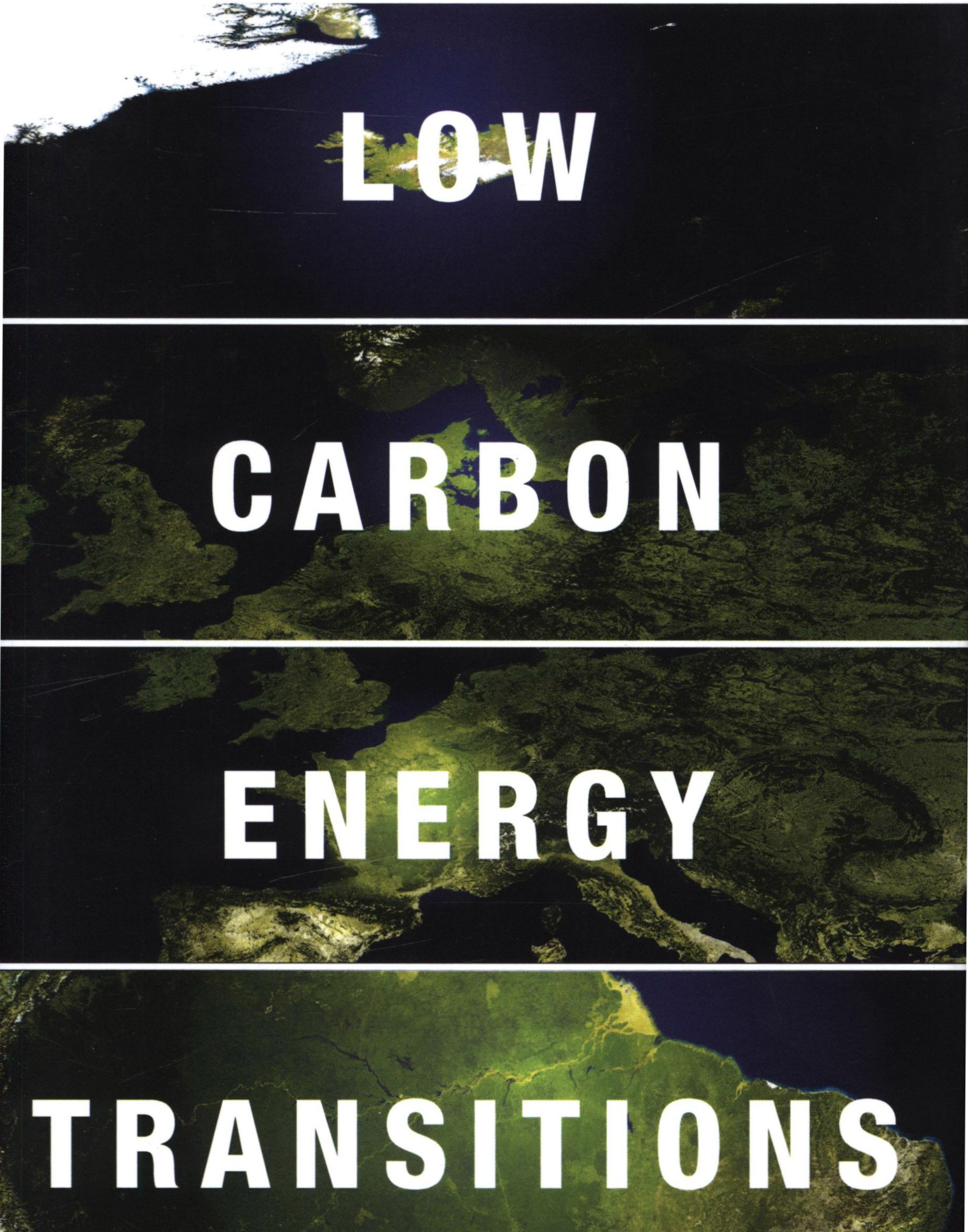
Turning Points in National Policy and Innovation



LOW CARBON ENERGY TRANSITIONS

KATHLEEN M. ARAÚJO

"In a world with fear for climate change, this book offers some ground for optimism. It presents insights into how national energy systems have been radically transformed. This book will be of interest not only for students and decision-makers. It shows that all citizens have a role to play in the transition process and, perhaps most importantly, that change is possible." —Bengt-Åke Lundvall, Professor Emeritus of Economics, Aalborg University, Denmark

"It is increasingly clear that our pursuit of sustainable development and climate change goals is driving a great energy transition. Dr. Araújo's compelling narrative deftly weaves together history, theory, and practice, providing an optimistic guide for all those who want to take well-informed action now, and to do so with confidence."

—Mark Radka, Chief, Energy and Climate Branch, UN Environment Programme

"The key challenge in energy policy has become to transform national energy systems towards a low carbon paradigm. For this, scholarly debates are in need of comparative studies informed by primary data, at the same time subscribing to principles of rigorous academic inquiry. This book perfectly delivers on these fronts." —Andreas Goldthau, Professor of International Relations, Centre of International Public Policy, Royal Holloway, University of London

"We are heading to a low carbon economy, both nationally and globally, and at an accelerated pace. Innovation and informed decision-making will be needed in technology, policy and regulation, and business models, all aligned for deep decarbonization on a generational time scale. Dr. Araújo's integrative approach provides important insights for those shaping the low carbon future."—Ernest J. Moniz, 13th Secretary of Energy, USA

"An essential reading for all interested in transformative energy change. The book presents comprehensive, case studies of radical change in energy systems, within a broader context of the history and theory of energy-systems evolution. It provides valuable insights into how radical change can be achieved." —Nebojsa Nakicenovic, Deputy Director General/Deputy Chief Executive Officer of the International Institute for Applied Systems Analysis (IIASA)

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Low Carbon Energy Transitions

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INTRODUCTION

If we don't change direction soon, we'll end up where we're heading . . . .
—Chinese proverb cited by the International Energy Agency, *2011a*

The world at large is wrestling with important energy choices. There is a strong sense today that we need to manage energy differently. Priorities in resilience, security, jobs, and access emphasize a need to substitute low carbon energy for traditional fossil fuels. Nevertheless, no one is entirely clear about how to carry out such a shift at the national or international levels. A widely-held view is that national energy transitions of any significance take several decades, if not longer, and entail least-cost economics as a principal driver. Based on this line of thinking, only energy sources that are low-cost have a chance to take hold. Although this appears reasonable, it can miss opportunities for wider gains. Some say that change will require an acceleration of innovation. Yet what assures innovation is also not entirely certain.

A century ago, a person observing the energy playing field would have found substantially less fossil fuels being used and a limited niche industry in electricity. At that time, biomass and coal supplied the majority of the global energy mix, with technologies like automobiles, gas turbines, and airplanes still emerging.

Today, more than 85% of the world's energy is derived from fossil fuels (BP, 2017). The environment is also showing signs of stress as air quality reaches dangerous levels in some regions (particularly those with heavy coal use) and change in the climate redraws our maps and ecosystems. Security of the energy supply is also brought into question, particularly when geopolitics flare up or prices spike. As all of this occurs, the world's population continues along a path in which projected growth by mid-century may represent an increase from 7 to

Table I-1. Market Shares of Low Carbon Energy Studied

Country and Low Carbon Energy	1970	2015
• Icelandic geothermal energy in power	Negligible	29%[a]
• Brazilian ethanol in primary automotive fuels	~1%	34%[a]
• Danish wind power in electricity	Negligible	42%
• French nuclear power in electricity	4%	76%
• Icelandic geothermal energy in space heating	43%	~90%

[a] Reflects data for 2014.

SOURCE: Compiled with data from various sources: Brazil (Ministry of Mines and Energy/MME, 2016); Denmark (Energinet, n.d.); France (IEA, n.d.); Icelandic power and space heating (Orkustofnun, 2016; Ragnarsson, 2015).

9 billion inhabitants. Importantly, regions where growth is expected to be the highest are also ones where energy access is currently challenged.

Low carbon priorities now regularly feature in public discussions.[1] One need only look at calls for decarbonizing change made by the United Nations, World Bank, and World Economic Forum. In line with such priorities, this book considers low carbon energy transitions in prime mover countries. For the purposes here, *transitions* reflect the displacement of at least 15% of traditional energy sources with a low carbon alternative in a given energy mix (relative change), and increased utilization of the same, low carbon alternative in absolute terms by 100% or more. *Prime mover countries* are ones that accomplished this feat. Histories of Brazilian biofuels, Danish wind power, French nuclear power, and Icelandic geothermal energy are examined in depth, here, for the period principally since 1970 (Table I-1).

This book highlights the interplay of technology, natural systems, and society with underlying logic that is rooted in planning and management, policy and applied history, and broader, sociotechnical systems. The research recognizes history as a valuable and often missed tool for decision-making and planning (Neustadt and May, 1986; Schaeffer, 2007; Diamond and Robinson, 2010; Sinclair et al., 2016), and puts forward tools for theoretical and practical scoping of transitions. Models of national readiness will integrate material and human aspects of change in a way that can be applied to structural shifts in energy as well as other sectors, including information or biomedicine. Complementing the models of readiness is a framework based on sectoral intervention that

1. *Low carbon* is used widely to refer to activity that produces much less carbon. The concept is discussed in Chapters 1 and 2.

provides ways to consider induced and emergent change. In doing so, this book emphasizes turning points, while linking theory and practice.

What lies behind national shifts may surprise some. Quick explanations of costs serve a purpose, but the influences behind such costs are much less understood. There is also a tendency to dismiss energy choices as being driven by an abundance of the "right" resources. Such ideas and others are considered, highlighting how government can play a role but not always lead the change. Broadly, this book is designed to challenge how we think about national energy objectives, and how strategies can evolve in energy transitions.

Given the aims and coverage, this book will be of interest to policymakers and practitioners, as well as to students and citizens who think about energy options. For policymakers and practitioners, the book provides ways to consider energy system change and course corrections with perspective from contemporary examples. For members of industry and funding agencies, as well as for think tanks and inter- or nongovernmental organizations, this book provides in depth insight into pivotal junctures that can emerge with energy path realignments. For students and interested citizens who want to better understand energy paths, these histories shed light on theory and better practices in technology diffusion and learning.

Overall, my aim is to show how challenges and opportunities arise in connection with energy, as well as how choices in this regard are made. Chapter 1 provides an overview of the current, energy playing field, outlining the rationale for low carbon change. Chapter 2 examines ideas in theory and practice relating to systems change, innovation, and policy. Chapter 3 outlines new, conceptual tools and the research design. It then turns to relevant developments in the global context and provides a preview of the four countries' transitions. Chapters 4 through 7 provide in depth histories of national energy system change, with a special emphasis on policy and innovations. Chapter 8 comparatively evaluates findings in the context of overarching themes and explores limits for the research. Chapters 8 and 9 then draw inferences for policymakers and scholars. Chapter 9 concludes with promising directions for future research. Those wishing to learn more about specifics of the energy technologies will find a technology primer on geothermal energy, nuclear energy, biofuels, and wind power in the Appendix. Timelines of each country's sociotechnical history are also available there.

CONTENTS

1

Rethinking Energy at the Crossroads

> We can't solve problems by using the same kind of thinking we used when we created them.
>
> —Albert Einstein

The discovery of oil in Pennsylvania in 1859 was a relatively inconspicuous precursor to what would become an epic shift into the modern age of energy.[1] At the time, the search for "rock oil" was driven by a perception that lighting fuel was running out. Advances in petrochemical refining and internal combustion engines had yet to occur, and oil was more expensive than coal. In less than 100 years, oil gained worldwide prominence as an energy source and traded commodity.[2]

Along similar lines, electricity in the early 1900s powered less than 10% of the homes in the United States. Yet, in under a half a century, billions of homes around the world were equipped to utilize the refined form of energy. Estimates

1. The term "discovery" of oil or petroleum is used loosely here. Prior to 3000 BC, recorded history indicates that oil was used as asphaltic bitumen in Mesopotamia (Giebelhaus, 2004). Later adaptations included its use in waterproofing of ships and in construction, in addition to applications in medicine, illumination, and incendiary devices. At the time of the Titusville discovery, other developments relating to petroleum were already under way in Azerbaijan and France (Smil, 2010).

2. As of 2015, global primary energy (i.e., the raw supply of energy) totaled 13,276 million tonnes of oil equivalent (Mtoe), with oil representing 33% (BP, 2017). Additional primary energy sources included: coal (28%), natural gas (24%), hydropower (7%), nuclear power (5%), and other renewables (3%) (BP, 2017). Sources of energy are discussed more fully later in the chapter.

indicate that roughly 85% of the world's population had access to electricity in 2014 (World Bank, n.d.*b*). For both petroleum and electricity, significant changes in energy use and associated technologies were closely linked to evolutions in infrastructure, institutions, investment, and practices.

Today, countless decision-makers are focusing on transforming energy systems from fossil fuels to low carbon energy which is widely deemed to be a cleaner, more sustainable form of energy.[3] As of 2016, 176 countries have renewable energy targets in place, compared to 43 in 2005 (Renewable Energy Policy Network for the 21st Century [REN21], 2017). Many jurisdictions are also setting increasingly ambitious targets for 100% renewable energy or electricity (Bloomberg New Energy Finance [BNEF], 2016). In 2015, the G7 and G20 committed to accelerate the provision of access to renewables and efficiency (REN21, 2016). In conjunction with all of the above priorities, clean energy investment surged in 2015 to a new record of $329 billion, despite low, fossil fuel prices. A significant "decoupling" of economic and carbon dioxide (CO_2) growth was also evident, due in part to China's increased use of renewable energy and efforts by member countries of the Organization for Economic Cooperation and Development (OECD) to foster greater use of renewables and efficiency (REN21, 2016).[4] In April 2016, 175 countries signed the Paris Agreement, which aims to slow the growth of greenhouse gases (GHGs), including CO_2, in the atmosphere in order to limit global warming to "well below" a 2°C or 3.6°F increase, relative to pre-industrial levels.[5] Despite an announcement in 2017 that the US would withdraw, the general global focus appears to be in tact.

Importantly, it is not just governments that are currently focused on low carbon change. Traditional energy companies also have carbon-based priorities in energy. Oil and gas companies and power utilities are being asked to include stress tests in their portfolio assessments to reflect carbon or climate impacts (Hulac, 2016). In June 2015, heads of some of the largest European

3. *Energy systems* provide services like heating, cooling, power, and transport. They consist of infrastructure, fuels, people, institutions (including markets), practices, and the ecosystems that enable the provision of such services. *Low carbon* refers to a path that utilizes notably less carbon. This differs from (but can overlap with) renewable energy, which is "any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use" (Moomaw, et al, 2011). For more detailed discussion, see Chapter 2 and Section 1.2.1 of the *Special Report on Renewable Energy Sources and Climate Change Mitigation* (SRREN) (Moomaw et al., 2011).

4. OECD country groupings are based on a classification system that was set up in 1961. Loosely defined, OECD states are industrialized countries and non-OECD states are developing countries. For a discussion of country classifications, see OECD (n.d.), UN (2008, 2014), Nielsen (2011), and Araújo (2014).

5. Greenhouse gases are discussed in the following section.