1 Introduction

This chapter seeks to answer a few questions of general interest:

– Why has energy economics developed as a separate discipline of economics?
– Why does energy economics cover more than the straightforward application of standard economic methods and models to energy markets?

What are the reasons for politicians to have a particular propensity to intervene in energy markets?

The variables used in this chapter are:

C Annual production cost
Π Annual profit
p Price per output unit
Q Annual output (quantity)

1.1 Philosophical and Evolutionary Aspects of Energy

"Energy is life". Energy in the form of light is seen as the origin of the genesis (Genesis 1: 2–3). According to Greek mythology, history of human life starts with the stealing of fire by Prometheus—an act for which he was condemned to eternal pain.

These citations may be sufficient to highlight the philosophical dimension of energy. According to the second theorem of thermodynamics (also known as the law of increasing entropy), all forms of life, i.e. the existence of complex structures, depend on the availability and utilization of employable energy.[1] The American economist and philosopher Georgescu-Roegen formulated this as follows, "Given

[1]Employable energy that is capable of performing work is also called exergy.

P. Zweifel et al., *Energy Economics*, Springer Texts in Business and Economics,
DOI 10.1007/978-3-662-53022-1_1

that even a simple cell is a highly ordered structure, how is it possible for such a structure to avoid being thrown into disorder instantly by the inexorable Entropy Law? The answer of modern science has a definite economic flavor: a living organism is a steady going concern which maintains its highly ordered structure by sucking low entropy from the environment so as to compensate for the entropic degradation to which it is continuously subject" (Georgescu-Roegen 1971, p. 191f). Thus, each living organism needs to acquire useful energy, which is associated with effort or cost. In spite of the abundant global availability of energy, in particular solar radiation, useful energy is always a scarce good.

A characteristic feature of biological evolution is the diversity of ways used by species to absorb energy. Individual species use a variety of food as energy source, and different methods of approaching these energy sources; moreover, they assimilate the energy contained in their food in manifold ways. The methods of acquiring, storing, and using energy belong to their distinguishing characteristics, which also determine their rank within the evolutionary hierarchy.

Securing a continuous energy supply—condition for the sustainable existence of species—requires the ability to shift to other energy sources (e.g. food) in case those used thus far are exhausted. In turn, such adaptations affect the existence and living conditions of other species. Therefore, biological evolution can be understood as a mutual development of energy systems used by species, which determine their population growth and living conditions. This co-evolution can occur fast or slowly; however, it is never stationary as long as life continues.

The suggested energy-related interpretation of evolutionary patterns in biology is also relevant for the evolution of social systems. In fact, historical development is characterized by phases of stability and phases of disruptive innovations:

– One of the conditions for the development of human civilization was the control of fire. Before, energy in form of biomass was used for the biological metabolism of human bodies. Now, the thermal use of biomass became possible. The thermal use of biomass by hominids may have begun around 800,000 years ago. The control of fire became a key distinction between the Homo erectus, the ancestor of the Homo sapiens, and other species. It was also causal for the first forms of cultural life with the family as its roots.
– A further milestone of human civilization was triggered by the Neolithic revolution with the emergence of agriculture and farming 10,000–20,000 years ago. It required technological know-how concerning the use of energy along with the division of labor for creating the first urban infrastructures. This important societal change also marks the beginning of scientific research.
– About 5000–6000 years ago, the use of other renewable energy sources (sailing boats, later on wind mills and water mills) created the conditions of advanced civilizations.
– With the first industrial revolution, muscular power of animals and humans (often slaves) was replaced by engines, with coal becoming the fuel of mechanization. Industrial development was concentrated in areas with easy access to coal: instead of transporting coal to the people, people were moved from rural

areas to industrial centers. The implications were significant socially, giving rise to so-called Manchester capitalism, trade unionism, as well as concerns for the environment. A piece of evidence is the artificial word 'smog', which combines 'smoke' from the burning of coal and 'fog'. Indeed, disastrous air pollution led to several thousands of premature deaths in London and other industrial centers.
- At the turn of the twentieth century, coal was partly replaced by crude oil as the leading energy source, foremost in the United States. The ample availability of this relatively cheap energy source made the realization of the American Dream (meaning material prosperity for all) possible—though associated with excess use and waste of energy.
- The service, information, and communication society (the outcome of the second industrial revolution) depends on electricity as its key energy source. Development of the necessary power systems started with large-scale thermal power plants, including nuclear. Currently, these capacities are being replaced by distributed power generation based on wind, solar, biomass, and cogeneration (also known as combined heat and power). This transition has just begun; at this time, a future steady state is not yet in sight. However, it is quite possible that the character of society may change again, due to a massive acceleration of innovation transforming its infrastructure.

This short overview indicates that stages in the development of energy systems have paralleled the evolution of societies. Therefore a comprehensive analysis of energy systems has to cover much more than its engineering and economic aspects. Contemporary critical writers decry the unsustainable development of present energy systems. Some claim that a transition to a sustainable, environmentally friendly energy system needs to go along with basic societal change modifying the way of life in modern industrial societies—not to mention that in developing countries. Others reject the economic approach to solving energy problems, maintaining that a transformation designed to achieve sustainability should not be driven by economics but rather by social and ethical ideas.

While most energy economists accept the importance of ethical responsibility and social justice within and between generations, they also point to historical experience suggesting that societal guidelines and governance can have rather disastrous results if individual preferences and welfare are neglected. Transforming an energy system is not feasible if political decisions and interventions lack the majoritarian support of the society. Consideration of people's preferences and constraints with regard to energy is key to energy economics. The remit of energy economics is to seek solutions that take into account the preferences of consumers, managers, and owners of companies as well as political leaders. Of course, individuals who are altruistic and take the welfare of others into account facilitate such solutions, yet a society consisting mostly of altruistic individuals is likely to be an idealistic assumption.

1.2 Why Energy Economics?

General economic theory provides a number of relevant insights for analyzing energy markets. Notably, energy sources belong to the category of scarce goods even if they are physically abundant. Like in other markets, prices coordinate individual decisions on the supply and the demand side. At first sight, the model of an ideal market seems to apply to many energy markets: They can be clearly defined, products traded on them are highly homogeneous at least from a physical point of view, and many prices are transparent. If the number of independent suppliers is large, the corresponding energy market fits the model of perfect atomistic competition. This means that individual suppliers can only choose the quantity of energy Q they would like to offer (acting as so-called price takers). Let them maximize their per-period profit, i.e. the difference between revenue $\bar{p} \cdot Q$ and total cost $C(Q)$,

$$\Pi(Q) = \bar{p} \cdot Q - C(Q). \tag{1.1}$$

The solution to this problem can be found by setting the derivative of the profit function (1.1) with respect to the produced quantity Q equal to zero,

$$\frac{d\Pi}{dQ} = \frac{d(p \cdot Q)}{dQ} - \frac{dC}{dQ} = \bar{p} - \frac{dC}{dQ} = 0 \quad \rightarrow \quad C' := \frac{dC}{dQ} = \bar{p}. \tag{1.2}$$

Under atomistic competition, producers cannot individually influence the sales price p, causing them to take it as a predetermined constant $p = \bar{p}$. Thus, as long as the sales price exceeds the extra cost of producing an additional unit C' (known as marginal cost), producers have an incentive to expand output. Otherwise, they will curtail production.

If each supplier decides according to the marginal cost rule, the resulting market price equals the marginal cost of the last unit needed to meet overall demand. The corresponding supplier is called marginal supplier, while those with marginal cost below the market price earn a producer surplus that allows them to recover at least part of their fixed cost of production.

On the demand side, marginal willingness to pay derives from marginal utility of consumption. Demand for a good is triggered as long as its marginal utility exceeds the marginal cost of consumption (the market price in this simple model). In the case of energy, this is a derived demand because utility does not emanate directly from the consumption of energy but rather from the services associated with it, such as lighting, heating, use of appliances, and transportation. Therefore, the contribution of energy to the production of these services (its marginal productivity to be precise) has to be taken into account to determine the marginal utility of energy.

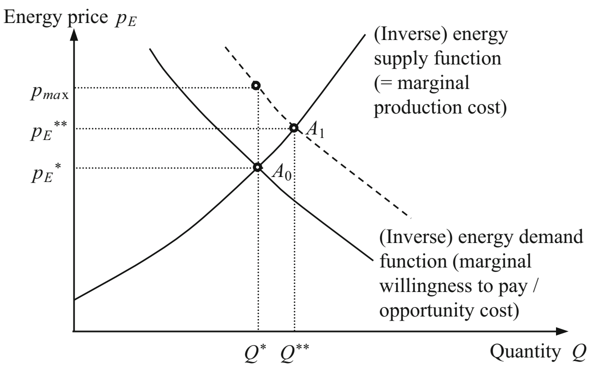
This description is highly simplified. In actual fact, consumers are interested in more than just one good. The rule, “Marginal utility equal price” therefore has to be generalized to become, “The ratio of any two marginal utilities equals the ratio of their prices”. Accordingly, the ‘utility of energy’ amounts to the marginal utility associated with the next-best alternative which the consumer foregoes when purchasing energy (so-called opportunity cost).

1.2.1 Price Mechanism and Market Coordination

In a market economy, the function of prices is the decentralized coordination of supply and demand. No market participant needs to have knowledge of the situation of other market participants (regarding their individual cost and opportunity cost in particular). Knowledge of the market price is sufficient for coordination through markets. For market prices to play their intended role, they need to have an impact on demand and supply quantities. This is generally the case. On the supply side, a higher sales price causes aggregate supply to increase (see the positive slope of the supply function in Fig. 1.1). In the short term, this means that producers are running down stocks and increasing capacity utilization, while in the long term, this entails an increase in production capacity by incumbents and market entry by newcomers. On the demand side, a higher price leads to reduced consumption (see the negative slope of the demand function in Fig. 1.1). An increase in price of the good in question drives up opportunity cost since its purchase leaves less income to be spent on other goods and services. Short-term reactions in the case of energy include setting thermostat values at a lower level and traveling shorter distances, while intermediate and long-term reactions can be purchasing energy-efficient appliances, insulating buildings, and substituting expensive fuels (e.g. gasoline) with less expensive fuels (e.g. diesel).

In Fig. 1.1, the price of energy (relative to that of other goods and services) is depicted on the vertical axis, although it is the argument of both the demand and the supply function (this is an idiosyncrasy of economists). As long as the demand function (shown as the solid decreasing line) describes the current behavior of energy consumers, the equilibrium energy price is p_E^* and the traded volume, Q^*. Costumers willing to pay at least this price are served, while suppliers asking for a price equal or below p_E^* can sell. Thus supply and demand are balanced at the

Fig. 1.1 Market price coordinating supply and demand



equilibrium, indicated by point A_0. For reaching this equilibrium, the only information that must be available to all agents is the market price. It permits each market participant to individually decide how much to demand and how much to supply, without taking into account the behavior of other market participants.

The coordinating function of a market also becomes evident when an exogenous change in market conditions occurs. For example, let an increase in income boost willingness to pay of consumers. This implies that they are prepared to pay a higher price of a given quantity of energy (depicted as the vertical shift of the demand curve to become the dashed line of Fig. 1.1). Alternatively, consumers can be said to demand a higher quantity at a given price, which amounts to an outward shift of the demand curve. Under either interpretation, the shift of the demand curve leads to a shift of the market equilibrium from A_0 to A_1, with a new, higher equilibrium price $p_E^{**} > p_E^{*}$ and a new, higher quantity transacted $Q^{**} > Q^{*}$.

However, supply may not be as flexible in the very short term as depicted. In the extreme, it does not respond to the higher sales price at first, implying that the supply curve runs vertical at point A_0. Accordingly, price will shoot up to the level p_{max}. The increased price signals to suppliers that it is profitable to expand production at the prevailing market price, causing prices to fall from $p_{\max}$ to p_E^{**} while the quantity transacted rises to Q^{**}.

Given perfect competition (no market power, no discrimination against any consumer or producer, no external effects, and transparency with respect to price), the equilibrium is Pareto-efficient. This means that no supplier and no consumer can reach a better position unless at least one market participant is made worse off. To see this, consider a price slightly higher than the initial equilibrium price p_E^{*}, with the solid demand curve obtaining. Of course, this would improve the situation of suppliers. However, consumers would suffer. Moreover, at p_E^{*} the minimum value of marginal willingness to pay of those served still suffices to cover the marginal cost of the extra unit of energy made available to them. This means there is no squandering of resources. Therefore, in a Pareto-optimal state the market allocation is efficient.

It would be desirable if this simple law of supply and demand offered conclusive answers to the strategic issues relating to energy, such as:

– How much scarce capital should be invested in the exploration, development, and distribution of new energy sources?
– What quantities of scarce production factors should be allocated to the extraction of already known energy deposits of inferior quality?
– What quantities of scarce factors of production should be made available for substituting fossil energy with renewable energies or the implementation of energy efficiency measures, respectively?
– How much should be invested in the abatement or management of environmental emissions?
– How much should be devoted to improving the safety of energy systems?

In many instances, the simple model of a competitive market may provide first hints towards answering these and similar questions. Yet deeper analysis shows that this model is not always appropriate for explaining and analyzing the complex reality of energy markets. Indeed, a simplistic model may in the extreme even result in misleading statements about a particular market characterized by crucial particularities.

1.2.2 Particularities of Energy Markets

If the idealized model of atomistic competition were a perfect representation of energy markets, there would be no reason for energy economics as a specific field of economics to exist. The role of energy economists would simply be the collection and evaluation of energy market data using standard economic concepts. However, energy economics is more than just the mere collection and statistical analysis of market data. Most markets for energy have particularities due to physical, geological, geographical, and technical properties of the energy source traded, making them deviate from the idealized economic model. The following list contains some of these characteristics:

- Without energy, no economic activity is possible. In economic language, energy is an essential factor of production, very much like labor (whereas a subsistence economy can do without physical and human capital). Disruptions of energy supply (e.g. the oil crisis of 1973/1974, electricity blackouts) can cause severe damages to the economy and society.
- Energy is necessary to satisfy basic human needs. Economic progress in many poor societies is hampered by an insufficient supply of energy, which in turn is often caused by a lack of ability to pay. Therefore, low incomes lead to unavailability of energy which in turn depresses productivity and hence incomes—the classical example of a poverty trap.
- Most energy infrastructure is characterized by long periods of planning, investment, and operation. As a consequence, its adjustment to economic and social change is slow. Since trends in energy demand cannot be easily predicted, relatively long spells of excess capacity and lack of capacity may occur.
- In many countries property rights of underground resources and hydropower are vested with the public rather than the private sector. Likewise, the construction of infrastructure (e.g. pipelines or transmission lines) often requires the right to use public grounds such as streets. Depending on the authority in charge (local, regional, or national government), energy markets are generally more dependent on political decisions (and with them public pressure) compared to other markets.
- Reserves of fossil energy reserves such as crude oil and natural gas are concentrated in a few countries, whose economy is dominated by the extraction industry. This facilitates a symbiosis between (often multinational) companies and domestic politicians which may be beset by corruption. In addition,

resource-abundant countries face a major challenge when their extraction industry starts to decline due to the depletion of resource deposits.

– A well-known and widely discussed issue is negative environmental impacts of the extraction, transformation, transmission, and use of energy. Indeed, the energy sector is the largest single source of emissions into air, water, and soil. In economic terms, these emissions represent negative externalities which are normally not reflected in the prices of energy sources, causing markets not to be Pareto-efficient.
– Another challenge of technical energy systems is the risk of large-scale accidents. This risk is not only relevant for nuclear power generation but also wherever large quantities of energy are locally concentrated, e.g. in a boiler or an oil tanker. Beginning in the nineteenth century, inspection authorities have been created whose mission is to protect people working in plants and living in surrounding areas. Yet, they suffer from an asymmetry of information in that plant managers know more about the level of safety achieved than the regulator (this is a core issue in the economic theory of regulation).
– Negative environmental externalities can be reduced by saving energy and improving energy efficiency, but demand for and supply of investment in energy efficiency is not developing as fast as intended due to a number of distortions. As a result, political interventions designed to speed up the process may be initiated.
– Physical depletion of fossil energy sources and the risk of climate change due to large scale emissions of greenhouse gases give rise to the issue of intergenerational justice. This type of justice requires that current decisions concerning energy systems should reflect the interests of both present and future generations in an efficient way.
– Many renewable energy technologies presently are not fully competitive but may become competitive in the future, when prices of exhaustible resources are bid up. Consumers may have an interest in their market entry being sped up, possibly justifying their subsidization by government in the aim of ensuring a sufficient future supply of energy. Since these new technologies may fail to become competitive, economic analysis designed to determine the conditions under which subsidies of this type are efficiency-enhancing and serving intergenerational justice is called for.
– Many energy markets are characterized by monopolies or oligopolies rather than perfect competition. In the transmission and distribution grid industries (natural gas, electricity, and district heat), the monopoly can even be said to be 'natural' since the establishment of competing infrastructures would be wasteful. The downside is a potential abuse of power by the single provider. In order to prevent this, governments generally regulate these industries.

In view of this long list, it is evident that many energy markets function and are governed by rules in ways that do not correspond to the model of a perfect market. They therefore need to be analyzed using more complex modeling approaches. While economists have developed a manifold of them, the analysis of monopolistic markets provides first guidance in many instances. The basic idea is that a monopolistic supplier does not consider its sales price p as an exogenously given market price but rather influences it by its own actions. Indeed, being a monopolist means being confronted with the aggregate demand function and its negative slope. This implies that quantity sold Q (and hence production) and sales price p are negatively related. Therefore $dp/dQ < 0$, contrary to the case of atomistic competition where $dp/dQ = 0$ (see Eq. 1.2). Using the quantity produced as the decision variable, one obtains the first order condition for profit maximization,

$$\frac{d\Pi}{dQ} = \frac{d(p(Q) \cdot Q)}{dQ} - \frac{dC}{dQ} = p + Q\frac{dp}{dQ} - \frac{dC}{dQ} = 0. \tag{1.3}$$

Here, Π again denotes profit per period (e.g. a year), Q production, C total production cost, and p the sales price. Equation (1.3) can be solved to yield

$$\frac{dC}{dQ} = p + Q\frac{dp(Q)}{dQ} < p. \tag{1.4}$$

Under atomistic competition each supplier determines its production according to the "marginal cost = price" rule (see Eq. 1.2). By way of contrast, the monopolist has an incentive to observe the inequality "marginal cost < price" by holding back its production in order to enforce a higher price. By holding back production, the monopolist in fact deprives some consumers of the good or service, although they are willing to pay a price that covers the extra cost of serving them. Therefore, this outcome cannot be (Pareto-) efficient.

1.2.3 Energy Policy

In cases where self-interested behavior of market participants alone fails to reach a Pareto-optimal state due to particularities of energy markets, the term 'market failure' applies. Market failures are an argument for energy policy to intervene into markets in order to correct market failures. Ideally, a Pareto-optimal state can be achieved.

Public energy policy has been in existence for a long time. Prior to the first oil price shock in 1973, its basic aim was to secure the supply of energy by stimulating investment in coal mining, oil extraction, power plants, as well as transmission and distribution grids. It was completed by government control of the safety and reliability of technical installations and of market power—with the exception of electricity, gas, and district heat where monopolies were even sometimes encouraged. Since 1973, energy policy has extended its scope. Triggered by the oil price shocks, the issue became securing the supply of energy, also by diversifying primary energy sources and transportation routes. In addition, energy saving and energy efficiency entered the political agenda. In the 1980s, the new themes were societal skepticism regarding nuclear power generation and the development of renewable energy supplies. Since the 1990s, the energy policy of many

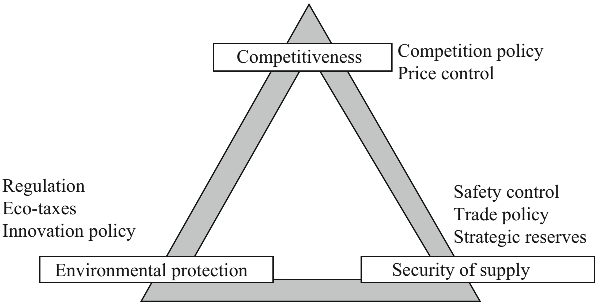


Fig. 1.2 Magical triangle of energy policy goals

countries has been focusing on the liberalization of energy markets, abatement of greenhouse gas emissions, and sustainable development. Yet from the viewpoint of energy economics, the common theme of all these challenges and debates is the attempt to correct different types of market failure.

To structure the debate, the so-called magical triangle shown in Fig. 1.2 has proved helpful. According to it, energy policy has a triple mission: It should secure the supply of energy, contribute to economic competitiveness, and render the use of energy compatible with the environment. While these objectives are generally accepted in principle, their pursuit by policy-makers meets with complications. Indeed, objectives can be related to each other in three different ways.

– Complementarity: In this case, progress in the achievement of one objective contributes to the achievement of the other. An example is the positive impact of a more efficient energy use on the security of energy supply.
– Neutrality: Progress in the achievement of one objective has no impact on the achievement of the other.
– Antagonism: Progress in the achievement of one objective undermines achievement of the other, forcing a trade-off on policy-makers. Trade-offs are typical for many decisions in energy policy, calling for their multi-criteria evaluation. Ideally, an objective function should be defined as the weighted sum of multiple target indicators with their weights reflecting individual preferences.

If individuals in a society have significantly different preferences, social decision-making meets with great difficulty. First, individual preferences need to be consistent. Someone who ranks compatibility with the environment higher than security of supply and ranking it in turn higher than economic competitiveness, is expected to also rank compatibility with the environment higher than the economic competitiveness when the two are pitted against each other.

But even when individual preferences are consistent, democratic decision-making used for their aggregation may lead to inconsistent social preferences. This was shown by Nobel Prize laureate Kenneth Arrow (1951) and can be demonstrated simply for a society consisting of three individuals with three different preference orderings,

– Individual 1: environment $\succ$ competitiveness $\succ$ supply security;
– Individual 2: competitiveness $\succ$ supply security $\succ$ environment;
– Individual 3: supply security $\succ$ environment $\succ$ competitiveness.

Here, the sign '$\succ$' symbolizes "strictly preferred to". Assuming democratic majority voting on pairwise alternatives, the outcome is

– environment *versus* competitiveness 2:1
– competitiveness *versus* supply security 2:1

An implication of these voting results is that compatibility with the environment is strictly preferred to supply security. However, a vote directly pitting supply security against the environment leads to the opposite preference ordering.

– supply security *versus* environment 2:1

This failure to achieve a consistent social preference ordering through simple majority voting has become known as the Arrow paradox. It is likely to occur in societies whose individual members and interest groups representing them have heterogeneous preferences. In this case, decision-making with respect to energy policy may be blocked, with the political debate producing no more than formal compromises, an outcome that can be often observed in real life.

Governments may try to prevent the blockade by avoiding a vote on energy issues. However, there is also the alternative of so-called logrolling. In the example above, it is sufficient for one individual to modify his or her preference ordering to achieve consistency in the aggregate. This modification can be brought about by the promise to support the individual on another issue. Logrolling in parliament therefore permits to reach consistency of social preferences; yet it is viewed by suspicion by voters who fear that their delegates betray them in their own personal interest (they also may not attribute much importance to the other issue facilitating the logrolling).

The Arrow paradox provides an explanation of the conditions that may lead to unsuccessful attempts at correcting failures in energy markets. Additionally, there is another problem. Political interventions are usually not costless. They require the gathering of information, impose costly controls, and may not be executed in an optimal manner. Selfish interests of political decision-makers and governmental institutions need to be taken into consideration as well, causing acts of energy policy not always to be in the overall interest of society. Therefore, the results of political intervention in energy markets may even be less Pareto-efficient than the situation without intervention, an outcome known as policy failure as opposed to market failure.

1.3 History of Energy Economics

Energy economics is a comparatively young field of teaching and research. Interest in it was triggered by an influential study published by the Club of Rome in 1972. Written by Dennis Meadows, it was titled "The Limits to Growth" (Meadows et al. 1972). His work used approaches borrowed from system dynamics to predict the collapse of the world economy as a consequence of declining oil reserves and increasing emissions harmful to the environment. Shortly after this publication, the two oil price shocks of 1973 and 1979 appalled the world, seemingly confirming this pessimistic view.

In response, a few economists began to develop new models, emphasizing the impact of price on the behavior of market participants. According to these models, the relative price of oil would have to rise, stimulating substitution processes long before the world runs out of oil. Therefore, the increase in the oil price was to be seen as a step towards the solution of the energy problem. In fact, global oil consumption began to decline, as predicted by the economic models. Among the best known contributions of the time are the Hudson-Jorgensen model (Hudson and Jorgenson 1974, 1978) and the ETA-MACRO model (Manne 1978). These and other early models improved the understanding of energy markets as well as the quality of recommendations guiding energy policy.

With the drop of oil prices in early 1986, the attention shifted to environmental problems. From the economist's viewpoint it was obvious that the price mechanism should again help to solve them. Energy prices were to not only reflect cost as calculated by the energy industry but also the external costs associated with environmental damage caused by producing, transporting, and using energy. Energy economists put considerable effort into the conceptualization and quantification of externalities and their evaluation as external costs. Perhaps the most prominent study in this regard is the ExternE project sponsored by the European Union between the early 1990s and 2005. The fruit of these efforts was the introduction of ecological taxes followed by tradable emission rights, constituting an instance of successful energy policy consulting.

Since its beginning in the 1970s, energy economics has also revolved around the analysis of institutions and rules governing energy markets, with market power in grid industries becoming a crucial topic. These activities resulted in concepts of competition and deregulation of grid industries, which started to be implemented by Ronald Reagan in the United States and Margret Thatcher in the United Kingdom in the early 1980s. Another cornerstone was the European single electricity market directive (EU Directive 96/92/EC). With the implementation of this directive, European power markets changed faster than ever before in their history. A few years later, similar developments occurred in the European gas industry (EU Directive 98/30/EC).

At present, ongoing reforms of electricity markets are not the only source of change affecting the energy industry. Volatile prices of fossil fuels and ever more frequent government interventions in terms of market regulation, emission trading, renewable energy, and capacity markets challenge actors in energy markets again and again. Business concepts that have been successful in the past may turn out to be a recipe for future disaster. A high degree of adaptability, fast and smart decision-making, and vigorous action are required for energy companies to succeed in a market environment that is difficult to predict.

In future, energy economics will be able to keep its consultancy role for business and public policy only by shifting its attention from processes of substitution to dynamic and complex processes of innovation. It was rather successful with its proposition that substitutability is the key to the solution of many energy problems. It has also been quite strong in elucidating the conditions that facilitate efficient solutions, e.g. in climate policy and renewable energy development. Given the recent acceleration of market dynamics, however, an understanding of the interactions between innovations and adaptive markets is critical. During the past 40 years, energy economics has developed into something far more than a mere academic activity. It is about to become as relevant to public policy as monetary economics and public finance. May this book accompany its readers on this path.

References

Arrow, K. J. (1951). *Social choice and individual values*. New York: Wiley.

Georgescu-Roegen, N. (1971). *The entropy law and the economic process*. Cambridge, MA: Harvard University Press.

Hudson, E. A., & Jorgenson, D. W. (1974). U.S. energy policy and economic growth 1975–2000. *The Bell Journal of Economics, 5*, 461–514.

Hudson, E. A., & Jorgenson, D. W. (1978). Energy policy and U.S. economic growth. *American Economic Review, 68*(2), 118–123.

Manne, A. (1978). ETA-MACRO: A model of energy-economy interactions. In R. Pindyck (Ed.), *The production and pricing of energy resources*, *Advances in the economics of energy and resources* (Vol. 2). Greenwich, CT: JAI Press.

Meadows, D. H., et al. (1972). *The limits to growth*. New York: Universe Books.