# European heat demand till 2050

## Master's Thesis

In partial fulfilment of the requirements for the degree
Master of Science in Mechanical Engineering
At the Department of Electrical and Computer Engineering
of the Technical University of Munich.

| | |
|---|---|
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| **Submitted on** | Munich, 30.09.2021 |

# Abstract

Changes on the structure of the energy carriers on the heat sector, which are nowadays mostly covered by fossil fuels, will be needed in the future. Knowing the heat demand it is possible to optimise how it will be produced, considering the optimisation of the cost of the energy system and at the same time limiting the CO2 emissions.

For this reason, it is crucial to forecast the heat demand in Europe by country and NUTS2 region, with the aim of doing a robust analysis of the future possible technologies that will suit the heat demand profile in Europe 2050. This will be done by means of an energy demand model focused on the whole industry sector, obtaining data of each industry sub-sector by NUTS2 resolution [1]. To assure the consistency of the data, a validation of the data with other national and European studies will be also done.

The model used to forecast the data is called *endemo* (Energy Demand Modelling) [2], which calculates not only the heat demand in Europe 2050 by NUTS2 but also the electricity and hydrogen demand. Once these useful energy demands are obtained, it is possible to do the coupling of these systems in Europe. This will be done in the optimisation tool *urbs* [3], generating a realistic future scenario that will help us to achieve the high goals of green gas emission reduction and keep the costs of our energy system realistic. The last aim of my project will be to select the most suitable and sustainable technologies for the future as well as to determine the end energy demands, depending on the analysis done in *urbs* and my forecasted data from *endemo*.

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Hereby confirm that the attached thesis,

**European heat demand till 2050**

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# List of Abbreviations

**CTS** Commercial, trade and services

**HP** Heat pumps

**LTRS** Long-term renovation strategy

**NUTS** Nomenclature of Territorial Units for Statistics

**O&M** Operations and Maintenance

**PV** Photovoltaic

# List of Tables

# 1. Introduction

## 1.1. Context and purpose of the thesis

With the European Green Deal, Europe has set itself the long-term goal of achieving greenhouse gas neutrality by the middle of the century and thus limiting climate change by cutting the greenhouse gas emissions by at least 55% by 2030. These measures not only aim to reduce greenhouse gas emissions, but also to adapt to the current and future impacts of climate change. As a major goal, Europe aims to be a climate-resilient society by 2050 while simultaneously being the world's first climate-neutral continent [4].

In addition to this, Germany, together with the Climate Action Plan 2050, has its own ambitious targets. Of central importance is the transformation of the energy industry, whose sector-specific emissions are to be reduced by 62% by 2030 compared to the reference year 1990 [5]. The steady expansion of renewable energies and the successive decarbonisation of electricity generation through the avoidance of around 203 million tonnes of CO2 equivalents in 2019 contribute significantly to achieving the climate protection goals. Overall, the share of renewable sources on the gross electricity consumption rose by 4,3 % compared to the previous year's value and amounts to 42,1 % (244 TWh), which means that for the first time more renewable electricity was generated than in all lignite and hard coal power plants combined [6].

Despite the environmental compatibility, one of the greatest challenges is simultaneous economic viability and security of supply. To achieve this, energy system models are of paramount importance to provide a realistic prediction and to be certain of which technologies are best suited to meet the above-mentioned objectives. Hence, the modelling of the energy demand is indispensable to ensure the successful development of the future energy systems. This expansion is highly dependent on the demand for heat and electricity and foreseeably for hydrogen, which is becoming increasingly important. Therefore, to make precise statements about possible scenarios for energy generation, it is necessary to forecast these demands and the associated technologies that cover them and compose the energy system.

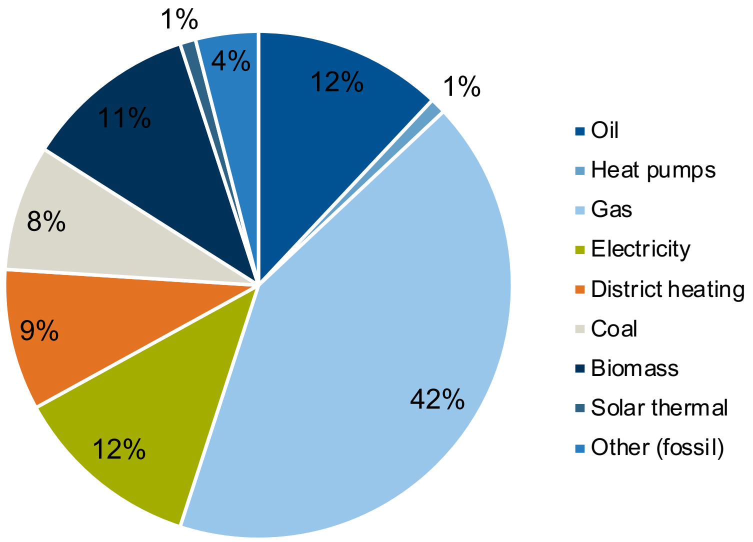


**Figure 1: Heating and cooling final energy by energy carrier in 2015 (EU-28) [7].**

Figure 1 shows the key to Europe's development towards a sustainable low-carbon future. Of the thermal energy, 66% was produced from fossil fuels and a much lower percentage, around 13%, came from renewable energies [7]. Thus, developing heat-focused demand models plays a significant role in improving energy systems.

## 1.2. Objectives

Having set the main objective of forecasting the heat demand in Europe in 2050, a geographical distribution of the energy demand with focus on industry sector in Europe on NUTS2 level has been modeled. The quality of the results is guaranteed by means of a verification of the data with national and European studies. To obtain the most cost optimal technologies a sector coupling to meet the end energy demand in 2050 was carried out.

Chapter 2 first describes the establishment of databanks, which will serve not only to further validate the results obtained, but also to gain some sensitivity as to what values should be derived from the prediction. The research is based both on European studies and on national guidelines specific to each European country. The creation of these databanks will provide the energy demand trends as well as the consumption and CO2 emissions limits that will be of utmost utility to restrict the following results of the predicted energy demand. The research on the industrial sector is outlined which will be necessary for the subsequent demand modelling and which consequently describes the focus of the project. The research concentrates on the location and capacity of all major industrial sub-sectors all over

Europe, which creates an overview of the future distribution and production of industry in 2050.

Chapter 3 describes the methodology divided in two main sections, first the forecast of the heat demand in Europe 2050 using the *endemo* model and afterwards the coupling of the different types of demand in *urbs*. *Endemo* is a current project of the Chair of Renewable and Sustainable Energy Systems (ENS) at the Technical University of Munich. This energy demand model links all types of sub-sectors, i.e., households, commercial, trade and services (CTS), industry and traffic in the different countries of Europe to finally obtain a forecast of the European energy demand for each year till 2050. The model provides not only the energy demand in Europe 2050 but also disaggregates it into heat, electricity and hydrogen demands by NUTS2 resolution. In particular, the extension of the model should be highlighted, which is based on a new distribution of demand by NUTS2 based on industrial capacities.

Once the useful energy demands are obtained from *endemo*, it is possible to perform the coupling of heat, electricity and hydrogen demands in Europe. It should be noted that due to the large size of the model, only Germany and its neighbouring countries will be considered. The coupling will be done in *urbs*, which is a linear programming optimization model which finds the minimum cost energy system to satisfy the demand. As a result, the end energy demands are obtained, as well as a predicted use of technologies that will be more feasible and sustainable in the future, based on the prognosed data from the *endemo* model and the coupling of the energy system in *urbs*.

The outcome of both models is shown in chapter 4, where the results both from the heat demand forecast provided from *endemo* will be compared with different European studies as well as the sector coupling from *urbs*, which both are verified with the previously created databanks. Finally, the conclusions and outlook of the project as well as further research are collected in chapter 5. These conclusions will help to improve the model and to be able to create forecasted energy systems, as an important tool to achieve the environmental targets.

# 2. State of the art

## 2.1. European and national studies guidelines

The decarbonisation of the energy system in Europe is certainly a long-term objective, even though it is unclear how the heat demand profile will develop in the future [8]. Hence, it is crucial to forecast the heat demand in Europe.

The research of validation data is based on two main lines, the research of the European studies and the guidelines of the national studies from different European countries, which have been carried out in parallel. The intention of the research of these databanks is to be able to know the direction of the development of the heat sector in the future. In addition, it is possible to make a comparison between the results obtained with the *endemo* model in the industry sector as well as the data on energy demand through the coupling in urbs with the data found from these studies. At the same time, these reference data is useful to calculate how the results are spread between the different studies.

### 2.1.1. Databanks on European forecasting studies

The studies conducted by the European Commission on mapping and analyses of the current and future heating/cooling fuel deployment [9] and by the HRE4 Project on the aggregated heating and cooling baseline [10], show a clear common trend on the industrial heat demand for each EU-28 country in different future years from nowadays till 2050 (Figure 2). Those are of ultimate importance to assure that the forecasted results from *endemo* are consistent. In general, a trend towards a reduction in heat demand can be observed in almost all countries, which is in line with European plans to limit consumption and thus greenhouse gas emissions.

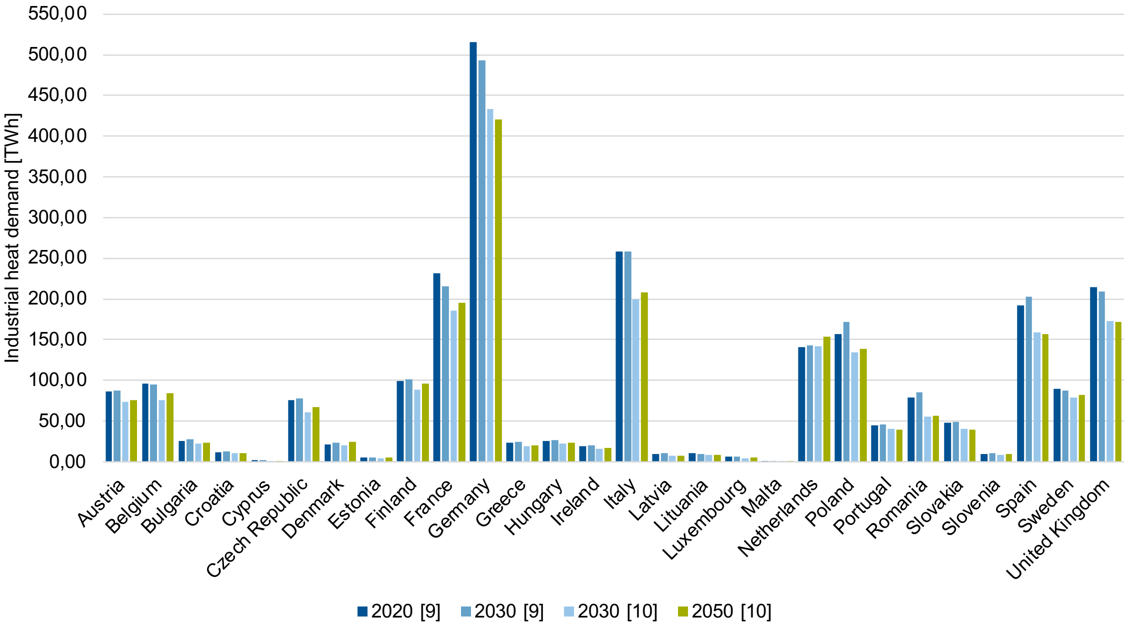


**Figure 2: Comparison of European studies representing the forecasted industrial heat demand in Europe, based on [9, 10].**

The databanks found are formed not only by forecasted heat demand data for the industry sector but also forecasted heat demand for each country, within all sectors that are heat demand users (households, CTS, and industry). It should be noted that the transport sector is not included in the studies as it does not have a heat demand. This latter case will be used to validate the whole country results once the forecast from the model is obtained from *urbs*. The following figure contains studies for different years representing the evolution of the heat demand in Austria until 2050 (Figure 3) conducted by Eurostat [11] and the national statistical institute of Austria [12] for the values corresponding to 2019, as well as the study of EU Energy, transport and GHG emissions including the trends to 2050 [13].

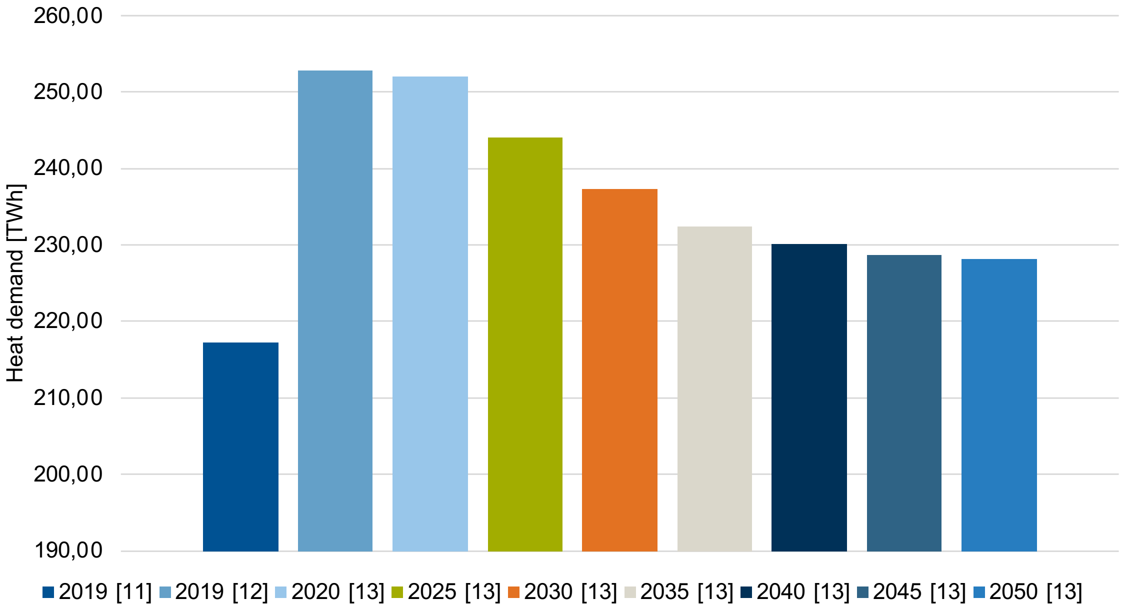


**Figure 3: Evolution of the heat demand in Austria till 2050, based on [11, 12, 13].**

It is important to note that the value from Eurostat has been calculated using the final consumption (energy use) minus the final consumption (energy use) for electricity [11]. This value was compared for the same year (2019) using the national values of the Austrian statistical institute [12], with the resulting heat demand being higher than Eurostat. This trend is observed for all countries, where the Eurostat values are lower than those provided by the national institutes.The trends for all countries for heat demand, heat demand in industry and heat demand due to heat and cooling (H&C) have been collected through different studies in a databank shown in Annex A.

The following table collects a summary of the studies used for the creation of the databank (Table 1). The studies and national statistical data shown have been collected to create a databank that is of great help in constraining the results of subsequent forecasting and modelling. The data included consists of national statistical data, international studies approved by the European Commission, as well as unpublished parts of these, which have been obtained by directly contacting such projects, e.g., HRE4 Heat Road Map.

| Source | Forecasted year | Type of data |
|---|---|---|
| European Commission: Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (2017) [9]. | 2020 and 2030 | Heat for industry sector [TWh] |
| HRE4 Project: Aggregated heating and cooling baseline HRE4 (2015) [10]. | 2030 and 2050 | |
| EU Energy, transport and GHG emissions: Trends to 2050 in Appendix 2: Summary energy (2015) [13]. | 2020 to 2050 (each 5 years) | Heat [TWh] |
| Eurostat: complete energy balances (2021) [11]. | 2019 | |
| EU Commission: Useful energy demand by country by end-use in 2030 [TWh] [14]. | 2030 | Heat for H&C [TWh] |
| Aggregated heating and cooling baseline HRE4: Total heating/cooling delivered [10]. | 2030 and 2050 | |

**Table 1: Collection of databases for different years and types of heat [9-11, 13-14].**

On the one hand, studies focusing only on the industrial sector are contrasted with the heat demand forecast for 2050 by NUTS2 obtained from *endemo*. On the other hand, those studies covering all sectors and demand types are compared with the results after modelling and sector coupling in *urbs*.

### 2.1.2. Energy efficiency guidelines from each country

Furthermore, a validation using national energy efficiency guidelines for each European country will be carried out. These guidelines offer targets for all European countries for years 2030 and 2050, encouraged by the European Commission. The CO2 and energy demand limits gathered there represent the goals of energy efficiency that each country must assure in the future. Thus, the results obtained in the model should meet the requirements to be realistic.

Following the same example as for the European studies, the table shows the limits set by Austria based on the national energy efficiency plan and the long-term renovation strategy (LTRS) (Table 2 and 3) [15,16]. The values are converted into [TWh], for a better comparison with other studies and results.

| **National contribution for energy efficiency** | **Target 2030 – 25% improvement** | **Target 2030 – 30% improvement** |
|---|---|---|
| Primary energy consumption | 28,712 Mtoe | 30,763 Mtoe |
| Primary energy consumption | 333,92 TWh | 357,773 TWh |
| Final energy consumption | 23,925 Mtoe | 25,634 Mtoe |
| Final energy consumption | 278,247 TWh | 298,123 TWh |

**Table 2: Energy consumption target for Austria 2030 [15].**

| **Long term renovation strategy (LTRS)** | **2030** | **2040** | **2050** |
|---|---|---|---|
| Total | 220,148 TJ | 219,241 TJ | 218,335 TJ |
| Total | 61,152 TWh | 60,900 TWh | 60,648 TWh |

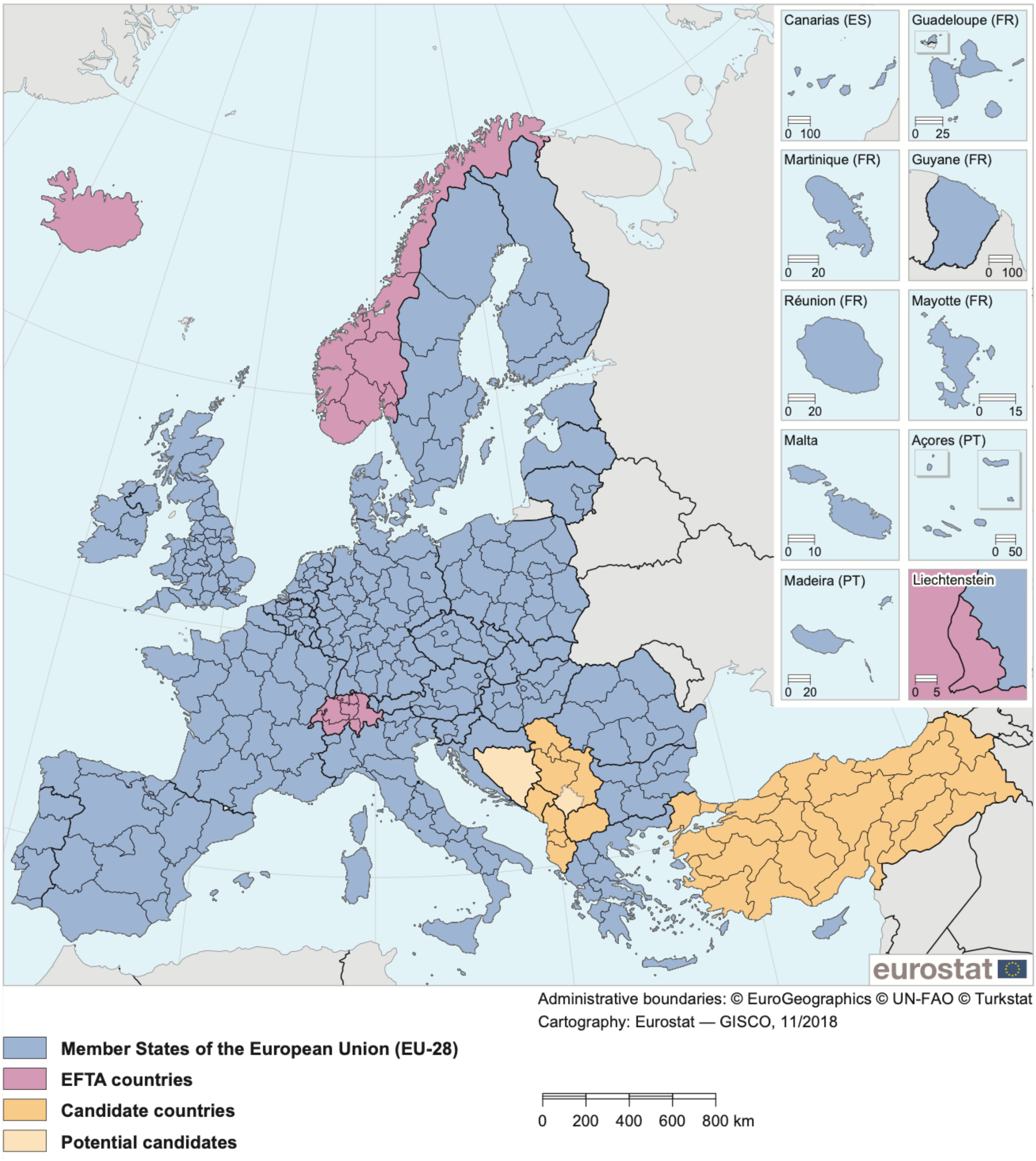
**Table 3: Total energy share for Austria till 2050 [16].**

Due to the ambitious climate targets of the Paris Climate Agreement of a maximum global warming of 2 ºC [17], all European countries have such plans and similar limits. These values are further parameters to check that the project results are realistic.

## 2.2. Industrial sector

Further research of the current industrial sector is needed to know its heat demand distribution per sub-sector. Out of the three main sectors that are heat demand users, which are households, CTS and industry, the work was focused on the research for an implementation of the industrial sector. This research into industry is of paramount importance because households and CTS are mainly dependent on the population but for industry a different approach was needed. The focus is based on other parameters on installed capacities or excess heat, as well as the location of all major industries in Europe.

In order to precisely locate the actual industry, a NUTS2 resolution has been used according to the Nomenclature of Territorial Units for Statistics (NUTS). This classification was developed by Eurostat to facilitate a decomposition of the European Union's economic territory into territorial units to produce regional guidelines as well as statistics [18]. The EU-28 countries and their NUTS2 areas are shown in Figure 4.



Administrative boundaries: © EuroGeographics © UN-FAO © Turkstat
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**Figure 4: NUTS 2 regions in the European Union (EU-28), with corresponding statistical regions in EFTA countries, candidate countries and potential candidates [1].**

The NUTS resolution guarantees harmonised standards in regional data collection and transmission, in addition to being officially restructured and updated approximately every 3 years, reflecting changes in each country. This classification is broken down into three levels, NUTS1, NUTS2 and NUTS3, those mentioned in growing resolution. As it is shown in Table 4 as an example of how the subdivisions in Germany, Spain Czechia and Italy are made.

| **NUTS level** | **Germany** | **Spain** | **Czechia** | **Italy** |
|---|---|---|---|---|
| NUTS1 | Bundesländer | Non-administrative aggregations | Území | Non-administrative aggregations |
| NUTS2 | Regierungsbezirke (Non-administrative aggregations) | Comunidades autónomas | Regiony soudržnosti (Non-administrative aggregations) | Regioni |
| NUTS3 | Kreise und Kreisfreie Städte | Provincias | Kraje | Province |

**Table 4: Examples of administrative and non-administrative units being designated as NUTS regions [12].**

A resolution of NUTS2 level is considered sufficient and adequate to precisely locate the largest industrial production sites in Europe. It should be noted that obtaining data with a fine resolution is important for the industrial sector, as industrial production is not evenly distributed in each country. Therefore, it is necessary to find the industrial clusters located in a certain region and subsequently associate the production data to that region. Each region of each country has an identifier according to NUTS2 resolution. The procedure was based on locating the large industries in each country, then determining in which region exactly they were located and finally linking this region with its corresponding NUTS2 identifier.

The data needed to implement this approach in the model was mainly to find the location by NUTS2 of the leading factories of each sub-sector and at the same time their installed capacities [‘000 tonnes/year]. In most cases the data collection was possible from international associations for each type of sub-sector. This procedure was performed for all main sub-sectors, such as steel, aluminium, paper, organic and non-organic chemicals, refineries, glass, and cement. As can be seen in the case of steel (Figure 5 and Table 5), the map with the production sites and the capacity of each site [19].

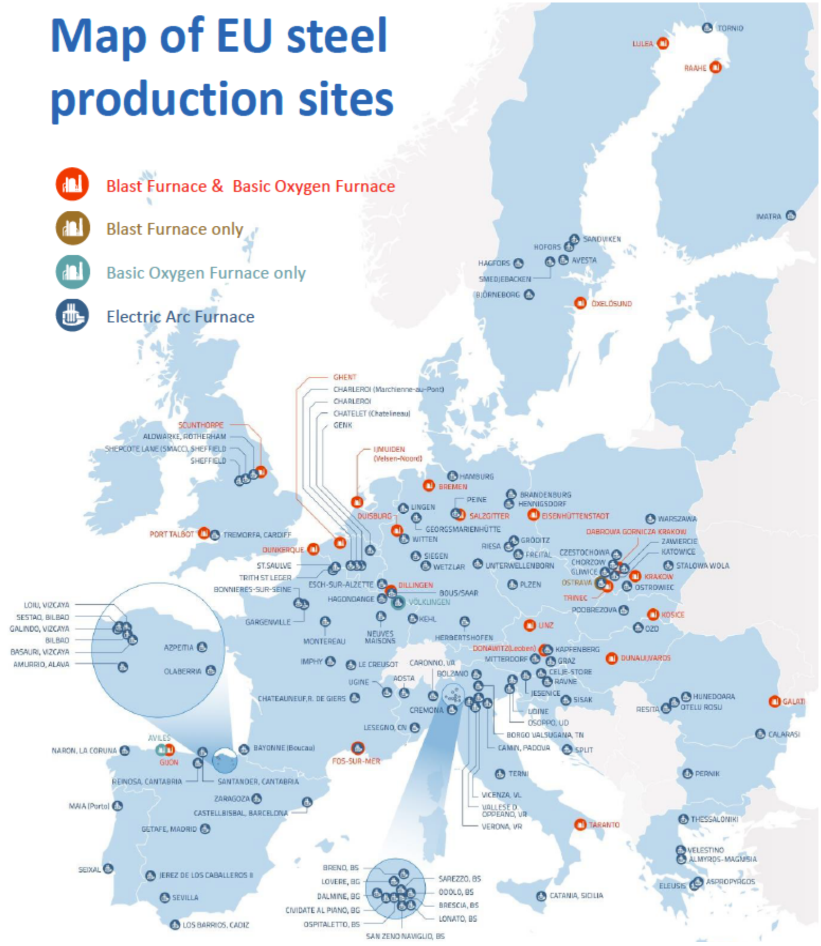

**Figure 5: Map of EU steel production sites and capacities [19].**

| **Location** | **Capacity ['000 tonnes / year]** |
|---|---|
| Graz | 365 |
| Kapfenberg | 180 |
| Mitterdorf | 300 |
| Charleroi | 1.200 |
| Chatelet | 1.000 |
| Genk | 1.200 |
| Pernik | 1.000 |

**Table 5: Capacities of the EU steel production for Austria, Belgium, and Bulgaria [19].**

This information is not available for all types of sub-sectors. In sub-sectors where no official data was provided, a database has been used to estimate the distribution based on the amount of industrial excess heat and fuel combustion per year, both in [TJ/a] [20]. This dataset is divided into 6 industrial sub-sectors, e.g., chemical industry or iron and steel.

Furthermore, the 1.842 industrial sites in EU-28 that the data contains, are georeferenced and listed per NUTS2 region. Thus, both excess heat and fuel demand parameters can be used for the distribution of heat demand in the NUTS2 regions indicated in the database. This is the case for the paper and printing industries as well as for glass and cement.

The quantified annual excess heat per unit of produced material can be expected the same within industrial sub-sector. Hence, the specific excess heat depends proportionally on the production and therefore on the energy consumption. For both parameters, there are two scenarios proposed, at current and maximal of internal heat recovery. Current rate of internal heat recovery was chosen for the study, as actual and not maximum data were used for all other sub-sectors with official data available. Moreover, a distinction is also made between three cooling temperature levels: Level 1: 25ºC, Level 2: 55ºC and Level 3: 95ºC. The last level was chosen for the study as being more similar to the processes that occur in such industries.

This research gives a clear picture of which NUTS2 region has the highest industrial production and therefore the highest heat demand. On the one hand, according to their capacities, and on the other hand, depending on the excess heat or fuel demand. This leads to an accurate distribution of the heat demand coming from industry in Europe that is further explained in section 3.1. All the main industrial sites as their capacities or excess heat together with fuel demand in each sub-sector were collected in an Excel sheet as input for further modelling, collected in Annex C.

# 3. Methodology

## 3.1. Implementation of the heat distribution in *endemo* model

The starting point for demand forecasting through the endemo model was a population-based approach. This focus was developed by ENS and involves distributing heat, electricity, and hydrogen according to the current population distribution to obtain a first approximation of the demand derivation per NUTS2. The *endemo* model works with data input as Excel sheets and through a linear regression the forecast of the energy demand for 2050 is obtained as an output (Figure 6).

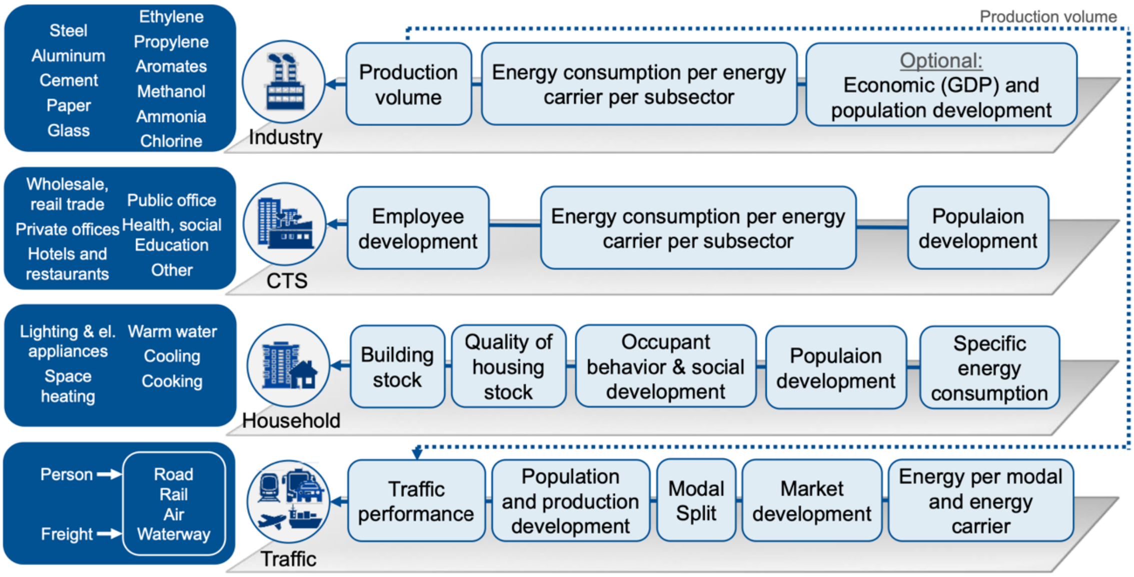

**Figure 6: Exemplary overview of the developed overall method of energy demand modelling [3].**

The population-based approach is accurate and reliable for households, as the energy profile is determined by where the population is located and therefore the consumers. In the case of CTS [21], a detailed study was carried out on the number of employees in each sub-sector of the service sector such as agriculture, tourism and hospitality, leisure and culture, media, and finance among others. The result was the distribution of the annual energy demand according to this criterion, the number of thousands of employees.

In terms of industry, the population-based approach was not sufficiently accurate, as many industries are far away from population centers or have limited employees due to the technological automation that is occurring nowadays. Thus, a new approach based on the industry's current production is necessary and has been the major focus of this part of the project.

### 3.1.1. Distribution of the energy demand by industrial capacities

Once the collection of data on the current location and capacity of the most important industries in Europe was completed, the implementation of this databank in the above mentioned *endemo* model was carried out. It should be noted that the certainty of this approach is due to the fact that the forecast is made for the year 2050 and in less than 30 years the industry does not radically change its position or its production. Industries that are known to be closed in the coming years have been removed from the databank.

The implementation of the industry capacities was done in the output of the model (Figure 7). In section 2.2 it was explained how the data on the distribution of the industry has been collected in an Excel sheet as input. The forecasted heat demand data obtained as an output from the model is distributed in proportion to the installed capacities of the factories and in the regions where the factories are.

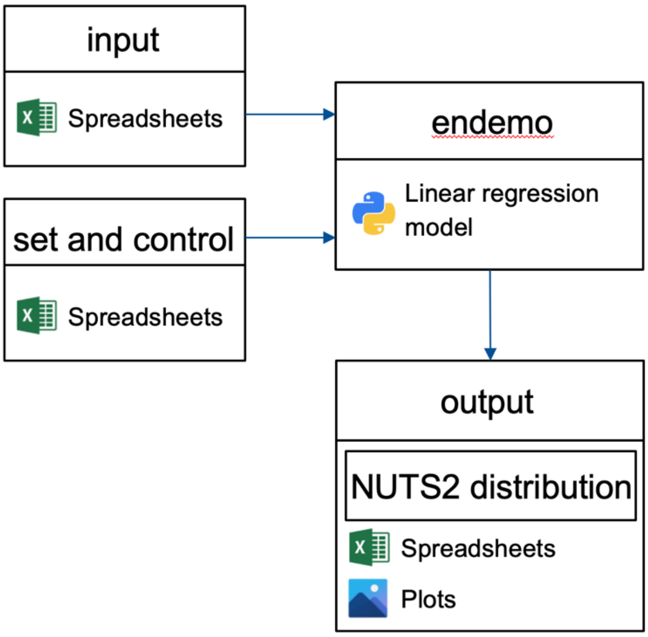

**Figure 7: Scheme on the implementation of the industry approach in *endemo*.**

The model generates heat, electricity and hydrogen demands for 2050 distributed spatially at the level of NUTS2 region depending on the industry's input of the actual distribution. In the last step, the forecast annual consumption [TWh] is then distributed over the 8760 hours of the forecasted year on an hourly basis.

## 3.2. Sector-coupling in *urbs*

The coupling of heat, electricity, and hydrogen useful demands is possible using *urbs*, a linear optimisation tool developed by ENS at the TUM. The model is focused on the optimisation of urban energy systems, through the insertion of technical and economic parameters, results in the minimum cost energy system for a territory, where the scale can vary from a neighbourhood to a continent [3]. Thus, it could be developed for whole Europe, but due to the large dimensions of the model, it has been carried out only for Germany and its neighbouring countries, i.e., Austria, Belgium, Czech Republic, Denmark, France, Luxembourg, the Netherlands, Poland, and Switzerland.

The operation on hourly-spaced time steps is configurable and provides a more accurate prediction. Due to the complexity of the model, the simulation has been performed for a quarter of a year, being 2160 hours for the year 2050.

### 3.2.1. Modelling of different energy sources

The modelling starts by defining the territory to be considered, which in this case has 10 different ones, one for each country denoted by its abbreviation (e.g., Austria as AUT). Associated to the territory, the model allows configuring the transmission of electricity, heat, and hydrogen between them. Heat transmission between countries is considered to be non-existent, but values are given for hydrogen pipelines and AC and DC electricity transmissions.

*Urbs* finds the minimum cost energy system to satisfy given demand time series for multiple commodities (e.g., heat). The hourly demand for each country is obtained from the output of the *endemo* model and implemented in *urbs* for electricity, hydrogen, and heat defined depending on the following levels:

- Heat Q1: output temperature under 60ºC.
- Heat Q2: output temperature between 60 and 100ºC.
- Heat Q3: output temperature between 100 and 200ºC.
- Heat Q4: output temperature above 200ºC.

As *urbs* is a model for multi-commodity energy systems, they will be defined for each country. The classification of commodities depends on the availability of the source, which are divided into stock, intermediate supply, demand, environment, and buy/sell commodities.

The model finds the optimal combination of these commodities to ensure the minimum cost of the energy system and to meet the demand. Hence, the cost associated with each commodity as well as its maximum limit are significant and should be well defined for the operation and extension of the power plants, detailed in section 3.2.1.2.

Each commodity is linked to a process, which acts identically in all countries. This assumption was made due to the complexity of the model and considering that the differences between these processes in Europe today are minimal. The process is determined in the system through the following parameters: the current installed capacity, investment cost, fixed and variable costs, the weighted average cost of capital and the depreciation period of each power plant in the energy system. Furthermore, these processes and commodities are linked by current efficiencies. For a process, it is established which commodities are needed as input and which are obtained as output, considering the conversion ratio between them.

The storage considered in *urbs* will be limited to electricity and hydrogen, as heat storage is assumed to be unprofitable. For electricity two technologies are taken into account, pumped storage and batteries, where the latter has a current installed capacity of zero. As for hydrogen, it is stored in hydrogen pipelines.

Parameters such as the amount of CO2 emissions can be limited, in order to limit some technologies to ensure the sustainability of the system as well as to test further possible scenarios. The global CO2 limit proposed for the European Environment Agency (EEA) is for 2050 is 418 million tons of CO2 equivalent and it can be seen in Figure 8 [22]. The value used in *urbs* must be proportional to the number of hours of the simulation, corresponding to one year (8760 hours) the value mentioned above.

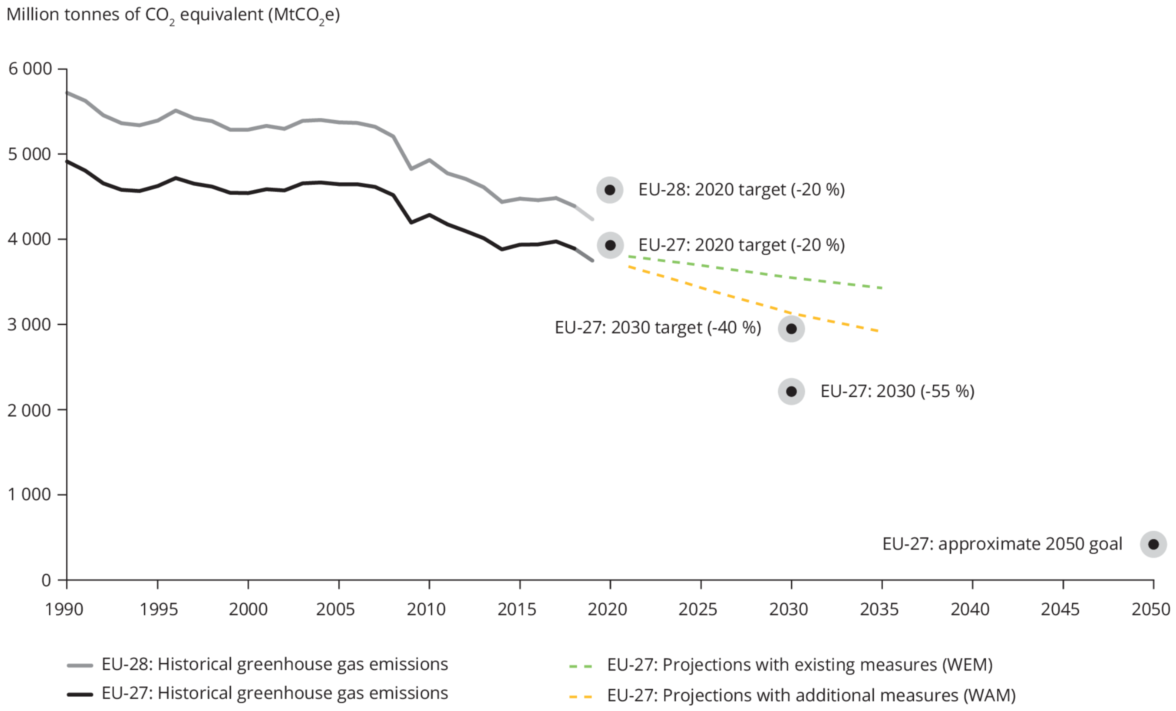

**Figure 8: Greenhouse gas emission targets, trends, and Member States MMR projections in the EU, 1990-2050 [22].**

It’s important to note that CO2 prices have been taken into account by rising the prices of fuels, this assumption has been taken from the ENS Chair and provided by M. Sc. Julia Gawlick [23].

#### 3.2.1.1. Input data collection

The input data for the *urbs* model regarding the heat, electricity and hydrogen demands was used from the *endemo* model. The input data for technologies covering electricity and hydrogen was provided by M. Sc. Julia Gawlick, from the ENS Chair. Also, the storage, transmission and necessary data for the intermittent supply sources was delivered from the same source [23]. The focus of this project has been to extend the model by completing the processes associated with heat coverage.

For the definition of commodities, the four levels of heat have been added as demand (heat Q1 to Q4), in addition to the resources that generate heat, mainly boilers. The fuel that feeds the boiler varies depending on the technology, with the main heat generators being natural gas, gasoil, coal, LPG (liquified petroleum gras), biomass, hydrogen, and air. All of them have been added for all countries, as in Europe the use of these technologies is equivalent. As explained in section 3.2.1, these commodities belong to the Stock category.

In determining which processes are involved in heat generation, the current installed capacity [MW] of each technology for the different heat levels has been taken into account. No upper limitation on installed capacities was made due to lack of availability of the information.

In addition, the efficiencies corresponding to each process with the required commodities have been collected. The efficiencies of most of the technologies are listed in Table 6 [24]. A detailed description of each process is given below.

| **System** | **Efficiency** | **CO2 emission per kWh of fuel [kgCO2/kWh]** |
|---|---|---|
| Coal boiler | 0,70 | 0,34 |
| Gasoil boiler | 0,80 | 0,28 |
| LPG boiler | 0,80 | 0,25 |
| Gas boiler | 0,80 | 0,19 |
| Heat pump | 3,20 | 0 |

**Table 6: Efficiencies and CO2 emissions for different primary energy sources [24].**

## Gas boiler

The process of a gas boiler for heat production takes place by introducing the natural gas commodity and obtaining heat and CO2 as output. The efficiency and CO2 emissions are listed in Table 2. Boilers vary in size and purpose, so that a gas boiler can have an outlet temperature of 50ºC as well as an industrial boiler can reach 240ºC [25]. Therefore, the process linked to the 4 types of heat must be considered. Since there is a lack of accurate studies on the number of gas boilers of each heat level, the total installed capacity has been distributed equally among the 4 levels. The total installed capacity for each country is shown in Table 7 [26].

| **Country** | **Total [MW]** |
|---|---|
| Austria | 930,922 |
| Belgium | 2.679,471 |
| Czech Republic | 1.365,277 |
| Denmark | 427,800 |
| France | 9.370,890 |
| Germany | 13.100,000 |
| Luxembourg | 65,033 |
| Netherlands | 6.394,080 |
| Poland | 1.213,872 |
| Switzerland | 256,820 |

**Table 7: Stock of natural gas boilers in the EU-28 and Switzerland in 2015 [26].**

## Gasoil boiler

Similar to natural gas, the process of gasoil boilers is based on an input of this fuel and consequently an output of CO2 and heat. The efficiency and CO2 emissions are also gathered in Table 2. For these boilers the temperatures vary as with natural gas boilers [27], which means that the total installed capacity (Table 8) [28] will be divided between the 4 types of heat, as explained above.

| Country | Total [MW] |
|---|---|
| Austria | 700,848 |
| Belgium | 1.697,927 |
| Czech Republic | 7,744 |
| Denmark | 328,440 |
| France | 4.210,110 |
| Germany | 6.000,000 |
| Luxembourg | 63,767 |
| Netherlands | 5,472 |
| Poland | 605,120 |
| Switzerland | 831,939 |

**Table 8: Stock of gasoil boilers in the EU-28 and Switzerland in 2015 [28].**

## Coal boiler

For the coal boilers, an input of coal is needed to extract heat and CO2 with the which has an efficiency and CO2 emissions as shown in Table 2. For coal boilers the temperature is usually between 120-160°C, although the flue gas before cooling has around 225°C. If the boiler has more than one stage, temperatures drop to 50ºC [29]. Due to the wide temperature range, depending on the characteristics of this technology, the same equal division of the total installed capacity (Table 9) [30] between Q1, Q2, Q3 and Q4 is assumed.

| **Country** | **Total [MW]** |
|---|---|
| Austria | 17,940 |
| Belgium | 96,771 |
| Czech Republic | 98,761 |
| Denmark | 0 |
| France | 90,000 |
| Germany | 19,523 |
| Luxembourg | 0 |
| Netherlands | 0 |
| Poland | 2.099,142 |
| Switzerland | 1,966 |

**Table 9: Stock of coal-fired boilers in the EU-28 and Switzerland in 2015 [30].**

**LPG boiler**

LPG boilers are a direct competitor to coal boilers. In the future they could be replaced by BioLPG boilers as well as emitting less CO2 and NOx emissions [31]. The process operation and efficiency are comparable to the gas boiler as they have similar properties (Table 6). No data on installed capacity is available, so the same data as for the coal boiler has been used for *urbs*. This is assumed because they are direct competitors but for both technologies the installed capacity is lower than for natural gas.

**Biomass boiler**

Biomass heaters are a technology with a high efficiency of around 85%, which may vary slightly depending on whether the fuel is wood chips or pellets [32]. On the other hand, due to the low amount of hydrogen in the fuel, the CO2 emissions are 0,35 kg per unit of fuel energy [kWh], which is quite a high value compared to other renewable and non-renewable technologies [33]. Biomass boilers operate at temperatures between 120-150°C, thus this technology belongs to heat level Q3 [32].

As for installed capacity, there is limited data available, but it is possible to find data on heat production from solid biofuels per unit of energy in each country in [Mtoe]. Data has been collected for 2018 and converted to the required units per *urbs* [MW], dividing this energy by the hours of a whole year (8760 h) (Table 10) [34].

| Country | Heat from bio-fuels [Mtoe] | Heat from bio-fuels [MW] |
|---|---|---|
| Austria | 0,536 | 1.327,625 |
| Belgium | 0 | 0 |
| Czech Republic | 0,038 | 50,449 |
| Denmark | 0,493 | 654,519 |
| France | 0,600 | 796,575 |
| Germany | 0,155 | 205,781 |
| Luxembourg | 0,004 | 5,310 |
| Netherlands | 0,056 | 74,347 |
| Poland | 0,080 | 106,210 |
| Switzerland | - | 1.323,059 [35] |

**Table 10: Installed capacity of biomass boilers in 2018, own elaboration based on [34, 35].**

In the case of Switzerland, data was taken on the amount of heat consumption in 2018 (342 PJ) of which 12,2% was biomass, thus obtaining the proportion of heat derived from this technology [35].

## Hydrogen boiler

A more innovative technology is the hydrogen boiler. By burning a fuel with 100% of H2 we obtain heat and CO2 zero emissions. The efficiency of this process is known to be around 85% on High Heating Value (HHV) [36]. There are currently not many reports on the current installed capacity of hydrogen boilers. Studies show that the technology is not yet ready for 100% hydrogen use, but it is expected to become viable by 2025. Gas and LPG boilers could be replaced with a clean hydrogen-based fuel, although currently only mixed fuel boilers with a certain percentage of hydrogen are available. Therefore, the installed capacity introduced in *urbs* is 0 MW. [37].

In terms of the level of heat to which this technology belongs, hydrogen boilers are expected to be a perfect choice to replace industrial gas boilers for heating, as they can reach very high temperatures and pressures. Therefore, the temperatures that are being considered are around 200ºC, which belongs to the ranges of Heat Q3 and Q4 [38].

**Heat pump**

Both geothermal and air-source heat pumps are heat generators with an efficiency of 300% (Table 2). The CO2 emissions depend largely on the primary resource of the supplied electricity for the heat pump [39], therefore if the electricity is generated by renewables (PV, wind, hydro), then the heat pump is 100% renewable and CO2-neutral [40]. For the model, it is assumed that the possible CO2 emissions of the resource from which the electricity for the HP is generated, are already accounted for in the emissions of that resource. Therefore, CO2 emissions due to HP are considered to be zero.

The installed capacity is difficult to obtain, as the heat pump (HP) capacity itself can vary from 3 to more than 20kW, because it depends on many factors such as, e.g., size, or outdoor temperature. For this reason, all data on installed heat pumps is measured in number of heat pumps in operation. An average power for heat pumps has been determined and the calculation has been made considering how many units are in operation in each country.

Table 11 shows the data for 2019, indicating how many heat pumps were installed together with the total installed capacity in Spain and the Netherlands [41]. With this, it is possible to calculate the average power of the heat pumps installed in each of these countries.

| **Country** | **Total installed HP capacity [MW]** | **Number of HP [units]** | **Average of HP capacity [kW]** |
|---|---|---|---|
| Spain | 3.168,5 | 446.926 | 7,089 |
| Netherlands | 6.371 | 731.871 | 8,705 |

**Table 11: Capacity of a HP in Spain and the Netherlands, own elaboration based on [41].**

Due to the fact that these values are not available in all countries, the average of both values: 7,897kW per HP, is assumed for the calculation of the installed capacity in Europe. Table 12 shows the installed heat pump units in each country [41] as well as the final installed capacity.

| Country | Total HP [units] | Total installed capacity [MW] |
|---|---|---|
| Austria | 235.941 | 1.863,226 |
| Belgium | 337.397 | 2.664,424 |
| Czech Republic | 176.756 | 1.395,842 |
| Denmark | 449.992 | 3.553,586 |
| France | 7.155.406 | 56.506,241 |
| Germany | 1.155.120 | 9.121,982 |
| Luxembourg | 2.665 | 21,045 |
| Netherlands | 731.871 | 5.779,585 |
| Poland | 173.146 | 1.367,333 |
| Switzerland | - | 2.088,2 [42] |

**Table 12: Installed capacity for HP in 2019 (Switzerland in 2017), own elaboration based on [41, 42].**

The usual temperature for HPs is known to be between 65-70°C so they belong to heat levels Q1 and Q2 [43], and the installed capacity is distributed equally. Although HPs with highly supply temperature (HTHP) > 100ºC exist today, there is no market data available with information on this temperature level of heat pumps. Therefore, it is assumed to be very small due to the lack of products [44].

#### 3.2.1.2. Costs

Having defined the processes and capacities, the next step is to find the exact costs for each of them. In the model it is necessary to define the costs for the commodities, except for those that are of the demand type, which the model calculates later. In addition to that, the investment costs, fixed and variable costs as well as the weighted average cost of capital (WACC) and the depreciation period of each power plant must be determined. Starting from the model provided by ENS for electricity and hydrogen, it is necessary to add prices for air, gasoil, and LPG commodities, as the rest were already part of the previous model. The air required for the heat pumps is unlimited at no cost, so a zero cost has been associated with it.

On the other hand, for gasoil and LPG boilers, the official prices of these fuels have been introduced [45]. To convert the official data into €/MWh, which are the units that *urbs* uses, the Lower Heating Value (LHV) has been used. The LHV for gasoil is 9.981,3 kWh/m$^3$ and for LPG 6.777,778 kWh/m$^3$ [46]. Table 13 gathers the official data within the necessary conversion.

| **Country** | **Price gasoil [€/1000l]** | **Price LPG [€/1000l]** | **Price gasoil [€/MWh]** | **Price LPG [€/MWh]** |
|---|---|---|---|---|
| Austria | 758,5 | 810 | 75,992 | 120 |
| Belgium | 651,2 | 623 | 65,242 | 92 |
| Czech Republic | 723,1 | 547,82 | 72,445 | 81 |
| Denmark | 1.477,2 | 1.480 | 147,997 | 218 |
| France | 903,31 | 851,7 | 90,500 | 126 |
| Germany | 774 | 712 | 77,545 | 105 |
| Luxembourg | 678 | 644 | 67,927 | 95 |
| Netherlands | 1.325 | 747 | 132,748 | 110 |
| Poland | 813,78 | 546,33 | 81,530 | 81 |
| Switzerland | 825 | 1.557 | 82,655 | 230 |

**Table 13: Summary of costs of Gasoil and LPG in July 2021, based on [45].**

For the remaining costs, it has been assumed that all technologies have the same costs in all countries and at all heat levels Q1 to Q4 (Table 14) [46-52]. The investment cost of a gas boiler is in the range of 70.000 €/MW [46]. The annual fix cost includes the costs related to operation and maintenance (O&M) over a year, which in the case of boilers, namely gas boilers are 2.000 €/MW/a [47]. On the other hand, the variable costs specify the remaining costs per unit of energy, excluding fuel costs. For boilers these are 1,1 €/MWh [47]. As for the two remaining parameters, WACC and depreciation, the standard values for boilers, 5% [48] and 30 years [49], have been taken.

Following the same structure of costs as for the gas boiler, the investment, fixed and variable costs are considered the same. The investment cost of the coal and LPG boilers is 40.000€/MW [50], lower than that of the previous boilers, while all other values are considered equal

As for the investment costs of the biomass boiler, they are considerably higher, reaching 430.000 €/MWh [50]. Likewise, the $H_2$ boiler has also costs of 120.000 €/MWh and a fixed cost twice as high as the previous boilers [51]. The most expensive technology compared to the previous ones are heat pumps, which have an investment cost of 730.000 €/MWh

[48] and a variable cost of 3,2 €/MWh [52], all other values remaining approximately the same as for boilers.

| Technology | Investment cost [€/MW] | Annual fix cost [€/MW/a] | Variable costs [€/MWh] | Weighted average cost of capital [%] | Depreciation period (a) |
|---|---|---|---|---|---|
| Gas boiler | 70.000 | 2.000 | 1,1 | 0,05 | 30 |
| Gasoil boiler | 70.000 | 2.000 | 1,1 | 0,05 | 30 |
| Coal boiler | 40.000 | 2.000 | 1,1 | 0,05 | 30 |
| LPG boiler | 40.000 | 2.000 | 1,1 | 0,05 | 30 |
| Biomass boiler | 430.000 | 2.000 | 1,1 | 0,05 | 30 |
| Hydrogen boiler | 120.000 | 4.000 | 1,1 | 0,05 | 30 |
| Heat pump | 730.000 | 2.000 | 3,2 | 0,05 | 30 |

**Table 14: Summary of costs of different boilers, based on [46-52].**

# 4. Results and discussion

## 4.1. Heat distribution

The results obtained from the forecast in *endemo* can be graphically shown using QGIS, an open-source geographic information system [53], as shown in the map of Europe for the steel industry (Figure 9). By importing the compatible file with the NUTS2 classification information [54], it can be merged with the input files for each type of industry as both files contain the NUTS2 identifier.

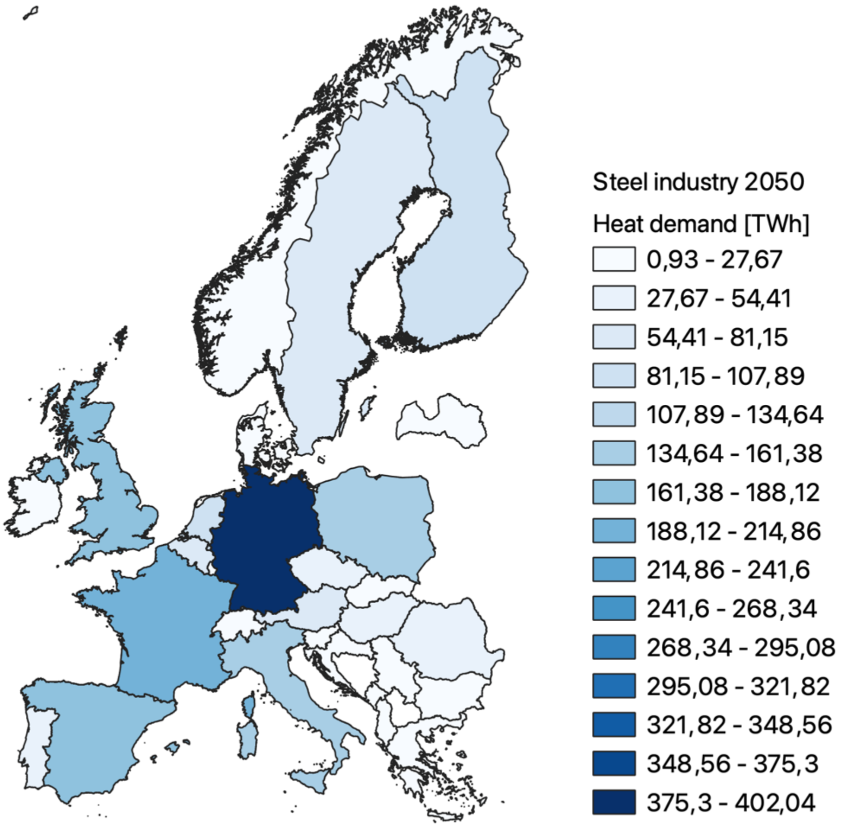

**Figure 9: Heat demand of steel industry in Europe 2050 by country.**

This heat demand can be divided according to the NUTS2 classification, based on the distribution explained in section 2.2. Therefore, a geographical model of Europe 2050 with the heat demand by country and NUTS2 has been obtained. As it is seen for the same example, the steel industry is divided depending on the proportion of its factories Figure 10).

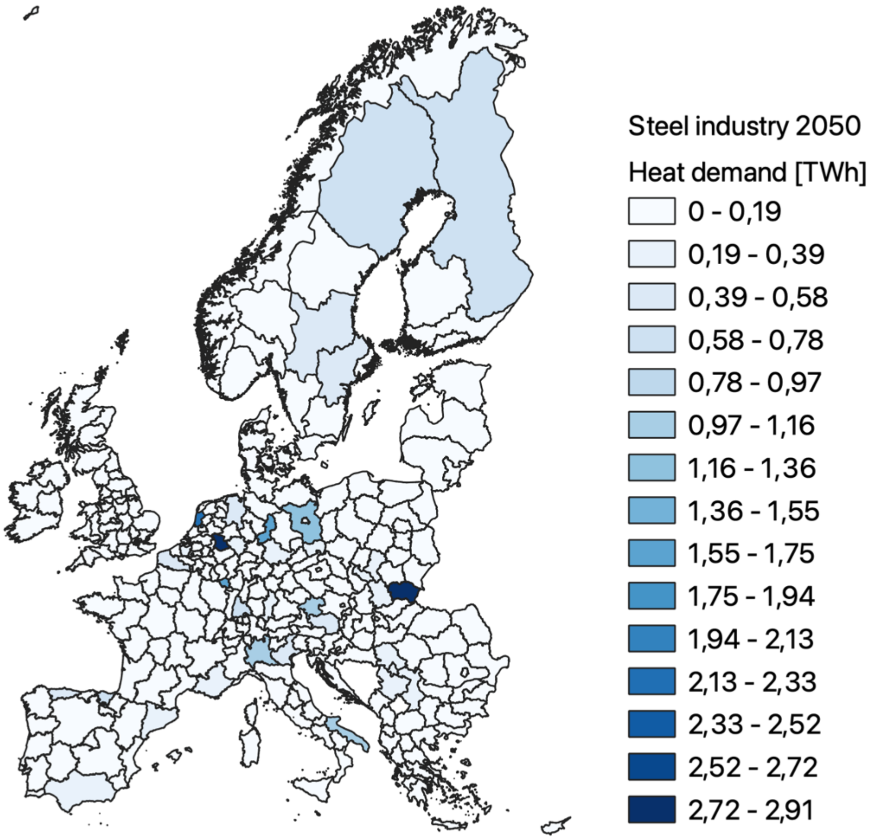

**Figure 10: Heat demand of steel industry in Europe 2050 by NUTS2.**

As the research has focused on large industries, there are cases where some countries have a concrete demand for a certain type of industry but no data on industrial capacities is registered for that country and that sub-sector. In this case, demand has been divided equally between the different NUTS2 regions of that country.

### 4.1.1. Comparison of both approaches

The geographic model can be transferred to all industries as a whole, giving a complete picture of the future description of the major industries in Europe 2050.

It should be noted that the results obtained for the chemical industries (methanol, ethanol and propylene) are that they will have a zero-heat demand. This is justified due to the future process substitution in these sectors. More hydrogen will be needed in order to complete the chemical reactions and less heat will be involved on them.

As explained, there are two approaches, the first being the main approach in my study, based on heat distribution by production capacities (Figure 11) and the second, in the approach developed by the ENS Chair, based on population distribution (Figure 12).

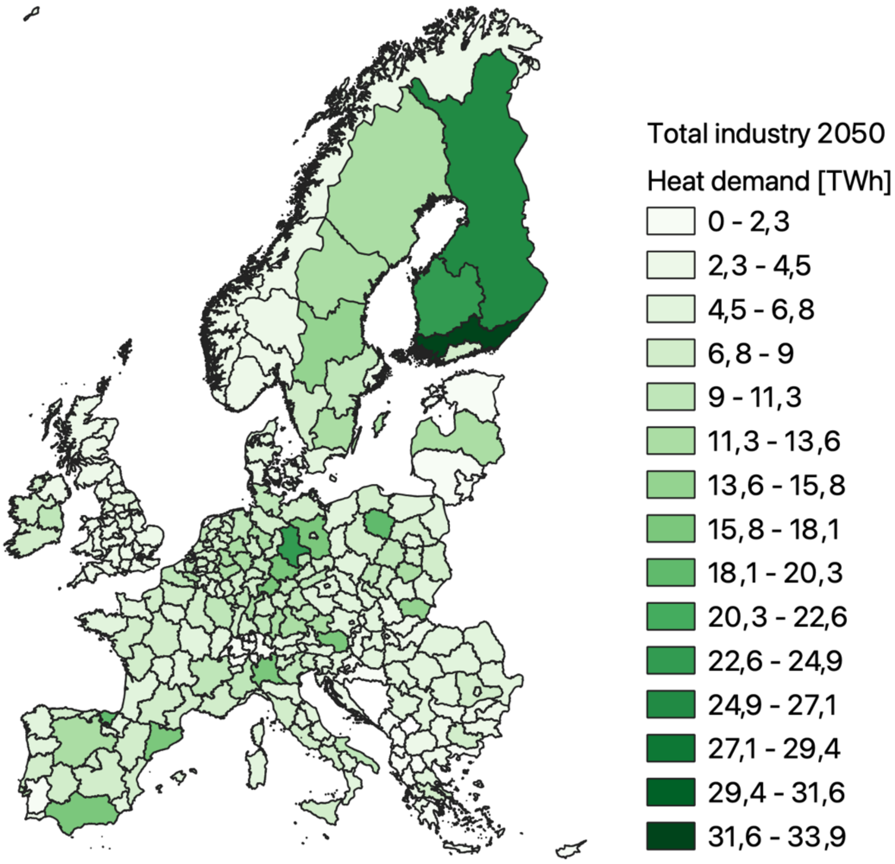

**Figure 11: Heat demand of the industry sector in Europe 2050, production capacities approach.**

A comparison of the two approaches shows a large difference between the two distributions. On the one hand, the approach based on industrial capacities has a more even distribution, since the vast majority of regions have industry in some sector. Industrial clusters are clearly visible. Some coincide with the second approach, as these are often located where most of the population lives.

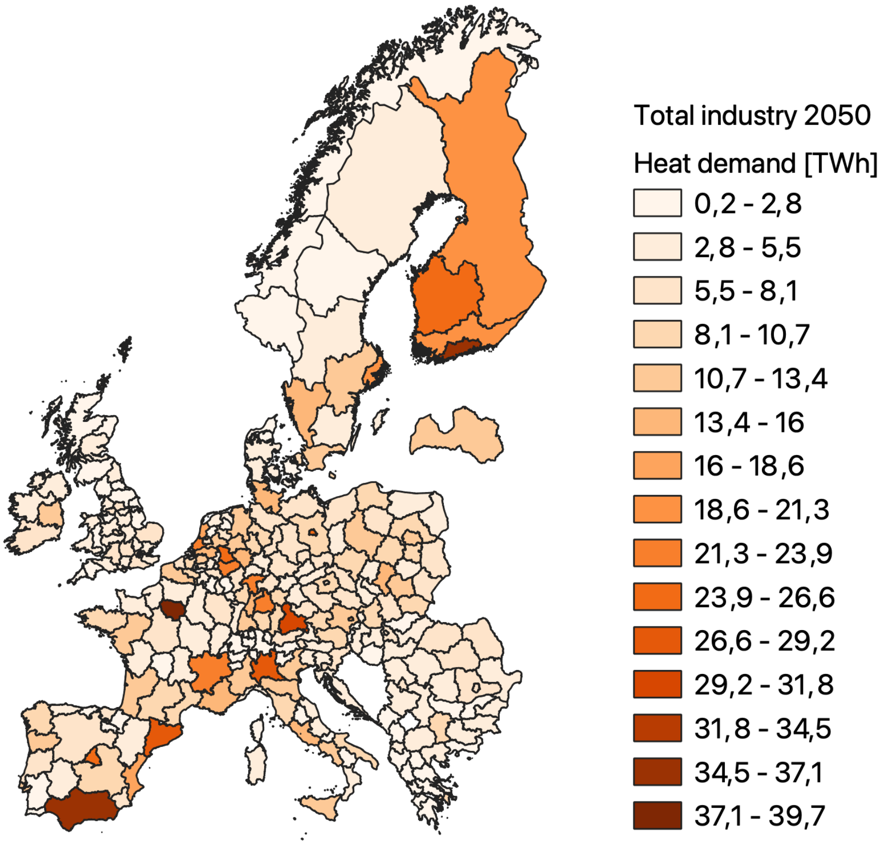

**Figure 12: Heat demand of the industry sector in Europe 2050, population approach.**

The big difference with the second approach is that it is much more drastic, leaving areas with extremely low heat demand compared to others. Nowadays this is rarely the case in Europe, and attempts are made to balance the different areas of a country in order to avoid depopulation. Therefore, it is concluded that both approaches have common points that verify the model, even though a distribution focused on production is considered more realistic for the industrial sector.

## 4.2. End energy demands

Once the *endemo* results have been verified, they are implemented in urbs. From this the distribution of heat generation in Europe 2050 is obtained. The results will be shown for Germany (Figure 13).

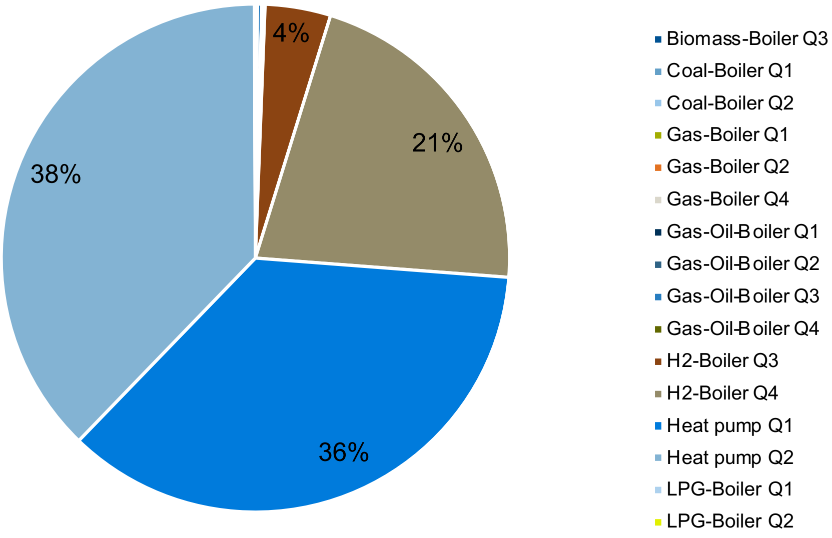

**Figure 13: Heat generation in Germany 2050.**

The most used technologies are heat pumps with 74% and hydrogen boilers with 25%. The heat pumps (in blue) are used to cover heat of type Q1 and Q2, which corresponds to heat at low temperature used for households and service sector. On the other hand, the hydrogen boilers (in brown) are covering the industry sector, which uses heat of type Q3 and Q4, for more than 100ºC. Other boilers using fossil fuels cover not even a 1% that could be lower in the future due to future changes on technologies such as LPG boilers expected to be reconverted to BioLPG in the near years.

It could be assumed that the heat generation is 100% renewable because neither the heat pumps nor the hydrogen boilers emit CO2, but this will directly depend on the electricity used as input for the heat pumps. This electricity feeding the heat pumps is not possible to be assured as 100% renewable, as it is shown in the next results.

This fact can be seen as well in the installed capacities (Figure 14). These installed capacities cover the heat generators already installed today (marked as previous in the plot) in addition to the ones that will be built till 2050. The reason why there are still some fossil fuel boilers is simply because the model cannot delete the number of boilers that are feed by fossil fuels today. However, it can be observed that almost no more fossil fuel boilers are being built by 2050.

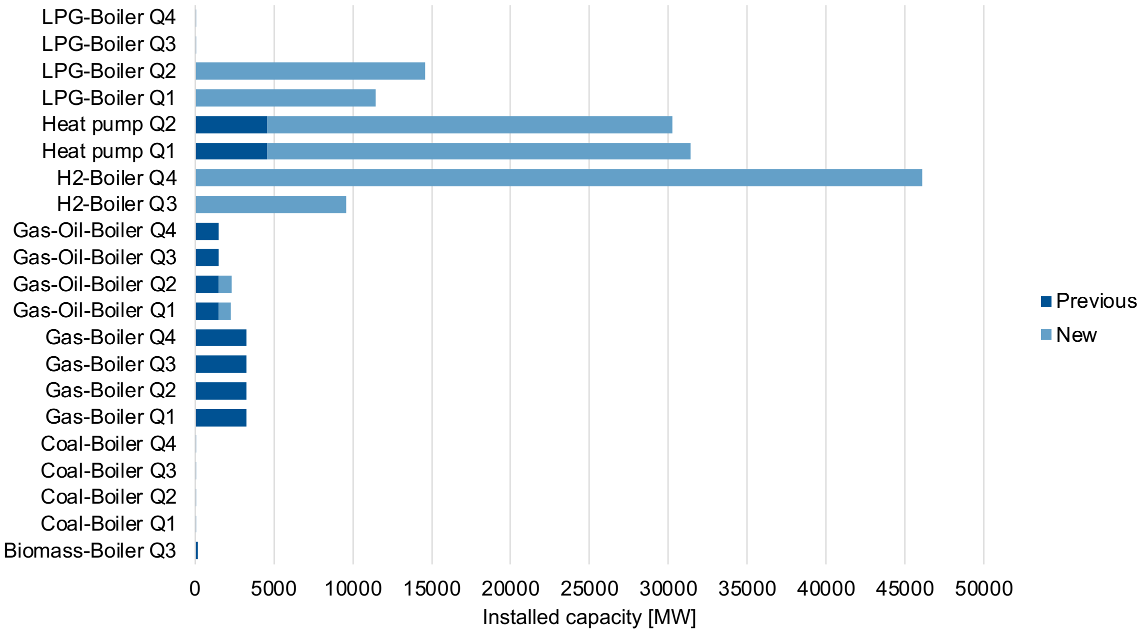

**Figure 14: Installed capacities for heat generation in Germany 2050.**

Similarly, the data obtained for electricity can be analyzed. With the results it is possible not only to have the output of the technologies for electricity generation but also the end use electricity demand depending on the balance between consumption and generation. The amount of electricity used to obtain heat and hydrogen is represented in the following electricity consumption plot (Figure 15). A 40% covers the electricity demand, but the rest is used with a 24% to produce heat and 34% for hydrogen.

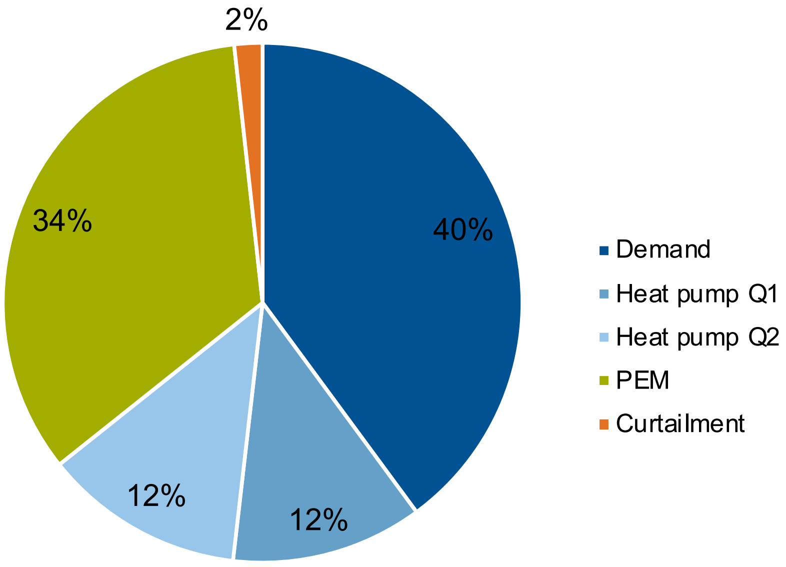

**Figure 15: Electricity consumption in Germany 2050.**

On the other hand, it is important to note, that the distribution of the electricity generation obtained is 90,22% made from renewable sources (Figure 16). The reason why the model could not calculate a 100% renewable electricity generation has to be improved in the future, because with the actual results, it is not possible to achieve the environmental targets, for instance the Climate Action Plan 2050 for Germany.

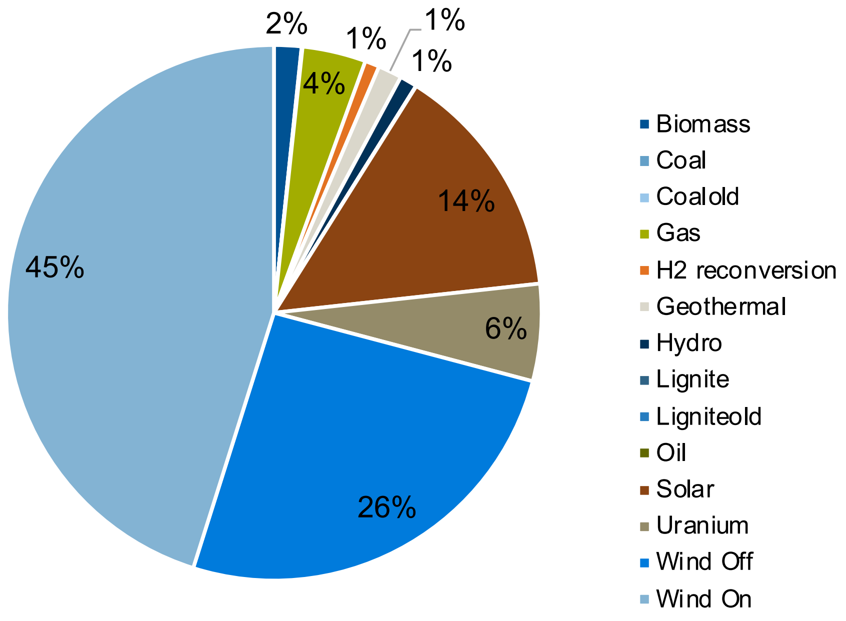

**Figure 16: Electricity generation in Germany 2050.**

This fact can also be seen in the following plot (Figure 17). In the case of Germany, an 85% of the electricity is covered just by wind on- and offshore and solar. These technologies are producing their maximum upper capacities installed, which are limited in *urbs*. In order to get a 100% renewable electricity generation, either these upper capacities have to be increased or other renewable technologies such as geothermal or biomass have to change their prices or efficiencies. As it can be observed, the model is building as solar and wind as possible and simultaneously keeping the fossil fuel technologies to zero new power plants.

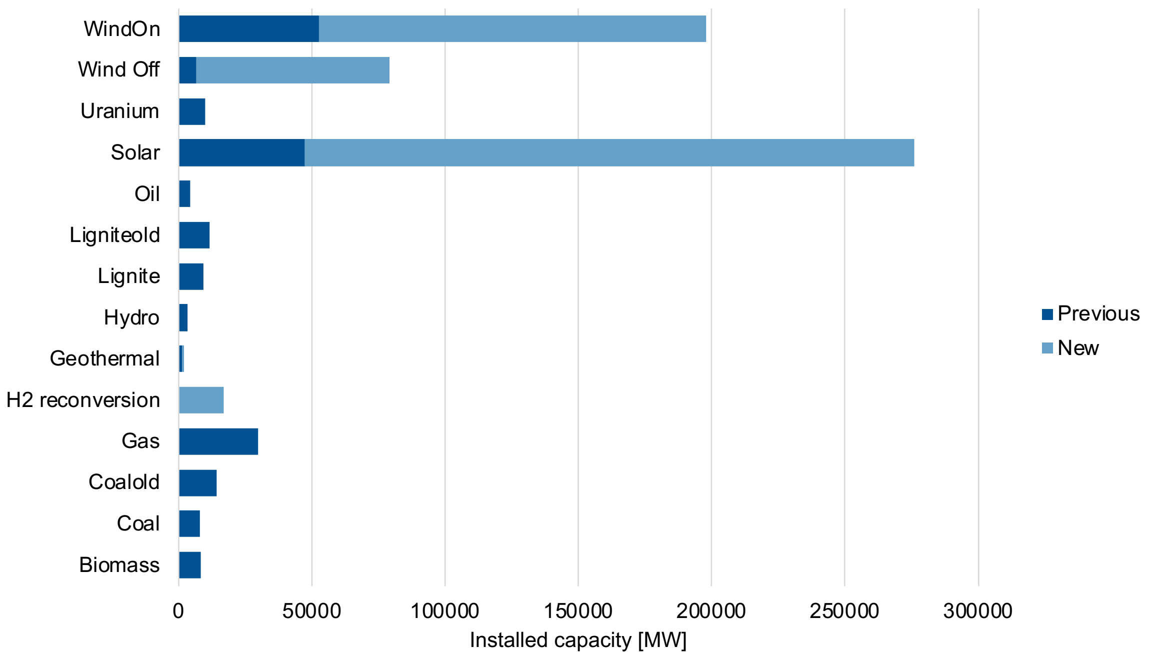

**Figure 17: Installed capacities for electricity generation in Germany 2050.**

For hydrogen in Europe 2050 the results are the following (Figure 18). From hydrogen, 54% is used to cover its own demand, 44% for heat production through hydrogen boilers and 2% for electricity production through hydrogen reconversion. The importance of hydrogen in the future is clearly observed, especially in the industrial sector, as almost all heat will be generated by the hydrogen boilers mentioned above.

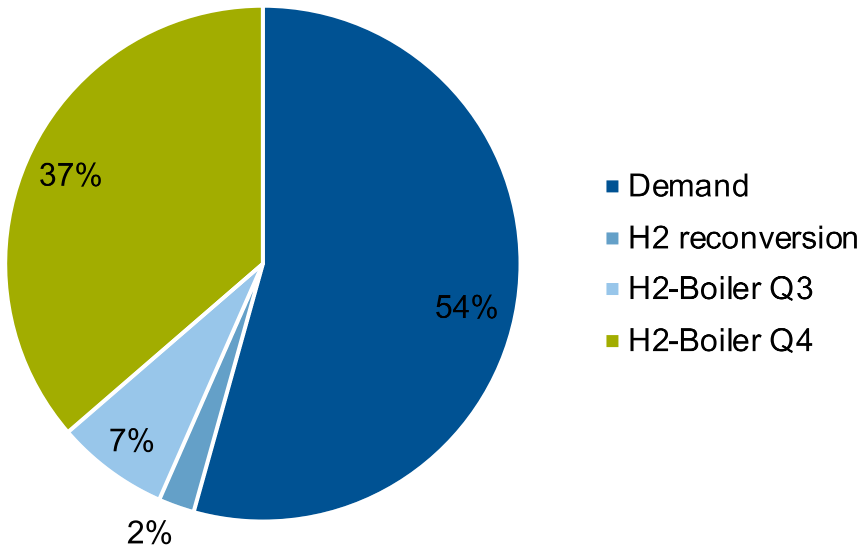

**Figure 18: Hydrogen consumption in Germany 2050.**

As for hydrogen generation, the only technology used is PEM (electrolysis), with a resultant installed capacity of PEM for Europe in 2050 of 781,85 GW.

## 4.3. Comparison with European studies

The *endemo* values representing the forecast of the industrial sector in Europe for 2050, can be linked to numerous European studies which have the same purpose. Based on the collection of studies explained before, it is possible to compare European studies for heat demand in industry in 2050 with the results obtained (Figure 19) [2, 9, 10].

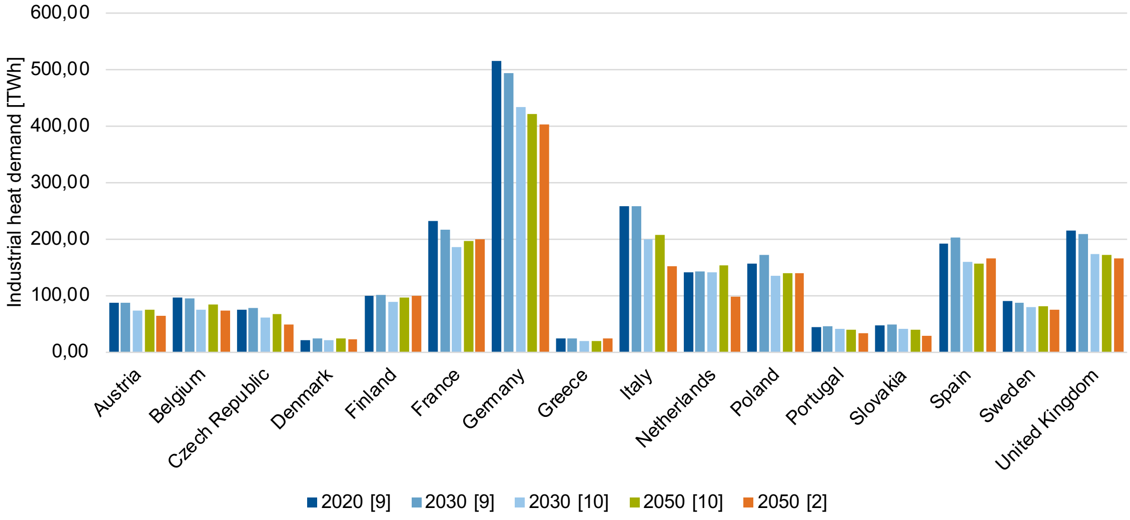

**Figure 19: Forecasted heat demand in industry 2050, based on [2, 9, 10].**

All of them follow the same trends for all European countries. Starting with the dark blue bar, current data from 2020 can be seen. The lighter blue bars represent two different studies for year 2030, with a clear trend of reduction of the demand. The green bar corresponds to forecasted data for 2050 that can be directly compared with the *endemo* results in orange. As it can be seen, the values are really similar and the reduction of the demand following the climate-neutral target is present in all of them. Therefore, it can be concluded that both the studies and the results of *endemo* are consistent and in line with European objectives.

## 4.4. Validation with national studies guidelines

In the same way, it is possible to compare other countries with the values obtained for the heat demand in *urbs* for three months. This value is adapted to a full year by obtaining its proportional value for 12 months. The following plot gathers different studies, such as national data for different years representing the heat demand in Austria. The last value corresponds to my result from the *urbs* model for 2050.

The reason why the heat demand in all other studies is slightly higher as the results obtained in *urbs,* is because all of them were conducted in between 2015 and 2017 and the European Green Deal for a 100% climate-neutral Europe was not yet in effect. Despite of this, the studies and the values obtained from urbs are following the same trend, as it can be observed in the plot (Figure 20) [3, 12, 13].

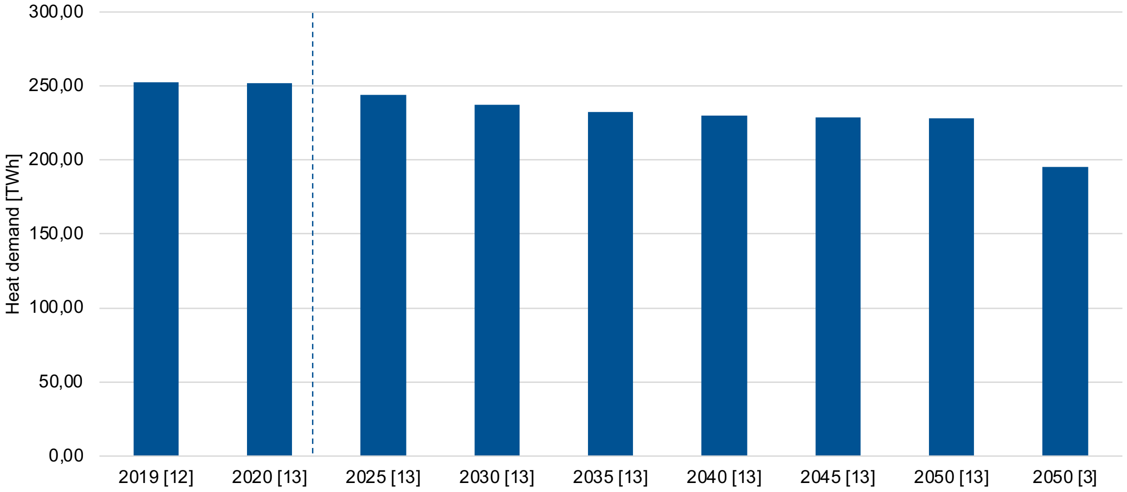

**Figure 20: Forecasted heat demand in Austria, based on [3, 12, 13].**

# 5. Conclusion and outlook

The study of the future European energy system has made it clear that a sustainable system that can meet demand for 2050 is possible. Focusing on a scenario where the limitation of CO2 emissions plays an important role, the results obtained show a realistic future energy system.

It should be noted that the energy demand will be covered thanks to the mentioned technologies that allow a 100% renewable heat generation to be obtained. As explained in section 4.1. this will depend entirely on whether the electricity that runs the heat pumps comes from a renewable source or not. However, heat pumps and hydrogen boilers will be very significant in Europe 2050.

Hydrogen will have a major role to play, both as a feedstock, as well as to cover a large part of the heat demand and, to a lesser extent, to cover the electricity demand. Through electrolysis (PEM) it will be possible to generate a large amount of hydrogen, which is not even conceivable today.

Regarding electricity, it is possible to achieve 90% of generation from renewable sources. Unfortunately, this is not enough to achieve a climate-neutral and fully renewable Europe. This directly implies that the reduction of current CO2 emissions is realistic but not possible to obtain a 100% renewable system. The solutions proposed are to increase the upper limit of the main renewable technologies used in the model (wind and solar) or to improve others that have less importance such as biomass, which means improving their efficiency or reducing their costs.

Finally, it is important to conclude that the model has been verified by numerous studies, all of them following the same trends of heat demand reduction. The results obtained for the heat demand of the industrial sector in *endemo*, as well as the results for the sector coupling *urbs*, show the lowest values when compared to the selected studies. This means that the modelling is sufficiently restrictive to meet the environmental targets for Europe 2050.

As further considerations, I recommend extending the model. The model built is a simplified overview of the future energy system, which could be improved implementing the following changes. The simulation in *urbs* can be done in the future for a whole year and the model can be extended to all European countries. Other important technologies could be added in the heat model, such as solar or geothermal energy for heat generation. These technologies are not as present today but could gain a lot of value in the years to come, so it would be advisable to take them into account. Lastly, it could be important to create be and validate a new scenario based on a limited cost and therefore optimal, thus finding a compromise between CO2 emissions and system costs.

Having demonstrated that the model is reliable and by applying these improvements, it is possible to obtain a very accurate forecast of future energy demand patterns and the optimal technologies for the future, which can help extremely well to meet the major environmental challenge facing Europe by 2050.

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# Annex A: Heat demand in industry [TWh]

| Country | 2015 [10] | 2020 [9] | 2030 [9] | 2030 [10] | 2050 [10] |
|---|---|---|---|---|---|
| Austria | 69,39 | 86,60 | 87,70 | 73,38 | 75,29 |
| Belgium | 74,2 | 96,20 | 95,30 | 75,52 | 84,42 |
| Bulgaria | 20,97 | 25,60 | 27,30 | 22,51 | 23,87 |
| Croatia | 9,68 | 11,80 | 12,50 | 10,14 | 10,69 |
| Cyprus | 1,03 | 1,60 | 1,60 | 0,99 | 0,97 |
| Czech Republic | 55,93 | 75,20 | 77,60 | 60,62 | 67,57 |
| Denmark | 18,32 | 21,30 | 23,30 | 20,64 | 24,37 |
| Estonia | 4,15 | 5,30 | 5,60 | 4,6 | 5,03 |
| Finland | 85,6 | 99,10 | 101,40 | 88,92 | 96,02 |
| France | 189,49 | 231,30 | 215,70 | 185,5 | 195,57 |
| Germany | 432,3 | 515,20 | 493,60 | 433,03 | 420,9 |
| Greece | 20,74 | 23,80 | 24,10 | 19,04 | 19,87 |
| Hungary | 19,81 | 25,80 | 26,40 | 22,3 | 23,41 |
| Ireland | 15,56 | 19,20 | 20,20 | 15,68 | 16,88 |
| Italy | 196,8 | 258,30 | 258,20 | 199,93 | 207,61 |
| Latvia | 7,01 | 9,90 | 10,70 | 7,64 | 7,51 |
| Lituania | 8,56 | 10,10 | 10,00 | 8,4 | 8,37 |
| Luxembourg | 4,4 | 6,40 | 6,10 | 4,7 | 5,02 |
| Malta | 0,11 | 0,10 | 0,10 | 0,12 | 0,13 |
| Netherlands | 130,58 | 141,00 | 143,10 | 141,66 | 153,57 |
| Poland | 116,75 | 156,50 | 171,80 | 134,32 | 138,79 |
| Portugal | 39,24 | 44,70 | 46,00 | 40,46 | 39,95 |
| Romania | 49,97 | 78,60 | 85,50 | 55,54 | 56,74 |
| Slovakia | 36,36 | 47,80 | 49,20 | 40,52 | 39,06 |
| Slovenia | 7,29 | 9,80 | 10,90 | 8,35 | 9 |
| Spain | 165,48 | 192,00 | 202,50 | 159,28 | 156,75 |
| Sweden | 76,7 | 89,50 | 87,20 | 78,69 | 81,64 |
| United Kingdom | 179,05 | 215,00 | 209,20 | 172,99 | 171,85 |
| Norway | - | 3,30 | 3,40 | - | - |
| Iceland | - | 30,00 | 30,00 | - | - |
| Switzerland | - | 24,40 | 25,20 | - | - |
| EU-28 | 2035,47 | 2498,00 | 2503,00 | 2085,47 | 2140,85 |

**Table 15: Heat demand in industry database [9, 10].**

# Annex B: Capacities of the steel industry

| **NUTS2** | **City** | **Installed capacity blast furnace/ oxygen** | **Installed capacity electric arc** | **Installed capacity steel** | **Steel %** |
|---|---|---|---|---|---|
| BE22 | Genk | 0 | 1200 | 1200 | 14,29% |
| BE23 | Ghent | 5000 | 0 | 5000 | 59,52% |
| BE32 | Charleroi<br>Chatelet |  | 2200 | 2200 | 26,19% |
| BG41 | Pernik | 0 | 1000 | 1000 | 100,00% |
| CZ03 | Plzen | 0 | 150 | 150 | 5,62% |
| CZ08 | Trinec<br>Ostrava | 2400 | 120 | 2520 | 94,38% |
| DE13 | Kehl | 0 | 2500 | 2500 | 5,72% |
| DE27 | Herbertshofen | 0 | 1180 | 1180 | 2,70% |
| DE40 | Eisenhüttenstadt<br>Brandenburg<br>Henningsdorf | 2400 | 2800 | 5200 | 11,89% |
| DE50 | Bremen | 3800 | 0 | 3800 | 8,69% |
| DE60 | Hamburg | 0 | 1100 | 1100 | 2,52% |
| DE72 | Wetzlar | 0 | 400 | 400 | 0,91% |

| | | | | | |
|---|---|---|---|---|---|
| DE91 | Salzgitter Peine | 5200 | 1000 | 6200 | 14,18% |
| DE94 | Georgsmarienhütte Lingen | 0 | 1720 | 1720 | 3,93% |
| DEA1 | Duisbirg | 11560 | 0 | 11560 | 26,43% |
| DEA5 | Siegen Witten | 0 | 1230 | 1230 | 2,81% |
| DEC0 | Dillingen Völklingen Bous/Saar | 6000 | 650 | 6650 | 15,21% |
| DED2 | Freital Gröditz Riesa | 0 | 1090 | 1090 | 2,49% |
| DEG0 | Unterwellenborn | 0 | 1100 | 1100 | 2,52% |
| EL30 | Aspropyrgos Eleusis | 0 | 1200 | 1200 | 34,78% |
| EL52 | Thessaloniki | 0 | 600 | 600 | 17,39% |
| EL61 | Almyros-Magnisia Velestino | 0 | 1650 | 1650 | 47,83% |
| ES11 | Naron | 0 | 700 | 700 | 3,11% |
| ES12 | Avilés Gijón | 5400 | 0 | 5400 | 23,98% |
| ES13 | Reinosa Santander | 0 | 990 | 990 | 4,40% |

| | | | | | |
|---|---|---|---|---|---|
| ES21 | Amurrio<br>Azpeitia<br>Basauri<br>Bilbao<br>Galindo<br>Loiu<br>Olaberria<br>Sestao | 0 | 8130 | 8130 | 36,10% |
| ES24 | Zaragoza | 0 | 500 | 500 | 2,22% |
| ES30 | Getafe | 0 | 600 | 600 | 2,66% |
| ES51 | Castellbisbal | 0 | 2400 | 2400 | 10,66% |
| ES61 | Jerez de los Caballeros<br>Los Barrios<br>Sevilla | 0 | 3800 | 3800 | 16,87% |
| FR10 | Bonnieres-Sur-Seine<br>Gargenville<br>Montereau | 0 | 1970 | 1970 | 10,43% |
| FRC1 | Imphy<br>Le Creusot | 0 | 240 | 240 | 1,27% |
| FRE1 | Dunkirk<br>St. Saulve<br>Trith St Leger | 6750 | 1530 | 8280 | 43,86% |
| FRF3 | Hagondange<br>Neuves Maisons | 0 | 1260 | 1260 | 6,67% |
| FRI1 | Bayonne | 0 | 1200 | 1200 | 6,36% |
| FRK2 | Chateauneuf, R. de Giers<br>Ugine | 0 | 350 | 350 | 1,85% |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| FRL0 | Fos-Sur-Mer | 5100 | 480 | 5580 | 29,56% |
| HR02 | Sisak | 0 | 350 | 350 | 65,42% |
| HR03 | Split | 0 | 185 | 185 | 34,58% |
| ITC1 | Lesegno | 0 | 600 | 600 | 1,76% |
| ITC2 | Aosta | 0 | 260 | 260 | 0,76% |
| ITC4 | Breno<br>Brescia<br>Caronno<br>Cividate al Piano<br>Cremona<br>Dalmine<br>Lonato<br>Lovere<br>Odolo<br>Ospitaletto<br>San Zeno Naviglio<br>Sarezzo | 0 | 11770 | 11770 | 34,60% |
| ITF4 | Taranto | 11500 | 0 | 11500 | 33,80% |
| ITG1 | Catania | 0 | 500 | 500 | 1,47% |
| ITH1 | Bolzano | 0 | 200 | 200 | 0,59% |
| ITH2 | Borgo Valsugana | 0 | 600 | 600 | 1,76% |
| ITH3 | Camin<br>Osoppo<br>Vallese D. Oppeano<br>Verona<br>Vicenza | 0 | 5870 | 5870 | 17,25% |

| | | | | | |
|---|---|---|---|---|---|
| ITH4 | Udine | 0 | 1270 | 1270 | 3,73% |
| ITI2 | Terni | 0 | 1450 | 1450 | 4,26% |
| LU00 | Esch-Sur-Alzette | 0 | 2250 | 2250 | 100,00% |
| HU21 | Dunauijvaros | 1650 | 0 | 1650 | 80,49% |
| HU31 | Ozd | 0 | 400 | 400 | 19,51% |
| NL32 | Ijmuiden | 7500 | 0 | 7500 | 100,00% |
| AT22 | Donawitz<br>Graz<br>Kapfenberg<br>Mitterdorf | 1570 | 845 | 2415 | 28,70% |
| AT31 | Linz | 6000 | 0 | 6000 | 71,30% |
| PL21 | Krakov | 2600 | 0 | 2600 | 21,51% |
| PL22 | Dabrowa Gornicza<br>Chorzow<br>Czestochowa<br>Gliwice<br>Katowice<br>Zawiercie | 5000 | 2600 | 7600 | 62,86% |
| PL72 | Ostrowiec | 0 | 900 | 900 | 7,44% |
| PL82 | Stalowa Wola | 0 | 240 | 240 | 1,99% |
| PL91 | Warszawa | 0 | 750 | 750 | 6,20% |
| PT11 | Maia | 0 | 600 | 600 | 35,29% |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| PT17 | Seixal | 0 | 1100 | 1100 | 64,71% |
| RO22 | Galati | 3200 | 0 | 3200 | 58,18% |
| RO31 | Calarasi | 0 | 470 | 470 | 8,55% |
| RO42 | Hunedoara<br>Otelu Rosu<br>Resita | 0 | 1830 | 1830 | 33,27% |
| SI03 | Celje-Store<br>Ravne | 0 | 290 | 290 | 36,71% |
| SI04 | Jesenice | 0 | 500 | 500 | 63,29% |
| SK03 | Podbrezova | 0 | 350 | 350 | 7,22% |
| SK04 | Kosice | 4500 | 0 | 4500 | 92,78% |
| FI1C | Imatra | 0 | 360 | 360 | 8,45% |
| FI1D | Raahe<br>Tornio | 2600 | 1300 | 3900 | 91,55% |
| SE12 | Öxelösund | 1700 | 0 | 1700 | 29,34% |
| SE31 | Avesta<br>Björneborg<br>Hagfors<br>Hofors<br>Sandviken<br>Smedjebacken | 0 | 1895 | 1895 | 32,70% |
| SE33 | Lulea | 2200 | 0 | 2200 | 37,96% |
| UKE1 | Scunthorpe | 3200 | 0 | 3200 | 28,70% |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| UKE3 | Aldwarke Sheffield Shepcote Lane | 0 | 1850 | 1850 | 16,59% |
| UKL1 | Port Talbot | 4900 | 0 | 4900 | 43,95% |
| UKL2 | Tremorfa | 0 | 1200 | 1200 | 10,76% |
| NO | No data |  |  |  | 14,29% per NUTS2 |
| CH | No data |  |  |  | 14,29% per NUTS2 |
| ME | No data |  |  |  | 100,00% per NUTS2 |
| MK | No data |  |  |  | 100,00% per NUTS2 |
| AL | No data |  |  |  | 33,33% per NUTS2 |
| RS | No data |  |  |  | 25,00% per NUTS2 |
| BA | No data |  |  |  | 100,00% per NUTS2 |
| LI | No data |  |  |  | 100,00% per NUTS2 |
| IS | No data |  |  |  | 100,00% per NUTS2 |

**Table 16: Production capacities in the steel sector by NUTS2, based on [19].**

# Annex C: Capacities of the steel stainless industry

| **NUTS2** | **City** | **Installed capacity steel stainless** | **Steel stainless %** |
|---|---|---|---|
| BE22 | Genk | 1200 | 47,06% |
| BE32 | Charleroi<br>Chatelet | 1350 | 52,94% |
| DE72 | Wetzlar | 400 | 18,87% |
| DEA5 | Siegen<br>Witten | 1230 | 58,02% |
| DEC0 | Völklingen | 300 | 14,15% |
| DED2 | Freital<br>Gröditz | 190 | 8,96% |
| ES13 | Reinosa | 240 | 9,76% |
| ES21 | Amurrio<br>Basauri<br>Loiu | 1020 | 41,46% |
| ES61 | Los Barrios | 1200 | 48,78% |
| FRC1 | Imphy<br>Le Creusot | 400 | 53,33% |
| FRK1 | Chateauneuf de Giers | 100 | 13,33% |
| FRK2 | Ugine | 250 | 33,33% |
| ITC2 | Aosta | 260 | 9,19% |

| | | | |
|---|---|---|---|
| ITC4 | Breno<br>Ospitaletto | 250 | 8,83% |
| ITH1 | Bolzano | 200 | 7,07% |
| ITH3 | Vicenza | 170 | 6,01% |
| ITH4 | Udine | 500 | 17,67% |
| ITI2 | Terni | 1450 | 51,24% |
| AT22 | Kapfenberg<br>Mitterdorf | 480 | 100,00% |
| PL82 | Stalowa wola | 240 | 100,00% |
| SI04 | Jesenice<br>Ravne | 640 | 100,00% |
| FI1D | Tornio | 1300 | 100,00% |
| SE31 | Avesta<br>Sandviken | 700 | 100,00% |
| UKE3 | Aldwarke<br>Sheffield<br>Shepcote Lane | 1870 | 100,00% |

**Table 17: Production capacities in the stainless-steel sector by NUTS2, based on [19].**

# Annex D: Capacities of the aluminium industry

| **NUTS2** | **City** | **Installed capacity primary aluminium** | **Primary aluminium %** | **Installed capacity secondary aluminium** | **Secondary aluminium %** |
|---|---|---|---|---|---|
| BE | No data | | 9,09% per NUTS2 | | |
| BG | No data | | 16,67% per NUTS2 | | |
| CZ | No data | | 12,50% per NUTS2 | | |
| DK | No data | | 20,00% per NUTS2 | | |
| DE11 | Deizisau<br>Stuttgart | 0 | 0 | 100 | 3,0% |
| DE13 | Bad Säckingen<br>Gundelfingen<br>Rheinfelden<br>Stockach<br>Wutöschingen | 0 | 0 | 203 | 6,0% |
| DE14 | Annaberg<br>Fridrichshafen<br>Neu -Ulm | 0 | 0 | 104 | 3,1% |
| DE21 | Garching<br>Markt Schwaben<br>Töging | 0 | 0 | 144 | 4,3% |
| DE22 | Landshut | 0 | 0 | 69 | 2,1% |

| | | | | | |
|---|---|---|---|---|---|
| DE27 | Dillingen<br>Kempten<br>Weissenhorn | 0 | 0 | 243 | 7,2% |
| DE30 | Berlin | 0 | 0 | 90 | 2,7% |
| DE60 | Hamburg | 135 | 21,39% | 190 | 5,7% |
| DE73 | Baunatal | 0 | 0 | 60 | 1,8% |
| DE91 | Göttingen | 0 | 0 | 60 | 1,8% |
| DE92 | Hannover | 0 | 0 | 107 | 3,2% |
| DEA1 | Rheinwerk<br>Neuss<br>Essen<br>Voerde<br>Grevenbroich<br>Heiligenhaus<br>Hilden<br>Neuss<br>Norf | 496 | 78,61% | 945 | 28,2% |
| DEA3 | Gelsenkirchen | 0 | 0 | 110 | 3,3% |
| DEA5 | Lüdenscheid<br>Lünen<br>Meinerzhagen<br>Nachrodt | 0 | 0 | 201 | 6,0% |
| DED5 | Rackwitz | 0 | 0 | 100 | 3,0% |
| DEE0 | Bernburg<br>Harzgerode<br>Hettstedt<br>Novelis | 0 | 0 | 631 | 18,8% |
| IE | No data | | 33,33% per NUTS2 | | |

| | | | | | |
|---|---|---|---|---|---|
| EL43 | Agios Nikolaos | 190 | 100,00% | 190 | 100,00% |
| ES11 | San Ciprian<br>La Coruña | 337 | 78,37% | 337 | 78,37% |
| ES12 | Aviles | 93 | 21,63% | 93 | 21,63% |
| FRE1 | Dunkirk | 285 | 66,28% | 285 | 66,28% |
| FRK2 | St Jean de Maurienne | 145 | 33,72% | 145 | 33,72% |
| HR | No data | | 25,00% per NUTS2 | | |
| IT | No data | | 4,76% per NUTS2 | | |
| CY | No data | | 100,00% per NUTS2 | | |
| LV | No data | | 100,00% per NUTS2 | | |
| LT | No data | | 50,00% per NUTS2 | | |
| NL11 | Delfzijl | 111 | 100,00% | 111 | 100,00% |
| AT | No data | | 11,11% per NUTS2 | | |
| PL | No data | | 5,88% per NUTS2 | | |
| PT | No data | | 14,29% per NUTS2 | | |

| | | | | | |
|---|---|---|---|---|---|
| RO41 | Slatina | 282 | 100,00% | 282 | 100,00% |
| SI03 | Kidricevo | 85 | 100,00% | 85 | 100,00% |
| SK03 | Ziar nad Hronom | 175 | 100,00% | 175 | 100,00% |
| FI | No data | | 20,00% per NUTS2 | | |
| SE32 | Sundsvall | 130 | 100,00% | 130 | 100,00% |
| UKM6 | Fort William | 42 | 100,00% | 42 | 100,00% |
| NO07 | Mosjøen | 221,5 | 15,63% | 221,5 | 15,63% |
| NO09 | Lista | 127,5 | 9,00% | 127,5 | 9,00% |
| NO0A | Sunndalsøra<br>Årdal<br>Karmøy<br>Husnes<br>Høyanger | 1068 | 75,37% | 1068 | 75,37% |
| CH | No data | | 14,29% per NUTS2 | | |
| ME00 | Podgorica | 120 | 100,00% | 120 | 100,00% |
| MK00 | No data | | 100,00% per NUTS2 | | |
| AL | No data | | 33,33% per NUTS2 | | |
| RS | No data | | 25,00% per NUTS2 | | |

| | | | | | |
|---|---|---|---|---|---|
| BA | No data | | 100,00% per NUTS2 | | |
| LI | No data | | 100,00% per NUTS2 | | |
| IS00 | No data | 1113 | 100,00% | 1113 | 100,00% |

**Table 18: Production capacities in the aluminium sector by NUTS2, based on [55, 56].**

# Annex E: Capacities of the chlorine industry

| **NUTS2** | **City** | **Installed capacity chlorine** | **Chlorine %** |
|---|---|---|---|
| BE21 | Antwerp | 460 | 44,49% |
| BE22 | Tessenderlo | 400 | 38,68% |
| BE35 | Jemeppe | 174 | 16,83% |
| BG | No data | | 16,67% per NUTs2 |
| CZ02 | Neratovice | 135 | 68,88% |
| CZ04 | Usti | 61 | 31,12% |
| DK | No data | | 20,00% per NUTS2 |
| DE21 | Burghausen<br>Gendorf | 230 | 4,43% |
| DE27 | Gersthofen | 45 | 0,87% |
| DE71 | Frankfurt | 167 | 3,22% |
| DE93 | Stade | 1585 | 30,56% |
| DE94 | Wilhelmshaven | 149 | 2,87% |
| DEA1 | Dormagen<br>Rheinberg<br>Uerdingen | 950 | 18,32% |

| | | | |
|---|---|---|---|
| DEA2 | Lülsdorf<br>Knapsack<br>Leverkusen | 717 | 13,82% |
| DEA3 | Marl<br>Ibbenbüren | 385 | 7,42% |
| DEB3 | Ludwigshafen | 385 | 7,42% |
| DEE0 | Leuna<br>Bitterfeld<br>Schkopau | 364 | 7,02% |
| DEF0 | Brunsbüttel | 210 | 4,05% |
| IE05 | Fermoy | 9 | 100,00% |
| EL30 | Marousi | 20 | 31,25% |
| EL52 | Thessaloniki | 40 | 62,50% |
| EL64 | Inofita Viotias | 4 | 6,25% |
| ES11 | Pontevedra | 34 | 4,57% |
| ES13 | Torrelavega | 63 | 8,47% |
| ES21 | Hernani | 15 | 2,02% |
| ES24 | Sabiñánigo | 30 | 4,03% |
| ES51 | Martorell<br>Vilaseca<br>Monzon<br>Flix | 554 | 74,46% |
| ES61 | Huelva | 48 | 6,45% |

|  |  |  |  |
|---|---|---|---|
| FRC2 | Tavaux | 360 | 25,37% |
| FRE1 | Loos | 18 | 1,27% |
| FRE2 | Harbonnières | 23 | 1,62% |
| FRF1 | Thann | 72 | 5,07% |
| FRJ2 | Fos | 300 | 21,14% |
| FRK2 | Pont de Claix<br>Jarrie<br>Pomblière | 285 | 20,08% |
| FRL0 | Lavera<br>St Auban | 361 | 25,44% |
| HR02 |  |  | 33,33% |
| HR03 |  |  | 33,33% |
| HR05 |  |  | 33,33% |
| ITC1 | Pieve Vergonte | 42 | 9,86% |
| ITF1 | Bussi | 25 | 5,87% |
| ITF2 | Campochiaro | 20 | 4,69% |
| ITG2 | Assemini | 150 | 35,21% |
| ITI1 | Volterra<br>Rosignano | 189 | 44,37% |
| CY | No data |  | 100,00% per NUTS2 |
| LV | No data |  | 100,00% per NUTS2 |

| | | | |
|---|---|---|---|
| LT | No data | | 50,00% per NUTS2 |
| LU | No data | | 100,00% per NUTS2 |
| HU31 | Kazincbarcika | 291 | 100,00% |
| NL11 | Delfzijl | 121 | 14,29% |
| NL33 | Botlek | 637 | 75,21% |
| NL34 | Bergen op Zoom | 89 | 10,51% |
| AT21 | Brückl | 70 | 100,00% |
| PL51 | Brzeg Dolny | 125 | 36,87% |
| PL61 | Wloclawek | 214 | 63,13% |
| PT16 | Estarreja | 116 | 81,69% |
| PT17 | Povoa | 26 | 18,31% |
| RO21 | Borzesti | 93 | 24,22% |
| RO41 | Rimnicu Valcea | 291 | 75,78% |
| SI03 | Hrastnik | 16 | 100,00% |
| SK02 | Novaky | 76 | 100,00% |
| FI1C | Joutseno | 75 | 65,22% |
| FI1D | Oulu | 40 | 34,78% |
| SE23 | Stenungsund | 120 | 100,00% |

| | | | |
|---|---|---|---|
| UKD6 | Runcorn | 707 | 96,98% |
| UKH1 | Thetford | 7 | 0,96% |
| UKI5 | West Thurrock | 15 | 2,06% |
| NO08 | Sarpsborg | 45 | 14,29% |
| NO09 | Rafnes | 260 | 82,54% |
| NO0A | Bremanger | 10 | 3,17% |
| CH03 | Pratteln | 27 | 100,00% |
| ME | No data | | 100,00% per NUTS2 |
| MK | No data | | 100,00% per NUTS2 |
| AL | No data | | 33,33% per NUTS2 |
| RS | No data | | 25,00% per NUTS2 |
| BA | No data | | 100,00% per NUTS2 |
| LI | No data | | 100,00% per NUTS2 |
| IS | No data | | 100,00% per NUTS2 |

**Table 19: Production capacities in the chlorine sector by NUTS2, based on [57].**

# Annex F: Capacities of the methanol industry

| NUTS2 | City | Installed capacity methanol | Methanol % |
|---|---|---|---|
| BE | No data | | 9,09% per NUTS2 |
| BG | No data | | 16,67% per NUTS2 |
| CZ | No data | | 12,50% per NUTS2 |
| DK | No data | | 20,00% per NUTS2 |
| DEA1 | Gelsenkirchen | 300 | 16,30% |
| DEA2 | Wesseling | 400 | 21,74% |
| DEB3 | Ludwigshafen | 480 | 26,09% |
| DEE0 | Leuna | 660 | 35,87% |
| EE | No data | | 100,00% per NUTS2 |
| IE | No data | | 33,33% per NUTS2 |
| EL | No data | | 7,69% per NUTS2 |
| ES | No data | | 5,26% per NUTS2 |
| FR | No data | | 3,70% per NUTS2 |
| HR | No data | | 25,00% per NUTS2 |
| IT | No data | | 4,76% per NUTS2 |

| | | | |
|---|---|---|---|
| CY | No data | | 100,00% per NUTS2 |
| LV | No data | | 100,00% per NUTS2 |
| LT02 | Jonava | 130 | 100,00% |
| LU | No data | | 100,00% per NUTS2 |
| HU | No data | | 12,50% per NUTS2 |
| MT | No data | | 100,00% per NUTS2 |
| NL11 | Delfzijl | 1000 | 100,00% |
| AT | No data | | 11,11% per NUTS2 |
| PL22 | Chorzow | 100 | 100,00% |
| PT | No data | | 14,29% per NUTS2 |
| RO12 | Victoria | 225 | 100,00% |
| SI0 | No data | | 50,00% per NUTS2 |
| SK | No data | | 25,00% per NUTS2 |
| FI | No data | | 20,00% per NUTS2 |
| UK | No data | | 2,44% per NUTS2 |
| NO06 | Tjeldberggodden | 900 | 100,00% |
| CH | No data | | 14,29% per NUTS2 |
| ME | No data | | 100,00% per NUTS2 |

| | | | |
|---|---|---|---|
| MK | No data | | 100,00% per NUTS2 |
| AL | No data | | 33,33% per NUTS2 |
| RS12 | Kikinda | 200 | 100,00% |
| BA | No data | | 100,00% per NUTS2 |

**Table 20: Production capacities in the methanol sector by NUTS2, based on [58].**

# Annex G: Capacities of the ethylene industry

| **NUTS2** | **City** | **Installed capacity ethylene** | **Ethylene %** |
|---|---|---|---|
| BE21 | Antwerp | 1120000 | 82,35% |
| BE23 | Kallo | 240000 | 17,65% |
| BG | No data | | 16,67% per NUTS2 |
| CZ04 | Litvinov | 272000 | 100,00% |
| DK | No data | | 20,00% per NUTS2 |
| DE21 | Burghausen<br>Munchmunster | 425000 | 15,04% |
| DEA1 | Gelsenkirchen | 525000 | 18,58% |
| DEA2 | Köln-Worringen<br>Wesseling | 1232500 | 43,63% |
| DEB3 | Ludwigshafen | 310000 | 10,97% |
| DED5 | Boehlen | 282500 | 10,00% |
| DEF0 | Heide | 50000 | 1,77% |
| IE | No data | | 33,33% per NUTS2 |
| EL | No data | | 7,69% per NUTS2 |
| ES42 | Puertollano | 51000 | 6,90% |
| ES51 | Tarragona | 688500 | 93,10% |

| | | | |
|---|---|---|---|
| FRD2 | Gonfreville<br>ND Gravenchon | 475000 | 34,05% |
| FRE1 | Dunkirk | 190000 | 13,62% |
| FRK2 | Feyzin | 125000 | 8,96% |
| FRL0 | Berre<br>Lavera | 605000 | 43,37% |
| HR | No data | | 25,00% per NUTS2 |
| ITF4 | Brindisi (BR) | 234000 | 29,44% |
| ITG1 | Priolo Gargallo (SR) | 279225 | 35,13% |
| ITH3 | Porto Marghera (VE) | 281600 | 35,43% |
| HU31 | Tiszaujvaros | 332500 | 100,00% |
| NL34 | Terneuzen | 912500 | 44,66% |
| NL41 | Moerdijk | 455000 | 22,27% |
| NL42 | Geleen | 675500 | 33,06% |
| AT12 | Schwechat | 250000 | 100,00% |
| PL92 | Plock | 350000 | 100,00% |
| PT18 | Sines | 500000 | 100,00% |
| RO | No data | | 12,50% per NUTS2 |
| SI | No data | | 50,00% per NUTS2 |

| | | | |
|---|---|---|---|
| SK01 | Bratislava | 110000 | 100,00% |
| FI1B | Porvoo | 210000 | 100,00% |
| SE23 | Stenungsund | 312500 | 100,00% |
| UKC1 | Wilton | 432500 | 37,04% |
| UKM7 | Grangemouth Mossmorran | 735000 | 62,96% |
| CH | No data | | 14,29% per NUTS2 |
| ME | No data | | 100,00% per NUTS2 |
| MK | No data | | 100,00% per NUTS2 |
| AL | No data | | 33,33% per NUTS2 |
| RS | No data | | 25,00% per NUTS2 |
| BA | No data | | 100,00% per NUTS2 |

**Table 21: Production capacities in the ethylene sector by NUTS2, based on [59].**

# Annex H: Capacities of the propylene industry

| NUTS2 | City | Installed capacity propylene | Propylene % |
|---|---|---|---|
| BE21 | Antwerp | 1120000 | 82,35% |
| BE23 | Kallo | 240000 | 17,65% |
| CZ04 | Litvinov | 272000 | 100,00% |
| DE21 | Burghausen<br>Munchmunster | 425000 | 15,04% |
| DEA1 | Gelsenkirchen | 525000 | 18,58% |
| DEA2 | Köln-Worringen<br>Wesseling | 1232500 | 43,63% |
| DEB3 | Ludwigshafen | 310000 | 10,97% |
| DED5 | Boehlen | 282500 | 10,00% |
| DEF0 | Heide | 50000 | 1,77% |
| ES42 | Puertollano | 51000 | 6,90% |
| ES51 | Tarragona | 688500 | 93,10% |
| FRD2 | Gonfreville<br>ND Gravenchon | 475000 | 34,05% |
| FRE1 | Dunkirk | 190000 | 13,62% |
| FRK2 | Feyzin | 125000 | 8,96% |

|  |  |  |  |
|---|---|---|---|
| FRL0 | Berre<br>Lavera | 605000 | 43,37% |
| ITF4 | Brindisi (BR) | 234000 | 29,44% |
| ITG1 | Priolo Gargallo (SR) | 279225 | 35,13% |
| ITH3 | Porto Marghera (VE) | 281600 | 35,43% |
| HU31 | Tiszaujvaros | 332500 | 100,00% |
| NL34 | Terneuzen | 912500 | 44,66% |
| NL41 | Moerdijk | 455000 | 22,27% |
| NL42 | Geleen | 675500 | 33,06% |
| AT12 | Schwechat | 250000 | 100,00% |
| PL92 | Plock | 350000 | 100,00% |
| PT18 | Sines | 500000 | 100,00% |
| SK01 | Bratislava | 110000 | 100,00% |
| FI1B | Porvoo | 210000 | 100,00% |
| SE23 | Stenungsund | 312500 | 100,00% |
| UKC1 | Wilton | 432500 | 37,04% |
| UKM7 | Grangemouth<br>Mossmorran | 735000 | 62,96% |

**Table 22: Production capacities in the propylene sector by NUTS2, based on [59].**

# Annex I: Capacities of the aromatic industry

| NUTS2 | City | Installed capacity toluene | Installed capacity benzene | Installed capacity orthoxylene | Installed capacity paraxylene | Installed capacity aromatic | Aromatic % |
|---|---|---|---|---|---|---|---|
| BE21 | Antwerp Geel | 65 | 690 |  | 600 | 1355 | 100,00% |
| DE21 | Burghausen |  | 160 |  |  | 160 | 3,97% |
| DE40 | Schwedt | 55 |  | 40 | 70 | 165 | 4,09% |
| DE94 | Lingen | 60 |  |  |  | 60 | 1,49% |
| DEA1 | Gelsenkirchen Dormagen | 350 | 680 | 70 | 190 | 1290 | 31,97% |
| DEA2 | Wesseling Godorf Köln | 250 | 1040 | 60 | 140 | 1490 | 36,93% |
| DEB3 | Ludwigshafen | 85 | 320 |  |  | 405 | 10,04% |
| DED5 | Boehlen |  | 320 |  |  | 320 | 7,93% |
| DEF0 | Heide | 130 |  | 15 |  | 145 | 3,59% |
| ES42 | Puertollano |  | 125 |  |  | 125 | 8,62% |
| ES51 | Tarragona |  | 190 |  |  | 190 | 13,10% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ES61 | Huelva Algeciras | 350 | 645 | 40 | 100 | 1135 | 78,28% |
| FRD2 | Gonfreville | 35 | 360 | 110 | 135 | 640 | 51,61% |
| FRF3 | Carling | | 325 | | | 325 | 26,21% |
| FRK2 | Feyzin | 35 | | | | 35 | 2,82% |
| FRL0 | Lavera | | 240 | | | 240 | 19,35% |
| ITG1 | Priolo | 100 | 440 | 70 | | 610 | 57,01% |
| ITG2 | Porto Torres Sarroch | | 220 | 90 | 100 | 410 | 38,32% |
| ITH3 | Porto Marghera | 50 | | | | 50 | 4,67% |
| HU12 | Szazhalombatta | 90 | | 50 | | 140 | 100,00% |
| NL33 | Botlek | 260 | 830 | 130 | 700 | 1920 | 51,34% |
| NL34 | Terneuzen | | 915 | | | 915 | 24,47% |
| NL41 | Moerdijk | | 550 | | | 550 | 14,71% |
| NL42 | Geleen | | 355 | | | 355 | 9,49% |
| PL61 | Wloclawek | | | 60 | 400 | 460 | 57,14% |
| PL92 | Plock | 285 | | 10 | 50 | 345 | 42,86% |
| PT11 | Oporto | 170 | | 50 | 140 | 360 | 100,00% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RO22 | Navodari | | | | 20 | 20 | 100,00% |
| SK01 | Bratislava | 40 | | 15 | 50 | 105 | 100,00% |
| FI1B | Porvoo | | 150 | | | 150 | 100,00% |
| UKC1 | Middlesbrough | | 510 | | | 510 | 40,96% |
| UKD6 | Stanlow | | 240 | | | 240 | 19,28% |
| UKE1 | Immingham | | 200 | | | 200 | 16,06% |
| UKM7 | Grangemouth | | 295 | | | 295 | 23,69% |

**Table 23: Production capacities in the aromatic sector by NUTS2, based on [60-63].**

# Annex J: Capacities of the paper industry

| NUTS2 | Excess heat paper | Paper % |
|---|---|---|
| BE21 | 4632635 | 17,8291% |
| BE22 | 7021884 | 27,0243% |
| BE23 | 11290458 | 43,4523% |
| BE31 | 1497788 | 5,7644% |
| BE33 | 1058888 | 4,0752% |
| BE34 | 481894 | 1,8546% |
| BG31 | 279328694 | 1,4808% |
| BG41 | 3400598306 | 18,0280% |
| BG42 | 15182982093 | 80,4912% |
| CZ04 | 264546116629 | 65,1581% |
| CZ05 | 313326 | 0,0001% |
| CZ06 | 1569720872 | 0,3866% |
| CZ07 | 7754353478 | 1,9099% |
| CZ08 | 132136009621 | 32,5453% |
| DK04 | 1 | 100,0000% |
| DE11 | 38086723102 | 1,5102% |

| | | |
|---|---|---|
| DE12 | 99892828330 | 3,9608% |
| DE13 | 5790829828 | 0,2296% |
| DE14 | 19327813068 | 0,7664% |
| DE21 | 142552909674 | 5,6523% |
| DE22 | 124340219373 | 4,9302% |
| DE24 | 2144730171 | 0,0850% |
| DE26 | 259425377138 | 10,2864% |
| DE27 | 140357856315 | 5,5653% |
| DE40 | 238137396846 | 9,4423% |
| DE71 | 23046879724 | 0,9138% |
| DE73 | 123048844164 | 4,8790% |
| DE91 | 755280529 | 0,0299% |
| DE92 | 127401608719 | 5,0516% |
| DE93 | 2458914 | 0,0001% |
| DE94 | 105733132039 | 4,1924% |
| DEA1 | 26587907292 | 1,0542% |
| DEA2 | 160489766578 | 6,3635% |
| DEA3 | 27579368352 | 1,0935% |

| | | |
|---|---|---|
| DEA4 | 2903573382 | 0,1151% |
| DEA5 | 36865495217 | 1,4617% |
| DEB1 | 20246947518 | 0,8028% |
| DEB3 | 78127971226 | 3,0978% |
| DED2 | 6649934904 | 0,2637% |
| DED4 | 22837674678 | 0,9055% |
| DED5 | 65413454521 | 2,5937% |
| DEE0 | 345477203885 | 13,6984% |
| DEF0 | 47214850169 | 1,8721% |
| DEG0 | 231581640082 | 9,1824% |
| EE00 | 654948 | 100,0000% |
| EL30 | 6943278552 | 29,6257% |
| EL51 | 2023302626 | 8,6331% |
| EL52 | 7751165434 | 33,0728% |
| EL61 | 2378511543 | 10,1487% |
| EL63 | 132361 | 0,0006% |
| EL64 | 4340278020 | 18,5192% |
| ES11 | 280692 | 0,0001% |

| | | |
|---|---|---|
| ES21 | 264364166671 | 64,2363% |
| ES22 | 1331063050 | 0,3234% |
| ES24 | 13593864343 | 3,3031% |
| ES30 | 48661481313 | 11,8240% |
| ES41 | 4030641952 | 0,9794% |
| ES51 | 69211870982 | 16,8174% |
| ES52 | 10324557904 | 2,5087% |
| ES61 | 31251212 | 0,0076% |
| FRB0 | 22378252717 | 5,0507% |
| FRC1 | 5759325 | 0,0013% |
| FRC2 | 7450841733 | 1,6816% |
| FRD1 | 122378128 | 0,0276% |
| FRD2 | 56711914308 | 12,7996% |
| FRE1 | 49711063719 | 11,2195% |
| FRE2 | 42850471588 | 9,6711% |
| FRF1 | 41157618547 | 9,2891% |
| FRF2 | 37946146622 | 8,5643% |
| FRF3 | 102324495663 | 23,0941% |

|  |  |  |
|---|---|---|
| FRG0 | 32357111880 | 7,3028% |
| FRI1 | 7360726719 | 1,6613% |
| FRI2 | 32530279449 | 7,3419% |
| FRI3 | 2072784912 | 0,4678% |
| FRJ2 | 35411512 | 0,0080% |
| FRK1 | 258138102 | 0,0583% |
| FRK2 | 45221075 | 0,0102% |
| FRL0 | 7757275506 | 1,7508% |
| HR03 | 184037097 | 100,00% |
| ITC1 | 93120557301 | 16,3849% |
| ITC3 | 4240627701 | 0,7462% |
| ITC4 | 25679947817 | 4,5185% |
| ITF1 | 6715770921 | 1,1817% |
| ITF3 | 15460794157 | 2,7204% |
| ITF4 | 4806403699 | 0,8457% |
| ITG1 | 3614911801 | 0,6361% |
| ITG2 | 208110315 | 0,0366% |
| ITH2 | 54287858831 | 9,5521% |

|  |  |  |
|---|---|---|
| ITH3 | 89562790115 | 15,7589% |
| ITH4 | 52090124685 | 9,1654% |
| ITH5 | 14743415601 | 2,5942% |
| ITI1 | 135729010552 | 23,8820% |
| ITI3 | 15497607599 | 2,7269% |
| ITI4 | 52575074743 | 9,2508% |
| LT01 | 3309025 | 97,2502% |
| LT02 | 93564 | 2,7498% |
| HU21 | 6455916 | 94,2057% |
| HU32 | 397083 | 5,7943% |
| NL11 | 300670 | 0,7302% |
| NL22 | 15706045 | 38,1424% |
| NL32 | 309789 | 0,7523% |
| NL41 | 8603465 | 20,8937% |
| NL42 | 16257432 | 39,4814% |
| AT12 | 23655401116 | 2,6834% |
| AT22 | 534650926466 | 60,6487% |
| AT31 | 303775918818 | 34,4592% |

| | | |
|---|---|---|
| AT32 | 7104626364 | 0,8059% |
| AT34 | 12366080727 | 1,4028% |
| PL21 | 3436156205 | 0,6795% |
| PL22 | 15710795617 | 3,1067% |
| PL41 | 5142848627 | 1,0170% |
| PL43 | 3180947226 | 0,6290% |
| PL51 | 9473579179 | 1,8733% |
| PL52 | 18017222456 | 3,5628% |
| PL61 | 410080820441 | 81,0905% |
| PL63 | 29313390704 | 5,7965% |
| PL92 | 11351680521 | 2,2447% |
| PT11 | 7085083152 | 48,2697% |
| PT16 | 3622463333 | 24,6793% |
| PT17 | 3970575826 | 27,0510% |
| RO11 | 46782 | 0,2678% |
| RO12 | 8293089 | 47,4815% |
| RO21 | 3449371 | 19,7491% |
| RO22 | 779324 | 4,4620% |

| | | |
|---|---|---|
| RO31 | 4897358 | 28,0395% |
| SI03 | 9720340 | 67,2682% |
| SI04 | 4729796 | 32,7318% |
| SK03 | 354096504 | 4,4981% |
| SK04 | 7518107784 | 95,5019% |
| FI19 | 1187107236408 | 25,6383% |
| FI1B | 110795049837 | 2,3929% |
| FI1C | 1872748915987 | 40,4462% |
| FI1D | 1459566036956 | 31,5226% |
| SE11 | 9471112902 | 0,2264% |
| SE12 | 525007892283 | 12,5489% |
| SE21 | 736445269966 | 17,6027% |
| SE22 | 213989938263 | 5,1148% |
| SE23 | 316050389656 | 7,5543% |
| SE31 | 905650392574 | 21,6471% |
| SE32 | 786396733395 | 18,7967% |
| SE33 | 700164610074 | 16,7355% |
| UKC2 | 1 | 0,0000% |

| | | |
|---|---|---|
| UKD1 | 44241240712 | 22,0530% |
| UKD3 | 41242444450 | 11,5939% |
| UKD4 | 22279452043 | 6,2631% |
| UKE4 | 1277610474 | 0,3592% |
| UKF1 | 4424043619 | 1,2437% |
| UKF2 | 9927075 | 0,0028% |
| UKG3 | 20666440473 | 5,8097% |
| UKH1 | 66471704901 | 18,6862% |
| UKJ4 | 98413433852 | 27,6655% |
| UKK1 | 410451 | 0,0001% |
| UKK2 | 9270861084 | 2,6062% |
| UKL1 | 8074021 | 0,0023% |
| UKL2 | 41059588883 | 11,5425% |
| UKM5 | 826104 | 0,0002% |
| UKM7 | 2063550144 | 0,5801% |
| UKM9 | 4296209793 | 1,2077% |

**Table 24: Production capacities in the paper sector by NUTS2, based on [20].**

# Annex K: Capacities of the cement industry

| NUTS2 | Excess heat cement | Fuel demand cement | Excess heat cement % | Fuel demand cement % | Cement % |
|---|---|---|---|---|---|
| BE32 | 2348,49582 | 14362,55684 | 65,00% | 74,72% | 74,72% |
| BE33 | 1264,379766 | 4858,722358 | 35,00% | 25,28% | 25,28% |
| BG31 | 1051,784939 | 4041,769042 | 64,69% | 47,84% | 47,84% |
| BG33 | 574,1862202 | 4406,727829 | 35,31% | 52,16% | 52,16% |
| CZ01 | 544,9141118 | 2093,980344 | 19,14% | 19,14% | 19,14% |
| CZ04 | 452,0437395 | 1737,100737 | 15,88% | 15,88% | 15,88% |
| CZ05 | 580,7195565 | 2231,572482 | 20,40% | 20,40% | 20,40% |
| CZ06 | 676,9466891 | 2601,351351 | 23,78% | 23,78% | 23,78% |
| CZ07 | 591,908758 | 2274,570025 | 20,79% | 20,79% | 20,79% |
| DK05 | 1907,92879 | 8379,124704 | 100,00% | 100,00% | 100,00% |
| DE11 | 513,5843477 | 1973,587224 | 2,40% | 2,28% | 2,28% |
| DE12 | 1062,97414 | 4084,766584 | 4,98% | 4,73% | 4,73% |
| DE14 | 2043,148189 | 7851,351352 | 9,56% | 9,09% | 9,09% |
| DE21 | 843,6657912 | 3242,014742 | 3,95% | 3,75% | 3,75% |
| DE23 | 975,6983683 | 3749,385749 | 4,57% | 4,34% | 4,34% |

| | | | | | |
|---|---|---|---|---|---|
| DE25 | 297,6327592 | 1143,734644 | 1,39% | 1,32% | 1,32% |
| DE26 | 1370,677181 | 5267,199017 | 6,42% | 6,10% | 6,10% |
| DE27 | 763,1035405 | 2932,432432 | 3,57% | 3,39% | 3,39% |
| DE40 | 1656,001818 | 6363,636363 | 7,75% | 7,36% | 7,36% |
| DE71 | 218,1894288 | 838,4520886 | 1,02% | 0,97% | 0,97% |
| DE73 | 228,2597101 | 877,1498771 | 1,07% | 1,02% | 1,02% |
| DE92 | 1048,011922 | 5071,086251 | 4,91% | 5,87% | 5,87% |
| DEA3 | 2635,056947 | 10125,92138 | 12,33% | 11,72% | 11,72% |
| DEA4 | 258,4705541 | 993,2432433 | 1,21% | 1,15% | 1,15% |
| DEA5 | 2797,300368 | 10749,38575 | 13,09% | 12,44% | 12,44% |
| DEB2 | 195,8110258 | 752,4570025 | 0,92% | 0,87% | 0,87% |
| DEB3 | 764,2224607 | 2936,732187 | 3,58% | 3,40% | 3,40% |
| DEE0 | 1695,164023 | 6514,127764 | 7,94% | 7,54% | 7,54% |
| DEF0 | 854,7046786 | 6559,633025 | 4,00% | 7,59% | 7,59% |
| DEG0 | 1141,29855 | 4385,749386 | 5,34% | 5,08% | 5,08% |
| EE00 | 277,0923348 | 2126,610602 | 100,00% | 100,00% | 100,00% |
| IE06 | 1782,561365 | 7831,529737 | 100,00% | 100,00% | 100,00% |
| EL30 | 166,7191019 | 640,6633905 | 3,78% | 2,82% | 2,82% |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| EL52 | 779,8873428 | 2996,928747 | 17,70% | 13,19% | 13,19% |
| EL61 | 1476,974595 | 5675,675677 | 33,52% | 24,99% | 24,99% |
| EL63 | 480,7040893 | 3250,236639 | 10,91% | 14,31% | 14,31% |
| EL64 | 1501,333848 | 10151,1312 | 34,08% | 44,69% | 44,69% |
| ES12 | 716,1088943 | 2751,842752 | 5,41% | 4,95% | 4,95% |
| ES13 | 414,0004545 | 1590,909091 | 3,13% | 2,86% | 2,86% |
| ES21 | 1061,85522 | 4080,466831 | 8,03% | 7,34% | 7,34% |
| ES24 | 399,4544927 | 1535,012285 | 3,02% | 2,76% | 2,76% |
| ES30 | 567,2925148 | 2179,97543 | 4,29% | 3,92% | 3,92% |
| ES41 | 1182,074552 | 7627,614128 | 8,94% | 13,72% | 13,72% |
| ES42 | 722,8224152 | 2777,641278 | 5,47% | 5,00% | 5,00% |
| ES43 | 438,6166978 | 1685,503686 | 3,32% | 3,03% | 3,03% |
| ES51 | 2995,813088 | 12793,74148 | 22,65% | 23,02% | 23,02% |
| ES52 | 642,2601647 | 2468,058968 | 4,86% | 4,44% | 4,44% |
| ES53 | 135,1471052 | 913,7847642 | 1,02% | 1,64% | 1,64% |
| ES61 | 3950,907041 | 15182,43243 | 29,87% | 27,31% | 27,31% |
| FR10 | 335,6760443 | 1289,92629 | 2,90% | 2,53% | 2,53% |
| FRB0 | 563,7909529 | 2348,87267 | 4,88% | 4,60% | 4,60% |

| | | | | | |
|---|---|---|---|---|---|
| FRC2 | 319,3161153 | 1402,352941 | 2,76% | 2,75% | 2,75% |
| FRD1 | 310,7438706 | 1364,705882 | 2,69% | 2,67% | 2,67% |
| FRD2 | 553,865473 | 2128,378378 | 4,79% | 4,17% | 4,17% |
| FRE1 | 405,4368349 | 3111,620795 | 3,51% | 6,09% | 6,09% |
| FRE2 | 132,0325774 | 507,3710075 | 1,14% | 0,99% | 0,99% |
| FRF1 | 250,638113 | 963,1449632 | 2,17% | 1,89% | 1,89% |
| FRF2 | 822,4063083 | 3160,31941 | 7,11% | 6,19% | 6,19% |
| FRF3 | 931,1600811 | 4089,411765 | 8,05% | 8,01% | 8,01% |
| FRG0 | 1064,09306 | 4089,066338 | 9,20% | 8,01% | 8,01% |
| FRI3 | 1586,507662 | 6403,645035 | 13,72% | 12,54% | 12,54% |
| FRJ1 | 1049,55 | 4033,17 | 9,08% | 7,90% | 7,90% |
| FRJ2 | 203,6059009 | 1376,662636 | 1,76% | 2,70% | 2,70% |
| FRK1 | 200,2867064 | 769,6560197 | 1,73% | 1,51% | 1,51% |
| FRK2 | 1846,281429 | 9964,525858 | 15,97% | 19,52% | 19,52% |
| FRL0 | 985 | 4052 | 8,52% | 7,94% | 7,94% |
| HR03 | 1418,203314 | 5449,83108 | 70,91% | 70,91% | 70,91% |
| HR05 | 581,9358227 | 2236,246314 | 29,09% | 29,09% | 29,09% |
| ITC1 | 850,3793121 | 3267,813268 | 6,90% | 6,32% | 6,32% |

| | | | | | |
|---|---|---|---|---|---|
| ITC4 | 3140,695789 | 13534,07919 | 25,49% | 26,16% | 26,16% |
| ITF1 | 195,8110258 | 752,4570025 | 1,59% | 1,45% | 1,45% |
| ITF2 | 510,2275872 | 1960,687961 | 4,14% | 3,79% | 3,79% |
| ITF3 | 585,1952371 | 2248,771499 | 4,75% | 4,35% | 4,35% |
| ITF4 | 1165,28026 | 4818,954422 | 9,46% | 9,31% | 9,31% |
| ITF6 | 261,3507311 | 1419,232243 | 2,12% | 2,74% | 2,74% |
| ITG1 | 1420,508853 | 5643,294857 | 11,53% | 10,91% | 10,91% |
| ITG2 | 371,4687548 | 1762,595754 | 3,02% | 3,41% | 3,41% |
| ITH1 | 471,7434477 | 1812,802212 | 3,83% | 3,50% | 3,50% |
| ITH2 | 750,7954189 | 2885,135135 | 6,09% | 5,58% | 5,58% |
| ITH3 | 343,5084852 | 1320,02457 | 2,79% | 2,55% | 2,55% |
| ITH4 | 281,507289 | 1903,385732 | 2,28% | 3,68% | 3,68% |
| ITH5 | 783,2441031 | 3009,82801 | 6,36% | 5,82% | 5,82% |
| ITI3 | 145,4596192 | 558,968059 | 1,18% | 1,08% | 1,08% |
| ITI4 | 1043,011269 | 4838,281597 | 8,47% | 9,35% | 9,35% |
| CY00 | 967,2755696 | 6540,145104 | 100,00% | 100,00% | 100,00% |
| LV00 | 758,6278599 | 2915,233415 | 100,00% | 100,00% | 100,00% |
| LT02 | 615,8256789 | 4726,299694 | 100,00% | 100,00% | 100,00% |

| | | | | | |
|---|---|---|---|---|---|
| LU00 | 613,1682408 | 2356,265356 | 100,00% | 100,00% | 100,00% |
| HU12 | 507,9897469 | 1952,088452 | 43,22% | 43,22% | 43,22% |
| HU23 | 667,3743273 | 2564,566953 | 56,78% | 56,78% | 56,78% |
| NL42 | 450,481727 | 1731,09828 | 100,00% | 100,00% | 100,00% |
| AT12 | 1037,390031 | 3986,452703 | 33,38% | 33,22% | 33,22% |
| AT21 | 419,5950553 | 1612,407862 | 13,50% | 13,44% | 13,44% |
| AT22 | 483,5256374 | 1915,287296 | 15,56% | 15,96% | 15,96% |
| AT31 | 612,0493207 | 2351,965602 | 19,70% | 19,60% | 19,60% |
| AT32 | 302,1084398 | 1160,933661 | 9,72% | 9,68% | 9,68% |
| AT33 | 252,8759533 | 971,7444716 | 8,14% | 8,10% | 8,10% |
| PL22 | 402,8112531 | 1547,911548 | 4,20% | 3,43% | 3,43% |
| PL52 | 1679,908239 | 10244,93447 | 17,51% | 22,72% | 22,72% |
| PL61 | 1197,244557 | 4600,737099 | 12,48% | 10,20% | 10,20% |
| PL71 | 1008,113211 | 7737,00306 | 10,51% | 17,16% | 17,16% |
| PL72 | 4043,777412 | 15539,31204 | 42,14% | 34,47% | 34,47% |
| PL81 | 1264,292995 | 5415,452569 | 13,18% | 12,01% | 12,01% |
| PT15 | 414,0004545 | 1590,909091 | 8,52% | 8,06% | 8,06% |
| PT16 | 1761,933978 | 7834,304591 | 36,24% | 39,68% | 39,68% |

| | | | | | |
|---|---|---|---|---|---|
| PT17 | 2685,408353 | 10319,41032 | 55,24% | 52,26% | 52,26% |
| RO11 | 1054,022779 | 4050,36855 | 18,28% | 18,28% | 18,28% |
| RO12 | 945,4875245 | 3633,292383 | 16,40% | 16,40% | 16,40% |
| RO21 | 635,948336 | 2443,804054 | 11,03% | 11,03% | 11,03% |
| RO22 | 949,9632052 | 3650,491401 | 16,47% | 16,47% | 16,47% |
| RO31 | 1643,693696 | 6316,339066 | 28,51% | 28,51% | 28,51% |
| RO42 | 537,0816708 | 2063,882064 | 9,31% | 9,31% | 9,31% |
| SI03 | 13,35878764 | 51,3347666 | 2,05% | 2,05% | 2,05% |
| SI04 | 638,9034042 | 2455,159705 | 97,95% | 97,95% | 97,95% |
| SK01 | 897,3739583 | 3448,402949 | 44,07% | 41,46% | 41,46% |
| SK02 | 970,1037679 | 3727,886978 | 47,64% | 44,82% | 44,82% |
| SK04 | 168,844767 | 1141,628416 | 8,29% | 13,72% | 13,72% |
| FI1C | 822,6109358 | 3925,881862 | 100,00% | 100,00% | 100,00% |
| SE21 | 2248,736339 | 8641,379607 | 85,43% | 85,43% | 85,43% |
| SE23 | 383,4248426 | 1473,414005 | 14,57% | 14,57% | 14,57% |
| UKD4 | 657,1171864 | 2525,151106 | 11,01% | 9,80% | 9,80% |
| UKE1 | 492,7390549 | 2163,981176 | 8,25% | 8,40% | 8,40% |
| UKF1 | 616,3392583 | 4167,321401 | 10,32% | 16,18% | 16,18% |

| | | | | | |
|---|---|---|---|---|---|
| UKF2 | 729,5359361 | 2803,439804 | 12,22% | 10,88% | 10,88% |
| UKG1 | 1024,326451 | 4498,574116 | 17,16% | 17,46% | 17,46% |
| UKG2 | 678,1002959 | 2605,784398 | 11,36% | 10,12% | 10,12% |
| UKL2 | 951,520742 | 3656,476658 | 15,94% | 14,19% | 14,19% |
| UKM7 | 481,7421181 | 1851,224816 | 8,07% | 7,19% | 7,19% |
| UKN0 | 338,9647717 | 1488,644706 | 5,68% | 5,78% | 5,78% |

**Table 25: Production capacities in the cement sector by NUTS2, based on [20].**

# Annex L: Capacities of the glass industry

| NUTS2 | Excess heat glass | Fuel demand glass | Excess heat glass % | Fuel demand glass % | Glass % |
|---|---|---|---|---|---|
| BE21 | 641,4941211 | 1410,36 | 29,08% | 21,20% | 21,20% |
| BE22 | 119,438147 | 459,9 | 5,41% | 6,91% | 6,91% |
| BE32 | 437,2779169 | 2564,68 | 19,82% | 38,56% | 38,56% |
| BE35 | 1008,06219 | 2216,28 | 45,69% | 33,32% | 33,32% |
| BG31 | 149,6242529 | 470,12 | 14,56% | 19,58% | 19,58% |
| BG33 | 878,2359991 | 1930,85 | 85,44% | 80,42% | 80,42% |
| CZ03 | 91,0756322 | 286,16 | 2,99% | 0,22% | 0,22% |
| CZ04 | 2559,186552 | 5843,19908 | 83,97% | 4,43% | 4,43% |
| CZ06 | 397,4800805 | 125808,2 | 13,04% | 95,35% | 95,35% |
| DK02 | 130,108046 | 408,8 | 100,00% | 100,00% | 100,00% |
| DE11 | 39,0324138 | 122,64 | 0,28% | 0,31% | 0,31% |
| DE12 | 305,473391 | 671,6 | 2,18% | 1,68% | 1,68% |
| DE13 | 117,0972414 | 367,92 | 0,84% | 0,92% | 0,92% |
| DE14 | 591,9916093 | 1860,04 | 4,23% | 4,66% | 4,66% |
| DE21 | 279,7322989 | 878,92 | 2,00% | 2,20% | 2,20% |

| | | | | | |
|---|---|---|---|---|---|
| DE23 | 1237,167234 | 2719,98 | 8,85% | 6,81% | 6,81% |
| DE24 | 419,4767172 | 5752,23356 | 3,00% | 14,40% | 14,40% |
| DE26 | 146,3715518 | 459,9 | 1,05% | 1,15% | 1,15% |
| DE40 | 554,5515901 | 1858,7625 | 3,97% | 4,65% | 4,65% |
| DE92 | 774,1428737 | 2432,36 | 5,54% | 6,09% | 6,09% |
| DEA1 | 253,7106897 | 797,16 | 1,81% | 2,00% | 2,00% |
| DEA2 | 1145,525216 | 2518,5 | 8,19% | 6,31% | 6,31% |
| DEA3 | 1145,525216 | 2518,5 | 8,19% | 6,31% | 6,31% |
| DEA4 | 78,0648276 | 245,28 | 0,56% | 0,61% | 0,61% |
| DEA5 | 182,1512644 | 572,32 | 1,30% | 1,43% | 1,43% |
| DEB1 | 149,6242529 | 470,12 | 1,07% | 1,18% | 1,18% |
| DEB3 | 149,6242529 | 470,12 | 1,07% | 1,18% | 1,18% |
| DED2 | 169,1404598 | 531,44 | 1,21% | 1,33% | 1,33% |
| DED5 | 1069,156869 | 2350,6 | 7,65% | 5,89% | 5,89% |
| DEE0 | 4526,377481 | 10295,19 | 32,37% | 25,78% | 25,78% |
| DEF0 | 149,6242529 | 470,12 | 1,07% | 1,18% | 1,18% |
| DEG0 | 500,9159771 | 1573,88 | 3,58% | 3,94% | 3,94% |
| EE00 | 149,6242529 | 470,12 | 100,00% | 100,00% | 100,00% |

| | | | | | |
|---|---|---|---|---|---|
| EL30 | 227,6890805 | 715,4 | 60,34% | 60,34% | 60,34% |
| EL61 | 149,6242529 | 470,12 | 39,66% | 39,66% | 39,66% |
| ES12 | 878,2359991 | 1930,85 | 12,23% | 10,64% | 10,64% |
| ES13 | 305,473391 | 671,6 | 4,25% | 3,70% | 3,70% |
| ES21 | 1547,165017 | 3072,57 | 21,55% | 16,94% | 16,94% |
| ES22 | 916,420173 | 2484,92 | 12,76% | 13,70% | 13,70% |
| ES24 | 149,6242529 | 470,12 | 2,08% | 2,59% | 2,59% |
| ES41 | 492,714095 | 1476,06 | 6,86% | 8,14% | 8,14% |
| ES42 | 852,5803999 | 2059,184 | 11,87% | 11,35% | 11,35% |
| ES43 | 263,4687932 | 827,82 | 3,67% | 4,56% | 4,56% |
| ES51 | 487,9051725 | 1927 | 6,79% | 10,62% | 10,62% |
| ES52 | 870,5991644 | 1914,06 | 12,12% | 10,55% | 10,55% |
| ES61 | 266,7214943 | 838,04 | 3,71% | 4,62% | 4,62% |
| ES70 | 149,6242529 | 470,12 | 2,08% | 2,59% | 2,59% |
| FR10 | 32,5270115 | 102,2 | 0,35% | 0,43% | 0,43% |
| FRC1 | 227,6890805 | 715,4 | 2,44% | 2,99% | 2,99% |
| FRD2 | 312,2593104 | 981,12 | 3,35% | 4,10% | 4,10% |
| FRE1 | 2385,008743 | 5620,416 | 25,60% | 23,51% | 23,51% |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| FRE2 | 1062,931983 | 2619,24 | 11,41% | 10,95% | 10,95% |
| FRF1 | 885,8728339 | 1947,64 | 9,51% | 8,15% | 8,15% |
| FRF2 | 591,9916093 | 1860,04 | 6,35% | 7,78% | 7,78% |
| FRF3 | 1371,517817 | 3156,52 | 14,72% | 13,20% | 13,20% |
| FRI3 | 79,09273695 | 394,565 | 0,85% | 1,65% | 1,65% |
| FRJ1 | 273,4215803 | 1087,7 | 2,93% | 4,55% | 4,55% |
| FRJ2 | 162,6350575 | 511 | 1,75% | 2,14% | 2,14% |
| FRK1 | 110,5918391 | 347,48 | 1,19% | 1,45% | 1,45% |
| FRK2 | 1820,390576 | 4566,88 | 19,54% | 19,10% | 19,10% |
| HR05 | 318,7647127 | 1001,56 | 100,00% | 100,00% | 100,00% |
| ITC1 | 1105,554979 | 2958,325 | 9,62% | 8,34% | 8,34% |
| ITC3 | 416,3457472 | 1308,16 | 3,62% | 3,69% | 3,69% |
| ITC4 | 914,9481609 | 7775,24259 | 7,96% | 21,91% | 21,91% |
| ITF1 | 1821,526021 | 4066,1 | 15,86% | 11,46% | 11,46% |
| ITF3 | 913,3077304 | 2149,12 | 7,95% | 6,06% | 6,06% |
| ITF4 | 1177,484505 | 2871,09 | 10,25% | 8,09% | 8,09% |
| ITG1 | 149,6242529 | 470,12 | 1,30% | 1,32% | 1,32% |
| ITH2 | 598,4970116 | 1880,48 | 5,21% | 5,30% | 5,30% |

| | | | | | |
|---|---|---|---|---|---|
| ITH3 | 2351,51192 | 6523,864 | 20,47% | 18,39% | 18,39% |
| ITH4 | 1139,300331 | 2787,14 | 9,92% | 7,85% | 7,85% |
| ITH5 | 149,6242529 | 470,12 | 1,30% | 1,32% | 1,32% |
| ITI1 | 451,1222099 | 1282,61 | 3,93% | 3,61% | 3,61% |
| ITI2 | 149,6242529 | 470,12 | 1,30% | 1,32% | 1,32% |
| ITI4 | 149,6242529 | 470,12 | 1,30% | 1,32% | 1,32% |
| LT02 | 299,2485058 | 1632,24 | 100,00% | 100,00% | 100,00% |
| LU00 | 1832,840346 | 4029,6 | 100,00% | 100,00% | 100,00% |
| HU33 | 1027,860252 | 2400,97 | 100,00% | 100,00% | 100,00% |
| NL22 | 824,7781557 | 1813,32 | 38,49% | 0,32% | 0,32% |
| NL33 | 573,5033118 | 1948,005 | 26,76% | 0,34% | 0,34% |
| NL41 | 594,8806537 | 568451,76 | 27,76% | 99,26% | 99,26% |
| NL42 | 149,6242529 | 470,12 | 6,98% | 0,08% | 0,08% |
| AT12 | 182,1512644 | 572,32 | 32,94% | 32,94% | 32,94% |
| AT22 | 247,2052874 | 776,72 | 44,71% | 44,71% | 44,71% |
| AT31 | 123,6026437 | 388,36 | 22,35% | 22,35% | 22,35% |
| PL21 | 213,8313737 | 470,12 | 3,14% | 2,71% | 2,71% |
| PL22 | 2145,099656 | 5010,72 | 31,46% | 28,90% | 28,90% |

| | | | | | |
|---|---|---|---|---|---|
| PL41 | 801,2972531 | 2344,76 | 11,75% | 13,52% | 13,52% |
| PL43 | 149,6242529 | 470,12 | 2,19% | 2,71% | 2,71% |
| PL51 | 78,0648276 | 245,28 | 1,14% | 1,41% | 1,41% |
| PL52 | 91,0756322 | 286,16 | 1,34% | 1,65% | 1,65% |
| PL61 | 300,6681105 | 1126,317 | 4,41% | 6,50% | 6,50% |
| PL62 | 65,054023 | 204,4 | 0,95% | 1,18% | 1,18% |
| PL71 | 1527,366955 | 3358 | 22,40% | 19,36% | 19,36% |
| PL72 | 763,6834775 | 1679 | 11,20% | 9,68% | 9,68% |
| PL82 | 162,6350575 | 511 | 2,39% | 2,95% | 2,95% |
| PL92 | 520,432184 | 1635,2 | 7,63% | 9,43% | 9,43% |
| PT11 | 448,2222185 | 1408,316 | 35,42% | 35,42% | 35,42% |
| PT16 | 644,0348277 | 2023,56 | 50,90% | 50,90% | 50,90% |
| PT17 | 173,0437012 | 543,704 | 13,68% | 13,68% | 13,68% |
| RO12 | 137,463026 | 302,22 | 6,14% | 5,85% | 5,85% |
| RO22 | 878,2359991 | 1930,85 | 39,24% | 37,37% | 37,37% |
| RO31 | 962,2411817 | 2115,54 | 42,99% | 40,95% | 40,95% |
| RO32 | 260,216092 | 817,6 | 11,63% | 15,83% | 15,83% |
| SI03 | 91,0756322 | 286,16 | 100,00% | 100,00% | 100,00% |

| | | | | | |
|---|---|---|---|---|---|
| SK02 | 139,8661495 | 439,46 | 100,00% | 100,00% | 100,00% |
| FI1C | 381,8417388 | 839,5 | 100,00% | 100,00% | 100,00% |
| SE23 | 1982,464599 | 4499,72 | 100,00% | 100,00% | 100,00% |
| UKD4 | 878,2359991 | 1930,85 | 13,67% | 11,30% | 11,30% |
| UKD6 | 195,162069 | 613,2 | 3,04% | 3,59% | 3,59% |
| UKD7 | 878,2359991 | 1930,85 | 13,67% | 11,30% | 11,30% |
| UKE1 | 1069,156869 | 2350,6 | 16,64% | 13,76% | 13,76% |
| UKE2 | 992,7885208 | 2182,7 | 15,45% | 12,78% | 12,78% |
| UKE3 | 442,3673564 | 1389,92 | 6,89% | 8,14% | 8,14% |
| UKE4 | 491,1578737 | 1543,22 | 7,65% | 9,03% | 9,03% |
| UKF1 | 715,7575535 | 2750,492629 | 11,14% | 16,10% | 16,10% |
| UKH3 | 162,6350575 | 511 | 2,53% | 2,99% | 2,99% |
| UKM7 | 149,6242529 | 470,12 | 2,33% | 2,75% | 2,75% |
| UKM9 | 149,6242529 | 470,12 | 2,33% | 2,75% | 2,75% |
| UKN0 | 299,2485058 | 940,24 | 4,66% | 5,50% | 5,50% |

**Table 26: Production capacities in the glass sector by NUTS2, based on [20].**

# Annex M: Capacities of the ammonia industry

| **NUTS2** | **City** | **Installed capacity ammonia** | **Ammonia %** |
|---|---|---|---|
| BE21 | Antwerp | 650 | 61,90% |
| BE32 | Tertre | 400 | 38,10% |
| BG33 | Varna | 372,6666667 | 33,33% |
| BG41 | Sofia | 372,6666667 | 33,33% |
| BG42 | Plovdiv | 372,6666667 | 33,33% |
| CZ01 | Prague | 350 | 100,00% |
| DEA1 | Gelsenkirchen | 260 | 7,99% |
| DEA2 | Cologne | 330 | 10,14% |
| DEB3 | Ludwigshafen | 875 | 26,88% |
| DEE0 | Lutherstadt Wittenberg | 1090 | 33,49% |
| DEF0 | Brunsbuttel | 700 | 21,51% |
| EE00 | Estonia | 200 | 100,00% |
| EL51 | Kavalla | 150 | 100,00% |
| ES42 | Puertollano | 200 | 32,52% |
| ES61 | Palos de la Frontera | 415 | 67,48% |

| | | | |
|---|---|---|---|
| FRB0 | Grandpuits | 390 | 24,68% |
| FRD2 | Le Grand Quevilly Le Havre | 790 | 50,00% |
| FRF1 | Ottmarsheim | 240 | 15,19% |
| FRI1 | Pardies | 160 | 10,13% |
| ITH5 | Ferrara | 500 | 100,00% |
| LT02 | Vilnius | 1118 | 100,00% |
| HU12 | Szalombatta | 191,5 | 50,00% |
| HU21 | Veszprem | 191,5 | 50,00% |
| NL34 | Sluiskil | 1700 | 63,67% |
| NL42 | Geleen | 970 | 36,33% |
| AT31 | Linz | 500 | 100,00% |
| PL41 | Pyzdry | 642 | 20,00% |
| PL61 | Varsovia | 1284 | 40,00% |
| PL71 | Lodz | 1284 | 40,00% |
| PT17 | Barreiro | 300 | 100,00% |
| RO12 | Brasov | 1088 | 50,00% |
| RO22 | Navodari | 362,6666667 | 16,67% |
| RO32 | Bucarest | 725,3333333 | 33,33% |

|  |  |  |  |
|---|---|---|---|
| SK01 | Bratislava | 429 | 100,00% |
| UKC1 | Billingham | 530 | 44,17% |
| UKD6 | Ince | 400 | 33,33% |
| UKE1 | Hull | 270 | 22,50% |
| NO09 | Porsgrunn | 500 | 100,00% |

**Table 27: Production capacities in the ammonia sector by NUTS2, based on [64].**