
Motivation and Organization of the Book

Marion King Hubbert, the geophysicist who famously predicted when oil production would hit its peak in the United States, once commented that all of industrial civilization was threatened by the incompatibility of two elemental systems: the age-old system of matter and energy (with which humans and other animals have evolved symbiotically for thousands of years) and the more recent money-based culture (which has operated without respect for limits and constraints on growth).¹ Hubbert believed that the two systems could coexist only so long as the matter-energy system had sufficient reserves to enable the industrial-monetary system to grow. He worried that the “disparity between a monetary system which continues to grow exponentially and a physical system which is unable to do so” would be the great challenge of the twenty-first century.

Although the merits of Hubbert’s prophecy can be debated, his classification of the two systems as prehistoric is apt. We rely on dwindling reserves of fossilized fuels that have existed for millions of years to provide a majority of our energy needs and services. The belief that civilization has a limitless opportunity to grow is also prehistoric in a sense, for it contravenes even rudimentary lessons from physics, thermodynamics, ecology, and biology. Much of what we can do to address climate and energy challenges we already know. But for business, social, cultural, and political reasons, societies all over the world allow their consumption of resources to damage the capacity of the planet. We agree with Hubbert that “our ignorance is not so vast as our failure to use what we know.”

Imagine if present-day policy makers were given the assignment of designing the global economy, human civilization, and the energy systems underpinning it from the start. Would they have wished for the following?

- global mobility that depends almost exclusively on the refined products of a single resource—crude oil—with known reserves that are concentrated in a handful of largely volatile places—notably the Middle East, Russia, Nigeria, and Venezuela

- a production system that puts billions of tons of toxic materials into the air, water, and soil every year, requiring vigilance by future generations
- thousands of complex health and safety regulations that are needed not to keep people safe, but to ensure that they are not poisoned passed “acceptable” thresholds
- more than 2 billion people who live on less than the equivalent of 2 US dollars per day; 1.6 billion people without access to electricity, 900 million people who do not have access to motorized transport, 1.8 million deaths per year due to unsafe drinking water, and 2.5 billion people without access to hygienic sanitation²
- at the same time, millions of people driving to and from work alone in powerful “sport utility vehicles” and later relaxing in spacious homes with more televisions than people, each television consuming 30 watts of electricity when turned off to enable an instantaneous “on”
- valuable materials placed in landfills and waste sites all over the planet, from which they can rarely be retrieved
- prosperity and wealth created and maintained by digging, cutting, mining, and burning natural resources
- the diversity of species, the beauty of tropical forests, and coastal habitats threatened by a warming climate and rising sea levels³

Clearly, no single person is responsible for oil dependence, waste, pollution, environmental destruction, climate change, and electricity and transport poverty. The modern economy was not designed from the ground up; it emerged in fits and starts through an iterative process that has spanned thousands of years. This exercise should, however, make readers wonder if there might be better technology and policy options than the ones on which we have relied to date.

1.1 Socio-Technical Approach

This book explicitly recognizes that the world’s energy-security and climate-change challenges occur at the intersection of technology, policy, and society—that is, they are socio-technical. Technology and policy options must be considered alongside the social and institutional context in which decisions about energy and climate are made.

Specifically, this book explores the commercially available technologies and practices that can enhance the secure provision of energy services and address global climate change, the barriers to their wider adoption, and the public policies that can overcome those barriers. In doing so, it informs readers about not only the causes and consequences of insecure energy and climate change, including water scarcity, deforestation, and environmental degradation, but also effective solutions to them.

(*Energy security* is broadly defined as the equitable provision of available, affordable, reliable, efficient, environmentally benign, properly governed, socially acceptable energy services to citizens.)

The book is motivated by the premise that tackling climate change and improving energy security are two of the most significant challenges to prosperity in the twenty-first century, and that success will require the provision of energy services (such as heating, mobility, computing, and lighting); improved standards of living; and the preservation of the natural environment without forcing tradeoffs among them.⁴ It argues that society has all the technologies it needs to meet these challenges, but that better public policy is crucial to ensuring their adoption while continuing to improve their performance and affordability. Without smart policies, “socio-technical gaps” will grow, with society continuing to invest in products, infrastructure, and practices that compromise their energy security and accelerate climate change. The book offers one of the most comprehensive assessments to date of potential policies that could shrink the gaps between technically possible solutions and actual social choices, evaluated within the context of behavior and values, market and policy failures, and catalysts for change in a global context.

The book refuses to approach the issues of energy security and climate change within disciplinary boundaries. It therefore differs from previous scholarship on climate and energy policy in four fundamental ways.

1.1.1 Interdisciplinary Interactions

Rather than focusing separately on technology, barriers, and policies, the book investigates how these components interact. Most books and academic articles treat climate and energy problems narrowly from either a technological approach, a public-policy approach, or a barriers-and-impediments approach. Rarely do these works combine them to look at how technologies, policies, values, and impediments relate to each other. Our book explores not only cutting-edge technologies but also simple ones (such as light bulbs), the broader social and economic factors that drive both types of technology, their limitations and challenges, and the government policies that can promote them. It simultaneously analyzes technology, people, and solutions, and the factors that intertwine them. This is because the human origins of energy insecurity and climate change have both proximate and indirect causes. The proximate causes relate deeply to such technical processes as converting coal into electricity, discharging heavy metals into rivers, and harvesting a forest. The indirect causes are influenced by broader social forces, including population growth, economic development, and changes in social institutions and in human values.⁵ Focusing on the proximate causes without understanding the indirect ones is like presenting *Hamlet* without the prince—it’s missing a central component of the story.

1.1.2 Global Scope

Our book is global in its coverage of technologies, barriers, and policies. Instead of discussing the climate-change challenges in the United States or in other developed economies, it draws from case studies and experiences in Europe, North America, Asia, the Middle East, and South America. It therefore discusses “high-tech” and “large-scale” energy systems and technologies such as fuel cells, nuclear reactors, and carbon sequestration alongside more “mundane,” “appropriate,” and “small-scale” technologies that are seen as empowering citizens, such as improved cook-stoves, mopeds, and white roofs.⁶ These examples are drawn from industrialized countries (including Germany, Japan, and the United States) and also from developing countries (e.g., Bangladesh, China, and Brazil).

1.1.3 Broad Coverage of Challenges

Rather than limiting the discussion about climate change to its principal determinants (electricity and transport, or “coal and cars”), we also address agriculture and forestry, waste and water, and other economic sectors and systems that emit greenhouse gases and threaten energy security. The book also strives to include the most up-to-date information on these different sectors and their technologies. Recent technological advances and improvements have accelerated the deployment of wind, solar, and energy-efficient technologies. Conversely, perpetually volatile oil prices, a worldwide economic downturn, the Fukushima nuclear accident, and the threat of cost overruns have slowed the momentum toward clean coal, nuclear, and hydrogen energy systems. The book assesses technology as it exists today and recent developments that suggest future trends.

1.1.4 Case Studies

We endeavored to conduct original research and to collect primary data that has either never been published before or is difficult to find. Our methodology is based on previous research that included interviews with more than 200 energy experts—interviews spanning more than 90 institutions in 11 countries that took 4 years to complete.⁷ Likewise, we conducted 106 additional interviews in 12 countries over the course of 2 years exclusively for the case studies presented in chapter 8. These interviews were supplemented by an exhaustive review of the contemporary scientific and technical literature on greenhouse-gas-reducing technologies, technological and social impediments faced by those systems, and public policies that have facilitated their acceptance among users and communities.

1.2 Climate Change and Energy Security

The primary motivation behind writing this book concerns the steady degradation of energy security and the global climate that has occurred in the past few decades.

Not only does the security theme connote a concern that most citizens of the world can relate to, but it also provides a platform for constructing a multi-faceted discussion of related environmental and security issues. As we will show, the unchecked growth in the consumption of fossil fuels, the acceleration of global climate change, and related water, waste, agriculture, and deforestation challenges act as “threat multipliers,” impinging on security around the world.⁸

How secure are today’s energy supplies and infrastructure, and what do trends portend for the future? To answer this question, we first must consider what is meant by “energy security.”⁹ The classic conception of energy security addresses the relative availability, affordability, and safety of energy fuels and services.¹⁰ The World Bank, for example, tells us that energy security is based on the three pillars of energy efficiency, diversification of supply, and minimization of price volatility.¹¹ Consumer advocates and users tend to view energy security as reasonably priced energy services without disruption. Major oil and gas producers focus on the “security” of their access to new reserves, while electric utility companies emphasize the integrity of the electricity grid. Politicians dwell on securing energy resources and infrastructure from terrorism and war.¹² From a distinct vantage point, scientists, engineers, and entrepreneurs characterize energy security as a function of strong energy R&D, innovation, and technology-transfer systems.¹³

These diffuse conceptions of energy security map onto distinct national energy-security concerns. In the United States, energy security has generally meant the availability of sufficient energy resources and services at affordable prices. The oil-security policy of the United States was formalized by the Carter Doctrine, which stated that any effort by a hostile power to block the flow of oil from the Persian Gulf would be viewed as an assault on the vital interests of the United States and/or would be repelled by “any means necessary, including military force.”¹⁴ Under various presidents, oil security has meant ending all oil imports, eliminating imports only from the Middle East, merely reducing dependence on foreign imports, and entirely weaning the country off oil.¹⁵ US energy-security policy has historically also included maintaining a strategic petroleum reserve, reducing physical threats to energy infrastructure, and preventing the proliferation of nuclear weapons in “non-nuclear-weapons states” and non-signatories to the Nuclear Non-Proliferation Treaty such as Iran and North Korea.¹⁶ More recently, concern about an increasingly fragile US electricity grid has become more evident because of the expanded electrification of US military operations.¹⁷

Other countries with limited energy resources have deployed different strategies to achieve security. Japan has pursued an energy-security strategy of diversification, trade, and investment, as well as selective engagement with neighboring Asian countries to jointly develop energy resources and offset Japan’s stark scarcity of domestic reserves.¹⁸ In the United Kingdom, energy security tends to be associated with promoting open and competitive energy markets that will provide fair access to energy

supplies, foster investment, and deliver diverse and reliable energy at competitive prices.¹⁹

Similarly, the focus on energy security in countries that are struggling to meet their energy requirements is quite distinct. China, for example, has viewed energy security as an ability to rapidly adjust to their new dependence on global markets and engage in energy diplomacy, shifting from its former commitments to self-reliance and sufficiency (*zi li geng sheng*) to a new desire to build a well-off society (*xiaokang shehui*). China's current approach to energy security entails buying stakes in foreign oil fields, militarily protecting vulnerable shipping lanes, and an all-out "energy scramble" for resources.²⁰

Among the countries with excess supplies of oil and natural gas, the focus on energy security takes on yet another emphasis. As one example, Russia appears to pursue an energy-security strategy of asserting state influence over strategic resources to gain primary control over the infrastructure through which it ships its hydrocarbons to international markets. Restricting foreign investment in domestic oil and gas fields is an important element of this strategy.²¹ Buoyed by this strategy, Russia was recently able to triple the price of natural gas exported to Belarus and Ukraine because those countries were completely dependent on Russian supply.

Other countries have enacted strategies shaped by their substantial endowments of energy resources. For example, Saudi Arabia pursues energy security by maintaining a "security of demand" for its oil and gas exports.²² In contrast, Australia's strategy involves cultivating a strong demand for uranium, natural gas, and coal trading.²³ Venezuela and Colombia focus on minimizing attacks on oil, gas, and electric infrastructure.²⁴

International comparisons of energy security highlight the interdependence of countries enmeshed in larger relationships between and within producers and consumers of energy fuels and services. Globally, trade in energy commodities amounted to 900 billion US dollars (696.5 billion euros) in 2006, including almost two-thirds of the oil produced in the world, and much of it was in natural gas and uranium.²⁵ As a result, few countries are truly energy independent. As figure 1.1 shows, the world's known oil reserves (1.2 trillion barrels) are concentrated in volatile regions, as are the largest petroleum companies. The three biggest petroleum companies—the Saudi Arabian Oil Company, the National Iranian Oil Company, and Qatar Petroleum—own more crude oil than the next 40 largest oil companies combined. The 12 largest oil companies control roughly 80 percent of petroleum reserves and are all state owned. Therefore, although oil and gas are internationally traded in what superficially resembles a free market, most supplies are controlled by a handful of government-dominated firms. The distribution of other conventional energy resources, including coal, natural gas, and uranium, is equally consolidated. Eighty percent of the world's oil can be found in nine countries that have only 5

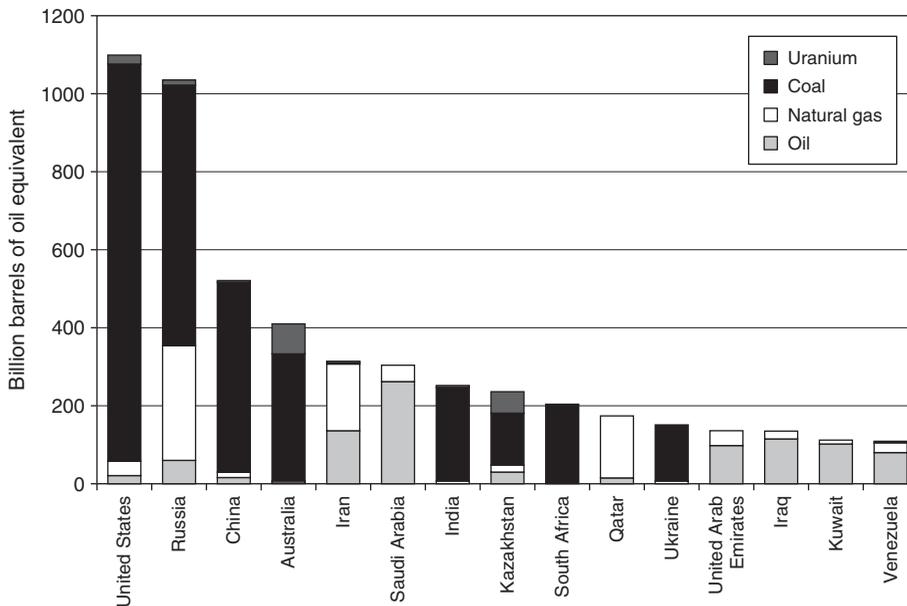


Figure 1.1

Global distribution of energy reserves (million barrels of oil equivalent) of the top 15 countries. Oil, gas, and coal data from Energy Information Administration, *International Energy Annual Review 2006*, (2006). Uranium data from International Atomic Energy Agency, *Uranium 2005—Resources, Production, and Demand*, 2006; Luis Echávarri and Yuri Sokolov, *Uranium Resource* (Nuclear Energy Agency and IAEA, 2006): 13, converted to million tons of oil equivalent using the rate of 65,000 tons of uranium ore = 24 quads of energy. (A quad is equivalent to 10^{15} British thermal units or 1.06×10^{18} joules.)

percent of the world's population, 80 percent of the world's natural gas is in 13 countries, and 80 percent of the world's coal is in six countries. Many of the same countries are among the six that control more than 80 percent of the world's uranium resources.²⁶

As a result, threats to energy security take distinct forms. Japan and Chile have essentially no domestic fossil fuels and thus are completely dependent on foreign supplies. Saudi Arabia is the largest exporter of crude oil but must import refined gasoline. Russia exports natural gas but must import uranium. The United States is a net exporter of coal but imports oil and natural gas. This interdependence explains why any discussion of energy security must consider the interactions between countries as much as it considers the resources of individual countries, serving as a useful reminder that energy security does not stand abstractly by itself; rather, it is most meaningful in a geographic context.

The deterioration of energy security has also become increasingly multi-dimensional as its links to other challenges have become clearer.

1.2.1 Growing Worldwide Demand for Energy

The growing worldwide demands for electricity and for mobility compound issues of energy security. The world is in transition from a position of abundant fossil energy supplies to a largely resource-constrained supply future. The demand for energy is expected to increase by 45 percent between now and 2030, and by more than 300 percent by the end of the century. Coal without carbon capture and sequestration is projected to account for the largest share of this overall rise, with oil and natural gas consumption also expanding rapidly. (See figure 1.2.)

1.2.2 Growing Imbalance between Supply and Demand

The growing imbalance of oil production and consumption exacerbates the risk of fuel shortages and interruptions in supply, which will take a fairly rapid turn for the worse for many countries if alternative fuels such as ethanol and biodiesel are not widely deployed. The likely geographic pattern of expected oil production and consumption over the next two decades suggests that oil dependence in Europe, China, India, and other Asian countries could grow rapidly, each importing 75 percent or more of its oil by 2030.²⁷ All of the growth in oil demand is forecast by the International Energy Agency to come from non-OECD countries, with China contributing 43 percent and the Middle East and India each about 20 percent. As figure 1.3 depicts, the increase in oil dependence in India is expected to be particularly dramatic, exceeding 90 percent by 2030.²⁸

1.2.3 The Link to Global Climate Change

The destabilization of the world's climate (or, to be more precise, of certain climatic zones), driven by relentless emissions of greenhouse gases, has the potential to exacerbate food and water shortages, advance the spread of infectious disease, induce mass migration, damage trillions of dollars of property, and precipitate extreme weather events—all of which could lead to increased conflict worldwide.²⁹

This broad range of threats to energy security necessitates a holistic treatment of causes and effects, including energy and climate issues as well as water and waste, and agriculture and forestry. Assembling all these pieces into a single book highlights important interactions that often go unnoticed. Without a fully articulated appreciation of these complexities, different strands of energy and climate policy run the risk of competing with each other or, worse, trading off so that the net result is continued emissions, higher prices, greater energy poverty, and degraded security.

1.3 Preview of Chapters

The book begins by extending our discussion of energy security and climate change to include five challenges that threaten the prosperity of future generations.

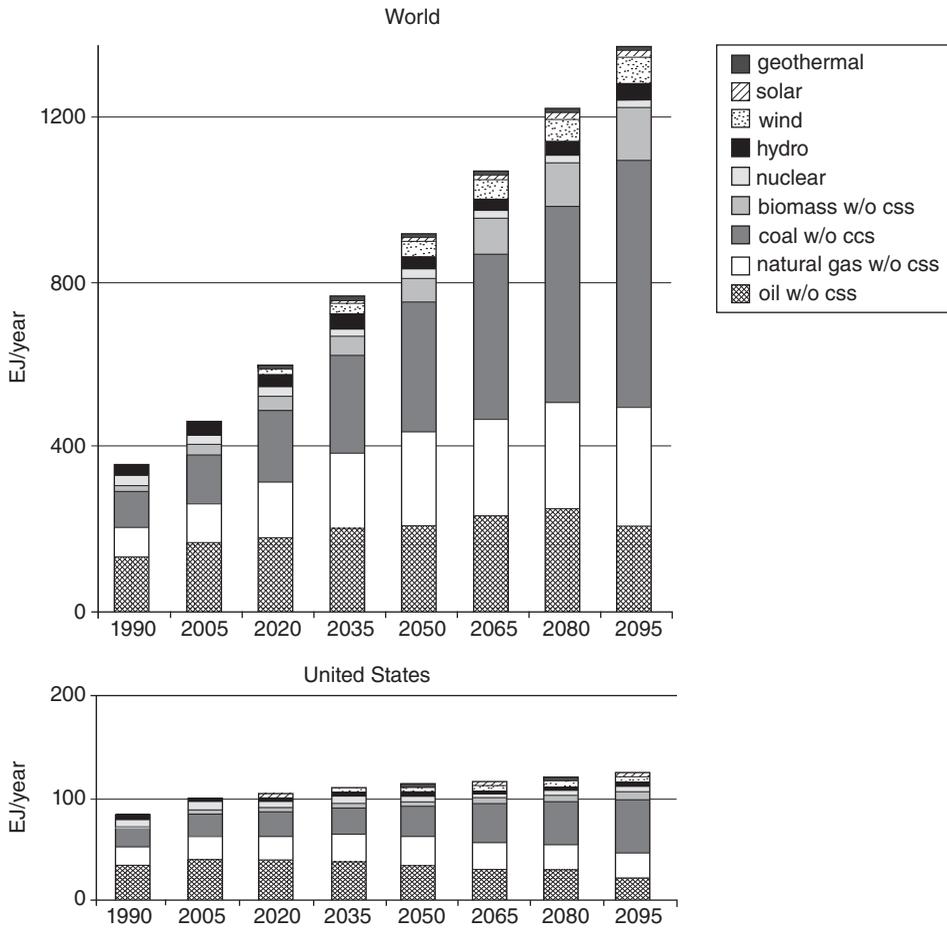


Figure 1.2
 Projections of world and US energy use, 1990–2095. Redrawn from data published in L. Clarke et al., *CO₂ Emissions Mitigation and Technological Advance*, Pacific Northwest National Laboratory Report PNNL-18075, 2009.

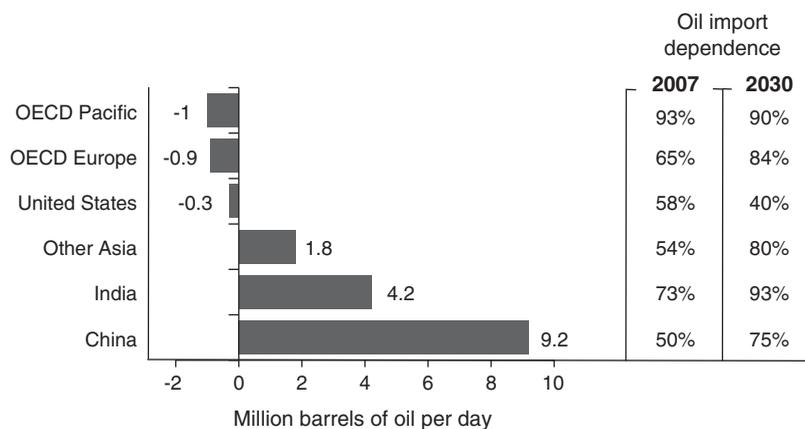


Figure 1.3

Change in oil demand in selected countries and regions, 2007–2030. Drawn from data published in International Energy Agency, *World Energy Outlook 2008* and in Energy Information Administration, *Annual Energy Outlook 2009*.

Specifically, chapter 2 describes four resource-intensive sectors of the global economy—electricity supply, transport, agriculture and forestry, and waste and water—that are responsible for a majority of the world’s emissions of greenhouse gases, then takes up the subject of climate change. The trends in each of these interrelated sectors are described from a global perspective, drawing on the experiences of developing and developed countries. By ending with a description of the science and consequences of climate change, the chapter underscores the need for transformational energy and climate technologies and policies. The chapter also describes the policy conflicts and complementarities that confound simultaneous solutions to climate-change and energy-security challenges.

Since greenhouse gases originate from almost every human activity, technologies that limit emissions of greenhouse gases are both numerous and diverse. Chapter 3 focuses on the array of plausible technology solutions to enhance energy security and mitigate climate change. Since it is difficult to speculate about which of the competing solutions currently in laboratory research will emerge victorious, we examine the best current practices and the best-performing technologies currently being prototyped and demonstrated.

Most of the scientific and policy dialog surrounding global climate change has focused on reducing emissions of greenhouse gases. Chapter 4 expands the discussion to include “geo-engineering” approaches—ways to remove CO₂ from the atmosphere and ways of reflecting sunlight to cool the Earth—as well as “adaptation”

approaches. In contrast with the mitigation technologies and approaches described in chapter 3, geo-engineering interventions tend to be more speculative and uncertain, and they are fraught with ethical and scientific complexities. Nevertheless, in view of the lack of evidence that societies around the world will successfully curb their emissions of greenhouse gases in the next several decades, it can be argued that geo-engineering is needed as a fallback option. Similarly, actions should be taken to reduce the vulnerability of humans and ecosystems to the effects of global climate change. Such “adaptation” actions can be either anticipatory or reactive. Stabilizing and then reducing the emissions of greenhouse gases is possible, but it looks very unlikely to occur before the end of the century. Attention is beginning to turn to ways to alter the climate and ways to adapt to the consequences of climate change.

Chapter 5 enumerates the tenacious barriers that prevent climate-friendly technologies from being rapidly adopted in the global marketplace. A thorough understanding of these impediments provides a basis for developing effective strategies to shrink the socio-technical gap between the cost-effective technologically feasible and the socially achievable. The chapter begins by briefly introducing the concepts of market failure, public goods, and policy failure. It then discusses a typology of 20 barriers and obstacles. The chapter ends by elaborating on the notion of “carbon lock-in” and what the presence of such barriers means for the promotion of climate-friendly technologies and programs.

Chapter 6 begins by explicating one final persuasive rationale for public-policy intervention, the precautionary principle, which is compared and contrasted with the more common “risk paradigm” in environmental policy making. The chapter offers a typology of public-policy mechanisms and summarizes different methods of evaluating policies, including cost-benefit analysis, cost-effectiveness analysis, and various hybrids. The chapter finishes by exploring the potential and pitfalls of putting a price on carbon, the dynamics of carbon cap-and-trade schemes, and how pricing carbon can be complemented with other policies in the electricity supply, transport, agriculture and forestry, and waste and water sectors.

Because of the diverse spatial dimensions connected to energy and climate problems, chapter 7 argues that similarly multi-dimensional scales must be utilized to implement policies that respond to them. In addition, success requires combining multiple stakeholders (such as government regulators, business leaders, and civil society). Polycentric approaches—those that blend scales and engage multiple stakeholder groups—have the potential to capture all the benefits of local, regional, and global action, and to reduce, or in some cases eliminate, their costs. The chapter begins by discussing five benefits to global action: consistency, economies of scale, equity, mitigation of spillovers, and minimization of transaction costs. It then discusses five strengths of local action (diversity, flexibility, accountability, simplicity,

and positive contagion) and explains the benefits behind polycentrism, or how properly designed policies can capture most of the advantages of both global and local action while avoiding their disadvantages. The chapter concludes by summarizing the challenges to multi-scalar governance.

Chapter 8 presents eight case studies that exemplify empirically successful approaches to improving energy security and reducing emissions of greenhouse gases: Denmark's approach to energy policy and wind power, Germany's feed-in tariff, Brazil's ethanol program, Singapore's congestion road pricing and vehicle moratoriums, Grameen Shakti's efforts to distribute small-scale renewable energy technologies in Bangladesh, China's improved cookstoves program, the Oasis Project in Brazil (which prevents deforestation and improves water quality), and the Toxics Release Inventory in the United States (which tracks hazardous pollutants). These approaches addressed social and technical barriers simultaneously, relied on polycentric scales of action, and rapidly achieved their goals. They illustrate the types of initiatives that are needed for a secure and sustainable energy future.

Chapter 9 presents our conclusions. It reemphasizes the socio-technical aspects of energy and climate challenges, and it argues that efforts to improve technologies and alter human behavior must work together to produce meaningful change. The chapter summarizes some of the changes in energy and climate policy that must be implemented. It furthermore explains why polycentric approaches tend to be the most successful at initiating such changes, implying that governments, individuals, corporations, and institutions at a variety of scales must all play mutually supportive roles.