



# BURNING UP

A Global History of  
Fossil Fuel Consumption

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This book is dedicated to the memory of my friend Pavel Sheremet, who was assassinated on 20 July 2016 in Kyiv, Ukraine. The fearless way that Pavel worked, as a journalist in Belarus, Russia and Ukraine, was and is a profound inspiration.



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# Units of measurement

*Energy.* The main units of measurement of energy in this book are tonnes of oil equivalent (toe) and kilograms of oil equivalent (koe). When discussing global and national energy balances, millions of tonnes of oil equivalent (mtoe) are usually used. Standard conversions between toe and other units of measurement of energy are shown in Table 1.

Table 1 Units of measurement of energy

To:	Terajoule (TJ)	Gigacalorie (Gcal)	Tonnes of oil equivalent (toe)	Gigawatt hour (GWh)
From:	Multiply by:			
TJ	1	238.8	23.88	0.2778
Gcal	0.0041868	1	0.1	0.001163
toe	0.041868	10	1	0.01163
GWh	3.6	860	86	1

Source: IEA website

Oil is often measured in barrels. In this book, as elsewhere, international oil prices are referred to in \$/barrel. 7.33 barrels of oil equivalent = one tonne of oil equivalent.

When coal was the dominant fuel, i.e. at least until the Second World War, tonnes of coal equivalent (tce) was a common unit of measurement. One tce is usually counted as 0.7 toe. In Chapter 1, I have left measurements given in tce in those units.

*Electricity* delivers energy. The *rate at which energy is generated in the form of electricity* is measured in watts (W), kilowatts (kW), megawatts (MW) or gigawatts (GW). The *amount of energy generated in the form of electricity* is measured as kilowatt-hours (kWh), megawatt-hours (MWh) or gigawatt-hours (GWh). A kilowatt-hour is the amount of energy produced by a 1-kilowatt current in one hour.

The capacities of generating stations and networks are usually measured in MW or GW; the amounts of energy they produce over periods of time in MWh or GWh.

It is common to express large volumes of energy produced as electricity in billion kWh (bn kWh), and I have followed this convention, for example, in Chapter 7. One billion kWh = 1000 GWh = 1 terawatt-hour (TWh).

*Vehicle fuel efficiency* is usually measured in litres/100 km. In discussion of the regulation of fuel efficiency in the USA, I have used miles per gallon (mpg). 10 mpg = 23.52 litres/100 km; 20 mpg = 11.76 litres/100 km; and 30 mpg = 7.84 litres/100 km.

# Acronyms and abbreviations

ABB – ABB (Switzerland), a major engineering company  
AC – alternating current  
AES – AES Corporation, a major electricity producer  
BP – formerly British Petroleum, an international oil company  
CCGT – combined cycle gas turbine  
CHP – combined heat and power plant  
CO<sub>2</sub> – carbon dioxide  
EAF – electric arc furnace  
EIA – Energy Information Administration (USA)  
EPA – Environmental Protection Agency (USA)  
FAO – Food and Agriculture Organisation of the United Nations  
GDP – gross domestic product  
GE – General Electric  
GM – General Motors  
GW – gigawatts  
ICE – internal combustion engine  
IEA – International Energy Agency  
IMF – International Monetary Fund  
IOCs – international oil companies  
IPCC – Intergovernmental Panel on Climate Change  
IPPs – independent power producers  
koe – kilograms of oil equivalent  
kW and kWh – kilowatts and kilowatt-hours  
LNG – liquefied natural gas  
LPG – liquefied petroleum gas  
mt – million tonnes  
mtoe – million tonnes of oil equivalent  
MW and MWh – megawatts and megawatt-hours  
NEPA – National Electric Power Authority (Nigeria)  
OECD – Organisation for Economic Cooperation and Development  
OPEC – Organisation of the Petroleum Exporting Countries  
PURPA – Public Utility Regulatory Policies Act (USA, 1978)  
PV – photovoltaic cells  
SEB – State Electricity Board (India)  
SUV – sport utility vehicle  
tce – tonnes of coal equivalent



toe – tonnes of oil equivalent

UNDP – United Nations Development Programme

UNEP – United Nations Environment Programme

UNFCCC – United Nations Framework Convention on Climate Change

USSR – Union of Soviet Socialist Republics, or Soviet Union

WMO – World Meteorological Organisation

WRI – World Resources Institute

WTO – World Trade Organisation

# Introduction

Each year, fossil fuels (coal, oil and gas) are consumed in ever-greater quantities, despite the danger of global warming, which makes such large-scale consumption unsustainable. The facts of consumption growth are at odds with ever more insistent claims that we are moving to a post-fossil-fuel era. Clearly, the causes of consumption growth are very strong. The purpose of this book is to put them into historical perspective.

The book covers the period since 1950, because it was in the second half of the twentieth century that fossil fuel consumption expanded to levels associated with dangerous global warming. The fossil fuel industries had taken a central place in rich countries' economies long before that, and taken their toll on humans and on the natural environment they live in. Tens of thousands of coal miners were burned, buried alive, gassed, blown up or otherwise killed in the production process. Millions of city dwellers' lives were painfully cut short by coal-related air pollution. But the threats to human society implicit in global warming – including the effects of rising sea levels, ruination of agriculture and the destabilising effects of storms – are on a still greater scale.

The accumulation in the atmosphere of the greenhouse gases that cause warming is foremost among the dangerous impacts of human economic activity on the natural world that have mounted over the past two centuries or so. Other notable impacts include the disruption of the nitrogen cycle and substantial loss of biodiversity. There is a consensus among researchers that these impacts signify that a new geological epoch has been reached: the Anthropocene (i.e. the 'new epoch of humans', from the Greek word *anthropos* (human)). Earth systems scientists, who work on integrated analyses of human-natural relationships, have concluded that since the mid-twentieth century there has been a 'great acceleration' of these impacts, and that fossil fuel use is the most significant cause.<sup>1</sup> The aim of this book is to throw light on this aspect of the problem.

The character of the damage done by excessive fossil fuel use has become clearer in the course of the time period covered by this book. It became apparent to climate scientists in the mid-1980s, and was accepted in international political forums in the early 1990s, that the global warming danger necessitated sharp reductions in the level of fossil fuel consumption. But it has kept rising. It swelled by more than half in the quarter century between 1990 – when the Intergovernmental Panel on Climate Change (IPCC) issued its First Assessment Report, formally urging a strategy to reduce consumption – and 2015.<sup>2</sup> At the Copenhagen climate summit in 2009, the world's most powerful governments

failed to agree on such a strategy, and by the Paris summit in 2015 admitted that they *could* not. In a century's time, when the impacts of global warming will be much more ruinous than they are today, people may look back at this failure as collective madness. There may be an analogy with the way that people today view Europe's descent in to the barbaric slaughter of the First World War, a century ago, as collective madness. It *was* madness, but it had definite political, social and economic causes that historians have sought to understand. In this book I will try to do likewise, with the madness that is producing global warming.

### *Consumption through systems*

Fossil fuels are consumed primarily by and through technological, social and economic systems, and these are this book's main focus. Relatively small quantities of coal, oil and gas are consumed directly by individuals and households, such as for heating or cooking, or (in the form of oil products) to fuel their cars. But most fossil fuels are consumed indirectly. They are used in the production of materials – from steel and cement to plastics and fertilisers – for industry and agriculture, which in turn produce goods for consumption; as fuel for industry and for transporting goods; for construction; or for military or other state functions. They are used as fuel to produce electricity or heat, which in turn have multiple uses. Where individuals consume fossil fuels directly in the technological sense – petrol in a family car, for instance – they do so in the context of social and economic systems over which they may have little control – in this case, urban development that sites homes, jobs and shops far from each other, work patterns that require them to make particular journeys, and so on. More broadly, technological systems that consume fossil fuels (e.g. electricity networks) are shaped by the social and economic systems in which they are embedded (e.g., in the late twentieth century, capitalism, or state socialism). Fuels are consumed not by undifferentiated humanity, but by people living in, and divided by, these unequal social and economic systems.

The interpretive approach of this book, focused on these technological, social and economic systems, is at odds with the assumption, shared by many economists, that the function of any economy is essentially to serve consumers' demand. In my view, production and consumption in the global economy have a symbiotic relationship, determined ultimately by relations of wealth and power in the economy. The driving forces for economic expansion lie ultimately in the constant urge of capital to accumulate, that is, for the wealth and power that dominates society to renew and reassert its dominance. (This view, formed in the Marxist tradition, is discussed in Chapter 11.) By making technological, social and economic systems the starting-point, my interpretation also contrasts with some writing about consumption, that concentrates on the cultural and social contexts in which mass consumption has expanded in rich countries

over the last century, and on consumers' psychological motivations. Cultural trends, and psychologies, form part of the story, but need to be considered in the context of the social, economic and technological systems.

These systems have since 1950 evolved, especially, through six social and economic processes, to which I shall repeatedly refer: *industrialisation*, and especially the expansion of energy-intensive industries such as steel and cement production; *technological and other changes in the labour process*, both in industry and in the domestic sphere; *electrification*, which was pretty well completed in rich countries during the post-war boom, but continued in most of the world since then; *urbanisation* and *motorisation*; and *household material consumption and the growth of consumerism*.

This book addresses a significant gap in historical literature. There is a rich historiography of the global development of fossil fuel industries, by writers including Vaclav Smil, Janet Ramage, Bruce Podobnik, Matthew Huber, Timothy Mitchell, Andreas Malm and many others.<sup>3</sup> The history of energy consumption is a narrower field, in which I have learned, especially, from the work of David Nye on the USA and Sunila Kale on India.<sup>4</sup> The expansion of fossil fuel consumption in recent decades has been the subject of a mountain of reports by international agencies, economists, energy specialists and NGOs, but much less work, so far, by historians.

Several historians have pointed out the need for a specific treatment of fossil fuel use. We lack 'a history sufficiently precise [...] to distinguish the share of responsibility of different technological choices for the climate crisis', that can identify 'the main institutions that have set us on the road to climate cataclysm', and by which historical processes, Christophe Bonneuil and Jean-Baptiste Fressoz complained. Frank Trentmann concluded his general history of consumption by calling for discussion of its environmental costs. Adam Tooze responded in a review that Trentmann's approach – which views consumption as 'individualistic, creative and cosmopolitan', 'essentially within our control', and subject to politics – did not allow examination of the way consumption is 'crashing against environmental limits'. The history of 'rampant fossil-fuel consumption' had to be addressed; we need 'a history that shows how consumption and production became tied together in an expanding feedback loop of ever greater economic and material scope'.<sup>5</sup> Hopefully this book is a step on that path.

I hope that understanding how fossil fuel consumption has spiralled out of control since the mid-twentieth century will help us all to shape the future transition away from fossil fuels. I cannot say how that will happen, and I am sceptical of those who pretend to be sure. Nor am I neutral about the future, though, and in Chapter 12 I have presented my view of the factors that I think will shape it. A theme running through that chapter is that the decisive actor is society – all of it, collectively – rather than political elites. For this reason I do

not offer what are sometimes called ‘policy recommendations’. I have tried to balance this general outlook with comments on specific ways in which technological, social and economic systems may change.

### *Some terms*

Fossil fuels are consumed in three main ways. 1. They are consumed directly, e.g. by a steel plant for processing heat, or a household for cooking. 2. They are transformed into other forms of energy (electricity or heat), or into intermediate products (e.g. petrol, kerosene or diesel fuel, all refined from crude oil) that are then consumed by businesses, state bodies or households. Following usual practice, I refer to this as *transformation*. 3. They are used as *raw materials*, e.g. in the petrochemicals industry to produce plastics, other industrial materials or chemical fertilisers for agriculture.

Since 1950, most fossil fuels were produced, transformed and supplied commercially, i.e. by corporations, state bodies and other economic actors. There are also non-fossil-fuel energy sources – hydro power from dams, nuclear power and modern forms of renewable energy (mainly solar and wind power) – that are produced commercially. The *commodification* of energy – i.e. the transformation of coal, oil and gas, their by-products, electricity, and heat into commodities traded in markets – is a theme that runs through the book. I distinguish between *commodified energy* and *energy supplied as a state benefit*; both of these are *commercial energy*.<sup>6</sup>

Hundreds of millions of people, mostly in rural areas outside the rich world, use *non-commercial* forms of energy. The most significant of these are *biofuels*: wood, other biomass and animal dung, collected from the natural environment mostly by the families that consume them directly.

*Energy* is defined in two main ways. For physicists, energy is the ‘ability to do work’ – a definition that includes human and animal labour power. That definition is too broad for people, including me, writing about energy in its social context. I describe labour as labour, and energy as *work done by physical or chemical resources, mobilised by people for that purpose*. This follows the Oxford Dictionary definition of energy as ‘the means of doing work by utilising matter or radiation’. That ‘work’ can include anything from running a power station to warming a room. A vital function of energy resources, including fossil fuels, has been to substitute for human labour, whether in industry, agriculture or in households.

A physicist would say that energy can neither be ‘produced’ or ‘consumed’, because humans’ energy systems simply take energy in one form and change it to another form. Nevertheless I have used these words in the usual way.

Fossil fuels, non-fossil energy sources such as nuclear fuel or solar panels, and manufactured forms of energy such as electricity are all *energy carriers*, i.e.



physical phenomena that carry within themselves the ‘ability to do work’. I have used this term when necessary for clarity, but I have also used the term ‘energy’ to refer collectively to energy carriers.

I use *renewables* to refer to solar, wind and tidal power, but not hydroelectric power, in line with common usage.

In the period after the Second World War, governments, international agencies and research institutions began systematically to compile national and international *energy balances* that counted economies’ total energy inputs and outputs.<sup>7</sup>

A final note on terminology: I refer throughout to the *rich world*. It is an unsatisfactory generalisation, covering the countries that were most completely industrialised, and achieved the highest living standards, before the Second World War: the USA and Canada, most of western Europe, Japan and Australia. Often, these countries have become, and stayed, rich at others’ expense, exploiting populations and resources through colonialism in the nineteenth and early twentieth centuries, and through economic domination in the period covered by this book. There are some patterns of energy use largely shared by those countries, some of which spread to other countries during the period covered. One way of defining the ‘rich world’ is to refer to the member countries of the Organisation of Economic Cooperation and Development (OECD). I have sometimes used this marker, but it is not always helpful. (For example the OECD includes Turkey, but not Saudi Arabia, whose per capita gross domestic product (GDP) is two-and-a-half times greater).<sup>8</sup> As for countries outside the rich world, I sometimes refer to them in just that way. In places I have fallen back on the term *developing countries*, while being well aware that it fails to encompass the way many countries’ development has been blocked and confounded.

### *How the book is organised*

Part I sets out contexts: historical (Chapter 1), technological (Chapter 2), and social and economic (Chapter 3). Chapter 4 presents a picture of fossil fuel consumption since 1950 as measured statistically. Part II is chronological. Chapter 5 covers the 1950s and 1960s, and Chapter 6, the 1970s. Chapter 7 compares the electrification of some key countries. Chapters 8, 9 and 10 cover, respectively, the 1980s, the 1990s and the 2000s. Part III draws together reflections and conclusions. Chapter 11 summarises the evolution of approaches in social theory to consumption in general, and fossil fuel consumption in particular. Chapter 12 is forward looking, and considers what history might tell us about the transition away from fossil fuels. Chapter 13 presents some conclusions.

Any author of a global history has to decide how much detail to include on any particular country. I have put in the foreground the USA (the twentieth century’s largest fossil fuel consumer); China (the largest consumer in the 2010s); India;

Nigeria (Africa's most populous country); South Africa (Africa's most industrialised country); western Europe; and the Soviet Union and successor states. Too little is included about some significant energy consumers (e.g. Japan), and many important countries with huge populations (e.g. in Latin America, the Middle East and South East Asia). I hope this is justified by the clarity added to the overall picture by details about the countries I have focused on.

# Part I

## Contexts



# 1

## Fossil fuels before 1950

The history of human consumption of fossil fuels can be divided into four time periods:

1. Human history before the European Industrial Revolution, when, apart from some local, temporary episodes, fossil fuels played no significant part in economic activity.
2. From the start of the Industrial Revolution in the mid-eighteenth century up to about 1870, when coal mining, coal-fired steam power and coke-fuelled iron making took centre stage.
3. From 1870 to the mid-twentieth century, when the second Industrial Revolution, fuelled by coal and to a lesser extent oil and gas, produced electricity networks, automated manufacturing, the internal combustion engine and petrochemicals. Such fossil-fuel-dependent systems became central to rich countries' economies.
4. From the mid-twentieth century to the present, when fossil fuel consumption expanded to many times its previous levels, fossil-fuel-dependent systems expanded outside the rich world, and oil surpassed coal as the most widely used fuel.

This chapter covers time periods 1–3. The fourth period is the subject of the book as a whole. Figure 1 shows how the use of fossil fuels has grown dramatically in periods 3 and 4.

In periods 2, 3 and 4, or since the mid-eighteenth century, a new relationship between human society and its natural surroundings has taken shape. The impacts of human activity on the earth and its natural systems have begun to operate on the same, or greater, scale as those systems themselves. These impacts include: destruction by agriculture and industry of biodiversity (the extinction of species at an unprecedented rate); disruption of the nitrogen cycle (the circulation of nitrogen through air, soil and water); and the acidification of oceans. But the most significant impact is the change to the atmosphere's chemical composition through the release of greenhouse gases – and the main cause of this is the burning of fossil fuels, which emits carbon dioxide (CO<sub>2</sub>). (See pp. 56–8.)

A consensus has formed between researchers, and many other people, that we therefore now live in a new geological epoch, the Anthropocene – as distinct from the Holocene that began at the end of the last Ice Age.<sup>1</sup> The exact dating



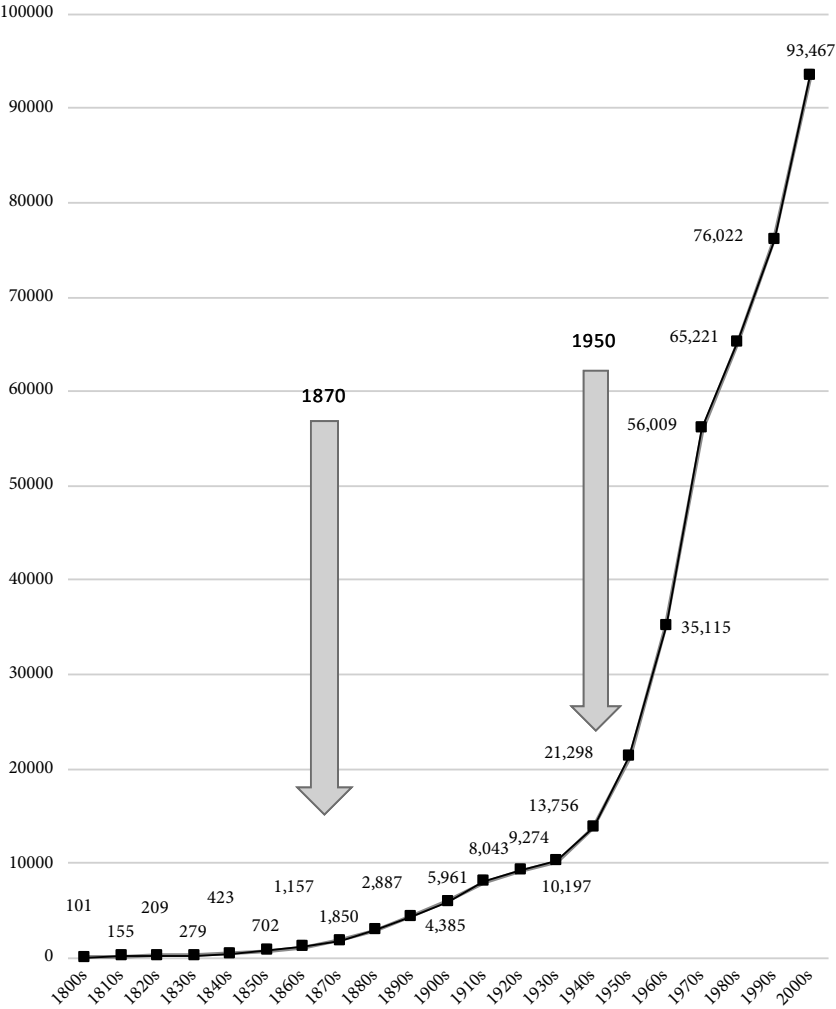


Figure 1 Fossil fuel production, 1800–2009  
Million tonnes of oil equivalent per decade

of the Anthropocene epoch, and other aspects of the concept, are subjects of controversy. But the natural scientists are clear, collectively, that there was a sharp upturn in the whole range of human impacts on natural systems from the mid-twentieth century – period 4 referred to above.

*From the beginnings to the Industrial Revolution (before 1870)*

For thousands of years, until the eighteenth century, human and animal labour power were the main sources of energy for economic activity. Water wheels

and windmills were used as prime movers (converters of source energy into mechanical energy), but much more energy was expended by domesticated animals, such as horses, oxen or donkeys, and humans themselves. Fields were ploughed, barges and carts pulled, treadmills worked and bellows operated by horses, slaves, serfs or free people.

During those thousands of years, people burned coal to produce heat and light, but surface outcroppings were rare, and coal churned out smoke. Plentiful wood was the main fuel. In some places, people used oil from the ground as a medicine or lubricant, but vegetable oils and animal fats were preferred. The first use of coal on an industrial scale was in China: in the eleventh century, shafts were sunk to mine it, and it was used extensively for metallurgy. The reasons why the Industrial Revolution did not happen in China have long been debated among historians; certainly the absence of a coal-fired prime mover were among the constraints, and the distances between coal deposits and urban settlements. From the eleventh century onwards, surface deposits of coal were mined in Scotland, England, Belgium and France, and used for forging iron, lime manufacture and evaporating seawater to prepare salt. But wood was the dominant fuel. Historians of London, for example, have shown that, even in the sixteenth century, when wood supplies were squeezed and prices rose, the additional cost of transporting coal to the city made it uncompetitive. The first European country in which a fossil fuel became dominant was the Netherlands, where peat largely replaced wood in the seventeenth century.<sup>2</sup>

It took the Industrial Revolution – the triumph of mechanised factories over workshops, of iron over other materials, and the rise of steam power – to give coal a central position in the economy. Coal's main function, in economic terms, was to substitute for animate – human and animal – labour power, vastly increasing industrial productivity. This transformation, which began in Britain in 1750–1830, was not only technological, but social. Capitalist wage-labour, which had roots going back centuries in English agriculture, took on a central role. Money made from the transatlantic trade, and slavery in America, helped Britain to finance the Industrial Revolution; that revolution, in turn, reinforced British supremacy over world trade and colonialism.<sup>3</sup>

Technologically, the Industrial Revolution started not with coal and steam but with the mechanisation of cotton manufacture. In the second half of the eighteenth century, mechanical spinning jennies, water frames and power looms were introduced and factory-based cotton manufacture soared, leaving behind the workshop-centred wool industry. The two crucial techniques that boosted coal demand – coke for iron making, and the steam engine – had both been used since the beginning of the eighteenth century, but were widely diffused only towards its end. Coke, made from coal – which in Britain was abundant and cheap – was burned in blast furnaces instead of charcoal. This cut the cost of making iron, which served as raw material for machines, farm

tools, water and gas pipes, and weapons of war. In the 1780s Britain made less iron than France; by the mid-nineteenth century it was making more than the rest of the world put together. The steam engine was the first machine that converted fossil energy resources into mechanical work, and not just heat. Concentrated volumes of mechanical power, previously available only from strong natural water flows, could be unleashed almost anywhere. The engine invented by Thomas Newcomen in 1705 was already used widely to pump water from mines by the mid-eighteenth century; it was James Watt's crucial improvement, the addition of a separate condenser, first applied commercially in 1776, that brought steam engines into general use. They became more fuel efficient and more adaptable, for use in factories, trains and ships.<sup>4</sup>

Steam and iron drove coal's dizzying expansion in Britain in the nineteenth century – but coal had begun to compete with wood long before that. Already in 1700, coal had overtaken wood as a source of thermal energy in Britain. The reasons that coal won out have been the subject of controversy among historians. The natural constraint on wood production, that Britain had only a fixed amount of land on which to grow it, was the focus of Edward Wrigley's analysis. Without coal and the shift from a wood-fuelled 'organic economy' to a 'mineral-based energy economy', he argued, economic growth would have faltered. Other historians were unconvinced: there *were* shortages of wood, but these were local (especially in densely populated areas) and transitory. Transport also made a difference: wood had to be collected from multiple locations, and was bulkier to move. Coal, despite being much dirtier to burn, got a foothold in such industries as pottery, brick- and glass-making, as well as iron-making.<sup>5</sup> But it was coal's sheer abundance and its ability to substitute for human labour that were decisive, argued Robert Allen. In eighteenth century Britain, the blast furnace, steam engine, spinning jenny and water frame increased the use of coal and capital relative to labour. These technologies were adopted and diffused in Britain more rapidly than elsewhere, because 'wages were remarkably high, and energy was remarkably cheap'.<sup>6</sup>

In the nineteenth century, steam engines became the leading consumers of coal. But they did not overtake wind and water power overnight. Early steam engines were very expensive and inefficient by any standards. The earliest ones had thermal conversion efficiencies of 1 per cent (the output was 1 per cent of the energy content of the fuel input) and it took a century to boost this to around 20 per cent.<sup>7</sup> Even with Watt's improvements, the engines were relatively inefficient, and wind and water remained dominant in industry. Steam had obvious advantages, though: cotton mills no longer had to be located near flowing water. Employers used the new technologies to reshape their social relations with workers. Factories could now be sited where employers could best force workers into them and best control them while at work. During a series of labour revolts culminating in the 1842 general strike, workers acted against the machines, as

the Luddites had a quarter of a century before, and disabled engine houses and pitheads. 'This was collective bargaining by rioting against the fossil economy,' Andreas Malm argued, coining Eric Hobsbawm's phrase.<sup>8</sup>

In 1800, Britain's coal consumption was 11–15 million tonnes (mt)/year; by 1845, 40–45 mt; by 1870, it was crossing the 100 mt mark. The spillover of steam engines into railways gave a further impetus to industrial development. Coal for steam engines, and wrought iron for rails and wheels, underpinned the British railway boom of the 1830s and 1840s. That boom in turn made coal more easily transportable, boosting its competitiveness against wood. Steam was also introduced into ships, but replaced sail only slowly – the US merchant fleet, for example, was 15 per cent steam powered in 1850 and 33 per cent by 1880.<sup>9</sup>

The British Industrial Revolution also led to unprecedented urban development. There had been many cities, including some very large ones, in world history. But industrial cities – populated by wageworkers and their families, full of factories, with streets underfoot and air above full of smoke and soot – had never existed on this scale. By 1860, 50 per cent of England and Wales was urbanised, compared to 25 per cent of Italy, Belgium and the Netherlands and 18 per cent of France. In nineteenth century Britain, the lighting of streets and factories made it possible to lengthen the working day; it went together with clean water and sewage systems designed to minimise the effect of regular and dreadful epidemics. In the USA, too, in the nineteenth century people began to receive water, gas and some steam heat from sources outside the home, well before electrification. This made it easier for male workers to be separated from the daily routine of work at home and to go to the factories. In the eighteenth century, municipal lighting had often used whale oil or vegetable oil; in the nineteenth century, increasingly, coal gas (methane recovered from coal).<sup>10</sup> Up to the 1870s, though, consumption of fossil fuels in people's homes was rare and statistically insignificant.

Coal and steam 'did not make the industrial revolution, but they permitted its extraordinary development and diffusion', historian David Landes pointed out.<sup>11</sup> From about 1830, the coal- and steam-based industrial system spread to France, Belgium, and to the states that would be unified in Germany in 1871. There followed a new round of colonisation led by Britain. As Bruce Podobnik wrote:

Coal-powered ships and railroads allowed Britain and its Continental rivals to seize control over territories in Asia, Africa and the Middle East that had long resisted conquest. Coal-driven transport systems then allowed for a radical increase in the volume of goods moved from the periphery into the core of the world-economy.<sup>12</sup>