CHAPTER 1

Introduction

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Abstract

The ongoing energy transition is driven by a need to mitigate climate change and switch from fossil to low-carbon fuels and renewable energy. However, while technologies such as onshore and offshore wind energy, solar energy, and batteries have made significant progress over the past decades, and they can increasingly compete directly with fossil fuels, their deployment is still only a fraction of what is needed to fully decarbonize our economy—a process that is going to take at least several more decades and is going to require major investments. Also, the intermittent character of especially wind and solar energy will require major changes in, for example, storage of energy (both heat and electricity). How this transition will play out, and which technologies will ultimately become winners and losers are highly relevant questions which this book will help to answer by providing both the individual market deployment and cost reduction trends per technology and the results of modeling a portfolio of energy technologies in various sector models and overall energy models.

Chapter outline

1.1 Introduction

1.1.1 Background and rationale

It is clear that the further development of various energy technologies is crucial to reduce the emission of greenhouse gases (GHGs), achieve other environmental targets, limit growing global energy demand, and ultimately enable the transition to a low-carbon society—preferably at low costs. These aims can only be achieved when a large number of technologies to supply renewable energy and to save energy become commercially available and thus are at the core of most energy and climate policies worldwide. Important scenario analyses of the world's future energy system and climate change mitigation

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scenarios illustrate that technological progress is key to minimizing costs of such development pathways. Given the need for drastic decarbonization, and related substantial investment needs, the political and public debate about the societal costs of this transition is increasing, making it even more important to point out possible cost reductions of novel energy technologies and ultimately the benefits of a low-carbon energy system. Furthermore, the speed of development is essential in order to meet required reductions and supply contributions on time. Many scenarios also highlight the positive economic and security impacts of strong support for research, development, demonstration and deployment of such technologies. Lastly, developing and deploying such energy technologies is seen as a major opportunity for development, (sustainable) industrial activity, and (high-quality) employment. Many (national) policies support both research and development (R&D) and market deployment of promising new energy technologies.

The latter, in particular, will require substantial investment. However, designing such policies effectively (e.g., timing and amount of incentives) has proved to be a challenge. The energy sector and manufacturing industry need strategic planning of their R&D portfolio and have to identify key market niches for new technologies (with or without policy support). Taken together, this situation makes an improved understanding of technological learning pivotal. Currently, most strategies and policies are only based to a limited extent on a rational and detailed understanding of learning mechanisms and technology development pathways. The conditions that provide efficient development routes are subject to much research, for example, in the innovation sciences. However, in addition to what may provide the optimal conditions and settings to achieve technological progress and rapid market deployment, it is clear that a detailed understanding of specific technologies, their performance, and factors influencing their performance are essential in order to design and implement effective policies and strategies. Historically, technological learning has resulted in the improvement of many technologies available to mankind, subsequent efficiency improvements and reduction of production costs, and has been an engine of economic development as a whole. Many of the conventional technologies in use today have already been continually improved over several decades, sometimes even over a century (e.g., most bulk chemical processes, cars, ships, and airplanes). Specifically for the electricity sector, coal-fired power plants have been built (and improved) for nearly a century now, while nuclear plants and gas-fired power plants have been built and developed since the 1960s and 1970s on a large commercial scale. Note that these well-established technologies are also still continuously improved, though this mainly leads to incremental improvements and concomitant cost reductions. Due to this long-term development, the established fossil fuel technologies have relatively low production costs. However, they also have a number of negative externalities, especially the emission of GHGs.

In contrast, many renewable/clean fossil fuel—energy technologies and energy-saving technologies used to have higher production costs, but lower fuel demands and GHG emissions. A few examples are electricity from biomass, offshore wind, and photovoltaics

(PVs), and energy-efficient lighting and space-heating technologies. For many of these new technologies the potential for further technological development and resulting production cost reductions is deemed substantial, and relatively high-speed cost reduction occurs compared to the conventional technologies. In the past 10 years, the gap between conventional and new technologies has been (largely) closed, and in some cases breakeven points have been reached. Electricity from onshore and offshore wind parks and large amounts of PV systems already today push out fossil generation units in Germany, as these technologies have no fuel costs. Crucial questions are, however, what will happen when intermittent electricity technologies will gain an even larger market share, making backup capacity and various forms of electricity storage (and associated additional investments) a necessity. Also, many renewable heating and transport technologies cannot yet compete with their fossil counterparts, so for these technologies, further technological progress is essential.

Thus the past and future development in time of production costs of (renewable) energy technologies (and the linked cost of CO_2 equivalent emission reduction) are of great interest, as the information allows policy makers to develop strategies for cost-effective implementation of these new technologies.

One approach to analyzing the reduction in production costs employs the so-called experience curve. It has been empirically observed for many different technologies that production costs tend to decline by a fixed percentage with every doubling of the cumulative production. As a rule of thumb, this cost reduction lies between 10% and 30%. To date, the experience curve concept has been applied to (renewable) energy technologies with a varying degree of detail.

The importance of progress in technological development of energy technologies is evident. Many (national) policies support R&D and provide the usually costly incentives for market deployment of targeted energy technologies. However, timing of incentives, the specific design of policy measures, and the amount of support that may be effective for success are very hard to determine. The resulting situation makes an improved understanding of technological learning extremely important. The relevance is clear from the urgency to achieve significant changes in the energy system (both in efficiency and in supply) at a rapid pace, to minimize costs and at the same time achieve competitive performance as soon as possible.

In recent years, much more insight has been gained into how learning regarding energy technologies has been acquired and also how their vital, further improvement can continue in the future. Many of these insights are derived from studies that have employed the experience curve approach. In 2009, Junginger, van Sark, and Faaij compiled a first comprehensive overview of experience curves for various energy technologies (both fossil and renewable). Since then, however, the energy transition has further progressed, and technologies have for the first time been commercially deployed on a significant scale (e.g., LED lamps and electric vehicles), which further matured (e.g., offshore wind and heat pumps) or regained new interest (such as green hydrogen production). In this book, less emphasis than previously has been put on the incumbent fossil energy technologies, and the focus has been put on these new technologies, which are likely to play an important role in the coming decades.

Also, the future energy system is challenged by the intermittent nature of renewables and requires therefore several flexibility options. Still, the interaction between different options, the optimal portfolio, and the impact on environment and society are unknown. It was the core objective of the H2020 REFLEX project to analyze and evaluate the development toward a low-carbon energy system with focus on flexibility options in the EU. The analysis was based on a modeling environment that considered the full extent to which current and future energy technologies and policies interfere and how they affect the environment and society while considering technological learning of low-carbon and flexibility technologies. By assessing the competitiveness of technologies and their interrelation, the cost-effectiveness of the whole system for future years as well as the systemic context demands for a well-founded energy system analysis including an appraisal of technological learning. Within REFLEX, this challenge was addressed by the integration of experience in an integrated energy models system. The main findings and lessons of integrating experience curves in the various sector models are of importance for modelers, but also policy makers and industry.

The renewed need for comprehensive overview of the technological learning progress of various technologies needed for the energy transition and the increasing interlinkage of the electricity, heat and transport sectors and the need to jointly model are the rationales for this book.

1.1.2 Objectives and structure

This book aims to provide an overview of the technological development and cost reductions achieved by the major energy technologies that are expected to be deployed as part of the ongoing energy transition. At the same time, it shows how future cost reductions and subsequent deployment of these technologies may shape the future mix of the electricity, heat and transport sectors. The central concept in this book is the experience curve, which quantifies the (past) cost reductions that occur together with the cumulative deployment of a technology.

The book first explains the concept in detail, including possible pitfalls and a new pedigree approach of mapping the quality of experience curves, discusses how this tool is currently implemented in models (and associated methodological challenges and solutions), and explores new applications of the concept, such as the ex ante assessment of environmental impacts of energy technologies (e.g., reduction of energy use of associated GHG emissions with increasing deployment). In a second part, nine chapters will focus on specific technologies that are relevant for the energy transition (e.g., PV and concentrated solar power, onshore and offshore wind, batteries and electric vehicles, heat pumps, power-to-hydrogen technologies, and space-heating technologies). For each technology the current market trends, past cost reductions and underlying drivers, available experience curves, and future prospects are treated in detail. In the third part of the book the results of various electricity supply, energy demand, and transport sector models play a key role. They also show how the future deployment of these technologies (and their associated costs) will determine whether ambitious decarbonization climate targets can be reached (and at what costs). The final chapter focuses on general lessons and recommendations for policy makers, industry, and academics, focusing on among others what technologies may require further policy support on the short term to have a major impact later on, which investments will be needed, and what scientific knowledge gaps remain for future research.