CHAPTER ONE

INTRODUCTION

What Needs to Be Explained

This book is an economic history of Europe viewed through the role that energy has played in that history. As such, it also aims to provide an account of the role energy can play in economic history more generally, and how energy consumption and economic development have been, are, and may be, entwined.

All things need energy, and all actions are transformations of energy. Every step, small or large, that a human takes, is part of an energy economy, and every object we treasure, use, or discard is similarly the product of that economy. We have always been "children of the sun,"[1] the final source of nearly all of the energy that those living on the surface of this planet will ever consume. The way this energy, with its origins in the nuclear processes at the heart of our nearest star, is obtained and used has put its stamp on human societies since time immemorial, whether of hunter-gatherers, farmers, industrial cities, or astronauts; and whether that energy is consumed as food from plants or animals, as the driving force of wind or water, as the heat of combustion or flow of electricity. All humans that have ever lived have been equally dependent on energy, but each society's energy economy has taken on distinct forms, and some previous great societal transitions have also been, in their own way, energy revolutions.

But in a very long human history nothing quite like the past couple of hundred years has ever occurred. No previous transformation has been of the scale and intensity of modern times. Indeed, this explosive and ongoing change in scale and speed is what we now evoke with the very word "modern." While the human population had for the first time advanced to a full billion by the early nineteenth century, less than two hundred years later there are seven times more of us. Yet this sevenfold advance pales beside the increase in our production, which has risen more than seventy-fold in the same period (fifty-five times in the case of Western Europe, the focus of this book). By this measure, the "average" inhabitant of planet Earth is today more than eleven times better off than in 1820, and in Western Europe, eighteen times better off.[2] Our technology can achieve feats barely

[1] Crosby, 2006.
[2] Maddison, 2003.

imaginable to our great-great-great grandparents, a mere five generations ago, and each generation continues to be astounded and bewildered by the achievements of the next, even in a world where such change is so commonplace as to have become the norm. Alongside such transformations we are also witnessing a "great acceleration" of impact on our environment, and the possibility that our economy is transgressing the "planetary boundaries" that provide a "safe operating space for humanity," threatening the functioning of ecosystems and threatening rapid climate change.[3] However we value the modern world, it is hard to describe the changes that have occurred without reaching for the lexicon of the big.

Unsurprisingly, a short era that has witnessed more economic growth than in the whole of previous history also has required much more energy. There have been many kinds of revolutions during the modern age. There has been an industrial revolution, or rather three industrial revolutions, which we will use as the organizing principle of the book. There has been an energy revolution or several energy revolutions too, as new energy conversions have been enabled or new energy carriers have been exploited.

We could provide an almost endless list of how radically different our lives have become in the modern, industrial period. Take the case of light. In the premodern world, darkness reigned once the sun slipped below the horizon. Only a handful of cities provided street illumination that cast a weak light into nocturnal streets where only a bright moon provided a guide for the eyes.[4] Indoors, most people, if they used artificial light at all, struggled with candles or rush-lights, dried strips of vegetation dipped into animal fat and giving off a foul smell for the short time they burned. How different were the summers and winters then in northern climes, the difference between long, bright nights and short, dim days. Heating was generally provided only when considered an absolute necessity, and then only for one chamber. Even the houses of the well-to-do have well-documented cases of wine freezing in glasses or ink in inkpots. Today manufacturing runs round the clock. Central heating raises temperatures to summer levels in every room irrespective of its use, while for some of us air conditioning seeks to keep the high summer temperatures at bay, out of doors. As centers of population cast their glow into space, we wonder if today's children will ever see the "true" night sky. By one estimate, the average Briton now consumes six and a half thousand times more artificial light than did their ancestor in 1800.[5]

The services we get from energy may be the same: heat of low and high temperature, motive power, and light. But in most of Europe in the twenty-first century, none of those services in a domestic home, aside from the work done by the people themselves, are coming from the same sources as they

[3] Costanza et al., 2007; Rockström et al., 2009.
[4] Koslofsky, 2011.
[5] Fouquet and Pearson, 1998.

did in the nineteenth century. Not a single one. Such a turnaround has never happened since humans learned to harness fire. And the heat, motion, and light do not just deliver much more of what we used to have, but entirely new services: pictures that come from screens (and can be seen in the dark), voices and music from speakers, conversations in real time that span the globe. This new technology did not just come from changes in knowledge, from the accumulation of generations of ingenuity, but required the use of "energy carriers" that, globally, had only previously been used on a trivial scale and that were inaccessible to most (such as coal, oil, natural gas), or were entirely new (electricity).

As societies and as individuals, our command over resources, and the degree of choice open to us, has vastly increased as a result of these transformations. In a very everyday sense, we have been empowered by the energy revolution; in the choice of what we can do with our time, in our liberation from heavy labor, and in that while we earn much, much, more, we have also benefited from a reduction in working hours since the nineteenth century. This empowerment has come above all in our material life, but in our political and social lives, too. There have also been costs; for many, there may be a sense of disempowerment: a sense of alienation from the natural world that has come with urbanization and the capacity to consume resources with little direct relationship to them. In this book we will stress material changes, but in the broader senses of the word, this is why we think this is a story of bringing power to the people.

Energy also redistributes political power (the more familiar use of "power" to historians). It has not done so in a standard, linear way. Greater energy availability does not, by any means, simply translate into greater democracy or indeed greater governmental control (which are not, in any case, necessarily contradictory). But new systems of harnessing and consuming energy have certainly greatly influenced the options open to governments, individuals, corporations, and countries, and given rise to new areas of contestation and co-operation. Even in the least liberal of European states, people have generally been greatly empowered as consumers relative to their forebears. Sometimes new energy systems have conferred power more directly, whether to the rulers of countries who held major oil reserves, or the political muscle of coalminers, railwaymen and dockers in periods when they populated key parts of the infrastructure.[6] The spread of information, whether via steam-powered printing, television, or the Internet, has provided significant new ways to hold leaders to account. Resource endowments have shaped geopolitics.

We can also put numbers to the expansion in energy use: indeed, one of the main contributions of this book is to provide, for the first time, reliable numbers on energy consumption for much of Europe and individual

[6] Mitchell, 2011.

countries within it, including traditional as well as modern energy carriers. The data we can now provide are path-breaking in two regards. First, they provide much more reliable estimates than previously existed on pre–fossil fuel era energy consumption, making much greater use of contemporary sources than pioneering work.[7] Second, we have established a consistent methodology for quantifying the economic consumption of energy that can be used for cross-country comparison and aggregation of our datasets.[8] These data, focusing on energy as an input into the economy, can then be combined with available long time-series of GDP, capital stocks, and labor to shed new light on what we characterize as "three industrial revolutions" that have occurred over the past two centuries, and their varied impact on energy use in society.

What do these numbers show? We can see in figure 1.1 that the path of the modern economy has not been a straightforward story of a constant rate of increase in the use of energy. Instead, the overall trajectory of energy use within Europe follows a logistic S-shaped curve. It is possible to discern three phases. The first phase, 1500–1800, was marked by little growth in overall energy consumption, and even slightly falling per capita energy consumption in the sixteenth and the eighteenth centuries. The second phase, 1800–1970, is the Industrial Age, which saw explosive expansion in energy use, except for during the World Wars and interwar period. However, industrialization took place at different moments and at different speeds in the countries of Europe, and the curve in figure 1.1, which aggregates the European experience as a whole, makes this change appear smoother than it might seem from a national or regional perspective. The third period, 1970–2008, is exceptional in that it was marked by stabilization in energy consumption per capita. It seems that after around 1970, economic growth has no longer been accompanied by the same level of increase in energy use. Rises in consumption have been modest, and in per capita terms, changed little. At the end of the twentieth century, we seem to have entered a new phase in the relationship between energy and economic growth.

The main thing we set out to explain in this book is why the shape of this curve looks the way it does.

In so doing, we need to investigate the relation between energy and economic growth. This relation is influenced by the kinds of energy carriers involved in the aggregate energy consumption at any point in time. Industrialization has not been just one change in the energy regime, but many: the transition to the first fossil fuel, coal, has been followed by the adoption of oil and natural gas, and the diffusion of electricity. This has affected energy consumption as well as economic growth. For instance, as the main shift

[7] Martin, 1988; Schurr and Netschert, 1978, for the United States; Smil, 1994; Fouquet, 2008.

[8] Etemad, 1991; Reddy, and Goldemberg, 1990.

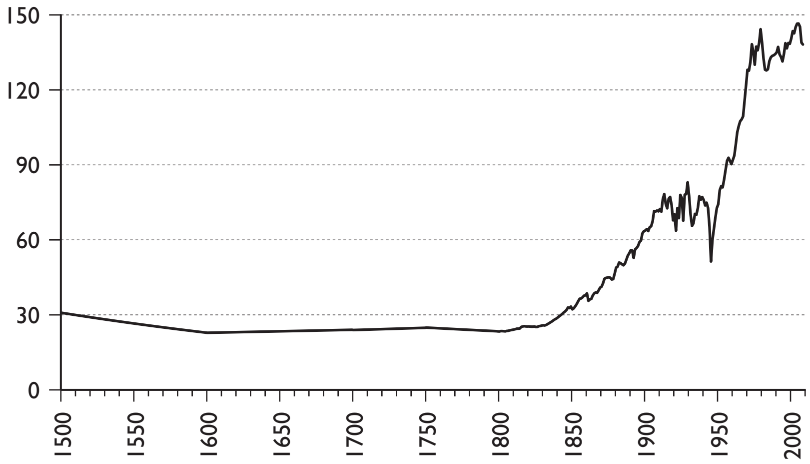

Figure 1.1. Energy consumption per capita in Europe (Gigajoules, 1500–2008)
Sources: Own detailed data, 1800–2008, see www.energyhistory.org. For the period 1500–1800 the trend is nothing more than a rough estimate. See chapter 3.

into the oil economy happened almost simultaneously across Europe after the Second World War, we see most clearly in the postwar decades, that "golden age" of growth, the explosive increase in energy use that swept the whole continent. Consequently, energy transitions are an important part of our story. Last, but not least, energy transitions influence the economic efficiency of energy use, expressed by the ratio GDP/energy, since different energy carriers form part of new growth complexes, which we call development blocks, using energy to different degrees.

Of course, bare numbers on energy consumption can only give a bare sense of how everyday life has been transformed, whether through improved access to information, or the much greater ease and speed with which we can accomplish domestic tasks (which means, in turn, that we also do them much more frequently than before, whether washing clothes or heating food and drink at home). Unsurprisingly, ours is a book that stresses material flows and our dependency on physical things. This is not to underplay either changes in, or the role of "wishes, habits, ideas, goals" in this history,[9] and these, as they relate to energy, are part of our story (although histories of such things very rarely touch on the role of energy in generating and disseminating them). More energy is not just a consequence of other revolutions, as if it could be hauled up from nothing, like the proverbial man lifting himself by his own bootstraps. We also see the energy revolution as

[9] Mumford [1934], 1963, 3.

one of the causes of the modern world, and we want to explain why and how this was achieved.

Research Questions and Main Arguments

At this stage we would like to spell out the main arguments we will make, and the three interrelated research questions we will address, and in doing so position ourselves relative to other approaches:

1. Energy and economic growth;
2. Drivers of energy transitions;
3. Economic efficiency of energy use.

Energy and Economic Growth

The relationship between energy and economic growth is the first and core research question that we deal with throughout the book. Is energy a driver of economic growth, or does economic growth simply bring about sufficient increases in the supply of energy? We think that the energy revolution of modern times was not optional, merely one path that was taken among a number that could have brought about similar changes. Major innovations in the field of energy were a *necessary* condition for the modern world and energy continues to play a large role in the economy, as intuitively grasped by the continuing general preoccupation with the geopolitics of energy, whether oil or natural gas.

Yet although it might seem commonsensical today to say that energy plays a central role within the economy, most economists do not include energy in their models of economic growth. According to some economists, raw materials (including energy) played virtually no determining role in the development of the economy. We can take as an important example Robert Solow, who claimed in 1974 that actually the economy can progress without natural resources.[10] Growth depended and continues to depend on knowledge, technical progress, and capital. The contribution of natural resources to past and present growth has been almost non-existent, in their view: the supply of energy and resources has always simply followed the demand generated by new forms of knowledge and techniques and has never played a constraining role in the economy. The implication is that energy resources have never exercised any significant restraint on growth, or shaped its course. Equally, and quite optimistically, this implies that future energy transitions, whether necessitated by the imperative to mitigate climate change

[10] In fact, as early as the 1860s, opponents of Stanley Jevons were arguing that the future exhaustion of coal reserves would not be a problem for Britain because it would shift to activities more reliant on skill than raw materials; see Jevons, 1866; Solow, 1974.

and pollution, or combat rising relative prices of fossil fuels, are unlikely to impose major costs on the economy. For such thinking, the fact that the energy sector presently makes up only a small part of the income of modern economies, generally less than 10 percent, indicates its insignificance.

We dispute the logic that cheapness means a lack of importance. In fact, it is the cheapness of energy that underpins much of the infrastructure of modernity, and an approach that apportions economic importance solely on the basis of the size of a sector in the national accounts misses out on essential qualitative drivers of economic development and success. In a pure cost sense, energy is certainly less of a limiting factor than it was in the pre-industrial era. Then, as we will show, a majority share of total economic activity in most places was devoted to obtaining energy in the form of food, fodder, and wood fuel. An advantage of modern energy sectors is that the energy return on investment (EROI) is very high, although this is something that might change again in the near future.[11]

The decrease in the cost of energy, at the same time that much greater quantities of it could be supplied, has allowed vast reserves of capital to be employed, delivering other kinds of goods and services rather than covering only basic energetic needs. Nevertheless, the expansion of many sectors of our economy has also depended on particular *development blocks*[12] with energy provision at their heart; and infrastructure whether in the design of suburbs and transportation systems almost wholly dependent on the Internal Combustion Engine (ICE), or the electric or gas-fired heating and cooling systems that make domestic and office life bearable in a variety of climates. The shrinkage of what we might consider as "the energy sector" to a much smaller part of the economy has not, then, allowed economic development to escape from dependence on particular forms of energy carrier. The fact that our economies have been built around development blocks based on certain energy carriers and their associated technologies also means the cost of energy transition may be high, requiring renewal of a significant part of our capital stock.

Drivers of Energy Transitions

The scale and drivers of each historical energy transition is the second of our main research questions in this book. Energy transition is a major preoccupation of twenty-first-century politics, but has already been a defining feature of modern life for at least one and a half centuries. The first of these transitions was between a variety of "traditional," or "organic" energy carriers that primarily were based on the products of the soil, to fossil fuel; at

[11] Cleveland, 2008; Murphy and Hall, 2011.
[12] For a technical definition of this term, see chapter 2.

first, coal.[13] These early energy carriers included wood, peat, fodder for draft animals, and food for humans. It may come as a surprise that human food is considered part of the energy sector. But much of what our ancestors consumed was fuel to power their muscles. Of course, there is more to human nutrition than calories; there is more to human work than brute power. Yet without understanding how agriculture was also an essential part of the energy regime, that an essential task of this sector *was* to produce calories that drove work, as well as proteins and vitamins, it is impossible to understand the organization of the pre-industrial world, or the nature of the transition to modern energy regimes. The capacity of the land to grow plants useful to humans and draft animals imposed a fundamental limit on our economy. Without the need to feed these "biological engines," much greater areas could have been used to supply firewood; these sources of energy stood in competition. The ability to transcend both the land constraint through the use of fossil fuel, and the muscle constraint through mechanization which increased power (largely fueled by coal) were founding acts of the modern world.

The transition to fossil fuels was not the end, but only the beginning of modern energy transitions, even if it has been (at least up until now) the most profound shift. Transition has continued, both in fossil fuels such as coal, oil, and natural gas, but also harnessing new forms of carriers—most importantly for generating electricity. This history of transition is in part a history of substitution, with societies shifting demand between, for example, wood and coal, or coal and natural gas according to their price, but some of the uses of certain energy carriers have no or very poor substitutes. Electricity is absolutely necessary to run a wide array of household devices such as vacuum cleaners, and technology with much wider applications: lighting, computers, machines in industry. Cars are best run on liquid or gaseous forms of energy. So historically there has been a strong complementarity between certain energy carriers and associated technology, something we will deal with extensively. Indeed, the most significant changes in the energy regime have required very major infrastructural developments and shifts in technology and the organization of society to accommodate them, and make best use of their capacities.

Transformation in the energy system derived from the progress of technical knowledge and associated innovations. These advances did not just occur in forms of energy generation or the invention of new processes (such as steam power or the internal combustion engine), but had to occur across a wide array of the supporting infrastructure required to put new technology into use. We use the expression *development blocks* to describe the series of systems of technology, infrastructure, energy sources, and institutions by which economic growth proceeded (for a fuller description see chap-

[13] Greenberg, 1992.

ter 2).[14] Shifting transportation networks to automobiles required a new infrastructure of tankers, refineries, gas stations, and metaled roads. Even when the end product is the same, such as electricity, the use of different forms of generation (wind, nuclear, coal) requires capital of different scales and capacities in the increasingly international supply network. Because of their scale, complexity, and level of interconnection or complementarity, development blocks formed discontinuous phases in economic development, and mean that there may be a significant lag between early inventions and the widespread adoption of a technology. Thus, while transition has been a common feature of the modern economy, and the process of growth is fairly continuous, we argue that this has been achieved through fundamentally *discontinuous* processes involving major structural shifts that take time to achieve. We develop a novel historical account of what forces have led to the emergence of the development blocks marking different periods and thus permitted the energy transitions of industrial society. This will be developed more fully in chapter 2.

Economic Efficiency of Energy Use

The third research question we address is the change and impact of the *economic efficiency of energy use*, indicated by the ratio of GDP/energy. We investigate how economic energy efficiency has developed in time and space. This is, among other things, a contribution to the debate about *dematerialization* of production and how far that can take us in reconciling ecological concerns with economic growth.[15] We find not only that increased economic energy efficiency has long been seen as desirable; it has also been the normal experience of some countries and sectors of the economy. Both energy transitions from lower to higher quality energy carriers and increases in the thermal efficiency of machines have stimulated increases in economic energy efficiency, i.e., unsurprisingly, producing more useful light or motion or heat out of the same input of energy has often contributed to the amount of income that can be won from each input of energy.

Nevertheless, the long-term story is more complex. Technological shifts related to development blocks and industrial revolutions have caused structural changes in the economy (changes in the relative importance of different activities) which have also affected economic energy efficiency to a considerable degree. Development blocks can be primarily *energy saving* or *energy expanding*. Yet these processes can interact. Efficiency improvements in a particular technology, like iron-smelting or the steam engine, can reduce the energy costs of production, but in doing so make the technology more

[14] Dahmén, 1950, 1988.

[15] Ausubel and Waggoner, 2008; Herman et al., 1990; Ming Sheng et al., 2010; Sun, 2000; Tapio et al., 2007;Vringer and Blok, 2000.

widely affordable, creating a huge expansion in its use. The net effect of a local saving can be an absolute expansion, paradoxical as that might seem. These *rebound* or *take-back* effects are an important part of the story of modern growth (see chapter 2 for a fuller explanation of these concepts). We also perceive a sequence in the historical evolution of development blocks, where they have become relatively more energy-saving over time.

However, this historical evidence of improving economic energy efficiency does not suggest a very strong dematerialization over time. Many economists believe so strongly in general efficiency increases (total factor productivity increases) being the reason behind modern economic growth that they also believe the economy can dematerialize, or get rid of its dependence on energy or other material resources almost entirely. We show that this is a false belief. Over the last two centuries the efficiency in the use of energy has doubled. The size of the economy is fifty times as large as it used to be and energy consumption, twenty-five times higher. This is very far from a dematerialization, and we offer as one of the main contributions of our book a resolution of this paradox of the economy being on a high-energy path, despite all of the advances in productivity. The "capital deepening" path of modern economic growth has been so strong as to outweigh most advances in the thermal efficiency of that capital. Technical change has been indeed *biased*, saving on labor much more than capital and energy in the long run. Indeed, it is this greater advance of capital and energy use compared to labor that has brought "power to the people."

Still, we also have a somewhat more positive message with regard to the prospects for some dematerialization. This pattern has changed since the 1970s; from this decade we show that the rate of improvement in economic energy efficiency has sped up as a consequence of the third industrial revolution, both affecting energy use in the manufacturing sector and contributing to a structural change in the economy, with a relative increase of the service sector. Energy consumption has ceased what seemed an inexorable rise, presenting some hope that future growth may become more energy-saving.

Our book is written at a time when there is large concern for and interest in the role of energy in economic growth.[16] This interest is related to contemporary urgent issues that humankind is facing: global warming, peak oil, and so on. We are neither the first to produce a quantitative energy history, nor to have engaged with our research questions. Looking back over four decades we can highlight the work of (among others!) Netschert and Schurr on the United States; Václav Smil and Arnulf Grübler respectively on global energy economies; Jean Marie Martin on long-term energy intensities for several countries; work undertaken independently of each other by Rolf-Peter Sieferle and Tony Wrigley on the European energy economies of the first industrial revolution; recent quantitative reconstructions by Fridolin

[16] Ayres and Warr, 2009; Stern, 2010b.

Krausmann, Heinz Schandl, and Roger Fouquet, and the team of Bob Ayres and Benjamin Warr; and a very wide range of literature that has touched on energy to a greater or lesser degree in examining historical change, whether the first industrial revolution, village-scale agricultural change, shifting "networked" cities, or the economic history of particular sectors of the economy.[17] Nearly all of these works would also argue that energy was important to industrialization and modern economic growth. Our book differs from these, in the provision of new time-series data, but also in our focus on long-term and internationally comparative economic development. We also differ with some of our colleagues on key points of interpretation. We do not, as do Ayres and Warr, argue that energy, or energy services, were the engine of growth in a unified way throughout modern history.[18] We argue that the influence of energy changed and was a discontinuous process during the three industrial revolutions. Equally, we want to draw attention to the varied, but interlinked, regional and national manifestations of these changes. The role of energy relative to shifts in technology that employs it altered especially from the 1970s, with the emergence of a development block founded on Information and Communication Technology (ICT).

The great revolutions of modern times have been phenomena of great breadth and have had an equally great breadth of academic studies and explanations devoted to them. Too often such texts are read and interpreted as if they are seeking to be all-embracing or mono-causal explanations, even when they insist they are not. When we say an energy revolution was part of these processes of modernity, this is not seeking to negate the validity of other approaches. We do not think that energy history is the key that by itself unlocks everything else; the transformation of the pre-industrial energy regime was *not* a sufficient condition for the industrial revolution or modern economic growth. It was however a necessary condition.

Energy resources could only be useful insofar as there was "useful knowledge" and the appropriate "state of mind" to make use of them.[19] The accumulation of knowledge, institutional change, and market expansion played an important role in the birth of the modern economy, as stressed nowadays by most economic historians and economists. But we strongly believe that knowledge and states of mind were only useful insofar as they have the right kind of material to work on, and in fact are only likely to develop if the uses are a realistic and imaginable prospect. In places that lack certain kinds of resources, ingenuity will flow in other directions, and rapid economic

[17] Schurr and Netschert, 1978; Martin, 1988; Sieferle, 1982, 2001; Smil, 1994; Grübler, 1998; Wrigley, 1962, 1988a, 2010; Krausmann and Haberl, 2002; Krausmann et al., 2009; Fouquet, 2008; Ayres and Warr, 2009.

[18] In their major book, *The Economic Growth Engine*, it is energy services that drive growth, but in a more recent publication from 2010 they also see information and communication technology as important for growth since the 1970s.

[19] Mokyr, 2002.

growth will not be the result. Consequently we take issue with accounts of economic change that give little place to material considerations and resource availability.

This debate has been most prominent in the vast literature about the industrial revolution, frequently asking why Britain took a clear early lead (especially as opposed to its near neighbor and political rival, France), or more generally, why western Europe and not the economies of south and east Asia industrialized first.[20] An earlier generation of scholars had explained national or regional economic advantage and its character broadly in terms of resource endowments, especially of fossil fuels.[21] In the 1970s, revisionist views argued that there was little to distinguish the economies of Britain and France in the eighteenth century, and that the British lead was thus entirely the result of contingent factors or even inexplicable in theoretical terms.[22] More recently, and following on from the work of Douglass North, who placed greater emphasis on the role of education or institutions in facilitating growth, many scholars have explained differential economic performance by variations in human capital, institutional capacity, or cultural differences.[23] Limitations or advantages did not lie in the availability of material resources, which imposed no essential restriction on supply; rather, conservative habits of mind had to be overcome to stimulate demand and ingenuity, and local success was steered by the disposition of key groups among the population, or the diffusion of Enlightenment values.[24] In these accounts, countries *were* significantly different, but in how they thought, not what they possessed. In contrast, a strong line of argument has persisted that the advantages of Britain and Western Europe more generally lay in the relatively low price of energy found where fossil fuels were easily accessible, stimulating the move into an industrial and capital-intensive economy.[25]

These intense debates among economic historians about the wellsprings of modern growth have had very little influence on modern growth theory, which has rarely perceived energy or natural resources in general as a constraint upon growth at all.[26] This has generally been because they think that other resources can substitute for energy or natural resources. Ecological economists on the other hand see energy as a limiting factor to growth. They think that substitution between capital and resources and technological change can only to some degree mitigate the scarcity of resources.[27]

[20] For a recent summary, see Griffin, 2010.
[21] Landes, 2003; Pollard, 1981; Habakkuk, 1962.
[22] Milward and Saul, 1973; Crafts, 1977.
[23] Rostow, 1960; North, 1973; Clark, 2007.
[24] Clark, 2007; Mokyr, 2009; McCloskey, 2006; Voigtlander and Voth, 2006; de Vries, 2008; Sharp and Weisdorf, 2012.
[25] Wrigley, 1988a, 2004, 2010; Pomeranz, 2000; Allen, 2009.
[26] Aghion and Howitt, 2009.
[27] Stern, 1997, 2010b.

We do not argue for a false choice between "ideas" and "materials" in driving growth, but will examine how they must advance in mutual interaction and co-dependence. In that sense we actually think that some of the debates in economic history today are a little artificial; dare we say it, some of their participants would concede that they generate more heat than light, and different rhetorical and analytical emphases in the literature may not represent genuine disagreement in principle.[28] Nevertheless, we firmly place ourselves among those who think that the availability and relative price of energy was a key determinant of growth patterns and differential economic performance. We will present clear evidence that the resources of the pre–fossil fuel economy were not sufficient to have underpinned modern industrial growth.[29] We agree that the accumulation of physical capital, requiring particular raw materials, and its utilization in ever more productive ways by using the complementary modern energy carriers, has been an essential part of the history of modern growth. Human capital, the set of knowledge and skills we possess, and our institutions for steering economic life, are necessary but not sufficient parts of this story.[30]

The Structure of the Book

In this book we adopt a commonly used division in economic history, of "three industrial revolutions."[31] We use them as the organizing principle of the book, and relate them to four development blocks that have played a particular role in shaping our modern energy economy and society over the last two centuries (figure 1.2).

To understand the transformation of the five centuries we take as our subject, we must first understand the energy economy of the premodern world, and its reliance on "traditional" energy carriers, largely the products of the land, but also water and wind power. The premodern world and the pressures upon its energy economy are set out in the first part of the book,

[28] In the Economic History World Congress of 2009, Joel Mokyr and Bob Allen had an intense debate about the roots of the industrial revolution. Mokyr confessed in the beginning of this debate that he actually agreed with Allen about many things and it is clear that he does think that technology, steam, and coal mattered, although he has come to stress the mind-set of people more in his recent writings. Mokyr has also rightly pointed out that the Industrial Revolution is one event with many competing explanations, and since it is only one event it is in fact overdetermined. We can never empirically distinguish between them.

[29] In distinction to authors such as Clark and Jacks, 2007, or Kunnas and Myllyntaus, 2009.

[30] Prados De La Escosura and Rosés, 2010b.

[31] The third industrial revolution does not only affect the manufacturing sector, but also the growth and content of the service sector to a large degree. It describes a general process of enhancing productivity by the use of ICT technology across sectors, and has seen continued advance in industrial production despite the shrinking share of industrial workers in the total workforce.

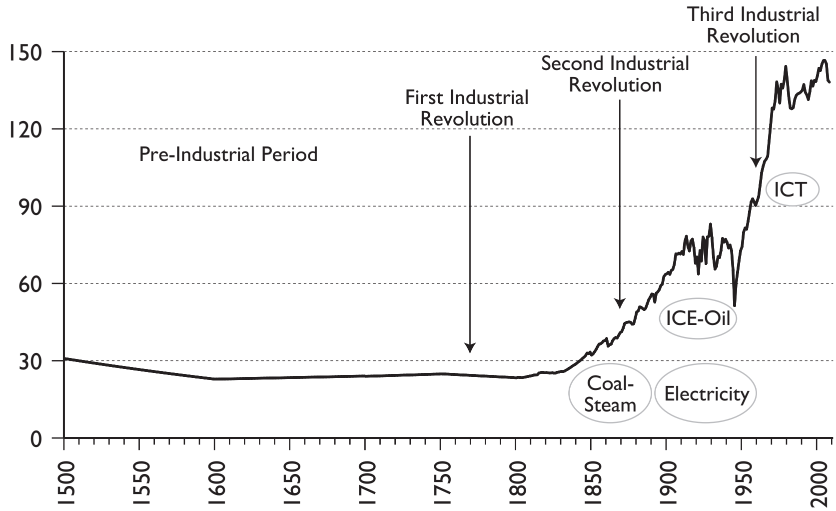

Figure 1.2. Three industrial revolutions and four development blocks
Source: See www.energyhistory.org.

written by Paolo Malanima. It has long been debated whether premodern, or "pre-industrial," society was profoundly trapped by its dependency on the land and thus a fundamental scarcity of resources that in the long run would lead to falling real wages as populations grow. We argue that this scarcity was real: the evidence points to stagnation or real falls in many parts of Europe. Growth, modest by later standards, was an exception, linked to very few regions that often had exceptional energy economies, like the Netherlands, and Britain. This is not to deny significant changes in the organizational and technological basis of this society that was an essential precursor to the revolutions that followed; not least, localized trends toward mechanization and the use of fossil fuels.

The first industrial revolution is the subject of the second part of the book, written by Paul Warde. This great transition emerged in a highly regionalized fashion out of the pressures and resource endowments of the premodern economy. This led to rising per capita energy consumption in the nineteenth century, after a long pre-industrial history of stagnation or even decline over much of the continent. This gradual rise at the aggregate level disguises much more rapid transitions in sectors, regions, and countries.[32] The core innovations associated with coal use were steam power and new iron-smelting techniques. We argue that both qualitatively and quantitatively coal was a necessary condition for the emergence of modern growth from the pre-industrial past. To us the evidence points to the impossibility

[32] Pollard, 1981.

of sustaining high levels of growth or transformation in a world wholly dependent on "organic" or vegetable sources of energy. Wood could not have done the job.

The third part of the book, written by Astrid Kander, covers the much more complex patterns of development to be found in the twentieth century. The second industrial revolution, based on electricity and oil, was already emerging in the late nineteenth century but only brought about a very major impact in Europe in quantitative terms in the Golden Age of growth after World War II. A third industrial revolution grounded in ever-widening use of electricity combined with Information and Communication Technology (ICT) has been a major factor in the stabilization of per capita energy consumption levels since around 1970. The alternative propositions that it is the transition to a service economy that have led the decline, or that it was driven by outsourcing energy-intensive production to less developed countries, are critically investigated.

Energy productivity (or its reciprocal energy intensity) will be affected by the structural changes brought on by the emergence of development blocks, since economic sectors differ with respect to their energy needs. We argue that the development block of the first industrial revolution was energy-expanding, with the importance of metals and steam technology widening the use of fossil fuels enormously. The second industrial revolution presents two different kinds of development blocks: one around oil, which had the same expansive character as the steam-coal-steel block; and another around electricity, which to a large degree increased energy productivity and was energy-saving. The third industrial revolution only had one large development block. It is basically a continuation of the electricity block, but is even more energy-saving than the electricity block. The different properties of the development blocks with respect to energy demand mean that the economy's dependence on energy (in a quantitative sense) will change over time; increasing with the first industrial revolution and also the second, but becoming less dependent on energy since the 1970s.

Across all of the five centuries we examine, we also wish to set out how energy relates to, and has indeed driven, the relative price of factors of production like capital and labor; shaped the structure of the economy; and related to physical constraints such as land or the possibility of "dematerialization." We trace these stories by using "seven propositions" in each part of the book, although as the economies examined changed, so must the emphasis and precise focus of each set of propositions. Some can be followed throughout the book; others must be more particular to the specific historical period. Through these propositions we aim to show both the continuous and the changing character of key relationships that relate energy and the economy.

Before we proceed to explaining the concepts we will use in more detail in chapter 2, we should add a brief discussion about the geographical coverage of this book. The energy data we have collected so far only covers Western Europe, and while we will at times discuss data from countries not covered by our own datasets, predominately in Eastern Europe, the weight of our analysis falls on the west. The three parts of the book also differ in what countries they emphasize. These are to some degree a reflection of the particular expertise of the authors of each section; the reader will find more of Italy at first, Britain in the second part, and Sweden in the third. Nevertheless, there are also solid intellectual grounds for these choices. Italy was a leading economy at the very start of our period that fell behind in early industrialization. Britain, it hardly needs repeating, was the flag bearer of the industrial revolution. Sweden was one of the countries that saw a growth spurt during the second industrial revolution, making major use of new technologies in manufacturing, and electricity. Although this book is mainly about Europe, we also seek to provide some global comparisons, especially as a contribution to the debates comparing Europe and East Asia in the eighteenth and nineteenth centuries, and in the third part of the book, with the inclusion of other rapidly growing economies like the United States and Japan in the twentieth century.