Christian von Hirschhausen
Clemens Gerbaulet · Claudia Kemfert
Casimir Lorenz · Pao-Yu Oei *Editors*

Energiewende "Made in Germany"

Low Carbon Electricity Sector Reform in the European Context

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Abbreviations

AC	Alternating Current
ACER	Agency for the Cooperation of Energy Regulators
AEG	Allgemeine Elektricitäts-Gesellschaft
AFRR	Automatic Frequency Restoration Reserve
ATC	Available Transfer Capacity
AtG	Atomgesetz (Law on Nuclear Energy)
BAU	Business as usual
BBPlG	Bundesbedarfsplangesetz (Law on transmission development)
BEMIP	Baltic Energy Market Interconnection Plan
BEWAG	Berliner Elektrizitätswirtschafts-Aktiengesellschaft (Berlin Utility)
BIP	Bruttoinlandsprodukt (gross domestic product)
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
BMWI	Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
bn	Billion
BNetzA	Bundesnetzagentur (German Federal Network Agency)
BWR	Boiling Water Reactor
CA-CM	Capacity Allocation and Congestion Management
CCGT	Combined Cycle Gas Turbine
CCTS	Carbon Capture, Transport and Storage
CDM	Clean Development Mechanism
CDU	Christlich Demokratische Union Deutschlands (Christian Democratic Union)
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CoBAs	Coordinated Balancing Areas

CPF	Carbon Price Floor
CSU	Christlich-Soziale Union in Bayern (Christian Social Union of Bavaria)
CWE	Central West Europe
DC	Direct Current
dena	Deutsche Energie-Agentur (German Energy Agency)
DIW Berlin	Deutsches Institut für Wirtschaftsforschung (German Institute for Economic Research)
DVG	Deutsche Verbundgesellschaft (German Network Association)
EC	European Commission
ECSC	European Coal and Steel Community
EDF	Électricité de France
EEEP	Economics of Energy & Environmental Policy
EEG	Erneuerbare-Energie-Gesetz (Law on Renewable Energies)
EESS	European Energy Security Strategy
EEX	European Energy Exchange
EIB	European Investment Bank
EMF	Energy Modeling Forum
EN	European Norm
EnBW	Energie Baden-Württemberg
EnEv	Energieeinsparverordnung (Energy Efficiency Ordinance)
EnLAG	Energieleitungsausbaugesetz (Law on Developing Electricity Transmission Infrastructure)
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EOR	Enhanced Oil Recovery
EPS	Emissions Performance Standard
ErP	Energy-Related Products
ETS	Emission Trading System
EU	European Union
EU-ETS	European Emission Trading System
EUR	Euro
EURATOM	European Atomic Energy Community
EVS	Energie-Versorgung Schwaben (Energy Supply Schwaben)
FAZ	Frankfurter Allgemeine Zeitung
FBMC	Flow-Based Market Coupling
FDP	Freie Demokratische Partei (Free Democratic Party) Germany
FERC	Federal Energy Regulatory Commission
FIT	Feed-in tariff
FOSG	Friends of the Supergrid
FRG	Federal Republic of Germany
G7	Group of Seven
GBP	British Pound
GDP	Gross Domestic Product

GDR	German Democratic Republic
GGM	Global Gas Model
GHG	Greenhouse Gases
GW	Gigawatt
GWh	Gigawatt hour
GWB	Gesetz gegen Wettbewerbsbeschränkungen (Law against Restraints of Competition)
H_2	Hydrogen
HEW	Hamburgische Elektrizitäts-Werke (Utility of Hamburg)
Hg	Mercury
HVDC	High-Voltage Direct Current
IA	Impact Assessment
IAEA	International Atomic Energy Agency
IAEE	International Association for Energy Economics
IEA	International Energy Agency
IGCC	International Grid Control Cooperation
IPCC	Intergovernmental Panel on Climate Change
ISO	Independent System Operator
ITC	Inter-TSO Compensation Mechanism
JI	Joint Implementation
JRC	Joint Research Centre
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
KWU	Kraftwerks Union
LCOE	Levelized Cost of Electricity
LNG	Liquefied Natural Gas
MENA	Middle East and North Africa
mn	million
MSR	Market Stability Reserve
Mt	Megaton
MW	Megawatt
MWh	Megawatt hour
NABEG	Netzausbaubeschleunigungsgesetz (Transmission Network Development Acceleration Law)
NAPE	National Action Plan on Energy Efficiency
NC EB	Network Code on Electricity Balancing
NC LFCR	Network Code on Load-Frequency Control and Reserves
NEP	Netzentwicklungsplan (Network Development Plan)
NGO	Non-governmental Organization
NOVA	Netzoptimierung, -verstärkung und -ausbau (Network Optimization, Strengthening and Expansion)
NO_X	Nitrogen Oxide
NPP	Nuclear Power Plant

NPS	New Policies Scenario
NRA	National Regulatory Authority
NRW	Nordrhein-Westfalen (North Rhine-Westphalia)
NSCOGI	North Seas Countries Offshore Grid Initiative
NTC	Net Transfer Capacity
OCGT	Open Cycle Gas Turbine
P2G	Power-to-Gas
P2H	Power-to-Heat
PC	Primary Control Reserve
PCR	Price Coupling of Regions
PLEF	Pentalateral Energy Forum
PS	Horsepower
PSP	Pumped Storage Power Plant
PV	Photovoltaic
PWR	Pressurized Water Reactor
R&D	Research and Development
RBMK	Reaktor Bolshoy Moshchnosty Kanalny (Graphite-Moderated Boiling Water Reactor)
RES	Renewable Energy Sources
RSK	Reaktor-Sicherheitskommission (Commission on the Security of Nuclear Reactors)
RWE	Rheinisch-Westfälisches Elektrizitätswerk
SC	Secondary Control Reserve
SME	Small and Medium-Sized Enterprises
SO_2	Sulphur dioxide
SOAF	Scenario Outlook and Adequacy Forecast
SOC	Social Overhead Capital
SoS	Security of Supply
SPD	Sozialdemokratische Partei Deutschlands (German Social Democratic Party)
StandAG	Standortauswahlgesetz (Site Selection Act)
StrEG	Stromeinspeisegesetz (Law on Renewable Feed-in)
t	Metric Tonne (1000 kg)
TC	Tertiary Control Reserve
tce	Tons of Coal Equivalent
TFEU	Treaty on the Functioning of the European Union
TSO	Transmission System Operator
TWh	Terawatt hour
TYNDP	Ten-Year Network Development Plan
UK	United Kingdom
UKR	Ukraine
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USA	United States of America

USD	US-Dollar
VEB	Socialist combine ("enterprise owned by the people")
VEW	Vereinigte Elektrizitätswerke Westfalen (Utility of Westphalia)
VVER	Wodo-wodjanoi Energetitscheski Reaktor (Water-Water Energetic Reactor)
WACC	Weighted Average Cost of Capital
WIP	Workgroup for Infrastructure Policy
WW	World War
WWF	World Wide Fund for Nature

Chapter 1
Introduction

Christian von Hirschhausen, Clemens Gerbaulet, Claudia Kemfert, Casimir Lorenz, and Pao-Yu Oei

> *"The second path combines a prompt and serious commitment to efficient use of energy, rapid development of renewable energy sources matched in scale and in energy quality to end-use needs, and special transitional fossil-fuel technologies. This path, a whole greater than the sum of its parts, diverges radically from incremental past practices to pursue long-term goals."*
> *Amory B. Lovins (1976). Energy Strategy: The Road Not Taken? Foreign Affairs, 6(20), p. 9.*

1.1 Introduction

When Amory Lovins, Director of the Rocky Mountain Institute, set out the conditions for a "soft path" of decentral, renewables-based energy development, in 1976 (see quote), he could not foresee that four decades later, he would receive the highest recognition for public service, the German Federal Cross of Merit

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("Bundesverdienstkreuz"), for having spearheaded what is now called "energiewende". And in fact, between the publication of the book "Energiewende" in 1980 by a scholar of Lovins', Florentin Krause et al. (1980) to the ground-breaking events in 2010/2011, pushing the energiewende further, many things happened in energy and climate policy, in Germany, Europe, and the world, that may have not been forecast by Lovins, and that have altered energy and climate policy altogether.

Yet, under the impression of the Fukushima nuclear power plant disaster in March 2011, the German government, legal system, civil society, and energy industry again changed course in long-term energy and climate policy, confirming earlier attempts to embark on a "soft path". On a timeline extending to 2050, plans were made to set strict emission caps on greenhouse gas (GHG) emissions, to rapidly decommission all nuclear power plants (NPP), to significantly increase the share of renewables in energy production, and to implement ambitious efficiency targets. The long germination period, since the mid 1970s, leading to the re-orientation of energy and climate policy—at a time when the German electricity sector was still largely reliant on coal and nuclear power—is now commonly referred to as the "energiewende" (*Wende* meaning turn or turnaround, sometimes also called the "energy transformation", "energy transition", etc.) and has attracted substantial attention, both in Germany and internationally. Initially considered a short-lived epiphenomenon by many observers and openly opposed by the incumbent conventional energy industry, the energiewende proved its critics and skeptics wrong, at least partially. Overall, the reforms of the last decade can be considered a success, with some of the targets being accomplished, and it still continues today with widespread public support.

The energiewende (term we will use throughout this book) emerged at a time of increasing debates of global warming and climate change (Houghton et al. 1990; Stern 2007; WBGU 2011). Many countries in Europe and around the globe were considering how to move to lower carbon energy systems, and most of them still are. Thus, the European Union is still pursuing its decarbonization objectives of a 40% reduction of greenhouse gas (GHG) emissions by 2030 (reference: 1990), and a reduction of 80–95% in the longer term. The US, too, launched a program to reduce GHG emissions under the Federal Clean Air Act, even though the current administration has set out to stop this initiative; nonetheless, the US power sector is constantly retiring coal plants, and is moving towards a coal exit as well (Heal 2017). Even in Asia, the region with the highest energy consumption growth rates worldwide, countries such as China and India have identified the need for more environmentally sustainable energy strategies and reduced coal consumption (IEA 2016). The 2015 Paris Agreement of the UN Convention on Climate Change, to limit the rise of the mean global temperature to 2° and possibly even to 1.5°C has increased pressure on governments and industry to accelerate their low-carbon transformation policies. It comes as no surprise, therefore, that the energiewende is being followed with great interest by observers worldwide, both with high hopes for its potential positive impacts and with skepticism about its costs and financial sustainability.

The objective of this book is to present an in-depth look at the energiewende, from its origins to its concrete implementation in Germany, as well as its impacts within the European context and its medium- and long-term perspectives. Our working hypothesis, based on extensive modeling exercises, policy consulting, personal on-site case studies, and the growing literature, is that the energiewende is a unique political-historical period that will transform the structure of the German energy sector, leading to more decentralized energy production and decision-making and transforming the structure of the energy industry within Germany and beyond. So far, the energiewende has been a success overall, in particular because the foundation for a renewables-based electricity system has been laid. Yet other objectives had to be postponed, though, such as the GHG emission reduction target for 2020 (−40%, relative to 1990). While the lessons of the energiewende do not apply directly to all countries and regions worldwide, they offer insights from the natural experiment of transforming a large-scale, conventional electricity system based on coal and nuclear energy into a renewables-based system. Our analysis focuses on the electricity sector, but we also address other challenges in the transport and heating sectors, as well as the upcoming interconnectedness between the three, called "sector coupling".

The next section of this introductory chapter spells out the key characteristics of the energiewende, which later chapters will analyze in more detail. Section 1.3 looks at the German energiewende in the context of the energy and climate policy literature. Section 1.4 presents a detailed outline of the book, and the last - Section concludes with acknowledgements.

1.2 The Main Ingredients of the Energiewende

The German term "energiewende" is now commonly used throughout the world and is now penetrating the English language the same was as have other German words like kindergarten, bratwurst, wanderlust, or zeitgeist. In this book, we use the term "energiewende" to refer to a political and societal process in the realm of energy and climate policy, that was ongoing for quite some time already, but that accelerated in Germany between September 2010, the German energy concept 2050, and June 2011, moment of the nuclear phase-out law. In the framework of the energiewende, a series of decisions were made to pursue an energy and environmental policy that would shift the German energy sector away from reliance on fossil fuels and nuclear energy and make it more efficient, more decentralized, and more renewables-based. The concrete targets include (see individual chapters for details):

- Reducing greenhouse gas emissions, compared to 1990 levels, by 40% by 2020, 55% by 2030, 70% by 2040, and 80–95% by 2050;
- Closing all nuclear power stations: seven units were taken offline in March 2011 and the remaining nine plants are scheduled to close by 2022;

- Increasing the share of renewables for electricity generation to at least 38% in 2020, 50% in 2030, 67% in 2040, and 80% in 2050, and the share of renewables in final energy consumption to at least 30% by 2030 and at least 60% by 2050;
- Setting ambitious targets for energy efficiency.

These quantitative objectives were designed with the general intention to foster civil society participation in decision-making processes, in the production of energy, and in the distribution of profits and rents. Thus, the energiewende has also introduced a new energy policy paradigm in which a large share of decentralized, individually and cooperatively owned companies generate power alongside "big energy" companies; in 2015, over 67% of the new renewable electricity (wind and sun) was generated outside the traditional utilities, by cooperatives, private producers, etc. Although this objective is not set down in law, it forms the basis of the public consensus on the energiewende (Rosenkranz (2014), Morris and Jungjohann (2016), Davidson (2012)).

1.3 Current State of the Literature

There is a small, but rapidly growing literature on the energiewende. Members of our team have done extensive work on the energiewende, including a first survey by Kemfert (2014), a symposium volume published in the *Journal Economics of Energy & Environmental Policy* (EEEP, Vol. 3, No. 2, Fall 2014, some of which has been updated for the present book), a study on deep decarbonization in Germany (Kemfert et al. 2013), and a collection of papers published by the German Institute for Economic Research (DIW Berlin) in the quarterly *Vierteljahreshefte* ("Quarterly Journal of Economic Research," see Kemfert et al. (2013), in German). Similar research by other scientists include a book by Unnerstall (2017) providing an assessment of the current status of the transformation, with a focus on corporate perspectives. Grubb et al. (2014) textbook on "Planetary Economics" contains many of the discussions around the low-carbon energy transformation. Another book by Schippl et al. (2017) covers virtually all facets of the energy transition but is, however, restricted to German-speaking audiences. Other academic work is extensively cited in the following chapters in this book.

A second, more policy-oriented branch of the literature looks at concrete technical, legal, and institutional aspects of the energiewende, mainly at the level of individual sectors and/or projects. This applied literature stems from formal government entities, public bodies, stakeholder circles, think-tanks, etc. The German government issues the yearly Monitoring Report "Energy of the Future" (see BMWi 2015, 2016), which is accompanied by a detailed assessment from an advisory board to the Ministry of Economics and Energy (see BMWi and BMU

2012; BMWi 2015, 2016; Löschel et al. 2015; Löschel et al. 2014, 2018). Agora Energiewende, a think-tank financed by private foundations, has a 20-expert team dedicated to analyzing the results of technical studies for the use in policy and the public debate (see, for example, Agora's twelve theses on the energiewende and the big study on "Energiewende 2030—The Big Picture", respectively (Agora Energiewende 2013, 2018)).[1] The same foundations also have a series of publications for journalists and the interested public, "Clean Energy Wire", including detailed off-the-shelf material.[2] Another political foundation produces a series of publications on the energiewende in an international context.[3] Morris and Pehnt (2016) and Morris and Jungjohann (2016) and Fechner (2018, in German) provide a detailed account of this policy-oriented research.

A third branch of literature consists of comparative analyses situating the German experience in a broader cross-country context. Early, most influential work on "The Big Transformation" was carried out by the German Advisory Council on Global Change (WBGU 2011), with several updates later on. The 2° target, that has become a benchmark for global climate policy, also originated from this work (see for details Schellnhuber (2015)). The German Section of the World Energy Council (2014) conducted a comparison of six country-specific energy transformation processes (in addition to Germany: USA, Brazil, China, Saudi Arabia, and South Africa). The International Energy Agency (IEA) (2014) published the report "The Power of Transformation—Wind, Sun and the Economics of Flexible Power Systems" on the perspectives of wind- and solar-based electricity systems. The Intergovernmental Panel on Climate Change (IPCC) on renewables provides valuable information at a very detailed level (IPCC 2012), and the IPCC 5th Assessment Report (IPCC 2014) discusses a variety of low-carbon pathways. Another book by Hager and Stefes (2016) provides a comparison of Germany's energy transition with international peers such as the US and Japan. There is also ample literature on other countries undergoing a low-carbon energy transformation, such as Denmark (Danish government (2011)), the UK (DECC (2011), Foxon (2013)), France (Criqui and Hourcade 2015), the USA (Burtraw et al. (2014) and Heal (2017)), China (Li et al. 2018), and India (Bhushan 2017; Singh et al. 2018). Last but not least, the energiewende has even prompted business consultancies to develop specific indicators to put the German experience into international context, such as McKinsey's "Energy Transition Indicator".[4]

[1] See https://www.agora-energiewende.de/en/

[2] See: https://www.cleanenergywire.org/

[3] See: https://energytransition.org/

[4] See: http://reports.weforum.org/fostering-effective-energy-transition-2018/?code=wr123

1.4 Structure of the Book

1.4.1 Part I: Historic Origins: The Energiewende and the Transformation of the German Coal Sector

This book is divided into four parts. Part I (Chaps. 2 and 3) lays out the historical origins of the energiewende with respect to the energy, environmental, and climate policies that led up to it, as well as the specific transformation of the German coal sector. In Chap. 2, we identify some long-term trends of energy policy in Germany, going back to the turn of the last century; we also retrace subsequent developments such as the Energy Industry Act of 1935, discuss similarities and differences between energy policies in East and West Germany and their consolidation after reunification, and look at more recent European attempts to liberalize national energy sectors and create a single market. The chapter also covers important developments that occurred with the "wind of change" in the early 1990s: the emergence of a European climate policy, the first formal pushes towards renewables targets, and the drafting of unbundling directives for the electricity and the natural gas sectors. We identify elements of the energiewende as we go through time, since 1980, but focus on the developments between September 2010 and summer 2011, which is, from a historical perspective, a crucial period. It took nothing less than the March 2011 nuclear disaster in Fukushima, Japan, to establish the broad consensus on the acceleration of the energiewende, i.e. the shutdown of nuclear power plants, in combination with GHG emission reductions, and renewables targets. This includes the historic decision by Chancellor Angela Merkel to declare a moratorium on the lifetime extension on nuclear power only three days after Fukushima and the closure of the seven oldest reactors in Germany.[5]

Chapter 3 provides an historic account of the German coal industry over the last 70 years, a unique transformation process dominated by steady decline of an industry that previously employed more than 700,000 people. One focus of this historic case study therefore lies on the Ruhr area—Germany's largest hard coal mining area that was particularly hit by this economically driven transformation. Likewise, in East Germany significant efforts were undertaken, after the reunification, to smooth the transformation process, and to rescue the lignite industry from the assault from West German competitors. The analysis is divided into the quantitative consideration of the significance of coal for the energy system and the regional economies, as well as an evaluation of implemented political instruments accompanying the reductions in the coal sector. The political instruments on regional, national and supranational level can be differentiated between measures for the conservation of coal production, the economic reorientation in the regions as well as easing negative social impacts. The good news for the upcoming final phase

[5]In fact, a narrow interpretation of the term energiewende would limit the actual "turn" to the 72 h between the Fukushima accident (March 11, 2011), and the "Declaration of the energiewende," including the nuclear moratorium (March 14, 2011).

out of coal in Germany is that the largest part of the transformation process is already achieved. The analysis of past transformation processes of mining areas and energy systems in Germany might provide other countries and regions with valuable lessons of how to structure their upcoming coal phase-out period and therefore provides a useful addition to the existing literature.

1.4.2 Part II: The Energiewende Underway in the Electricity Sector

Part II leads us straight into the "engine room" of the energiewende, a process with very concrete, hands-on technical, institutional, and economic issues. In this part, we shed light on diverse facets of the energiewende based on our own research work, official data and publications, and a survey of the literature. We address the main issues at the heart of the energiewende, with a focus on the electricity sector: decarbonization, the closure of nuclear plants, the focus on renewables, efficiency targets, and infrastructure, and the emergence of coupling between the electricity, transport, and heat sectors.

Decarbonization of the electricity sector and the phase-out of coal is a key element of the energiewende addressed in Chap. 4; the objectives for GHG emission reductions set out in the energy concept were 40% in 2020, 55% in 2030, 70% in 2040, and 80–95% in 2050 (base year: 1990). However, between 1990 and 2017, this reduction was only 30%, and projections for 2020 hovered around a 33% reduction. Due to the collapse of the European Union CO_2-trading price, which had fallen from an average €20/t to around €5/t, there was even a slight increase of CO_2 emissions in 2013 and 2014. Thus, the German government decided to develop more focused national policy instruments to accompany European efforts and to curb national coal consumption. This resulted in the Climate Action Program 2020 and the subsequent longer-term Climate Plan 2050. The chapter discusses different instruments, their economic effects on the electricity market, and concludes that the decarbonization targets imply the phasing-out of coal in Germany in the 2030s.

Chapter 5 is dedicated to nuclear policies in Germany, a particularly controversial field. The chapter focusses on the period between the first phase-out decision, taken in 1998, and the second, final one, in June 2011. Immediately following the March 2011 Fukushima accident, a moratorium was decided on German nuclear power plants, seven of which were shut down immediately; until 2022, all others will follow. Looking back, the effects of the nuclear moratorium on the German and Central-West European electricity markets were small, because ample generation capacity was available to compensate for the loss of capacity. After the March 2011 moratorium, wholesale electricity prices increased slightly by €2–3/megawatt hours (MWh), whereas the German net export surplus declined slightly. Germany turned into a net exporter again in the subsequent year, 2012, when it showed record net exports of 54 terawatt hours (TWh). The chapter also looks forward to 2022, when the last remaining reactors will close, and examines German nuclear policy in a European context as well. While the closure of the nuclear power plants is irreversible from a political perspective, policies to structure and facilitate the process are still needed, in particular with respect to the decommissioning of the plants and the final storage of radioactive waste. Chapter 5 thus also provides an analysis of the post-closure challenges, the uncertainties surrounding this process, and the financial stakes and the expected timelines, which extend over centuries of dealing with the legacies of nuclear power.

Chapter 6 looks in more depth at another focus of the energiewende: renewables targets. As we observe, the targets defined in 2010/2011 have now been translated into concrete policy measures. For example, the "scenario framework"—the planning document that the energy network regulator has to produce every year as a framework for network development—covers renewables targets for a 20-year time period, during which other fuels such as hard coal and lignite will be reduced. In 2017, the share of renewables in electricity production was 37%, with no signs of instability of the system. Given the strong institutional framework, there seems to be no obstacle to reaching the 2030 target of beyond 50%. The chapter also describes the evolution of support schemes for renewables in Germany and the effects of investment strategies in conventional and renewable capacity, as well as the costs associated with this policy.

Energy efficiency is a crucial element of any low-carbon transformation process, as the most cost-effective kilowatt hour (kWh) is an hour that is not used at all ("saved"). Traditionally energy efficiency policies have had a difficult time gaining support from both policy makers and the general public, and the "energy efficiency gap"—the difference between observed consumption and a hypothetical reference case—has been a topic of debate for some time. It comes as no surprise, therefore, that energy efficiency policies are among the most challenging elements of the energiewende. Chapter 7 focuses on energy efficiency, and reports that although some successes have been observed in the reduction of primary and gross electricity consumption, energy productivity improvements still lag behind the targets. A significant gap remains with respect to the 2020 primary energy consumption target (−20%), and further energy productivity increases are necessary to stay on track. The chapter also describes specific approaches to energy efficiency in the construction, industry, and transport sectors, and provides concrete recommendations for how to move this difficult reform process forward.

Chapter 8 focusses on the role of electricity transmission infrastructure in the energiewende. The chapter analyzes approaches to and developments in the electricity network infrastructure, and asks if the glass is half full or half empty. In fact, skeptics of the energiewende see transmission bottlenecks everywhere, whereas optimists insist on the steady progress of the modernization and extension of the high voltage grid in Germany. Our analysis tends to see the glass half full: Although some expansion projects are behind schedule, grid reconstruction is advancing steadily, thanks to the considerable progress made in recent years on several essential lines connecting the states of the former East and West Germany. Congestion management measures, in particular redispatch, have been necessary, but have caused no major problems to the system. We even observe that the current methodology for the long-run grid expansion planning tends to overestimate expansion needs because it assumes a “copper plate” when siting generation. The chapter concludes that while electricity transmission is an important element of any reform process, the debates around network expansion have exaggerated the potential pitfalls, and the focus should be on sustainable electricity generation.

Chapter 9 extends the analysis of electricity sector reform to other important sectors of the energiewende. The first stage of the energy transformation was characterized by the nuclear phase-out and the parallel endeavor to decarbonize the German electricity sector. Yet, in order to reach the climate goal of a 40% reduction in greenhouse gases by 2020, with an additional 80 to 95% reduction in the coming decades until 2050, the second stage needs to focus on all energy usage, especially heat, transportation, and usage as a raw material in the chemical industry. Enhancing energy efficiency, reducing primary energy usage until 2050, and the increased use of renewable power from wind and photovoltaics is the predominant strategy to further decrease greenhouse gas emissions in all energy sectors. However, this strategy requires an increased coupling of energy sectors and is the corner stone for an integrated approach, activating additional degrees of freedom in the energy system facilitating the further integration of renewable energy sources. The chapter sketches out the technical-economic foundations of sector coupling, and then compares different analyses for Germany. While these differ in the level of detail, they all consider ambitious climate targets to be feasible, provided that appropriate institutions and incentives be put in place. Consequently, the distinct energy sectors coalesce and have to be assessed in an integrated way.

1.4.3 Part III: The German Energiewende in the Context of the European Low-Carbon Transformation

The German energiewende is not a national phenomenon: it is taking place within an increasingly integrated European market and in the context of close relationships to Germany’s “electrical neighbors”. The very nature of the interconnected European electricity system means that the reform process in Germany has effects on the broader European market, including price effects, cross-border flows, and the sharing of backup capacity. In return, the German electricity sector is affected by developments in its neighboring countries, be they EU members or not. Part III of the book therefore addresses important questions concerning the interdependence between the German energiewende and the European low-carbon transformation reform process at large.

Chapter 10 analyzes the electricity mix in the European low-carbon transformation and highlights similarities to and differences from the German energiewende. The European Union, too, has set ambitious decarbonization targets (−40% GHG emissions by 2030, −80 to 95% by 2050), but the EU’s current roadmap to attaining them is different from that of the German energiewende, since it still includes high shares of fossil fuels (with carbon capture) and nuclear energy. The chapter first reviews the broad trends in European energy and climate policy since the 1950s, explaining that the European electricity mix was based on coal and nuclear from the beginning, through the 1951 Treaty of the European Coal and Steel Community (ECSC) as well as the 1957 EURATOM Treaty. The chapter then takes a closer look at the 2030 and 2050 targets, at instruments such as the European Emission Trading System (ETS), and at the fuels that will be used to attain these targets: conventional fossil fuels, nuclear, and renewables. In particular, we ask whether the Energy Roadmap 2050, the analytical basis of the strategy, properly reflects recent technological developments in Europe and elsewhere. For instance, the continued use of coal electrification was based on the assumption that a clean and economic technology known as Carbon Capture, Transport, and Storage (CCTS) would be available soon, and despite considerable research and development (R&D) and demonstration attempts, these projects have not brought about significant progress so far. Nuclear power has high and rising private costs and by far the highest social costs of all energy sources, due not only to high capital costs and unknown costs of long-term storage of nuclear waste, but also to the risks of accidents, which no market has been able to insure. Two of the post-World War II nuclear countries, the UK and France, have expressed serious intentions to build new nuclear power plants, which we explain by the synergy effects they expect to reap from the civil and military use of nuclear power. Renewable energy sources offer not only the cleanest but potentially also the most economical alternative for many Member States, a development that has not been given adequate consideration in the European scenario process to date.

Chapter 11 analyzes the importance of infrastructure for the European low-carbon energy transformation. In this area, “easy” solutions surface frequently in the scientific and policy communities, but implementation on the ground has proven to be much more difficult. Thus, during the first years of the energiewende, a large number of pan-European “supergrid” projects were proposed, including electricity highways stretching from Saudi Arabia to Iceland, and from Morocco to the Arctic Circle. However, none of these mega-projects has materialized, and more realistic, more focused, and less complex solutions need to be found and developed. Using our own modelling results, as well as a large model comparison in the framework of the international Energy Modeling Forum No. 28 (“The Effects of Technology Choices on EU Climate Policy”) subgroup on infrastructure, we discuss alternatives to the pan-European infrastructure development plans in three critical sectors: electricity transmission, natural gas, and CO_2-pipeline infrastructure. It turns out that the finding for the German electricity network infrastructure (Chap. 8) can, to a certain extent, be transposed to the European level: energy infrastructure can help the low-carbon transformation, but is not really a critical factor thus far.

Chapter 12 discusses how the German electricity sector and energiewende fits into the regional and European context. The chapter also draws some general conclusions on the role of cross-border and other cooperation in the German energiewende and the European low-carbon transformation. Very different forms of cooperation can be observed, ranging from bilateral mechanisms (e.g., Austrian