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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.

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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]

At the same time, Rinkinen and Shove under- 11
score 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.

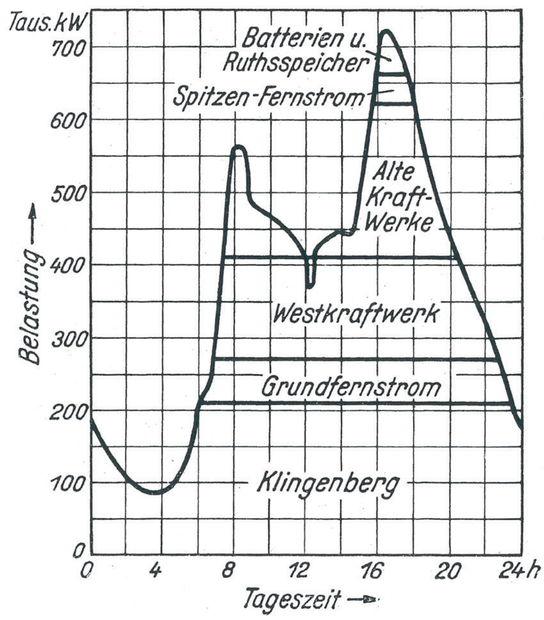

Figure 1: Electricity demand in Berlin in 1928, illustrating how the base load was covered primarily by the city's own power plants (Klingenberg, Westkraftwerk) and the peak load by older power plants and storage facilities, with minimal imports (Fernstrom) in both cases. Source: Martin Rehmer, "Die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

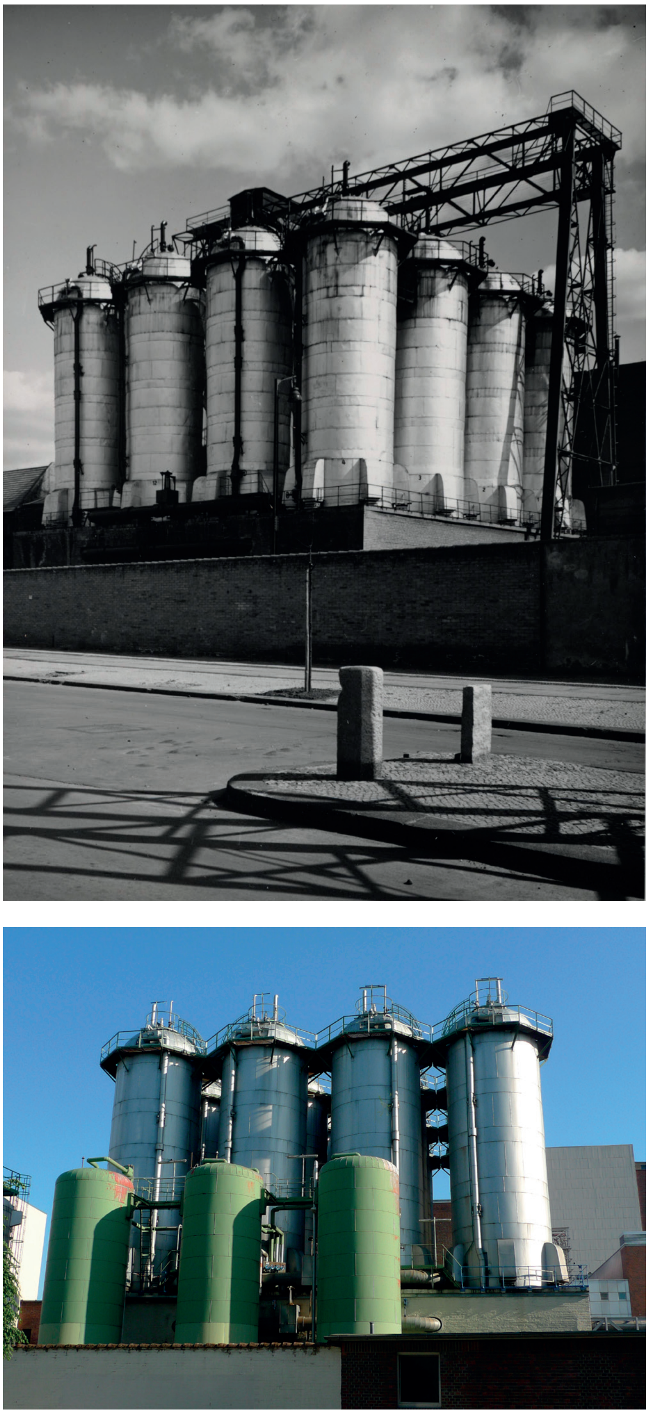

Figure 2: The Ruths steam storage facility, built in 1929 (pictured in 1952 and 2018). Sources: Landesarchiv Berlin (LAB) F Rep. 290 (07), no. 0019330, photo by Willi Nitschke, 8 April 1952. Photo by Timothy Moss, 2018.

22 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

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 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. 25

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.

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] 29

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 30

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.

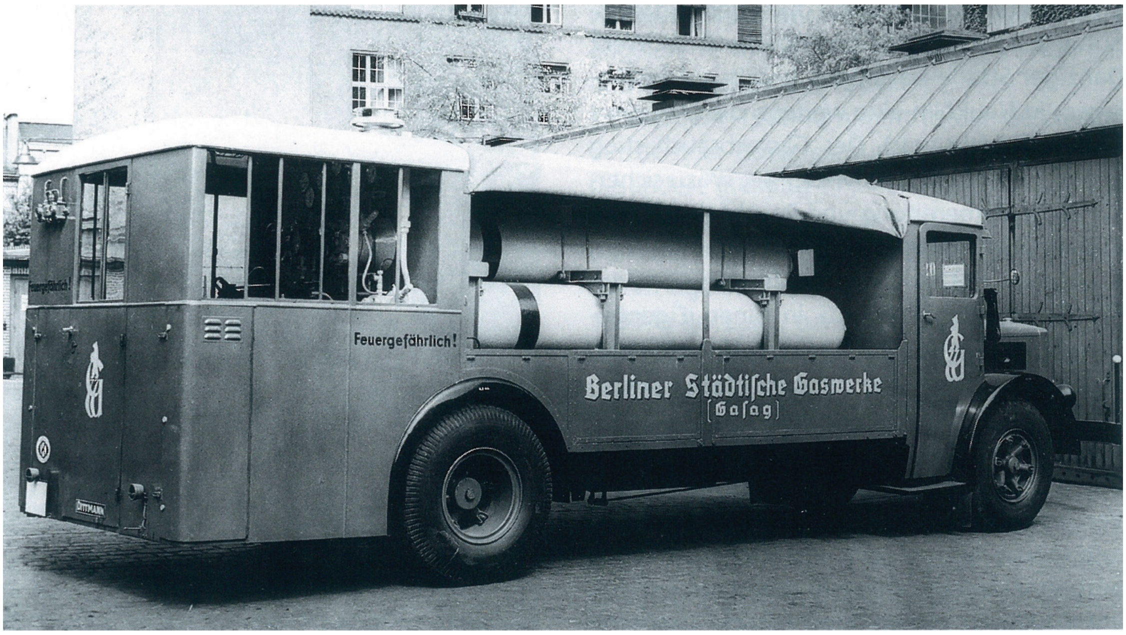

Figure 3: A gas-powered lorry of the Berlin gas utility used to deliver gas to filling stations. Source: Hilmar Bärthel, *Die Geschichte der Gasversorgung in Berlin. Eine Chronik* (GASAG Berliner Gaswerke Aktiengesellschaft, Berlin: Nicolai, 1997), 93.

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]

31 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.

Engaging with the energy consumer

32 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

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 daytime 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 (E^3) 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.

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]

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.

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.

39 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.

40 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

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 city-wide 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.

60 Finally, the Berlin case traces a trajectory of 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.