Gebr. Mann Verlag, 2006), 204.

37 Curt Bahde, Manfred Bohge, Klaus Bürgel and Joachim Schlede, "Das Stromversorgungssystem der Bewag", *Elektrizitätswirtschaft*, vol. 76.6, 1977, 131.

38 H.-J. Mielke and Heinrich Weiß, "Kraftwerksbau im Landschaftsschutzgebiet Spandauer Forst," *Berliner Naturschutzblätter*, vol. 20.59, 1976, 219-224. On the disputed power plant at Oberhavel, see the documentation in LAB B Rep. 016, Nos. 426, 427, 428, 429, 430, 431, 433 and 436.

39 Hilmar Bärthel, *Die Geschichte der Gasversorgung in Berlin. Eine Chronik* (GASAG Berliner Gaswerke Aktiengesellschaft, Berlin: Nicolaische Verlagsbuchhandlung, 1997), 145.

40 Idem, 154.

26 In short, the city's early insistence on producing its own electricity and town gas, as far as possible, was instrumental in the emergence of technologies of provision designed to balance loads locally. Choosing self-generation – whether out of free volition (in the Weimar Republic) or under geopolitical duress (in West Berlin) – meant relying on local measures, rather than on a national grid, to manage peak and off-peak loads.

Exploring alternative and complementary energy sources

27 The prevalence of locally-produced gas and electricity across Berlin's recent history created opportunities for adapting the fuel mix to suit geopolitical, as well as economic, circumstances. Decisions to use alternative or complementary sources of energy were invariably informed by their potential contribution to balancing supply and demand, whether on a daily or seasonal basis. The heavy reliance on coal as the fuel source for electricity and gas production had revealed West Berlin's energy vulnerability during the blockade of 1948-1949. From 1960 onwards, the city built several oil-fired turbines for electricity generation to diversify the fuel source. These turbines had the additional advantage of being able to feed power into the grid within around ten minutes, making them particularly suitable for covering peak demand.[41] By the late 1970s, these oil-fired turbines provided around 25% of West Berlin's electricity.[42]

28 Similarly, gas production was converted from coal to oil from the mid-1950s onwards, also to enable greater flexibility. The ability to fire up a gas works faster was seen as an essential response to the growing disparities in daily and seasonal demand loads described above.[43] By 1987, almost all the town gas produced in West Berlin was oil-fired, using thermal catalytic high-pressure splitting plants.[44] The downside of diversifying the fuel input, however, was that oil was significantly more expensive than coal, especially in the wake of the global oil crises of the 1970s. Flexibility via fuel substitution came at a price that went beyond simply balancing supply and demand; it implicated questions of energy security as well as political and financial stability and self-dependence for an insular urban context.

29 Previously, Berlin had experimented with alternative fuels and technologies for gas and power production for reasons of national autarky as well as resource efficiency.[45] The practice of using sewage gas from the city's wastewater treatment plants to produce methane for vehicles and to generate on-site electricity in the late 1920s was promoted by the Nazis as a powerful symbol of national self-reliance. Although the amounts of methane gas produced were never enough to significantly reduce demand for coal or oil, they nevertheless helped the city through severe wartime shortages of fuel. In 1946, the gas utility Gasag sold 1.9 million cubic metres of methane gas for gas-powered vehicles, a figure which only declined sharply in 1949 when petrol imports increased (fig. 3).[46]

30 Another energy technology that affected the city's ability to respond to flexibility challenges was district heating. The localised nature of electricity generation in Berlin lent itself to the co-generation of heat and power. For this reason, many of Berlin's power plants from the late 1920s

41 Berliner Kraft- und Licht(Bewag)-Aktiengesellschaft (ed.), *100 Jahre Strom für Berlin. Ein Streifzug durch unsere Geschichte in Wort und Bild 1884-1984* (Berlin: Bewag, 1984); Senat von Berlin (ed.): *Berlin. Chronik der Jahre 1959-1960* (Berlin: Heinz Spitzing Verlag, 1978).

42 Martin Haase, "Kraftwerks- und Stadtheizungsbetrieb", *Elektrizitätswirtschaft*, vol. 83.9/10, 1984, 427. In West Germany, by comparison, only around 2% of electricity was generated with oil at that time. H.-J. Ziesing, "Strukturelle und Sektorale Entwicklung des Energieverbrauchs in Berlin (West)" *in* Deutsches Institut für Wirtschaftsforschung (ed.) *Wochenbericht,* vol. 52, 1985, 236.

43 ÖTV Berlin, *Erd-GASAG – vom Energieversorgungs- zum Energiedienstleistungsunternehmen* (Berlin: Gasag, 1984), 11.

44 J.D. Aengeneyndt, "Das Erdgas-Versorgungssystem für Berlin", *Gesundheitsingenieur*, vol. 108, 1987, 181.

45 On the following, see Timothy Moss, "Discarded Surrogates, Modified Traditions, Welcome Complements: The Chequered Careers of Alternative Technologies in Berlin's Infrastructure Systems", *Social Studies of Science*, vol. 46.4, 2016, 559–582.

46 LAB C Rep. 105, Nos. 4611 & 4608.

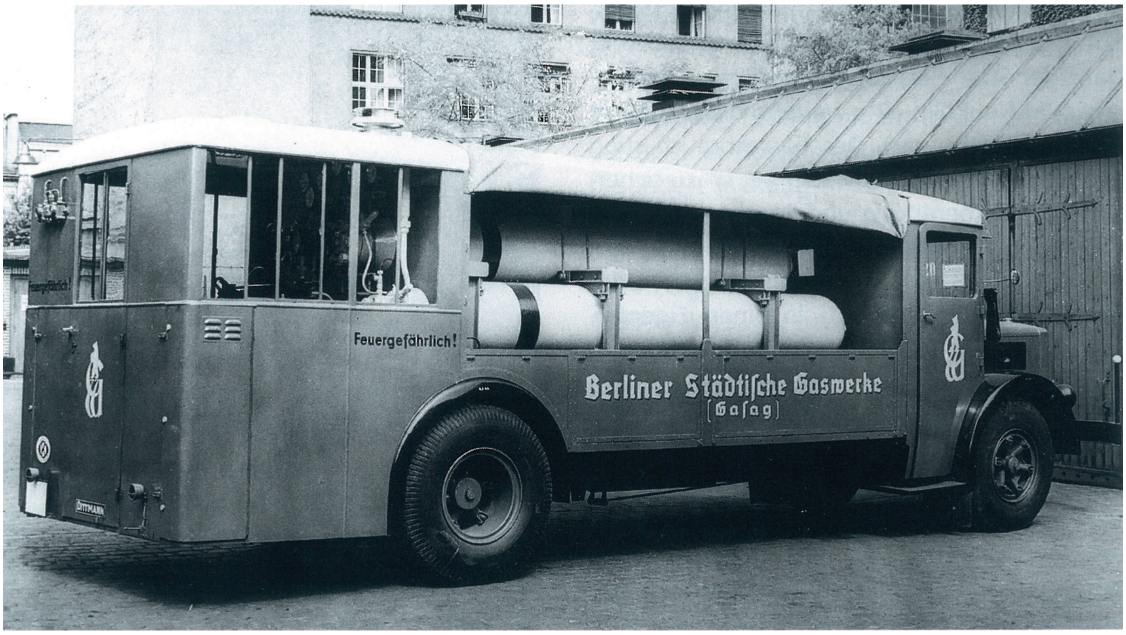


Figure 3: A gas-powered lorry of the Berlin gas utility used to deliver gas to filling stations. Source: Hilmar Bärthel, *Die Geschichte der Gasversorgung in Berlin. Eine Chronik* (GASAG Berliner Gaswerke Aktiengesellschaft, Berlin: Nicolai, 1997), 93.

onwards, but especially in West Berlin during the Cold War, provided both electricity and district heating. In East Berlin district heating was also well established, but produced without electricity, which was supplied largely from external sources in the GDR. The combination of power and heat generation may have been logical in terms of energy efficiency, but it created new problems of imbalanced demand loads. Seasonally, demand for electricity varied little, whereas district heating was needed only in the cold months. In East Berlin it was observed that providing heat for purely residential areas, such as the showcase Stalinallee development, created a huge imbalance between summer and winter demand.[47] On winter days, high evening demand for heat created the need in West Berlin to simultaneously sell more co-produced electricity. Such seasonal and daily imbalances were particularly problematic when growth curves for electricity and heating diverged, as in the late 1920s.[48]

What is dramatically revealed by the Berlin case is how these efforts to increase flexibility with the aid of alternative energy sources emerged in direct relationship with the material fabric and political context of the city. The alternative fuel sources, such as sewage gas, that were initially developed during the Weimar era to maximise energy use from existing production processes were subsequently enrolled by the Nazis in a campaign for national autarky and independence from imported oil. Storing huge quantities of gas in underground geological cavities would never have been contemplated – let alone implemented – without the geopolitical pressure on West Berlin to protect itself from disruption to external natural gas supplies. The co-generation of heat with power may have emerged in the 1920s, but it became the predominant form of energy transformation only under conditions of territorial confinement in West Berlin, when power plants were by necessity located in densely populated settings. 31

Engaging with the energy consumer

Although adaptations to supply were always the preferred strategy of Berlin's energy utilities and regulators, demand management has featured as a key response to load imbalances, particularly 32

47 H. Lehmann, "Fernheizung der Wohnstadt Berlin-Friedrichshain und der Stalinallee", *Energietechnik*, vol. 4.5, 1954, 195.

48 Tepasse, *Stadttechnik*, 85 (cf. note 36).

at times of crisis. Whether to stimulate energy demand during recession or to dampen it during war or division, attempts to influence the consumer have a long pedigree in the city.

33 In 1926, Bewag introduced a hire-purchase scheme, branded Elektrissima, designed to make electrical appliances more affordable for a greater number of Berlin households (fig. 4).[49] This innovative scheme – another first in Germany, at least – quickly caught on, facilitating 112,000 sales in 1927 and 171,000 in 1929, and was soon copied by Gasag.[50] Marketed as a way of democratising electricity consumption, it was originally established, in the words of a Bewag director, "to create a significant increase in the consumption of electricity".[51] This motive soon shifted, however, as demand for power rocketed, creating problems of load imbalances between day- and night-time use. The utility responded by introducing a night-time tariff at half the day-time rate and refining the Elektrissima scheme to promote the sale of appliances that used electricity at off-peak times, such as night storage heaters, hot-water storage boilers and – extraordinarily, from today's perspective – batteries for electric vehicles.[52] Separate meters were installed to facilitate tariff distinction. Household appliances were, effectively, being used to store energy at off-peak times.[53]

34 The focus of Elektrissima changed once again during the Depression, when it became enrolled in political efforts to boost the urban economy. Based on the astute observation by the power utility that household electricity consumption was relatively immune to shifts in the economy, the hire-purchase scheme was revitalised during the late Weimar Republic and early Nazi era to help compensate for the sharp drop in demand by industry and commerce from 1929 onwards. The Bewag newsletter run by the utility's National Socialist works council, *Der Stromkreis*, was full of adverts exhorting employees to promote the sale of electrical appliances in the national cause. After the war, Elektrissima was re-introduced in West Berlin to promote post-war recovery and showcase Western lifestyles. By 1956, it had 250,000 customers on its books, with hire-purchase agreements totalling 45 million Deutschmark.[54] The history of this demand management scheme reveals how an instrument of energy flexibility could become enrolled by highly diverse regimes to serve very political purposes.

Figure 4: Adverts of the Berlin power utility Bewag, announcing the Elektrissima (E³) scheme and cheap night-time tariffs. Source: Berliner Kraft- und Licht(Bewag)-Aktiengesellschaft, *100 Jahre Strom für Berlin*, year 1932. Copyright: Bewag/Vattenfall.

49 On the following, see Beate Binder: *Elektrifizierung als Vision*, 340-351 (cf. note 26); Timothy Moss, "Socio-Technical Change and the Politics of Urban Infrastructure: Managing Energy in Berlin between Dictatorship and Democracy", *Urban Studies*, vol. 51.7, 2014, 1432-1448.

50 Conrad Matschoß *et al.*: *50 Jahre Berliner Elektrizitätswerke*, 76 (cf. note 27).

51 R. Kauffmann, "Das Abzahlungsmodell des Bewag", *Elektrizitätswirtschaft*, vol. 26.427, 1927, 83.

52 Conrad Matschoß *et al.*, *50 Jahre Berliner Elektrizitätswerke*, 73 (cf. note 27).

53 Nina Lorkowski, "Managing Energy Consumption: The Rental Business for Storage Water Heaters of Berlin's Electricity Company from the Late 1920s to the Early 1960s", *in* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies* (Bielefeld: Transcript, 2014), 143-145.

54 Bewag, *100 Jahre Strom für Berlin* (Berlin, Bewag, 1956).

35 If Berlin's energy managers were justifiably confident of their ability to influence demand upwards, whether to take up excess capacity or boost the local economy, they were always sceptical of efforts to reduce electricity or gas consumption. Since Berlin experienced several periods when energy supply was seriously disrupted, however, they often had little option but to exhort or coerce consumers to cut down on energy use. During the early years of the war, adverts called on households to save energy in the national interest (fig. 5). Overtly, this was about prioritising military production, but the authorities were also keen to avert energy rationing for fear of its negative psychological effects on the population. Rationing of electricity and gas was introduced in Berlin only after the war, when deliveries of coal to the occupied city were so low that each household was permitted just 0.5 kWh of electricity a day (plus 50 Watts per person) in September 1945. The use of warm water boilers, vacuum cleaners and room heaters was strictly prohibited at home and work. Many chose to ignore or circumvent these restrictions, however, despite the draconian fines if caught. This revealed the limited effectiveness of coercion as a method of saving energy, at least when not backed up by adequate monitoring capacity. Clearly frustrated, the councillor responsible for energy supply, Jirak, reported to the city council in December 1945: "The Berlin population has failed 100%. People just glibly exceed their quota."[55] The immediate post-war winters were marked by a severe imbalance between extremely limited power generation and ineffective controls on electricity use, prompting repeated disruptions to supply.

Figure 5: Newspaper advert to turn off electric heaters to save electricity, 1942. Source: Bezirksamt Charlottenburg von Berlin. *Stadt unter Strom. Zur Kulturgeschichte der Elektrifizierung*. Berlin: Heimatmuseum Charlottenburg, 1990:48.

36 Efforts to save energy were reintroduced in East Germany during the 1950s, when supply fell substantially short of meeting growing demand. Beyond appeals to the public, socialist planning targets were introduced to limit electricity and gas consumption in factories and offices. In East Berlin, a special unit of energy inspectors was created to monitor adherence to energy-saving quotas.[56] Their reports suggest that many industrial managers were willing to pay the fines rather than jeopardise production targets, whilst public employees proved ingenious at concealing electric room heaters. In West Berlin, saving energy was never seriously considered as part of the city's response to the geopolitical limitations to its electricity and gas supply. It was repeatedly dismissed as ineffective and unnecessary so long as enough power stations and gas works could be built.[57]

55 *Die Sitzungsprotokolle des Magistrats der Stadt Berlin 1945/46. Teil I. 1945* (Berlin: Berlin Verlag Arno Spitz, 1995), 708.

56 See the correspondence in LAB, C Rep. 752, No. 38.

57 See a sceptical report on energy saving by the (West) Berlin Senate Department for Economics of September 1977, LAB, B Rep. 016, No. 458.

37 Demand management, these examples illustrate, is not a recent phenomenon, but a dimension of flexible energy provision with a long and rich pedigree. Its drivers may be iterative patterns such as seasonal flux or a particular rupture to consumption patterns or shortages in supply capacity. Both play a role in energy suppliers' cumulative experience with demand management and in shaping the legacy of energy flexibility in the long term. Those responsible for providing electricity and gas to Berliners – in the city utilities and administration – have been trying to shape demand for energy in multiple ways and for a variety of purposes at different moments in time. They encouraged – or 'demanded' – demand whenever the local economy and the energy providers stood to benefit. When confronted with levels of peak demand that they found 'demanding', they responded by trying to guide energy use to those times of the day and year when the power and gas networks were under-utilised. Efforts to reduce energy demand during supply crises – through exhortations, incentives or restrictions – proved largely ineffective, whether under fascist, state-socialist or democratic rule.

Accessing external energy sources

38 The fourth strategic response to flexibility challenges – to import electricity or gas to complement the city's own production – was regarded by many Berlin administrations as a measure of last resort. This might seem odd from a technical perspective, since increasing energy imports meant, effectively, externalising the problems of load management to the national grid or gas network. Decisions on energy management in Berlin, however, were never wholly – or even primarily – based on technical considerations. During the 1920s, maximising energy self-dependence was a central feature of a socially distributive and territorially integrative municipal policy. The city successfully resisted the repeated approaches of Germany's major utilities to serve Berlin in the 1920s and 1930s, only succumbing to pressure under the Nazi regime to import at least some of its gas and electricity from these sources.[58] Bad experiences with imported town gas supplied from the Reichswerke Hermann Göring strengthened Berlin's immediate post-war resolve to reduce dependence on external sources.

Following the division of the city, East Berlin gradually embraced imported electricity and gas. Municipalism had no place under a state-socialist regime and the East German capital was gradually enrolled in a programme of national energy provision. The proportion of East Berlin's electricity consumption generated in the city fell from 100% in 1955 to 55% in 1970 and just 6% in 1980.[59] Imports of town gas increased from the 1960s onwards, reaching 60% of gas supplied in 1973 and 85% in 1978.[60] East Germany's strategic partnership with the Soviet Union enabled East Berlin to convert to natural gas far earlier than its neighbour. 39

Whereas East Berlin received its first delivery of Soviet natural gas in the early 1970s, it was not until October 1985 that West Berlin imported natural gas for the first time. This momentous step followed years of tortuous deliberation in West Berlin about the necessities and risks of opening up to external supplies of both electricity and gas.[61] The city's growing inability to build enough power stations and gas works to meet rising demand prompted a reappraisal of the merits and viability of isolationism from the mid-1970s onwards. Encouraged by a political thaw in East-West relations, the West Berlin authorities, with the backing of the West German government, engaged in discussions with the East Germans and the Soviets over connections to the (East German) electricity grid as well as to natural gas pipelines. The idea was for imported power to cover the base load, and local capacity to cover peak demand. But fears of supply 40

58 Otto Büsch, *Geschichte der Berliner Kommunalwirtschaft*, 119 (cf. note 27); Hilmar Bärthel, *Die Geschichte der Gasversorgung*, 92 (cf. note 39).

59 VEB Energiekombinat Berlin (ed.): *40 Jahre Deutsche Demokratische Republik. 40 Jahre Sozialistische Energiewirtschaft in Berlin – Hauptstadt der DDR* (Berlin, VEB, 1989), 18.

60 Hilmar Bärthel, *Die Geschichte der Gasversorgung*, 116 (cf. note 39).

61 See the correspondence in LAB, B Rep. 155, Nos. 143, 144 and 146.

insecurity were deeply ingrained. The contract to deliver natural gas from the Soviet Union to West Berlin was not signed until March 1983.[62] It was only in March 1988 that an agreement was finally reached between the GDR, the power utility Preußen-Elektra and Bewag to link West Berlin to the power grid.[63]

41 The 40 years of political division produced, therefore, two diametrically opposed responses to energy provision within the same urban conurbation. While East Berlin was required to externalise electricity and gas production – and the associated flexibility challenges – to national energy planning, West Berlin pursued a strategy of urban energy autarky that called for huge flexibility reserves in an insular system. By the 1980s, both were confronting the limitations to their strategic pathways: East Berlin in the form of failing infrastructure and West Berlin in the form of the pollutive impacts of local generation.

LEGACIES AND LESSONS FOR THE POST-UNIFICATION ERA

42 When the Berlin Wall fell in November 1989 and the two halves of the divided city were reunited the following year, expectations were high that Berlin would thrive as it returned to 'normalcy', with its capital status and territorial integrity restored. Once the physical and organisational structures of separation had been removed, it was widely held, there would be no holding back. The reconnection of West Berlin to the national electricity grid and natural gas network, as well as the restoration of power and gas utilities serving the whole city, were symbolic manifestations of urban and national reunification in the early 1990s.

43 Berlin's infrastructure past, however, proved hard to discard. While the rhetoric was all about returning to the fold, the reality was far more about dealing with the multiple legacies of division, self-supply, pollution and protest. Past technologies and policies of energy flexibility – once celebrated as pillars of energy security – came to haunt the providers and regulators of energy services in the city.

The most immediate of these legacies from the past were physical. The huge production capacities for electricity and town gas built to protect supply and balance loads in West Berlin lost their pivotal function once the city was reconnected to the national power and gas networks. By May 1996 gas production at urban gas works had ceased.[64] In December 1994 a new 380 kV transmission line connected West Berlin to the West European electricity grid UCPTE, which now also served the former East Germany.[65] A cable linking the two halves of the city became operative in 1996, enabling electricity supply to be balanced across the whole city. These connections rendered much of (West) Berlin's power generation capacity obsolete. When the European electricity market was liberalized in the late 1990s, many of the remaining facilities proved uncompetitive, resulting in several being decommissioned (fig. 6). The infrastructure built to sustain West Berlin's insular policy of self-generation has, to some extent, become redundant today, posing a liability to operational efficiency, as in the case of the underground gas storage facility described in the introduction. 44

Drawing on a greater proportion of electricity and gas from outside the city since 1990 has certainly helped externalise solutions for energy flexibility to the wider electricity grid and gas network, but this has not resolved the problems emanating from Berlin's long-standing reliance on fossil fuels for energy provision. The continued existence of urban cogeneration plants powered 45

62 J. D. Aengeneyndt: "Das Erdgas-Versorgungssystem für Berlin", 181 (cf. note 44).
63 Betriebsrat der Berliner Kraft- und Licht(Bewag)-Aktiengesellschaft (ed.), *Im Licht der Zeit. 90 Jahre Betriebsvertretung bei der Bewag* (Berlin: Betriebsrat der Berliner Kraft- und Licht(Bewag)-Aktiengesellschaft, 1998), 143.
64 Hilmar Bärthel, *Die Geschichte der Gasversorgung*, 168 (cf. note 39).
65 Clemens Fischer, "BEWAG—vom Inselversorger zum Verbundpartner", Special edition, *Energiewirtschaftliche Tagesfragen*, vol. 12, 1992; Dietmar Winje, "Integration des West-Berliner Netzes in den deutschen Verbund", *Elektrizitätswirtschaft*, vol. 93.13, 1994, 726–732.

Figure 6: *Dismantling the Oberhavel power plant in Berlin, 2007.* Source: Photo by Timothy Moss.

by oil, gas, coal or lignite over 30 years after the fall of the Wall is testimony to the obduracy of fossil fuels in Berlin's energy mix. This further physical legacy of the past has proved a major obstacle to attempts by the city to decarbonise electricity provision.

46 Other legacies are political, rather than physical. Criticism of the environmental costs of power and gas provision, in West Berlin since the 1970s and East Berlin since the 1980s, had a powerful influence on early energy policy in the reunified city. Protests by Berlin residents against supply-oriented energy policy before the fall of the Wall inspired a policy shift towards a more environmentally sustainable form of 'energy urbanism'. A red-green coalition elected in West Berlin in 1989 launched an ambitious programme to promote energy efficiency, advance renewables and reduce carbon emissions that carried forward into the united city after 1990. An Energy Task Force was established to spearhead a new, alternative energy policy. It coordinated a citywide energy concept, promoted pilot projects for energy efficiency, set up an energy advisory agency for local businesses and launched a contracting partnership for energy saving in public buildings that received nationwide acclaim.[66] A State Energy Saving Act passed in 1990 required the city-state of Berlin to orientate all its plans and policies around the provision of resource-efficient, low-cost and environmentally sustainable energy. This policy agenda – embracing demand management and alternative energy sources as key components of urban energy – marked a radical shift away from supply-oriented solutions to flexibility challenges. Once again, we note how a particular socio-technical reconfiguration emerged out of a spatially and temporally specific interaction of – in this instance – political, infrastructural and organisational forces.

66 Jochen Monstadt, *Die Modernisierung der Stromversorgung. Regionale Energie- und Klimapolitik im Liberalisierungs- und Privatisierungsprozess* (Wiesbaden, VS Verlag für Sozialwissenschaften, 2004), 303, 312-315, 352-357. On the energy agency, Senatsverwaltung für Stadtentwicklung und Umweltschutz: *Energieagentur Berlin. Konzeptstudie. Neue Energiepolitik für Berlin, Heft 2* (Berlin: Senatsverwaltung für Stadtentwicklung und Umweltschutz, 1990), 4–6. On the contracting model for energy-saving partnerships, Klaus Kist and Willibald Lang, "Energiesparpartnerschaften Berlin—ein Modellprojekt geht in Serie", *in* Umweltbundesamt (ed.) *Energiespar-Contracting als Beitrag zu Klimaschutz und Kostensenkung. Ratgeber für Energiespar-Contracting in öffentlichen Liegenschaften* (Berlin: Umweltbundesamt, 2000), 25–26.

47 By the mid-1990s, however, Berlin's growing public debt – itself, in part, a legacy of political division – was stifling state intervention, including the measures to reconfigure energy provision and use in the city around demand management principles. Besides a sharp drop in public funding for energy efficiency schemes, the privatization of the city's power utility Bewag in 1997 and gas utility Gasag in 1998 reduced significantly the city government's influence over these two key players.[67] Berlin lost its pioneering role in sustainable urban energy and climate policy, which – in the absence of the necessary financial and corporate support – became increasingly reliant on non-binding voluntary agreements with the local energy utilities.[68] For instance, in 2008 Vattenfall, the new owner of Bewag, entered into a climate protection agreement with Berlin as part of the city's Climate Alliance, committing to reduce CO_2 emissions by 50 percent against 1990 levels. The city government's traditional reliance on its local power and gas utilities to deliver urban energy policy was seriously undermined when it lost ownership and control of them in the 1990s. With the long-standing compact between local utility and city regulator disturbed, Berlin has struggled to find an effective form of urban energy governance.

48 Help may be coming from an unexpected source, however. Public dissatisfaction with the privatisation of the city's utilities and the slow-down of its sustainable energy policies has inspired the recent emergence of civil society groups challenging the status quo. The Berlin Energy Roundtable (Berliner Energietisch), a network of around 50 activist groups, is pressing the city to re-municipalise the urban electricity grid and gas network, whilst the energy cooperative Citizen Energy Berlin (BürgerEnergie Berlin) aspires to take over the running of the power grid itself. Both organisations advocate a paradigm shift from fossil fuels to renewables and greater participation of energy consumers in decision making.[69] It is not a return to the status quo ante of municipally owned, but largely self-dependent, utilities that they are advocating, but a new genre of municipal utility that is environmentally sustainable, socially responsible and democratically accountable. Energy justice has become central to this agenda, with affordability issues, socio-spatial disparities and the unequal costs of energy transitions emerging as prominent themes.

Although the two organisations failed in their immediate aim of using a referendum to force the city government to re-municipalize the power grid in 2013, they have succeeded in persuading the city government to re-engage with a pro-active energy policy. The Berlin authorities have recently set up an alternative, city-owned energy utility – Berliner Stadtwerke – with a political remit to minimise energy use and CO_2 emissions via more renewable sources. Although the urban and energy contexts today are very different from the days of division, it is no exaggeration to claim that the social movements campaigning for an alternative energy policy are standing on the shoulders of past activists in the city and that the body politic is, under this pressure, rediscovering its environmentalist ambitions of the immediate reunification era. This marks an apt moment to draw attention to the combination of continuity and change that has always characterised the energy infrastructural legacy of Berlin's history, and to take instruction from the ways in which the old and the new get layered in place- and time-specific configurations. 49

67 Jochen Monstadt, "Urban Governance and the Transition of Energy Systems: Institutional Change and Shifting Energy and Climate Policies in Berlin", *International Journal of Urban and Regional Research*, vol. 31.2, 2007, 330.
68 Jochen Monstadt, *Die Modernisierung der Stromversorgung*, 321 and 477–478 (cf. note 66).

69 On the following, Sören Becker *et al.*, "Reconfiguring Energy Provision in Berlin: Commoning between Compromise and Contestation", *in* Mary Dellenbaugh, Markus Kip, Majken Bieniok, Agnes Katharina Müller, and Martin Schwegmann (eds.) *Urban Commons: Moving beyond State and Market* (Basel: Birkhäuser, 2015), 196-213; Thomas Blanchet, "Struggle over Energy Transition in Berlin: How Do Grassroots Initiatives Affect Local Energy Policy-Making?", *Energy Policy,* vol. 78, 2015, 248–249; Sören Becker *et al.*, "Between Coproduction and Commons: Understanding Initiatives to Reclaim Urban Energy Provision in Berlin and Hamburg", *Urban Research and Practice,* vol. 10.1, 2017, 67–68.

50 What are the lessons that can be drawn from these legacies of the technologies, policies and practices surrounding urban energy provision, demand management and flexibility over a period of 100 years? Bringing a socio-spatial historical perspective to bear has, we argue, timely relevance for social science research on energy flexibility, and more generally for urban energy transitions scholarship. It places the 'presentist' take on flexibility debates of today in a broader temporal context that discloses many parallels and precursors to contemporary challenges and responses. This encourages us to use evidence from the past to scrutinise the assumptions and expectations that underpin present-day understandings of energy flexibility. It sensitises us, further, to the historical legacies that linger in the physical constitution of urban energy systems, the infrastructural logics and planning rationalities underpinning them and the issues of contestation they have unleashed over time.

51 Analyses of what is logistically and politically feasible in Berlin today must be situated, therefore, within its complex tapestry of socio-technically contingent enactments of 'energy urbanism'. Being shaped so powerfully by spatial and temporal contexts, energy flexibility options for Berlin – as for any other city – are likely to be quite distinct from responses to similar issues elsewhere. The detailed analysis of real-life trajectories of energy flexibility over a long time period – especially in a city with such a turbulent history as Berlin – challenges overly simplistic narratives of energy history oriented around the path dependence of large technical systems or moments of system transition. The messy, non-linear and politically mobile nature of energy flexibility in Berlin across the past century points to the importance of appreciating the specificities of socio-material configurations in particular spatial-temporal contexts, both at definitive moments of rupture and in terms of legacies that are imbricated over time. Sensitivity to the provenance of current challenges also enhances understanding of the framing of future action. The energy flexibility issues faced by Berlin today are direct legacies of past energy policies, structures, practices and perceptions, and cannot be addressed effectively without consideration of them, as we have shown through a wide range of examples. The Berlin case makes apparent how infrastructural legacies have long shaped the evolution of energy flexibility in ways that manifest peculiarly at the urban scale, with its spatial concentration and density of energy demand and energy infrastructures.

CONCLUSION

This long-term analysis of flexibility in Berlin's electricity and gas systems over a historically volatile period has generated a deeper understanding of what energy flexibility in cities can comprise, how it reflects the multiple socio-material geographies of urban energy and how it gets embroiled in and co-constitutes political visions and conflicts over energy. In this conclusion, we revisit the three research questions posed in the introduction and distil their relevance for social and historical research on energy flexibility. 52

In response to the first question – about the kinds of energy flexibility challenges experienced by Berlin over the past century – it is clear that these reach far beyond the common problems of satisficing fluctuating demand at different times of the day or year. Berlin certainly did have to deal with issues of peak and off-peak loads to its power and gas systems, but these were frequently exacerbated by societal trends or disruptive interventions. Flexibility responses were particularly needed: when the local economy could not sustain demand, as during the hyper-inflation and Depression; when the systems of energy provision were disrupted or threatened, as during the war and political division of the city; and when demand for energy exceeded supply capacity, as in East Berlin under the state planning regime. These challenges were never, the narrative reveals, purely technical or economic in character, but invariably embroiled in socio-political constructs of the time. 53

How Berlin's urban and infrastructure managers responded to these challenges was the second guiding question. The empirical analysis revealed 54 four overlapping strategies pursued in different ways and in varying intensity across the 100 years of study. Maximising energy reserves and storage was one response that morphed across multiple political regimes, being used to enable a high degree of self-generation of electricity and town gas in Weimar Berlin and to strengthen system resilience in an insular West Berlin. This rich experience of self-provision revealed how difficult it is to address fluctuations in demand and supply within the confines of a single (half-) city. Full municipal control over energy production came at a price, in the form of high capacity levels and expensive back-up systems.

55 Experimenting with alternative energy sources was a second strategy. Developed during the 1920s, this approach experienced its apogee during the Nazi era when commandeered into a national campaign of energy autarky, subsequently falling into disrepute because of this political association. It re-emerged, though, in the form of fuel substitution – from coal to oil and gas – in West Berlin in the 1970s. Today, technologies deriving biogas from sewage or waste in the city are being heralded as innovations, although they are unwitting successors to ones originally introduced nearly a century ago. This highlights not only non-linearity in energy infrastructure trajectories, but also collective amnesia when dealing with uncomfortable pasts.

56 Managing the demand side of the equation was a third strategy, proving remarkably successful from the 1920s onwards in helping to reduce peak loads and address problems of over-capacity. The Berlin case illustrates how deeply political demand management can be, with examples ranging from enrolment in the national recovery effort of the Nazi regime and showcasing capitalist consumerism in West Berlin to following state planning targets in East Berlin. By contrast, efforts to limit (rather than redirect) demand often proved ineffectual and were used as a means of last resort, when coal resources or generating capacities were severely limited. Energy-saving campaigns – whether under the Nazi regime, Allied military occupation or state socialism – were widely ignored or circumvented. This experience has had the long-term impact of discouraging energy planners from considering energy saving as a component of any energy efficiency drive. Today's energy users are proving demanding in novel ways. Many are no longer content to follow the script as a passive consumer, but are campaigning for alternative modes of urban energy provision that are more environmentally sustainable and democratically accountable.

The fourth flexibility response, accessing external energy sources, was a reflection of the limits to local self-sufficiency in electricity and gas provision. The aspiration of urban energy autarky, invigorated by the creation of the unitary city in 1920 and revitalised by West Berlin's insularity following political division in 1948-49, was hugely significant in terms of local control over energy provision. Yet it was ultimately limited by the extent to which the city could generate its own power and gas with predominant fossil-fuel sources. The (re-)connection of Berlin to national and international electricity and gas networks after 1990 has, effectively, externalised the challenges of energy flexibility to the wider grids. It has, at the same time, reduced the potential of the city government to shape energy policy. This potential, the Berlin experience tells us, was never a direct function of municipal ownership, but always one of political will. 57

How, then, can the Berlin experience enrich broader scholarship on energy flexibility? This was the third guiding question to this paper. The case of Berlin may be unusual – even extreme – but it reveals in stark relief the embroilment of politics, materiality and geography in adapting energy systems to fluctuating demand and supply. It has shown, first and foremost, that managing energy demand to suit energy infrastructures is not a recent phenomenon. Urban energy managers have engaged with consumers in a variety of ways and for a wide range of political, economic and symbolic purposes at different times. Energy use has for many years been steered to meet infrastructure capacity, but various attempts to limit energy use in a crisis have largely failed. The legacy of this 58 experience, it is argued, has a significant bearing on current attempts to reconfigure patterns of energy use through interventions such as the roll-out of digital technology to monitor real-time energy use.

59 Using a variety of flexibility technologies to address shifts in demand and supply is also not new, as the Berlin example testifies. They have been enrolled to raise capacity, provide reserves, store energy in various forms and substitute fuels at times of shortage. Social studies of energy would do well to heed the histories of such flexibility technologies. These histories can be insightful about not only the socio-technical configurations of urban energy, but also the legacy of these technologies for a city's energy systems today. Urban studies, in particular, can seek inspiration from the layered complexities of 'energy urbanism' that the Berlin case brings forth as drivers that shape energy flexibility. A sensitivity towards past attempts to flexibilise urban energy systems can help understand how their legacies – whether political or physical – can frame contemporary policy responses to flexibility challenges just as they can constrain or enable options for new energy infrastructures such as smart meters.

Finally, the Berlin case traces a trajectory of 60
popular resistance to the predominant flexibility response of 'build and supply'. This, too, has been shown to have strong roots, going back to the 1970s. Calls for urban energy provision to be responsive to users and the environment, rather than to fluctuating demand curves alone, have a long pedigree in Berlin. It is worth exploring how this concern for energy justice with respect to flexibility challenges emerged over time in other cities. This knowledge can provide valuable insight about how ethical arguments have been, and can be, mobilised to develop and sustain a discourse around energy values. These values, the Berlin case warns, are never benign, but always expressive of a political vocation. History, we have argued, can contribute to contemporary debates on energy transitions by correcting presumptions, revealing legacies and providing inspiration. At the same time, we have demonstrated how issues of current concern can generate new topics for historical research, complementing or challenging established narratives.

Bibliography

Aengeneyndt J. D.
"Das Erdgas-Versorgungssystem für Berlin", *Gesundheitsingenieur*, vol. 108, 1987, 181-184.

Bahde Curt, Bohge Manfred, Bürgel Klaus, Schlede Joachim
"Das Stromversorgungssystem der Bewag", *Elektrizitätswirtschaft*, vol. 76.6, 1977, 129-141.

Bärthel Hilmar
"Anlagen und Bauten der Elektrizitätserzeugung", in Architekten- und Ingenieur-Verein zu Berlin (ed.), *Berlin und seine Bauten. Teil X, Band A (2) Stadttechnik* (Petersberg: Michael Imhof Verlag, 2006).

Die Geschichte der Gasversorgung in Berlin. Eine Chronik (GASAG Berliner Gaswerke Aktiengesellschaft, Berlin: Nicolaische Verlagsbuchhandlung, 1997).

Becker Sören, Naumann Matthias, Moss Timothy
"Between Coproduction and Commons: Understanding Initiatives to Reclaim Urban Energy Provision in Berlin and Hamburg", *Urban Research and Practice,* vol. 10.1, 2017, 63–85.

Becker Sören, Beveridge Ross, Naumann Matthias
"Reconfiguring Energy Provision in Berlin: Commoning between Compromise and Contestation", *in* Mary Dellenbaugh, Markus Kip, Majken Bieniok, Agnes Katharina Müller, and Martin Schwegmann (eds.), *Urban Commons: Moving beyond State and Market* (Basel: Birkhäuser, 2015), 196-213.

Berliner Kraft- und Licht (Bewag) - Aktiengesellschaft (ed.)
100 Jahre Strom für Berlin. Ein Streifzug durch unsere Geschichte in Wort und Bild 1884-1984 (Berlin: Bewag, 1984).

Berliner Städtische Elektrizitätswerke Akt.-Ges.
Zur Zukunft der Berliner Elektrizitäts- Versorgung (Berlin: Bewag, 1928).

Betriebsrat der Berliner Kraft- und Licht(Bewag)-Aktiengesellschaft (ed.)
Im Licht der Zeit. 90 Jahre Betriebsvertretung bei der Bewag (Berlin: Betriebsrat der Berliner Kraft- und Licht(Bewag)-Aktiengesellschaft, 1998).

Binder Beate
Elektrifizierung als Vision. Zur Symbolgeschichte einer Technik im Alltag (Tübingen: Tübinger Vereinigung für Volkskunde e.V., 1999).

Blanchet Thomas
"Struggle over Energy Transition in Berlin: How Do Grassroots Initiatives Affect Local Energy Policy-Making?", *Energy Policy,* vol. 78, 2015, 246–254.

Bouzarovski Stefan, Simcock Neil
"Spatializing Energy Justice", *Energy Policy*, vol. 107, 2017, 640-648.

Bridge, Gavin *et al.*
Energy and Society: A critical perspective (Abingdon: Routledge, 2018).

Bulkeley Harriet, McGuirk Pauline, Dowling Robyn
"Making a Smart City for the Smart Grid? The Urban Material Politics of Actualising Smart Electricity Networks", *Environment and Planning A: Economy and Space*, vol. 48.9, 2016, 1709-1726.

Büsch Otto
Geschichte der Berliner Kommunalwirtschaft in der Weimarer Epoche (Berlin: Walter de Gruyter, 1960).

Castan Broto Vanesa, Bulkeley Harriet
"A Survey of Urban Climate Change Experiments in 100 Cities", *Global Environmental Change*, vol. 23.1, 2013, 92-102.

Fischer Clemens
"BEWAG—vom Inselversorger zum Verbundpartner", Special edition, *Energiewirtschaftliche Tagesfragen,* vol. 12, 1992.

Fleischer W.
"Lastverteilung bei der Berliner Städtische Elektrizitätswerke Akt.-Ges.", *Elektrizitätswirtschaft*, vol. 28.493, 1929, 502-507.

Fouquet Roger
"Historical Energy Transitions: Speed, Prices and System Transformation", *Energy Research & Social Science*, vol. 22, 2016, 7-12.

Haarstad Håvard
"Where are Urban Energy Transitions Governed? Conceptualizing the Complex Governance Arrangements for Low-Carbon Mobility in Europe", *Cities*, vol. 54, 2016, 4-10.

Haase, Martin
"Kraftwerks- und Stadtheizungsbetrieb", *Elektrizitätswirtschaft*, vol. 83.9/10, 1984, 426-441.

Kauffmann R.
"Das Abzahlungsmodell des Bewag", *Elektrizitätswirtschaft*, vol. 26.427, 1927, 81-83.

Kist Klaus, Lang Willibald
"Energiesparpartnerschaften Berlin—ein Modellprojekt geht in Serie", *in* Umweltbundesamt (ed.), *Energiespar-Contracting als Beitrag zu Klimaschutz und Kostensenkung. Ratgeber für Energiespar-Contracting in öffentlichen Liegenschaften* (Berlin: Umweltbundesamt, 2000), 25-31.

Lehmann H.
"Fernheizung der Wohnstadt Berlin-Friedrichshain und der Stalinallee", *Energietechnik*, vol. 4.5, 1954, 194-202.

Lorkowski Nina
"Managing Energy Consumption: The Rental Business for Storage Water Heaters of Berlin's Electricity Company from the Late 1920s to the Early 1960s", *in* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies* (Bielefeld: Transcript, 2014), 137-162.

Malm Andreas
"Long Waves of Fossil Development: Periodizing Energy and Capital", *Mediations*, vol. 32.1, 2018, 17-40.

Matschoß Conrad *et al.*
50 Jahre Berliner Elektrizitätswerke 1884-1934 (Berlin: VDI-Verlag, 1934).

Meyer Aubrey
Contraction & Convergence: The Global Solution to Climate Change (Green Books, 2000).

Mielke H.-J., Weiß Heinrich
"Kraftwerksbau im Landschaftsschutzgebiet Spandauer Forst," *Berliner Naturschutzblätter*, vol. 20.59, 1976, 219-224.

Monstadt Jochen
"Urban Governance and the Transition of Energy Systems: Institutional Change and Shifting Energy and Climate Policies in Berlin", *International Journal of Urban and Regional Research*, vol. 31.2, 2007, 326-343.

Die Modernisierung der Stromversorgung. Regionale Energie- und Klimapolitik im Liberalisierungs- und Privatisierungsprozess (Wiesbaden, VS Verlag für Sozialwissenschaften, 2004).

Moss Timothy
Remaking Berlin. A History of the City through Infrastructure, 1920-2020 (Cambridge, MA: The MIT Press, 2020).

"Discarded Surrogates, Modified Traditions, Welcome Complements: The Chequered Careers of Alternative Technologies in Berlin's Infrastructure Systems", *Social Studies of Science*, vol. 46.4, 2016, 559–582.

"Socio-Technical Change and the Politics of Urban Infrastructure: Managing Energy in Berlin between Dictatorship and Democracy", *Urban Studies*, vol. 51.7, 2014, 1432-1448.

"Divided City, Divided Infrastructures: Securing Energy and Water Services in Postwar Berlin", *Journal of Urban History*, vol. 35.7, 2009, 923-942.

New Daggett Cara
The Birth of Energy: Fossil Fuels, Thermodynamics, and the Politics of Work (Durham: Duke University Press, 2019).

Nicholls Larissa, Strengers Yolande
"Peak Demand and the 'Family Peak' Period in Australia: Understanding Practice (in)Flexibility in Households with Children", *Energy Research & Social Science*, vol. 9, 2015, 116-124.

ÖTV Berlin
Erd-GASAG – vom Energieversorgungs- zum Energiedienstleistungsunterneh men (Berlin: Gasag, 1984).

Papaefthymiou Georgios, Dragoon Ken
"Towards 100% Renewable Energy Systems: Uncapping Power System Flexibility", *Energy Policy*, vol. 92, 2016, 69-82.

Powells Gareth, Fell Michael
"Flexibility Capital and Flexibility Justice in Smart Energy Systems", *Energy Research & Social Science*, vol. 54, 2019, 56-59.

Powells Gareth, Bulkeley Harriet, McLean Anthony
"Geographies of Smart Urban Power", *in* Simon Marvin, Andrés Luque-Ayala, Colin McFarlane (eds.), *Smart Urbanism* (Abingdon: Routledge, 2015), 141-160.

Presse- und Informationsamt des Landes Berlin (ed.): *Perspektiven der Stadtentwicklung* (Berlin: Haupt & Kosta, 1974).

Rehmer Martin
"Der Ausbau und die Betriebsführung der Bewag seit dem Jahre 1924", Sonderabdruck aus der *Zeitschrift des Vereins deutscher Ingenieure*, vol. 78.18, 1934, 539-545.

Rinkinen Jenny, Shove Elizabeth, Torriti Jacopo (eds.)
Energy Fables. Challenging Ideas in the Energy Sector (Abingdon: Earthscan, 2019).

Rinkinen Jenny, Shove Elizabeth
"Energy Demand" *in* Jenny Rinkinen, Elizabeth Shove and Jacopo Torriti (eds.), *Energy Fables. Challenging Ideas in the Energy Sector* (Abingdon: Earthscan, 2019), 7-14.

Sareen Siddharth, Rommetveit Kjetil
"Smart Gridlock? Challenging Hegemonic Framings of Mitigation Solutions and Scalability", *Environmental Research Letters*, vol. 14, 2019.

Sareen Siddharth, Haarstad Håvard
"Bridging Socio-Technical and Justice Aspects of Sustainable Energy Transitions", *Applied Energy*, vol. 228, 2018, 624-632.

Schick Lea, Gad Christopher
"Flexible and Inflexible Energy Engagements: A Study of the Danish Smart Grid Strategy", *Energy Research & Social Science*, vol. 9, 2015, 51-59.

Schivelbusch Wolfgang
Disenchanted Night: The Industrialization of Light in the Nineteenth Century (Berkeley: University of California Press, 1995).

Senat von Berlin (ed.)
Berlin. Chronik der Jahre 1959-1960 (Berlin: Heinz Spitzing Verlag, 1978).

Senat von Berlin
Berlin 1953. Jahresbericht des Senats (Berlin: Kulturbuch-Verlag, 1954).

Senatsverwaltung für Stadtentwicklung und Umweltschutz
Energieagentur Berlin. Konzeptstudie. Neue Energiepolitik für Berlin, Heft 2 (Berlin: Senatsverwaltung für Stadtentwicklung und Umweltschutz, 1990).

Sommer E. M. K.
"Die Öffentliche Stromversorgung in der DDR seit 1945 und Tendenzen ihrer weiteren Entwicklung", *Energietechnik*, vol. 11.3, 1961, 99-103.

Sovacool Benjamin, Dworkin Michael
Global Energy Justice (Cambridge: Cambridge University Press, 2014).

Tepasse Heinrich
Stadttechnik im Städtebau Berlins. 20. Jahrhundert (Berlin: Gebr. Mann Verlag, 2006).

Torriti Jacopo
"Flexibility" *in* Jenny Rinkinen, Elizabeth Shove and Jacopo Torriti (eds.), *Energy Fables. Challenging Ideas in the Energy Sector* (Abingdon: Earthscan, 2019), 103-111.

Vad Mathiesen Brian *et al.*
"Smart Energy Systems for Coherent 100% Renewable Energy and Transport Solutions", *Applied Energy*, vol. 145, 2015, 139-154.

VEB Energiekombinat Berlin (ed.)
40 Jahre Deutsche Demokratische Republik. 40 Jahre Sozialistische Energiewirtschaft in Berlin – Hauptstadt der DDR (Berlin, VEB, 1989).

Winje Dietmar
"Integration des West-Berliner Netzes in den deutschen Verbund", *Elektrizitätswirtschaft,* vol. 93.13, 1994, 726–732.

Wood Nathan, Roelich Katy
"Substantiating Energy Justice: Creating a Space to Understand Energy Dilemmas", *Sustainability*, vol. 12.5, 2020, 1917.

York Richard, Bell Shannon Elizabeth
"Energy Transitions or Additions? Why a Transition from Fossil Fuels Requires more than the Growth of Renewable Energy", *Energy Research & Social Science*, vol. 51, 2019, 40-43.

Zeiler Wim *et al.*
"Flexergy: An Ontology to Couple Decentralised Sustainable Comfort Systems with Centralized Energy Infrastructure", in *Proceedings of 3rd International Conference on Smart and Sustainable Built Environments*, 2009.

Ziesing H.-J.
"Strukturelle und Sektorale Entwicklung des Energieverbrauchs in Berlin (West)" *in* Deutsches Institut für Wirtschaftsforschung (ed.) *Wochenbericht,* vol. 52, 1985, 227-238.

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR
Michael J. Fell
UCL Energy Institute,
michael.fell@ucl.ac.uk
Twitter: @mikefsway

POST DATE
01/02/2021
ISSUE NUMBER
JEHRHE #5
SECTION
Special issue
THEME OF THE SPECIAL ISSUE
Historicising Flexibility
KEYWORDS
Heat, Enterprise, Carbon, Precarity
DOI
in progress

TO CITE THIS ARTICLE
Michael J. Fell, "The History of Heat-as-a-Service for Promoting Domestic Demand-Side Flexibility: Lessons from the case of Budget Warmth", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 01 fevrier 2021, URL: energyhistory.eu/en/node/239.

The History of Heat-as-a-Service for Promoting Domestic Demand-Side Flexibility: Lessons from the case of Budget Warmth

Abstract
Heat-as-a-Service (HaaS) involves the provision of agreed room temperatures at certain times for a fixed fee, instead of charging for energy use on a per-unit basis. This arrangement enables the operator to remotely manage the heating system to use electricity when it is cheaper, thereby maximising profits, and exploiting opportunities for 'flexibility' in response to information about the state of the wider power system. In this article I present the case of Budget Warmth, a HaaS tariff offered commercially in Great Britain in the 1980s. I suggest reasons for its failure (despite early enthusiasm), including tensions between occupant expectations and operators' commercial interests, and lack of incentives to provide flexibility within the system as whole. I then consider the extent to which these challenges exist for HaaS offerings today.

Acknowledgements
I gratefully acknowledge funding for workshop attendance from the UKRI Centre for Research into Energy Demand Solutions (grant number EP/R035288/1). I would like to thank the special issue editors and anonymous reviewers for their helpful direction, Irene Pallua for very useful feedback on a draft, Phil Russell for early background discussion, and participants at the above workshop for their constructive input. Any errors are mine alone.

Plan of the article

ISSN 2649-3055

INTRODUCTION

1 The United Kingdom (UK), in line with many other industrialised countries, is exploring ways to rapidly decarbonise its energy system. In the domestic sector, the largest source of energy demand and carbon emissions is heating[1], which is therefore a key target for decarbonization efforts. Multiple challenges exist in decarbonising heat, including reducing heating demand, increasing the adoption of low-carbon heating systems and, when they are powered by electricity, the management of large and potentially peaky loads which can cause network management problems.

2 One response to these challenges that is increasingly the focus of research is the provision of heat-as-a-service (HaaS). In essence, this involves a shift from selling units of energy to customers to selling a package which assures a certain level of heating for a fixed price, independent (as far as the customer is concerned) from energy use. Operators then endeavour to reduce the energy input required to provide the agreed level of warmth, and manage overall energy usage patterns in as cost-effective a way as possible. This approach makes it easier to spread the costs of expensive low-carbon heating systems over time, also giving customers and suppliers with the reassurance of a regular, and reliable fee.

3 HaaS has the potential to support decarbonisation in three key ways. First, it incentivises suppliers to minimise required heating energy input overall (and therefore carbon emissions associated with this energy). Second, it can support uptake of heating systems powered by lower-carbon energy sources (e.g. electricity rather than natural gas, in many countries). And third, it incentivises suppliers to use energy at times when it is cheapest – and for electricity, this often coincides with times of high (low marginal cost) renewable generation[2].

Because of the potential of this approach to contribute to decarbonisation, it is important not only to research new HaaS offerings, but also to consider those that have already been tried out to see if there are any lessons to be learned. To that end, in this paper I examine the case of a HaaS tariff called “Budget Warmth” which was first made available in Great Britain (GB, or the UK excluding Northern Ireland) in the 1980s. I describe how and why that tariff came about, how it worked, and consider why it did not lead to further widespread development and adoption of HaaS offerings. This work is based on archive material (including industry journals, reports, and newsletters, as well as government records) plus an oral history interview with a former economist at the Electricity Council. (For more details on the process for identifying these materials, please see Appendix A.) 4

In the last part of the paper, I compare the situation that pertained in the 1980s with the present, in order to identify points of continuity and difference. While there have been significant steps forward in areas such as data collection, control capabilities, and user-centred design, challenges still remain. These include limited market incentives for suppliers to stimulate demand-side flexibility, the requirement for (potentially long) contracts to cover the cost of installed technology, and issues around fairness. First, however, I provide some further background on the concept of HaaS and its connection to the concept of flexibility. 5

HEAT-AS-A-SERVICE: WHAT AND WHY?

Today, people in cool and temperate climates heat the spaces they live in for a variety of reasons, including creating a healthy and comfortable environment for themselves and others, to 6

1 *Digest of United Kingdom Energy Statistics 2019* (London: National Statistics, Department of Business, Energy and Industrial Strategy, 2019), **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/840015/DUKES_2019_MASTER_COPY.pdf.**

2 Iain Staffell, “Measuring the Progress and Impacts of Decarbonising British Electricity”, *Energy Policy*, 102, 2017, 463-475. DOI:10.1016/j.enpol.2016.12.037.

maintain the fabric of buildings, to dry clothes, and so on. The basic elements of space heating are:

- a space to heat (which may be better or worse at keeping the heat in)
- a heat source such as a boiler
- possibly a storage option like a hot water tank and/or distribution system such as a network of radiators
- possibly an additional control system such as a thermostat
- and an input of fuel such as gas.

7 According to a definition I have previously set out, the energy service 'space heating' is used to provide the 'end service' of a warm environment[3].

8 How is this warm environment usually paid for by users? Generally, the infrastructure – the space to be heated, the heat source and distribution system – is owned outright or rented by the occupants from a landlord. The fuel or vector, such as electricity or gas, is bought from an energy supplier through a combination of a standing charge to cover fixed costs (such as network charges) and a price per unit used (kilowatt hour). In this case, occupants do not pay for a 'warm environment' – rather they pay for the combination of infrastructure and energy input to provide the energy service of space heating, which creates the warm environment.

9 Heat-as-a-service models charge for warm environments more directly. For example, occupants might pay to have a certain number of hours at a certain temperature, independent of the amount of energy input (as was the case in recent trials by the Energy Systems Catapult in the UK[4]; for more detail see below, this section). Occupants no longer pay for heating as such; they pay for a warm environment. Indeed warmth-as-a-service – which conveys the meaning of heat as an outcome rather than a process or output – could be an alternative description (see also[5]). A HaaS provider may own, operate or influence any part – or all – of the infrastructure. For example, such an organisation could replace and maintain the heating system, or improve insulation in a home. The service provider then buys in sufficient energy input to meet their commitment to delivering a certain level of warmth.

10 Such models have several interesting implications. If providers are tasked with creating a warm environment for a fixed fee, part of their profit opportunity comes from minimising their own costs. They can do this in two main ways – by bearing down on the lifetime costs (i.e. installation and maintenance) of infrastructure, and by minimising the cost of the energy input. The latter can be achieved in two ways – one, by reducing the total amount of energy input required (such as by insulating a home to reduce heat loss or using a more efficient heating system), and two, by delivering any remaining energy input in the lowest cost way possible. This is where the ability of HaaS models to support flexibility comes to the fore.

11 In the UK and many other countries, electricity can be sold and bought on wholesale markets by suppliers. It is traded in 30 minutes slots. As in any market the price is determined by a wide array of factors, but prominent among these are the expected level of final demand, and the cost associated with generating the electricity. Because demand for electricity in the UK is usually high during the evening peak (~4-8pm weekdays), wholesale prices are also high at this time[6]. Low wholesale prices are also associated with higher proportions of renewable generation, since the marginal costs of operating

3 Michael James Fell, "Energy Services: A Conceptual Review", *Energy Research & Social Science*, 27, 2017,129-140. DOI:10.1016/j.erss.2017.02.010.

4 Judy Osborn, Tom Furlong, and Amal Anaam, "Using the Living Lab to Sell Consumer Centric Heat Services That Encourage Adoption of Low Carbon Heating: Winter Trial 2018/19", *Energy Systems Catapult*, December 2019, **https://es.catapult.org.uk/reports/living-lab-trials-to-sell-low-carbon-heat-services/**

5 Delta-EE, "Defining Heat as a Service", October 2019, https://www.delta-ee.com/delta-ee-blog/defining-heat-as-a-service.html.

6 Nord Pool day-ahead auction prices for the UK can be seen at **https://www.nordpoolgroup.com/Market-data1/GB/Auction-prices/UK/Hourly/?view=chart**.

Time of use tariff with smart controls	Heat-as-a-service
Standard TOU tariff users may not have, or be able to afford, electric heating system with smart controls.	HaaS providers can actively install electric heating systems with smart controls in affordable way as the cost for user is spread over time.
Response to TOU tariffs relies on householders either actively choosing to change electricity usage patterns in response to pricing, or automating such changes.	HaaS providers can promote such responses directly and remotely, with no need to rely on active involvement from householders.
Shifting demand has only small cost saving potential for individual TOU users depending on tariff, likely to be of limited motivational value for many.	HaaS providers have a stronger motivation as they benefit from the aggregation of all the small shifts they are able to effect, which can make a substantial impact on profitability.
TOU has an implicit 'compromise' framing, suggesting a trade-off for householders between price and what their preference would otherwise be for use of heating (or doing other electricity-using activities).	The central HaaS offering is a non-comprised service regardless of what flexibility-related actions may be taken behind the scenes by the provider, potentially increasing its attractiveness to users.

Table 1: Reasons for superiority (in principle) of HaaS in comparison to TOU tariffs when it comes to unlocking flexibility.

renewable plant is lower[7]. As suggested above, HaaS providers profit by minimising the wholesale cost of electricity they buy. It is therefore in their interest to ensure that, as far as possible, they operate their customers' heating systems such that heating coincides with cheaper periods (i.e. outside the evening peak, or when renewable generation in plentiful). The potential to operate the final demand technology (the heating system) in response to the state of the wider electricity system (as expressed through wholesale electricity price) is what constitutes flexibility in the context of HaaS.

12 It is worth briefly rehearsing the ways in which HaaS arrangements might in principle be viewed as superior to a more standard units-based offering from a system operator perspective when it comes to unlocking flexibility of this kind. After all, wholesale price signals can be passed on to users by other means, such as time of use (TOU) tariffs, which have been shown to prompt changes in electricity usage patterns[8].

13 The ideal net results of HaaS arrangements are less wasted energy (as determined by a level of warm environment per unit of energy input), and more flexible and responsive patterns of interaction with energy networks – both of which are widely seen as necessary for supporting transition to a low-carbon energy system[9]. As well as these potential societal benefits, HaaS also offers features which may be attractive to customers, such as providing the assurance of comfort for a fixed monthly charge.

14 Because of these benefits, there is interest amongst policymakers in the potential for HaaS. The UK Government has been supporting investigation of new heating-related business models, including HaaS, through the Energy System Catapult's "Smart Systems and Heat" programme. This resulted in the most prominent UK trial to date, which took place between 2017 and 2019 in a "Living Lab" of 100 households in four English locations. Participants were offered various heat plans, which included paying for a

7 Guy Lipman, "Power Price vs Carbon Intensity", *Medium*, April 2019, **https://medium.com/@guylipman/power-price-vs-carbon-intensity-d97ee6a70aaa**; Staffell, "Measuring the Progress and Impacts of Decarbonising British Electricity", (cf. note 3).

8 Frontier Economics and Sustainability First. *Demand Side Response in the Domestic Sector - a Literature Review of Major Trials* (London, UK: Department of Energy and Climate Change, Report to DECC, 2012).

9 HM Government, 'Upgrading Our Eergy System: Smart Systems and Flexibility Plan' (London, UK, July 2017), **https://www.ofgem.gov.uk/system/files/docs/2017/07/upgrading_our_energy_system_-_smart_systems_and_flexibility_plan.pdf.**

number of "warm hours" each week on a weekly or pay-as-you-go basis, sometimes including installation of a new heating system. Between 20 and 25 of the households opted to sign up to a heat plan each year, with key motivating factors being certainty over cost and comfort (the key reason which put people of from participating was perceived high cost). While the plans on offer did not include installation of a low-carbon electricity-powered heating system, substantially more participants in this small sample indicated they would be happy to install such a system in combination with a heat plan than without. For more details on the findings of the trial, see[10]. Because examples of recent research of this kind are still somewhat limited, there is potential utility in looking to previous experience of HaaS and HaaS-like offerings. The next section summarises this experience very briefly as a way of sketching the lineage of the Budget Warmth tariff that is the main focus of the paper.

HAAS: EXPERIENCES FROM THE PAST

15 HaaS-like models have been available for a long time. If the central element of HaaS is payment for a warm space rather than energy input, then its most longstanding use is probably in multi-occupancy dwellings with lodging arrangements. Any tenancy agreement which includes the provision of either fuel or heat directly as which does not charge by unit of use could be considered to be a form of HaaS, although they are not often described as such. For example, *The New York Supplement* of 1889 lists details of a case brought:

> "…for the breach of an oral contract to provide a family of five persons with board, and with three specified rooms as lodgings in a boarding-house, and to light and heat such rooms for a specified period, at the weekly rate of $75."[11]

(For further examples[12] and[13].) The same sort of incentives applies in this example, as they do today: thus the landlord might try to use as little fuel (e.g. wood or coal) as possible, while the tenant benefits from even and predictable bills. Then as now, landlords may be tempted to save costs by under-supplying heat. 16

District heating systems spread this model beyond the heating of a single dwelling. Often block or district heating systems work on a service arrangement for the infrastructure – that is, occupants pay a regular fee through rent or a service charge for access to the heat source, network, and space (i.e. their dwelling) – but still have a per unit charge for heat usage determined by a heat meter. This could be thought of as warm-space-infrastructure-as-a-service, with the actual heat added as a top-up. In such cases, the operator has little direct incentive to seek energy cost reductions through efficiency or flexibility. Alternatively, some district heating schemes operate on an unmetered basis, where all infrastructure and heat input is paid for through rent or a service charge independent of the amount of energy input to a particular dwelling[14]. This is effectively a HaaS arrangement, and 17

10 Osborn, Furlong, and Anaam, "Using the Living Lab to Sell Consumer Centric Heat Services That Encourage Adoption of Low Carbon Heating: Winter Trial 2018/19", (cf. note 4).

11 "Oliver v. Moore", *The New York Supplement,* vol. 6 (Eagan, Minnesota, USA: West Publishing Company, 1889), 415. **https://books.google.co.uk/books?id=HeU7AAAAIAAJ&q=lodging++board+heat+rent&dq=lodging++board+heat+rent&hl=en&sa=X&ved=2ahUKEwjNiM67kY7qAhVNQUEAHfwUDVUQ6AEwAXoECAIQAg.**

12 "A Sketch of the Life of James A. Garfield", in *History of Trumbull and Mahoning Counties*, vol. 1 (Cleveland, Ohio, US: HZ Williams and Bro., 1882), 488. **https://books.google.co.uk/books?id=MU0RAwAAQBAJ&pg=PA488&lpg=PA488&dq=lodging+arrangements+fuel+and+board+history&source=bl&ots=0_6TaDLOrz&sig=ACfU3U0ACP8Zi1infTHY1Iu4Ql_rAldSOg&hl=en&sa=X&ved=2ahUKEwi4qbq4j47qAhVtSxUIHSxdCYMQ6AEwCnoECA0QAQ#v=onepage&q=lodging%20arrangements%20fuel%20and%20board%20history&f=false.**

13 "Reports of the Principle", in *Documents of the Ninety-First Legislature of the State of New Jersey* (New Brunswick, New Jersey: J. F. Babcock, 1867), 354. **https://books.google.co.uk/books?id=nWcZAAAAYAAJ&pg=PA354&dq=rent+lodging+board+heat+light&hl=en&sa=X&ved=2ahUKEwir94WEko7qAhUUTcAKHXTWB7MQ6AEwA3oECAAQAg#v=onepage&q=rent%20lodging%20board%20heat%20light&f=false.**

14 Anna Carlsson-Hyslop, "Past Management of Energy Demand: Promotion and Adoption of Electric Heating in Britain 1945-1964", *Environment and History*, 22, n°1, 2016, 75-102, doi:10.3197/096734016X14497391602242.; Paula in certain countries (such as Denmark, Sweden, and Finland) paying for and receiving heat on a fixed-fee basis is common[15].

18 District heating of this kind therefore presents a rich source of past experience of HaaS and HaaS-like tariffs. However, it does not demonstrate certain characteristics which are likely to be important in countries such as the UK which currently have more limited penetration of heat networks. Most important among these is that it is all but impossible for a customer at a certain address to switch between different heat networks – they are overwhelmingly likely to have access to a single network only. The main implication of this is that payment for heat is often directly or effectively tied to rental or other address-linked service charges, rather than being offered as one among several competing options which individual customers can pick and choose between, as is the dominant energy retail market model in the UK. The importance of individual customer tariff choice, except as mediated through choice of where to live, is therefore less prominent.

19 Many technical capabilities are required to make HaaS work effectively as a business model in a distributed, competitive retail market, including the potential for the operator to control the user's heating system remotely. This is necessary so that the provider can take financial advantage of the scope to influence patterns of energy input. This was often missing in the historical development of larger scale HaaS systems. While in theory operatives could be sent out to adjust the settings on heating systems, in reality some remote method of control is necessary. In smaller geographical settings, such as a block of flats or city district, control can be achieved directly by moderating the amount of heat supplied to the building or network, which in turn limits how much users are able to extract from it. The Cyclo-control system, introduced in London to provide heating in tower blocks, relied on encoding signals in mains electricity flows to use cheap electricity overnight to charge up floor heating systems[16]. However, for any HaaS offering to be made offered across a wide geographical area, such as a whole country rather than on a network-by-network basis, a larger scale system of communication to coordinate between sites of supply and demand is a fundamental prerequisite. Such a system would in principle allow HaaS to be offered independent of rental or other accommodation service agreements. The radio teleswitch, developed at the start of the 1980s, had that potential and it was this that eventually enabled the Budget Warmth tariff.

CENTRALISED CONTROL THROUGH THE RADIO TELESWITCH

Since the creation of the first electricity networks, network operators have tended to seek to maximise their networks' utilisation – that is, to operate them at near to capacity at all times. This is because the more evenly the network is used, the higher the total amount of electricity that can be sold through it, increasing profitability throughout the supply chain – while also making the network easier to manage. However, operators face a challenge in that people demand energy services, and therefore electricity, at some times much more than others, resulting in peaky network usage profiles including significant periods of underutilisation, along with times when the opportunity to sell extra electricity is limited by network constraints. 20

In response to this challenge, operators have sought ways to directly influence when electricity is used in people's homes. One of these 21

Morgenstern, Robert Lowe, and Lai Fong Chiu, "Heat Metering: Socio-Technical Challenges in District-Heated Social Housing", *Building Research & Information*, 43, n°2, 2015, 197-209, doi:10.1080/09613218.2014.932639.

15 London Economics, "Best Practice from Denmark in Price Setting for Heat Tariffs", July 2015, **https://londoneconomics.co.uk/wp-content/uploads/2015/08/Vanguards-Best-practice-from-Denmark.pdf**; Eli Sandberg, Daniel Møller Sneum, and Erik Trømborg, "Framework Conditions for Nordic District Heating - Similarities and Differences, and Why Norway Sticks Out", *Energy*, 149, 2018, 105–119, doi:10.1016/j.energy.2018.01.148.

16 EDF Energy, "Off Peak and Electricial Heating Tariffs", January 2017, **https://www.edfenergy.com/sites/default/files/time_of_use_heating_tariffs.pdf**.

is by promoting appliances that are used when electricity use is traditionally lower, such as overnight. An example of such a technology is the electric night storage heater, which uses electricity to heat up slowly overnight, and then releases heat into a space during the day. In the UK, storage heaters were heavily pushed in the 1960s and 70s as industry sought to maximise demand while minimising peaks[17]. Their use was encouraged through the introduction of tariffs such as Economy 7, which offers a cheaper rate for electricity overnight.

22 Traditionally, storage heaters were controlled by a timer, ensuring they come on and off at the right times to take advantage of lower-cost electricity. However, this approach brought with it several problems. It was unable to account for bi-annual time changes for daylight saving, and also tended to result in many large loads all turning off and on at more or less the same time, which was challenging for network managers to cope with. It also meant there was no scope to charge up or turning off of storage heaters at other times of day or night. What was needed was a way of turning large numbers of storage heaters off and on in direct response to some central control.

23 The solution which the UK opted for was the radio teleswitch. Working with the British Broadcasting Corporation (BBC), the Electricity Council[18] arranged for an inaudible signal to be encoded in the transmission for Radio 4 Longwave (best known in the UK for its coverage of five-day long cricket test matches). Broadcast across the country, this signal could be used to tell groups of storage heaters (equipped with a radio receiver) to turn off or on remotely, and it was also used to switch between on- and off-peak electricity metering. There was now the unprecedented (theoretical) potential to control loads in a way that could make them responsive to near-real-time state of the electricity system. From the system operator's perspective this was the holy grail, promising direct influence over patterns of domestic demand. Developed at the beginning of the 1980s, the signal is still being broadcast today. (For more on the history of the radio teleswitch, please see[19].)

The introduction of the radio teleswitch paved the way for more sophisticated dynamic and load control based tariffs. In an industry (pre-privatisation) in which electricity was bought and sold through a 'pool' arrangement with substantial price fluctuations, there was a drive to find new ways to make the most of the capacity for load control. 24

At the time when interest in load management was at a high, the issue of energy affordability was gaining attention. The concept of fuel poverty, introduced in the late 1970s in the wake of the oil crisis, was on the political agenda, and specific benefit payments were in place to subsidise heating. A new communication and control technology –the radio teleswitch– came together with the challenge of energy affordability to create an environment in which the Budget Warmth tariff was conceived. 25

BUDGET WARMTH

The Budget Warmth tariff was introduced in 1985/86[20]. It was targeted at low-income, elderly customers and promised to provide them with at least one warm room at all times (between October and April/May). As part of the offer, one or more electric storage heaters would be installed in their home, controllable remotely via the radio teleswitch by the local energy board (the regional agencies responsible for supplying 26

17 Carlsson-Hyslop, "Past Management of Energy Demand" (cf. note 14).

18 The Electricity Council was the governmental body with oversight of the electricity industry on matters including efficiency, financing, research, and advising the Secretary of State for Energy.

19 Michael J. Fell, "The Radio Teleswitch: An Historical Perspective on the Roll-out of Domestic Load Control", in *9th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL)*, 2018, **https://publications.europa.eu/en/publication-detail/-/publication/a270a15c-fb38-11e7-b8f5-01aa75ed71a1/language-en**.

20 Letter to J Tross (Department of Health and Social Security) from G Duley (Electricity Council), February 1986, Box Number 146/157, The National Archives (United Kingdom).

energy to customers at the time). The heater(s) would be charged overnight for long enough to ensure sufficient heating during the following day (with the possibility of an afternoon top-up if necessary), based on weather forecasts. The cost of the equipment and anticipated electricity use was spread evenly in weekly charges throughout the year. The electricity used by the heaters was unmetered, meaning that all fees were based on estimates of the amount of electricity input that would be required.

27 Budget Warmth fits almost exactly the description of the kind of HaaS services that are being developed today (see "Heat-as-a-service: what and why?"). What was paid for was a warm environment, and this was done through a regular flat fee, rather than reflecting energy input directly. The cost of installing and maintaining the heating infrastructure was included in the fee. The whole system was based around central control, and could be used to support electricity network management by filling overnight troughs in demand. Although the cost could be included as part of rent or accommodation service charge, householders could also opt for this service as a standalone product.

28 Budget Warmth was initially developed by the Electricity Council, before being taken up by certain local area boards. According to Colin Gronow, an economist at the Electricity Council, when he was interviewed as part of an oral history of the UK electricity supply in 2015, the development of Budget Warmth was primarily driven by welfare concerns:

> "There was a great deal of trouble with elderly people getting cold in the winter, and quite a storm politically about it. And after that, because of our sort of thinking about it, and I think well [...] what about them having a storage heater in their living room? [...] They've got to pay for it on a weekly basis. [...] And you pay for the units but you don't pay them as they arrive. Because most of them can arrive in December Jan Feb, you pay for it right through the constant amount per week. [...] And we arranged [...] that the pensioners when they're going in and getting their pension, they can pay the Post Office, the few pounds per week that it costs."[21]

At the time that Budget Warmth was introduced, a number of government-funded financial support schemes were in place to help people who would otherwise struggle to pay their energy bills. These included Fuel Direct, where bills could be paid directly through a benefits payment (this still exists today), and there was also a special support scheme known as 'estate rate heating additions' for people who lived with in district-heated buildings that were acknowledged to be hard to heat and had heating systems that were disproportionately expensive to run[22]. The energy sector was still pre-privatisation, and more closely aligned with the wider public sector. Area boards regularly reported on the challenge of providing affordable heat in their annual reports in sections relating to 'disadvantaged customers', such as the following from Southern Electricity: 29

> "Southern Electricity co-operated with local authorities to ensure that people at risk from cold in winter had an opportunity to benefit from «Budget Warmth». This revolutionary, remote-controlled heating scheme, which uses modern technology including radio teleswitches, provides single room electric heating to a comfortable level, day and night, from October to April. ... At the year end seven hundred customers in ten local authorities within the Board's area had «Budget Warmth» installed." [23]

As the New Scientist reported in 1987, Budget Warmth recipients were actually selected by the then Department of Health and Social Security[24]. 30

21 Interview of Colin Gronow (part 9 of 9) by Thomas Lean (for *An Oral History of the Electricity Supply in the UK*). Digital recording, January 2015. **https://sounds.bl.uk/Oral-history/Industry-water-steel-and-energy/021M-C1495X0028XX-0009V0**.

22 Bill Sheldrick, "Hard-to-Heat Estates: Evaluating the Benefits of Heating and Insulation Improvements", *Energy Policy*, 15, n°2, 1987, 145-157, DOI:10.1016/0301-4215(87)90122-4.

23 Southern Electricity, "Annual Report and Accounts 1986/7", 10, 1987, The SSE Archive.

24 John Lamb, "Tune in , Turn on, Warm Up", *New Scientist*, November 1987.

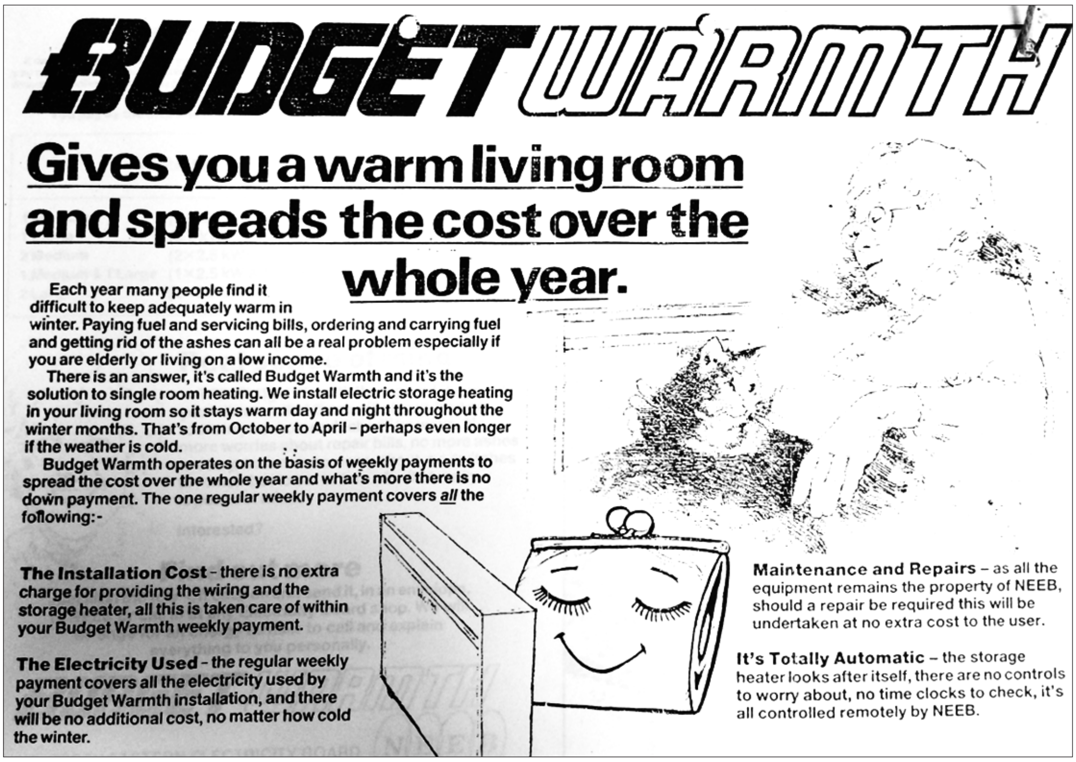


Figure 1: North Eastern Electricity Board leaflet promoting Budget Warmth (North Eastern Electricity Board, Box Number 146/157, 1986, National Archives, London)

While it was in this context – welfare – that Budget Warmth was primarily discussed at the time, its relevance for network management was also acknowledged. As the same source reports:

> "The heater is charged up at the times most convenient to the CEGB [Central Electricity Generating Board[25].] The CEGB attempts to match weather conditions with its own desire to spread demand for electricity across the day."[26], p37

31 The promotion of Budget Warmth was consistent with wider efforts to promote the growth of electricity for heating in general, particularly through the adoption of night storage heaters. North Eastern Electricity Board advertised the warmth the scheme guarantees, the spreading of cost over the year (including of installation and maintenance), and the ease of use due to its centrally-controlled nature. In addition, it addressed the "real problem, especially if you are elderly or on living on a low income" of "paying fuel and servicing bills, ordering and carrying fuel and getting rid of the ashes" (see Figure 1).

This is consistent with other industry messaging of the time that emphasise the clean and user-controllable nature of electric heating in comparison particularly to solid fuel alternatives[27]. 32

At the time that Budget Warmth was introduced, many of the target population lived in hard-to-heat buildings supplied by a district heating system. They were likely therefore in receipt of the benefit described above that was intended to subsidise their (unavoidably high) heating costs. In early 1986, the Electricity Council contacted the Department of Health and Social Security to enquire whether switching a customer to Budget Warmth (away from the estate heating system) would affect their entitlement to this 33

25 The Central Electricity Generation Board was responsible for generation and transmission of electricity across the country. Local area boards were responsible for managing distribution and were the organisations to whom customers paid their bills.

26 Lamb, "Tune in , Turn on, Warm Up", 37 (cf. note 24).

27 Carlsson-Hyslop, "Past Management of Energy Demand", (cf. note 14).

supplementary benefit[28]. The Department clarified that their benefit would indeed be affected – either being removed entirely or, if the premises itself were still considered to be 'hard to heat', reduced. The main insight from this exchange is that Budget Warmth appears in part to have been intended to attract customers to 'defect' from district heating systems. This might have made sense for certain individuals, but if fewer customers are connected to the heat network, operating costs, which are spilt between fewer parties, will rise for those who remain.

34 There were other concerns regarding the introduction of Budget Warmth. It was not universally liked by the area boards, and only six ultimately offered it to their customers. Some were worried about the unmetered nature of the supply. Colin Gronow, in an oral history interview, commented:

> "I thought he [named Electricity Council representative] was gonna love this. [...] what PR! Yeah, well, probably about half of them [the area boards] did and half didn't. And they were all of them a bit afraid, because it wasn't going to be metered. [...] if people are cheating, doing all sorts of things [...] [but] this was purely a heater with a connection through to the supply and there was no chance that they were going to do that."[29]

35 Gronow's statement hints at a wariness about introducing a disconnect between units used and price paid.

36 Whatever the pros and cons, mentions of Budget Warmth in industry literature diminish substantially after the end of the 1980s. The highest adoption figures I have been able to locate suggest that total installations were in the low thousands[30]. In the latter years of the 1980s, the tariff is consistently mentioned in the section of Southern Electricity's annual report dealing with special provisions for elderly and vulnerable people. However, following privatisation and its change to Southern Electric, there is no reference to Budget Warmth – instead this section simply deals with the provision of advice. Occasional references are made to the tariff after this point, such as in reviews of Ofgem's Social Action Plan[31], where it is mentioned as a product offered by Scottish and Southern Energy (SSE). It is listed in a 2005 article in the Daily Mirror concerning help for elderly people in cold homes[32]. In the same year, an Ofgem review of suppliers' corporate social responsibility initiatives lists the product under SSE, but states there is "no target set" (pA24) on the target number of vulnerable customers, than none were helped in 2004/5, and that 2500 had been helped since the beginning of the scheme[33]. The tariff is still (in 2019) listed as having radio teleswitch user ID and groups assigned[34], although it is not clear whether any customers are still being billed under this arrangement.

The Budget Warmth tariff, despite the excitement, optimism and recognition surrounding it as an innovative service offering based around new load control infrastructure, ultimately did not achieve wide success. Nor did it pave the way to a variety of other service offerings; indeed, almost all consumer energy products available since (while the exception of district heating schemes) have continued to charge on a per-unit basis. The next section considers the possible reasons for the failure of Budget Warmth. 37

28 Letter to J Tross (Department of Health and Social Security) from G. Duley (Electricity Council), (cf. note 20).
29 Interview of Colin Gronow (part 9 of 9) by Thomas Lean (for *An Oral History of the Electricity Supply in the UK*), (cf. note 21).
30 Lamb, "Tune in , Turn on, Warm Up", (cf. note 24); "Electricity Council Wins Technology Award", *Southern Electricity Magazine*, January 1987, The SSE Archive.
31 Ofgem, "Protecting Vulnerable Customers" (London, UK: Ofgem, January 2002), **https://www.ofgem.gov.uk/ofgem-publications/76201/1107-factsheet090201may.pdf; Ofgem, 'Social Action Plan Annual Review March 2001' (London, UK: Ofgem, January 2001), https://www.ofgem.gov.uk/ofgem-publications/57092/250-30march01-pdf**.
32 "The Cold War", *The Mirror*, December 2005, **https://www.mirror.co.uk/money/personal-finance/the-cold-war-569217**.
33 Energy Services Partnership, "Review of Suppliers' Corporate Social Responsibility Initiatives", Report prepared for Ofgem, January 2005, **https://www.ofgem.gov.uk/ofgem-publications/57153/11023-15505bpdf**.
34 Elexon, "Radio Teleswitch - Standard Settlement Configuration Mapping" (London, UK: Elexon, 2019).

REASONS FOR THE FAILURE OF BUDGET WARMTH AND HAAS MORE GENERALLY

38 Given that schemes like Budget Warmth appear to offer many advantages to providers and consumers, what explains their lack of success? In the case of Budget Warmth in particular, I believe some reasons relate to the characteristics of the service itself, and that others reflect changes in the structure of the energy industry as a whole.

39 An important characteristic of the Budget Warmth tariff is that occupants had no control over its operation. While couched in the language of ease of use, the NEEB leaflet (figure 2) states that "the storage heater looks after itself, *there are no controls to worry about* … it's all controlled remotely by NEEB" (emphasis added). A letter from the Assistant Chief Accountant of the Electricity Council to the Department of Health and Social Security confirms that "The essential features of the Scheme are … no customer regulation of the heater output" [35]. An early report of satisfaction with the service provided was positive, but vague:

> "There has been virtually no customer reaction to the use of radio teleswitches. The response of all districts in EMEB [the East Midlands Electricity Board] to an enquiry was that no adverse comments had been received. In fact, hardly any comments have been made by the public. In those boards where the Budget Warmth scheme is in operation, both customers and boards are pleased with the facilities and the possibilities opened up by the use of the radio teleswitching system."[36]

40 But there are also indications that success in consistently meeting the target temperature was limited. Because the radio teleswitch only provides for one-way signalling, neither the central controller not the occupant we able to recognise and respond to deviations from the target temperature. While I have not been able to identify any reports of research into target vs attained temperatures[37], minutes of a meeting between the two organisations mentioned above reveal the following information: "The system heats one room to around 20°C … *The system maintains a broad range of temperatures in practice*" (emphasis added)[38].

There is more general evidence of dissatisfaction with the levels of comfort provided by electric storage heaters of the period (1980s) [39]. Their operation is quite different from other forms of heating, and lack of familiarity with how to run them in a cost- and comfort-effective way has contributed to this dissatisfaction[40], while Brunner *et al.* (2012)[41] highlight the complex considerations involved in their domestication. The introduction of Budget Warmth occurred during a period of rapid growth in central heating, from featuring in a quarter of homes in 1970 to three-quarters in 1990[42]. This was co-constitutive with an increasing expectation and ability 41

35 Letter to J Tross (Department of Health and Social Security) from G. Duley (Electricity Council), (cf. note 20).
36 G. O. Hensman *et al.*, "Radio Teleswitching Tariff And Load Management System", in *Fifth International Conference on Metering Apparatus and Tariffs for Electricity Supply* (Edinburgh, UK: 1987), 272-276, 276.

37 Indeed, I have not been able to locate reports of detailed consumer research on Budget Warmth from the time.
38 R. Lane, "Notes of Meeting with Electricity Council, 20.3.86", March 1986, Box Number 146/157, The National Archives (United Kingdom).
39 Consumer Focus, "From Devotees to the Disengaged: A Summary of Research into Energy Consumers' Experiences of Time of Use Tariffs and Consumer Focus's Recommendations" (London, UK, October 2012); Maria Teresa De Haro and Alison Koslowski, "Fuel Poverty and High-Rise Living: Using Community-Based Interviewers to Investigate Tenants' Inability to Keep Warm in Their Homes", *Journal of Poverty and Social Justice*, 21, n° 2, 2013, 109-121, doi:10.1332/175982713X668917.
40 De Haro and Koslowski, 'Fuel Poverty and High-Rise Living', (cf. note 39).
41 Karl-Michael Brunner, Anja Christanell, and Markus Spitzer, "Energy Consumption Practices and Social Inequality: The Case of Low-Income Households", *in* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies: How Energy Connects Politics, Technologies and Cultures* (Bielefeld, Germany: Transcript Verlag, 2012), 195-220.
42 Jason Palmer and Ian Cooper, "United Kingdom Housing Energy Fact File 2013" (London, UK: Department of Energy and Climate Change, December 2013), **https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/345141/uk_housing_fact_file_2013.pdf**.

to spend time and carry out activities in multiple rooms of the home[43]. Research at the time recommended the installation of gas central heating, rather than storage heaters, to mitigate negative health impacts of cold for elderly people[44], and gas heating is generally a cheaper option[45]. Taking these factors together, when compared to the controllability and more comprehensive home coverage of gas central heating, it is reasonable to suppose that Budget Warmth may have presented a less attractive prospect.

42 Budget Warmth's relative ease of adoption may have contributed to its lack of longevity. It differed from similar offerings available at the time, such as Cyclo-control, in that it could be introduced on a dwelling-by-dwelling basis, rather than only for whole blocks. The implication of this was that individual customers may have been able to change their heating system or tariff relatively easily – in other words, the infrastructure associated with the provision of Budget Warmth was less obdurate[46]. The Barbican Estate in London was constructed to use an off-peak underfloor heating system run using Cyclo-control that gave residents similarly low levels of control. There is evidence of dissatisfaction with this system, and of people opening windows to avoid overheating[47]. However, the tenancy and leasehold agreements in that building meant that residents were simply unable to switch away from the system. The Cyclo-control system (albeit no longer operated under that name) continues to operate there[48]. The fact that such systems have continued while Budget Warmth does not is perhaps less a reflection of occupant satisfaction with service provision than of physical and legal ability to switch to another system.

Turning from user- to supply-side issues, another possible reason for lack of uptake and eventual decay could have been the lukewarm support given to it by the area boards. As suggested in the previous section, there were already concerns around the unmetered nature of the supply. In addition, and since the scheme was targeted at specific consumers (i.e. elderly, low-income), it was unlikely to be a major source of profit. Since Budget Warmth was often positioned as a welfare measure, the fact of its existence may have been more important than the absolute number of customers who benefited from it. Although important as a means of demonstrating innovation and commitment to vulnerable customers – what today would be termed corporate social responsibility – area boards might not have vigorously promoted its use. There is evidence of concern (with some justification) in other sectors that technology investment may be motivated more by maximising public exposure than properly commercialising the services that could be offered[49]. 43

Related to this, the development of Budget Warmth may have been guided more by what was technologically possible (and economically desirable) than by close assessment of the needs of the intended user group. In 1987, Hensman *et al.*[50] said of the radio teleswitch that 44

43 Lenneke Kuijer and Matt Watson, "'That's When We Started Using the Living Room': Lessons from a Local History of Domestic Heating in the United Kingdom", *Energy Research & Social Science*, 28, 2017, 77-85, doi:10.1016/j.erss.2017.04.010.

44 T. Rose, W. J. Batty, and S. D. Probert, "Comparing Alternative Strategies for Achieving Thermal Comfort in Pensioners' Homes", *Applied Energy*, 32, n°2, 1989, 101-116, DOI:10.1016/0306-2619(89)90072-X.

45 Geoffrey Milne and Brenda Boardman, "Making Cold Homes Warmer: The Effect of Energy Efficiency Improvements in Low-Income Homes A Report to the Energy Action Grants Agency Charitable Trust", *Energy Policy*, 28, n°6, 2000, 411-424, DOI:10.1016/S0301-4215(00)00019-7.

46 Elizabeth Shove, Matt Watson, and Nicola Spurling, "Conceptualizing Connections: Energy Demand, Infrastructures and Social Practices", *European Journal of Social Theory*, 18, n°3, 2015, 274-287, DOI:10.1177/1368431015579964.

47 Carrie Behar, "Utilising Resident Feedback to Inform Energy-Saving Interventions at the Barbican", *Local Environment*, 19, n°5, 2014, 539-559, DOI:10.1080/13549839.2013.810205.

48 "Heating", *Barbican Living* (blog), September 2015, **http://www.barbicanliving.co.uk/flats/services-2/heating/**.

49 Robert van den Hoed, "Commitment to Fuel Cell Technology? How to Interpret Carmakers' Efforts in This Radical Technology", *Journal of Power Sources*, 141, n°2, 2005, 265-271, doi:10.1016/j.jpowsour.2004.09.017.

50 Hensman *et al.*, "Radio Teleswitching Tariff and Load Management System", (cf. note 36).

"prospects for innovative tariff and load control developments is a major source of favourable comment as well as furthering off-peak sales" (p276). Yet in 1996, Woolner and Hannon[51] observed that the radio teleswitch infrastructure had been "significantly under utilised ever since the availability of industry specifications and the widespread introduction of the system in 1984" (p20). The creation of the radio teleswitch infrastructure created an expectation and demand (in the industry) for products and services that used its capabilities. Budget Warmth met such a demand. The role of infrastructural development in contributing to new demand for, and provision of, the services they can underpin has been widely observed, including in electricity[52] and gas[53] networks.

45 Other issues contributing to the slow uptake and eventual decline of Budget Warmth and similar offers are associated with wider aspects of the structure and operation of the electricity industry at the time[54]. During the 1980s, the inability to settle customers' usage on a half-hourly basis was viewed as limiting the financial benefits that suppliers could realise through dynamically controlling customers loads, a key functionality permitted by products such as Budget Warmth[55].

46 Domestic consumers were able to switch suppliers in 1998[56], but if they did so, the new supplier was very unlikely to be aware of whether new customers had the equipment necessary to permit remote switching of the kind needed for Budget Warmth or similar solutions. Where there was no two-way communication (like that permitted by today's smart meters), acquiring relevant information would necessitate a personal visit to the property, making it (and therefore the development of tariff that depend on it) practically infeasible.

47 As highlighted in Wood (2008)[57], the subsequent vertical disintegration of the industry meant different actors had different interests in influencing customers' electricity usage patterns. The ability to use the radio teleswitch infrastructure was split between the new suppliers and the distribution network operators – but incentives to use it differed. Supply companies wanted to make sure they were buying and selling balanced amounts of electricity, while network operators needed to manage network constraints. There was no method of coordinating between these actors to maximise value for all.

48 Many of the reasons why Budget Warmth failed are features of this historical context. What, if anything, does this experience tell us about the opportunities and risks for HaaS today?

BUDGET WARMTH COMPARED TO THE HAAS OF TODAY

49 From a technological point of view, the ability to monitor, control and communicate thermal conditions in homes has improved substantially since the 1980s. This is likely to be appealing both to potential HaaS customers, who are able to tailor conditions more precisely to their liking, as well as to operators, which are able to collect much richer data on their customers which can be used to inform other products and services. This is coupled with a generally more consumer-focused approach to product development, as demonstrated by the substantial social research element in recent Energy

51 L. Woolner and T. Hannon. "Demand Side Management-Latest Developments in Tele-Technology", in *Eighth International Conference on Metering and Tariffs for Energy Supply (Conf. Publ. No. 426)*, 1996, 20-24. https://doi.org/10.1049/cp:19960470.

52 Carlsson-Hyslop, "Past Management of Energy Demand", (cf. note 14).

53 Clare Hanmer and Simone Abram, "Actors, Networks, and Translation Hubs: Gas Central Heating as a Rapid Socio-Technical Transition in the United Kingdom", *Energy Research & Social Science*, 34, 2017, 176-183, DOI:10.1016/j.erss.2017.03.017.

54 Fell, "The Radio Teleswitch", (cf. note 19).

55 Ralph Turvey and Brian Cory, "Inefficiencies in Electricity Pricing in England and Wales", *Utilities Policy*, 6, n°4, 1997, 283-292, DOI:10.1016/S0957-1787(97)00029-5.

56 Peter Pearson and Jim Watson, *UK Energy Policy 1980-2010: A History and Lessons to Be Learnt* (London, UK: The Parliamentary Group for Energy Studies, 2012).

57 Janet Wood, "Silver Service", *Utility Week*, September 2008, 10-11.

System Catapult trials[58]. Half-hourly settlement for small customers is now available to suppliers on a voluntary basis (soon to be mandatory). This means suppliers are responsible for the ultimate cost of electricity their customers have actually used in a given half hour, rather than on modelled assumptions. This in turn increases the incentives to seek and unlock flexibility through products such as HaaS, by minimizing demand in high-cost periods. Given these shifts, is there anything that we can learn about the prospects or potential impacts of HaaS today from the experience of Budget Warmth?

50 Budget Warmth, which was often seen as a means of supporting the health and wellbeing of people likely to be in vulnerable situations, did not allow 'users' any control. This was done for a combination of reasons, including: to ensure that stored heat was not 'used up' too soon; to prevent people from turning down the heating and going cold[59]; to prevent levels of electricity consumption incompatible with economic running of the tariff; and to yield network management benefits. But for users, the result of this was that the effective price of a warm room and a fixed charge, was for their home to join a kind of 'flexibility factory' under the sole control of a central operator. This may be a fair trade, if expected and healthy standards of comfort are met. And there is certainly reason to believe that today's offerings would give much more priority to customer preferences. It is, for example, better appreciated that the retention of supervisory control[60] through the provision of override ability and heat top-up options as described in Osborn *et al.* (2019)[61] is an important contributor to user satisfaction. Under such circumstances there is evidence of the relative acceptability of externally controlled flexibility offerings compared to those requiring a more user-driven response (although there is a still a substantial proportion who do not find such as arrangement to be attractive)[62].

Even so, it is important to recognise that there are different interests in play and that 'customers' are not always 'users'. Budget Warmth marketing material suggests that the scheme was targeted at specific households (i.e. elderly, low-income) – but often via local authorities, as housing providers (see[63]). As landlords, local authorities (and now housing associations) are be expected to act with the welfare of their occupants as a priority when procuring heating services. However, around a fifth of households today live in private rental accommodation[64], in which landlords have no such responsibility. Service-based models, similar to district heating systems, are much more likely than volumetric charging models to be rolled into a rental or service charge because of their fixed, regular nature. In such cases, while tenants are the service users, landlords become the customer – and their interests may take priority. These could include profiting from occupant data (depending on privacy terms) or allowing temperature levels to fluctuate (for instance in a building with poor thermal efficiency) in ways that have negative consequences for the occupants' health. 51

58 Osborn, Furlong, and Anaam, "Using the Living Lab to Sell Consumer Centric Heat Services That Encourage Adoption of Low Carbon Heating: Winter Trial 2018/19", (cf. note 4).

59 Desmond Banks, "Heating Problems: Strategy Proposal". HL Deb (11 February 1987), vol 474, col 670. **https://hansard.parliament.uk/Lords/1987-02-11/debates/3570fdab-4759-48bd-b01d-d5faab460b60/HeatingProblemsStrategyProposal**.

60 Thomas B. Sheridan, "Human Supervisory Control", *in* Gavriel Salvendy (ed.), *Handbook of Human Factors and Ergonomics* (Hoboken, NJ: John Wiley & Sons, Inc., 2012), 990-1015.

61 Osborn, Furlong, and Anaam, "Using the Living Lab to Sell Consumer Centric Heat Services That Encourage Adoption of Low Carbon Heating: Winter Trial 2018/19", (cf. note 4).

62 Michael J. Fell *et al.*, "Public Acceptability of Domestic Demand-Side Response in Great Britain: The Role of Automation and Direct Load Control", *Energy Research & Social Science*, 9, 2015, 72-84, DOI:10.1016/j.erss.2015.08.023.

63 Southern Electricity, 'Annual Report and Accounts 1986/7', 1987, The SSE Archive, (cf. note 23).

64 Office for National Statistics, "UK Private Rented Sector: 2018", January 2019, **https://www.ons.gov.uk/economy/inflationandpriceindices/articles/ukprivaterentedsector/2018**.

Figure 2: Excerpt from advert for GEC 'Nightstor' Central Heating, October 1964. Note the 'protected' heating option (GEC, 1964).

52 This suggests another area in which Budget Warmth may have fallen short. Budget Warmth was very much a supply-side solution to the problem of providing heat in a more affordable (or at least more predictably-priced) way. It did nothing to affect demand for heat, and in this respect neglected one of the key ways in which HaaS providers may profit. Indeed, in a House of Lords debate on 'heating problems' and energy efficiency in 1987, Lord Banks wrongly describe the scheme as one where "the Electricity Council will insulate a nominated room in the house of an elderly person [...] They will install heating and they will control that heating by remote control at the appropriate temperature" [65]. In fact no such insulation element was included, and indeed the exchange described earlier regarding the possible impact on estate rate heating additions suggest that there was more focus on compensating people for the heat they wasted than reducing the waste. HaaS trials today are still predominantly framed around the heating system and its controls, rather than on fabric efficiency. This has not always been so, as illustrated in promotional material from the 1960s (figure 2).

A framing based more around warmth-as-a-service, with a focus on comfort, might be expected to focus on insulation. However, the failure to do so highlights another challenge for service offerings in general – that of measurement. As we have seen, Budget Warmth neatly sidestepped this issue, avoiding both metering and temperature regulation, and relying instead on calculations based on charging times. Modern HaaS offerings are much more sophisticated [66], but the measurement and control of temperature, let alone warmth, is still a challenge. For example, depending on the height above the ground at which temperature is measured, variation of several degrees Celsius can occur [67]. This means experiences of temperature can be very different depending on whether people sit or stand in a room, for example, creating potential for uncertainty around whether contracted services are being delivered. Furthermore, the pursuit of meeting minimum temperature limits combined with the desire to unlock flexibility can result in overheating in some circumstances [68]. The implication of all this is that consumer satisfaction is by no means guaranteed, even if the specific terms of a service agreement (to heat to a certain minimum measured temperature between certain times) are met. This poses new challenges for how to regulate services whose delivery is measured in the form of outcomes, 53

65 Banks, "Heating Problems: Strategy Proposal", (cf. note 59).

66 Osborn, Furlong, and Anaam, "Using the Living Lab to Sell Consumer Centric Heat Services That Encourage Adoption of Low Carbon Heating: Winter Trial 2018/19", (cf. note 4).

67 S. Gauthier and D. Shipworth, "Variability of Thermal Stratification in Naturally Ventilated Residential Buildings", in *Conference Proceedings: 2014 Building Simulation and Optimization Conference*, 2014, 1-7, **http://eprints.soton.ac.uk/378788/**.

68 Trevor Sweetnam *et al.*, "Domestic Demand-Side Response with Heat Pumps: Controls and Tariffs", *Building Research & Information*, 47, n°4, 2018, 344-361, DOI:10.1080/09613218.2018.1442775.

which present greater ambiguity in appropriate forms of measurement than current input-based models.

54 The parallel between HaaS offerings and district heating schemes (many of which have many HaaS-like properties) goes even further. Tenants or leaseholds in properties with district heating tend to be locked into inescapable contracts over which they have little control, and they are therefore vulnerable to being exposed to high prices which they are unable to avoid. The same is potentially true for new HaaS offerings. Where a substantial cost is involved in installing new heating equipment, distribution, controls, energy efficiency improvements, etc., and the cost of removing them again would be high, any contract associated with that offering is likely to be either quite long or to have high exit fees – or, in the case of tenants, the contract may not be possible to leave at all. (In the case of Budget Warmth, the terms in one area were "open ended with an initial year take and then one month's notice"[69].) More expensive modern heating systems such as heat pumps, or the installation of efficiency measures, are likely to require even longer periods of commitment. In Great Britain, regulation is only just beginning to catch up and provide protection to households that are locked in to district heating contracts[70]. Similar protections are likely to be needed for HaaS offerings which do not provide for easy exit, such as for tenants/leaseholders or which come bundled with expensive new equipment.

55 Finally, it is not clear that the structural and incentive issues in the electricity sector that may have contributed to the demise of Budget Warmth and other flexibility-related products have been resolved, at least in Great Britain. While distribution network operators are taking on a more active role in managing flexibility through their transformation to distribution system operators, this is still a relatively recent development[71]. While it is expected to become mandatory for domestic customers to be settled on a half-hourly basis where possible (i.e. where a smart meter is fitted), this is not the case at the time of writing[72]. This means that electricity suppliers have no strong incentive to attempt to influence electricity usage patterns in the ways that HaaS could permit. Until these and other structural incentives are addressed, HaaS is likely to remain a relatively niche offering.

CONCLUSION

In this article I have described the heat-as-a-service business model and shown how it might be used to unlock flexibility in electricity demand. I then considered the case of a commercial example of HaaS from the 1980s, the Budget Warmth tariff. Primarily framed as a tool to support low-income elderly customers, it was designed to provide reliable warmth in one or two rooms, based on remote control via radio teleswitch, with a flat weekly fee to cover equipment, installation and usage. While was adopted in thousands of homes and was trumpeted by the local area boards which offered it, after just a few years it was no longer actively promoted. HaaS, at least in this form, did not prove to be a success. I suggest this was due to a combination of user-related issues (such lack of controllability) and structural changes in the industry which meant that demand-side flexibility and welfare considerations became lower priorities. 56

69 Lane, "Notes of Meeting with Electricity Council, 20.3.86", (cf. note 38).

70 Department of Business, Energy and Industrial Strategy, "Heat Networks: Building a Market Framework" (London, UK: Department of Business, Energy and Industrial Strategy, January 2020), **https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878072/heat-networks-building-market-framework-condoc.pdf**.

71 Ofgem, "Position Paper on Distribution System Operation: Our Approach and Regulatory Priorities" (London, UK: Ofgem, June 2019), **https://www.ofgem.gov.uk/system/files/docs/2019/08/position_paper_on_distribution_system_operation.pdf**.

72 Ofgem, "Electricity Retail Market-Wide Half-Hourly Settlement: Consultation" (London, UK: Ofgem, June 2020), **https://www.ofgem.gov.uk/system/files/docs/2020/06/mhhs_draft_impact_assessment_consultation_-_final_-_published_17_june_2020.pdf**.

57 The HaaS offerings of today, while sharing the same basic characteristics of Budget Warmth, also differ from it in important ways. Principal among these are the richer data they base their operation on, and the more thoroughgoing user involvement in service design. Nevertheless, challenges to the HaaS business model that were faced by Budget Warmth remain. These include the long contract periods required to recoup high upfront equipment costs, and enduring lack of incentives to provide demand-side flexibility. If and when HaaS offerings are offered more widely, similar challenges will be faced in balancing their potential to provide affordable warmth with risks of lock-in to unfavourable contract terms, and managing potential tensions between occupant comfort and wellbeing and operators' economic interests.

58 On the face of it, the idea of selling energy services has attractions for both system users and operators. The former can benefit from expensive new technologies and confidence in a specified measure of service (e.g. room temperature) for the comfort of a fixed regular fee. The latter get to extend their influence into the operation of domestic loads, making it easier for them secure changes in demand levels when needed. Drawing on historical accounts of Budget Warmth I have highlighted a number of practical obstacles to the smooth functioning of such models. It is also useful to question the fundamental assumptions embedded in service-based models. Budget Warmth promised a warm room at all times, while modern offerings offer 'warm hours' or other similar measures of service. These framings serve the purpose of locking in expectations of what acceptable levels of warmth are, and reproducing the view that the condition of warmth is best provided through heating, perhaps through building efficiency, and not all through other means such as activity or clothing. In this way these schemes reinforce a reality in which a certain size of electricity system is needed to furnish these expectations, and in which a degree of flexibility is needed to help manage them.

The electrification of heat (combined with the decarbonisation of electricity) is a key cornerstone of many cool and temperate countries' decarbonisation plans, and in this paradigm, HaaS has the potential to play a key role. The example of Budget Warmth serves as a reminder that the hurdles energy service-based business models have to get over have a longer history than is usually recognised, and that there is much to learn from the relative failures of the past. 59

APPENDIX A: RESEARCH APPROACH

60 This paper is based on desk-based research. This section briefly describes the process followed to identify and draw on material relating to the Budget Warmth tariff. While I did not define precise inclusion or exclusion criteria, I sought to identify as much material as possible that mentions the tariff. I conducted online searches for the terms “Budget Warmth” or “radio teleswitch” (in quotes to identify the entire phrase) on the following websites:

- Google
- UCL Explore (University College London library catalogue)
- UK Parliament
- Gov.uk (the UK government website)
- Scopus
- Web of Science
- IEEE Xplore
- The IET library catalogue (available to members and onsite)
- The SSE Heritage Collection

61 Generally search results were quite limited in number, especially when searching only for “Budget Warmth”. I read through returned search results and downloaded any which include more than a passing mention (such as a line in a spreadsheet listing of tariffs) to the reference manager Zotero. One result was for an oral history interview, of which I transcribed the relevant section.

I also conducted archival research. I searched the catalogue of The National Archives using these and a broader range of search terms that my existing material suggested was most likely to identify relevant boxes (such as [“department of health and social security” heating]). I then hand searched 11 potentially relevant boxes for any mention of the tariff, and photographed relevant pages. I reviewed catalogues of the archives of the Electricity Council and the Central Electricity Research Laboratory, but no relevant material was identifiable and more detailed searches were not possible given the resources available for this project. I engaged with the librarian of the SSE Heritage Collection who was able to share with me a number of relevant documents, and I was also able to download all documents from the most relevant years (1985 to 1990) in order to perform keyword searches for “Budget Warmth” offline in Adobe Acrobat Professional. (Full access to documents from the SSE Heritage Collection appears to no longer be available.) Finally, I searched my own small archive (which includes one of the advertisements reproduced in this article). I read through all material and extracted details relating to the Budget Warmth tariff, then categorised these thematically to inform the discussion presented here. Additional references were identified through checking of reference lists, informal searches, and my own reference archive. 62

Bibliography

Banks Desmond
"Heating Problems: Strategy Proposal", HL Deb (11 February 1987), vol 474, col 670. https://hansard.parliament.uk/Lords/1987-02-11/debates/3570fdab-4759-48bd-b01d-d5faab460b60/HeatingProblemsStrategyProposal.

Behar Carrie
"Utilising Resident Feedback to Inform Energy-Saving Interventions at the Barbican", *Local Environment*, 19, n°5, 2014, 539-559. https://doi.org/10.1080/13549839.2013.810205.

Brunner Karl-Michael, Christanell Anja, Spitzer Markus
"Energy Consumption Practices and Social Inequality: The Case of Low-Income Households", *in* Nina Möllers and Karin Zachmann (eds.), *Past and Present Energy Societies: How Energy Connects Politics, Technologies and Cultures* (Bielefeld, Germany: Transcript Verlag, 2012), 195–220.

Carlsson-Hyslop Anna
"Past Management of Energy Demand: Promotion and Adoption of Electric Heating in Britain 1945-1964", *Environment and History*, 22, n° 1, 2016, 75–102. https://doi.org/10.3197/096734016X14497391602242.

Consumer Focus
"From Devotees to the Disengaged: A Summary of Research into Energy Consumers' Experiences of Time of Use Tariffs and Consumer Focus's Recommendations" (London, UK, October 2012).

De Haro Maria Teresa, Koslowski Alison
"Fuel Poverty and High-Rise Living: Using Community-Based Interviewers to Investigate Tenants' Inability to Keep Warm in Their Homes", *Journal of Poverty and Social Justice*, 21, n° 2, 2013, 109–121. https://doi.org/10.1332/175982713X668917.

Delta-EE
"Defining Heat as a Service", October 2019. https://www.delta-ee.com/delta-ee-blog/defining-heat-as-a-service.html.

Department of Business, Energy and Industrial Strategy
"Digest of United Kingdom Energy Statistics 2019" (London, UK: Department of Business, Energy and Industrial Strategy, 2019). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/840015/DUKES_2019_MASTER_COPY.pdf.

"Heat Networks: Building a Market Framework" (London, UK: Department of Business, Energy and Industrial Strategy, January 2020). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878072/heat-networks-building-market-framework-condoc.pdf.

Duley G.
"Letter to J Tross (Department of Health and Social Security) from G Duley (Electricity Council)", February 1986. Box Number 146/157. The National Archives (United Kingdom).

EDF Energy
"Off Peak and Electrical Heating Tariffs", January 2017. https://www.edfenergy.com/sites/default/files/time_of_use_heating_tariffs.pdf.

"Electricity Council Wins Technology Award", *Southern Electricity Magazine*, January 1987.

Elexon
"Radio Teleswitch - Standard Settlement Configuration Mapping" (London, UK: Elexon, 2019).

Energy Services Partnership
"Review of Suppliers' Corporate Social Responsibility Initiatives", Report prepared for Ofgem, January 2005. https://www.ofgem.gov.uk/ofgem-publications/57153/11023-15505bpdf.

Fell Michael J.
"The Radio Teleswitch: An Historical Perspective on the Roll-out of Domestic Load Control" in *9th International Conference on Energy Efficiency in Domestic Appliances And Lighting (EEDAL)*, 2018. https://publications.europa.eu/en/publication-detail/-/publication/a270a15c-fb38-11e7-b8f5-01aa75ed71a1/language-en.

"Energy Services: A Conceptual Review", *Energy Research & Social Science*, 27, 2017, 129–140. https://doi.org/10.1016/j.erss.2017.02.010.

Fell Michael J., Shipworth David, Huebner Gesche M., Elwell Clifford A.
"Public Acceptability of Domestic Demand-Side Response in Great Britain: The Role of Automation and Direct Load Control", *Energy Research & Social Science*, 9, 2015, 72–84. https://doi.org/10.1016/j.erss.2015.08.023.

Frontier Economics and Sustainability First
"Demand Side Response in the Domestic Sector - a Literature Review of Major Trials", Report to DECC (London, UK: Department of Energy and Climate Change, 2012). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48552/5756-demand-side-response-in-the-domestic-sector-a-lit.pdf.

Gauthier Stephanie, Shipworth David
"Variability of Thermal Stratification in Naturally Ventilated Residential Buildings", in *Conference Proceedings: 2014 Building Simulation and Optimization Conference*, 2014, 1–7. http://eprints.soton.ac.uk/378788/.

GEC
"GEC Central Heating Plus from Only £65 (Advert)", *House & Garden*, October 1964.

Gronow Colin
"Interview of Colin Gronow (part 9 of 9) by Thomas Lean (for An Oral History of the Electricity Supply in the UK)", digital recording, January 2015. https://sounds.bl.uk/Oral-history/Industry-water-steel-and-energy/021M-C1495X0028XX-0009V0.

Hanmer Clare, Abram Simone
"Actors, Networks, and Translation Hubs: Gas Central Heating as a Rapid Socio-Technical Transition in the United Kingdom", *Energy Research & Social Science*, 34, 2017, 176–183. https://doi.org/10.1016/j.erss.2017.03.017.

"Heating", *Barbican Living* (blog), September 2015. http://www.barbicanliving.co.uk/flats/services-2/heating/.

Hensman G. O., Fidgett J., Gray F. M., Mahoney A.P.
"Radio Teleswitching Tariff and Load Management System" (Edinburgh, UK, 1987), 272–276.

History of Trumbull and Mahoning Counties, Volume 1 (Cleveland, Ohio, US: Williams, HZ and Bro, 1882). https://books.google.co.uk/books?id=MU-0RAwAAQBAJ&pg=PA488&lpg=PA488&dq=lodging+arrangements+fuel+and+board+history&source=bl&ots=o_6TaD-LOrz&sig=ACfU3U0ACP8Zi1in-fTHY1Iu4Ql_rAldSOg&hl=en&sa=X&ved=2ahUKEwi4qbq4j47qAhVtSx-UIHSxdCYMQ6AEwCnoECA0QAQ#v=onepage&q=lodging%20arrangements%20fuel%20and%20board%20history&f=false.

HM Government
"Upgrading Our Energy System: Smart Systems and Flexibility Plan" (London, UK: HM Government, July 2017). https://www.ofgem.gov.uk/system/files/docs/2017/07/upgrading_our_energy_system_-_smart_systems_and_flexibility_plan.pdf.

Hoed Robert van den
"Commitment to Fuel Cell Technology?: How to Interpret Carmakers' Efforts in This Radical Technology", *Journal of Power Sources*, 141, n° 2, 2005, 265–271. https://doi.org/10.1016/j.jpowsour.2004.09.017.

Kuijer Lenneke, Watson Matt
"'That's When We Started Using the Living Room': Lessons from a Local History of Domestic Heating in the United Kingdom", *Energy Research & Social Science*, 28, 2017, 77–85. https://doi.org/10.1016/j.erss.2017.04.010.

Lamb John
"Tune in , Turn on, Warm Up", *New Scientist*, November 1987.

Lane R.
"Notes of Meeting with Electricity Council, 20.3.86", March 1986. Box Number 146/157. The National Archives (United Kingdom).

Lipman Guy
"Power Price vs Carbon Intensity", *Medium*, April 2019. https://medium.com/@guylipman/power-price-vs-carbon-intensity-d97ee6a70aaa.

London Economics
"Best Practice from Denmark in Price Setting for Heat Tariffs" (presented at the *Vanguards District Heating Conference*, July 2015). https://londoneconomics.co.uk/wp-content/uploads/2015/08/Vanguards-Best-practice-from-Denmark.pdf.

Milne Geoffrey, Boardman Brenda
"Making Cold Homes Warmer: The Effect of Energy Efficiency Improvements in Low-Income Homes A Report to the Energy Action Grants Agency Charitable Trust", *Energy Policy*, 28, n° 6, 2000, 411–424. https://doi.org/10.1016/S0301-4215(00)00019-7.

Morgenstern Paula, Lowe Robert, Chiu Lai Fong
"Heat Metering: Socio-Technical Challenges in District-Heated Social Housing", *Building Research & Information*, 43, n° 2, 2015, 197–209. https://doi.org/10.1080/09613218.2014.932639.

New Jersey Legislature
Documents of the Legislature of the State of New Jersey (New Brunswick, New Jersey: J. F. Babcock, 1867). https://books.google.co.uk/books?id=n-WcZAAAAYAAJ&pg=PA354&dq=rent+lodging+board+heat+-light&hl=en&sa=X&ved=2ahUKEwir94WEko7qAhUUTcAKHXTWB-7MQ6AEwA3oECAAQAg#v=onepage&q=rent%20lodging%20board%20heat%20light&f=false.

Office for National Statistics
"UK Private Rented Sector: 2018", January 2019. https://www.ons.gov.uk/economy/inflationandpriceindices/articles/ukprivaterentedsector/2018.
Ofgem, "Electricity Retail Market-Wide Half-Hourly Settlement: Consultation" (London, UK: Ofgem, June 2020). https://www.ofgem.gov.uk/system/files/docs/2020/06/mhhs_draft_impact_assessment_consultation_-_final_-_published_17_june_2020.pdf.

Ofgem
"Position Paper on Distribution System Operation: Our Approach and Regulatory Priorities" (London, UK: Ofgem, June 2019). https://www.ofgem.gov.uk/system/files/docs/2019/08/position_paper_on_distribution_system_operation.pdf.
Ofgem, "Protecting Vulnerable Customers" (London, UK: Ofgem, January 2002). https://www.ofgem.gov.uk/ofgem-publications/76201/1107-factsheet-090201may.pdf.

"Social Action Plan Annual Review March 2001" (London, UK: Ofgem, January 2001). https://www.ofgem.gov.uk/ofgem-publications/57092/250-30march01-pdf.

Osborn Judy, Furlong Tom, Anaam Amal
"Using the Living Lab to Sell Consumer Centric Heat Services That Encourage Adoption of Low Carbon Heating: Winter Trial 2018/19" (Energy Systems Catapult, December 2019). https://es.catapult.org.uk/reports/using-the-living-lab-to-sell-consumer-centric-heat-services-that-encourage-adoption-of-low-carbon-heating/?download=true.

Palmer Jason, Cooper Ian
"United Kingdom Housing Energy Fact File 2013" (London, UK: Department of Energy and Climate Change, December 2013). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/345141/uk_housing_fact_file_2013.pdf.

Pearson Peter, Watson Jim
UK Energy Policy 1980-2010: A History and Lessons to Be Learnt (London, UK: The Parliamentary Group on Energy Studies, 2012).

Rose T., Batty W. J., Probert S. D.
"Comparing Alternative Strategies for Achieving Thermal Comfort in Pensioners' Homes", *Applied Energy*, 32, n° 2, 1989, 101–116. https://doi.org/10.1016/0306-2619(89)90072-X.

Sandberg Eli, Møller Sneum Daniel, Trømborg Erik
"Framework Conditions for Nordic District Heating - Similarities and Differences, and Why Norway Sticks Out", *Energy*, 149, 2018, 105–119. https://doi.org/10.1016/j.energy.2018.01.148.

Sheldrick Bill
"Hard-to-Heat Estates: Evaluating the Benefits of Heating and Insulation Improvements", *Energy Policy*, 15, n° 2, 1987, 145–157. https://doi.org/10.1016/0301-4215(87)90122-4.

Sheridan Thomas B.
"Human Supervisory Control", *in* Gavriel Salvendy (ed.) *Handbook of Human Factors and Ergonomics* (Hoboken, NJ: John Wiley & Sons, Inc., 2012), 990–1015. http://onlinelibrary.wiley.com/doi/10.1002/9781118131350.ch34/summary.

Shove Elizabeth, Watson Matt, Spurling Nicola
"Conceptualizing Connections: Energy Demand, Infrastructures and Social Practices", *European Journal of Social Theory*, 18, n°3, 2015, 274–287. https://doi.org/10.1177/1368431015579964.

Southern Electricity
"Annual Report and Accounts 1986/7", 1987. The SSE Archive. Staffell Iain, "Measuring the Progress and Impacts of Decarbonising British Electricity", *Energy Policy*, 102, 2017, 463–475. https://doi.org/10.1016/j.enpol.2016.12.037.

Sweetnam Trevor, Fell Michael J., Oikonomou Eleni, Oreszczyn Tadj
"Domestic Demand-Side Response with Heat Pumps: Controls and Tariffs", *Building Research & Information*, 47, n° 4, 2018, 344-361. https://doi.org/10.1080/09613218.2018.1442775.

"The Cold War", *The Mirror*, December 2005. https://www.mirror.co.uk/money/personal-finance/the-cold-war-569217.

The New York Supplement, Volume 6 (Eagan, Minnesota, USA: West Publishing Company, 1889). https://books.google.co.uk/books?id=HeU7AAAAIAAJ&q=lodging++board+heat+rent&dq=lodging++board+heat+rent&hl=en&sa=X&ved=2ahUKEwjNiM67kY7qAhVNQUEAHfwUDVUQ6AEwAXoECAIQAg.

Turvey Ralph, Cory Brian
"Inefficiencies in Electricity Pricing in England and Wales", *Utilities Policy*, 6, n° 4, 1997, 283–292. https://doi.org/10.1016/S0957-1787(97)00029-5.

Wood Janet
"Silver Service", *Utility Week*, September 2008, 10–11.

Woolner L., Hannon T.
"Demand Side Management-Latest Developments in Tele-Technology", in *Eighth International Conference on Metering and Tariffs for Energy Supply (Conf. Publ. No. 426)*, 1996, 20–24. https://doi.org/10.1049/cp:19960470.

JEH RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR

Simone Abram
Department of Anthropology, Durham University.
simone.abram@durham.ac.uk orcid.org/0000-0002-8063-3144

Antti Silvast
Department of Interdisciplinary Studies of Culture, Norwegian University of Science and Technology.
antti.silvast@ntnu.no orcid.org/0000-0002-1026-6529

POST DATE
05/05/2021

ISSUE NUMBER
JEHRHE #5

SECTION
Special issue

THEME OF THE SPECIAL ISSUE
Historicising Flexibility

KEYWORDS
Electricity, Gas, Maintenance, Regimes, Networks

DOI
in progress

TO CITE THIS ARTICLE
Simone Abram, Antti Silvast, "Flexibility of real-time energy distribution: the changing practices of energy control rooms", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 05 May 2021, URL: energyhistory.eu/en/node/254.

Flexibility of real-time energy distribution: the changing practices of energy control rooms

Abstract

This paper examines the linked concepts of flexibility and control, focusing on how these are enacted in the operation of control rooms in Distribution Network Organisations. We discuss the limits to flexibility, and the kinds of flexibility that are at stake in distribution network control of gas and electricity. We do not present a general history of flexibility in UK energy system control rooms, but we show how the legacy of past ideas and practices of energy distribution control feed into current control operations, and how they shape flexibilities in control systems. The article examines the kinds of flexibility demanded of control room engineers in the face of imperfect systems and unpredictable faults.

Acknowledgements

The research underpinning this article was funded by EPSRC through a Flex Fund grant awarded by the National Centre for Energy Systems Integration (Award no FFC1-022). The research team included the authors and Andrew Wright, to whom we are very grateful for his advice and guidance.

Plan of the article

INTRODUCTION

1 In the context of energy systems, the notion of flexibility is generally associated with the need to match supply with demand. If either is fixed, it follows that the other must be flexible. From this point of view flexibility and control are not opposites but two ways of conceptualising the means by which a system is managed. In this paper, however, the focus is not on the work of maintaining a balance between supply and demand. Rather than identifying flexibility in the organisation of energy demand or in the ability to produce supply at short notice, we look directly at the process of controlling this relationship, asking whether there is room for flexibility in how this work is configured and organised.

2 We focus specifically on the function and emergence of 'control rooms' in the energy distribution networks (gas and electricity), drawing on a qualitative study based in the North East of England. Once we began to look closely at control room operations, it became clear that despite the extremely tight regulation of what goes on in control rooms, the skill, intuition, creativity and flexibility of the control room operators, so-called 'shift engineers' and 'shift managers' is crucial.

3 In this paper, we look at the role of distribution-level control rooms in the DNOs (Distribution Network Organisations – currently being reframed as Distribution System Organisations or DSOs), asking what flexibility staff have to operate in new ways, what the limits are to their flexibility, and what kinds of flexibility are at stake. The work undertaken in these control rooms is primarily grid management and maintenance, including fault-response and the remote supervision of on-site repairs by sub-contractors and contracted staff. Load-balancing is managed at the Transmission Network level (in the UK, by National Grid) for both gas and electricity networks. Distribution network control rooms play a crucial role, however, in maintaining the smooth operation of the distribution network, linking transmission to supply, managing safety and security, and supervising the planning and implementation of repairs and installation of new equipment. Although operations are closely regulated by the national regulator (OFGEM), control room staff are highly trained to use their own experience and intelligence to manage both foreseen and unforeseen situations. Hence, we argue that despite the tight security and strict procedures, flexibility and creativity are required of the staff.

We do not present a general history of flexibility in UK energy system control rooms, but we do draw on historical documentation in explaining what prove to be key features of control room 'work'. In prioritising a contemporary view, we consider how the legacy of past ideas and practices of energy distribution control feed into current practices, and how the types of flexibility encountered in control systems emerge out of 'legacy assets' as well as conventions and changing traditions of practice. 4

FLEXIBILITY IN ENERGY SYSTEMS AND CONTROL ROOMS

Any study of contemporary energy systems in the UK inevitably has to address the jumble of old and new 'assets', or items of equipment that constitute the energy infrastructure that has accrued over time. Far from being an ideal rational system, energy distribution relies on layers of infrastructure that date back many decades. These include complex material and regulatory infrastructures, alongside equipment that may have been installed up to 70 years ago, staff of various degrees of longevity in different organisations, and enduring conceptual understandings and common principles. In this article, we report on a short research project looking at the degree and kinds of flexibility this leaves for control room operators (or engineers) in two distribution control rooms in the electricity and gas sectors in the UK. 5

Using ethnographic methods (primarily participant-observation and in-depth interviews), we were able to discuss these different types of legacy with control room engineers, and to 6 reflect on the lived memory of change and continuity over recent decades. Hence, this paper takes a distinctive approach to energy history, using anthropological and historiographic methods to consider how past socio-material practices live on in the present in the form of material 'assets' or equipment, infrastructures, modes of doing, and memories of changing practices. We discuss the workings of distribution network control rooms to show where flexibility is found and how it is changing over time.

7 The kind of flexibility we consider here is more operational and finer grained than that which features in normative abstracted discourses of flexibility. Blue *et al*[1] suggest that energy providers, policy makers, and some researchers see flexibility as a technical capacity of the whole energy system, or as a commodity that can be traded or managed through specialized techniques such as demand-side management. Whilst some social researchers treat flexibility as a function of the technical infrastructure,[2,3,4] others take a broader view, conceptualising it as "an emergent outcome of the historical development of constellations of practices that make up social life".[5]

8 In this paper we complement these accounts by homing in on the 'room for manoeuvre' in distribution control rooms as a means of exploring the possibilities for new forms of inter-sector cooperation. We therefore focus on how distribution control is conceptualised, managed and operated in these sites and what this means for shift engineers in their day to day work in control rooms. In other words, we take a more colloquial approach to flexibility as an idea, asking whether and where there is room for creativity or innovation in control room practices, rather than in the management of supply and demand. We could reiterate here also that we are not taking a normative approach to improving the operation of control rooms, but making an empirical enquiry into infrastructure practices in a contemporary but historicised context.

Control room[6] operations themselves are relatively rigid. Routine and procedure tied to lengthy and rigorous training programmes are the primary methods used to ensure that safe and reliable operations are enacted in the control room practices we discuss below. Each routine is in itself backed up by a folder of specifications, rooted in regulatory codes and licence conditions. A closer look at distribution control rooms helps to illustrate how tightly-regulated control room practices are, where the interstices are that allow for different kinds of flexibility, as well as how restricted the discussion of flexibility has tended to be in the energy literature so far. Our findings contribute to an understanding of the changing politics of flexibility in anticipation of low-carbon energy systems which may be anticipated to require some integration of control between different energy 'vectors' such as gas and electricity systems. 9

1 Stanley Blue, Elizabeth, Shove, Peter Forman, "Conceptualising flexibility: Challenging representations of time and society in the energy sector", *Time & Society*, vol. 29, n° 4, 2020, 923-944.

2 Elizabeth Shove, Noel Cass, "Time, Practices and Energy Demand: implications for flexibility. Insights across DEMAND", 01/05/2018. Url: **http://www.demand.ac.uk/wp-content/uploads/2018/06/Time-practices-and-energy-demand-final.pdf** (accessed 07/08/2020).

3 Jacopo Torriti, "Flexibility", *in* Jenny Rinkinen, Elizabeth Shove, Jacopo Torriti (eds.), *Energy Fables: Challenging Ideas in the Energy Sector* (London: Routledge, 2019).

4 Gareth Powells, Michael J. Fell, "Flexibility capital and flexibility justice in smart energy systems", *Energy Research & Social Science*, n° 56, 2019, 56-59.

5 Blue et al "Conceptualising Flexibility" 12 (cf. note 1).

6 Henceforth we use the term 'control room' to imply distribution-network system control rooms

MATERIALS AND METHODS

10 Empirical studies of infrastructure control rooms often use on-site interviews and observational field research methods,[7,8,9,10,11,12] while workplace studies and ethnomethodological research often draw on video-based studies of interactions in control rooms and conversations recorded in those videos.[13] Our project used observational and interview methods, including in-depth interviews and participant-observation in the North of England in 2019, in an electricity distribution and a gas distribution network company respectively. In total, 6 gas control room operators and 12 electricity control room operators have been interviewed and observed, and we conducted over 30 hours of participant observation in the respective control rooms.[14] Given the security issues around system control operations in critical infrastructure such as energy, we must necessarily leave many details out, and occasionally blur the information we present, out of respect for the safety requirements in the system. We hope that this leaves sufficient detail to satisfy the reader.

In addition the paper draws on selected historical documents, including those published in trade journals, technical academic journals, oral histories of energy-industry engineers, and secondary historical sources. These allowed us to incorporate perspectives on the historical emergence of control in energy systems and to show how flexibilities emerge as part of supply-demand relationships at different times.[15] The views expressed in these secondary articles on hierarchies of control, systems theories, and early calculative techniques of energy systems situate present flexibilities as part of longer term processes that continue to influence the life-cycles of infrastructures, and thus the strategies enacted in the control rooms of the present. 11

THE PRACTICES AND HISTORIES OF CONTROL ROOMS IN GAS AND ELECTRICITY DISTRIBUTION

Histories of control rooms in gas and electricity distribution

The character of flexibility in control room operations today is certainly shaped by the development of control-rooms as a means of operation within the development of energy systems more generally. In this section we briefly summarise how control rooms emerged in the gas and electrical systems to offer historical context for the study we go on to describe. 12

There are relatively few documented histories of energy system control in the UK although there are accounts of energy supply and system 13

7 Lucy Suchman, "Centers of coordination: A case and some themes", *in* Lauren B. Resnick, Roger Säljö, Clotilde Pontecorvo, Barbara Burge (eds.), *Discourse, Tools, and Reasoning: Essays on Situated Cognition* (Berglin: Springer-Verlag, 1997), 41-62.

8 Mark de Bruijne, Michel van Eeten, "Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment", *Journal of Contingencies and Crisis Management*, vol. 15, n° 1, 2007, 18-29.

9 Emery Roe, Paul Schulman, *High Reliability Management: Operating on the Edge* (Stanford: Stanford Business Books, 2008).

10 Andrés Luque-Ayala, Simon Marvin, "The Maintenance of Urban Circulation: An Operational Logic of Infrastructural Control", *Environment and Planning D: Society and Space*, vol. 34, n° 6, 2016, 191-208.

11 Antti Silvast, *Making Electricity Resilient: Risk and Security in a Liberalized Infrastructure* (London: Routledge, 2017).

12 Antti Silvast, "Co-constituting supply and demand: managing electricity in two neighbouring control rooms", *in* Elizabeth, Shove, Frank Trentmann (eds.), *Infrastructures in practice: the evolution of demand in networked societies* (London: Routledge, 2018), 171-183.

13 Christian Heath, Paul Luff, *Technology in Action* (Cambridge: Cambridge University Press, 2000).

14 The research was carried out under the auspices of the National Centre for Energy Systems Integration (CESI) in a flex-fund project that sought to study the implications of energy systems integration on control room practices and regulations. The project aimed to open up questions about the potential and challenges for control room integration, in response to anticipated changes in energy system management.

15 We are particularly grateful to Peter Forman and Julie Cohn for their advice and guidance.

control from the US context.[16,17,18,19] However, there is a wealth of technical and historical literature on gas systems, often written by gas engineers themselves,[20,21,22] with some attention to regional systems. In relation to electrical systems, most attention has been devoted to research on grid-scale transmission and control, with far less attention given to the distribution systems that are the focus of this paper. Finally, while extensive histories of early electrification are available for the UK,[23] Germany, and the United States,[24] these histories do not cover the late 20th century or early 21st century. In this paper we draw on this range of sources in describing how control rooms emerged in electricity and gas distribution, why, and what issues they created.

14 What is particularly striking in accounts of the development of system control in the UK (and elsewhere) is the significance of automation and digitisation. In the electricity industry, digitisation has been central in a way that Slayton derides as "digital utopianism" and traces to the deregulation of the energy sector in the 1980s and the 1990s.[25] However, debates about automation and remote-control go back to almost the start of the development of grids. Gas networks were monitored from centralised control rooms (or governor houses) from the 1860s,[26] while emerging grids, such as the 'Sheffield Grid' had control centres from the 1930s.[27] Eight area gas boards were established in the 1960s, which progressively set up grid controls, with shift control officers appointed to a centralised (national) grid control function in 1967. Regional grid control had been set up for the North East of England in 1955, including responsibility for 'co-ordinating day to day operations of all gas production plant, liaison with the Coal Board (for coke oven gas) and with other private supplies'.[28] After conversion to natural gas, control was consolidated and computerised, with telemetry control rooms established by 1981 across the North of England, and updated systems commissioned from 1991 onwards.[29] In this context, controlling gas included the management of pressure and the content of holders, at first through networks of sub-control rooms, and latterly through the regional boards' unitary control rooms. Gas control subsequently evolved to mirror electrical control operations, with centralised transmission control rooms for high voltage/high pressure transmission, and regional distribution control rooms operated by the 8 boards (later companies). Francis notes the introduction of remote-control valves from 1973, and remote-control compressors from 1981.

In the electrical system, analogue machines of the 1950s and earlier provided scale models of the electricity network that were used by electricity systems operators,[30] but by the 1920s automatic frequency control had been introduced in order to keep the alternating current 15

16 Eg. Aristotle Tympas, "Perpetually Laborious: Computing Electric Power Transmission Before the Electronic Computer", *International Review of Social History* vol. 48, supplement, 2003, 73-95.

17 Rebecca Slayton, "Efficient, Secure, Green: Digital Utopianism and the Challenge of Making the Electrical Grid 'Smart'", *Information & Culture*, vol. 48, n° 4, 2013, 448-478.

18 Julie Cohn, "'The old was analogue. The new was digital': Transitions from the Analog to the Digital Domain in Electric Power Systems", *IEEE Annals of the History of Computing*, vol. 37, n° 3, 2015, 32-43.

19 Julie Cohn, *The Grid: Biography of an American Technology* (Cambridge, MA, MIT Press, 2017).

20 E.g. F. S. Charnley, *Some Aspects of Distribution Control as Applied to Interlinked Undertakings, Meeting: 3 November 1951* (Rotherham: Yorkshire Association, 1951).

21 W. Moorcroft, *The Design and Operation of an Automatic Distribution Centre, Meeting: 20 January 1960* (Manchester: Manchester Association).

22 R. F. Francis, *Grid Control – Past, present and future. Presented to Institution of Gas Engineers, Wales District Session 1991/1992* (Kegworth: Institution of Gas Engineers, 1991).

23 L. Hannah, *Electricity before nationalisation: a study of the development of the electricity supply industry in Britain to 1948* (Baltimore: Johns Hopkins University Press, 1979).

24 Thomas P. Hughes, *Networks of power: electrification in western society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983).

25 Rebecca Slayton, "Efficient, Secure, Green" (cf. note 17)

26 Francis, *Grid Control* (cf. note 22)

27 Ibid., 8

28 Ibid., unnumbered appendix

29 Ibid.

30 Julie Cohn, "'The old was analogue. The new was digital'" (cf. note 20) on the grid as close as possible to 50Hz. If we associate "computing" with its definition as performing calculations, there was already an infrastructure of human calculators and electric network analysers in the late 19th century, introduced to help calculate 'processes' of electrification.[31] The emergence of digital technologies and computers in the 1950s increased speed, accuracy, and capacity to address complexity. As Cohn[32] suggests: "Digital computers ... processed larger quantities of data at a faster speed and produced more accurate results. ... They could handle almost any degree of complexity and produced logical decisions."

16 In the electricity sector, centralised computerised control was primarily developed in relation to transmission. In the USA, centralisation was framed in relation to security, especially following the major blackouts of 1965. According to Dy Liacco,[33,34] an electrical engineer referred to as the father of modern energy control rooms, computer software should be imagined as a means to embed security and remove danger and risk from electricity: "Security functions are now incorporated into computer programs to deal with operating conditions as well as with disturbances that could lead to equipment overloads, voltage degradation, frequency decay, system instability, service interruption, or the ultimate catastrophe of a system shutdown".[35] The UK's Central Electricity Generating Board (CEGB) also developed a computer simulation of the security of the national power grid in 1965,[36] with both US, UK and European engineers comparing notes and influencing one another's ideas; Jack Casazza claimed to have been inspired by European ideas for a project to computerise 'total system control' using a 'security assessor' when developing system control in New Jersey following a blackout in Philadelphia.[37]

17 What emerged from this gradual accretion of control operations was a relatively standardised form of centralised control-room that we discuss below.

What is a control room?

18 In the most general terms, control rooms can be understood as the locus of management for distributed infrastructure. Roe and Schulman, for example, note that, 'control rooms across many infrastructures share the same overarching aim: managing a critical service reliably and safely, in real-time, given their system definitions and the specifics of their governing reliability standards.'.[38]

19 In focusing on control rooms, our study is reinforced by decades of theoretical interests developed in workplace studies and organisational studies based on the well-known idea that systems with interactive complexity and tight coupling are prone to unanticipated failures.[39] While the notion of distributed infrastructures provides a compelling example of such systems,[40] studies of vital infrastructures in general and electricity grids in particular have rarely found that these anticipated failures actually manifest.[41,42] Control room workers are faced with complexity, yet develop vigilance and concentration by their working habits, skills, and a culture

31 Aristotle Tympas, "Perpetually Laborious" (cf. note 18)
32 Ibid., 37.
33 Tomas Dy Liacco, "Real-time computer control of power systems", *Proceedings of the IEEE,* vol. 62, n° 7, 1974, 884-891.
34 Tomas Dy Liacco, "System Security: The Computer's Role", *IEEE Spectrum*, vol. 15, n° 6, 1978, 43-50.
35 Ibid., 43.
36 Julie Cohn, *The Grid"* (cf. note 19., 243)
37 Loren J. Butler, Jack Casazza, "An oral history conducted in 1994, IEEE History Center, Hoboken, NJ, USA", 01/02/1994. Url: **https://ethw.org/Oral-History:Jack_Casazza** (accessed 07/08/2020).
38 Emery Roe, Paul Schulman, "A reliability & risk framework for the assessment and management of system risks in critical infrastructures with central control rooms", *Safety Science,* vol. 110, 2018, 80-88, 2.
39 Charles Perrow, *Normal Accidents: Living with High Risk Technologies* (Princeton: Princeton University Press, 1984/1999).
40 See Antti Silvast, Ilan Kelman, "Is the Normal Accidents Perspective Falsifiable?", *Disaster Prevention and Management*, vol. 22, n° 1, 2013, 7-16.
41 Mark de Bruijne, Michel van Eeten, "Systems that Should Have Failed." (cf. note 10)
42 Emery Roe, Paul Schulman, *High Reliability Management*" (cf. note 11)

of safety. The literature developing these arguments about control rooms (including space, aviation, nuclear, and military applications), known as high reliability theory,[43] argues that organisations can achieve high reliability in spite of complexity and coupling. Conversely, systems failures can also be due to organisational culture and management rather than being just traits of systems.[44] This leaves room for asking where the flexibility lies within such systems, but the question is not at the forefront of this literature.

20 In parallel, Science and Technology Studies, and particularly in the tradition of ANT, have attended to a broad range of centres of power and control that are understood as political as well as physical. Law's work on 'action at a distance', for example, shows how centres for navigation acted also as political mechanisms to control distant envoys and empires.[45] It is possible to see that system control centres through their management and development of nation-wide infrastructures also have a nationalising role, embedding state-provided or state-regulated services across the nation-state, and also negotiating terms between nation-states (in the case of national grids, through interconnectors, for example). However, perhaps more relevant to our study of regional distribution network control is the notion launched by Latour[46] of 'centres of calculation', where various data including diagrams, maps, logs, and statistics are accumulated and transformed into broadly accepted knowledge. Both indicate that centres of control exist only in relation to distant actions, and rely on technologies of knowledge that transport information about the world to the calculative centre, which transforms it into knowledge as the basis for infrastructures to be set out again for the purpose of action at a distance.

21 What constitutes the actual 'room' in which control is exercised is therefore debateable, and much of the preparatory work for our field-research consisted of identifying what was meant by 'control room' operations, and which physical location we were actually interested in observing, suggesting to us that the very definition of 'control room' contains a greater degree of flexibility than we had anticipated. On the one hand, there is the physical room in which remote-information system monitors are situated, and where shift engineers and shift managers undertake the tasks of control room operation. But the physical room with its participants and their activities is intrinsically tied into systems created and managed in other arenas. There is a layer of control room planning and management that usually happens outside the physical control room itself, for example. This 'support' may include the management of the communications software and its configuration, detailed planning and scheduling of site-based routine maintenance or repair works (i.e. 'out there' on the grid infrastructure), liaising with outside agencies and sub-contractors, organising the shifts of staff in the control room, and so on.

22 Occasionally a support engineer (that is someone responsible for managing the kinds of support outlined above) may sit in the room to monitor the operation of the system and observe where improvements need to be introduced, but in the UK transmission and distribution network world that we have observed, control operations and support are generally seen as separate, if linked functions. The room in which control functions are enacted on a day-to-day basis has thus achieved a degree of fetishization in the energy industries. By this we indicate a degree of reverence that is created by the heightened security around control room access and operation. The apotheosis of this is the centralised transmission-system control rooms of the National Grid, with glass viewing-platforms for visitors, and

43 Gene Rochlin, Todd La Porte, Karlene H. Roberts. "The self-designing high-reliability organization: Aircraft carrier flight operations at sea", *Naval War College Review* vol. 40, n° 4, 1987, 76-92.

44 E.g., Diane Vaughan, "Theorizing disaster: Analogy, historical ethnography, and the Challenger accident", *Ethnography* vol. 5, n° 3, 2004, 315-347.

45 John Law, "On the Methods of Long Distance Control: Vessels, Navigation, and the Portuguese Route to India", *in* John Law (ed.), *Power, Action and Belief: A New Sociology of Knowledge?* (London: Routledge, 1986), 234-263.

46 Bruno Latour, *Science in action: How to follow scientists and engineers through society* (Harvard: Harvard University Press, 1987), 232.

the supposedly secret location of the emergency backup Control Room to be used in cases of extreme national emergency. While the degree of reverence is rather less pronounced at the distribution level, all staff know that control room engineers should not be unduly disturbed, and that office sociality would always be subservient to disturb control room operations (as we detail below). Even our request for access to observe the control room operations for research purposes went through several rounds of approvals and was allowed on condition that we kept quiet and out of the way and did not disturb operators.[47] We were also asked, in one instance, not to indicate to our taxi driver the function of the building we were travelling to.

23 A control room is, by definition, linked through communication systems to the broader infrastructure, whether that is by the data system communications, emails, telephone lines or, (perhaps surprisingly still) fax machines, such that the tentacles of control reach in and out of the room where the shift engineers operate. The equipment and activities in the control room itself are subject to a suite of regulatory codes, legal strictures and safety routines, as well as management procedures and protocols. As control room staff use communications equipment such as telephones, their reach extends to remote sites through communication with site-engineers.

Taking these layers into account, even based on a narrow definition, the control room can be conceived to include:

- The physical space (the control room).
- The people who work within that physical space (operators).
- Physical equipment within that physical space, which is connected to distributed monitoring and control systems (control and monitoring systems).
- Tools and systems for analysing and forecasting data from monitoring systems and recommending actions.
- A framework of procedures, rules, guidelines, protocols.
- Connections and communications to external infrastructures.
- A support system of planning and operation agents.
- A broader framework of commercial operations in which the company operates.

A control room may therefore be conceptualised as a physical space housing control equipment and operators, but is intimately connected to diverse and distant elements of infrastructure by physical, conceptual and governmental means. It is certainly a 'centre of calculation', even if much of the literally calculative action is nowadays managed through digital systems leaving shift engineers to organise off-site responses to distant maintenance issues, faults and repairs. Changes to the calculative system itself (ie the workings behind the digitised systems) are undertaken by separate groups of support engineers usually located outside the core control room (as noted above). 24

Such generic descriptions of control rooms leave out the specific histories and politics of how they have been set up in different periods and contexts. The energy sector includes various kinds of control rooms, from large scale power-station operations to distribution and transmission networks. These serve different purposes under the general engineering rubric of 'control'. For example, DNOs are responsible for the distribution of energy from the transmission system to the supply level, but while they are required to despatch energy to meet demand within the constraints of the distribution network, their primary role is to maintain the system in working order, and oversee outages and repairs on the ground from the control room. Procedures, rules, codes and guidelines are intended to reflect the requirement to prioritise safety and reliability, but they also relate to the commercial and regulatory framework within which the critical service operates. 25

47 Indeed, we were pleasantly surprised by how much the operators were actually prepared to converse with us in practice and talk us through their activities, although we were told clearly when that was not possible, as engineers responded to calls and so forth.

26 The control of energy in terms of distribution (moving it from here to there) is separated from the forms of control involved in the commercial 'arm' of the organisations at the practical level. Distribution control operators inform us that they have little contact with the company's commercial operations, which are removed to another site (so much so that they appeared to know little, if anything, about it). In other words, control room operation at DNOs is strictly demarcated around safety and distanced from commercial imperatives. Control room operators are not required to use any creativity or flexibility in relation to the commercial interests of the company, since budgeting and accounting for repairs and maintenance is managed in another area (eg in 'support' or planning operations), although shift engineers in some companies are taken off the front line every few years to work on the support side, where they have an opportunity to use their experience to reflect more strategically. Even so, one shift manager who had come up with a scheme to improve the efficiency of maintenance schedules was actively rebuffed by the organisation's management.

What happens in the control rooms we visited?

27 The control rooms we visited shared certain key features. Each was housed in an innocuous-looking office block, and consisted of a suite of office tables and computer monitors. On the walls were TV screens showing weather forecasts, and in the electricity control rooms, a wall monitor displayed the frequency of the grid in real-time. Control engineers claimed that this was largely ignored, being present only to fulfil regulatory requirements, since alerts about system frequency would be picked up through other monitoring systems without the need for the wall monitor. The weather monitor they used only to check if significant electrical storms might be approaching, or to be alert for potential faults. By contrast in the gas control room, weather information fed into daily forecasts for day-ahead demand.

28 Each desk had two or three monitors and a telephone, while the electricity control room desks also had head-pieces for the telephones, which could be doubled and shared. Operators have printed lists to work with, as well as an operating system that gives them multiple views of the external energy infrastructure network. The remote system is known as SCADA which stands for Supervisory Control And Data Acquisition, a commonly used system in various applications. The system works at various scales, so that operators can see the whole network, or zoom in as far as individual 'assets' or pieces of equipment on a schematic basis (ie through symbolic diagrams, not via satellite imagery for example). The system shows a selection of conditions of local equipment – for gas they show pressures and valve positions in various pumps and treatment assets, while the electricity system provides details of voltages, currents, switch positions, etc.. This information remains partial, only indicating asset ratings or certain faults. The degree of remote control is equally partial, with some transformers or circuit breakers operated from the control room while others require manual operation on site. Most of the operations happening in the control room could be better described as communication management rather than remote operations. Control room engineers have oversight of the whole system, and take responsibility for one area during their shift, which might extend to a whole geographic county or a larger region. Within that area, they will be furnished (by the planning and support office) with a list of repairs and maintenance activities that are to be undertaken during the shift, and they will respond to faults or errors that crop up. These might appear on an 'alert' screen as unexpected conditions that require attention, or they may be routed through the customer service centre if members of the public call in to report faults or outages, or occasionally they might be telephoned in by site engineers.

Each control room housed only a very small number of engineers, between 4 and 6, with each taking responsibility for a large area of the regional network. In response to either scheduled work or fault alerts, the shift engineers speak to (mostly sub-contracted) on-site engineers to ensure that 29 the site operations are carried out safely and to the required specifications. In both gas and electricity control rooms, the engineers follow a protocol to ensure that communications are fully understood, with a particularly strict protocol of call and repeat observed in the electricity control room. Control room engineers read step-by-step from a script prepared by the support engineers, requiring the on-site engineers to repeat back word for word, to ensure that what is recorded in the control room matches what is happening on the ground, so that both sides know whether and where currents may be flowing, to protect workers and assets.

30 This method, well-established at the time of our study, enables the control room engineers to extend their surveillance of the external network beyond the digital information systems that feed their monitors, effectively giving them contact with 'eyes on the ground'. Hence when a field engineer reports that a breaker is closed while it is showing on the SCADA system as open, they can discuss why this might be, where the fault lies and what the remedy might be. For example, the field engineer might recognise this fault from a previous occasion, and know that a worn part allows this particular breaker to close itself, and the instruction to close the breaker can be aborted. This will then be logged on the information system as a known fault, either to be recognised next time, or to be fed into a schedule of repairs to be corrected in the future. In detail the 'history' of the system is built up by accretion of details like these. Control room engineers and, indeed, engineers on the ground, use their own knowledge and experience to complement the information from the digital information systems they use, and can operate these systems flexibly, in that sense, based on their knowledge of its shortcomings and limitations.

31 In both control rooms, a general tenor of relaxed but alert operation is noticeable. There is little chit-chat, although at very quiet times the engineers may have light-hearted conversations. Instilled into them during a long period of training is the imperative of professional safety management, and the recognition that other people's safety – people's lives, indeed - relies on their professional conduct. Outside the control room itself, such as in the office where the support staff work, there might be a social gathering to send off a member of staff who is leaving, with cakes and drinks being shared but this would not happen in the control room. In fact, neither control room event instituted formal breaks, with staff informally making each other cups of tea and coffee, covering each other's desk for comfort breaks, and either bringing their own packed lunches or ordering in food rather than taking time out, since that would require an additional layer of formal staffing that neither organisation offered. Since the control rooms were organised to respond to unexpected events as well as manage routine maintenance, breaks were flexible too, fitting into moments of quiet and being disrupted if any kind of emergency cropped up. Both control rooms had trainee staff on hand who could cover for less-regulated tasks within their level of qualification, thus also learning to be flexible in their approach to the work.

Attention is always primarily on the SCADA system, the schedules of operations, and on any emerging conditions that may require attention. A pervasive atmosphere of calm, focused attentiveness is almost palpable, reinforcing the sense that things are 'under control'. In other words, the control room engineers exert a degree of emotional control that minimises external distractions (e.g. from interpersonal frictions). This helps them keep focused on the tasks at hand while controlling the potential stress of dealing with multiple and sometimes unpredictable or complex fault responses that, at the same time, require them to think flexibly and creatively to solve problems efficiently and, above all, safely. 32

Specificities of the gas and electricity control rooms

While much of the control room operation was similar for each network, there were a few notable differences that shape the degree of flexibility available to the engineers. Gas control engineers monitor pipe pressures, check on the condition of gas being fed into the system from biogas generators and on particular requests 33 for supply that might have come in from major consumers, as well as emerging faults or routine maintenance schedules, while watching weather forecasts that might alert them to possible changes in demand. Electricity control engineers also watch the weather forecasts, although only to check for electrical storms that might cause faults.[48] They also have a grid frequency monitor in the room to comply with regulations, but tell us that if the frequency were to go awry, they would probably know about it already from other indicators, as noted above. In both cases, reports of faults that come in from members of the public are routed through a call centre, which triages the calls and forwards details of any significant problems that must be dealt with.

34 Gas control room engineers calculate day-ahead forecasts at five points during the day, which are then sent to the transmission network operators to help plan the next day's supply, a duty that is not undertaken in the electricity control room. The gas control room engineers use modelling software to help them match expected demand patterns to historical patterns, aggregated for comparison, but they also combine this with experience, giving them a sense of the likelihood of particular patterns arising, based on a broad set of contextual factors (including patterns of changing weather, season, day of the week, public events, and so on). Forecasting is a process that clearly builds on past patterns and trends. Completely unprecedented events cannot be forecast, but known upcoming events can be evaluated, compared to other known events in the past, and estimated. We understand that control room activities were intense and challenging in response to the Covid-19 lockdown, when demand patterns changed dramatically in response to quite new scenarios.[49]

These circumstance aside, we see remarkable continuities in gas distribution control operations over the last half century or more. In 1951, Charnley described the importance of gas forecasting for optimising compression and gas costs, highlighting the significance of weather forecasting and the regular consultations between the gas boards and the Met office. He also outlined the duties of a shift control engineer who: 35

> determines demand for next 24 hours, correcting for rapid variations in temperature; arranging production of peak load gas by various works; directing flow of gas to balance stocks and make us of all available storage; planning daily gas pumping programme for most economical distribution and minimising transmission power charges; accommodating day to day repairs and breakdown when necessary.[50]

In the gas distribution control room that we observed, only gas production was no longer something the shift engineers worried about, but all other tasks were similar, if updated. 36

In contrast, electricity control room engineers do not engage in forecasting, which is managed at transmission level, but manage a more complex set of infrastructure assets than on the gas network. This requires complex calculation and knowledge of system flows, including positive and reactive currents. They may deal with voltage variations coming from solar PV inputs, and need to be alert to which transformers can take directional currents and which cannot. 37

While routine operations may appear mundane, all control engineers are also trained to respond to major incidents, whether caused in their network or requiring a response. At these points, they may potentially be required to work in another region, when they become aware that each control room 'speaks a different language'. Each instruction has to be 'translated' to ensure that they fully understand one another. At the local level, each control 38

48 Tasks such as balancing demand and supply are managed at the transmission (national) level in the UK and not in these distribution control rooms.

49 Precisely because of these conditions, we have been unable to observe these changes and can only report secondary reports and informal communications. At a general level, National Grid have published reports on their response to the changing demand patterns. See NG Summer Outlook (April 2020) **https://www.nationalgrideso.com/document/167541/download** and the National Grid Energy Systems Operator data portal https://data.nationalgrideso.com

50 F. S. Charnley, *Some Aspects of Distribution Control as Applied to Interlinked Undertakings*" (cf. note 20, 704.)

room has its own history, developing a unique institutional culture and way of doing things that is peculiar to that one organisation, and tied to the particularities of the infrastructure in that region. That is, engineers may develop particular skills in relation to the grid's adaptation to heavy industry in one area, or remote rural networks in another. Although the regions are large, covering urban and rural areas, the particular layout of the grid including the legacy of generations of infrastructure, requires attention to different issues, fragilities and weaknesses in the grid. And, as in any small geographically located community, local dialects develop, and routines adapt to the personalities of the engineers, as well as particular shift patterns being adopted over time.

39 What was stressed to us throughout our observations and interviews was primarily the continuity in control room operation, the strict adherence to protocols and routines, alongside the lack of coherence in the grids due to the wide variety of equipment – in age, style, manufacturer and reliability – that they have to manage. Engineers also stressed the combination of planned and responsive activities, and the need to adapt to circumstances, particularly in managing diverse maintenance and repair operations on different sections of the grid at the same time. Shift engineers need to be able to multi-task while maintaining focus on safety and regulations. These things remain constant, while the details are constantly changing. We interpret this to mean that control room engineers are always using their own flexibility and creativity to ensure that the system remains under control. How they achieve this is something that changes over time in both gradual and iterative ways, and in their reflections, some of the more established engineers were able to identify changes that are otherwise not apparent on a day to day basis.

How have control rooms changed in the last three decades?

40 In our discussions with control room staff, and particularly with more experienced control room managers, the primary reflections on change over time followed a retrospective horizon across the span of their careers. The kinds of change that they wanted to discuss with us included the skills for the job, changing recruitment, and to some degree, changing management practices (particularly in relation to different owners, as the businesses were bought and sold between different international conglomerates).

They emphasised first the flexibility of control room engineers to adapt to changing control technologies over the course of their careers. Among the most significant changes concerned the shift to digital systems. Until the 2000s, control room engineers were typically recruited from among field engineers. People who had previously worked on the 'assets' on site, making repairs, fixing faults, installing equipment, were considered to have a knowledge of the system that would equip them to be control room operators. Knowing the equipment and understanding the network were highly valued skills, and engineers with this background could easily translate the systematic diagrams, site locations and fault types into recognisable situations, meaning that they could both envisage how the problem looked on the ground, and communicate effectively with site engineers telephoning in with information from the 'real world'. What's more, as older, more experienced engineers, they would have had time to accrue 'life skills', and could be more robust in the face of emergencies, and more reliable as employees in charge of crucial infrastructure. 41

More recently, though, the shift engineers have realised that (typically) men in their 40s (and, we should add, primarily practical engineers) are often not ideally suited to working in the multi-functional, multi-tasking environment of the contemporary IT-driven control room. 'They're used to doing one job at a time', a shift manager explained to us. 'Here there are time pressures, and so forth, and they don't thrive'. In the last five years, he continued, many have been withdrawn or left the control room, and newer recruitment strategies aim to find younger, more agile, more IT-literate operators who are good multi-taskers and quick learners. These recruits can then be trained and given the 42 knowledge and experience required to manage the system. In fact, one engineer hinted that video gaming, with its requirement to focus on multiple factors and respond quickly and accurately to emerging and unexpected tasks, offered a valuable set of skills, although they hastened to add that system control was not a game. As one of the shift managers told us, his background as an apprentice electrician, later qualifying as an electrical engineer and achieving promotion into the control room was not a career path that would be possible today, and at his age (early 50s), he would certainly not be appointed now. Possible career paths of engineers have thus changed in response to changes in technology, bringing life histories in and out of sync with the technologies of grid control.

43 The training of control room engineers also entailed a combination of absolute rigidity and remarkable flexibility. Following a safety hierarchy that prioritises the safety of staff and public, then the assets, then customer supplies, engineers are trained via a strict sequence of modules that require them to learn system layouts, regulatory requirements, emergency responses and so on. These are specified, approved and regularly updated in liaison with the regulatory authority. However, the time taken to complete the training was highly variable. The priority was in ensuring that the trainee became competent, rather than the time taken to achieve competence. This meant that training schemes could be completed according to the trainees' learning capacity. For example, operational elements of system management were taught by layering up safety management constraints through 5 different levels of training. First, trainees develop IT skills over approximately 6-12 months. Then it may take around 12-18 months to learn about the company generally, another 6 months to learn the low-voltage system, moving up gradually to the next level of system-voltage. All the time, the trainee may be taking on small or non-critical tasks, observing and assisting in the control room, and gradually beginning to operate the control desk under supervision. They pass through to the next stage of training when they have built the confidence to proceed, and when their supervisor agrees that they are competent (as well as passing various kinds of test). Training, in other words, follows a strict pattern in terms of content and progression to the next level of authorisation, following a 'competency profile', but it is also flexible in terms of the time trainees are given to progress to the next stage.

The pace of technological change is such that engineers also have to complete retraining at regular intervals, and in the electricity network, shift managers were also expected to move into the planning section for a year every few years, bringing their operational expertise into the planning of operations, and, at the same time, escaping the gruelling routine of working to shift patterns. Within the control room, shift patterns themselves also combined rigidity and flexibility. While strict rules about rest-periods applied, engineers could work within them to swap shifts to make space for family events, for example, or holidays. And engineers were also expected to display a degree of flexibility in allocating hours when they could be called upon to respond to emergencies. Employee flexibility has also been apparent through the Covid-19 lockdown, with companies reporting that control room engineers have moved into temporary accommodation on-site, so as to avoid the lockdown conditions that might otherwise prevent them from carrying out their duties. 44

The everyday flexibility of engineers could also be seen in relation to the historical rigidities and weaknesses of the networks. Network management, and in particular maintenance regimes, can be evaluated in terms of risk. The ideal is to achieve 100% operation – operation of all of the grid at all times - but design standards always entail degrees of risk around potential losses, outages for maintenance, degrees of redundancy that are affordable in the system, and so forth. Control room engineers work with the unpredictability of asset-failures and faults, using their ingenuity and problem-solving skills within the limits of safety and security rules that are largely treated as absolute. 45

46 In fact, control room systems and control room engineers have adapted to significant system changes in the past two to three decades. The introduction of distributed generation – i.e. the shift from large fossil-fuelled power plants to lower-powered renewable generation sources - means that new knowledge and procedures are required to keep operations safe when flow-directions cannot be calculated. In particular, where legacy assets, such as ageing transformers without remote control, cannot send adequate information through the SCADA system, operators have to be particularly alert to ensure that areas under maintenance are entirely safe.

47 The information system is not based on dynamic modelling, and does not offer prediction, so power flows can be difficult to identify in the current context of increasingly distributed generation (i.e. power now flows in both directions along some parts of the grid). Some parts of the system have excess capacity while others are considerably constrained, and this must be managed by engineers who internalise the flexibility required to adapt to diverse conditions on the network, as well as changing contextual circumstances (from changing weather to local, regional or even national emergencies). Control room engineering can therefore be characterised as a curious combination of routine and exception, banality and intense creativity, tedium and action.

48 The engineers also spent a great deal of time describing their shift patterns, and the changes in shift-patterns they had dealt with throughout their careers. Shift patterns are complex, going through changing cycles of day/evening/night shifts and rest periods, including on-call periods, over the space of around six weeks that ensure that at least one shift manager is on site during the daytime hours when maintenance is mostly scheduled. Throughout the shift, though, there are no scheduled rest breaks. Engineers can operate one another's desks, and co-operate amongst themselves if they need to take a break for refreshment or relief. Some brought their own food (particularly for the night shift) or ordered in sandwiches, while they tended to make rounds of tea and coffee for one another throughout the shift. To this degree, they flexibly managed their own shifts, since taking fixed breaks would require cover, which they accepted as an inefficiency.

As these examples indicate, control room engineers have to manage a very broad range of infrastructure assets of different ages, quality and predictability, based on partial information and through rolling patterns of shift-work. In responding to these challenges they describe multiple forms of flexibility. The demands they face, and the forms of flexibility that are consequently called for gradually shift over time, but at any one moment, day to day practices appear relatively stable. These are not unusual experiences. Other studies of control rooms indicate that people such as shift engineers operate according to their own theories of skill, achievement and 'working well'[51,52,53] and that different forms of flexibility are required as technologies change over time, as complex systems unfold and as 'legacy' and experience mesh with innovation and novelty. Hence we consider adaptability as another form that flexibility can take among control engineers. 49

CONCLUSIONS

In this article we have described how the notion of centralised control emerged as a standard form in network management, and we give a detailed description of everyday distribution control room operation today. In doing so, we show how the operation of system control requires a degree of flexibility among the engineers who operate the control function. Rather than focus on the flexibilities of supply and demand, we have considered the personal qualities of flexibility, both in regard to the daily operations of managing the diverse tasks required in control operations and across 50

51 Lucy Suchman, "Centers of coordination" (cf. note 7)
52 Christian Heath, Paul Luff, *Technology in Action*" (cf. note 13)
53 Antti Silvast, "Monitor Screens of Market Risks: Managing Electricity in a Finnish Control Room", *STS Encounters*, vol. 4, n° 56, 2011, 145-174.

the life course or career-path of control engineers. We have noted the changing demands on control room engineers, and the limits to their flexibility that lead to the retirement of some engineers and the recruitment of those with different sets of skills.

51 From this, our main conclusion is that flexibility can be identified in many areas of the energy system, not merely in the matching of supply and demand. As we learned, flexibility is required to maintain functioning networks, whether that depends on the response rates of equipment or the ability of engineers to extemporise, apply their knowledge and skills to new situations, make judgements and predictions to generate forecasts, or adapt to changing shift-work patterns in their daily lives. Control rooms have emerged in gas and electricity distribution systems along with the development of networks and grids. In both cases, there is a common mentality and approach based on an underlying principle of system-control, alongside a pragmatic acceptance that the system is in fact far from perfectly controllable. The outcome of this ambivalence is that control room engineers must act flexibly in the detail of their work and in how they develop their careers and life-paths. Even in the most rigidly controlled systems, imperfections, errors and breakdowns call for creativity, the application of intelligence to interpret rules and protocols in response to new circumstances. In our view, the multiple histories of diverse kinds of flexibility warrant closer attention.

Bibliography

Blue Stanley, Shove Elizabeth, Forman Peter
"Conceptualising flexibility: Challenging representations of time and society in the energy sector", *Time & Society*, vol. 29, n° 4, 2020, 923-944.

Butler Loren J., Casazza Jack
"An oral history conducted in 1994, IEEE History Center, Hoboken, NJ, USA", 01/02/1994. Url: https://ethw.org/Oral-History:Jack_Casazza (accessed 07/08/2020).

Charnley F. S.
Some Aspects of Distribution Control as Applied to Interlinked Undertakings, Meeting: 3 November 1951 (Rotherham: Yorkshire Association, 1951).

Cohn Julie
"'The old was analogue. The new was digital': Transitions from the Analog to the Digital Domain in Electric Power Systems", *IEEE Annals of the History of Computing*, vol. 37, n° 3, 2015, 32-43.

The Grid: Biography of an American Technology (Cambridge, MA: MIT Press, 2017).

de Bruijne Mark, van Eeten Michel
"Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment", *Journal of Contingencies and Crisis Management*, vol. 15, n° 1, 2007, 18-29.

Dy Liacco Tomas
"Real-time computer control of power systems", *Proceedings of the IEEE,* vol. 62, n° 7, 1974, 884-891.

"System Security: The Computer's Role", *IEEE Spectrum*, vol. 15, n° 6, 1978, 43-50.

Francis R. F.
Grid Control – Past, present and future. Presented to Institution of Gas Engineers, Wales District Session 1991/1992 (Kegworth: Institution of Gas Engineers, 1991).

Hannah L.
Electricity before nationalisation: a study of the development of the electricity supply industry in Britain to 1948 (Baltimore: Johns Hopkins University Press, 1979).

Heath Christian, Luff Paul
Technology in Action (Cambridge: Cambridge University Press, 2000).

Hughes Thomas P.
Networks of power: electrification in western society, 1880–1930 (Baltimore: Johns Hopkins University Press, 1983).

Latour Bruno
Science in action: How to follow scientists and engineers through society (Harvard: Harvard University Press, 1987).

Law John
"On the Methods of Long Distance Control: Vessels, Navigation, and the Portuguese Route to India", *in* John Law (ed.), *Power, Action and Belief: A New Sociology of Knowledge?* (London: Routledge, 1986), 234-263.

Luque-Ayala Andrés, Marvin Simon
"The Maintenance of Urban Circulation: An Operational Logic of Infrastructural Control", *Environment and Planning D: Society and Space*, vol. 34, n° 6, 2016, 191-208.

Moorcroft W.
The Design and Operation of an Automatic Distribution Centre, Meeting: 20 January 1960 (Manchester: Manchester Association, 1960).

Perrow Charles
Normal Accidents: Living with High Risk Technologies (Princeton: Princeton University Press, 1984/1999).

Powells Gareth, Fell Michael J.
"Flexibility capital and flexibility justice in smart energy systems", *Energy Research & Social Science*, n° 56, 2019, 56-59.

Rochlin Gene, La Porte Todd, Roberts Karlene H.
"The self-designing high-reliability organization: Aircraft carrier flight operations at sea", *Naval War College Review* vol. 40, n° 4, 1987, 76-92.

Roe Emery, Schulman Paul
High Reliability Management: Operating on the Edge (Stanford: Stanford Business Books, 2008).

"A reliability & risk framework for the assessment and management of system risks in critical infrastructures with central control rooms", *Safety Science,* vol. 110, 2018, 80-88.

Shove Elizabeth, Cass Noel
"Time, Practices and Energy Demand: implications for flexibility. Insights across DEMAND", 01/05/2018. Url: http://www.demand.ac.uk/wp-content/uploads/2018/06/Time-practices-and-energy-demand-final.pdf (accessed 07/08/2020),

Silvast Antti
"Monitor Screens of Market Risks: Managing Electricity in a Finnish Control Room", *STS Encounters*, vol. 4, n° 56, 2011, 145-174.

Making Electricity Resilient: Risk and Security in a Liberalized Infrastructure (London: Routledge, 2017).

"Co-constituting supply and demand: managing electricity in two neighbouring control rooms", *in* Elizabeth, Shove, Frank Trentmann (eds.), *Infrastructures in practice: the evolution of demand in networked societies* (London: Routledge, 2018), 171-183.

Silvast Antti, Kelman Ilan
"Is the Normal Accidents Perspective Falsifiable?", *Disaster Prevention and Management*, vol. 22, n° 1, 2013, 7-16.

Slayton Rebecca
"Efficient, Secure, Green: Digital Utopianism and the Challenge of Making the Electrical Grid 'Smart'", *Information & Culture*, vol. 48, n° 4, 2013, 448-478.

Suchman Lucy
"Centers of coordination: A case and some themes", *in* Lauren B. Resnick, Roger Säljö, Clotilde Pontecorvo, Barbara Burge (eds.), *Discourse, Tools, and Reasoning: Essays on Situated Cognition* (Berglin: Springer-Verlag, 1997), 41-62.

Torriti Jacopo
"Flexibility", *in* Jenny Rinkinen, Elizabeth Shove, Jacopo Torriti (eds.), *Energy Fables: Challenging Ideas in the Energy Sector* (London: Routledge, 2019), 103-111.

Tympas Aristotle
"Perpetually Laborious: Computing Electric Power Transmission Before the Electronic Computer", *International Review of Social History* vol. 48, supplement, 2003, 73-95.

Vaughan Diane
"Theorizing disaster: Analogy, historical ethnography, and the Challenger accident", *Ethnography* vol. 5, n° 3, 2004, 315-347.

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

REVIEWS

ISSN 2649-3055

JEH
RHE

Journal of Energy History
Revue d'histoire de l'énergie

AUTHOR
Francesca Sanna
Post-doc researcher at Université Paris Est Créteil - Gustave Eiffel, Lab'Urba

POST DATE
14/04/2021

ISSUE NUMBER
JEHRHE #5

SECTION
Reviews

KEYWORDS
Territory, Sovereignty, Power, Politics, Transition

DOI
in progress

TO CITE THIS ARTICLE
Francesca Sanna, "Powering Up Canada: A History of Power, Fuel, and Energy from 1600 (Ruth W. Sandwell, ed., 2016)", *Journal of Energy History/Revue d'Histoire de l'Énergie* [Online], n°5, published 14 April 2021, URL: energyhistory.eu/en/node/251

Powering Up Canada: A History of Power, Fuel, and Energy from 1600 (Ruth W. Sandwell, ed., 2016)

Bibliographic reference

Ruth W. Sandwell, ed. *Powering Up Canada: A History of Power, Fuel, and Energy from 1600* (Montreal and Kingston: McGill-Queen's University Press, 2016)

Abstract

Powering Up Canada investigates the problem of energy in Canada with an interdisciplinary approach and a historical *longue durée* perspective. Edited in January 2016 by R. W. Sandwell, the volume follows a symposium organized in 2013 by the *Network in Canadian History and Environment* around a common question: what History for energy in Canada? *Powering Up Canada* aims at being a first comprehensive overview of the role that different forms of energy and private and public actors had in shaping the history of this country.

Plan of the article

ISSN 2649-3055

A GENERAL OVERVIEW

1 *Powering Up Canada* investigates the problem of energy in Canada with an interdisciplinary approach and a historical *longue durée* perspective. Edited in January 2016 by R. W. Sandwell,[1] the volume follows a symposium organized in 2013 by the *Network in Canadian History and Environment* around a common question: what History for energy in Canada? *Powering Up Canada* aims at being a first comprehensive overview of the role that different forms of energy and private and public actors had in shaping the history of this country.

2 The volume is structured in two parts provided with a contextualising introduction and a conclusion. The first part explores forms of energy like food, water, wind, and wood, while the second is focused on coal, hydroelectricity, oil, gas and nuclear power. This division could seem very scholastic but is not obvious. It explicitly refers to E.A. Wrigley's hypothesis about a 18th-century shift from an organic energy regime (seasonal, sun, land, and water-based energy) to a mineral one (constant, concentrated, transportable energy). However, the final purpose of the book is to offer some criticism of Wrigley's theory. With an interdisciplinary approach, the essays demonstrate how continuities and differences have equally helped shape the Canadian energy landscape.

TWO PARTS, ONE SCOPE

3 Through the different contributions, the book provides a portrait of each form of energy since the time of the first settlers, whose energy "fuel" - nutrition – was provided by indigenous animal species. The specific richness of these resources in Canada thus provided a solid base for the expansion of colonial trading networks as shown by George Colpitts[2] (Chapter 2). The same crucial role of animals is underlined by J. I. Little[3] (Chapter 3) and by Joanna Dean[4] and Lucas Wilson[5] (Chapter 4). For Little, horses are "living machines", used for a long time in urban areas, even in contemporary times. Therefore, he contests the interpretation of these animals as a pre-industrial form of energy. This idea meets Dean and Wilson's contribution, which considers urban workhouses as "industrialized organisms" and horses as a bridge between human-powered and steam-powered metropolitan labour. A similar pattern comes from Joshua MacFadyen's[6] contribution about the history of wood energy (Chapter 5). In his view, the energy transition from wood to coal is overestimated due to a lack of recording on the uses of wood. Then, Eric

1 Ruth W. Sandwell is Professor at the University of Toronto and Fellow at the Rachel Carson Center. She explores the history of energy and everyday life in Canada in the nineteenth and twentieth centuries. She edited *Powering Up Canada: A History of Fuel, Power, and Energy from 1600* (Montreal, Kingston: McGill-Queen's University Press, 2016), and published *Canada's Rural Majority, 1870–1940: Households, Environments, Economies* (Toronto: University of Toronto Press, 2016), both in 2016.

2 George Colpitts teaches environmental history at the University of Calgary. His publications include *Pemmican Empire: Food, Trade, and the Last Bison Hunts in the North American Plains, 1780-1882* (Cambridge: Cambridge University Press, 2015); *North America's Indian Trade in European Commerce and Imagination, 1580-1850* (Leiden: Brill, 2014), and *Game in the Garden: A Human History of Wildlife in Western Canada to 1940* (Vancouver: UBC Press, 2002).

3 Jack Little, Emeritus Professor in the Department of History at Simon Fraser, is specialized in Canadian history, particularly on Quebec. He wrote various essays ranging from political history to cultural studies and landscape analysis. His latest publication is *Fashioning the Canadian Landscape: Collected Essays* (Toronto: University of Toronto Press, 2018).

4 Joanna Dean is Associate Professor of History at Carleton University, where she teaches animal history and environmental history. She runs a lecture series, *Beastly Histories*, and co-edited in 2017 *Animal Metropolis: Histories of Human Animal Relations in Urban Canada* (Calgary: University of Calgary Press 2017).

5 Lucas Wilson is a lawyer based in Toronto with an interest in the history of animal welfare. He studied history at Queen's University, Kingston.

6 Joshua MacFadyen is Assistant Professor of environmental humanities in the School of Historical Philosophical and Religious Studies and the School of Sustainability. His work examines the social and ecological problems of energy in Canadian and U.S. agriculture, particularly during the transition from traditional to modern agroecosystems. In 2016 he coedited *Time and a Place: An Environmental History of Prince Edward Island* (Montréal, Kingston: McGill-Queens University Press, 2016).

W. Sager[7] (Chapter 6), Jenny Clayton[8] and Philip Van Huizen[9] (Chapter 7) devote their research respectively to wind and waterpower. Born before the era of electricity, water mills rapidly began to process metals and became a key issue for verticalization while wind resource remains constantly dispersed and limited in Canadian history.

4 The second part addresses the so-called "mineral energies" which are extracted through inorganic resources. All the authors underline how geography is a key to understand the energy balance of inorganic resources. In this regard, the relation between coal and hydroelectricity in central Canada is a clear example provided by Andrew Watson's,[10] Matthew Evenden's[11] and Jonathan Peyton's[12] essays (chapter 8 and 9). Their point is that the natural poverty of coal in some specific Canadian regions improved the development of hydroelectricity, but they also specify that the process of transforming a resource into energy is not understandable through the lenses of geographical determinism. In fact, coal and hydroelectric power were differently employed: the first supplied nuclear stations, the second was for private and other public uses. The segmentation of the energy market responded to the agency of public actors, in a sort of primordial energy policy. In this context, the authors interestingly underline that this policy was not always guided by a cheaper and better rationality. A study of political geography is thus essential to understand the whole issue of a national economic policy on energy without being deterministic.[13] This assumption is confirmed by Steve Penfold[14] (chapter 10) who shows how, inversely, Canadian geography, that is the political division of the Canadian space, depended on a political decision concerning foreign and indigenous oil supply. However, public actors are not the only players in the game because, as shown by Ruth W. Sandwell and Colin Duncan[15] (chapter 11), multinational companies had an interest in shaping natural

7 Eric Dr. Sager is former Professor of the University of Victoria and a member of the Atlantic Canada Shipping Project, the Director of the Canadian Families Project, and a co-investigator on Canadian Century Research Infrastructure. He is a member of the Executive of Landscapes of Injustice. His research has earned him membership in the Royal Society of Canada.

8 Jenny Clayton is an independent scholar at the University of Victoria, where she has taught courses on Canadian and Environmental History at the University of Victoria and at Vancouver Island University. For her dissertation, she explored the history of parks and outdoor recreation in twentieth-century British Columbia, a project that involved archival research, oral history interviews, and hiking.

9 Philip Van Huizen is Professor at British Columbia University and former L. R. Wilson Assistant Professor at the Wilson Institute for Canadian History. As environmental historian of Canada-US energy development, he received his PhD from the University of British Columbia with a dissertation on conflict over power development in the Skagit Valley, which won the American Historical Association's prize for the best doctoral dissertation on the North American West.

10 Andrew Watson is Assistant Professor in History at the College of Arts and Science at the University of Saskatchewan. His main project deals with rural identity in Ontario, the history of coal in Canada and the Sustainable Farm Systems project, which explores the socioecological transition in agriculture. His thesis defended in 2014 was entitled *Poor Soils and Rich Folks: Household Economics and Sustainability in Muskoka 1850-1920.*

11 Matthew Evenden is Professor of Geography in the University of British Columbia. His research deals with an environmental history and water issues, with particular focus on rivers. He is a founding executive member of NiCHE, the Network in Canadian History and Environment, and Chair of Canadian Studies at UBC. He published *Allied Powers: Mobilizing Hydroelectricity during Canada's Second World War* (Toronto: University of Toronto Press, 2015).

12 Jonathan Peyton works in the Department of Environment and Geography, University of Manitoba. He is specialized in environmental, historical and cultural geography. His current research is on the policy implications of northern energy infrastructure megaprojects in subarctic North America.

13 Cfr. Martin Jones, Rhys Jones, Michael Woods, Mike Woods, *An Introduction to Political Geography: Space, Place and Politics* (London: Psychology Press, 2004).

14 Steve Penfold is Associate Professor & Acting Associate Chair at the University of Toronto, specialized in the social, cultural, and political history of twentieth century Canada. His current research is in energy history, including an examination of British Columbia Premier Duff Pattullo's heated dispute with American oil companies during the 1930s. He published notably *The Donut: A Canadian History* (Toronto: University of Toronto Press, 2008).

15 Colin Duncan teaches environmental history and modern British history at Queen's University and McGill University. He is specialized in agriculture studies with an interdisciplinary approach. He published, among others *The Centrality of Agriculture: Between Humankind and the Rest of Nature* (Ontario: McGill-Queen's University Press, 1996).

oil geography. Confirming this overview, Laurel Sefton MacDowell[16] (chapter 12) notes that the growth of the nuclear sector came more from the protection of mining interests than from a real increasing demand for power.

STRUCTURE ANALYSIS AND PROBLEM DESCRIPTION

5 Ruth W. Sandwell points out in her introduction that we have to remember that *Powering Up Canada* aims to be a sort of introductory anthology to the energy history of Canada. In this perspective, essays appear as monographic studies, or general overviews, on specific *types* of energy resource. Therefore, this book has to be intended as a handbook, with all the pros and cons specific to the genre.

6 Sandwell provides in the introduction the key to understand the elements of the underlying structure of the essays. The first is the divergence from the model of British industrialization. As it is now a classic of economic history (for example in Mediterranean studies),[17] Sandwell points out that Canada shows a special path to industrialization, characterized by five conditions: a great consumption of energy per capita, a late transition from organic to inorganic forms of energy, the variety of these forms of energy (which is responsible for the transition delay) and, in the 20th century, the particular balance and segmentation of the energy market (inorganic resources were mostly exported, organic resources were mostly used as energy supplies), a particular land policy for which subsurface rights are mostly governmental. Thus, for Sandwell, the Canadian case is significant for historical reasons, for a geographical magnitude and for contemporary issues because, as is known, Canada is today an important producer of inorganic resources like bituminous schists and it is the siege of the most powerful mining companies in the world (BHP Billiton for example).

7 In the first part, the essays point out very clearly the effects of a hybrid and *longue durée* transition, contesting the Manichean divide between organic and mineral regimes. It is clear that the authors want to revisit Wrigley's hypothesis or, more probably, some uses (or abuses) that have crystallized on it. In this respect, Wrigley's model remains a constant presence throughout the book, for example in its very structure – part one dealing with organic forms of energy and part two dealing with inorganic ones. However, the transition between part 1 and part 2 of the book suggests the idea of an *energy transition* in which hybrid solutions are a frequent pattern. In a very evocative way, this passage is underlined by water flowing from a kinetics energy to hydroelectricity.

8 In the second part, the authors show multiple case studies that underline the diverse political response to the energy issue in the attempt to structure a national energy balance. We may affirm that this part could be read as a political history of energy in the sense that *political* is not only related to public policy, but also to public and private agency. To this extent, this second part aims to suggest a methodological and an interpretative response to the general question of the book (What History for Energy in Canada?). Methodologically, the essays warn against the attempts to model political behaviour regarding energy issues. They reaffirm the essential role of a qualitative analysis in tandem with a quantitative one, in order to avoid superimposing rigid theories or models (the "cheap and better" rationality for example) on the problem of agency or, as we said, of the political behaviour of actors. However, this relativisation does not fall into an anarchical perspective, because all the authors show a certain coherence in their hypothesis. The *fil rouge* is that the energy history of Canada is a matter of political geography and, for this very reason, only an interdisciplinary approach provides a solid analysis.

16 Laurel Sefton MacDowell is Emeritus Professor at University of Toronto Missisauga. Her research interests are in Canadian working class and North American environmental history. She is the author of *'Remember Kirkland Lake': The Gold Miners' Strike 1941-42* (Toronto: University of Toronto Press 1983 ; 2nd edition 2001) and *An Environmental History of Canada* (Vancouver: UBC Press, 2012) which is a text for classes and a book for the general public.

17 Cf. Gérard Chastagnaret, "L'industrie en Méditerranée : une histoire en construction", *Méditerranée*, vol. 87, n°3-4, 1997, 5-12.

9 In a more general perspective the book remains sometimes trapped in the pattern of *first/latecomers* for which, in economic history, Britain stands as the implicit model of comparison.[18] This is the scheme of traditional analysis regarding the Industrial Revolution, mostly developed in the 1950s-1960s following the well-known Rostow Model. Even if the hypothesis of universal causes for backwardness had already been criticised in the 1960s, by Gerschenkron for example,[19] the stage model still stands as the most pervasive in the common discourse about industrial development. In the 1980s, historians tried to break this perspective by introducing a new methodology, like for example comparative studies. Citing only the most debated, famous and relatively recent one, Kenneth Pomerantz affirmed a new perspective according to which Britain is not the idealized model of development, but a real term of comparison on the same level as others.[20] As global history showed in the case of the "globalization problem" in modern times, it is also possible to exclude Britain from a comparative analysis, when the case study is not directly connected to the British experience.[21] These examples show that the problem is not really to have Britain as a term of comparison, but to crystallize the scheme *first/latecomers* and to point out the appearance of a phenomenon (for example the Canadian transition from organic to inorganic resources in the 1950s) as a *backwardness* or an *anticipation* in absolute terms. In fact, the absolutization of these evaluative categories does not erase their incorporated comparison to the British case, which becomes in this sense crystallized and, in a way, more illusory because invisible. In the case of *Powering Up Canada,* the relation to the British case is in some ways inescapable: historically because of the multiple bonds with Britain (the colonial and technological ones, just to give two examples) and methodologically because the main point of reference is Wrigley and his analysis of the British Industrial Revolution. From this point of view, the reference to the British example is not a demerit point for the book.

CHOICES EXPLAINED

Why Canada specifically? Sandwell underlines that this country has a peculiar energy trajectory in comparison to other industrialized countries: its wealth in organic energy resources made it a *latecomer* in relation to the transition to mineral energy regimes. But from 1950s, Canada engaged in a rapid catching up process to become one of the world's top producers of fossil fuels and hydropower. To this extent, Sandwell makes a "declaration of intent" in the introduction, evoking the contemporary questions that invited the authors to question Canada's energy history. She argues, as Wrigley did too, that historians have tended to naturalize the energy issue, preferring to study other aspects, such as urbanization. These aspects are, in her view, the *effects* of industrialization (direct or collateral) while the energy issue is *structural* to industrial revolution. The naturalization of the energy issue in History is linked to its unrecognised status as a historical object. Moreover, the lack of analytical framework is due to the tyranny of sources, whose imperium is not yet overcome, even in this book, where secondary literature is more frequently used than archival sources. 10

However, Sandwell recognises that, for the Canadian case (but we can enlarge the perspective) history of energy in not a "no man's land", because some studies have been carried out since the 1970s.[22] However, these were mainly economic or geopolitical essays, inspired by contemporary questions after the oil crisis of 1973 and the beginning of the decline of Fordim. 11

18 Cf. Giorgio Riello, Patrick K. O'Brien, "Reconstructing the Industrial Revolution: Analyses, Perceptions and Conceptions Of Britain's Precocious Transition to Europe's First Industrial Society", Working Paper n°84/04, LSE, May 2004 [URL: <http://eprints.lse.ac.uk/22337/1/WP84.pdf >].
19 Alexander Gerschenkron, *Economic Backwardness in Historical Perspective. A Book of Essays* (Cambridge: Harvard University Press, 1962).
20 Kenneth Pomeranz, *The Great Divergence: China, Europe, and the making of the Modern World Economy* (Princeton, Oxford: Princeton University Press, 2000).
21 Cf. Shmuel N. Eisenstadt, "Multiple Modernities", *Daedalus,* n°129, 2000, 1-29.
22 Ruth W. Sandwell, "Introduction" in *Powering Up Canada*, note 8, 28.

As Fordism was not only a style of productive management, but also part of a complex phenomenon, its crisis had a huge impact on social equilibriums, underlining the degeneration of urban life in cities like Detroit, and massive de-industrialization, with a violent increase of unemployment rates.[23] This crisis probably questioned historians more about that kind of issue than about energy in the same way as today sensibility to energy is probably linked to a different kind of crisis.

12 So why Canada? Why not. Exploring or re-exploring the history of energy in a specific country is anything but archaic in the era of global history, which requires the introspection and the depth of singular studies to be scientifically heuristic. Without national, regional and local studies to provide data, details and specificity of knowledge, global history would be blinded and generalist, which is not what History is. To this extent, if every history is a contemporary history,[24] Canadian historians (but also the Canadian people) are nowadays deeply questioned by recent (and less recent) events and tendencies regarding energy in their country: pollution, industrial disasters, social and environmental desertification led by de-industrialization, but also new mining concessions, resource nationalism and the ecological challenge of renewable energy transition. So it becomes the *fil rouge* of the book to "highlight, problematize, and probe very specific ways in which Canadian people [...] produced, consumed energy in the past and how they made [energy nda] transition [...]"[25] in which we obviously underline the concept of *transition*.

13 In her conclusion, Sandwell again evokes the introductory intent to wish a greater mobilization around energy history. However, *Powering Up Canada could be seen a*s a handbook ("primer and sampler" as Sandwell says) in its domain, providing a sort of model of analysis to connect and collect interpretations on energy and its historical context. However, as was said before, this handbook needs also to be considered as a book of history within its context and its historiographical references. In conclusion, *Powering Up answers* some questions about energy historiography and gives also new perspectives on the Post-Carbon era. At the same time, it leaves some questions unanswered and, like every good book of history, it suggests new paths to investigate.

23 Robert Boyer, Jean-Pierre Durand, *L'après-fordisme* (Paris: Syros, 1998).

24 Benedetto Croce, *Teoria e storia della storiografia*, 2 vol. (Napoli, Bibliopolis, 2007 [original edition 1917]).

25 Sandwell, "Introduction", 5.

Additional references

Boyer Robert, Jean-Pierre Durand
L'après-fordisme (Paris: Syros, 1998).

Chastagnaret Gérard
"L'industrie en Méditerranée : une histoire en construction", *Méditerranée*, vol. 87, n°3/4, 1997, Industries en Méditerranée de la marginalisation à la mondialisation, 5-12.

Croce Benedetto
Teoria e storia della storiografia (Napoli: Bibliopolis, 2007 [original edition 1917]).

Eisenstadt Shmuel N.
"Multiple Modernities", *Daedalus,* n°129, 2000, 1-29.

Gerschenkron Alexander
Economic Backwardness in Historical Perspective. A Book of Essays, (Cambridge, Mass.: Harvard University Press, 1962).

Jones Martin, Rhys Jones, Michael Woods, Mike Woods
An Introduction to Political Geography: Space, Place and Politics (London: Psychology Press, 2004).

Pomeranz Kenneth
The Great Divergence: China, Europe, and the making of the Modern World Economy (Princeton and Oxford: Princeton University Press, 2000).

Riello Giorgio, Patrick K. O'Brien
"Reconstructing the Industrial Revolution: Analyses, Perceptions and Conceptions Of Britain's Precocious Transition to Europe's First Industrial Society", Working Paper n°84/04, LSE, May 2004. URL: <http://eprints.lse.ac.uk/22337/1/WP84.pdf >