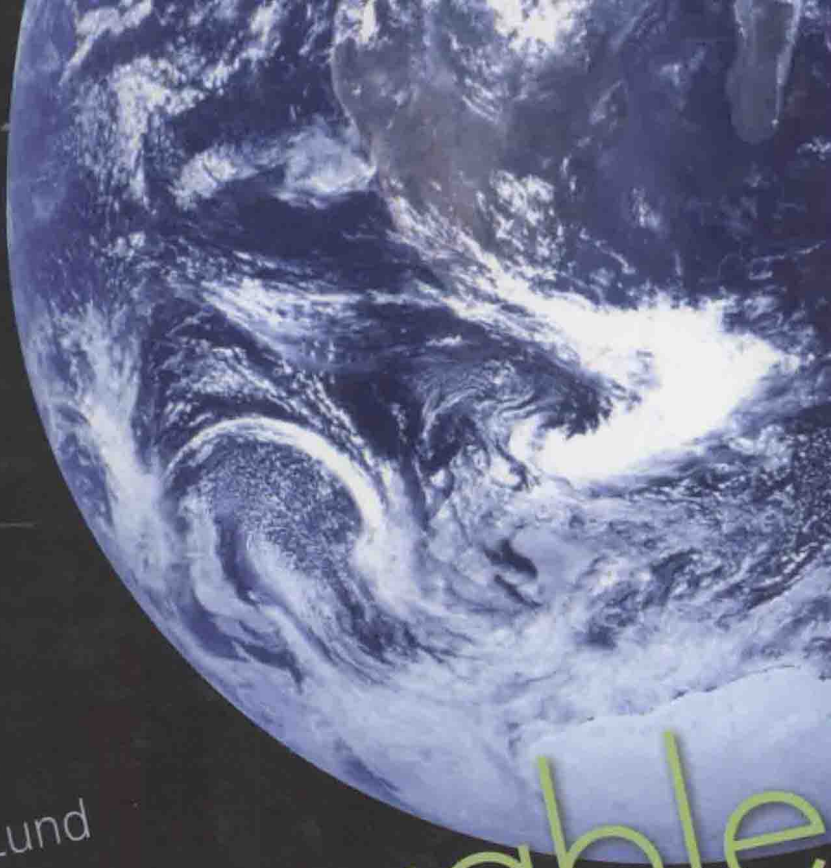

Henrik Lund

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The Choice and Modeling of 100% Renewable Solutions

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Contents

8. Conclusions and Recommendations

Chapter 1

Introduction

How can society convert to 100 percent renewable energy? The answer to that question is the main topic of this book. Two important aspects must be considered. First, from a technical point of view, which technologies can we use to make sure that the resources available meet the demands? To answer this question, this book presents an energy system analysis methodology and a tool for the design of renewable energy systems. This part includes the results of more than ten comprehensive energy system analysis studies. The large-scale integration of renewable energy into the present system has been analyzed, as well as the implementation of 100 percent renewable energy systems.

Second, in terms of politics and social science, how can society implement such a technological change? To answer that question, this book introduces a theoretical framework approach, which aims at understanding how major technological changes, such as renewable energy, can be implemented at both the national and international levels. This second aspect involves the formulation of the Choice Awareness theory, as well as the analysis of 11 major empirical cases from Denmark and other countries.

With regard to the implementation of the change from fossil fuels to renewable energy, Denmark is an interesting case. Like many other Western countries, Denmark was totally dependent on the import of oil at the time of the first oil crisis in 1973. Almost all transport and residential heating was based on oil. Furthermore, 85 percent of the electricity supplied in Denmark was produced from oil. Altogether, prior to the oil crisis, more than 90 percent of the primary energy supply was based on oil.

Denmark, like many other countries, was unprepared for the sudden rise in oil prices. Danish energy planning had been based on the principle of supplying whatever was demanded. Power stations were planned and built on a prognosis based on the historical development of needs. Denmark had no minister of energy and no energy department, no action plans in the case of being cut off from oil supplies, and no long-term strategy for the future in case oil resources were depleted.

Nevertheless, more than 30 years later, Danish society has proved its ability to implement rather remarkable changes. Figure 1.1 shows the development of the primary energy supply of Denmark since 1972 and illustrates two important factors: Half of the oil consumption has been replaced by other

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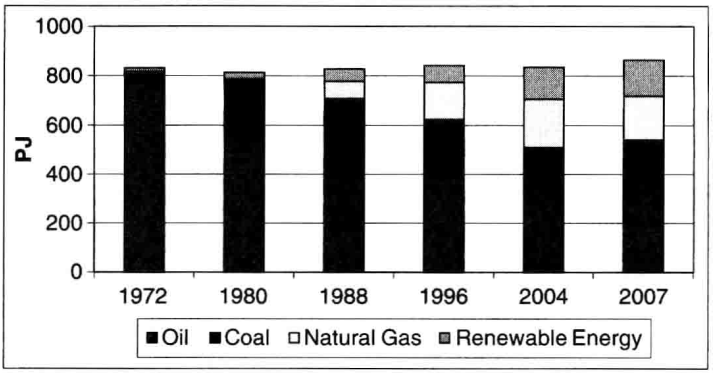

FIGURE 1.1 Danish primary energy supply.

fuels—for example, coal, natural gas, and, to some extent, renewable energy—and Denmark has managed to stabilize the primary energy supply at the same level as in 1972. This stabilization is unique compared to other countries, as it has been achieved simultaneously with a "normal western European" economic growth.

The primary means have been energy conservation and efficiency improvements in supply. Buildings have been insulated, and CHP (combined heat and power) production has been expanded. Thus, 30 years later, the primary energy supply for heating has been reduced to two-thirds of what was used prior to 1973, even though the heated space area has increased by more than 50 percent in the same period. The renewable energy share of the primary energy supply has increased from around zero in 1972 to 16 percent in 2007, and wind power production has become equal to a 20 percent share of the electricity demand. Moreover, Denmark has started to produce oil and natural gas from the North Sea and has, since 1997, been more than self-supplied with energy. However, the Danish oil and gas resources are scarce and are likely to last for only a few decades. An interesting question is, therefore, can Denmark convert to 100 percent renewable energy within a few decades, or will it have to return once again to the former dependence on imported fossil fuels? Such question is indeed relevant not only to Denmark but to Europe in general as well as the United States, China, and many other nations around the world.

The idea of this book is to unify the results and deduce the learning of a number of separate studies and thereby contribute to a coherent understanding of how society can implement renewable energy systems. The book is based on 25 years of involvement in a number of important and representative political decision-making processes in Denmark and other countries. As we shall see, these processes reveal the lack of ability of organizations and institutions linked to existing technologies to produce and promote proposals and alternatives based on radical changes in technology.

On the other hand, the stabilization of the primary energy supply shown in Figure 1.1 proves that the ability to act as a society has been possible, despite conflicts with representatives of the old technologies. In Denmark, during this period, official energy objectives and plans have been developed due to a constant interaction between Parliament and public participation. In this interaction, the description of new technologies and alternative energy plans has played an important role.

The theory of Choice Awareness seeks to understand and explain why the best alternatives are not described and developed per se and what can be done about it. Choice Awareness theory argues that public participation, and thus the awareness of choices, has been an important factor in successful decision-making processes and puts forward four strategies to help along such processes.

1. BOOK CONTENTS AND STRUCTURE

Figure 1.2 shows the structure of this book. The Choice Awareness section (the gray area) includes a theoretical understanding and a framework for the development of renewable energy system analysis tools and methodologies (the white area). This chapter introduces both aspects and provides some important definitions.

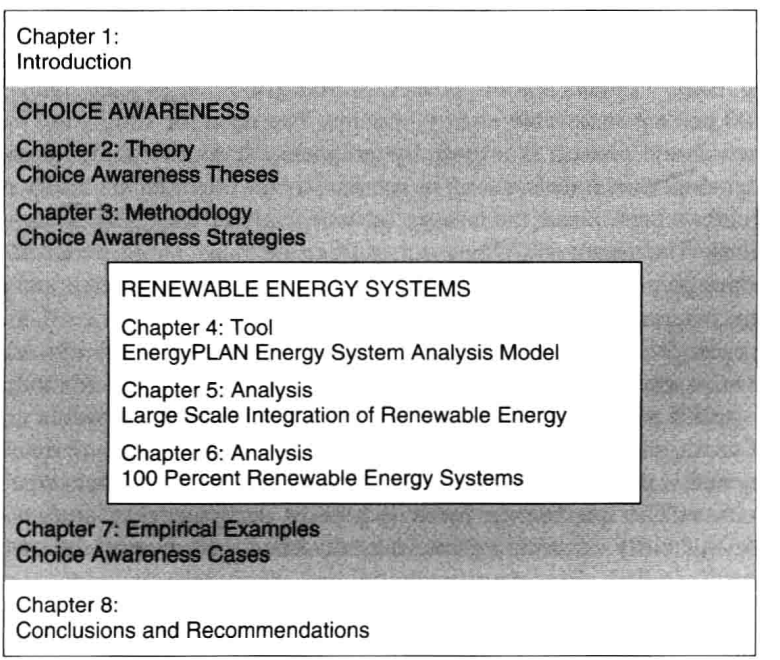

FIGURE 1.2 Contents and overall structure of the book.

Chapter 2 introduces the Choice Awareness theory, which deals with how to implement radical technological changes such as renewable energy systems. This theory argues that the perception of reality and the interests of existing organizations will influence the societal perception of choices. Often these organizations seek to hinder radical institutional changes by which they expect to lose power and influence. Choice Awareness theory states that one key factor in this manifestation is the societal perception of having either a *choice* or *no choice*.

The Choice Awareness theory presents two theses: The first states that when society defines and wishes to implement objectives implying radical technological change, existing organizations will often seek to create the perception that the radical change in technologies is not an option and that society has *no choice* but to implement a solution involving the technologies that will save and constitute existing positions. The second thesis argues that, in such situation, society will benefit from focusing on Choice Awareness—that is, raising the awareness that alternatives *do* exist and that it is possible to make a choice. Four key strategies are identified which society will benefit from following when seeking to raise Choice Awareness.

Chapter 3 elaborates on the Choice Awareness strategies related to the second thesis: the design of concrete technical alternatives, feasibility studies based on institutional economic thinking, the design of public regulation measures, and the promotion of a democratic infrastructure based on new corporative regulation.

Chapter 4 describes the method of designing concrete technical alternatives based on renewable energy technologies. This method distinguishes among three implementation phases: introduction, large-scale integration, and 100 percent renewable energy systems. The need for simulation tools in the two latter phases is especially emphasized. Both methodology and tool development are discussed in relation to the theoretical framework of Choice Awareness, and the energy system analysis tool, EnergyPLAN, is described. The EnergyPLAN model is freeware that can be accessed from the home page, *www.EnergyPLAN.eu*, together with documentation and a training program.

Chapter 5 refers to and deduces the essence of a wide range of studies of the Danish energy system. In these studies, the EnergyPLAN model has been applied to the analysis of large-scale integration of renewable energy. The Danish energy system is characterized by a high share of renewable energy and is therefore a suitable case for the analysis of further large-scale integration. The question in focus is how to design energy systems with a high capability of utilizing intermittent renewable energy sources. The chapter describes important methodology developments and compares the capability of different systems, including how they treat the fact that the fluctuations and intermittence of, for example, wind power differ from one year to another.

Chapter 6 presents recent results achieved by applying the EnergyPLAN tool to the design of 100 percent renewable energy systems. The question in focus is how to compose and evaluate such systems. The chapter treats the principal changes in the methods of analysis and evaluation applied to such systems compared to systems based on fossil fuels with or without large-scale integration of renewable energy.

Chapter 7 returns to the discussion of the theoretical framework. The chapter refers to a number of cases applying Choice Awareness strategies to specific decision-making processes of energy investments in the period since 1983. Typically, researchers have been involved in these processes by designing and introducing concrete technical alternatives and/or applying other Choice Awareness strategies to the situation. The cases refer to a large number of publications and documentation. Chapter 7 seeks to deduce what can be learned from the cases with regard to the Choice Awareness theses and strategies formulated in Chapters 2 and 3.

Chapter 8 returns to the concerted discussions of the two aspects: Choice Awareness and renewable energy systems. The chapter presents reflections and conclusions drawn from this study in terms of the implementation of renewable energy systems at the societal level.

2. DEFINITIONS

Both the issue of Choice Awareness and the case of renewable energy systems involve some basic definitions, which are provided in the following.

Choice Awareness

The theory of Choice Awareness addresses the societal level. It concerns collective decision making in a process involving many individuals and organizations representing different interests and discourses, as well as different levels of power to influence the decision-making process. The term *choice* obviously plays an important role in the definition of Choice Awareness. The *Oxford English Dictionary* (2008) defines *choice* as "the act of choosing; preferential determination between things proposed; selection, election." Choice involves the act of thinking and the process of judging the pros and cons of multiple options and selecting one of the options for action. This book distinguishes between a *true* choice and a *false* choice.

A *true* choice is a choice between two or more real options, while a *false* choice refers to a situation in which the choice is some sort of illusion. Some examples of false choices are a Catch-22 and a Hobson's Choice—in other words, a free choice in which actually only one option is offered. These two types of false choices will be explained further in Chapter 2. More examples of false choices are blackmail and extortion, both involving the condition to either do what you are told or suffer unpleasant consequences.

The *Oxford English Dictionary* (2008) defines *awareness* as "the quality or state of being aware; consciousness." In biological psychology, awareness comprises a person's perception and cognitive reaction to a condition or event. In principle, awareness does not necessarily imply understanding, just an ability to be conscious of, feel, or perceive. However, here the term is combined with *choice*, which implies the acts of thinking and judging. Thus, *Choice Awareness* does involve an element of understanding. Choice Awareness is therefore used here to describe the *collective perception* of having a *true choice*. Moreover, this situation involves a cognitive reaction in terms of judging the merits of relevant options and selecting one of them for action.

Collective perception is defined as a general perception in society. It does not include a few individuals who know better or different; the fact that a single person comes up with new ideas or invents new alternatives does not change the collective perception, as long as the person keeps these ideas to him- or herself. Only if individuals raise awareness by convincing or informing the public in general, such knowledge becomes part of the collective perception. In the same manner, the collective perception may be manipulated by individuals or organizations if they prove successful in convincing society in general that a certain alternative does not exist—that is, that it does not comply with technical requirements or other regulations.

Choice-eliminating mechanisms influence the collective perception in the direction of not having a choice at all or having a false choice, as just described. *Raising Choice Awareness* involves influencing the collective perception in the direction of having a true choice and identifying and understanding the pros and cons of relevant alternatives.

Radical Technological Change

Choice Awareness theory is concerned with the implementation of radical technological change. *Technology* is defined as one of the means by which mankind reproduces and expands its living conditions. The definition of *technology* embraces a combination of the four elements—technique, knowledge, organization, and products—and is discussed further in Chapter 2.

Radical technological change is defined as a change of more than one of the four elements of technology. In Choice Awareness, special focus is placed on the change of existing organizations, and a distinction is made between organizations and institutions. *Organization* is defined as a social arrangement that pursues collective goals, controls its own performance, and has a boundary that separates it from its environment. Typical examples of organizations are companies, NGOs, businesses, and administrative units. *Institutions* are structures and mechanisms of social order and cooperation. They govern the behavior of more than one individual and/or organization, and they include a formal regime for political rule making and enforcement. Thus, in short,

one may say that institutions are organizations including all of the written laws and regulations and all of the unwritten codes of culture regulating them.

Applied and Concrete Economics

Choice Awareness theory involves four strategies in which concrete institutional economics, as opposed to applied neoclassical economics, plays an important role. *Applied neoclassical economics* is defined as neoclassical-based methods, such as cost-benefit analyses and equilibrium models, applied to existing real-life market economies. This is seen as opposed to theoretically correct methods applied to market economies that fulfill the theoretical assumptions of a free market. As discussed further in Chapter 3, the theory of neoclassical market economics is based on a number of assumptions that are not fulfilled in real-life market economies. The critique of neoclassical-based methods of this book is directed toward the real-life applications of the methods, and it is not decisive whether this critique is valid for theoretically correct applications or not.

Concrete institutional economics is defined as economics that deals with the concrete institutional conditions which form the development of a specific society. *Institutional economics* focuses on the understanding of the role of human-made institutions in the shaping of economic behavior. The concrete institutional conditions vary from one society to another, and the method linked to concrete institutional economics therefore deals with defining analytical aims, contexts, and aggregation levels for the analysis of the concrete societal institutions in a specific society (Hvelplund 2005, pp. 91–95).

Renewable Energy

Renewable energy is defined as energy that is produced by natural resources—such as sunlight, wind, rain, waves, tides, and geothermal heat—that are naturally replenished within a time span of a few years. Renewable energy includes the technologies that convert natural resources into useful energy services:

- Wind, wave, tidal, and hydropower (including micro- and river-off hydropower)
- Solar power (including photovoltaic), solar thermal, and geothermal
- Biomass and biofuel technologies (including biogas)
- Renewable fraction of waste (household and industrial waste)

Household and industrial waste is composed of different types of waste. Some parts are considered renewable energy sources—for example, potato peel—whereas other parts, such as plastic products, are not. Only the fraction of waste that is naturally replenished is usually included in the definition. In this book, however, for practical reasons, the whole waste fraction is included as part of the renewable energy sources identified in most analyses.

Renewable Energy Systems

Renewable energy systems are defined as complete energy supply and demand systems based on renewable energy as opposed to nuclear and fossil fuels. They include supply as well as demand. The transition from traditional nuclear and fossil fuel–based systems to renewable energy systems involves coordinated changes in the following:

- Demand technologies related to energy savings and conservation
- Efficiency improvements in the supply system, such as CHP
- Integration of fluctuating renewable energy sources, such as wind power

A distinction can be made between *end use* and *demand*. *Energy end use* is defined as the human call for energy services such as room temperature, transportation, and light. *Energy demand* is defined as consumer demands for heat, electricity, and fuel. Consumers include households and industry as well as public and private service sectors. Fuel may be used for heating or transport. Heat demand may be divided into different temperature levels such as district heating and process heating.

Within end use, one may distinguish further between, on the one hand, basic needs such as food, basic temperatures, and transportation from home to work and, on the other, specific requirements such as a certain number of square meters with a certain room temperature and a certain number of kilometers of driving. This distinction can be critical—for example, when analyzing the transportation infrastructure related to food production or to transportation between home and work. However, in the analyses presented in this book, it has not been necessary to make such a distinction.

Changes such as insulation and efficiency improvements of electric devices leading to changes in the energy demand for heat, electricity, or fuel are defined as *changes in the demand system*. In addition to the preceding renewable energy technologies, renewable energy systems include both technologies, which can convert from one form of energy into another—for example, electricity into hydrogen—as well as storage technologies that can save energy from one hour to another. Mathiesen (Mathiesen and Lund 2009) and Blarke (Blarke and Lund 2008) comprise these technologies under the designation relocation technologies. However, in the following, the difference between *energy conversion* and *energy storage* technologies is emphasized.

Energy conversion technologies are technologies that can convert from one demand (heat, electricity, or fuel) to another, such as the following:

- Conversion of fuel into heat and/or electricity by the use of technologies such as power stations, boilers, and CHP (including steam turbines as well as fuel cells)
- Conversion of electricity into heat by the use of technologies such as electric boilers and heat pumps