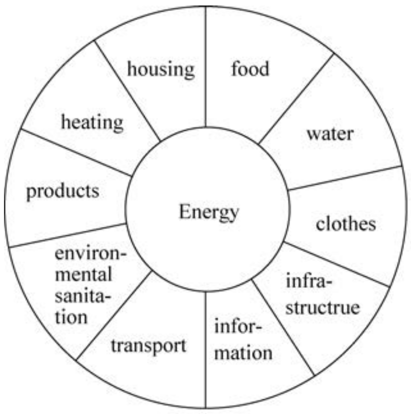
1 Aspects of energy economy

1.1 Importance of energy supply

A sufficient high, economic attractive and safe supply of energy is an essential condition for the welfare of the human beings[1-6]. For the production of food, water supply, for heating and cooling, for the transport sector and for the infrastructure as well as for the production of goods for consumption, large amounts of energy are necessary in industrialized countries. Energy for the organization and preservation of environment is necessary too with rising importance. Figure 1.1 gives an overview on these aspects and some numbers characteristic for German conditions. Transportation, industry and house heating require the major part of energy.



(a)

Sector of energy economy	Share/%
industry + trade	38
house heating	28
transportation	26
non-energetic consumption	8
total consumption (6 t HCU/person·a)	100

(b)

Figure 1.1 Overview on the importance of energy for the human life

(a) General overview on fields of application of energy; (b) Some data for Germany (consumption of primary energy in different sectors of energy economy; total = 6t HCU/(person · a), HCU = hard coal units)

Here and later often the unit HCU (hard coal unit) is applied to characterize energy carriers. The hard coal unit 1t HCU corresponds to 8.3MW · h (thermal) or 30GJ. For the different primary energy, conversion factors corresponding to Table 1.1 can be applied.

Table 1.1 Conversion factors for different energy carriers (in relation to hard coal units HCU)

Energy carrier	Heating value/(MJ/kg)	Heating value/(kW · h/kg)	Conversion/(kg HCU/kg)
hard coal	30	8.3	1
lignite	8	2.2	0.27
crude oil	43.9	12.2	1.4
natural gas	42	11.6	1.43
uranium *	605 000	170 000	20 480

* natural uranium, 0.7 wt% U235.

Sometimes energy balances use the unit 1 t of oil with a heating value of around 12.2kW·h or 43.9MJ as a further unit. Electrical energy often is valuated with an average efficiency of 33%. The delivery of 1kW·h_{el} from renewable or nuclear energy to the energy economy corresponds than to 3kW·h_{th}. The energy demand of the people has raised up very much during the past (Figure 1.2): from some 100kgHCU/(person·a) to around 6t HCU/(person·a) (in Germany) and around 2.3t HCU/(person·a) as an average value worldwide today.

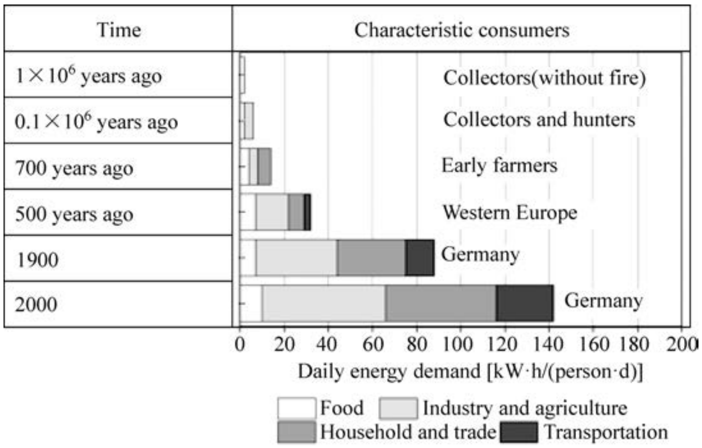


Figure 1.2 Daily demand on primary energy (kW·h/(person·d)) of people at different times of the human development

Further improvements regarding supply in many countries are necessary. Today as example in India just around 0.84t HCU/(person·a) are available. For many other countries similar numbers are relevant (Figure 1.3). This situation must be improved in the future to avoid large problems in the interaction of countries worldwide. To save energy, which is propagated mainly in western countries (as example for the conservation of climate), is necessary for those countries, but it is not a solution for countries, which don't have a sufficient energy supply today.

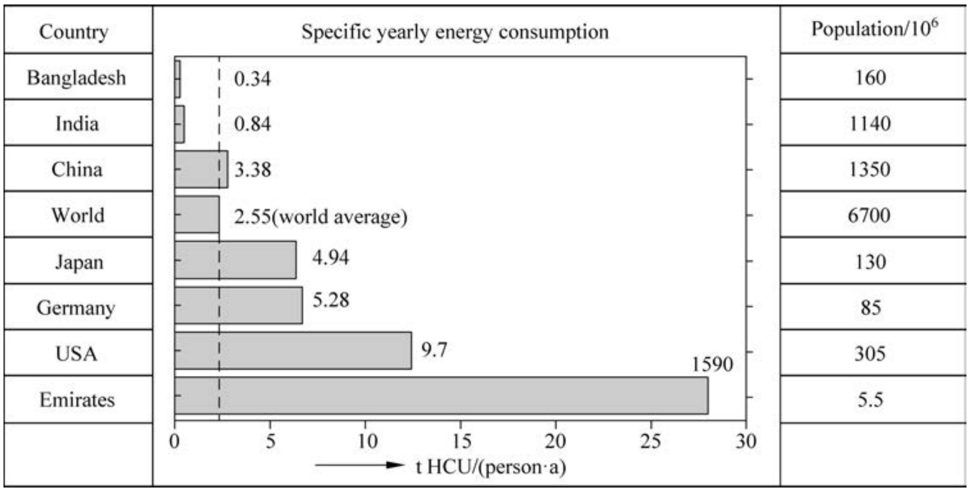
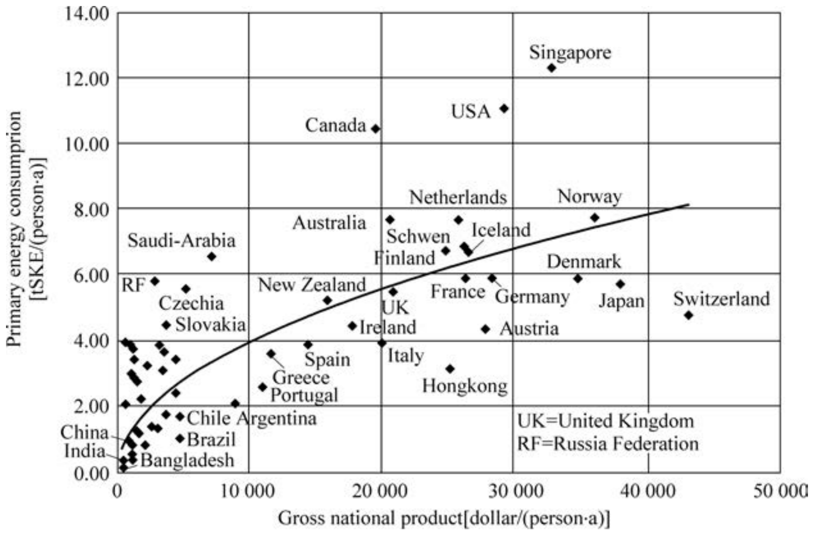


Figure 1.3 Specific consumption of primary energy in some countries and population (2019)

The energy supply furthermore is correlated to the Gross National Product (GNP) and to the quality of life. Maybe this can be expressed by the expectation of lifetime of people in different countries. Figure 1.4 shows the differences of GNP in countries indicating large differences of energy supply. Figure 1.5 correlates this value with the lifetime. The values in Figure 1.4 and Figure 1.5 are valid for the year 1997. In some countries, like China, the numbers have changed, for instance, the specific energy consumption is already in the order of 4.5t HCU/(person·a), the average life time today is in the order of 75 years.

The discrepancies of these values worldwide is not acceptable in the future and will cause serious problems. Improvements are necessary.



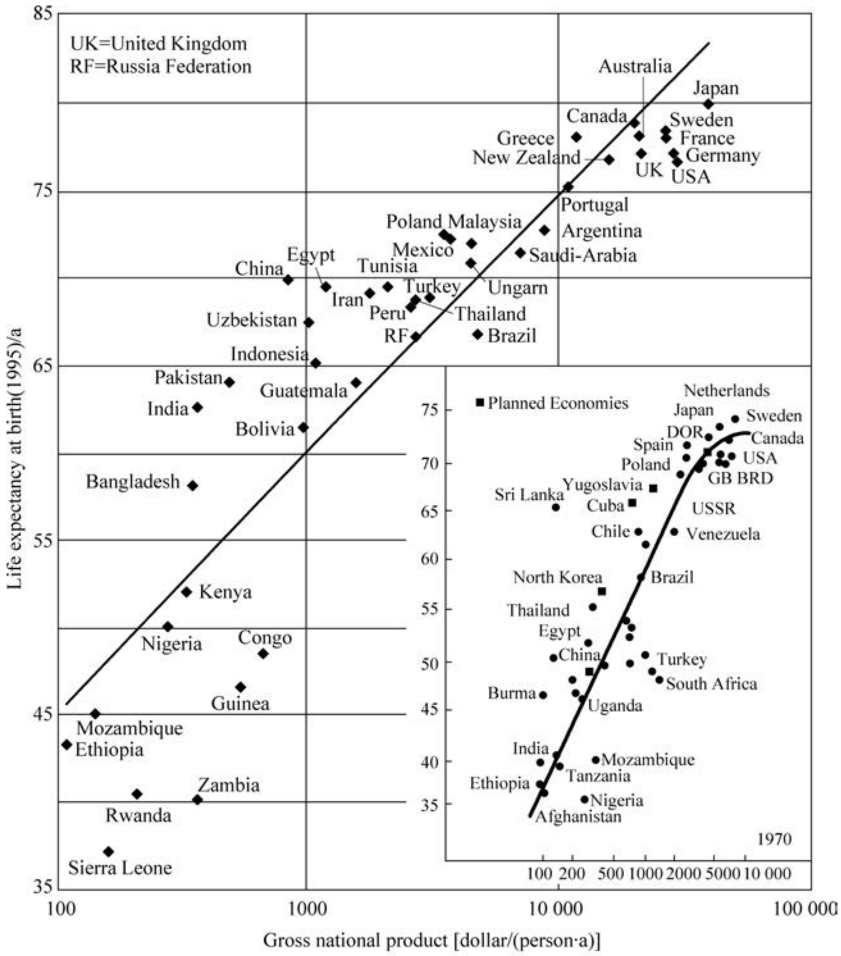
(a)

Year	Specific primary energy consumption /[kW·h$_{el}$/(person·a)]	Gross national product/ [dollar/(person·a)]
2000	1.3	1150
2010	2.8	4500
2019	3.3	10 100

(b)

Figure 1.4 Correlation between primary energy supply and gross national product

(a) Values in different countries and cities worldwide(status: 1997); (b) Development in China



(a)

Figure 1.5 Correlation between expected lifetime and the Gross National Product (1997)

(a) Values for some elected countries worldwide(status: 1997); (b) Development in China

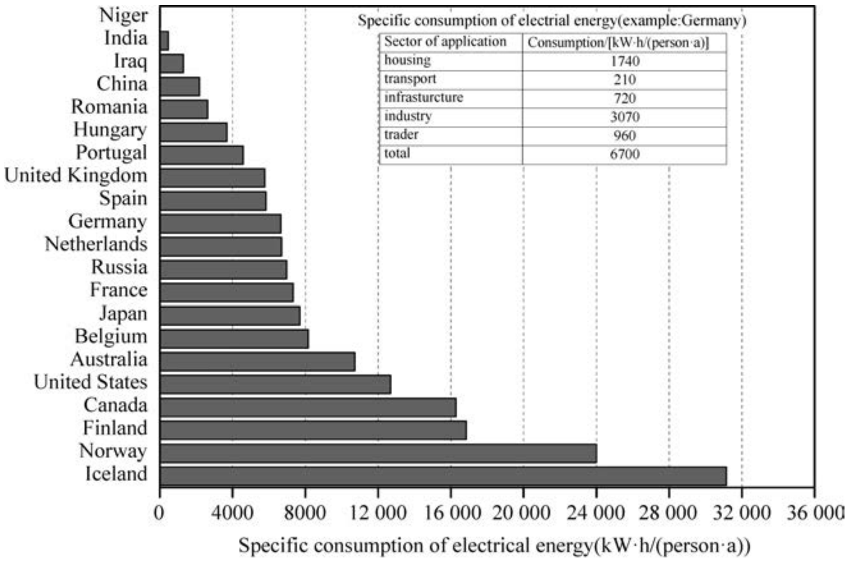
Year	Specific primary energy consumption /[kW·h_{el}/(person·a)]	Energy life time(years)
2000	1.3	71.4
2010	2.8	74.4
2019	3.3	75.8

(b)

Figure 1.5 (Continued)

In the meantime, some countries made large progress: as example, the values in China are now around 10 000 dollar/(person · a) for the gross national product and higher than 3.3t HCU/(person · a) for the specific energy consumption. The average life time became larger and has now a value about 75 years.

A sufficient high standard of life is a precondition for a good prognosis for expectation of lifetime of population worldwide. These standards are coupled with a sufficient high production of food, good standards of hygiene and medical services and a functioning infrastructure. All these aspects require a sufficient and effective structure of energy supply. To realize this goal worldwide will require large efforts and the investment of very large capitals. Additionally rising environmental problems have to be considered in this connection. Especially the CO_2-question will have importance. Similar consideration as for primary energy supply are valid for the supply with electrical energy. Figure 1.6(a) gives an overview on the status in some countries worldwide regarding this energy carrier, which indicate that there are large differences. In China much progress was realized with respect to the rise of the production of electrical energy. In the last 20 years there was a rise by a factor of 5(Figure1.6(b)).



(a)

Year	Specific electrical energy consumption /[kW·h_{el}/(person·a)]
2000	1100
2005	1700
2010	3200
2015	4000
2019	5100

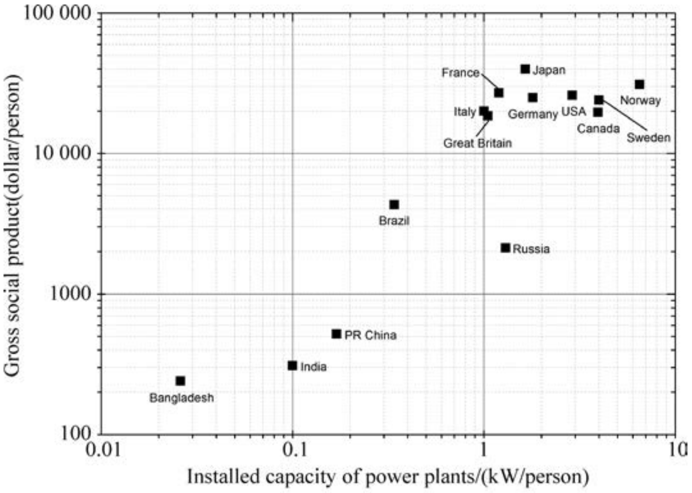
(b)

Figure 1.6 Production and consumption of electricity per year and per person

(a) Comparison for different countries (status: 1998); (b) Development in China

Around 30% of the primary energy, which is applied worldwide, is used to produce electricity. As an average around 3200kW · h_{el}/(person · a) is available for the world population; in Germany, this value is nearly 6700kW · h_{el}/(person · a). However in some countries like India even in 2019 just 1000kW · h_{el}/(person · a) is characteristic for the supply of the people. This situation, in more detail explained in Figure 1.6, requires intensive work and effort to improve the conditions of life worldwide.

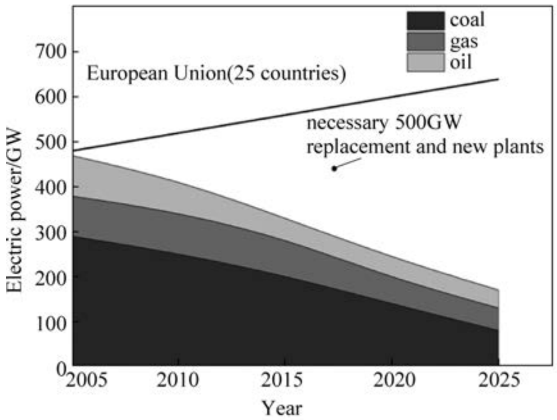
Corresponding to this disadvantageous supply for people in many countries, the height of installed capacities for the production of electrical energy today still is extremely different in important countries (Figure 1.7). Countries with an insufficient height of installed electrical capacity have low values of gross national product and low standards of life. Figure 1.7 shows that there is a huge demand of additional power plants, transportation systems and grids to be built in the future. Additionally many old power plants have to be replaced by new ones, because they have reached their end of life and



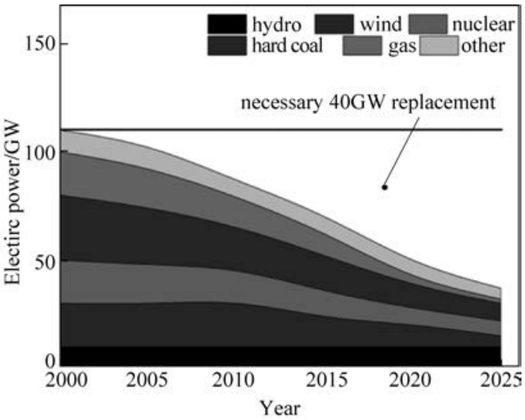
(a)

Country	Population/10^6	Installed capacity/GW_{el}
Africa	1370	
Asia	4650	
Europe	740	
North America	370	
South America	660	
Oceania	50	
Total world	7850	
China	1410	1974
India	1370	400
France	67	130
Bangladesh	165	10
Brazil	212	122

(b)



(c)



(d)

Figure 1.7 Aspects of supply with electrical energy: time dependent development of capacities

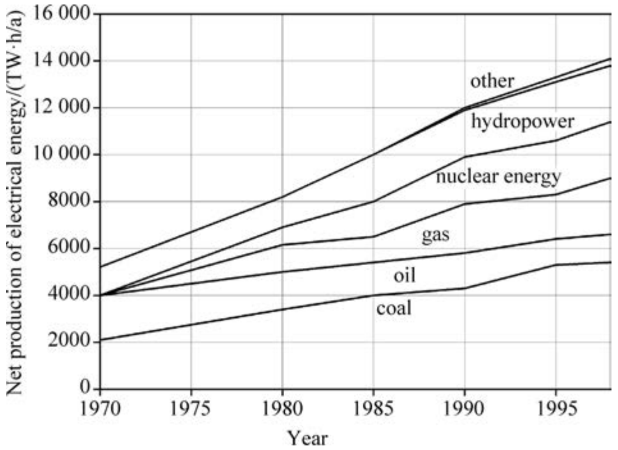
(a) Correlation between gross national product and installed capacity of power plants (kW/person) in different countries (status: 1998); (b) Population and installed capacities in different regions of the world (status: 2019); (c) Development of capacities of power plants in the past and expectations (example: European Union (25 countries)); (d) Development of capacity of power plants in a country (example: Germany): time dependence in the past and expectations efficiencies should be improved. Furthermore, storage systems for electrical energy have to be developed and introduced, if the share of renewable energies rises up.

As example in the European Union(EU), where a capacity of around $600GW_{el}$ is installed, in the next 30 years additional $200GW_{el}$ have to be added to the grid. Furthermore, old plants have to be substituted. Some countries with lower state of development have huge demand. In totally it is estimated that around $500GW_{el}$ have to be built in the EU. In Germany, the number is 40GW in the next 10 years (expectation 2015). This must be mainly base load plants. Because in the meantime political decisions have been made in Germany to go out of use of fossil fuels and of nuclear power reacts the capacities of wind energy converters and of photo voltaic installations have been enlarged drastically.

The wind capacity was $6.1GW_{el}$ in 2000 and $62GW_{el}$ in 2019. The photo voltaic installations rised up from $0.1GW_{el}$ in 2000 to $54GW_{el}$ in 2019. These changes were realized by massive subventions from the government. Especially the changing offer of wind energy and solar energy require the installation of very large capacities and storages.

Some differences regarding the supply structures worldwide can be explained by climatic conditions naturally too. However, it is understandable that all countries, which have values below average worldwide numbers, aspire changes and progress. This is the case at least for more than 50% of the world population. In totally the energy demand of the world will rise up dramatically in the next decades and one of the most important questions of future worldwide development will be to fulfill this requirement. It is important for the people in the world to establish similar conditions of life everywhere (Figure 1.8 (a)).

The safe, economic reliable energy supply is very important for all requirements of daily life. However, in many countries the intensive use of fossil fuels is connected to burden for the environment, as example of CO_2 emission. Data in Figure 1.8 (b) indicates the big differences regarding important data for some countries and of the worldwide average. Therefore it is understandable that there is a big movement in the world to change the conditions and to equalize the differences.



(a)

Year	Production of electricity/(TW·h/a)
1990	12 000
1995	13 200
2000	15 400
2005	18 300
2010	21 600
2015	24 300
2019	26 000

(b)

Figure 1.8 Aspects of energy supply in different countries of the world

(a) Worldwide electricity production (in the past till 1997); (b) Development of production of electricity in the world since 1990; (c) Some data relevant for life conditions in different countries(status: 2019)

Aspect	Dimension	World average	Germany	China	India
Primary energy	t HCU /(person · a)	2.3	5	3.3	< 1.0
Consumption of electrical energy	$kW \cdot h_{el}$/(person · a)	3200	6800	5100	1000
Power plant capacity	kW/ (person · a)	<1	2.6*	1.4	< 0.3
CO_2 emission	t CO_2/(person · a)	4.6	8.6	7	1.8
Gross National Product	dollar/(person · a)	≈1100	35 000	10 000	2800

*The high value is caused by the high share of wind energy converters and photo voltaic installations

(c)

Figure 1.8 (Continued)

1.2 Development in the past and status of world energy economy

The worldwide primary energy supply has been raised up strongly during the last decades (Figure 1.9)[6]. The doubling time in the past was around 30 years. In 2019 nearly 1.8×10^{10} t HCU/a worldwide were inserted for the supply. This corresponded at a population of the world of 7.7×10^9 people to an average supply of 2.3t/HCU/(person · a).

The world population has raised up in the last 100 years by a factor of more than 4, mainly caused by medical progress and improved structures of food supply. Even severe disturbances like World War 1 and 2 or big crisis of oil supply and very high oil prices did not influence the general tendencies of rise of world population and of energy demand very much (Figure 1.9 (b)).

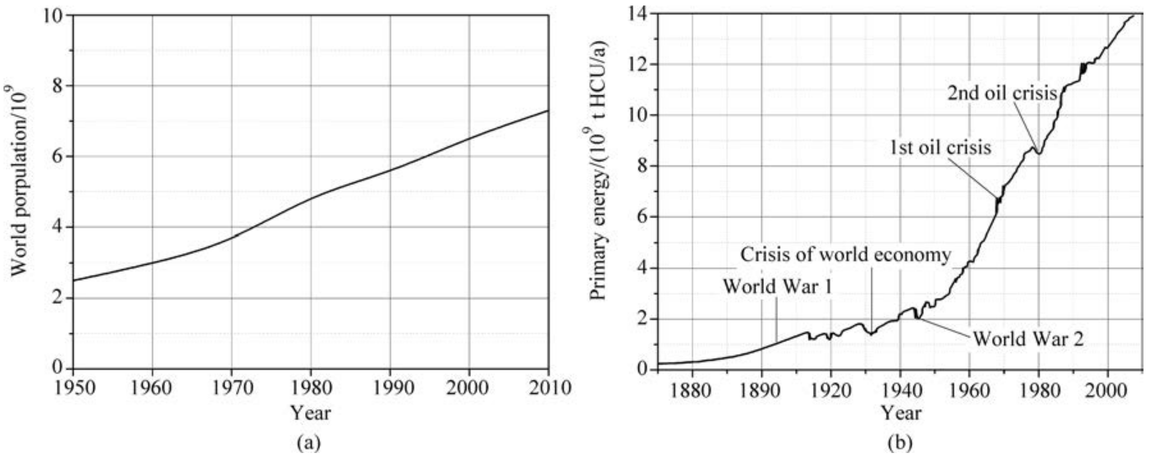


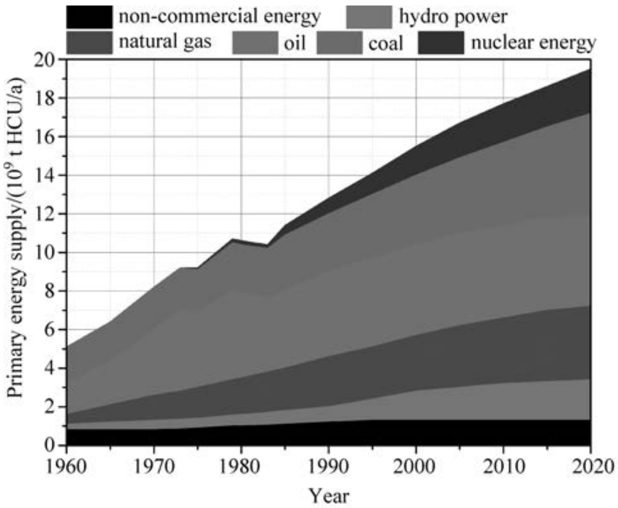
Figure 1.9 Development of the world population and the energy supply in the world (in the past)

(a) World population(value in 2019: 7.7×10^9); (b) Primary energy supply worldwide(value in 2019: 1.8×10^{10}t HCU/a)

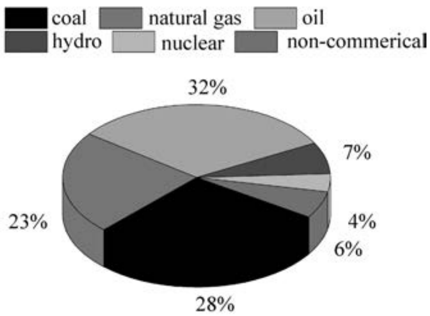
Mainly the increase of population in the world and improvements of standard of life in some countries caused this development on the energy sector. Figure 1.3 to Figure 1.7 indicated however, that there are still large differences of consumption and therefore of life conditions worldwide. There are countries with very large population in the world like India, Pakistan, Bangladesh or many states in Africa, where the specific consumption of electrical energy is smaller by a factor of 4 compared to the average value worldwide. Naturally the supply in these countries must be improved in the future to a large extent to avoid social problems, migration of people and wars. In the countries indicated above as example, the transportation sector today is practically not at all developed compared to the situation in USA, Europe or some countries in Asia like China and Japan.

Until now the supply was based mainly on the fossil energy carriers as coal, crude oil and natural gas

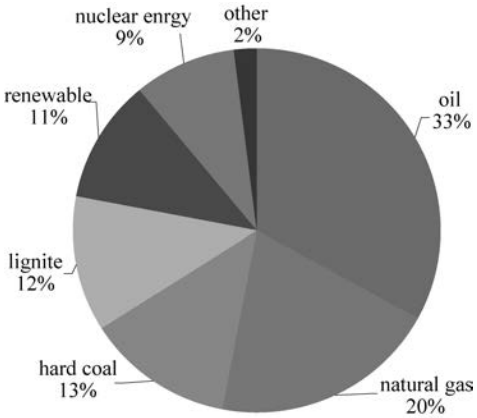
(Figure 1.10). Renewable and nuclear energy play a role in the order of just 10% of the total supply structure. However their importance is growing up. The expectation is that they will take over a share of nearly 30% of the demand after the next three decades worldwide. To estimate the share of noncommercial energy carriers always contains some uncertainties. In some countries they represent the most important part of the energy supply.



(a)



(b)



(c)

Region (country)	Share of supply of world in 2019/%	Change from year 2010 to 2019/%
Europe	13.85	−5
Africa	3.6	+24
Asia	46	+31
North America	21	+3
South America	5.1	+8
China	25.5	+36.5
India	6.1	+51
Germany	2.3	−5
World	100	+10.3

(d)

Figure 1.10 Contribution of different energy carriers to the worldwide supply with primary energy

(a) Development of different energy carriers (worldwide); (b) Shares of different primary energy carriers on the worldwide energy supply (example: 2012; total energy supply: 1.7×10^{10} t HCU/a); (c) Shares of different primary energy carries on the energy supply of a country (example: Germany; 2012; total energy supply: 4.60×10^{8} t HCU/a); (d) Shares and changes of primary energy consumption in different regions and specific countries (2019)

Special developments took place in the last decades in the field of worldwide electricity production. Table 1.2 includes some data for production differentiated to the energy carriers. The supply of regions was already shown in Figure 1.8. Sometimes strong changes in the energy supply systems can occur. An example is Germany, where after the accident in Fukushima (2011) the decision was made to shut down 7 large nuclear plants immediately and to go out of nuclear supply totally till the year 2022. The substitution of the missing electrical energy shall be done by use of wind energy and electricity from photovoltaic systems (Table 1.2(b)). Naturally as a consequence in future, large storage capacities and extended grids for transport have to be realized. Furthermore, much higher capacities and costs for electrical energy have to be accepted.

Table 1.2 Aspects of development of the production of electrical energy TW・h/a

Year	Coal	Nuclear energy	Oil	Natural gas	Hydro power + renewable	Total
1970	2075	80	1625	—	1175	4955
1980	3163	714	1661	976	1802	8316
1990	4286	1989	1216	1632	2212	11 335
2000	5759	2407	1402	2664	2968	15 200
2005	7040	2640	1240	3750	3550	18 220
2010	8330	2725	828	4560	4290	20 733
2015	8950	2330	900	4750	4900	≈22 500
2019						≈27 000

(a) Development of electrical energy production worldwide (share of energy carriers)

Primary energy carrier	Capacity of plants/GW	Share of capacity/%	Production of electricity(brutto) /(TW・h/a)	Share of production/%	Remark
Lignite	20.9	9.7	136.5	22	Massive reduction(1)
Hard coal	25.3	11.7	84.4	13.6	Massive reduction(2)
Nuclear energy	10.8	5.0	72.0	11.6	Massive reduction(3)
Natural gas	29.8	13.8	83.8	13.5	Massive reduction(4)
Oil + other	6.6	3.7	18.0	8.9	Massive reduction(5)
Wind energy	55.7	25.8	104.2	16.8	Massive subvention
Bio mass	7.8	3.6	49.0	7.9	Massive subvention
Photovoltaic	43.2	20.0	39.8	6.4	Massive subvention
Hydro energy	5.6	2.6	19.8	3.2	Massive subvention
Other	10	4.7	12.4	2.1	Massive subvention
Total	≈216	100	≈620	100	

(b) Production of electricity and capacities of plants (example: Germany, 2017)

1,2—coal production has been reduced; since 2018 no more have coal mining in Germany; 3—large nuclear power reacts were taken out of operation after the accidents in Fukushima(2011); 4—massive reduction of use of natural gas in future; 5—oil for electricity production in Gase load plants is practicly forbidden

Worldwide today 70% of the electricity is produced on the basis of fossil fuel. Europe and North America still consume more than 60% of the electricity. Africa and South America need large progress regarding the production of electrical energy. Large investments in power plants, grids and distribution systems are necessary to realize this goal.

The need and supply of energy develops very fast in some countries worldwide, as example in China. Figure 1.11 and Figure 1.12 indicate some important parameters of the energy economy in China.

All data related to consumption and supply is rising up strongly, corresponding to the progress in this country. Further aspects related to special branches of energy economy are explained by Figure 1.12.

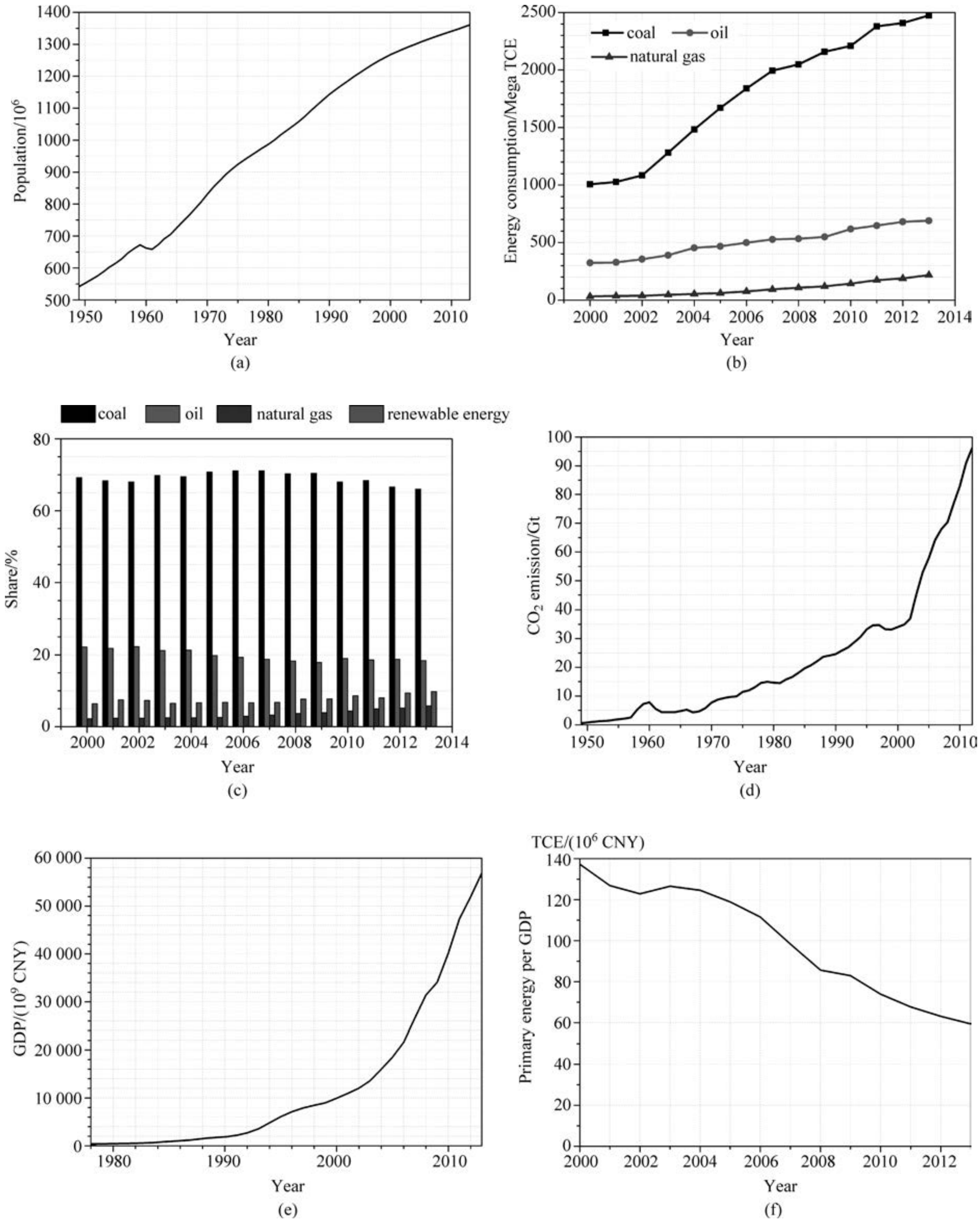


Figure 1.11 Important parameters of energy economy developing in time (example: China)[7-8]

(a) Population(value in 2019: 1.4×10^9); (b) Primary energy (CE = coal equivalent)(value in 2019: 4.76×10^9 t HCU/a); (c) Shares of energy carriers; (d) CO_2 emission(value in 2019: $\approx1\times10^{10}$ t CO_2/a); (e) Gross national product(value in 2019: 10 000 dollar/(person · a)); (f) Ratio of primary energy applied to the gross national products