1

Introduction

1.1 Why Study Power System Economics?

If kilowatt-hours could be stacked on a shelf – like kilograms of flour or television sets – ready to be used as soon as the consumer flips the switch or starts the industrial process, electricity would be a simple commodity, and there would be no need for this book. Despite recent advances in electricity storage, distributed generation, and demand-side flexibility, most electrical energy is still produced by large power plants and delivered to consumers through vast transmission and distribution networks. Any commercial transaction between a buyer and a seller of electrical energy thus has an impact on the state of the power system. Since consumers have high expectations regarding the reliability of their electricity supply, commercial transactions that could endanger the stability of the system cannot be allowed. Trading in electrical energy thus requires closer supervision than markets for traditional commodities. Power system economics is thus closely linked to power system operation.

Building the infrastructure required to generate electrical energy and delivering it to consumers requires enormous amounts of capital. Decisions about what facilities should be built must therefore balance the investment expenses against the benefits that they will provide in terms of reducing the cost to consumers, improving reliability and resilience, as well as meeting environmental objectives. The assessment of an investment project must therefore consider not solely its profitability but also how it would affect the operation of the entire system.

The drive to decarbonize our economies to mitigate climate change affects both the short-term operational economics and the development of the infrastructure. Conventional fossil-fired generating plants are rapidly being replaced by wind and solar generation that have very different economic and operational characteristics. At the same time, the electrification of transport, heating, and industrial processes increases the demand for electrical energy and hence the need for large infrastructure investments. Developing market frameworks that align profitability, reliability, and sustainability objectives is thus a challenging and critical task.

Development of smart control paradigm will support cost effective transition to low carbon energy future.

1.2 Industry Structure

This section discusses the common types of electricity supply industry structures and how a particular structure determines the responsibilities different entities have in the electricity markets.

1.2.1 Vertically Integrated Monopoly Utility

A vertically integrated monopoly utility generates electrical energy, transmits it from the power plants to the load centers, and distributes it to individual consumers. It has a monopoly on the supply of electricity in a given geographical area, which means that consumers have no choice: if they want to purchase electricity from the grid, they must buy it from their local utility. This industry structure was universal for most of the twentieth century, and it remains the model in many parts of the world. Some of these utilities are regulated investor-owned companies, while others are government agencies or government-owned companies.

Electric utilities operating under this model made truly remarkable contributions to economic activity and quality of life. Most people living in the industrialized world have access to an electricity distribution network. For several decades, the amount of energy delivered by these networks doubled about every eight years. At the same time, advances in engineering improved the reliability of the electricity supply to the point that in many industrialized countries, the average consumer is deprived of electricity for less than two minutes per year. These achievements were made possible by ceaseless technological advances. Among these, let us mention only the development and erection of transmission lines operating at over 1,000,000 V and spanning thousands of kilometers, the construction of power plants capable of generating more than 1,000 MW, and the online control of the networks connecting these plants to the consumers.

Figure 1.1 illustrates this traditional industry structure. Commercial activity is limited to consumers purchasing electricity from their local electric utility. This utility makes all the operational decisions (e.g., how much power each of its plants should produce to supply the load) and investment decisions (e.g., what type of power plants should be built and where they should be located).

Because monopolies could take advantage of the fact that their customers don't have a choice to charge them extortionate prices, they must either be government entities or be subject to oversight by a government department called the regulator. This regulator enforces the regulatory compact, which is an agreement that gives the utility a monopoly on the supply of electricity over a given geographical area. In exchange, the utility agrees that its prices will be set by the regulator, that it will supply all the consumers in that area, and that it will maintain a certain quality of service.

This vertically integrated monopoly model does not preclude bilateral energy trades between utilities that have a monopoly over different geographical areas. Such trades take place at the wholesale level, i.e., through interconnections between transmission networks.

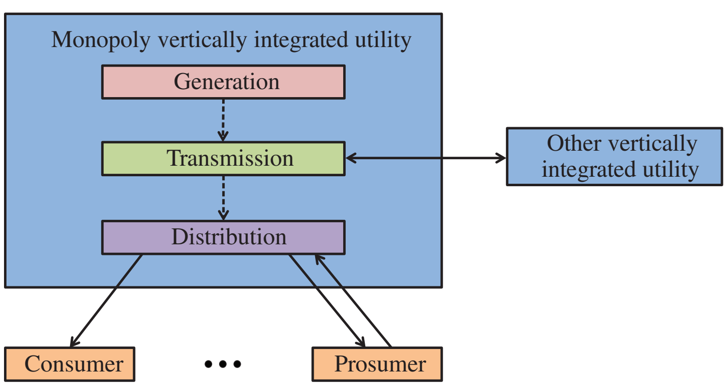

Figure 1.1 Flows of electrical energy in a monopoly vertically integrated industry structure.

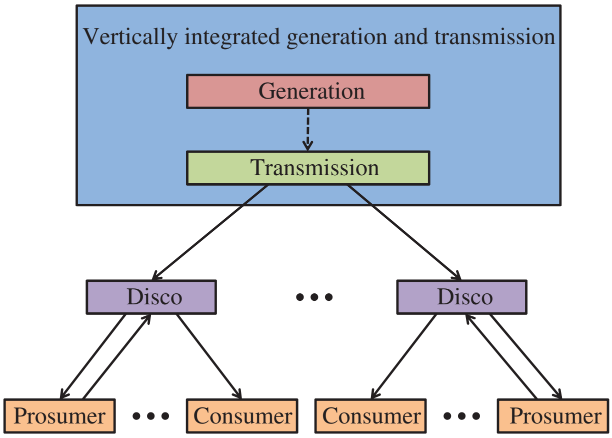

Figure 1.2 Flows of electrical energy in the variant of the monopoly vertically integrated industry structure.

An increasing number of consumers have installed photovoltaic (PV) panels or other forms of distributed generation on their premises. Such a consumer becomes a producer when the power output of its generator is larger than its load. This excess power then flows back into the distribution network, and the utility has to buy it from these *prosumers*.

Figure 1.2 shows a fairly common variant of the vertically integrated monopoly model. In this variant, one organization has a monopoly over the generation and transmission over a fairly wide area and sells electrical energy to several distribution companies (*Discos*), each of which has a local monopoly over the sale of electricity to consumers.

1.2.2 The Dawn of Competition

In the 1980s, some economists started arguing that the vertically integrated monopoly utility model had run its course. They said that the monopoly status of the electric utilities removed the incentive to operate efficiently and encouraged unnecessary investments. They also argued that the cost of the mistakes that investor-owned utilities made should not be passed on to the consumers. Closer supervision by the regulator would not be effective because the operations of the utilities were rather opaque, making it difficult for regulators to assess where improvements could be made. On the other hand, publicly owned utilities were often too closely linked to the government. Politics could then interfere with good economics. For example, the revenues from some public utilities were used to support other government expenditures, while others were prevented from setting rates at a level that reflected costs or were deprived of the capital that they needed for essential investments.

These economists suggested that prices would be lower and the overall economy more efficient if the supply of electricity were subjected to the discipline of a competitive market rather than monopoly regulation or government policy. This proposal was made in the context of the general deregulation of Western economies that started in the late 1970s. Before attention turned toward electricity, this movement had already affected airlines, transportation, and the supply of natural gas. In electricity and these other sectors, regulated markets or monopolies had previously been deemed the most efficient way of delivering the “products” to the consumers. It was felt that their special characteristics made them unsuitable for trading on free markets. Advocates of deregulation argued that the special characteristics of these products were not insurmountable obstacles and that

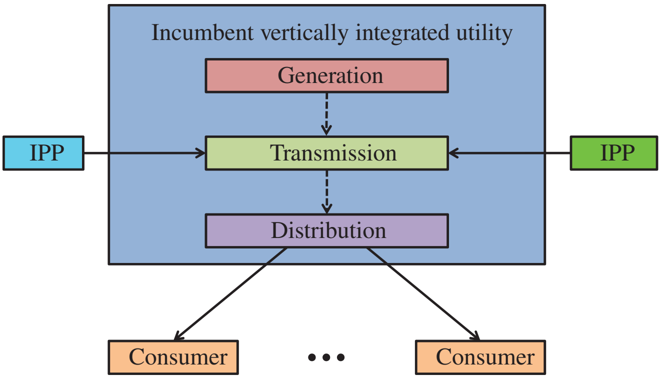

Figure 1.3 Incumbent vertically integrated utility with independent power producers (IPPs).

they could and should be treated like all other commodities. If companies were allowed to compete freely for the provision of electricity, the efficiency gains arising from competition would ultimately benefit the consumers. In addition, competing companies would probably choose different technologies. It was therefore less likely that the consumers would be saddled with the consequences of unwise investments.

Since then, many jurisdictions around the world have implemented one of the levels of competitive electricity markets described in the following sections. In other areas, the vertically integrated monopoly model persists, either for political reasons or because the small size and isolated nature of the power system mean that the cost of implementing a market would be higher than the potential benefits.

1.2.3 Introducing Independent Power Producers

A first step toward a more competitive industry structure consists of allowing *independent power producers* (*IPPs*) to generate part of the electrical energy that the incumbent vertically integrated utility must supply to its customers. Figure 1.3 illustrates this arrangement. Since incumbent utilities view the introduction of IPPs as a threat to their business model, they usually must be obligated by law to purchase the electrical energy that IPPs generate. Determining the price at which this energy should be traded is difficult. The incumbent utility would like to pay as little as possible to discourage the IPPs from expanding their generation capacity. On the other hand, given that the incumbent must purchase their production, the IPPs try to get as high a price as they can. In the absence of a market-based mechanism for setting the price (see Chapter 2), the regulator has to decide based on limited information what an equitable price would be. While this model introduces a degree of competition at the generation level, the result is often economically inefficient.

1.2.4 Wholesale Competition

A further step toward competitive electricity markets consists in getting rid of the incumbent utility. As illustrated in Figure 1.4, all the companies that own large generating plants (*Gencos*) then compete on an equal basis to sell electrical energy. Distribution companies purchase the electrical energy consumed by their customers on the wholesale electricity market. Large industrial consumers are often allowed to participate directly in this market. As we will discuss in Chapter 3, this wholesale market can operate in a centralized manner or can be based on bilateral transactions.

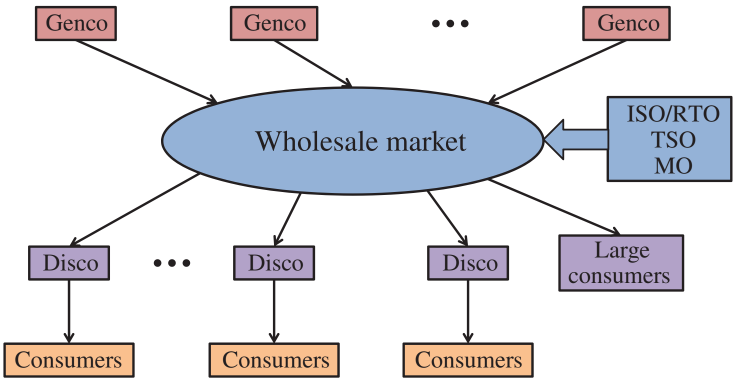

Figure 1.4 Wholesale electricity market structure.

In this model, the wholesale price of electricity is determined by the interplay of supply and demand. On the other hand, the retail price of electrical energy must remain regulated because each distribution company retains a local monopoly over the sale of electrical energy flowing through its network. These distribution companies are often called *load serving entities* (*LSE*).

When the wholesale market is operated in a centralized manner, an organization called *independent system operator* (*ISO*) or *regional transmission organization* (RTO) must be created to fulfill two main functions. First, it must manage the market in an impartial and efficient manner. Second, it is responsible for the reliable operation of the transmission system. As its name implies, to ensure the fairness of the market, the ISO has to be institutionally independent from all market participants.

In a bilateral wholesale market, these functions are often split between one or more *market operators* (*MO*), whose role is to facilitate commercial transactions between buyers and sellers of electrical energy, and a *transmission system operator* (*TSO*), which keeps the system in balance and operationally reliable. While TSOs often own the transmission assets (lines, transformers, substations, etc.), ISOs do not.

1.2.5 Retail Competition

Competition can also be introduced at the retail level. This leads to the structure illustrated in Figure 1.5, where *retailers* purchase electrical energy in bulk on the wholesale market and resell it to small- and medium-sized consumers. In this model, the "wires" activities of the distribution companies are normally separated from their retail activities because they no longer have a local monopoly for the supply of electrical energy in the area covered by their network. One can view the wholesale market as operating over the transmission network, while the retail market takes place over the distribution network. Building and operating the transmission and distribution networks remain monopoly activities because it is generally agreed that building competing sets of wires would be wasteful. The regulator thus has to decide what investments in network assets are justified and how the cost of these investments should be allocated to the users of the networks.

Once sufficiently competitive markets have been established, the retail price no longer has to be regulated because small consumers have the option to change retailers if they are offered a better price or better service. As we will see in Chapter 2, this is desirable because market interactions lead to the discovery of economically efficient prices.

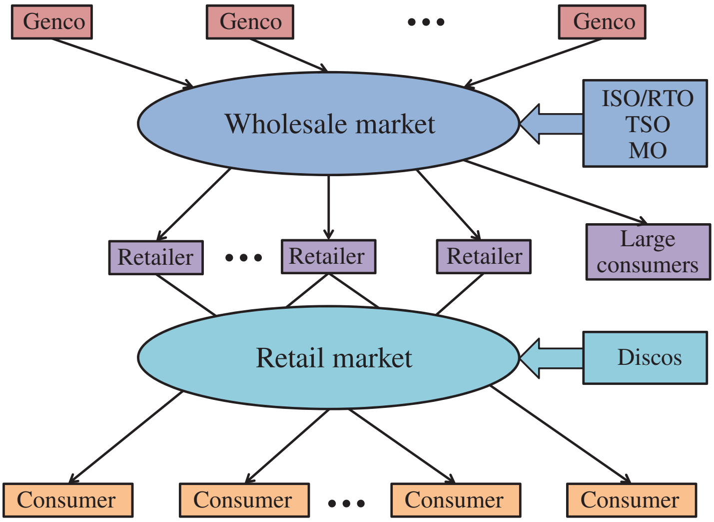

Figure 1.5 Structure of an electricity market with competition at the wholesale and retail levels.

1.2.6 Incorporating Distributed Energy Resources

In many parts of the world over the last three decades, public policies aimed at reducing carbon emissions have significantly altered the mix of generation technologies. Because wind and solar generation now contribute a substantial fraction of the overall production of electrical energy, electricity markets have had to adapt to accommodate the natural variability of these resources. To deal more efficiently with the larger imbalances between generation and load that renewable generation causes, markets need more participants that are flexible – those that can adjust rapidly the amount of power they inject into the system. While this flexibility has traditionally been provided by thermal power plants, the demand side can help maintain this balance. However, marshaling consumer-owned resources is challenging because they tend to be small and distributed throughout the system. Direct participation in the wholesale electricity markets by distributed energy resources (such as demand response, small-scale energy storage, and PV generation) is not possible because it would vastly increase the number of market participants and render these markets unmanageable. In addition, the rules of the wholesale markets are complex and the requirements for participation are strict, making the transaction costs prohibitively expensive for small participants. To overcome this problem, new entities called *aggregators* are emerging. Their role is to serve as a commercial and technical intermediary between the wholesale markets and the owners of distributed energy resources.

1.3 Dramatis Personae

The previous section introduced some of the types of organizations that operate under various market structures. This section describes in more detail the functions that these organizations perform. In some markets, a single commercial entity or subsidiaries of this entity may be allowed to perform multiple functions. The names given to different types of organizations may also differ from country to country.

Vertically integrated utilities own and operate all the assets needed to supply electrical energy: the generating plants, the transmission network, and the distribution networks. In a traditional regulated environment, such a company has a monopoly on the supply of electricity over a given geographical area. Once a wholesale electricity market has been established, the functions and assets of the vertically integrated utilities are divided between other types of organizations.

Generating companies (*Gencos*) own generating plants and sell electrical energy. They may also sell services such as regulation, voltage control, and reserve that the system operator needs to maintain the quality and operational reliability of the electricity supply. A generating company can specialize in the operation of a specific technology (e.g., wind or nuclear) or own a portfolio of plants of different technologies. Generating companies that coexist with vertically integrated utilities are called *IPP*s.

Distribution companies (*Discos*) own and operate distribution networks. Unless a retail market has been organized, discos have a monopoly on the sale of electrical energy to all consumers connected to their network. When a retail market is in operation, discos are no longer responsible for the sale of energy to consumers, and their role is limited to the operation and development of the distribution network.

Retailers buy electrical energy on the wholesale market and resell it to consumers who do not wish or are not allowed to participate in this wholesale market. Retailers do not have to own any power generation, transmission, or distribution assets. Some retailers are subsidiaries of generation or distribution companies. All the customers of a retailer do not have to be connected to the network of the same distribution company.

Load serving entities (*LSEs*) is a term used to describe distribution companies when there is no retail market or retailers when there is one.

Market operators (*MOs*) run computer systems to match the bids and offers that buyers and sellers of electrical energy submit. They also take care of the settlement of the accepted bids and offers – i.e., they forward payments from buyers to sellers following delivery of the energy. Independent for-profit market operators often manage electricity markets that close some time ahead of real time. On the other hand, the ISO runs the market of last resort, i.e., the market where load and generation are balanced in real time.

The primary responsibility of an *ISO* is to maintain the stability and operational reliability of the power system. It is called independent because in a competitive environment, the system must be operated in a manner that does not favor or penalize one market participant over another. ISOs normally own only the computing and communications assets required to monitor and control the power system. An ISO usually combines its system operation responsibility with the role of operating the market of last resort. ISOs are also called regional transmission organizations (*RTOs*).

Transmission companies (*Transcos*) own transmission assets such as lines, cables, transformers, and reactive compensation devices. They operate this equipment according to the instructions of the ISO.

Transmission system operators (*TSOs*) are organizations that combine the function of ISOs with the ownership of transmission assets.

Small consumers buy electrical energy from a retailer and lease a connection to the power system from their local distribution company. Their participation in the electricity market usually amounts to no more than choosing one retailer among others when they have this option. However, **aggregators** contract with a number of small consumers to reduce or shift their demand in time on request. The combined effect of these individual actions is then sufficiently large to be sold on the wholesale market.

On the other hand, **large consumers** often have the skills and technical resources needed to trade directly on the wholesale electricity markets.

Storage companies perform arbitrage by charging batteries or other forms of storage when the price of electricity is low and discharging them when the price is high. They can also provide various services to the system operators.

The **regulator** is the unit of the executive branch of government responsible for ensuring the fair and efficient operation of the electricity sector. It determines or approves the rules of the electricity market and investigates suspected cases of abuse of market power. The regulator also sets the prices for the products and services that are provided by monopolies. Regulatory functions are sometimes divided between two levels of government. For example, in the United States, the Federal Energy Regulatory Commission regulates interstate transmission and wholesale electricity markets, while the public utilities commission of each state regulates the retail markets and the distribution networks. In addition to their purely economic function, regulators also set the rules required to ensure the reliability and quality of the electricity supply. In some cases, the technical details of these rules are administered by a specialist organization, such as NERC in North America or ENTSO-E in Europe.

1.4 Competition and Privatization

In many countries, the introduction of competition in the supply of electricity has been accompanied by the privatization of some or all components of the industry. Privatization is the process by which the government sells publicly owned utilities to private investors. These utilities then become investor-owned, for-profit companies. While privatization is not an absolute prerequisite for the introduction of electricity markets, competition between government-owned entities and private companies is usually considered undesirable as the former are perceived as having unfair advantages, particularly because they are typically able to access capital on more favorable terms.

1.5 Experience and Open Questions

In the monopoly utility model, all technical decisions regarding the operation and development of the power system are taken within a single organization. In the short term, this means that, at least in theory, the operation of all the components of the system can be coordinated to achieve the least cost operation. For example, the maintenance of the transmission system can be scheduled jointly with the maintenance of the generation units to co-optimize reliability and economy. Similarly, the long-term development of the system can be planned to ensure that the transmission capacity and topology match the generation capacity and location.

Introducing competition implies renouncing centralized control and coordinated planning. A single integrated utility is replaced by a constellation of independent companies, none of which has the responsibility to supply electrical energy to all the consumers. Each of these companies decides independently what it will do to maximize its private objectives. When the idea of competitive electricity markets was first mooted, it was rejected by many on the grounds that such a disaggregated system could not keep the lights on. There is now ample evidence to demonstrate that separating the operation of generation from that of the transmission system does not necessarily reduce the operational reliability of the overall system.

Having a separate, independent organization in charge of operating the power system has the significant advantage of making processes more open and transparent. Buyers and sellers have an interest in exploring how market rules and operational procedures can be improved to reduce costs and improve the profitability of their assets. This attitude has led to markets operating much closer to real time and to the development of "products" to accommodate the increasing amount of renewable energy sources, as well as new technologies such as demand-side participation and energy storage. Innovation flourishes much more readily in a competitive environment than within the confines of a vertically integrated monopoly.

Electricity markets have also grown geographically because bigger markets provide more trading opportunities and are thus more liquid and efficient. This growth happened either through additional participants joining an existing market or through the establishment of market coupling mechanisms. Increased trading opportunities result in more frequent and larger transactions between distant generators and loads. Such power flows increase the physical interdependence between parts of the grid that used to be loosely connected. Maintaining the stability and operational reliability of large interconnections under these conditions has forced system operators to enhance the scope and functionality of their data acquisition and analysis capabilities.

As we will discuss in Chapter 5, electricity markets have some unique characteristics that facilitate the abuse of market power. Many, if not most, electricity markets therefore have had to deal with the fact that they were often less than perfectly competitive. This has led to a number of inquiries by regulators, the creation of market monitoring bodies, the implementation of price caps, and other less controversial measures to mitigate market power.

In terms of long-term development, the argument in favor of competition is that central planners always get their forecasts wrong. In particular, monopoly utilities have a tendency to overestimate the amount of generation capacity that will be needed. Their captive consumers are then obliged to pay for unnecessary investments. With the introduction of competition, it is hoped that the sum of the independent investment decisions of several profit-seeking companies will match the actual evolution of the demand more closely than the recommendations of a single planning department. Competing companies are also likely to invest in different technologies, which produces a more diversified and less risky generation portfolio. Finally, underutilized investments by a company operating in a free market represent a loss for its owners and not a liability for the customers, as is the case with a monopoly utility.

Some markets rely entirely on the profits that power plants can obtain from the sale of energy and services to motivate investments in generation capacity. In other jurisdictions, market designers have introduced additional revenue streams to ensure that enough generation capacity is available to supply the load in a reliable manner. There is currently a significant amount of debate on whether either approach will sustainably deliver decarbonized generation portfolios at a pace that matches the need to decarbonize the overall economy. We will discuss this issue in more detail in Chapter 8.

Vertically integrated utilities can plan the development of their transmission network in tandem with the construction of new generating plants. In a competitive environment, no single entity decides where and when generating plants will be built. This uncertainty makes the transmission planning process much more difficult because transmission is no longer built to deliver power from new plants to specific load centers. Instead, transmission expansion should maximize the overall economic benefits while respecting environmental constraints and should not unduly harm any stakeholder. Since the expected growth in renewable generation capacity and demand for electricity will require a concomitant and significant increase in transmission capacity, there is an urgent need to develop processes that foster consensus on what ought to be built.

The transmission and distribution networks have so far been treated as natural monopolies. Having two separate and competing sets of transmission lines or distribution feeders clearly does not make sense. From the economic and reliability points of view, all lines, feeders, and other components should be connected to the same system. On the other hand, some economists and some entrepreneurs argue that not all these components must be owned by the same company. They believe that independent investors should have the opportunity to build new transmission facilities to satisfy the specific needs that they have identified. Taken individually, such opportunities could be lucrative for the investors. However, the prevalent view is that such investments must take place within a framework that maximizes the overall benefits derived by all users of the network while minimizing their environmental impact. Chapter 9 addresses transmission expansion issues.

As we discuss in subsequent chapters, electricity is not a simple commodity whose trading is governed solely by the basic principles of classical economics. In addition to the need to maintain reliability, electricity markets are also affected by policy decisions driven by a desire to promote renewable energy sources and protect the environment, concerns about energy security and independence, as well as subsidies aimed at spurring the development of new technologies or helping a national industry.

1.6 Problems

P1.1 Determine the electricity market structure that exists in your region or country or in another area where you have access to sufficient information. Discuss any differences that you observe between the basic model described in this chapter and the electricity market implementation in this area.

P1.2 Identify the companies that participate in the electricity market in the area that you chose for Problem P1.1. Map the basic functions defined in this chapter with these companies and discuss any difference that you observe. Identify the companies that enjoy a monopoly status in some or all of their activities.

P1.3 Identify the regulatory agency or agencies that oversee the electricity supply industry in the area that you chose for Problem P1.1.

P1.4 Identify the organizations that fulfill the functions of market operator and system operator in the area that you chose for Problem P1.1.

P1.5 Identify policies that have been implemented or proposed to promote the development of renewable energy sources in your region or country or in another area where you have access to sufficient information.

P1.6 How is the demand for electrical energy forecast to evolve in your region or country or, if necessary, another area?

P1.7 What is the current mix of generation technologies in your region or country or, if necessary, another area? How is this mix forecast to evolve?

Further Readings

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