TrustEE

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Report on current status of Process Heat in Europe: sectors, processes, geographical distribution, system layouts and energy sources (D1.1)

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D1.1

TrustEE

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INNOVATIVE MARKET BASED TRUST FOR ENERGY EFFICIENCY INVESTEMENTS IN INDUSTRY

Report Prepared by:

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1 Executive summary

The techno-economic feasibility of PHES applications in industry depends on numerous factors, among others, related to the industrial end-user side. Different industrial sectors are characterized by different shares of heat consumption in total energy consumed, specific heat consumptions and temperature levels at which heat is delivered to the industrial process.

In order to characterize potential industrial end-users for PHES applications, this report gathers information on industrial sector dimension by country, heat consuming processes and heat production technologies and energy sources. This was done for EU28 Member States and for the following industrial sectors: non-metallic minerals, pulp and paper, food and beverages and wood and wood products.

The report compiles data presented by different sources: Eurostat, EU documents and policy instruments, industrial associations and various reports, all listed in the reference section.

Some global aspects related to EU28 energy consumption in industry are:

- The industrial sector is strongly dependent on fossil fuels to satisfy its energy demand.
- The impact of industry in fossil fuel depletion is relevant.
- Most of the energy consumed by the EU28 industry is used for heating purposes, mainly for process heat.
- Process heat consumption contributes significantly to the global EU energy consumption.
- There are substantial differences between EU28 Member States and industrial sectors.

Five industrial sectors represent more than two thirds of the heat consumed by the EU28 industries. These sectors are: iron and steel, chemical and petrochemical, non-metallic minerals, paper and pulp and food, beverages and tobacco. Improving the deployment of renewable energies as well as the energy efficiency in these industrial sectors has a significant influence on the reduction of the energy consumption and of the environmental impact of the European industry.

At the present time, the European industry largely relies on fossil fuels to produce process heat. Natural gas, coal and other fossil fuels are mainly used to produce medium/high temperature process heat. Biomass, the fourth most used energy carrier in the European industry, is predominantly consumed to generate heat at low temperatures. It is the only renewable energy source that has a significant use in the European industry.

Even though biomass can be burnt to generate high temperature heat, not all renewable energy sources can deliver medium or high temperatures to an industrial process, hence characterizing the temperature levels at which process heat is delivered is important for assessing the viability of implementing PHES applications. Most of the process heat demand in EU28 industry is above 500 °C. This is so in the iron and steel, chemical and petrochemical and non-metallic minerals industries. The pulp and paper, and food, beverages and tobacco industries mostly use heat at low temperatures.

Germany, Italy, the United Kingdom, France and Spain consume more than half of the process heat in the European Union. In these countries, natural gas is the most relevant energy carrier. As far as renewable energy sources are concerned, in Sweden, Latvia, Finland and Portugal, biomass is an important fuel.

As far as the non-metallic minerals sector is concerned, this report analyzes the manufacture of glass, cement and lime, and ceramic products. The sector is highly energy-intensive, particularly in process heat consumption, and requires temperature levels above 1000 °C. The heating processes occur in specific combustion systems, such as glass melting furnaces, kilns for cement clinker production and ovens or kilns for ceramic manufacture. The sector mainly uses fossil fuels to generate heat, although in the production of cement, wastes are increasingly used.

Contrary to what happens in the non-metallic minerals sector, most of the heat delivered in the pulp and paper industries requires temperatures below 200 °C. The heat-intensive processes are related with drying operations. There are two main configurations for the energy systems used in the sector: sole heat production and CHP. Biomass is the main energy source, followed by fossil fuels (mainly gas).

The food and drinks sector is highly diversified. This report analyses the following sub-sectors: meat, dairy, brewing, fruit and vegetables, sea products, bakery and vegetable oils. The basic system layout for process heat in the food and drink industry generates heat in a steam boiler. Natural gas, diesel and light fuel oil are the fuels conventionally used by the sector, but also biomass and biogas produced from residual biowaste or wastewater can be used.

As far as the wood and wood products sector is concerned, this report analyzes the manufacture of wood-based panels and pellets. In these two sub-sectors, most of the energy consumed is used for heating purposes, being drying the most heat-intensive process. Heat is produced in boilers and the main fuels used are wood-derived residues.

The industrial production of process heat is characterized by very different conversion technologies. Heat delivered at high temperatures is provided by industrial furnaces, while steam boilers and CHP units are mainly used to deliver heat at lower temperatures.

2 Introduction

This report is part of the TrustEE Project (Innovate Market Based Trust for Energy Efficiency Investments in Industry) funded by the European Union's Horizon 2020. TrustEE is coordinated by the Institute for Sustainable Technologies (AEE-INTEC), and the other partners are Fraunhofer Institute for Solar Energy Systems (Fraunhofer-ISE), REENAG Holding GMBH, European Council for an Energy Efficient Economy Forening (ECEEE), Universidade de Évora (UEvora) and AINIA – Centro Tecnológico (AINIA).

The main objective of the project is the definition and implementation of a market based financing model for Process Heat Efficiency and Sustainability (PHES) applications, gathering financial resources among a wide base of investors and ensuring the investment capital for small and medium-sized enterprises (SMEs) industries.

In the context of the TrustEE project, a tool enabling the estimation of the PHES market potential and impacts under different framework scenarios is being implemented. The viability and economical interest of PHES applications in industrial facilities depend on numerous parameters, among others, on the industrial end-user side. Therefore, the development of this tool encompasses gathering information on industrial sector dimension by country, heat consuming processes and heat production technologies and energy sources. This was done, at European Union (EU) level, for different heat consumption driven and energy-intensive industrial sectors.

The scope of this deliverable is to present the information gathered by the TrustEE partners on the current status of industrial process heat in different European industrial sectors and to briefly characterize these same sectors. The data presented in this document is reported by different sources: Eurostat, EU documents and policy instruments, industrial associations and various reports. This information is dispersed and collecting and analysing it was needed.

Europe's heat consumption in industry is not directly reported in Eurostat energy statistics, which poses difficulties in assessing its current status. The European Commission is aware of the inexistence of sufficient understanding of the heating and cooling sector as a whole and of its important contribution to the EU's energy and climate objectives. As a consequence, efforts have been recently made to characterize and define strategies for this sector. An example of such efforts is the European Strategy on Heating and Cooling (European Commission, 2016b).

The rest of the document is organized as follows:

- First a general overview of process heat in Europe is made. Particular attention is given to quantifying the process heat consumption in EU industry and its energy-intensive sectors, as well as temperature levels and energy sources used. Whenever possible, the information was given by EU Member State.

- Since the TrustEE project is focused on SMEs an overview of the EU SMEs of the manufacturing sector is made in chapter 2. At this point, the sectors where the SMEs were most relevant in sectoral total are identified.

- Chapters 3 to 6 present a characterization of process heat in different industrial sectors, namely, non-metallic minerals, pulp and paper, food and beverages and wood and wood-products.

- Before the conclusions, a chapter on heat production technologies and system layouts is presented. Since heat production is similar among some of the sectors characterized, this description was made at the end of the report and not in chapters 3 to 6.

2.1 General overview of process heat in Europe

Greenhouse gas (GHG) emissions from industry are mainly caused by converting fuels into useful energy in combustion processes occurring in energy production systems that generate electricity and heat needed for the industrial processes. These emissions are related to the direct use of primary energy sources in industry (mainly fossil fuels and biomass) since indirect emissions are caused by acquired electricity, still highly dependent on fossil resources (in 2014, 42% of the electricity produced in the EU was generated from fossil fuels, 28% from renewable energy sources (RES) and 27% from nuclear resources, according to Eurelectric (2015)).

The industrial sector is strongly dependent on fossil fuels to satisfy its energy demand. In 2014, fossil fuels had a 55% share in the industrial total energy consumption, electricity 31% and RES 7% (Eurostat, 2016a). The impact of industry in fossil fuel depletion is important. In 2012, the share of industry on final consumption of natural gas was 37%, of solid fuels 75% and of petroleum products 22% (European Commission, 2014). The share of industrial electricity consumption in total electricity consumption was 36%.

Heating in the industrial sector represents around 18% of the EU energy consumption and also relies heavily on fossil fuels. This share varies substantially from Member State to Member State, depending, among others, on its climate and economic structure. The production and consumption of process heat is characterized by very different energy conversion technologies and uses among the several, distinct industries; therefore, the analysis of the current status of process heat in Europe presented in this report focuses individually on various industrial sectors (chapters 3 to 6).

Heat dominates the energy consumption of industry in the 28 European Member States. Fraunhofer et al. (2016) estimated that, in 2012, the share of heating in the final energy demand of the European industry was 71% (60% for process heating and 11% for space heating). These estimates are presented in Figure 2.1, along with the share of cooling and non-heating and cooling uses of energy (mainly mechanical applications driven by electricity).

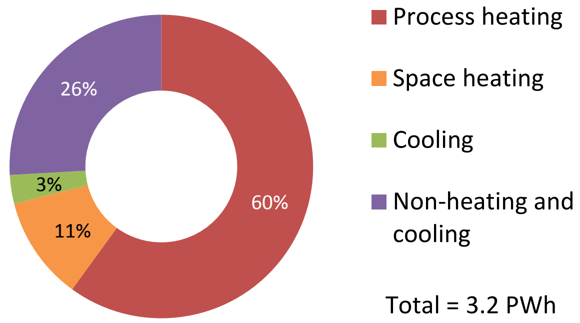

Figure 2.1: Share of the different end-uses in the final energy demand in industry for EU28 in 2012 [Adapted from Fraunhofer et al. (2016)].

The share of heat consumption in the European industry in 2012 (71%) is a global figure. The different industrial sectors are very diverse, consume energy in many distinct industrial processes and energy conversion technologies. In fact, these differences go down to the plant level within a specific industry sub-sector. Figure 2.2, shows an estimate for the disaggregation of the final energy demand into several industrial sectors. In most of them, heating, mainly process heating, takes the largest share. Exceptions are the machinery and transport and the non-ferrous metal industries, where significant amounts of electricity are consumed.

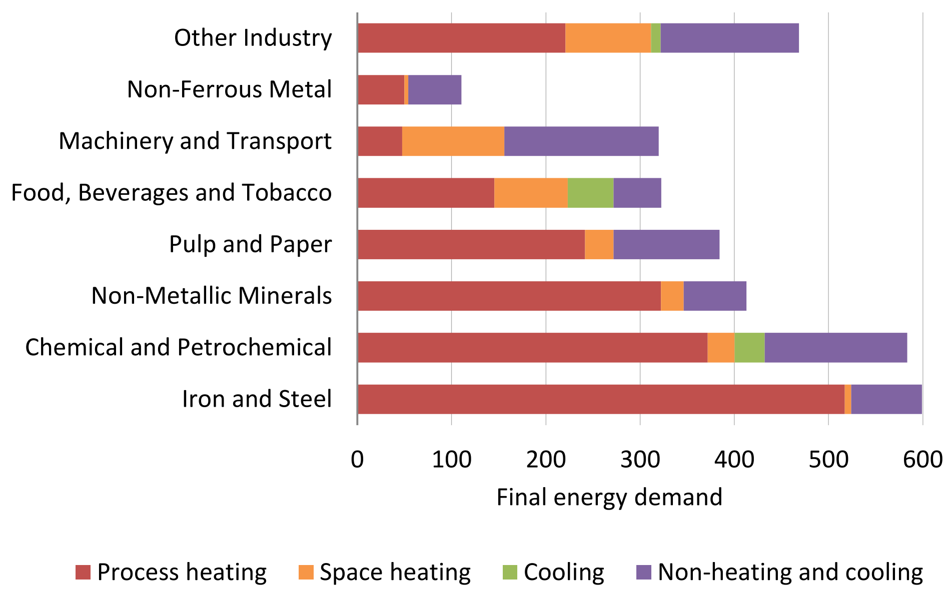

Figure 2.2: Final energy demand by end-use in industrial sectors for EU28 in 2012 [Adapted from Fraunhofer et al. (2016)].

The relative importance of various industrial sectors in the final heating and cooling consumption for the European industry is accounted for in Figure 2.3. The contribution of cooling is small, and mainly in the food, beverages and tobacco, and chemical and petrochemical industries (Figure 2.2); therefore, conclusions about the importance of each sector to the heating consumption in the industrial sectors can be easily drawn from Figure 2.3. The iron and steel, chemical and petrochemical, non-metallic minerals, paper and pulp and food, beverages and tobacco industries represent more than two thirds of the heat consumed by the European industries. Promoting energy efficiency and/or implementing renewable energies technologies in these five industrial sectors has a big impact on the reduction of energy consumption and GHG emissions in industry.

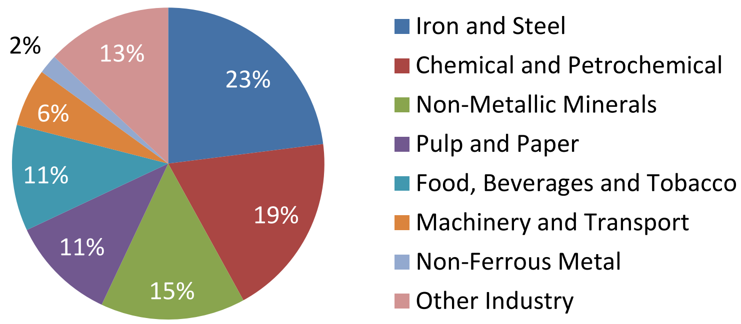

Figure 2.3: Heating and cooling final energy consumption by industrial sector for EU28 in 2012 [Adapted from European Commission (2016a)].

The breakdown of the final energy consumed in several industrial sectors into end-uses was also recently estimated by ICF (2015) and can be seen in Table 2.1. Note that in this study, process heat excludes electrical heating and HVAC - heating, ventilation and air conditioning (both considered in the electricity share). Some industrial sectors, of which the non-ferrous metals industry is a good example, consume high quantities of electricity for heating. According to this study, the highest share of process heat occurs in the petroleum refineries, followed by the iron and steel industry. Once again, one can see that process heating is the most significant energy use for these eight industrial sectors: the estimate is that 66% of the total final energy consumption in industry is for process heating. The study of Fraunhofer et al. (2016) reports 60% when considering the industry as a whole (not only the sectors analysed in ICF (2015)).

Knowing the temperature levels at which heat is delivered to the industrial processes is important to assess the potential for substitution of fossil fuels with renewable energy sources, since not all RES can deliver medium or high temperatures. Figure 2.4 presents the final energy demand for process heat and the share of temperature levels in industry for EU28 in 2012. When looking at the European industries as a whole (“All Sectors”), one can see that most process heat demands are above 500 °C. This heat is provided by industrial furnaces (Fraunhofer et al., 2016). For delivering heat below this temperature, the European industry mainly uses steam boilers and combined heat and power (CHP) units. When looking at specific sectors individually, one can see that the iron and steel industry was the one that consumed the largest amount of process heat in EU28 in 2012, as already depicted in Figure 2.2. For this industrial sector, and also for the chemical and petrochemical and non-metallic minerals, process heat is mostly delivered above 500 °C.

The pulp and paper, and food, beverages and tobacco industries mostly use heat at low temperatures (below 200 °C).

Table 2.1: Share of process heating, process cooling and electricity in 2013 for EU28 [Adapted from ICF (2015)].

Industrial sub-sector	Fraction of energy for process heating (%)	Fraction of energy for process cooling (%)	Fraction of energy for electricity (%)
Industry average	***66***	***1.0***	***26***
Pulp, paper and print	59	0.3	31
Iron and steel	75	0.4	19
Non-metallic mineral	74	0.2	17
Chemical and pharmaceutical	58	0.6	30
Non-ferrous metal	32	-	57
Petroleum refineries	84	0.6	7
Food and beverage	62	10.0	34
Machinery	40	1.0	53

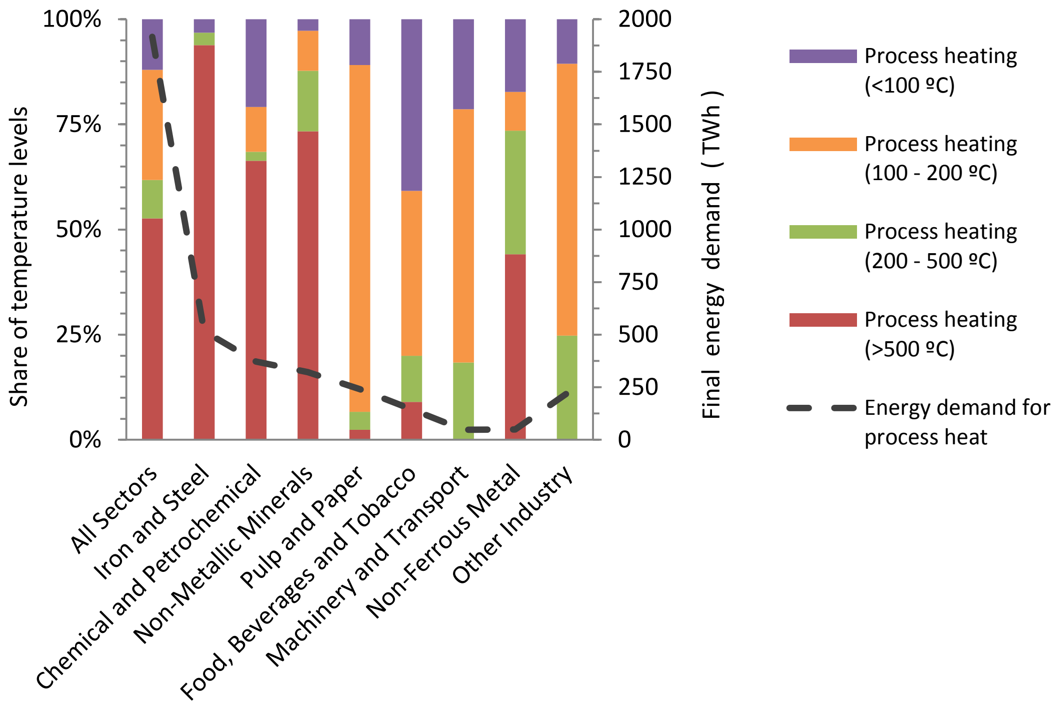

Figure 2.4: Final energy demand for process heat and share of temperature levels by industrial sector for EU28 in 2012 [Adapted from Fraunhofer et al. (2016)].

Figure 2.5 presents the final energy demand for process heat in industry broken down by energy carrier and temperature level for EU28 in 2012. The European industry greatly relies on natural gas to produce process heat (Fraunhofer et al., 2016). It is mainly used for medium/high temperature process heat. Coal and other fossil fuels are also important in the European final energy demand for heat, being mainly used to produce high temperature heat. Biomass is the only RES that has a significant use in the European industry, and is mainly utilized to supply heat at low temperatures. Solid biomass, biogas, biofuels and biowaste can be used for high temperature process heating, though. From Figure 2.5 it is possible to see that other RES have minimal shares in the European industry.

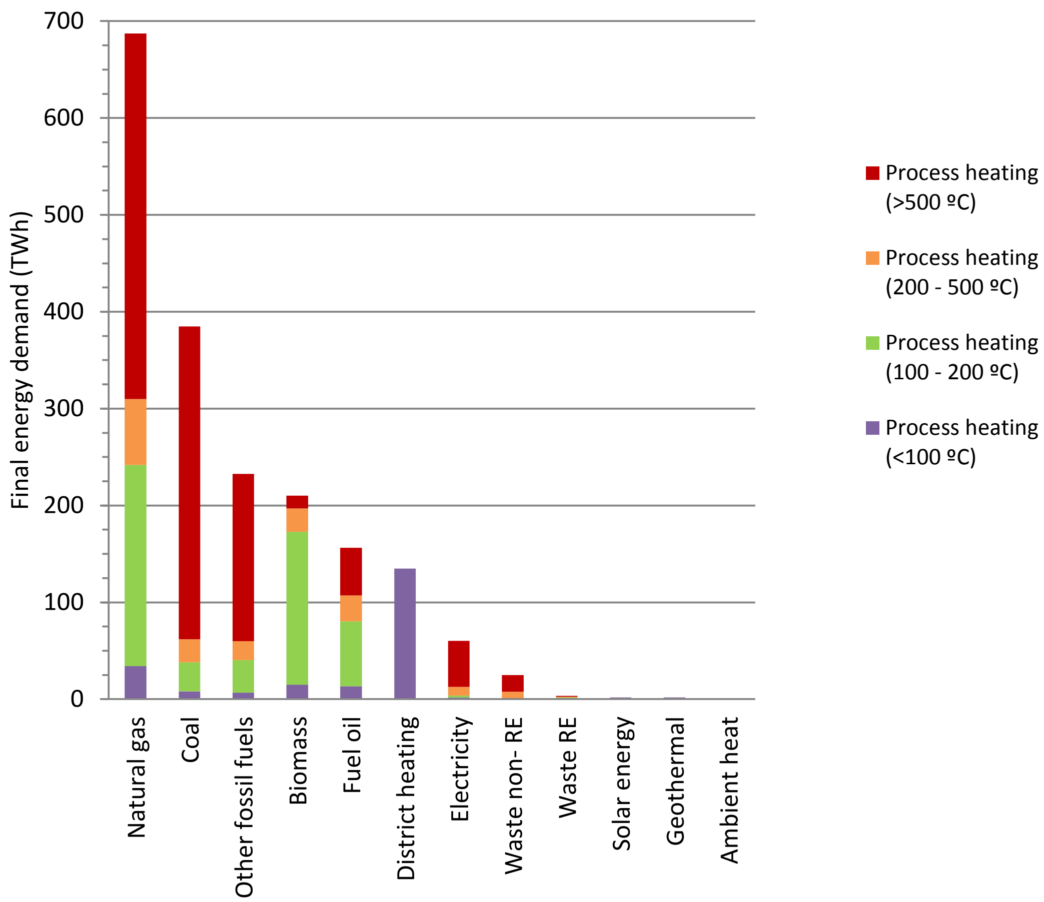

Figure 2.5: Final energy demand for process heat in industry by energy carrier and temperature level for EU28 in 2012 [Adapted from Fraunhofer et al. (2016)].

When looking at the geographical distribution of process heat consumption in Europe, Figure 2.6, the Member State with the highest consumption in 2012 was Germany, followed by Italy, the United Kingdom, France and Spain (Fraunhofer et al., 2016). In 2012, these five countries consumed almost 60% of Europe's process heat, while the five countries of the TrustEE project (Austria, Germany, Portugal, Spain and Sweden) consumed 40% of the total thermal energy used in industrial processes.

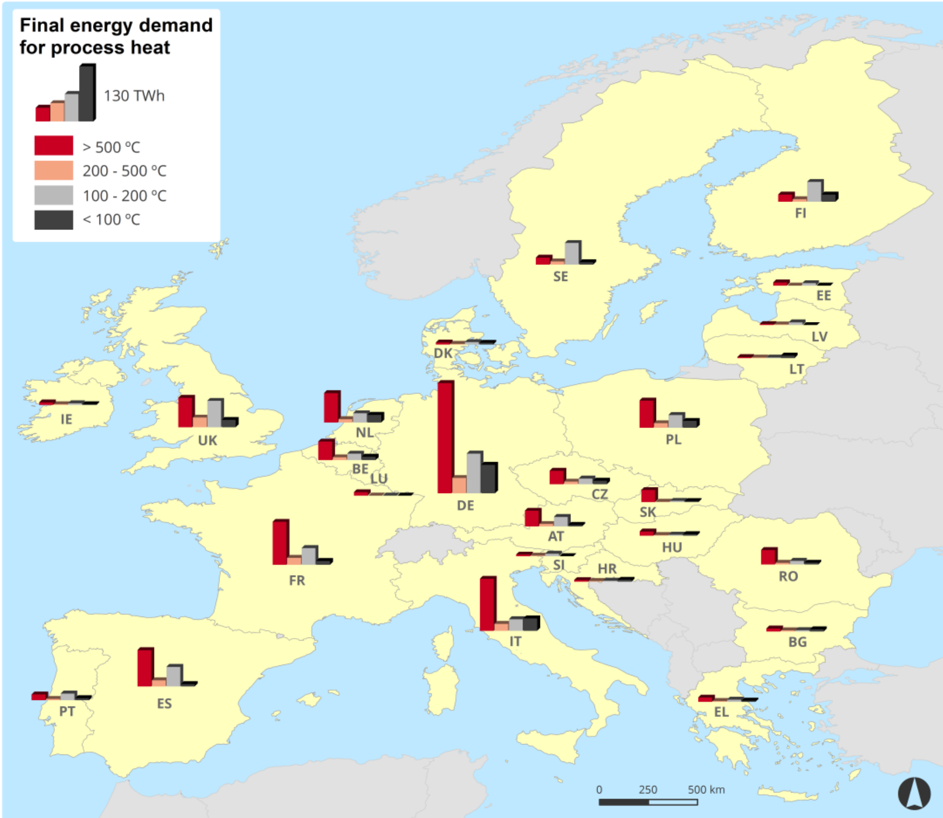

Figure 2.6: Final energy demand for process heating by Member State and temperature level in 2012 [Adapted from Fraunhofer et al. (2016)].

Figure 2.7 shows the comparison of the industrial use of energy carriers to generate thermal energy in the 28 European Member States in 2012 (Fraunhofer et al., 2016). Natural gas is important in most of the countries. Exceptions are Cyprus, Finland, Iceland, Malta and Sweden, where the share of natural gas is low. Coal is also an important industrial energy carrier. It is particularly important in countries where large iron and steel industries exist and in eastern European countries. In Sweden, Latvia, Finland and Portugal biomass is an important energy carrier. Figure 2.8 shows by EU Member State the final energy demand for thermal energy in industry. Germany is the major consumer, followed by France, Italy, the United Kingdom and Spain.

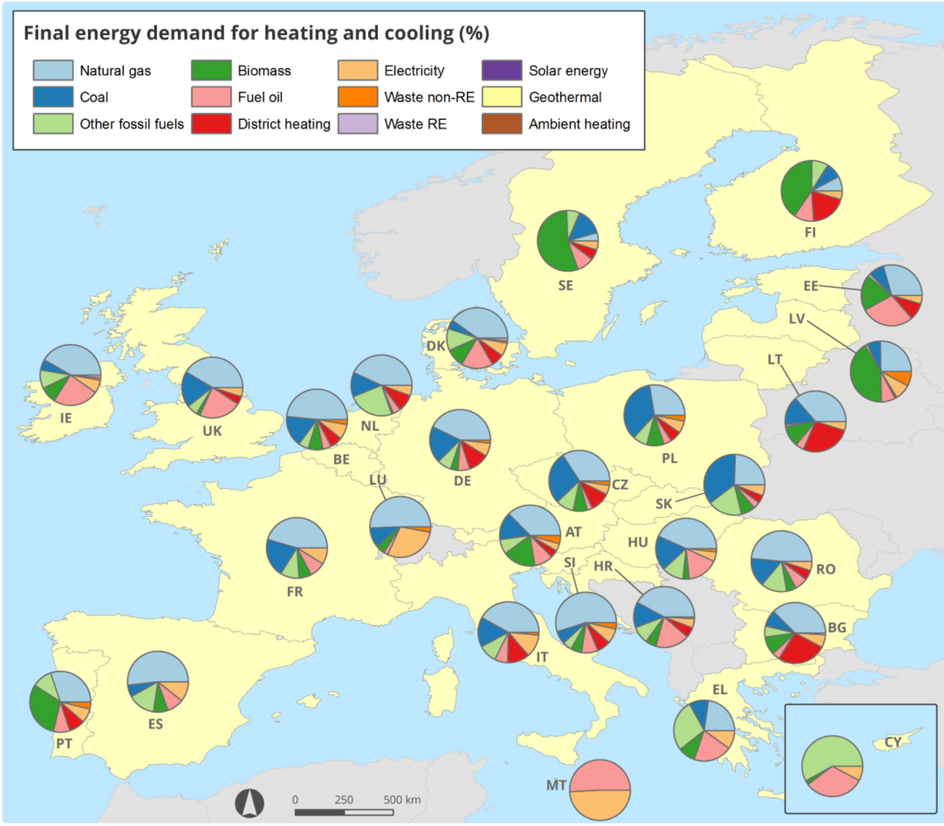

Figure 2.7: Share of energy carriers in the final energy demand for thermal energy by for EU28 countries in 2012 [Adapted from Fraunhofer et al. (2016)].

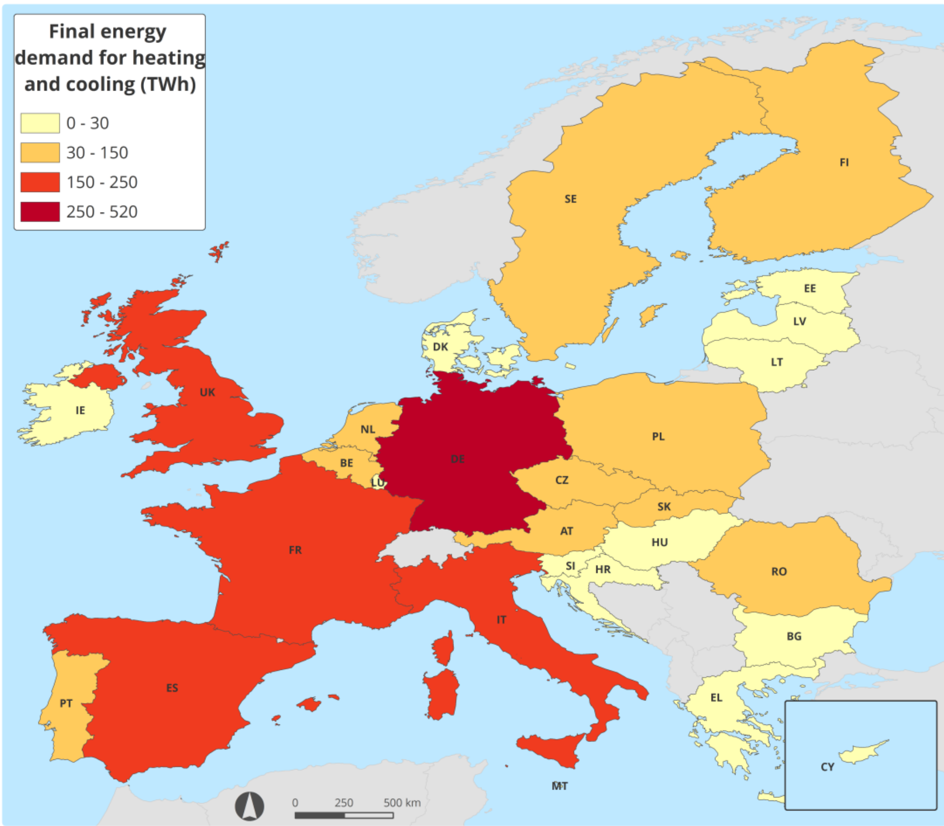

Figure 2.8: Final energy demand for heating and cooling by energy carrier for EU28 countries in 2012 [Adapted from Fraunhofer et al. (2016)].

2.2 Overview of SMEs in Europe

Since the focus of the TrustEE project is on small and medium-sized enterprises, an overview of SMEs in the EU industry follows. SMEs are defined as enterprises with fewer than 250 employed, provided they are independent (of other enterprises) and do not have sales that exceed EUR 50 million or an annual balance sheet that exceed EUR 43 million. In Eurostat, however, the only way to identify SMEs is by employment size. Large enterprises have 250 or more employees, SMEs less than 250. These are the categories considered in this section.

Almost all enterprises active within the EU27's non-financial business economy in 2012 were SMEs (Gagliardi et al., 2013). In the manufacturing sector, more than 99% of the enterprises employed less than 250 workers. However, the share of their economic contribution was not so high. Together, the SMEs in the European manufacturing sector in 2012 contributed 59% to the total employment and generated 44% of the sector's value added. These two indicators of economic performance had the same values in 2014 (Muller, 2015).

Table 2.2 shows the percentage of SMEs by number of enterprises, employees and value added in sectoral total for several industrial sub-sectors for EU27 in 2008 reported by Schmiemann (2008). The differences in terms of number of companies are not relevant from sector to sector (only the tobacco products and the coke, refined petroleum and nuclear fuel sub-sectors had shares below 90%). However, the differences in terms of percentage of employment and value added in sectoral total differ substantially from sub-sector to sub-sector.

The fourteen sub-sectors with above average share of employment and/or value added in sectoral total are highlighted in green in Table 2.2 and are:

- other mining and quarrying;
- food products and beverages;
- textiles;
- wearing apparel, dressing, dyeing of fur;
- tanning, dressing of leather, luggage;
- wood and wood products;
- publishing, printing, reproduction of recorded media;
- rubber and plastic products;
- other non-metallic mineral products;
- metal products, except machinery and equipment;
- machinery and equipment n. e. c.;
- medical, precision and optical instruments;
- furniture; manufacturing n. e. c.;
- recycling.

Table 2.2: Key indicators on SMEs for EU27 in 2008 [Adapted from Schmiemann (2008)].

	Share of SMEs in sectoral total (%)		
Industrial sub-sector	Number of enterprises	Number of employees	Value added
Industry average	***99.0***	***57.1***	***42.3***
Coal and lignite, extraction of peat	94.8	5.3	7.1
Extraction of crude petroleum, natural gas	93.6	-	29.5
Mining of uranium and thorium ores	-	-	-
Mining of metal ores	90.9	7.9	-
Other mining and quarrying	99.2	81.1	74.8
Food products, beverages	99.1	63.0	47.1
Tobacco products	79.0	15.6	6.3
Textiles	99.2	71.5	72.3
Wearing apparel, dressing, dyeing of fur	99.7	73.6	73.3
Tanning; dressing of leather, luggage	99.7	79.1	78.3
Wood and wood products	99.5	84.4	78.1
Pulp, paper and paper products	97.3	53.4	41.5
Publishing, printing, reproduction of recorded	99.4	72.1	59.8
Coke, refined petroleum and nuclear fuel	89.8	13.9	6.9
Chemicals and chemical products	95.8	35.5	25.6
Rubber and plastic products	98.9	65.3	57.6
Other non-metallic mineral products	99.1	63.2	53.4
Basic metals	95.4	32.9	25.8
Metal products, except machinery and equipment	99.8	83.2	78.4
Machinery and equipment n. e. c.	99.8	57.1	51.2
Office machinery and computers	99.1	47.2	33.3
Electrical machinery and apparatus n. e. c.	99.2	43.0	37.8
Radio, TV and communication equipment	98.4	34.4	23.2
Medical, precision and optical instruments	99.4	65.5	51.8
Motor vehicles, trailers and semi-trailers	93.9	17.3	12.3
Other transport equipment	98.2	27.7	16.3
Furniture; manufacturing n. e. c.	99.1	75.8	73.0
Recycling	100.0	88.5	86.7
Electricity, gas, steam and hot water supply	96.3	16.8	17.6
Collection, purification and distribution of water	96.5	35.8	33.1

2.3 Sectors characterized in this report

From the two previous sections, one can conclude that:

- The most heat consumption driven and energy-intensive industrial sectors in Europe are: iron and steel; chemical and petrochemical; non-metallic minerals; pulp and paper; food, beverages and tobacco. Together, these sectors account for more than two thirds of the European final heat consumption in the industry.

- From the interception of these sectors with the sub-sectors listed in Table 2.2 that have the biggest share of SMEs in sectoral total in terms of number of employees and value added, it is particularly interesting to analyse two sectors: non-metallic minerals; food, beverages and tobacco.

These two sectors will be described in the next sections in terms of production and heat consuming processes and heat production technologies and energy sources used. Additionally an analysis of the pulp and paper and wood and wood products industries will be included in this report. Both these sectors generate large quantities of residual biomass, already used to some extent, which contributes to the greater availability of solid biomass. Valorising efficiently these resources is important for Europe's objectives to build a more secure, sustainable and resilient economy. Additionally, the pulp and paper sector is the fourth biggest process heat consumer in EU28 and the SMEs that belong to this sector have a share in sectoral total in terms of economic performance that is very close to the average share of the SMEs in industry.

3 Non-metallic minerals

3.1 Industry overview: structure and dimension

The non-metallic minerals sector can be grouped in three sub-sectors that include the glass industries, ceramic industries and cement and lime industries. Figure 3.1 shows the relevance of each sector through their share in total production value. The cement and lime industry is the most important sub-sector in terms of production value.

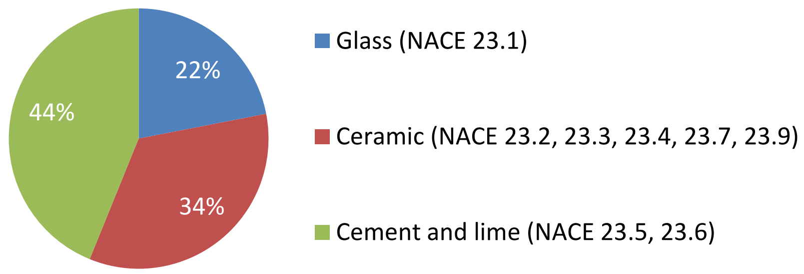

Figure 3.1: Share of the non-metallic minerals sub-sector sin terms of production value in 2012 for EU28 [Source: Eurostat (2016b)].

Table 3.1 shows the key indicators that characterize the sector dimension in 2012 for EU28.

Table 3.1: Non-metallic minerals sector dimension key indicators in 2012 for EU28 [Source: Eurostat (2016b)].

	Turn over (million €)	Number of companies	Number of persons employed
Glass	45 000	15 711	305 862
Ceramic	72 728	57 664	505 242
Cement and lime	89 792	24 600	448 163

The geographically distribution of the number of companies by sub-sector is presented in Figure 3.2. Italy has the highest number of companies in all the sub-sectors that compose the non-metallic minerals sector. Germany, Spain, France, Poland and Czech Republic also play an important role in all the three sub-sectors.

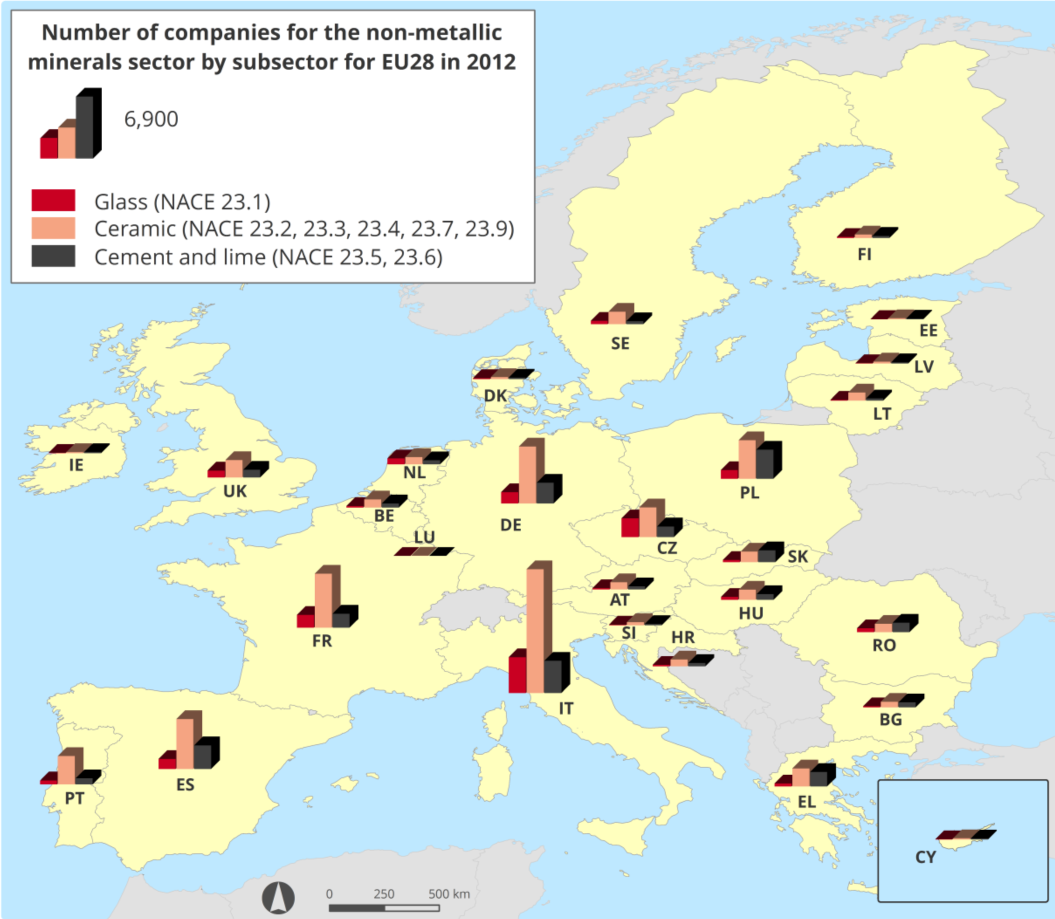

Figure 3.2: Number of companies for the non-metallic minerals sector by sub-sectors and by country for EU28 in 2012 [Source: Eurostat (2016b)].

Glass, ceramic, cement and lime manufactures are all energy-intensive industries. In Table 3.2 an estimative for the final energy demand for those industries is presented, as well as their share on the total final energy demand of the sector under analysis.

Table 3.2: Estimative of the final energy demand for the non-metallic minerals sub-sectors in 2012 for EU28 [Adapted from ICF (2015)].

	Final energy demand (ktoe)	Share on final energy demand (%)
Glass	6 075	17
Ceramic	6 790	19
Cement	20 726	58
Lime	2 144	6
Total	35 735	100

Most process heat delivered in the non-metallic minerals sector occurs in industries where furnaces and Table 1s are in operation. In the glass manufacture, the majority of the most relevant companies have melting furnaces in operation, more specifically the flat glass, container glass, filament fibre glass and domestic glass industries. Melting furnaces are also present in the mineral wool industry. The cement and lime industries have kilns in operation and many companies of the ceramic industry, such as the one that manufacture bricks, wall, floor and roof

tiles, also require high amounts of process heat for their kilns. The glass and the cement and lime industries are analysed in the next section, in terms of their heating processes and energy consumption for process heat.

3.2 Heating processes and heat consumption

3.2.1 Glass and glass products

The most energy consuming heating process in the glass manufacture occurs in the melting furnace. Melting process can be defined has a combination of chemical reactions and physical processes occurring under high temperature conditions. The first reactions occur around 500 °C and glass starts to melt between 750 and 1200 °C. Operating temperatures in furnaces usually range between 1300 and 1650 °C. Molten glass is obtained by continuously feeding the furnace with raw material batches and providing high amounts of heat above it. Molten glass is withdrawn from the furnace but its mass should be kept constant inside the furnace.

In Figure 3.3, the contribution of the production processes in terms of energy consumption for the main sub-sectors of the glass and glass products industry (NACE 23.1) is indicated. As already mentioned, the most heat-intensive consumption process is glass melting. Other relevant heat-intensive processes are the forehearth step and the annealing lehr process, the latter having high relevance in domestic glass production. The amount of process heat required for melting processes can vary substantially, from about 3.3 up to 40 GJ/melted tonne. This requirement is strongly dependent on the furnace design, its capacity, operation method and type of glass.

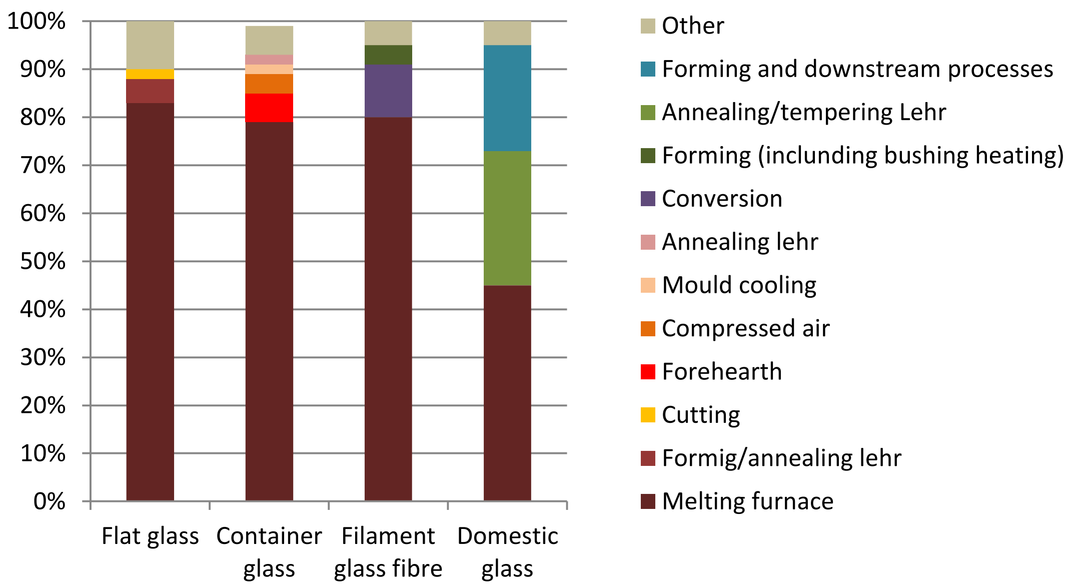

Figure 3.3: Share of production processes in terms of energy consumption for the glass and glass industries by different products [Source: Scalet et al. (2013)].

Reference values for thermal energy requirements in melting processes can be provided by theoretical calculations. In Table 3.3 energy requirements for the melting of the most common glasses (without cullet recycling) are given. The values presented do not consider the additional energy to refine, form and finish the glass, and represent the theoretical minimum energy consumption for melting.

Table 3.3: Theoretical energy requirements for melting common glasses from batch formulations [Adapted from Scalet et al. (2013)].

Type of glass	Theoretical energy requirement (GJ/t)
Soda-lime (flat/container glass)	2.68
Borosilicate (8% B_2O_3)	2.25
Borosilicate (13% B_2O_3)	2.40
Crystal glass (19% PbO)	2.25
Crystal glass (24% PbO)	2.10
Crystalline glass with Barium	3.24

With the use of modern furnace technology, the real heat requirements are approaching the ones estimated from the theoretical models. Regenerative furnaces can have an overall thermal efficiency of up to 65% (DOE, 2002). Heat losses occur mainly through flue gases, and furnace walls. Table 3.4 reports the energy balance for the flat glass and container glass industry operating with regenerative furnaces. Table 3.5 presents the specific energy consumptions for different glass furnaces used in the main industries.

Table 3.4: Energy balance for producing flat glass and container glass [Adapted from Scalet et al. (2013)].

Type of glass	Flat glass	Container glass
Type of furnace	Float, regenerative cross-	Regenerative, end-fired
Pull rate	600 t/day	260 t/day
Cullet	25%	83%
Total energy consumption	6.48 GJ/t melted glass	3.62 GJ/t melted glass
Water evaporation (batch humidity)	1%	1.5%
Endothermic reactions	6%	2.4%
Sensible heat glass melt (net)	33%	44.2%
Wall heat losses	15%	18.3%
Cooling and leakage heat losses	9%	3.7%
Flue-gas losses from bottom	32%	27.6%
Regenerator heat losses (structure)	4%	2.3%

Table 3.5: Examples of specific energy consumption for a range of glass furnaces [Adapted from Scalet et al. (2013)].

Tank furnace type	Glass type	Melting area[1] (m^2)	Glass bath depth melting end (mm)	Tank capacity melting end (t)	Length/width ratio of the tank bath	Output (t/d)	Specific output (t/m^2d)	Specific energy consumption[2] (kJ/kg glass)
Cross-fired furnace with regenerative air preheating	Container glass	15—155	1200—1700	50—500	1.9—3.0:1	40—500	2.5—4.0	4200
Regenerative end-fired furnace	Container, glass	15—140	1200—1700	50—500	1.9—2.5:1	40—450	2.5—4.0	3800
Recuperative furnace	Container glass	Up to 250	1100—1600	50—650	2.0—2.8:1	40—450	2.0—3.0	5000
Oxy-fuel fired furnace	Container glass	110—154	1300—1700	390—600	2.0—2.4:1	350—425	2.3—3.5	3050—3500[3]
Cross-fired furnace with regenerative air preheating	Flat glass	100—400	1200—1400	300—2500	2.1—2.8:1	150—900	2.3—2.7	6300
Cross-fired furnace with regenerative air preheating	Television tube glass (screen)	70—300	900—1100	160—700	2.0—3.0:1	100—500	1.1—1.8	8300
Furnace with recuperative air preheating	Tableware	15—60	1100—1300	40—180	1.8—2.2:1	15—120	1.0—2.0	6700—11000[4]
Cross-fired furnace with regenerative air preheating	Tableware	30—40	800—1000	65—100	2.0—3.0:1	40—60	1.2—1.6	8000—11000
Regenerative end-fired furnace	Tableware	45—70	800—1800	100—250	1.8—2.2:1	120—180	2.0—3.0	5000—6000
Furnace with recuperative air preheating	Glass wool	15—110	800—1500	50—200	2.8:1	30—350	3.4	4300—6500

[1]Surface area of glass furnace for glass melting and refining; normally the area between the doghouse and the throat; in the case of float glass furnaces, without the unheated conditioning area.

[2]Specific energy consumption without working end and feeder during start-up and nominal load operation (energy consumption will generally increase by 0.1 to 0.2 % per month, due to ageing of the furnace, without electrical boosting, melt preheating and secondary waste heat utilisation) is standardised to: 70 % cullet for container glass; 20 % cullet for float glass; 40 % cullet for television tube glass and tableware. Energy savings per cent of additional cullet used: 0.15 to 0.3 %. The specific energy consumption figures given are approximate guide values for new medium-size and large plants. They are not suitable for energy balance considerations owing to the large differences which occur in individual cases. The effective specific energy consumption is dependent not only on the cullet content and the tank age, but also, *inter alia*, on batch composition, air preheating, specific tank loading, insulation of the tank and the required glass quality standard.

[3]The data indicated are based on the operating experience with two commercial plants using oxy-fuel technology. The energy required for oxygen production is not included in the specific energy consumption.

[4]The lower range of specific energy consumption for recuperative furnaces may be related to a lower quality standard of the glass produced. In general, regenerative furnaces present lower specific energy consumptions than recuperative furnaces.

For filament glass fibre, melting is the highest heat-intensive process (Figure 3.3). Table 3.6 gives reference information for energy consumption in this sub-sector.

Table 3.6: Energy consumption for filament glass fibre industry [Adapted from Scalet et al. (2013)].

Typical energy consumption for melting (GJ/t of melt)	7 - 18
Energy consumption for melting in specialised compositions and small furnaces (GJ/t of melt)	30
Total energy consumption(GJ/t of finished product)	10 - 25
Average total energy consumption (GJ/t of finished product)	16.5
Share of fossil fuels	75%
Share of electricity	25%
Direct emissions (fossil and processes) (kg CO_2/ t of finished product)	770

In domestic glass production, the contribution from energy-intensive processes in energy consumption is presented in Figure 3.3 and reference specific consumption for melting process is given in Table 3.5. Table 3.7 shows other reference information for energy consumption in this sub-sector of the glass industry. In lead crystal production the melting process occurs in small scale furnaces and pot furnaces. Process heat consumption can have a share of 16 to 85% of the overall energy consumption.

Table 3.7: Energy consumption for domestic glass industry [Adapted from Scalet et al. (2013)].

Energy consumption for downstream activities (GJ/t of glass)	5-10
Energy consumption for electric melting (GJ/t of glass)	4-7
Energy consumption for melting in conventional furnaces (GJ/t of melted glass)	4.8-10
Overall Energy consumption in lead crystal production (GJ/ t of glass)	up to 28
Overall Energy consumption in lead crystal production with electric melting (GJ/t of glass)	up to 25

In the mineral wool industry, more specifically in glass wool production, the heat consumption contribution is evenly shared between the melting, fiberising and curing processes. In stone wool production, melting is the major consumer of process heat, similarly to what happens in the flat glass, container glass and filament glass fibre industries; the curring process is also a relevant heat consumer, though. Table 3.8 presents the contribution of energy-intensive processes for the mineral wool industry. The range of total energy consumption by tonne of finished product is also given.

Table 3.8: Energy-intensive processes share on total consumption for mineral wool industry [Adapted from Scalet et al. (2013)].

Energy distribution	Glass wool	Stone/slag wool
	GJ/t finished product	
Total energy consumption	9-20	7-14
	% of total energy	
Melting	20-45	60-80
Fiberising	25-35	2-10
Curing	25-35	15-30
Other	6-10	5-10

Typical values for specific energy consumption are indicated in Table 3.9 for the main sectors of the glass and glass products manufacture, including special glass, high temperature insulation wool and frits industries.

Table 3.9: Values of specific energy consumption in the main sectors of the glass and glass products manufacture [Adapted from Scalet et al. (2013)].

Sector	Furnace type/capacity	GJ/t melted glass[1]	GJ/t finished product[2]
Container glass			
Bottles and jars	<100 t/d	5.5 - 7	<7.7
	>100 t/d	3.3 - 4.6	
	Electric furnaces	2.9 - 3.6	
Flacconage	<100 t/d	7 - 9	<16
	>100 t/d	4.8 - 6	
Flat glass			
	All capacities	5 - 7	<8
Continuous filament glass fibre			
	All capacities	7 - 14	<20
Domestic glass			
	Conventional furnaces		<24 for capacities <100 t/d[3]<18 for capacities >100 t/d
	<100 t/d[3]	6.7 - 9.5	
	>100 t/d	5 - 6	
	Electric furnaces[4]	3.4 - 4.3	
Special glass			
All products	Electric furnaces[4]	3.9 - 4.5	<20
Soda-lime glass	Conventional furnaces	5 - 10	
Borosilicate glass		10 - 15	
Mineral wool			
Glass wool	All capacities	2.7 - 5.5	<14
Stone wool	All capacities	4.2 - 10	<12
High temperature Insulation Wool			
	All capacities	6.5 - 16.5	<20
Frits			
	Oxy-fired furnaces	≤9	
	Air/fuel and enriched air/fuel fired furnaces	≤13	

[1]Data refers to the furnace energy consumption
[2]Data refers to the overall energy consumption of the installation
[3]Values do not include installations equipped with pot furnaces or day tanks which energy consumption for the melting process may be in the range of 10-30 GJ/t melted glass
[4]Data reported refer to energy at the point of use and are not corrected to primary energy

Heat process consumption for melting operations dominates the energy requirements of the glass and glass industries analysed. Heat production in the melting furnace is based on the combustion of fossil fuels such as fuel oil and natural gas. Electricity is also used for resistive heating furnaces and for less heat-intensive processes such as the forehearth step in container glass production or even in small melting furnaces.

The energy sources used in the main industries of the sector are listed in Table 3.10. Fuels, such as propane, butane and light fuel oil are mostly used has backup fuels, for example fir space heating.

Table 3.10: Fuels used in the main industries of the glass and glass products sector [Scalet et al. (2013)].

Container glass	Flat glass	Filament fibre glass	Domestic glass	Mineral wool
fuel oil natural gas electricity butane propane	fuel oil natural gas electricity light fuel oils	fuel oil natural gas electricity	fuel oil natural gas electricity butane propane acetylene	natural gas electricity coke light fuel oils butane propane

3.2.2 Cement and lime

The most important process in terms of heat consumption in the cement and lime industry production occurs in kilns. A kiln is a type of oven where the process temperature is sufficiently high to carry out chemical/mineralogical changes in raw materials. For cement, process heat is also required for drying the cement raw material (see Figure 3.4).

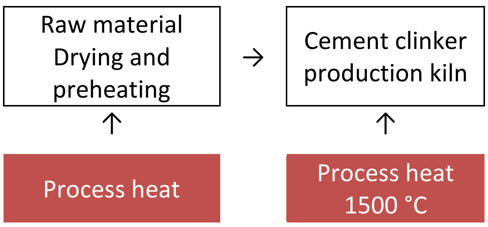

Figure 3.4: Heat-intensive processes in cement production.

Cement manufacture starts in the kiln with the decomposition of calcium carbonate into calcium oxide (lime) at about 900 °C (called calcination process). This step is followed by the clinkering process, which consists in the reaction of calcium oxide with other inorganic compounds at temperatures between 1400 and 1500 °C and where the clinker is produced. After this step, the clinker is milled with gypsum and other additives to produce cement.

Table 3.11 presents the specific energy used for process heat in different steps of the production of cement clinker in a kiln.

Table 3.11: Specific thermal energy demand in cement manufacturing in EU27 [Adapted from Schorcht et al. (2013)].

Specific thermal energy demand (MJ/t clinker)	Process
3 000—<4 000	For the dry process, multistage (three to six stages) cyclone preheaters and precalcining kilns
3 100—4 200	For the dry process rotary kilns equipped with cyclone preheaters
3 300—5 400	For the semi-dry/semi-wet processes (Lepol kiln)
up to 5 000	For the dry process long kilns
5 000—6 400	For the wet process long kilns
3 100—6 500 and higher	For shaft kilns and for the production of special cements

Lime manufacture is based in the burning of calcium and/or magnesium carbonate with a temperature level between 900 and 1200 °C to obtain the calcium oxide (CO_2 is released as well in clinker production). For burned dolomite, temperature level can reach 1800 °C. Operations regarding crushing, milling and screening can occur after the kiln step.

In Table 3.12 indicates the specific energy use (heat and electricity) for different types of production processes of lime in a kiln.

Table 3.12: Typical heat and electricity used for lime and dolime manufacture in EU27 [Adapted from Schorcht et al. (2013)].

Kiln type	Energy type used for lime and dolime manufacture	
	Heat use/consumption[1] GJ/t	Kiln electricity use kWh/t
Long rotary kilns (LRK)	6.0—9.2	18—25
Rotary kilns with preheater (PRK)	5.1—7.8	17—45
Parallel flow regenerative kilns (PFRK)	3.2—4.2	20—40
Annular shaft kilns (ASK)	3.3—4.9	18—35[2] up to 50([3])
Mixed feed shaft kilns (MFSK)	3.4—4.7	5—15
Other kilns (OK)	3.5—7.0	20—40

[1]Heat use/consumption represents about 80% of the total energy consumption to produce lime
[2]For limestone grain sizes of between 40 and 150 mm
[3]For limestone grain sizes of <40 mm

The fuels used in the cement and lime industries are similar and mainly fossil fuels and waste. The kiln firing is provided mostly by solid fuels such as coal, petroleum coke and lignite. Liquid fuels are also used, mainly fuel oil, including highly viscous fuel oil. Gaseous fuels utilization is based on natural gas. The use of waste fuels to cover the energy demand is also very significant. The substitution of fossil solid fuels by waste fuels has been increasing substantially over the years. Some individual cement plants can reach a share of waste fuels in their total energy demand of up to 80%. Examples of waste fuels and their typical calorific value are given in table 3.13.

Table 3.13: Examples of calorific values for different types of waste fuels used in the cement industry in EU27 [Adapted from Schorcht et al. (2013)].

Examples of types of waste fuels (hazardous and non-hazardous)	Examples of calorific values (MJ/kg)
Wood	Approx. 16
Paper, cardboard	3—16
Textiles	up to 40
Plastics	17—40
Processed fractions (RDF)	14—25
Rubber/tyres	approx. 26
Industrial sludge	8—14
Municipal sewage sludge	12—16
Animal meal, fats	14—18, 27—32
Animal meal (carcase meal)	14—21.5
Coal/carbon waste	20—30
Agricultural waste	12—16
Solid waste (impregnated sawdust)	14—28
Solvents and related waste	20—36
Oil and oily waste	25—36
Oil-shale based fuel mix (85-90% oil-shale)	9.5
Sewage sludge (moisture content >10%)	3—8
Sewage sludge (moisture content <10 to 0%)	8—13

3.2.3 Ceramic

The heat-intensive process in the manufacture of ceramic products takes place in kilns used to "cook" the ceramic products. Ceramic production begins with a mixture of powdered base materials, binders and stabilizers compounds. The mixture is "formed" into shapes and then fired (sintered) in kilns at temperatures between 1800 °C and 2000 °C. The manufacturing process can take days or weeks, depending on the type of ceramic product and process specificities. Table 3.14 presents the overall specific energy use for the main production activities of the ceramic industry in terms of energy intensity.

Another heat-intensive process in the ceramic industry is the drying (before kiln firing) of ceramic products. Heat for drying air is mainly supplied by gas burners and by hot air recovered from the kilns. Other fuels are used such as coal, biomass, biogas and petroleum coke.

Table 3.14: Specific energy use for the ceramic industry [Adapted from ICF (2015)].

Production activity	Energy use (GJ/t)
Brick and roof tiles	2.31
Wall and floor tiles	5.60
Refractory products	5.60
Sanitary-ware	21.90
Vitrified clay pipes	45.20
Table and ornamental-ware	50.40
Technical ceramics	50.40

4 Pulp and Paper

4.1 Industry overview: structure and dimension

Europe is the second largest producer of pulp, paper and board in the world. Its role in the sector is important, having Europe contributed with one fourth of the total world production in 2013. For the countries of the Confederation of European Paper Industries (CEPI), in 2014, the total pulp production was around 36.5 billion tonnes and the paper and board 91.1 billion tonnes (CEPI, 2015a). Figure 4.1 shows the production of paper and board by grade in CEPI countries in 2014.

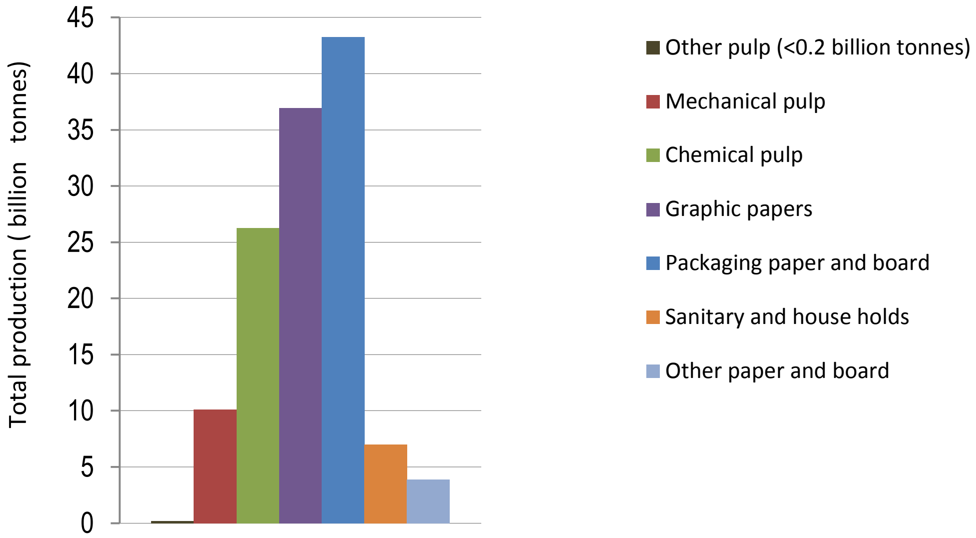

Figure 4.1: Production contribution by grade for CEPI countries in 2015 [Adapted from CEPI (2015a)].

As can be seen from Figure 4.1 it is usual to divide the products manufactured by the pulp industry according to their production process, while the paper and board goods are categorized by its end-use. As far as mill types are concerned, production facilities can belong to each of the following categories: non-integrated mills, integrated mills and multi-product mills.

A non-integrated facility is a pulp mill where market pulp[1] is produced, but where no paper machine is run. Alternatively, a non-integrated facility can be a paper mill that simply reconstitutes pulp manufactured elsewhere and produces paper.

Integrated production means that pulp and paper are produced in the same plant. The pulp is not dried before paper manufacture. However, integrated mills can also use some dried pulp acquired elsewhere. The level of integration can vary from a normal integrated mechanical pulp and paper mill to multiproduct integrated mills. The term “multi-product mill” refers to a production site where a large variety of wood-based products of

[1]Market pulp is pulp manufactured and normally dried at one mill location to be sold to paper manufacturers at other locations.

manufactured (sawn goods, chemical pulps, mechanical pulps or pulps from processing paper for recycling, different paper and board grades and wood-derived by-products). There are mainly the following types of integrated mills: chemical pulp mills (kraft or sulphite pulp) with papermaking; mechanical pulping with papermaking; mills processing paper for recycling with papermaking; mixture of mechanical pulping and processing paper for recycling with papermaking; other mixtures, e.g. chemical pulp and paper for recycling can be used at the same site for the manufacture of a single product. Some additional mechanical pulp may also be produced in some mills; multi-product mills.

As seen in Figure 4.2, Sweden and Finland dominate de pulp market, representing more than half (60%) of the total production in CEPI countries. Germany and Portugal follow, each having a 7% share. Sweden and Finland also are the second largest producers (22%) for the paper and board market, only surpassed by Germany (25%). Italy and France also have a significant contribution to the paper and board market, representing together 19% of the total production.

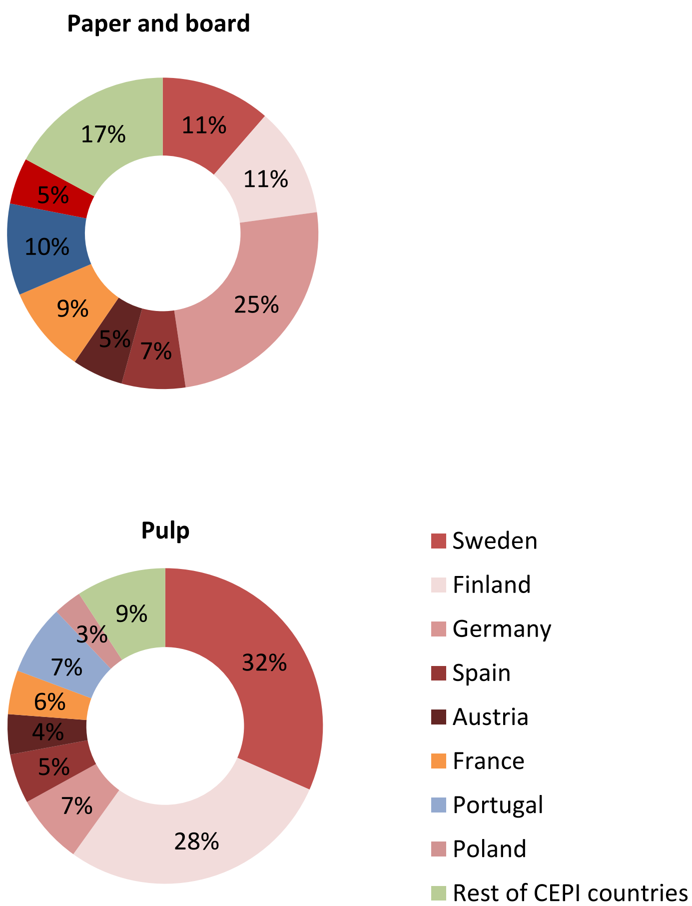

Figure 4.2: Pulp and paper/board production by CEPI country in 2014 [Adapted from CEPI (2015a)].

Table 4.1 shows the key indicators that characterize the industry dimension for CEPI countries. It can be seen that since the 90's the number of mills declined nearly to 40% and the number of employees decreased more than half. However, turnover fell by only around 6%, although there was a significant decrease in added value and in the investments area, about 34% and 38% respectively.

Table 4.1: Dimension key indicators for pulp, paper and board industry.

	1991	2000	2005	2010	2013	2014
Number of mills	1 570	1 309	1 224	992	941	920
Pulp	296	233	218	172	163	159
Paper and board	1 274	1 076	1 060	820	778	761
Number of companies	1 032	929	831	674	636	628
Number of employees	411 113	279 987	246 785	194 849	183 690	181 111
Turnover (million €)	n.a.	79 388	74 537	76 226	75 337	74 500
Added value (million €)	n.a.	24 494	18 254	16 560	16 500	16 000
Investments (million €)	n.a.	5 637	5 318	2 728	3 425	3 500

It can be seen from Figures 4.3 and 4.4 that around 70% of the pulp mills have a production volume larger than 100 thousand tonnes per year and that only around 30% of the paper and board facilities have such production volumes. In fact, nearly 53% of the paper and board factories have a volume production lower than 50 thousand tonnes per year and the category of paper and board mills that have the highest number of factories fall is the "lower than 10 thousand tonnes per year".

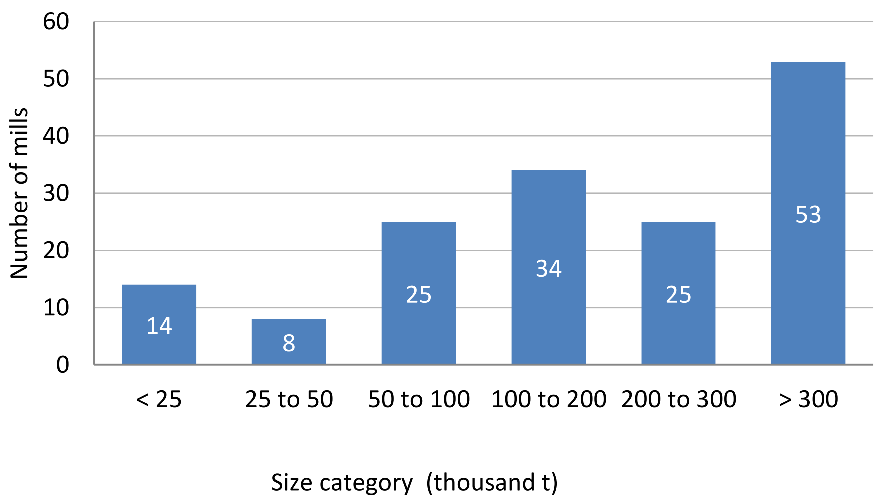

Figure 4.3: Number of pulp mills by volume of pulp production for CEPI countries in 2014 [Adapted from CEPI (2015a)].

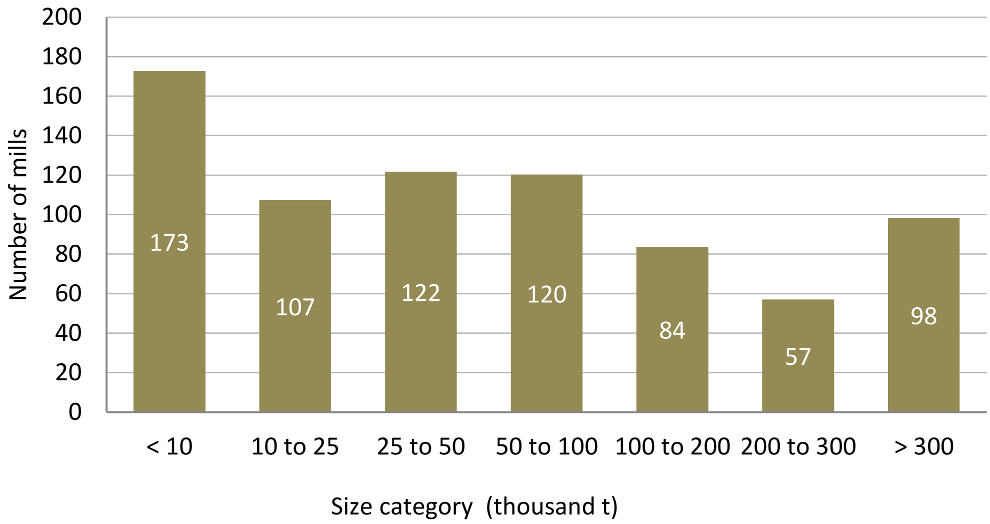

Figure 4.4: Number of paper and board mills by volume of paper and board production for CEPI countries in 2004 and 2014 [Adapted from CEPI (2015a)].

4.2 Heating processes and heat consumption

Paper is essentially a sheet of cellulose fibres, to which, when necessary, a number of constituents are added to enhance the quality of the sheet and its suitability for the intended end-use. The pulp for papermaking may be produced from virgin fibres by chemical or mechanical processes or by the "repulping" of paper for recycling (RCF).

In the paper production process, first wood logs are debarked and chipped into small pieces and then water and heat are added. By mechanical or chemical methods, the wood is separated into individual fibres (pulping). After screening, cleaning and sometimes refining, the fibres are mixed with water. Then this pulp slurry is sprayed onto a flat wire screen which moves very quickly through the paper machine. Water drains out, and the fibres bond together. The web of paper is pressed between rolls which squeeze out more water and press it to make a smooth surface. Heated cylinders then dry the paper, and the paper is split into smaller rolls, and sometimes into sheets. In chemical pulping, chemicals are used to dissolve the lignin and free the fibres. In the mechanical pulping process, mechanical shear forces are used to pull the fibres apart and the majority of the lignin remains with the fibres, although some organics are still dissolved. All the process of production requires high energy input in the form of heat and power, more specifically for the purposes indicated in Table 4.2.

Table 4.2: Energy driven processes for the pulp, paper and board industry.

Process heat	Power
Heating water, wood chips, pulp fibers, air and chemicals to process temperature	Grinders and refiners for the production of groundwood pulp, thermomechanical pulp (TMP) and chemical and thermo-mechanical pulp (CTMP)
Heating the cooking liquor in chemical pulping	Pulpers to slush purchased pulp or in recycled fibre pulping
Evaporating water from spent kraft and sulphite pulping liquors in the evaporators before firing the liquor in the recovery boilers	Pulp beating and pulp refining
Dispersion in paper for recycling stock preparation (heating of the stock in dispergers in some cases)	Drive for paper machines and other pulp and paper machinery
Evaporating water from the pulp or paper sheet in the dryer section of the paper or pulp machine	Transport with pumps, fans, belt and screw conveyors
Drying of coated paper	Mixing of fluids and suspensions; chemical preparation on site; vacuum pumps; compressors

Table 4.3 presents the pulp and paper production intensive-energy consumption processes that can occur in the different types of mills. Refining, grinding, pressing and drying have the highest energy demand. In mills where a refining process is undertaken, this is normally the largest power consumer in the mill. In the pressing process, energy is consumed for the hydraulic units, the drive of the press section and the generation of high vacuums. Drying is the highest process heat consumer.

Pulp, paper and board is an energy-intensive industry. In Europe, it is the fourth largest industrial consumer of energy, having consumed 11.5 % of the total final energy for industry in 2014 (around 31.7 Mtoe), which represents 3% of the total final energy consumption in EU28 (Eurostat, 2016a).

It can be seen from Figure 4.5 that the largest energy demand in the sector is for process heat and that 95% of this energy is used for process heat with a temperature level below 200 °C, while the remaining part requires a higher temperature level.

Table 4.3: Intensive energy processes and their relevance for energy consumption.

Refining	Energy-intensive refiners are used for mechanical pulping (e.g. TMP refiners) and for the post-refining of GWP mills. In paper mills using virgin fibres, refining affects the mechanical properties of the pulp and paper product.
Grinding	Grinding is applied in GWP mills to produce mechanical pulp from pulpwood.
Pressing	Pressing takes place in the press section of the paper machine, where the paper web is mechanically dewatered by press rolls.
Drying	Drying takes place after leaving the press section where the paper is further dewatered by thermal evaporation of the remaining water.
Screening	Screening is operated in all paper mills to classify pulp qualities by fibre length and to remove contaminants. Therefore in mills using virgin fibres, the energy intensity is lower.
Approach flow	Approach flow is where pumping energy is needed for moving the first white water circuit where the stock reaches the water system of the paper machine.
Forming	Forming is the core process of papermaking. Energy is used for the drives of the wire section and for the production of mostly low vacuums for web dewatering.
Bleaching	Bleaching is where energy is used for heating the bleaching tower and for the preparation of the chemicals. Consumption depends on the bleaching process and the brightness requirements of the product.
HC cleaning	HC cleaning refers to the use of hydrocyclones for removing heavy contaminants from the raw material in the stock preparation.
Thickening	Thickening is the mechanical dewatering of pulp. It is needed for pulp washing, a subsequent HC-bleaching process, and for loop separation.
Coating	Coating includes the application of pigments and binders on the surface of the raw paper to achieve defined surface properties of the finished paper. It varies between mills, depending on the type of coating and energy consumption.
Wood handling	Covers the debarking, chipping, preheating and conveying of pulpwood for mechanical mills.
Mixing	Mixing includes the production of the blend for the paper machine. Energy is needed for pumping and agitating the various components for the paper product.

Energy consumption relevance

very high	high	medium

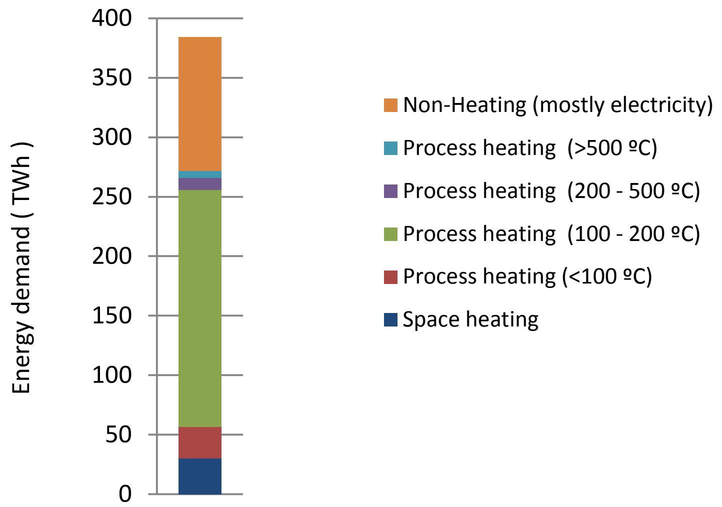

Figure 4.5: Final energy demand for the pulp, paper and board industry by end-use for EU28 in 2012 [Adapted from Fraunhofer et al. (2016)].

Figure 4.6 shows the evolution of the final energy consumption in terms of energy sources used in pulp and paper industry between 1991 and 2013. Biomass is the main energy carrier, representing around 57% of the energy consumption in 2013; gaseous fuels follow with approximately 35%.

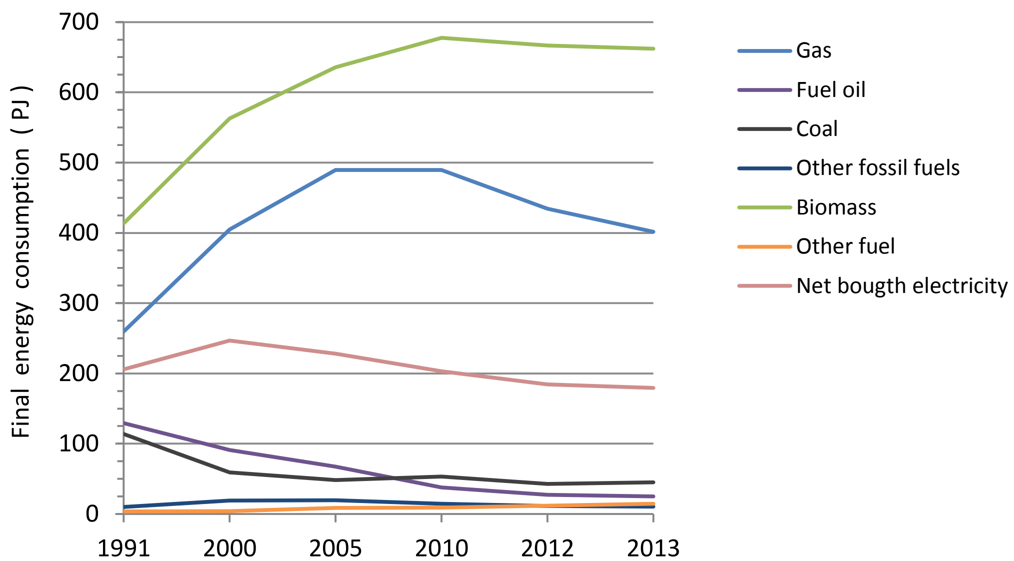

Figure 4.6: Final energy consumption in the pulp and paper industry by energy carriers [Adapted from CEPI (2015a)].

Table 4.4 summarizes the fuels used for energy production (heat and power) in the pulp and paper industry.

Table 4.4: Main fuels used in the pulp and paper industry.

Biomass	Gas	Fossil solid	Fuel oil	Wastes
Bark Wood residues Wood chips Black liquor biosluge	Natural gas	Coal Lignite peat	Heavy Gas oil	Paper mill residues Refuse-derived fuel

In the pulp and paper industry, it is usual to have energy production systems that use a mix of fuels in co-combustion of biomass, mill residues and fossil fuels. There are two main configurations for the energy systems used in the sector: production of heat alone and combined heat and power production (CHP).

Energy supply is one of the major production factors in the pulp and paper industry due to its high contribution in the total production costs. The sector produces practically all the required heat and half of the electricity demand in their energy production plants (see Table 4.5).

Table 4.5: Relevant energy consumption indicators in the pulp and paper sector. The contribution of electricity produced by CHP is compared with the total on-site generation [Adapted from CEPI (2015a)].

	1991	2000	2005	2010	2012	2013
Production of market pulp and paper/board (thousand tonnes)	71 971	98 691	109 644	106 084	103 638	102 810
Specific primary energy consumption (TJ/1000 t)	15.8	14.1	13.7	14.0	13.3	13.0
Specific electricity consumption (GWh/1000 t)	1.2	1.1	1.0	1.1	1.0	1.0
Total electricity produced at site (GWh)	29 416	41 930	50 462	56 780	53 797	51 704
% of electricity produced through CHP	88.0	90.4	94.4	95.4	96.4	96.4

5 Food and Beverages

5.1 Industry overview: structure and dimension

The food and drink manufacturing industry is a major part of the EU economy with the turnover of €1 089 billion in 2014 and employing 4.25 million people. It is the largest manufacturing sector in the EU by turnover (14.9%) and employment (15%) (FoodDrink Europe, 2016). The industry therefore has an important role to play in Europe's objectives to secure smart and sustainable economy. Its input in the environmental targets and development is equally vital. Five countries - Germany, France, Italy, Spain and the UK - account for 66% of the turnover for EU25 in 2016 (Table 5.1, Figures 5.1a to 5.1e).

Table 5.1: Food and drink values [Adapted from FoodDrink Europe (2016)].

	Employment ranking in manufacturing	Turnover (billion €)	Value added (billion €)	Number of employees (1000)	Number of companies
Austria	-	22.0	5.1	82.6	3 872
Belgium	1	48.0	7.6	88.5	4 532
Bulgaria	2	4.9	0.9	94.7	5 963
Croatia[1]	1	5.1	4.7	37.7	2 970
Czech republic	4	11.6	1.9	92.4	7 538
Denmark	2	25.8	4.3	44.8	1 589
Estonia	2	1.9	0.4	15.1	525
Finland[1]	3	11.2	2.7	38.0	1 700
France	1	184.5	36.2	619.5	62 225
Germany[2]	3	172.2	35.2	559.8	5 828
Greece[3]	1	14.5	2.0	86.4	1 330
Hungary	2	11.2	1.9	99.8	6 700
Ireland[4]	1	26.4	7.1	39.2	607
Italy	3	132	27.0	385.0	54 931
Latvia	1	1.8	0.4	25.8	1 000
Lithuania	1	4.2	0.7	42.5	1 601
Netherlands	1	68.8	10.9	126.3	5 639
Poland	1	49.5	10.6	423.8	14 625
Portugal	1	14.9	2.7	104.3	10 807
Romania	1	11.1	-	178.9	8 798
Slovakia[2]	3	3.8	0.7	28.1	268
Slovenia	3	2.2	0.5	16.0	2 160
Spain	1	93.4	28.0	479.8	28 343
Sweden	4	18.4	4.3	54.0	3 965
United Kingdom	1	120.9	33.4	415.0	6 360

[1]2015 data except for turnover
[2]Companies with more than 20 employees
[3]Small food and drink producers excluded
[4]2012 data

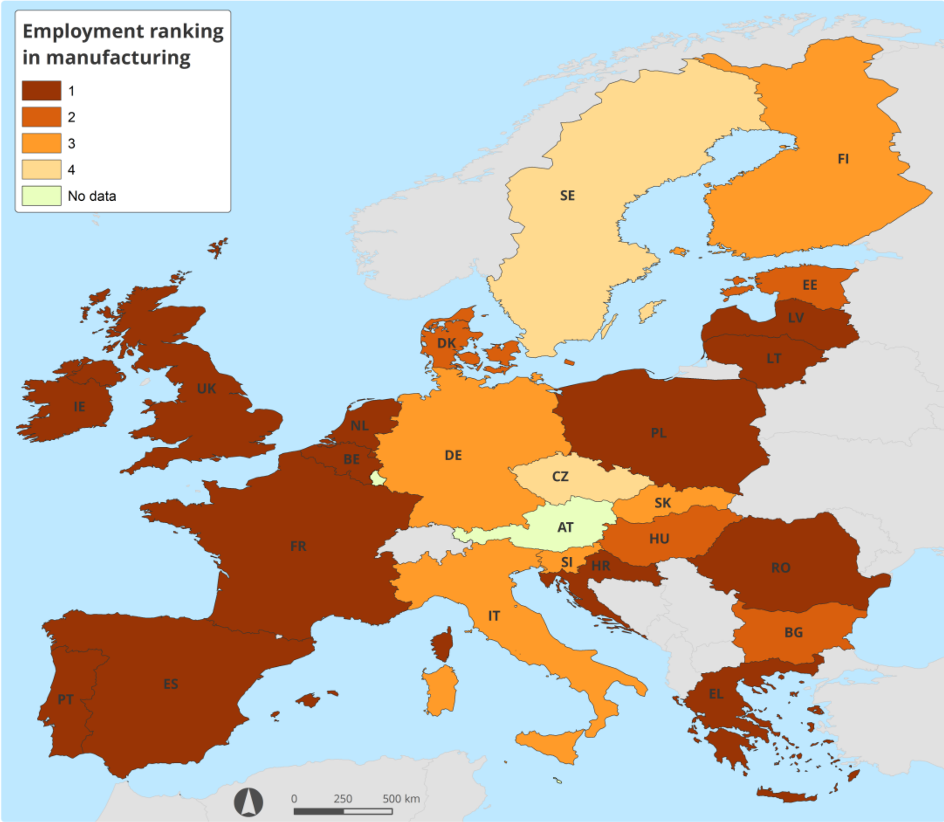

Figure 5.1a: Employment ranking in manufacturing.

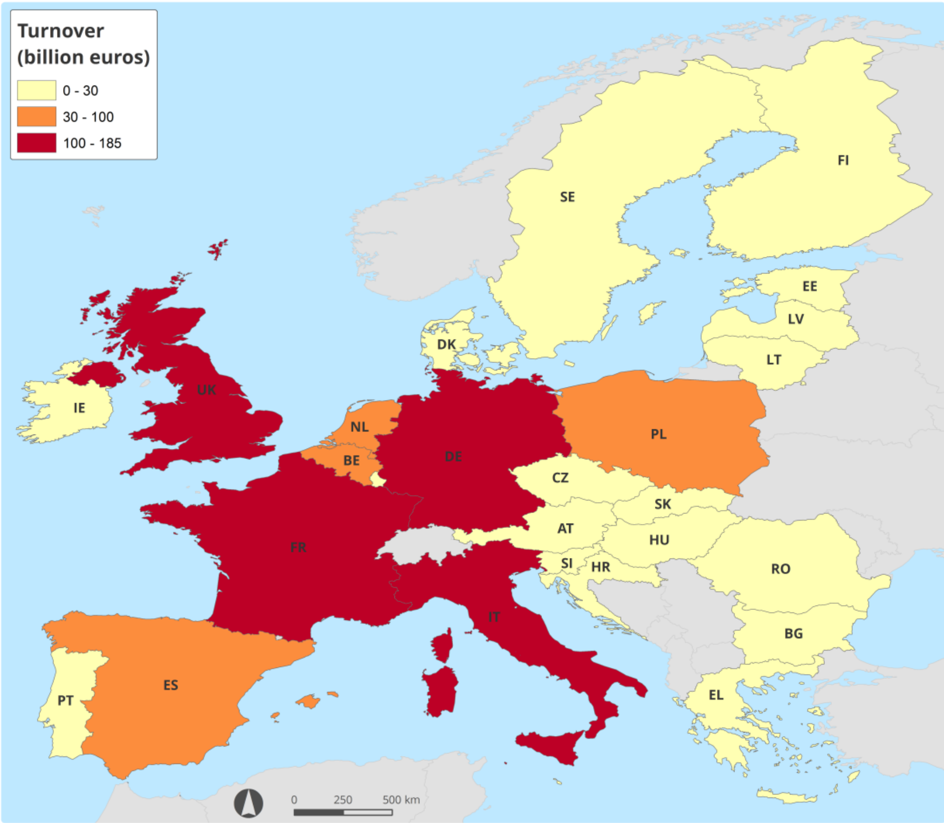

Figure 5.1b: Turnover (billion €).

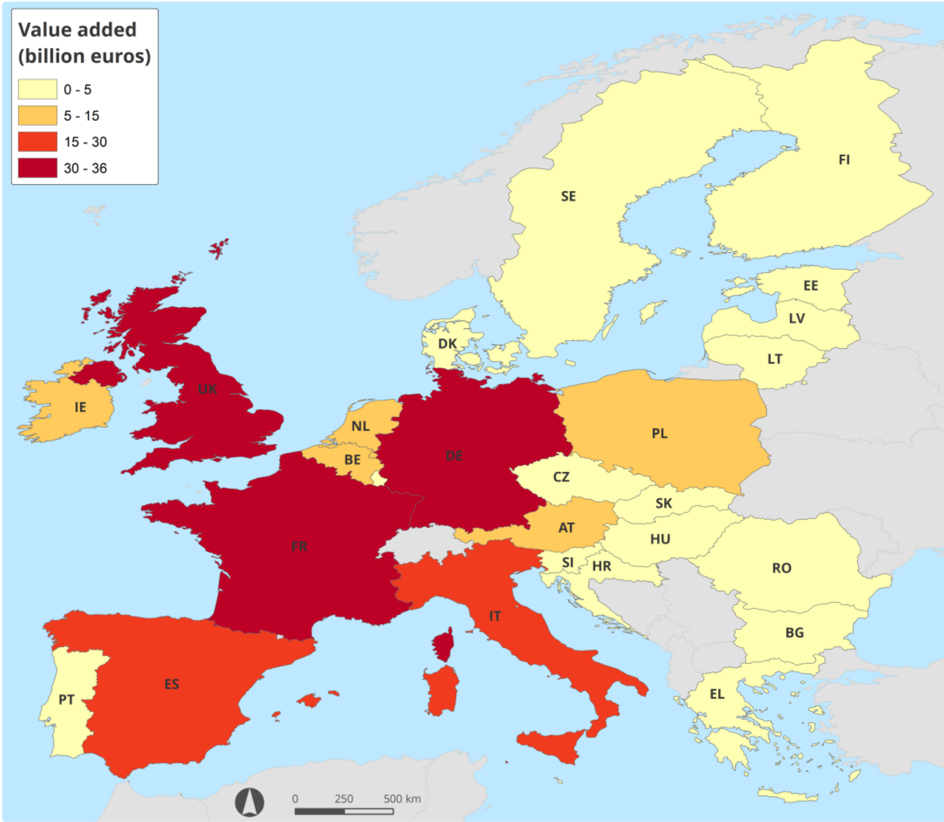

Figure 5.1c: Value added (billion €).

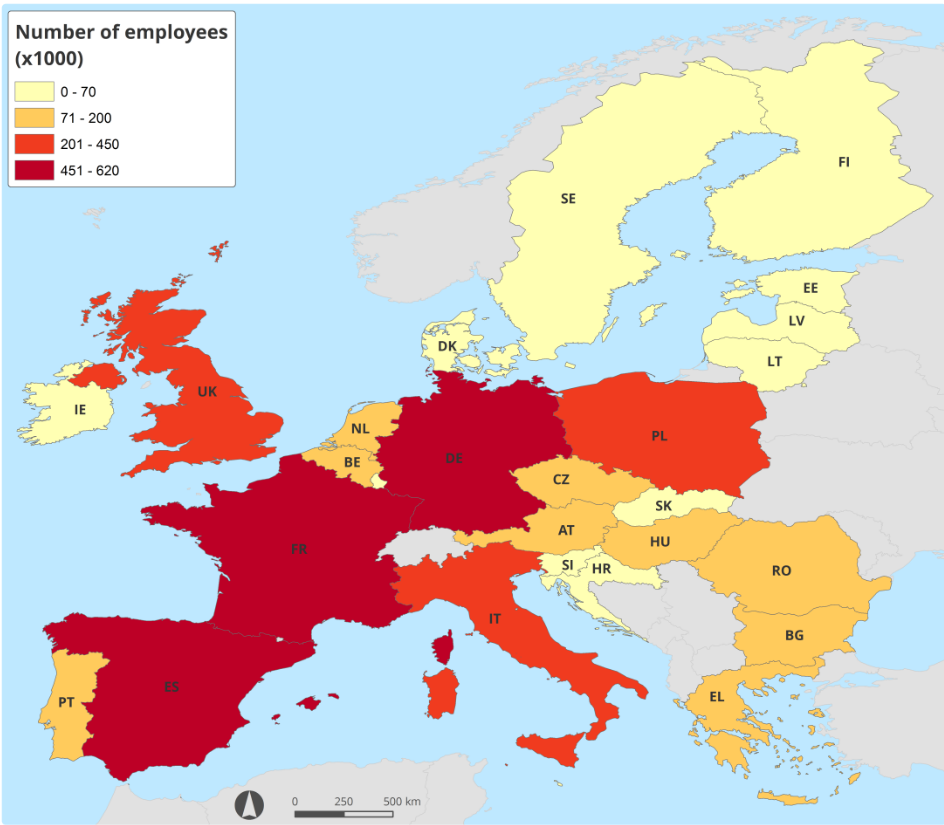

Figure 5.1d: Number of employees (x1000).

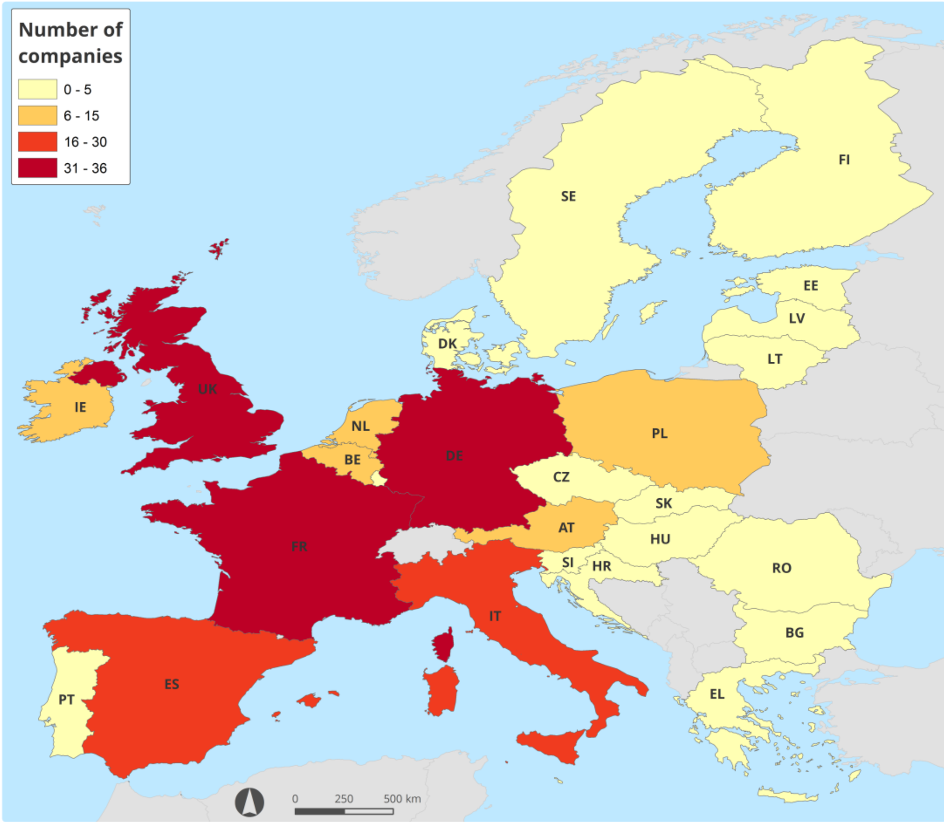

Figure 5.1e: Number of companies.

The food and drink industry is a highly diversified sector with many companies of different sizes. 99.1% of the food and drink companies are SMEs. These SMEs generate almost 50% of the food and drink industry turnover and value added and provide two thirds of the employment of the sector. The food and drink industry accounts for more than 285 000 SMEs.

With such high number of SMEs, the industry is therefore less capable of adapting innovative technologies quickly. Food SMEs typically have limited financial resources and do not have the financial strength required by banks for on-balance-sheet financing for energy efficiency and RES projects.

The EU food and drink industry is diverse, with a variety of sectors ranging from fruit and vegetable processing to dairy production and drinks (Figure 5.2).

The top 5 sectors (bakery and farinaceous products, meat sector, dairy products, drinks and "various food products" category) represent three quarters of the total turnover and more than 80% of the total number of employees and companies.

The European food and drink industry accounts for approximately 5.3% of industrial energy use worldwide. The industry emits approximately 1.5% of total EU GHG emissions. From 1999-2008 the industry cut its GHG emissions by 18% whilst production rose by 29%.

In 2010, food and drinks (and tobacco) manufacturing consumed 29 million tonnes of oil equivalents of final energy in EU-27 countries which represented a 10% share of the total energy consumed by the EU-27 industry. This puts the food industry fourth behind iron and steel, chemicals and petrochemicals and non-metallic minerals (Eurostat, 2012).

The food and drink processing industry accounted for 0.9% of total EU-15 GHG emissions in 2012 (EEA, 2014).

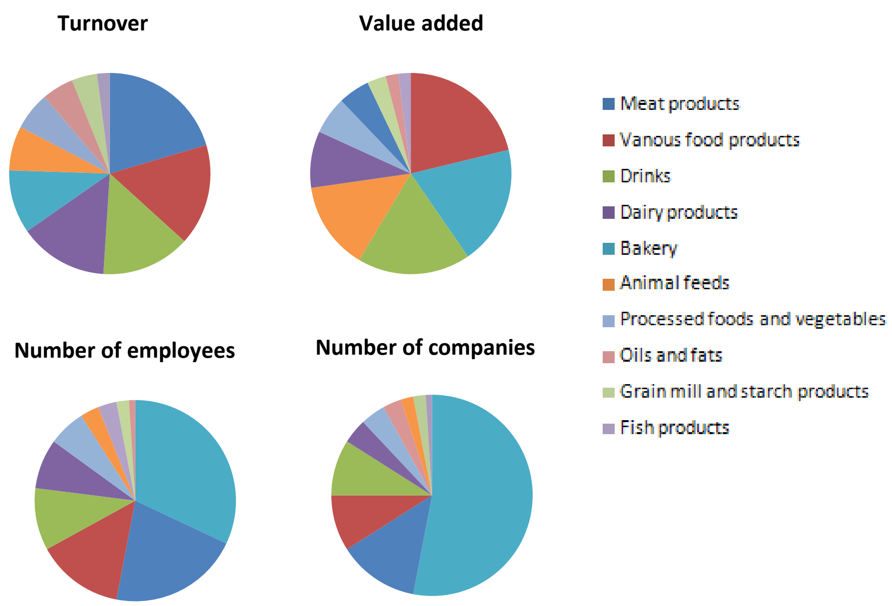

Figure 5.2: Turnover, value added, number of employees and companies in food and drink industry sectors (2013, %) [Adapted from FoodDrink Europe (2016)].

5.2 Heating processes and heat consumption

5.2.1 Meat sector

In the meat sector, a considerable amount of thermal energy is used in processes involving heat treatments such as boiling, cooking, pasteurising, sterilising drying and smoking. Other large energy consuming operations are chilling, freezing, thawing, and cleaning and disinfection.

The most relevant operations for electrical and thermal demand are indicated in Tables 5.2 and 5.3.

Table 5.2: Most relevant operations for energy demand in slaughterhouses.

Energy	Most relevant operations for energy demand
Thermal	Cleaning and disinfection Washing of carcasses Scalding (pig) By-products conditioning (offal)
Electricity	Chilling and freezing chambers Compressed air Wastewater treatment plant

Table 5.3: Most relevant operations for energy demand in meat industry.

Energy	Most relevant operations for energy demand
Thermal	Cleaning and disinfection Cooking/smoking
Electricity	Motor Chilling chambers Drying/curing Compressed air Generación de aire comprimido

Around 66% of the energy is consumed as thermal energy from the combustion of fossil fuels into boilers to generate steam and hot water (see Table 5.4).

Table 5.4: Energy consumption rates in slaughterhouses.

	Total (kWh/t carcass)	Electricity (kWh/t carcass)	Heat (kWh/t carcass)	Source
Slaughterhouses (general)	55-193			Ministerio Medio Ambiente (2006a)
Slaughterhouses (beef and pork, UK)	36-154			European Commission (2006a)
Slaughterhouses (pork)	280-380	1/3	2/3	European Commission (2006a)
Slaughterhouses (pork)		70-300	138-250	COWI (2000)
Slaughterhouses (beef)		70-250	55.5-138	COWI (2000)

Energy consumption increases significantly when offal operations are carried out in the same installation.

5.2.2 Dairy sector

Dairies have significant energy consumption. Around 80% of the energy is consumed as thermal energy from the combustion of fossil fuels into boilers to generate steam and hot water. It is used for heating operations and cleaning. The remaining 20% is consumed as electricity to drive machinery, refrigeration, ventilation, and lighting. The most energy consuming operations are pasteurization, evaporation and drying of milk, sanitation of equipment (Table 5.5)

A wide range of energy consumption data has been reported for the European dairy industry. Figures are included in Table 5.6.

Table 5.7 shows an example of distribution of energy by process in Dutch dairies. The cleaning in place can account for as much as 10-26% of the energy use for processing.

Table 5.5: Most relevant operations for energy demand in dairy industry.

Energy	Most relevant operations for energy demand
Thermal	Pasteurization Sterilization Sanitation
Electricity	Motor and Pumps Compressed air Cooling Lightning Wastewater treatment

Table 5.6: Energy consumption rates in European dairies [Adapted from European Commission (2006a)].

Products	Energy consumption (GJ/t processed milk)		
	Electricity	Fuel	Remarks
Market milk and yoghurt	0.15-2.5	0.18-1.5	Minimum for liquid milk, Maximum for specialties
	0.09-1.11*		
Cheese	0.08-2.9	0.15-4.6	Depends on the type of cheese and production run. Maximum fuel for whey evaporation
	0.06-2.08*		
Milk and whey powder	0.06-3.3	3-20	Maximum fuel for whey products
	0.85-6.47*		

*Approximately kWh/l (assuming milk has a density of 1 kg/l)

Table 5.7: Average percentage of primary energy demand for selected products and processes in Dutch dairies [Adapted from Ramirez et al. (2006)].

Product	Process	Energy consumption (%)
Fluid milk	Reception, thermization	2.0
	Storage	7.0
	Centrifugation/homogenization/pasteurization	38.0
	Packing	9.0
	Cooling	19.0
	Pressurized air	0.5
	Cleaning in place	9.5
	Water provision	6.0
	Building (lightening, space heating)	9.0
Cheese	Reception, thermization	19.0
	Cheese processing	14.0
	Cheese treatment/storage	24.0
	Cooling	19.0
	Pressurized air	5.0
	Cleaning in place	19.0
Butter	Cooling	66.0
	Pressurized air	8.0
	Cleaning in place	26.0
Milk powder	Thermization/pasteurization/centrifugation	2.5
	Thermal concentration/evaporation	45.0
	Drying	51.0
	Packing	1.5

Table 5.8 shows that for majority of dairy products the thermal energy requirement is greater than electrical with processes that include milk concentration consuming the most energy and raw milk the least.

Table 5.8: Energy requirement in modern milk processing plants (Adapted from GREENFOODS project (2015)].

Final product	Energy requirement (MJ/t of milk)	
	Heat	Electricity
Milk in bottles:		
Pasteurized	600	200
Sterilized	720	250
Milk in one-way containers:		
Pasteurized	250	180
UHT	360	325
Skim milk powder and butter	2100	325
Full cream milk powder	1900	290
Ripened chesses:		
Without whey processing	450	270
With whey processing	1660	360
Evaporated and condensed milk	1060	220

Dairy industries in Spain (2006) reported electricity consumption values of 39-448 kWh/t received milk, and thermal energy of 25-884 kWh/t received milk (Ministerio Medio Ambiente, 2006c).

5.2.3 Brewing

Breweries need both electrical and heat energy. Thermal energy is consumed as steam and hot water produced into boilers using fossil fuels.

The main heat consuming process steps are mashing, wort boiling, generation of hot liquor, CIP, sterilising, bottle/keg cleaning and pasteurising (Table 5.9).

Table 5.9: Most relevant operations for energy demand in brewing industry.

Energy	Most relevant operations for energy demand
Thermal	Mashing Wort boiler Pasteurisation Cleaning in place
Electricity	Refrigeration Cooling Operating machinery Packaging Ventilation Lighting Wastewater treatment

A brewery without a sophisticated heat recovery system consumes about 27.78 – 55.55 kWh/hl beer. Heat consumption for some departments is given in Table 5.10.

Table 5.10: Heat consumption for different brewery processes [Adapted from European Commission (2006a)].

Department/process	Minimum	Mean	Maximum	Literature[1]	Measured[2]
	Figure			Range	
	(MJ/hl beer)				
Brewhouse	87	92	121	84-113	50-80
Bottling installation	58	86	94	25-46	38-58
Kegging installation	8	11	13	8-13	-
Process water	3	4	8	4-8	-
Service water	-	-	-	8-17	-
Miscellaneous	-	-	-	33-46	95
Total	***156***	***193***	***236***	***162-243***	***183-233***
	(kWh/hl beer)				
Brewhouse	24.17	25.56	33.61	23.33-31.39	13.89-22.22
Bottling installation	16.11	23.89	26.11	6.94-12.78	10.56-16.11
Kegging installation	2.22	3.06	3.61	2.22-3.61	-
Process water	0.83	1.11	2.22	1.11-2.22	-
Service water	-	-	-	2.22-4.72	-
Miscellaneous	-	-	-	9.17-12.78	26.39
Total	***43.33***	***53.62***	***65.55***	***44.99-67.50***	***24.44-64.72***

[1]20000 to 500000 hl beer sold/yr
[2]300000 to 500000 hl beer sold/yr

5.2.4 Fruit and vegetables

Energy consumption in the fruit and vegetables processing sector is very variable because of the variety of raw materials transformed and multiple possible processing routes and processing technologies.

The main heat consuming process steps are heating, blanching, drying, evaporation, sterilisation, pasteurisation and sanitation. Thermal energy carriers are steam or hot water, produced into combustion boilers using fossil fuels. Almost every process step requires electricity, but the main electricity consuming operations are chilling, freezing and cooling storage (Table 5.11).

Data from Spanish companies give values of energy consumption of 50 to 275 KWh/t raw material processed for canning companies, and 200 to 600 Kwh/t raw materials processed for frozen vegetables (Ministerio de Medio Ambiente, 2006b).

Table 5.11: Most relevant operations for energy demand in vegetable processing industry.

Energy	Most relevant operations for energy demand
Thermal	Blanching Drying Concentration/Evaporation Sterilisation Pasteurisation Sanitation
Electricity	Chilling Freezing Cool storage Lighting Wastewater treatment

5.2.5 Sea products

Energy consumption in the sea product processing sector is very variable because of the variety of raw materials transformed and multiple possible processing routes and processing technologies.

Processes which involve heating, such as canning and fishmeal production need more energy than other processes. Thermal energy is used in the form of steam and hot water. For fish and fish meal processing, energy is required for cooling, cooking, sterilizing, drying, evaporation, can cleaning, fork-lifting (Table 5.12).

Table 5.12: Most relevant operations for energy demand in sea products processing industry.

Energy	Most relevant operations for energy demand
Thermal	Thawing Cooking Sterilisation Sanitation
Electricity	Chilling Freezing Refrigeration Compressed air

Electricity consumption in Spanish sea product companies range from 223.5 to 2557.9 kWh/t raw material, and thermal energy ranges from 7.5 to70.3 kWh/t (Ministerio de Medio Ambiente, 2006b).

On average, filleting consumes from 65 to 87 kWh/t of fish and canning consumes from 150 to 190 kWh/t of fish (European Commission, 2006a).

Table 5.13 shows the energy consumption for different fish processes using average technology.

Table 5.13: Energy consumption for different fish processes using average technology [Adapted from COWI (2000)].

Process	Energy consumption
Filleting white fish	Ice: 10–12 kWh Freezing: 50-70 kWh Filleting: 5 kWh
Filleting oily fish	Ice: 10–12 kWh Freezing: 50-70 kWh Filleting: 2-5 kWh
Canning	150-190 KWh
Fish meal and fish oil production	Fuel oil: 49 L Electricity: 32 kWh

The most common use of energy in fish processing is for refrigeration, which can account for 65%-85% of electricity use. Process equipment (such as de-headers, scalers, filleters) account for about 10% of electricity whilst the remainder is for lighting and air-conditioning (GREENFOODS project, 2015).

5.2.6 Bakery

In an industrial bakery, the prover, oven, cooler and associated steam boiler plant typically account for 50% to 60% of the energy consumption, with the oven using the most energy. Electrical energy is required for ingredients handling, conveyors and compressed air (Table 5.14).

Table 5.14: Most relevant operations for energy demand in bakery industry.

Energy	Most relevant operations for energy demand
Thermal	Prover Oven Sanitation
Electricity	Cooler Refrigeration Conveyor belts Compressed air

Table 5.15 presents the average specific energy consumption in the bakery sector by energy carriers. Fossil fuels contribute the most to the total consumption.

Table 5.15: Average specific energy consumption by energy carrier in the bakery sector (Carbon Trust, n.d.).

Energy	Energy consumption
Fossil fuels (predominately gas)	551 kWh per tonne of product
Electricity	218 kWh per tonne of product

The average specific energy consumption by equipment in the UK bakery plants is given in Table 5.16. The highest requirements are for the operations developed in the oven.

Table 5.16: Average specific energy consumption of equipment in UK Bakery plants (Carbon Trust, n.d.).

Equipment		Energy requirement (kWh/tonne product)
Prover	Steam heated	5.5
	Gas heated	1.9
	Electricity	0.29-0.31
Oven	Directly fire	221
	Indirectly fire	590
	Electricity	Direct 6; indirect 32
Cooler	Old (30yrs)	0.025-0.098
	Modern	0.005-0.02

5.2.7 Vegetable oils

The energy consumption during the production of crude vegetable oil depends on the type of raw material, the equipment and the manufacturing processes. Heating, cooling, drying, milling, pressing, evaporation and distillation are the major energy consuming steps (Table 5.17).

Table 5.17: Most relevant operations for energy demand in vegetable oil industry.

Energy	Most relevant operations for energy demand
Thermal	Heating Drying evaporation distillation
Electricity	Milling Cooling Pressing

Steam consumption in seed oil production is in the range 200 – 500 kg steam/t processed seed (155 – 390 kWh/t) and the electricity need is in the range 25 – 50 kWh/t processed seed (European Commission, 2006a).

Energy consumption in olive oil production range 90 – 117 kWh/t. (CAR/PL, 2000). Table 5.18 shows the energy consumption in the main operation of crude vegetable oil refining process.

5.2.8 Heat production systems

The basic configuration of the heat production system in the food and drink industry is a boiler with a specific burner where fossil fuel (natural gas, diesel, light fuel oil) combustion takes place. Natural gas and fuel oil are the most convenient fuels. However, a few food and drink installations in EU still burn solid fuels such as coal. In some cases, biomass and biogas produced from residual biowaste or wastewater are also used as fuel.

Table 5.18: Energy consumption in crude vegetable oil refining.

Processing step	Total energy	Steam	Electricity
(MJ/t final product)			
Neutralization	145-330	112-280	22-44
Soap splitting	620-2850*	560-2800*	11-36*
Deodorization	510-1350	420-1120	60-150
Hardening	400-1000	n.d.	n.d.
Bleaching	n.d.	n.d.	n.d.
(kWh/t final product)			
Neutralization	40-92	31-78	6-12
Soap splitting	172-792*	156-778*	3-10*
Deodorization	142-375	117-311	17-42
Hardening	111-278	n.d.	n.d.
Bleaching	n.d.	n.d.	n.d.

[1]Calculated using 2.8×kg steam/t=MJ/t
* MJ/t soap or kWh/t soap
n.d. data not available
Final product=refined vegetable oil

Heat is transferred to the consumers equipment by means of a heat transfer media, normally steam, but also hot water or thermal oil are possible energy carriers. The hot flue-gas and heat transfer media are separated from each other by a specially designed heat-exchange system.

In other cases, steam is directly used onto the food product for heating (i.e. direct pasteurization, steam furnaces singeing, etc.). In some cases, products are heated up by means of direct radiation with open flames or convection with directly heated process air. In this particular case, natural gas is generally used as fuel.

An in-house CHP system is also a valuable alternative for the food, drink and milk manufacturing processes when heat and power loads are balanced. CHP systems can be technically and economically feasible systems in sectors with both high heat and cooling demand (i.e. brewing, dairies, fruit juices or fish processing) The overall fuel utilisation factor of CHP systems exceeds 70 % and is typically about 85 %. Energy efficiency can be up to 90 or 95 % when the exhaust gases from a waste heat recovery system, such as a steam boiler, are used for other drying purposes.

6 Wood and wood products

6.1 Industry overview: structure and dimension

The wood and wood products industry is organized in three main groups of activity: sawmilling and planning of wood, manufacture of products of wood and cork (includes products of straw and plaiting materials) and manufacture of furniture. Figure 6.1 shows the relevance of each sector through their share in total production value.

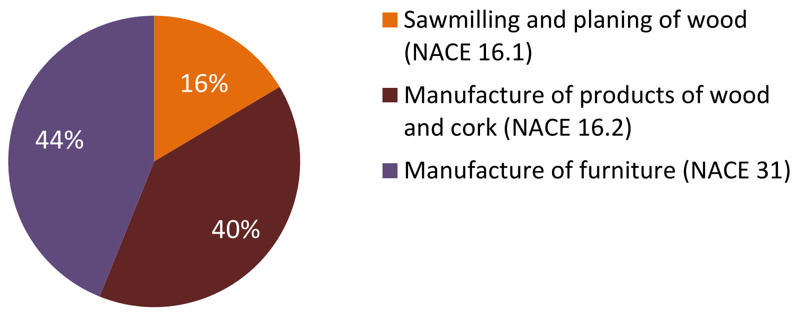

Figure 6.1: Share of the wood and wood products sectors in total production value for EU28 in 2013 [Source: Eurostat (2016b)].

Manufacture of furniture is the most important sub-sector in terms of production value followed by the manufacture of products of wood and cork sector. Table 6.1 shows the key indicators that characterize the dimension of the wood and wood products industry for EU28 in 2013.

Table 6.1: Wood and wood products sector dimension key indicators for EU28 in 2013 [Source: Eurostat (2016b)].

	Turn over (million €)	Number of companies	Number of employees	Persons employed per company
Sawmilling and planing of wood (NACE 16.1)	35000	35314	217000	7
Manufacture of products of wood and cork (NACE 16.2)	83000	136454	606100	5
Manufacture of furniture (NACE 31)	91656	119921	867700	8

The geographical distribution of companies of the wood and wood products industry by sub-sector is presented in Figure 6.2. Italy and the Czech Republic are the Member States with the largest number of companies, particularly in the manufacture of products of wood and cork.

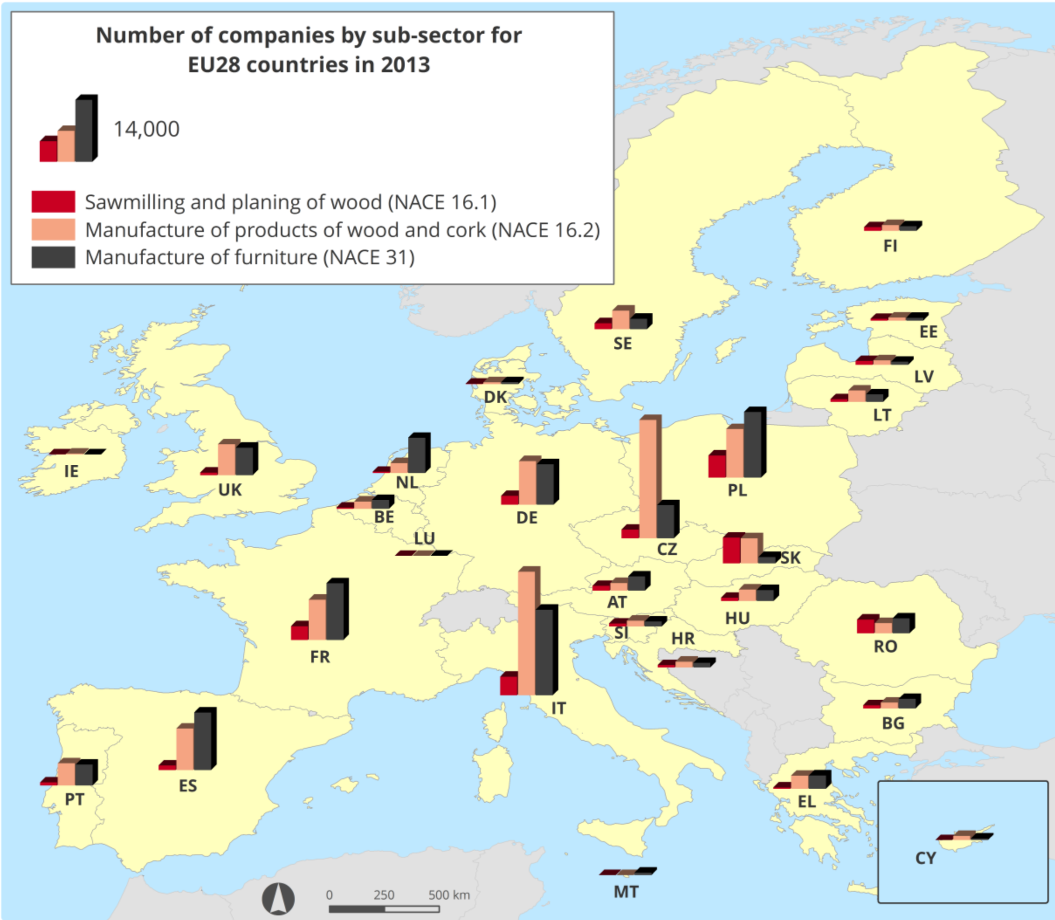

Figure 6.2: Number of companies of the wood and wood products industry by sub-sector for EU28 in 2013 [Source: Eurostat (2016b)].

Slovakia, Poland, Romania and Italy are the most relevant Member States as far as the number of companies in sawmilling and planning of wood is concerned. They are followed by France, the Czech Republic and Germany. In the sector of manufacture of furniture, Italy, Poland, France, Spain and Germany have the highest number of companies, followed by Netherland, the United Kingdom and Portugal.

Two of the most heat-intensive industries in the sector are the wood-based panel (WBP) industry integrated in NACE 16.21 and the wood pellets industry integrated in NACE 16.29. Those industries are analysed in the next section concerning their heating processes and energy consumption (in particular process heat consumption). For the WBP industry the main types of panel installations – Particle Board (PB) panels and Fibre Board (FB) panels – are analysed. Fibre board panels include oriented strand broad (OSB), low-density fibre board (LDF), medium-density fibre board (MDF) and high-density fibre board panels (HDF).

6.2 Heating processes and heat consumption

6.2.1 Wood-based panels industry

The main processes are similar in the different types of wood-based panels (WBP) plants (see Figure 6.3), even though the sequence of the production processes is not necessarily the same for the different industry facilities.

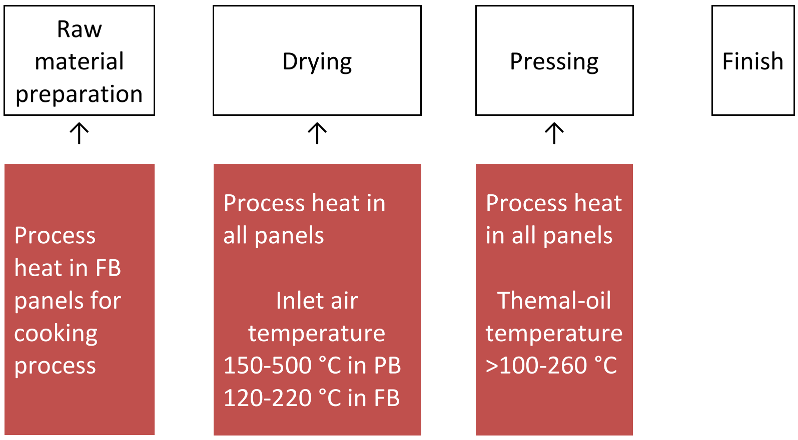

Figure 6.3: Main production processes for WBP and areas with process heat needs.

The drying and pressing sectors contain the main processes in the production of wood-based panels and are also the most energy-intensive. Fibre board panel production includes the refining process for preparation of the raw material before drying process. This step also needs process heat for cooking the wood fibres. Figure 6.4 shows the sequence of the production processes for different wood-based panel products and indicates which are the most intensive in terms of process heat.

The production of wood-based panel is significantly intensive in terms of energy. In all types of industrial units, the major contribution for energy consumption comes from the heat demand and the MDF panel facilities have the highest energy consumption both in terms of heat and power (see Table 6.2).

Table 6.2: Heat and power consumption range for typical WBP installations [Adapted from Stubdrup et al. (2016)].

	PB	OSB	MDF
Annual Process heat consumption (GWh/year)	28 - 750	33 - 112	231 - 887
Specific process heat consumption (MWh/m^3)	0.18 - 1.7	0.11 - 0.69	0.30 - 2.9
Annual Power consumption (GWh/year)	11 - 101	35 - 49	53 - 230
Specific power consumption (MWh/m^3)	0.07 - 0.24	0.10 - 0.13	0.25 - 0.76
Process heat fraction of total energy consumption (%)	54 - 90	46 - 86	36 - 87
Power fraction of total energy consumption (%)	10 - 46	14 - 54	13 - 64

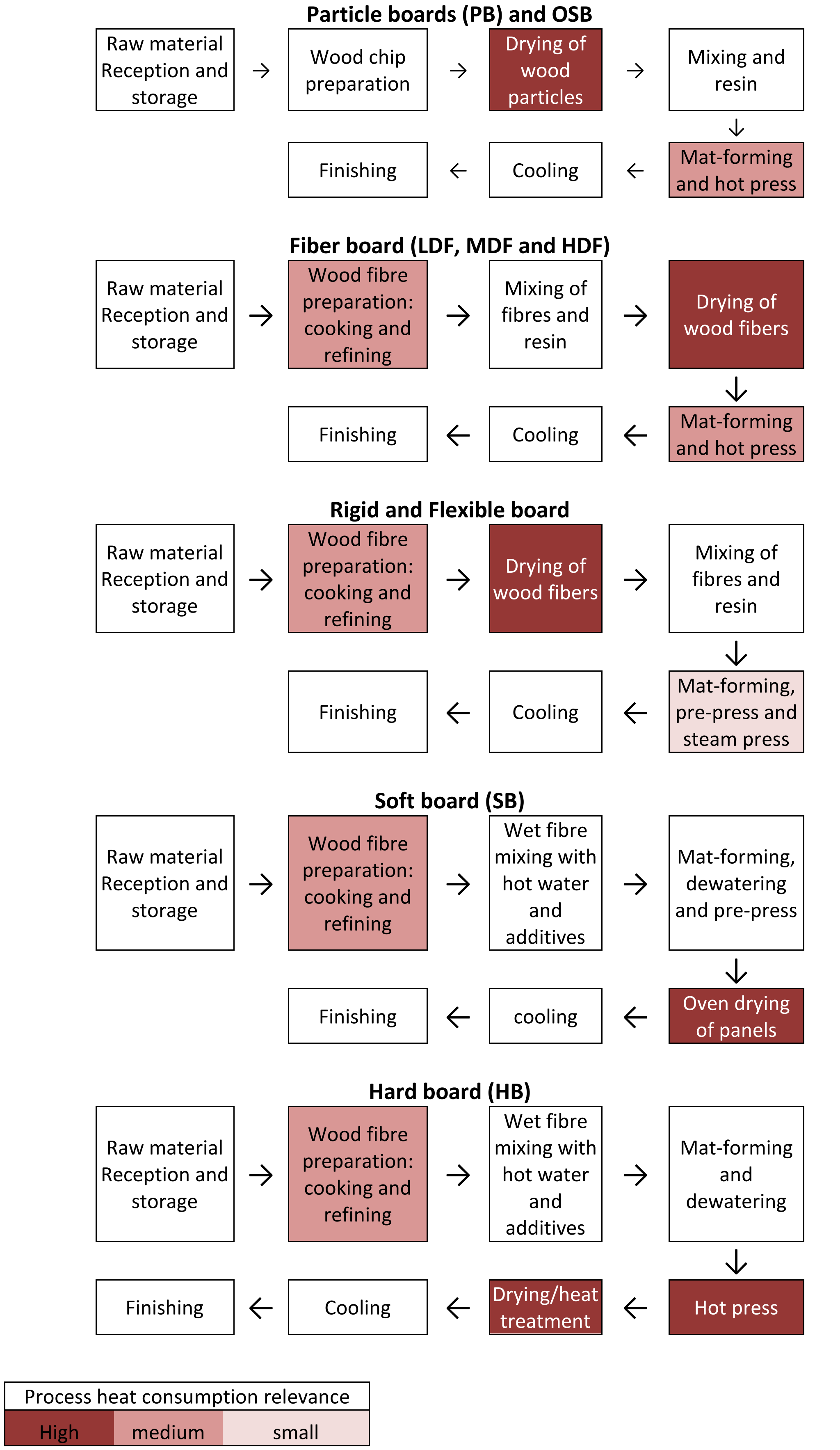

Figure 6.4: Scheme of the sequence of production processes for different wood-based panel products and their relative importance in terms of process heat consumption.

In FB production, heat consumption can be two to four times greater than in PB and OSB heating processes. This is due to the additional process heat demand of the refining step, whose heat consumption is almost equivalent to the heat demand of the drying process. Drying is the most heat-intensive process in all grades of panels, but also the most power-intensive process (dryer operation, fans and raw material transport).

The heat production in the WBP industry occurs mainly in the combustion units, where fuels are burned and thermal energy generated. The most important fuels used are wood residues obtained from internal and external sources (see Table 6.3). Nevertheless, other fuels are also used, such as conventional fossil fuels and renewable energy sources other than wood-derived biomass.

Table 6.3: Fuels used in WBP industry.

Internal sources	External sources	
Recovered wood material	*Recovered wood material*	*Coventional fuels*
wood dust from finishing operations	sawdust	natural gas
collected trimings	post-consumer wood materials	fuel oil (light and heavy)
rejected panels	roots and stubs	solid fossil fuels
woodsludge material		
barking from debarking		
wood residues from chipping and milling		
impregnated paper		

Heat production in WBP industry mainly occurs in combustion plants depending on the type of fuel. Plant capacities range from 10 MW to 50 MW, operating the larger combustion plants in CHP configuration.

6.2.2 Pellets production industry

The production of pellets consists of successive steps that start with the arrival of the raw material and end up in obtaining a densified solid biomass fuel. The process flow diagram of pellets production is represented in Figure 6.5. The installation receives, as primary raw material, solid biomass, mainly residues, derived from forest, agriculture or industry. After that, it is necessary to transform the biomass residues into sawdust. This occurs in the comminution process usually performed by a hammer mill. This process can be preceded by a grinding operation depending on the dimension and state of raw biomass.

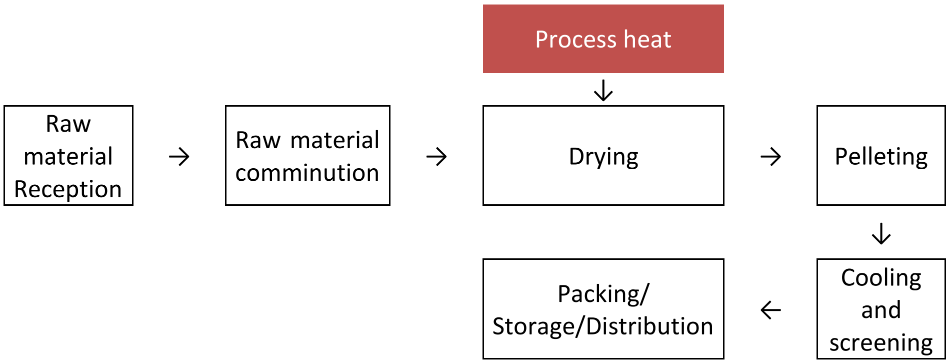

Figure 6.5: Process flow diagram for pellets production.

The next step is the drying of the primary raw material, with the objective of reducing its moisture content (10% or less for a high quality product). The raw material is then forwarded to the pelleting system; before this step a conditioning process to achieve better physical properties of raw material can occur. After the pelleting process (which corresponds to pellets extrusion), the product is quenched with cooled air (25 °C) to harden it. At last, a screening process is carried out before storage or packing.

Energy consumption in the production of wood pellets is dominated by the drying process, which represents around 85% of the total energy consumption in a pellets production installation. Figure 6.6 shows the share of energy consumption by end-use in total energy consumption.

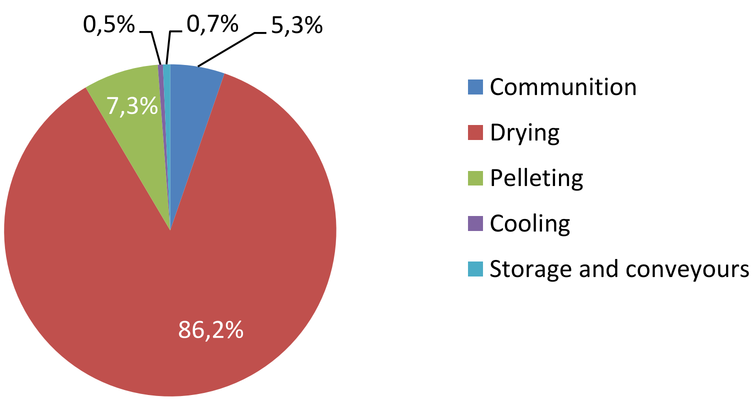

Figure 6.6: Share of energy consumption by end-use in total energy consumption for the production of pellets [Adapted from EUBIA (2016)].

Table 6.4 indicates reference values for the specific consumption of heat and power in typical pellets installations. For heat, the specific consumption is given per ton of water need to be evaporated from the raw material.

Table 6.4: Specific heat and power consumption for typical pellets installations [Adapted from EUBIA (2016)].

Specific heat consumption (kWh/t water)	950
Specific power consumption (kWh/t)	80 - 150
Specific energy consumption (kWh/t)	1 140

Heat production in the pellets industry occurs mainly in the combustion units. The main fuels used are wood-derived residues and pellets obtained from internal sources. Other fuels are also used such as solid fossil fuels acquired from external sources. Figure 6.7 presents a flow diagram for heat production in pellet mills, showing the main existent possibilities.

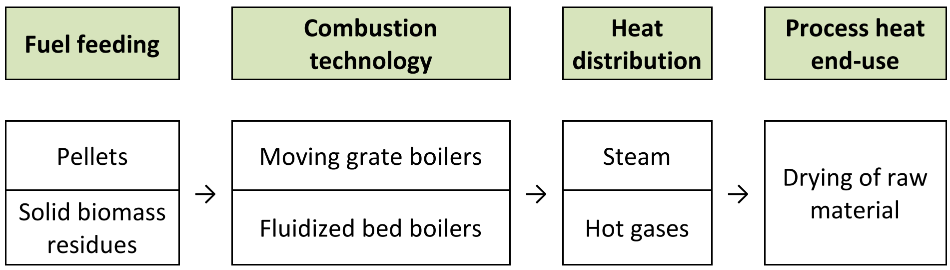

Figure 6.7: Heat production flow diagram for the pellets production industry.

7 Conventional heat production systems

The thermal systems that are conventionally used by the industrial sector to generate process heat rely on fuel combustion. In some industries, the heat produced by those systems may be also utilized for power generation, in CHP systems.

Process heat is delivered in different forms depending on the specificities of the production process. In industry, the most-widely used heat carriers are steam and hot gases from the combustion process. Combustion boilers are, therefore, commonly used in industry as the main heat production system. When power generation is sought, combustion often provides thermal energy for steam and gas turbine generators, where energy is converted into mechanical energy used to generate electricity. Internal combustion engines coupled to a generator shaft for direct conversion of fuel energy into mechanical energy can also be used.

Some of the industrial sectors covered in this report rely on specific technologies for process heat production. Those are the melting furnaces used for glass production and the cement/lime production kilns. In these two cases, the combustion heat is delivered directly “over” the material that is being processed, so that both the combustion and industrial processes occur in same chamber and at the same time. They are described at the end of this chapter.

The combustion boilers used in industrial heat production plants can differ in technology, thermal capacity, fuels burnt, load conditions and purpose. The choice of a specific system is strongly dependent on the energy load requirements and availability of fuels. Industrial combustion boilers usually have a nominal thermal capacity between 10^2 and 10^5 kW. The largest industrial plants are comparable in size to the power plants used by the energy industry (> 200 MW_{th}). Also very small-scale systems can be used (< 100 kW_{th}) in small-sized industries.

There are two types of boilers: water tube and fire tube. Water tube boilers heat water in tubes and the hot combustion gases are contained in the space around the tubes. Fire tube boilers have hot combustion gases contained inside tubes and the water is circulated around these.

The advantages of steam as energy carrier are its low toxicity, safety in use with flammable or explosive materials, ease of distribution, high efficiency, high heat capacity and low cost. Steam holds a significant amount of energy on a unit mass basis (2300 - 2900 kJ/kg), mainly stored as latent heat, so a large quantities of heat can be transferred efficiently at a constant temperature, which is a useful attribute in many process heating applications. Steam pressure is directly related to temperature, so that, temperature can be adapted easily by modifying the pressure.

Water can be used as heat transfer media where the required temperature do not exceed 100 °C, but pressurised water (to avoid boiling) can be used for temperatures above 100 °C. Thermal oils have a higher boiling point; however, they typically have lower heat capacities and heat transfer coefficients than steam.

In process heating, the steam transfers its latent heat to a process fluid in a heat exchanger. Any condensate (steam that has condensed) is captured and returned to the condensate return system for reuse.

7.1 Grate furnaces

As its name indicates, in grate furnaces solid fuels are oxidized on a grate. The basic configuration of grate furnaces can be seen in Figure 7.1. In this type of furnaces, only solid fuels are used (fossil fuels, biomass and wastes). Fuel particles size plays a very important role in the combustion process since particles that are too small fall unburned through the grate and particles that are too large are not completed burned (European Commission, 2006b).

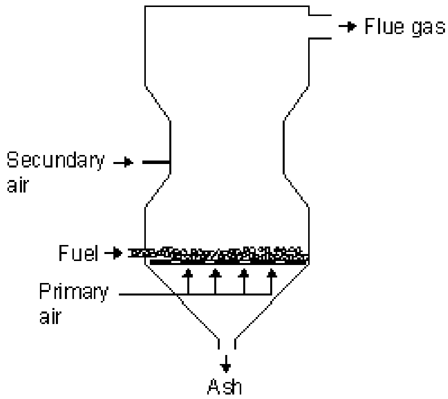

Figure 7.1: Basic layout of a grate furnace.

Regarding the grate movement, grate furnaces can be classified as fixed, moving or vibrating grate, among others.

In a fixed grate furnace, the fuel is transported over the grate due to fuel feeding and due to the inclination of the grate itself. A disadvantage of this system is that the fuel mass flow cannot be well controlled. It is often used in small-scale applications but it became obsolete for modern combustion plants, where it is no longer applied (van Loo and Koppejan, 2008).

The moving grate systems can be of two types: inclined moving grates or horizontally moving grates. The inclined moving grate system consists in a set of grate files fixed and movable, in which horizontal forward and backward movements of movable files occur in an alternating manner. Different solid fuels can be burned in this type of furnace. In the horizontally moving set up, the grate files are in diagonal position, so all the fuel bed is displayed horizontally. The main advantages of this technology are: more homogeneous distribution of the burning material on the grate surface, no slag formation due to hot spots and less overall height (van Loo and Koppejan, 2008).

The vibrating grate system integrates a leaning finned tube wall fixed on springs. The combustion chamber is fed by spreaders, screw conveyors or hydraulic feeders. The vibrators transport the fuel and the ashes. The primary air enters below the fuel bed through holes in ribs of the tube wall. An advantage of this system is the inhibition of large slag particles formation, so it is also suitable for fuels with sintering and slagging tendencies (e.g. straw and waste wood). Their disadvantages are the higher fly-ash and CO emissions due to the vibrations and the incomplete burnout of the bottom ash due to the difficulty in control ash and fuel transport (van Loo and Koppejan, 2008).

7.2 Pulverized solid fuel combustion

The general operation principle of pulverized solid fuel combustion is that fuel is reduced to powder to be fed into the combustion chamber. Coal and lignite burners can be single wall-fired (see Figure 7.2), opposed wall-fired, tangential-fired and vertical-fired.

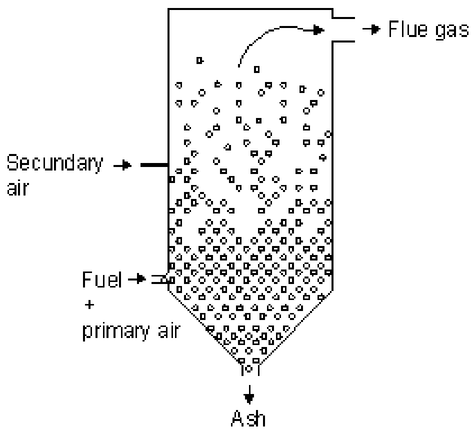

Figure 7.2: Basic layout of a pulverized fuel combustion boiler with a single wall–fired burner.

Pulverized coal fired boilers (PCFB) are widely used for power generation, presenting two types of technology: dry bottom boilers and wet bottom boilers.

Dry bottom systems have operating temperatures well below the melting point of the ash to ensure there is no slag formation over the chamber walls and the heat exchanger; bottom ashes are collected in the solid state and flying ashes carried out by flue-gases are removed in electrostatic precipitators. Coal and lignite are widely used with this type of systems. Wet bottom systems operate at temperatures above the melting point of the ash to ensure that the ashes are liquid. Liquid ashes flow down the chamber walls and are collected through the boiler bottom. The flying ashes can be recycled into the combustion chamber to generate slag and then be removed by the bottom ash collector. Having low amounts of volatile compounds, hard coal (anthracite) is mostly used in this system.

7.3 Fluidized bed combustion boilers

In fluidized bed combustion (FBC) boilers, solid fossil fuels, biomass and wastes can be fed into an inert material bed (sand, gravel and also ashes), which is fluidized by a combustion gas injected from the bottom of a porous and perforated plate. During the process, larger particles have the tendency to cease the fluidization and fine particles tend to be blown out from the fluidized bed.

There are three main types of fluidized bed combustion systems for industrial application: bubbling, circulating and pressurized fluidized bed boilers (BFBC, CFBC and PFBC boilers respectively). BFBC and CFBC boilers operate at atmospheric pressures, while PFBC boilers operate at higher pressures. Figure 7.3 shows the basic layouts for the bubbling and circulating fluidized bed boilers, which are the most used technologies in industries that rely on fluidized bed combustion.

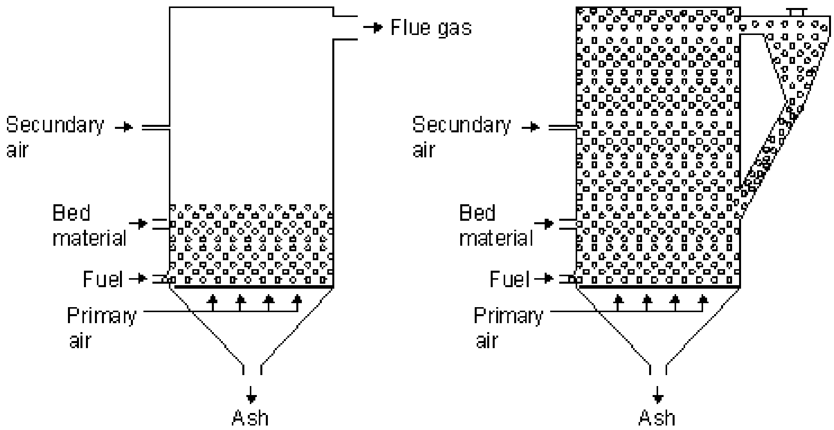

Figure 7.3: Basic layout for BFBC and CFBC boilers.

The main structural difference between bubbling and a circulating fluidized bed boiler is that circulating boilers include a cyclone separation system directly connected to the combustion chamber (or furnace) that allows the captured particles to be recycled into the fluidized bed.

In a circulating fluidized bed process, the superficial velocity of the combustion gas injected (primary air and/or steam) is high enough so that most part of the particles is blown upward and that the process will extend to the entire volume of the furnace in a fast fluidized bed regime. The bigger particles remain fluidized near the bottom or can be carried way (to cyclone system) after size reduction due to chemical consumption, thermal shocks and grinding (mostly caused by particles attrition).

In BFBC boilers the fluidized bed occupies a lower region in the furnace once the superficial velocity of the combustion gas is also lower compared with CFBC. The bubbles formation phase starts when the superficial velocity reaches the minimum bubbling velocity and at this point, and for higher velocities, the combustion gas pressure drop across the bed (pressure loss per unit of bed length) remains almost constant. For higher thermal capacities CFBC boilers are preferred to BFBC boilers since they can achieve higher combustion efficiency.

7.4 Liquid and gas firing boilers

Fuel oil and natural gas are widely used in combustion boilers. Both fuels have similar moisture and ash content, release similar amounts of flue gas during combustion and also burn in gaseous conditions with closely homogenous combustion flame (Teir, 2002). These characteristics make the design of gaseous and liquid boilers similar and allows coupling to the boiler chamber liquid and gaseous fuel burners operating in a fuel co-combustion mode. All clean gaseous and liquid fuels can be combusted at the boiler bottom since they have reduced amounts of ashes. Only heavy fuel oils have high amounts of ash.

In gas and liquid boilers fuel is directly fired with air and the burners are disposed in several levels in the combustion chamber walls (single wall-fired or opposed wall-fired configuration) or tangentially in the corners of the chamber. In liquid boilers fuel is sprayed into the furnace through nozzles producing very small droplets atomized by high pressure steam.

7.5 Combined heat and power (CHP)

Cogeneration is the production of heat and power in one single process, improving the overall system efficiency. Most of the electricity and heat produced by industrial facilities are consumed on site; however, some manufacturers sell electricity to the grid. CHP is considered one of the most cost-efficient solution for reducing carbon emissions from heat production systems in cold climates and the most energy efficient method of energy conversion from fossil fuels or biomass into electricity (Vatopoulos et al., 2012). Another advantage of using CHP systems is their flexibility.

Some of the possible ways to simultaneously produce heat and power is through the use of steam turbines, gas turbines or both in a combined cycle, where each turbine is connected to an electricity generator.

7.5.1 Steam turbines

Steam turbines are connected to a boiler that produces high pressure steam and are fired by any type of fuel. There are two main types of steam turbine technologies for CHP applications (or electricity generation only): extracting back-pressure turbines and extracting condensing turbines (Figures 7.4 and 7.5). Systems with extracting condensing turbines have higher electric efficiency and power to heat ratio compared with extracting back-pressure turbines, yet this last configuration has a higher overall thermal efficiency because exhaust heat is used for thermal processes instead of being rejected in the condenser. Extracting condensing turbines can have higher installation and maintenance costs due to the condenser and the condenser refrigeration system (e.g. cooling tower).

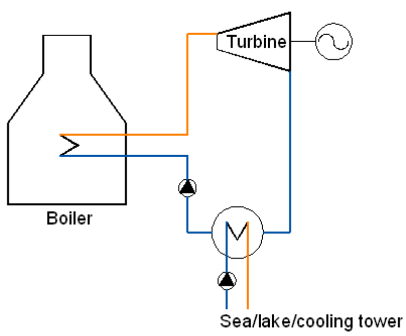

Figure 7.4: Basic layout for an extracting condensing steam turbine system.

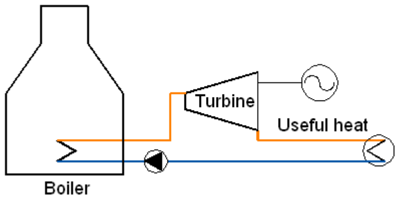

Figure 7.5: Basic layout for an extracting back pressure steam turbine system.

7.5.2 Gas turbines

The basic layout of a gas turbine system can be seen in Figure 7.6. They operate in a similar manner to steam turbines. However, in gas turbine systems, it is the combustion products that expand in the turbine (instead of steam). The turbine also drives a compressor that supplies air to the combustion chamber, where gas or liquid fuels are also fed. Only clean fuels can be used with gas turbines since flying ashes can damage the turbine.

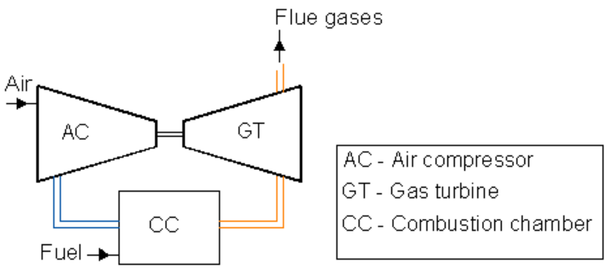

Figure 7.6: Basic layout for a gas turbine system.

7.5.3 Internal combustion engines

Internal combustion engines can have one or more cylinders in which fuel combustion occurs. The engine is connected to the shaft of the generator, providing the mechanical energy to drive the generator to produce electricity.

7.6 System layouts

7.6.1 Energy production flow diagram and system performance

There are two main configurations of energy systems used in industry: systems that only generate heat and plants for combined heat and power production (CHP). Figure 7.7 presents a flow diagram for the possible energy production systems usually applied in industrial facilities.

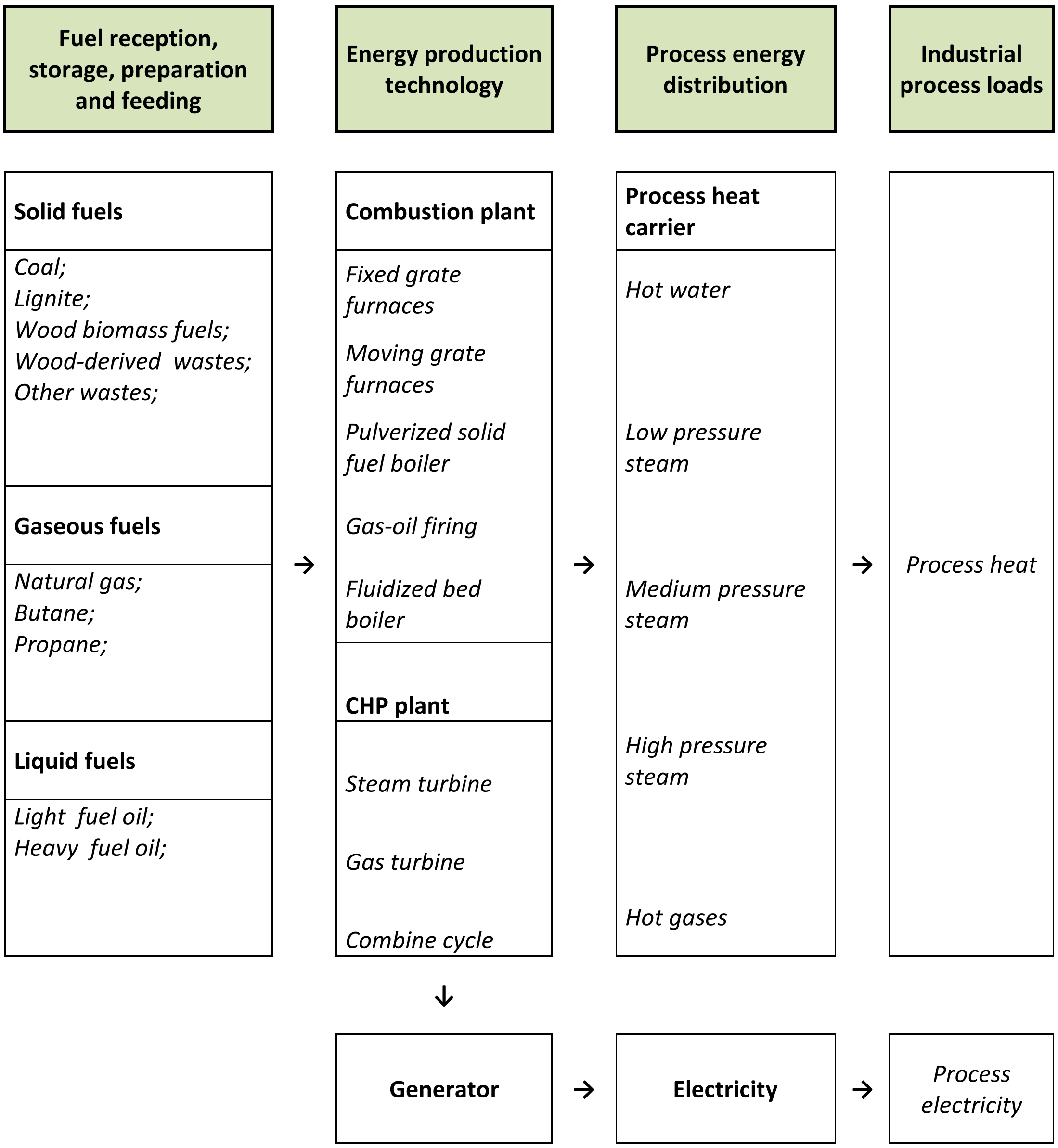

Figure 7.7: Schematic heat production system layout possibilities usually applied in industrial facilities.

Different installations have different energy production systems layouts that mainly depend on the production size, fuels accessibility, process heat loads and the age of the installation. One of the most important parameters to evaluate a given energy production system or to compare energy production systems is the efficiency of energy conversion. The most widely used combustion systems applied in industry have a fuel conversion efficiency above 0.5 and combustion boilers can achieve efficiencies of 0.95. In CHP technology, the overall fuel conversion efficiency depends on the electrical energy output, on the usable heat output, and on the thermal losses within the system. An example of a CHP plant optimized for heat production integrates a combustion boiler for steam production and a back pressure steam turbine for power generation. This system presents a fuel efficiency of 0.8 where usable heat energy output is 60% and power output is 20%. Table 7.1 gives reference values for fuel conversion efficiencies of different energy production systems and the correspondent fraction of power and usable heat output. The temperature for each production system is also indicated.

Table 7.1: Examples of energetic efficiencies of different types of combustion plants [Adapted from European Commission (2006b)].

Energy production system	Usable heat energy output (%)	Electrical energy output (%)	Total energy output (fuel efficiency)
Heat production: heating boiler for space heating (70 ºC)	90	0	0.90
Electricity generation: combined cycle technology (200ºC)	0	55	0.55
Industrial CHP plant: steam boiler + back pressure steam turbine (200ºC)	60	20	0.80
Industrial CHP plant: combined cycle with steam tapping (200ºC)	12	50	0.62
Industrial CHP plant: gas turbine with recovery steam boiler (200ºC)	48	32	0.80
Industrial CHP plant: gas turbine with recovery steam boiler and back pressure steam turbine (200ºC)	45	35	0.80
Small-scale CHP plant: gas engine with heat-exchanger (200ºC)	55	35	0.80

7.6.2 Heat production plant layout

In installations where only heat production units are in operation, there is no on-site electricity generation. Steam boilers are frequently used with different combustion technologies (grate furnaces, pulverized fuel and fluidized bed technologies) and types of fuel. Figure 7.8 illustrates a basic configuration of this type of heat production systems.

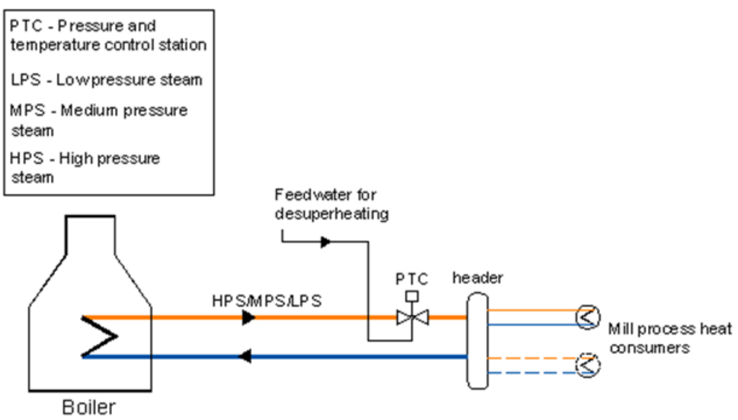

Figure 7.8: Example of basic layout of a heat production plant.

7.6.3 Steam CHP plant layout

In some industrial sectors where both heat and power are needed, CHP units have been frequently installed. Figure 7.9 shows an example of a CHP plant operating with steam turbines often used in the pulp and paper industry. In the figure, option A represents a system with an extracting back pressure turbine while option B represents a system with extracting condensing turbine. Both turbines can be applied in the same CHP.

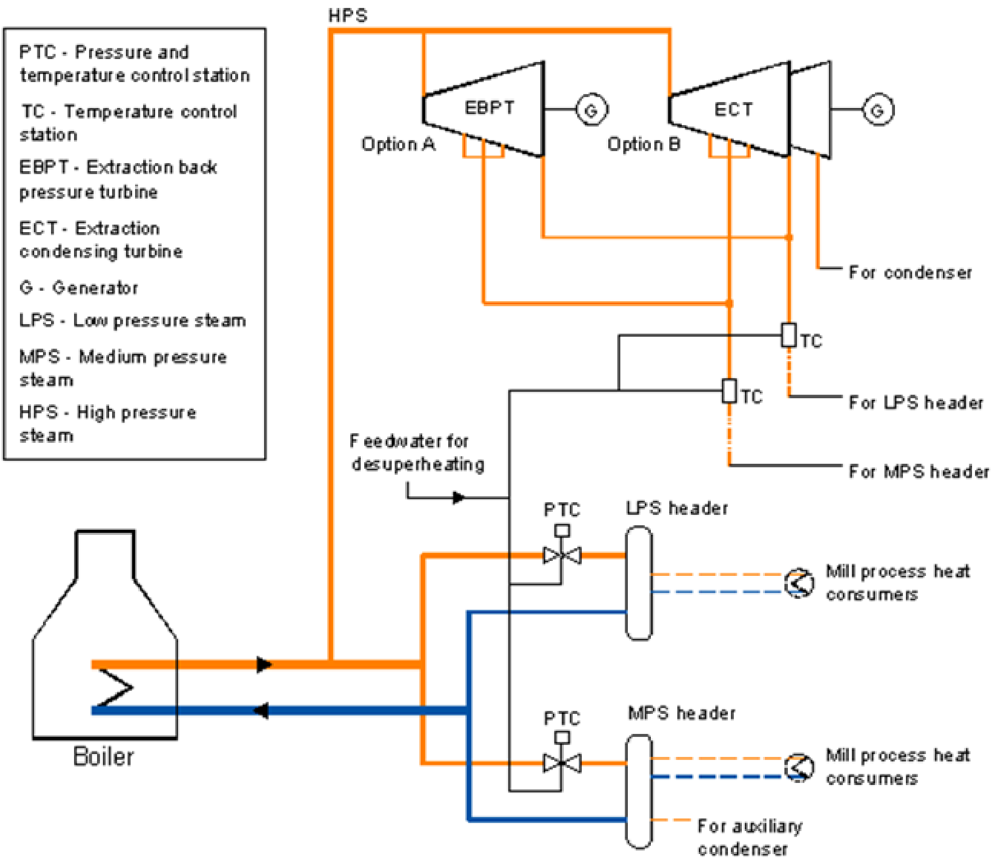

Figure 7.9: Example of basic layout for a steam CHP plant in a pulp and paper mill [Adapted from Suhr et al. (2015)].

7.6.4 Combined cycle CHP plant layout

A particular CHP plant is the combined cycle gas turbine (CCGT) where the hot gases from the gas turbine are recovered to obtain steam that is used to drive a steam turbine. Figure 7.10 shows the basic layout for this type of application.

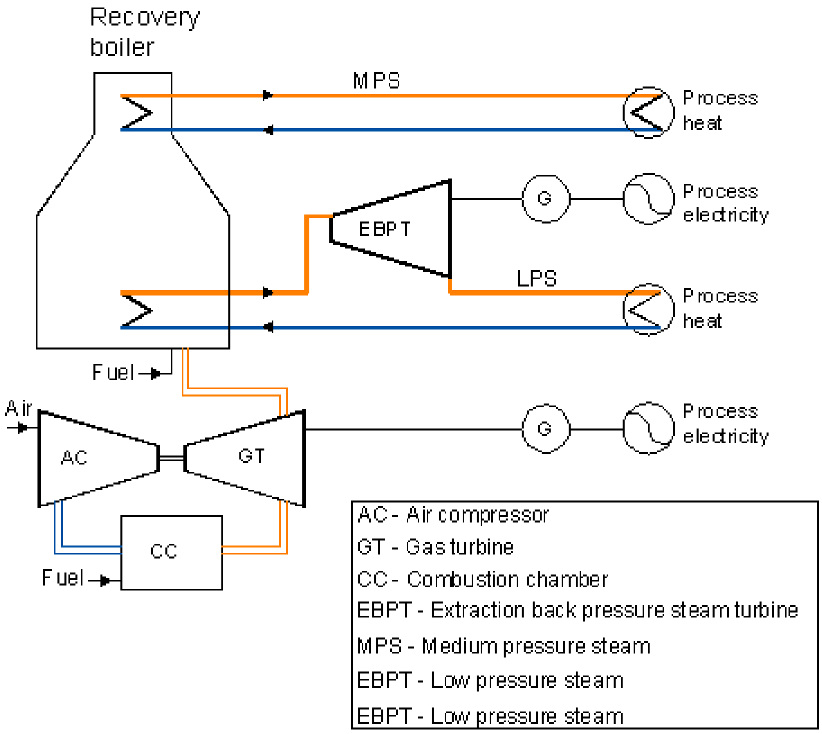

Figure 7.10: Example of basic layout for a combined cycle CHP with a back pressure turbine and a saturated steam circuit [Adapted from Suhr et al. (2015)].

7.7 Other combustion systems

7.7.1 Glass melting furnaces

Glass melting is a combination of complex chemical reactions and physical processes that occur in the glass raw materials (silica sand being the most important) at high temperatures and that result in the production the molten glass. The residence time of the glass melt in the furnace is a fundamental parameter to ensure glass quality and to control process heat consumption. The longer the residence time in the furnace, the higher is the quality of the glass.

The melting technique used in glass production depends on various factors where the most important are: the energy requirements for melting, the glass formulation, the fuel prices, the existing infrastructure and the environmental constraints. As a general guide, the choice of the melting furnace can be based on the criteria indicated in Table 7.2.

Glass production is a highly energy-intensive industry, therefore the melting technique applied, the efficiency of the melting operation and the environmental performance of the system are heavy cost factors for glass facilities planning.

Table 7.2: General criteria for the choice of a glass melting furnace [Adapted from Scalet et al. (2013)].

Production Capacity	Type of furnace
Large capacity (>500 t/day)	- Cross-fired regenerative
Medium capacity (100 to 500 t/day)	- Regenerative end port furnaces - Cross-fired regenerative - Recuperative unit melters - Oxy-fuel melters (less cases) - Electric melters (less cases)
Small capacity (25 to 100 t/day)	- Recuperative unit melters - Regenerative end port furnaces - Electric melters - Oxy-fuel melters (less cases)

7.7.2 Cement kilns

The clinker burning occurs conventionally in a long rotary kiln, where all process heat is consumed. The kiln is fed with the cement raw material that is dried, preheated, calcined and sintered to produce cement clinker. Optimisation techniques led to different system designs where the drying, preheating and calcination processes occur in separated sequential steps. The most used techniques for cement kilns are indicated in Table 7.3.

Table 7.3: Types of kilns for cement production [Schorcht et al. (2013)]

Long rotary kilns	
Rotary kilns with preheater	Grate preheater
	Suspension preheater
	Shaft preheater
	Four stage cyclone preheater
Rotary kilns with preheater and precalciner	
Shaft kilns	

The recovery of waste heat and cogeneration can be applied in cement production facilities. Usually, the majority of the applications are based in the recovery of the heat from the clinker burning on the kiln to drying and dry grinding processes.

Like glass production, cement production is a highly energy-intensive industry, so the kiln system and the environmental control are cost factors that strongly affect the cement facilities planning.

7.7.3 Ceramic kilns

The firing process in ceramic kilns is a key step for the manufacture of ceramic products. The basic purpose of this process is to provide products that have the following properties:

mechanical strength, abrasion resistance, dimensional stability, resistance to water and chemicals and fire resistance.

The most important modifications related to the firing process involve the breakdown of the lattice structure of the original clay minerals, followed by the formation of new crystalline compounds and glassy phases. Vitrification (glass formation) occurs at different temperatures according to the mineralogical compounds of the clay, but usually the temperatures can range from 750 to 1800 °C for the different types of products. The most used techniques for the firing process are: intermittent (periodic) kilns, continuous kilns, clamp firing, rotary kilns and fluidized bed kilns. For more detail information see European Commission (2007).

8 Summary and conclusion

Heat consumption in the industrial sector is relevant for the total energy consumption in EU28, since it represents around 18% of the EU energy consumption. Looking at the energy consumed by the industry in 2012, the share of heating in the final energy demand of the European industry was 71% (60% for process heating and 11% for space heating). This share varies from industrial sector to industrial sector; nevertheless, in the ones that consume the most energy, process heating takes the biggest share of the total energy consumption. These sectors are the iron and steel, chemical and petrochemical, non-metallic minerals and paper and pulp. With the food, beverages and tobacco, these sectors account for more than two thirds of the heat consumed by the EU28 industry.

In EU28, most process heat is delivered at temperatures above 500 °C. The strong contribution for this requirement comes from the industries that consume the most heat: iron and steel, chemical and petrochemical and non-metallic minerals. The pulp and paper and the food, beverage and tobacco industries mostly use heat at temperatures below 200 °C.

The energy carriers most frequently used to satisfy the European demand for process heat are fossil fuels (mainly natural gas, followed by coal). They are used to produce high temperature heat. Biomass is the only renewable energy source with a non-negligible share in process heat generation, generally used to supply heat at low temperatures.

Knowing which sectors consume more heat and the temperature levels to which this process heat is delivered is important to assess the impact of promoting changes in the way energy is used and generated in the European industry. Acting on the sectors that consume the most heat has a higher potential impact; however, when thinking on the promotion of renewable energies in industry, it is also important to look at the temperature requirements, since not all renewable energy sources are capable of delivering heat at high temperatures.

Knowing the geographical distribution of the process heat consumption in EU28 is also important when developing and implementing a financing model for PHES applications. The most important process heat consumers in Europe are: Germany, Italy, the United Kingdom, France and Spain. In these countries, natural gases is the most relevant fuel used.

The non-metallic minerals industries analyzed in section 3 integrate, essentially, the industrial activities related to the manufacture of glass, cement and lime, and ceramic products. The sector is highly energy-intensive, particularly in process heat consumption for temperature levels above 1000 °C. Heating processes occur in specific combustion systems such as glass melting furnaces, kilns for cement clinker production and ovens or kilns for ceramic manufacture. Energy requirements and specific energy consumptions related to heat-intensive processes are given for possible, future energy analyses. The main energy sources used for process heat production in the non-metallic minerals sector are natural gas, fuel oil and electricity. In cement industry, waste fuels have a relevant contribution in the overall energy consumption.

In the pulp and paper industry, 95% of the process heat demand is for processes with a temperature level below 200 °C. The heat-intensive processes are related to drying operations. Energy demand is one of the major production factors in the pulp and paper industry due to its high contribution in the total production costs. The sector produces practically all the required heat and half of the electricity demand in their energy production plants. Biomass is the main energy source for energy production, representing 58% of the total fuel consumption. Gaseous fuels, mainly natural gas, are the second most-widely used type of fuels in the paper and pulp sector. Fuel oil and coal also have relevant contributions on fuel consumption.

In 2010, food and drinks (and tobacco) manufacturing consumed 29 million tonnes of oil equivalents of final energy in EU27 countries, which represented a 10% share of the total energy consumed by the EU27 industry and the fourth industrial sector in energy demand in EU. The food and drink processing industry accounted for 0.9% of total EU15 GHG emissions in 2012. The food and drink industry is a highly diversified sector with many companies of different sizes. 99.1% of the food and drink companies are SMEs. The top 5 sectors (bakery and farinaceous products, meat sector, dairy products, drinks and "various food products" category) represent three quarters of the total turnover and more than 80% of the total number of employees and companies. Energy consumption patterns of main food industry sector have been described.

The basic heat system layout used in the food industry is a steam system made up of four components: the boiler, the distribution system (steam and condensate network), the consumer (i.e. plant/process using the steam/heat) and the condensate recovery system. Natural gas, diesel, light fuel oil are the most conventional fuels, but also biomass and biogas produced from residual biowaste or wastewater can be used.

The wood and wood products industries analyzed in section 6 integrate the industrial activities related to the manufacture wood-based panels and pellets. The production of wood-based panels is intensive in terms of energy demand. Most of the energy consumed in the manufacture of all types of panels is in the form of heat, being drying the most heat-intensive process (and also the most power-intensive process). The heat production occurs mainly in combustion boilers. The main fuels used are wood residues obtained from internal and external sources. Other fuels are also used such as fossil fuels and renewable energy sources other than wood-derived biomass.

In the pellets production industry, process heat demand is mostly used for the drying process of the primary raw material. It represents around 85% of the total energy consumption in a pellets production facility. Heat production in this industrial sub-sector occurs mainly in combustion boilers and the main fuels used are wood-derived residues and pellets obtained from internal sources. Other fuels are also used such as solid fossil fuels acquired from external sources.

The different industrial sectors are very diverse and consume energy in many distinct industrial processes and energy conversion technologies. Heat delivered at high temperatures is provided by industrial furnaces; for delivering heat at lower temperatures, the European industry mainly uses steam boilers and CHP units. Heat production plants can achieve efficiencies of up to 0.95, while electricity generation plants 0.55. In a CHP unit, the overall fuel efficiency can reach values of up to 0.8. Cogeneration systems can be optimised for satisfying heat or power requirements. At present, CHP systems are considered the most efficient for intensive energy driven industrial sectors. The major part of heat and power produced by industrial facilities is consumed on site. In some industries (e.g. pulp and paper), some industrial units generate excess power and sell it to the grid.

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