3 Energy Demand

Covering the demand for energy services is the driving force of the whole energy sector, and this indicates the importance of demand in the energy value chain. However, policy instruments in place (see Chap. 6) and investment activities frequently focus on the supply side, whereas the demand side is often treated rather poorly.

To deliver the desired energy services (e.g. an illuminated room), useful energy (e.g. light) has to be provided, which is done by transforming final energy carriers (e.g. electricity). Although energy services may be considered the real driver (see Chap. 2), this chapter will mainly focus on the demand for final energy carriers, particularly for electricity and heat, as energy services and useful energy are difficult to quantify. Nevertheless, it is worth mentioning again that the first step in making the energy transformation chain more sustainable is to analyse whether the requested energy services can be reduced (without any loss of comfort) or provided more efficiently (see Sect. 2.4.1). Key questions to be answered in this chapter are as follows:

- What are the key drivers and characteristics of electricity and heat demand?
- What do electricity load profiles look like?
- By which instruments can the demand side be influenced?
- Which methods are used to forecast the future electricity demand?
- How can electricity tariffs be differentiated?

These questions are discussed starting with the final energy carrier electricity in Sect. 3.1; subsequently, the heat demand is analysed in Sect. 3.2, as it is partly produced jointly with electricity in so-called combined heat and power (CHP) plants (see Chap. 4). Both subchapters will have a focus on households as the most homogenous sector.

Key Learning Objectives
After having gone through this chapter, you will be able to

C. Weber et al., *Economics of Power Systems*, Springer Texts in Business and Economics, https://doi.org/10.1007/978-3-030-97770-2_3

- Describe the level, the structure and the key components of electricity and heat demand.
- Understand the basic ideas of different methods to forecast energy demand.
- Define the key concepts of demand-side management (DSM) and different electricity tariffs.

3.1 Electricity Demand

3.1.1 Basics

An important parameter to describe the **electricity demand** of a region/country is the net electricity consumption, composed of the electricity demand of the different sectors (transport, households, tertiary and industry) in this region/country. To calculate the gross electricity consumption, the losses in electricity transportation and distribution as well as the electricity needed to operate the power plants (including pump storage power plants) have to be added. The gross electricity consumption can also be computed by adding electricity imports to and subtracting electricity exports from the gross electricity production in the region/country.

Worldwide electricity consumption has been growing for many years. Meanwhile, the net electricity consumption[1] has gone beyond the mark of 20 PWh (see Sect. 2.2). According to Eurostat, the net electricity consumption of the EU28 was about 2,700 TWh in the year 2015 (cf. Eurostat 2019). The share of the transport sector is minor, the industry sector is responsible for about 40% and the household and the tertiary sector each for about 30% of the net electricity consumption (see Fig. 3.1).

Net electricity consumption in Germany as an example for an industrialised country was about 527 TWh in 2018, the industry sector having a share of slightly below 50% and households and the tertiary sector a share of about a quarter each and transport a share of about 2% (cf. BDEW 2019). The final energy carrier electricity is used to provide a variety of energy services in the different sectors, whereby mechanical energy and process heat dominate in Germany (cf. Ströbele et al. 2010, p. 218). To satisfy its demand of energy services, a German single-person household needs about 2,000 kWh of electricity per year on average. Of course, there are considerable differences in electricity consumption of different households; the demand typically increases with, e.g. the dwelling space and the appliances used. A higher consumption also occurs if electricity is also used for heating purposes. The additional electricity demand if having more than one

[1] Comparing the net electricity consumption with the gross electricity production (see Sect. 2.2) provides an indication of the losses in the system.

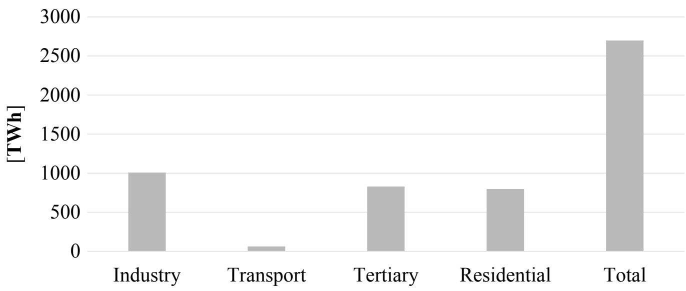

Fig. 3.1 Net electricity consumption in EU28 in the year 2015. *Source* Own illustration based on data from (Eurostat 2019)

member in the household usually is below these 2,000 kWh. In other words, the electricity demand per person is falling with an increasing size of the household. This can be explained, e.g. by the fact that households of double size do not necessarily have double the number of devices and appliances, e.g. to provide the energy services of illuminated rooms or cooling of food.

3.1.2 Applications on the Demand Side

Electricity demand is the sum of the electricity consumption of the demand-side technologies employed in the considered system. Therefore, the electricity demand can be calculated by considering the installed appliances, their specific electricity demand and their time of use. The demand-side technologies can be described by characteristics also used for supply-side technologies (e.g. investment costs, efficiency, etc.; see Sect. 4.3). The main difference is that the demand-side applications transform the final energy carrier electricity into useful energy, which is then used to provide the desired energy service. Examples for such technologies are in the industry sector electrolysis processes and electric arc furnaces, in the residential and tertiary sector fridges, freezers and electric heating systems. Given the relatively homogenous structure of the household sector – especially compared to the industrial sector – the share of the different appliances in the electricity demand of an average household can be determined rather easily (see Fig. 3.2).

With regard to the technologies used, cross-cutting technologies such as pumps, fans and compressors, which are used in many sectors and subsectors, may be distinguished from sector-specific technologies, like electric arc furnaces used in the iron and steel sector. As cross-cutting technologies are applied in totally different sectors, improvements in the efficiencies of these technologies will reduce electricity consumption in many places.

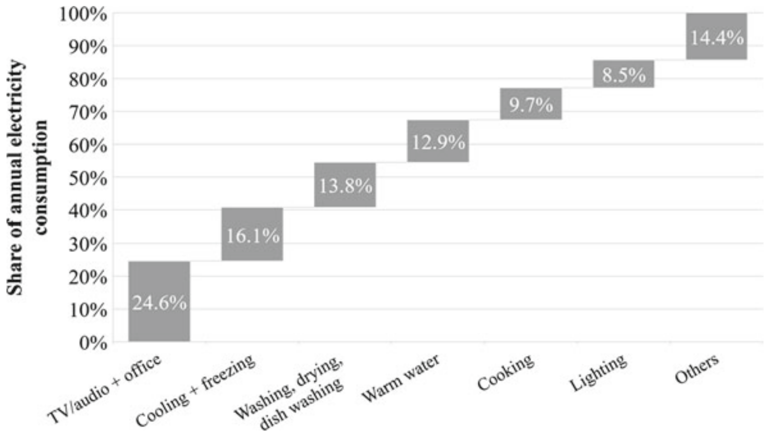

Fig. 3.2 Electricity consumption in German households in the period 2007–2011. *Source* Own illustration based on (Oberascher 2013)

As soon as new technologies using electricity as an input factor emerge, this impacts the electricity demand of the customers, sectors and countries. This might be of huge importance for the future energy system as more and more technologies are expected to use electricity instead of fossil-based energy carriers and sectors like the transport sector will become more and more electrified (so-called sector coupling or energy system integration), as electricity can rather easily be decarbonised. Therefore, promising applications like **electric vehicles** and **heat pumps** can have a considerable impact on future electricity demand, e.g. an electric vehicle will considerably increase the electricity demand of a household. Assuming an average annual mileage of a passenger car of 14,000 km and an average consumption of 15 kWh/km, this results in an additional yearly electricity demand of 2,100 kWh.[2]

3.1.3 Load Profiles

A **load profile**, also called load shape, shows the power consumption variation, measured, e.g. in watt, over time. The applications used in a system determine the shape of the load curve of this system. This load curve is of paramount importance since possibilities for storing electrical energy are limited (see Sect. 5.2). The load profile of a region consists of the superposition of the profiles of the customers (from different industry branches as well as from sectors like transport, households and tertiary) or appliances in this region. Fortunately, the load profiles of different customers have different forms, as these demand electricity at different times; e.g.

[2] From a system perspective, it has to be considered that this new electricity demand will, in most cases, be accompanied by a reduction of energy carriers used up to now in internal combustion engines (ICE) like diesel or gasoline.

households typically demand electricity mainly in the evening in winter time, when people frequently come home from work, whereas demand from bakeries has its peak during early morning hours. So, the electricity demand peak in a region is not equal to the sum of all electricity demand peaks of the customers in this region, as the peaks of the different customers are not simultaneous. The so-called **coincidence factor** is frequently used to consider this effect in the planning process. The coincidence factor is computed by dividing the demand peak of a system/region by the sum of all demand peaks of the electricity demanding entities in this system/region.

Load profiles can be interpreted as a combination of deterministic and stochastic processes. In households, the profiles are the result of switching on and off different electrical appliances. Therefore, load profiles are influenced by factors like occupant characteristics. Although the time of use of some appliances is easily foreseeable, other appliances seem to be switched on and off more or less randomly, introducing a stochastic component to electricity load profiles (cf. e.g. McLoughlin et al. 2010).

For customers with relatively small consumption quantities like households, load profiles have until recently mostly not been measured, but typical load structures have been clustered to obtain so-called standardised **load profiles**. The reason for not measuring the details of the electricity consumption is that due to the limited amount of electricity delivered to these customers, it was for a long time not seen to be economically justified to install the necessary metering equipment – a fact that is just beginning to change due to modern smart meter technologies. The standardised load profiles are typically used by load serving entities to determine the demand structure of a bundle of such customers, e.g. some thousands of households. Of course, the true load profiles of single households (see Fig. 3.3) might be distinct from these standardised load profiles showing much more fluctuations (e.g. due to the use of an electric kettle in the morning). But these fluctuations average out as soon as a larger number of customers is considered. For major customers like industrial plants (typically with a yearly demand of more than 100,000 kWh), the consumed energy is measured in a more elaborated way, e.g. for every 15 min interval.

If the hourly load over the whole year is sorted in descending order, the resulting graph is called a sorted annual **load duration curve** (see Fig. 3.4). Load duration curves have often been used during the planning process of new generation capacities as they indicate, which capacity is needed for which duration. With the help of the load duration curve, the so-called base load, which is the minimum load over the whole year (point A in Fig. 3.4), can easily be identified.

Many factors are influencing the load profile of different customers, like lifestyle, attendance or working times or the stock of installations. Additionally, the diffusion of emerging technologies using electricity as an input factor (e.g. **electric vehicles**) might drastically change the future load profiles of customers and so the total load profile of the system/region. Furthermore, customers tend to produce more and more electricity by themselves, e.g. with the help of rooftop PV (see e.g. Sect. 4.2.3). These so-called **prosumers** (see also Sects. 6.1.4 and 12) reduce the

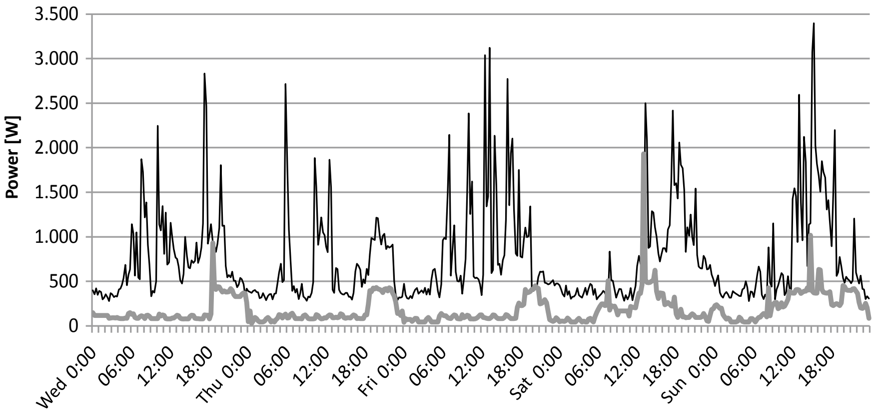

Fig. 3.3 Selected load curves of two households. *Source* Own illustration based on (Kaschub 2017, p. 20)

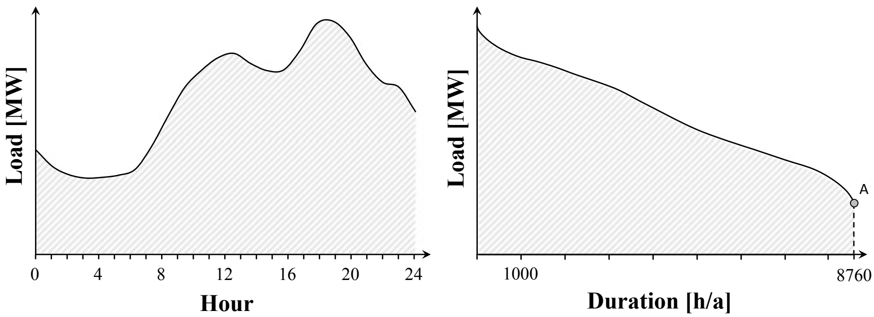

Fig. 3.4 Daily load profile (left) and annual load duration curve (right)

amount of electricity taken out of the power grid and change the electricity demand profile still to be delivered to these customers (so-called net or residual load) from the grid.

3.1.4 Demand-Side Management

Demand-side management[3] comprises activities on the demand side to reduce the load of customers[4] in general (energy efficiency objective) or to reduce or increase their load during specific periods (load shifting objective) (cf. Kostkova et al. 2013). Both ideas have been on the agenda for many years. Increasing the energy efficiency on the demand side helps to diminish emissions and the depletion of

[3] There is no clear differentiation of the technical terms demand-side management (DSM), demand response (DR) and load management (cf. e.g. Albadi and El-Saadany 2008; Kostkova et al. 2013).
[4] Or at least their purchase of electricity from the electric grid.

resources by reducing the electricity produced. Recently, load shifting has received increased attention as it is seen as a flexibility option, which can compensate fluctuations of electricity production by wind and PV.

To react in the desired way, customers need to be incentivised, e.g. by price-based or incentive-based programmes (cf. DoE 2006). Within an incentive-based programme, customers get a payment for actively reducing their demand or for agreeing that a pre-defined entity, e.g. their power company or the system operator, is allowed to remotely control the use of some of their devices during critical hours. Therefore, this form of incentivising load shifting is also called direct load management. In contrast, price-based programmes comprise tariff forms setting different charges in different situations (see Sect. 3.1.6). This form of incentivising load shifting is called indirect load management.

While typically the responsiveness of many customers, e.g. from the household sector, is relatively low, the establishment of such programmes helps increase and use the customers' responsiveness. The **price elasticity** of demand (sometimes – to put it simply – just called demand elasticity) indicates thereby how the (incremental) demand (q) changes in response to an (incremental) price (p) change (see 3.1):

$$\varepsilon = \frac{dq}{dp} \cdot \frac{p}{q}. \tag{3.1}$$

In the electricity sector, demand is said to be relatively price inelastic (absolute value of ε is below one), as a change in prices typically results in a rather small change in the quantity of electricity consumed. Of course, the price elasticities of electricity demand depend on many different aspects, like the customers considered, the point in time, etc. Subject to the considered period, demand elasticity is typically differentiated into a short-term and long-term price elasticity of demand. While the long-term price elasticity of electricity demand is still lower than price elasticities in many other sectors, it is higher than the short-term price elasticity of electricity demand. The reason is that customers can find substitutions for energy-intensive devices, e.g. more efficient devices still using electricity or appliances using other energy carriers, like natural gas, to provide the needed energy service. In the short term, customers have hardly any further possibility of reacting than changing their usage habits.

Not all applications are suitable for **load shifting**. Applications like lighting, TV and PC, which are used when there is a direct demand for the corresponding service, can hardly be used for demand response because there will be little willingness to accept such an intervention into daily life. Much more promising are appliances, the operation of which is projectable, like dishwashers and dryers. Very suitable for demand response are appliances that can decouple the electricity consumption and the service provision, e.g. due to the availability of a storage unit (cf. e.g. Boßmann 2015, pp. 19 and 23). In this context, it is advantageous if the user does not even notice that the regular demand has been changed; an example could be the premature use of a refrigerator's compressor. Hopes are especially placed in potentials for load shifting realised by appliances like electric vehicles and heat pumps, which are becoming more and more important in the context of decarbonisation and associated sector coupling strategies (see Chap. 12), as these appliances lead to a high additional electricity demand that can rather easily be shifted within certain boundaries.

Despite the interest in the topic, there are many barriers to the realisation of demand-side management, which could result in an underinvestment (so-called energy efficiency gap). Many customers do not have the necessary information about energy-saving and load shifting measures. Overcoming this barrier might lead to additional costs, so-called transaction costs. Concerning short-term activities, the main barrier seems to be the resistance to deviate from traditional behaviour patterns. As soon as investments have to be realised, capital limitations and long payback times hinder demand-side activities. Especially in the industrial sector, short payback times are usually required (often in a range between 2 and 3 years). This can be a considerable hindrance for investments in energy-efficient technologies, which often have long lifetimes far exceeding these payback times. Therefore, investment opportunities, that would be rather promising if other investment criteria (e.g. the net present value) were used, will not be realised.

3.1.5 Projecting Electricity Demand

Electricity supply and demand have to be always in equilibrium to keep the frequency at the foreseen level (cf. Chap. 5). Therefore, it is essential to forecast the electricity demand[5] on a short-term basis (e.g. for the next hours), a medium-term basis (e.g. for the next weeks and months), as well as on a long-term basis (e.g. for the next years or even decades). Short-term projections of **electricity demand** are required, e.g. to adjust the operation of the existing generation units (see Sect. 4.4), medium-term projections, e.g. to plan necessary maintenance operations of these installations and long-term projections, e.g. to identify the requirements for additional generation capacity.

In general, electricity demand in the different sectors of the energy system, households, tertiary, industry and transport is influenced by many factors, which have to be projected to forecast electricity consumption. Factors influencing the long-term electricity demand are, e.g. the stock of installations, taking into account the efficiency of the used appliances, the lifestyle of the population, the structure of the whole economy, the industry structure (share of energy-intensive production), the gross value added (GVA), socio-demographic factors, the available income and the price of electricity. In addition to these factors, for short-term projections of electricity demand with a much higher temporal resolution, additional information is necessary, e.g. the start of the broadcast of a football match or the weather conditions in the next hours.

A multitude of qualitative and primarily quantitative methods exists to forecast electricity demand on the short-term, medium-term and long-term basis – many of

[5] As well as, e.g. the fluctuating supply.

these methods are also used to forecast electricity prices (a comprehensive classification of electricity price modelling approaches can, e.g. be found in Weron (2014), an overview of stochastic models used in electricity markets in Möst and Keles (2010). To forecast the development of long-term electricity demand, fundamental drivers of demand and their further development are typically analysed. The so-called top-down approach tries to model electricity demand as a function of macroeconomic variables like the demographic and the economic development, as electricity consumption typically increases with the growth of the gross value added or the population (cf. Zweifel et al. 2017, pp. 89–110 and Chap. 2). In contrast, the so-called bottom-up approach takes into account much more detailed information about the appliances in the different sectors and the intensity of their use (cf. Zweifel et al. 2017, pp. 65–87). Nevertheless, also demand projections based on a bottom-up approach start by estimating the development of macroeconomic variables like the gross domestic product (GDP), the population and wholesale prices. This data is used to determine more disaggregated factors like the sectoral gross value added (GVA), the physical production, the employment and energy prices for the different end-users. In a next step, this information is used to derive the main drivers of the electricity demand in the different sectors, like the value added in the different industrial branches, the numbers of employees in the different subsectors of the tertiary sector, the number of households and their net dwelling areas and the tonne- and passenger-kilometres in the transport sector (cf. e.g. Fraunhofer-ISI et al. 2015). To model electricity demand in such a comprehensive way, a variety of data about the technologies available in the different sectors and their specific electricity consumption have to be taken into account, which already illustrates the challenge of data availability.

More emphasis has to be put on a higher temporal resolution of the forecast for shorter forecasting periods. Here, e.g. econometric time-series models are often applied, which are based on the idea to identify patterns in historical time series and to use these patterns to develop a forecast. Time-series models employ statistical methods, like regression and smoothing techniques, to forecast future electricity demand. Furthermore, approaches from the emerging field of artificial intelligence (AI), like neural networks, can be used to forecast electricity demand. With the help of neural networks, a forecast of the electricity demand can be developed without knowing any details about the relationship between this output and different inputs, like, e.g. weather conditions. Finally, it should be mentioned that different forecasting methods, e.g. a long-term model based on fundamentals of the system and a model trying to represent short-term stochasticity, can also be combined, leading to so-called hybrid methods.

3.1.6 Electricity Tariffs

Electricity tariffs describe the payment structure customers face when they pay for electricity usage. Electricity tariffs might consist of different components, like an annual base rate (€/a), energy rates (€Cent/kWh) and capacity rates (€/kW). Under such a system with different components, the total bill to be paid by the customer cannot be calculated by just multiplying the quantity (kWh) consumed by the specific price (€Cent/kWh), which is why such pricing systems are called **nonlinear pricing systems** (cf. Oren 2012).[6] By paying the tariff, the customer not only settles the costs to deliver the electricity but also the costs caused by the necessary use of the electricity grid (use-of-system charges, see Chap. 6) as well as fees (e.g. to finance the extension of renewable energies or very efficient technologies like cogeneration units) and taxes. Electricity tariffs of different customers vary in their components and their relative importance. Typically, households and other small customers only pay a base rate and essentially a **volumetric electricity price** – a rate per kWh electricity used. A tariff (€Cent/kWh) which is more or less based on volumetric end-user prices typically is much higher than the average electricity wholesale price (€Cent/kWh) as it incorporates, e.g. grid charges, levies and surcharges. However, such tariffs may not give the appropriate incentives to the consumers, especially concerning sector coupling and self-consumption (see Chap. 12). Industrial companies are also charged a rate for their yearly peak demand (in kW) called a non-peak-coincident demand charge. As the peak demand of a company does not necessarily coincide with the peak demand of the whole system, activities to reduce the company-specific peak demand do not necessarily have a positive effect on the entire system. To consider the contribution of the company to the **peak load** in the whole system, so-called **peak-coincident demand charges** can be used. These charges consider the demand of the company during the time of peak demand in the system. Furthermore, different forms of discounts might be given to the customers, e.g. the transportation and distribution system operators can reduce the use-of-system charges for energy-intensive companies if their delivery structure is untypical (high company-specific demand in times of low demand in the whole system).

The energy rates of electricity tariffs (€Cent/kWh) can be constant (simple rate) or vary over time, which seems to fit better to the time-varying costs of electricity production (see, e.g. Boiteux 1960). Energy rates may depend on the amount of delivered electricity; there are tariffs with different thresholds for the delivered electricity with higher energy rates as the demand of the customer increases (tiered rate). Alternatively, energy rates may depend on the time of delivery, e.g. the hour of the year. This form of letting the customers participate in the volatility of wholesale prices is called dynamic pricing (cf. Joskow and Wolfram 2012). Time depending tariffs can be differentiated into

- **Time-of-use (TOU) tariffs**: The prices change according to different pre-defined time periods (e.g. day–night).
- **Critical peak pricing (CPP) tariffs**: Higher prices are applied if pre-defined critical events (high demand) occur.
- **Real-time pricing (RTP) tariffs**: The prices vary rather often, e.g. on an hourly basis – but also here the customers usually know the tariffs in advance.

[6] Another form of price discrimination – so-called Ramsey prices – will be discussed in Sect. 6.1.4.

Tariffs offering dynamic forms of adaptability provide the possibility to incentivise load shifting activities of customers on a short-term basis, a feature that might be beneficial in energy systems with a high share of fluctuating electricity production (see Sect. 3.1.4).

In contrast to time-dependent tariffs, load-dependent tariffs have the feature that the price for electricity (€Cent/kWh) depends on the required capacity. As soon as a threshold concerning the load (kW) is passed, the electricity rate will be changed. Furthermore, the capacity rates (€/kW) can vary (so-called load-variable tariffs): the rates will increase with the customer's load that has to be served. Having the proper measuring and controlling installation in place such tariffs may even foresee that the power consumption of a customer is limited to a contracted guaranteed power level.

3.2 Heat Demand

Heat demand is responsible for a large part of the final energy demand. The importance of the heating sector may be illustrated with the following data: in 2019, more than 50% of the final energy demand has been used for heating purposes in Germany (i.e. more than 1300 TWh), in the household sector even about 90% (cf. e.g. Arbeitsgemeinschaft Energiebilanzen 2020). According to the European heat roadmap, the heat demand in the largest EU member states[7] was almost 4,500 TWh in 2015 (Paardekooper et al. 2018). More than half of this demand is related to space heating purposes, especially in the residential sector (see Fig. 3.5). In industry, most of the heat is needed to provide process heat, e.g. for drying or melting applications. These different forms of heat are insofar different products as they have different temperature levels and therefore different thermodynamic values, as the exergy of heat depends on the temperature level (see Sect. 2.1.2). Process heat is typically needed at much higher temperatures (partly even above 1,000 °C) than space heat or hot water. The temperature level also influences the technology used to provide the requested heat. The heat production process is typically realised locally, rather close to the point of demand,[8] because heat transport is limited by the low-energy density of hot fluids like hot water and steam. Furthermore, unlike electricity, heat can be stored quite efficiently, so heat production does not exactly have to follow heat demand. Typically, the demand for process heat is relatively constant during the year, of course strongly depending on the activity level of the industrial process for which the heat is needed. The demand for **hot water** is also relatively constant over the year but with sporadic peaks during the day (e.g. due to the daily shower in the morning). The absolute level (e.g. in one building/region/country) mainly depends on the number of users. In contrast to process heat and hot water, the demand for **space heating** shows considerable

[7] These 14 EU member states are responsible for about 90% of the EU heat demand.

[8] Nevertheless, there are district heating systems, which transport the heat up to about 50 km to the customers.

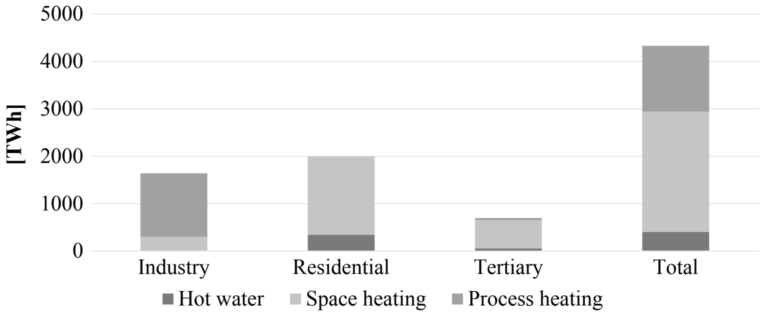

Fig. 3.5 Heat demand in the largest EU member states in 2015. *Source* Own illustration based on data from (Paardekooper et al. 2018)

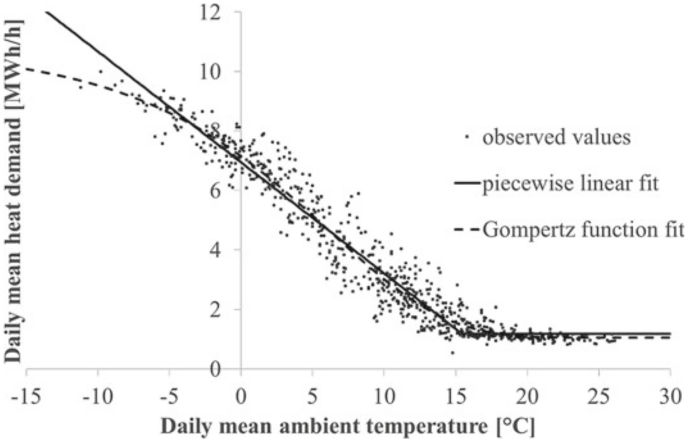

Fig. 3.6 Exemplary energy demand for space heating as a function of outside temperature

seasonal variations as it is strongly dependent on the outside temperature. Furthermore, the demand for space heating depends on the floor area to be heated within the considered system.

According to the first principles of (non-radiative) heat transfer, heating energy demand should increase linearly when the outside temperature drops below a threshold temperature, sometimes labelled "heating limit temperature" (see Fig. 3.6). The dashed, sigmoid line in Fig. 3.6 considers some smoothening and limiting effects in real-world systems, including the heterogeneity of the "heating limit temperature" within any sample of buildings and occupants. On the other hand, the dimensioning of the heating equipment (radiators, heat exchangers, boilers, etc.) limits demand at extremely low temperatures.

Process heat demand arises in multiple sectors, ranging from primary materials fabrication (e.g. steel or plastics) to food processing (e.g. bakeries). There are multiple types of processes that require heat on a relatively high-temperature level, e.g. for drying, melting, chemical conversion or cleaning applications. In the iron and steel, non-ferrous metals, glass, ceramics and cement industries process temperatures of several hundred degrees are needed (cf. e.g. McKenna and Norman 2010). A common characteristic of process heat demand is the independence or limited dependence on the outside temperature. However, some correlation may be observable, e.g. when the ambient air is heated and used for drying purposes.

3.3 Further Reading

Borenstein, S., & Holland, S. (2005). On the efficiency of competitive electricity markets with time-invariant retail prices. RAND Journal of Economics, 36, 469–493.

In this paper, the different effects of real-time pricing are discussed.

Zweifel, P., Praktiknjo, A., & Erdmann, G. (2017). Energy Economics – Theory and Applications. Berlin, Heidelberg: Springer.

The book Energy Economics gives a comprehensive overview of energy economics and focuses in two chapters on bottom-up and top-down analysis of energy demand.

Blesl, M., & Kessler, A. (2017). Energieeffizienz in der Industrie. 2nd edition. Berlin, Heidelberg: Springer Vieweg.

This book gives an extensive introduction into energy-saving measures in the industry in German language.

McKenna, R., & Norman, J. (2010). Spatial modelling of industrial heat loads and recovery potentials in the UK. Energy Policy, 38, 5878–5891.

This paper presents a comprehensive estimation of the heat demand, differentiated according to different temperature levels, and the technical recovery potential for industrial sectors in the UK.

3.4 Self-check of Knowledge and Exercises

Self-check of Knowledge

1. What is the level of the yearly electricity and heat demand in Europe?
2. Which different forms of heat do you know?
3. Which sectors are responsible for which shares of the total electricity/heat demand in the European Union?
4. Which quantitative methods are typically used for forecasting energy demand on a short-term and on a long-term basis?
5. Define the price elasticity of demand!

6. Name different factors influencing short-term and long-term demand for electricity, space heating, hot water and process heating.
7. What is the difference between a load profile and a load duration curve?
8. Which forms of electricity tariffs do you know?

Exercise 3.1: Investments in Efficient Demand-Side Technologies
You need a new washing machine and a new gas-based heating system for your household (interest rate: 4%). To reduce your contribution to climate change, you decide to invest in the first step in one of the two cases in a very efficient appliance. As you have different opportunities, you want to identify this appliance using the performance figure "Euro per tonne of CO_2 avoided" (€/t CO_2). Your local energy company runs a steam power plant fired with hard coal and offers the following tariffs: electricity tariff: 30 Cent/kWh, gas tariff: 7 Cent/kWh. In which of the two more efficient technologies should you invest? The local energy company announces to switch from coal to gas (CCGT). Does this influence your decision?

	Lifetime [years]	Additional investment compared to the standard	Yearly energy demand compared to the standard
Washing machine	10	200 €	45 kWh (standard: 90 kWh)
Heating system	10	650 €	9,500 kWh (standard: 10,000 kWh)

Exercise 3.2: Forecasting Electricity Consumption
In the following table, the net electricity consumption in Germany in the years 2010–2019 is depicted. Forecast the net electricity consumption in Germany in the year 2025, applying linear regression using the least square method. Critically discuss your result.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
[TWh]	540	535	530	535	525	525	525	530	520	515

Exercise 3.3: Introducing Time-of-Use Tariffs
Calculate the yearly electricity bill of a household with an annual consumption of 4500 kWh according to the following load profile (in % of the total demand) under a fixed electricity tariff of 30 Cent/kWh.

hour	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
[%]	3%	2%	2%	2%	2%	3%	4%	5%	4%	4%	4%	5%
hour	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00
[%]	4%	4%	4%	4%	5%	6%	7%	7%	6%	5%	5%	3%

The energy supply company wants to introduce a time-of-use tariff with two different zones: peak time from 8 am to 8 pm and off-peak time from 8 pm to 8 am. During the off-peak time, the tariff is supposed to be 20 Cents/kWh. How high must the tariff be during peak time to realise the same revenues assuming

(a) that customers will not change their behaviour,
(b) that customers will shift 10% of their current demand in peak hours into off-peak hours?

References

Albadi, M., & El-Saadany, E. (2008). A summary of demand response in electricity markets. *Electric Power Systems Research, 78*, 1989–1996.

Arbeitsgemeinschaft Energiebilanzen (2020). *Anwendungsbilanzen zur Energiebilanz Deutschland.* Available at: https://ag-energiebilanzen.de/wp-content/uploads/2020/10/ageb_20v_v1.pdf [Accessed May 27, 2022].

BDEW. (2019). *Nettostromverbrauch nach Verbrauchergruppen*. Available at: https://www.bdew.de/service/daten-und-grafiken/nettostromverbrauch-nach-verbrauchergruppen/ [Accessed May 5, 2019].

Boßmann, T. (2015). *The contribution of electricity consumers to peak shaving and the integration of renewable energy sources by means of demand response*. Fraunhofer Verlag and Dissertation: Karlsruhe Institute of Technology (KIT).

Boiteux, M. (1960). Peak-load pricing. *The Journal of Business, 33*, 157–179.

DoE. (2006). *Benefits of demand response in electricity markets and recommendations for achieving them. Technical report*. Washington. U.S. Department of Energy. Available at: https://www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/DOE_Benefits_of_Demand_Response_in_Electricity_Markets_and_Recommendations_for_Achieving_Them_Report_to_Congress.pdf [Accessed May 27, 2022].

Eurostat. (2019). *Supply, transformation and consumption of electricity, Final energy demand by sectors, Table nrg_cb_e*. Available at: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_e&lang=en [Accessed April 19, 2019].

Fraunhofer ISI, IREES, & TEP. (2015). *FORECAST/eLOAD*. Available at: http://www.forecast-model.eu/forecast-wAssets/img/methodology/forecast_tabelle_05.png [Accessed May 5, 2019].

Joskow, P., & Wolfram, C. (2012). Dynamic pricing of electricity. *American Economic Review, 102*, 381–385.

Kaschub, T. (2017). *Batteriespeicher in Haushalten unter Berücksichtigung von Photovoltaik, Elektrofahrzeugen und Nachfragesteuerung Produktion und Energie (23)*. KIT Scientific Publishing and Dissertation: Karlsruhe Institute of Technology (KIT).

Kostkova, K., Omelina, L., Kycina, P., & Jamrich, P. (2013). An introduction to load management. *Electric Power Systems Research*, *95,* 184–191.

McKenna, R., & Norman, J. (2010). Spatial modelling of industrial heat loads and recovery potentials in the UK. *Energy Policy*, *38,* 5878–5891.

McLoughlin, F., Duffy, A., & Conlon, M. (2010). The generation of domestic electricity load profiles through Markov chain modelling. *Euro-Asian Journal of Sustainable Energy Development Policy, 3*.

Möst, D., & Keles, D. (2010). A survey of stochastic modelling approaches for liberalised electricity markets. *European Journal of Operational Research, 207*, 543–556.

Oberascher, C. (2013). *Stromverbrauch und Stromverwendung der privaten Haushalte in Deutschland. Ergebnisse einer Studie im Auftrag von HEA, BDEW und EnergieAgentur.NRW, 2012*. Available at: https://www.yumpu.com/de/document/view/10605406/energieverbrauch-und-energieverwendung-im-haushalt-hea [Accessed May 26, 2022].

Oren, S. (2012). Nonlinear pricing. In Özer, Ö., & Phillips, R. (Eds.), *The Oxford handbook of pricing management*. Oxford University Press. Available at: https://doi.org/10.1093/oxfordhb/9780199543175.013.0022 [Accessed May 27, 2022].

Paardekooper, S., Lund, R. S., Mathiesen, B. V., Chang, M., Petersen, U. R., Grundahl, L., David, A., Dahlbæk, J., Kapetanakis, I. A., Lund, H., Bertelsen, N., Hansen, K., Drysdale, D. W., & Persson, U. (2018). *Heat Roadmap Europe 4: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps*. Aalborg Universitetsforlag.

Ströbele, W., Heuterkes, M., & Pfaffenberger, W. (2010). *Energiewirtschaft - Einführung in Theorie und Politik* (2nd ed.). Oldenbourg.

Weron, R. (2014). Electricity price forecasting: A review of the state-of-the-art with a look into the future. *International Journal of Forecasting, 30,* 1030–1081.

Zweifel, P., Praktinjo, A., & Erdmann, G. (2017). *Energy economics—Theory and applications*. Springer.