Introduction

What is the *Economics of Electricity* about? This is an interesting question that has no easy answer. We could take the safe path and claim that it is the study of the electricity markets. But, as economists already know, there is already a specific economic field devoted to the study of industries, called Industrial Organization. So, are there any specific features of the economics of electricity that justify a reference textbook? We believe so. It is true that the economics of electricity is, after all, just another applied study of economics; but the way the models and tools that are (or should be) in the hands of any well-trained economist are applied in this field makes all the difference. There are specific features of power systems, accruing from the laws of physics and the way power systems have been created and developed throughout history, which require a careful understanding before applying economic analysis. Moreover, they imply that the standard approaches of economics, such as welfare maximization and competition studies, when applied to the electricity sector, also drive new and interesting results. For instance, economists are trained that competition induces a selection of technologies and therefore only the most efficient players survive in the market. In the electricity sector, however, it is natural for technologies with different efficiencies to coexist; actually, this is even a desirable feature. Every student knows that an equilibrium with a negative price makes no sense. In electricity markets, this may occur. And we could continue, but we do not want to reveal all now. Just read the book through, and you will find those interesting results yourself.

One final word about a second question that might require a preliminary explanation. To what extent is this textbook new? There are other textbooks on electricity markets, or power systems, or electricity sector regulation, such as Biggar and Hesamzadeh (2014), Hunt (2002), Kirschen and Strbac (2004), Perez-Arriaga (2013), Stoft (2002). They are excellent references, and we have also made use of them. However, we think that a comprehensive yet accessible textbook on the economics of electricity is missing. This is the purpose of this book, aimed at all those who have a basic training in economics, perhaps in Industrial Organization, but who lack the specific knowledge required in applying economic models to the electricity sector. We aim to bridge this gap, and, we assure you that studying it will be worthwhile. It is a rewarding experience; at least, it has been for us.

Content of the Book

The book contains an exhaustive and up-to-date discussion of electricity economics. It seeks to address questions such as: What are the properties of electricity as an economic commodity? What are electricity markets, why do they exist, and how do they work? What are the economic principles behind trade, supply, transportation and distribution of power to consumers and firms? Are there any specific aspects of the economic analysis applied to electricity systems? How are the different markets organized and why? How should they be optimally designed and what elements should be taken into account to deliver electricity effectively and efficiently? How can electricity production be decarbonized?

The style of the book is technical, yet accessible to all those who have a basic training in economics. The main and most widely accepted tools of economic analysis are used. An introduction to the basic elements of power system elements and engineering is also provided, to help most economics students to become acquainted with the basics of electricity that have to be taken into account when delivering meaningful and useful analysis of the sector. Moreover, students in the field of engineering, political sciences, and physics, who have already had introductory courses in economics will be able to follow the rationale of the analyses developed and gain insights into the economics of electricity systems.

The structure of the book is modular. It spans twenty-seven chapters, grouped in eight parts. The sequence we have chosen reflects a logical path that helps teaching courses on electricity economics. It can be undertaken sequentially from the first to the last chapter, or sub-sequences could be constructed depending on instructors' needs.

Several chapters discuss and provide concrete references to real-world cases that refer to the concepts developed and explained in the text. Moreover, quick exercises developed as simple examples help to understand the various theoretical concepts that are introduced. At the end of each chapter, the learning outcomes focus on key-point messages.

Part I – Chapters 1 and 2 – presents an introduction to energy and electricity. Chapter 1 covers definitions and unit measures. It deals with the definitions of energy, electricity, and power; energy sources and carriers; unit measures and energy conversion principles. Chapter 2 presents a brief history of electricity and electricity markets. Examples on energy unit measures and conversion help students unfamiliar with those concepts to become acquainted with them. The fundamental notions of electricity production costs are then detailed.

Part II – Chapters 3, 4 and 5 – covers the basic features of the power systems and the design of electricity markets. Chapter 3 describes the Electricity Supply Chain (ESC), divided into production, transmission, dispatching, distribution, metering and retailing; it describes their features and specificities. Chapter 4 distinguishes between the physical and economic delivery of electricity. Chapter 5 describes four different market arrangements under which the ESC can be organized. The time structure of the economic delivery of electricity, from production to real-time, is also explained. Chapter 6 is an

overview of the main principles of regulation in the power sector, a brief yet useful reference to understand the specific problems of regulation in electricity.

Parts III to V are linked by a progressive removal of simplifying assumptions, toward a more accurate and realistic description of the electricity sector.

Part III – Chapters 7 to 11 – considers simplified isolated markets without network congestion. Chapter 7 looks at main characteristics of the load (or demand) and power generation. Chapter 8 explains demand-supply matching. It presents the basic tool for analyzing the principle of optimal dispatching, namely, the concept of Economic Dispatching, in centralized markets. While Chapter 8 takes the point of view of a fully integrated monopoly, Chapter 9 describes the welfare maximization solution of a central planner, when load is time-varying. Chapter 10 shows under which conditions a full market solution replicates the optimal planned one. Chapter 11 is devoted to specific markets delivering services whose aim is to ensure stability and reliability. In particular, we study how balancing services can be exchanged effectively and efficiently. At the end of Part III, we provide a link to a web-based platform that introduces a market game. This simulation replicates the features of a stylized power exchange. The exercise allows interested readers to become acquainted with the technical side of power plants (technologies, costs, efficiency, maintenance, CO_2 emissions, varying load) and practice the profit-maximization strategies and the market consequences studied in this part.

Part IV – Chapters 12 and 13 – explains why electricity markets are vulnerable to market power. The arguments are developed both from a theoretical and an empirical point of view. First, the main models of market power are analyzed (Chapter 12). Then the issue of market power measurement is discussed (Chapter 13).

Part V – Chapters 14 to 18 – introduces the economic analysis of transmission networks, both internally and for import and export of energy. Chapter 14 introduces the basic problem of finding the optimal dispatching in a two-nodes network, by means of nodal pricing. The notion of congestion is also introduced. The consequences of Kirchhoff's laws in meshed networks are considered in Chapter 15, using the simple three-nodes case as a reference. Chapter 16 describes the concepts, characteristics and properties of nodal and zonal pricing in practice. Chapter 17 tackles the issue of network expansion and the incentives to invest in transmission capacity. Chapter 18 shows the complexity of setting transmission rights, either physical or financial, and the possibility of risk hedging with transmission rights and contracts for differences.

Part VI reviews the characteristics and specificities of electricity retailing markets. Chapter 19 is an overview of theoretical models of competitive electricity retailing activities, whereas Chapter 20 is devoted to practical examples and implementation issues in different countries.

Part VII tackles the issue of investments in generation capacity. Following the same approach as in Part III, in Chapter 21 the optimal investment problem in a planned setting is introduced first, followed by the competitive market analysis. In real-world situations, however, incentives to invest can be sustained by specific mechanisms to remunerate capacity. The theoretical comparison of generation capacity investments with and without remuneration schemes is carried through in Chapter 22. Then, various existing capacity remuneration mechanisms are presented and discussed in Chapter 23.

Part VIII explains the role and importance of the environmental dimension in the electricity markets and the evolution of the electricity system, with reference to demand-side advances and innovation at the production, transmission and distribution levels. Long-term decarbonization scenarios are presented in Chapter 24. The role and features of renewable electricity production are considered in Chapter 25. The issues arising from the integration of non-programmable energy sources in electricity systems are studied in Chapter 26. Finally, Chapter 27 focuses on the Electricity Supply Chain evolution, with regard to smart grids and new retail services.

Possible Teaching Sequences and Sub-Sequences

The content of the teaching depends on the length of the course, its level, audience and students' backgrounds, as well as on the instructor's interests. Teaching all of the chapters would require a full-length semester course of sixty hours or more. While this might sometimes be required, several sub-sequences can be taken out of the structure of the content of the book.

A typical masters-level course for economics students can be served by teaching Parts I to V, possibly also including Part VII. If the teaching material has to be shared with other topics in energy economics, typically gas markets, Parts II and V can be left out, and Parts I, III, IV taught. When the class focuses on competition and regulation in electricity markets, we recommend including Part V, and perhaps skipping Part II. There are also classes on "Energy and Environment." In this case, the teaching material would be Parts I, II, IV and VIII. Second-year masters students in energy economics could go for Parts I to VI. If students are familiar with the basics of power systems, they can skip Part I and, depending on their background, also Part II. Undergraduate students can refer to Parts I to IV of the book.