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Thermodynamics revisited: the political ecology of energy systems in historical perspective

Gustav Cederlöf

Energy systems have rarely been on the lips of political ecologists. The silence is striking in leading texts (e.g. Blaikie and Brookfield, 1987; Bryant and Bailey, 1997; Robbins, 2012). Yet access to centralized energy infrastructures (or the lack thereof) strongly reflects who can take part in ‘development’ and ‘progress’. Today many centralized energy systems appear in the contradictory position of too much carbon causing climate change and too little carbon causing ‘peak oil’ (Bridge, 2010). But the infrastructures rarely take centre stage: instead discussions are about fuels and emissions, the energy mix and carbon offsets (Bumpus and Liverman, 2008). Still, Bridge (2010; also Mitchell, 2011; Zimmerer, 2011) addresses the social and technological networks through which energy resources are produced; and Bennett (2010) reconceptualizes the electricity grid as a socio-physical event with great potential to better understand links between politics, infrastructure and hydrocarbons. Here, I build on such promising work by addressing the *historical* nature of electricity infrastructure as part of a wider effort to encourage a historically-informed political ecology of energy systems.

This task is all the more important given widespread but misguided thinking on the possibility of simply substituting ‘clean’ for ‘dirty’ energy. To survive peak oil and changing climate crises, it is often assumed that the energy potential of fossil fuels must be substituted for an equal amount of renewable energy (York, 2012). Hence, a huge amount of biomass, wind farms or solar panels are needed to replace an oil barrel kilowatt for kilowatt. Such a low-carbon transformation would have severe consequences in that it would devour large land areas, prompting a dramatic expansion in the size of ‘violent environments’ linked to energy production (Peluso and Watts, 2001).

But in this chapter I wish to emphasize a different point, namely that the very assumption about ‘easy’ technological substitution underpinning such thinking is wrong. Electricity systems – configurations of metal wires, hydrocarbons, turbines and electron movements – are fundamentally

historical products reflecting quite specific political and economic interests. Today's electricity grids demand high energy input to satiate those interests. Yet the energy demand of an energy system is not inherently about the technology; infrastructure is not just 'out there' requiring a new energy source. Rather, political and economic interests are manifest in the technology. This point has momentous political, economic and ecological implications: historically-specific and usually unjust interests that energy systems embody can and must be challenged through scholarly and activist means rather than devoting effort to blindly go down the path of a false technological substitution; substitution that not only avoids challenging powerful political and economic interests but actually facilitates further large-scale land grabbing on their behalf – this time in the name of alternative energy.

My aim in this chapter is to develop a historically-based kind of understanding that ought to guide political ecologists as they engage more systematically than hitherto in critical analysis of energy systems. To do so, I focus on electricity infrastructure beginning with a brief introduction to key concepts from thermodynamics and systems ecology. While energy systems are profoundly political, these social relations are also contingent on how energy physically behaves in relation to a given infrastructure. I then draw on work on the history of electrification in the United States, the Soviet Union and the former Third World to show how energy systems are socially produced across time, space and political ideology. I conclude by suggesting avenues for future research into the political ecology of energy systems.

Politicizing thermodynamics

Let me first reacquaint the reader with the washing machine. As Hans Rosling (2010) recounts, this is a spectacular machine which frees up much time, often for women, when manual scrubbing and pounding is replaced by its centrifugal powers. To operate, the washing machine needs mechanical energy. This could be supplied from the motion of wind through a turbine to the drum with one single energy conversion. Yet this kind of mechanical low-tech system is often regarded as 'traditional'. Most 'modern' washing machines run on electricity generated from fossil fuels.

Fossil fuels originate in the sun. Through photosynthesis, sunshine is converted into green plants and algae. Algae go through their life cycles before they decompose and end up on the sea floor. Over hundreds of millions of years other biomass covers the algae; pressure builds up, the temperature rises and they slowly become petroleum. Year-millions of solar energy are thereby stored in the molecular bonds of hydrocarbons. Fossil fuels can thus be conceptualized as a historical accumulation of land (or sea) area on which the sun once shone. If such fuels were substituted for contemporary land area it would immediately become a political question of how land is managed and distributed – with ensuing conflict pitting humans against each other as well as against the nonhuman world (Dukes, 2003; Hermele, 2012; Howard *et al.*, 2009).

The petroleum is next pumped from the subsoil by a multinational oil company and then transported to a thermoelectric power plant (Ferguson, 2005; Watts, 2004). There it is set on fire. This releases energy stored in the hydrocarbon bonds and converts it into heat. The heat is used to evaporate water which is set in motion. The moving steam is led into a turbine where it is transformed into mechanical energy. This energy is used to spin a magnet in a generator which transforms the mechanical energy into electricity. The current is then prepared for transmission. The voltage is stepped up to reduce the amount of electricity dissipating as heat. When the current has travelled to a location where there is a concentrated consumer demand, the voltage is stepped down to a level that can be used by a washing machine. It is distributed to its consumer, comes out of a socket and enters the washing machine where the energy is transformed anew into mechanical energy to spin the drum.

Across the millions of years that have passed since the energy was first generated by the sun, none has been destroyed. It has only been transformed. This is known as the First law of thermodynamics (Smil, 2008). In each transformation, however, energy has not only been converted into the form required to finally spin the washing machine drum. It has also transformed into heat. This heat is rarely of use as it dissipates into the atmosphere. Therefore, as soon as energy is set to work, the quantity of useful energy diminishes: its 'entropy' increases. This phenomenon defines the Second law of thermodynamics. The efficiency with which energy is transformed from one form to another is (with a bit of simplification) the 'conversion efficiency' (Lovins, 2004). The aggregate conversion efficiency of using wind to spin a washing machine drum is much higher than the efficiency of using electricity.

The Second law states that entropy increases spontaneously in all energy processes. This means that energy always is a one-way flow; that energy use never can be reversed. Consequently, new high-quality energy must enter the system continuously to sustain a process like a spinning washing machine drum. The amount of energy available to do work in a system is called 'exergy'. The low efficiency of electricity production in a thermoelectric power plant means that much more exergy must be imported to sustain the washing machine than is necessary in a system powered by the wind. On Earth, a wind-powered washing machine drum can be spun as long as the wind, blowing due to the sun's uneven heating of the atmosphere, provides exergy. Fossil fuels, in contrast, form over the extreme *longue durée*. In a process dependent on fossilized exergy sources, exergy is therefore consumed at a much faster pace than new energy potential can enter the system.

In the 1970s thermodynamics (or 'energetics') became a concern for social scientists. Most notably, Nicholas Georgescu-Roegen (1971) argued that all economic processes increase entropy. The economy is therefore in constant need of exergy and raw material input which, Georgescu-Roegen argued, inevitably puts limits to growth. Daly (1974) elaborated this idea by outlining a steady-state economy which would be environmentally and economically sustainable. These perspectives today thrive in the field of ecological economics and in the 'de-growth' movement (Healy *et al.*, this volume).

Occasionally, political ecologists have engaged with the issue of thermodynamics. In the 1980s, Stephen Bunker (1985) infused Georgescu-Roegen's thesis with neo-Marxist dependency theory by

arguing that production in the world industrial core was enabled by a transfer of energy and matter from peripheral extractive economies. He also drew on work on energy in ecological anthropology (White, 1959; Adams, 1975) to argue that the core's ability to harness great amounts of energy enabled it to develop more complex social organization. Meanwhile, the social organization of the periphery, drained of energy and matter, became simplified and underdeveloped. Later, Alf Hornborg (2001) strengthened Bunker's analysis by freeing it of its functionalism through incorporation into the world-systems perspective. Hence, industrial technology is not an index of cultural 'progress', but rather an index of accumulation whereby a population's technological capacity (i.e. amount of energy harnessed) above all defines its position in the world system.

Many historians of technology in contrast are sceptical about this sort of grand explanation. Nye (1998), for example, frames his analysis in terms of specific energy systems and associated cultures. In the following, I draw on such historical literature linking it to concepts of energy, entropy and exergy. By doing this, I affirm the value of historically-grounded political ecologies. This has long been a mainstay in work on natural resource struggles (Guha, 1989; Peluso, 1992) but has not yet been sufficiently explored in relation to science and technology themes which are gaining currency in the field today. Moreover, my analysis will enable me to argue that the question of how society can substitute renewable energy sources for existing fossil fuels on a one-to-one basis is a treacherous one which conceals the political-ecology dynamics of energy systems in a way ultimately injurious to many people and environments.

Extending the grid: the US experience

The United States is the world's largest energy consumer per capita. It is also where the world's first electricity system was developed, in the Wall Street district of New York City, by Thomas Edison and his team of engineers. Thomas Hughes is a leading chronicler of Edison and his electricity grid. Hughes argues that an electricity system in general is a network of interrelated parts which usually are under central control. The extent of this control delimits the extent of the system (Hughes 1983). When Hughes (1983: 41-2) analyses Edison's creation, the emphasis on centrality is clear: 'Edison's ultimate objective was to introduce central-station supply ... A central station would distribute electric light to the public, in contrast to generating plants, or isolated stations, which would be used only by their owners.' This design would enable customers to receive 'an unusually effective light without hazardous and noxious fumes. In the Wall Street district the station would also catch the attention of financiers and the investing public, persons who were needed to fund Edison stations elsewhere' (Hughes, 1983: 41-2). Thus, the centralized technological design was clearly a product of Edison's own making. Central control even turns out to be not only a design but an argument for a cleaner city and a business strategy. However Hughes, somewhat against the grain of his overall argument, turns this historical product into a general definition of the electrical grid. The definition he uses to analyse electrification thus derives

from the very materiality he seeks to explain. Hence, so strong is the idea that electricity systems extending over space like a spider spinning its web are controlled by and from the centre. That other definitions are possible here is evident, for instance, from Bennett's (2010) Deleuzian engagement with the electricity grid as an assemblage of the human and non-human.

Edison's system was based on a central station to which coal was transported and from which a direct current (DC) was distributed throughout the district. Edison's design can be seen as an alliance forged between the social and economic aspirations he wanted to serve and the behaviour of electricity in the wires that extended around Wall Street. Soon, however, Edison exported his central station system and the wish to transport electricity over longer distances arose. For instance, this was a precondition to incorporate hydropower into the system. As a source with huge energy potential (high exergy content) there were great economic interests involved. The demand for long-distance transmission changed the circumstances in relation to which the Wall Street system had been designed. It strained Edison's alliance with the current.

The problem was that as soon as an electric current passes through a metal wire it causes it to heat up. It is the resistance of the wire that bothers the current. Engineers know this phenomenon as Joule's first law. According to Joule, the heat generated (Q) is proportional to the resistance of the wire (R) multiplied by the square of the current (I). Or for short, $Q \propto I^2R$. What this equation captures had dramatic consequences for the politicians and engineers who wanted to extend the grid geographically to boost the economy. As the power line gets longer its resistance to the current increases. This means that more electric energy is transformed into heat, dissipating into the atmosphere, when it has to travel over longer distances. But this also stands in proportion to the current that runs through the line. A low current generates less heat while a high current generates more. In Edison's Wall Street system this was not a problem since the direct current only had to travel a short way to reach its consumers.

With a last twist of electromagnetic theory, the trick to make long-distance transmission feasible is that a low current requires a high voltage. In fact, to minimize the increase of entropy during transport, the voltage must be so high that it hardly can be used in domestic or industrial appliances. In today's transmission networks transmission generally takes place at between 115 000 and 800 000 volts whereas the electricity that comes out of the socket usually rates 110 or 230 volts. In Edison's day, there were no transformers available that could reduce a high DC transmission voltage to a low voltage for use. Thus, the cost of transmitting DC over long distances prohibited the extension of the grid that seemed so economically lucrative.

To fulfil their economic and social dreams, politicians and engineers had to seek new alliances with the current. What resulted became known as the 'Battle of the Currents' (Hughes, 1983: ch. 5). With alternating current (AC), as opposed to DC, it is an easy task to transform voltages. But Edison ferociously favoured DC. One reason was that he only had patents for a DC design. The argument he voiced, however, was the danger of AC which by accident or on purpose could be used for electrocution. In his campaign for a DC standard, Edison publicly electrocuted cats and dogs to prove the danger of

AC, culminating in him electrocuting a circus elephant named Topsy with 6600 volts in 1903. AC, on the other hand, was favoured among others by George Westinghouse as it cheaply enabled long-distance transmission. AC ultimately won the battle, which is evident from the national and intercontinental grids that span the world today. Electricity is also ‘lost’ as heat in these power lines and the World Bank (2014) estimates that 6 per cent of the total energy output was ‘lost’ in US grids in 2011. The estimate was 11 per cent for Egypt, 16 per cent for Cuba, 21 per cent for India, with Haiti topping the list at 55 per cent. It should be noted that these numbers, which in a deceptively exact way indicate a difficult thing to measure, also include pilferage – itself an interesting act of resistance to the political ecology of electricity systems.

These losses can be endured by supplying the grid with energy sources that have enormous energy potential: hundreds of millions of years of sunshine fossilized in hydrocarbon bonds; water gushing through monumental dam gates; and the subatomic energy of enriched uranium. Yet these energy sources all have adverse effects on the socio-environmental systems they interact with. Coal, gas, oil and peat partly transform into carbon dioxide as they are burned, while dam reservoirs are one of the world’s greatest emitters of methane (Bates *et al.*, 2008) – both highly active greenhouse gases. Nuclear fission meanwhile produces radioactive waste and thermal pollution.

In the 1930s, where Hughes’s book ends, the energy intensity of the United States’ economy increased sharply (Nye, 1998). In particular, the Tennessee Valley Authority (TVA) became emblematic of American ‘progress’. The TVA is among other installations a series of almost thirty hydroelectric dams; a project described as ‘Democracy on the March’ by David Lilienthal, the TVA’s first leader. TVA was part of Roosevelt’s New Deal and was seen as a technological intervention that at once would make the Tennessee River navigable, electrify the ‘backward’ southern states, improve flood control and industrialize agriculture in the Tennessee Valley (Klingensmith, 2007). Lilienthal explained how construction of the dams—large nodes of electricity production supplying a central transmission line—had followed a rational, technocratic plan of progressive engineering. Daniel Klingensmith (2007; also Ekbladh, 2002) shows how this narrative rapidly gained currency. But while the dams became entwined with a narrative of modernizing America, the TVA was decidedly not the result of a pre-existing technician’s plan. Klingensmith (2007) argues instead that it was the product of an intervention in the debate on public vs. private ownership; of a vision of dominating nature for social benefit; of a solution of what to do with a First World War fertiliser plant and hydroelectric dam in Alabama; of a drive to make a river usable for transport; and more. The TVA also led to forced resettlement to make way for the reservoirs as well as subsequent displacement of ‘uncompetitive’ small farmers in an era of industrializing agriculture (the latter being a process enabled by the building of dams). So strong was the belief, however, that the engineering and design of the energy system were apolitical, scientifically objective practices that ‘political considerations’ could not ‘influence the selection of particular dam sites or technologies’ (Klingensmith, 2007: 60). And so it became an

apolitical issue that 125 480 people, by an official count, were forcefully resettled to make space for the reservoirs.

With the TVA, electrification became a symbol of national progress in the US. At the same time, electrification took an equally central position in the nascent Soviet Union.

Powering up the Soviet Union

Russia's electrification had been a low priority for the tsar. The future of the empire was believed to be linked to the railway. But after the First World War and subsequent Russian Civil War (1918-1921) the railroads lay in ruin. When the Bolsheviks seized power priorities changed and electrification superseded railway-building as the dominant government concern. 'The century of steam was the century of the bourgeoisie', Lenin proclaimed (1920 cited in Cummins, 1988: 105), 'and the century of electricity is the century of socialism'.

Just as in America, the technological structure of the Soviet grid was not the result of the inexorable advance of the national productive forces. In 1920 a grand plan was compiled by the State Commission for the Electrification of Russia (GOELRO) at the behest of Lenin. While the plan framed electrification as a technological imperative, it nonetheless strongly reflected political and economic calculations. It specified construction of a large network of 27 regional thermoelectric power plants. Yet, as Coopersmith (1992: 153) argues, '[t]he challenges to GOELRO may have been phrased technically, but they concerned the very nature and direction of the Soviet state. Would it be directed from the center or guided from below? The choice of electrification embodied in GOELRO strengthened the first direction.'

Electricity loomed large in Lenin's rhetoric epitomized in his motto that 'Communism is Soviet power plus electrification of the whole country'. Electricity would both figuratively and literally bring the masses into the light, while bridging the gap between city and country as the 'backward' peasantry was modernized. 'Of course', Lenin (1966: 517) declared in presenting the plan to the Eighth All-Russian Congress of Soviets in 1920,

to the non-Party peasant masses electric light is an 'unnatural' light; but what we consider unnatural is that the peasants and workers should have lived for hundreds and thousands of years in such backwardness, poverty and oppression under the yoke of the landowners and capitalists. ... What we must now try is to convert every electric power station we build into a stronghold of enlightenment to be used to make the masses electricity-conscious, so to speak.

Lenin (1966: 516) argued that only by introducing 'a new technical base' could 'the internal enemy' (i.e. a potential capitalist class taking grip in the countryside) be undermined and the socialist state prevail. Somehow, a long-distance transmission network featuring 27 central nodes of fossil-fuel-based electricity generation responded to this belief. Cummins (1988: 28) remarks with reference to the 1934 Moscow edition of the *Tekhnicheskaiia Entsiklopediia* (Technical Encyclopaedia) that 'In the Soviet

technical lexicon, electrification is the transfer of a nation's economy to a technical base of contemporary large-scale machine-building industry through the concentration of generating capabilities primarily in large regional power stations.' And so, Lenin's vision had seemingly become 'objective' knowledge by the 1930s. In light of Stalin's brutal collectivization buttressed by this new technical base, however, it is debatable how far the GOELRO grid actually lit the peasant's hitherto 'dark' world. Rather, the capacity to dramatically (re) organize energy flows was above all a strong source of political-ecological power – power to organize certain kinds of environments for human interaction.

Yet the GOELRO plan for a centralized grid had been hotly contested. Lenin's support for it met stiff opposition, notably among political leaders such as Alexei Rykov and Leon Trotsky (Cummins, 1988). The plan was also opposed by urban and municipal utilities who favoured a decentralized grid (Coopersmith, 1992). At the time, only Petrograd (Saint Petersburg) and Moscow had a limited electricity supply underpinned by the tsar's railways which transported peat and coal to their central stations. Opposition to Lenin's plan amounted to a struggle over the physical layout of the grid – that is, whether electrification should be controlled by central or local government. This political conflict stalled implementation of the GOELRO plan in the early 1920s compromising in turn the New Economic Policy announced in 1921. And yet, such political turmoil masked an underlying process that eventually came to define the Soviet state and, later on, other Communist states around the world: a combination of central planning and heavy technological construction that became almost synonymous with state socialist practice and Marxist-Leninist theory (Cummins, 1988).

After Lenin's death in 1924 and Stalin's subsequent seizure of political power, GOELRO became part of the State General Planning Commission (Gosplan) which would lead the Soviet Union's five-year planning until its dissolution in 1991. When the first five-year plan was completed in 1932, GOELRO's goals had been fulfilled as they were part-and-parcel of Stalin's accelerated industrialization campaign (Coopersmith, 1992). During this plan the budget for electrification was quadrupled but with generation capacity concentrated in a few key industrialized areas only: 'This realization of the GOELRO plan reinforced the centralized nature of industrial development and control' (Coopersmith, 1992: 258). Hence, the physical form of the energy system closely meshed with the interests of the Stalin-directed central government and GOELRO engineers. The physical and human geography of this energy system – where it reached, who could (or could not) access it, the purposes it served and the interests it embodied – was thus deeply embedded in a new set of (revolutionary) social relations. These relations were in turn maintained by the exergy content of the peat, coal and oil that fuelled the system.

However, after the Second World War something peculiar happens. The turbulent histories of US and Soviet electrification are forgotten. Electrification becomes an abstraction, an 'objective' technological intervention that other countries must replicate in order to 'develop'.

The current moves South

In 1944, William Voorduin travelled to wartime India. A former TVA engineer, he was dispatched there by the TVA leader David Lilienthal to advise the British-Indian government on the building of a series of dams on the Damodar River west of Kolkata. The presence of TVA engineers in India, though, would continue long past independence from Britain in 1947:

From the 1940s to the 1960s there were plans for new ‘TVAs’ in India, China, Palestine, Peru, Iran, Colombia and several other countries. Or more precisely, there were plans for river development in these lands that to varying degrees invoked TVA as their inspiration and called for TVA personnel to help implement them (Klingensmith, 2007: 68; see also Ekbladh, 2002).

This was the image of TVA that had solidified in the United States, becoming a symbol of American ‘progress’, that subsequently travelled the world. Engineers like Voorduin ‘looked at the Damodar and saw in it the Tennessee as it had been before 1933, and looked at Bihar and Bengal and saw in them the American South’ (Klingensmith, 2007: 73). In 1948, the DVC (Damodar Valley Corporation), a thermal and hydropower generating authority, was created on the TVA model to manage the Damodar.

For political leaders in what was becoming the ‘Third World’ (Escobar, 1995), electrification was a core priority. ‘Modern’ electric energy was replacing ‘traditional’ energy forms such as motion to propel pumps and spin drums. As in the United States, a strong narrative was developed around the idea that electrification was a purely technical and therefore apolitical matter. Once again, electrification was a necessity in the pursuit of progress – a view that crossed ideological lines. Hence, it was pursued with alacrity by both pro-Western countries (e.g. Thailand, the Philippines) and pro-Communist nations (e.g. China, Cuba). Indeed, much of what international financial institutions have done in the post-1945 era has been linked directly or indirectly to electrification. In fact, the World Bank was still lending money for electrification projects and the formation of national utilities into the 1990s (Collier, 1984; Goldman, 2005). During that decade though, the policy was changed as the World Bank promoted a neo-liberalization agenda. Thus, power grids were ‘unbundled’ into generation, transmission, distribution and retail segments so as to allow competition to flourish throughout (Xu, 2006). The World Bank’s interest in large-scale development projects like electrification and dam-building was not coincidental but is at the heart of this organization: ‘TVA, as Lilienthal represented it, was a key point in the articulation of the world view on which the World Bank was based’ (Klingensmith, 2007: 62).

For Third World leaders, meanwhile, no primary energy source shared the symbolic power of hydropower. ‘The TVA idea’ joined hands with notions of development, nation, independence, modernization, industry and progress – ‘so important were dams in the mid-1950s, Jawaharlal Nehru spoke of them as the “temples” of a new, progressive India’ (Klingensmith, 2007: 5). To not have access to electricity was also integral to modernization narratives whereby ‘poor’ people were defined as such for ‘lacking’ electricity and development (Chakrabarty, 2000).

Even grander plans were afoot in Communist China where Chairman Mao in one of his poems from 1956 envisioned the damming of the Yangtze River. By 2008 the vision of the Three Gorges Dam stood completed: 181 metres high and with 32 turbines to generate hydroelectric energy (Schapiro, 2001; Smil, 2004). Yet the ever more expensive pursuit of high exergy sources to fuel ever more extensive electricity networks, underpinning development, has had severe social and environmental impacts throughout the Third World or South (Goldman, 2005). By redistributing physical power across space, dams unevenly distribute the costs and benefits of ‘progress’ in modernizing states across people and ecosystems. With Jamal Abd al-Nasser’s Aswan dam in Egypt in mind, Mitchell (2002: 21) argues that ‘[f]or many postcolonial governments, this ability to rearrange the natural and social environment became a means to demonstrate the strength of the modern state as a techno-economic power.’ Hence, resonating with the experiences of the United States and the Soviet Union, the technological infrastructures and transformed environments these policies leave behind cannot be separated from the political-economic interests and imaginaries that their foundations were cast within. And those embedded interests and imaginaries now have global ecological implications: for instance, the dams that supply the vast amounts of exergy fuelling Indian development contribute a whopping 18.5 per cent of India’s total greenhouse gas emissions from the methane that their reservoirs release (Dharmadhikary, 2008: 29).

But electrical dreams were not only the preserve of countries aided by the United States. The Soviet idea of a socialist technical base also travelled the world, reaching China, as noted, by the 1950s and Cuba by the 1960s. Thus, as Cuban economist Santiago Rodríguez Castellón (1988: 150, my translation) argued, ‘[a] country like Cuba, in full progress of development, that works to build the socialist techno-material base and that pays constant attention to the objective of trying to meet the most elementary necessities and aspirations of our [sic] people, necessarily must increase its energy consumption.’ Indeed, revolutionary success was interpreted in terms of per capita electricity consumption – up from 377 kilowatt-hours per person pre-Revolution (i.e. 1958) to 1106 kilowatt-hours per person in 1988 (Rodríguez Castellón, 1988: 154). This discourse is strikingly similar to Lenin’s. But the similarities went further.

The Cuban National Electricity System (the SEN) was completed in 1976. It seems in many ways like a carbon copy of the GOELRO plan. The grid stretches across the island from Pinar del Río in the west via Havana to Santiago de Cuba and Guantánamo in the east. In the late 1970s, nine thermoelectric power plants were dispersed along this high-voltage AC line, most of them named after heroes of the Cuban anti-colonial struggle. By 1989, 95 per cent of the Cuban population had access to centralized electricity supply in comparison to 56 per cent before the Revolution (Bérriz and Madruga, 2000: 4). Here, a point made by Cummins (1988: 8-9; cf. Lenin, 1966: 518) about Soviet electrification rings (partly) true: ‘[it] created the myth that a backward country with plentiful energy resources can become a modern, industrial state within a short period of time by developing its economy on the basis of one technology, namely electrification.’

And yet, Cuba unlike the Soviet Union lacked ‘plentiful energy resources’. The nine power plants all relied on crude oil imported from the Soviet Union. The Cuban socialist project therefore developed its new technical base and economic growth on West Siberian and Caspian exergy reserves. That such an import-reliant energy system represented a good thing for Cubans was always debatable. After the Soviet Union’s collapse in 1991, however, the debate was over as Cuban oil imports rapidly plummeted by 87 per cent and with them national electricity output (ONE, 2012). What remained of the once-mighty SEN was a local joke as one ethnographic account records:

Here we do not have *apagones* [cuts in electricity], we have *lumbrones* (a longer period of light) ... There was no water for hours on end in buildings that depended on electric pumps. After dark, no house work could be done, no books or papers read, no television watched and no meetings held. People often just stood or sat around in their yards smoking and chatting with their neighbors (Rosendahl, 1997: 169).

In this country of the South, electrification was no longer a heady abstraction – a prediction of development long foretold by political and economic elites. The material loss of current has had decidedly tangible consequences for large parts of society.

Conclusion

This chapter has explored the political ecology of energy systems via the example of electrification. It shows how such systems are inevitably historical products that are deeply shaped by political and economic interests and rationales. As the case studies from the United States, the Soviet Union and the former Third World also illustrate, dreams of electricity has fundamentally shaped notions of ‘development’ and ‘progress’ across time, space and even political ideology – albeit, in location-specific ways. However articulated and justified, these energy systems do not necessarily represent ‘better’ or more ‘progressive’ technologies than ‘old’ less ‘modern’ ones. Rather, they represent specific political and economic interests and rationales that are fulfilled or not and contested or not.

At the same time, as seen with electricity networks, the existence of energy systems is equally dependent on specific alliances forged with exergy reserves, metal wires and thermodynamic properties. To recall the starting point: a particular energy system demands a particular quantity of energy input. If the task is to spin a washing machine drum, it could be spun with mechanical energy generated through one single conversion from the motion of the wind. But to do the same thing with electricity supplied through a long-distance AC transmission grid, a significantly longer sequence of energy transformations occurs and hence a much larger supply of exergy is required. The combination of peak oil and climate change are condemning this current system based on fossil-fuel exergy. But simply making a wholesale switch to renewable energy sources as some argue is a recipe for disaster as land grabbing for the latter will only mean the proliferation of ‘violent environments’ (Peluso and Watts, 2001). Indeed, calls for

such a switch reflect a basic lack of understanding of the political and ecological dynamics that are associated with *every* type of energy system.

To ever make genuine progress in tackling global energy and carbon crises that bedevil humans and non-humans today, it is absolutely imperative to begin by understanding those political and ecological dynamics. Here, a challenging and multifaceted research agenda awaits political ecologists. Clearly, and building on some of the research selectively noted in the introduction, the political and economic interests and rationales that are tenaciously bound up with fossil-fuel dependent infrastructure must be critically examined. These include connections between infrastructure and processes of nation-state formation (Swyngedouw, 2007), encompassing the sorts of historically-based formative events and processes emphasized in this chapter. This work requires systematic elaboration, particularly in the South, where the challenges are today most acute and relatively little attention as yet has been given to the political ecology of energy systems.

Another research area concerns the question of how energy systems resonate with notions of everyday modern life in relation to political dynamics influenced by gender, ethnic and other social factors (Arnold, 2013). How poor women and ethnic minorities, for example, may be involved in conflicts over access to electricity and other energy systems taps into a long-standing political ecology theme (albeit, usually discussed in relation to agrarian and other natural resources) but requires more attention than it has been given to date. And yet, scholars need to be somewhat sceptical about concepts such as energy poverty (Buzar, 2007; Harrison and Popke, 2011) and energy justice (Bickerstaff *et al.*, 2013) that sometimes reflect a wider development discourse in which some people are seen as ‘lacking’ development – hence requiring ‘expert’ intervention. Instead, research needs to examine one key but often overlooked question: why are certain forms of energy use that often demand little exergy input often seen as ‘lacking’ in terms of development in contrast to more energy-intensive uses for the same purpose that are propelling humanity into global crises? The point here of course is not to romanticize all ‘traditional’ knowledge but rather to assess how far such knowledge can be a basis for alternatives to current development pathways. This quest can also draw on thinking in ecological economics on new models of energy use embedded in de-growth or steady-state societies that reject notions of modernity and the nation-state manifest in currently hegemonic energy systems.

Detailed ethnographic work on how low-carbon energy use is socially negotiated in different contexts in the contemporary period is vital here (Strauss *et al.*, 2013). This would also play to existing political-ecology methodological strengths. Such studies would help to ‘de-familiarize’ Western norms of high-exergy energy use by juxtaposing it with existing alternatives (Boyer, 2011; Bridge *et al.*, 2013). In parallel, more research is needed on how socially and ecologically marginalized people negotiate and resist dominant energy systems, for example by pilfering on power lines, tapping into pipelines or inventing their own local-level schemes (Mitchell, 2011). These processes may include counter-narratives that re-frame how specific energy systems are seen as positive or negative.

These sorts of research issues and questions bespeak an important topic area that has yet to receive the systematic attention it requires. The role of history is often central here too as unequal power relations shape the introduction of energy systems with far-reaching and long-lasting consequences, as this chapter has shown. For political ecology to persist as a vibrant research field in the face of current crises such as climate change and peak oil, such historically-informed analysis of energy systems is nothing less than essential.

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