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THE POLITICAL ECONOMY OF CLEAN ENERGY TRANSITIONS

Edited by
Douglas Arent, Channing Arndt, Mackay Miller, Finn Tarp, and Owen Zinaman

UNU-WIDER STUDIES IN DEVELOPMENT ECONOMICS

THE POLITICAL ECONOMY OF CLEAN ENERGY TRANSITIONS

UNU World Institute for Development Economics Research (UNU-WIDER) was established by the United Nations University as its first research and training centre and started work in Helsinki, Finland, in 1985. The mandate of the institute is to undertake applied research and policy analysis on structural changes affecting developing and transitional economies, to provide a forum for the advocacy of policies leading to robust, equitable, and environmentally sustainable growth, and to promote capacity strengthening and training in the field of economic and social policy-making. Its work is carried out by staff researchers and visiting scholars in Helsinki and via networks of collaborating scholars and institutions around the world.

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The Political Economy of Clean Energy Transitions

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Foreword

Sustainable energy transitions involve the shift of resources between competing industrial sectors and political constituencies. Stakeholders in this process have varying degrees of political and economic power, and understanding how political economic factors influence clean energy transitions is crucial to effective policy formulation and facilitating transitions to sustainable energy systems. In partnership with the Joint Institute for Strategic Energy Analysis (JISEA), UNU-WIDER gathered together a substantial group of experts from around the world—from both developed and developing countries—to launch a multidisciplinary research project seeking to contribute to our enhanced understanding of these factors. The project sought to facilitate an energy transition that will generate very large environmental and economic benefits, particularly over the long run. The beneficiaries of clean energy transitions are highly diffuse and include future generations not yet born.

This book is the distilled essence of the cross-cutting academic project. I express my sincere and professional appreciation to the large group of expert authors for their dedication to the project, and to my fellow editors in helping bring together the book for readers to enjoy and absorb along with the findings and policy implications.

Finn Tarp
Helsinki, January 2017

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We also thank the international team of authors—each of whom are experts in their own fields—for their dedication to the project, and their patience when reworking and revising the various versions of the individual studies which now make up the polished chapters of the book. This multi-authored book would not have been possible without their expert field knowledge and extremely valuable inputs.

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Douglas Arent, Channing Arndt, Mackay Miller,
Finn Tarp, and Owen Zinaman

[1] The Joint Institute for Strategic Energy Analysis is operated by the Alliance for Sustainable Energy, LLC, on behalf of the US Department of Energy's National Renewable Energy Laboratory, the University of Colorado-Boulder, the Colorado School of Mines, the Colorado State University, the Massachusetts Institute of Technology, and Stanford University. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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List of Abbreviations

21CPP	21st Century Power Partnership
ADB	Asian Development Bank
ADEME	Agence de maîtrise de l'énergie
AEC	ASEAN Economic Community
AFTA	ASEAN Free Trade Area
AGDI	Agencia Gaucha de Desenvolvimento e Promoção de Investimento (Brazil)
AGRESTE	Service de la statistique, de l'évaluation et de la prospective agricole (France)
AGW	anthropogenic global warming
ANBERD	Analytical Business Enterprise Research and Development
ANC	African National Congress
ANT	actor network theory
AOA	Agreement on Agriculture
APEC	Asia-Pacific Economic Cooperation
ARRA	American Recovery and Reinvestment Act 2009
ASEAN	Association of Southeast Asian Nations
ASTAE	Asia Sustainable and Alternative Energy Program
BAT	best available technology
BAU	business-as-usual
BCAs	border carbon adjustments
BDEW	Bundesverband der Energie- und Wasserwirtschaft
BECCS	bioenergy with carbon capture and storage
BEE	Black Economic Empowerment (S Africa)
BEE	Bundesverband Erneuerbare Energien
BEPE	Environmental Protection and Energy
BEST	Biomass Energy Strategy (Rwanda)
BJP	Bharatiya Janata Party (India)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Germany)
BMWI	Federal Ministry of Economics and Technology (Germany)
BNDES	Banco Nacional de Desenvolvimento Econômico e Social (Brazil)
BOF	Budget Office of the Federation (Nigeria)

BP	British Petroleum
BPD	barrels per day
BPE	Bureau of Public Enterprises (Nigeria)
BRICS	Brazil, Russia, India, China, and South Africa
BUSA	Business Unity South Africa
BWE	Bundesverband Windenergie
CAFTA	China–ASEAN Free Trade Agreement
CANACERO	Cámara Nacional del Acero (Mexico)
CAPEX	capital expenses
CAPS	Centre d'Analyse, de Prévision et de Stratégie
CAT	Climate Action Tracker
CBN	Central Bank of Nigeria
CCGT	combined cycle gas turbine;
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CEEE	Companhia Estadual de Energia Elétrica (Brazil)
CEER	Council of European Energy Regulators
CEMAGREF	Centre d'Étude du Machinisme Agricole et du Génie Rural des Eaux et Forêts
CENACE	Centro Nacional de Control de Energía (Mexico)
CERI	Centre for Educational Research and Innovation
CERs	Certificates of Emissions Reductions
CESPEDES	Comisión de Estudios del Sector Privado para el Desarrollo Sustentable
CEST	Centro de Estudos Sociedade e Tecnologia (Brazil)
CfD	Contracts for Difference
CFE	Comisión Federal de Electricidad
CHESF	Hydroelectric Company of San Francisco
CHP	combined heat and power
CME	coordinated market economy
CNI	Confederação Nacional da Indústria (Brazil)
CO_2	carbon dioxide
CoP	Conference of Parties to UNFCCC
CoP1	First Conference of Parties to UNFCCC (1995)
CoP15	Fifteenth Conference of Parties to UNFCCC (2009)
CoP16	Sixteenth Conference of Parties to UNFCCC (2010)
CoP20	Twentieth Conference of Parties to UNFCCC (2014)
CoP21	Twenty-first Conference of Parties to UNFCCC (2015)

COSS	cost-of-service study
CPC	Communist Party of China
CPUT	Cape Peninsula University of Technology (S Africa)
CRE	Energy Regulatory Commission (Mexico)
CSIR	Council for Scientific and Industrial Research (S Africa)
CSP	concentrated solar power
CUB	Citizens' Utility Board
CUREJ	College Undergraduate Research Electronic Journal
DA	Democratic Alliance (S Africa)
DANIDA	Danish International Development Agency
DECC	Department of Energy & Climate Change (UK)
DEFG	Distributed Energy Financial Group
DER	distributed energy resources
DG	distributed generation
DGNREEC	Direktorat Jenderal Energi Baru Terbarukan dan Konservasi Energi
DISCOs	distribution companies
DME	Department of Minerals and Energy (S Africa)
DMEA	Department of Mineral and Energy Affairs (S Africa)
DMR	Department of Mineral Resources (S Africa)
DoE	Department of Energy (S Africa)
DPE	Department for Public Enterprises (S Africa)
DPI	Database of Political Institutions
DRS	deposit and refund schemes
DSB	Dispute Settlement Body
DSM	demand-side management
DSO	distribution service operator
DST	Department of Science and Technology (S Africa)
E3	Energy and Environmental Economics
E3G	Third Generation Environmentalism
EC	European Commission
ECN	Energy Commission of Nigeria
EDPRS	Economic Development and Poverty Reduction Strategy (Rwanda)
EDSO	European Distribution System Operators
EEAG	Environmental and Energy State Aid Guidelines
EEG	Energy Economics Group
EFF	Economic Freedom Fighters (S Africa)
EGSS	Environmental Goods and Services Sector
EGUs	electrical generating units

EIA	Energy Information Administration
EIAs	environmental impact assessments
EPA	Environmental Protection Agency
EPS	environmental policy stringency
EPSA	Electrical Power Supply Association
EPSRA	Electric Power Sector Reform Act (Nigeria)
ERC	Energy Research Center (S Africa)
EREC	European Renewable Energy Council
EROI	energy returned on investment
ESCS	Energy Security Cabinet Subcommittee (S Africa)
ETS	Emissions Trading System
EU	European Union
EU-ETS	European Union Emissions Trading System
EUAs	European Union Allowances
EUEI	European Union Energy Initiative
EVs	electric vehicles
EWEA	European Wind Energy Association
FAO	Food and Agriculture Organization
FCBA	Forêt Cellulose Bois-construction Ameublement
FDI	foreign direct investment
FEMSA	Fomento Económico Mexicano
FERC	Federal Energy Regulatory Commission
FFS	fossil-fuel subsidy
FFFSR	Friends of Fossil-Fuel Subsidy Reform
FFVs	flex-fuel vehicles
FIT	feed-in tariff
FS-UNEP	Frankfurt School-United Nations Environment Programme
FYPs	five-year plans
GATT	General Agreement on Tariffs and Trade
GCF	Green Climate Fund
GDP	gross domestic product
GEA	Global Energy Assessment
GGKP	Green Growth Knowledge Platform
GHG	greenhouse gas
GIZ	German Aid Organization
GMS	Greater Mekong Sub-Region
GNI	gross national income

GOI	Government of Indonesia
GoI	Government of India
GoR	Government of Rwanda
GSI	Global Subsidies Initiative
GTAI	Germany Trade & Invest
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
GW	gigawatts
GWEC	Global Wind Energy Council
HHI	Herfindahl-Hirschman Index
ICEM	International Centre for Environmental Management
ICSID	International Centre for Settlement of Investment Disputes
ICT	information and communication technology
IDASA	Institute for Democracy in South Africa
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IFAD	International Fund for Agricultural Development
IFN	Inventaire Forestier National
IGN	Institut géographique national
IGS	Instituto Global para la Sosteniblidad
IMF	International Monetary Fund
INC	Indian National Congress
INDC	Intended Nationally Determined Contributions
INRA	Institut National de la Recherche Agronomique (France)
IPCC	Intergovernmental Panel on Climate Change
IPP	independent power producer
IPR	integrated resource plan
ICRG	International Country Risk Guide
IQR	interquartile
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
ISMO	Independent System Markets Operator
ISO	International Organization for Standardization
ITT	Ishpingo-Timbococha-Tiputini
IWES	Institute for Wind Energy and Energy System Technology
JIM	joint implementation mechanism
JISEA	Institute for Strategic Energy Analysis
JRC	Joint Research Centre of the European Commission

LAERFTE	Law for the Use of Renewable Energy and Financing of Energy Transition (Mexico)
LASE	Law for Sustainable Use of Energy (Mexico)
LCET	low-carbon energy technologies
LGCC	General Climate Change Law (Mexico)
LDCs	least developed countries
LIE	Law of Electric Industry (Mexico)
LMB	Lower Mekong Basin
LME	liberal market economy
LMP	localized marginal price
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LSE	London School of Economics
LSEs	load-serving entities
LTE	Law on Energy Transition
MCTI	Ministry of Science, Technology and Innovation (Brazil)
MEC	minerals-energy complex
MEMR	Ministry of Energy and Mineral Resources (Indonesia)
MHI	Manitoba Hydro International
MINECOFIN	Ministry of Finance and Economic Planning (Rwanda)
MININFRA	Ministry of Infrastructure (Rwanda)
MINIRENA	Ministry of Environment and Natural Resources (Rwanda)
MIT	Massachusetts Institute of Technology
MMA	Brazilian Ministry of Environment (Brazil)
MME	Ministry of Mines and Energy (Brazil)
MoU	Memorandi of Understanding
MR	Mekong region
MRB	Mekong River Basin
MRC	Mekong River Commission
MRGP	maximum refinery gate price
MW	megawatt
MWh	megawatt hour
MYTO	multi-year tariff order
NAEC	Nigeria Atomic Energy Commission
NAFTA	North American Free Trade Area
NAMA	nationally appropriate mitigation actions
NAPTIN	National Power Training Institute of Nigeria

NBET	Nigerian Bulk Electricity Trading
NCP	National Council on Privatization (Nigeria)
NDA	National Democratic Alliance
NDBP	National Domestic Biogas Programme (Rwanda)
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NEC	National Energy Commission
NECSA	Nuclear Energy Cooperation South Africa
NELMCO	Nigerian Electricity Liability Management Company
NEPA	National Electric Power Authority (Nigeria)
NERC	Nigerian Electricity Regulatory Commission
NERSA	National Energy Regulator South Africa
NFFO	non-fossil fuel obligation
NGO	non-governmental organizations
NIASA	Nuclear Atomic Industry Association
NIMBY	not in my back yard
NIPP	National Integrated Power Project (Nigeria)
NISP	National Improved Stove Programme (China)
NISR	National Institute of Statistics of Rwanda
NLGACCERCER	National Leading Group on Climate Change Energy Conservation and Emissions Reduction
NNEECC	Nuclear Energy Committee (S Africa)
NOx	nitrogen oxide
NPC	National Planning Commission
NPCC-RS	National Policy on Climate Change and Response Strategy
NPL	Northwest Power Ltd
NPV	net present value
NREL	National Renewable Energy Laboratory
NUM	National Unions of Mineworkers (S Africa)
NYMEX	New York Mercantile Exchange
OCGT	open-cycle gas turbine
OECD	Organisation for Economic Co-operation and Development
OFGEM	Office of Gas and Electricity Markets
OPEX	operational expenses
PAIA	Promotion of Access to Information Act
PBMR	pebble-bed modular reactor
PCT	Patent Cooperation Treaty

PDD	Project Design Documents
PECC	National Strategy on Climate Change (Mexico)
PEMEX	Petróleos Mexicanos
PHCN	Power Holding Company of Nigeria
PLB	Planbureau voor de Leefomgeving
PMP	predominant method of production
PPA	power purchase agreement
PPMs	processes and production methods
PRA	Participatory Rural Appraisal
PROINFRA	Programa de Incentivo a Fontes Alternativas de Energia Elétrica (Brazil)
PSCW	Public Service Commission of Wisconsin
PUC	Public Utilities Commission
PV	photovoltaic
PWR	pressurized water reactor
R&D	research and development
RACER	relevant, accepted, credible, easy to monitor, and robust
RAP	Regulatory Assistance Project
RD&D	research, development, and demonstration
RE	renewable energy
RE IPPPP	Renewable Energy Independent Power Producers' Programme
REDD+	Reducing Emissions from Deforestation and Forest Degradation
REFIT	renewable energy feed-in tariff
REG	Rwanda Energy Group
REN21	Renewables 2015 Global Status Report
RES	renewable energy sources
RESA	Renewable Energy Sources Act (Germany)
RETs	renewable energy technologies
RFS2	Renewable Fuel Standard Program
RO	renewables obligation
ROI	return on investment
RPS	renewable portfolio standard
RSA	Republic of South Africa)
SABC	South African Broadcasting Corporation
SCADA	supervisory control and data acquisition systems
SCC	social cost of carbon
SCM	Subsidies and Countervailing Measures
SCOT	social construction of technology

SEC	state-owned electricity company
SEMARNAT	Secretaría del Medio Ambiente y Rescursos Naturales
SENER	Secretariat of Energy (Mexico)
SERC	State Electricity Regulatory Commission (China)
SHP	solar heat and power
SIP	state implementation plan
SNV	Netherlands Development Organization
SO_2	sulphur dioxide
SOE	state-owned enterprise
SON	Standards Organisation of Nigeria
Sox	sulfur oxide
SPRU	Science Policy Research Unit
SSA	sub-Saharan Africa
SST	social shaping of technology
TCN	Transmission Company of Nigeria
tCO_2	tonne of carbon dioxide
TEPs	tradable emission permits
THC	thermohaline circulation
TOR	terms of reference
TSO	transmission system operator
TW	terawatt
TWh	terawatt hour
UFBA	Federal University of Bahia
UHV	ultra-high voltage
UK	United Kingdom
UMB	Upper Mekong Basin
UN	United Nations
UNCSD	United Nations Conference on Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNU-MERIT	United Nations University–Maastricht Economic and Social Research Institute on Innovation and Technology
UNU-WIDER	United Nations University World Institute for Development Economics Research
US	United States
USAID	United States Agency for International Development

USDOE	United States Department of Energy
USGCRP	US Global Change Research Program
V2G	vehicle-to-grid project
VC	venture capital
VIUs	vertically integrated utilities
VoC	Varieties of Capitalism
WDI	World Development Indicators
WEC	Wisconsin Energy Corporation
WEPCO	Wisconsin Electrical Power Corporation
WGI	World Governance Indicators
WNN	World Nuclear News
WTI	West Texas Intermediate
WTO	World Trade Organization
WTP	willing to pay
WWF	World Wildlife Fund
YGCs	Yasuni Guarantee Certificates
YNP	Yasuni National Park

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Part I

The Political Economy of Clean Energy Transitions

1

Introduction and Synthesis

Douglas Arent, Channing Arndt, Mackay Miller, Finn Tarp, and Owen Zinaman

1.1 MOTIVATION

Climate change is frequently referred to as one of the defining challenges of the twenty-first century. We concur. In broad terms, the climate challenge is relatively straightforward. Global average temperatures are rising as a consequence of anthropogenic emissions of greenhouse gases. In the absence of deliberate and global action to first substantially reduce and then eliminate (or even turn net negative) greenhouse gas (GHG) emissions, global temperature rise within this century is very likely to surpass two degrees Celsius (IPCC 2014), which is the (somewhat arbitrary) threshold set by the international community as a tolerable level of warming.[1] Continuation of current levels of emissions or (worse) continued growth in emissions throughout the twenty-first century could result in warming far above the two-degree threshold with very bad implications for the environment of the planet and for human societies, particularly poor people.

These observations constitute the core arguments for serious efforts to reduce emissions, called mitigation policy, at the global level. A principal element to mitigation policy relates to energy use. Specifically, energy use must transition from technologies that emit substantial volumes of GHGs to technologies with limited or zero emissions. A 'clean energy transition' refers broadly to a substitution of technologies and associated fuel inputs across the full set of energy subsectors and consumers of energy, both as intermediates and final goods. This is the 'clean energy transition' referred to in the title of this book.

[1] A more ambitious 1.5-degree target has been set forth in recent negotiations arguing that it is 'a significantly safer defense line against the worst impacts of a changing climate' (UNFCCC 2015).

While the broad contours of the climate challenge, of which the mitigation challenge is a subset, are well understood, the specificities of almost all aspects of the climate challenge are deeply complex. Enormous efforts have been dedicated to the science of global change (IPCC 2014, 2013). While much remains to be learned, climate science provides solid foundations to the core arguments for serious efforts to reduce emissions. The technical challenge of inventing low emissions energy technology has been absorbing the attention of some of the world's top scientists and engineers for decades and has become increasingly commercial over the past decade. Further, a new wave of promising technologies is forming.

But, in the end, a solid foundation for action derived from climate science combined with an array of promising technologies for reducing emissions are not likely to be enough to catalyse a clean energy transition. A key phrase in the very first paragraph of this introductory chapter is 'deliberate and global action'. A clean energy transition is highly unlikely to occur on its own. Policies must be put in place that will foment a clean energy transition, and these policies must be effective globally (as opposed to just shifting emissions from one region to another). The challenge, perhaps the largest of them all, is implementing policies and programmes that actually achieve the necessary global emissions reductions. Here, political economy considerations take a leading role. These perspectives motivate our focus on the political economy of clean energy transitions.

1.2 A NEW ERA

For the purposes of avoiding the potentially execrable outcomes associated with climate change referred to in Section 1.1, a long series of global agreements and meetings have taken place under the auspices of the United Nations. In the jargon that sprouts from such efforts, the first conference of the parties (CoP1) to the United Nations Framework Convention on Climate Change (UNFCCC) took place in 1995 in Berlin. Through the twentieth meeting (CoP20) in 2014 in Lima, relatively little was accomplished in terms of actually changing the trajectory of the global emissions of GHGs that drive climate change. CoP21 in Paris in late 2015 represents a potential breakthrough that ushers in a new era for climate mitigation.

The successful conclusion of CoP21 reflects three features of the current landscape that differ significantly from previous major attempts to set the planet on a more desirable GHG emissions trajectory. The most recent major attempt, prior to CoP21, occurred at CoP15 in 2009 in Copenhagen. First, CoP21 represented the culmination of a shift in the negotiation framework. At CoP15, the negotiations retained more of a 'top-down' approach wherein, essentially, a global emissions trajectory was determined and negotiators sought to parse country-level responsibilities for achieving this path.[2] In contrast, CoP21 in Paris employed a 'bottom-up' offer system, wherein individual countries propose what they perceive to be achievable and fair emissions trajectories for their particular circumstances. These offers are formally called Intended Nationally Determined Contributions (INDCs). In this new negotiating framework, the resulting projected global emissions trajectory is the sum of individual country INDCs.

Second, the rapid pace of technological advances in renewable energy technologies and systems, even if one considers just the past six years, is in the process of influencing the political economy of clean energy transitions (USDOE 2015). Historically, governments aiming to take deliberate action to correct the colossal market failure of GHG emissions have suffered from a 'chicken and egg' problem. Specifically, many technologies that offered long-run potential to support a clean energy transition were also small-scale, immature, and relatively high-cost. As a result, they were largely unattractive to private investors. While these factors provide a solid economic rationale for government support, the politics of supporting small-scale, immature, and relatively high-cost technologies are nonetheless difficult. Difficult politics inevitably constrains the ambition of policies that are crucial for technology development.

In sum, a circle exists wherein politics drives policy, policy drives technology, and the state of technology circles back to influence politics. Today, from the perspective of advancing clean energy technologies, this circle shows evidence of becoming virtuous as opposed to vicious. Since 2008, the year before CoP15 notably failed to produce a move towards effective global mitigation, the global solar module price index has fallen by a factor of nearly four, a rate of technical advance vastly more rapid than nearly all predictions (Feldman et al. 2014). Declines in the cost of wind power—while not as dramatic—have been rapid by any common standard (Moné et al. 2015). These advances both spur private investment and generally ease the politics of supporting clean energy transitions. Investments in energy production have reflected these shifts. In 2014, for the first time in history, the amount of new renewable generation capacity surpassed that of new fossil fuel-based systems on a global basis (Sawin et al. 2015). This trend continued in 2015 with new renewable capacity outstripping fossil fuels again (Frankfurt School-UNEP Centre/BNEF 2016).

Third, the developing world confronts climate change issues with a far deeper and more sophisticated knowledge base than in 2009 (Arndt and Tarp 2015). In Copenhagen at CoP15, the critical role that developing countries must play in any effective global mitigation regime had become clear

[2] CoP15 also arguably seeded the approach taken in Paris at CoP21 through the discussions of nationally appropriate mitigation actions (NAMA).

simply as a matter of arithmetic. Yet, the complex implications of climate change impacts, adaptation policies, and mitigation policies had really only begun to penetrate the major decision-making apparatuses of developing countries. For instance, the World Bank's *Economics of Adaptation to Climate Change* study, which was meant to serve as a critical input to developing countries for CoP15 in 2009, was only published in 2010, *after* the Copenhagen CoP meeting had ended. In our experience at the time around CoP15, work on climate change issues, particularly when one spoke to personnel from the critical central finance and planning units in developing countries, frequently amounted to delivering primers on climate change and energy transition policy basics. The process of internalizing the information and assessing appropriate policy responses had only just begun.

It would be an overstatement to say today that climate change information has been fully internalized and appropriate policies assessed in developing countries. Nevertheless, the process of doing so is much more advanced than it was in 2009. In country after country, the central decision-making units have engaged. This is critical. The profound economic transformations inherent in a clean energy transition will need to be fully integrated into economic decision-making. The contributions from developing countries in this book are evidence of this increasingly sophisticated and nuanced view of the climate challenge. The more than 160 INDCs on the UNFCCC website are perhaps the most salient evidence.

India and China are cases in point. In 2009, it is fair to say that India's negotiation strategy aimed to position climate change as a developed country problem. In contrast, India's INDC offers serious attempts to reduce the carbon intensity of its GDP. China has gone further, offering to peak emissions by 2030 with declines thereafter. Taken as a whole, the INDCs presented at CoP21 represent *a decisive break from past emissions trends*. Recent analysis of the INDCs by the International Energy Agency (2015) indicates that nearly every country will have a strong focus on emissions mitigation, driving clean energy to more than 50 per cent of world energy by 2040. The scope and ambition of these offers stem from long and often difficult processes of internalization and policy option assessment that has taken place within both developed and developing countries.

These three shifts now combine to place country decision-making and country policies at centre stage. Like it or not, there is no current prospect for a unified global policy, such as a global carbon tax or cap-and-trade scheme, to which all nations agree to adhere. Rather, nearly all countries on the globe will set about to achieve their contributions in their own ways, and their means for achieving these ends will vary enormously. For example, the United States, a leading advocate in international fora for reliance on markets, looks set to pursue a domestic policy of regulatory edict. China, the paragon of the developmental state, announced intention for a nationwide cap-and-trade system in September 2015. Overall, the range of policies pursued, and hence the degree of policy experimentation, looks virtually certain to be very large.[3]

Before proceeding, the technology drivers mentioned in this section merit a closer examination.

1.3 TECHNOLOGY DRIVERS

> In controversies about technology and society, there is no idea more provocative than the notion that technical things have political qualities (Langdon Winner 1980).

The rate of technological advancement in the renewable energy space has been notably rapid. Established institutions, once isolated from rapid change, are now presented with a dynamic landscape of pathways for simultaneously achieving decarbonization goals and sustainable development objectives. With affordable low-carbon energy readily available or imminent in most contexts, institutional innovation is arising—out of necessity—across public policy, finance, business models, markets, planning, and other dimensions to promote deployment. These innovations—and the technical and political qualities they possess—are interacting with a range of incumbent actors and interests, and influencing the political economy of the clean energy transitions. Thus, a brief assessment of technology drivers is worthwhile.

The growing cost-competitiveness and advanced capabilities of renewable energy technologies, predominantly wind and solar, is a key pillar of clean energy innovation and technological advancement. We observe, in many contexts, the price of a newly constructed wind farm or solar plant is now at or below the cost of competing fossil fuel alternatives, even without considering the fuel price variability or environmental or health impacts (Stark et al. 2015). With their geographically diverse and variable nature, these resources are reshaping, in particular, how power systems are planned, operated, governed, and even conceptualized (Miller et al. 2015). Furthermore, the modularity of solar panels enables a viable alternative to the traditional provider–customer relationship, quite literally empowering consumers through technology, regulation, and business model innovation to create their own energy.

The qualities of clean energy technologies also have implications for energy security in both developed and developing country contexts. Renewable technologies offer the prospect of reducing dependence on fuel imports. Energy

[3] Backsliding in policies to achieve a clean energy transition is also a clear possibility in numerous countries.

trade between countries may or may not decline, however. There are portfolio effect gains from renewable energy generation over broad areas driven by the simple observation that it is likely to be windy and/or sunny somewhere (Keane et al. 2011). In addition, hydropower resources are often concentrated in a few locations. Both of these factors point to increased regional energy trade as a potential corollary to increased dependence on renewable energy sources. As a result, energy security under a renewable energy future may take on a much more regional hue (see Part VIII).

At the same time, the inherent dispersion of wind and solar resources, combined with new technologies and business models, present increasingly attractive pathways to expanding energy access from the bottom up, potentially leapfrogging the need for some of the cumbersome and difficult-to-finance infrastructure investments associated with traditional power systems. As will be discussed in Section 1.4, this dispersed nature of renewable energy may be particularly relevant for rural zones and smaller concentrations of demand located a distance from functional grids. Advances in data systems, communication technologies, and energy storage costs are accelerating decentralization and heterogeneity of the energy sector (Zinaman et al. 2015).

While technology is a fundamental driver, it has become increasingly clear that the availability of technology is not in itself sufficient to accelerate a clean energy transition; innovative and nationally-customized deployment strategies—hinging on public policy and regulation, market reforms, private sector engagement, and strong analytical tools and data—remain important factors.

More often than not, regulation and governance lag behind technology innovation, compelling forms of institutional innovation in order to play catch up. Ongoing innovations in energy systems often require either adaptations of established regulatory constructs to accommodate new technologies (a form of incremental change) or broad-based reform of the regulatory constructs themselves (perhaps via more reconstructive or evolutionary approaches) (see, for example, Zinaman et al. 2015). Across all contexts, addressing the techno-institutional complex perpetuating carbon-intensive systems—termed by some as 'carbon lock-in' (see, for example, Unruh 2000)—is a common theme.

Technology is highly likely to remain one of the key driving factors influencing climate commitments and energy-related development goals, both in terms of goal-setting and implementation. What is technically possible and economically attractive today vis-à-vis decarbonization and sustainable development is much greater than it was during (for example) the Kyoto Protocol era. Continued rapid rates of technical advance are expected. In order to seize the opportunities offered by this technical advance, equally innovative approaches to regulation and policy are likely to be required. This highlights the inherent political economic factors to be considered, as various pathways are weighed and implementation efforts are mounted.

1.4 CHALLENGES IN DEVELOPING VERSUS DEVELOPED ECONOMIES

The political economy of energy transitions is of interest across both the developed and developing worlds, and a defining feature of this book is a review of experiences from a diversity of contexts. As emphasized, the mitigation challenge cannot be addressed by developed countries alone. The volume of current emissions from developing countries combined with their rapid growth trajectories highlight the importance of developing countries in any effective global mitigation regime.

Developing countries simultaneously confront enormous development challenges. Eliminating absolute poverty is also a defining challenge of the twenty-first century, as set forth in the Sustainable Development Goals. Developing countries are highly unlikely to shelve their developmental aspirations in favour of mitigation objectives. Thus, the political economy of clean energy transitions in the developing world present some of the thorniest and most important challenges.

With respect to the developed world, their historical emissions, relatively comfortable material circumstances, institutional capabilities, and technical knowhow lead to the expectation that they will lead the energy transition. This means reducing absolute emissions in the near term and achieving very deep cuts by mid-century. This change must be undertaken by energy systems characterized by weak or even negative energy demand growth as well as deeply entrenched actors and interests.

In sum, the challenges facing both developing and developed countries are not to be taken lightly. While developed countries are expected to lead—for example, with respect to government commitments to research, development, demonstration, and deployment activities for new technologies—the critical role of regulatory frameworks, policies, and institutions have already been emphasized. These require localized solutions in both developing and developed country contexts. The dividing line between these two broad country groups is neither clear nor fast in other respects as well. Citizens of developed countries expect economic progress through time along with environmental stewardship, and developing countries certainly have their share of entrenched interests.

Nevertheless, the broadly defined challenges facing developed and developing economies do differ in important ways. In particular, driven by population/labour force growth, technological catch-up, a relatively high marginal product of capital and substantial growth aspirations, developing countries' economies can be expected to grow more rapidly than developed economies. Accordingly, the demand for new energy supply is likely to be much greater in the developing than developed world.

There are multiple edges to this challenge. On the one hand, the INDCs set forth by developing countries point to a reorientation away from the well-trodden path of employing massive fossil energy to fuel development. This charting of a new path, or new paths, is almost surely less straightforward than following prior recipes. As institutional and human capabilities in developing countries are characteristically weak relative to developed countries, the need to chart new paths and confront new challenges provokes legitimate concern.

On the other hand, fossil-based systems have a series of, by now, well-known shortcomings. First, developing countries frequently encounter difficulties implementing fossil-fuel-based systems, particularly for electricity generation. These difficulties arise from numerous factors. The bottom line is that unreliable power supply has long been a hallmark of many developing country cities and is frequently pointed to as a substantial brake on economic development (see Foster 2008). While intermittency in output is a characteristic of many renewable generators, that variability reduces substantially at a system level; and meeting or improving upon the reliability levels currently attained in many developing country contexts is often a fairly low bar of accomplishment. The relatively modular nature and short investment lead times of wind and solar power generation systems also favour developing countries where demand growth tends to be much more variable and much less predictable than in developed country contexts.

Second, fossil-fuel-based systems are poorly suited to rural areas. This is particularly true of electricity generation. Around 1.2 billion people (about 17 per cent of the world's population) lack access to electricity, and the vast majority of these people live in rural areas of developing countries (IEA 2015). Rural inhabitants in zones that lack access to electricity are frequently absolutely poor. In short, existing fossil-based power systems serve the least well off of the world's population very badly. Various renewable technologies have been shown to scale effectively in these areas. Biopower systems currently serve dozens of villages in South Asia (Bhattacharyya 2014), and next generation bioenergy systems also hold out additional promise for rural zones. With the rapid advances in solar and battery technology, distributed solar systems provide a potentially unprecedented opportunity to extend electricity access to some of the world's poorest citizens.

Third, localized pollution impacts of fossil-fuel-based systems can be intense. Poor air quality gives rise to serious health concerns. New Delhi and Beijing are just the most recent examples of places where low air quality seriously impacts wellbeing. Clean energy systems have the potential to diminish or even effectively remove these real costs.

Fourth, fossil-based systems both fuel and disrupt development. Experience in countries with fossil fuel endowments indicate that they are not an unalloyed boon for their economies in general and the welfare of their citizenry in particular. The vagaries of fossil fuel prices, and concomitant macroeconomic instability, combined with the tendency for revenues derived from sale of fossil resources to concentrate in a few hands have not been helpful for development patterns in many countries leading some authors to proclaim a 'resource curse' (Frankel 2010). For most fossil fuel importers, variations in fossil fuel prices have large impacts, often with implications for political stability (e.g., Arndt et al. 2012).

Finally, developing countries may possess inherent advantages in terms of clean energy endowments. Many developing countries are relatively well endowed with sun, wind, and unexploited hydropower potential. In a world dominated by clean energy systems, many developing countries may possess an inherent comparative advantage in energy-intensive activities.[4]

For these reasons, a clean energy transition is not necessarily an impediment to the growth aspirations of the developing world. And, there are a series of solid rationales for developed countries to assist developing countries in realizing a clean energy transition. Not least, a failure on the part of developing countries to transition to cleaner energy sources implies a failure to stabilize the global climate, with negative implications for everyone.

Developed countries are also responsible for a disproportionate share of the stock of greenhouse gases in the atmosphere. This would be highly problematic if the lack of space for even greater stocks of atmospheric GHGs imposed a tight trade-off between the development aspirations of the citizens of developing countries over the next few decades and a permanent alteration of the global climate. The fact that the developed world has effectively claimed squatters' rights on the global atmospheric commons becomes a lot less problematic if new paths to fuelling development are opened as the fossil fuel pathway is foreclosed.

The practical and ethical arguments for assisting developing countries in taking these new pathways are strong. At the same time, it is not a question of simply willing a clean energy system into place whatever the cost. As emphasized, the changes inherent in a clean energy transition are profound, involving the full economic system with implications for competiveness and economic growth. Improperly done, those costs could easily be very high and would likely sap the will for undertaking that very transition.

Hence, economic efficiency and reasonable equity are key. Efficient and relatively low-cost transitions to a stable global climate are widely viewed as

[4] Of course, whether developing countries are capable of actually capitalizing on these advantages (if they indeed exist) is another question. This is an important area for future research.

imminently possible.[5] The cost estimations in the Fifth Assessment Report of the IPCC indicate approximately a year or two of global growth by around mid-century. In other words, global GDP per capita with mitigation would reach the same level in 2055 as it would have attained in about 2053 without mitigation. These calculations typically ignore the benefits of mitigation in terms of climate change impacts avoided as well as health benefits from reduced pollution. Also, there are real possibilities to enhance the equity of the energy transition through, for example, more rapid rural electrification and better urban air quality in developing countries.

1.5 THIS BOOK

This book takes as a starting point that a new era of reducing emissions at scale has begun. The proximate challenges of this new era are codified in the emissions reductions offers (INDCs) from 165 countries available on the UNFCCC website. To date, the scale of emissions reductions efforts has been nowhere near adequate to the task. But, this does not mean that nothing has been tried. Considerable experience has been gained, and many features of the political economy of clean energy transitions have been revealed. It makes sense to profit from this experience in order to help meet the challenge of greatly scaling up emissions reductions efforts.

As countries and regions grapple with the complex task of reducing emissions in accordance with their INDCs while providing better lives for their citizenry, the demand for sharing of experience and lessons learned looks set to increase dramatically. This applies both to successes and to failures. Advancing this process of knowledge-sharing, to the benefit of all, but especially the most vulnerable of present and future generations, is the *raison d'être* of this book.

This book presents 27 cases, reviewing country experience, regional experience (e.g., the European Union), and international experience/cross-cutting issues, with a focus on the political economy aspects of the clean energy transition.

The book's parts are organized by major political economy subject matter areas germane to characterizing clean energy transitions. While many of the individual chapter topics are cross-cutting in nature, we, the editors, believe this organizing framework to be a useful construct. A short introduction to each part highlights the issues and the main points drawn from the constituent chapters.

[5] Llavador et al. (2015) disagree. They find that global mitigation objectives can only be met through reductions in the rate of growth of GDP.

There are eight major parts.

In Part I, Chapter 1 introduces readers to the layout of the book. Chapter 2 examines the history and politics of energy transitions and draws lessons for today.

Part II features policies designed to advance clean energy and combat climate change from a global or general perspective.

Part III features chapters that explore how institutions and governance influence the processes of energy innovation, deployment, and policy formation.

Part IV features chapters that raise key political questions about the role of actors, interests, and institutions in the energy sector: who has the power to change, who sets the terms of transition, and for whom?

Part V features chapters that explore relationships and tensions between emerging clean energy sectors and incumbent stakeholders.

Part VI features chapters that discuss the drivers, obstacles, and implications of energy sector reforms which shift the balance of public and private participation in clean energy transitions.

Part VII features chapters that explore the role of clean energy, as an enabler of economic growth and development, and social inclusion.

Part VIII features chapters that explore how clean energy transitions challenge traditional national boundaries and differentially impact regions within national boundaries.

1.6 LOOKING FORWARD

A clean energy transition is not easy. This is amply illustrated in the case studies. Even if the technical path is clear and fully illuminated, a clean energy transition will involve the shift of resources between competing economic sectors and political constituencies alongside changes in institutional and policy frameworks. Stakeholders in this process have varying degrees of political and economic power. Regardless of the society or the political system, understanding how political economy factors influence clean energy transitions is crucial to effective policy formulation and facilitating transitions to sustainable energy systems.

Despite the challenges, this introductory chapter has adopted a purposefully optimistic tone. This seems appropriate. CoP21 does represent a substantial break from the past. Technological change in clean energy sectors has been very rapid. Institutional and policy changes are evident in many countries. And, resource allocations are shifting as evidenced by the large investments in clean energy systems that are occurring worldwide. In effect, the set of INDCs derived from CoP21 pledge an essentially global transition towards clean energy systems. Put differently, global mitigation efforts have begun in earnest.

While the first steps have been taken, much more effort is required. Over the next few years, countries need to follow through on their INDCs. Looking further ahead, it is well known that the sum of the commitments in the INDCs does not result in an energy system that is sufficiently environmentally benign as to be compatible with a stable global climate. Even more ambitious commitments/transformations will be necessary in future.

While a freewheeling 'bottom-up' approach appears to have been well suited to getting started, it is likely that limitations to the highly dispersed approach adopted in Paris at CoP21 will become apparent. For example, the solicitation of INDCs is not an approach that is particularly well suited to addressing the vexing and inter-related issues of international trade, carbon trade, and footloose industries/carbon leakage. Thoughts on future stages of the clean energy transition are discussed in Chapter 29. Chapter 29 also provides forward perspectives on the research agenda.

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2

The History and Politics of Energy Transitions

Comparing Contested Views and Finding Common Ground

Benjamin K. Sovacool

2.1 INTRODUCTION

Transitioning away from our current global energy system is of paramount importance (Riahi et al. 2012: 1203–306). As Grubler (2012: 8) has compellingly written, 'the need for the "next" ' energy transition is widely apparent as current energy systems are simply unsustainable on all accounts of social, economic, and environmental criteria'. Miller et al. (2013: 136) add that, 'The future of energy systems is one of the central policy challenges facing industrial countries'. Unfortunately, however, neither private markets nor government agencies seem likely to spur a transition on their own (Fri and Savitz 2014). Moreover, shifts to newer, cleaner energy systems such as sources of renewable electricity (Painuly 2001; Sovacool 2009) and electric vehicles (Sovacool and Hirsh 2009; Nielsen et al. 2015) often require significant changes not only in technology, but also in political regulations, tariffs, and pricing regimes, and the behaviour of users and adopters.

Thus, the speed at which a transition can take place—its timing, or temporal dynamics—is a critical element of consideration (Sovacool 2016). According to the International Energy Agency (2012: 3), for example, if 'action to reduce CO_2 emissions is not taken before 2017, all the allowable CO_2 emissions would be locked-in by energy infrastructure existing at that time'. In other words, if a transition does not occur quickly, or soon, it may be too late. Giddens (2009) went so far as to call this the 'climate paradox', the fact that by the time humanity may come to realize fully how much they need to shift to low-carbon forms of energy, they will have already passed the point of no return.

The notion of 'energy transitions' sits at the heart of this polemical discussion. O'Connor (2010) once defined an energy transition as 'a particularly significant set of changes to the patterns of energy use in a society, potentially affecting resources, carriers, converters, and services'. In other words, to those subscribing to this definition, an energy transition refers to the time that elapses between the introduction of a new primary energy source, or prime mover, and its rise to claiming a substantial share of the overall market. According to one view, energy transitions take an incredibly long time to occur. As the geographer Vaclav Smil (2010a: 141–2) writes, 'all energy transitions have one thing in common: They are prolonged affairs that take decades to accomplish, and the greater the scale of prevailing uses and conversions, the longer the substitutions will take.' Fast transitions, when they occur at all, are anomalies, limited to countries with very small populations or unique contextual circumstances that can hardly be replicated elsewhere.

Another view argues the opposite. Broadening the discussion beyond simply national sources of energy supply and substantial shifts of their composition, it suggests that there have been many transitions—at varying scales, involving different things including fuels, services, and end-use devices—that have occurred quite quickly, that is, between a few years and a decade or so, or within a single generation. At smaller scales, the adoption of cookstoves, air conditioners, and flex-fuel vehicles (FFVs) are excellent examples. At the state or national scale, almost complete transitions to oil in Kuwait, natural gas in the Netherlands, and nuclear power in France took only a decade, roughly, to occur. Indeed, the second part of this chapter presents ten case studies of energy transitions that, in aggregate, affected almost 1 billion people and needed only 1–16 years to unfold. Clearly, this antithetical view proposes that some energy transitions can occur much more quickly than commonly believed.

Which side is right? Similar to other controversies in the energy studies literature (Sovacool et al. 2016), this chapter holds that both are. After presenting evidence in support of both theses, it elucidates a common ground consisting of four arguments. First, sometimes the 'speed' or 'scale' at which an energy transition occurs has less to do with what actually happened and more to do with what or when one counts. Second, what may seem a sweeping transition can actually be a bundle of more discrete minor conversions or substitutions. Third, energy transitions are complex, and irreducible to a single cause, factor, or blueprint. Fourth, most energy transitions have been, and will likely continue to be, path dependent rather than revolutionary, cumulative rather than fully substitutive.

2.2 ONE SIDE: ENERGY TRANSITIONS ARE LONG, PROTRACTED AFFAIRS

This view holds that energy transitions—defined by some as the time that elapses between the introduction of a new fuel or technology (sometimes called a 'prime mover') and its rise to 25 per cent of national market share—takes a significant amount of time (Smil 2010a). The Global Energy Assessment (GEA) (2012: 788), a major international, interdisciplinary effort to understand energy systems, notes that 'transformations in energy systems' are 'long-term change processes' on the scale of decades or even centuries. This view holds that, as two Stanford University scientists write, 'it appears that there is no quick fix; energy system transitions are intrinsically slow' (Myhrvold and Caldeira 2012: 1). Support for this side comes from (1) the historical record, (2) the validity of looking at the 'big picture', and (3) the literature on 'lock-in' and 'path dependency'.

2.2.1 History Shows Major Transitions Taking Decades to Centuries

In the USA, crude oil took half a century from its exploratory stages in the 1860s to capturing 10 per cent of the market in the 1910s, then 30 years more to reach 25 per cent. Natural gas took 70 years to rise from 1 per cent to 20 per cent. Coal needed 103 years to account for only 5 per cent of total energy consumed in the USA and an additional 26 years to reach 25 per cent (Smil 2012). Nuclear electricity took 38 years to reach a 20 per cent share, which occurred in 1995.

Globally, we see even longer time frames involved with energy transitions. Coal surpassed the 25 per cent mark in 1871, more than 500 years after the first commercial coal mines were developed in England. Crude oil surpassed the same mark in 1953; about nine decades after Edwin Drake drilled the first commercial well in Titusville, Pennsylvania, in 1859. Hydroelectricity, natural gas, nuclear power, and 'other' sources such as wind turbines and solar panels *still* have yet to surpass the 25 per cent threshold—as Figure 2.1 depicts—with only nuclear reaching the meagre 5 per cent mark.

Assessing prime movers rather than fuels, Smil (2010b) adds that steam engines were designed in the 1770s, but didn't take off until the 1800s, and the gasoline-powered internal combustion engine, first deployed by Benz, Maybach, and Daimler in the middle of the 1880s, reached widespread acceptance in the USA only in the 1920s, and even later for Europe and Japan. As Smil (2012: 3) deduces from these examples:

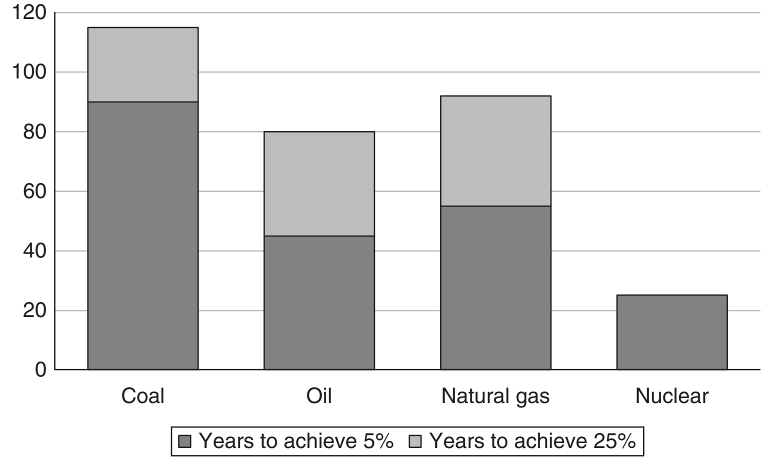

Figure 2.1. Major transitional shifts in global energy supply, 1750–2015.
Source: Author's illustration based on Smil (2012).

> Energy transitions have been, and will continue to be, inherently prolonged affairs, particularly so in large nations whose high levels of per capita energy use and whose massive and expensive infrastructures make it impossible to greatly accelerate their progress even if we were to resort to some highly effective interventions.

This is why he calls energy systems 'a slow-maturing resource' and jokes that 'energy sources, they grow up so…slowly' (Smil 2012: 2–3). As he remarks, 'it is impossible to displace [the world's fossil fuel-based energy] super-system in a decade or two—or five, for that matter. Replacing it with an equally extensive and reliable alternative based on renewable energy flows is a task that will require decades of expensive commitment. It is the work of generations of engineers' (Smil 2012: 3).

The notion that energy transitions are inherently lengthy events finds further support from energy analysts Peter Lund and Roger Fouquet. Lund (2006) found that market penetration of new energy systems or technologies can take as long as 70 years. Short 'take-over times' of less than 25 years are limited to a few end-use technologies such as water heaters or refrigerators, and are not common for major infrastructural systems like those involving electricity or transport. A second study of Lund's (2010a: 650) exploring 'how fast new energy technologies could be introduced on a large scale' estimated that the earliest wind could produce more than 25 per cent of world electricity, and solar 15 per cent, would be 2050—40 years from the date of his study. As Lund (2006: 3318) noted, 'the inertia of energy systems against changes is large, among others because of the long investment cycles of energy infrastructures or production plants' and the 'rate of adoption of these new [renewable energy] technologies would not exceed that of oil or nuclear in the past' (Lund 2010b: 3580). Analogously, Fouquet (2010) studied various transitions between both energy fuels and energy services from 1500 to 1920, and found that, on average, each single transition has an innovation phase exceeding 100 years followed by a diffusion phase approaching 50 years.

2.2.2 Analysts Need to Focus on the Big Picture

Furthermore, proponents of this view argue that one must look at the 'big picture', that is, the absolute change in energy systems, rather than discrete growth within a particular market, and the overall impact on society.

For instance, an energy system can grow rapidly, in an absolute sense, but still fail to grow in a comparative sense. Hydroelectricity in the USA was a low-cost source of energy in the 1950s and 1960s, where it grew in capacity *threefold* from 1949 to 1964. However, during this time, because other sources of energy (and demand for electricity) grew faster, hydropower's overall national share dropped from 32 per cent to 16 per cent (O'Connor 2010). Similarly, from 2000 to 2010, global annual investment in solar photovoltaic (PV) power increased by a factor of 16, investment in wind grew fourfold, investment in solar heating threefold. This sounds impressive—yet the overall contribution of solar (heating and PV) and wind to total final energy consumption grew from less than one-tenth of 1 per cent to slightly less than 1 per cent over the same period (Sovacool 2016), hardly a drop in the bucket.

Furthermore, part of a big picture approach means realizing that energy transitions do not always produce desirable results. The massive energy transitions that occurred in Japan from 1918 to 1945, North Korea in the 1990s, and Cuba in the 1990s saw societies grapple with sudden shifts in the availability of energy. Japan lost upwards of 70 per cent of its oil imports due to the US trade embargo of 1941, North Korea dropped 90 per cent of their oil imports from the Soviet Union in 1991, and Cuba saw a decline of energy imports from the Soviet Union of 71 per cent between 1989 and 1993. In each case, national planners responded to energy scarcity with military force (Japan) or by preserving the privileges of the elite at the expense of ordinary people (North Korea and Cuba) (Friedrichs 2013).

2.2.3 'Path Dependency' and 'Lock-In' Make Future Transitions Difficult

A final thread of this thesis is that desirable energy transitions are so difficult to achieve because of the momentum, path dependency, or obduracy of the existing system exerts on actors. In the case of national energy systems, such large sums of labour, capital, and effort are 'sunk' into them that they create their own 'inertia' (Knox-Hayes 2012; Steinhilber et al. 2013). On top of that, institutional legacies protect the status quo, and political regulations, tax codes, and even banks and educational institutions come to support a particular energy pathway, along with associated coalitions (Goldthau and Sovacool 2012). The result is that energy transitions, breaking out of these embedded systems, require a 'long-term transformation' that is 'a messy, conflictual, and highly disjointed process' (Meadowcroft 2009). Collectively, these technological and behavioural forces 'lock' us into a carbon-dependent energy system that highly resists change (Unruh 2000). In the case of prime movers, we see similar resistance. As Smil (2010a: 140) writes, 'There is often inertial reliance on a machine that may be less efficient (steam engine, gasoline-fueled engine) than a newer machine but whose marketing and servicing are well established and whose performance quirks and weaknesses are known. The concern is that rapid adoption of a superior converter may bring unexpected problems and setbacks.'

In order to counteract this inertia, scholars looking at energy transitions have argued that truly 'transformative change' must be the result of alterations at *every* level of the system, simultaneously, that is, one must alter technologies, political and legal regulations, economies of scale and price signals, and social attitudes and values together, making transition a gruelling process. Or to use parlance from sociotechnical systems theory, it is rare that innovation niches become regimes and rarer still for those regimes to influence the broader, global landscape (Geels and Schot 2007; Schot and Geels 2008). This parallels what feminist scholar, Eve Kosofsky Sedgwick (1993) termed, the 'Christmas Effect' to describe the way that institutions, technology, and behaviour can coalesce around a common goal. During the holidays, the institutions of Western society come together and speak 'with one voice' for the Christmas holiday. Christian churches build nativity scenes and hold a greater number of masses; state and federal governments establish school and national holidays; and the media 'rev up the Christmas frenzy' and 'bark out the Christmas countdown' (Sedgwick 1993). Such sociotechnical inertia favouring the Christmas holiday exerts profound and lasting influence over our behaviour, and the argument runs that a similar alignment of values and incentives occurs with energy. This could be why, in their forecasts about the future, the US EIA (2013) still predicted in 2013 that in 2040, three-quarters of energy in the USA would come from oil, coal, and natural gas. The International Energy Agency (2012: 51) similarly projected that in 2035, under their 'Current Policies' scenario, 80 per cent of total primary energy supply worldwide would come from 'traditional' fossil fuels.

2.3 THE OTHER SIDE: ENERGY TRANSITIONS CAN HAPPEN QUICKLY

Contrary to those emphasizing the longevity or difficulty of energy transitions, an alternate view is that under certain conditions (or, if one chooses to count different things), energy transformations can occur rather speedily. Arguments in support of rapid transitions hold that (1) we have seen numerous fast transitions in terms of energy end-use, (2) plentiful examples of national-scale transitions litter the historical record, and (3) we can sufficiently learn from these trends so that favourable future energy transitions can be expedited. This section of the chapter explores no less than ten 'quick' energy transitions, five of them focused on end-use devices such as lighting and air conditioning, and five of them focused on national systems such as oil in Kuwait and nuclear power in France. Table 2.1 provides an overview of these cases, which collectively involved almost a billion people.

2.3.1 History Shows Speedy Transitions in Energy End-Use Devices

At least five transitions in end-use devices, or prime movers, have occurred with remarkable rapidity: lighting in Sweden, cookstoves in China, liquefied

Table 2.1. Overview of rapid energy transitions

Country	Technology/fuel	Period of transition	Number of years (from 1 to 25 per cent market share)	Approximate size (population affected in millions of people)
Sweden	Energy-efficient ballasts	1991–2000	7	2.3
China	Improved cookstoves	1983–1998	8	592
Indonesia	Liquefied petroleum gas (LPG) stoves	2007–2010	3	216
Brazil	Flex-fuel vehicles (FFVs)	2004–2009	1	2
USA	Air conditioning	1947–1970	16	52.8
Kuwait	Crude oil	1946–1955	2	0.28
Netherlands	Natural gas	1959–1971	10	11.5
France	Nuclear electricity	1974–1982	11	72.8
Denmark	Combined heat and power (CHP)	1976–1981	3	5.1
Canada (Ontario)*	Coal	2003–2014	11	13

Note: * The Ontario case study is the inverse, showing how quickly a province went from 25 per cent coal generation to zero.

Source: Author's compilation.

petroleum gas (LPG) stoves in Indonesia, ethanol vehicles in Brazil, and air conditioning in the USA.

Sweden was able to phase in an almost complete shift to energy-efficient lighting in commercial buildings in about nine years (Lund 2007). Swedish Energy Authorities arranged for the procurement of high-frequency electronic ballasts for lights in office buildings, commercial enterprises, schools, and hospitals, devices which saved 30–70 per cent compared to ordinary ballasts, in 1991. They used a multipronged approach of standardization and quality assurance, direct procurement, stakeholder involvement, and demonstrations to disseminate those ballasts. They began by collaborating with experts to develop a list of lighting quality factors for commercial buildings, and then asked for competitive tenders from manufacturers that met these standards. Then, the government directly purchased almost 30,000 units in a pilot phase, and worked with real estate management companies (for new buildings) and owners of public, commercial, and industrial buildings (for retrofits) to ensure that they were installed (Ottossen and Stillesjo 1996). After the pilot phase, they promoted distribution through government subsidies, sponsored demonstrations of the technology among the commercial sector, and involved consumer groups in discounted bulk purchases. Due to these concerted efforts, self-supporting volume effects were reached as early as 1996, catalysing very rapid market penetration, which jumped from about 10 per cent that year to almost 70 per cent by 2000. In essence, this meant that between 1991 and 2000, 2.3 million Swedish workers experienced changes in their office lighting.

The Chinese Ministry of Agriculture managed an even more impressive National Improved Stove Programme (NISP), managed by the Bureau of Environmental Protection and Energy (BEPE), from 1983 to 1998 (Smith et al. 1993; Brown and Sovacool 2011a: 292–301). The BEPE adopted a 'self-building, self-managing, self-using' policy focused on having rural people themselves invent, distribute, and care for energy-efficient cookstoves, and it set up pilot programmes in hundreds of rural provinces. From the start of the programme until 1998, the NISP was responsible for the installation of 185 million improved cookstoves and facilitated the penetration of improved stoves from less than 1 per cent of the Chinese market in 1982 to more than 80 per cent by 1998—reaching half a billion people, as Table 2.2 shows. The cookstoves being installed in China in 1994, during the height of the programme, were equivalent to 90 per cent of all improved stoves installed globally. As a consequence, Chinese energy use per capita declined in rural areas at an annual rate of 5.6 per cent from 1983 to 1990.

Indonesia also ran a large household programme focusing on the conversion from kerosene stoves to LPG stoves to improve air quality. Under leadership from their vice president, Jusuf Kalla, the Indonesian 'LPG Mega-project' offered households the right to receive a free 'initial package' consisting of a 3 kilogram LPG cylinder, a first free gas-fill, one burner stove, a hose,

Table 2.2. Households adopting improved stoves under the Chinese National Improved Stove Programme (NISP) and affiliated provincial programmes

	NISP households (million)	Households under provincial programmes (million)	Total households/ year (million)	Total people/ year (million)
1983	2.6	4.0	6.6	21.1
1984	11.0	9.7	20.7	66.2
1985	8.4	9.5	17.9	57.3
1986	9.9	8.5	18.4	58.9
1987	8.9	9.1	18.0	57.6
1988	10.0	7.5	17.5	56.0
1989	4.5	5.0	9.5	30.4
1990	3.6	7.8	11.4	36.5
1991–1998	7.8	57.2	65.0	208.0
Total	66.7	118.3	185.0	592.0

Source: Author's compilation based on Brown and Sovacool (2011a).

and a regulator. The government, in tandem, lowered kerosene subsidies (increasing its price) and constructed new refrigerated LPG terminals to act as national distribution hubs. Amazingly, in just three years from 2007 to 2009, the number of LPG stoves nationwide jumped from a mere 3 million to 43.3 million, meaning they served almost two-thirds of Indonesia's 65 million households (or about 216 million people). Six entire provinces, including that of Jakarta, the capital, were declared 'closed and dry'—meaning that the programme reached all of its targets, and that all kerosene subsidies were withdrawn (Budya and Arofat 2011).

Brazil has perhaps the fastest energy transition on record, though (to be fair) it depends on what one counts. Brazil created its Proálcool programme in November 1975 to increase ethanol production and substitute ethanol for petroleum in conventional vehicles, and in 1981, six years later, 90 per cent of all new vehicles sold in Brazil could run on ethanol—an impressive feat. However, a more recent transition, connected in part to the Proálcool programme, is even more noteworthy. The Brazilian government started incentivizing FFVs in 2003 through reduced tax rates and fuel taxes. These Brazilian FFVs were capable of running on any blend of ethanol from zero to 100 per cent, giving drivers the option of switching between various blends of gasoline and ethanol depending on price and convenience. The first year FFVs entered the market in 2004, they accounted for 17 per cent of new car sales but they rapidly jumped to 90 per cent in 2009—meaning 2 million FFVs were purchased in total over the first five years of the programme (Brown and Sovacool 2011b).

Air conditioning in the USA is a final example. In 1947, mass-produced, low-cost window air conditioners became possible, enabling many people to enjoy air conditioning without the need to buy a new home or completely renovate their heating system (National Academy of Engineering 2013). That year, only 43,000 units were sold, but by 1953, the number had jumped to 1 million, as air conditioners became endorsed by builders eager to mass produce affordable, yet desirable, modern homes and electric utilities that wanted to increase electricity consumption throughout the growing suburbs (Rosen 2011). Consequently, more than 12 per cent of people (occupying 6.5 million housing units) reported to the US Census in 1960 that they owned an air conditioner, rising to 25 per cent in 1963, and 35.8 per cent in 1970, representing 24.2 million homes and more than 50 million people (US Census Bureau 1960, 1970). Since then, the presence of air conditioning in single-family homes jumped from 49 per cent in 1973 to 87 per cent in 2009 (US EIA 2011). In hot and humid places such as southern Florida, its use grew from 5 per cent in 1950 to 95 per cent in 1990. American motorists also use 7–10 billion gallons of gas annually to air condition their cars. In aggregate, the USA on an annual basis now consumes more electricity for air conditioning than the entire continent of Africa consumes for all electricity uses (Cox 2012). Or, in other terms, the USA currently utilizes more energy (about 185 billion kWh) for air-conditioning than all other countries' air conditioning usage combined (Sivak 2013).

2.3.2 Fast Transitions in National Energy Supply Have Occurred

Proponents of this alternative view can also point to five other transitions that have occurred at the national level: to crude oil in Kuwait, natural gas in the Netherlands, nuclear electricity in France, combined heat and power (CHP) in Denmark, and coal retirements in Ontario, Canada.

Two concurrent modifications, in electricity and transport, catalysed an almost complete shift in Kuwait's national energy profile in about nine years. Oil use catapulted from constituting a negligible amount of total national energy supply in 1946 to 25 per cent in 1947, and more than 90 per cent in 1950 (Kuwait Ministry of Planning 1988). In 1938, when Kuwait was still a small, impoverished British protectorate, geologists discovered the Burgan oil field, which proved to be the world's second largest accumulation of oil following Saudi Arabia's Ghawar oil field. Commercial exploitation began in earnest (after a suspension of operations due to the Second World War) in 1946, increasing from 5.9 million barrels that year to 16.2 million barrels in 1947, and 398.5 million barrels in 1955, in tandem with the development of other oil fields (Al-Marafie 1989). Within five years, 1945–49, the Kuwaiti oil industry was transformed from one dependent on five gallon barrels being distributed manually to customers, carried on camels, donkeys, or wooden push carts to one characterized by huge volumes and scale economies that were dependent on motorized trucks and tankers, pipelines, and filling stations. Simultaneously, Kuwait began using oil for electricity generation. The Kuwait Oil Company obtained and commissioned its first 500 kW generator in 1951 and in 1952, built a 2.25 MW steam power station at Al-Shewaikh, essentially tripling national electricity capacity in three years. Demand for such electricity grew considerably, doubling again by 1960, and then increasing (in per capita terms) from 1473 kWh to 9255 kWh in 1985 (Al-Marafie 1988). Thereafter, a rapid expansion of distillation units, refineries, petrol stations, and the establishment of the Kuwait National Petroleum Company in 1960, the same year Kuwait helped form the Organization of Petroleum Exporting Countries, saw oil's rise continue so that in 1965, Kuwait became the world's fourth largest producer of oil (behind the USA, the Soviet Union, and Venezuela, and ahead of Saudi Arabia). As even energy transition sceptic Smil (2010b: 55) concedes, 'In energy terms Kuwait thus moved from a pre-modern society dependent on imports of wood, charcoal, and kerosene to an oil superpower in a single generation'.

The Netherlands—thanks in large part to the discovery of a giant Groningen natural gas field in 1959—started a rapid transition away from oil and coal to natural gas (Smil 2010b). That year, coal supplied about 55 per cent of Dutch primary energy supply followed by crude oil at 43 per cent and natural gas at less than 2 per cent. In December 1965, however, one year after gas deliveries began from Groningen, natural gas supplied 5 per cent of the Netherland's primary energy, rising quickly to 50 per cent by 1971, an ascent visually depicted in Figure 2.2. To facilitate the transition, the government decided in December 1965 to abandon all coal mining in the Limburg province within a decade, doing away with some 75,000 mining-related jobs impacting more than 200,000 people. What made the transition successful was

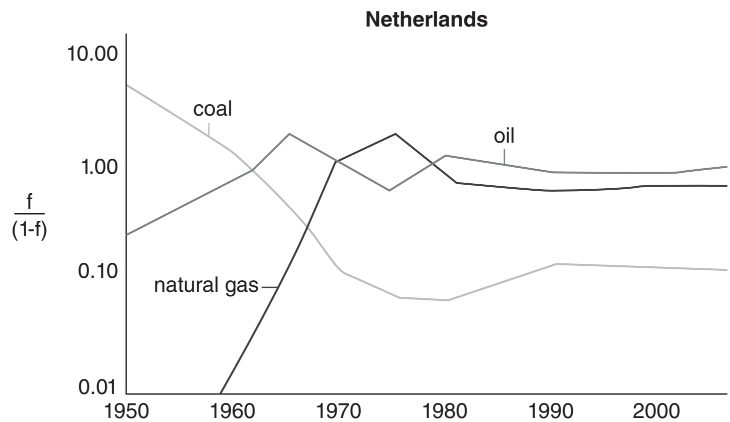

Figure 2.2. Coal, natural gas, and oil supply in the Netherlands, 1950–2010.
Source: Author's illustration based on Smil (2010a).

that the government strategically implemented countermeasures such as subsidies for new industries, the relocation of government industries from the capital to regions of the country hardest hit by the mine closures, retraining programmes for miners, and offering shares in Groningen to Staatsmijnen (the state mining company). After its peak output in the mid-1970s, extraction of gas at Groningen was purposely scaled back to maximize the lifetime of the field, though natural gas continued to play a prominent role in the nation's energy mix. In 2010, for instance, natural gas still provided 45 per cent of total primary energy supply, larger than any other source (EC 2010).

The French transition to nuclear power was also swift. Following the oil crisis in 1974, Prime Minister Pierre Messmer announced a large nuclear power programme intended to generate all of France's electricity from nuclear reactors to displace the Republic's heavy dependence on imported oil. As the maxim went at the time, 'No coal, no oil, no gas, no choice!' The 'Messmer Plan' proposed the construction of 80 nuclear power plants by 1985 and 170 plants by 2000. Work commenced on three plants—Tricastin, Gravelines, and Dampierre—immediately following the announcement of the plan and France ended up constructing 56 reactors in the period 1974–89. As a result, nuclear power grew from 4 per cent of national electricity supply in 1970 to 10 per cent in 1978 and almost 40 per cent by 1982 (Araujo 2013). As Grubler (2010: 5186) has noted, 'the reasons for this success lay in a unique institutional setting allowing centralized decision-making, regulatory stability, dedicated efforts for standardized reactor designs and a powerful nationalized utility, EDF, whose substantial in-house engineering resources enabled it to act as principal and agent of reactor construction simultaneously'.

Though Denmark is perhaps more famous for a transition to wind energy, a far more accelerated transition occurred in the 1970s and 1980s. This transition, also partially in the electricity sector, was away from oil-fired electricity to other fossil fuels and CHP plants. From 1955 to 1974, almost all heating in Denmark was provided by fuel oil, which meant the oil crisis had particularly painful impacts on the country's economy (Sovacool 2013). The Danish Energy Policy of 1976 therefore articulated the short-term goal of reducing oil dependence, and it stated the importance of building a 'diversified supply system' and meeting two-thirds of total heat consumption with 'collective heat supply' by 2002. Moreover, it sought to reduce oil dependence to 20 per cent, an ambitious goal that involved the conversion of 800,000 individual oil boilers from natural gas and coal. In a mere five years, 1976–81, Danish electricity production changed from 90 per cent oil-based to 95 per cent natural gas- and coal-based. Stipulations in favour of CHP were further strengthened by the 1979 Heat Supply Act, whose purpose was to 'promote the best national economic use of energy for heated buildings and supplying them with hot water and to reduce the country's dependence on mineral oil' (Sovacool 2013: 833). As a result, CHP production