D2.3 WP2 Report – Open Data Set for the EU28

Prepared by Simon Pezzutto, Stefano Zambotti, Silvia Croce, Pietro Zambelli, Giulia Garegnani, Chiara Scaramuzzino, Ramón Pascual Pascuas, Franziska Haas, Dagmar Exner, Elena Lucchi, Nives Della Valle, Alyona Zubaryeva (EURAC), Andreas Müller (e-think), Michael Hartner (TUW), Tobias Fleiter, Anna-Lena Klingler, Matthias Kühnbach, Pia Manz, Simon Marwitz, Matthias Rehfeldt, Jan Steinbach, Eftim Popovski (Fraunhofer ISI)

Reviewed by Lukas Kranzl, Sara Fritz (TUW)

04.09.2019

Funded by the Horizon 2020 programme
of the European Union

Project Information

Project name	**Hotmaps** – Heating and Cooling Open Source Tool for Mapping and Planning of Energy Systems
Grant agreement number	723677
Project duration	2016-2020
Project coordinator	Lukas Kranzl Technische Universität Wien (TU Wien), Institute of Energy Systems and Electrical Drives, Energy Economics Group (EEG) Gusshausstrasse 25-29/370-3 A-1040 Wien / Vienna, Austria Phone: +43 1 58801 370351 E-Mail: kranzl@eeg.tuwien.ac.at **info@hotmaps-project.eu** www.eeg.tuwien.ac.at www.hotmaps-project.eu
Lead author of this report	Simon Pezzutto Eurac Research +39 0471 055622 simon.pezzutto@eurac.edu

Legal notice

The sole responsibility for the contents of this publication lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the INEA nor the European Commission is responsible for any use that may be made of the information contained therein.

The Hotmaps project

The EU-funded project Hotmaps aims at designing a toolbox to support public authorities, energy agencies and urban planners in strategic heating and cooling planning on local, regional and national levels, and in line with EU policies.

In addition to guidelines and handbooks on how to carry out strategic heating and cooling (H&C) planning, Hotmaps will provide the first H&C planning software that is

- **User-driven**: developed in close collaboration with 7 European pilot areas
- **Open source**: the developed tool and all related modules will run without requiring any other commercial tool or software. Use of and access to Source Code is subject to Open Source License.
- **EU28 compatible**: the tool will be applicable for cities in all 28 EU Member States

The consortium behind

Scientific partners

TECHNISCHE UNIVERSITÄT WIEN Vienna | Austria

AALBORG UNIVERSITET

cem

energycities WHERE ACTION & VISION MEET

Hes·so Haute Ecole Spécialisée de Suisse occidentale Fachhochschule Westschweiz University of Applied Sciences and Arts Western Switzerland

EURAC research

Fraunhofer ISI

e think Energy Research

PlanEnergi

e· energy center

Pilot areas for developing and testing the tool

Aalborg Kommune

VILLE DE GENÈVE

Bistrita Municipality

STADT FRANKFURT AM MAIN Energiereferat > Die kommunale Klimaschutzagentur

MILTON KEYNES COUNCIL

Kerry County Council

donostiasustapena fomentosansebastián DONOSTIAKO GARAPEN EKONOMIKOA

Executive Summary

The scope of this report is to summarize the process of data collection required for the open source tool Hotmaps as generic default information with regard to the 28 European Union member states at different spatial levels. Data has been collected at national or if available at regional/local levels. Data has been generated for four different sectors: residential (single family houses, multifamily houses, and apartment blocks), service (offices, trade, education, health, hotels and restaurants, and other non-residential buildings), industry (iron and steel, non-ferrous metals, paper and printing, non-metallic minerals, chemical industry, food, drink and tobacco, engineering and others not classified), and transport (passenger transport - public, private, rail and freight transport - heavy goods and light commercial vehicles).

Data for heating, cooling and domestic hot water differ widely in their quality regarding completeness, accuracy, and reliability. Concerning buildings, in contrast to space heating and domestic hot water, the European Union space cooling market is barely explored in scientific literature. While the focus of previous research has been on the residential sector, a shortfall of data for services exists. With regard to the industrial sector, national average values are used even though there is a high variety of production processes, utilized energy carriers and efficiency measures for industrial sites within the same subsectors. Regarding transport, data availability on the electricity need is underexplored.

All collected information on space heating, space cooling and domestic hot water have been filtered and statistically evaluated. According to the number of sources, the coefficient of variation has been used as statistical indicator of uncertainty and to exclude values outside a range of plus or minus the standard deviation around the average. The filtered values have been used to compute a more robust average.

Filling in the gaps, implied not only extrapolating and assembling data from large data tools (e.g. EU Building Stock Observatory, Invert/EE-Lab, BPIE etc.), but also researching data source-by-source from single scientific literature fonts as journal papers, conference proceedings and project deliverables. It is only by following such an in-depth approach that we were able to fill lacks of data.

With regard to the total useful energy demand (residential and service sectors) for space heating, space cooling and domestic hot water within the entire European Union 28, the highest position is held by space heating with approximately 2685 TWh/y, followed by domestic hot water with around 429 TWh/y and space cooling (207 TWh/y). The European Union 15 is responsible for practically the entire useful energy demand for space cooling of the European Union 28, with about 87%.

Concerning nearly zero-energy building, it has to be pointed out that the Energy Performance of Building Directive implementation at national level is very diverse from country to country and some member states have not defined yet what a nearly zero-energy building is. This makes almost impossible a direct comparison between member states. The requirements used in national nearly zero-energy building definitions accustomed to be principally the same, i.e. primary energy, share of renewable energy and thermal transmittance of building envelope components. Nevertheless, the methodologies to calculate primary energy are different, and the shares of renewable energy, as well as the values of the primary energy factors, are politically defined by each member state. Concerning the other nearly zero-energy building requirements, these tend to depend on climatic conditions.

Regarding the heat density maps, it was possible to produce these at hectare level – 100 x 100 m.

Concerning the climate context, it was possible to collect the main variables with a spatial resolution of 1 km in average.

With regard to industrial processes, results include an EU-wide database on energy consumption and excess heat potentials of energy-intensive companies, a dataset with techno-economic characteristics of steam generation technologies, and benchmarking indicators for energy consumption in industrial sectors.

The part on heating and cooling supply provides two data sets related to heat supply. First, the regional heat supply mix by type of energy carrier broken-down to the European Union 28 regions. Second, techno-economic characteristics of heat supply technologies.

Concerning the renewable energy sources data collection and potential review, it was possible to assess the potential for the entire European Union 28 at hectare level regarding forest biomass, solar energy, and wind. In contrast, other renewable energy sources potentials (e.g. municipal solid waste, agriculture biomass etc.) could be estimated at regional level.

With regard to the hourly load profiles, results contain a data set for useful heating and cooling energy demand in industry, services and residential sectors. The data set provides time series for all European Union 28 regions.

The data sets on electricity, include hourly electricity prices, CO_2 emissions and the generation mix per country. These data will be used to link heating and cooling planning with the electricity system in the Hotmaps toolbox.

Concerning transport, the dataset was created specifically to analyse the heating and cooling use within the project, it includes sets of data on final energy consumption in different transport sectors and specific data on the electricity utilization for transport and rail.

There is still room for improvement in the quality as well as coverage of data. Therefore, we added a section on the specific limitations of provided data in each chapter.

INDEX

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

a	annum
AB	Apartment block
AC	Air-conditioning
ACs	Air-conditioners
AHU	Air handling unit
AHUs	Air handling units
CAC	Central air-conditioning
CACs	Centralized air-conditioners
CET	Central European Time
CLC	Corine land Cover
CDD	Cooling degree days
CHP-IC	Combined heat and power – internal combustion
CSPF	Cooling Seasonal Performance Factor
CV	Coefficient of varation
DEA	Danish Energy Agency
DH	District heating
DHW	Domestic hot water
EER	Energy efficiency ratio
ENTSO-E	European Network of Transmission System Operators for Electricity
EPBD	Energy Performance of Buildings Directive
ER	Equivalence ratio
EU	European Union
EU-DEM	European Union - Digital Elevation Model
EUR	Euro
e.g.	Example given
el	Electric
FCU	Fan coil unit
FCUs	Fan coil unit
FEC	Final energy consumption
GDP	Gross domestic product
GIS	Geographic information system
GISCO	Geographical Information System of the Commission

GJ	Gigajoule
HDD	Heating degree days
HP	Heat pump
HPs	Heat pumps
H&C	Heating and cooling
h	Hour
IEA	International Energy Agency
IEE	Intelligent Energy Europe
i.e.	Id est
K	Kelvin
km	Kilometer
km²	Square kilometer
kg	kilogram
kW	Kilowatt
LAU	Local administrative unit
MFH	Multi family house
Mil.	Million
MS	Member state
MSs	Member states
MSW	Municipal solid waste
M²	Square meter
Mm²	Million square meter
MJ	Megajoule
m	Meter
m²	Square meter
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NR	Non residential
Nr	Number
NUTS	Nomenclature of units for territorial statistics
nZEB	Nearly energy-zero building
nZEBs	Nearly energy-zero buildings
OSM	OpenStreetMap
O&M	Operation and mantainance

PE	Primary energy or population equivalent
PJ	Petajoule
RAC	Room air-conditioning
RACs	Room air-conditioners
RE	Renewable energy
RES	Renewable energy sources
SC	Space cooling
SFH	Single family house
SH	Space heating
STS	Solar thermal system
STSs	Solar thermal sytems
s	second
TW	Terrawatt
TJ	Terrajoule
Thous.	Thousend
TDHP	Thermally driven heat pump
TDHPs	Thermally driven heat pumps
t	Tonne
th	Thermal
UED	Useful energy demand
UFO	Used frying oil
URL	Uniform resource locator
VRF	Variable refrigerant flow
W	Watt
WP	Work package
y	year

LIST OF SYNONYMS

Air-conditioning	Space cooling
Attitude	Habit
Consumption	Final energy consumption
Demand	Useful energy demand
Sector	Branch
Service sector	Tertiary sector

1. Introduction

The aim of this deliverable is to shed light into the data collection and generation required for the open source tool Hotmaps as generic default information regarding the European Union (EU)28 on spatial disaggregated level. In addition to the provided data set, the user will be able to run planning modules by importing their own data. In this stage of the project, we analysed, calculated and homogenized the information for the EU member states (MSs, nomenclature of units for territorial statistics - NUTS0) at respective regional levels (NUTS2 and 3) and local level (local administrative unit - LAU2). The results of this initial part of the Hotmaps project are fundamental for its following stages. The database provides the main input for the development of energy system planning module tools and scenarios. Additionally, more detailed data are collected for the demonstration of the Hotmaps toolbox concerning pilot areas.

In this deliverable, we describe the approaches for data collection and analysis in the different sectors (i.e. residential, service, industrial and transportation sectors). The data has been provided as default for the entire EU28 with the aim to support local, regional and national heating and cooling (H&C) planning. This part of the project provides basic data to the Hotmaps toolbox that consist in:

- Task 2.1 Building stock analysis;
- Task 2.2 Space heating, cooling and domestic hot water demand;
- Task 2.3 Climate context;
- Task 2.4 Industrial processes;
- Task 2.5 Heating and cooling supply;
- Task 2.6 Renewable energy sources data collection and potential review;
- Task 2.7 Hourly loads profiles;
- Task 2.8 Electricity system module and
- Task 2.9 Transport.

Depending on the availability, data has been collected at one of the three territorial units for statistics (i.e. NUTS0, NUTS2 and NUTS3 levels). In a second step of the Hotmaps project, these data are spatialized by taking into account other variables, such as land use and population density. Other data has a higher spatial resolution depending on the original dataset; for instance, the Corine Land cover data set [1] is available with a spatial resolution of 100 m by 100 m, and the European Settlement Map 2017 [2] with a resolution of 2.5 by 2.5 m.

Metadata is provided alongside in order to facilitate the access to relevant information. All data generated within this project stage are downloadable from the Hotmaps Git repository (https://gitlab.com/hotmaps).

The present report is subdivided by task (mentioned above), according to which detailed information on methodologies applied, to main outcomes at aggregated level (EU28), to limitations of data needed and finally to references are provided.

2. OPEN data set for the EU28

The quality of the results depends on the input data as well as on the methodology utilized. Hence, before outlining the main results at EU28 level, we start by describing the quality of the input data. We chose the following criteria: spatial resolution, spatial extent, temporal resolution, consistency, and measure type. An overview of the different criteria is presented in Table 1.

Spatial resolution refers to the measure of the spatial accuracy of a map. In case of vector layers, this indicates the territorial scale (NUTS0, 1, 2 and 3 or LAU 1 and 2); while in case of raster layers, it indicates the size of each raster pixel in meters. E.g. the size of a square delaminating the elementary area of an image.

Spatial extent indicates the smallest rectangular shape, including all georeferenced data of a given map. In this case, we refer to the smallest administrative unit including all the pertaining data (e.g. EU28).

Temporal resolution relates to the time accuracy characterizing the data (e.g. year, day, hour etc.).

Consistency refers to the degree of similarity between data collected from various information sources [3].

Measure type relates to the description of the data value and the methodology used to derive it. We consider some of the characteristics suggested by EUROSTAT [4].

Table 1. Qualitative assessment of the input data quality.

	Spatial resolution	Spatial extent	Temporal resolution	Consistency	Measure type
Building stock	low	high	low	medium	measured + estimated
Space heating	high	high	low	high	measured + estimated
Space cooling	low	high	low	low	estimated + measured
Domestic hot water	high	high	low	medium/ high	measured + estimated
Climate	high	high	medium	high	measured + estimated
Industrial Sites	high	high	low	medium	measured + estimated
Industrial energy demand	low	high	low	medium	estimated + measured
Heating & cooling supply	low	high	low	high	measured + estimated
Renewable energy sources potential	medium	high	low	low	estimated
Hourly load profiles	medium/ low	low	high	high	modelled
Electricity system	low	high	medium	medium	measured + estimated
Transport	medium	medium	low	high	measured + estimated

Building stock data are available on NUTS0 level at some large data tools as well as in single literature fonts (e.g. journal papers, conference papers and project deliverables). The collected data cover the entire EU28 countries. Assembled information are mainly measured data; however, missing data has been estimated. The data for the residential building stock differ from those of the service sector in their consistency, especially considering the historic building stock. For example, hardly any statistics are available for the service sector before 1945.

Space heating data are well researched and extensively described in scientific literature for various spatial levels – even for single buildings in specific cases. Identified data cover the entire EU28 countries. Information found usually refer to annual values. A high consistency between information provided is given. The collected information are mainly measured data; however, also estimated data can be found.

Space cooling largely lacks of information within scientific literature. Almost no data is available for the air-conditioning (AC) sector – not even at NUTS0 level. Identified information refers to annual values and sets of multiple years. In this case, data widely fail to be consistent, with differences diverging up to a factor of ten. Assembled information are mostly estimated; only for a very limited amount of cases, measured information has been found.

Domestic hot water data are well researched and extensively described in scientific literature for various spatial levels – even for single buildings in specific cases. Identified data cover the entire EU28 countries, and usually refer to annual values. A high consistency between information provided is given; however, some limitations are present for the service sector. The collected information is mainly measured data, but also estimated data can be found.

Climate data has a high spatial resolution, being all raster layers. The spatial extent is the EU28 area; in some cases raster data cover the whole world. Data are usually aggregated on a monthly base. Data are characterized by a high consistency and are the result of both measurement and estimation.

Industrial site data within this project consist in a georeferenced database including coordinates with extensive data about subsector, emissions and annual production. It covers all EU28 countries and is based on two main openly available sources covering the emissions data, resulting in major deviations in some cases. Annual production is included using national average values.

Industrial energy demand is provided by a generic dataset, which includes the fuel and electricity need per produced tonne of product for over 60 different production processes. It is based on various literature sources. These values are average for the entire EU28 countries.

Heating and cooling supply data is provided at NUTS0 level. The spatial extent is the EU28 area, with average values for each MS. The temporal resolution is the year. The data represents results from existing (measured) market data combined with indices and estimations for each MS.

Renewable energy sources potential data are re-elaborated at NUTS3 level. The spatial extent is the EU28 area. The temporal resolution is the year. The data are the result of estimations.

Hourly load profiles are based on daily average temperature data and empirical demand profiles that reflect consumer behaviour. The profiles are provided on NUTS2 level for the residential, tertiary and industry sectors.

Electricity system data in the Hotmaps toolbox is available on NUTS0 level. The data will be used to assign each location in the Hotmaps toolbox with an electricity market region to reflect the situation on the electricity sector in the regions of interest. The datasets include the electricity generation mix per country on yearly time resolution as well as day ahead electricity wholesale market prices and CO_2 emission data on hourly resolution for the year 2015. The main data source for those datasets is the European Network of Transmission System Operators for Electricity (ENTSO-E) transparency platform [5]. Electricity generation data is available for all EU28 MSs. For countries where no electricity prices were available, reference countries were used to provide a full default dataset for all countries within the Hotmaps toolbox.

Transport data is provided by using the dataset of EUROSTAT [4], PRIMES-TREMOVE [6] and Urban Audit [7] for data at EU28, and NUTS2 as well as 3 levels. Most of the data is derived from publicly available data sources, the data for the NUTS2 and NUTS3 levels is estimated.

2.1. Building stock analysis

The present task provides data with following characteristics:

Table 2. Characteristics of data provided within Task 2.1 Building stock analysis. The database of given task is available at: https://gitlab.com/hotmaps/building-stock

	Spatial resolution	Temporal resolution
Building characteristics	NUTS0	-
Nearly zero-energy buildings	NUTS0	-
Building surface volume ratio	Raster @ 100 X 100 m	-

The data collected in the building stock analysis are used as starting point to calculate the useful energy demand (UED) for space heating (SH), space cooling (SC), and domestic hot water (DHW) for each EU28 MS down to its local level (Task 2.2), and to derive scenarios for the future development of the UED. The Hotmaps toolbox generates raster maps with characteristic building stock indicators (UED, gross floor area, etc.) with a resolution of 100 x 100 m covering the entire EU28 building stock. The map is based on aggregated values at NUTS0, using, among others, the population (EUROSTAT: CENSUS 2011 [8]) land-use data (CORINE land cover, 2006 [1]), the European Settlement Map layer [2] the data from the Global Human Settlement project [9] and data from the OpenStreetMap database as proxy.

Furthermore, within this task, we derive the UED layer ("Heat density map") using the raster map of building stock characteristics (gross floor area, building volume, share by construction period, building surface-to-volume ratio), the Digital Elevation Model (EU DEM) and the climatic data retrieved in Task 2.3. Based on this analysis, basic statistics on the need per UED category could be extracted for the EU at regional/local level.

2.1.1. Methodology

Data have been collected per country, and organized within the residential and service sectors, addressing specific types of buildings and time periods.

The residential sector has been subdivided based on the following building typologies:

- Single family houses (SFHs);
- Multifamily houses (MFHs);
- Apartment blocks (ABs – high-rise buildings that contain several dwellings and have more than four storeys [10]).

The service sector includes the following categories:

- Offices: composed of private and public offices; this section includes also office blocks;
- Trade: individual shops, department stores, shopping centres, grocery shops, car sales and garages, bakeries, hairdresser, service stations, laundries, congress and fair buildings, and other wholesale and retail infrastructures;
- Education: primary, secondary and high schools. Furthermore, universities, infrastructure for professional training activities, school dormitories, and research centres/laboratories are part of this sector;
- Health: private and public hospitals, nursing homes, medical care centres;
- Hotels and restaurants: hotels, hostels, cafés, pubs, restaurants, canteens, and catering in business;
- Other non-residential buildings: warehouses, transportation and garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sport facilities (e.g. sport halls, swimming pools, and gyms) [11].

In order to present a complete picture of the MSs' building stock and to describe time-related specifications, the following construction periods have been defined:

- Before 1945: buildings constructed before 1945 are generally classified as historic buildings. The historic building stock is highly inhomogeneous, making it difficult to apply a standardized assessment. Nevertheless, certain characteristics may still be generalized, such as the use of massive construction methodologies for residential buildings;
- 1945-1969: buildings erected after World War II and before 1969 are generally characterized by nearly missing insulation and inefficient energy systems, caused by the choice of cheap construction materials and by short construction times. These results in higher specific UED;
- 1970-1979: buildings built between 1970 and 1979 present the first insulation applications (as a consequence to the world energy crises of the 1970´s);
- 1980-1989 and 1990-1999: buildings constructed during these two periods reflect the introduction of the first national thermal efficiency ordinances (around 1990);
- 2000-2010: buildings considered to be influenced by the impact of the EU Energy Performance of Buildings Directive (2002/91/EC and following recasts);
- After 2010: recently constructed buildings are analysed to understand the impact of the economic crisis on Europe´s construction branch. The present analysis contains data updated until the year 2016.

With regard to the building typologies and construction periods previously described, the following features have been analysed:

Constructed, heated, and cooled floor areas	[Mm^2]

Number of dwellings/units, and of buildings	[Mil.]
Owner occupied, private rented, social housing dwellings/units	[Mil.]
Occupied, vacant, and secondary dwellings units – and others[1]	[Mil.]
Thermal transmittance – U-values – walls, windows, roof, and floor	[W/m² K]

Construction materials and methodologies

Walls:

Construction material	– brick, concrete, wood, others[2]	[%]
Construction methodology	– solid wall, cavity wall, honeycomb bricks/hollow blocks wall, others[3]	[%]
	– insulation or not	[%]

Windows:

Construction material	– wood, synthetic/pvc, aluminium	[%]
Construction methodology	– single glazing, double glazing, triple glazing	[%]
	– low-emittance or not	[%]

Roof:

Construction material	– wood, concrete, concrete + bricks	[%]
Construction technology	– tilted, flat – insulation or not	[%]

Floor:

Construction material	– wood, concrete, concrete + bricks, and others[4]	[%]
Construction methodology	– concrete slab, wooden floor, others[5]	[%]
	– insulation or not	[%]

Technologies for SH, SC, and DHW

Technologies used for SH:

Individual, central, or district heating	[level of presence]
Boiler (condensing or not), combined, stove, electric heating, Solar Collectors, Heat pumps	[level of presence]
Fossil fuels (solid, liquid, gas), electricity, biomass	[level of presence]

Technologies used for SC:

SC or not	[level of presence]

[1] Abusive homes, neither registered, occupied nor vacant or secondary dwellings

[2] Construction materials less frequently used, such as stone or stone/brick and stone/concrete mixed structures

[3] Prefabricated panels and lightweight exterior walls

[4] Mainly stone floors

[5] Less diffused construction technologies for floors (e.g. vaulted or coffered ceilings)

Technologies used for DHW preparation:

Individual, central, or district heating	[level of presence]
Boiler (condensing or not), combined, stove, electric heating, Solar Collectors, Heat pumps	[level of presence]
Fossil fuels (solid, liquid, gas), electricity, biomass	[level of presence]

UED

SH	[kWh/m² y], [TWh/y]
SC	[kWh/m² y], [TWh/y]
DHW	[kWh/m² y], [TWh/y]

FEC

SH	[kWh/m² y], [TWh/y]
SC	[kWh/m² y], [TWh/y]
DHW	[kWh/m² y], [TWh/y]

Concerning the collected information, it is important to distinguish between useful energy demand (UED) and final energy consumption (FEC). The UED represents the net energy required to cover SH, SC, and DHW needs. On the other hand, the FEC is the empirically measured energy input into the supply system, which is required to satisfy the abovementioned demand. The two quantities thus differ by disparate conversion factors [11], which take into account the efficiency of each supply technology as well as the distribution losses, but may also differ due to user behaviour. For example, if SH and DHW is provided by a boiler, the FEC is higher than the UED, since the efficiency of this technology is < 1 (0.8-0.9 for currently installed technologies in Europe). On the contrary, the FEC for space cooling is lower than the UED in case of electrically driven technologies (e.g. heat pumps) that have an energy efficiency ratio greater than one (EER > 1 - around 2-3 for currently installed technologies within the EU). It has to be stressed that, while it is correct to compare UED for SH, SC and DHW purposes, FEC in form of electricity (in heat pumps and air-conditioners) can be compared to fuel consumption (e.g. gas in a gas boiler) only by performing an adequate conversion into primary energy. Indeed, the two energy carriers have a different content of grey energy; primary energy (usually expressed in kWh or toe) accounts for the use of resources (fossils and non) providing a basis for a correct comparison among different energy carriers [12].

Data quality, completeness, accuracy, and reliability are key aspects in the process of generating the default datasets of the Hotmaps project. Hence, the following features have been taken into consideration in this process:

- Data inventory;
- Data reliability;
- Data definition and comparability.

Data inventory

One of the major challenges in developing an inventory of UED data for SH, SC, and DHW in different sectors is to provide an almost complete list of existing information. In general, the advantage of using data coming from EU information providers and EU projects is that these are available for large territories (e.g. BPIE [13]). However, the data provided are rarely fully complete. Therefore, national statistics have been used as data sources with the aim to increase data coverage.

The data collection process implied not only extrapolating and assembling data from data tools available online (e.g. TABULA [14]), but also researching data source-by-source from single scientific literature sources as journal papers (e.g. [15]), conference proceedings (e.g. [16]) and project deliverables (e.g. [17]). Only through such an in-depth approach, the already mentioned lacks of data per energy type (SH, SC and DHW) and nation, could be filled.

One important aspect of the data inventory is to ensure the understandability and correct interpretability of information. Together with the data, standardized structured information is provided, including the specification of author/s, titles, time reference, and if available the universal resource locator (URL).

Data reliability

All sources taken into consideration have been analysed to assess the reliability of the gathered data. In particular, the methodology applied to generate data of the utilized fonts has been taken to a closer look. Furthermore, the gaps in information have been completed by in-depth investigations on scientific literature.

Data definition and comparability

The data have been collected per country, with reference to the most recent year; the majority of data refer to the year 2016. Despite the majority of the data providers utilize standardized data formats and units, this does not necessarily mean that data are fully comparable. Adjusting differences and inconsistencies among different data characteristics (e.g. time references) to improve data comparability is one of the most important aspects in the process of data elaboration.

Apart from the use within Hotmaps and other existing tools, the developed database is expected to improve data quality for users in the energy sector, and to provide data useful to monitor the progress towards the achievement of the goals defined in EU energy related Directives.

In the following paragraphs, the main sources and the methodology of data elaboration are described for all the main features in the database. The data regarding *Covered area* have been retrieved for each construction sector, building type and period, from Invert/EE-Lab database [18]. The total values for the residential and service sectors have been obtained by summing the data of all the building typologies for each time period. With regard to the heated and cooled floor area, data refer to several sources; among all, the most used are [19]–[22].With regard to the *Tenure/ownership status and distribution* and *Occupancy* fields of the database, the data for the residential sector have been obtained from the EU Building Stock Observatory [23]; while for the service sector, several sources have been used for each MS.

The section Construction features contains the U-values of the main building elements (i.e. walls, windows, roof, and floor). The data have been obtained for each building typology from TABULA web-tool [24] for the residential sector, and from the EU building database [25] and the results of the project iNSPiRe [20] for the service sector. The total values of thermal transmittance for each sector have been calculated by weighting the U-values of the single subsector with the respective constructed floor area.

The main sources for the sections *Construction materials and methodologies*, and *Technologies for SH, SC and DHW* for the residential sector is the TABULA web-tool [14]. The descriptions of the construction features have been collected for each building typology (SFHs, MFHs, and ABs) and construction period. Data has been organized in sub-sections for walls, windows, roof and floor. The percentages presented in the database resulted from weighting the data for the total floor area of each building typology.

Similarly to the construction features, also the data concerning SH, SC and DHW have been mainly collected using the TABULA Web-tool. However, the web site indicates for each building typology and construction period only the most widespread technology. For this reason, the database section *Technologies for SH, SC and DHW*, does not contain the data in percentage, but indicates only the diffusion of each technology and fuel. The data has been calculated for the total residential sector, weighted on the total floor area of each building typology, and has been grouped based on the percentage of diffusion as follows:

- > 75%: most widespread technology/fuel;
- 25% to 75%: widespread technology/fuel;
- < 25%: less widespread technology/fuel.

With regard to the service sector, the TABULA Web-tool does not contain any data. Furthermore, the scientific sources detailing typical construction features and technologies for SH, SC and DHW are scarce. Hence, an expert questioning has been carried out. A questionnaire containing all features already included in the database for the residential sector has been sent to two experts per country. The collected data has been analysed and the results have been clustered in geographical areas. The utilized questionnaire is attached in the annex (see Section 4), while the filled questionnaires are not enclosed and the names of the interviewees are not listed for privacy issues.

The clusters, based on the geographical proximity of the countries, are the following:

- Northern Europe: Denmark, Finland, Sweden, Estonia, Latvia, Lithuania;
- Central Europe: Austria, Belgium, Germany, Netherland, Luxembourg, France, United Kingdom, and Ireland;
- Eastern Europe: Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania;
- Southern Europe: Spain, Italy, Greece, Cyprus, Malta, and Portugal.

The results have been counterchecked with the few sources available on the topic [26]–[28].

The main source for the fields *Useful energy demand* for space heating, cooling, and DHW is Invert/EE-Lab database [29]. Based on these values, the *Final energy consumption* has been calculated by multiplying the useful energy demand by the ratio values obtained in Task 2.2. The *Total useful energy demand* have been obtained as follows:

- Space heating + domestic hot water [TWh/year]:

$$\frac{(Mm^2\ heated\ floor\ area \times SH\ demand) + (Mm^2\ total\ floor\ area \times DHW\ demand)}{1000}$$

- Space cooling [TWh/year]:

$$\frac{Mm^2\ cooled\ floor\ area \times SC\ demand}{1000}$$

Finally, the *Total final energy consumption* has been calculated with the following equations:

- Space heating + domestic hot water [TWh/year]:

$$\frac{(Mm^2\ heated\ floor\ area \times SH\ consumption) + (Mm^2\ total\ floor\ area \times DHW\ consumption)}{1000}$$

- Space cooling [TWh/year]:

$$\frac{Mm^2\ cooled\ floor\ area \times SC\ consumption}{1000}$$

With regard to all the sections of the database, the totals *Residential sector_Total* and *Service sector_Total* (units: Mm², Mil., TWh/y) have been obtained by summing up the values for the respective subsectors.

Since it was not possible to fill all the cells of the database, estimations have been performed for the missing data. Please see Section 2.1.2.1 *Limitations of data* for further information on these estimations.

In the following Section **Error! Reference source not found.** ***Error! Reference source not found.***, the main results are described, together with figures significant of the database content. Figure 1 is based on data retrieved for each building typology and construction sector with a unit of Mm². The percentages indicated are based on the respective floor area. In contrast, Figure 2 shows the percentages calculated on the amount of buildings erected.

Figure 3 and Figure 4 describe the trend of UED, which has been obtained by weighting the demand values [kWh/m² y] of each construction period on the heated or cooled floor area for SH and SC respectively. For DHW the entire floor area has been taken into consideration. It has to be underlined that Figure 3 and Figure 4 display the actual specific UED values (kWh/m² y), which have been subdivided on the various construction periods.

Due to a very high amount of references, in coming Section 2.1.2 solely major sources are indicated. This applies also to following Task 2.2 sections.

2.1.2. Main results (EU28)

This section presents a selection of main results obtained from the analysis of the data included in the Building stock analysis database. For further information on the data sources see: https://gitlab.com/hotmaps/building-stock.

In Figure 1, the EU28 building stocks of residential and service sector erected per construction period are compared.

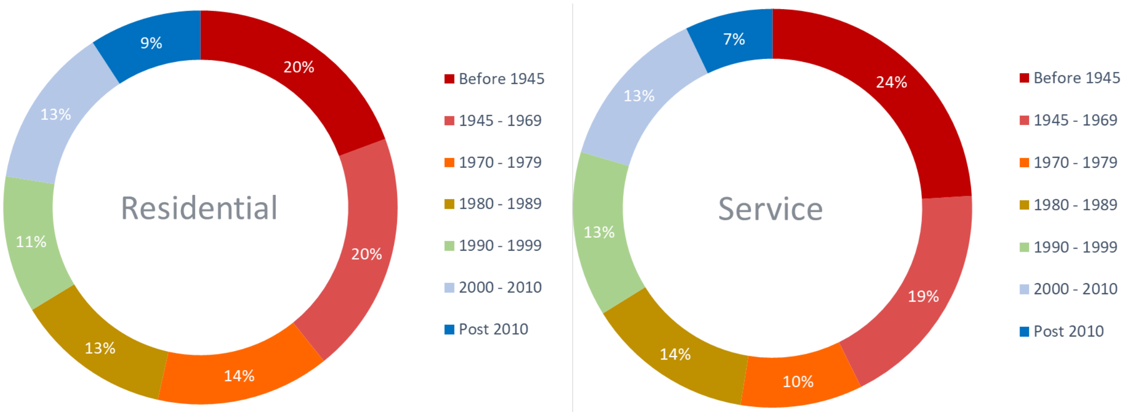


Figure 1. Split of the residential and service building stocks raised per construction periods (%, European Union 28). Sources: [12], [14], [17], [18], [25]

The historic buildings (i.e. construction period *Before 1945*) show highest percentages in both residential and service sectors. However, this is due to the fact that the period before 1945 covers the entire historic building stock and thus includes more years than the other analysed time periods. It emerges that historic buildings are present in a nearly equal percentage in the service sector than in the residential section, being 24% and 20% respectively.

From the analysis of the building stock, excluding buildings constructed before 1945, emerges that both sectors have a peak in built construction per year during the period *1945-1969*, with values around 20%. However, it has to be highlighted that this construction period consists of 14 years, while the subsequent periods (i.e. from 1970 on) include only 10 years each. In the time periods from 1970 on, the percentages decrease until recent years. This trend is confirmed by a number of recent studies for the entire EU building stock [11], [12], [30]. A certain homogeneity in the amount of Mm^2 floor area erected per construction period is visible for both residential and service sector, with percentages that vary between 0% and 4%.

Figure 2 visualizes the breakdown of different subsectors representing building types within the residential and service sectors of the EU28.

Residential buildings are usually characterized by 2-3 floors in the case of SFHs, MFHs by 4-8, and ABs usually have more than 4 floors [10], [12], [14], [31].

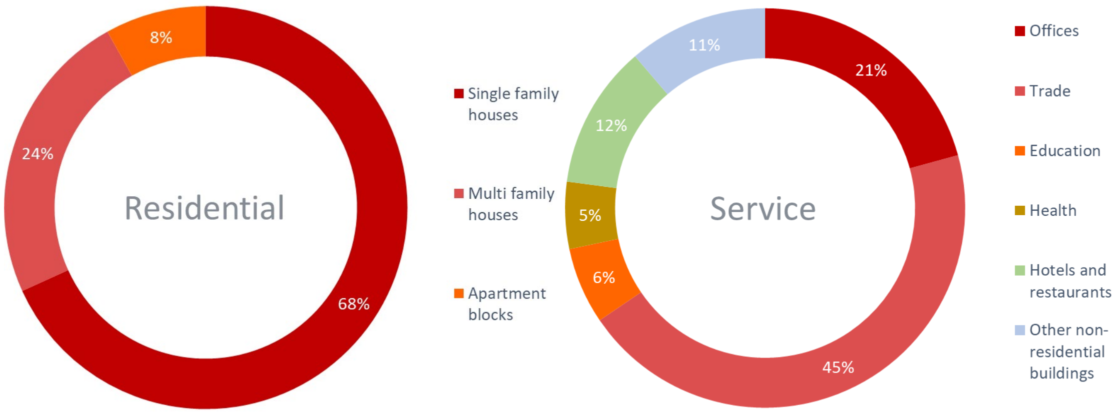


Figure 2. Split of the number of residential and service buildings per different subsectors (%, European Union 28). Sources: [13], [18], [25]

The residential sector is dominated by SFHs with almost 70%, followed by MFHs and ABs with approximately 20% and 10% respectively. Within the service sector, the absolute majority of building usage is covered by trade with almost 50%. It is followed by offices (about 20%), hotels and restaurants as well as other non-residential buildings (both > 10%), and education and health (around 5%).

Figure 3 indicates the development of the specific UED for SH and DHW of the residential and service sectors from the construction period *Before 1945* until today (2016).

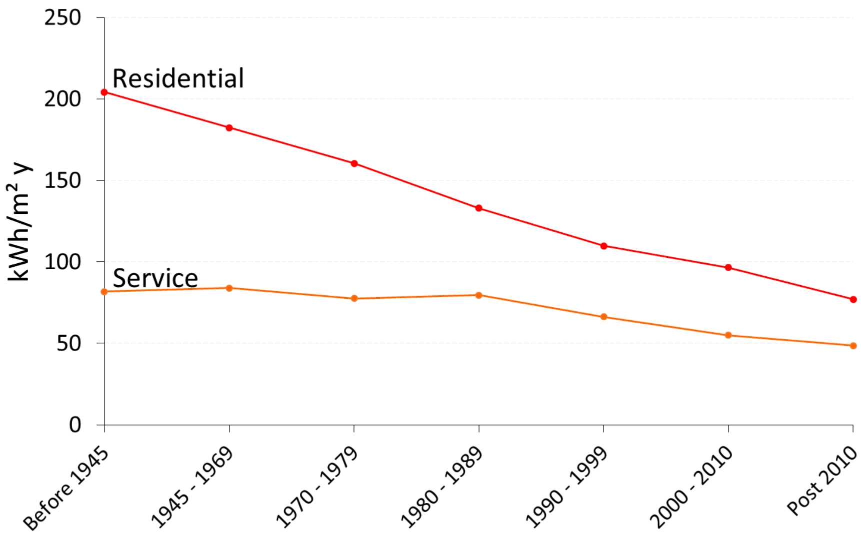


Figure 3. Development of the specific useful energy demand for space heating and domestic hot water in the residential and service sectors (Before 1945 - Post 2010), (kWh/m² y), European Union 28). Sources: [12]–[14], [16], [18], [25]

As shown in Figure 3, the historic building stock is characterized by the highest specific UED for SH and DHW of both sectors. From *Before 1945* to present time, the specific UED for SH and DHW decreases from approximately 200 to 80 kWh/m² y in the residential sector. In the service sector, the specific UED declined from 80 to 50 kWh/m² y. Thus, the specific UED for SH and DHW is in average about twice as high for households as for services.

Like shown in Figure 3, the mentioned discrepancy regarding UED for SH and DHW between the residential and service sectors, is much more accentuated in the time period from *Before 1945* to *1980-1989*; it declines afterwards.

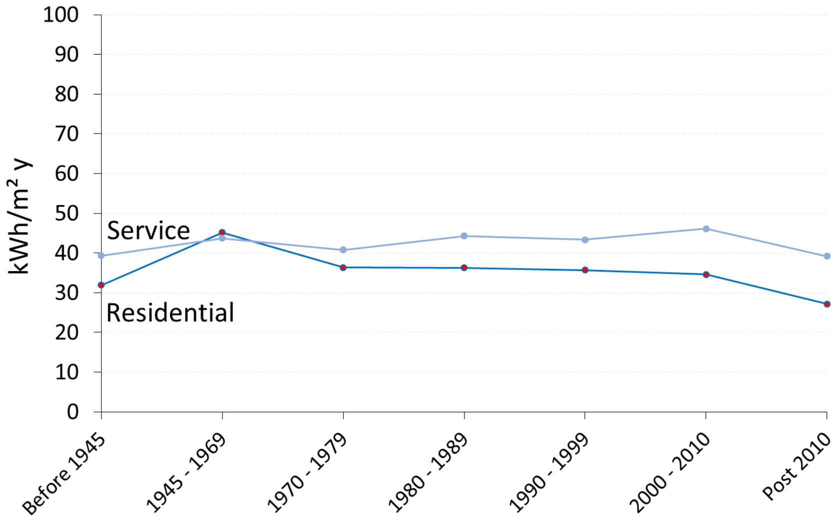


Figure 4. Specific useful energy demand for space cooling in buildings from the residential and service sectors for different construction periods (Before 1945 - Post 2010), (kWh/m² y, European Union 28). Sources: [12], [13], [18], [25], [28], [32]

Figure 4 displays the trend of specific UED for SC of the two analysed sectors. As emerges from the figure, specific UED for SC develops relatively constant both in the residential and the service sectors between 1970 and 2010. On the contrary, an increase in specific UED is visible in the period 1945-1969 for the residential sector, exceeding the specific UED in the service sector within this construction period. The specific UED for SC grows from 30 to almost 50 kWh/m² y and in the buildings constructed after 1970 it decreases to about 30 kWh/m² y. A similar trend is visible also for the service sector; however, it is less accentuated. The values for the service sector have a peak in the buildings constructed between 2000-2010 with approximately 50 kWh/m² y and decreases to 40 kWh/m² y after 2010.

There are a number of possible reasons leading to a rather flat space cooling demand. First increased comfort standards by the European population, second global warming and third modern building architecture with larger glazing areas. The third possible reason has a rather low impact, while the other two mentioned might have a pertinent influence.

For further information, please see: https://gitlab.com/hotmaps/building-stock

2.1.2.1. Limitations of data

Building stock data are available on NUTS0 level by a number of large data tools (e.g. EU Building Stock Observatory [23]) as well as single literature sources (e.g. journal papers, conference papers and project deliverables). However, unfortunately, it was not possible to fill all the cells in the database with information; therefore, estimations have been carried out. The cells containing estimated values are marked by grey colour in the database.

The following estimations/assumptions have been performed (listed according to the unit of the estimated data):

- Mm²: values have been estimated by linear regression in case at least three values were available within the same time period (i.e. from *Before 1945* to *Post 2010*). The mentioned procedure was mostly applied for data referring to *Post 2010.* In other cases, interpolation has been applied, but only in case that the values surrounding the empty cell were not estimated. The same applies for data gaps within the *Thermal transmittance* (i.e. U-values) section of the database as well as for specific UED values (kWh/m² y) for SH, SC and DHW;
- Mil. – Nr. of buildings: the number of units was assumed to be equal to the number of buildings for the cases of health (e.g. hospitals) and education (e.g. schools) sectors;
- Mil. – Social housing: it has been assumed that social housing is not present in the service sector.

Moreover, for the cases, in which information concerning ABs were missing, the data of the MFHs for the same country have been considered (e.g. U-values). In a few cases, data has been transposed from one country to another one. In these case, the two nations have to comply with a set of criteria presenting similar geographical, socio-economic and historical features (e.g. Czech Republic and Slovakia).

With regard to specific UED for DHW, different values with a unit of kWh/m² y have been found per construction period only in a few cases. Most times only one value for the entire construction period has been found in literature.

The main obstacles faced in the analysis were the often erroneous use of the terms UED and FEC, and the scarce availability of data regarding data for SC.

With regard to the first obstacle, we correctly distinguished between the two terms by analysing the methodology related to the data found. Data without any documentation has been excluded from the database. UED data for SH and DHW has been transformed into FEC by dividing them with values derived from Task 2.2 *Bottom-up approach* database ("Top-down approach") referring to the two energy types. A mean value has been applied as conversion factor for each sector (residential, serives) and country. The mentioned values lie around 0.85, corresponding to the average efficiency of currently installed boilers within the EU [33]. The same procedure has been applied for SC. In this case, the obtained conversion factors result to be in the range of 2 to 3, which corresponds to the mean efficiency of SC equipment installed in Europe [12].

Regarding the second obstacle, it has to be underlined that at present time, a huge amount of data concerning the SC market in Europe is based on estimations [32], [34]. The same difficulties have been faced in Task 2.2 *Bottom-up approach.*

2.1.3. Heat Density Map

The top-down heat density map developed in the Hotmaps project builds on several pillars. At the top-level, we derived the UED and FEC based on an extensive literature for the NUTS 0 level (countries). At the second level, the UED is distributed to the NUTS3 level using an approach developed in the recently finished study “Territories and low-carbon economy” (ESPON Locate) [35]. This approach combines several indicators to estimate the share of UED for SH, SC and DHW for the different NUTS3 regions within each country.

For residential buildings, the following indicators are used:

- Data provided by the European Census Hub 2011 [36] (Census 2011, Population and Housing Census 2011):
    - Useful floor area per dwelling
    - Population
    - Number of dwellings
    - Number of dwellings per building type
    - Number of dwellings per construction period
- Heating and cooling-degree days (HDD and CDD) on NUTS2-level based on Eurostat [37]. Within the NUTS2 level, the HDD and CDD on the NUTS3 level are calculated based on the average HDD (18.5/18.5) and CDD (22.5/22.5) calculated from the observed daily temperatures on a 25 x 25 km grid for the period 2002-2012 (see [38]).
- FEC per m² floor area and building type are based on Invert/EE-Lab model results derived within the European project “Mapping_HC: Mapping and analysis of the current and future (2020-2030) heating/cooling fuel deployment (fossil and renewables)” (EC service contract ENER/C2/2014-641/SI2.697512) [39].

For non-residential buildings, the following parameters are considered:

- Population, HDD and CDD, the FEC per m² floor area and building type based on the Invert/EE-Lab building stock database [36]
- The estimated share per construction periods are based on the distribution of the construction periods of apartment buildings [36]
- The total value added of the service sector [40]
- The sectoral value added (VA): (a) Accommodation, restaurants, stores and warehouses, (b) other private services and (c) public buildings, research and education, art, culture and health sector [40].
- For a more detailed description of the approach, please be referred to the report of the European Spatial Planning Observation Network (ESPON) Locate project [35].

Top-down heat density map on the hectare level

A core element of the Hotmaps project is the development of a heat density map on hectare level for the EU28 countries. We achieved this goal by developing a new approach, which correlates information on the local built environment with its UED for SH, SC and DHW generation. To do so, we derived a spatial distribution function based on similar indicators as used for the NUTS0 to NUTS3 transformation. Again, the approach builds on the central idea that the UED correlates with the population number within a certain plot area, the economic activity and the climatic conditions.

An overview on the process and main data sources used gives Figure 5.

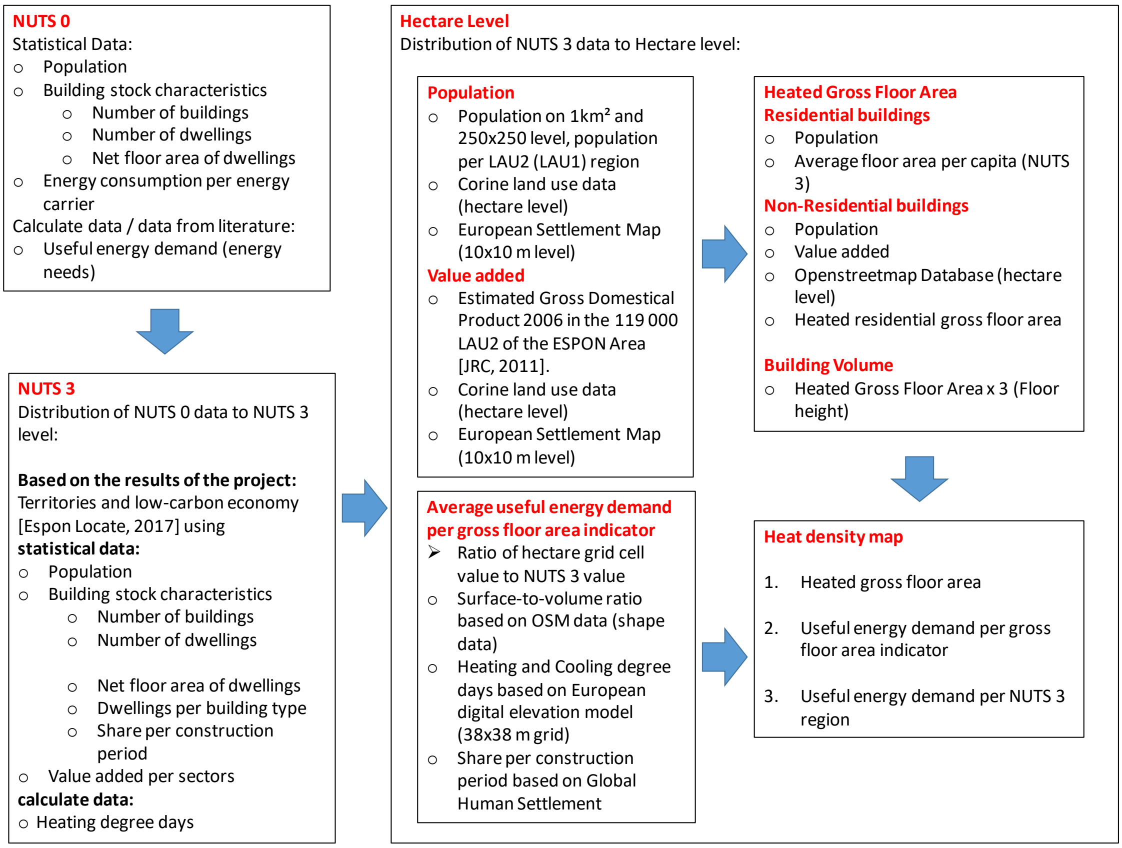


Figure 5. Schematic process of how we derived data maps on the hectare level for the EU-28 countries

Population Distribution on the hectare level

For the population distribution we draw on data for the European population in 2006 on the level of 1km² [41]. Another available dataset for the population in 2014 on the level of 250 x 250 m [42] turned out to be less reliable then the coarser one.

Figure 6. Comparison of the plot area covered by buildings in a 10 x 10 m level (blue) and the population in 2014 per 250 x 250 m. Sources: [2], [42]

However, [36] partly covers area, which is not covered by [35]. Therefore, for the subsequently derived spatial population data we calculated a data set for the population on 1km² level as follows: If our primary population layer indicated no population on 1km², we used the 1xkm² layer derived from [36] as a fall-back option. An analysis of the resulting quality of the combined layer indicated that:

a.) The combination actually improves the quality in those areas, where the primary population layer has uncovered areas

b.) It also tends to introduce a bias in less densely populated areas as a (non-systematic) shift in the (1 x 1km²) grid cells between the primary and secondary population layer can be observed in many regions.

This has the effect that when applying the so derived population distribution function on the population data on the NUTS3 level, the distribution is distorted towards rural areas. To reduce this adverse effect, the population of the fall-back option [36] is weighted with a factor of 30%. This value has been chosen, based on the assessment of results derived by different weighting factors (in the range of 10% - 100%) for different effected regions, in order to balance the two effects: the described effect of overestimating population in rural areas which occurs versus the underestimating of population in areas, which are not covered by [35]. We, however, have not performed any systematic analysis on the optimal level for the applied weighting factor.

Within the 1 km² grid cells we used the information of the Corine land cover data [37] (available on the hectare level, Figure 7) and the European Settlement Map layer on the 10 x 10 m level [2] to distribute the population to the hectare level.

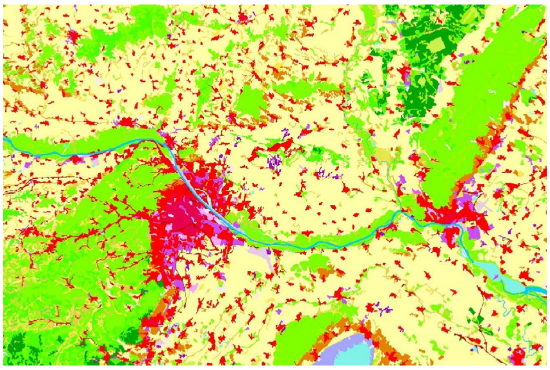


Figure 7. Corine land cover data on the information of land usage type on the hectare level. Source: [43]

Using this data, we calculate the population for the local administrative units (LAU). According to [44] these are around 115 thous. and regions (using the LAU2, except for Greece and Latvia, where we used LAU1). We then compared the so derived population with the population in local administrative units of statistical data sources ([36], [45], [46]). Then we adjust the local weighing factor of the population to find a compromise between the population on 1 km², population per LAU region, as well as upper limits for the population density per hectare level. For the upper limit we analysed the 95%/99%-percentile of the ratio of population compared to the population in the corresponding 1 x 1 km grid cell (for all cells, which exceed a mean ratio by a factor of 2), clustered by the population densities on the 1 km² grid level. Based on this analysis we define an upper limit for the population on a hectare level as shown in Figure 8.

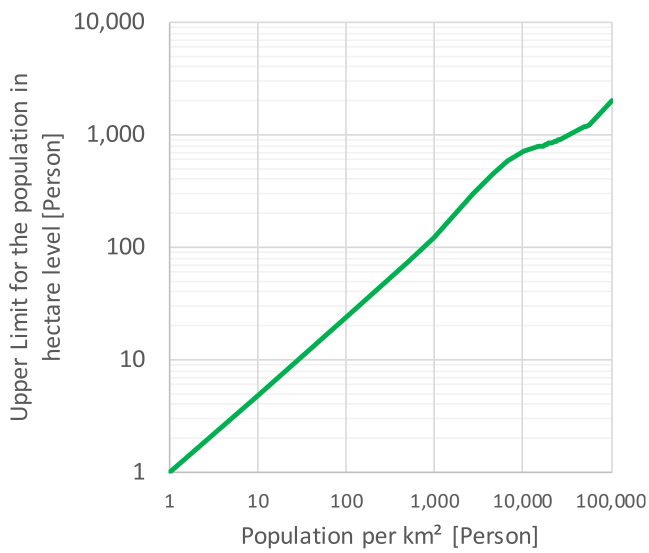


Figure 8. Upper limit for the population density on the hectare level

Gross floor area of buildings on the hectare level

For the estimated gross floor area of buildings on the hectare level, we use two independent approaches. The first approach builds on the population grid on the hectare level and derives the estimated gross floor area using the average gross floor area per dwelling and the average persons per household; this data is available from the building census for most European NUTS3 regions. While this approach is quite reasonable for the residential building stock, its prediction quality is quite poor for areas with a high share of non-residential buildings. Therefore, we build a second independent layer of the gross floor area.

For the second approach to derive the gross floor areas we use the data from the European Settlement Map and data from the building layer of the OpenStreetMap (OSM) database [47]. For the European Settlement layer [2] we estimate the gross floor area from the share of the plot area that is counted as sealed by buildings and a building height model considering the average share of sealed area. For the estimated gross floor area derived from the OpenStreetMap (OSM) [47] database, we evaluate the share of covered plot area per hectare level for all buildings covered by this data source. The gross floor area is then calculated from a generic building height model (Figure 9), accompanied by the average regional floor height derived from those buildings (~6 Mil. buildings spread over Europe) in the local neighbourhood, for which information on the number of floors is stored in the OSM database.

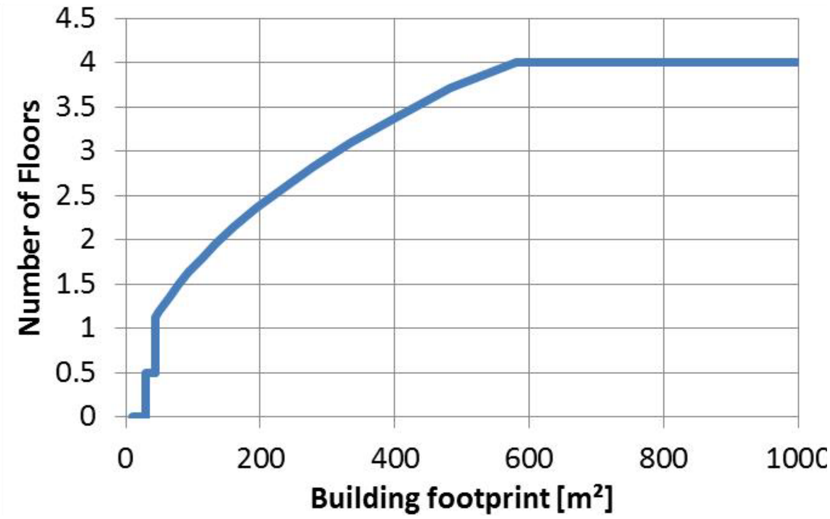


Figure 9. Generic building height model applied to the buildings covered in the OpenStreetMap database. This generic height model is accompanied by the average regional floor height derived from those buildings (~6 Mio. buildings spread over Europe), for which information on the number of floors is stored in the OpenStreetMap database [47].

In a next step, the so derived gross floor areas are compared against that from the population based approach. If the OSM-based approach derives lower areas, the areas are scaled (up to a factor of 4) accordingly. If the OSM-based approach results in an average floor area per inhabitant in a grid cell of less than 15m², then a quality indicator, which defines the completeness of the OSM data (see Figure 10), is reduced and the weight of the population-based approach that given grid cell is then reduced subsequently.

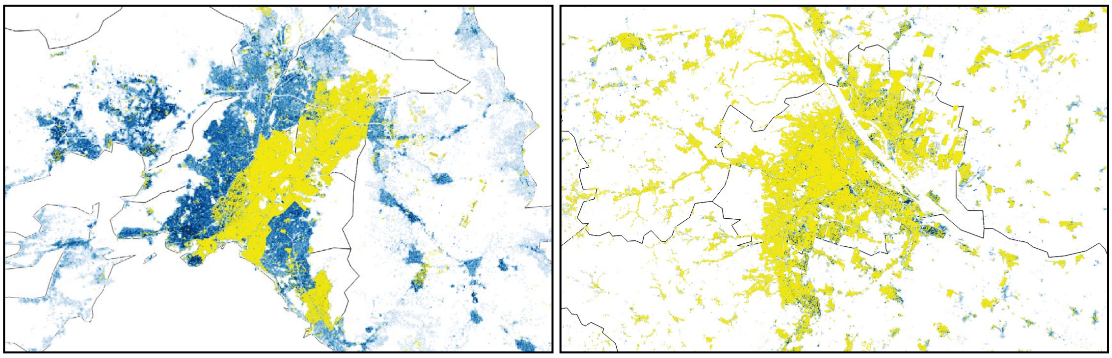


Figure 10. Completeness of OpenStreetMap-building stock data: Comparison of the OpenStreetMap-data (yellow) against European Settlement Map (blue) for the region of Athens (left map) and Vienna (right map) Sources: [2], [47].

For the estimate of the gross floor areas of residential buildings, we set a higher weight on the population-based approach. For the floor area of non-residential buildings we use (a) the value added (population per grid cell times per-capita value added of LAU region [45]) instead of the population indicator and (b) give the OSM-based approach a comparatively higher weight – 50% given that the data quality of the OSM data is estimated to be high and the corresponding grid cell is indicated as continuous urban fabric by the Corine land cover data. The detailed set of weighting factors for different land cover classes is given in Table *3*.

Table 3. Weighting of population/value added (VA) based versus OSM based approach for calculating the heated gross floor area, given that the OSM data quality is estimated to be high.

Corine land cover class	Residential gross floor area		Non-residential gross floor area	
	Weight factor of approach based on			
	Population	OSM data	Population x VA per capita of LAU region	OSM data
1: Continuous urban fabric	1	0.05	1	1
2: Discontinuous urban fabric	0.9	0.05	0.9	1
3: Industrial or commercial units	0.7	0.05	0.7	1
10: Green urban areas	0.1	0.05	0.1	1
11: Sport and leisure facilities	0.1	0.05	0.1	1
18: Pastures	0.5	0.05	0.5	1
20: Complex cultivation pattern	0.5	0.05	0.5	1
21: Land principally occupied by agriculture	0.5	0.05	0.5	1
Other classes	0.015	0.05	0.015	1

If the data quality of the OSM data is considered to be low, the weight of the OSM approach is reduced accordingly.

Heating and cooling degree-days on the hectare level

For the HDD and CDD, we use the observed average daily temperatures on the 25 x 25 km raster [38] and apply an environmental lapse rate of 6.5°C per 1000 m elevation gain according to the specifications of the International Standard Atmosphere model using the digital elevation model over Europe (EU-DEM) layer on the 30 x 30 m grid level [48] (see Figure 11).

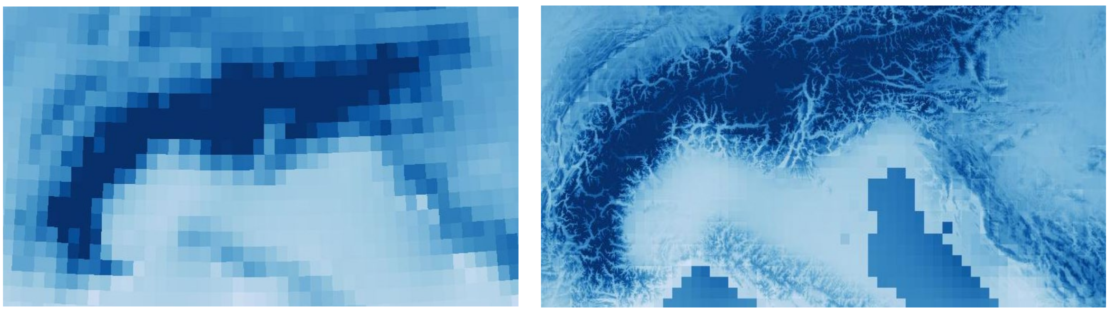


Figure 11. Heating degree days for the 25 x 25 km grid (left side) and the refined grid on hectare level after applying the environmental lapse rate of the International Standard Atmosphere model using elevation data from the European Union-Digital Elevation Model [48].

The UED for SH on a local level are corrected by applying the ratio between the calculated site specific heating degree days and the heating degree days on NUTS3 level using an elasticity of 0.5. By reducing the weight of the local heating degree-days we account for uncertainties involved as well as the (plausible) assumption, that in general buildings in colder areas (on higher elevation) might already have a higher energy performance than those in warmer (lower) areas.

Surface-to-volume ratio of buildings and local construction periods

For the spatial distribution of UED and FEC for SH we furthermore consider the surface-to-volume ratio of buildings and the share of building in different construction periods. For the surface-to-volume ratio, we build on the data derived from the OSM building layer: the building footprint and the estimated building height. For the share of buildings per construction period, we draw on soil sealing data for 1975, 1990, 2000 and 2014 on a 38 x 38 m raster [9], provided by the Global Human Settlement project. By considering the current share of soil sealed by buildings against the total share of sealed soil per grid cell (hectare level) as well as generic assumptions on building demolition[6], we derive the share of buildings per construction period for each grid cell. Exemplarily, Figure 12 depicts the results for Vienna.

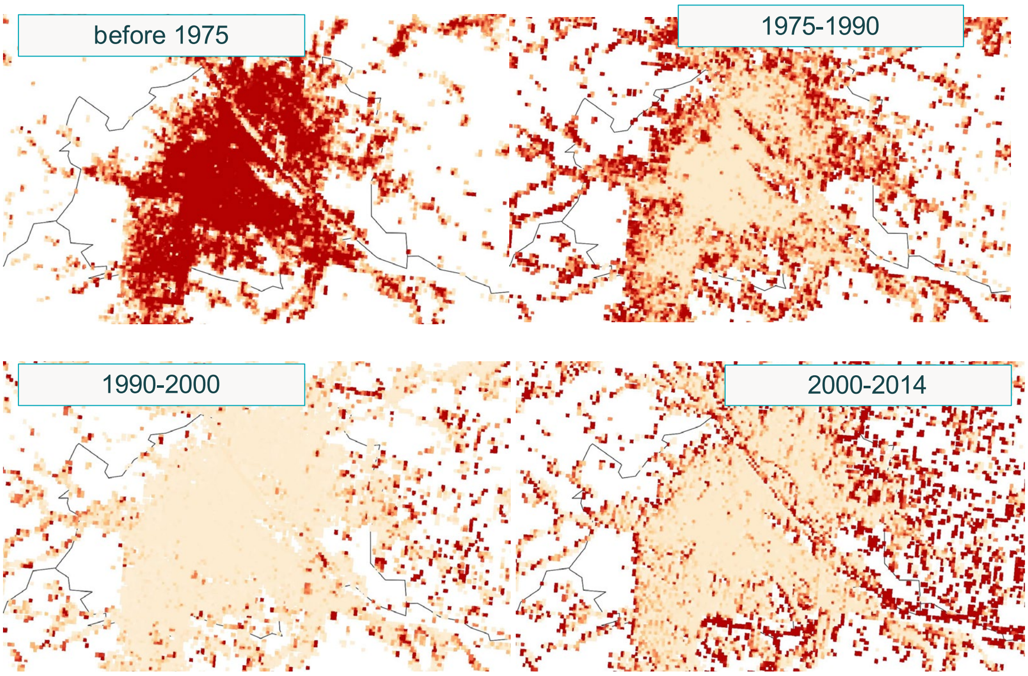


Figure 12. Estimates share of buildings per construction period for the region of Vienna. High shares are color-coded in red, low shares in beige.

[6] Own estimations: 0.2% annual demolition rate for buildings constructed before 1975, 0.1% annual demolition rate for buildings created between 1975-1990 for the period from 2000 onwards; furthermore: at least 0.75% of the soil sailing share in each period (1975/1990/2000/2014) must stem from buildings constructed in the latest construction period, e.g. if the soil sealing is 40% for a given grid cell in 1990, then the share of soil sealed by buildings constructed between 1975 to 1990 must be at least 40%x0.75% = 0.3%.

Even though the results are plausible on a general level, we are aware, that the uncertainties entailed in the methodology to calculate the surface-to-volume ratio and the share per construction period are significant. Therefore, we give these two factors a rather low weight. For the surface-to-volume ratio, we apply an elasticity of 33%. For specific UED per construction period, we assign buildings constructed after 2000 a UED of 80%, buildings constructed before 1990 a UED of 125% compared to buildings constructed between 1990 and 2000.

2.1.3.1. Limitations of data

For the use and the estimation of the reliability of the data it is important to keep in mind that the data maps build on a statistical approach and do not take site specific or local conditions into account.

Regarding the population data, the data are quite accurate up to a level between 250 x 250 and 500 x 500 m. Furthermore, the data are consistent with statistical data on LAU regions – given the limitations that statistical population data on LAU regions are not available for all census years and LAU regions (or contain inconsistencies) and therefore average population data for the years 2008 to 2016 are used. Manually performed checks, performed for many regions, where we estimated the number of inhabitants using satellite images and estimated number of persons per building type assured that the data are plausible also for higher resolutions.

For the residential heated gross floor area, statistical data are available for most countries on the level of NUTS3. Again, manually performed data quality checks indicate that results are plausible on the hectare level of most regions. However, as of now, we do not factor in the fact, that the heat area per inhabitant often decrease with an increasing population density. For NUTS3 regions with a strong urban versus rural area gradient, this might lead to overestimation of the heated residential gross floor area in urban areas. Regarding the heated gross floor area of non-residential buildings, data sources are even uncertain on the NUTS0 level. Data quality checks indicate that the sum of residential and non- residential heated gross floor area are plausible as well as the ratio between residential and non-residential gross floor area, even though the later indicator might not hold for grid cells which contain only few buildings.

Regarding the UED (energy needs) map (heat density map), the data are calculated on the NUTS0 level from statistical data on the energy consumption as well as the national building stock characteristics. In order to derive grid cell specific energy demand-per-floor area data, we assessed the surface-to-volume ratio of buildings based on the OpenStreetMap database, the share per construction periods as well as the heating and cooling degree days. The first two indicators are plausible, but in the end highly uncertain. Therefore, we put only a low weight on these indicators in our calculations. The last indicator, the heating and cooling degree days are of higher accuracy, even though we used a simple atmospheric temperature lapse rate model, which cannot account for local site specific wheatear and thus climate conditions. However, additional uncertainty stem from the fact, that is unknown to which degree colder (or warmer) local climate conditions already factored in the construction of building. Since we assume that this might be the case to some extent, we lowered the weight of the climate indicator compared to what is usually considered to be actual degree of influence. Again, data quality checks indicate that results are plausible, however we recommend to use individual data on the heated area-specific UED whenever local data are available.

2.1.4. Nearly zero-energy buildings (nZEB)

According to article 2 of the EPBD (Energy Performance of Buildings Directive) [49], "*nearly zero-energy building* means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."

Concrete numeric thresholds or ranges are not defined in the EPBD, therefore these requirements leave space for interpretation and allow MSs to set their nearly zero-energy building (nZEB) definition in a flexible way considering their country specific climate conditions, primary energy (PE) factors, ambition levels, calculation methodologies and building traditions. Furthermore, the EPBD makes nZEBs a standard by 2021 for all new buildings and by 2019 for all new public buildings.

With this background, the EPBD implementation in Europe presents three main variables [50]:

1) Unique legislation for all EU MSs
2) Legislation at regional level: A region can apply the national regulation or can apply its own regulation adapted to the regional characteristics, but it has to be always within the national and European legal framework (e.g. Italy and Spain)
3) Regions apply the EPBD implementation, as they were independent countries (e.g. Belgium and United Kingdom)

The aim of the nZEB database generated within the Hotmaps project is to show a broad overview of existing nZEB definitions in the EU28 and assess the penetration of nZEBs in the current building stocks. Besides, it aims at assessing the different PE uses in nZEBs (e.g. SH, SC, DHW aso.) and at quantifying the proportion of energy from renewable energy (RE) sources for this kind of buildings.

2.1.4.1. Methodology

In most of the cases, the nZEB definition includes limits on PE, share of use of RE and thermal transmittances of the building envelope components, but the definition can include other requirements like airtightness or efficiency of specific technologies. The nZEB database provides information on these requirements for SFHs, MFHs and non-residential (NR) buildings for the different countries. In addition, the database gives information on the share of new buildings fulfilling the national nZEB standards and the new yearly constructed nZEB floor area for a selected year (generally 2014) and for each MS.

In the case of the PE limit, it has been identified, if the national definition includes or does not include the share of RE. Finally, the distribution of the PE for the different energy end-uses has been indicated, i.e. SH, SC, DHW, auxiliary aso.

The data collection has been based on the most recent and reliable sources at European and national level as far as possible. The closing date of the data collection was end of 2016 and the base year 2014, since most of the sources were dated at the end of 2014. Nevertheless, by 2015 about 40% of the MSs did not have a detailed nZEB definition in place [51]. Some MSs have laid out their detailed nZEB definition in a legal document, but some others have the definition as a draft. This makes the EPBD implementation a continuous and changeable process, which means that new nZEB definitions are emerging little by little, but also that amendments can arise for existing definitions.

The used sources at European level for the nZEB definitions are mainly reports of the Concerted Action on the EPBD [52], the EU Buildings Database [25] and the results of previous EU projects like ZEBRA2020 [53]. At national level, the sources are principally the definitions provided in the nZEB National Plans [54] and national building codes, like in the case of Italy [55], Austria [56] or United Kingdom (UK) [57].

Concerning the penetration of new nZEBs in the existing building stock, the sources are mainly the EU Buildings Stock Observatory [23], ZEBRA2020 project [53] and National Institutes of Statistics.

Despite the existence and availability of various sources for nZEBs, still a remarkable lack of data on nZEBs is prevailing. This is not only due to nonexistence of nZEB definitions in many countries, but also because there is a lack of detailed specifications like limits on different energy uses, limits on the thermal transmittance of building envelope components or the nZEB penetration in each MS. Therefore, and in order to avoid these data gaps, several assumptions and estimations were needed – see chapter 2.1.4.3 *Limitations of data*.

2.1.4.2. Main results (EU28)

Primary Energy limits in nZEBs

The nZEB limits on the global PE, which includes RE and non-RE sources, varies considerably from MS to MS. As shown in Figure 13, Denmark and Lithuania have values relatively low for the global PE, while in Finland and Austria the values are relatively high.

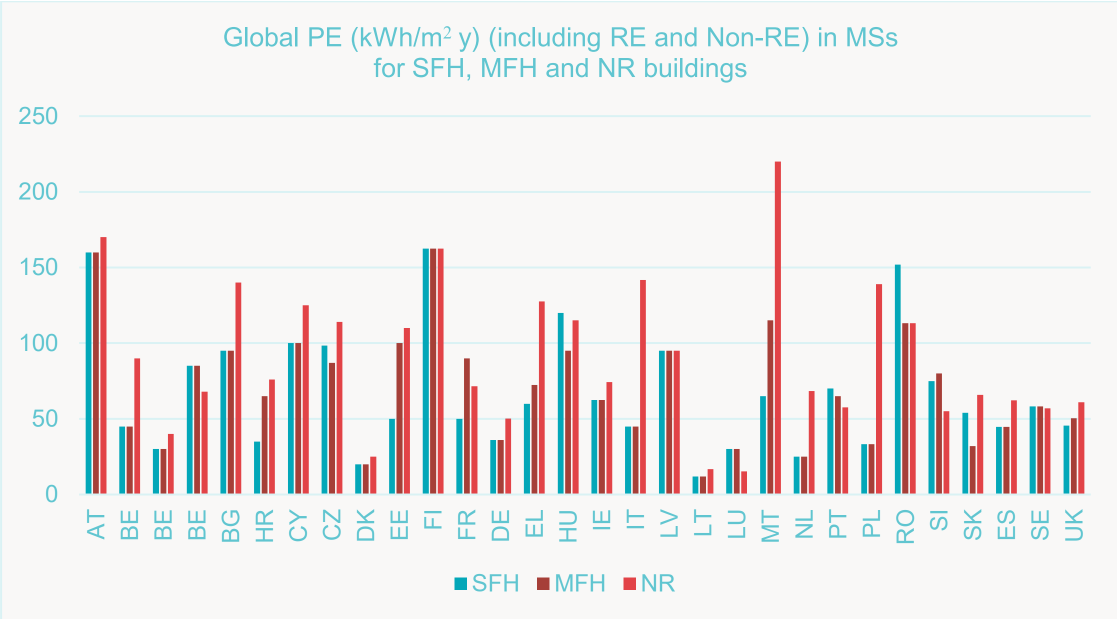


Figure 13. Global primary energy in member states for single family houses, multiple family houses and non residential buildings in 2014. Source: own elaboration

Due to a lack of data, for some countries assumptions have been made following the criteria defined in the next chapter 2.1.4.3 *Limitations of data*.

nZEB penetration

The share of new buildings constructed according to the national nZEB standards on the overall newly constructed buildings in the EU MSs is shown in Figure 14. Most MSs show shares between 10 and 20%, with the exceptions of France, where new building with nZEB standard is compulsory since 2013, and UK and Czech Republic, where the nZEB penetration seems to be still low.

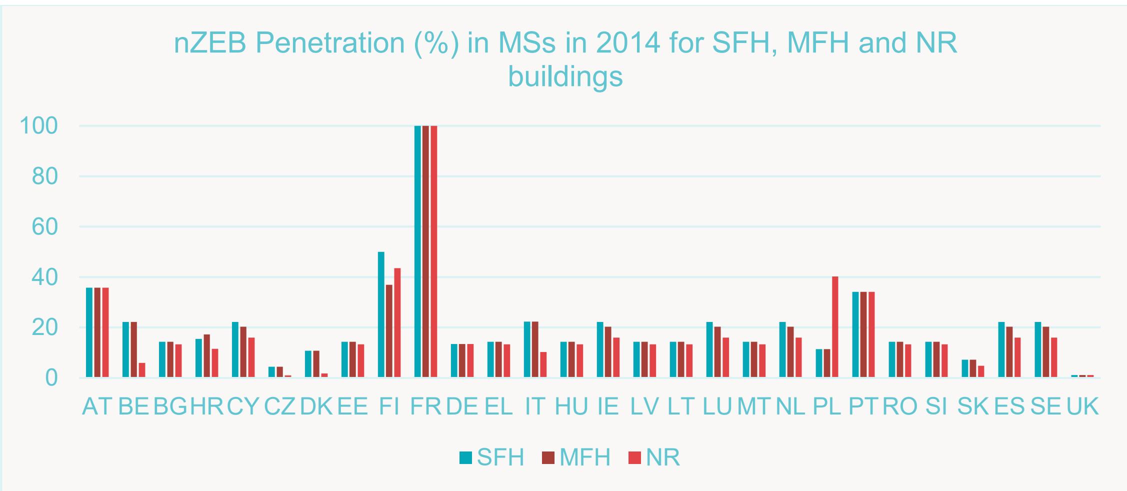


Figure 14. Nearly zero-energy buildings penetration (%) within member states in 2014 for single family houses, multi family houses and non residential buildings. The present statistic bases on amount of buildings. Source: own elaboration

Due to lack of data, in some countries assumptions have been made following the criteria defined in the next chapter 2.1.4.3 *Limitations of data*.

nZEB thermal transmittance requirements

The requirements for the thermal transmittance of the building envelope components are strongly influenced by climate conditions. As shown in Table 4 and according to the classification of MSs climates [58] as defined in Figure 15, countries located in warmer zones (zones 1 and 2) have higher nZEB thermal transmittance limits, which means less efficiency of the envelope components. On the other hand, countries located in colder zones (e.g. zone 5) have lower limits, since climate conditions in this zone requires less transmittance of building envelope.

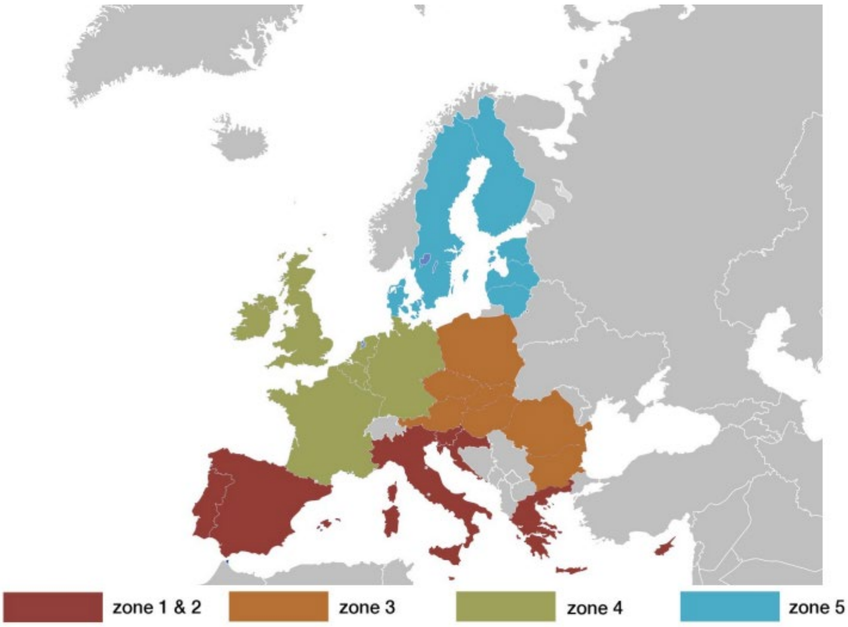


Figure 15. Member states according to different climate zones. Source: [58]

Table 4. Average nearly zero-energy buildings thermal transmittance requirements of member states by climate zones. Source: own elaboration

U-Value	Zone 1&2			Zone 3			Zone 4			Zone 5		
	SFH	MFH	NR	SFH	MFH	NR	SFH	MFH	NR	SFH	MFH	NR
Wall	0.33	0.33	0.33	0.24	0.24	0.24	0.19	0.19	0.20	0.14	0.14	0.17
Roof	0.31	0.31	0.31	0.16	0.16	0.16	0.17	0.17	0.20	0.09	0.09	0.11
Floor	0.33	0.33	0.33	0.29	0.29	0.29	0.19	0.19	0.21	0.12	0.12	0.16
Window	1.83	1.83	1.83	1.13	1.13	1.13	1.21	1.21	1.28	0.95	0.95	1.17

Due to a lack of data, in some countries assumptions have been made following the criteria defined in the next chapter.

Share of RE required for nZEBs

The minimum share of RE use for nZEBs is very variable from MS to MS, but in most of the countries the share is between 30% and 50%, as shown in Figure 16. It has to be noted that the required share of RE use for nZEBs is affected by the national energy mix.

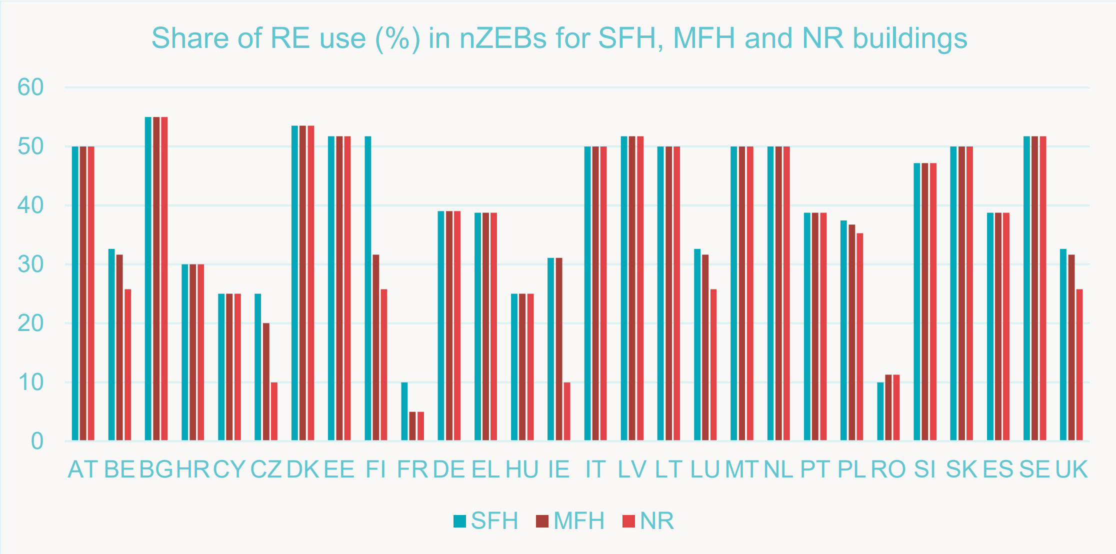


Figure 16. Share of renewable energy use (%) in nearly zero-energy buildings for single family houses, multi family houses and non residential buildings. Source: own elaboration

Due to a lack of data, in some countries assumptions have been made following the criteria defined in the next chapter 2.1.4.3 *Limitations of data*.

2.1.4.3. Limitations of data

The lack of definitions and data in some MSs have been overcome with different estimations and assumptions (see Annex *4.2 Assumptions for nearly Zero-Energy Buildings*), which have been made dependent on the availability of data and adjusted according to the similarities between the different MSs (e.g. climate zone or gross domestic product - GDP).

For each indicator, the following assumptions and estimations have been performed:

- Share of new nZEBs (%):
  - When no data was available, we assumed the same share as the average share of MSs with similar GDP.
  - When data in a specific type of building was missing, we assumed the same share as the other types of buildings.
  - When there was a lack of data for the reference year, we assumed the data for the nearest year available.
  - When there was no nZEB definition or no amount of nZEBs is registered, we assumed the share of new buildings in class A and A+ to be equivalent to nZEB buildings, if available.
  - Some values were provided as estimations in nZEB national plans.

- New yearly constructed nZEB floor area (1000 m²):
  - When there was a lack of data for the reference year, we assumed the data for the nearest year available.
  - When there was no data of constructed floor area but there was data of the constructed volume, we calculated according to estimated height of the floors.
  - When there was no data on floor area but there was data on number of building permits, we assumed an average floor area of the building.
  - When there was no disaggregated data between residential and non-residential, the floor area was estimated according to the disaggregated number of existing buildings, if available.
- Share of Renewable Energy:
  - When there was no data available, we assumed the average value of MSs in similar climate.
  - When different shares for different RE sources were provided, the provided value in the database was the average share of all the RE sources.
- Primary Energy:
  - When no PE limit exists, we applied the proposed value (e.g. PE of class A building) in the different sources.
  - The different PE values (i.e. PE total, PE renewable and PE non-renewable) have been calculated according to the provided value and the share of RE.
- PE distribution for different uses:
  - When there was no distribution of PE for the different energy uses, we assumed the average distribution of selected nZEB examples [12] in a similar climate, or the distribution of PE proposed in reference buildings in the TABULA WebTool [13] with an nZEB standard.
- Inclusion of renewable energy in the PE limit:
  - When no information was included, we estimated depending on the size of the proposed value.
- Thermal transmittance of building envelope components:
  - When U-values were not available, we assumed same value as the average U-values of MSs with similar climate.
  - When U-values for specific components were missing, we estimated that U-values for walls and roofs have the same value.

2.2. Space heating, cooling and domestic hot water

The present task provides data with following characteristics:

Table 5. Characteristics of data provided within Task 2.2 Space heating, cooling and domestic hot water. The database of given task is available at: https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

	Spatial resolution	Temporal resolution
Space heating, cooling and domestic hot water statistics	NUTS0	yearly
Inventory of technologies	NUTS0	-
Assessed space heating and cooling demand	Raster @ 100 X 100 m	yearly
Assessed domestic hot water demand	Raster @ 100 X 100 m	yearly

This Task assesses the UED and FEC for SH, SC and DHW at NUTS0 level deviding between residential and service sectors. Based on this analysis, basic statistics on the UED per category could be developed for the EU28 at regional/local level.

Generated datasets will also be used as input information to carry out the analysis of Chapter 2.5 *Heating and cooling supply*.

The present Chapter 2.2 is subdivided in *Top-down approach* (Chapter 2.2.1) and *Bottom-up approach* (Chapter 2.2.2). Chapter 2.2.2 is in turn subdivided in SH and DHW, and SC.

The data provided by Task 2.1 feed the Hotmaps toolbox with regard to SH, SC and DHW (and not data collected within Task 2.2) due to Task 2.1 numbers show a higher level of detail. In contrast to Task 2.2, Task 2.1 values have been assembled per various subcategories of the residential (SFHs, MFHs, and ABs) and service sectors (offices, trade, education, health, hotels and bars, and other non-residential buildings). Moreover, Task 2.1 data for SH, SC and DHW has been researched per various construction periods (before 1945, 1945-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2010, post 2010) while this is not the case for Task 2.2. Whereas Task 2.1 and 2.2 *Top-down approach* values largely match concerning SH, SC and DHW, Task 2.2 *Bottom-up approach* numbers differ significantly from results provided by Task 2.1 and 2.2 *Top-down approach*.

2.2.1. Top-Down Approach

2.2.1.1. Methodology

Data on UED and FEC for SH, SC and DHW (kWh/m² y) were collected from various sources, divided by MS (EU28) and ordered within the households and service sectors. Thus, in this case, in contrast to sections 2.1 and 2.2.2 *Bottom-up approach* SC, no subsectors (SFHs, MFHs and ABs as well as offices, trade, education, health, hotels and restaurants, and other non-residential buildings) are considered.

The heated and cooled floor area, as well as the whole floor area in the residential and service sectors (Mm²) was identified for the different EU MSs. For the graph shown with a unit of kWh/m² y (Figure 17) the average line is obtained by weighting the mean of the single nations´ UED and FEC on the heated or cooled floor area of the respective country.

In the case of DHW preparation the entire floor area has been taken into consideration.

In the chart shown with a unit of kWh/inhabitant y (Figure 18), the average line is obtained simply by calculating the mean of the UED and FEC values for the different EU28 countries. The following values with a unit of kWh/inhabitant y (residential sector) or kWh/employee y (service sector) mainly indicate the specific energy use habits of the inhabitants or employees in the various EU28 MSs. The columns given in kWh/inhabitant y have been calculated by dividing the UED or FEC per application type (SH, SC or DHW) in TWh/y by their respective amount of occupants within the households sector.

The total SH and SC per country in TWh/y have been obtained by multiplying the average UED and FEC per country in kWh/m² y with the respective heated or cooled floor area in Mm². These show the related distribution of the UED and FEC among the EU28 nations.

Following values regarding UED and FEC for DHW purposes and MS in TWh/y have been calculated by multiplying the average UED for DHW preparation and FEC per country in kWh/m² y with the respective entire households or service sector floor area of each country in Mm².

Additionally, the UED for DHW purposes and MS in TWh/y has been calculated by means of population and households by multiplying the UED per person[7] and dwelling with respective amount of inhabitants and number of dwellings[8]. Due to found indications of UED per person and dwelling relate to FEC solely, a conversion to FEC took place taking into consideration indications found in[9].

---

[7] UNEP Solar Water Heating Project, Domestic hot water for single family houses, 2018 http://www.estif.org/fileadmin/estif/content/publications/downloads/UNEP_2015/factsheet_single_family_houses_v05.pdf

[8] Fuentes E., Arce L., Salom J., A review of domestic hot water consumption profiles for application in systems and buildings energy performance analysis, 2018 https://www.sciencedirect.com/science/article/pii/S1364032117308614#bib1

[9] K. Kovacova, M. Kovac, ENERGY EFFICIENCY OF DOMESTIC HOT WATER DISTRIBUTION SYSTEM, 2016
Index mundi, Demographics: Population, 2017 https://www.indexmundi.com/map/

Not all collected information has been used to form the statistics. Data, which lie outside a range of plus or minus one standard deviation around the average of the respective data pool, have been discarded. The filtered values have then been used to compute a more robust average.

Due to the impossibility of creating complete energy statistics by collecting climate corrected information, this type of data has been excluded by the investigation.

Most recent data has been assembled. Values characterized by a reference year more than a decade ago have not been taken into consideration. Specifically, the data used to obtain the figures and values of the *Main results (EU28)* section covers the period until 2016.

In Figure 17, characterized by a unit of kWh/m² y, the numbers straight over the top of the columns indicate the amount of information used to calculate the values for each column, the error bars show their standard deviation and the percentages above their coefficient of variation (CV). In the case of charts with a unit of TWh/y, the percentages at the top of the columns indicate the CV of the data used to form the respective columns and the error bars represent their standard deviation.

Once more, due to the large number of references taken into account, in the section *Main results (EU28)* only major sources are indicated. For further information concerning references utilized, please see: https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

2.2.1.2. Main results (EU28)

Figure 17 shows the relation between UED and FEC for SH of the residential sector in kWh/m² y between the different EU28 countries.

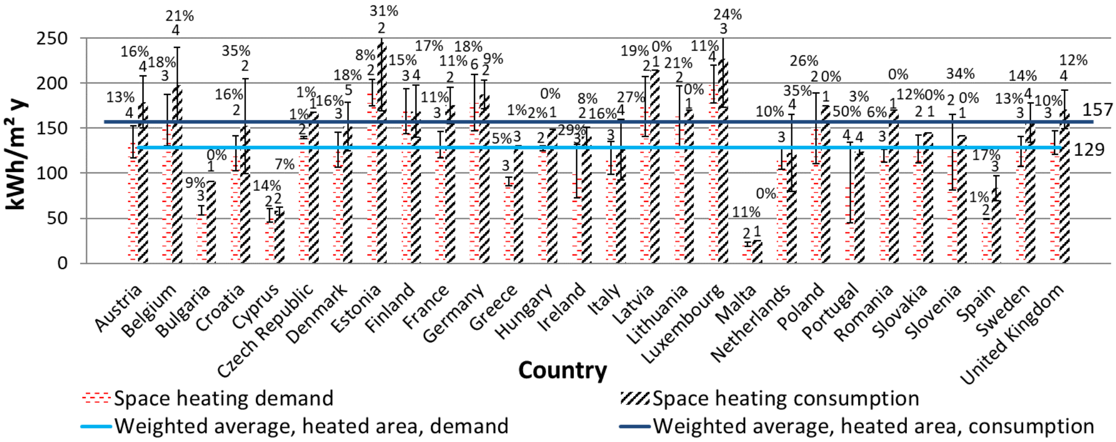


Figure 17. Useful energy demand and final energy consumption for space heating per country, residential sector, kWh/m² y. Sources: [12], [15], [17], [43], [59]

The average UED and FEC for SH in the residential sector results to be about 130 and 160 kWh/m² y, respectively. This results in a ratio of about 1:1.2. Figure 17 shows a certain homogeneity regarding the UED and FEC for SH per country. MSs with colder climates demonstrate more useful UED and FEC for SH than nations with warmer climates. The CV percentages shown in Figure 17 demonstrate that the selected data to form the bars are rather similar. The average value is around 15 and 11% for the UED and FEC respectively. Respective mean values for DHW result to be 22 (UED) and 31 (FEC) kWh/m² y.

Concerning the service sector, the UED and FEC for SH comes out to be approximately 120 and 157 kWh/m²y.

With regard to SC, following average numbers are obtained:

- 36 kWh/m² y (residential, UED);
- 12 kWh/m² y (residential, FEC);
- 75 kWh/m² y (service, UED);
- 30 kWh/m² y (service, FEC).

Like visible from the values displayed above, the UED for SH appears to be highly similar between households and the service sector, while for SC an enormous difference is given. The specific UED as well as FEC values show to be nearly double as high than in the residential sector.

If the energy use habits of the different EU28 citizens are compared concerning UED and FEC for SH, once more a wide gap emerges (see Figure 18).

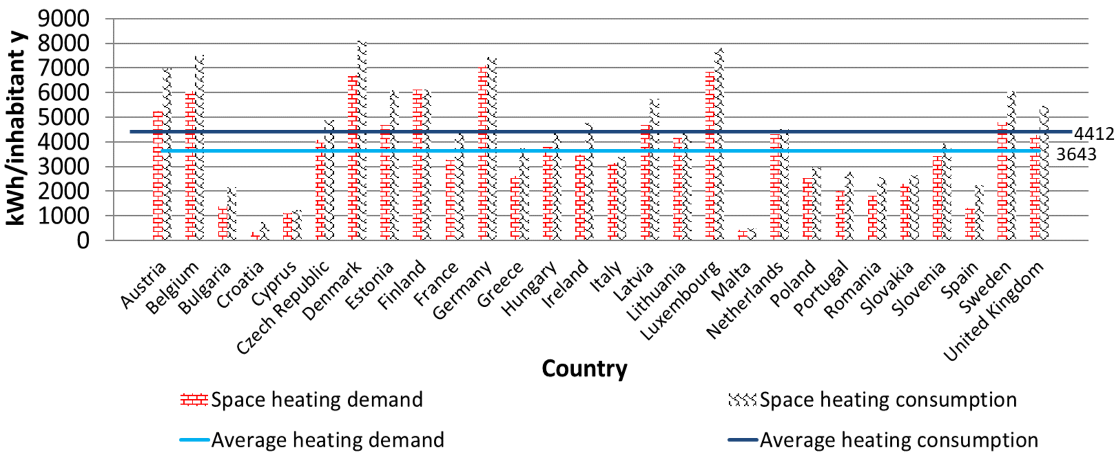


Figure 18. Useful energy demand and final energy consumption for space heating per country, residential sector, kWh/inhabitant y. Sources: [12], [15], [17], [59], [60]

The mean value concerning the UED and FEC for SH in the residential sector is about 3600 and 4400 kWh/inhabitant y. The highest UED as well as FEC for SH value in Figure 18 is given by Germany, Denmark and Luxembourg. These countries are characterized by relatively low energy prices and/or high purchasing power per person [61], [62]. Moreover, the bar for France appears to be smaller in Figure 18 compared to Figure 17 for the same kind of application. One reason for that is, French dwellings being typically smaller than the EU28 mean; France has about 89 m² average floor area per dwelling and the EU28 mean per living unit is around 93 m² [63].

Respective average values for DHW and SC purposes (UED and FEC) result to be:

- DHW
  - 763 kWh/inhabitant y (residential, UED)
  - 1065 kWh/inhabitant y (residential, FEC)
- SC
  - 207 kWh/inhabitant y (residential, UED)
  - 80 kWh/inhabitant y (residential, FEC)

While at the residential sector the UED and FEC attitudes of the different EU28 citizen have been shown through a unit of kWh/inhabitant y, concerning the service sector, the unit of kWh/employee y is used. See Figure 19:

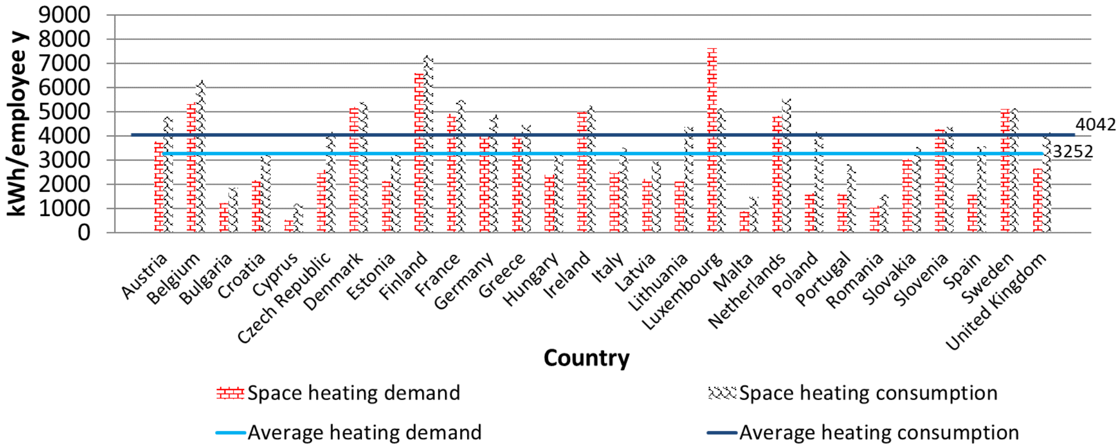


Figure 19. Useful energy demand and final energy consumption for space heating per country, service sector, kWh/employee y. Sources: [12], [15], [17], [59]

This graph shows the attitude of the work active population concerning the different EU28 countries. At Figure 19, the average UED value for SH is about 3250 kWh/employee y. If this value is compared with the average UED value of the residential sector (around 3640 kWh/inhabitant y) a reduction of about 11% in the service sector is recognizable. The respective reduction for FEC concerning SH comes out to be around 8%.

Respective average values for DHW and SC purposes (UED and FEC) result to be:

- DHW
  - 146 kWh/employee y (service, UED)
  - 224 kWh/employee y (service, FEC)
- SC
  - 788 kWh/employee y (service, UED)
  - 310 kWh/ employee y (service, FEC)

The UED for SH in the residential sector of the EU28 is around 1953 TWh/y. In comparison, the respective FEC is about 2326 TWh/y. See Figure *20*.

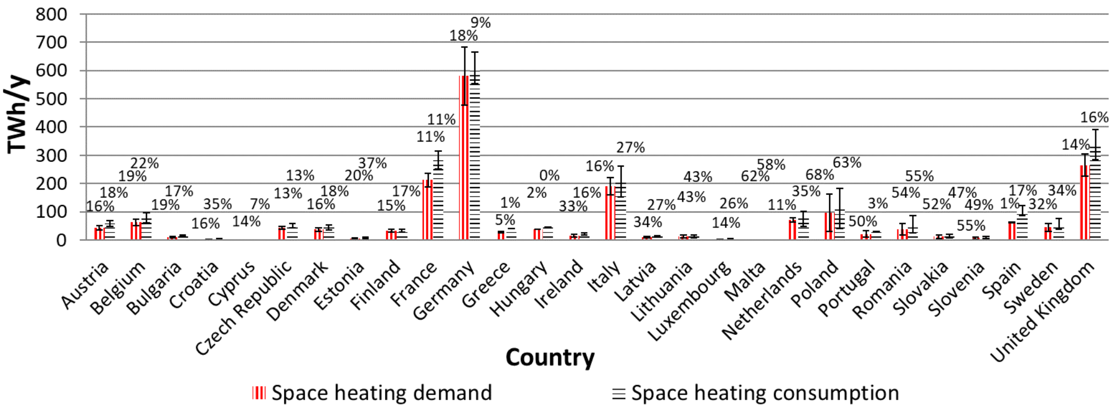


Figure 20. Useful energy demand and final energy consumption for space heating per country, residential sector, TWh/ y. Sources: [12], [15], [17]

Within the service sector, values result to be 732 and 989 TWh/y for UED and FEC respectively.

Total values for DHW and SC purposes (UED and FEC) in the residential and service sectors come out to be:

- DHW
  - 396 TWh/y (residential, UED)
  - 530 TWh/y (residential, FEC)
  - 33 TWh/y (service, UED)
  - 50 TWh/y (service, FEC)

- SC
  - 54 TWh/y (residential, UED)
  - 27 TWh/y (residential, FEC)
  - 153 TWh/y (service, UED)
  - 81 TWh/y (service, FEC)

With regard to the UED for DHW purposes and MS in TWh/y calculated by means of population and households the results come out to be approximately 390 and 419 TWh/y respectively. Thus, the difference to the values shown above (calculated by multiplying the average UED for DHW preparation per country in kWh/m² y with the respective entire households floor area) appears to be 2% and 6% respectively.

Regarding the total UED (residential and service sectors) for SH, SC and DHW within the entire EU28, the highest position is held by SH with approximately 2685 TWh/y, followed by DHW with around 429 TWh/y and SC (207 TWh/y). Respective values concerning the FEC result to be 3315 TWh/y for SH, 581 TWh/y for DHW, and 108 TWh/y for SC. Thus, a relation of approximately 6 times is given between UED for SH and DHW as well as a relation of around 13 times between UED for SH and SC. Regarding FEC, a relation of approximately 6 times is given between SH and DHW and around 31 times between SH and SC.

The EU15 countries (European nations which joined the EU before its enlargement in 2004 [64]) are responsible for practically the entire UED and FEC for SC of the EU28, with about 87 and 91% respectively.

Analysing the data published within the past decade (UED and FEC) shows a reduction in specific residential SH and DHW for EU28 countries. The same applies to respective data within the service sector. In contrast, Europe´s specific SC data (residential and service sectors) remain rather constant.

For further information, please see:
https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

2.2.1.3. Limitations on data

Like already mentioned above in Chapter 2.1, a number of difficulties apply also to the work performed for Task/Chapter 2.2.

Even though there are some uncertainties, on the national level, SH, SC and DHW data related to specific UED and FEC (kWh/m² y) is available from projects (EU and national), journal papers as well as conference proceedings and further scientific literature (e.g. presentations). The same applies to heated, cooled and total floor areas (Mm²) for the residential and service sectors.

Unfortunately, not all cells of the database could be filled ad hoc by assembling information from scientific literature and therefore estimations have been performed. Data has been transposed from one country to another one, if similar geographical, socio-economic and historical features characterize the two countries (e.g. Bulgaria and Romania). Those cells that were filled with estimated data are marked in grey within the database.

In the case solely FEC values were available, these have been transformed in UED data. The indicated values are marked in grey. The transformation has been carried out like indicated above (subchapter 2.1.1), by dividing the FEC values through 1.15.

it was not always possible to assemble two or more data per each researched value; thus, in these cases, no statistical elaboration has been performed.

Once more, main obstacles encountered in our study relate to the erroneous interchange of the concepts regarding UED and FEC as well as the scarce availability of SC data. We registered a random use of UED and FEC within scientific literature. We correctly distinguished between different kinds of information by analysing the methodology related to the data found. In case of missing data documentation, these data have been excluded from the database. Almost no data is available for SC. At the moment a huge amount of data concerning the SC market in Europe is based on estimations [32], [34].

2.2.2. Bottom-Up Approach

2.2.2.1. Space heating and domestic hot water

Methodology

Chapter 2.2.2.1 *Space heating and domestic hot water* analyses the distribution of technologies for SH and DHW, equivalent full-load hours, and number of units installed in the residential and service sectors. In this case, in contrast to Chapter 2.1 *Building stock analysis* and Chapter 2.2.2.2 *Space cooling*, no subsectors are considered. A further classification per sector identified the units' typology, their installed capacity, their energy efficiency at full-load, and yearly hours of operation.

In order to retrieve reliable values, an extensive literature analysis has been performed; i.e. only scientific literature sources have been used for data collection. All collected information have been filtered and evaluated statistically. As far as the number of sources allowed, data lying outside the range of plus or minus the standard deviation around the average have been discarded from the respective data pool. Then, the filtered values have been used to compute a more robust average.

Moreover, the work input per SH and DHW equipment has been calculated. To obtain these values, the average capacities per equipment have been divided through their respective energy efficiency at full-load.

The FEC by equipment type and sector has been calculated. To obtain the yearly FEC for SH and DHW purposes and sector, the quantity of units (Nr.) per sector has been multiplied by their average equivalent full-load hours (T: time) within a year and its work input (W). See equation 1:

$$Final\ energy\ consumption_{\ SH\ and\ DHW} = Nr._{units} \times T_{equivalent\ full-load\ hours} \times W \qquad (1)$$

Furthermore, we collected information (in percentage at NUTS0 level) concerning system types (central or individual) applied as well as resources used of the equipment taken into consideration. Here also qualitative information has been provided due to a number of SH and DHW technologies considered are either centralized or individual per definition.

The main sources of data collection for this study have concentrated on preceding investigations. In particular, the projects Heat Roadmap Europe, Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables), the deliverable Intermediate analysis of the heating and cooling industry, reports of Solar Heat Worldwide, [EUROHEAT & POWER publications, EUROSTAT, and the TABULA WebTool [14], [65]–[70].

Again, due to a very high amount of references, in next Section 2.2.2.1 *Main results (EU28)* only major references are indicated. For further information on data sources, please see:
https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

Main results (EU28)

The following SH and DHW equipment types have been identified in order to analyse the market:

- Boiler
  - Non-condensing
  - Condensing
- Stoves
- Electric radiators
- Heat Pumps
  - Aerothermal
  - Geothermal
- Solar thermal
  - Unglazed collectors
  - Flat-plate collectors
  - Evacuated tube collectors
- Combined heat and power – Internal combustion (CHP-IC)
- District heating (DH) [12], [69], [70]

With regard to the classification shown above, it has to be stressed that furnace has been added to the section “Boiler, Non-condensing”.

The resources utilized in SH and DHW equipment have been classified as follows:

- Oil;
- Gas (Natural gas/Biogas);
- Coal (Briquet);
- Renewables;
- Other fuels [12], [69], [70].

Regarding the class *Renewables*, the database contains also information on biomass. The section *Other fuels* refers to less diffused combustibles like peat, coke etc. [68].

Figure 21 provides information concerning the number of installed SH and DHW units per type.

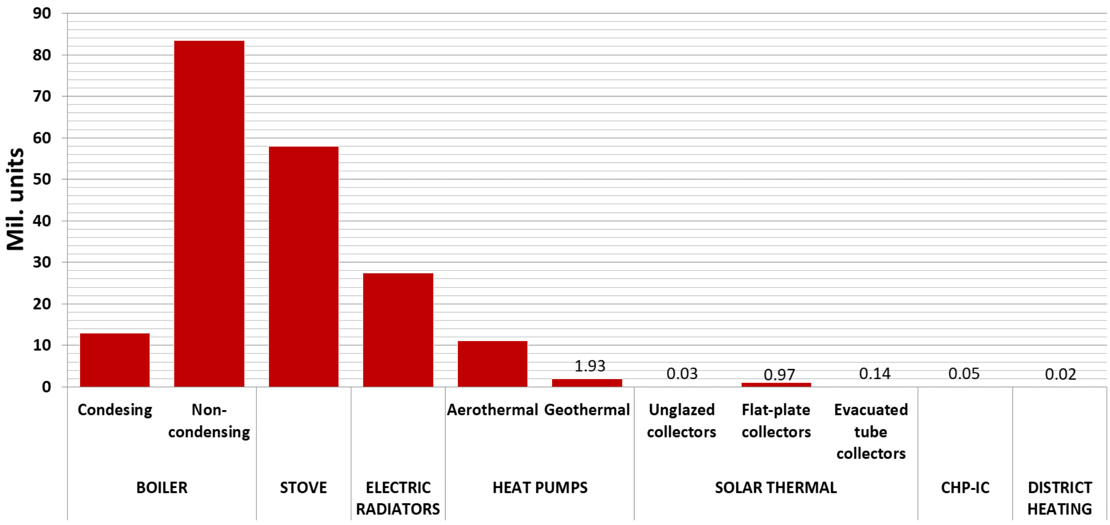


Figure 21. Number of operative units for space heating and domestic hot water per equipment type, European Union 28. Sources: [12], [69]–[71]

Non-condensing boiler account for the majority of units with more than 80 million (Mil.) installed devices. Stoves follow with nearly 60 Mil. Successively, in order of diffusion: electric radiators (around 30 Mil. units), condensing boiler and aerothermal heat pumps (HPs) (more than 10 Mil. units respectively), geothermal HPs (2 Mil. units) and solar thermal systems (STS)-flat-plate collectors (1 Mil. units). The remaining technologies are STS-evacuated tube collectors, CHP-IC, STS-unglazed collectors, and DH, with 0.14, 0.05, 0.03, and 0.02 Mil. units respectively.

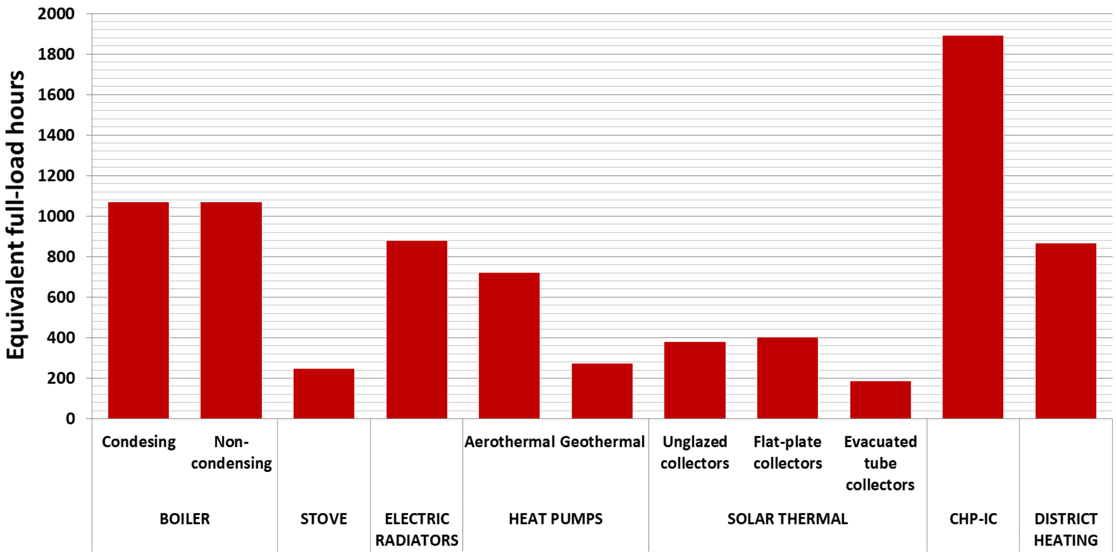


Figure 22. Distribution of average space heating and domestic hot water units' equivalent full-load hours per equipment type, European Union 28. Sources: [12], [66], [70], [72]

Figure 22 shows the distribution of equivalent full-load hours per each technology. CHP-IC units are characterized by the highest mean value of full-load hours per year (i.e. more than 1800 h). Boiler (non-condensing and condensing) follow with more than 1000 h. Electric radiators and DH show values around 900 h. Close behind we find aerothermal HPs, with more than 700 h, and STS-flat-plate and STS-unglazed collectors with 400 h each. Geothermal HPs follow with around 300 h; while stoves and STS-evacuated tube collectors are last positioned with approximately 200 h.

Next, Figure 23 indicates the average installed capacity per equipment type in kW.

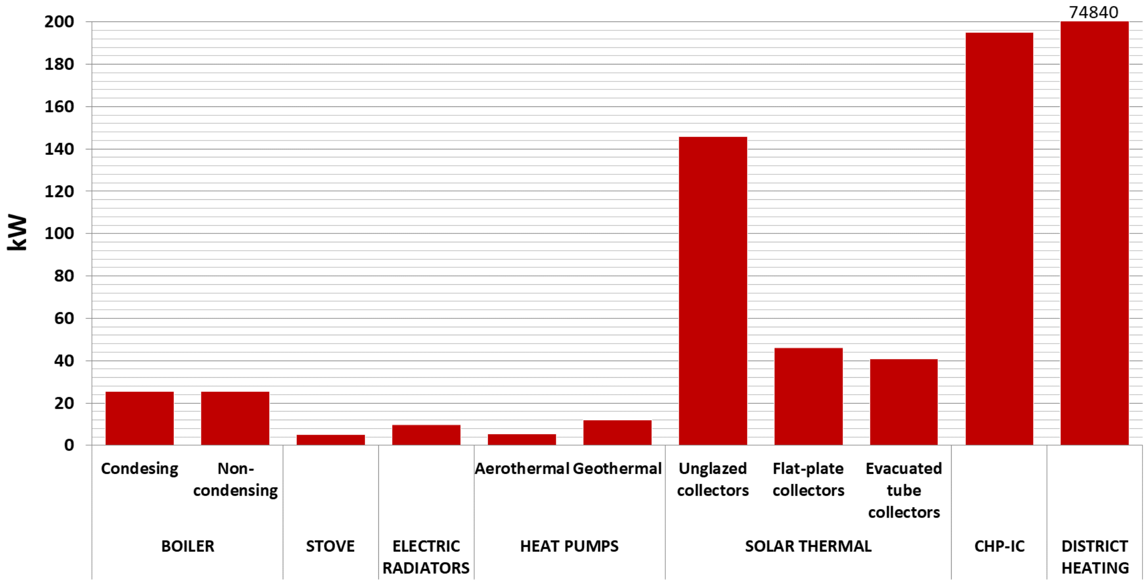


Figure 23. Average installed capacity per equipment type, European Union 28. Sources: [12], [67], [70]

DH reaches a mean value largely exceeding Figure 23 axis indication, reaching a value of nearly 75000 kW. CHP-IC are characterized by an average amount of almost 200 kW. STS-unglazed collectors follow with more than 140 kW. The remaining STS types (i.e. flat-plate and evacuated tube collectors) come next with about 40 kW. Boiler (non-condensing and condensing) show an average installed capacity around 20 kW. Geothermal HPs and electric radiators follow with approximately 10 kW each. Finally, aerothermal HPs and stoves are the last positioned with about 5 kW respectively.

Figure 24 provides information concerning the energy efficiency values at full-load.

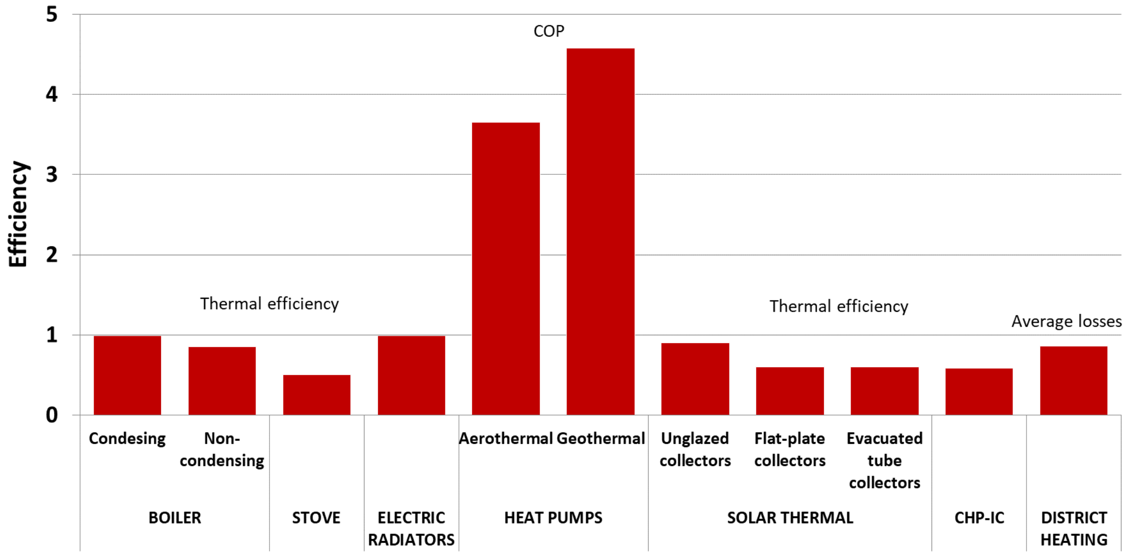


Figure 24. Energy efficiency coefficients at full-load per equipment type, European Union 28. [12], [65]–[67], [70]–[73]

With regard to the technologies having thermal efficiency as coefficient, condensing boiler and electric radiators show a mean value of nearly 100%. STS-unglazed collectors and non-condensing boiler follow with around 90% and 85% respectively. The remaining STS systems (i.e. flat-plate and evacuated tube collectors) show a value around 60%. Finally, CHP-IC have an efficiency of 58%, and stoves of 50%.

Regarding technologies characterized by the coefficient of performance (COP), geothermal HPs come out to be significantly more efficient than aerothermal ones, with values of approximately 4.5 and 3.5 respectively. Due to taking into consideration the full-load operation hours for HPs, which are country specific, the chosen efficiency indicator (COP) includes the average operative (outdoor) conditions.

To provide indications concerning the efficiency of DH systems, the average losses taking into consideration heat losses of the DH networks [74] have been used. The mean value at EU28 level appears to be 13.7%.

Finally, including the data shown in Figure 21 to Figure 24 in equation (1), Figure 25 results.

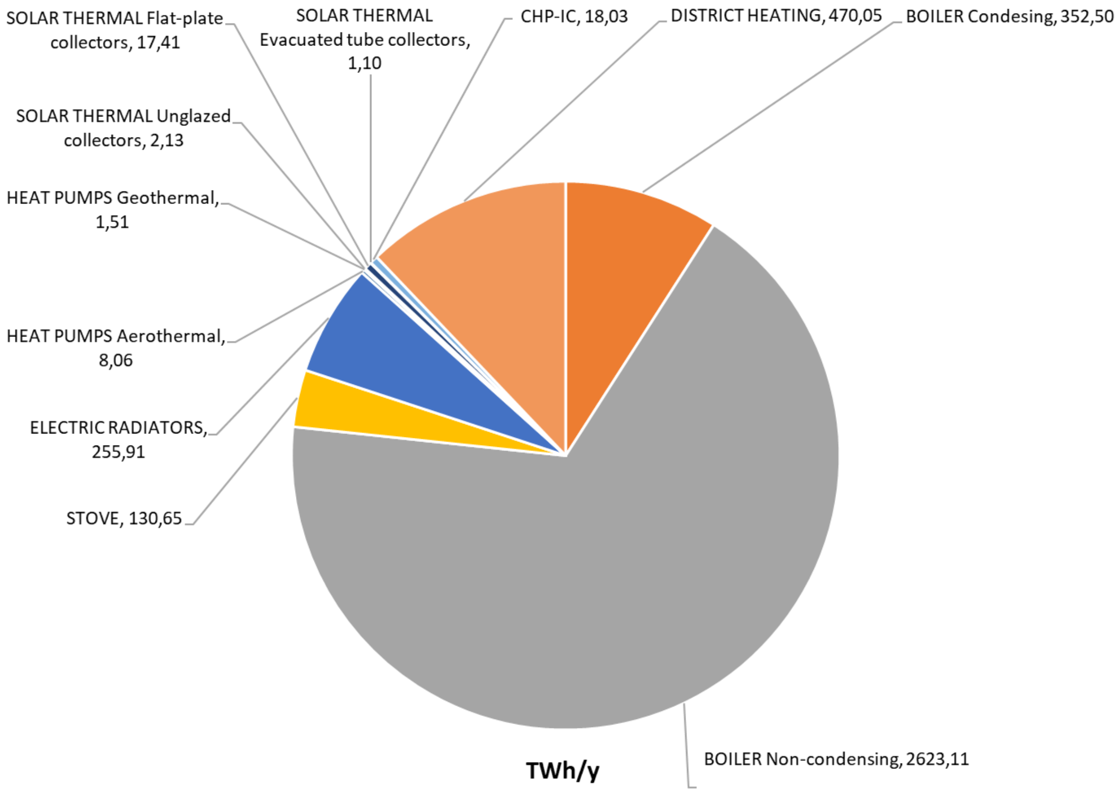


Figure 25. Final energy consumption per type, European Union 28. Sources: [12], [65]–[67], [70]–[72]

The total amount of FEC for SH and DHW equipment at EU28 level results to be around 3880 TWh/y. The majority of FEC is given by non-condensing boiler with more than 2600 TWh/y, corresponding to 67% of total. DH follows with nearly 500 TWh/y (i.e. 13% of total). Condensing boiler show a FEC value of around 350 TWh/y (i.e. 9% of the total). Electric radiators consume nearly 250 TWh/y (around 6% of total). Stoves come next with about 130 TWh/y (approximately 3% of the above indicated 3880 TWh/y). CHP-IC, STS (flat-plate collectors), aerothermal HPs, STS (unglazed collectors), geothermal HPs and STS (evacuated tube collectors) are last positioned, accounting together for around 2% of total.

For further information, please see:
https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

Limitations of data

As already mentioned above, all collected data has been filtered and evaluated statistically. As far as the number of sources allowed, data lying outside the range of plus or minus the standard deviation around the average have been discarded from the respective data pool. Then, the filtered values have been used to compute a more robust average. Unfortunately, it was not always possible to assemble two or more data per each researched value; thus, in these cases, no statistical elaboration has been performed.

Not all collected information appear to be trustworthy – especially those indicated by heat pump equipment manufacturers. These data concern in particular market size and efficiency values for SC equipment. Those have been excluded from the calculations.

In a few cases, data has been transposed from one country to another one if the two nations presented similar geographical, socio-economic and historical features (e.g. Latvia and Lithuania). These cases concern only equivalent full-load hours, efficiency, and average installed capacity. With regard to the average installed capacity for DH systems, no assumptions have been performed.

With regard to the resources used of the equipment taken into consideration, in a number of cases the percentages inserted for "other fuels" have been estimated by detracting the values given for selected resource types (oil, gas, coal and renewables) from 100%. This estimation (marked in grey) has been applied solely in case a value for all resources types besides "other fuels" was present. The same methodology has been applied to determine in a number of cases the percentages concerning system types (central or individual). In case a value has been found indicating either the percentage for central or individual systems, the missing value has been inserted reaching 100% in total.

Values equal to zero have been only inserted in the case one or more sources confirmed this information – e.g. in Malta there are no DH systems present so far [75].

For a few cases only information at EU28 level have been found and thus those have been applied to all MS equally – e.g. average installed capacity of stoves [65].

2.2.2.2. Space cooling

Methodology

In chapter 2.2.2.2 *Space cooling*, the different SC technologies installed in Europe have been analysed. Due to a significantly different classification of SC types present in the scientific literature, a breakdown based on different AC generation (air-to-air or air-to-water) and distribution systems (decentralized or centralized) has been carried out.

Ventilators, as well as natural cooling/passive cooling/natural ventilation technologies, and thermally driven heat pumps (TDHPs), have not been taken into consideration. The reason for this is that there is the perception of a cooling effect during ventilation as air moves across the skin and dries sweat. However, in contrast to room air-conditioners (RACs) and centralized air-conditioners (CACs), ventilation alone cannot lower the indoor temperature below the ambient temperature [10, 48]. With regard to TDHPs, the current market penetration is negligible compared to electrically driven heat pump systems [76].

Beginning from the given AC technologies breakdown, an analysis of the SC market has been performed. With regard to the various SC technologies, different sectors (residential, and various service sectors: offices, trade, education, health and hotels and bars have been taken into consideration. Thus, in contrast to the analysis performed in chapter 2.1, in this case the residential part is not characterized by subsectors as well as hotels and bars and not hotels and restaurants are taken into consideration. Furthermore, no information could be found for the section "Other non-residential buildings".

How the different SC technologies, equivalent full-load hours, cooled floor area and number of AC units installed are distributed between the sectors named above was analysed. Further classification identified their installed capacity, their cooling seasonal performance factor (CSPF) values and yearly hours of operation per sector. Moreover, the work input (electricity) per AC type has been calculated. To obtain these values, the average capacities per SC type have been divided through their respective CSPF means.

In order to retrieve reliable values, within the indicated bottom-up approach, an extensive literature analysis has been performed. Only scientific literature sources have been utilized for data collection. Once more, all collected information have been filtered and evaluated statistically. As far as the number of sources allowed, data which lie outside a range of plus or minus one standard deviation around the average of the respective data pool have been discarded. The filtered values have then been used to compute a more robust average.

Conclusively, the FEC (electricity) by SC type and sector has been calculated. To obtain the yearly FEC for SC purposes and sector, the quantity (Nr.) of SC units per sector has been multiplied by their average equivalent full-load hours (T: time) within a year and its work input (W electricity). See equation 2:

$$Final\ energy\ consumption_{\ SC} = Nr._{units} \times T_{equivalent\ full-load\ hours} \times W_{electricity} \qquad (2)$$

Due to input data for equation 2 only being available for the EU15, initially values concerning these MSs have been collected. Then the obtained results have been projected for the entire EU28. Hence, to obtain Figure 31 for the entire EU28, results for the EU15 have been multiplied by 1.1. Approximately 90% of the EU28 final SC consumption is caused by EU15 states (see above "Main results EU28", Task 2.2, "Top-down approach"). In this regard, it has to be underlined that the EU15 countries account for around 80% of all EU28 inhabitants [77].

The main sources of data collection for this study have concentrated on preceding investigations. In particular, the "Armines—Mines de Paris/Mines Paristech Graduate School" was involved in a number of projects and publications to analyse the present topic, including: the Intelligent Energy Europe (IEE) projects AUDITAC (field benchmarking and market development for Audit methods in Air Conditioning) [78] and EECCAC (Energy Efficiency and Certification of Central Air Conditioners) report [19]; as well as a number of relevant publications in this field (e.g. [79])

Again, due to a very high amount of references, in next Chapter 2.2.2.2 *Main results (EU28)* only major references are indicated. For further information on data sources, please see: https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

Main results (EU28)

Figure 26 summarizes the breakdown structure for different SC application. Letters A-G have been assigned to denote the various AC technologies within the scheme. Moreover, Figure 26 shows the utilization of air handling units (AHUs) and fan coil units (FCUs) for the various AC equipment. AHUs condition the outdoor/recirculating air, supply the conditioned air to the conditioned space and extract the return air from the space through ductwork and space diffusion devices. In contrast, FCUs are factory made assemblies, which provide the function of

SC air by using chilled water or refrigerant with air flowing to spaces, ensured by local electrically driven fans [12].

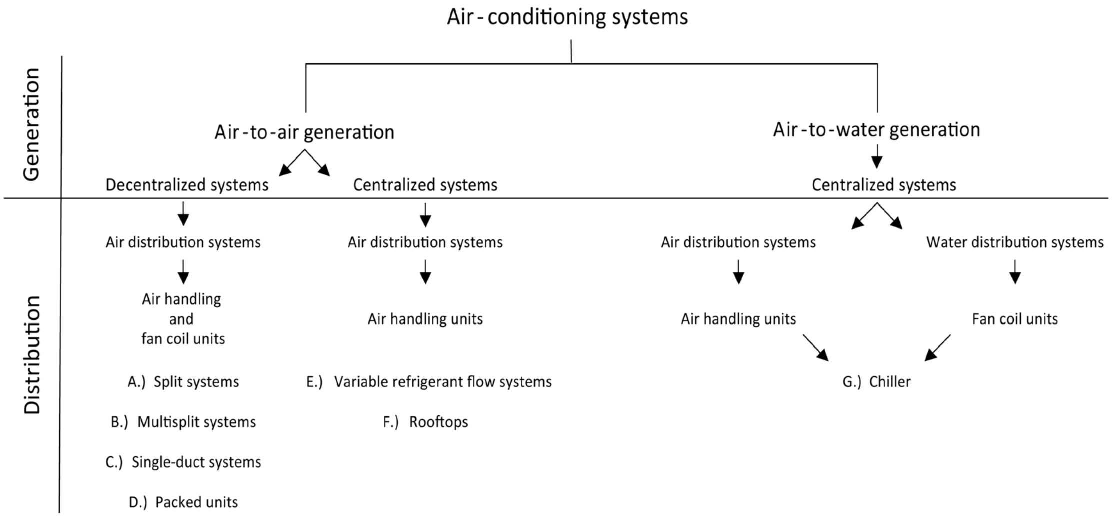


Figure 26. Breakdown of different air-conditioning typologies. Source: [80]

As is visible in Figure 26, given technology mix analysis for SC purposes in Europe indicates four different types of RACs:

- Split systems (A);
- Multisplit systems (B);
- Single-duct systems (C);
- Packed units (D);

As well as three diverse kinds of CACs:

- Variable refrigerant flow systems (E);
- Rooftops (F);
- Chiller (G).

So-called portable units relate to (C) single-duct systems. Single-duct systems are appliances in which the condenser rejects hot air to the outside by a duct [10].

Figure 27 provides information concerning the number of installed AC units per type.

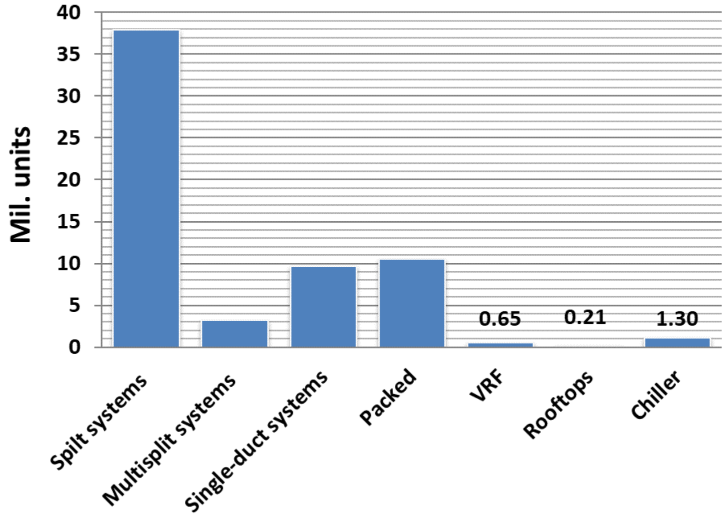


Figure 27. Number of operative units per air-conditioning type, European Union 15. Sources: [12], [80]

Split systems account for the majority of AC units per type with more than 30 Mil. installed devices. Packed and single-duct systems follow with approximately 9 and 8 Mil. systems respectively. The least represented room air-conditioning (RAC) system type are multi-split systems, with less than 3 Mil. units. The amount of installed CAC systems is in order: 1.30 Mil. chiller, 0.65 Mil. VRF systems and finally 0.21 Mil. rooftops. Summing up, there are almost 60 Mil. installed AC units within the EU15.

With regard to Figure 28, it was not possible to find any source with indications concerning the average AC equivalent full-load hours for the education and health sectors. However, for the health sector a number of case studies have been found studying AC application in Austria and Italy [64-66]. Taking into consideration these cases, the health sector has been estimated to require more than 1000 equivalent full-load hours of SC a year.

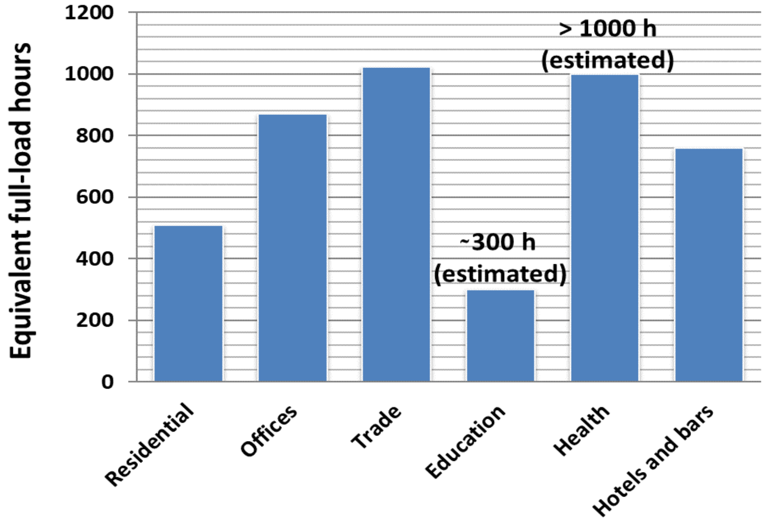


Figure 28. Distribution of average air-conditioning equivalent full-load hours per sector, European Union 15. Sources: [80]–[82]

The total amount of FEC from two separate sources was used to estimate the average amount of AC used in the educational sector [81], [82]. Both sources indicate a total final AC consumption value for this sector of about 6 TWh/y. This available data makes it possible to use equation (2) to identify the average equivalent full-load hours in the education sector. The result is equal to approximately 300 equivalent full-load hours.

Next, Figure 29 indicates the average installed capacity per AC type and sector in kW.

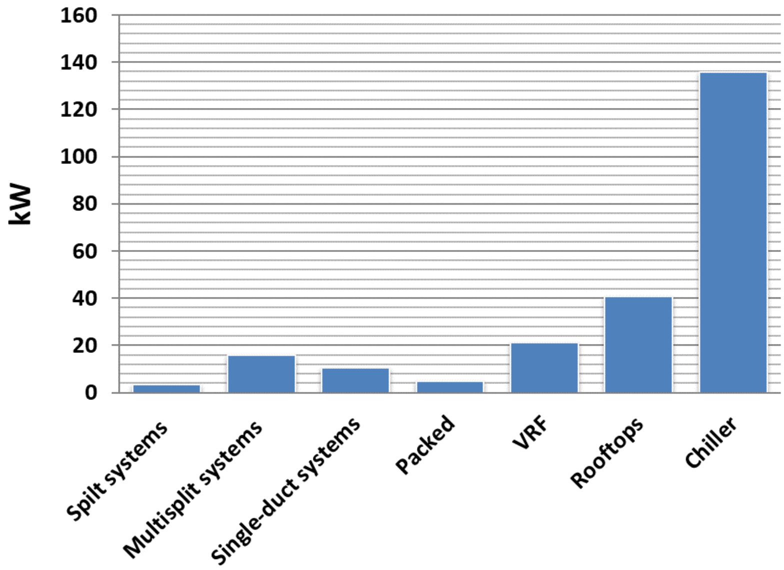


Figure 29. Average installed capacity per air-conditioning type, European Union 15. Source: [80]

Centralized AC systems are characterized by a larger mean installed capacity than RAC units, because as previously mentioned, CACs are applied to provide SC for entire buildings, while RACs are used to cover SC necessities in single rooms. Average values for chiller, rooftops and VRF systems are around 140, 40 and 20 kW each. Multi-split systems have the largest average installed capacity within RACs, representing approximately 16 kW, followed by single-duct systems with about 11 kW. The penultimate and last positions are packed and split systems with about 5 and 4 kW respectively. Hence, split systems are at the same time the most widely diffused and smallest capacity AC systems.

Furthermore, Figure 30 provides information concerning the CSPF.

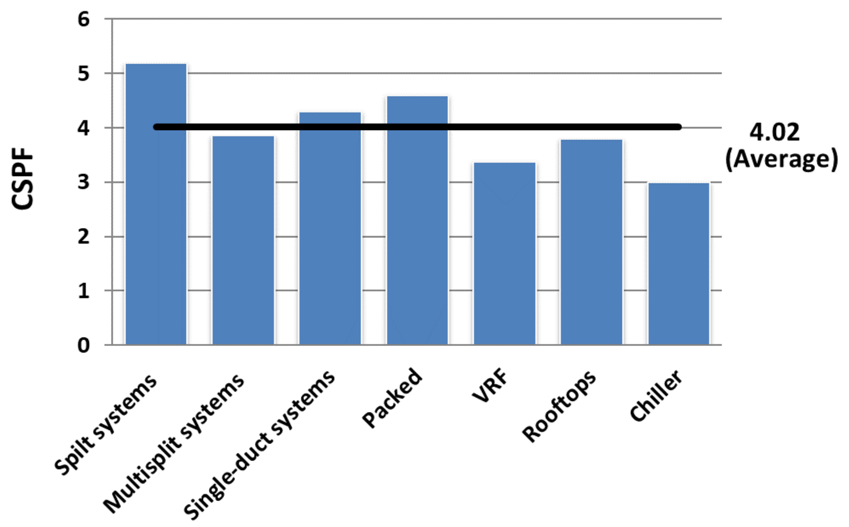


Figure 30. Cooling seasonal performance factor per air-conditioning type, European Union 15. Sources: [12], [83]

The most efficient AC type emerges to be split systems with a CSPF value of > 5. Packed and single-duct systems follow with a CSPF of around 4.4. Multi-split systems and rooftops come next with a CSPF of about 3.8. VRF and chiller show the lowest CSPF numbers with values around 3.2. As it can be seen in Figure 30, the simple average of CSPF values per AC technology is slightly higher than 4. The CSPF values per AC equipment presented in the figure above are lower than those claimed by a number of manufacturers. Through the collected average capacity and CSPF values per AC type the corresponding electricity input in kW has been calculated.

Finally, including the data of Figure 27 to Figure 30 in equation (2) Figure 31 results.

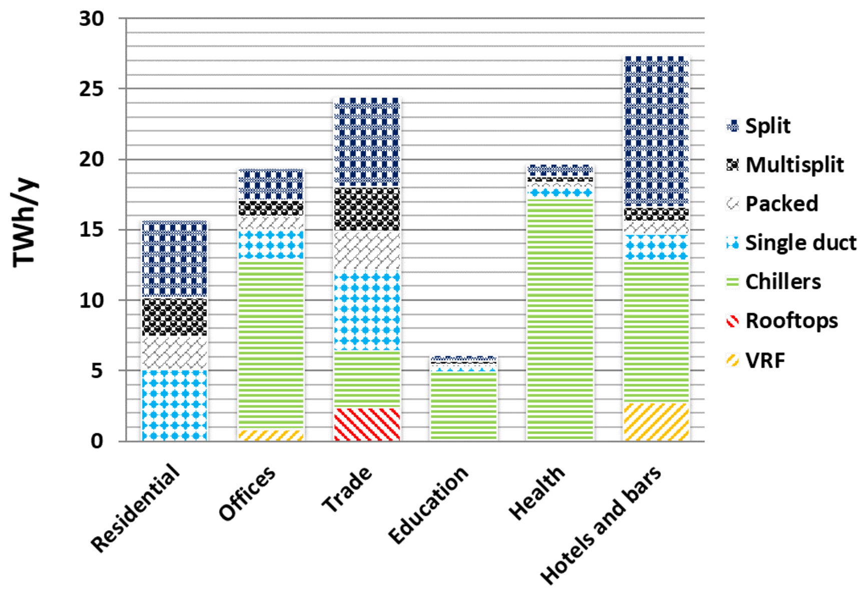


Figure 31. Air-conditioning energy consumption per type and sector, European Union 28. Sources: [12], [80]–[83]

As is visible in Figure 31, Hotels and bars is the most energy consuming sector for AC purposes with more than 25 TWh/y. Trade is the second largest regarding SC purposes within the considered sections with nearly 25 TWh/y. Offices and health are found at the third and fourth position with almost 20 TWh/y FEC for AC application each. The residential sector follows with about 15 TWh/y and education is last, representing slightly more than 5 TWh/y. Summing up, the total FEC for AC purposes within the considered sectors is approximately 110 TWh/y.

The most energy consuming AC type is the chiller with approximately 40% of the total SC energy use registered. Split systems come next with about 20% of the AC FEC. Single-duct, multi-split and packed units follow with about 10% each. Finally, there are rooftops and VRF systems, consuming less than 5% of the AC application per SC typology respectively. As shown in Figure 31, households use solely RAC units (split systems, multi-split systems, packed units and single-duct systems). However, that might not be fully correct as a limited presence of other AC technologies in the residential sector is given by e.g., district heating and cooling systems as well as CACs like rooftops [12].

The FEC for AC purposes within the service section is more than six times higher than that given in the residential part: 95 versus 15 TWh/y respectively.

For further information, please see:
https://gitlab.com/hotmaps/space_heating_cooling_dhw_demand

Limitations of data

While for SH and DHW preparation sufficient information is available, for AC little information exists.

Like already mentioned above, all collected data has been filtered and evaluated statistically. As far as the number of sources allowed, data which lie outside a range of plus or minus one standard deviation around the average of the respective data pool have been discarded. The filtered values have then been used to compute a more robust average. Unfortunately, it was not always possible to assemble two or more data per researched value and thus in these cases no statistical elaboration has been performed.

Not all collected information appear to be trustworthy – especially those indicated by HP manufacturers. These data concern in particular market size, revenue streams and efficiency values for SC equipment. These data has been excluded from carried out calculations.

In case different sources indicated exactly the same values (with two digits) as original data (e.g. for information collected regarding distribution of installed AC units and cooled floor area) only one source has been utilized to carry out the statistics.

Values equal to zero have been only inserted in the case one or more sources confirmed this information.

A review of previous research provides contrasting outlooks. Investigations have both shown the European SC market to be characterized by moderate growth (e.g. [84]), but have also indicated the field to be a booming market (e.g. [85]).

Once more, it has to be underlined that at present time, a huge amount of data concerning the SC market in Europe is based on estimations [32], [34].

2.3. Climate context

The present task provides data with following characteristics:

Table 6. Characteristics of data provided within Task 2.3 Climate context. The database of given task is available at: https://gitlab.com/hotmaps/climate

	Spatial resolution	Temporal resolution
Heating degree days and cooling degree days	NUTS3	monthly
Land surface temperature	Raster @ 250 X 250 m	annual mean 2002-2012
Wind speed	Raster @ 10 X 10 minutes	annual mean
Precipitation	Raster @ 1 x 1 km	monthly
Relative humidity	Raster @ 10 X 10 minutes	annual mean
Solar radiation	Raster @ 1 X 1 km	annual mean

2.3.1. Methodology

Climate data are here presented with the purpose of providing background data for the estimation of the UED for H&C. The datasets provided in the Hotmaps toolbox were gathered within the framework of other projects by research institutes with a specific expertise on the subject.

Since these data set were not generated by the Hotmaps project but collected by the partner consortium, this section of the deliverable will not describe the methodology. The only process that has been performed, whenever the license of the original data set allow the redistribution of the data, is reproject the data into Lambert Azimuthal Equal Area projection using the European Terrestrial Reference System 1989 (ETRS89 / LAEA Europe, EPSG:3035).

Within the toolbox, these data are on the one hand visualized for the user and on the other hand used for different calculation modules within the toolbox. Here a short description of the layer provided for the Hotmaps toolbox is given:

2.3.1.1. Heating and cooling degree days

EUROSTAT provides average heating degree days (HDD) and cooling degree days (CDD) for each EU28 NUTS3 region. The monthly and yearly values were computed using the following equations (3) and (4):

If $T_i m \leq 15°C$ then $HDD = \sum_i(18°C - T_i m)]$ else $HDD = 0$ (3)

If $T_i m \geq 24°C$ then $CDD = \sum_i T_i m - 21°C)$ else $CDD = 0$ (4)

where $T_i m$ is the mean air temperature of day i

2.3.1.2. Humidity

A raster layer contains the data on the yearly average humidity at world level. These data come from Palebluedata [86], [87], an open web dataset of global climate layers with a 10 x 10 km^2 spatial resolution.

2.3.1.3. Land surface temperature

Data on the annual mean land surface temperature at world level are MODIS data [88] being re-elaborated by the Edmund Mach Foundation. These data are open and expressed in *Degree Celsius* and multiplied by a factor of 10 to reduce the size of the data. Daily data set with four images per day (from the Moderate Resolution Imaging Spectroradiometer - MODIS-terra and MODIS-acqua) are available at [89]. Monthly average are available at [90], [91].

2.3.1.4. Precipitation

Raster data on the average monthly precipitation in mm are available at world level. These data come from WorldClim [92], an open web dataset of global climate layers with a 1 x 1 km^2 spatial resolution.

On the Gitlab repository only the annual average is available, since the data license of the original dataset states: *"The data were created by Steve Fick and Robert Hijmans. You are not allowed to redistribute these data."*

The monthly values can be displayed by the Toolbox platform and used by the Hotmaps computational modules.

2.3.1.5. Solar radiation

Monthly raster data on solar radiation on optimally inclined surfaces in kWh/m^2 at world scale are available at 1 km^2 spatial resolution. The data are provided by the Institute for Energy and Transport (European Commission) through the photovoltaic geographic information system (PVGIS) tool [93].

2.3.1.6. Wind speed

Raster data on the annual average wind speed in m/s are available at world level. These data come from WorldClim [92], an open web dataset of global climate layers with 1 km^2 spatial resolution. Monthly data set are available from the original website.

2.3.2. Limits of data

Data for the climate context can be considered accurate and reliable given the involvement in their elaboration of distinguished institutions.

Data availability

For further information on the data, please refer to Table 7.

Table 7. Links to data repositories for renewable energy potentials.

Renewable source	Repository
Heating and cooling degree days	https://gitlab.com/hotmaps/climate/climate_heating_cooling_degreeday
Humidity	https://gitlab.com/hotmaps/climate/climate_humidity
Land surface temperature	https://gitlab.com/hotmaps/climate/climate_land_surface_temperature
Precipitation	https://gitlab.com/hotmaps/climate/climate_precipitation
Solar radiation	https://gitlab.com/hotmaps/climate/climate_solar_radiation
Wind speed	https://gitlab.com/hotmaps/climate/climate_wind_speed

2.4. Industrial processes

The present task provides data with following characteristics:

Table 8. Characteristics of data provided within Task 2.4 Industrial processes. The database of given task is available at: https://gitlab.com/hotmaps/industrial_sites

	Spatial resolution	Temporal resolution
Performance and cost data of industrial steam and district heating generation technologies	-	yearly
Benchmark for H&C FEC and excess heat potentials for industrial processes	NUTS3	yearly
Heating and cooling for energy intensive plants	georeferenced	yearly
Excess heat of energy intensive plants	georeferenced	yearly

The data set on industrial H&C energy demand comprises of three main elements. These include:

1. Performance and cost data of industrial steam and district heating generation technologies
2. Benchmarks on H&C Final energy consumption (FEC) and excess heat potentials for industrial processes
3. Industrial plants FEC and excess heat potentials

The method and content of data is described in the following sections. The main focus, however, is on part 3, the development of an industrial plants database for estimation of excess heat potentials.

2.4.1. Performance and cost data of industrial steam and district heating generation technologies

The objective of this subtask is to develop a consistent EU-wide performance and cost dataset for industrial steam and hot water and DH generation technologies. This dataset shall provide the basis for modelling of technology choices.

Steam and hot water for process heating and DH accounts for about 30% of industrial FEC for H&C. Steam and hot water is mainly used in the paper, chemicals and food industry, but to a lower extent also in other industries. Figure 32 shows the distribution of FEC for H&C by subsector and temperature level. Process heating below 500°C can be regarded as steam and hot water generation, while process heat above 500°C is mainly related to industrial furnaces.

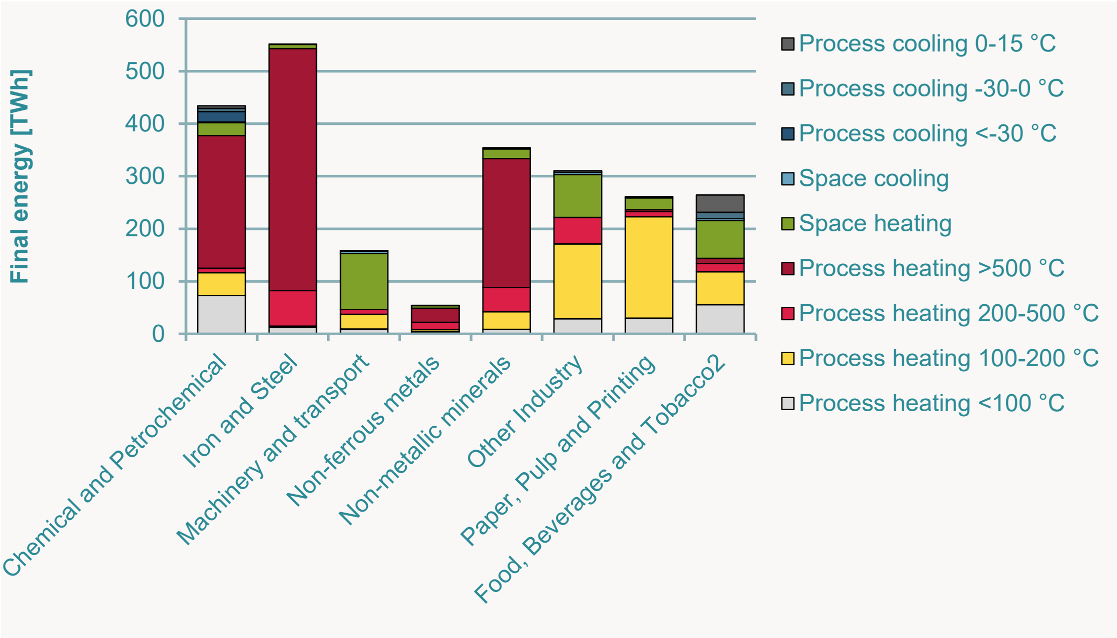


Figure 32. Heating and cooling final energy consumption for the European Union 28 industry in 2015 by sub-sector and temperature level. Source: [94]

Industrial steam and hot water can be provided by a variety of different technologies including combined heat and power but also classical separate generation of heat in boilers. For the lower temperature range, HPs and DH can be used. In order to provide a comprehensive set required for technology choices, the following technologies are included in the dataset.

Table 9. List of steam and hot water and district heating generation technologies included in the dataset

Technology	CHP	Energy carrier
Internal combustion engine	Yes	Natural gas
Internal combustion engine	Yes	Liquid biofuels
Internal combustion engine	Yes	Light fuel oil
Gas turbine	Yes	Natural gas, process gases
Steam turbine	Yes	Light fuel oil
Steam turbine	Yes	Biomass
Steam turbine	Yes	Natural gas
Steam turbine	Yes	Hard coal
Steam turbine	Yes	Waste
Combined cycle gas turbine	Yes	Natural gas, process gases
Fuel cell	Yes	Natural gas
Boiler	No	Natural gas
Boiler	No	Hard coal
Boiler	No	Light fuel oil
Boiler	No	Biomass
Boiler	No	Other
Boiler	No	Waste
Boiler	No	Electricity
District heat	No	-
Heat pump sorption	No	Natural gas, other
Heat pump compression	No	Electricity
Solar district heat	No	-
Geothermal heat pump	No	Electricity

The techno-economic data derived for each technology consists of the following elements:

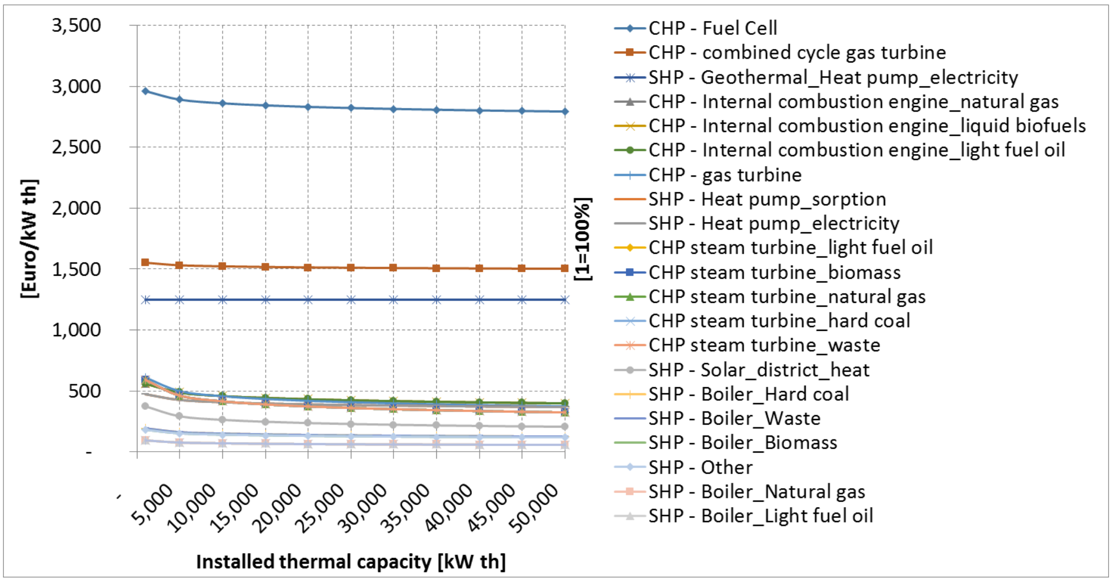
- Capital expenditures (CAPEX);
- Operation and maintenance expenditures (OPEX);
- Efficiency (thermal);
- Efficiency (electric);
- Power-to-heat ratio;
- Lifetime.

A challenge in developing an EU-wide data set is the very low availability of empirical data for such technologies. Steam boilers and even more CHP units are tailor made installations. Price cataloguers are not available. Consequently, literature values were collected and combined for individual technologies. Main sources used include [95], [96], [97], [98]. For a discussion of available literature see [99]. Based on a small set of collected data points, the complete set of technology performance data was calculated for all countries. This requires assumptions on cost differences between countries as well as functional relations between e.g. the installed power and the specific capital expenditures. The parameters and formulas used as well as a comprehensive selection of results are available in the online dataset.

In the following, a few selected results are shown. These comprise steam generation technology investment costs for France for the year 2015 and a visual comparison of all technologies between Germany and Poland.

Table 10. Resulting specific CAPEX per kW installed power for industrial steam generation and district heating technologies in France for 2015 [€/kWth]

Technology	1,000	5,000	10,000	15,000	20,000
CHP - Internal combustion engine_natural gas	563	489	460	444	433
CHP - gas turbine	613	501	459	436	421
CHP - combined cycle gas turbine	1551	1530	1522	1517	1513
CHP - Internal combustion engine_liquid biofuels	563	489	460	444	433
CHP - Fuel Cell	2966	2895	2865	2847	2835
Boiler_Natural gas	93	76	70	67	64
Boiler_Hard coal	194	162	150	144	139
Boiler_Light fuel oil	93	76	70	67	64
Boiler_Biomass	181	151	140	134	130
Heat pump_sorption	471	424	405	394	387
Heat pump_electricity	471	424	405	394	387
District heating	93	76	70	67	64
CHP - Internal combustion engine_light fuel oil	563	489	460	444	433
Other	181	151	140	134	130
Boiler_Waste	194	162	150	144	139
Boiler_Electricity	93	76	70	67	64
CHP steam turbine_light fuel oil	592	463	416	391	374
CHP steam turbine_biomass	592	463	416	391	374
CHP steam turbine_natural gas	592	463	416	391	374
CHP steam turbine_hard coal	592	463	416	391	374
CHP steam turbine_waste	592	463	416	391	374
SHP Geothermal heat pump	1247	1247	1247	1247	1247
SHP Solar district heating	376	292	262	246	235



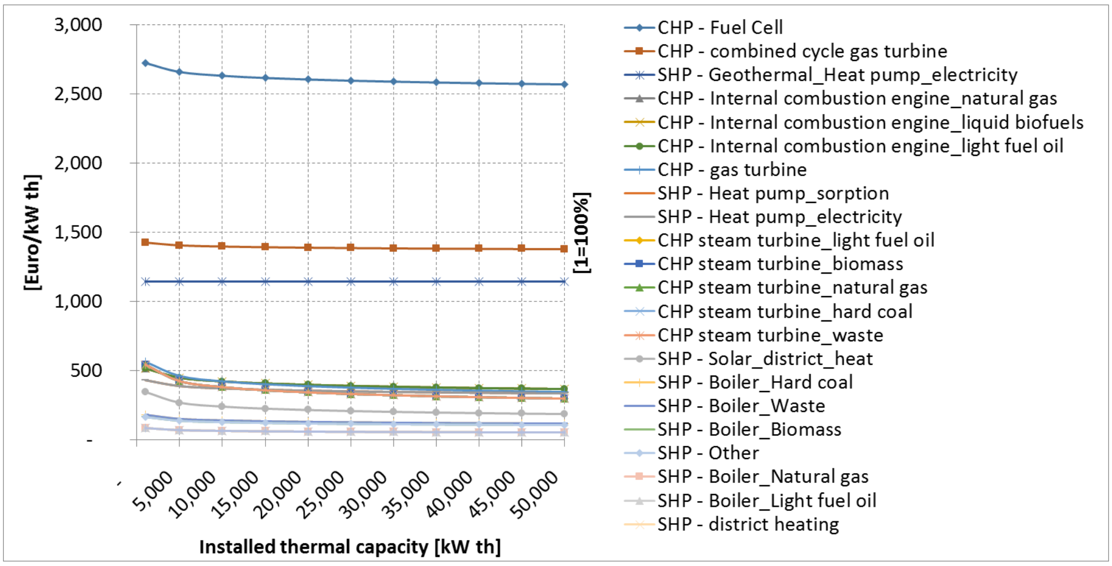


Figure 33. Resulting specific cost per kWth for industrial steam generation technologies in Germany (top) and Poland (bottom) for 2015

Limitations of the data set are mainly related to uncertainty, which is estimated to be relatively high, due to two main reasons. First, the empirical foundation of the dataset is small, with only selected literature values for individual countries, technologies and capacities. The empirical data is not sufficient to benchmark and validate the method used to transform data across countries. Further, only little is known about the stock of steam generation technologies in Europe. Compared to SH technologies, this is still an unexplored field, but with a very high relevance in terms of energy demand.

2.4.2. Benchmarks for heating and cooling demand and excess heat potentials for industrial processes

The developed dataset distinguishes more than 60 individual processes/products from the basic materials industry. These comprise the production of the most energy-intensive products. A complete list of processes is provided in Table 11.

Table 11. Overview of processes/products covered in the dataset. Source: Fraunhofer ISI

	Chemicals	**Non-ferrous metals**
Container glass	Adipic acid	Aluminium, primary
Flat glass	Ammonia	Aluminium, secondary
Fibre glass	Calcium carbide	Aluminium extruding
Other glass	Carbon black	Aluminium foundries
Houseware, sanitary ware	Chlorine, diaphragma	Aluminium rolling
Technical, other ceramics	Chlorine, membrane	Copper, primary
Tiles, plates, refractories	Chlorine, mercury	Copper, secondary
Clinker Calcination-Dry	Ethylene	Copper further treatment
Clinker Calcination-Semidry	Methanol	Zinc, primary
Clinker Calcination-Wet	Nitric acid	Zinc, secondary
Preparation of limestone	Oxygen	
Gypsum	Polycarbonates	
Cement grinding	Polyethylene	
Lime milling	Polypropylene	
Bricks	Polysulfones	
Lime burning	Soda ash	
	TDI	
	Titanium dioxide	

Iron and steel	**Food, drink and tobacco**	**Pulp and paper**	**Others**
Sinter	Sugar	Paper	Plastics: Extrusion
Blast furnace	Dairy	Chemical pulp	Plastics: Injection moulding
Electric arc furnace	Brewing	Mechanical pulp	Plastics: Blow moulding
Rolled steel	Meat processing	Recovered fibres	
Coke oven	Bread & bakery		
Smelting reduction	Starch		
Direct reduction			

For each process, the following information is included in the dataset:

- Specific FEC (fuel/electricity) [GJ/t];
- Share of FEC used for H&C;
- Share of temperature level in H&C distinguishing 8 temperature levels in total;
- Excess heat potentials as share of fuels/electricity consumption distinguishing three temperature levels.

Table 12. Definition of temperature levels for process cooling and process heating.

End-use	Temperature level	Comment
Process cooling	< - 30°C	Mostly air separation in chemical industry
	- 30-0 °C	Mostly refrigeration in food industry
	0-15 °C	Mostly cooling in food industry
Process heating	<100°C	Low temperature heat (hot water) used in food industry and others
	100-200 °C	Steam, of which much is in paper, food and chemical industry
	200-500 °C	Steam used mostly in chemical industry
	500-1000 °C	Industrial furnaces mainly in chemical industry
	>1000 °C	Industrial furnaces in steel, cement, glass and other industries

Main results are shown in the following two tables below. All process specific data is collected without country distinction. On the one side, there is hardly liable information on country differences e.g. in the specific FEC of such processes and on the other side differences are expected to be of low importance, because plants are owned by large multinational companies, technology providers are global and apply similar technologies across different countries.

Table 13. Specific final energy consumption and share of process heat use by temperature level for energy-intensive processes (for references see next table).

Subsector	Process or product	Final energy consumption [GJ/t]		Share for process heat use [1=100%]		Temperature distribution heating [1=100%]				
		Fuels	Electricity	Fuels	Electricity	<100°C	100°C - 200°C	200°C - 500°C	500°C - 1000°C	>1000°C
Iron and steel	**Sinter**	2.24	0.13	1.00	0.00	-	-	0.20	0.80	-
	Blast furnace	11.64	0.60	1.00	0.00	0.01	0.01	0.11	0.20	0.67
	Electric arc furnace	0.98	2.28	1.00	0.95	-	0.01	-	0.10	0.89
	Rolled steel	2.39	0.60	1.00	0.10	-	-	-	0.20	0.80
	Coke oven	3.20	0.12	1.00	0.00	-	-	-	0.20	0.80
	Smelting reduction	15.00	0.42	1.00	0.00	-	-	-	0.20	0.80
	Direct reduction	15.00	0.42	1.00	0.00	-	-	0.20	0.80	-
Non-ferrous metals	**Aluminum, primary**	5.20	53.64	1.00	0.05	-	-	-	1.00	-
	Aluminum, secondary	9.00	1.67	1.00	0.30	0.28	-	0.30	0.42	-
	Aluminum extruding	4.20	4.80	1.00	0.30	-	-	1.00	-	-
	Aluminum foundries	7.20	5.60	1.00	0.30	-	-	-	1.00	-
	Aluminium rolling	3.30	2.20	1.00	0.30	-	-	1.00	-	-
	Copper, primary	8.00	2.79	1.00	0.20	-	-	-	-	1.00
	Copper, secondary	4.00	2.33	1.00	0.10	-	-	-	1.00	-
	Copper further treatment	2.00	3.78	1.00	0.15	-	-	1.00	-	-
	Zinc, primary	1.00	15.90	1.00	0.01	-	-	-	-	1.00
	Zinc, secondary	1.00	0.60	1.00	0.01	-	-	1.00	-	-
Pulp and paper	**Paper**	5.50	1.91	1.00	0.01	0.05	0.88	0.05	0.02	-
	Chemical pulp	12.65	2.30	1.00	0.01	-	1.00	-	-	-
	Mechanical pulp	-2.01	7.92	1.00	0.01	1.00	-	-	-	-
	Recovered fibers	0.54	0.94	1.00	0.01	-	1.00	-	-	-
Non-metallic minerals	**Container glass**	5.78	1.41	1.00	0.04	0.02	0.19	0.19	0.30	0.30
	Flat glass	10.92	3.32	1.00	0.00	0.02	0.21	0.43	0.12	0.22
	Fiber glass	4.92	1.81	1.00	0.20	0.02	0.19	0.19	0.30	0.30
	Other glass	11.48	5.05	1.00	0.17	0.02	0.22	0.22	0.22	0.32
	Houseware, sanitary ware	24.24	4.82	1.00	0.01	0.30	-	-	0.05	0.65
	Technical, other ceramics	12.11	3.23	1.00	0.01	0.30	0.15	0.15	0.25	0.15
	Tiles, plates, refractories	5.46	0.88	1.00	0.01	0.07	0.11	0.07	0.18	0.57
	Clinker calcination-dry	3.50	0.14	1.00	0.00	-	-	0.10	0.60	0.30
	Clinker calcination-semidry	4.00	0.16	1.00	0.00	-	-	0.10	0.60	0.30

Subsector	Process or product	Final energy consumption [GJ/t]		Share for process heat use [1=100%]		Temperature distribution heating [1=100%]				
		Fuels	Electricity	Fuels	Electricity	<100°C	100°C - 200°C	200°C - 500°C	500°C - 1000°C	>1000°C
	Clinker calcination-wet	5.50	0.16	1.00	0.00	-	-	0.10	0.60	0.30
	Preperation of limestone	0.00	0.13	1.00	0.00	1.00	-	-	-	-
	Gypsum	1.00	0.20	1.00	0.00	-	0.50	0.30	0.20	-
	Cement grinding	0.00	0.20	1.00	0.00	1.00	-	-	-	-
	Lime milling	0.00	0.16	1.00	0.00	1.00	-	-	-	-
	Bricks	1.40	0.20	1.00	0.00	0.20	-	-	0.60	0.20
	Lime burning	3.70	0.14	1.00	0.00	-	-	-	0.40	0.60
Basic chemicals	Adipic acid	26.91	1.44	1.00	0.00	-	0.50	0.25	0.25	-
	Ammonia	11.27	0.48	1.00	0.00	-	-	-	0.66	0.33
	Calcium carbide	6.12	8.32	1.00	0.95	-	-	-	-	1.00
	Carbon black	64.75	1.78	1.00	0.00	-	-	-	-	1.00
	Chlorine, diaphragma	0.00	10.69	1.00	0.00	-	-	-	-	-
	Chlorine, membrane	1.85	10.04	1.00	0.00	-	1.00	-	-	-
	Chlorine, mercury	0.00	12.82	1.00	0.00	-	-	-	-	-
	Ethylene	35.90	0.00	1.00	0.00	-	-	-	1.00	-
	Methanol	15.03	0.49	1.00	0.00	-	-	-	0.22	0.78
	Nitric acid	-0.07	0.00	1.00	0.00	-	-	-	-	-
	Oxygen	0.00	0.95	1.00	0.00	-	-	-	-	-
	Poly carbonate	12.86	2.66	1.00	0.00	-	1.00	-	-	-
	Poly ethylene	0.64	2.04	1.00	0.00	-	1.00	-	-	-
	Poly propylene	0.79	1.15	1.00	0.00	-	1.00	-	-	-
	Poly sulfones	24.49	3.06	1.00	0.00	-	1.00	-	-	-
	Soda ash	11.33	0.33	1.00	0.00	0.30	0.40	-	-	0.30
	TDI	26.69	2.76	1.00	0.05	-	1.00	-	-	-
	Titanium dioxide	34.23	3.34	1.00	0.00	-	0.30	0.23	0.35	0.12
Food, beverages and tobacco	Sugar	4.61	0.69	1.00	0.00	0.10	0.60	-	0.30	-
	Dairy	1.56	0.53	1.00	0.05	0.90	0.10	-	-	-
	Brewing	0.94	0.38	1.00	0.05	0.55	0.45	-	-	-
	Meat processing	2.01	1.51	1.00	0.05	0.40	0.60	-	-	-
	Bread & bakery	2.40	1.45	1.00	0.45	0.20	0.33	0.47	-	-
	Starch	3.74	1.35	1.00	0.10	1.00	-	-	-	-
Other indus tries	Extrusion	1.62	3.01	1.00	0.20	0.20	0.50	0.30	-	-

Subsector	Process or product	Final energy consumption [GJ/t]		Share for process heat use [1=100%]		Temperature distribution heating [1=100%]				
		Fuels	Electricity	Fuels	Electricity	<100°C	100°C - 200°C	200°C - 500°C	500°C - 1000°C	>1000°C
	Injection moulding	3.92	7.28	1.00	0.20	0.20	0.50	0.30	-	-
	Blow moulding	2.85	5.30	1.00	0.20	0.20	0.50	0.30	-	-

Table 14. Process cooling use and related temperature level distribution.

Subsector	Process or product	Share for process cooling use [1=100%]		Temperature distribution of total process cooling [1=100%]			
		Fuels	Electricity	<-30°C	-30-0°C	0-15°C	
Iron and steel	Sinter	-	-	-	-	-	[100], [101]
	Blast furnace	-	-	-	-	-	[100], [101]
	Electric arc furnace	-	-	-	-	-	[100], [101]
	Rolled steel	-	-	-	-	-	[100], [101]
	Coke oven	-	-	-	-	-	[102]
	Smelting reduction	-	-	-	-	-	[103], [104]
	Direct reduction	-	-	-	-	-	[105], [106]
Non-ferrous metals	Aluminum, primary	-	-	-	-	-	[107], [108]
	Aluminum, secondary	-	-	-	-	-	[109]
	Aluminum extruding	-	-	-	-	-	[109]
	Aluminum foundries	-	-	-	-	-	[107], [109]
	Aluminium rolling	-	-	-	-	-	[109]
	Copper, primary	-	-	-	-	-	[107], [108]
	Copper, secondary	-	-	-	-	-	[108]
	Copper further treatment	-	-	-	-	-	[108]
	Zinc, primary	-	-	-	-	-	[108]
	Zinc, secondary	-	-	-	-	-	[108]
Pulp and paper	Paper	-	0.01	-	-	1.00	[107], [110],[111]
	Chemical pulp	-	-	-	-	-	[107], [110], [112]
	Mechanical pulp	-	-	-	-	-	[107], [110], [113]
	Recovered fibers	-	-	-	-	-	[107], [110], [113]
Non-metallic minerals	Container glass	-	0.06	-	-	1.00	[114], [115]
	Flat glass	-	0.06	-	-	1.00	[114], [115]

Subsector	Process or product	Share for process cooling use [1=100%]		Temperature distribution of total process cooling [1=100%]			
		Fuels	Electricity	<-30°C	-30-0°C	0-15°C	
	Fiber glass	-	0.06	-	-	1.00	[114], [115]
	Other glass	-	0.06	-	-	1.00	[114], [115]
	Houseware, sanitary ware	-	0.06	-	-	1.00	[116], [115], [107]
	Technical, other ceramics	-	0.06	-	-	1.00	[116], [115], [107]
	Tiles, plates, refractories	-	0.06	-	-	1.00	[116], [115], [107]
	Clinker calcination-dry	-	-	-	-	-	[117], [118], [115]
	Clinker calcination-semidry	-	-	-	-	-	[117][117], [118], [115]
	Clinker calcination-wet	-	-	-	-	-	[117], [118], [115]
	Preperation of limestone	-	-	-	-	-	[107]
	Gypsum	-	-	-	-	-	[119], [115]
	Cement grinding	-	-	-	-	-	[107]
	Lime milling	-	-	-	-	-	[107]
	Bricks	-	-	-	-	-	[107], [120]
	Lime burning	-	-	-	-	-	[121], [115]
Basic chemicals	Adipic acid	-	0.06	0.20	0.30	0.50	[107], [122]
	Ammonia	-	0.06	0.20	0.30	0.50	[107], [115]
	Calcium carbide	-	0.02	0.20	0.30	0.50	[107], [122]
	Carbon black	-	0.06	0.20	0.30	0.50	[107], [115]
	Chlorine, diaphragma	-	0.05	0.20	0.40	0.40	[107], [115]
	Chlorine, membrane	-	0.05	0.20	0.40	0.40	[107], [115]
	Chlorine, mercury	-	0.04	0.20	0.40	0.40	[107], [115]
	Ethylene	-	-	0.15	0.50	0.35	[107], [122]
	Methanol	-	0.04	-	0.40	0.60	[107], [122]
	Nitric acid	-	0.01	0.20	0.30	0.50	[107]
	Oxygen	-	0.96	0.80	0.10	0.10	[107]
	Poly carbonate	-	0.02	-	0.40	0.60	[107]
	Poly ethylene	-	0.02	-	0.40	0.60	[107]
	Poly propylene	-	0.04	0.05	0.40	0.55	[107]
	Poly sulfones	-	0.04	-	0.40	0.60	[107]
	Soda ash	-	-	0.05	0.45	0.50	[107], [115]
	TDI	-	0.02	-	0.30	0.70	[122]
	Titanium dioxide	-	0.01	-	0.40	0.60	[107], [115]

Subsector	Process or product	Share for process cooling use [1=100%]		Temperature distribution of total process cooling [1=100%]			
		Fuels	Electricity	<-30°C	-30-0°C	0-15°C	
Food, beverages and tobacco	**Sugar**	-	0.42	-	0.20	0.80	[107], [123]
	Dairy	-	0.57	-	0.30	0.70	[107], [123]
	Brewing	-	0.41	-	0.35	0.65	[107], [123]
	Meat processing	-	0.61	-	0.30	0.70	[107], [123]
	Bread & bakery	-	0.44	-	0.10	0.90	[107], [123]
	Starch	-	0.11	-	0.20	0.80	[107]
Other industries	**Extrusion**	-	0.07	-	-	1.00	
	Injection moulding	-	0.03	-	-	1.00	
	Blow moulding	-	0.04	-	-	1.00	

The data set is generally based on literature values, and was compared and benchmarked with energy balances. Still, there is substantial uncertainty in the individual values. Uncertainty not only results from the quality of data sources, but also is a result of aggregation and industrial structure. E.g. the paper production is aggregated as an average process "paper". However, in reality, the product mix varies across the countries with different shares for newsprint, hygienic paper, graphic paper etc. Specific FEC of these paper grades might range by +/- 50% around the average value included in the data set.

2.4.3. Industrial plants and excess heat potentials

Industrial process heat demand contributes to about 16% of the FEC in EU28. This number illustrates the importance of heating demand and supply in the industry sector. Furthermore, industrial excess heat as supply for DH can contribute to the efficiency and decarbonisation of the heating sector. Thus, expansion or implementation of DH networks is a feasible heating strategy for decarbonising the heating supply in buildings. This requires spatially disaggregated data of industrial processes and heating demand in buildings.

Excess heat, sometimes also referred to as waste heat, is the amount of energy, which is released to the environment via waste water, latent heat or exhaust gases on different temperature levels from combustion or industrial processes (mainly process heat and steam generation) [124]. Industrial excess heat potentials provided by this task are defined as the heat released through exhaust gases above 100°C from industrial processes in industrial subsectors defined by the European statistics Eurostat.

The overall aim of this task is to derive a georeferenced default dataset of energy-intensive industries, including emissions, processes, production capacities as well as FEC of each site.

2.4.3.1. Methodology

The approach presented here uses the georeferenced emission data of energy intensive processes for estimation of fuel and electricity demand and excess heat potentials on different temperature levels. For this purpose, several available databases were matched, e.g. ETS (European Emission Trading System), E-PRTR (European Pollutant Release and Transfer Register) and sectoral databases (glass, cement, steel, paper etc.), using an algorithm which considers company name, location and activity. With this approach, georeferenced production capacity is made accessible for energy intensive industry sectors in EU28. As the data from commercial databases cannot be published site-specific due to license restrictions, the retrieved data about production capacities is aggregated at country level and then broken down on individual industrial sites using the emission data as a distribution key. With the development of a generic database with specific FEC per produced tonne of a specific product, the fuel and electricity demand can be derived for each process. A comparison is included of those approaches to estimate the deviations included in the open data set.

Matching of databases

Different data sources are matched and analysed to gain information like GHG emissions, subsector (NACE and ETS activity), process and production (capacity) of georeferenced industrial sites in EU28. All emission and production data in this analysis refer to the year 2014. Commonly used databases are E-PRTR[10] ([125]), EU ETS[11] ([126]) or national pollutant recordings ([127], [124]). The advantage of the E-PRTR database is that coordinates for EU28 countries for industrial sites emitting pollutants and greenhouse gases are included. It was matched with the ETS-database, covering 40% of total CO_2-emissions in the EU, including further industrial sites as the number of relevant entries in E-PRTR is 1600 and in ETS over 4500. These numbers are obtained after excluding non-relevant sectors and countries as well as non-GHG emissions. Furthermore, the CO_2-equivalents values are assumingly more accurate in the ETS-register as this is the main purpose of the database. The entries from the ETS database, which could not be matched to an E-PRTR entry needed to be georeferenced afterwards.

[10] European Pollutant Release and Transfer Register

[11] European Emissions Trading System

Table 15. Overview of included industrial databases and information provided.

Database	Company	Geographical Data			Product		Quantity produced/ emitted		
	Name	Address	Country	Lat/Long	NUTS3	Product/ NACE	Effective Production	Production Capacity	Emissions
E-PRTR	Yes	Yes	Yes	Yes	No	Yes	Few	No	Yes
ETS	Yes	No	Yes	No	Few	Yes	No	No	Yes
Cement (Global Cement Directory)	Yes	Few	Yes	No	No	No	Few	Yes	No
Paper (RISI Pulp and Paper)	Yes	No	Yes	Yes	No	Yes	Yes	No	No
Steel (VDEh)	Yes	No	Yes	No	No	No	No	Yes	No
Glass (glassglobal)	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Chemicals (internet research)	Yes	Few	Yes	No	Few	No	No	Yes	No

This combined ETS and E-PRTR database is the base for the inclusion of additional sectoral databases as listed in Table 15. The main advantage of including the sectoral databases is a more precise description of the activity, mainly by a more specific definition of the processes used on site (e.g. electric steel, oxygen steel, steel rolling, flat glass, container glass, etc.) and by providing information on yearly production output or capacity in physical terms (e.g. tonnes of rolled steel). As the table illustrates, the information provided by the original databases is heterogeneous, especially regarding sectoral differentiation (4-digit NACE or ETS-activity), resolution of location (from coordinates, address, city or just country) and emissions or capacity/effective production.

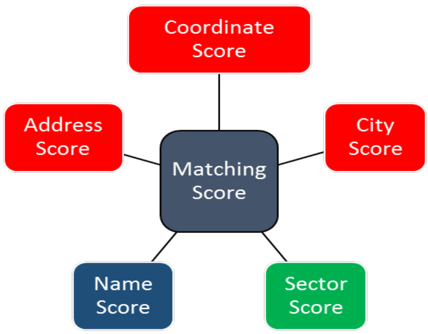


Figure 34. Calculation of the matching score for two datasets by the matching algorithm.

For the matching process, a matching algorithm was implemented, which takes into account several indicators like company name, location and sector for each country. As not all databases contain this information completely or some only in poor quality, a matching score ranging from 0 to 100 was calculated and adapted for each database. See Figure 34 for the considered indicators. Consequently, the matches with a high matching score needed to be confirmed afterwards, as in the worst cases only the company name was a valid indicator.

This approach was conducted for the two emission databases first, ETS and E-PRTR. After matching all industrial sites in EU28, a database consisting of over 5000 individual site entries could be retrieved. From these entries, almost 1000 are matched, about 600 are coming from non-matched E-PRTR entries, and about 3500 are from ETS.

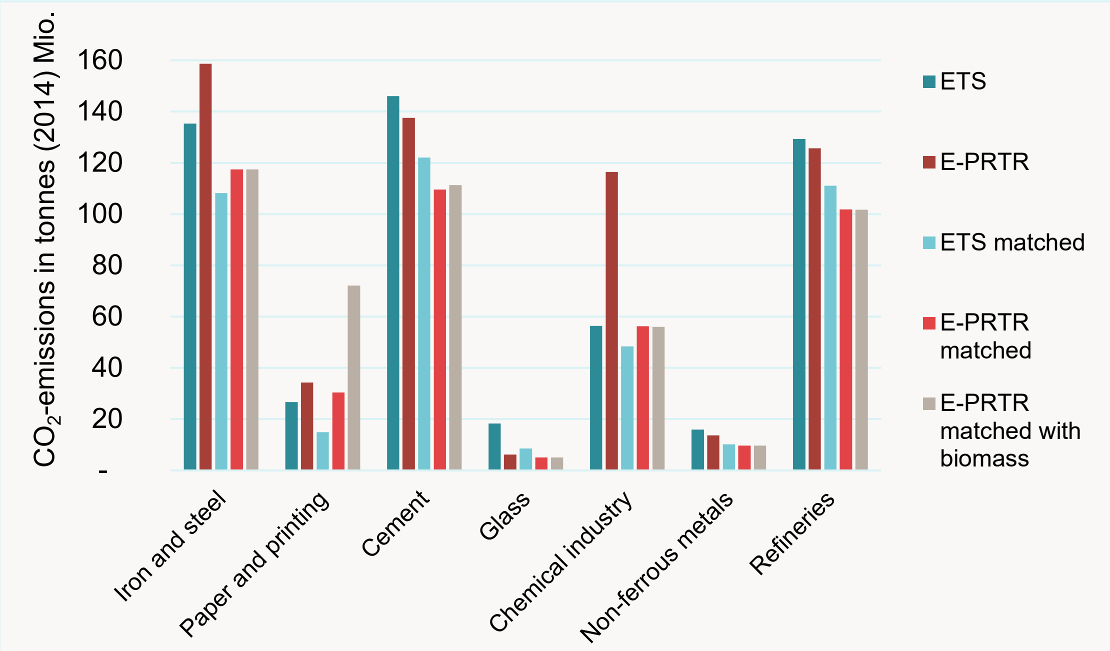


Figure 35. Comparison of emission values in the databases European Pollutant Release and Transfer Register and European Emission Trading System: Non-matched and matched sites of both databases and inclusion of biomass emissions.

The emissions in the year 2014 from all sites in the database were compared to assess structural differences of ETS and E-PRTR. There are two main issues with the comparison of the databases: ETS-emissions include CO_2-emissions for all processes, and additionally N_2O from several chemical products and PFCs from aluminium production. Therefore, respective emissions per sector are included from E-PRTR for comparison. In Figure 35, the influence of the consideration of biomass emissions is depicted. Especially for the pulp and paper sector, where the main fuel source is wood-based production residuals, structural differences can be observed in the E-PRTR values. As in ETS no emissions are accounted for the use of biomass as well, the E-PRTR values excluding the use of biomass are considered, which makes the emissions from both databases more comparable. Thus, the further elaborated emission factors per produced product for each process cannot be considered as realistic values as they do not represent the actual emissions, especially when the fuel source is strongly based on biomass. Even though the total emissions by each subsector differ for both databases, the emissions for matched sites converge after the matching. Furthermore, the matching covers most of the ETS-emissions, which corresponds to the expectation, that sites with high emissions are represented in both databases. Nevertheless, in the sectors paper and printing and glass a deviation of the emission data of 50% and 65% respectively remains. In the other sectors, the values are below 10% deviation. Possible reasons may be the used measurement and calculation methods, differing threshold values for single units and the consideration of system boundaries as e.g. the inclusion of on-site generation units. Consequently, different emission factors for both sources are derived. For further calculation, ETS emissions for matched sites are used, and the corresponding origin database for non-matched sites.

Furthermore, the sectoral databases of energy intensive industries are included. The sectors steel, paper, glass, and cement are included first, as they account for about 40% of industrial fuel demand and have the highest potential for the use of excess heat, as high temperature processes are typical for these sectors.

A challenge was the different definition of system boundaries, as for example, the ETS-database includes emissions from a whole steel-producing plant, but in the sectoral databases different processes are listed. The production capacity or actual production is linked with the processes, and these are linked to the industrial site. Even though the sectoral databases are extensive, there are still entries from ETS and E-PRTR, which could not be matched.

Calculation of useful energy demand and excess heat potentials

From this dataset with emissions and production capacity, fuel and electricity demand as well as excess heat potentials can be derived. Due to license restrictions of the sectoral databases, the production capacity can only be published country specific. Thus, based on the production by process and the emission data, two different approaches are combined. As most literature takes the emissions as a basis for excess heat analysis ([125], [128]), this approach is refined by taking into account the annual production by process in each county and using the site-specific emissions as a distribution key.

Based on literature, specific FEC indicates the fuel and electricity consumption per tonne produced product of each significant process of the considered energy-intensive industries (Figure 36). As expected, the most energy-intensive processes are the steel making process and paper and glass production with high temperature ranges above 500°C. By multiplying these values with the site-specific production or production capacity, the theoretical FEC in GJ/year is calculated. These values are considered for validation to the energy balances from Eurostat. As a next step, the utilization rate needs to be considered. For that, production statistics are compared to the values achieved by country.

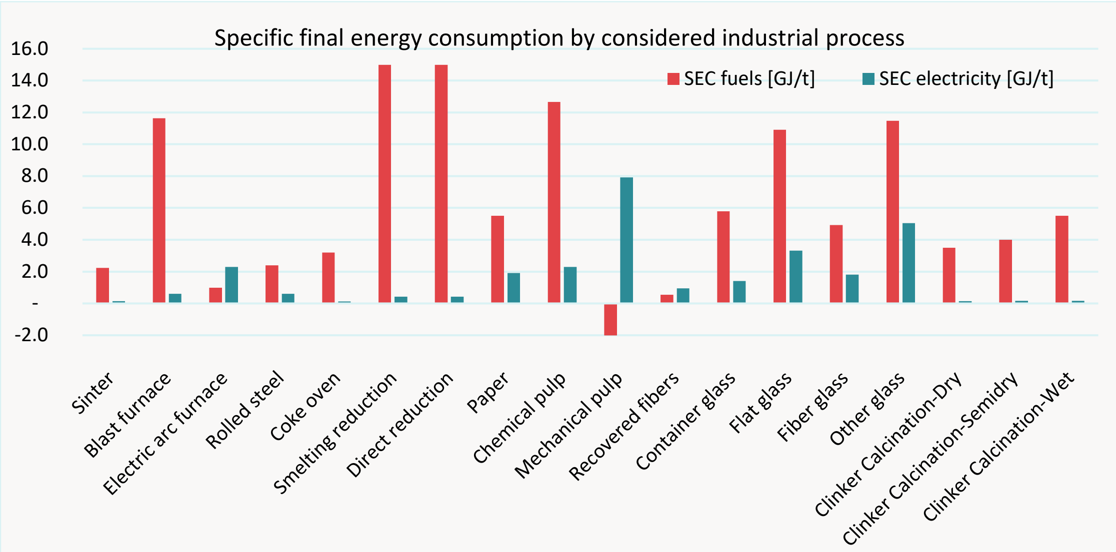


Figure 36. Specific final energy consumption (fuels and electricity) values in GJ per tonne produced product. Sources: [129], [130]

With the calibrated production in tonnes/year, country-specific emission factors per produced tonne can be derived for each process of matched sites. For each process and country, the total emissions and the total production are summed up and divided to obtain the emission factor as CO_2-emission per tonne produced product. As mentioned before, the emissions data do not represent the physical CO_2-emissions due to negligence of biomass use. As an example, in Figure 37 the CO_2-emission factors for the dry clinker calcination process are depicted. Especially in cement production, the fuels used for high temperature processes are very heterogeneous from coal, gas and waste, which leads to different emission factors. This emphasizes the need for site-specific analysis, even the country-specific values are a simplification as it neglects the differences between different companies. For sites that are included in ETS/E-PRTR but not in the sectoral databases, the process is not known and an average value for the whole sector is assumed. As the emissions differ even for the same sites in the databases of ETS and E-PRTR, two emission factors are calculated. The observed difficulties reveal that the emission-based excess heat calculation does not eliminate these deviations originating from measurement methods and needs to cope with this uncertainty.

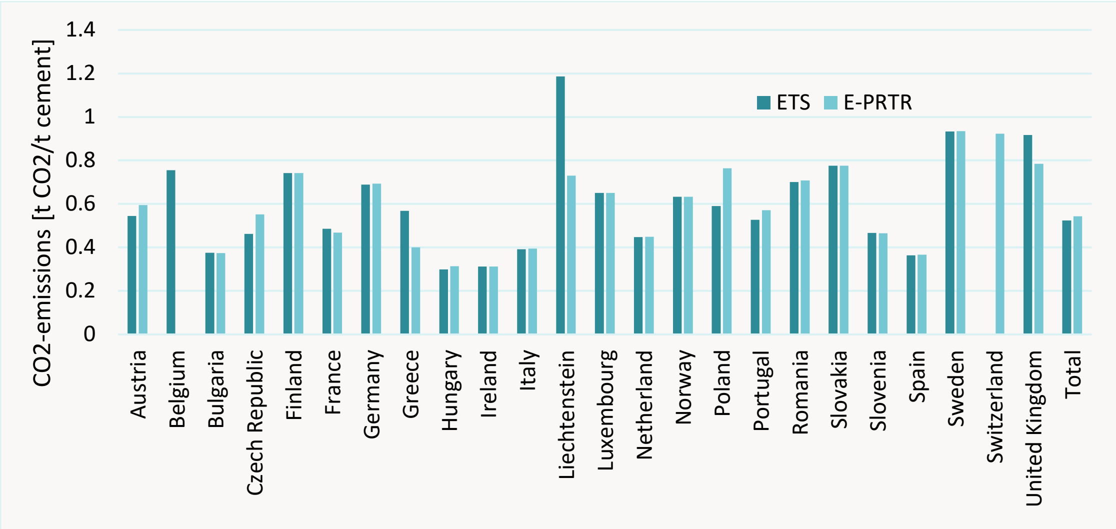


Figure 37. Calculated specific emissions of clinker calcination (dry process) for each country with emissions from European Emission Trading System and European Pollutant Release and Transfer Register. Considered are matched sites, for which the cement production is known from the cement database. Source: [131]

Production values via CO_2

Deriving average CO_2-emission factors for each country and production process enables the estimation of yearly production for each site of ETS and E-PRTR from emission data. Additionally, it is possible to include sites that could not be matched with sectoral databases and therefore have no production values. In Figure 38, the median and deviation of the derived production value from the actual production from the sectoral databases for each matched site are shown, for the sectors paper, steel, glass and cement. Even though for most countries the median is close to one, major deviations can be observed especially for smaller countries and heterogeneous sectors like steel and paper.

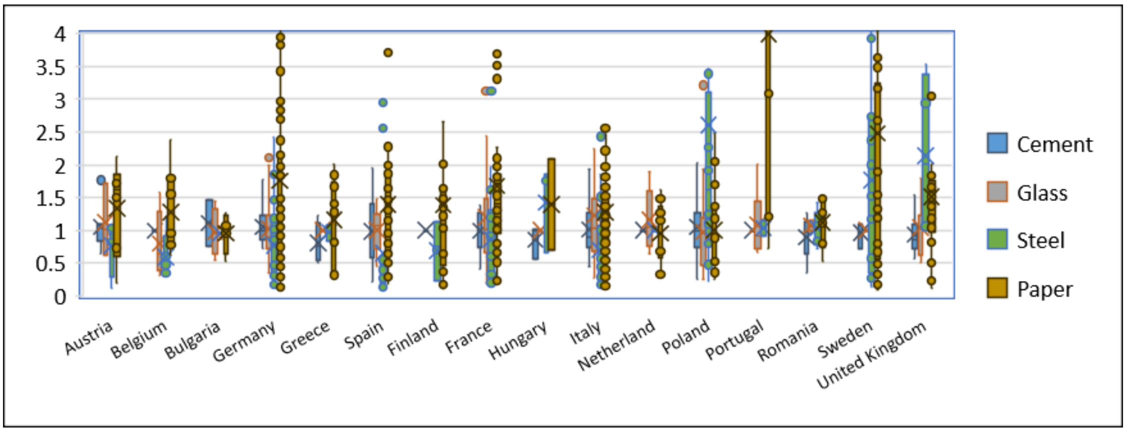


Figure 38. Deviations from the median of production values derived from emission data, shown for main countries.

Excess heat via production

From the production in tonnes per year, the excess heat potential can be derived with process-specific values shown in the Table 16. For results shown in this report, the actual production data was integrated instead of the calculated one, as the accuracy is higher for this approach based on production data. The excess heat potentials for each process are assumed to be identical for all countries and were derived from literature and own assumptions ([126], [129]). Included are the temperature ranges above 100°C and differentiated by three ranges. These values are based on specific fuel and electricity consumption values per tonne produced product already shown above multiplied with excess heat shares. In comparison to the specific FEC values, only the processes with excess heat potentials are included here. For most of the processes, the excess heat share is based on fuel consumption as the exhaust gas originates from combustion processes. However, electric arc furnaces have excess heat potentials above 500°C based on their electricity consumption.

Table 16. Excess heat potential per produced product for industrial processes, derived from specific final energy consumption.

Industrial sector		**Excess heat potential per tonne of product [GJ/t]**			**Source/based on**
Subsector	**Process**	**100-200°C**	**200-500°C**	**>500°C**	
Iron and Steel	Sinter	-	0.7	-	[126]
Iron and Steel	Blast furnace	0.3	-	-	[126]
Iron and Steel	Electric arc furnace	-	0.3	0.2	[132], [129]
Iron and Steel	Rolled steel		0.3		[129]
Iron and Steel	Coke oven	-	-	1.9	[126]
Iron and Steel	Direct reduction	-	3.8	-	[129]
Non-ferrous metals	Aluminium secondary		1.8		[129]
Non-ferrous metals	Aluminium foundries		1.4		[129]
Non-ferrous metals	Copper	3.3			[129]
Non-ferrous metals	Zinc secondary		0.2		[129]
Pulp and paper	Paper	0.6	-	-	[126]
Non-metallic minerals	Container glass	-	1.2	-	[129]
Non-metallic minerals	Flat glass	-	-	2.2	[126]
Non-metallic minerals	Clinker calcination (dry)	-	0.5	-	[126], [132]
Non-metallic minerals	Clicker calcination (semidry)	-	0.6	-	[126], [132]
Non-metallic minerals	Clinker calcination (wet)	-	0.8	-	[126], [132]

2.4.4. Main results (EU28)

In Figure 39 the country-specific excess heat potentials for the main energy-intensive industrial sectors cement, glass, steel and paper are shown, more than half of the total excess heat potential is contributed by the four countries Spain, Germany, Italy and France.

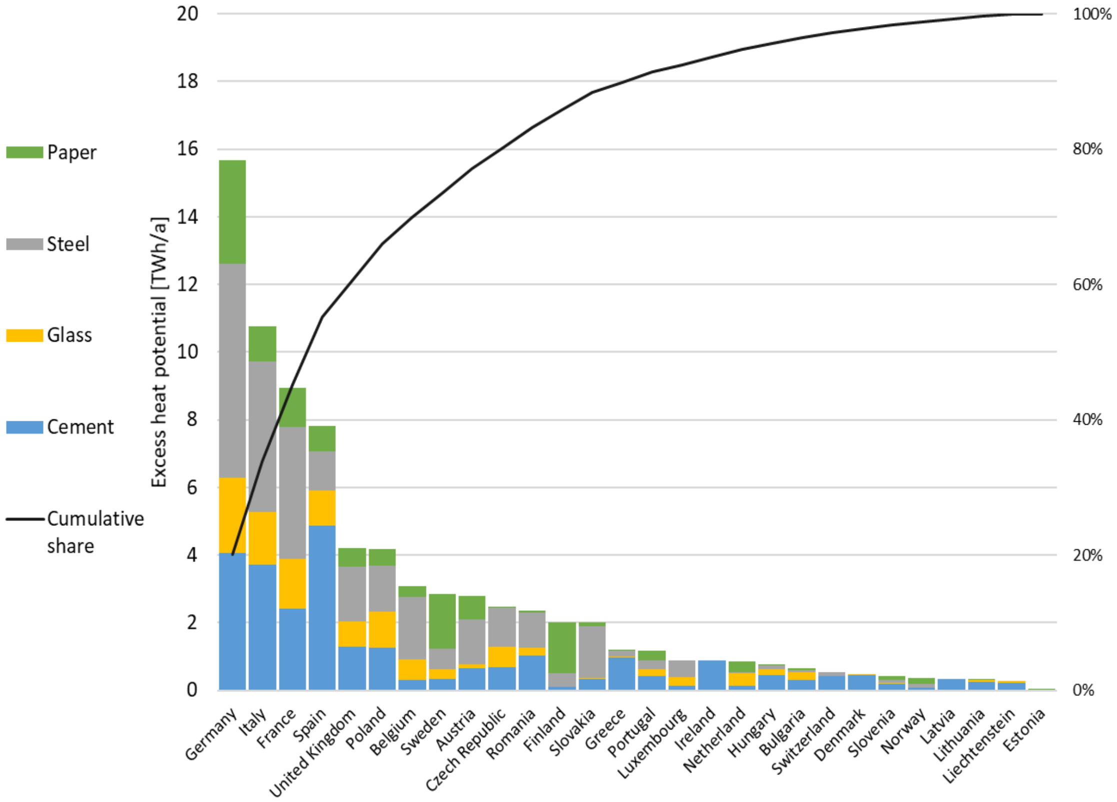


Figure 39. Country-specific excess heat potentials for European countries of the sector cement, glass, steel and paper.

The highest share of the excess heat potential of exhaust gases are in the temperature range between 200°C and 500°C, as depicted in Figure 40. This is mainly because of the available excess heat of the cement sector of 25 TWh in this temperature range. The pulp and paper industry typically integrates excess heat in higher temperature ranges already for drying processes, thus only low temperature excess heat below 200°C is available, while glass and steel also have excess heat potentials above 500°C from high-temperature furnace processes.

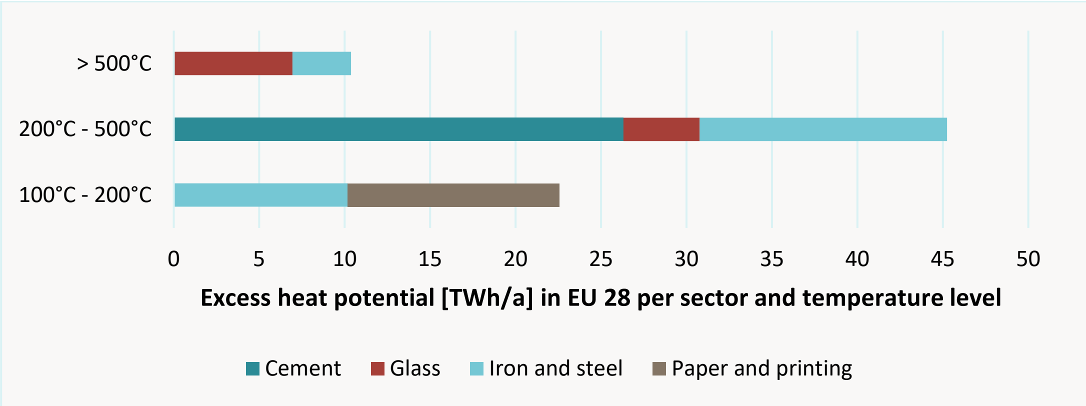


Figure 40. Excess heat potential for the sectors cement, glass, paper and steel for different temperature ranges.

The industries included in the industrial database are visualised in Figure 41, differentiated by the amount of CO_2-emissions per year and by subsectors. These are the industrial sites retrieved from ETS and E-PRTR databases. While some sectors are characterised by few but big plants with high emissions like refineries, steelmaking and cement, other sectors are charaterized by smaller plants like paper and non-metallic mineral products. Furthermore, sectors like refineries that are reliant on imports of raw materials are located near the coastline contrasting sectors like non-metallic minerals, which are located close to sources of natural minerals like limestone and clay.

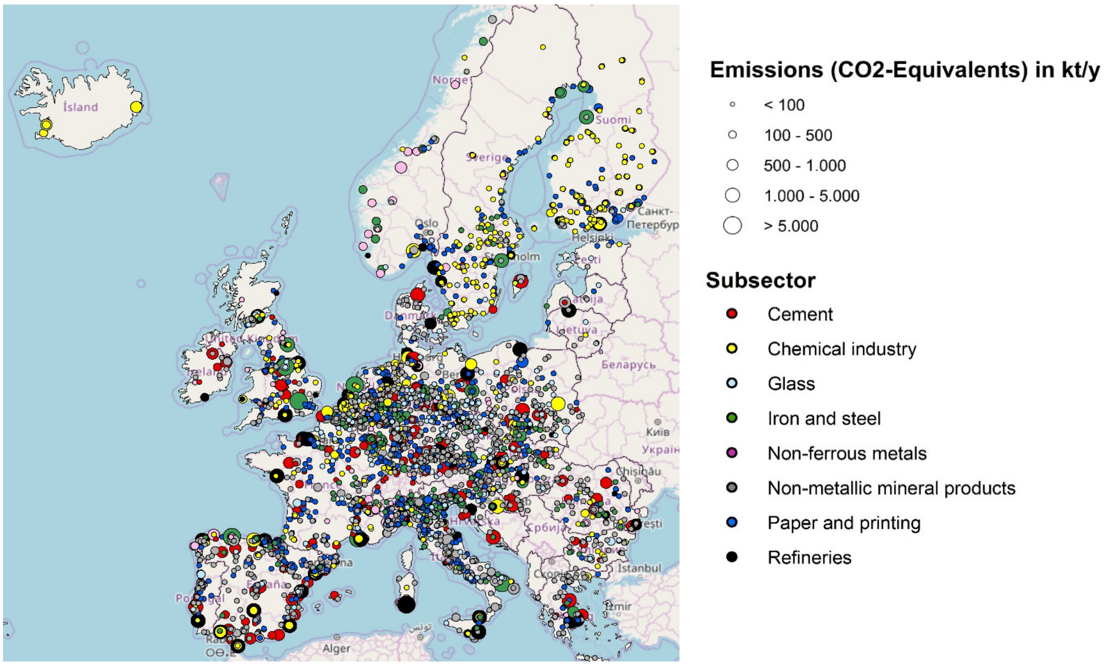


Figure 41. Georeferenced dataset of European Emission Trading System and European Pollutant Release and Transfer Register for European Union 28 + Norway and Switzerland, differentiated by subsector and emission quantities.

Analysing the spatial site-specific excess heat potential for Europe (Figure 42) differences can be observed for the sectors comparable to the site-specific emissions. While steel manufacturing plants have high excess heat potentials above 1000 GWh per site, the distribution is scarce across the countries, and the sectors cement, glass and paper have many locations with medium excess heat shares.

In total, the excess heat potential above 100°C for the sectors steel, paper, glass and cement adds up to 63.3 TWh annually.

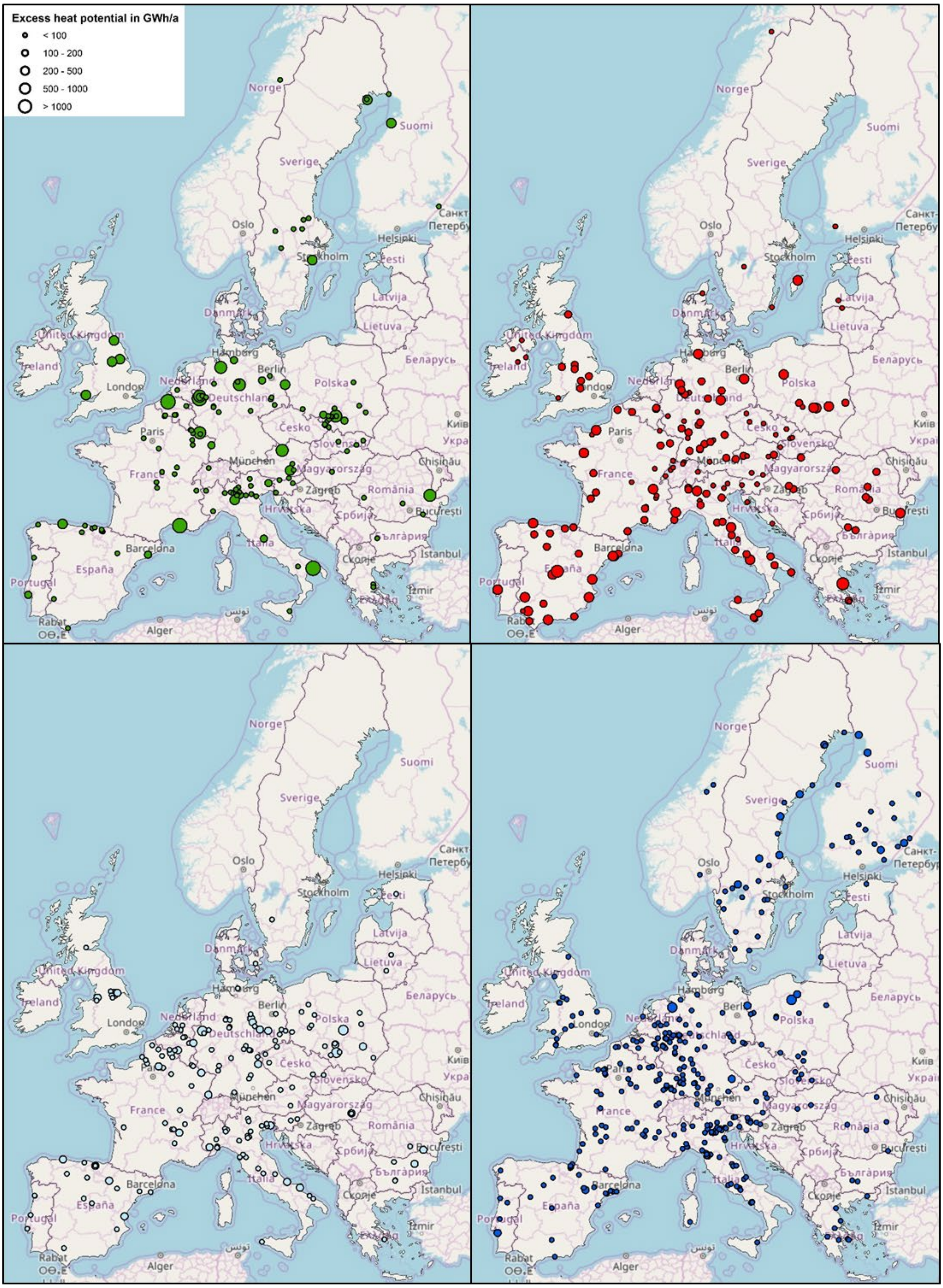


Figure 42. Site-specific excess heat potentials for Europe of the sectors steel (green), cement (red), glass (grey) and paper (blue) in GWh per year.

2.4.5. Limitations on data

Comparing the excess heat potentials for the EU28 to the value of 2580 TWh/y by [125], who included not only all relevant industrial sectors but also power plants, and to the top-down value of 752 TWh by [133] for industrial excess heat, the here presented bottom-up value for energy-intensive industrial sectors is expectedly substantially lower. Comparison with other sectoral studies leads to comparable values e.g. for Germany ([128]) or Denmark ([127]).

The calculation of annual production or FEC from emissions is a valid approach if no production data are available, but includes more uncertainty as the calculation of UED of industrial process as it is better correlated to the physical production than emissions, even though they are a good indicator, as shown by the emission factors in this study. Also, the different measurement methods and system boundaries were identified as uncertainties.

Tackling the excess heat potentials in Europe requires the inclusion of more subsectors. Furthermore, to assess the potential for the new generation of DH networks with low temperatures and the combined use with HPs, excess heat potentials below 100°C can be included as well. The technical and economic potential for the utilization of excess heat requires the analysis of temperature profiles of each process, the mapping with UED for heat of different temperature levels as well as the development of scenarios of future demand and supply.

2.5. Heating and cooling supply

The present task provides data with following characteristics:

Table 17. Characteristics of data provided within Task 2.5 Heating and cooling supply. The database of given task is available at: https://gitlab.com/hotmaps/heat

	Spatial resolution	Temporal resolution
Deployed energy sources	NUTS3	yearly
Conversion efficiencies of supply technologies	NUTS0	yearly
Specific investment costs of supply technologies	NUTS0	yearly
Operation and maintenance of supply technologies	NUTS0	yearly

2.5.1. Analysis of deployed energy sources on regional level

The objective of the regional energy sources deployment is to evaluate each region individually and to determine the possibility of higher RES integration. The distribution of the total heat demand is determined as percentage of the total UED and FEC for SH per country from Figure 19 with additional definition of the existing supply structure, which consists of six energy carriers: natural gas, biomass, electricity, district heating, other fossil fuels, and other renewables. By combining, for example the regional data for the useful space heating and final energy consumption with excess heat potentials from Figure 42, possible synergies via DH excess heat utilization are determine.

2.5.1.1. Methodology

The methodology to calculate the deployed energy sources on regional level have been developed in the ESPON project by TU Vienna and Fraunhofer ISI and further refined in Hotmaps [134]. The methodological approached combines top-down national energy consumption data with structural data on regional level and bottom-up modelling and simulation of buildings' energy demand. Figure 43 depicts the approach as it has been outlined in [134].

The disaggregated national energy consumption data provided in Task 2.2 on the level of different end-uses (space heating, hot water, process heating, appliance) for each country are used as basis for the break-down on NUTS 3 level consumption and energy source use patterns. The methodology is a combination of top-down *statistical approach* with a bottom-up *engineering approach* using a model with building physical input data [135].

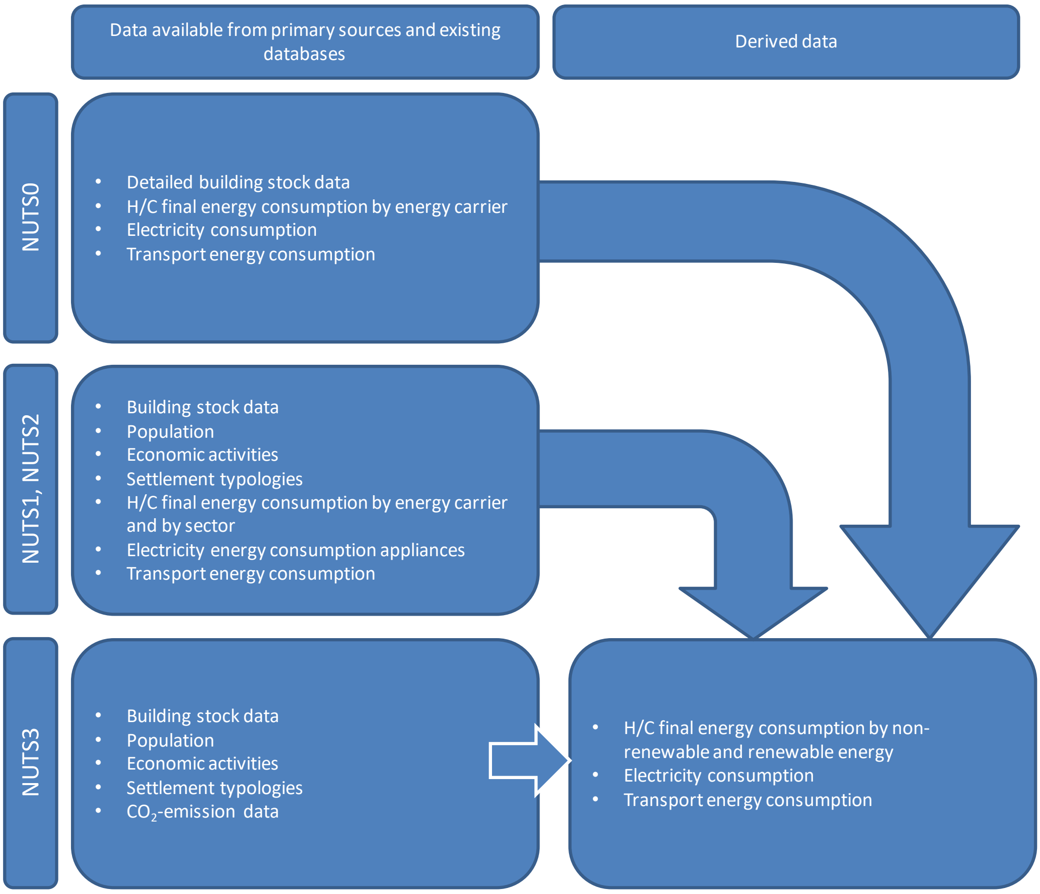


Figure 43. Approach to derive energy consumption patterns on NUTS 3 level as derived in ESPON project. Source: TU Vienna and *[134]*

Top-down statistical approach

Similar to energy consumption data, structural data needed for a bottom-up model are not all available on a regional level. As first step, available data are on NUTS 3 level are collected and missing data are broken from national level. Thereby correlations between structural data such as population, floor space or income and energy consumption patterns as well as other relevant structural data needed for bottom-up modelling approach such as the regional structure of building types and vintages are derived.

The following structural data have been considered for the calculation of regional conversion matrices:

- Population
- Floor area residential buildings
- Classification in shrinking and growing regions which allows conclusions regarding construction periods and heating system mix of buildings
- Economic activities as a proxy for the floor area of non-residential buildings
- Structural business statistics by NACE Rev. 2

- Share of settlement type within each NUTS 3 region based on *CORINE* land cover data.[12]
- Share of single-family households/multi-family households (*Mapping H/C*)
- Share of energy carriers split between urban and rural region (*Mapping H/C*)
- Information on gas grid 2012
- FEC of natural gas by sector and length of gas distribution of network on NUTS0 level
- Information on renewable DH systems (2012)
- Locations and plant size of renewable DH and combined heat and power (CHP) plants based on *UDI World Electric Power Plants Database* (*Platts Database)*.[13] and the BioSustain project.[14]
- Additional data on H&C statistical data on NUTS 2 level available for some MS offices e.g. Germany.

Bottom-up modelling of regional heating supply

In the second step, a bottom-up model is applied to calculate final energy demand of SH and hot water based on technology and building stock data.

This simulation approach builds on detailed building stock data on national level and uses the structural data on NUTS3 level, such as share of different building categories, building floor area or number of dwellings per construction period to calculate the heat supply on regional level.

The building stock model *Invert/EE-Lab* is used for the bottom-up simulation.[15]. It has been applied in many European and nation projects to analyse building related energy consumption patterns, related RES potentials and scenarios. The basic idea of the model is to describe the residential and non-residential building stock and the heating, cooling and hot water systems on highly disaggregated level, calculate related energy needs and delivered energy and determine reinvestment cycles and new investment of building components. The model Invert/EE-Lab up to now has been applied in all countries of EU-28 (+ CH, IS, NO). A representation of the implemented data of the building stock is presented at [136] . A detailed description of the methodology can be found at: [18] and in Müller 2015 [137] or Steinbach 2015 [138].

2.5.1.2. Main results (EU-28)

In Figure 44 an example of the distributed UED for SH and hot water on regional level (top) and the supply structure (bottom) for Austria in 2015 are presented.

---

[12] https://land.copernicus.eu/pan-european/corine-land-cover

[13] https://www.platts.com/products/world-electric-power-plants-database

[14] Sustainable and optimal use of biomass for energy in the EU beyond 2020 – An Impact Assessment

[15] www.invert.at

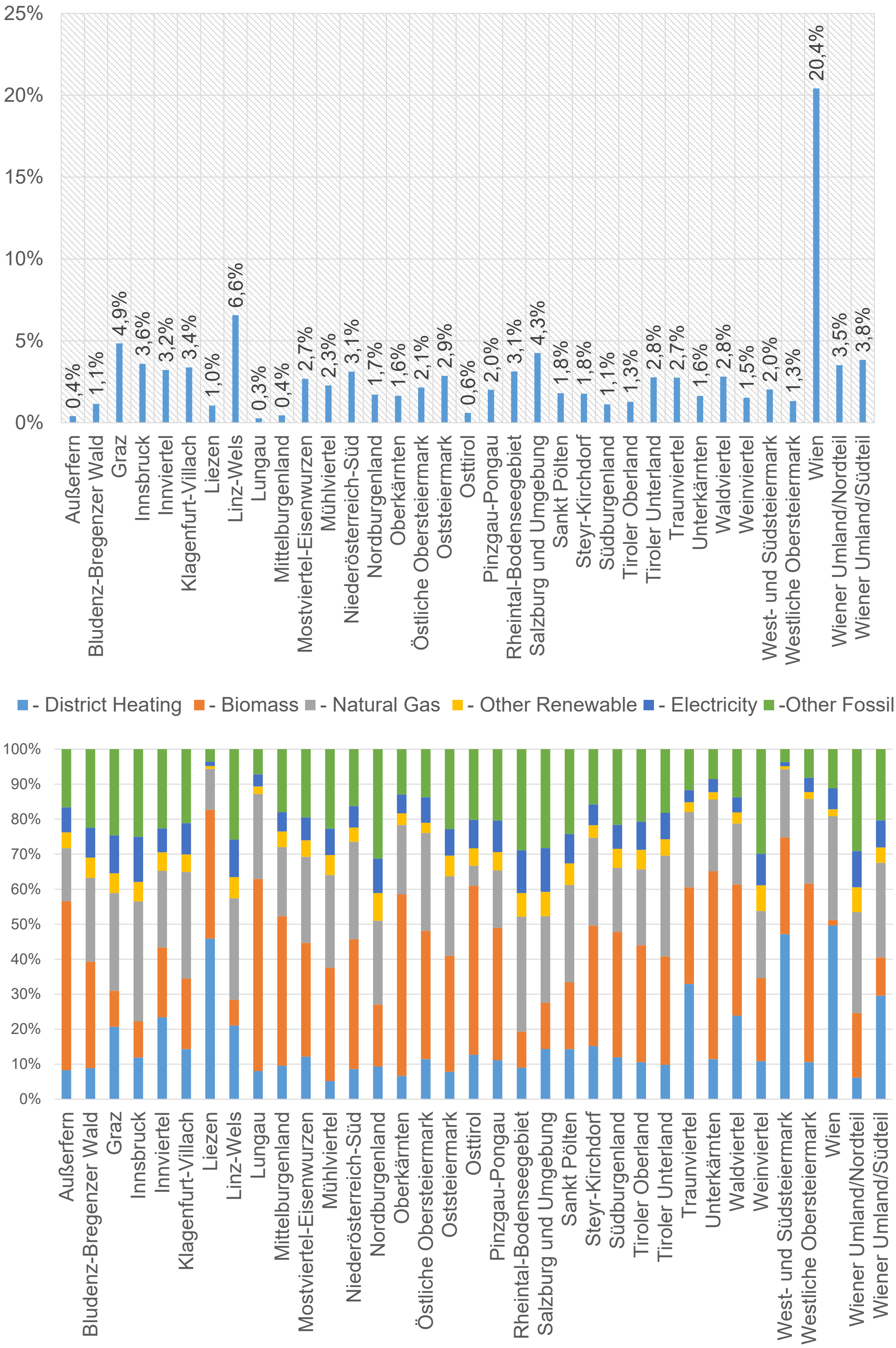


Figure 44. Distribution of useful energy demand on NUTS3 level (top) and supply share per energy carrier (bottom) for Austria in 2015

2.5.2. Assessment of heating and cooling systems

The main goal of this task is to determine the required indicators for defining the H&C supply for each MS. The necessary indicators for different supply technologies in creating the database for each country are specific investment cost (as EUR/kW), equipment and installation cost (as a percentage of total investment), annual efficiency, fixed (EUR/kW) and variable O&M costs (EUR/kWh), and the technical lifetime (year). The data was aggregate at NUTS0 level for each MS assuming no differences between different regions inside countries.

2.5.2.1. Methodology

In order to divide the H&C technologies in different capacity groups, four type of buildings are analysed:

- Existing SFH with c.a. 10-15 kW_{th} installed capacity;
- Existing MFH with max 400 kW_{th} installed capacity;
- New SFH with c.a. 4-10 kW_{th} installed capacity;
- New MFH with max 160 kW_{th} installed capacity.

As a starting and reference point, technology data for individual heating plants from the Danish Energy Agency (DEA) catalogue were used [139]. In Table 18 an overview of some of the most important indicators that are considered as a referent point are presented. For the electric panel heaters the values are self-assessed. Some of the values are presented in a range (e.g. solar heating systems), as certain price development is expected throughout the years.

Table 18. Overview of some of the indicators based on the Danish Energy Agency catalogue. Source: [139]

	Area of application	Installed capac. [kWth]	Spec. invest. [€/kWth]	Equipment costs [%]	Installation costs [%]	Fixed O&M [€/kW.a]
Oil-fired boiler	existing SFH	15	400	70%	30%	16
	existing MFH	400	85	70%	30%	2
	new SFH (Bio-oil)	15	667	70%	30%	16
	new MFH (Bio-oil)	160	175	70%	30%	3,5
Natural gas boiler	existing SFH	10	320	63%	37%	20
	existing MFH	400	63	84%	16%	2
	new SFH	10	320	63%	37%	20
	new MFH	160	110	80%	20%	3
	existing SFH	10	700	80%	20%	50
	existing MFH	400	225	80%	20%	5

Biomass, automatic stoking	new SFH	10	700	80%	20%	50
	new MFH	160	335	80%	20%	7
Biomass, manual stoking	existing SFH	30	230	80%	20%	2
	new SFH	30	230	80%	20%	2
Wood stove, existing/ new SFH	without water tank	6	415	100%	0%	25
	with water tank	15	270	85%	15%	14
Heat pump, air-to-air	existing SFH	4	450	85%	15%	43
	new SFH	2,5	480	75%	25%	68
Heat pump, air-to-water	existing SFH	10	1000-760	70%	30%	29
	existing MFH	400	375-285	70%	30%	4
	new SFH	4	1750-1250	60%	40%	73
	new MFH	160	470-350	60%	40%	10
Heat pump, brine-to-water	existing SFH	10	1600-1200	65%	35%	29
	existing MFH	400	660-500	60%	40%	4
	new SFH	4	3000-2250	55%	45%	73
	new MFH	160	595-420	50%	50%	10
Solar heating system	existing SFH	4,2	950-640	65%	35%	16
	existing MFH	140	615-480	65%	35%	3
	new SFH	4,2	645-450	65%	35%	16
	new MFH	140	580-430	65%	35%	3
Electric heaters*	existing/ new SFH	5	80	100%	0%	0
Ind. DH substation	existing SFH	10	210	70%	30%	6
	existing MFH	400	40	70%	30%	0,4
	new SFH	10	210	70%	30%	5,5
	new MFH	160	70	70%	30%	0,7

*self-assessment

In Figure 45, a cost-capacity function based on the values from Table 18 is derived. As expected, the most costly technology (based on the specific investment costs) is a brine-to-water heat pump, whereas the least expensive is the indirect DH substation.

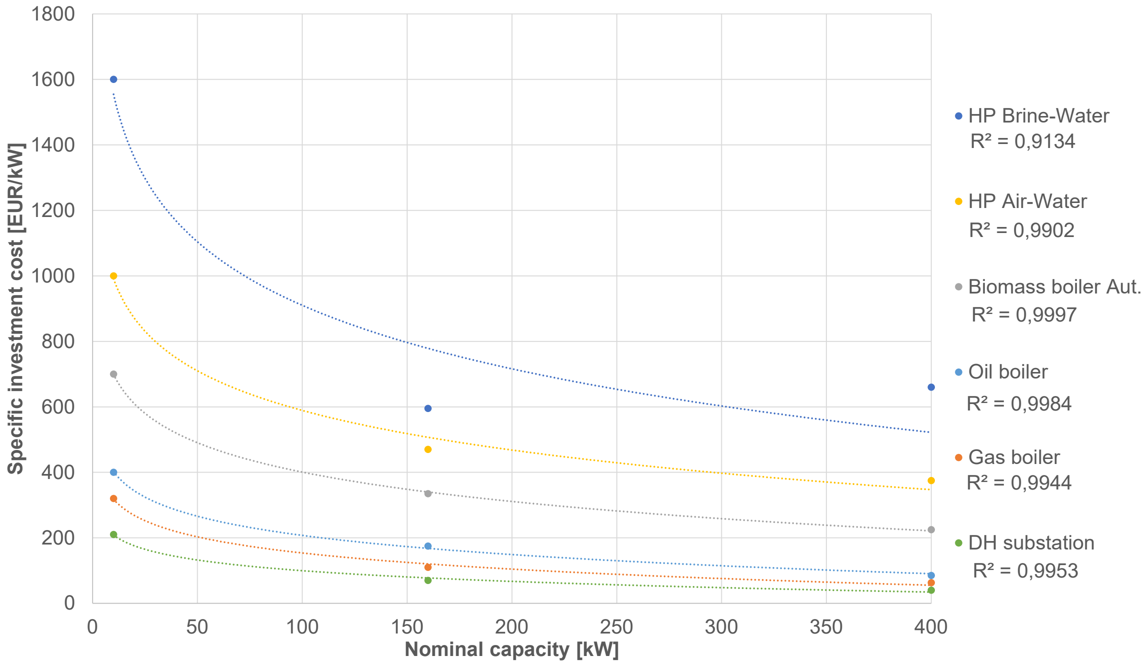


Figure 45. Cost-capacity function from Danish Energy Agency catalogue. Source [139]

In order to define the costs for each MS based on the data from the catalogue, labour, material, and maintenance costs indices are determined (Table 19) with Denmark as a referent MS. By multiplying these indices with the cost data from the DEA, country specific values are calculated. For the labour cost index data from EUROSTAT for the cost per hour in the construction sector in 2016 was used [140], whereas for the price index the home appliances index from the price level indices group was used [141]. As for the equipment and maintenance, household furnishings, equipment and maintenance index [142] was used.

Table 19. Labour and price indices.

Country	Price index 2016 (Home appliances)	Labour cost index 2016 (construction)	Equipment and maintenance 2016
Austria	0.82	0.81	0.90
Belgium	0.92	0.88	0.88
Bulgaria	0.73	0.09	0.52
Croatia	0.83	0.23	0.66
Cyprus	1.02	0.36	0.73
Czech Republic	0.80	0.24	0.63
Denmark	**1.00**	**1.00**	**1.00**
Estonia	0.82	0.30	0.72
Finland	0.94	0.87	0.92
France	0.93	0.80	0.84
Germany	0.89	0.69	0.82
Greece	0.81	0.29	0.74
Hungary	0.76	0.15	0.57
Ireland	0.87	0.69	0.83
Italy	0.94	0.60	0.87
Latvia	0.76	0.19	0.68
Lithuania	0.81	0.18	0.66
Luxembourg	0.98	0.64	0.92
Malta	1.16	0.24	0.85
Netherlands	0.87	0.86	0.88
Poland	0.66	0.19	0.52
Portugal	1.00	0.30	0.77
Romania	0.80	0.11	0.57
Slovakia	0.81	0.24	0.66
Slovenia	0.88	0.30	0.73
Spain	0.89	0.51	0.82
Sweden	1.01	1.02	0.98
UK	0.87	0.71	0.85

To determine the technological and price development over the evaluated period, four reference years were analysed (2015, 2020, 2030, and 2050). Eleven different types of individual technologies are considered based on the type and size of the relevant buildings (Table 20).

Table 20. Analysed technologies and relevant buildings.

Technology	Existing buildings		New buildings	
	Single-family	Multi-family	Single-family	Multi-family
Oil-fired boiler	x	x	x	x
Natural gas boiler	x	x	x	x
Biomass boiler, auto. stoking	x	x	x	x
Biomass boiler, manual stoking	x		x	
Wood stove	x		x	
Heat pump, air-to-air	x		x	
Heat pump, air-to-water	x	x	x	x
Heat pump, brine-to-water	x	x	x	x
Solar heating system	x	x	x	x
Electric panel heaters	x		x	
Ind. DH substation	x	x	x	x

2.5.2.2. Main results (EU28)

In Table 21, an example of selected technologies for existing SFH in 2015 for few countries are presented. The total annual net efficiency is given as an average value and it will be calculated for a specific, user defined supply/return temperatures.

Table 21. Example of selected technologies for existing single-family house in 2015.

Country	Oil boiler	Natural gas	HP Air-to-Water	HP Brine-to-Water
Denmark				
- Spec. investment costs [EUR/kW]	400	320	1000	1600
- Equipment cost share [%]	70%	63%	70%	65%
- Installation cost share [%]	30%	37%	30%	35%
- Fixed O&M [€/kW.a]	16	20	29	73
- Variable O&M [€/kWh]	0.00	0.00	0.00	0.00
- Technical lifetime [years]	20	20	18	20
- Total annual net efficiency [%]	93%	98%	300%	330%
Germany				
- Spec. investment costs [EUR/kW]	332	261	829	1311
- Equipment cost share [%]	70%	63%	70%	65%
- Installation cost share [%]	30%	37%	30%	35%
- Fixed O&M [€/kW.a]	13	16	24	60
- Variable O&M [€/kWh]	0.00	0.00	0.00	0.00
- Technical lifetime [years]	20	20	18	20
- Total annual net efficiency [%]	93%	98%	300%	330%
Poland				
- Spec. investment costs [EUR/kW]	208	156	520	795
- Equipment cost share [%]	70%	63%	70%	65%
- Installation cost share [%]	30%	37%	30%	35%
- Fixed O&M [€/kW.a]	8	10	15	38
- Variable O&M [€/kWh]	0.00	0.00	0.00	0.00
- Technical lifetime [years]	20	20	18	20
- Total annual net efficiency [%]	93%	98%	300%	330%
Romania				
- Spec. investment costs [EUR/kW]	236	173	590	889
- Equipment cost share [%]	70%	63%	70%	65%
- Installation cost share [%]	30%	37%	30%	35%
- Fixed O&M [€/kW.a]	9	11	16	41
- Variable O&M [€/kWh]	0.00	0.00	0.00	0.00
- Technical lifetime [years]	20	20	18	20
- Total annual net efficiency [%]	93%	98%	300%	330%

In Figure 46, the specific investment cost and the fixed O&M costs for oil-boilers in an existing SFH in 2015 are presented. The specific investment costs price range varies from ca. 210 EUR/kW for countries like Bulgaria and Poland, to up to 400 EUR/kW for countries like Denmark and Sweden. In the figure, the fixed operation and maintenance costs for each MS are presented as well with a price range from 8 up to 16 EUR/kW annual costs.

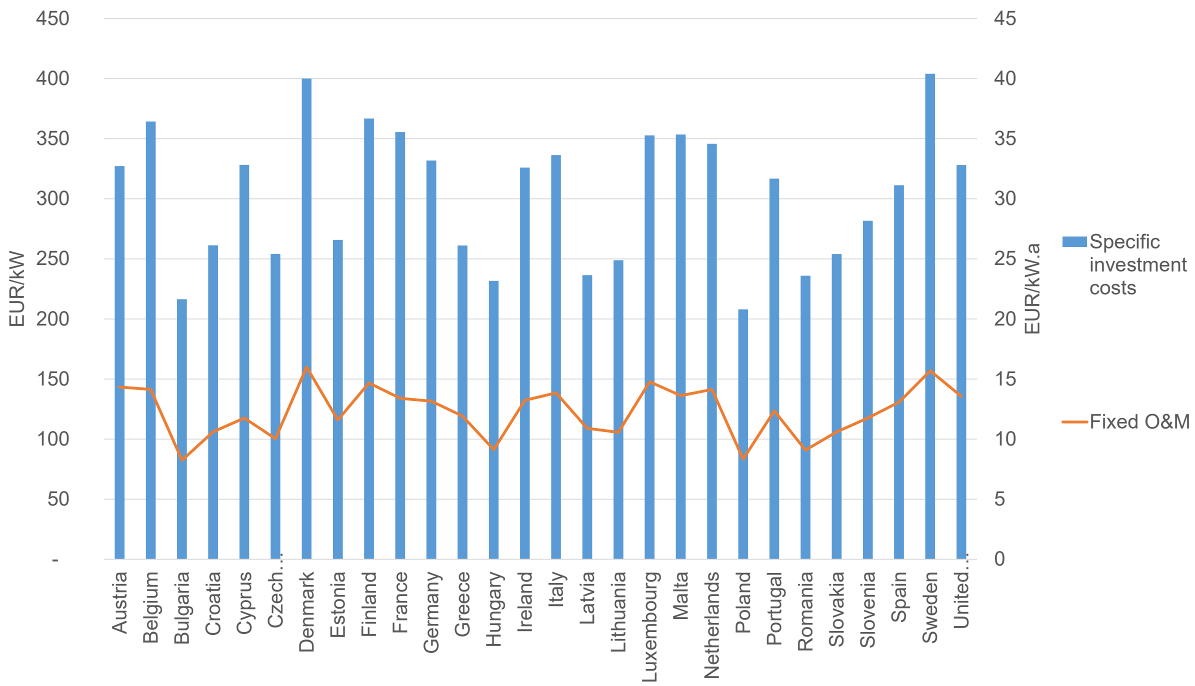


Figure 46. Specific investment costs (left axis) and fixed operation and maintenance (right axis) for oil-boilers in a single family house in 2015.

2.5.3. Limitations on data

While the generated technical and financial data are providing sufficient and reliable information's about the individual H&C technologies currently used in the existing EU building stock, forecasting the future market developments can pose a major challenge. Even though lower investment prices are predicted and expected for some technologies like HPs and solar thermal collector, the forecasted price development may vary from one country to another. Furthermore, the price and labour cost indices presented in this study are constant over the years in order to simplify the calculation process even though this certainly will not be the real case and similarly to the forecasted price developments, should be taken with a dose of uncertainty. In order to improve the quality and reliability of the data, future updates are necessary.

Another limit of the generated data are the presented operation and maintenance costs (O&M). A simplified solution by multiplying the O&M country specific price index with the data from Denmark provides sufficient data, as the operation and maintenance cost represents a small share of the total H&C supply (assuming electricity costs for heat pumps are calculated as a fuel costs). The reason behind this simplification is more or less similar with the previously presented limits like labour and price cost index development.

Furthermore, some limitations of the representation of the cost-capacity function in Figure 45 are to be noted. As the H&C technologies are not produced for each kW nominal capacity, the correlation between the specific costs (EUR/kW) and nominal capacity (kW) is a provisional one. In other words, different houses with different capacities might have the same installed unit, leading to the conclusion that the house with a lower demand has higher specific installation costs. This is particularly relevant for very small heating demands and thermal capacities below 10 kW.

Further, the method used is not able to capture particularities of heat technology markets across the EU that go beyond general differences in labour and price indices. Factors are the maturity of markets, the level of competition and financial support. E.g., it is expected that gas boilers are cheaper in the Netherlands than calculated the conversion through labour and price indices. Also for HPs, the European markets are very diverse and experience a varying level of maturity. In order to capture such effects, more empirical studies are needed making surveys in selected EU countries.

2.6. Renewable energy sources data collection and potential review

The present task provides data with following characteristics:

Table 22. Characteristics of data provided within Task 2.6 Renewable energy sources data collection and potential review. The database of given task is available at: https://gitlab.com/hotmaps/potential

	Spatial resolution	Temporal resolution
Biomass availability	NUTS0	yearly
Wind potential	EU28	yearly
Solar potential	EU28	yearly
Shallow geothermal potential	Vector	-
Wastewater	EU28	yearly

In this task, we collected and re-elaborated data on energy potential of renewable sources at national level, in order to build datasets for all EU28 countries at NUTS3 level. We considered the following renewable sources: biomass, waste and wastewater, shallow geothermal, wind, and solar energy. These data will be used in the toolbox to map the sources of renewable thermal energy across the EU28 and support energy planning and policy. The data provided in this deliverable try to estimate only the potential of the resource, that means that the technology used to convert the RES potential into energy is not investigated on this document. In this way we reduced the number of assumptions at the minimum and the planners and policy makers are free to assume the efficiency of the process that convert this potential into energy. The Hotmaps platform will provide specific computational modules, developed in Task 3.3, that support the users in converting this potential into energy.

2.6.1. Biomass

Data on availability and potential of agricultural and forest biomass were retrieved from a 2014 report by Intelligent Energy Europe for the Biomass Policies project, “Outlook of spatial biomass value chains in EU28” [143]. The report presents data on the energetic potential of biomass expressed in PJ at NUTS0 level, without accounting for energy conversion or giving any indication of the technology employed to extract such potential.

The agricultural residues considered for energy generation have been selected from those included in the report, according to sustainability criteria. Residues from agricultural production and processes and effluents from livestock breeding have been included, while crops cultivated purposely for biofuel production have been excluded due to the prospective environmental impacts in terms of land use change, biodiversity losses and water resources depletion.

Agricultural residues are summarized in Table 23.

Table 23. Agricultural residues included in the calculation of energy potential from agricultural biomass.

Crop	Production Process	Biomass
Cereals (excluding maize and rice)	Cereal production for food and fodder	Straw
Maize	Maize production for food and fodder	Stover
Oilseed rape and sunflower	Oil production	Stubble
Sugar beet	Sugar production	Leaves and tops
Rice	Rice production	Straw
Olives	Oil production	Pits
Olives	Olive and oil production	Residues from pruning
Citrus	Citrus production	Residues from pruning
Grape	Wine production	Residues from pruning

The livestock effluents considered for energy generation were solid and liquid manure from breeding of cattle, pigs and poultry.

Forest biomass includes two categories of residues originated from forest management, and in particular from wood harvest and processing residues (from industrial production and non):

- Fuelwood and roundwood;
- Fuelwood and roundwood residues.

Tables on energy potential in PJ for each biomass at NUTS0 level have been extracted from the report, elaborated in R and unified in three (agriculture, forest, and livestock residues) output datasets containing the energy potential of biomass in PJ at national level.

2.6.1.1. Methodology

Agricultural biomass

To spatialize the data on energy potential of agricultural biomass at NUTS3 level, we used the LUCAS [144] framework, a survey that provides statistics on land use and land cover in the EU28 territory. LUCAS data are organized as a grid of georeferenced points, each characterized by a land use/cover class.

In order to identify the points of the LUCAS grid with land cover classes relevant to our research, i.e. those relative to the selected biomasses, the LUCAS database has been elaborated in R and the following land cover classes were extracted based on the residues:

- Cereal straw: B11 – common wheat, B12 – durum wheat, B13 – barley, B14 – rye, B15 – oats, B19 – other cereals
- Grain maize stover: B16 – maize
- Rice straw: B17 – rice
- Sugar beet leaves: B22 – sugar beet
- Rape and sunflower stubble: B31 – sunflower, B32 – rape and turnip rape
- Citrus pruning: B76 – oranges, B77 – other citrus fruit
- Olive pruning and pits: B81 – olive groves
- Vineyard pruning: B82 – vineyards

The LUCAS grid, including only the points belonging to the above listed classes, was then imported in GRASS GIS environment, where it was possible to cross it with a vector file of the EU28 area at NUTS0 and NUTS3 level. The LUCAS points were counted at NUTS0 and NUTS3 level and again in R it was possible to establish the percentage of land cover points at NUTS3 level based on the total of each NUTS0 area. These percentages were finally multiplied by the energy potential of each type of biomass at national level, resulting in an estimate of the potential of each biomass at NUTS3 level. The underline assumption of this elaboration is that the biomass residues production is homogenous at country level (NUTS0). The results are stored in a .csv table in the repository but they can also be visualized as a color-coded map created in QGIS.

Forest biomass

For the spatialization of data on energy potentials of forest biomass at NUTS3 level we used Corine Land Cover [1]. In Grass GIS it was possible to extract the land cover classes related to forest:

- 3.1.1. Broad-leaved forest
- 3.1.2. Coniferous forest
- 3.1.3. Mixed forest
- 3.2.1. Natural grassland
- 3.2.2. Moors and heathland
- 3.2.3. Sclerophyllous vegetation
- 3.2.4. Transitional woodland shrub

The raster file with the extracted classes was then used as a proxy to spatialize the data on forest potential at national level, at NUTS3 level. The results are stored in a .csv table in the repository but they can also be visualized as a color-coded map created in QGIS.

Livestock effluents

In order to spatialize the data on the energy potential of livestock effluents we used the EUROSTAT database statistics [145] on livestock head counts at NUTS2 and NUTS0 level for cattle, pigs and poultry.

In R it was possible to establish the percentage of cattle, pigs and poultry at NUTS2 level, based on the total of each NUTS0 area. These percentages were multiplied by the energy potential of each effluent at national level, resulting in an estimate of the potential of each biomass type at NUTS2 level. The data were first imported in Grass GIS for the creation of the vector at NUTS2 level and finally the visualization of results was performed in QGIS. An estimate at NUTS3 level was also possible, without considering the type of animal, from which the effluents come from and using as proxy for the number of manure storage facilities at NUTS3 level. The transformation of NUTS2 data to NUTS3 level assumes that in average the manure storage facilities collect the same number of animals and that within the NUTS2 the distribution of the type of animal is homogenous. The results are stored in a .csv table in the repository but they can also be visualized as a color-coded map created in QGIS. The results are stored in a .csv table in the repository but they can also be visualized as a color-coded map created in QGIS.

2.6.1.2. Main results (EU28)

Agricultural and forest biomass and livestock effluents

Figure 47 shows the potential in PJ (expressed as the value variable on the y-axis) of agricultural residues for all EU28 countries. As shown in Figure 47, the potential from cereal straw is the most relevant among those of agricultural residues in all European countries. Mediterranean countries such as Italy, Spain and Greece, have a large variety of agricultural products and a widespread distribution of potential at NUTS3 level. Most European countries present a significant potential from forest biomass, except from Malta, the Netherlands and the UK. The potential from livestock effluents is relevant in Belgium, Switzerland, Denmark, Greece, Spain, Ireland, Malta and the Netherlands.

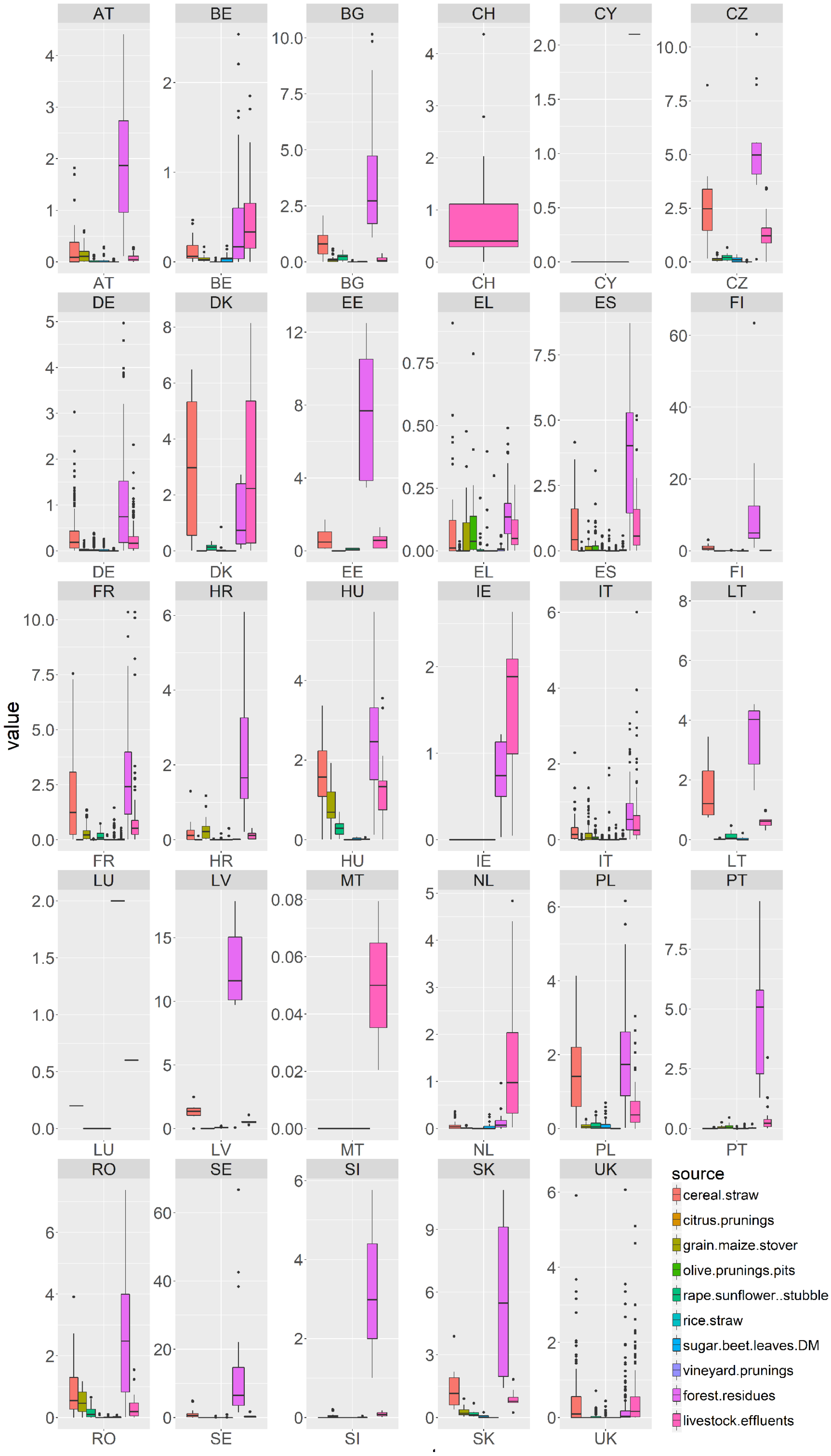


Figure 47. Agricultural and forest biomass potential in PJ of the distribution at NUTS3 level in European Union 28 countries and Switzerland.

2.6.2. Wastewater

2.6.2.1. Methodology

This indicator considers the thermal recovery from wastewater treatment plants, not from the sewer system. Data on the energy potential of wastewater treatment plants have been drawn from the European Environment Agency database. For each plant in the EU28 zone, geographical coordinates and capacity in population equivalent (PE) are available. In order to calculate the actual energy potential from wastewater treatment only plants suitable for energy generation must be considered. Certain plants are more suitable for energy generation than others, and suitability has been determined according to the plant capacity and its proximity to urban areas [146], as described in Figure 48.

	Size Category		Spatial Context			
			A within the settlement	B near to the settlement	C far from the settlement	Sum
Amount of WWTPs	0	2000–5000 PE	78	74	97	249
	1	5001–50,000 PE	124	98	98	320
	2	50,001–150,000 PE	25	8	14	47
	3	>150,000 PE	11	2	3	16
		Sum	**238**	**182**	**212**	**632**
			suitable	conditionally suitable	not suitable	

Figure 48. Wastewater treatment plant suitability for energy generation. Source: [146]

Based on their capacity, expressed in population equivalent (PE), plants can be divided in four classes:

- 2 000 – 5 000 PE
- 5 001 – 50 000 PE
- 50 001 – 150 000 PE
- 150 000 PE

The proximity to urban areas has been defined following three categories

- Within the settlement: the plant is located up to 150 m from the nearest urban area, which must cover at least 25 ha within the 1000 m radius around the plant;
- Near the settlement: the plant counts at least 25 ha of urban areas within the radius between 150 m and 1000 m around it;
- Far from the settlement, the plant is located in an area where a 1000 m radius drawn around it does not contain significant shares of urban areas.

In this approach, we established that urban areas are those characterized by the following classes of the Corine Land Cover:

1. Continuous urban fabric (class 1.1.1.)
2. Discontinuous urban fabric (class 1.1.2.)
3. Industrial or commercial units (class 1.2.1.)

The thermal potential of each plant in kW was computed by multiplying the heating value of wastewater (c) by the difference in temperature (ΔT) by the volume of water flowing through the plant (V), as described by the following equation (5).

$$P = c * \Delta T * V \quad (5)$$

We assumed the thermal capacity was equal to 1.16 kWh/m^3/K [146]. The average wastewater temperature in the heating period is estimated at 10 °C. The wastewater in the effluent would be cooled down to 5°C, so that 5 K can be extracted. The volume V is computed under the assumption of a daily flow rate (D) per person into the collector system equal to 200 l/day/inhabitant[16] and 18 equivalent hours per day (n) – see equation 6:

$$V = PE * D/n \quad (6)$$

The new dataset containing the geographical coordinates, capacity and power of each wastewater treatment plant was transferred into GRASS GIS, together with a raster file including classes 111, 112 and 121 of the Corine Land Cover. The suitability of the plants for the generation of thermal energy was determined by creating a query on plant capacity and proximity to urban areas. The latter was tested by creating two types of buffer, respectively of 150 and 1000 m radius, around the plants, and counting the hectare of urban areas within these buffers.

The map shown in Figure 49 classifies the plants by colour according to their suitability for the production of thermal energy. Green dots represent plants where energy production is feasible; yellow dots represent plants where energy production is feasible under certain conditions; red dots represent plants where energy production is not feasible.

[16] Helena Köhler, *Individual metering and debiting (IMD) in Sweden: A qualitative long-term follow-up study of householders' water-use routines*, 2017. https://doi.org/10.1016/j.enpol.2017.06.005.
Pietro Elia Campana, Steven Jige Quan, Federico Ignacio Robbio, Anders Lundblad, Yang Zhang, Tao Ma, Björn Karlsson, Jinyue Yan, *Optimization of a residential district with special consideration on energy and water reliability*, 2017. https://doi.org/10.1016/j.apenergy.2016.10.005.
Liliana N. Proskuryakova, Ozcan Saritas, Sergey Sivaev,*Global water trends and future scenarios for sustainable development: The case of Russia,* 2018. https://doi.org/10.1016/j.jclepro.2017.09.120.

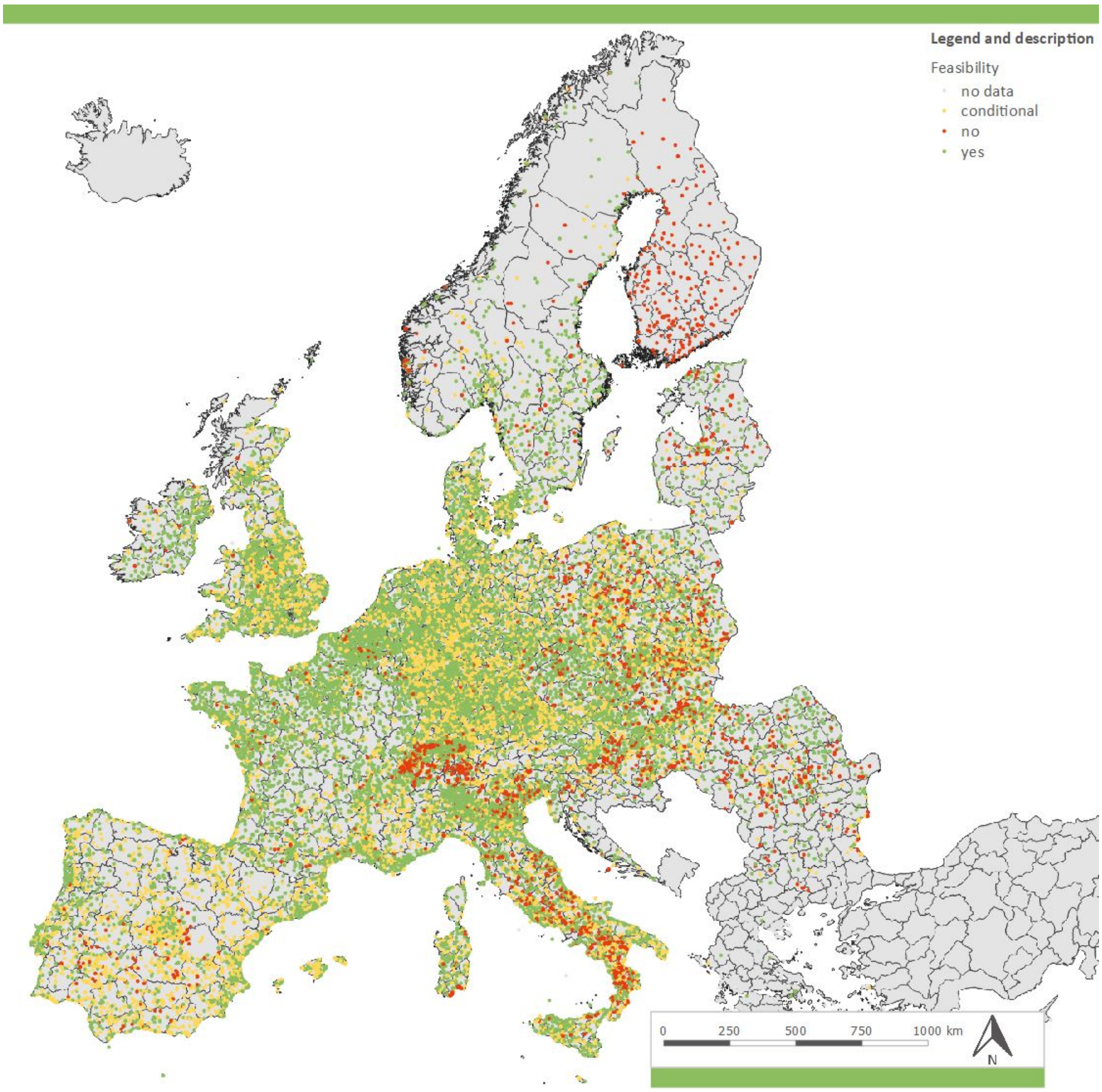


Figure 49. Wastewater treatment plants classified by feasibility for energy generation.

The grid of suitable plants was then crossed with the structure of EU28 at NUTS3 level, in order to determine the potential of wastewater treatment plants in each province. GRASS GIS allowed us to count the plants for each NUTS3 area and to sum up their energy potential, previously calculated, giving in the end the total potential from wastewater for each NUTS3 region. A second color-coded map represents the potential for each province (see Figure 49).

2.6.2.2. Main results (EU28)

As shown in Figure 50, the potential from wastewater present a heterogeneous distribution through the EU28. The provinces showing higher values for the potential of wastewater are urban areas. One can easily identify the European capitals of Rome, Madrid, Lisbon, Wien, Budapest, and Stockholm.

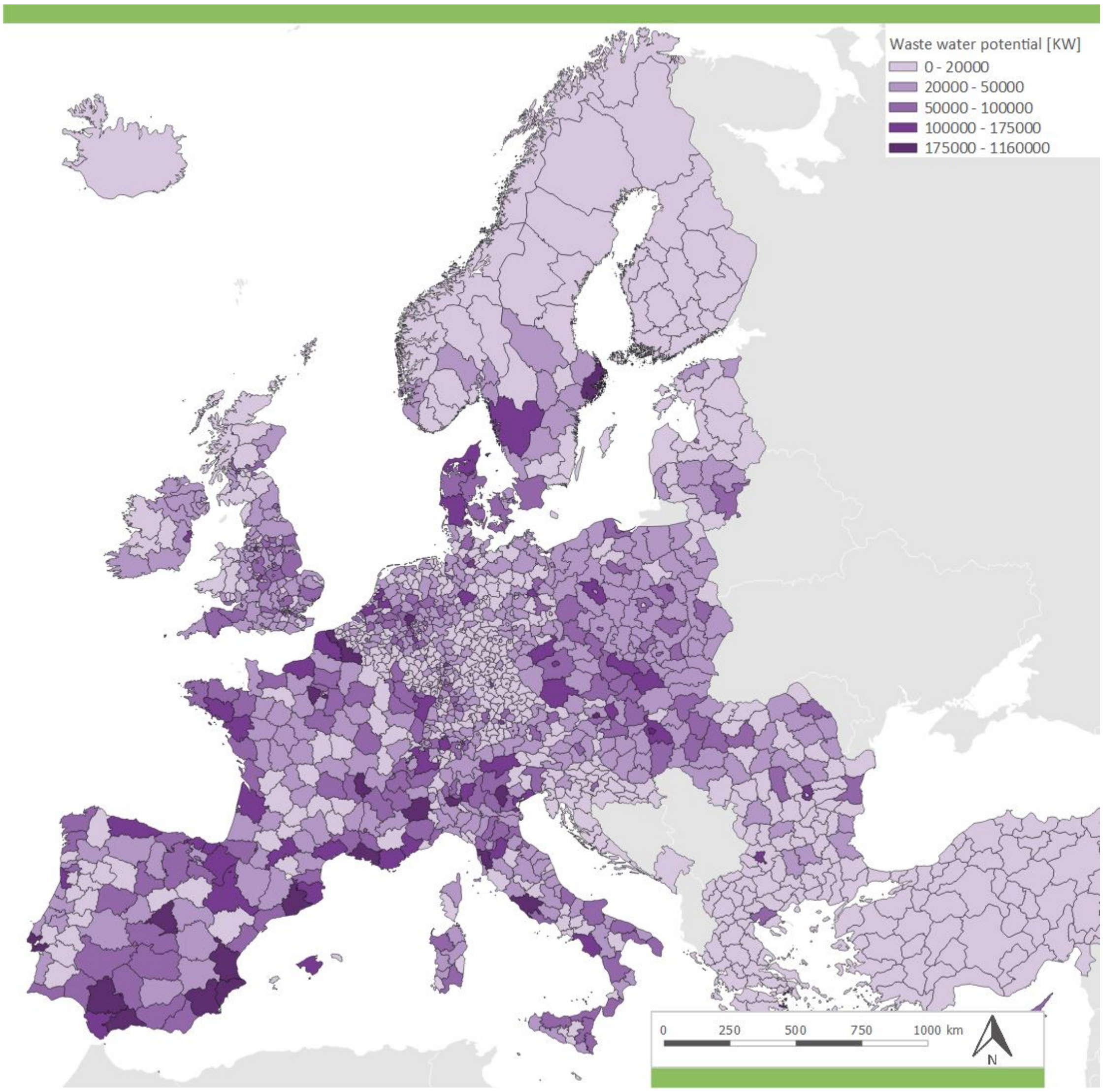


Figure 50. Yearly energy potential from wastewater in kW at NUTS3 level.

2.6.3. Municipal solid waste

For calculating the energy potential of waste we decided to consider only one type of waste: municipal solid waste (MSW). Again, this decision was motivated by sustainability criteria: all recyclable waste should not be considered as energy source, hence the exclusion of paper and cardboard and wood waste. Food, vegetal waste and used frying oil (UFO) should not be included in the estimation of the potential since they should be employed in compost production. The method for generating thermal energy from MSW is not specified here: it could either be combustion or anaerobic digestion. Thus, the numbers stated for the potential of municipal solid waste are given in terms of its calorific value.

2.6.3.1. Methodology

The data on municipal solid waste generation from households and economic activities (NACE) in the EU28 in tons were collected from the Eurostat Database for the year 2014. By using the parameters presented in Table 24 [147], it was possible to quantify the energy potential of waste from household and NACE activities in PJ.

Table 24. Parameters for calculating energy potential of municipal solid waste. Source: [147]

Parameter	Value	Unit
Waste low heating value (c)	13.81644	MJ/Kg
Equivalence ratio (ER)	0.340656	-

In R, we obtained the value for waste potential in PJ at national level, according to the following equation (7), where Pwaste is the potential of waste and Qwaste the quantity of available waste [147].

$$P_{waste} = Q_{waste} * c * ER \qquad (7)$$

Household waste

Once we had the potential of MSW at national level we used the population statistics from the Eurostat Database for the year 2011 as proxy to spatialize the potential of household waste at NUTS3 level. R elaborations allowed us to calculate the percentages of population in each province with respect to the total national populations and to multiply the results by the energy potentially generated from this waste.

Economic activities waste (NACE)

The potential of MSW from different NACE activities at NUTS3 level was obtained by using the GDP statistics at NUTS3 level from the Eurostat Database for the year 2014 as a proxy. The procedure adopted was then the same of the one used for household MSW.

2.6.3.2. Main results (EU28)

Figure 51 shows the potential of municipal solid waste in PJ (the *value* variable on the y-axis) for each EU28 country. As presented in Figure 51, the share of municipal solid waste potential from households is generally greater than the one from economic activities, except for Belgium and Malta.

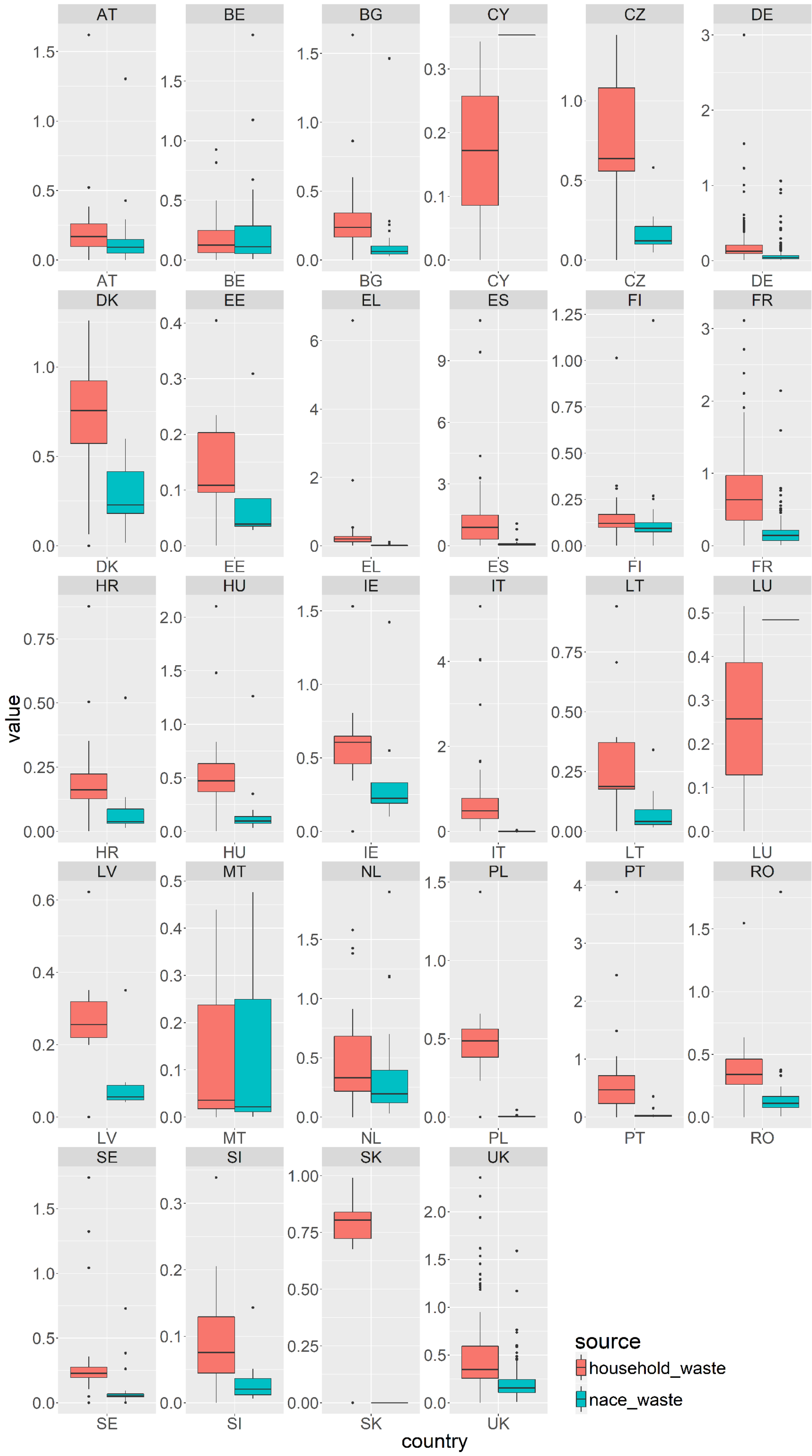


Figure 51. Municipal solid waste potential in European Union 28.

2.6.4. Wind power

Data on the wind-energy potential in W/m^2 have been drawn by the Global Wind Atlas (DTU Department of Wind Energy) for 50, 100, 200 m hub heights.

2.6.4.1. Methodology

For the calculation of wind energy potential we considered only areas with low or sparse vegetation, and bare and burnt areas (classes from 3.2.1. to 3.2.4. and 3.3.3., 3.3.4. of Corine Land Cover - CLC). We then excluded the following areas according to sustainability criteria:

- Areas above 2500 m.a.s.l.;
- A 1 km buffer from urban areas (classes from 1.1.1. to 1.4.2. of the CLC);
- Corridors for bird connectivity (Common Database on Designated Areas [148]);
- Exclusion of protected areas of the Nature 2000 network [149].

We then considered a distance among wind hubs of 300 m and found the most frequent value (median) of potential from wind energy for each NUTS3. The results are stored in a .csv table and a raster layer in the repository but they can also be visualized as a color-coded map created in QGIS, as shown in Figure 52.

2.6.4.2. Main results (EU28)

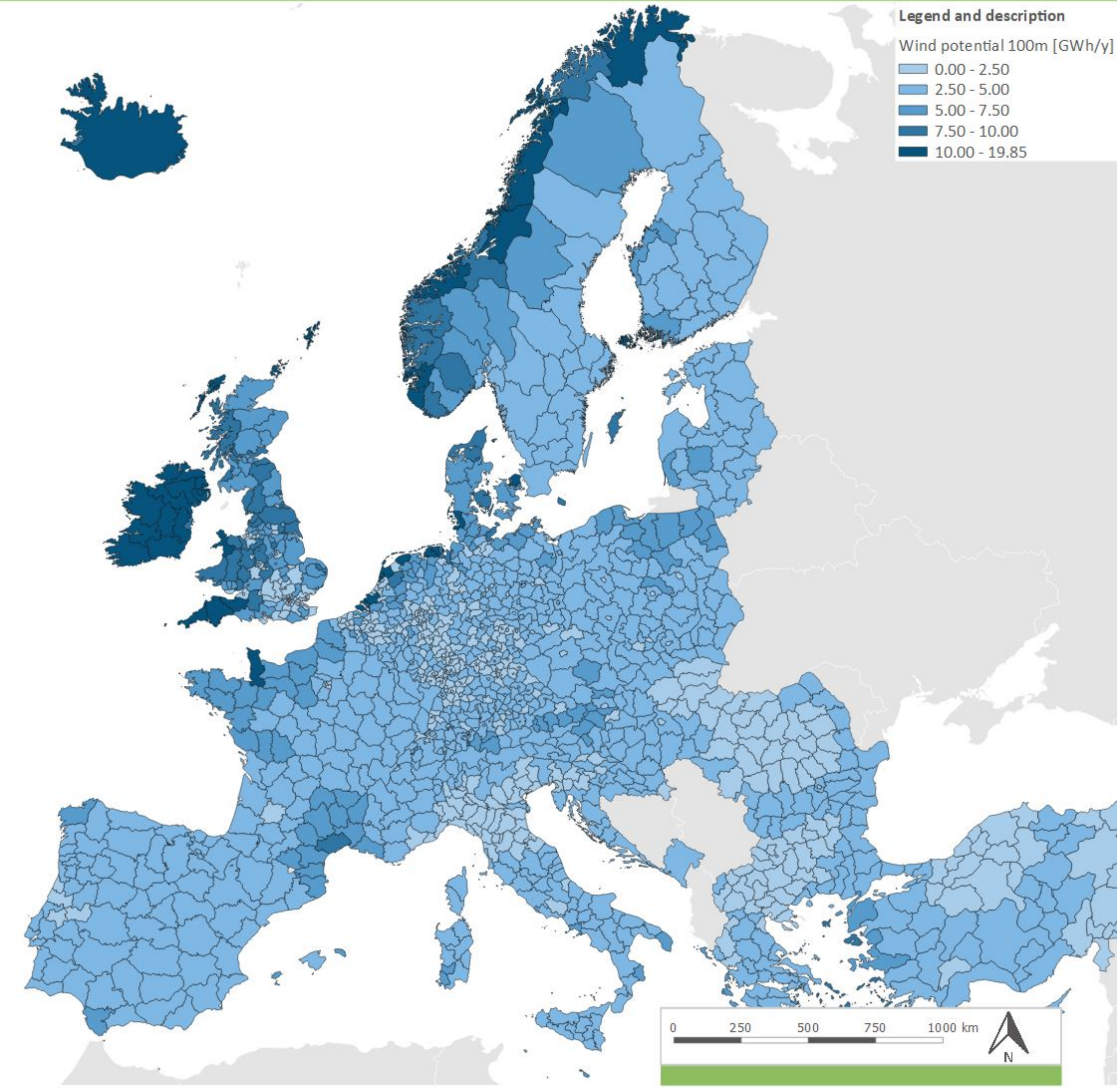


Figure 52. Wind energy potential in GWh on areas of 300 m x 300 m for 100 m high hubs at NUTS3 level.

2.6.5. Solar energy

Data on annual global radiation on globally inclined surfaces in kWh/m^2 were retrieved from the PVGIS as a 1km x 1km raster layer [93].

2.6.5.1. Methodology

The raster file mapping the solar radiation was imported in GRASS GIS and crossed with the building footprint. The value of solar potential was calculated as the median of the solar radiation in each NUTS3 area in kWh/m² y. The results are stored in a .csv table and a raster layer in the repository but they can also be visualized as a color-coded map created in QGIS.

2.6.5.2. Main results (EU28)

The distribution of potential from solar radiation depends on the latitude of the country, as shown in Figure 53. Mediterranean provinces have higher potential than northern European countries.

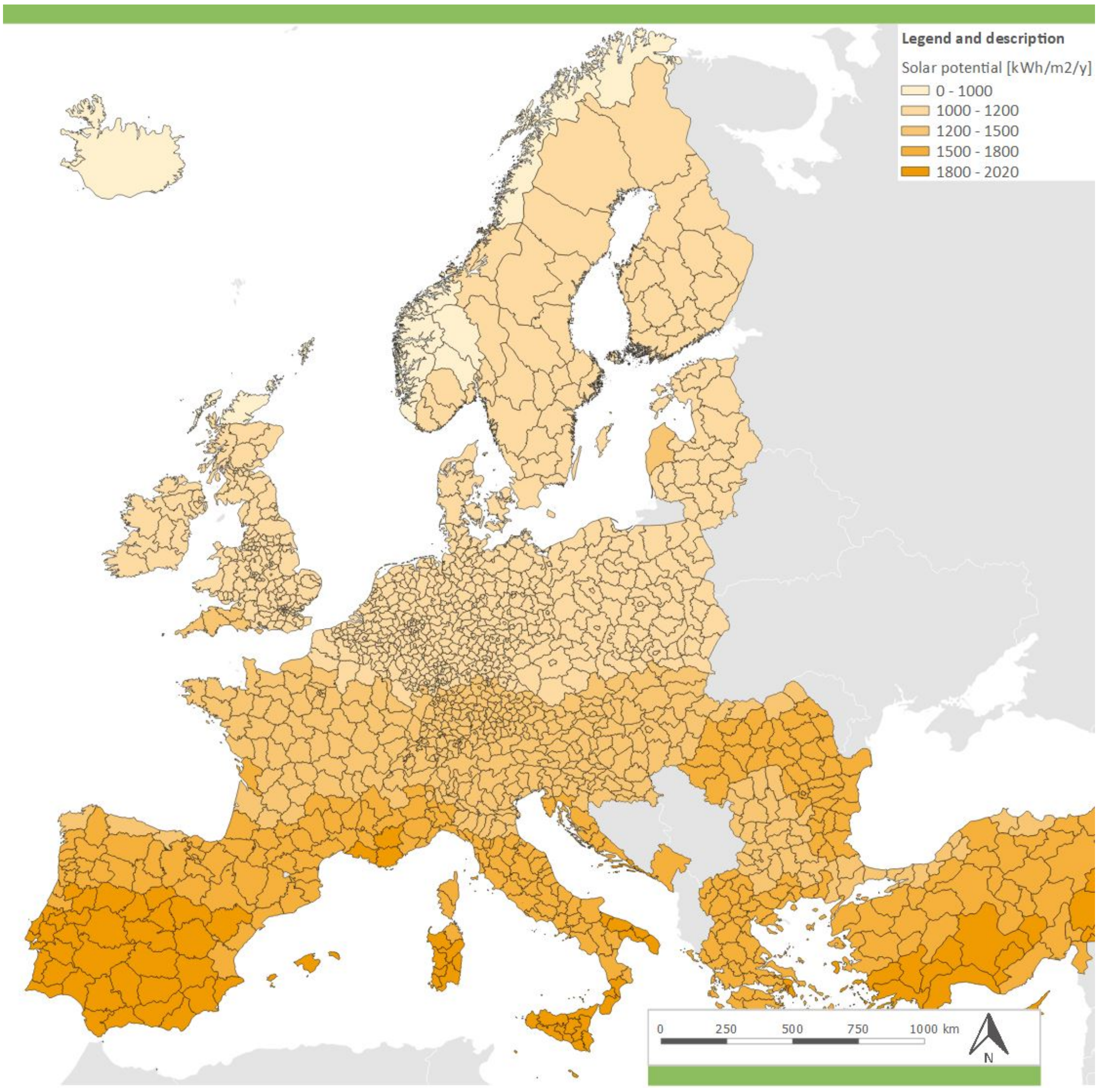


Figure 53. Solar energy potential in kWh/m² at NUTS3 level.

2.6.6. Geothermal energy

Data on very shallow geothermal energy potential in W/m K were retrieved from the EC co-funded project ThermoMap as a vector layer and presented here without further elaboration. [150].

2.6.7. Results for Pilot areas of the Hotmaps Toolbox

The Hotmaps project include among its partners, seven pilot areas. These are municipalities within EU28, which agreed to serve as testing ground for the project, providing feedback on the results of data collection and elaboration and evaluating the toolbox.

The pilot areas of the project are here summarized:

- Geneva (CH013) is an area with medium/high potential from both municipal solid waste and waste water treatment plants.
- Frankfurt (DE712) is an area with medium/high potential from both municipal solid waste and waste water treatment plants.
- Aalborg (DK051) is an area with very high potential from agricultural biomass and high potential from waste water treatment plants.
- San Sebastian (ES212) is an area with high potential from municipal solid waste.
- Kerry (IE025) is an area with very high potential from wind energy.
- Bistrita (RO112) is an area with medium/high potential from municipal solid waste.
- Milton Keynes (UKJ12) is an area with medium/high potential from both municipal solid waste and waste water treatment plants.

Results at NUTS3 level for the above mentioned renewable sources (except geothermal energy) are summarized for the pilot areas in the table below.

Table 25. Data on renewable energy potentials for Hotmaps pilot areas.

Source/NUTS3	CH013	DE712	DK051	ES212	IE025	RO112	UKJ12	Unit
Agricultural residues	30	20	1560	0	0	80	80	GWh/y
Forest residues	20	40	650	680	360	970	4	GWh/y
Livestock residues	no data	7	2080	70	730	170	10	GWh/y
Municipal solid waste	no data	330	320	370	370	90	140	GWh/y
Waste water	60	120	100	100	50	10	20	MW
Solar potential	1.4	1.1	1.1	1.5	1.1	1.5	1.1	$MWh/m^2/y$
Wind potential 50 m	0	0	6	3	8	2	0	GWh/y
Wind potential 100 m	0	0	9	3	12	2	0	GWh/y
Wind potential 200 m	0	0	17	5	21	4	0	GWh/y

Please notice that, for the solar potential the indicators refer to the median value by considering only building footprint, while the three wind potentials are in competition and the choice of the hub height should be done before choosing the most appropriate indicator.

2.6.8. Limitations of data

The data here calculated are estimations of the energy potential from renewable energy sources. The hypotheses we made when deciding what data to consider, when re-elaborating the data at more aggregated territorial levels and finally when deciding how to convey the results, can influence the results.

In some cases, we underestimated the actual potential (biomass), by downscaling the available resource for sustainability reasons, in others, we overestimated the potential (wind, solar) due to our assumption of using all available areas, according only to some GIS sustainable criteria, where energy generation is feasible without considering economic profitability.

The potentials here reported **do not account for any type of energy conversion**: when estimating the actual potential, the user will need to choose the technology through which the potential can be exploited (for example COP for the wastewater treatment plant or the efficiency for solar thermal, photovoltaic and wind).

For these reasons, the data must be considered **as indicators, rather than absolute figures** representing the actual energy potential of renewable sources in a territory.

2.6.9. Data availability

For further information on the data, please refer to Table 26.

Table 26. Links to data repositories for renewable energy potentials.

Renewable source	Repository
Biomass	https://gitlab.com/hotmaps/potential/potential_biomass
Forest biomass	https://gitlab.com/hotmaps/potentia/potential_forest
Wastewater	https://gitlab.com/hotmaps/potential/WWTP
Municipal solid waste	https://gitlab.com/hotmaps/potential/potential_municipal_solid_waste
Wind	https://gitlab.com/hotmaps/potential/potential_wind
Solar	https://gitlab.com/hotmaps/potential/potential_solar
Shallow geothermal	https://gitlab.com/hotmaps/potential/potential_shallowgeothermal

2.7. Hourly load profiles

The present task provides data with following characteristics:

Table 27. Characteristics of data provided within Task 2.7 Hourly load profiles. The database of given task is available at: https://gitlab.com/hotmaps/load_profile

	Spatial resolution	Temporal resolution
Heating load profiles for different subsectors in the industry (thermal)	NUTS0 (considering regional climatic context)	hourly
Heating and cooling load profiles for the service sector (thermal)	NUTS2 (considering regional climatic context and user behaviour)	hourly
Heating and cooling load profiles for the residential sector (thermal)	NUTS2 (considering regional climatic context and user behaviour)	hourly
System load (electrical)	NUTS0	hourly
RES generation (PV, wind offshore, wind onshore)	NUTS0	hourly
Residual load (electrical)	NUTS0	hourly

In this chapter, we describe the methodology we applied to represent UED for H&C on an hourly time resolution in a consistent way. The generated hourly UED profiles for H&C are based on daily average temperature data and empirical demand profiles that reflect consumer behaviour. The profiles are provided on NUTS2 level for the residential, tertiary and industry sector.

2.7.1. Preparation of temperature data on NUTS2 level

As UED for H&C depends largely on weather and outside temperature, we provide a consistent temperature dataset for the EU28 that originates from open source weather data.

The geographical information used to produce a consistent temperature data set includes:

- Daily average E-OBS temperature data on 25x25 km² level[17];

[17] For more information regarding the temperature dataset it is referred to the European Climate Assessment & Dataset project (www.ecad.eu)

- CORINE land cover[18] data >> temperature data of settlement areas (Continuous urban fabric, discontinuous urban fabric, sport and leisure facilities);
- Geo-coded information of the borders of NUTS2-regions

Match of 25x25 km² raster data to NUTS-2-regions

In a first step, the temperature data provided on the 25 x 25 km² raster is mapped to the NUTS2 regions. It is defined that a 25 x 25 polygon will only be allocated to one single NUTS2 region. To ensure this, temperature information is transferred to each raster's central point to make the allocation unique.

Four regions (AT13, UKI3, UKI4, UKI7) do not contain any of the rasters' central point. In these cases, the rasters with the largest surface on these particular regions are manually allocated.

Weighted average of temperature data

It is assumed, that both households and businesses are not homogenously spread across all regions. Thus, instead of using the simple average temperature of all polygons in one NUTS2 region, the temperature data is weighted under consideration of settlement areas and industrial sites. In order to do so, all 25 x 25 km² rasters are matched to the EU's "Corine Landcover" dataset (containing information on land use). Thereby, each raster's share of industrial and residential land use is calculated.

In the last step, a weighted average temperature for every NUTS2 region for all 365 days in the year 2010 is produced. This is done by normalizing each raster's share and summing up the shares within each NUTS2 regions.

Examples for a day in winter are given in Figure 54, showing particularly temperature differences between northern and southern countries, but also slight differences within cuntries.

[18] CORINE Land Cover was initiated by the EU as an inventory of land cover classes and is now organized by the European Environment Agency (see https://www.eea.europa.eu/publications/COR0-landcover)

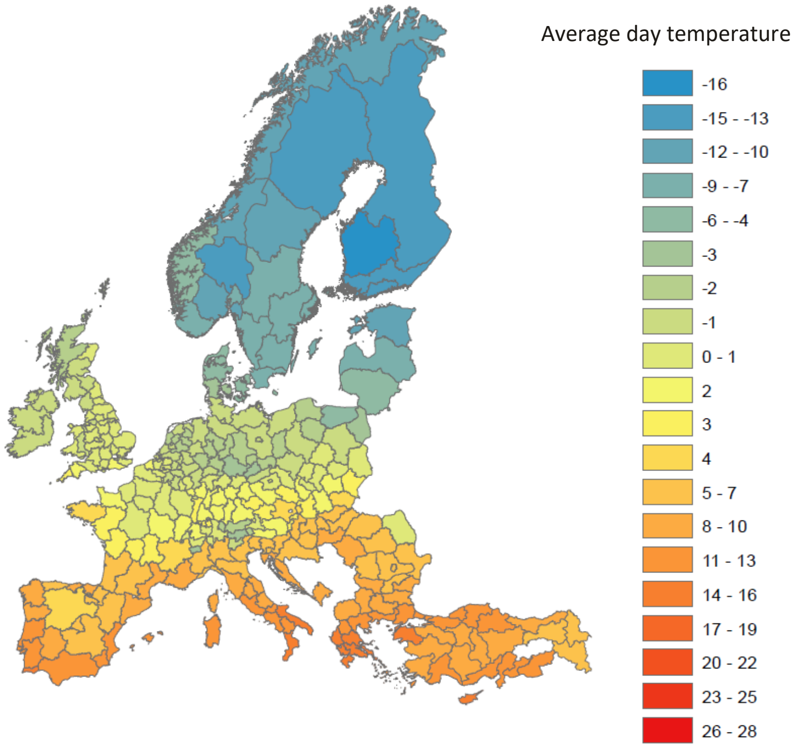


Figure 54. Average outdoor temperature on 1st Janurary 2010 of settlement areas mapped to NUTS2 level.

2.7.2. Residential sector profiles

The residential H&C demand profiles are based on typical day profiles adapted to reflect the behaviour in the different EU countries. The typical day profiles are assembled to a yearlong profile considering the regional temperature as well as the structure of days in the year and national holidays.

2.7.2.1. Preparation of typical day profiles

Residential useful energy demand for heating

Space heating: Mainly temperature dependent

The hourly structure of heat demand for SH is mainly dependent on the outside temperature. Since only daily average temperature values are available from the E-OBS database, we use hourly demand profiles for each temperature level to reflect the diurnal variation of the SH demand. Figure 55 shows the applied space heating profile. The profile originates from the German standard load profile for HPs[19].

[19] Munich City Utilities, Synthetic load profile heat pump, 2012 https://www.swm-infrastruktur.de/strom/netzzugang/bedingungen/waermepumpe.html

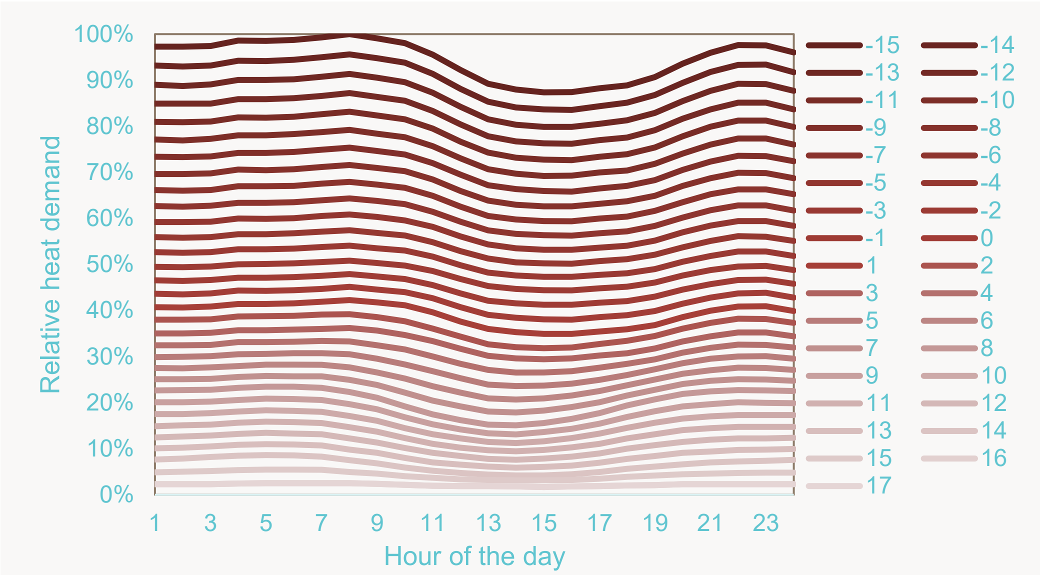


Figure 55. Temperature dependent space heating profile. Source: own calculation based on standard load profile heat pumps.[20]

Hot water: Mainly behaviour dependent

Relative to the heat demand for SH, the demand for DHW varies only little between different temperature levels, as it mainly depends on the consumers' behaviour. Thus, the UED for heating profiles are distinguished between typical days, i.e. between nine different day types (weekday / weekend x summer / transition / winter). Figure 56 depicts the applied demand profile for hot water in Germany. The profile is a synthetic direct electric heating profile that reflects the active hours, which differ between working days and weekend days.

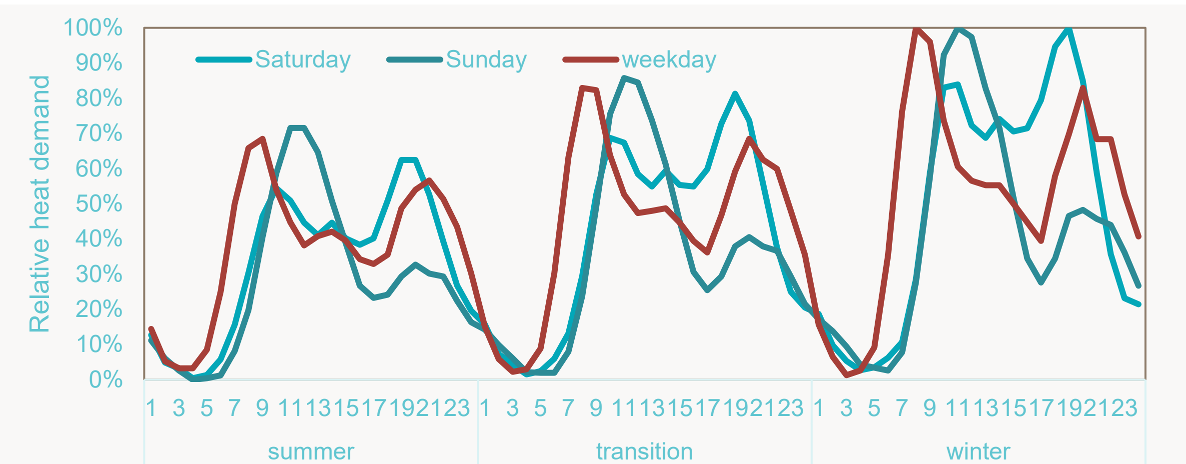


Figure 56. Useful energy demand for domestic hot water profile for typical days. Source: own calculations based on data from Germany

---

[20] Munich City Utilities, Synthetic load profile heat pump, 2012 https://www.swm-infrastruktur.de/strom/netzzugang/bedingungen/waermepumpe.html

Since the UED for DHW depends strongly on behaviour, the demand profile is adjusted for the different EU countries. Based on the findings in the harmonized European time use survey (HETUS[21]), the EU28 countries are classified in four different groups (see Table 28). We compared the activity levels for "main and second job" on weekdays and "sleep" on weekend days in order to shift the SHW profile from Germany in time so it matches the behaviour in other EU countries. In general, people in southern EU countries sleep and work later (the profile is shifted by +1 and +2 hours), while eastern EU countries show similar working hours but get up earlier on weekend (we) days (the profile is shifted only on weekend days by -1 hour).

Table 28. Classification of the European Union countries according to their activity behaviour relative to Germany. In bold, countries for which harmonised European time use surveys data is available.

Group	Countries
+2h	Cyprus, Greece, Portugal, **Spain**
+1h	**Belgium**, **Estonia**, Ireland, **Italy**, **Latvia**, Malta, **France, UK**
+/-0h	Austria, Denmark, **Finland**, **Germany**, Luxembourg, Netherlands, **Sweden**
-1h (we)	**Bulgaria**, Croatia, Czech Republic, Hungary, **Lithuania**, **Poland**, Slovakia, **Slovenia**, Romania

Relation of SH to DHW demand

The relation of UED for SH to DHW differs between individual countries: countries with a relatively warm climate, such as Portugal or Cyprus, show less demand for SH compared to DHW, countries with a colder climate, e.g. Finland, or with less building insulation feature a much higher UED for SH. Consequently, the UED for DHW is small in comparison. Figure 57 depicts the shares of SH and DHW in the FEC for residential heating purposes.

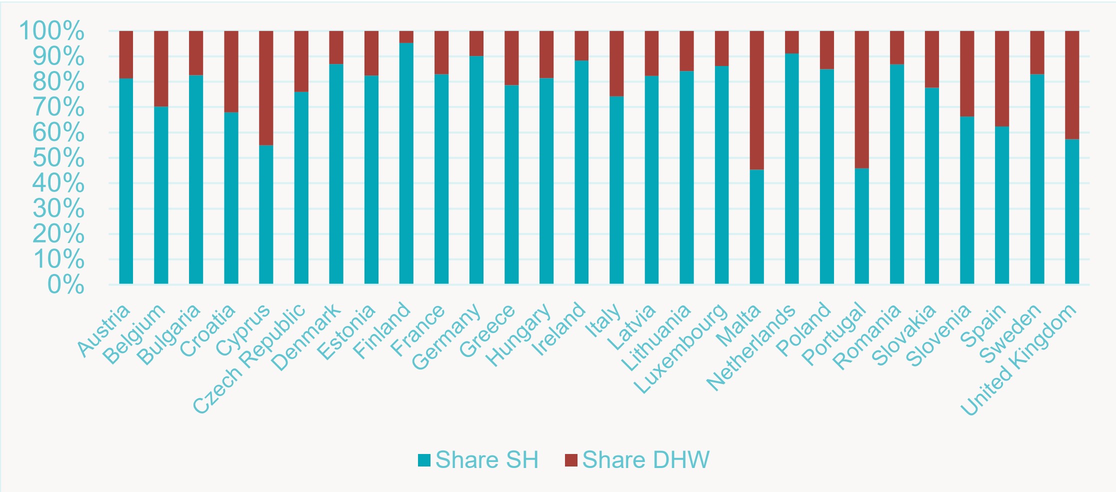


Figure 57. Share of space heating and domestic hot water in the European Union 28. Source: Hotmaps WP2

[21] The "Harmonised European Time Use Surveys" is a publication by Eurostat collecting data regarding living and working behavior in 15 European countries. For this study, data from the year 2009 is used. For more information we refer to http://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/KS-RA-08-014

Residential UED for cooling

Similar to the residential UED for heating, the hourly structure of UED for cooling is mainly dependent on the outside temperature. Since only daily average temperature values are available from the E-OBS database, we use hourly demand profiles for each temperature level to reflect the diurnal variation of UED for SC. Figure 58 shows the applied cooling profile. The synthetic profile originates from Germany.

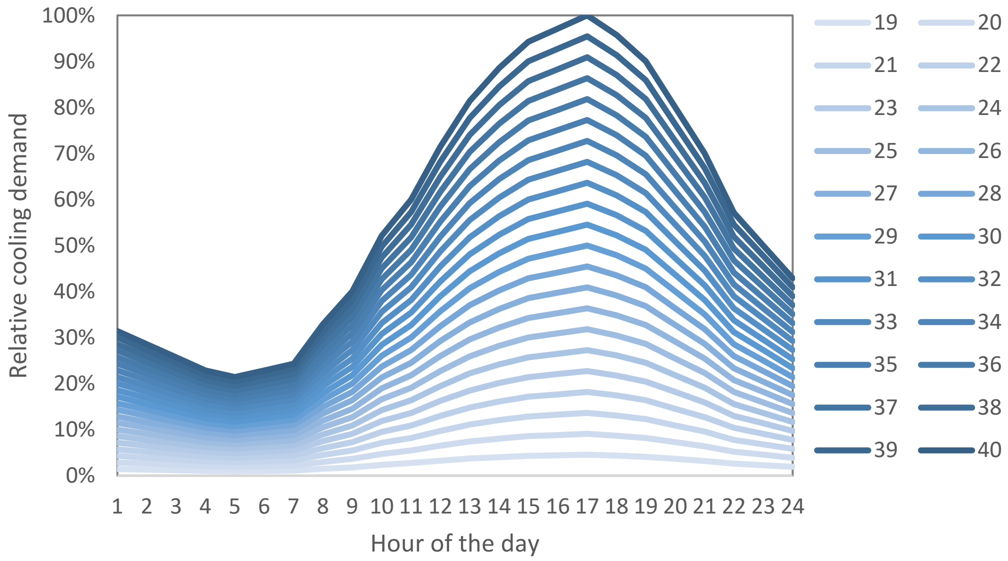


Figure 58. Temperature dependent cooling profile. Source: Own calculations based on data from Germany

2.7.2.2. Assembling of yearlong profiles

In a last step, the typical day profiles are assembled to yearlong profiles according to the time series of daily average temperature and the structure of days in the year, i.e. the distribution of Saturdays, Sundays and country-specific national holidays.

Following the steps described above, temperature profiles and FEC profiles are shifted with regard to regional behaviour, and are assembled to yearlong profiles for the year 2010.

2.7.2.3. Missing data

Unfortunately, the dataset used to produce temperature profiles for every NUTS2 region does not cover all islands and autonomous regions, which are part of the EU28 as well as some regions in Greece. Missing regions are given in Table 29. For these regions, no heat load profiles is generated.

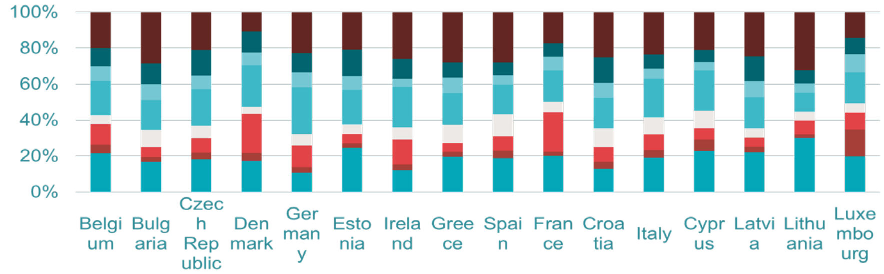
Table 29. NUTS-2 regions in the European Union 28, for which temperature data is not provided.

FRA2	Martinique
ES64	Ciudad Autonoma de Melilla
MT00	Malta
PT20	Regiao Autonoma dos Açores
ES63	Ciudad Autonoma de Ceuta
PT30	Regiao Autonoma da Madeira
EL62	Ionia Nisia
EL65	Peloponnisos
EL30	Attiki
EL41	Voreio Aigaio
EL43	Kriti
ITG1	Sicilia
FRA4	La Reunion
FRA5	Mayotte
FRA1	Guadeloupe
FRA3	Guyane

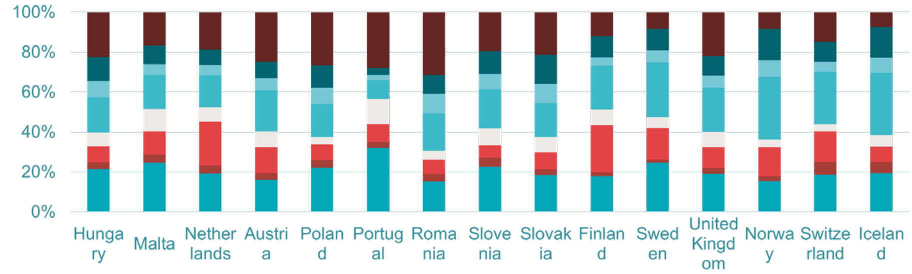
2.7.3. Tertiary sector profiles

The profiles for the tertiary sector are created in accordance to the above described methodology for the residential sector. Further, the methodology is extented to account for the tertiary sector's specific differences.

Analogous to the residential sector we distinguish between the same three profile types pt. One profile type represents UED for DHW pt_{DHW}, the second type represents SH profiles pt_{SH} and the third type of profiles represents UED for cooling pt_{CD} for the tertiary sector of each country c of the EU28. However, unlike the profiles for the residential sector, profiles of type pt_{SH} and pt_{CD} differ between the subsector sub and therefore the sector's profiles are adjusted regarding the energy share of each subsector in each country $es_{sub,c}$. The energy shares for SH of each subsector and country are depicted in Figure 59. The energy shares for cooling are depicted in Figure 60.

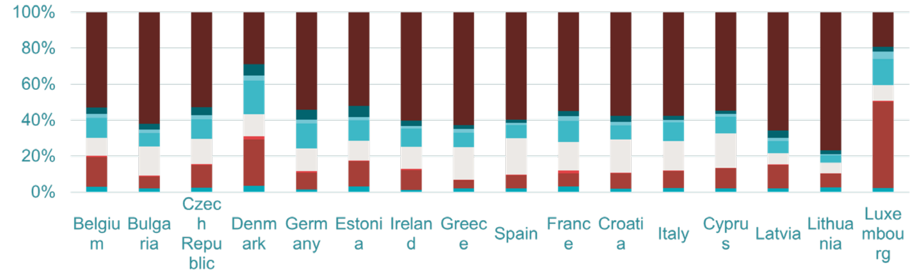


	Belgium	Bulgaria	Czech Republic	Denmark	Germany	Estonia	Ireland	Greece	Spain	France	Croatia	Italy	Cyprus	Latvia	Lithuania	Luxembourg
Wholesale and retail trade	20%	29%	21%	11%	23%	21%	26%	28%	28%	17%	25%	24%	21%	25%	32%	14%
Traffic and data transmission	10%	11%	14%	12%	11%	15%	11%	9%	7%	7%	14%	8%	7%	14%	8%	9%
Public offices	8%	9%	8%	7%	8%	8%	5%	8%	6%	8%	8%	5%	5%	9%	5%	10%
Other services	19%	17%	20%	23%	26%	19%	22%	18%	16%	17%	17%	22%	22%	17%	10%	17%
Hotels, cafes, restaurants	5%	10%	7%	4%	6%	5%	7%	10%	12%	6%	10%	9%	10%	5%	5%	5%
Health	12%	6%	8%	22%	12%	5%	14%	5%	8%	22%	8%	9%	6%	5%	8%	9%
Finance	5%	3%	4%	4%	3%	2%	3%	3%	4%	2%	4%	4%	6%	3%	2%	15%
Education	22%	17%	18%	17%	11%	25%	12%	20%	19%	20%	13%	19%	23%	22%	30%	20%

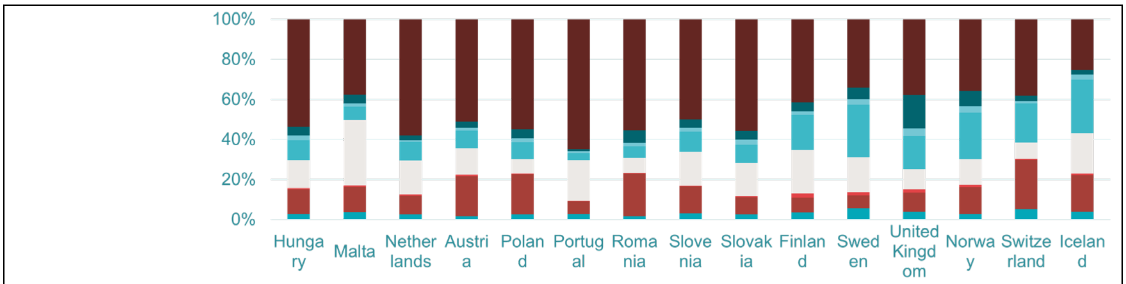


	Hungary	Malta	Netherlands	Austria	Poland	Portugal	Romania	Slovenia	Slovakia	Finland	Sweden	United Kingdom	Norway	Switzerland	Iceland
Wholesale and retail trade	22%	17%	19%	25%	26%	28%	31%	19%	21%	12%	8%	22%	8%	15%	7%
Traffic and data transmission	12%	9%	8%	8%	11%	3%	9%	11%	15%	10%	11%	10%	16%	10%	15%
Public offices	8%	5%	5%	6%	8%	3%	10%	8%	10%	4%	6%	6%	8%	5%	8%
Other services	17%	17%	16%	20%	16%	10%	19%	19%	17%	22%	27%	22%	31%	26%	31%
Hotels, cafes, restaurants	7%	11%	7%	8%	4%	13%	4%	9%	8%	8%	5%	8%	4%	4%	6%
Health	8%	12%	22%	13%	8%	9%	7%	6%	8%	23%	16%	10%	15%	15%	8%
Finance	3%	4%	4%	4%	4%	3%	4%	5%	3%	2%	2%	3%	2%	6%	5%
Education	22%	25%	19%	16%	22%	32%	15%	23%	18%	18%	25%	19%	15%	19%	20%

Figure 59. Energy shares of the useful energy demand for space heating of each subsectors and country.



	Belgium	Bulgaria	Czech Republic	Denmark	Germany	Estonia	Ireland	Greece	Spain	France	Croatia	Italy	Cyprus	Latvia	Lithuania	Luxembourg
Wholesale and retail trade	53%	62%	53%	29%	54%	52%	60%	63%	60%	55%	58%	58%	55%	66%	77%	19%
Traffic and data transmission	4%	3%	5%	6%	5%	6%	3%	2%	2%	3%	3%	2%	2%	4%	2%	3%
Public offices	2%	2%	2%	3%	2%	2%	1%	2%	1%	3%	2%	1%	2%	2%	1%	4%
Other services	11%	7%	11%	19%	14%	11%	10%	8%	7%	12%	8%	10%	9%	7%	4%	15%
Hotels, cafes, restaurants	10%	16%	14%	12%	13%	11%	12%	18%	20%	16%	18%	16%	19%	6%	6%	9%
Health	1%	0%	0%	2%	1%	0%	1%	0%	0%	2%	0%	0%	0%	0%	0%	0%
Finance	17%	7%	13%	26%	9%	14%	11%	5%	7%	7%	9%	9%	11%	13%	8%	48%
Education	3%	2%	2%	4%	1%	3%	1%	2%	2%	3%	2%	2%	2%	2%	3%	2%



	Hungary	Malta	Netherlands	Austria	Poland	Portugal	Romania	Slovenia	Slovakia	Finland	Sweden	United Kingdom	Norway	Switzerland	Iceland
Wholesale and retail trade	54%	38%	58%	51%	55%	65%	55%	50%	56%	42%	34%	38%	36%	38%	25%
Traffic and data transmission	4%	4%	2%	3%	4%	1%	6%	4%	4%	4%	6%	17%	8%	3%	2%
Public offices	2%	2%	1%	1%	2%	1%	2%	2%	3%	2%	3%	4%	3%	1%	3%
Other services	10%	7%	9%	9%	8%	4%	6%	10%	9%	17%	26%	17%	23%	20%	27%
Hotels, cafes, restaurants	14%	32%	17%	13%	7%	20%	7%	17%	16%	22%	18%	10%	13%	8%	20%
Health	0%	1%	1%	1%	0%	0%	0%	0%	0%	2%	2%	2%	1%	1%	1%
Finance	12%	13%	9%	20%	20%	6%	21%	13%	9%	7%	6%	10%	13%	25%	18%
Education	3%	4%	3%	2%	3%	3%	2%	3%	3%	4%	6%	4%	3%	5%	4%

Figure 60. Energy shares of useful energy demand for space cooling of each subsector and country.

To obtain country specific profiles of type pt_{SH} and pt_{CD} we rate subsector specific profiles with the country's energy share of each subsector . The result is a country specific profile for the complete tertiary sector $p_{ter,c}$ – see equation (8).

$$for\ each\ c: p_{ter,c} = \sum_{sub} e_{sub,c} \cdot p_{sub} \tag{8}$$

The subsector specific cooling and SC demand profiles p_{sub} originate from a German data set.

We also perform a temperature dependency on these profiles. All profiles $p_{ter,c}$ of type pt_{SH} are multiplied with each temperature level tl of the heat pump profile $p(tl)$ of section 2.7.2.1. Analogous we multiply all profiles $p_{ter,c}$ of type pt_{CD} with profiles of the different tl for the cooling demand $p(tl)$ – see equation (9).

$$for\ each\ p_{ter,c}\ and\ each\ tl: p_{ter,c}(tl) = p_{ter,c} \cdot p(tl) \tag{9}$$

Next, a time shift for all profile types (pt_{SHW}, pt_{SH} and pt_{CD}) is performed. We use the country specific activity patterns from Table 28. The methodology is summarized in Figure 61.

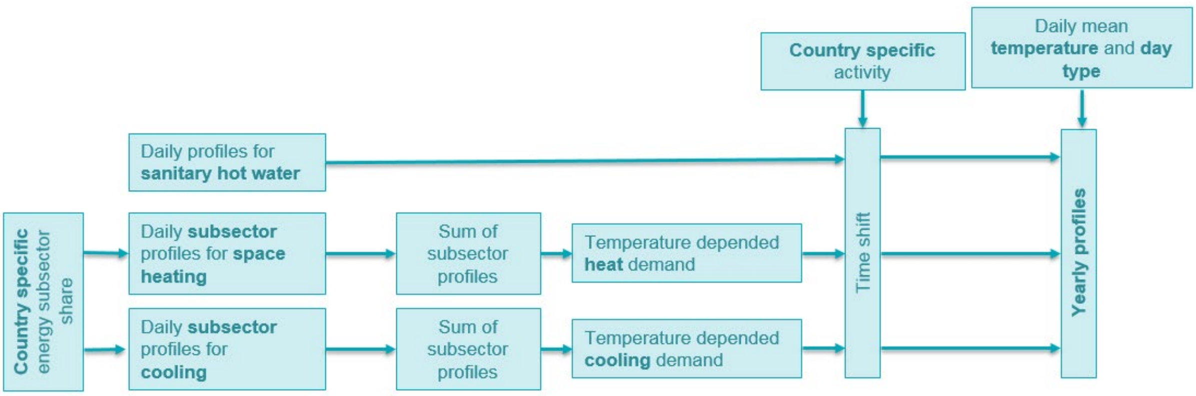


Figure 61. Overview of the methodology for generating profiles for the tertiary sector.

Normalized profiles for the summer, transition and winter season are shown in Figure 62 for a German (DE), a Spanish (ES) and an Irish region (IE).

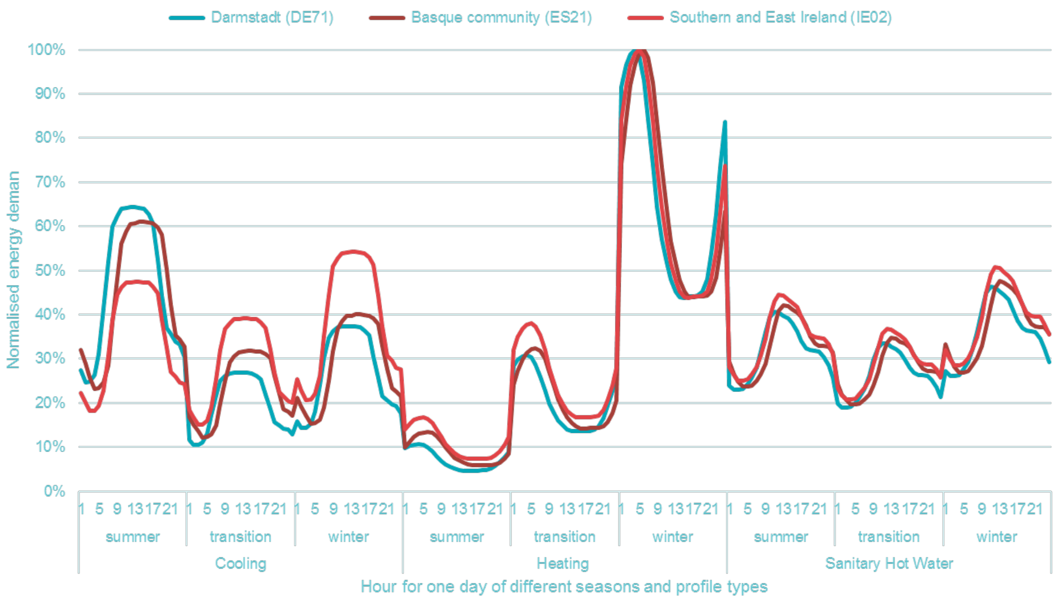


Figure 62. Normalized load curve for heating, cooling and domestic hot water for the tertiary sector, the NUTS-2 regions Darmstadt (DE), Basque (ES) community and Southern and East Ireland (IE).

2.7.4. Industry sector profiles

2.7.4.1. Methodological overview

In contrast to the residential and tertiary sector, the main contribution to total UED for heating in the industry sector is process heat [151-152]. Here, individual process and production output and process-specific parameters are more important than external, country dependent factors like outdoor temperatures. Thus, we use a different approach to model industrial H&C profiles: we model industrial processes individually. Due to high UED for steel, paper, minerals, cement, chemical products and food we focus on the following five industrial subsectors [153]:

- Iron and Steel
- Pulp and Paper
- Non-Metallic Minerals
- Chemical and Petrochemical Products
- Food, Beverages and Tobacco

Each resulting profile, from the here developed methodology, represents the total process UED for heat of the respective industry (there is no differentiation regarding temperature levels).

Country-dependent differences are taken into account by considering the total UED for heat per year, distinguished by industry and particularly monthly production. Nevertheless, the developed methodology allows considering region-specific impact factors for industrial profiles by connecting the profiles with available regional information (this has not been done yet, but could be done by the user).

2.7.4.2. General approach

In order to generate profiles with hourly resolution, we combine data on a yearly, seasonal, quarterly and monthly basis. We use the data to derive a month-season-factor, a type of week, and a type of day factor:

- Month-factors: Information regarding country-specific monthly output is gathered on each of the five industrial subsectors mentioned above [154]. It is used to first extract information on quantitative differences between quarters or months, according to the precision of the input data, the so-called "month -factors".
- Type-of-day-factors: Using data on employees' labour times differences between weekdays, Saturdays and Sundays are modelled to get "type-of-day-factors" [155], [156]
- Intra-day-factors: Type-of-day-factors are combined with the month-factors to "Intra-day"-factors. Thus, 12 × 3 factors (twelve months and three types of days) are calculated. Additionally, we use labour times with information on shift work schedules to differentiate within days [155], [156]. We particularly consider information on night or evening labour and shift work patterns.

Finally, the different day-profiles are assembled to a yearlong profile, considering the daily structure of the year. The yearly profile is smoothed to prevent sharp edges.

Figure 63 shows normalized profiles for five energy intensive industrial subsectors. Here, mean values for all days in one month are depicted, showing subsector-specific heat demand over the course of a year and within a day. In Figure 63 no distinction between weekdays and weekends is made. this is however considered in the profiles, which are part of the corresponding dataset.

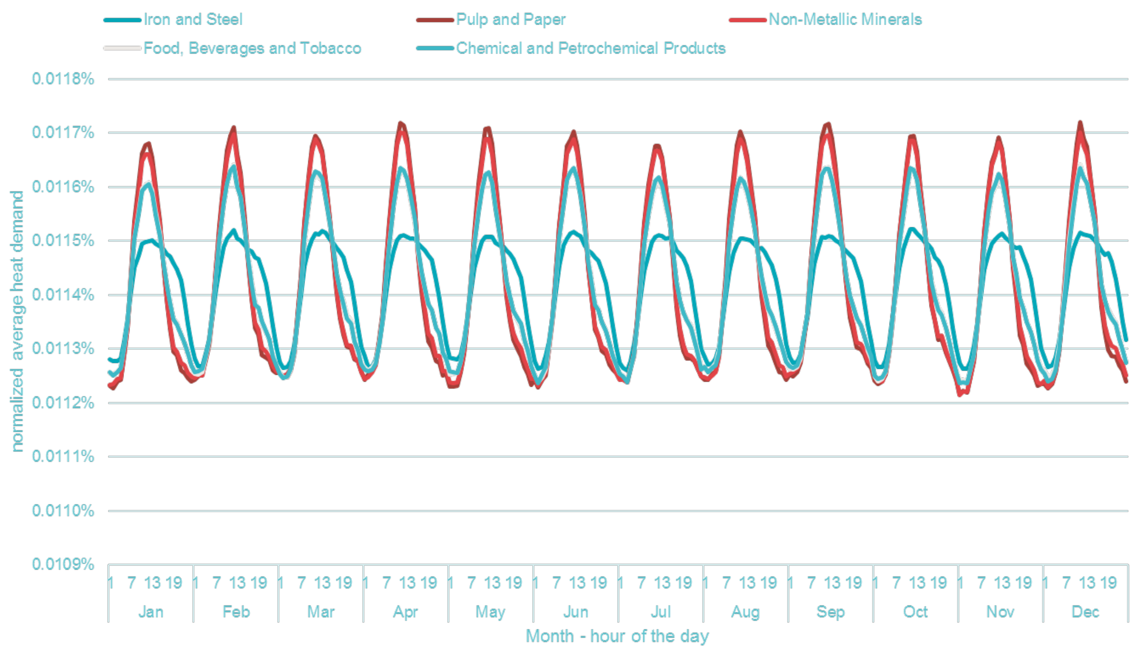


Figure 63. Daily mean useful energy demand per month for energy intensive industrial subsectors (normalised).

An overview of the different conversion steps is presented in Figure 64.

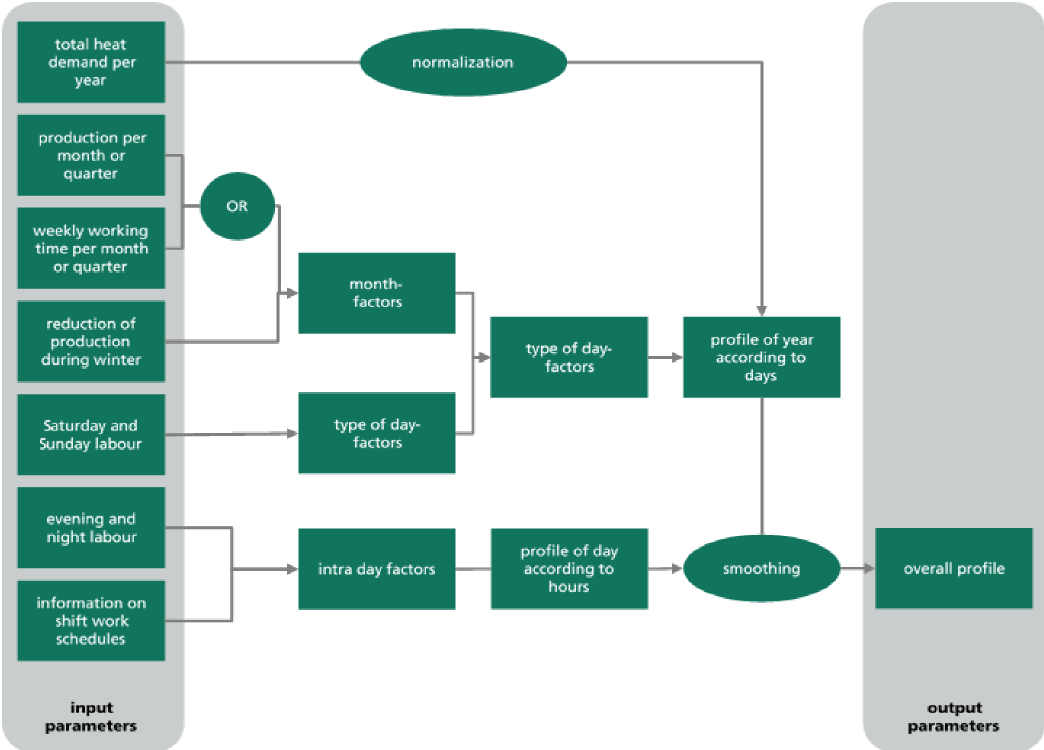


Figure 64. Flowchart visualizing steps applied to model industrial profiles.

2.7.5. Limitations

The major limitation to the modelling of UED for H&C is the limited availability of empirical data for the results validation: for the residential and tertiary sector, empirical data is available for the operation of H&C appliances only for some countries. Hourly data on UED for heat of the industry sector could not be found. In this section, we therefore summarize our main assumptions, to make them as transparent as possible, and stimulate a discussion that could lead to a future improvement of the quality of the data set.

We use geo-coded information to assign profiles for the heat UED of the residential, tertiary and industrial sector. We assume that the H&C UED for the residential and tertiary sector strongly depends on outdoor temperature, while UED for the industry sector depends on industrial processes. Within our model, these factors have a strong impact on the resulting profiles.

The H&C UED profiles for the household and tertiary sector for each region are based on profiles that originate from German data. We modify these profiles based on activity patterns and daily mean temperatures, but the general shape of the profiles is maintained. While this approach ensures consistency over all NUTS2 regions, we neglect the impact on the profile shape due to more specific differences in H&C behaviour.

For the industry sector, we focus on processes with a high UED. To which extent the neglected processes with a low UED impact the profile shape/structure is unknown. Further, we modify the profile shape based on working times in the subsectors. This means, a dependency between the working hours and the UED is assumed. Table 30 gives an indication on spatial and temporal characteristics of the profiles we produced within this work package. We consider the temporal resolution (hourly) to be high, while spatial extent is limited, as all profiles are based on German load profiles. The spatial resolution for household and tertiary sector profiles is NUTS2, while industrial profiles are modelled on NUTS0 level.

Table 30. Qualitative assessment of the input data quality.

	Spatial resolution	Spatial extent	Temporal resolution	Consistency	Measure type
Household profiles	medium	low	high	high	modelled
Tertiary sector profiles	medium	low	high	high	modelled
Industrial profiles	low	low	high	high	modelled

2.8. Electricity system module

Within Task *2.8 Electricity system module* the following three data sets were developed and provided for the Hotmaps toolbox.

Table 31. Characteristics of data provided within Task 2.8 Electricity system module. The database of given task is available at: https://gitlab.com/hotmaps/load_electricity

Data set name	Space resolution	Time resolution	Source	Link on gitlab
Electricity_prices_2015	NUTS0	hourly	[5]	https://gitlab.com/hotmaps/load_electricity/electricity_prices_hourly
Emissions_hourly	NUTS0	hourly	[157]	https://gitlab.com/hotmaps/load_electricity/electricity_emissions_hourly
Electricity_generation_yearly	NUTS0	yearly	[157]	https://gitlab.com/hotmaps/load_electricity/electricity_generation_yearly

The data will be used to assign each location in the Hotmaps toolbox with an electricity market region to reflect the situation on the electricity sector in the regions of interest. The data will be used by several calculation models in the Hotmaps toolbox to derive costs, primary energy demand and resulting CO_2 emissions of electric heating systems like HPs and direct electric heaters. All data sets are based on data from the year 2015 using the ENTSO-E Transparency platform [5] as main data source.

2.8.1. Methodology

The following section provides a brief overview of the methodology for deriving a complete default data set for the annual electricity generation mix of MSs, CO_2 emission factors and hourly electricity prices for Hotmaps.

2.8.1.1. Electricity generation mix

The ENTSO-E power statistics platform [158] provides the annual generation mix for each MS per energy carrier. The monthly electricity generation by source has been downloaded for all countries included in the Hotmaps toolbox (see [158]). It should be noted that the electricity generation data per country are only an indicator for the primary energy demand induced by consumption of electricity within a country as imports and exports are not considered in this indicator. Furthermore, the datasets only show electricity output by source and not the primary energy carriers used to generate electricity. The generation mix included in the dataset is based on generation data for the year 2015.

2.8.1.2. CO_2 emission factors

From the monthly (m) electricity generation data downloaded from ENTSO-E described above CO_2 emission factors ($f_{c,m}$) were derived for each country (c). For each energy carrier (ec) an emission factor (em_{ec}) and average conversion efficiency (η_{ec}) was assumed to derive CO_2 emissions from monthly electricity generation ($\mathrm{q}_{ec,m}$) per energy carrier using the following relationship – see equation (10):

$$f_{c,m} = \frac{\sum_{ec=1}^{EC} \frac{\mathrm{q}_{ec,m}\mathrm{em}_{ec}}{\eta_{ec}}}{\sum_{ec=1}^{EC} \mathrm{q}_{ec,m}} \tag{10}$$

Emission factors for energy carriers and conversion efficiencies of power plants for each energy carrier were assumed to be uniform over all countries and are given in the following table.

Table 32. Assumed efficiency of power plants and emission factors of energy carriers.

Energy carrier	Efficiency η_{ec} [-]	Emission factor em_{ec} [t_{CO2}/MWh_prim]
Lignite	0.35	0.407
Hard coal	0.39	0.337
Natural gas	0.51	0.201
Fuel oil	0.4	0.3
Other fossil fuels	0.4	0.3

Monthly emission factors are transformed into hourly emission factors assuming constant emission factors for each hour within a month.

2.8.1.3. Electricity prices

The data set on hourly electricity prices represents day-ahead prices for the year 2015. As within the Hotmaps toolbox typical years are used for most calculation models the data set is based on an index representing the hours of the year [1, 2 until 8760]. The time series is based on the Central European Time (CET) with hour #1 representing the first hour of the year in CET (01.01.2015 00:00 to 01:00). Hours where no value was available were replaced with prices from the same hour of the following day or the corresponding hour of the next day where data was available. All prices are given in €/MWh. As day ahead prices were not available for all countries covered by the Hotmaps toolbox, reference countries were used for those missing time series. Table 33 provides an overview of electricity price data availability on the ENTSO-E Transparency platform for day ahead prices of the year 2015. In countries with multiple price zones the price zones in which the capital city is located was chosen for the default data base in Hotmaps.

Table 33. Overview of data availability and applied reference countries for day ahead prices for the data set.

Country	Data availability	Reference country	Source
AT	Yes		ENTSO-E Transparency
BE	Yes		ENTSO-E Transparency
BG	No	RO	ENTSO-E Transparency
CY	No	IT (Sicily)	ENTSO-E Transparency
CZ	No	DE	ENTSO-E Transparency
DE	Yes		ENTSO-E Transparency
DK	Yes		ENTSO-E Transparency
EE	No	LT	ENTSO-E Transparency
ES	Yes		ENTSO-E Transparency
FI	Yes		ENTSO-E Transparency
FR	Yes		ENTSO-E Transparency
GR	Yes		ENTSO-E Transparency
HR	No	IT	ENTSO-E Transparency
HU	Yes		ENTSO-E Transparency
IE	No	IE	ENTSO-E Transparency
IT	Yes		ENTSO-E Transparency
LA	No	LT	ENTSO-E Transparency
LT	Yes		ENTSO-E Transparency
LU	Yes		ENTSO-E Transparency
MT	No	IT (Sicily)	ENTSO-E Transparency
NL	Yes		ENTSO-E Transparency
PL	Yes		ENTSO-E Transparency
PT	Yes		ENTSO-E Transparency
RO	Yes		ENTSO-E Transparency
SE	Yes		ENTSO-E Transparency
SI	Yes		ENTSO-E Transparency
SK	No	DE	ENTSO-E Transparency
UK	Yes		ENTSO-E Transparency

2.8.2. Main results

The following section provides an overview of the content of each data set created in Task 2.8.

2.8.2.1. Electricity generation mix

Table 34 shows annual electricity generation data in GWh per year and energy carrier. Figure 65 illustrates the shares of each energy carrier based on the data set, which is integrated in the Hotmaps toolbox. It can be clearly seen that the generation mix and renewable shares deviate significantly between the regions. The data will be used to estimate the environmental impact of electrical heating systems within the Hotmaps toolbox.

Table 34. Electricity generation by energy carrier in 2015 [GWh].

	Nuclear	Lignite	Hard coal	Natural gas	Oil	Other fossil fuels	Biomass	Hydro	Wind	PV	No information on source
AT	0	0	2972	7536	854	0	0	36240	3989	0	7755
BE	24572	0	4016	20835	101	0	2794	1367	5380	3038	175
BG	14305	18772	966	1321	0	0	193	6155	1436	1371	0
CH	22095	0	0	0	0	0	0	39554	132	0	0
CY	0	0	0	0	4174	0	0	0	231	0	0
CZ	25340	32238	4825	4902	41	0	1893	2963	563	2223	0
DE	86767	143068	107131	53155	5245	10876	38465	23657	75680	35150	0
DK	0	0	6911	3514	81	0	2345	20	14086	593	0
EE	0	0	0	0	0	0	757	28	696	0	0
ES	54755	4459	48581	48594	13005	0	4636	30813	48107	13305	1265
FI	22323	0	5518	5034	184	2719	10685	16586	2329	0	779
FR	416796	0	8605	22082	3375	0	7878	58724	21067	7432	0
GB	65681	0	84756	84613	11	0	0	7973	23963	0	1427
GR	0	19417	0	7269	0	0	221	6099	3744	3573	0
HR	0	0	2096	808	41	221	0	5657	788	0	0
HU	14861	5493	492	3160	49	0	1642	227	670	13	0
IE	0	2522	4843	11483	32	0	0	1086	6536	0	0
IS	0	0	0	0	2	0	0	13670	11	0	0
IT	0	0	38380	91451	4163	28010	18805	44562	14706	23913	0
LT	0	0	0	1469	0	590	385	1013	805	73	0
LU	0	0	0	807	0	0	52	1533	95	98	87
LV	0	0	0	2031	0	615	360	1860	146	0	0
NL	4034	0	0	0	0	0	4002	108	7134	95	0
NO	0	0	0	3491	0	0	0	139014	2515	0	0
PL	0	48987	68443	4059	0	0	6682	2459	10365	44	0
PT	0	0	13679	9806	99	0	2632	9614	11336	759	0
RO	10695	14467	1740	4496	0	4260	522	16545	6993	1982	0
SE	54347	0	518	1015	146	1001	9805	73972	16618	0	0
SI	5361	3806	0	6	0	0	155	4060	4	245	140
SK	14103	1635	878	1781	267	0	1103	4280	6	549	58

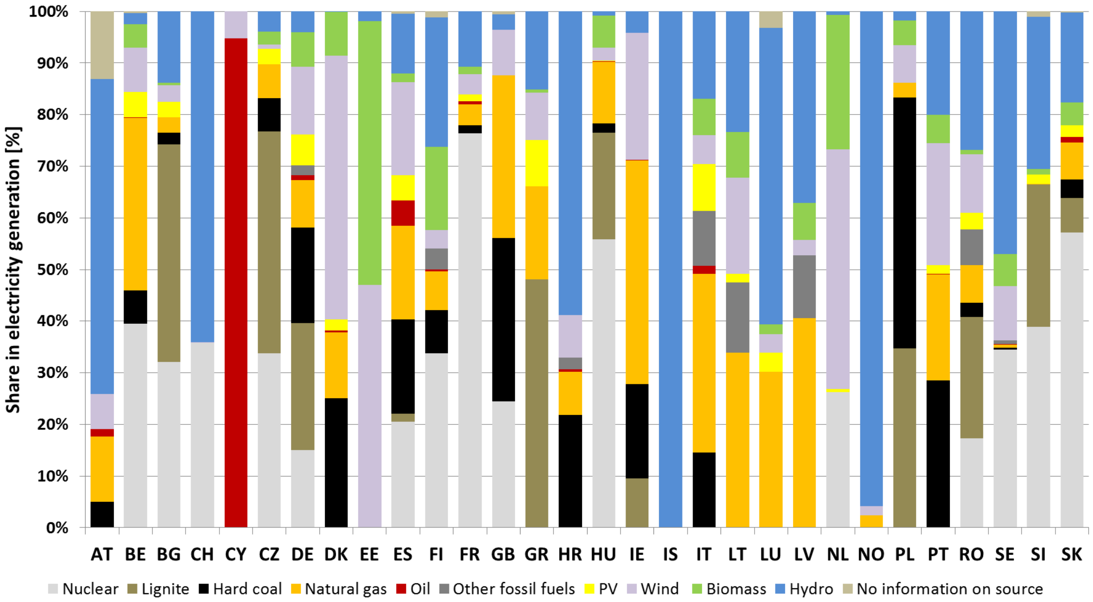


Figure 65. Electricity generation mix per country in the year 2015. Source: [158]

Figure 66 shows the generation mix for all EU28 MSs, Switzerland, Island and Norway. It can be seen that the overall electricity mix is dominated by nuclear energy (around 27%) and fossil fuel (around 38%) while renewables make up for the remaining 35% of electricity generation with electricity from hydro being the main renewable electricity source in 2015.

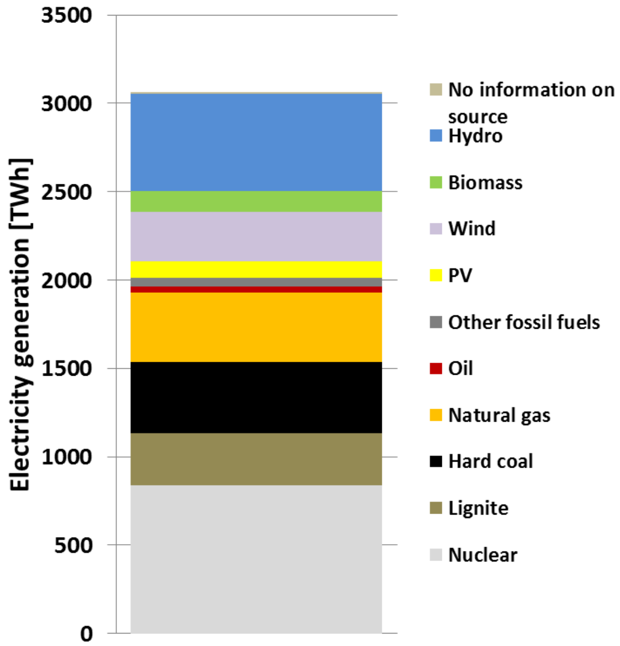


Figure 66. Electricity generation mix European Union 28+CH+IS+NO in the year 2015. Source: [158]

2.8.2.2. CO_2 emission factors

The differences in the electricity generation mix result in significantly different CO_2 emission factors per country ranging from up to 800 kg_{CO2}/MWh electricity in countries where electricity from lignite plants make up for high shares of electricity generation to emission factors below 50 kg_{CO2}/MWh in countries with high shares of generation from renewables or nuclear.

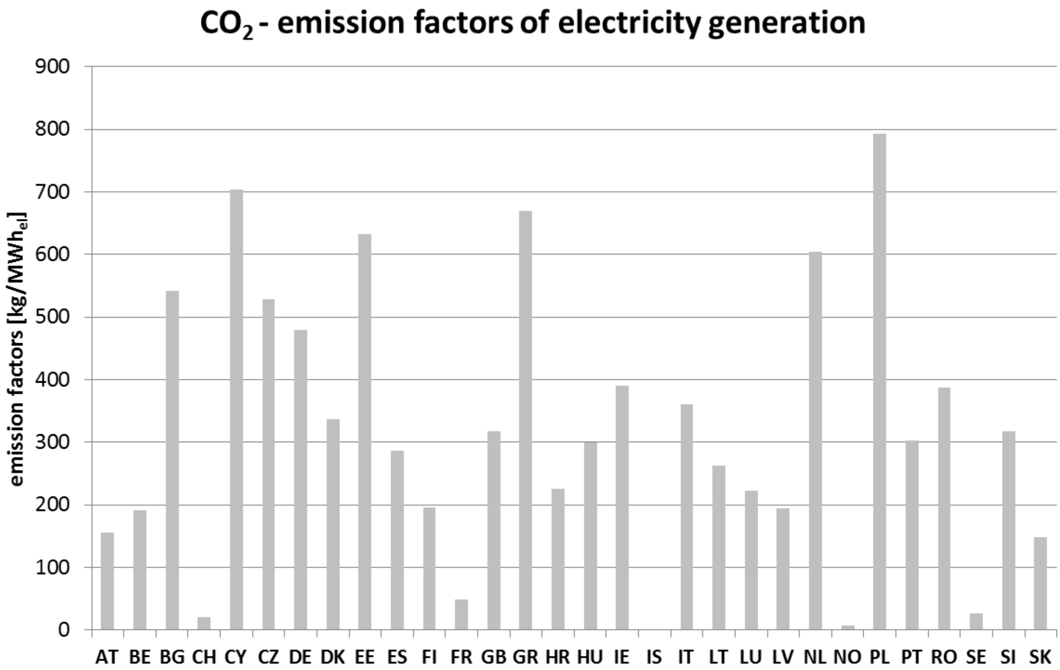


Figure 67. Annual CO2 emission factors per country. Source: own calculations based on European Network of Transmission System Operators for Electricity generation data for 2015.

Figure 68 illustrates monthly CO_2 emission factors for Austria, Germany, Denmark and Spain. These data are available for all countries but only visualized for exemplary countries in this report. It can be seen that emission factors follow a seasonal trend in some countries (e.g. Austria), while in other countries emission factors have been rather stable throughout the year 2015. Those seasonal patterns will be applied in the Hotmaps toolbox to be able to evaluate the impact of emissions of electrical H&C systems where UED also follows a seasonal pattern.

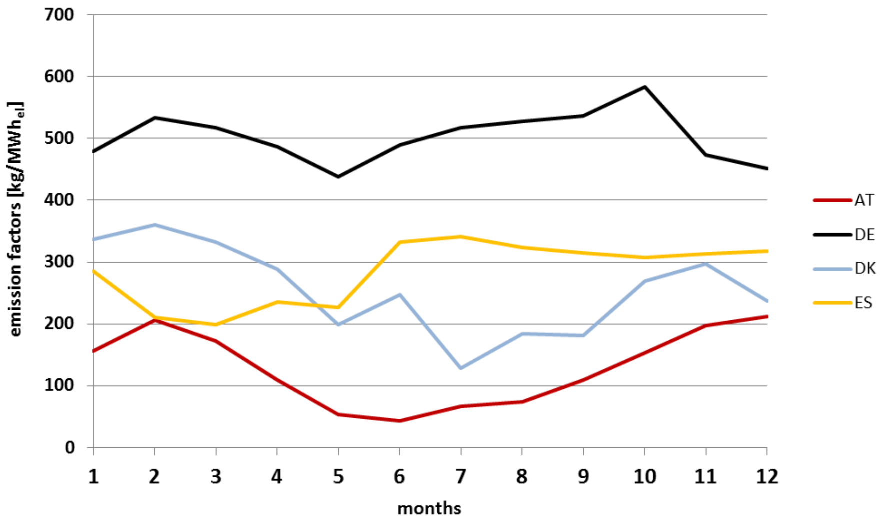


Figure 68. Monthly CO_2 emission factors for selected countries.

2.8.2.3. Electricity prices

Figure 69 illustrates hourly electricity prices for Germany and Spain throughout the year 2015. These data and illustrations will be available for all countries in the Hotmaps toolbox. The hourly prices will be used to calculate the optimal dispatch of CHPs and large scale HPs in the DH module of the Hotmaps toolbox. Hourly price patterns will also be used to estimate the optimal dispatch of demand response ready technologies for individual heating systems.

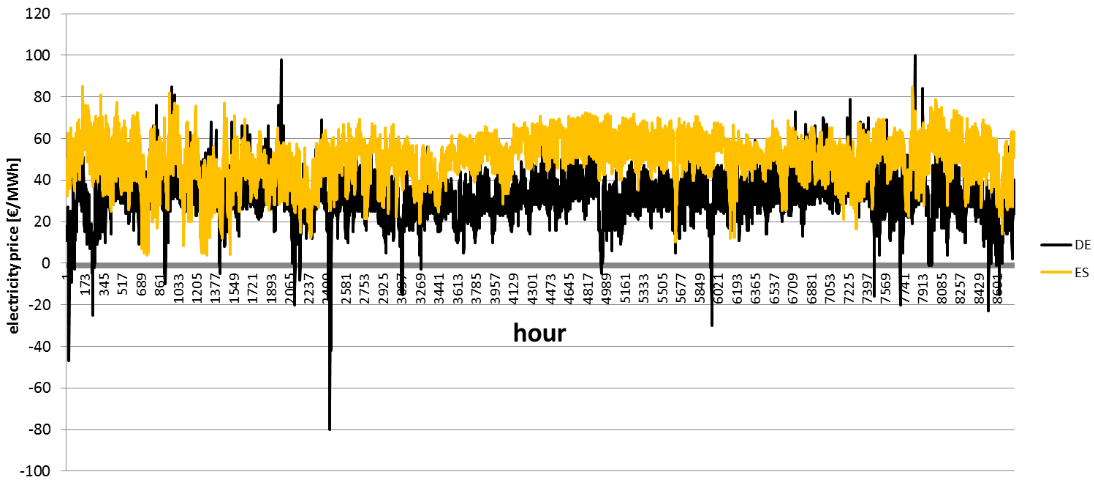


Figure 69. Hourly electricity wholesale market prices for Germany and Spain in 2015.

2.8.3. Limitations on data

The data sets provided have to be interpreted as simplified indicators to link the analysis that can be carried out within the Hotmaps toolbox with the electricity sector. It should be noted that the toolbox focuses on H&C planning and not on electricity system analysis for which the usage of more detailed data is required. The following main limitations have to be considered when interpreting the results:

Data on the electricity generation mix is only provided on an annual basis. The generation mix of individual hours can deviate significantly from the annual average mix. It also has to be noted that import and export of electricity is not considered and the data only provides information on the generation mix within country boarders.

The same applies for the data provided on emission factors. Emission factors for individual hours can deviate significantly from monthly averages in particular when cross-border electricity flows are considered. The emission factors are also based on average conversion efficiencies and average emission factors for primary energy carriers. In reality, the conversion efficiencies for individual countries can deviate significantly depending on the age of the power plant fleet within each country and on the specific energy carriers used to generate electricity.

The hourly day-ahead prices only represent wholesale market prices. Wholesale prices only account for a rather small share of end-user prices, which also include grid costs, taxes and other surcharges. This has to be considered when assessing generation costs for heating with HPs or direct electric heaters both from the perspective of households and services as well as from the perspective of DH operators. The same holds for assess the value or potential revenue of electricity generation from CHPs within the Hotmaps toolbox when using default day-ahead prices provided in the toolbox.

Wholesale prices for the countries where no price data was available might deviate significantly from the prices of the reference countries used to set up the default data on electricity prices. It also has to be noted that electricity prices depend on various exogenous parameters such as fossil fuel prices, CO_2 prices, weather year or the installed capacity of renewables, which have all been subject to rather dynamic development in recent years. Therefore, the prices provided in this data set have to be interpreted as a snapshot of the conditions in the year 2015. It is highly recommended to use additional price information and sensitivity runs when assessing technologies and costs based on electricity prices within the Hotmaps toolbox.

2.9. Transport

Within Task *2.9 Transport* following data sets were developed and provided for the Hotmaps toolbox.

Table 35. Characteristics of data provided within Task 2.9 Transport. The database of given task is available at: https://gitlab.com/hotmaps/transport

Parameters	Space resolution	Time resolution	Data sources
Vehicle stock and projections	-	yearly	[4], [7]
Final energy consumption by transport mean and activity	NUTS0	yearly	[4], [7], [159]
Electricity use for all transportation modes (rail and electrified urban transport)	georeferenced	yearly	[4], [7]
FEC for transport	georeferenced	yearly	[4], [7]

These data will be the used for the scenario development in the forthcoming work.

2.9.1. Methodology

The datasets (EU28 MSs, NUTS0) containing the time series for each parameter for the period from 1990 to 2050 were compiled based on the data as shown in Table 35. The historical data points were extrapolated based on future trends for selected indicators derived from the PRIMES –TREMOVE EU 2016 reference scenario [7] as described in [159], [160].

2.9.2. Main results (EU28)

In Figure 70 and Figure 71 the example of the data that is available in the database is shown at NUTS0 and NUTS2 level for the parameter vehicle stock.

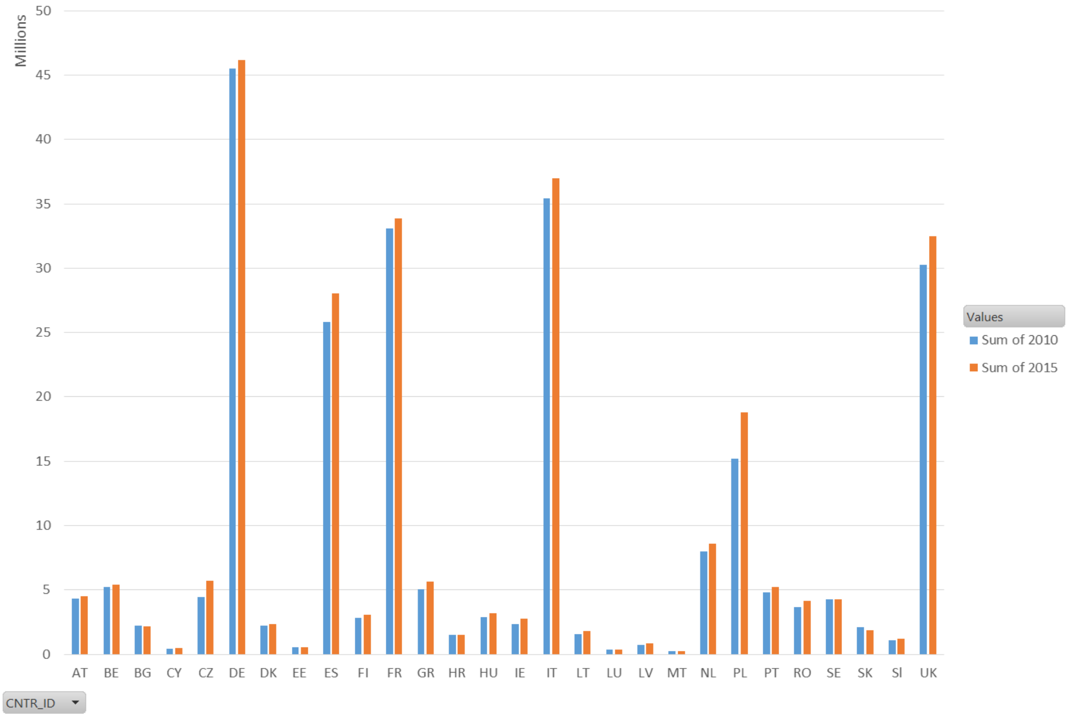


Figure 70. Passenger private vehicle stock in the European Union 28. Source: own elaboration (the y-axis displays Mil. units)

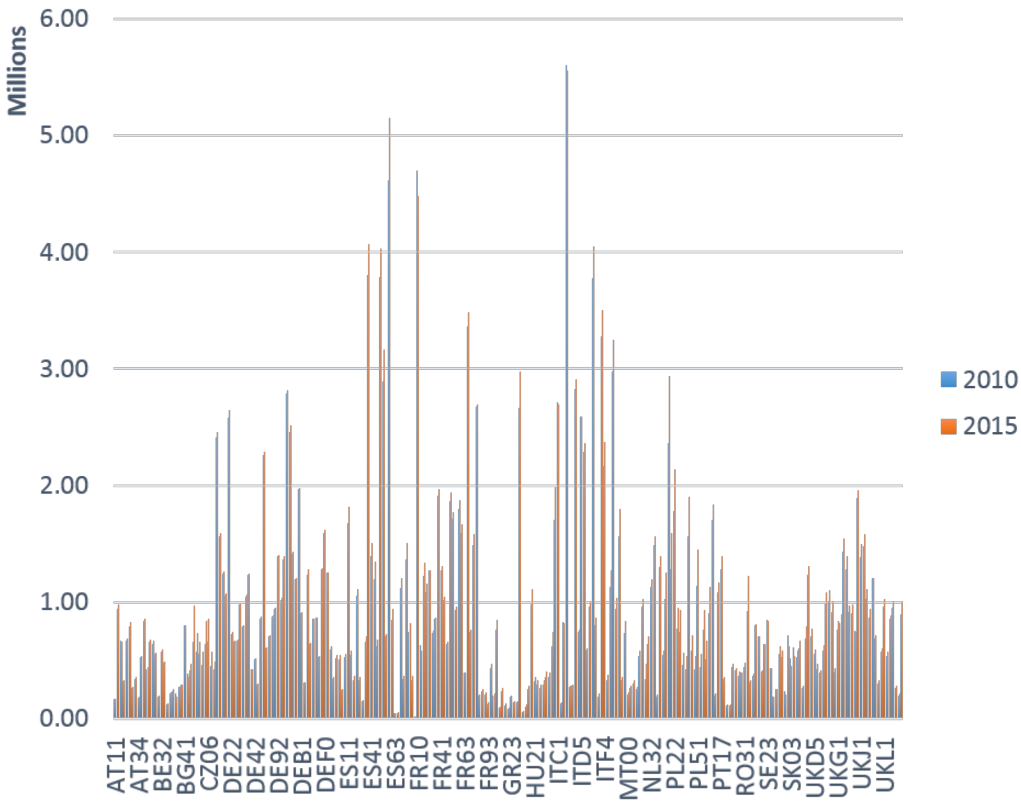


Figure 71. Passenger private vehicle stock at NUTS2 level. Source: own elaboration

2.9.3. Limits of data

As the parameters at NUTS2 datasets were extrapolated based on NUTS0 data, these data has to be treated cautiously. The data is provided at the annual basis, therefore cannot be used for the evaluation of the daily load profiles directly.

3. References

[1] European Environmental Agency, "Corine Land Cover 2006," 2016. [Online]. Available: http://ec.europa.eu/eurostat/web/population-and-housing-census/census-data/2011-census.

[2] Joint Research Center, "European Settlement Map." copernicus, 2017.

[3] "Consistency," *Cambridge Dictionary*. 2018.

[4] Eurostat, "Database Information," 2018. [Online]. Available: http://ec.europa.eu/eurostat/data/database/information.

[5] "ENTSO-E Transparency Platform," 2018. [Online]. Available: https://transparency.entsoe.eu/. [Accessed: 23-Feb-2018].

[6] Transport & Mobility Leuven, "TREMOVE economic transport and emissions model," *TREMOVE economic transport and emissions model*. [Online]. Available: http://www.tmleuven.be/methode/tremove/home.htm.

[7] European Commission, "EU Reference Scenario 2016." [Online]. Available: https://data.europa.eu/euodp/data/dataset/energy-modelling.

[8] European Statistical System, "Census Hub," 2011. [Online]. Available: http://ec.europa.eu/eurostat/web/population-and-housing-census/census-data/2011-census.

[9] Pesaresi, Martino; Ehrilch, Daniele; Florczyk, Aneta J.; Freire, Sergio; Julea, Andreea; Kemper, Thomas; Soille, Pierre; Syrris, Vasileios, "GHS built-up grid, derived from Landsat, multitemporal (1975, 1990, 2000, 2014). [Dataset]." European Commission, Joint Research Centre (JRC), 2015.

[10] Ministry of the Interior and Kingdom Relations, "Housing Statistics in the European Union 2010," OTB Research Institute for the Built Environment, Delft University of Technology, The Hague, 2010.

[11] Buildings Performance Institute Europe, *Europe's Buildings under Microscope. A country-by-country review of the energy performance of buildings.* 2011.

[12] S. Pezzutto, "Analysis of the space heating and cooling market in Europe," Doctoral Thesis, University of Natural Resources and Life Sciences, Vienna, 2014.

[13] Building Performance Institute Europe, "Data Hub for the Energy Performance of Buildings," 2015. [Online]. Available: https://www.buildingsdata.eu/.

[14] TABULA, "TABULA WebTool," 2016. [Online]. Available: http://webtool.building-typology.eu/#bm.

[15] S. Pezzutto, S. Toleikyte, and M. De Felice, "Assessment of the space heating and cooling market in the EU28: a comparison between EU15 and EU13 member states.," *Int. J. Contemp. Energy*, vol. 2, pp. 35–48, 2015.

[16] H. Mahlknecht, S. Avesani, M. Benedikter, and G. Felderer, "Refurbishment and monitoring of an historical building. A case Study.," presented at the 47°AICARR Int. Conference, Tivoli, Rome, 2009.

[17] S. Birchall, I. Wallis, D. Churcher, S. Pezzutto, R. Fedrizzi, and E. Causse, "iNSPiRe. D2.1a - Survey on the energy needs and architectural features of the EU building stock," 2014.

[18] Vienna University of Technology, "Invert/EE-Lab," 2015. [Online]. Available: http://www.invert.at/.

[19] J. Adnot, "Energy Efficiency and Certification of Central Air Conditioners (EECCAC). Final Report," Apr. 2003.

[20] S. Birchall, I. Wallis, D. Churcher, S. Pezzutto, R. Fedrizzi, and E. Causse, “iNSPiRe. D2.1a - Survey on the energy needs and architectural features of the EU building stock,” 2014.

[21] Werner, Sven, “The European Heat Market. Final Report,” Euroheat & Power, 2016.

[22] ODYSSEE-MURE, “ODYSSEE database on energy efficiency data & indicators,” 2017. [Online]. Available: http://www.indicators.odyssee-mure.eu/energy-efficiency-database.html.

[23] EU Building Stock Observatory, “EU Building Stock Observatory,” 2015. [Online]. Available: https://ec.europa.eu/energy/en/eu-buildings-database.

[24] TABULA, “TABULA WebTool,” 2016. [Online]. Available: http://webtool.building-typology.eu/#bm.

[25] EU Building Stock Observatory, “EU Buildings Database,” 2015. [Online]. Available: https://ec.europa.eu/energy/en/eu-buildings-database.

[26] L. Itard and F. Meijer, “Towards a sustainable Northern European housing stock. Figures, facts and future.,” TU Delft, 22, 2008.

[27] R. Ortlepp, K. Gruhler, G. Schiller, and C. Deilmann, “The other „half of the city“. Analysis of non-residential building stock and its materials.,” in *SASBE 2015 Proceedings*, Pretoria, South Africa, 2015.

[28] TABULA Project Team, “Typology approaches for non-residential buildings in five European Countries – Existing information, concepts and outlook.,” Deliverable D.9, 2012.

[29] Vienna University of Technology, “Invert/EE-Lab,” 2015. [Online]. Available: http://www.invert.at/.

[30] F. Meijer, L. Itard, and M. Sunikka-Blank, “Comparing European residential building stocks: performance, renovation and policy opportunities,” *Build. Res. Inf.*, vol. 37, no. 5–6, pp. 533–551, 2009.

[31] S. Pezzutto, F. Haas, D. Exner, and S. Zambotti, “Europe’s Building Stock and its Energy Demand: a Comparison between Austria and Italy,” presented at the SSPCR 2017, Bolzano, 2017.

[32] P. Dalin, J. Nilsson, and A. Rubenhag, “The European Cold Market. Final Report.,” Euroheat & Power, 2012.

[33] E. R. Schramek, H. Recknagel, and E. Sprenger, *Taschenbuch für Heizung + Klimatechnik 09/10*. Oldenbourg: Industrieverlag, 2008.

[34] J. Adnot, “Energy Efficiency of Room Air-Conditioners (EERAC),” 1999.

[35] C. Schremmer *et al.*, “Territories and low-carbon economy (ESPON Locate), Annex to the Final Report (Scientific Report),” ÖIR GmbH, Vienna, Jul. 2017.

[36] Eurostat, “CensusHub2,” *2011 Census database (Census Hub 2)*. [Online]. Available: https://ec.europa.eu/CensusHub2/query.do?step=selectHyperCube&qhc=false. [Accessed: 15-Feb-2018].

[37] Eurostat, “Heating degree-days by NUTS 2 regions – annual data [nrg_esdgr_a].” 26-Jun-2013.

[38] Haylock, M.R., van den Besselaar, E. J. M., van der Schrier, G., and Klein Tank, A. M. G., “A European daily high - resolution observational gridded data set of sea level pressure,” *J. Geophys. Res.*, vol. 116, 2011.

[39] Fleiter, Tobias *et al.*, “Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables),” Fraunhofer Institute for Systems and Innovation Research (ISI), Karlsruhe, EC service con¬tract ENER/C2/2014-641/SI2.697512, 2016.

[40] Eurostat, “Gross value added at basic prices by NUTS 3 regions [nama_10r_3gva].” Eurostat, 2016.
[41] Gallego F.J., “A population density grid of the European Union.” Population and Environment. 31:460-473, 2012.
[42] European Commission, Joint Research Centre (JRC); Columbia University, Center for International Earth Science Information Network - CIESIN, “GHS population grid, derived from GPW4, multitemporal (1975, 1990, 2000, 2015).” European Commission, Joint Research Centre (JRC) [Dataset], 2015.
[43] European Environment Agency (EEA), “Corine Land Cover (CLC) 2012, Version 18.5.1.” European Environment Agency (EEA).
[44] Eurostat, “Communes - Eurostat.” [Online]. Available: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/communes. [Accessed: 15-Feb-2018].
[45] Joint Research Center, “Estimation of the Gross Domestical Product 2006 in the 119 000 LAU2 of the ESPON Area.” ESPON, 2011.
[46] Eurostat, “Correspondence table LAU 2 – NUTS 2010, EU-27.” Eurostat, 2010.
[47] *OpenstreetMap*. 2018.
[48] European Environmental Agency, “Copernicus Land Monitoring Service - EU-DEM,” 2017. [Online]. Available: https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem.
[49] European Parliament, “Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).” European Parliament, 18-Jun-2010.
[50] A. García-Hooghuis and F. J. Neila, “Informes de la construcción.” Informes de la construcción, Jun-2013.
[51] H. E.-K. Hans Erhorn, “Overview of nZEB definitions.” EPBD Concerted Action, Apr-2015.
[52] “EPBD Concerted Action,” *EPBD Concerted Action*. [Online]. Available: https://www.epbd-ca.eu/ca-outcomes/2011-2015.
[53] ZEBRA2020 Project, “ZEBRA2020 Project.” [Online]. Available: http://zebra2020.eu.
[54] European Commission, “Nearly zero-energy buildings,” *European Commission*. [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings.
[55] Ministero dello sviluppo economico, “Decreto interministeriale 26 giugno 2015.” Ministero dello sviluppo economico, 26-Jun-2015.
[56] Österreichisches Institut für Bautechnik, “OIB-RICHTLINIE 6.” Österreichisches Institut für Bautechnik, Mar-2015.
[57] Zero Carbon Hub, “DEFINING A FABRIC ENERGY EFFICIENCY STANDARD FOR ZERO CARBON HOMES.” Zero Carbon Hub, Nov-2009.
[58] N. BEAR-iD, “PVSITES Project.” Sep-2016.
[59] K. Klobut and P. Touminen, “Energy savings potential in the building stock of nine member states of European Union,” 2009.
[60] index mundi, “Thematic Map. Population - World,” 2017. [Online]. Available: https://www.indexmundi.com/map/.
[61] Eurostat, “GDP per capita in PPS,” 2017. [Online]. Available: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tec00114& plugin=1.
[62] European Commission, “Energy prices and costs in Europe,” 2014.

[63] Ministry of Regional Development, “Average useful floor area per dwelling and per person.,” Czech Republic, 2009.
[64] VIMENTIS, “Lexicon: EU 15,” 2011. [Online]. Available: https://www.vimentis.ch/d/lexikon/485/EU-15.html.
[65] R. Fedrizzi and R. Marchetti, “Deliverable 2.1 Intermediate analysis of the heating and cooling industry,” 2016.
[66] W. Weiss, M. Spörk-Dür, and F. Mauthner, “Solar Heat Worldwide,” International Energy Agency, Edition 2017, 2017.
[67] EuroHeat & Power, “District heating and cooling - Country by country - 2015 Survey,” 2015.
[68] Eurostat, “Energy Data,” 2015. [Online]. Available: http://ec.europa.eu/eurostat/web/energy/data.
[69] HRE, “Heat Roadmap Europe 4. A low-carbon heating and cooling strategy for Europe,” 2016. [Online]. Available: http://www.heatroadmap.eu/.
[70] European Commission, “Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables). Work package 1: Final energy consumption for the year 2012.,” 2016.
[71] EurObservER, “Heat Pumps Barometer,” 2016.
[72] F. Mauthner, W. Weiss, and M. Spörk-Dür, “Solar Heat Worldwide,” International Energy Agency, 2016.
[73] AEE - Institute for Sustainable Technologies, “Thermal Use of Solar Energy,” 2009.
[74] Ecoheatcool, “Possibilities with more district heating in Europe,” 2006.
[75] Office of the Prime Minister, “Malta’s National Energy Efficiency Action Plan,” Apr. 2017.
[76] IEA Task 28. Solar Air Conditioning and Refrigeration, “State of the Art on Existing Solar Heating and Cooling Systems,” 2008.
[77] Eurostat, “European Demography.,” 2011. [Online]. Available: http://ec.europa.eu/eurostat/documents/2995521/ 5037986/3-28072011-AP-EN.PDF/2d0d6e39-1e13-46a5-abb2-4a52c650ee81.
[78] *Field benchmarking and Market development for Audit methods in Air Conditioning (AUDITAC)*. .
[79] J. Adnot, *“Central” (Commercial) air-conditioning systems in Europe*. 2002.
[80] S. Pezzutto, M. De Felice, R. Fazeli, L. Kranzl, and S. Zambotti, “Status Quo of the Air-Conditioning Market in Europe: Assessment of the Building Stock,” *Energies*, vol. 10, no. 9, p. 1253, 2017.
[81] G. Trnka, M. Mitterndorfer, G. Simader, and T. Barth, “Analyse des Energieverbrauchs von Wiener Krankenanstalten. Gliederung des Energieverbrauchs nach Energieträgern und Zuteilung zu einzelnen Verbrauchern bzw. Verbrauchergruppen,” European Union - European Regional Development Fund, 2012.
[82] W. Grassi *et al.*, “Valutazione dei consumi nell’edilizia esistente e benchmark mediante codici semplificati: analisi di edifici ospedalieri,” ENEA, RSE/2009/117, 2009.
[83] A. M. Carreno, “Cooling benchmarking study report,” 2011.
[84] CCO, “RESCUE – Renewable Smart Cooling for Urban Europe. EU districts cooling markets and trends,” 2012.
[85] European Technology Platform on Renewable Heating and Cooling, “2020 – 2030 – 2050 Common Vision for the Renewable Heating & Cooling sector in Europe,” European Union, 2011.

[86] P. Jones and W. Wint, *Data set produced by Waen Associates for Environmental Research Group Oxford, Limited, funded by the International Research Consortium on Dengue Risk Assessment, Management and Surveillance (IDAMS), European Union\u2019s Seventh Framework Programme for research, technological development and demonstration under grant agreement no 281803*. 2015.
[87] M. New, D. Lister, M. Hulme, and I. Makin, *A high-resolution data set of surface climate over global land areas. Climate Research 21*. 2002.
[88] M. Metz, D. Rocchini, and M. Neteler, "Surface Temperatures at the Continental Scale: Tracking Changes with Remote Sensing at Unprecedented Detail," *Remote Sens.*, vol. 6, no. 12, pp. 3822–3840, Apr. 2014.
[89] Esa, *Earth Online*. 2018.
[90] *US GOVERNMENT COMPUTER*. 2018.
[91] NASA, *Earth Data*. 2018.
[92] "WorldClim - Global Climate Data | Free climate data for ecological modeling and GIS." [Online]. Available: http://www.worldclim.org/. [Accessed: 05-Feb-2018].
[93] European Commission, "PVGIS," 2012. [Online]. Available: http://re.jrc.ec.europa.eu/pvgis/. [Accessed: 12-Feb-2018].
[94] Fleiter, Tobias; Elsland, Rainer; Rehfeldt, Matthias; Steinbach, Jan; Reiter, Ulrich; Catenazzi, Giacomo et al., "Profile of heating and cooling demand in 2015," Fraunhofer ISI; TEP Energy; Utrecht University; Armines, Karlsruhe, Zürich, Utrecht, Paris, Heat Roadmap Europe 4, 2017.
[95] G. Erdmann and L. Dittmar, *Technologische und energiepolitische Bewertung der Perspektiven von Kraft-Wärme-Kopplung in Deutschland*. 2010.
[96] K. Darrow, R. Tidball, J. Wang, and A. Hampson, *Catalog of CHP Technologies*. 2015.
[97] F. Matthes and H. J. Ziesing, *Zur Wirtschaftlichkeit von Kraft-Wärme-Kopplungs-Anlagen. Band 1: Der KWK-Wirtschaftlichkeitsindikator COGIX – Methodenband. Studie für den Verband kommunaler Unternehmen e.V. (VKU)*. 2016.
[98] P. Lako, *Combined Heat and Power. Hg. v. International Energy Agency - Energy Technology Systems Analysis Programme (IEA ETSAP)*. 2010.
[99] Fraunhofer ISI; Fraunhofer ISE; TU Wien; TEP Energy; IREES, Observer, "Mapping and analyses for the current and future (2020 - 2030) heating/cooling fuel development (fossil/renewables)," Karlsruhe, 2017.
[100] Arens et al., "Energy intensity development of the German iron and steel industry between 1991 and 2007," *Energy*, vol. 45, pp. 786–797, 2012.
[101] Arens et al., "Pathways to a low-carbon iron and steel industry in the medium-term - the case of Germany," *J. Clean. Prod.*, 2016.
[102] H. Brauer, *Produktions- und produktintegrierter Umweltschutz*, vol. 2. Springer Verlag Berlin Heidelberg New York, 1996.
[103] Hara et al., "Smelting Reduction Process with a Coke Packed Bed for Steelmaking Dust Recycling," *ISIJ Int.*, vol. 3, no. 40, pp. 231–237, 2000.
[104] Primetals, "COREX® Efficient and Environmentally Friendly Smelting Reduction. Company brochure." .
[105] Midrex, "The MIDREX Process. Company brochure." .
[106] Cheeley, "Gasification and the MIDREX Direct Reduction Process," presented at the 1999 Gasification Technologies Conference, San Francisco, 1999.
[107] Fleiter, T.; Schlomann, B.; Eichhammer, W., *Energieverbrauch und CO2-Emissionen industrieller Prozesstechnologien - Einsparpotentiale, Hemmnisse und Instrumente*. Stuttgart: Fraunhofer-Verlag, 2013.

[108] Winnacker-Küchler, *Chemische Technik Prozesse und Produkte, 6a Metalle*. Darmstadt, Germany.
[109] Krone, *Aluminiumrecycling Vom Vorstoff bis zur fertigen Legierung*. Düsseldorf, Germany: Aluminium-Verlag, 2000.
[110] Fleiter et al., “Energy efficiency in the German pulp and paper industry – A model-based assessment of saving potentials,” *Energy*, no. 40, pp. 84–99, 2012.
[111] van Deventer, “Feasibility of energy efficient steam drying of paper and textile including process integration,” *Appl. Therm. Eng.*, no. 17, pp. 1035–1041, 1997.
[112] Bakhtiari et al., “Opportunities for the integration of absorption heat pumps in the pulp and paper process.,” *Energy*, no. 35, pp. 4600–4606, 2010.
[113] Laurijssen et al., “Benchmarking energy use in the paper industry: a benchmarking study on process unit level,” *Energy Effic.*, no. 6, pp. 49–63, 2013.
[114] BREF Glass, “Best available Techniques (BAT) Reference Document for the Manufacture of Glass.” 2013.
[115] Büchel et al., *Industrielle Anorganische Chemie*, 3rd Edition. Weinheim, Germany: Wiley-VCH Verlag, 2013.
[116] BREF Ceramic 2007, “Reference Document on the Best Available Techniques in the Ceramic Manufacturing Industry.” 2007.
[117] Rahman et al., “Impact of alternative fuels on the cement manufacturing plant performance,” *Procedia Eng.*, no. 56, pp. 393–400, 2013.
[118] Patil and Khond, “Alternative Fuels for Cement Industry: A Review,” in *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management*, 2014.
[119] Bundesverband der Gipsindustrie 2013, “Gips-Datenbuch.” 2013.
[120] Dondi et al., “Recycling of Industrial and Urban Wastes in Brick Production – A Review.,” *Tile Brick Int*, vol. 13, no. 3, 1997.
[121] Gutierrez and Vandecasteele, “Exergy-based indicators to evaluate the possibilities to reduce fuel consumption in lime production,” *Energy*, no. 36, pp. 2820–2827, 2011.
[122] Weissermel and Arpe, *Industrielle Organische Chemie*, 5th Edition. Weinheim, Germany, 1998.
[123] Lauterbach et al., “The potential of solar heat for industrial processes in Germany,” *Renew. Sustain. Energy Rev.*, no. 16, pp. 5121–5130, 2012.
[124] Brückner, S., TU München, 2016.
[125] Persson, U.; Möller, B.; Werner, S., “Heat Roadmap Europe: Identifying strategic heat synergy regions,” *Energy Policy*, vol. 74, pp. 663–681, 2014.
[126] McKenna, R.C.; Norman, J.B., “Spatial modelling of industrial heat loads and recovery potentials in the UK,” *Energy Policy*, vol. 38, pp. 5878–5891, 2010.
[127] Bühler, F.; Nguyen, T.; Elmegaard, B., “Energy and exergy analyses of the Danish industry sector,” *Appl. Energy*, vol. 184, pp. 1447–1459, 2016.
[128] Brückner, S.; Arbter, R.; Pehnt, M.; Laevemann, E., “Industrial waste heat potential in Germany - a bottom up analysis,” *Energy Effic.*, vol. 10, pp. 513–525, 2017.
[129] Rehfeldt, M.; Fleiter, T.; Toro, F., “A bottom-up estimation of the heating and cooling demand in European industry,” *Energy Effic.*, 2017.
[130] Fleiter, T.; Schlomann, B.; Eichhammer, W., *Energieverbrauch und CO2-Emissionen industrieller Prozesstechnologien - Einsparpotentiale, Hemmnisse und Instrumente*. Stuttgart: Fraunhofer-Verlag, 2013.
[131] “Global Cement Directory.” 2016.

[132] Element Energy, Ecofys, Imperial College London, “The potential for recovering and using surplus heat from industry,” Final report for the Department for Energy and Climate Change, 2014.
[133] Miro, L, Brückner, S., Cabeza, L.F., “Mapping and discussing Industrial Waste Heat (IWH) potentials for different countries,” *Renew. Sustain. Energy Rev.*, vol. 51, pp. 847–855, 2015.
[134] C. Schremmer *et al.*, “Territories and low-carbon economy (ESPON Locate),” Luxembourg, 2017.
[135] L. G. Swan and V. I. Ugursal, “Modeling of end-use energy consumption in the residential sector: A review of modeling techniques,” *Renew. Sustain. Energy Rev.*, vol. 13, pp. 1819–1835, 2009.
[136] *ENTRANZE*. .
[137] A. Müller, “Energy Demand Assessment for Space Conditioning and Domestic Hot Water : A Case Study for the Austrian Building Stock,” Technische Universität Wien, 2015.
[138] J. Steinbach, *Modellbasierte Untersuchung von Politikinstrumenten zur Förderung erneuerbarer Energien und Energieeffizienz im Gebäudebereich*. Stuttgart: Fraunhofer Verlag, 2015.
[139] Danish energy agency (DEA), “Individual Heating Plants and Energy Transport, Technology data for energy heating installations.” .
[140] Eurostat, “Labour cost levels by NACE Rev. 2 activity [Call ID: lc_lci_lev],” 08-Jun-2017. .
[141] Eurostat, “Price index for household appliances based upon purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates [Call ID: prc_ppp_ind],” 14-Dec-2017. .
[142] Eurostat, “Household furnishings, equipment and maintenance index based upon purchasing power parities (PPPs), price level indices and real expenditures for ESA 2010 aggregates [Call ID: prc_ppp_ind].” .
[143] B. Elbersen, I. Staritsky, G. Hengeveld, and L. Jeurissen, “Outlook of spatial biomass value chains in EU28,” Intelligent Energy Europe, Sep. 2014.
[144] EU, “LUCAS - Land Use and land Cover Survey,” 09-Jan-2018. [Online]. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/LUCAS_-_Land_use_and_land_cover_survey. [Accessed: 09-Jan-2018].
[145] European Commission, “Database - Eurostat.” [Online]. Available: http://ec.europa.eu/eurostat/data/database. [Accessed: 08-Jan-2018].
[146] G. Neugebauer, F. Kretschmer, R. Kollmann, M. Narodoslawsky, T. Ertl, and G. Stoeglehner, “Mapping Thermal Energy Resource Potentials from Wastewater Treatment Plants,” *Sustainability*, vol. 7, no. 12, pp. 12988–13010, Sep. 2015.
[147] U. Arena, “Process and technological aspects of municipal solid waste gasification. A review,” *Waste Manag.*, vol. 32, no. 4, pp. 625–639, Apr. 2012.
[148] European Environment Agency, “Common Database on Designated Areas - CDDA International,” *European Environment Agency*, 2002. [Online]. Available: https://www.eea.europa.eu/data-and-maps/data/external/common-database-on-designated-areas. [Accessed: 12-Feb-2018].
[149] European Commission, “Natura 2000 sites,” 2016. [Online]. Available: http://ec.europa.eu/environment/nature/natura2000/data/index_en.htm. [Accessed: 12-Feb-2018].
[150] “ThermoMap - www.eurogeosurveys.org,” - *www.eurogeosurveys.org*. .
[151] Stadtwerke München, “Normiertes Lastprofil Wärmepumpe.” .

[152] C. Schmid *et al.*, “Möglichkeiten, Potenziale, Hemmnisse und Instrumente zur Senkung des Energieverbrauchs branchenübergreifender Techniken in den Bereichen Industrie und Kleinverbrauch,” 2003.
[153] AEE Intec, Fraunhofer ISE, Reen AG, and Universidade de Evora, “TrustEE - Report on current status of Process heat in Europe: sectors, processes, geographical distribution, system layouts and energy sources,” vol. 2016, p. 74, 2016.
[154] eurostat, “Employment at atypical working time as percentage of the total employment, by European socio-economic group,” 2018.
[155] Federal Statistical Office Germany, “Bevölkerung und Erwebstätigkeit,” 2016.
[156] L. Delson, F. Bauer, G. Cette, and M. Smith, *Comparative Analysis of Operating Hours and Working Times in the European Union*. Heidelberg: Physica-Verlag, 2009.
[157] ENTSO-E, *Statistical Database*. .
[158] “ENTSO-E - European Network of Transmission System Operators for Electricity.” [Online]. Available: https://www.entsoe.eu/db-query/production/monthly-production-for-all-countries. [Accessed: 23-Feb-2018].
[159] C. Thiel et al., “Modelling Electro-mobility: An Integrated Modelling Platform for Assessing European Policies”, *Transp. Res. Procedia, Transport Research Arena TRA2016* 14, 2544–2553, 2016.
[160] A. Zubaryeva, C. Thiel, N. Zaccarelli, E. Barbone, and A. Mercier, “Spatial multi-criteria assessment of potential lead markets for electrified vehicles in Europe,” *Transp. Res. Part Policy Pract.*, vol. 46, no. 9, pp. 1477–1489, 2012.

4. ANNEXES

4.1. Expert questioning form

Table 36 and Table 37 show the content of the form sent to the experts for the expert questioning carried out for collecting data regarding the service sector in the building stock analysis.

Table 36. Questionnaire for experts questioning regarding construction materials and methodologies.

Construction element	Construction material	Construction methodology	Further specification	
WALL	□ Brick □ Concrete □ Wood □ Other	□ Solid wall □ Cavity wall □ Honeycomb bricks/Hollow block wall □ Other	Insulation	□ yes □ no
WINDOW	□ Wood □ Synthetic/PVC □ Aluminium	□ Single glazing □ Double glazing □ Triple glazing	Low-emittance glass	□ yes □ no
ROOF	□ Wood □ Concrete □ Concrete and bricks	□ Tilted roof □ Flat roof	Insulation	□ yes □ no
FLOOR	□ Wood □ Concrete □ Concrete and bricks □ Other	□ Concrete slab □ Wooden floor (rafters + boards) □ Other	Insulation	□ yes □ no

Table 37. Questionnaire for experts questioning regarding technologies for space heating, space cooling, and domestic hot water.

Purpose	Specification	Technology	Fuel	
SPACE HEATING	□ Individual	□ Boiler non-condensing	□ Fossil	□ Solid
	□ Central	□ Boiler Condensing		□ Liquid
	□ District Heating	□ Stove		□ Gas
		□ Electric Heating	□ Electricity	
		□ Heat Pump	□ Biomass	
SPACE COOLING	□ No space cooling			
	□ Space cooling present			
DHW	□ Individual	□ Boiler non-condensing	□ Fossil	□ Solid
	□ Central	□ Boiler Condensing		□ Liquid
	□ District Heating	□ Combined		□ Gas
		□ Solar collectors	□ Electricity	
		□ Heat Pump	□ Biomass	

4.2. Assumptions for nearly Zero-Energy Buildings

4.2.1. nZEB penetration

The estimation of the share of new nZEB has been done by creating two groups of countries according to their GDP per capita (above and below the EU median for 2014: 19.665 € year), as shown in Table 38. With the existing values of penetration it has been done an average, which has been considered for the non-existing values of the MSs located in the same group of GDP.

Table 38. Member States above or below the European median gross domestic product per capita. Source: [61]

GDP per capita	
< 19664	**> 19665**
Bulgaria	Belgium
Czech Republic	Denmark
Estonia	Germany
Greece	Ireland
Croatia	Spain
Latvia	France
Lithuania	Italy
Hungary	Cyprus
Malta	Luxembourg
Poland	Netherlands
Portugal	Austria
Romania	Finland
Slovenia	Sweden
Slovakia	United Kingdom

4.2.2. Member States climate classification

In order to be more accurate in the assumptions, it has been elaborated a group of MSs according to the climate conditions, as shown in Figure 72.

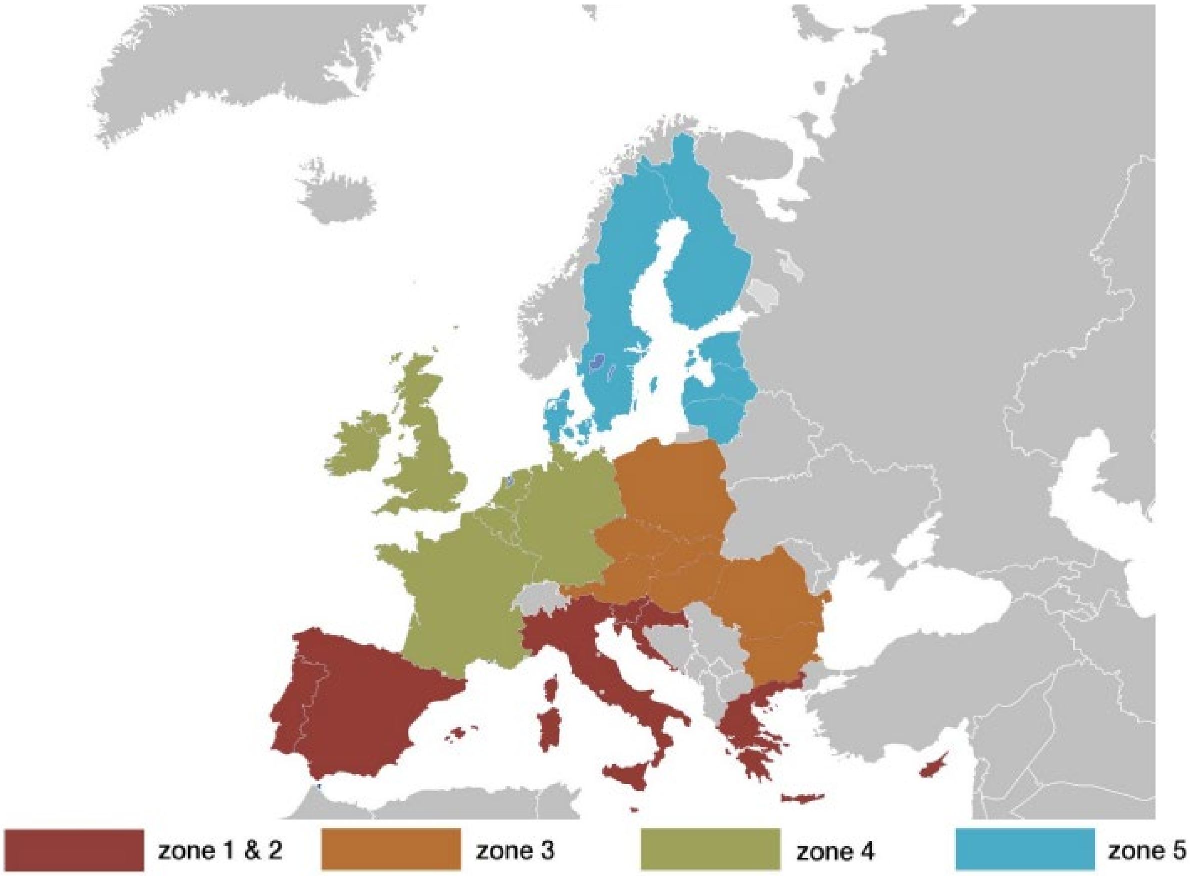


Figure 72. Member states according to different climate zones. Source: [58]