CHAPTER 1

HISTORY AND FUTURE OF ENERGY USE

1. Introduction

Energy has been a topic of discussion for centuries. In their time, Malthus (1798) and Ricardo (1817) were already issuing warnings for high population growth. The growth in population would bring about an era of diminishing returns in agriculture and would increase the scarcity of non-renewable resources. Later, Jevons (1865) used detailed estimates of available coal reserves in the UK and combined these estimates with the potential new uses of coal in order to predict the increasing scarcity of coal in the world.

In this chapter, we provide a macroeconomic and long-term view of energy and resources. In the second section, we present what economics as a science sees as the driving forces of energy use. The ultimate driving factors will be population, technological progress, institutions, and availability of resources. These factors determine economic growth, energy use, and energy prices. In the third section, this framework is used to very briefly analyze the historical development of energy use. In the fourth section, we draw some lessons for the future. In the final section, we present an overall scheme for understanding developments on the energy markets.

2. Drivers of energy use and energy prices

The demand for energy (or energy use) is a derived demand. Energy as such has no value, but when combined with – for example – capital, energy services are produced that create value for those who use these services. To understand the long run and short run demand for energy, one therefore needs to understand what drives the demand for these energy services. The next sections present two simple frameworks that help us to better understand the demand for energy services and energy in the production and household sector. Both frameworks take a microeconomic perspective.

2.1 Energy use in the production sector

In order to structure the determinants of energy use and prices, we need a small formal representation of an economy. We do this with the help of a few equations. We have two final goods: a general good Y that serves all purposes and a final energy good E (electricity, coal, gas or oil delivered to firms or households). The first equation is a production function for the general good Y:

$$Y = F(\rho, \theta, K, L, E, A)$$

This equation gives the maximal output of the general good Y that can be produced by combining efficiently four types of input: capital K, labor L, energy E, and land A. The overall output level depends on two more factors: technological progress ρ and institutional quality θ. It is useful to express the production possibilities per capita (where small letters represent the quantity per capita) and leave out land as a production input, as we mainly discuss industrial production:

$$y = F(\rho, \theta, \mathrm{k}, \mathrm{e})$$

The output per capita y depends on the available capital k (e.g. machines, buildings, vehicles) and the available quantity of energy e. Energy has to be understood in a very broad sense, covering manpower and horse power, energy provided by a combustion engine (power) or an electric engine (electric power) as well as heating oil, diesel and gasoline.

For any given level of inputs *(k,e)* the ultimate production level will also depend on the level of technology (ρ). The level of technology will determine the overall efficiency of the production process including the conversion efficiency of energy. Take for example moving an object in the production process: one can do this manually, using horse power, a small truck, or a robot. The higher the level of technology, the fewer inputs are needed for a given level of output. Technologies can be 'oriented' in the sense of saving more of one input: it can be energy saving, labor saving etc. If one production factor (say energy) becomes more expensive, it pays off to look for new technologies that allow substituting the expensive production factor by cheaper production factors (investment in insulation, fine-tuned heaters).

A second factor that plays a key role to increase the level of output for given inputs are the institutions. Institutions represent all organizational aspects in an economy: the political system, the legal system that includes property rights and company law. But it also includes less formal elements such as social norms. The political and legal systems will be important in understanding under which forms the production process can be organized. If one needs a certain scale of operation, one needs sufficient capital and coordination. A private firm that can call upon the capital market (a corporation in the legal sense) is one of the most important institutions that can increase the productivity of an economy. Another important institution is a patent law that allows an inventor to sell his knowledge to the users. When there is no patent protection, the incentive for inventors to look for better techniques will be much smaller. Acemoglu and Robinson (2012) demonstrate the importance of institutions by comparing areas that have identical geographical conditions but show large differences in economic performance. One of their examples is about two border towns, one located in Mexico and the other one in Texas. Both towns have the same genes and the same climate but the average income is three times higher in Texas due to a different institutional environment. There are many other examples: North and South Korea or the Dominican Republic and Haiti. In both cases, the countries occupy the same island but their productivity is dramatically different because of the differences in institutional structure.

For given institutions and technological know-how, the output per capita depends on the available capital and energy. To some extent, capital and energy inputs are exchangeable, an idea that is captured in iso-output lines or isoquants. Figure 1.1 represents two extreme cases: a fixed proportion technology (‘Leontief-type’ production function) and the full substitutability case (‘linear’ production function). In the first case, in order to move from a level of output per capita of y° to y^*, one needs to increase the inputs in the same proportion. For example: one tractor always needs a given amount of fuel to work for one hour. Having more tractors or more fuel but not both is useless as they will not generate more output. Very poor substitution possibilities between energy, land, and other inputs were implicit assumptions in Malthus’ and Ricardo’s reasoning. If over time the amount of energy or land per capita is decreasing, once one has passed a critical ratio, the overall level of output per capita has to decrease over time. In Figure 1.1, the bold arrow shows a possible development of the production inputs over time. It is a development with increasing energy scarcity. If there are no substitution possibilities, the total output will go down once one passed point A.

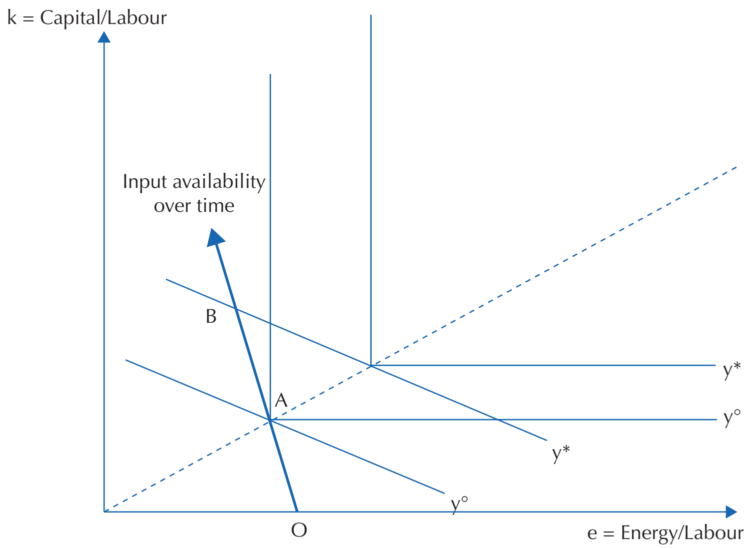


FIGURE 1.1. Substitution possibilities in the production sector.

The other extreme view is represented by the linear isoquants for levels $y°$ and y^*. When the isoquants are linear, one can always substitute one input by another by substituting 1 unit of energy by a fixed number of units of capital. Take again the example of a tractor: by spending x units more on a tractor, one can always save z units of fuel and continue to have the same agricultural production. If, for one reason or another, the available quantity of energy per capita decreases over time, as suggested by the arrow in Figure 1.1, the production possibilities of the economy could still increase as long as one can compensate for the decrease in energy availability with more capital. The substitution possibilities in the economy will thus be a crucial parameter for the 'sustainability' of economic growth. We return to this issue in chapter 5.

In a market economy, an efficient use of available capital, labor, as well as energy inputs in the production of goods requires that the relative prices of inputs are the same in all production sectors and that all production units minimize their costs. The intuition for these conditions is simple: relative prices of inputs signal the relative scarcity of the inputs in the whole economy. If a particular input is more productive in another sector, one should use it there. Cost minimization means that no inputs are wasted. A minimum of scarce inputs are used to produce a given output level at given prices for the inputs.

Once we allow prices to organize the use of resources, we can work on a more partial scale and use demand functions for inputs rather than production functions. A demand function for inputs is a functional relation between the demand for one input and exogenous drivers that are taken as given (prices of the input, other prices, production levels). A demand function represents the input choices of the firm. Demand functions can be aggregated at the level of the sector, at the level of the economy etc. The demand function for energy use in one production sector can be derived by minimizing the production costs TC for given production function F( ) and given output level Y°:

$$\text{Minimize } \mathrm{TC} = \mathrm{p}_E E + \mathrm{p}_K K + \mathrm{p}_L L$$
$$\text{w.r.t. E,K,L}$$
$$\text{subject to } F(\rho, \theta, K, L, E) \geq \mathrm{Y}°$$

Based on the Lagrange function, we find

$$\mathrm{p}_E = \lambda \frac{\partial F}{\partial E}; \quad \mathrm{p}_K = \lambda \frac{\partial F}{\partial K}; \quad \mathrm{p}_L = \lambda \frac{\partial F}{\partial L}$$

$$\frac{\mathrm{p}_E}{\mathrm{p}_K} = \frac{\frac{\partial F}{\partial E}}{\frac{\partial F}{\partial K}}; \quad \frac{\mathrm{p}_E}{\mathrm{p}_L} = \frac{\frac{\partial F}{\partial E}}{\frac{\partial F}{\partial L}}$$

Using the first order conditions of this cost minimum problem, one can derive a demand function for energy use in a firm, in a sector and in the production sector of an economy as a function of the exogenous elements (volume of production and all prices of inputs):

$$D_E = d(p_E, p_K, p_L, Y°)$$

So, the demand function for energy incorporates all substitution possibilities between inputs (the curvature of the isoquants or the functional form of the production function). For given prices of other inputs, one expects the demand for energy from an industrial sector to be a decreasing function of its price, and this reaction will be stronger in the long-term than in the short-term. The reaction in the long term will be stronger because there are more substitution possibilities when one can opt for other technologies and new equipment. This process takes time as running existing installations for some time is usually cheaper. When the demand function is formulated at the level of the country, the composition of the industrial production can change because energy-intensive goods may become more or less expensive. This affects the demand for the different types of output and thus the sectoral composition of the economy. So changes in energy prices work through the whole economy via changes in technology per sector and changes in the sectoral composition of the industrial activity.

2.2 Energy use by final consumers

Energy is used for production purposes but also for example for heating, lighting, and passenger transport. We formulate the energy demand problem of the consumer in its simplest form as follows. Consumer preferences for energy services x_2 (e.g. heating a house) and other consumption goods x_1 are given by the utility function $U(x_1, x_2)$, which is increasing in both arguments. A utility function is a mathematical expression of the preferences of the consumer and such a function is used to structure the choices of a consumer. As preferences differ among individuals, there are as many utility functions as there are individuals. Structuring the choices with a utility function is useful because it allows setting restrictions on the choice behavior of consumers.

The consumer who maximizes his utility function faces two constraints. The first one is the budget equation, which says that total expenditures on consumer goods and on energy (e) cannot be larger than the income of the consumer: $p_1 x_1 + p_e e \leq I$. The second constraint is the production function of energy services at home, a simple example being $x_2 = ke$, where k is the efficiency of conversion of energy into energy services. If the consumer optimizes consumption under these two constraints, this generates the demand functions:

$$x_1 = F\left(p_1, \frac{p_e}{k}, I\right)$$

$$x_2 = G\left(p_1, \frac{p_e}{k}, I\right)$$

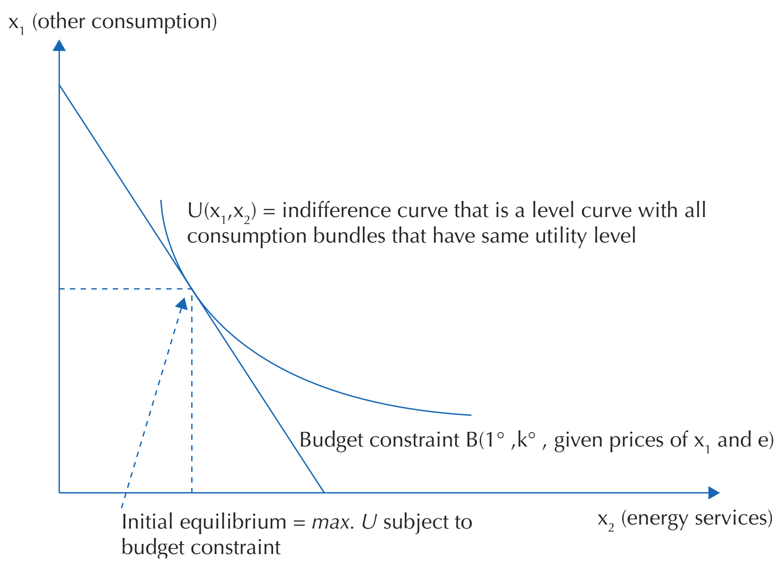


FIGURE 1.2. Initial consumer equilibrium.

This problem is a simplified version of the one where the consumer has to solve a more complex problem where he also chooses the level of efficiency (k) by investing in more efficient equipment (better heater, higher level of insulation) next to choosing the level of energy services and of other consumption goods. The initial consumer equilibrium is shown in Figure 1.2. The budget constraint defines the border of a set that represents all combinations of x_1 and x_2 that can be bought with a budget $I°$. The utility function is represented by level curves that each represent the combinations of the volumes of consumption goods and energy services that generate the same level of utility. A consumer always prefers a higher level curve. The consumer equilibrium then is that combination of the consumption of the two goods that maximizes his utility and is still feasible given his budget.

In Figure 1.3, one can observe the consumer's response to a decrease in the income level (ΔI). The budget curve shifts down, and the corresponding indifference curve shows a lower level of utility as the consumption of both goods is now lower. Typically, energy services are considered as a necessity, they tend to be less sensitive to income changes: in the short run, the elasticity with regard to income ($\frac{dx_2}{x_2}\frac{y}{dy}$) will be smaller than 1. In the longer run, this elasticity can increase as the consumer has more time and alternatives to adapt his behavior (insulation, other heating equipment, larger house etc.) to changes in income.

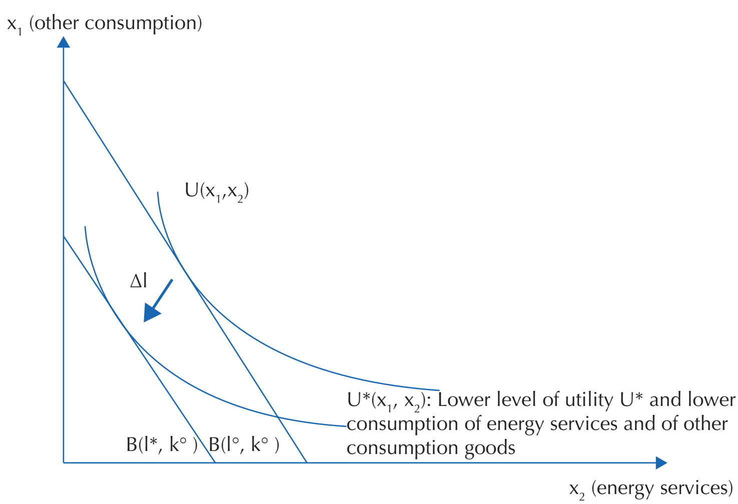


FIGURE 1.3. Consumer response to decrease in income.

In Figure 1.4, the consumer response to an increase in energy efficiency is graphically displayed. In this example, an improvement of conversion efficiency allows us to enjoy the same level of energy services at a lower cost as the price of the energy service has decreased. This saving can be used either to buy more other consumer goods and/or to increase the consumption of energy services. This depends on the preferences of the consumer. The increase in energy service use when a more energy efficient technology is used, is called the "rebound effect". The rebound effect can be small (about 5%) but also large (about 50%), depending on the type of energy services. It is important to realize that a gain in energy efficiency does not lead to a proportional reduction in energy consumed. The price elasticity of energy services is typically negative and is defined as:

$$\frac{\partial x_2}{\partial p}\frac{p}{x_2}$$

In the long run, when conversion technology can be adapted, the (absolute value of the) price elasticity will be larger.

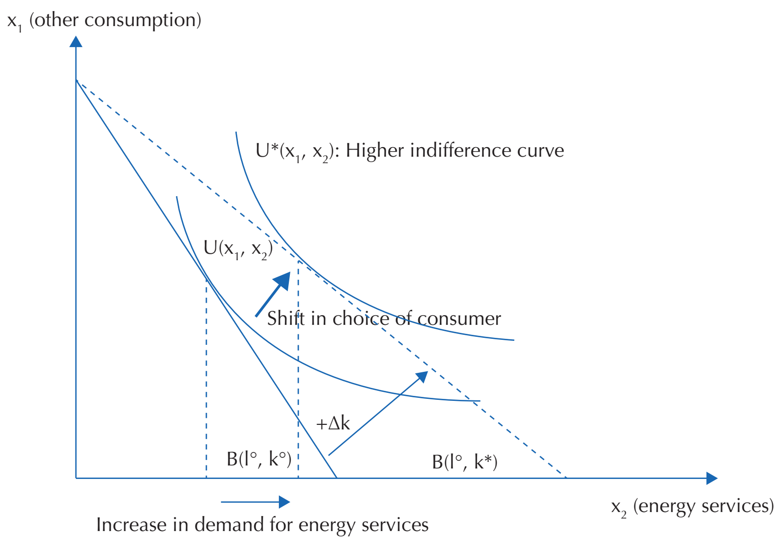


FIGURE 1.4. Consumer response to increase in conversion efficiency.

2.3 Main drivers of energy use

In sum, there are two main types of energy users: households and industry (in a broad sense), each with two main drivers of energy use. The first one is common to both and is the price of energy services, which equals the price of energy divided by efficiency (where efficiency is technology driven). The second driver is income (per capita) for households and economic activity for industry. Demand for energy services for households could increase when the price decreases, which happens when either efficiency increases or energy prices decrease. Demand for energy services can also increase because of changes in preferences for comfort at the consumer end (for example more rooms heated, higher room temperature, more air conditioning, more transport) or other exogenous changes in the living circumstances (other climate, better roads leading to more driving). We also know that demand for energy reacts to changes in energy conversion technology and that this reaction is not necessarily proportional (see section 2.2).

Demand for household energy services can also increase when income increases. There is a direct effect on the consumption of energy by households from heating, transport, etc. because of the higher demand for comfort. An income increase also implies higher demand for (non-energy) consumption goods that also require energy to be produced, which also positively affects demand for energy by industry and service sectors.

Energy use by the production sector (industry, services, agriculture) has two main drivers: demand for goods and services by the production sector and energy intensity of production. Demand for outputs depends on the relative prices of goods and on income levels of local households and foreign consumers. The energy intensity of a production sector depends on the relative prices of energy and other inputs as well as on the technology.

Clearly, household and firm decisions at the micro level will, through population and industry size, also influence evolutions at the aggregate level. And technological progress, population growth, institutional changes and changes in the economic structure, will also impact the evolution of energy use over time. One typical measure to describe a country's evolution of energy use over time is 'energy intensity', which is defined as the amount of energy used (measured in some common unit) to produce one unit of output (measured by GDP). In combination with population size and income per capita, energy intensity explains energy use. The following expression (actually an identity) makes this clear:

$$E_t = Population_t \times \frac{GDP_t}{Population_t} \times \frac{E_t}{GDP_t}$$

This expression will help us to discuss the evolution of energy use both in historical and forward looking perspective.

3. Energy in historical perspective

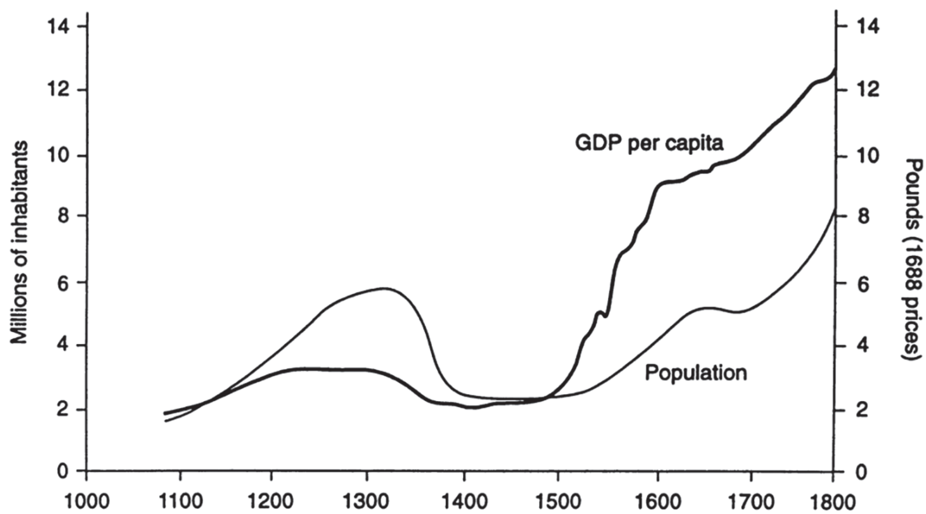
A detailed study of energy in a historical perspective would take us too long. In this course we will mainly study recent developments (after 1950), but it is useful to briefly look back in time.

Our early ancestors were hunters and tended to eat their kill raw. Before they knew fire they lived on an energy budget of 8 MJ/day. Fire use increased energy consumption to 17 MJ/day and domestication of animals raised it to 40 MJ/day. Once coal was used more intensively, consumption in the US rose to 400 MJ/day in the early 20th century and it continued to grow to 1000 MJ/day in 2000 (Aubrecht, 2006).

To discuss the main drivers of energy use throughout history, we rely on the work of Fouquet and Pearson (1998) and Fouquet (2009, 2011). Most of this work is related to the UK for which good historical data is available. The analysis focuses on the period after the 13th century.

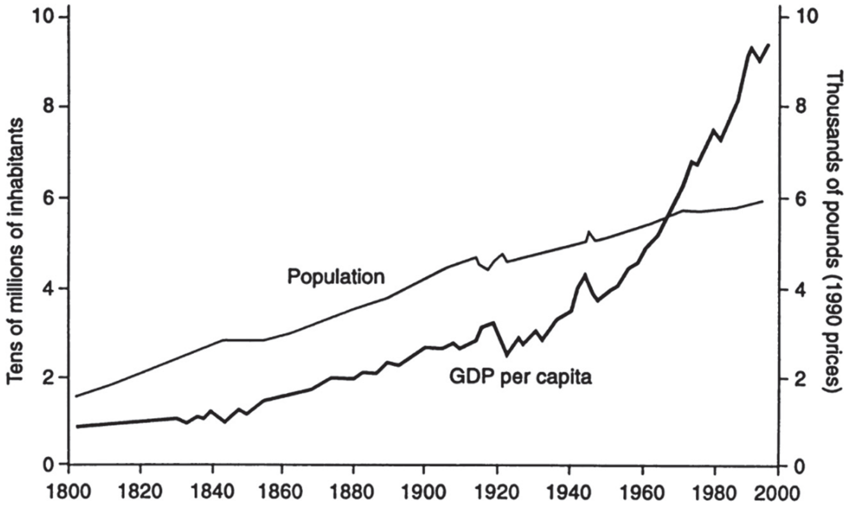
3.1 Income and population growth

Figures 1.5 and 1.6 show how population and GDP per capita evolved over the last 700 years. In the second half of 14th century there was a very strong decrease of the population due to the Black Death. This created a scarcity of labor and allowed some countries, such as the UK, to get rid of the feudal system. The poor people in this feudal system virtually had no rights but because they were in high demand, they could now start to claim more rights.



Source: Fouquet and Pearson (1998).

FIGURE 1.5. Estimates of population and real GDP per capita (1086-1800).



Source: Fouquet and Pearson (1998).

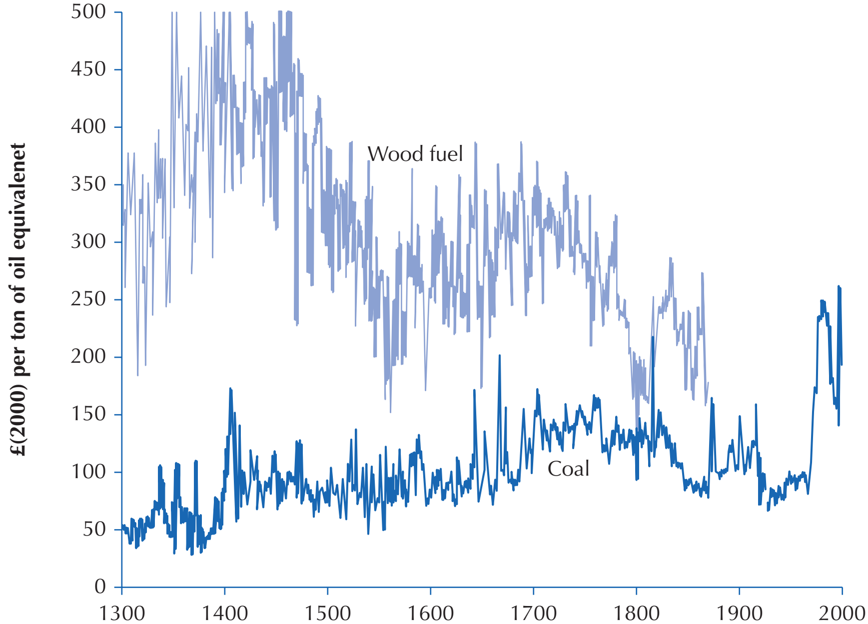
FIGURE 1.6. Estimates of population and real Gross Domestic Product per capita (1800-2000).

This gave rise to more institutional changes in the UK: a parliamentary system, property rights, etc. Combined with inventions in textile, power use, etc. this was the start of a sustained growth process and GDP per capita increased with a factor 5 or 6 between 1450 and 1800.

Another round of inventions generated even more growth in the 19th and 20th centuries when GDP per capita increased again by a factor 8 to 10. This strong growth was only possible because there was a sufficient supply of energy services. On the other hand, the increase in income also strongly stimulated energy demand for industry and for households.

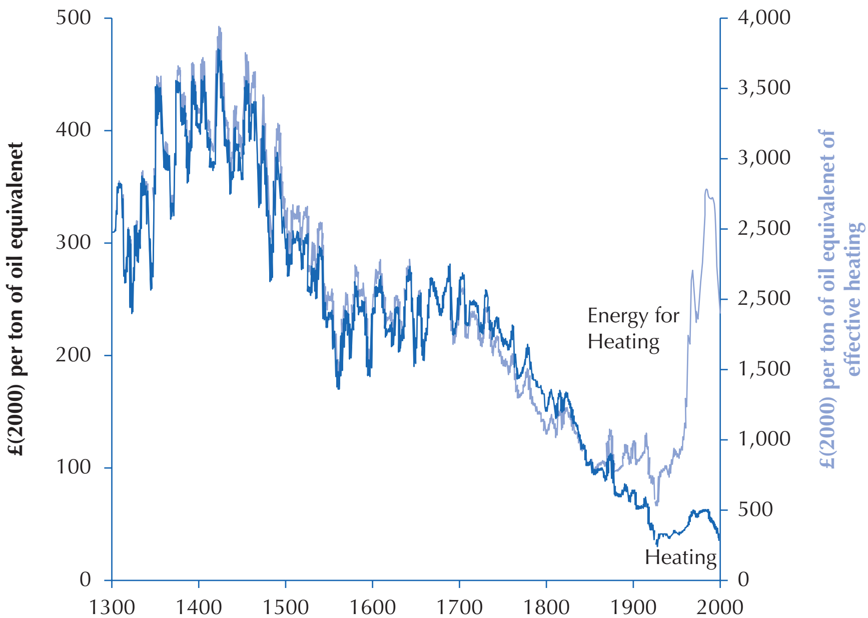
3.2 Energy use for household heating

Figure 1.7 represents the prices of wood fuel and coal. With more and more of the population living in cities from the 16th century onwards, it was increasingly difficult to supply enough wood fuel to the cities. In addition, one tends to first use the wood supplies near the city. Because coal supply could be extended, coal became more important in home heating. It is interesting to note that coal could be more easily taxed than wood because coal supply is concentrated in a mine. The result was that, in the mid-18th century, one-third of the consumer price of coal consisted of taxes (Fouquet, 2011).



Source: Fouquet (2011).

FIGURE 1.7. Wood fuel and coal prices in England (1300-2000).



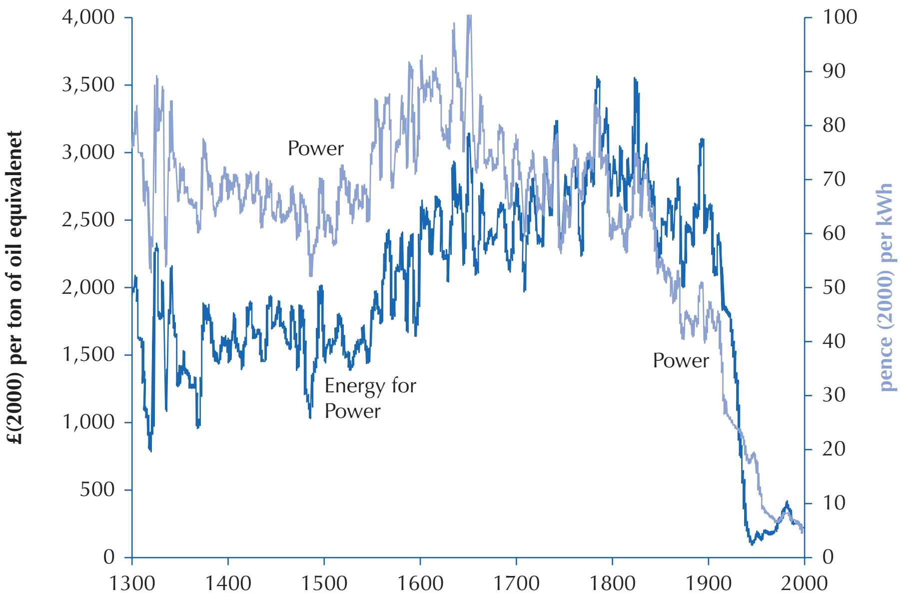
Source: Fouquet (2011).

FIGURE 1.8. Prices of energy (for heating) and price of household heating services in England (1300-2000).[2]

The price of home heating services (useful output of the heating system) decreased from the 15th century onwards and this decrease was stronger than the decrease of the price of heating energy (the input into the heating system). This is shown in Figure 1.8. The main innovations responsible for the strong decrease in the price of energy services were better fireplaces, better stoves, and in the last 60 years, better gas and electricity boilers. In the latter period, the price of energy inputs increased because coal was gradually substituted by natural gas and electricity. However, this raise in input costs was more than compensated by an improvement of efficiency.

3.3 Energy use for power

Before the industrial revolution, oxen and horses were the main suppliers of power. The energy for these animals (hay, oats, and peas) was provided by agriculture. The price of this type of energy was increasing in the 16th century, despite some innovations in the agricultural techniques (see Figure 1.9). The technical innovation that kept prices from increasing too much was the breeding of more efficient horses. With the steam engine (early 18th century), coal could take over as main source of energy. The efficiency of the steam engine tripled between 1850 and 1900. This was the reason why the price of power decreased more strongly than the price of coal.

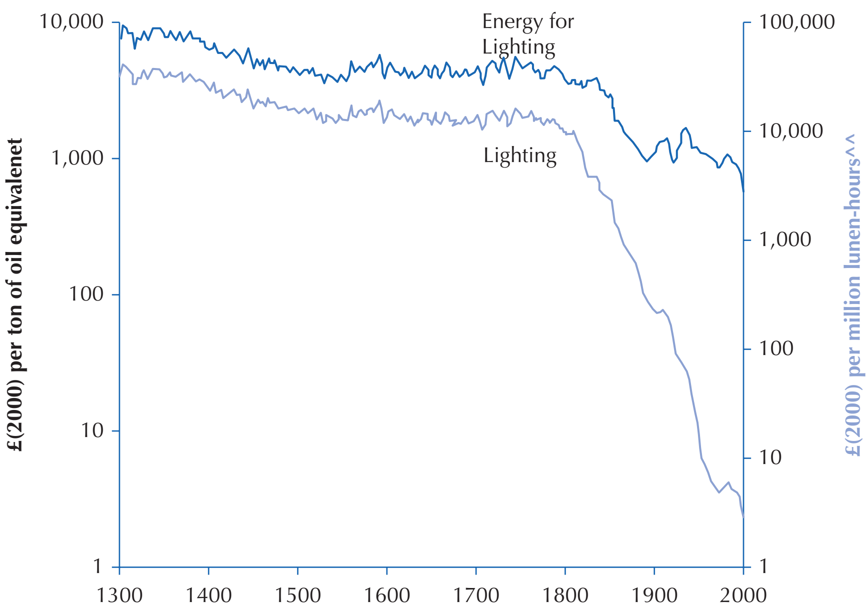


Source: Fouquet (2011).

FIGURE 1.9. Prices of energy (for power) and power in the UK (1300-2000).[3]

3.4 Price of lighting services

The most dramatic decrease in the price of energy services can be found for lighting. For lighting, people has used very different technologies over time: a candle, an oil lamp, a gas lamp, different types of electric lamps, etc. To show the decrease in prices of light, one needs a logarithmic scale as the price of a lumen (one unit of light) has decreased by a factor 5,000 or more over the last 300 years. Lighting prices in the UK (for the period 1300-2000) are shown in Figure 1.10.



Source: Fouquet (2011).

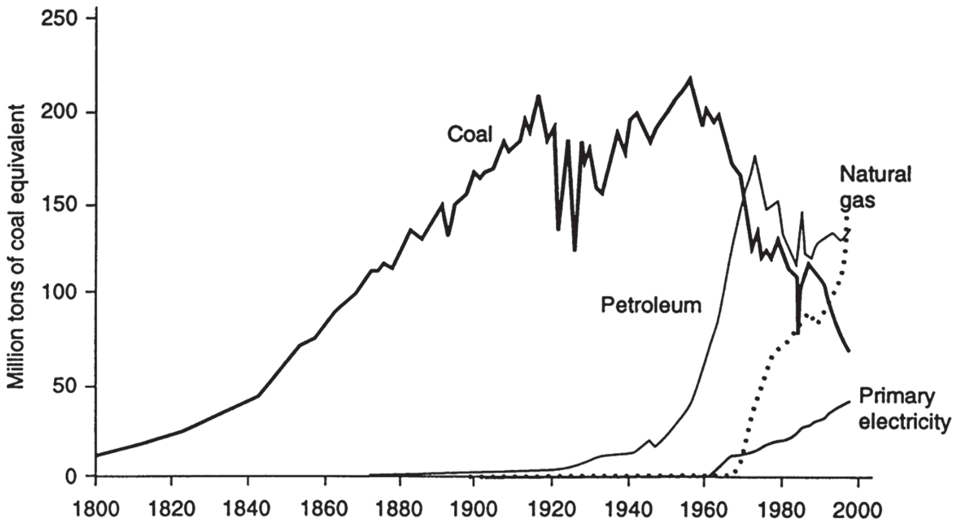
FIGURE 1.10. Prices for energy (for lighting) and lighting in the UK (1300-2000).[4]

3.5 What happened to energy prices and the price of energy services over the last 700 years?

Two elements are worth noting. First, overall energy input prices have almost always fluctuated. However, strong price increases generated, be it with some delay, additional supply that brought prices down again. This took the form of additional supplies of the same source (in the case of coal) and sometimes a substitution by another source took place (wood fuel substituted by coal). Second, the price of energy services has decreased, sometimes very strongly. This was mainly due to the appearance of more efficient conversion techniques.

3.6 Energy consumption

A strong increase in income and a decline in the price of energy services gave rise to a strong increase in energy use, according to Fouquet and Pearson (1998) and Fouquet (2009) who analyzed energy use in the long term for the UK. As can be seen in Figure 1.11, consumption of energy has increased more than 20-fold over the last 200 years where coal has been partly substituted by oil, natural gas, and primary electricity (nuclear, wind, etc.).

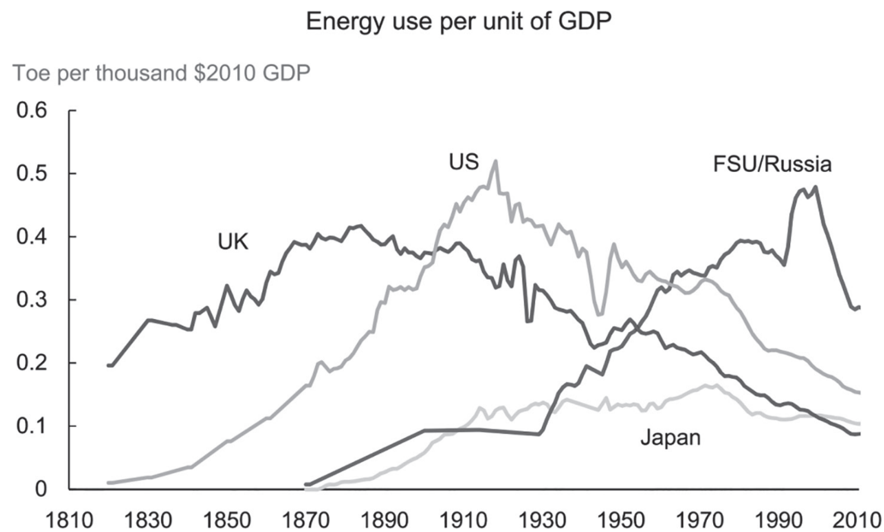


Source: Fouquet and Pearson (1998).

FIGURE 1.11. Primary energy consumption in the UK.

4. Future trends

The past has shown strong variations in income and energy prices. One could use the historical experience of developed countries to better understand the evolution of energy use in developing countries. Merely focusing on income elasticities or Energy/GDP ratios can, however, be misleading because technologies have developed strongly over time and these technologies find their way to developing countries as well. Figure 1.12 represents the historic Energy/GDP ratios for certain developed countries. The energy use is the sum of industrial and household energy use. How can the – apparently typical – bell shape be explained? When income increases, one expects a higher level of industrial production and a higher household income level. Both factors normally contribute to a higher consumption of energy. Viewed over a long period of time, we see that energy use increases strongly in the initial industrial phase where an agricultural economy is replaced by an economy based on industry. Later, industrial activity becomes less energy-intensive and more and more people start to work in the less energy-intensive service industry. Once industrial activity becomes less important, it is the households' use of energy that continues to increase when GDP increases. But interpretation of the ratios is difficult as energy use technology has also changed strongly over time.



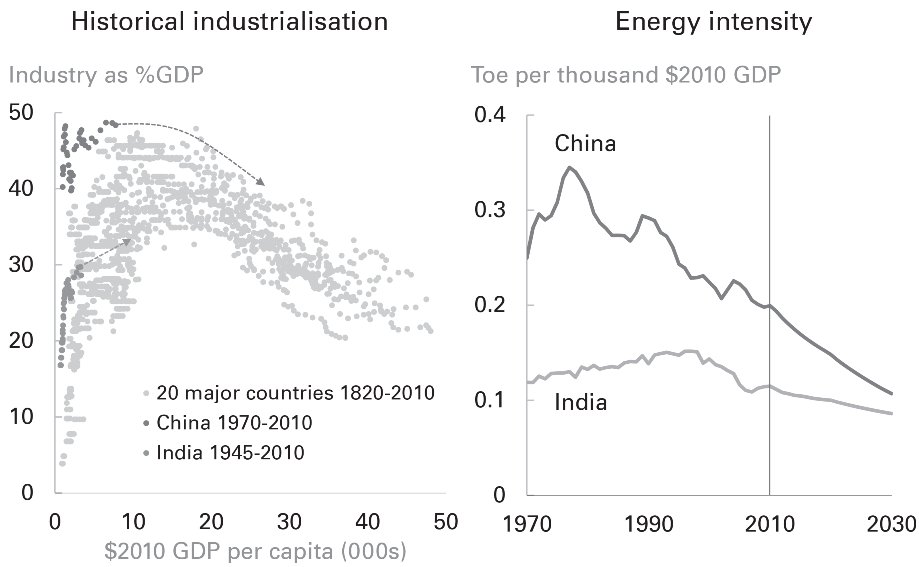
Source: Rühl, et al. (2012).

FIGURE 1.12. Historical trends of energy intensity.

As technologies and the sectorial composition of industrial activity can be very different, the Energy/GDP ratios observed in the past for developed countries cannot be transferred to newly industrializing countries.

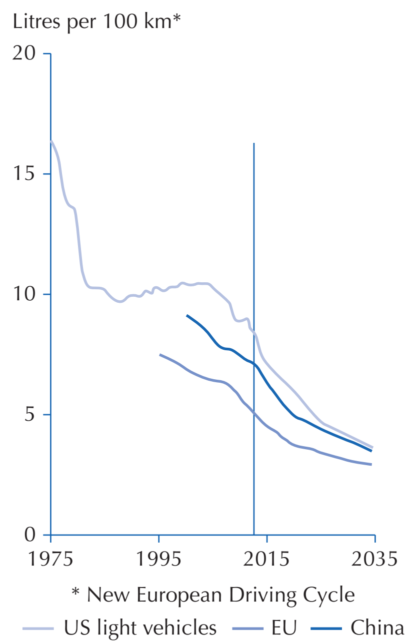
Figure 1.13 illustrates the Energy/GDP ratios for countries like China and India. It is clear that a country like China is much more energy-intensive than India, although their GDPs were not that different.

The importance of the evolution of technologies can easily be illustrated in the case of a homogenous good like cars. Figure 1.14 shows the fuel economy of new cars in the EU, China and the US (for light vehicles). One sees that technological progress spreads quickly over the world and car efficiencies in China are approaching those of the EU.



Source: BP Energy Outlook 2030 – January 2012.

FIGURE 1.13. Historical industrialization and energy intensity.



Source: BP Energy Outlook 2035 – January 2014.

FIGURE 1.14. Fuel economy of new cars.

Finally, note that the level of energy intensity of a country does not reveal very much about the level of energy efficiency of that country. Consider two countries A and B, with country A having a higher level of energy intensity than country B. This can be due to the fact that country A has a more energy intensive economic structure than country B, but it does not necessarily imply that country A is less energy efficient than country B. As a matter of fact, both countries could be using the same state of the art energy efficient technologies.

5. Understanding world energy markets

In the next chapters we will analyze in more detail the supply and demand of different energy commodities. While doing that, it is instructive to keep a global view in mind. Figure 1.15 represents a schematic view of the world energy markets. Three primary energy markets are represented (oil, gas and coal) as well as the market for electricity.

The first thing to note is that the market for oil and to a lesser extent that for coal need to be considered at world level because the transport costs of oil and coal are smaller than those of natural gas and electricity, so that any demand or supply shock in one region (defined as a shift in the demand or supply function of that region) triggers arbitrage. Arbitrage here means selling (buying) primary energy in a region where it is more expensive (cheaper). This is much less the case for natural gas and electricity as one needs expensive and dedicated transport infrastructure (LNG ports, pipelines, transmission lines). Natural gas and electricity are to be analyzed more at a regional level.

The second thing to note is that electricity generation based on fossil fuels requires the input of fossil fuels and therefore contributes to the demand for those fuels.

5.1 Aggregate energy demand by type of energy

We can now consider the driving factors of energy demand in a given region i.

The level of economic activity and its composition will determine the level of production by the industrial sector (IP). Every industrial sector defines a demand function for each type of energy (oil, gas, coal, electricity) related to the relative prices of the different types of energy j. Aggregating the demand of the different industrial sectors then defines the total industrial demand for a particular type of energy j in a region.

As an example, consider the demand for oil by industry I in a given region i: this will be a function $D_{oil,I,i}(p_{oil}, p_{gas}, p_{coal}, IP)$ where some of the prices can also be indexed regionally.

The second part of the demand for a primary fuel will come from households. Household demand for a type of energy (e.g. oil) will be determined by the relative prices and by the household income HI so that we have for region i: $D_{oil,H,i}(p_{oil}, p_{gas}, p_{coal}, HI)$. Household income results from payments by the industrial sector (salaries, wages, rent, interest, profit) for production inputs provided by households.

The third part of the demand for a primary fuel is the demand from the electricity sector. The needs of this sector for primary fuels are a function of relative prices of primary fuels, prices of renewables, nuclear fuel and the level of electricity production.[5]

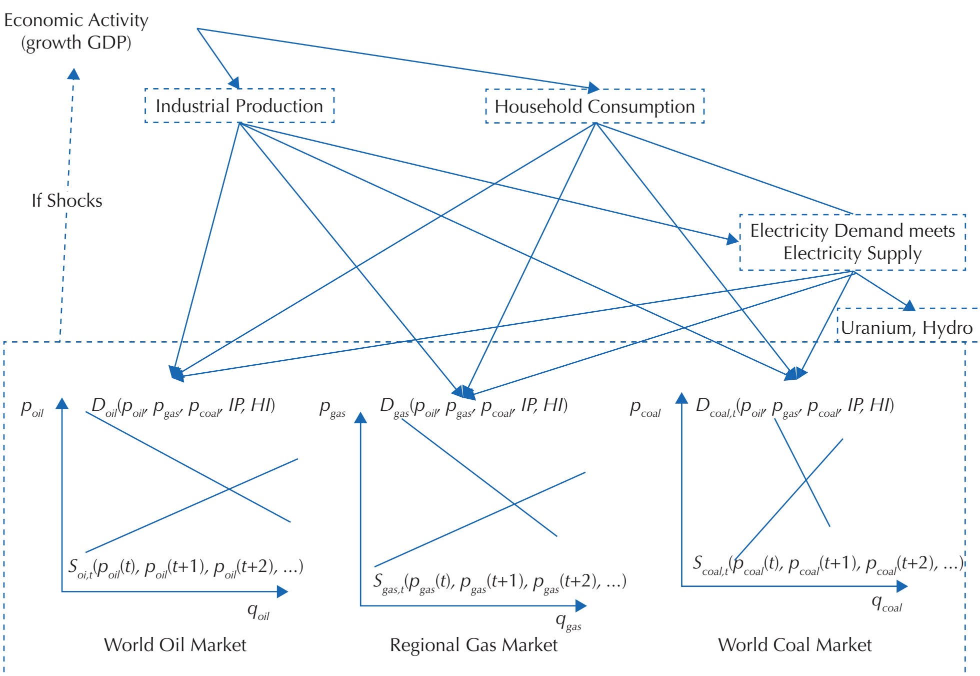


FIGURE 1.15. Overall scheme for analysis of energy markets.

Aggregating the demand functions from the three demand categories produces one demand function for one type of primary energy j in that region: $D_{j,i}(p_{oil}, p_{gas}, p_{coal}, IP, HI)$. Aggregating the demand for oil over all regions in the world then leads to an aggregate demand function for oil. Aggregating demand functions is easy: for each price level look for the total demand using the demand functions for all sectors (cf. refresher chapter 0). A demand function for one type of primary energy is a function of the prices of substitute energy forms. This implies that whenever the price of a substitute (say gas) increases, the demand for that type of energy decreases (movement along the demand curve) and for the other primary energy forms (oil, coal) there will be a shift of the demand functions to the right. This is a direct substitution effect for the household and industry use of primary fuels and an indirect substitution effect for the use of primary fuels via the shift in production techniques in the electricity sector.

5.2 Aggregate energy supply by type of energy

The supply of each primary fuel is driven only by the price of that fuel when there is perfect competition. When there is imperfect competition, a supplier will use his knowledge of the demand function to increase prices and earn more profits on a market. In the next chapter we will note that for most primary fuels, the total resource stock is given: this means that each supplier will trade off selling now or in the future, which implies that his supply function in period t will also depend on all future prices. Selling in the future is the alternative for selling now. For example, the supply function of oil in period t is written as $S_t(p_{oil,t}, p_{oil,t+1}, p_{oil,t+2}, \ldots)$. The total supply function of a fuel in a region is constructed by aggregating the functions of all suppliers of that fuel. It shows total supply of the fuel for each price level (cf. refresher chapter 0).

5.3 Equilibrium on the energy markets

Some exogenous factors will create shifts in the demand functions (user technologies, economic growth...) and other exogenous factors will shift the supply functions (exploration technology changes, changes in expected future prices...). Finally, there will also be a feedback effect from the price of energy to the level of economic activity. Production possibilities of the economy will be smaller when energy is scarcer. When the oil price increases suddenly (an 'oil price shock'), this may also create macro-economic disequilibria that translate into a lower level of economic activity. An equilibrium on the world energy market is therefore a set of current and future prices by region, so that quantities demanded equal the quantities supplied for each region, for the current and all future periods. The whole energy system can therefore be analyzed using a system of simultaneous equations that represent demand and supply of energy in the different regions in the world over time. This is then driven by a macro-economic growth model that predicts production by sector and income levels for the different regions. A good forecast and scenario model relies on this type of equations.

5.4 Why is making scenarios for the future difficult?

Scenarios or forecasts for the future are important as we need to make investment decisions now. More generally, we also need to anticipate problems related to energy scarcity and to the environmental impact of energy use (e.g. climate damage).

What makes these scenario exercises difficult? We distinguish four factors:
1. There are unforeseen natural events; these can be technical or organizational breakthroughs (low cost shale gas production in the US, climate negotiations breakthrough or failure etc.). The best way to incorporate this information is to have a tree of events and determine the likely development for every branch of the tree (this is called a scenario analysis).
2. The economic growth can be much higher or much lower than expected. Recently we had the covid pandemic and the war between Russia and Ukraine. How long and to what extent will it impact economic growth?
3. The future is the result of many firms and governments making decisions and they may all be based on different anticipations. So even making scenarios for exogenous events can be difficult.
4. Behavior of firms and consumers in reaction to an identical shock may be different from what happened in the past – this implies that learning from past behavior is incomplete.

Adding subjective probabilities to the different branches that represent possible future developments, allows using stochastic optimization: what is the best decision now, given the influence of current decisions on future options?

In this course we will mainly use BP's historical statistics and scenarios for the future because they are regularly updated and available since 1960 and are probably less politically driven than the scenarios produced by the European Commission, the International Energy Agency (IEA) or the Energy Information Agency (EIA – a US agency).

6. Conclusion

This chapter looked into the drivers of energy developments, both from a microeconomic and a macroeconomic perspective. The energy supply is driven by geological availability as well as by technology and technological developments. Energy demand is driven by economic growth, prices and energy service technology. A market equilibrium on the energy market requires that in each region and for all sources of energy, demand equals supply. This market equilibrium is reached by adjusting prices.

7. Exercises

1. Develop a scenario for household use of energy in your country for the next 20 years using assumptions on energy price developments, income growth and population growth.
2. Imagine for 2035 a world where only renewables would be available. It would be a supply of energy without any greenhouse gas emissions but would cost twice as much as now to generate. Can you spell out what this would mean for energy efficiency and energy use? Is there any historical development that could help you?

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