1. Introduction

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1.1 BACKGROUND RATIONALE

It is evident that the technological development of energy technologies is crucial to limit growing global energy demand, reduce the emission of greenhouse gases (GHG) and achieve other environmental targets, 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 scenarios illustrate that technological progress is key to minimizing costs of such development pathways. Furthermore, the speed of development is essential in order to meet required reductions and supply contributions on time. For example, in their World Energy Outlook (IEA, 2009) the International Energy Agency (IEA) predicts significantly higher fossil fuel energy prices for 2030 if penetration of renewable energy and energy efficiency technologies is limited, compared to a situation in which their development and deployment is pursued with more vigour. Furthermore, many scenarios highlight the positive economic and security impacts of strong support for research, development, demonstration and deployment (RDD&D) 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, can require substantial investment. However, designing such policies effectively (for example, 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

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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 (for example most bulk chemical processes, cars, ships and airplanes, and so on). 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 continually 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 greenhouse gases.

In contrast, many renewable/clean fossil fuel energy technologies and energy-saving technologies still have higher production costs, but lower fuel demands and GHG emissions. A few examples are electricity from biomass, wind and photovoltaics (PV), 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. It is thus anticipated that in many cases the gap between conventional and new technologies can in principle be closed, that is a break-even point could be reached. Crucial questions are, however, whether this point will be reached, and when and under what circumstances (especially how this depends on policy support). This situation varies for each individual technology, and has been the subject of much debate. 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 analysing 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 per cent. 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. However, an aggregated overview of lessons learned about technological learning in the energy sector and how such findings may lead to improved policies is so far not really available. This provides the rationale for this book.

1.2 OBJECTIVES

This book builds, to a large extent, on existing literature, and reviews it critically. In the past, studies investigating a specific technology such as the Photex (Schaeffer et al., 2004) or Extool reports (Neij et al., 2003) have been used extensively. However, this book aims to be more comprehensive (for example to include demand-side technologies), and intends (also building on the lessons drawn by Wene (IEA, 2000) and Neij et al. (2006)) to further identify methodological bottlenecks and compare and synthesize lessons on the use of the experience curve for policy support.

This book therefore aims to provide:

- A comprehensive and up-to-date review of studies on techno-logical development and cost reductions using the experience curve approach for a large range of energy technologies, including renewable energy technologies, (clean) fossil fuel technologies and energy efficient technologies;
- An overview and thorough analysis and discussion of the pitfalls of applying the experience curve approach including aspects such as geographical system boundaries, whether the slope of the experience curves is constant or not, statistical error and sensitivity analysis of experience curves, and whether the experience curve approach can be utilized to quantify improvements in energy efficiency;
- A clear set of recommendations for academia, policy makers and industry actors on how the experience curve approach can be used.

1.3 STRUCTURE OF THIS BOOK

This book is structured in three parts: Part I consists of Chapters 2 to 5. In Chapter 2, a general introduction and history of the experience curve concept is given, followed by a simple formal description of the experience curve formula and a brief description of applications of the experience curve for energy technologies and its use for policy makers. Next, in Chapter 3, typical caveats and methodological issues of applying the experience curve approach are described. To put the experience curve in context, Chapter 4 highlights some issues of the experience curve approach from an innovation studies perspective; it examines how theories of learning mechanisms and innovation systems can contribute to a better understanding of technological learning (and associated cost reductions). It also discusses whether and how these concepts could be used to complement the experience curve approach. Finally, Chapter 5 presents an analysis of how the experience curve approach is used in various energy and climate models, what the main advantages and drawbacks of this endogenous method are, and what policy makers should be aware of when interpreting results from these models.

The second part of this book consists of Chapters 6 to 18, in which numerous case studies for energy technology are presented, including renewable, fossil and nuclear energy supply technologies, several energy demand technologies (such as household appliances), and technologies that have a high energy consumption (such as the production of fertilizer or polymers). Each of these chapters provides a general description of the technology (including economics and policy support), followed by an overview of the (main) literature studies that have described experience

curves for the technology under scrutiny. These studies are then discussed, as are possible reasons for the cost reductions observed. Each chapter also attempts to provide an outlook towards possible future cost reductions, and discusses relevant lessons for policy makers and industry.

The third part of this book is a synthesis of Parts I and II: in Chapter 19, an overview and comparison is provided of most technologies analysed in Part II. Chapter 20 distils common methodological issues and points of attention for scientists from Parts I and II, while Chapter 21 first briefly recapitulates the main lessons for policy and industry from the individual technology chapters, and then gives an overview of topics that have been found for several technologies. It finishes by providing recommendations about how policy makers and industry actors may better utilize the results of experience curve analyses, and gives a framework for actions required by both groups in order to enable the improved and enhanced set-up and use of the experience curve approach in the future for existing and novel technologies.