WP3 – “Multiple energy grids planning tool”

D3.1 – Mapping tool (sources and demand) prototype

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Multi Utilities Smart Energy GRIDS

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D3.1 – *Mapping tool (sources and demand) prototype*

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Background

The main purpose of this report is to document selected methodologies for mapping at local level the energy demand and supply. The methodologies are chosen, so they can provide the input data to be used in the MUSE GRIDS Energy planning tool developed in Task 3.4 and described in Deliverable 3.2. The tool will be applied in the two specific demo sites of MUSE GRIDS project and results will be included in Deliverable 3.3 report (to be released in 2021). The final version of the MUSE GRIDS Energy planning tool is Deliverable 3.4 (to be released in 2021).

The report is structured so that it presents the general data collection methodology and approach. Then follows the specific chapters on energy demands (electricity, heating and cooling), heat generation, power generation, renewable energy (wind power, photovoltaics, hydro, geothermal and biomass), transport and industry.

As the aim of the report is to provide methodologies that can be applied in any country, each of the chapters on energy demands and supply (Chapter 2-8), have a generic approach, that typically uses general national statistics as input data. However, as the MUSE GRIDS Energy planning tool is created with the purpose of modelling local municipality energy systems, a more detailed approach is provided for the most relevant demands and resources. The detailed approach is a methodology that can be applied in areas with a good data availability, typically defined as data on a local municipal level or even down to the specific site.

Nomenclature

Name	Description
BHV	Baseline Heating value
BSO	Building Stock Observatory
CDD	Cooling Degree Days
CENER	The National Renewable Energies Centre (Spain)
CHP	Combined Heat and Power
COP	Coefficient of performance
CSV	Comma-Separated Values
DH	District Heating
E-PRTR	The European Pollutant Release and Transfer Register
GEZ	Global Ecological Zones
GIS	Geographic Information Systems
GMTED2010	Global Multi-resolution Terrain Elevation Data
HDD	Heating Degree Days
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC	The Joint Research Centre of the European Commission
JSON	JavaScript Object Notation
MERRA-2	Modern-Era Retrospective analysis for Research and Applications
NAI	Net Annual Increment
OSM	Open Street Maps
PRIMES	Price-Induced Market Equilibrium System (Model)

PV	Photovoltaics
PVGIS	Photovoltaic Geographical Information System
RES	Renewable Energy Sources
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan
SoDa	Solar radiation Data
TABULA	Typology Approach for Building Stock Energy Assessment
TSO	Transmission System Operator

1 Data collection methodology and approaches

This chapter describes the general approaches for collecting the data necessary to make an energy system model in the MUSE GRIDS Energy planning tool. Some data needs to be collected manually, while other data can be downloaded automatically through the tool. In general, each section is structured to provide data collection in different levels of detail and the associated approaches, so that it is both possible to model an energy system in areas with scarce or limited data availability as well as in areas with better availability.

1.1 General Data structure

The purpose of the mapping of demands, supply and renewable energy sources is to serve as input for the MUSE GRIDS Energy planning tool developed in Task 3.4. The energy planning tool serves as a user interface for a simulation core based on EnergyPLAN which is an advanced energy system analysis computer model, widely used in the energy modelling practice [1]. The primary intention with the tool, is to enable local authorities to make renewable energy system scenarios in order to investigate the implications of different choices in the planning of an energy system transition.

The mapping tool assist the Energy Planning Tool by establishing the data basis for the scenario analyses. For this it should be able to automatically download data for any municipality, while also include an option for the user to add data manually, if needed. In Figure 1, a general overview of the data input for the mapping is shown. The mapping is an integral part of the MUSE GRIDS Energy planning tool but will only serve as part of the inputs to the tool. Other parameters, such as economic parameters and specific EnergyPLAN parameters will not be part of the mapping. Table 1 elaborates on the tool's data type inputs.

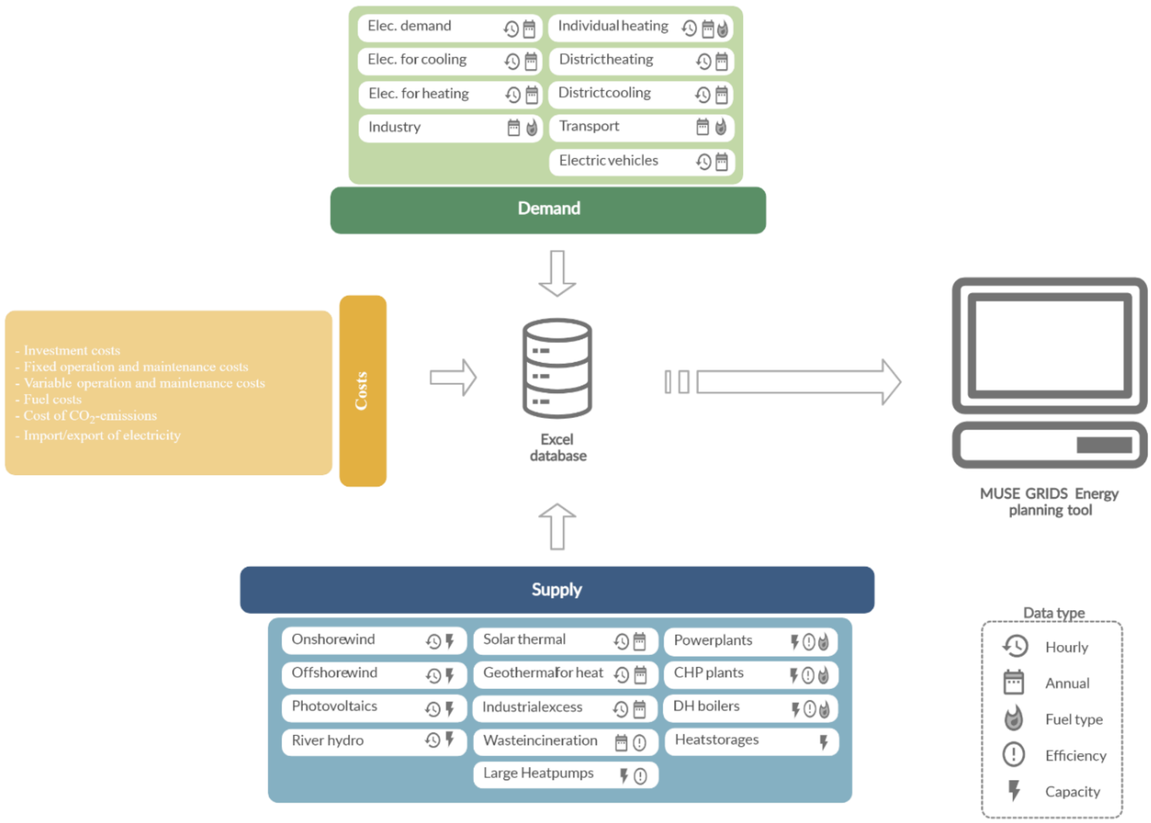


Figure 1 MUSE GRIDS Energy planning tool data input overview

Table 1 MUSE GRIDS Energy planning tool input data type

Data type	Description
Hourly data	8784 data values for the time series (including 24 hours for a leap year day)
Annual data	A single aggregated number for one year $GWh/year$
Fuel type	A categorization of demand/supply based on fuel types (For example power plants or boilers. Fuel types include biomass, oil, gas, and coal.
Efficiency	A coefficient on the input vs. the output of a specific conversion technology
Capacity	The maximum output of energy that a facility can produce typically MW

In the report chapters, the required data is described at two different levels based on the data availability. The first level is the *generic approach* which can be used in cases with low data availability while the second level is the *detailed approach* that can be used in areas with good data availability. As mentioned previously, the detailed approach is typically defined as data on a local municipal level or even down to the specific site. There are two main reasons to consider when choosing if a generic or detailed approach should be applied. The main reason for choosing a generic approach over a detailed approach is data availability, if a municipality does not have e.g. data on building level, the generic approach can be applied. The other reason, for choosing the generic approach, is resource or time constraints related to the specific analysis. If a municipality only have limited resources, it might be feasible to apply the generic approach in some situations, as this typically require less data gathering and management, which reduces the amount of resources spent. Here, the user of the MUSE GRIDS Energy planning tool should decide on what are the relevant energy systems to include in the analysis. If e.g. the main interest is the heating sector, then a detailed approach could be applied in heating, and then generic approaches could be applied to other sectors like transport and industry. If the tool user has detailed data available and enough time, it would always be preferable to use the detailed approaches as these give a better data input for the tool.

It is worth mentioning that only the energy resources and demands that are relevant for municipal energy planning are included in the document, thus large-scale production facilities like power plants, nuclear power plants and offshore wind parks are not included. In terms of energy demands at municipal level, international shipping and aviation are considered not relevant. For certain resources, only a generic approach is included, therefore the following note is made on its usage.

1.2 Generic approach procedure

In most of the generic approaches presented in this deliverable, population data is required to estimate the shares for the local area based on national statistics. There are several online resources for attaining population data, and in general it can be recommended to use a local statistical office, as these are most likely to have the most updated data. However, a fairly decent reference is City Population [2] where both national and local population can be attained by a simple search. The approach is simply to first search for the country and then for the local population, which is then used to estimate the share that needs to be used in the local energy model. Using the Italian Municipality Osimo as an example; along with its estimated population data for 2020, the Osimo share will be:

$$Osimo's\ population\ share = \frac{Municipality\ population}{National\ population} = \frac{35{,}155}{60{,}36M} = 0.058\ \%$$

The share is then multiplied by the national aggregate to calculate the partial contribution to the national energy figure. To obtain a municipal or national GWh energy unit, the conversion factors listed in Table 2 can be used.

Table 2 General conversion factors [3]

To / **From**	TJ	$Gcal$	$Mtoe$	$MBtu$	GWh
	Multiply by:				
TJ	1	238.8	$2.388\ x\ 10^{-5}$	947.8	0.2778
$Gcal$	$4.1868\ x\ 10^{-3}$	1	10^{-7}	3.968	$1.163\ x\ 10^{-3}$
$Mtoe$	$4.1868\ x\ 10^{4}$	10^{7}	1	$3.968\ x\ 10^{7}$	11630
$MBtu$	$1.0551\ x\ 10^{-3}$	0.252	$2.52\ x\ 10^{-8}$	1	$2.931\ x\ 10^{-4}$
GWh	3.6	860	$8.6\ x\ 10^{-5}$	3412	1

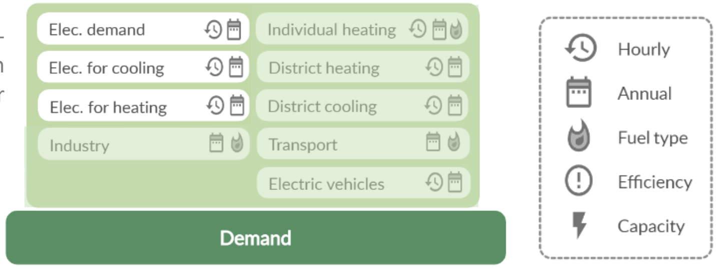
2 Electricity demands

MUSE GRIDS Energy planning tool demand input

What is *electricity demand*?
The demand covering what is traditional electricity consumption and is primarily related to electricity usage in buildings and industry. This includes electricity used for heating and cooling.

What data is needed for *electricity demand*?
- Annual data demand
- Hourly data demand

*(See **Table 1** for data type specification)*



For electricity demands, the annual demand in $GWh/year$ as well as an hourly distribution for one year is needed. Firstly, a generic approach is described in this report, as typically detailed data on electricity consumption is difficult to get access to on a detailed municipal and local level.

2.1 Generic approach

Annual national electricity consumptions can be found in the IEA national energy balances [4]. The information is found by choosing electricity in the energy category, as well as the relevant country and year. The electricity demands that are needed are the one categorized as *Final consumption* and the *Losses*. Adding the losses to the final electricity consumption and multiplying with the population share of the demand, outputs the annual demand in a local area. It is however, strongly recommended to use local data if available, which can typically be found by contacting the local electricity distribution company.

Alternatively, a per capita electricity consumption can be obtained through the Our World in Data graphical online tool [5]. That database combines a series of datasets available both in tabular and visual means. Historical data is available on energy consumption, as well as various other energy-related indicators at a country level. A screenshot of the tool follows in Figure 2.

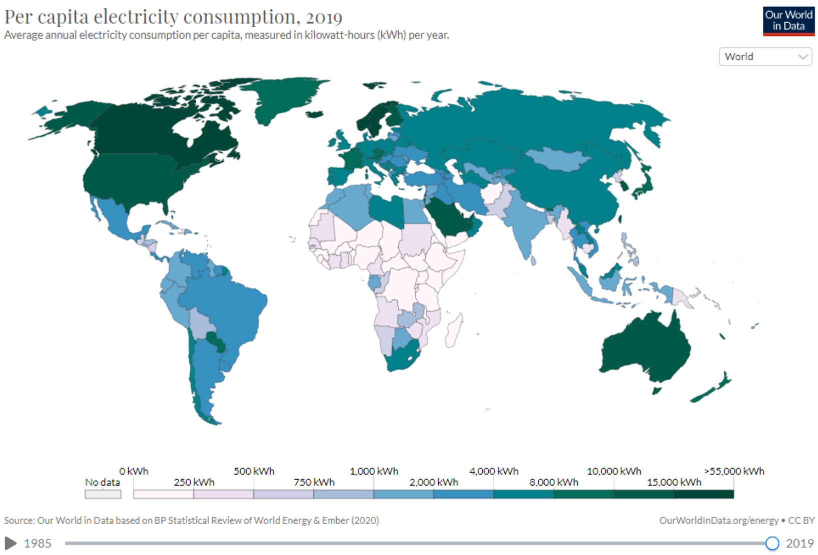


Figure 2 Per capita electricity consumption in 2019 [5]

Hourly electricity demand profiles for a country can be found by contacting the TSO (Transmission System Operator) in that specific area. However, if this is not possible a synthetic electricity profile can be used, and a good source for this data is [6], where electricity demand profiles have been projected for 180 countries, based on hourly load data from 57 countries and a regression analysis considering the impact of electric heating, tourism, industrial, air conditioning amongst others. For exemplifying, Figure 3 portrays a plot of the electricity demand profiles for both India and Germany, extracted from [6]. It should be noted that the data from this source is not publicly available and in order to access the profiles, access to the scientific journal published Elsevier's database ScienceDirect [7] is required.

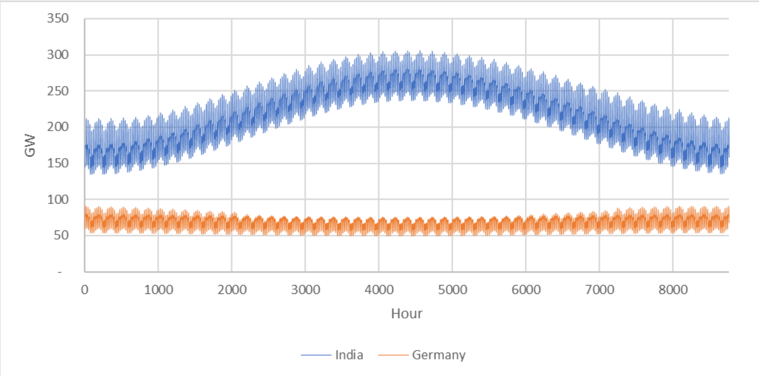


Figure 3 Synthetic hourly electricity demand profile example for India and Germany based on data from [6]

2.2 Detailed approach

As a large share of the local electricity use is in buildings, a more specific approach to electricity consumption in buildings using the data coming from Building Stock Observatory (BSO) [8], can be considered. Besides the data form BSO, some default data have been indicated, for covering regions not included in BSO. The database has information about the typical electrical consumption for residential and non-residential building classified by electricity usages, as seen in Table 3.

Table 3 BSO database related to electricity usage in buildings

Electricity usage	**Dwelling type**	
	Non-residential	**Residential**
	Space cooling	
	Space heating	
	Water heating	
	Lighting	
	Cooking	
	Appliances	

The data are organized by country and year of construction periods for both residential and non-residential building. Besides, the data are indicated in energy consumption per floor area m^2. Therefore, the approach followed is to take the total floor area by type and the specific electricity consumption per floor area and calculate the total electricity demand.

Finally, the electricity is gathered in the following groups: cooling electricity consumption, heating electricity consumption, hot water electricity consumption and other electricity consumption.

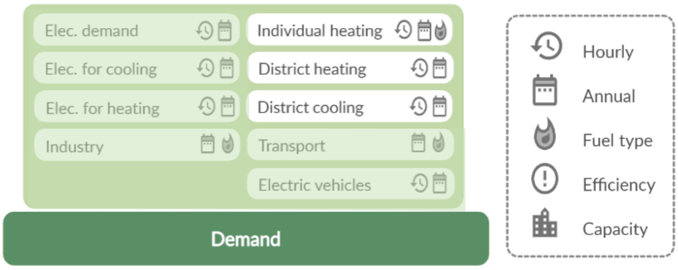
3 Heat and cooling demands

MUSE GRIDS Energy planning tool demand input

What are *heat and cooling demands*?
The demand covering the energy used for space heating and cooling primarily in buildings and industry, including Domestic Hot Water (DHW). The demand can be satisfied in either individual or district systems.

What data is needed for *heat and cooling demands*?
- Annual data demand
- Hourly data demand
- Fuel type

*(See **Table 1** for data type specification)*



The heating and cooling sector is an important part of a regional and municipal energy system as it is directly related to the local conditions in terms of the spatial structure of the built environment. In the MUSE GRIDS Energy planning tool, the inputs needed for the heating demands are split into individual heating (single-building/apartment heating systems) and District Heating (DH) systems.

a) For individual heating an annual aggregated end-use demand for space heating and domestic hot water in $GWh/year$ grouped by fuel type - oil, gas, biomass, electricity, heat pumps - and an hourly temporal distribution for one year - just a single aggregated profile for all individual buildings - is required. Furthermore, an average annual demand per building is needed.
b) For DH systems an aggregated annual end-use heat demand for space heating and domestic hot water in $GWh/year$ as well as an annual percentage heat loss for the DH grid is needed. Furthermore, an hourly distribution profile for one year is needed. The hourly profile should reflect the hourly values for both space heating, domestic hot water, and heat losses.

For heating and cooling demands both a generic approach as well as a detailed approach is provided in subsections 3.1 and 3.2.

3.1 Generic approach

In many countries, the energy used for heating buildings is a significant part of the total final energy consumption though this of course depends on the specific climate. A large proportion of this heat is used for heating residential buildings. A generic approach for estimating the energy demand used for buildings in a smaller region, can be to use average numbers of that region, either based on the total floor area or the number of buildings in that region.

There are several databases that include relevant building information, one example is the Entranze project [9] where average values on floor area per capita, heat demand per floor area, etc. can be found . Contents from this project are also consulted when exemplifications of international building energy usage data sources are made [10], amongst others. Generally, it is convenient to get information on dwellings including building use, construction year, renovation level and size. Energy demands depend heavily on such parameters, hence the more detailed information available on buildings, the better estimates that can be made.

To get hourly profiles for space heating and cooling, the Heating Degree Days (HDD) and Cooling Degree Days (CDD) methodologies are typically used. Both use a temperature baseline, which differs according to regional climate. When the outdoor temperature is below the base temperature, the difference between the outdoor temperature and the baseline temperature is the estimated number of HDD for that day. The annual demand can subsequently be distributed to daily values, using the number of heating degree hours for each day. For hourly values, the space heating demand can typically be assumed constants throughout the 24h diurnal cycle. For heating, the demand for domestic hot water can be added, as a constant for each hour. Here, domestic hot water is typically around 20-30% of the annual end-use heat demand in buildings.

If DH exists in the system, then heat losses of the DH network must be added to each hour. Typically, this is done in a similar way as the domestic hot water, with a constant value for each hour, and based on the annual end-use heat demand for space heating and domestic hot water where network heat losses are around 20-25% of the end-use heat demand. There are also a few research projects that could be relevant. One of them where building heat demand profiles for 16 European countries can be downloaded, is the When2Heat project [11] where hourly demand profiles for different building types are available. The heat demands in the source are estimated based on gas load profiles, temperatures, and wind speed data. Another relevant project for European countries is the Hotmaps project [12] where the user can select any area in Europe and through the calculation module “CM - Heat load profiles” estimate the hourly heat load profiles. Figure 4 shows an example of the heat load profiles that can be downloaded from Hotmaps.

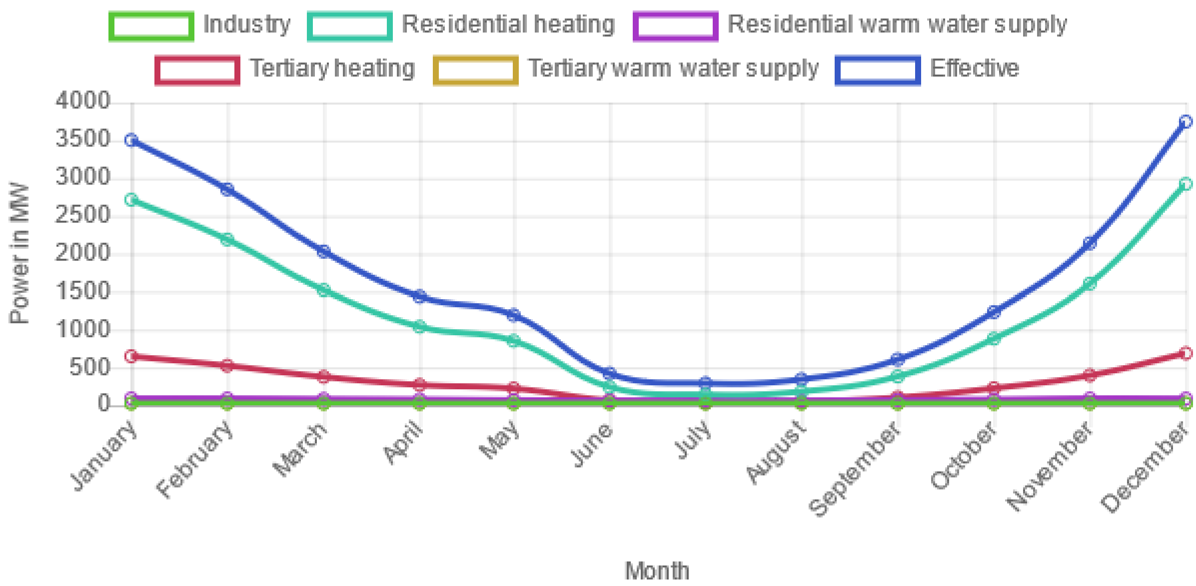


Figure 4 Example of heat load profiles downloaded from the Hotmaps project

3.2 Detailed approach

This sub-section includes the necessary information to generate a spatial mapping of the annual heating and cooling demand in buildings, taking as references open code and data resources, and looking at developing a procedure that can be used worldwide with minor modifications, but more detailed than the method presented in 3.1.

In general, in order to understand the main elements of the method proposed, the elements are presented following the process depicted in Figure 5:

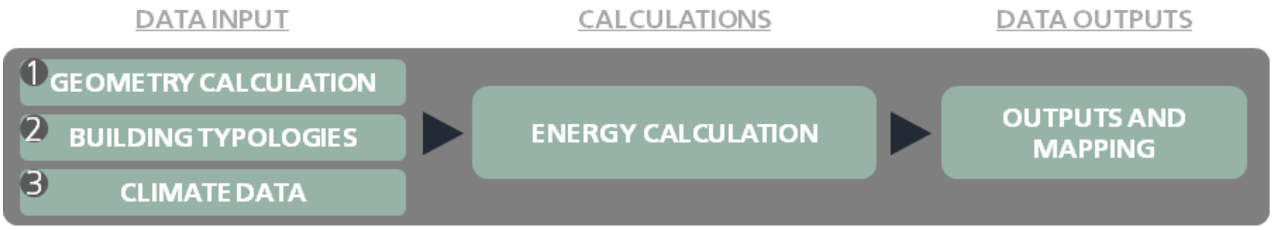


Figure 5 General procedure for the heating map generation

Firstly, the **data input** for the method should be established. The data input is composed mainly of three elements:

1. Geometry calculation (building dimensions and location),
2. Building typologies (characterisation of the buildings according to their year of construction and other parameters) and
3. Climate data, which determines the climatic conditions in which the building is located, which strongly impact the results obtained in the energy demand calculation.

The latter is key, since is linked to the area and volume to be heated or cooled, as well as the quality of the construction in the building, which will affect the heat transfer to and from the exterior.

Secondly, robust **calculations** for the assessment of heating and cooling energy demand should be established. In this context, the reliance on standards for the calculation of the energy demand is highly important; even when strong assumptions should be established due to the nature of the problem at hand. To this end, the most relevant are the ISO 52000 standards family. In particular the following: 52000-1 [13] on general procedures, 52003-1 [14] on indicators, 52010-1 [15] on climatic conditions, 52016-1 [16] on energy needs, and 52018-1 [17] on indicators for thermal balance.

Finally, the **data output** should be treated in order to serve the needs for which it has been devised. In this case, the objective is to have a heat density map, as well as hourly energy demand values for the whole municipality. Nevertheless, more detailed outputs will be obtained from this method, considering that the heating and cooling parameters aggregated will provide the annual end-use heating demand needed for the MUSE GRIDS Energy planning tool. Additionally, derived from the granularity of the data used and the implemented calculations, more detailed outputs could be extracted after further analysis.

In the following pages, the detailed method proposed for the calculation of heating and cooling demand is presented in a practical and straightforward way following three processes, which are illustrated in Figure 6, for the domestic hot water, heating and cooling demand calculation. For each of the processes shown there, a table describing the sub-process with input, procedure and output, are included in the following sections. Additionally, for more details on concepts and assumptions used in each of the processes, please refer to Annex II.

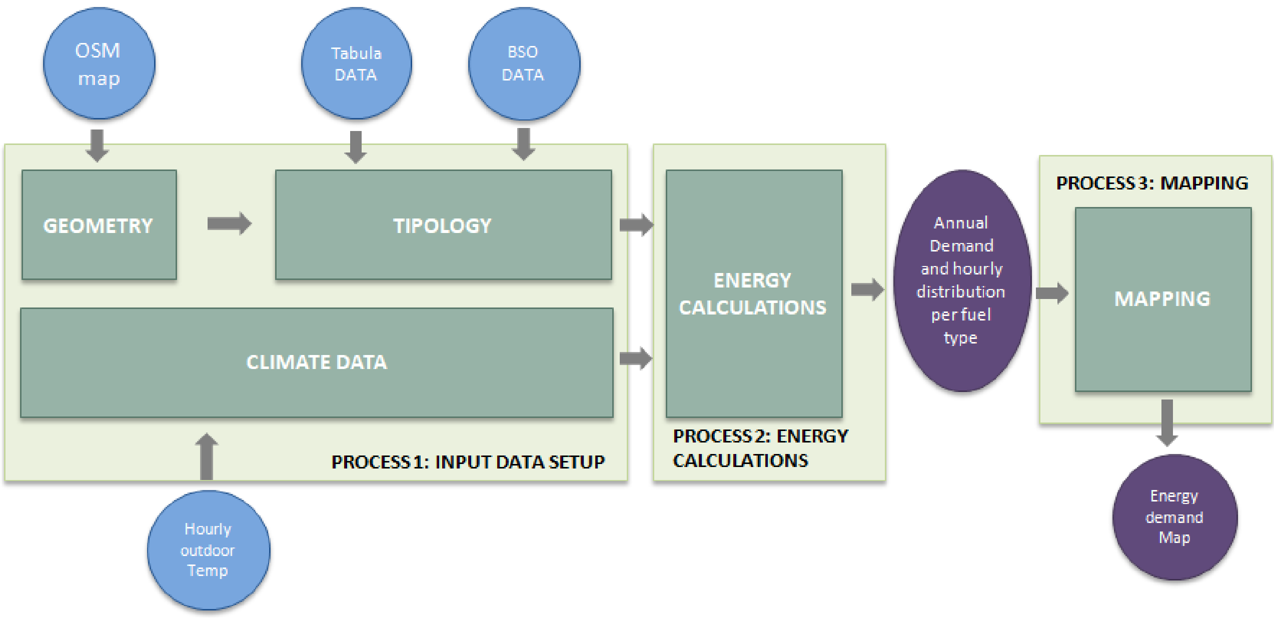


Figure 6 Methodology for domestic hot water, heating and cooling demand calculation

3.2.1 Process 1: Input Data setup

The first process is presented as the first processing of the data before the calculations. There are three main sub-processes in this process: geometry, typology and climate data processing. Table 4 presents the methodology's sub-process for heating and cooling demand calculation and each process is explained subsequently.

Table 4 Heating and cooling demand calculation

PROCESS 1: INPUT DATA SETUP	
Input	- A map from the location in Open Street Maps (OSM) with information about the geometry at least in OSM format compatible with JSON (JavaScript Object Notation). See the guide to download the data in section 11 - Annex I - Hourly outdoor temperature data from a whole year from the location
Procedure	1. (GEOMETRY) Complete (if necessary) the OSM cartography of the desired zones by completing information of as many buildings as possible. This will be done with the online OSM tool or the desktop version. The result will be publicly available. Download these data from OSM – refer to Annex I. Later, the geometry module extracts the geometrical data from the buildings 2. (TYPOLOGY) Selection of the typology of each residential building considering the country, the year of construction, and other parameters if available. This can be done by using table values from Tabula/Episcope and Building Stock Observatory (BSO) [8]. If the year of construction of the buildings is unknown, default values of year of construction of each country will be used (extracted from the Building Stock Observatory [8]) 3. (CLIMATE DATA) Automatized generation of the HDD and CDD values from temperature data. The process requires four temperature values. 1) Baseline Heating value (BHV) and 2) Baseline cooling value (BCV), each specific for the local case. For every hour of the year, 3) HDD_{hourly} = BHV – outdoor temperature, being 0 for values of temperature higher than BHV. 4) CDD_{hourly} = outdoor temperature – BCV, being 0 for values of temperature inferior to BCV.
Output	• OSM maps from selected areas with available data coverage in a GeoJSON file format • Typologies selected for each residential building from internal program variables • HDD and CDD yearly arrays of data for selected areas from internal program variables.

Geometry sub-process

The Energy planning tool requires the processing of a map with georeferenced information of the buildings and building usage. For this purpose, the maps offered by OSM are used. Before the execution of the tool, it is necessary to download the map corresponding to the municipality of interest. In Annex I, under Importing OSM data section, an explanation on how to download the OSM used by the tool is provided.

The geometry processing module extracts the geometric information from the OSM by analysing the geographical information. Additionally, the gross floor area, the surface of the façade, roofs and floors of the building are calculated in order to be used in the subsequent calculations. For every building in the selected location, only the building with a minimum quantity of data are selected (geometrical surface/area) and other parameters have default values in case of not having them (some can be configured, like the mean number of floors per building). This process couldn't have been done manually, considering the number of existing buildings in a single location, even for small municipalities.

Typologies sub-process

From OSM not only information about the morphology (shape) of the building is used; OSM often contain information about the use of the building. If available, this information can be found in different tags from the OSM. The tags analysed for the categorization of the buildings are the following: building, aerialway, aeroway, amenity, barrier, boundary, craft, emergency, geological, highway, historic, land use, leisure, man-made, military, office, place, power, public transport, railway, route, shop, sport, telecom, tourism and waterway.

Considering these tags, the buildings are classified into three main groups: residential, non-residential and discard. The "discard" group includes the buildings that are not conditioned and will not have an energy demand (this energy demand includes heating/cooling, domestic hot water and electricity uses). Thus, these buildings are ignored in the energy calculations in the next process. Besides, if there is enough information, the residential group is divided further into other groups with more information, which contributes to further refining the categorisation of the different typologies. The groups are: apartment buildings, single family houses, multi-family houses and terraced houses. For more information about how the buildings are organized considering the information of the OSM please refer to section 12.2.2.2 - Annex II.

It is important to note that this information is not always available, consequently, for some buildings the exact category is unknown. Thus, "by default" cases are needed in order to solve this issue.

Henceforth, the workflow depicted in Figure 7 is followed by deciding how building information is used on each building for the calculation of the energy demand:

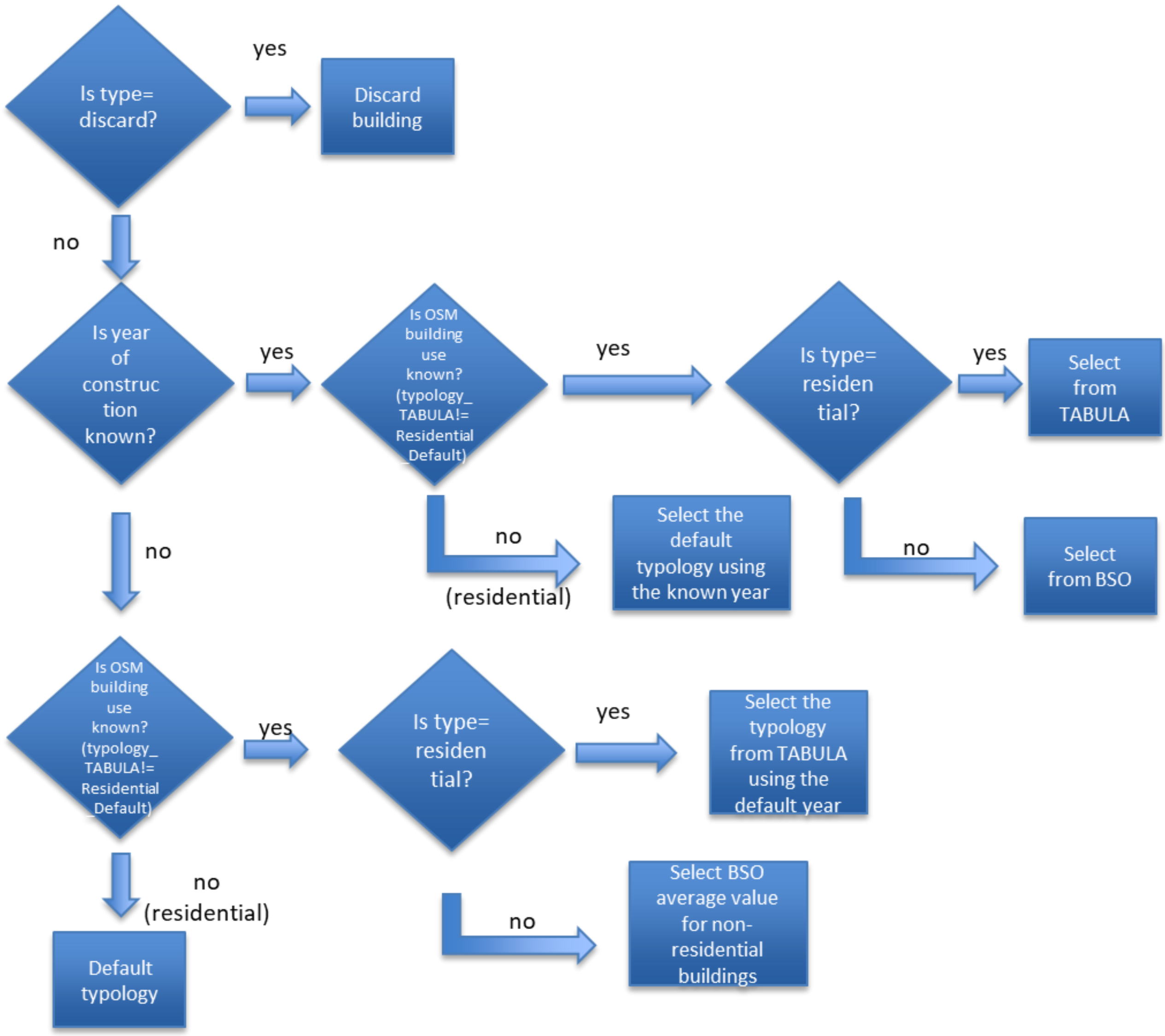


Figure 7 Logical decision tree in order to select the building typology

As seen in Figure 7, the aim is to use information of the typologies extracted from TABULA for residential buildings as this is the only use type covered in this data source. And then to use the information extracted from the Building Stock Observatory (BSO) for non-residential buildings. The buildings will be characterized taking this into account. For more information about the buildings' characterization, refer to section 12.2.2.2 - Annex II.

Climate data sub-process

The first step is to obtain the data for one complete year for the selected location. Unfortunately, the availability of reliable free weather data sources has declined during the last years, making the work of automatizing the data gathering sub-process impossible.

For the goal of obtaining valid values for the project, the data have been obtained from [18] MERRA-2 (Modern-Era Retrospective analysis for Research and Applications) initiative from SoDa (Solar radiation Data) website presented in Figure 8.

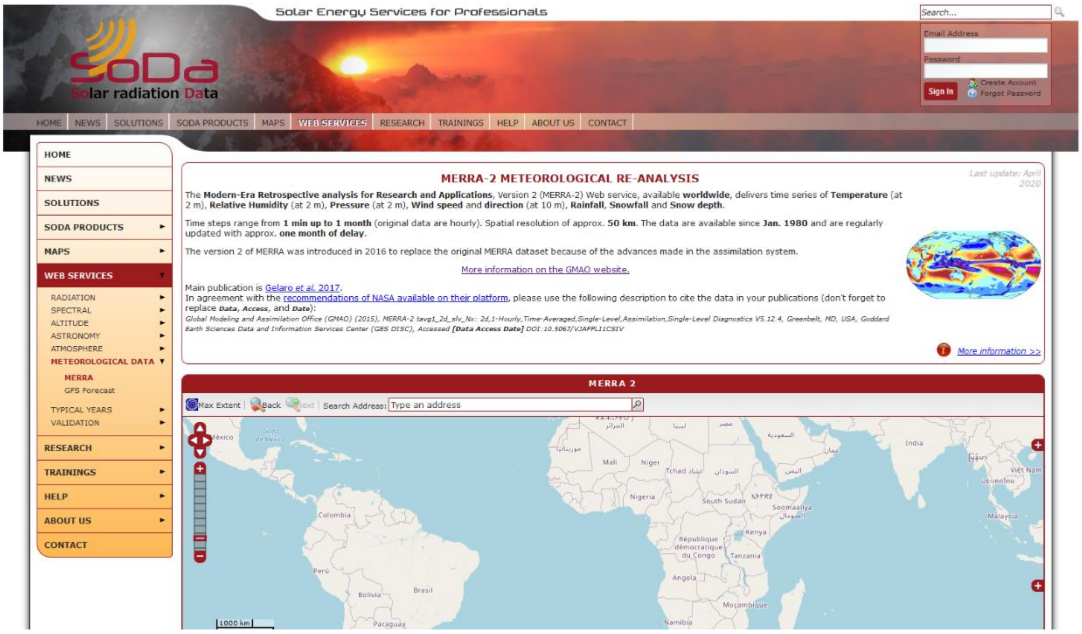


Figure 8 MERRA-2 in SoDa website [19]

On the website, a geographical location can be selected, as well as one whole year of weather data indicating the first and last days of a required year. Also, it is necessary to indicate the desired hourly time step. The downloading process is somewhat time consuming and results in an output in CSV file format. The next step is to format the CSV file in order to eliminate the unnecessary header, leaving only the row with the column names and the values themselves.

Once the data file is available and put in the resources folder of the program (typical with configuration files, CSV files as tables and so on), the data will be ready to be used. The energy tool itself through a specific module can find discontinuities, errors and other issues, and add one day to February if necessary (the processing of the final data requires a fixed number of energy values per year, and it is here where this must be fixed).

As it is detailed in Section 12.2.1 - Annex II, along with the comfort values of the location considered (these are tabulated values), the HDD and CDD values can be calculated for the whole year, and these values will be directly used for the energy needs calculations.

3.2.2 Process 2: Energy calculations

Table 5 presents the energy demand calculations for heating and cooling demands.

Table 5 Energy demand calculations

PROCESS 2: ENERGY CALCULATIONS	
Inputs	- A map from the location in Open Street Maps with information about the geometry at least in OSM format compatible with JSON - Typologies selected for each residential building (internal program variables) - HDD and CDD yearly arrays of data for selected areas (internal program variables)
Procedures	1. Calculation of the heating demand: $Q = P_{specific} * HDD_{hourly} / 1000$, where HDD_{hourly} is the HDD but for a specific hour of the day, and not the entire interval. This goes against the usual usage of HDD and CDD but keeping in mind that the hourly data as output is needed, instead of daily. The $P_{specific} = U *$ Surface of the building, where the Surface is the area of the envelope (roof and façade), that is extracted of the geometrical information from the OSM. The

	U value should be, in a first approach, a mean value depending on the typology building indicated beforehand. An example with real calculations can be seen in [20]. U is expressed in W/m^2 K, the surface in m^2, $P_{specific}$ in W/K, HDD in K/24 hours and Q in kW 2. Calculation of the cooling demands using a similar approach that for the heating demand but applying the corresponding CDD_{hourly}. 3. The hot water demand is also calculated following the next formula: $Q_{hotwater}= Q_{hotwater/m^2}$*Gross floor area. This $Q_{hotwater/m^2}$ is taken differently if the building is residential or non-residential using information from TABULA and Building Stock Observatory, respectively. 4. After having obtained the energy demand, the energy consumption is calculated per energy vectors: Gas, Oil, Biomass, Electricity, District Heating and Coal. These vectors are considered because they are the vectors indicated by TABULA. The energy consumption is calculated for the heating and for the hot water. The consumption of the cooling is considered electric and it is calculated in the electrical part 5. With the total energy consumption (heating and hot water) for all buildings, the percentage for each vector is calculated 6. Considering the hourly HDDs and CDDs, and the total values for the total heating and cooling demands, the energy hourly demand, and then consumption, are calculated

Outputs	• Set of hourly domestic hot water, heating and cooling demand generated per all the buildings in the municipality (8760 values per category in an array of data)
	• One map (in Python dataset format) with the following values per building:
	  • Cooling demand
	  • Heating demand
	  • Domestic hot water
	  • Heating consumption per vector
	  • Domestic hot water consumption per vector

More information about the energy calculations can be seen in Section 12.2.3 - Annex II.

3.2.3 Process 3: Data output and mapping

Table 6 presents the data output and mapping of the heating and cooling demands.

Table 6 Data output and mapping

PROCESS 3: DATA OUTPUT AND MAPPING	
Inputs	The building map with the elements only with necessary fields for the calculation (python dataset object with geometry, energy and typology values)
Procedures	1. Using GIS procedures, split the OSM map into 100m x 100m squares. Then, associate each building through its centroid to each square 2. Sum up each building heating and hot water demand value with the others belonging to the same square location 3. Creating a raster file with this information than can be visualized and also used for feeding other tools
Outputs	One single map with the heating & hot water demands generated with 100x100m² resolution

More information about the mapping can be seen in Section 12.2.4 - Annex II.

Examples of the output can be seen here: firstly the sum of the heating demand and hot water demand for each building in a municipality (see Figure 9) and, secondly, the sum of the heating demand and hot water demand but in this case for each 100m x 100m tile (see Figure 10). Both mapping demand are referred to Osimo Municipality.

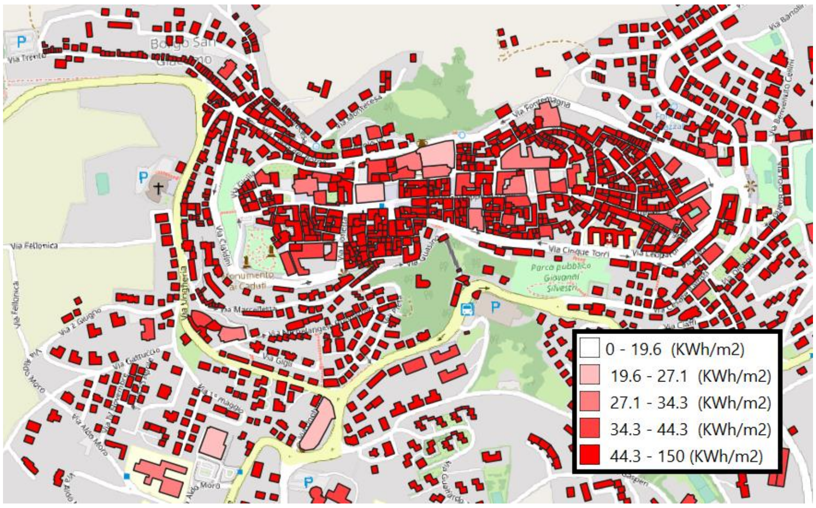


Figure 9 Example of Heating and Hot water demand map per building (Osimo municipality)

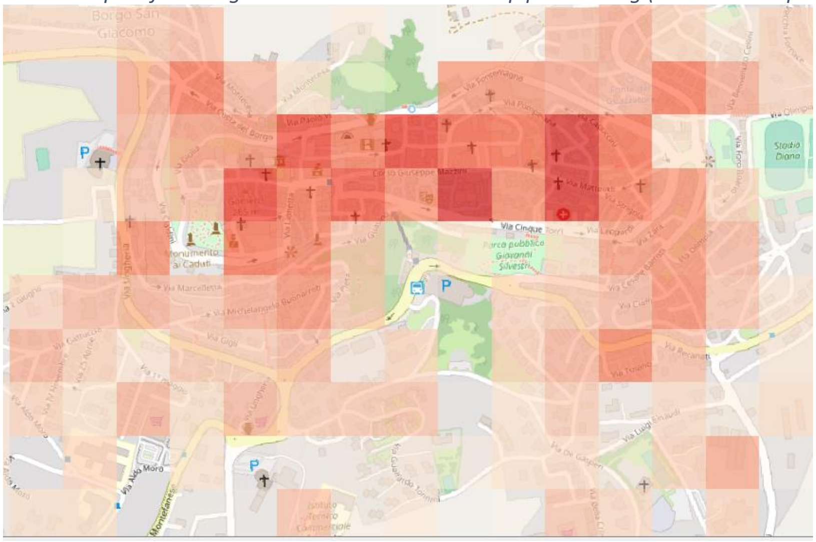


Figure 10 Heating and Hot water demand in 100m x 100m grid (Osimo municipality)

4 Heat generation

MUSE GRIDS Energy planning tool supply input

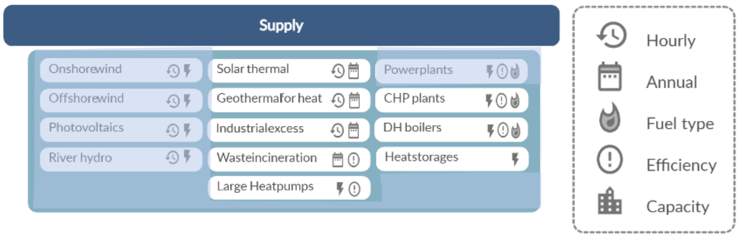
What is *heat generation supply*?

The supply covering space heating and Domestic Hot Water (DHW) demands primarily in buildings and industry. The demand can be satisfied in either individual or district systems and can also be supplied by industrial excess heat and/or CHP power plants, etc.

What data is needed for *heat generation supply*?

- Annual data*
- Hourly data*
- Fuel type*
- Capacity*
- Efficiency*

**Varies according to supply type*
*(See **Table 1** for data type specification)*



The heat generation technologies are grouped by application, so that first building level individual heat supply is presented, which is followed by different types of heat supply in DH systems. For heat generation only a generic approach is presented, as a detailed approach requires a specific data collection, depending on which local area is to be modelled.

4.1 Individual supply

This paragraph includes an overview of the most common heating systems encountered in the residential and tertiary sectors. To find more detailed descriptions and technical and economic parameters for the different individual heating supply technologies a good reference is the *Technology Data for Individual Heating Plants* catalogue published by the Danish Energy Agency [21] and updated regularly.

Data on common heating appliances are elaborated from the analyses performed within the Heat Roadmap Europe project [22]. In this context, common heating and cooling appliances are defined through a combination of specific technologies (e.g. heat pump) and energy carriers (e.g. natural gas), which can be associated with a specific appliance only indirectly.

For this work, appliances considered for heating purposes are boilers, DH systems, resistance heating systems (of which the supply technologies will be described in the next chapter), solar thermal systems and heat pumps. Boilers can be associated to energy vectors such as biomass, coal, oil and natural gas, whereas electricity can feed resistance heating systems and heat pumps.

Table 7 illustrates the share of demand satisfied using each technology and related energy carriers, with respect to the total heating demand of the EU28 residential sector as example.

Table 7 Use of appliances for heating purposes in the residential sector in EU28 [22]

Country	Boilers				District Heating	Resistance Heating	Heat Pumps	Solar Thermal
	Biomass	Coal	Oil	Gas				
Austria	31%	-	19%	22%	14%	10%	1%	3%
Belgium	7%	1%	36%	47%	-	8%	-	-
Bulgaria	46%	9%	1%	3%	20%	18%	2%	1%
Croatia	56%	-	6%	26%	7%	6%	-	-
Cyprus	0%	-	48%	-	-	5%	-	47%

Czech Republic	24%	10%	-	32%	23%	10%	1%	-
Denmark	23%	-	7%	17%	44%	7%	1%	-
Estonia	42%	1%	-	6%	35%	14%	1%	-
Finland	24%	-	9%	-	34%	30%	2%	-
France	21%	1%	18%	37%	4%	17%	2%	-
Germany	11%	1%	28%	44%	10%	4%	1%	1%
Greece	18%	-	51%	11%	1%	9%	2%	7%
Hungary	16%	3%	2%	60%	11%	8%	-	-
Ireland	1%	20%	42%	25%	-	11%	-	-
Italy	21%	-	7%	56%	3%	10%	3%	1%
Latvia	50%	1%	4%	9%	32%	4%	-	-
Lithuania	44%	5%	3%	8%	38%	1%	-	-
Luxembourg	5%	-	36%	55%	-	4%	-	-
Malta	-	-	-	-	-	100%	-	-
Netherlands	6%	-	-	85%	4%	4%	1%	-
Poland	14%	40%	1%	16%	24%	5%	-	-
Portugal	32%	-	22%	35%	-	7%	-	4%
Romania	61%	1%	1%	20%	16%	1%	-	-
Slovakia	2%	1%	-	65%	27%	4%	-	-
Slovenia	52%	-	17%	13%	8%	10%	-	1%
Spain	24%	1%	26%	37%	0%	9%	-	2%
Sweden	18%	-	1%	1%	49%	23%	8%	-
United Kingdom	5%	2%	9%	76%	-	9%	-	-
AVERAGE	**23%**	**3%**	**14%**	**29%**	**14%**	**12%**	**2%**	**3%**

Table 8 illustrates the share of demand satisfied using each technology and related energy carriers, with respect to the total heating demand of the EU28 tertiary sector as example.

Table 8 Use of appliances for heating purposes in the EU28 tertiary sector [22]

Country	**Boilers**				**District Heating**	**Resistance Heating**	**Heat Pumps**	**Solar Thermal**
	Biomass	**Coal**	**Oil**	**Gas**				
Austria	7%	-	13%	28%	43%	6%	1%	2%
Belgium	1%	-	27%	57%	4%	8%	1%	2%
Bulgaria	11%	-	4%	20%	24%	13%	2%	29%
Croatia	3%	-	16%	42%	11%	8%	-	18%
Cyprus	29%	-	43%	-	-	14%	-	-
Czech Republic	4%	1%	-	58%	25%	10%	-	-
Denmark	4%	-	4%	14%	66%	10%	-	1%
Estonia	3%	-	10%	27%	47%	7%	-	3%
Finland	5%	-	13%	2%	59%	18%	-	2%
France	4%	-	20%	57%	7%	11%	-	1%
Germany	10%	-	31%	45%	6%	6%	1%	1%
Greece	9%	-	23%	30%	-	23%	2%	13%
Hungary	11%	-	2%	74%	8%	4%	1%	-
Ireland	4%	2%	28%	49%	2%	8%	1%	5%
Italy	3%	-	7%	76%	4%	6%	1%	4%
Latvia	21%	2%	11%	26%	34%	4%	-	2%
Lithuania	12%	12%	2%	16%	49%	7%	-	2%
Luxembourg	-	-	20%	43%	33%	3%	-	-
Malta	-	-	71%	-	-	14%	-	-

Netherlands	4%	-	2%	81%	4%	7%	2%	-
Poland	5%	15%	10%	38%	23%	6%	1%	2%
Portugal	13%	-	23%	35%	4%	21%	-	3%
Romania	1%	-	6%	64%	17%	7%	1%	3%
Slovakia	1%	13%	2%	70%	7%	7%	1%	-
Slovenia	7%	-	28%	17%	17%	17%	-	14%
Spain	4%	-	30%	40%	1%	17%	-	6%
Sweden	1%	-	14%	4%	53%	26%	1%	-
United Kingdom	1%	-	8%	71%	5%	13%	1%	1%
AVERAGE	**6%**	**2%**	**17%**	**39%**	**20%**	**11%**	**1%**	**4%**

Finally, Table 9 shows the percentage share of demand satisfied using each technology and related energy carriers, with respect to the total heating demand of both the residential and tertiary sector in Europe. Note that minor imperfections in balances of percentages are related to rounding of decimal figures.

Table 9 Use of appliances for heating purposes [22]

Country	Boilers				District Heating	Resistance Heating	Heat Pumps	Solar Thermal
	Biomass	**Coal**	**Oil**	**Gas**				
Austria	24%	-	17%	24%	23%	9%	1%	3%
Belgium	6%	1%	34%	50%	1%	8%	-	1%
Bulgaria	38%	7%	2%	7%	21%	17%	2%	7%
Croatia	49%	-	7%	28%	7%	6%	-	3%
Cyprus	8%	-	47%	-	-	8%	-	37%
Czech Republic	19%	8%	-	39%	23%	10%	-	-
Denmark	19%	-	7%	17%	49%	7%	1%	-
Estonia	32%	1%	3%	12%	38%	12%	1%	1%
Finland	18%	-	10%	1%	42%	27%	2%	1%
France	16%	-	19%	43%	4%	15%	1%	-
Germany	11%	1%	29%	44%	9%	5%	1%	1%
Greece	17%	-	47%	14%	1%	11%	2%	8%
Hungary	14%	2%	2%	64%	10%	7%	-	-
Ireland	2%	15%	38%	32%	1%	10%	1%	2%
Italy	17%	-	7%	61%	3%	9%	2%	1%
Latvia	42%	1%	6%	14%	33%	4%	-	1%
Lithuania	35%	7%	3%	11%	41%	2%	-	1%
Luxembourg	4%	-	31%	51%	12%	4%	-	-
Malta	-	-	50%	-	-	40%	-	-
Netherlands	5%	-	1%	84%	4%	5%	1%	-
Poland	12%	34%	3%	21%	24%	6%	-	1%
Portugal	25%	-	22%	35%	1%	12%	-	3%
Romania	49%	1%	2%	29%	16%	2%	-	1%
Slovakia	2%	5%	1%	67%	20%	5%	-	-
Slovenia	43%	-	19%	14%	10%	11%	-	3%
Spain	19%	1%	27%	38%	-	11%	-	3%
Sweden	12%	-	5%	2%	51%	24%	5%	-
United Kingdom	4%	1%	9%	75%	1%	10%	-	-
AVERAGE	**19%**	**3%**	**16%**	**31%**	**16%**	**11%**	**1%**	**3%**

In the generic approach, the heating demand at national level taken from National Energy and Climate Plans [23] can be scaled down to municipality level based on population data, and the resulting municipal heating demand can be split among different technologies and appliances adopting the percentage values above, considering the distribution at municipal level to be the same as at national level.

In a detailed approach, data can be gathered for example from Sustainable Energy Action Plans (SEAP) or Sustainable Energy and Climate Action Plans (SECAP) prepared by most of European municipalities following the signature of the Covenant of Mayors [23]. These documents include an analysis of the energy systems of the municipalities in terms of electricity, heating and cooling, mobility among which also the details on total heating demand. This approach avoids scaling national values to municipality level based on population and uses shares of different heating appliances and fuels/energy carriers which avoids using national average data in contrast to the generic approach.

4.2 District heating supply

For DH supply basically, all technologies that can provide the required temperature level of heat can be used. The DH supply needs to be able to cover the winter peak heat demand of the district heating system including heat losses in the network. Typically, district heating systems use a combination of different supply technologies, where some technologies provide the base load, while others provide the peak load. Normally, a base load plant has a low operation cost and a high investment cost, while a peak load plant is the opposite with high operation costs and a low investment cost. Due to the higher investment cost, it will be too expensive to build a baseload plant that covers the full peak heat demand, as the full capacity will not be used in most of the year. Thus, a peak load plant with a higher operation cost can be a cheaper solution as it will only operate in few days a year and the investment cost are significantly lower. Appropriate operation of a heat storage can accomplish some of the same benefits – but cannot give the same contingency reserve as a boiler, thus, to ensure that the heat costumers always have heat, it is often seen that DH suppliers have a boiler that can cover the peak heat demand in case of interruption on the cheaper production units.

The most basic supply plants are heat only boilers that can handle a variety of fuels such as oil, natural gas, coal, waste, electricity, biogas and biomass. The technology differs for handling the different fuel types, providing a variety in efficiency and flexibility. For example, fuel boilers typically have conversion efficiencies around 90-100% of the fuel input and power plants around 35-45%. A way to increase the fuel conversion efficiency is to use combined heat and power (CHP) plants, where instead of producing heat with an efficiency of 90-100% in boilers and electricity with an efficiency of 35-45%, a CHP plant with and overall efficiency of 95% can be used. Please note that in some countries, biomass boilers can have efficiencies above a 100%, which is because the efficiency is calculated based on the lower calorific value of the fuel. Thus, a biomass boiler with flue gas condensation can have an efficiency around 115%. For technology-specific data on efficiencies, please look in Generation of Electricity and District Heating [24] .

Another important supply technology is excess heat from waste incineration and high temperature industrial processes. These sources are typically cheaper as the heat is an excess product of an already ongoing process. They typically also have a production profile that is constant over the year, meaning that they are usually used as baseload production plants. With reduced temperatures in DH and increases in renewable electricity supply, utilizing excess heat from lower temperature sources is also an option. Examples of low-temperature sources are e.g. metros, waste water treatment, data centres, food production and retail. An important contribution to this source of heat is found in the ReUseHeat project which explores unconventional heat potential [25]. When using low-temperature sources, a compression heat pump is often used to boost the heat output to the needed temperature level of the DH system.

Some renewable energy sources are also feasible in DH where solar collectors and geothermal heat are important. The heat production from solar collectors follows the solar radiation and thus the production varies a lot from hour to hour and is evidently higher in the summer months. To avoid overinvestments in solar collectors for DH, they are typically dimensioned to cover the domestic hot water demand in the summer, however this depends on the availability of heat storages in the system and other heat sources. With seasonal heat storages, the solar collectors can be utilised better and could be dimensioned to cover higher shares than the summer domestic hot water demand.

In areas with subsurface geothermal reservoirs, these can potentially be used for DH purposes as well. Geothermal is relatively investment heavy, due to drilling costs and risks in terms of resources availability, however when successful, geothermal can result in a stable and renewable heat supply.

Finally, large-scale compression heat pumps are also relevant in future DH systems. With increasing renewable shares in the electricity production, the heat pumps become an efficient way to convert renewable electricity to heat and to provide flexibility for the electricity system. In relation to heat pumps it is important to consider a relevant heat source for the heat pump, which could be e.g. seawater, solar, geothermal or low-temperature industrial or tertiary sector excess heat.

To find more detailed descriptions and technical and economic parameters for the different DH supply technologies a good reference is the *"Technology Data for Generation of Electricity and District Heating"* catalogue published by the Danish Energy Agency [24] and updated regularly.

4.3 Industrial excess heat

An important heat source for DH is industrial excess heat, as it can be available at high temperatures and low economic costs. The methods for mapping the available excess heat from industrial sources developed for the PLANHEAT project [26] are hereby presented. Two different methods are described below, to consider different levels of data availability. For large industries, the method is based on CO_2 emissions that are correlated to the energy consumption of the plant in line with the Heat Roadmap Europe project [22]; for smaller industrial facilities, a correlation has been retrieved between available excess heat and the footprint area of buildings based on the experience of RINA-C in carrying out energy audits at smaller industrial facilities.

Industrial excess heat assessment based on CO_2 emissions

The method for larger facilities is based on CO_2 emission values taken from the E-PRTR (European Pollutant Release and Transfer Register) database [27] that includes data on pollutant releases from industries belonging to nine industrial macro-sectors (energy, production and processing of metals, mineral industry, chemical industry, waste and wastewater management, paper and wood production and processing, intensive livestock production and aquaculture, animal and vegetable products from the food and beverage sector, and other activities).

The CO_2 emissions are directly connected to the fuel input of the specific industry through the emission factor for the fuel used; adapting values from IPCC, the following conversions are used:

- 1 tCO_2 corresponds to 4.95 MWh of input natural gas (EF 0.202 $kgCO_2/kWh$);
- 1 tCO_2 corresponds to 3.56 MWh of input oil (EF 0.281 $kgCO_2/kWh$);

- 1 tCO_2 corresponds to 2.89 MWh of input coal (EF 0.346 $kgCO_2/kWh$).

Once the fuel type is known, the input energy can be calculated as described above.

After that, the amount of available excess heat can be estimated by considering the amount of heat that is not recoverable because used in the industrial process or lost into the environment.

Therefore, the formula used to estimate available excess heat is:

$$WH_{avail} = E_{CO_2} \cdot \frac{1}{EF_{fuel}} \cdot (1 - rec_{int})$$

Where:

- WH_{avail} is the annual amount of excess heat available (MWh/y);
- E_{CO_2} is the annual amount of CO_2 emitted (tCO_2/y);
- EF_{fuel} is the fuel emission factor (tCO_2/MWh);
- rec_{int} is the fraction of heat not recoverable because used in the industrial process or lost into the environment (%)

For each industrial sector, the typical fuel used (and, therefore, the related emission factor) as well as the typical rec_{int} factor are presented in Table 10, together with the typical temperature level of the available excess heat. In case more accurate data regarding the fuel used and/or the degree of internal heat recovery and/or the temperature level are available, the values obtained will be more accurate.

Table 10 Default values per industrial sector to assess the excess heat supply based on CO_2 emissions

Sector	**Fuel typical**	$\frac{1}{EF_{fuel}}$ **[MWh/tCO_2]**	rec_{int} **typical**	**Temperature Level**
Animal and vegetable products from the food and beverage sector	NG	4.95	10%	Low (<40°C)
Chemical industry	NG	4.95	25%	High (>70°C)
Energy sector	mix	3.80	50%	Medium (40-70°C)
Intensive livestock production and aquacul-ture	NG	4.95	10%	Low (<40°C)
Mineral industry	coal	2.89	25%	Medium (40-70°C)
Refining of mineral oil	oil	3.56	50%	High (>70°C)
Other activities	NG	4.95	25%	Medium (40-70°C)
Paper and wood production processing	NG	4.95	25%	Medium (40-70°C)
Production and processing of metals	coal	2.89	25%	High (>70°C)
Waste and wastewater management	NG	4.95	25%	Low (<40°C)

Assessment based on the footprint area of buildings

For smaller industries, not included in the E-PRTR database, the selected method is based on the area of the industrial building and on typical values of fuel consumption per unit of surface, available from a database of energy audits carried out by RINA-C. Since buildings of the same area can have a significantly different energy input based on the number of working hours (represented, e.g., by the number of daily working shifts), also this factor is considered in the estimation of the available excess heat.

Therefore, the formula used to estimate available excess heat is:

$$WH_{avail} = A_{ind.build.} \cdot FC_{spec} \cdot N_{shifts} \cdot (1 - rec_{int})$$

Where:

- WH_{avail} is the annual amount of excess heat available (MWh/y);
- $A_{ind.build.}$ is the footprint area of the industrial building (m^2);
- FC_{spec} is the annual fuel consumption per unit of building area and working shift ($MWh/m^2/y/shift$);
- N_{shifts} is the number of daily shifts (-);
- rec_{int} is the fraction of heat not recoverable because used in the industrial process or lost into the environment (%)

For each industrial sector, the typical values for FC_{spec}, N_{shifts} and rec_{int} are presented in Table 11. The values obtained will be more accurate, if specific data regarding the fuel consumption, the number of daily shifts and/or the degree of internal heat recovery are available.

Table 11 Default values per industrial sector to assess the excess heat supply in case CO_2 emissions are not known

Sector	FC_{spec} typical [$MWh/m^2/y/shift$]	N_{shifts} typical	rec_{int} typical
Manufacture of food products, beverages and tobacco products	0.25	3	10%
Manufacture of textiles, apparel, leather and related products	0.20	2	25%
Manufacture of wood and paper products, and printing	0.20	2	25%
Manufacture of coke, and refined petroleum products	0.25	3	25%
Manufacture of chemicals and chemical products	0.20	2	25%
Manufacture of pharmaceuticals, medicinal chemical and botanical products	0.20	2	25%
Manufacture of rubber and plastics products, and other non-metallic mineral products	0.25	3	25%
Manufacture of basic metals and fabricated metal products, except machinery and equipment	0.25	3	25%
Manufacture of computer, electronic and optical products	0.15	2	25%
Manufacture of electrical equipment	0.15	2	25%
Manufacture of transport equipment	0.20	3	25%
Electricity, gas, steam and air-conditioning supply	0.25	3	25%
Generic industrial area	0.15	2	25%

5 Power generation

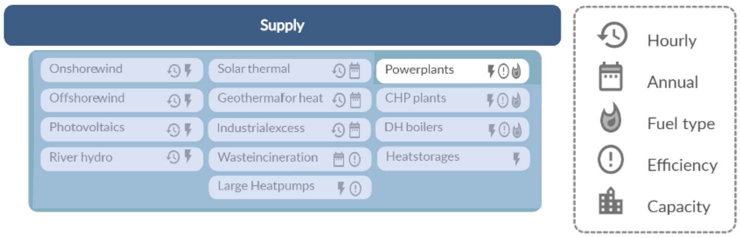
MUSE GRIDS Energy planning tool supply input

What is *power generation supply*?
The supply covering the local electricity demand by means of Power Plants.

What data is needed for *power generation supply*?

- Fuel type
- Capacity
- Efficiency

*(See **Table 1** for data type specification)*



For power generation, the production types will be split between non-renewable (Chapter 5) and renewable (Chapter 6). In terms of non-renewable electricity production, the main category is power plants. What is needed in the MUSE GRIDS Energy planning tool is the existing capacity in MW (aggregated for the area), efficiency (average for all plants), and fuel types (the shares of each fuel type). The data input for this production category is therefore simpler, as it does not need an hourly distribution.

5.1 Generic approach

For the generic approach, data from the IEA annual electricity information statistics [28] can be used. The reference is only available through payment, but many libraries has access to the data. In the statistics, national data on net maximum electricity generating capacity in GW divided by types of fuel (natural gas, coal, waste etc.) and generation type (steam turbine, gas turbine etc.). The annual production and fuel input for each type is available as well, thus the efficiencies can be estimated. Alternatively, general technology-based efficiencies from the Technology Data Catalogue [24] can be used. As with the other generic approaches, the total capacity of power generation needs to be divided by e.g. the population share of the whole country.

5.2 Detailed approach

For a detailed approach on power generation, site-specific data can be used instead of the national statistics. Typically, these can be found by searching in the local area or contacting the electricity transmission/distribution operators, or they can be found in the Sustainable Energy Action Plans (SEAP) or Sustainable Energy and Climate Action Plans (SECAP) prepared by most of European municipalities following the signature of the Covenant of Mayors [23] . Alternatively, in 2018, The World Resource Institute established a Global Power Plant Database [29], which includes around 30,000 georeferenced plants in 164 countries. Figure 11 shows a partial mapping of the database. The plants are split by fuel types: nuclear, geothermal, coal, hydro, natural gas, oil and biomass. The database does not directly include the efficiency of the plants, but for many of them both the annual power generation and fuel consumption is estimated, making it possible to estimate an efficiency for these plants.

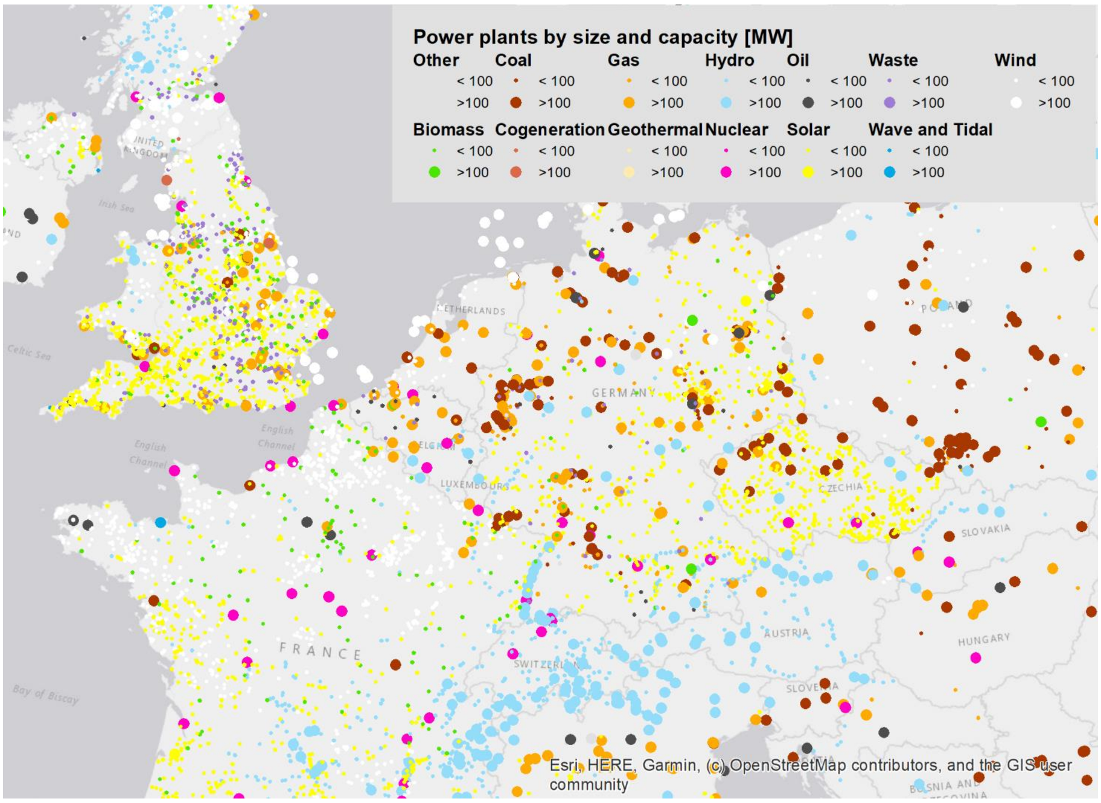


Figure 11 Global Power Plant Database example. Map showing power plants by size and capacity [MW]

Finally, there are some interesting references for general energy consumptions and demand data. One of the references, is the Open Power System Data [30] website [31], where many different data packages are available, both related to energy production and demand. Another notable reference is the Electricity Map [32], where energy demand and production data from various sources, are collected into a common map, where the data can be downloaded.

In general, the needed input to the MUSE GRIDS Planning tool is the total power plant capacity is needed, with an average efficiency and a distribution of fuel sources. For example, if an area has the following three power plants:

1. Capacity: 200 MW, Efficiency: 0.45, fuel: coal
2. Capacity: 75 MW, Efficiency: 0.40, fuel: natural gas
3. Capacity: 400 MW, Efficiency: 0.33, fuel: natural gas

Then the MUSE GRIDS Planning tool inputs can be calculated as the following:

- Total capacity: 200 + 75 + 400 = **675 MW**
- Average efficiency: (0.45 + 0.40 + 0.33) / 3 = **0.39**
- Fuel factors:
    - Coal: 200/675 = **0.3**
    - Natural gas: (400+75)/675 = **0.7**

If available, the best way to calculate the fuel factors, is to base the shares on the annual fuel consumption, instead of the maximum capacities of the plants, as this indirectly consider the operation hours of each plant.

6 Renewable energy

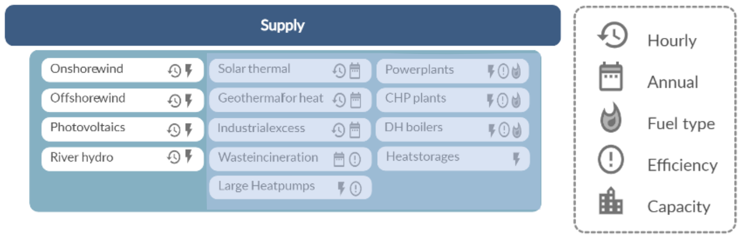
MUSE GRIDS Energy planning tool supply input

What is *renewable energy supply*?
The supply that can cover energy demands through the usage of renewable energy sources.

What data is needed for *renewable energy supply*?

- Hourly data
- Capacity
- Efficiency*

**Varies according to supply type*
*(See **Table 1** for data type specification)*



In terms of renewable energy resources, the MUSE GRIDS Energy planning tool requires both existing and potential capacity. Renewable energy resources are classified into wind power, photovoltaics, hydro power, geothermal and biomass resources. For all, both a generic approach and a detailed approach is presented. For all of these resources, the existing capacity in MW and the annual production GWh/year is given, while for wind, photovoltaics and hydro an hourly production profile is also needed in, to estimate the fluctuating nature of these energy sources.

6.1 Generic approach

6.1.1 Wind power

For wind power, two main parameters are required; the existing capacity in MW and the hourly profile for the wind production. The existing capacity for onshore wind farms can be found in The Wind Power Database [33] and for offshore wind in the Global Offshore Renewables website [34].

The hourly wind production can be estimated using Renewables.ninja [35], where the global NASA dataset MERRA-2 (Modern-Era Retrospective analysis for Research and Applications) [36] is used to estimate wind profiles for any place in the world. The user needs to choose wind, dataset, year, capacity, hub height and turbine model and run the model, either through the website or the automated tool – see Figure 12. The output is the hourly production profile in CSV format, which can be saved to be used in the MUSE GRIDS Energy planning tool. For users of the MUSE GRIDS Energy planning tool, downloading hourly distributions from Renewables.ninja has been directly integrated into the tool, an explanation of how to use this function is further detailed in [37].

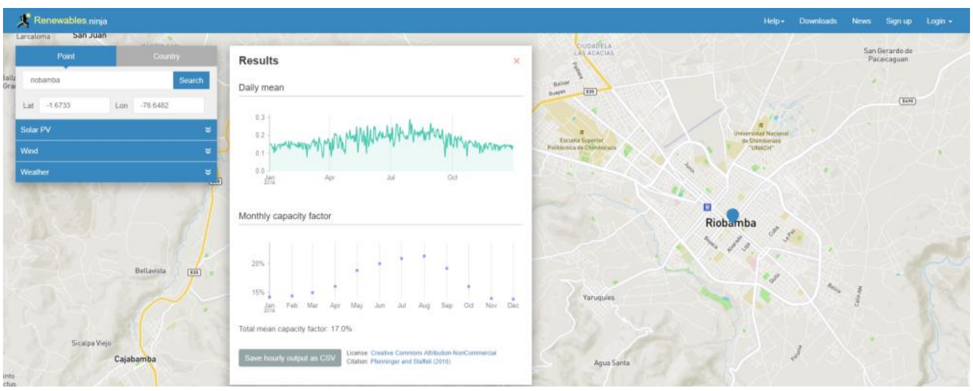


Figure 12 Example of renewables.ninja wind data

For a geographic mapping of resource availability, the Global Wind Atlas [38] can be used to download raster data files for specific countries both for wind speeds and power density. This data is typically expressed in annual averages.

6.1.2 Photovoltaics

The hourly production from photovoltaics can be estimated using Renewables.ninja [39]. For photovoltaics it is possible to use two different datasets; the MERRA-2 data for global use and the CM-SAF (SARAH-E)[40] for Europe, where the quality of data is higher. See map attached in Figure 13.

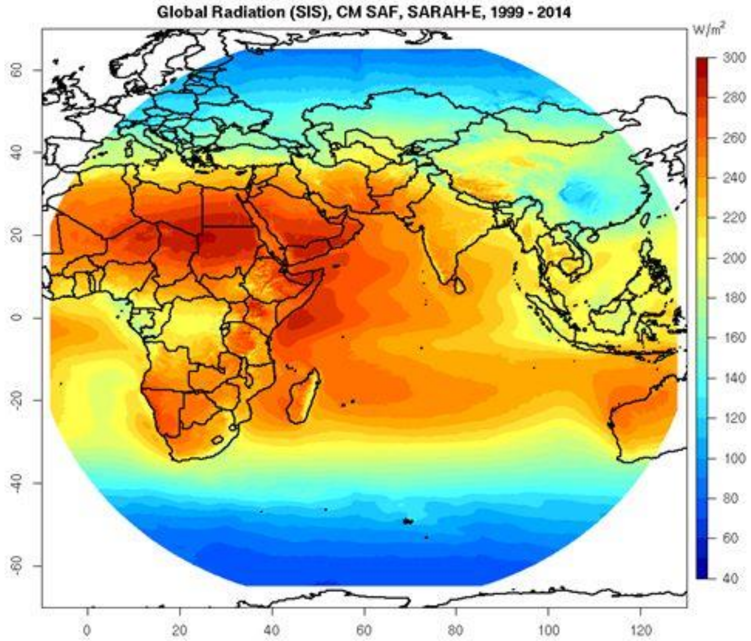


Figure 13 Example of the Global Surface Solar Radiation data set made by CM SAF and JRC [40]

To get the temporal production profile the user needs to add a capacity in kW, a system loss fraction, tilt and azimuth values. The output is the hourly production profile in CSV format which can be saved to be used in the MUSE GRIDS Energy planning tool.

A good alternative, to using Renewables.ninja is to use PV-GIS [41] tool developed by the JRC. Figure 14 shows global irradiation values in Europe on a theoretical optimally inclined south-oriented solar module, as derived by PV-GIS. The map is made available also with resolution of 1 km, thus suitable for GIS-based elaborations.

On the other hand, for a generic approach, Table 12 provides an insight of country-average global irradiation values, calculated for the optimum angle for each country respectively.

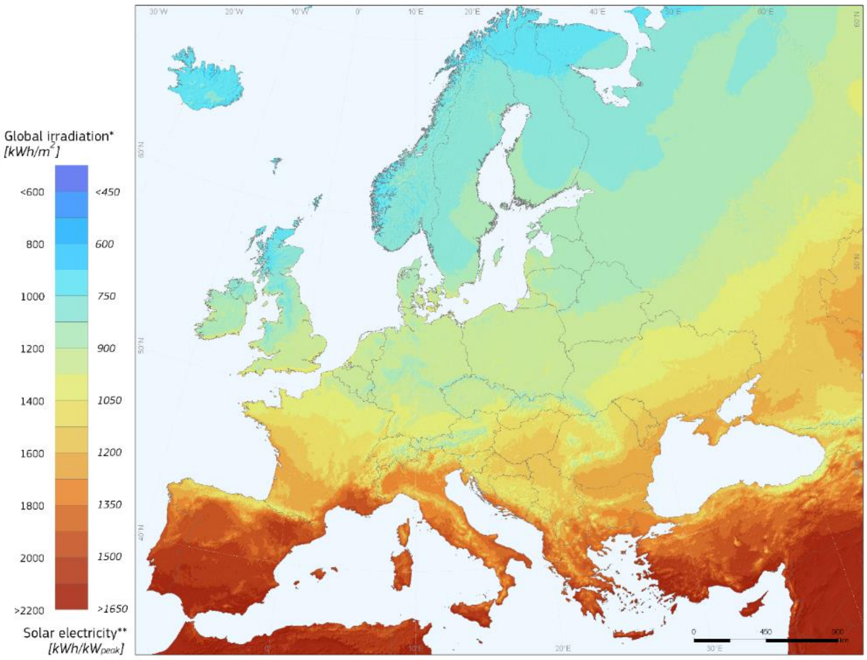


Figure 14 Global Irradiation in Europe from PVGIS [38]

Table 12 Country-average global irradiation in [kWh/m2]

Country	Global Irradiation
Austria	1,325
Belgium	1,238
Bulgaria	1,631
Croatia	1,570
Cyprus	2,217
Czech Republic	1,256
Denmark	1,211
Estonia	1,151
Finland	1,054
France	1,513
Germany	1,251
Greece	1,897
Hungary	1,490
Ireland	1,174
Italy	1,750
Latvia	1,175
Lithuania	1,183
Luxembourg	1,243
Malta	2,155
Netherlands	1,242
Poland	1,252
Portugal	1,996
Romania	1,496
Slovakia	1,333
Slovenia	1,444
Spain	1,948
Sweden	1,084
United Kingdom	1,153

6.1.3 Hydro power

The existing hydro power capacity can be found in the same sources as the power generation, presented in Chapter researchers from TU Delft have assessed the global potential for hydro power [42] and the data can be downloaded from [43]. The dataset is an assessment of hydropower plants locations based on an elevation dataset from GMTED2010 (Global Multi-resolution Terrain Elevation Data) [44] dataset and runoff data by the Global Runoff Data Centre. Figure 15 shows a global map of the hydropower potential distribution, taken from [42].

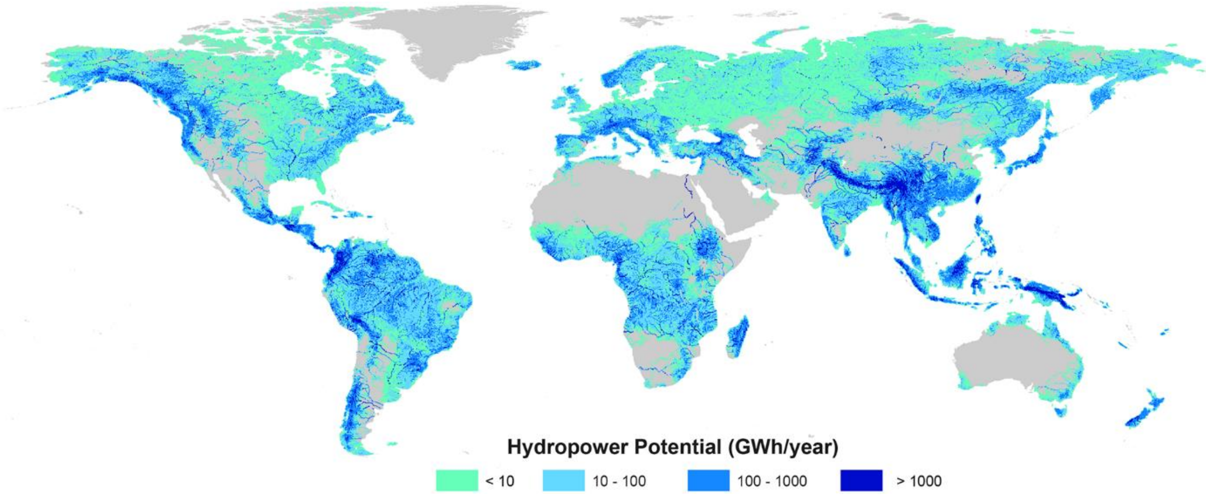


Figure 15 Global map of gross hydropower potential distribution [42]

6.1.4 Geothermal power plants

The JRC has a global list of geothermal power plants with coordinates, capacities and temperature levels [45]. Typically, these plants are only relevant in areas with high-temperature resources deep underground such as Iceland, California, and the Philippines. Currently, around 24 countries have geothermal power plants. Figure 16 shows a map of the European geothermal power plants.

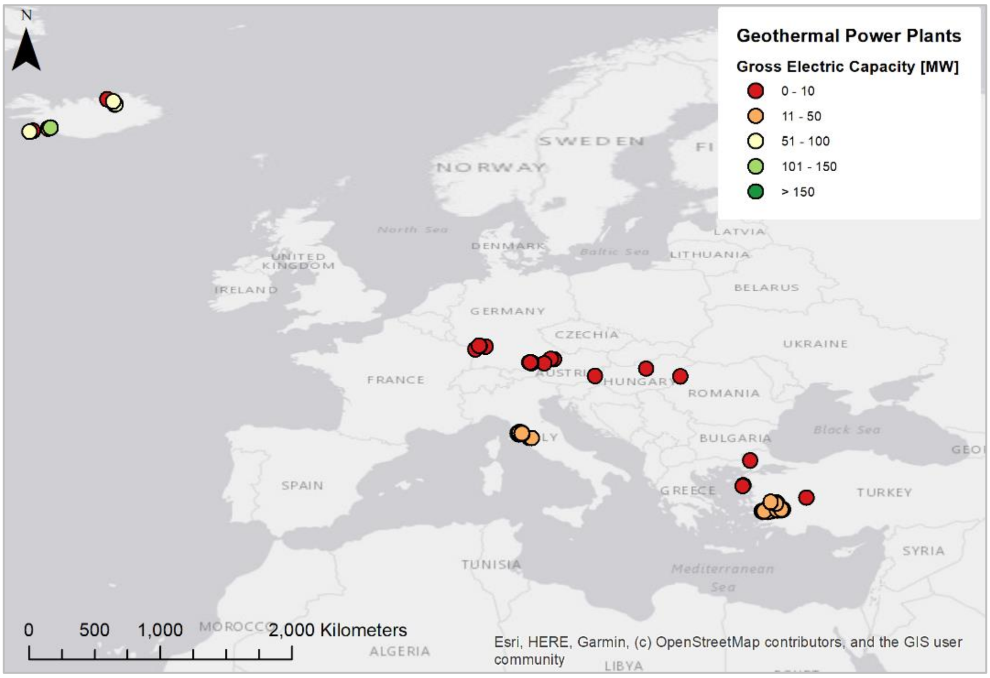


Figure 16 Geothermal Power Plants from [45]*. Own illustration of Europe.*

6.1.5 Biomass plants

To find the capacities of existing biomass plants, the same references as in the power generation (Chapter 5) can be used. There are several European projects that assess the potentials for biomass. One analysis from 2019 was made looking into sustainable crop residues for energy purposes [46]). The dataset on the statistical NUTS2 level is available from [47]. The Bioboost project [48] , finished in 2015, also mapped different biomass potentials in Europe. The official website for the data is [49], however it is also available from the Heat Roadmap Europe website [50], where information on potentials of straw, pruning residues, forest residues and biowaste [PJ] can be found on NUTS3 level.

6.2 Detailed approach

6.2.1 Wind power

Existing plants

Due to the discrete number of this kind of plants, the solution presented in the generic approach is valuable also for the detailed approach, since the location and power of wind power plants is known at European level. More specific data compared to those available at EU level can be found for example from Sustainable Energy Action Plans (SEAP) or Sustainable Energy and Climate Action Plans (SECAP) prepared by most of European municipalities following the signature of the Covenant of Mayors [23]. These documents typically include the power of existing renewable-based power plants installed at municipality level.

Potential new plants

The following section gives a short overview of the algorithms that can be used to estimate the potential for new wind power plants in a local area. The kinetic energy associated to the movement of a mass of air could be converted in electrical energy by the wind turbines. Wind turbines are classified by the position of the rotation axle (almost exclusively horizontal), the numbers of blades (most frequently three) and the power level and these characteristics influence the evaluation of the energy potential of this RES.

In this document the wind turbines with rotor swept area of less than 200 m^2 and having a rated power below about 50 kW are considered. The aerogenerators with these characteristics are classified as small wind turbines [51].

The algorithm used to evaluate the yearly potential energy at a specific height for wind turbines (both with horizontal or vertical axle) is the following:

$$E_h = 8760\, \eta_m\, \eta_{el}\, \eta_{aux} \sum_{w=w_{low}}^{w_{high}} P_h(w) f(w)$$

Where:

- E_h is the technical potential [W h];
- 8760 are assumed to be the yearly operative hours of the wind turbine [h];
- w is the wind speed [m/s];
- $P_h(w)$ is the potential power [W];
- $f(w)$ is the Weibull distribution (that is the probability distribution of wind's velocity about specific locality and height) [-];
- w_{high} is the maximum velocity with which the wind turbine can work and is named "cut off" velocity [m/s];
- w_{low} is the minimum velocity with which the wind turbine can work and is named "cut in" velocity [m/s];
- η_m is the mechanical efficiency linked to the shaft and the gear box [-];
- η_{el} is the electrical efficiency of the alternator [-];
- η_{aux} is the efficiency of the auxiliaries [-].

Both the maximum and the minimum velocity in the formula above depend on the wind turbine type however their values could be assumed respectively about 25 m/s and 4 m/s for a preliminary evaluation.

The potential power is determined by the formula:

$$P_h = \sum_{w=w_{low}}^{w_{high}} \frac{1}{2}\, \rho\, A\, w^3\, C_p$$

Where:

- ρ is the air density [kg/m^3];
- A the swept area - I.e. the area of the wind turbine that is orthogonal to the direction of the wind (approximated as a circle if the axel is horizontal and as a square area if the axel is vertical) [m^2];
- C_p is named power coefficient, it is the ratio between the maximum power that a wind turbine can produce and the whole available power from the wind and its maximum theoretical value is equal to 0.593 [-] (Magdi Ragheb & Adam M. Ragheb, 2011).

The Weibull distribution is described by the following equation:

$$f(w) = \left(\frac{\beta}{\eta}\right)\left(\frac{w}{\eta}\right)^{\beta-1} e^{-\left(\frac{w}{\eta}\right)^{\beta}}$$

Where β and η are respectively the shape parameter and the scale parameter. They are obtained from the database and assume different values at different heights at the same locality.

The height at which the wind turbine is placed should be set. The β and η parameters are available from the CENER database at 10 m, 50 m, 100 m, 150 m and 200 m from the ground; so if the height set is equal to a value present in the database the equation above can be use. In the other cases, the reconstruction of the wind velocity profile is necessary to calculate the technical potential. The wind velocity at a specific height can be evaluate with the following formula:

$$\overline{w_z} = \overline{w_0}\left(\frac{z}{z_0}\right)^{\alpha}$$

Where:

- $\overline{w_z}$ is the average wind velocity at a specific height z [m/s];
- $\overline{w_0}$ is the average wind velocity at the reference height z_0 [m/s];
- α is the coefficient depending on the installation site [-].

The α coefficient is evaluate knowing the wind average velocity at two specific heights with the following equation:

$$\alpha = \frac{log\left(\frac{\overline{w_1}}{\overline{w_0}}\right)}{log\left(\frac{z_1}{z_0}\right)}$$

The α coefficient may also be assessed based on landscape using standard values as it is a measure of how much the landscape alters wind speed.

The wind average velocities ($\overline{w_1}$ and $\overline{w_0}$) are evaluate with:

$$\overline{w} = \sum_{w=w_{low}}^{w_{high}} w\, f(w)$$

After these passages the technical potential can be calculate with:

$$E_h = 8760\, \eta_m\, \eta_{el}\, \eta_{aux}\, \frac{1}{2}\, \rho\, A\, \overline{w_z}^3 C_p$$

Moreover, the wind turbines must be properly spaced. In general, the positioning of a wind turbine should be designed to have a distance at least equal to four diameters from the other wind turbines in order to reduce the effect of the turbulence due to the wake. Finally, to take into account the spatial constrains the information recorded in Nature 2000 database are considered [52].

6.2.2 Photovoltaics

Existing plants

In the detailed approach, data can be gathered for example for Sustainable Energy Action Plans (SEAP) [23] or Sustainable Energy and Climate Action Plans (SECAP) prepared by most of European municipalities following the signature of the Covenant of Mayors. These documents typically include the power of existing renewable-based power plants installed at municipality level as well as their total annual electricity production.

Potential

In a detailed approach, a methodology is to use rooftop areas and locations from the local cadastre, if available, or from OpenStreetMap as a potential alternative. As concerns solar radiation data, data measured at the specific location can be used if available, otherwise the methods proposed in the generic approach (Renewables.ninja and PV-GIS) can be adopted. In case statistical data related to the annual production and hourly production profile of photovoltaic plants in the municipality are available, they can be used for extrapolating the expected production of the potential new plants.

Figure 17 shows an extract of the map of buildings for Osimo taken from OpenStreetMap using QGIS software, whereas Figure 18 shows an extract of the table of attributes for each building. The footprint area is shown and a dedicated field has been added to calculate the potential productivity in kWh/y of a rooftop-mounted photovoltaic plant. The total potential electricity production of photovoltaic plants in the municipality can be calculated by summing all the values in that column and multiplying the total value for the share of buildings that can be realistically provided with a PV plant (e.g.: 30% as default values). Users can edit this value based on their knowledge of the local building stock.

For the detailed approach, it is proposed to use building areas from local cadastre or other municipality-based database and 1 km-resolution solar irradiation data from PVGIS.

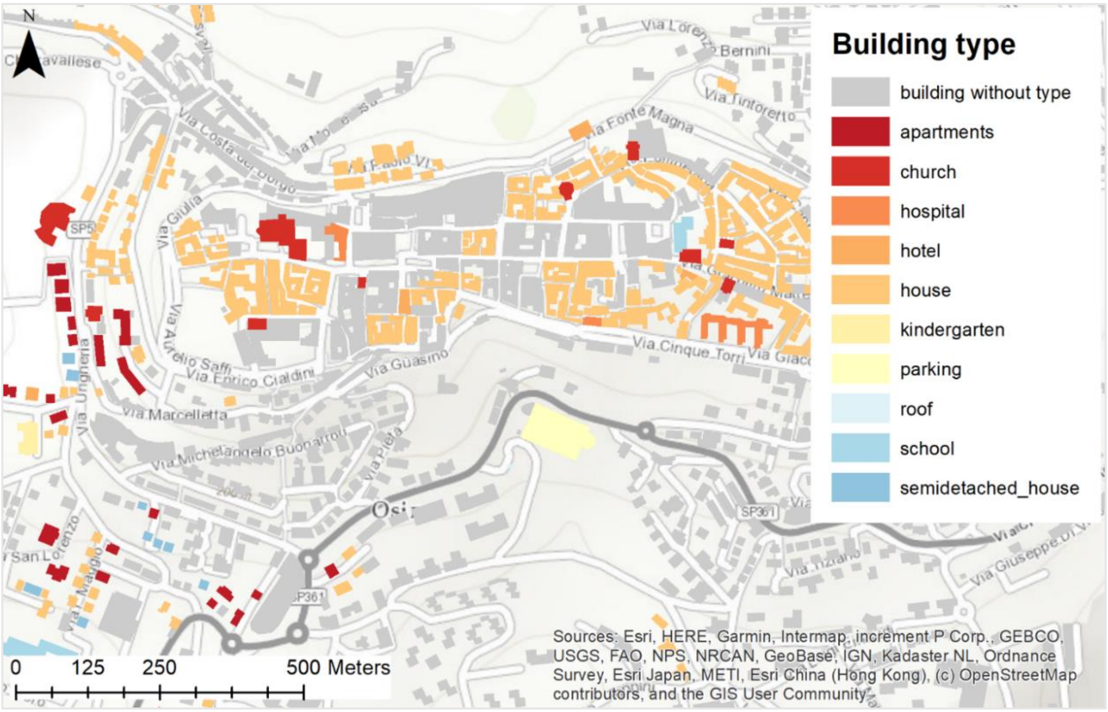


Figure 17 Example of Buildings in Osimo from Open Street Map through QGIS

	full_id	osm_id	osm_type	building	area	PV_output	type
1	w781726491	781726491	way	house	42	5401	
2	w781726492	781726492	way	house	180	23343	
3	w781726493	781726493	way	house	59	7712	
4	w781704518	781704518	way	house	146	18989	
5	w781704519	781704519	way	yes	55	7193	
6	w781704520	781704520	way	house	186	24244	
7	w781704521	781704521	way	semidetached_...	328	42590	

Figure 18 Screenshot of table of attributes for buildings in Osimo from OSM, using QGIS

If detailed LIDAR data is available, an alternative detailed approach is presented in [53], where the inclination and shadowing effects of the roofs is also considered.

6.2.3 Hydro power

Existing plants

The location and power of hydro power plants is known at European level; more specific data can be found at local level, for example from Sustainable Energy Action Plans (SEAP) or Sustainable Energy and Climate Action Plans (SECAP) prepared by most of European municipalities following the signature of the Covenant of Mayors [23]. These documents typically include the power of existing renewable-based power plants installed at municipality level and their annual electricity production.

Potential new plants

The following section provides a short overview of the algorithm that can be used to estimate the potential for a hydro power plant on a specific river. The kinetic energy associated to the movement of a mass of water with a certain head could be converted in electricity by different types of turbines.

The algorithm used to evaluate the annual potential energy production of a hydro power plant at a specific location is the following:

$$E_y = \eta_m \, \eta_{el} \, \eta_{aux} \sum_{h=1}^{8760} m_h g h$$

Where:

- E_y is the annual technical potential [W h];
- η_m is the mechanical efficiency linked to the shaft and the gear box [-];
- η_{el} is the electrical efficiency of the alternator [-];
- η_{aux} is the efficiency of the auxiliaries [-];
- 8760 are assumed to be the yearly operative hours of the turbine [h];
- m_h is the hourly water mass flow rate [kg];
- g is the gravitational acceleration (9.81 m/s^2) [m/s^2];
- h is the head (difference in level between the water intake and the turbine) [m].

The hourly mass flow rate for a specific river can be retrieved at local level from the River Basin Authority or equivalent organizations, which typically have availability of statistical data regarding water flow rate calculated over different time ranges. Moreover, the head can be estimated during surveys on site or based on altimetric maps available for the area. This process can be further investigated in Elsevier's Hydropower discussion [54].

6.2.4 Geothermal power plants

Existing plants

Due to the discrete number of geothermal plants, the solution presented in the generic approach is valuable also for the detailed approach, since the location and power of geothermal power plants is known at European level.

Potential new geothermal heating plants

The potential for new geothermal plants is classified into deep and shallow geothermal.

6.2.4.1 Deep Geothermal

Deep geothermal energy is already harvested in several places in Europe, however the potential is dependent on the exact location and the temperature at various depths in the ground. The heat energy present in the ground is harvested, either for electricity production via Organic Rankine Cycle, or for input to a DH network via a common heat exchanger. In this section, the methodology for taking into account the potential for deep geothermal energy for heating and cooling purposes is outlined. In Table 13 the default map to be used in case more detailed information is not available, as well as the mapped variable and the data specification is presented for each item.

Table 13 Deep Geothermal Required Maps

Map	Mapped variable [unit]	Data specification	Default maps
1	Spatial constraints (optional)	To indicate the areas where a geothermal well cannot be developed, for example because of unsatisfactory temperature levels or in protected areas	EEA – Natura2000 areas [55]
2	Technical potential for deep geothermal	The technical potential power output in MW of wells at a depth of 7 km	Geoelec Online Viewer [56]
3	Ground Temperature (°C)	The soil temperatures at various depths	Geoelec Online Viewer [56]

The methodology for the deep Geothermal part is based on the GEOELEC project [57,58]. In this project, the theoretical, technical, and economic potential of deep geothermal is calculated. In this project individual studies on temperature levels at various depths were collected and a model was used to derive a temperature map below the surface.

Step 1: Technical potential at 7 km depth

This temperature map is used to derive the potential energy yield of deep geothermal systems. The theoretical available heat H in the ground layer is given as follows:

$$H = Vrock \times \rho_{rock} \times C\rho_{rock}(T_z - T_r)$$

Where:

- Vrock volume of the rock
- ρ_{rock} density of the rock (kg/m^3)
- Cρ_{rock} heat capacity (J/(kgK)
- $(T_z - T_r)$ temperature difference with the reinjected water

The theoretical potential for the thermal power of a deep geothermal plant is then given by:

$$P_{theory} = \frac{H \times \eta_{th}}{t}$$

Where:

- *H* theoretical available heat in place
- *t* lifetime of the system
- η_{th} thermal efficiency of a plant

The thermal efficiency of a plant can be approximated by:

$$\eta_{th} \approx \frac{(T_z - T_0)}{(T_z + T_0)} \times \eta_{relative}$$

In the GEOELEC approach a value of 0.58 is selected for $\eta_{relative}$. however, for the MUSE GRIDS project we are interested in the heat of a deep geothermal system. Therefore, this efficiency factor of 0.58 is removed as it concerns conversion to electricity, and the energy efficiency for heat exchange (in the context of a district heating/cooling grid for instance) can be very close to 1.

The resulting technical potential however, can be limited by several factors:

- Limitations in available land area;
- Limitations in the recovery of heat from a fracture network;
- Limitations due to 'Temperature Drawdown' effect [57].

The first limitation is covered by overlapping the geospatial map with the spatial constraints, excluding nature areas etc. For the other two effects, the GEOELEC project estimates an 'Ultimate Recoverability' factor (UR) of 0.125 (0.14 for fracture network and 0.9 for temperature drawdown).

The technical potential is hence given by:

$$P_{technical} = P_{theory} \times UR$$

With *UR* a factor of 0.125, taking into account the limiting factors for fracture network and temperature drawdown.

This technical potential can be assumed to be constant, so for obtaining the annual energy it must be multiplied with an operating time of 8,760 h/y.

Step 2: Rescaling the potential for a different depth

In the GEOELEC project[58], the technical potential is calculated at a depth of 7 km, however deep geothermal systems rarely drill this deep. Therefore, the MUSE grids project will rescale the potential at other depths using the following formula:

$$P_{tech,heat,1km} = \frac{T_{1km} - T_r}{T_{7km} - T_r} P_{tech,heat,7km}$$

Where:

- $P_{tech,heat,1km}$ the potential power of a geothermal plant at depth of 1km (MW)
- $P_{tech,heat,7km}$ the power of the same plant at a depth of 7 km (MW)
- T_{1km} the temperature at 1 km depth (°C)
- T_r the reinjection temperature (°C)

6.2.4.2 Shallow Geothermal

For shallow geothermal using ground source heat pumps, the drilling is much more limited in depth, from 10-15 meters to more than 100m. The temperature of the soil at these depths is much more constant than the temperature at the surface, which is sensitive to weather and seasonal effects. In this chapter, we will calculate the potential from the soil only. Table 14 shows the default map to be used in case more detailed information is not available, as well as the mapped variable and the data specification is presented for each item.

Table 14 Required maps for shallow geothermal

Map	Mapped variable	Data specification	Default maps
1	Soil type maps (optional)	Soil type of the surface	JRC – soil type map [59]
2	Spatial constraints	To indicate the areas where a geothermal well cannot be developed, for example in high density historic centres of the city	Corine Land cover [60]

In this report, we will calculate the potential heating and cooling from the soil. Usually, this potential is accessed via ground-sourced heat pumps.

Step 1: Calculate the maximal heat content to be extracted from the ground

Using the following formula, we calculate the possible yearly heat transfer from the soil:

$$E = \rho \times V \times C \, \Delta T \qquad \text{[kWh]}$$

Where:

- E Yearly Energy potential heat extraction from the soil [J]
- V Volume of the ground [m^3]
- ρ Soil density [kg/m^3]
- C Specific heat of the soil [J/kg·K]
- ΔT Temperature difference [K]

The density of earth soil is around 1750 kg/m^3, and the specific heat around 1500 J/kg·K.

Unlike deep geothermal, which can typically reach hundreds to thousands of meters deep to harvest the heat of the underlying ground layer, for ground-sourced heat pumps the depths are much more shallow, around 15-150m depending on the location. For this example, we assume that a ground-sourced heat pump takes 5x5m place and has a drilling depth of 100m. Hence, heat can be extracted from the ground with a volume of 49,000 m^3. For the temperature difference of the soil we assume 10°C.

In this example, using the above formula, the potential becomes:

$$E_{heat,\ soil} = 18.3\ MWh/year$$

Step 2: Seasonal considerations

Aside from the heating potential, the soil can also be used as a source of cooling potential. In addition to the 18.3 MWh yearly heating potential, the same amount of cooling potential is available.

Comments:

- The expertise for drilling the required boreholes is often quite local. For instance, in many countries the granite soils are not accessible for heat pumps, however in Sweden they do. In principle it is possible to extract heat from any soil type. The soil type is therefore relevant for techno-economic reasons only.
- The coefficient of performance (COP) will decrease over time during the heating season, as the soil cools due to the heat extraction. This effect increases when a lot of heat pumps are installed in the same area. This effect can be taken up in the planning module when more realistic future scenarios are drafted.
- In many local areas, a spatial constraint is present for drilling the required boreholes. In Belgium for instance, usually an outdoor space with 8.5x2.5 m^2 is required for the installation. However, more compact systems do exist to drill boreholes in the soil, so this constraint is not considered.

6.2.5 Biomass plants

For the mapping of existing capacity of biomass plants, the same references as in the generic approach (Section 6.1.5) can be used. Specifically, as for other renewable sources, detailed information related to the presence of biomass power generation or cogeneration plants and their annual energy production, as well as of the share of biomass in the energy mix for heating purposes, can be found in the Sustainable Energy Action Plans (SEAP) or Sustainable Energy and Climate Action Plans (SECAP) prepared by most of European municipalities following the signature of the Covenant of Mayors [21].

The biomass potential is more articulated and will be considered separately for biomass from forestry and biomass from agricultural activities. The following two paragraphs present the methodology for the evaluation of the potential in terms of required inputs (default maps to be used if more specific local information is not available), reference values and equations to be used.

6.2.5.1 Potential from forestry

The stem-wood net annual increment in forests can provide a valuable resource for heating supply. Depending on the forest type and the global ecological zone in Europe (boreal – temperate – subtropical), different average biomass growth and forest productivity can be expected. Also, forests located in the vicinity of the city can be considered. Typically, a maximum distance of 20 km is assumed, but this parameter can be changed. In

Table 15 the default map to be used in case more detailed information is not available, as well as the mapped variable and the data specification is presented for each item, whereas Table 16 presents the reference values to be adopted for the estimation of the potential.

Table 15 Biomass Required Maps

Map	Mapped variable [unit]	Data specification	Default maps
1	Forest cover [ha]	Map indicating the forests, split in Broadleaved Forest, Coniferous Forest, Mixed forest	Corine Land cover [60]
2	Protected areas or other spatial constraints (optional)	Natura2000 sites in Europe or other sites that should be excluded for energy production	EEA – Natura2000 areas [55]
3	Global ecological zones	Classification of forests into Global ecological zones	Global ecological zones (2010) [61]

Table 16 Biomass Generic Data Inputs

Data	Variable [unit]	Data specification	Default values
1	Net annual increment (NAI) [m^3/ha.year]	Based on GEZ and forest type	IPCC *GEZ - Temperate forests:* - Coniferous: 3.0 ton_{DM} per ha•yr - Broadleaf: 4.0 ton_{DM} per ha•yr - Mixed C-B: 4.0 ton_{DM} per ha•yr *GEZ - Boreal forests:* - Coniferous: 2.5 ton_{DM} per ha•yr - Broadleaf: 1.5 ton_{DM} per ha•yr - Mixed C-B: 1.5 ton_{DM} per ha•yr *GEZ - Subtropical forests:* - Coniferous: 0.9 ton_{DM} per ha•yr - Broadleaf: 0.9 ton_{DM} per ha•yr - Mixed: 0.9 ton_{DM} per ha•yr
2	Net calorific value [MWh/ton_{DM}]	Density of the different wood species	IPCC - Coniferous: 19.2 MWh/ton_{DM} - Broadleaf: 19.0 MWh/ton_{DM} - Mixed C-B: 19.1 MWh/ton_{DM}

Data processing:

The workflow is based on the workflow proposed in the Biomass Energy Europe project [62]. The following instructions explain the different steps of the proposed method in detail:

Step 1: Forest area map

Create a forest area map describing the location and the size of the broad-leaved forests, coniferous forests and mixed forests.

The European Corine Land Cover map (2012) provides default data for Europe:

- Land cover class 311: Broad-leaved forest
- Land cover class 312: Coniferous forest
- Land cover class 313: Mixed forest

If available, more detailed maps can be used instead of the Corine Land Cover map. The mapping tool will calculate the corresponding area from the GIS-data.

Step 2: Combination with net annual increment

The net annual increment (NAI) gives an indication on average biomass growth and forest productivity. This approach utilizes statistics from IPCC based on ecological zones. The statistics below are linked with the geographical data describing the location of the global ecological zones.

As seen above:

GEZ - Temperate forests:

- Coniferous: 3.0 ton_{DM} per ha•yr
- Broadleaf: 4.0 ton_{DM} per ha•yr
- Mixed C-B: 4.0 ton_{DM} per ha•yr

GEZ - Boreal forests:

- Coniferous: 2.5 ton_{DM} per ha•yr
- Broadleaf: 1.5 ton_{DM} per ha•yr
- Mixed C-B: 1.5 ton_{DM} per ha•yr

GEZ - Subtropical forests:

- Coniferous: 0.9 ton_{DM} per ha•yr
- Broadleaf: 0.9 ton_{DM} per ha•yr
- Mixed: 0.9 ton_{DM} per ha•yr

The combination of step 1 and step 2 provides the spatial distribution of the average annual increment in stem-wood, in tons dry matter, expressed per pixel size as defined by the user which typically is 50x50m:

$$SW\_NAI = FA * NAI\_reg$$

Where:

- *SW_NAI* raster of average stem-wood net annual increment per pixel ($tonnes_{DM}$ per yr)
- *FA* forest area of specific forest type (ha)
- *NAI_reg* average stem-wood net annual increment per region based on inventory statistics (ton_{DM} per ha•yr)

Step 3: Excluding protected areas

Protected forest areas are excluded from the analysis because harvesting of such sites is either restricted or completely prohibited. All forested sites located in the Natura2000 network are set to zero in the rasters of SW_NAI. Other sites can also be excluded.

Step 4: Assessment of the amount of primary energy (PE) for every type of wood

- Coniferous: 19.2 MWh/ton_{DM}
- Broadleaf: 19.0 MWh/ton_{DM}
- Mixed C-B: 19.1 MWh/ton_{DM}

The resulting raster shows the spatial distribution of the primary energy from forestry (PE_FT), in MWh/y per pixel:

$$PE\_FT = SW\_NAI * PE$$

Where:

- *SW_NAI* raster of average stem-wood net annual increment per pixel ($tonnes_{DM}$ per yr)
- *PE* primary energy production for every type of forest (MWh/ton_{DM})

6.2.5.2 Potential from agriculture

Agricultural residues are a potential source for bioenergy for rural areas in particular, rather than cities. Yet, a simplified method to quantify and map the potential of biomass from agriculture is presented to estimate the potential supply from the agricultural areas in or around the municipality. Important to note is that other uses for agricultural biomass may be relevant as well, such as feedstock for animal feeding.

The presented method considers the regionally available statistical data on crop production from EUROSTAT. The spatial scale of this database is the NUTS2 level. In Table 17 the default map to be used in case more detailed information is not available, as well as the mapped variable and the data specification is presented for each item, whereas Table 18 presents the default values to be adopted for the estimation of the potential.

Table 17 Agricultural Biomass Required Maps

Map	Mapped variable [unit]	Data specification	Default maps
1	Agricultural parcels [ha]	Map indicating the land in use for agriculture, split in different categories	Corine Land cover [60]
2	Spatial constraints (optional)	Parcels that have to be excluded for energy production	Not applicable (needs to be defined locally)

Table 18 Agricultural Biomass Generic Input Data

Data	Variable [unit]	Data specification	Default values
1	Cultivated area per region	Specific annual area with production of crops	NUTS database on Crop production from Eurostat [63]
2	Yield in ton/ha for different types of crops	Productivity per unit of area of land	NUTS database on Crop production from Eurostat [63]
3	Specific calorific value of the crop (residue) [MJ/ton or kWh/ton]	Specific calorific value of the crops or crop residues taking the moisture content into account	BEE best practices and methods handbook [64].
4	Technical availability	Share of the residues that can be recovered and reused	50%, but can be changed by the user

Step 1: Identifying the agricultural areas in the proximity of the city

The land use categories of the Corine Land Cover map are used as a basic input; it considers following agricultural land uses:

- 211: Non-irrigated arable land
- 212: Permanently irrigated land
- 213: Rice fields
- 221: Vineyards
- 222: Fruit trees and berry plantations
- 223: Olive groves
- 231: Pastures
- 241: Annual crops associated with permanent crops
- 242: Complex cultivation patterns
- 243: Land principally occupied by agriculture, with significant areas of natural vegetation
- 244: Agro-forestry areas

Within this step, especially categories 211 and 241-244 are relevant because the following crops are the most interesting for energy production from agricultural biomass:

- Cereals for grain
- Wheat
- Barley
- Rape seeds
- Grain maize

As with forests, agricultural areas are not expected to be found within cities. Therefore, a radius around the city is chosen of which the biomass can be converted to heat for the city. This radius is 20km by default.

Step 2: Excluding agricultural parcels

It is possible to exclude specific agricultural zones in the supply mapping.

Step 3: Identifying the type and yield of the crops on the fields

The actual type and yield of crops per ha of cultivated area are not known to a local detail. However, regional averages at the NUTS2 level on crop production are available from Eurostat. An average crop yield is then allocated to the relevant agricultural land cover from the Corine Land Cover map. Next, this yield is converted into a potential supply of bio-energy taking a specific fraction of the crops into account that can be sourced and a specific calorific value.

Apart from this average approach that can be applied to all European contexts, a more detailed approach is also available in case the user has detailed maps with the location of the five different crop types described above. In that case, the theoretical supply will be calculated separately for every crop type by combining the area of the agricultural parcels with the crop yield reported at NUTS2 level for that specific crop type.

The specific crop yield is further converted into a potential straw yield (BEE Best practices and methods handbook [64]):

$$StrawYield\left(\frac{ton}{ha}\right) = CropYield\left(\frac{ton}{ha}\right) \times 0.769 - 0.129 \times arctan\left[\left(CropYield\left(\frac{ton}{ha}\right) - 6.7\right)/1.5\right]$$

Step 4: Technical availability

The produced straw quantities are not entirely available for bioenergy. Environmental constraints and competitive uses must also be considered. A part of the straw should remain on the terrain of agricultural land with unfavorable soil conditions for recycling of nutrients (fertilizing). Additionally, straw is used for animal feeding and bedding. Technical availability for energy usage is set by default at 50 %, but it can be changed by the user.

Step 5: Energy content of the crop types

In a final step, the energy available for conversion to heat will be determined from the straw yield. For this step, averages are used from the BEE Best practices and methods handbook [64]. The values in Table 19 take the moisture content into account for every crop, this is typically around 15%.

Table 19 Energy yield from different crop types

Crop	Energy/yield (MJ/kg)
Cereals for grain	14.5
Grain maize	17.3
Barley	14.7
Wheat	14.4
Rape seeds	14.3

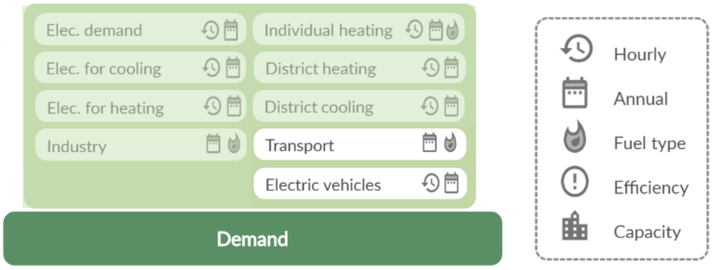
7 Transport

MUSE GRIDS Energy planning tool demand input

What is *transport demand*?
The demand of energy coming from all modes within the transport sector. The demand is categorized by fuel type consumption.

What data is needed for *transport demand*?
- Annual data demand
- Fuel type demand
- Efficiency of charging

*(See **Table 1** for data type specification)*



Traditionally, in energy system models, the transport is mainly focussing on annual fuel consumption uses for various modes of transport and their related emissions. However, with the introduction of electric vehicles the hourly charging consumptions also becomes relevant. As with the other sectors, the report will present both a generic approach and detailed approach for the transport sector.

7.1 Generic approach

Annual fuel consumption for transport split into fuels can be found in the IEA national balances [4]. The national information is similarly acquired as in section 2.1. The transport demand that is needed is the one categorized as *Transport* when selecting a specific country and *Balances* as *Energy Category*. By looking at the transport category as a whole and later digging into the different *Energy Categories*, the data can be obtained. Taking the numbers for the different fuel type and multiplying them by the population share detailed in 1.2 will provide the annual transport demand needed. The fuel types needed for the MUSE GRIDS Energy planning tool are categorized in the following: oil derived (Diesel, petrol, LPG and jet fuel), natural gas, hydrogen and electricity in $GWh/year$.

If electric vehicles are added to the energy system, hourly charging profiles are required. In the tool, the user can add a profile both for dump and smart charge vehicles. Figure 19 shows an example of a dump and a smart charge profile for 3 days. Dump charging means that the electric vehicles follow a fixed profile that is not dependent on any system constraints while the smart charging permits the vehicles to act more intelligently and schedule charging to when it is appropriate for the system – while not compromising with the users' need for transportation.

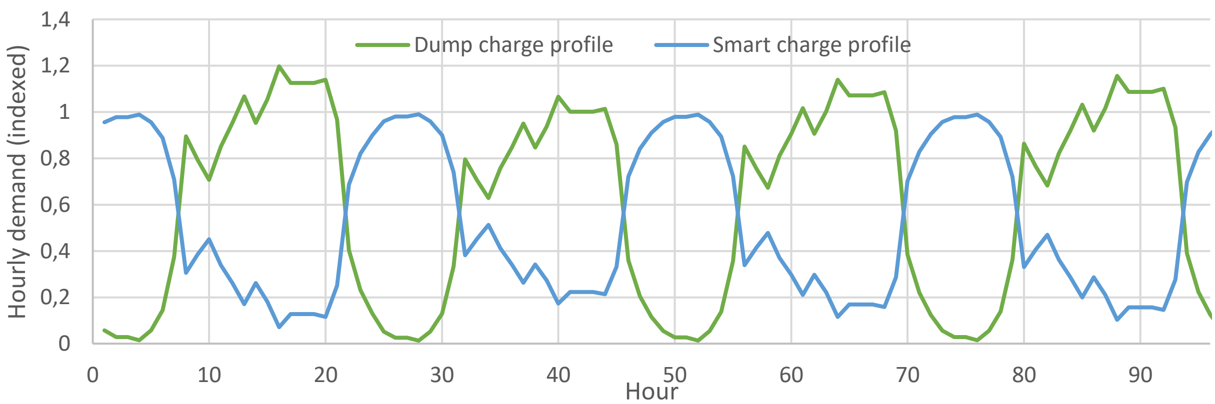


Figure 19 Electric vehicle profile example from United States 2001 [65]

To get profiles for electric vehicles, these can either be estimated using general assumptions about driving and charging patterns or by using specific measured local data on transport and electric vehicles. In 2012 a JRC report [66], used national travel survey data to estimate charging patterns in different countries.

7.2 Detailed approach

7.2.1 Methodology and data acquisition

There are two goals to reach: the calculation of an annual fuel consumption split into fuel types, and an hourly driving pattern at country level. The first objective is reached through a procedure with three steps:

1. Acquisition of data and selection of variables that could affect the fuel consumption in both municipalities.
2. Data filtering considering the variables highlighted in the previous step, generating a consumption environment.
3. System output, indicating the consumptions for the different fuel types.

The driving pattern will be taken from the corresponding sources (for both cases, published surveys at a country level). It is not possible to reduce the granularity of these data due to the lack of sources on the topic at local levels.

7.2.2 Data and environment variables

In the same way as with the building energy data, the transport data are strongly affected by the features of the area examined. Generally speaking, the concept is to adapt general data (country-level) filtered by the local variables/data when possible. For example, we will have the share of vehicles by fuel type at national level, but we can also count on the vehicle list at local level (car, trucks, etc.).

Design of consumption environment

The design of a consumption environment will be strongly restricted by the availability of data. To the date, amongst the documents and research papers containing transport numbers in Europe, two kinds of data sets can be found:

- Generic data from countries, regions and provinces (between NUTS 0 and NUTS 3) delivered mainly by European institutions.
- Detailed data from demonstration sites in European projects or private research included in research papers.

Even certain projects that intend to be exhaustive with the data contain large regions (or even countries inside the EU28) with no data at all. Considering the countries outside the EU, we can find a range of availability from large sets of real data to no data at all, due to privacy policies but mostly since many countries have very few data in digital format. In this context, it is not possible to establish a homogeneous procedure in order to gather these data.

Considering the data scenario, the methods to obtain information in certain zones (like the ones considered in this project) are limited to statistic procedures and extrapolation of general data into each case. Despite the risk of losing compatibility in the calculations and procedures with other zones, one feasible way to proceed is to apply the concrete peculiarities of each municipality to the general data, so there could be a realistic convergence to the desired results.

7.2.3 Calculation procedure

To reach the final energy values of consumption for every type of vehicle, up to five sets of data would be necessary to reach to these results:

- Number of vehicles. It is critical to have national, regional and/or local numbers, as long as the number proportion can be utilized in order to extrapolate values, in case that any of the other data sources couldn't be found for the municipality considered.
- Typology of the vehicles (per energy source). These numbers should indicate the proportion of vehicles that use a certain source of energy, including gasoline, gas (GNV, LPG, CNG), hydrogen and electric batteries as primary examples. The specific cases of hybrid technologies must be extrapolated in terms of allocating a proportion between both energy sources (e.g., a hybrid car can be considered as 6% of distance electric and 94% combustion, as in [67].
- Mean consumption values for vehicle typology. These values come from testing performed by the corresponding associations/institutions, and in any case, it might be considered as standard values, although it is true that the evolution in car motor technologies varies in terms of efficiency through the years.
- Kilometres done by one vehicle of one energy typology. These are data that can be useful in order to provide with some driving routines associated to drivers considering the type of car they are using. In case of not having these values, a flat rate for all cases is applied, otherwise, they are used as a proportional ratio to adjust energy consumptions by energy source.
- Energy equivalent (electricity) for each energy source per km. These are also standard values indicating the conversion values from one source of energy into equivalent electric energy.

The calculation cascade goes down the line of parameters specified beforehand:

- The first part is to get the total number of cars, and then the proportion of cars from each type.
- Then, the km driven and the energy consumed is calculated, in mean values, for each vehicle in each type of energy source.
- The energy consumed, in all cases, is converted to equivalent electric energy.
- Finally, the aggregated numbers of energy are put together to get the final numbers for every energy source.

Through the whole process, the main issue can be the fact that sometimes local data (optimal case) is available, but in other cases only regional or even national values are available. For these cases, it is mandatory to extrapolate values as near as possible to the original source. In other words, it is better to use the proportion of vehicles in one municipality in respect to the national values, instead of using the relation of population values that would be less accurate. Only working this way, is it possible to reach final and realistic values.

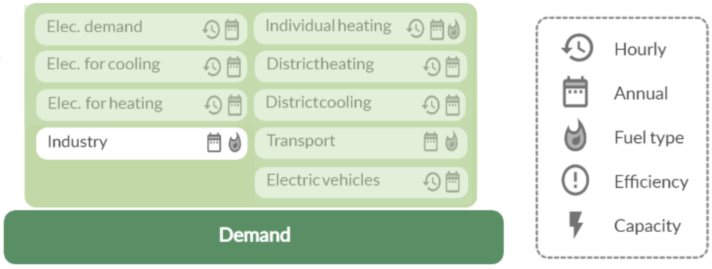
8 Industry

MUSE GRIDS Energy planning tool demand input

What is *industry demand*?
The demand of energy coming from all industry sectors. The demand is categorized by fuel type consumption.

What data is needed for *industry demand*?
- Annual data demand
- Fuel type demand
- Efficiency of charging

*(See **Table 1** for data type specification)*



8.1 Generic approach

The annual industry energy consumption by fuel type can be found in the IEA national balances [4]. The national information is similarly acquired as in section 2.1. The industry demand that is needed is the one categorized as *Industry* when selecting a specific country and *Balances* as *Energy Category*. By looking at the Industry category, the data can be obtained. Taking the numbers for the different fuel type and multiplying them by the population share detailed in 1.2 will provide the required annual industry demand. The fuel types needed for the MUSE GRIDS Energy planning tool are categorized in the following: oil derived, natural gas and biomass. In the MUSE GRIDS Energy planning tool industrial demands are only annual values and are not integrated with the other energy sectors.

8.2 Detailed approach

The role of industry within an energy system varies largely depending on the scale of the analysis. Therefore, it is recommended to perform the identification of energy intensive industries and its respective added value/production for each geographical location as a proxy to relevance. This subsection describes a detailed approach for the matter. When additional documentation is available at a regional/zonal scale for the estimation of final energy demand per industrial sub-sector and EU country, a bottom-up methodology is proposed – See Figure 20. The process starts by identifying and mapping the different types of main industry sub-sectors. Some sources currently provide geo-information of the most relevant industries at a European level, hereby a map is made using the openly available georeferenced data on industry that could be obtained from the D5.1. sEEnergies project [68] - Figure 21.

Figure 20 Industry detailed approach process

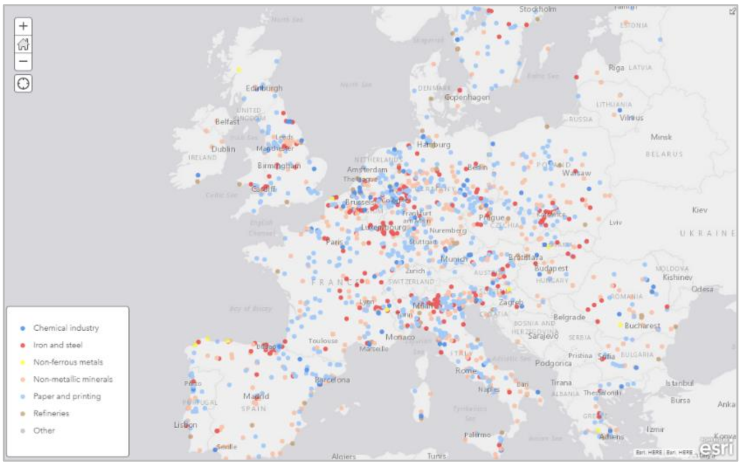


Figure 21 Georeferenced industrial sites in EU28, showing six energy-intensive industrial sectors [68]

After the industries have been identified, the classification process makes it possible to find that nexus between type of industry and final energy demand. The process is followed by industry type disaggregation according to their respective energy type. Table 20 and Table 21 show both the industry sub-sector and energy type classification mostly used in current related projects such as Heat Roadmap Europe and sEEnergies project [22,69,70].

Table 20 Main industry sub-sector classification

Main industrial sub-sectors
Chemicals
Iron and steel
Non-ferrous metals
Non-metallic minerals
Paper and pulp
Others

Table 21 Industry energy type classification

Energy types
Coal and coal products
Oil products
Natural gas
Biofuels and waste
Peat and peat products
Heat
Geothermal
Solar/wind/other
Electricity

Later, data on specific energy consumption for main industrial products can be obtained from technology datasets which provide assumptions for selected technologies regarding the specific fuel, electricity and energy consumption. Various sources consulted use PRIMES modules that provide reference and future scenarios for all EU28 countries considering 18 industrial sectors and 23 industry sub-sectors with several technologies split [71,72]. An extract from PRIMES summary energy balance and indicators dataset are shown in Figure 22, taking Denmark as example.

SUMMARY ENERGY BALANCE AND INDICATORS (B)												Denmark: Reference scenario			
	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'00-'10	'10-'20	'20-'30	'30-'50
												Annual % Change			
ENERGY EFFICIENCY															
Primary energy consumption	**19432**	**19264**	**19777**	**16536**	**16473**	**15971**	**16115**	**16249**	**16027**	**16414**	**16732**	0.2	-1.8	-0.2	0.2
Final Energy Demand	**14717**	**15497**	**15606**	**14800**	**14735**	**14603**	**14405**	**14347**	**14522**	**14844**	**15170**	0.6	-0.6	-0.2	0.3
by sector															
Industry	2934	2864	2417	2568	2716	2654	2585	2476	2528	2605	2741	-1.9	1.2	-0.5	0.3
Energy intensive industries	1156	1107	849	908	937	863	788	706	703	711	716	-3.0	1.0	-1.7	-0.5
Other industrial sectors	1778	1757	1569	1659	1779	1792	1797	1770	1825	1894	2025	-1.2	1.3	0.1	0.6
Residential	4162	4453	4916	4345	4170	4150	4100	4126	4157	4253	4294	1.7	-1.6	-0.2	0.2
Tertiary	2805	2856	3094	2879	2884	2950	2935	2967	3005	3066	3132	1.0	-0.7	0.2	0.3
Transport[5]	4816	5324	5179	5009	4966	4848	4784	4777	4833	4920	5004	0.7	-0.4	-0.4	0.2

Figure 22 Summary energy balance and indicators extract for Denmark for years 200

9 Economic costs

MUSE GRIDS Energy planning tool costs input

What is the *costs input?*
The different costs associated with the supply of energy demands in a determined energy system. The costs related to initial investment or acquisition of a technology, and the cost of operation referring to its maintenance and administration.

- Investment costs
- Fixed operation and maintenance costs
- Variable operation and maintenance costs
- Fuel costs
- Cost of CO_2-emissions
- Import/export of electricity

Costs

Several costs are needed when using the MUSE GRIDS Energy planning tool, these can be categorized in the cost categories presented in Table 22, all dependant on the technology in question:

Table 22 Description of MUSE GRIDS Energy planning tool costs input

Cost type	Description
Investment costs	Covering the initial investment cost of the equipment needed and corresponding installation cost. The tool uses annualized investment costs for a specific lifetime and interest rate.
Fixed operation and maintenance costs	Recurring annual costs that occur due to operation and do not vary with production or consumption. Usually, it is expressed as a percentage of the investment cost.
Variable operation and maintenance costs	Recurring annual costs that occur due to operation and do vary with production or consumption. Usually, it is expressed as a cost per unit generated.
Fuel costs	Cost of different fuel used to produce heat or power. They are referred as supply fuel costs.
Cost of CO_2-emissions	Cost of CO_2 emissions expressed in CO_2-equivalents. This can be generated locally or coming from the import and export of electricity.
Import/export of electricity	Costs associated with the importing and exporting of electricity from and to the energy system.

There are different sources that can be visited for this input category. The Sustainable Energy Planning Research Group at Aalborg University updates and maintains a compendium of costs associated to different technology gathered from various sources. This technology and cost database can be downloaded from the EnergyPLAN tool webpage [73], a screenshot of the database follows in Figure 23. Another relevant source for this input category is the Danish Energy Agency technology data catalogues found in [74]. The catalogues are classified by technology and usage such as the ones previously mentioned in [21,24] for individual heating, and electricity generation and district heating correspondingly, amongst others.

CostYear	Category	Technology	EP_names	TechDescription (Subtype or Aggregation)	BaseRegion	Units	Investmen	Lifetime (	FixedOM (
2020	Heat and Electricity	Small CHP plants	Small CHP units	Biomass (woodchips): 20 MW feed	DK	MWe	6.50	25.00	4.44
2020	Heat and Electricity	Small CHP plants	Small CHP units	Biomass (Straw), 20 MW feed	DK	MWe	6.80	25.00	4.68
2020	Heat and Electricity	Small CHP plants	Small CHP units	Biomass (Straw), 50 MW feed	DK	MWe	3.80	25.00	3.94
2020	Heat and Electricity	Small CHP plants	Small CHP units	SCGT: 5-40 MW	DK	MWe	0.73	25.00	2.67
2020	Heat and Electricity	Small CHP plants	Small CHP units	Gas Engine: 1-10 MW	DK	MWe	0.95	25.00	1.03
2020	Heat and Electricity	Small CHP plants	Small CHP units	Biogas Engine: 1-10 MW	DK	MWe	0.95	25.00	1.03
2020	Heat and Electricity	Small CHP plants	Small CHP units	Biomass (woodchips): 80 MW feed	DK	MWe	3.60	25.00	4.27
2020	Heat and Electricity	Large CHP plants	Large CHP units	CCGT: 100-500 MW	DK	MWe	0.88	25.00	3.33
2020	Heat and Electricity	Large CHP plants	Large CHP units	CCGT: 10-100 MW	DK	MWe	1.30	25.00	2.25
2020	Heat and Electricity	Large CHP plants	Large CHP units	SCGT: 40-125 MW	DK	MWe	0.59	25.00	3.30
2020	Heat and Electricity	Large CHP plants	Large CHP units	Coal: 400-700 MW	DK	MWe	1.90	40.00	1.63
2020	Heat and Electricity	Large CHP plants	Large CHP units	Biomass (pellets): 250-400 MW	DK	MWe	1.90	40.00	1.63
2020	Heat and Electricity	Heat Storage CHP	Heat Storage CHP	Average	DK	GWh	3.00	20.00	0.70
2020	Heat and Electricity	Waste CHP	Waste CHP	Average	DK	TWh/year	215.62	20.00	
2020	Heat and Electricity	Absorption HP (waste)	Absop. HP (Waste)	Absorption heat pump, district heating	DK	MWth	0.56	25.00	0.35
2020	Heat and Electricity	Central DH HP	Heat Pump gr. 3	Average	DK	MWe	2.64	25.00	0.30
2020	Heat and Electricity	DHP Boiler group 1	Boiler for Direct DH	Average	DK	MW	0.52	21.25	0.00
2020	Heat and Electricity	Boilers gr. 2 and 3	DH: Boilers Group 2 & 3	Woodchip boiler: 1-12 MW	DK	MWth	0.80	20.00	
2020	Heat and Electricity	Boilers gr. 2 and 3	DH: Boilers Group 2 & 3	Gas boiler: 0,5-10 MW	DK	MWth	0.06	25.00	3.25
2020	Heat and Electricity	Boilers gr. 2 and 3	DH: Boilers Group 2 & 3	Straw boiler: 1-12 MW	DK	MWth	0.80	20.00	
2020	Heat and Electricity	Boilers gr. 2 and 3	DH: Boilers Group 2 & 3	Wood-pellets: <2 MW	DK	MWth	0.40	20.00	
2020	Heat and Electricity	Large Power plants	Large Power Plants	CCGT: 100-500 MW	DK	MWe	0.88	25.00	3.33
2020	Heat and Electricity	Large Power plants	Large Power Plants	CCGT: 10-100 MW	DK	MWe	1.30	25.00	2.25
2020	Heat and Electricity	Large Power plants	Large Power Plants	SCGT: 40-125 MW	DK	MWe	0.59	25.00	3.30
2020	Heat and Electricity	Large Power plants	Large Power Plants	Coal: 400-700 MW	DK	MWe	1.90	40.00	1.63
2020	Heat and Electricity	Pump hydro	Pump	Average	DK	MWe	0.60	50.00	1.50
2020	Heat and Electricity	Industrial CHP electricity	Indust. CHP Electr.	Average	DK	TWh/year	65.80	31.00	2.13
2020	Heat and Electricity	Industrial CHP heating	Indust. CHP Heat	Average	DK	TWh/year	65.80	31.00	2.13

Figure 23 EnergyPLAN cost database screenshot [73]

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11 Annex I: OpenStreetMap data

This annex has been included in order to help users of the MUSE GRIDS energy planning tool to understand how the Open Street Maps works and which data can be obtained from this source and its level of accuracy.

11.1 Handling data from OSM sources

This section describes a procedure to handle data from Open Street Map (OSM) sources. In the methodology presented in this deliverable, it supports the implementation of the methods contained in section 2.4.2 for the detailed calculation of heating and cooling demands.

It is not possible to have access to the general properties of buildings depending on each country and specific location. To the date, the norms concerning the information necessary and/or available (physical values like the year of construction or whether refurbishment has been taking place, to name a few examples) can vary from place to place even inside the same country.

The initiatives conducted by several local institutions in different countries from EU28 have served at least to show what can be done in order to make some important information available, making possible the usage of these sets of data for valuable operations, like the evaluation of potential energy demand for an upcoming district heating or showing the necessity of take measures at city level in a concrete neighbourhood.

One way to mitigate the effect of the lack of information is to use the data contained in the OpenStreetMaps application. It has several interesting features:

- The data has been inserted by users and volunteers so there are no issues concerning the property of these data.
- It is a homogeneous data source, so it is available worldwide, and the data has no frontiers, meaning that one user from Australia can see the info from a Colombian cycling route or a detached single-family house in the outskirts of Mogadishu.
- The data files that are obtained with the export options are easily translated and read by most GIS applications.

The use of this data source also has an important drawback that is the absence of data in certain zones, because of the irregular work of identifying the map elements on each location.

11.1.1 Evaluation of the available data in a location

The first thing to do with the OSM data is a preliminary evaluation of what is included in every location considered, just if possible. The criteria to assess data values contained in the location map are given by the work or project being developed, and consequently must be carefully considered.

The data in OSM are grouped into specific tags that cover most of the elements in a street (buildings, constructive elements, urban elements, roads, etc.) and most of their characteristics (especially on buildings, covering the type, usage, height, etc.).

Figure 1 Example of building with three tags defined (down left), including building, name and type of office

As it has been commented, there are groups of tag categories and some of them also include sub-categories with pre-set values.

Due to the ease of use of the online application to insert data in OSM, certain tags are more utilized than others, and that would be reflected into the quantity of data available for certain building characteristics. These ones combined with the graphic polygon representing the building (we will centre our efforts on these elements) should be enough when the data had to be processed.

The problems arise from both the quantity and quality of the data. For the first case, there are still large sections of the municipalities with little or almost no information inserted. In the second case, some valuable characteristics can be missing. In fact, it is not uncommon to find out that a map contains lots of building references, but these references are limited by only one single tag (e.g., building=yes, as this is the most common one).

If the location cannot be changed for another one with more info (or more accurate), then the solutions might include the following:

- Search for help to complete the missing information. This can be done through the channels that are available in OSM. Inside there is a local community of OSM users who could be interested in collaborating with the project, considering that the final goal is to have the local maps as complete as possible.
- Try to complete the data personally. There are various options in order to perform this, but it is important to notice that the task is usually time-consuming in order to organize the work. This issue with be discussed in this document.

Related to the availability of data is the availability of layers. The OSM tools (online and offline) have some layer maps available, depending on the location, at country level. This means that for certain countries there would be good and updated layers, consisting of recent aerial photos with good quality, or a national cadastre layer (invaluable), or other options that could be better or worse depending on what is available in each country. For example, in Spain the cadastre layer lets a user define the surface of a building with high precision; meanwhile a user had to use a blurry aerial photo in a country with few layers available.

Figure 2 Cadastre layer vs aerial layer in order to contrast usefulness

11.1.2 Data insertion with OSM

Before going further with OSM, it is important to note that there is very useful documentation about how to insert new data in OSM in the following links:

- General learning questions: https://learnosm.org/en/
- JOSM general WIKI: https://wiki.openstreetmap.org/wiki/JOSM/Guide
- JOSM manual [1]:

When it is necessary to complete data on a map, the default procedures are found at:

- Use the online modification tool (https://www.openstreetmap.org).
- Use the offline modification tool (https://josm.openstreetmap.de/).

For the first case, it has obvious advantages: only a browser is necessary, the changes can be rapidly uploaded, one can take advantage of the local auxiliary layers available (layers from local maps that could contain useful information, like cadastre maps, or simply aerial photos to name two examples), the editing is very simple with draw and click actions and simple menus, and simple advice/warning service. The main disadvantage about this method is a limited set of resources (layers) that in some cases might be insufficient, and also limited options available for tagging (just tagging menus, though, any existing tag can be inserted manually if the key is known).

The second case requires the installation of the JOSM software. It is free to install and use, and is updated regularly. The advantages for its usage are the large set of tools inside the program to perform complex tasks with the OSM data, and the precision of these tools. As disadvantages it can be indicated that the data need to be uploaded after the process has been finished, the program needs regular updates that can be sometimes annoying, and the usage can be difficult sometimes due to precisely the big set of options included with it.

11.1.3 Data needs and levels of accuracy

Before performing the insertion of data, it is also important to fix the balance between the precision and the quantity of the data. It is assumed that the time to edit the data in OSM would be limited and considering that in the typical scenario most of the data are missing yet, it is important to maximize this effort in order to get quality information for the data gathering processes.

Reducing the topic of the data needs to efficiency in buildings issues (including consumption/demand calculations and so on), the best way is to classify the data that could be entered into levels of accuracy, attending specially to the easiness of inserting these kinds of data, using the previous methods commented.

Two data types are the minimum elements required, and should be considered the basics for energy calculations:

- Element geometry. It is called “Area” and will be a polygon that specifies the surface occupied by the building.
- Basic building tag. It is a tag called “building” that differentiates between constructive elements and other elements that can be marked in OSM like landmarks, frontiers, administrative zones, use of the land, roads and streets, business locations and many other things that can be found and marked in a map.

The building tag can have different values - the default being “yes”. It can be defined as “house”, “church”, “apartments”, etc. But the most basic value is the distinction between the OSM elements with building tag or not. This is the first level of accuracy and will be used when typical values are the norm and good enough for the calculations. It will give off data distribution based on building scattering through the map in a fashion usually utilized in Europe-sized maps with little to no accuracy.

As it has been commented, using the tag “building” with custom values is a better and more accurate step of the process. Doing this, each building is defined with a typology that could be used to refine the model used for the calculations. Moreover, some buildings like the ones that are not dwellings can be separated or discarded from the set.

The next level of accuracy includes the usage of other tags that can help to identify completely the building, in order to get it associated to an EPISCOPE/TABULA building typology. The list (not exhaustive) can include:

Number of floors (subtag building:levels). The ground floor has to be included, but not if there is a roof level, that would be marked as roof:levels. For underground levels, use the subtag building:levels:underground.

Height (tag height). The total height of the building, not per floor. Marked in metres or feet. It uses the point to separate decimals.

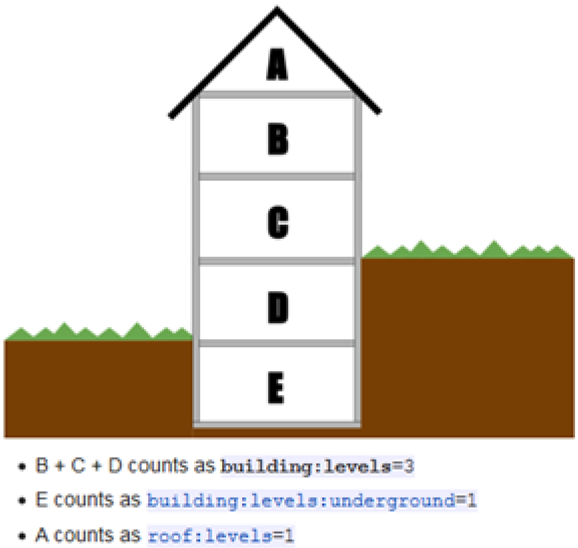

Figure 3 Building levels [2]

Address (tag addr with a subgroup of tags for every value). The address of the building. This can be useful in order to correlate the information with a dataset containing referred energy values, like Energy Performance Certificates (EPCs). This case is the ideal and ultimate accurate source, as long as it would contain information related to demand, consumption, equipment, etc.

The final comment concerning necessary data, is the fact that there is no way to get certain data like energy values or the date of the building, its equipment, or if refurbishment procedures have been applied on the building unless these data could be associated to other complementary data source. OSM data is usually limited to what an observer could assess considering real scouting of the zone (visual data and GPS values) and the translation of the local layer maps into OSM.

Just in case we needed to work offline with the data (with JOSM), the original OSM data must be imported. The procedure can be done:

- Directly with the Export button in the online application.
- Using the OSM API, giving out the coordinates of the square including the elements that we want to edit.

The result is a file of type *.osm that can be read from GIS applications without problems.

Generally speaking, the *.osm file is an XML file so it can be easily viewed and modified with any text editor. Moreover, it could be easily processed in any computer language using XML libraries (for example, xml package for Python).

There could be exceptions from these procedures, one of them being the OSM in Belgium. In order to guarantee the correct process of data import, these data are collected and put into JOSM application using previously an online application called AIV GRB (https://grbosm.site/) that works online and connects directly with the JOSM installed in the personal computer. For more info, consult the MATRIX manual [3]. This could also be the case in other countries, so it is usually important to contact the local OSM community before making any changes in the maps.

Whatever method has been used to get the *.osm file, it can now be processed via different GIS applications or programs, in order to edit them properly and visualize the data.

As a final note, it is possible to import data to several GIS applications that have plug-ins to connect directly to OSM. For example, with QGIS it is possible to get all the OSM items from one location, or restrict them to certain sets of tag values, etc. This would be performed in a different way depending on each GIS application. For these cases, the visualization of data becomes quite simple considering that the tags work as variables that can be accessed, organized and viewed, generating all kinds of customized maps.

OSM and different GIS tools

After the *.osm file has been imported, the work with the file depends on what is needed to be done with them and how.

For automated processes, the *.osm file has been acquired through the API call previously indicated, through a GET procedure. The programme, then, will translate the XML structure into arrays off data to be automatically processed and evaluated.

But back to the editing and addition of data in OSM, as it is obvious the process cannot be automated, needing of tools that could modify the *.osm and keep it compatible with OSM. Apart from GIS tools, the two ways to do it are the ones previously commented, online with the OSM tool or offline with JOSM.

From the programming point of view, the translation from *.osm format into *.gml format can be done with a Python script available online that uses the library called ogr2ogr from GDAL.

Regarding visualization, there are some GIS applications of interest:

- ArcGIS [4] is a commercial set of applications to create maps, making then collaborative and doing also related data analysis and management.
- QGIS (https://www.qgis.org/en/site/). It is a free and Open-Source Geographic Information System.

There are other options less known as GeoDa, or limited like Google Earth, and other programs of applications for analysis that could use GIS data and get it processed, like Stata, R Studio (to make processing data scripts) and some others, but both ArcGIS and QGIS are the most popular options.

11.2 Annex I References

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12 Annex II: Considerations for the implementation of a detailed approach for heating and cooling demand estimations

12.1 Implementation approaches and levels of detail of the data

The different levels of detail in the data has an impact on the accuracy of the results. This section presents some considerations on the different levels of detail that are available for specific datasets that are required in the estimation of heating and cooling demand. To illustrate and summarise this, the following table is presented.

As it can be seen the following table, there are certain inputs that, depending on the degree of availability, can help to make a better calculation approach or not, being the Low the case extreme with very little or almost no data, and High the ideal case where all the data is available.

Table 1 Level of data value for each implementation approach

	Level of data value for the calculations		
Input data required	**Low**	**Medium**	**High**
Real position of the homesteads	Statistics with the number of dwellings.	Building density map of the zone.	Geometrical surface and height.
Consumption value of the homesteads	National statistics for consumption values.	Consumption values by building typology and/or energy equipment systems at home.	Real values from EPCs.
Technical characteristics of the building	Mean values from the country taken from TABULA.	Partial building identification by open data sources like OSM.	Building characteristics identified by cadastre/EPC documents.
Building equipment and energy sources	Mean values from the country taken from TABULA.	Custom values from zonal/regional preferences.	Real values from EPCs.
Weather parameters	Mean values from corresponding climate zone.	Usage of one typical year from a near weather station.	Usage of the last year data from the nearest weather station in a similar climate zone.

Considering the calculation needs, a table relating the CDD (cooling degree days) and HDD (heating degree days) with the surface of a generic dwelling is also necessary. This dwelling is a virtual fabrication of a statistically average homestead considering the location. The output for this table is the mean consumption for this range of CDD/HDD and the surface interval. In order to achieve this, it is important to gather the yearly CDD and HDD, or at least the temperature values during one year in intervals of one hour (to comply with the set arrays of data necessary for the processing), the constructive features of the archetype dwelling, and the consumptions associated to this kind of building in the selected zone, linked to its surface. This late requirement is the main challenge to develop this approach. Initially, we can rely on Tabula [1] data from Episcope/Tabula to get some general values, including constructive and energy features from every single building typology grouped into range of year of construction and containing also specific levels of refurbishment where elements like the heating systems are also indicated.

12.1.1 Ideal case for High level of data

The label "ideal case" suggests that all the parameters necessary for the calculations are available, something that it is not currently possible because in some cases the data is simply non-existent, and in other cases the data is not available or just not easily accessible. For example, in Europe and thanks to the efforts of the EU institutions, more and more data can be obtained and are made available for the public.

One theoretical example could be an open data platform containing the whole info about all the homes in the world, containing the necessary data linked in single registers. The format might be JSON objects containing all the required fields. The advantage is that computer programs and scripts could be easily programmed in order to extract the required values from the data base. The order could be:

- Connect to an open data service, getting the set of elements in a determined zone.
- Extract every single element from the list previously obtained.
- Graphically map the elements extracted and group the results in a map grip through typical GIS applications.

The advantage of this procedure is that the users could customize whatever they want to do with the data. The way to automatize this would be an application where the coordinates of the whole map would be given, and then the program would send a request to the open data service, get the set of data, and these data would be processed directly or through the usage of filters set by the user. Finally, the application could have a graphic screen to show the processed data to the user.

12.1.2 Approach on Medium level of data

The former procedure can be considered as the ideal case. A second approach supposes that the data can be gathered or calculated indirectly, thanks to the existence of the proper data and measurements, as they were commented beforehand (technical data, weather values, etc.).

Part of the availability of data can be defined by their accessibility: nowadays it is not useful to have data only available in paper-format. In fact, the availability of data should include a procedure to access the storage online, or at least a way to link the data if an automated procedure is not provided by the source. At a world-level scale, the UN has some data [2], but these data blocks are fragmented among different organizations, and it seems that they still prefer to launch completed reports with processed data than having an open database where to gather all the information. Sometimes certain governmental institutions like NASA have some data available (like the MERRA-2 values for historic weather that are intensively used [3], but the dependence on these groups could compromise the availability and quality of data for a variety of reasons (there is an equivalent example of how an error signal was included in the GPS system in the past by the American army).

For this case, the order of the procedure can be the following:

- Connection to the data sources containing the different elements necessary for the calculations. They should be open data or at least should be reachable online. The usage of temporary data sources like static files will be done only if open online data are not available.
- Data processing. The application will calculate the values like the energy demand (the main feature) through the processing of the gathered data. And the results are grouped into elements that represent the single dwellings.
- Mapping of the elements. The elements calculated beforehand should have map references or coordinates, so they could be placed on a map and shown graphically.

12.1.3 Feasible layout for Low level of data

The previous cases show situations where the data exists - aggregated or not. But in the worst-case scenario some of the necessary data should be approached through different methods in order to reach a minimum level of data availability:

- **Statistic inference.** This can be done by making acceptable assumptions about the interrelation between variables. For example, maybe we do not have the heating consumption, but we have the outdoor temperature, and we can link both variables in a semi-inverse relation: colder weather means more heating demand. There are two big problems about this: one is to find the relations with their proper justifications, and the other one is to indicate the degree of reliability of the calculation in respect to the real result, in case of having been available.
- **Lower granularity approach**. It happens when there are no data available at local level, but there are global values than can be extrapolated into local ones. The challenge in this case is to find a local variable that could be directly related to the global variable without additional dependences.

These approaches face some big challenges in order to make them generic for all cases, being the most notable hurdles the following:

The cultural and social differences between countries [4]: this is by far the largest issue concerning EU policies and action plan and has been limiting the creation of generic procedures and the harmonization of results in research projects in general. Each country faces different user behaviours, different norms, different procedures, etc. And the consequence is that in absence of objective data, the inference of values through approaches and suppositions can be strongly misleading thus reducing the validity of results and forcing precisely to generate specific methods for each case (sometimes even at a local level).

Data unavailability: this problem includes the total absence of data, the data not publicly available, the data only available through payments, physical procedures or restricted to certain professionals, the data non-existent in digital format, values strongly outdated and/or with erroneous numbers (as an example, the GPS errors in Spanish cadastre and energy efficiency certificates repositories).

Another problem to solve is the translation of data, especially the energy data, in order to have a homogeneous input dataset. For example, it could be a good idea to show efficiency value levels (A to F with the corresponding colour code) if this can be easily identified and understood by any user. Moreover, in an automated procedure it is necessary this homogeneity of data, otherwise it would make it necessary to design a new interface for every country or region with special or specific data nomenclatures.

There are other problems regarding data, considering distributions, problems with the balance of observations and similar issues, considering the mathematical approach to the data [5].

The following sections describe more precisely the challenges faced for each of the four key elements previously identified for the calculation of heating and cooling energy demand.

12.2 Key steps in the heating and cooling estimation

The key steps in the heating and cooling estimation are presented in the following subsections, as per the following figure.

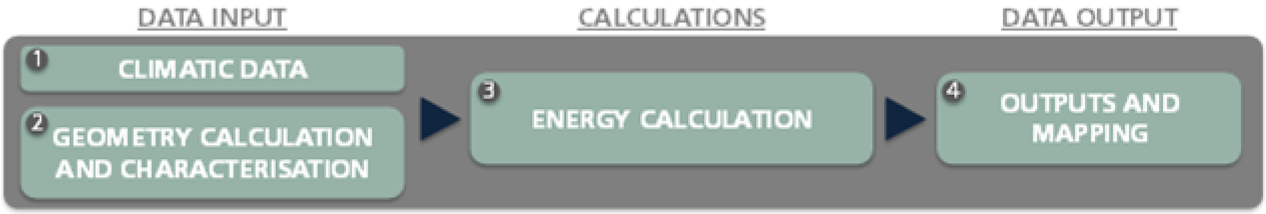

Figure 1 General procedure for the heating map generation

Thus, more information on the methodology and hypothesis applied can be found about climatic data in section 3.2 for the following: geometry calculation and characterisation, energy calculations and outputs and mapping.

12.2.1 Data input: climatic data

Considering the data obtained from weather stations, there are two kinds of data that these devices typically provide. One is the weather values in real time. These values are useful for devices or methods for weather prediction or intelligent control systems that require a continuous input of these values. The other one is the historical set of data that is useful for data analysis and it is precisely the one required for our case.

The first challenge considering the climate data is to obtain a proper set of values that:

- Is accessible through automated means.
- Is free of charge.
- Is not be limited by legal or normative issues.
- Represent faithfully the weather of the zone selected.
- Has an acceptable quantity of values to work with.

All these features will help to refine the search of proper data sources, considering all the possibilities that will be filtered through these criteria.

For example, for our initial tests we have been using a free network of [6] **raspberry-based weather stations** that can be accessed freely through API calls. The network has a small number of stations, and the data are scarce, but they are free of charge and do not require special preparations or installing anything, and the output data format is simple JSON files that can be easily processed. Unfortunately, the data has not been updated since the end of 2018, and consequently contemporary sets of data are not currently available this way.

Another approach could be the download of a list of values in a file, but this way the solution would be restricted to the locations with their corresponding historic weather file, something that should be avoided in the definitive solution. The obvious disadvantage is the reduction of automatization of the process.

Currently there is not a final approach to suggest, although some options have been finally discarded mainly due to their attachment to payment methods. The solutions being evaluated are:

- **EnergyPlus** (https://energyplus.net/weather). Amongst its applications for energy calculation, it has a weather application that might be useful in order to gather data. The preliminary tests only show data output files from a single year that cannot be freely selected.
- **SoDa** (http://www.soda-pro.com/web-services): It contains lots of accessories regarding solar radia-tion, and one of these (Modern-Era Retrospective analysis for Research and Applications) contains a

tool to download online historic values of weather data. These data can be used both for heat demands and PV assessment.

Currently, the lack of automated means for downloading the data from these locations makes it difficult to establish a workable solution. The process of data gathering is being done through web interfaces that force to make the download process manually.

The next step once the weather data is available is the calculation for the energy consumption in buildings. It depends on many different factors: usage typology, building typology, weather, equipment and other cultural factors specific from each region considered.

Temperature variables involved in energy needs calculation.

The important point is to establish a direct relation between the external temperature and the energy needs to heat or cool the buildings. As it has been commented, in the equations the building features are included in the form of a U value for thermal transmittance for the building envelope.

The modelling of the effect of the temperature is created through the usage of four variables:

- Heating comfort temperature - the temperature heating must establish for indoor comfort.
- Cooling comfort temperature - the temperature cooling must establish for indoor comfort.
- Heating base temperature - the temperature at which the resident starts feeling too cold and activates heating (and energy demand begins).
- Cooling base temperature - the temperature at which the resident starts feeling too warm and activates cooling (and energy demand begins).

It is common to find in the bibliography that the comfort temperature is considered as a single value instead of a range of temperatures, naming it “neutral temperature” in terms of comfort sensation, but that has to be considered as a simplification of the problem, less accurate and realistic than the consideration of a base range of temperatures, in line with the range of comfort temperature of the dwellers.

The equations used to calculate the degrees per hour (difference of degrees from the comfort interval during a time interval of 1 hour) are:

Hourly CDD.

Hourly CDD = 0 if Temperature < Cooling base Temperature.

Otherwise

Hourly CDD = Temperature – Cooling Comfort Temperature.

Hourly HDD.

Hourly HDD = 0 if Temperature > Heating Base Temperature.

Otherwise

Hourly HDD = Heating Comfort Temperature – Temperature.

The following figure shows a curve of energy demand considering a range of comfort temperature between 18°C and 21°C, and thresholds of 15°C and 24°C respectively, considered as the "standard case" for statistics in EUROSTAT [7]:

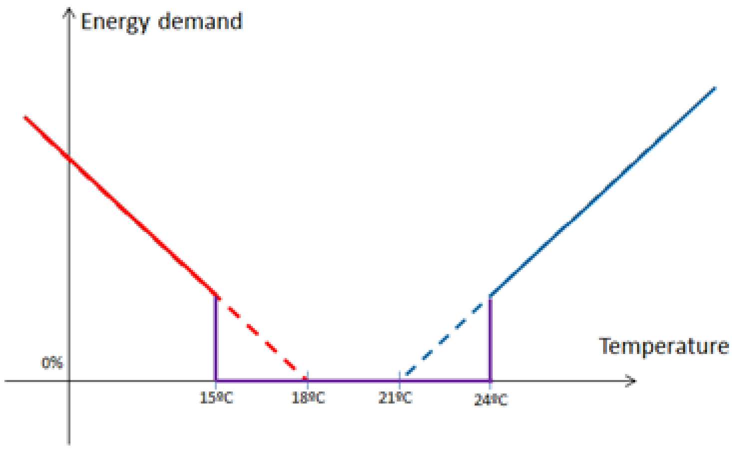

Figure 2 Consumption curve considering heating and cooling

The logical behaviour described in the consumption curve is that even though the linear increase in the usage of the heating and cooling might be referred to the base temperature range (18°C and 21°C), the systems are not activated by the users until they reach "critical" values, that act as a threshold for switching on/off the devices, in this case 15°C and 24°C.

The lines do not start on the base values because the heating/cooling has to cover a previous "demand" of energy that has not been satisfied until the threshold has been reached. For example, for the cooling proceeding, during the interval between 21°C and 24°C, the dwelling needs to be refreshed to go back into comfort values, but the user can still have the usual activities without much complaint. It is when the temperature rises to 24°C when the user decides to connect the cooling system, indicating the system that the house needs to be at 21°C even though it is now at 24°C, thus indicating that 3°C have to be lowered with the usage of energy for cooling.

To make the comment clearer, the "K/hour" that will be used to calculate the energy needs can be represented with a set of tables:

Table 2 Example of K/hour in a summer day (I)

Time	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00
Temp	17.0	16.2	15.6	15.0	14.6	14.2	14.0	14.6	15.6	17.0	17.8	18.4
ºC/hour	0	0	0	3.0	3.4	3.8	4.0	3.4	0	0	0	0

Table 3 Example of K/hour in a summer day (II)

Time	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00
Temp	19.0	20.6	22.6	25.0	24.4	22.6	19.5	17.7	15.8	14.0	12.2	10.3
ºC/hour	0	0	0	4.0	3.4	0	0	0	0	4.0	5.8	7.7

The tables were constructed with the data from the weather station in Falconara (Italy), for a day in August 2019. The values considered for the comfort interval and the base are the mean European ones from EUROSTAT [7].

The HDD and CDD are considered for a whole day, so the separated values would be, for HDD (red values): 35.1 K/day, and for CDD (blue values): 7.4 K/day. Considering the total real consumption, this would give a CDD+HDD = 42.5 K/day for this day in concrete.

Cultural considerations on heating and cooling usage and base comfort.

It is complicated to cover certain issues transcends mere technical circumstances, but there is an impact on data simply because some of the cultural/social effects stockpile instead of becoming statistically diluted. One example of the later can be the differences in physical activity or in clothing values (the “clo” variable in equations for the calculation of comfort [8].

The most important variable affecting the behaviour of the dwellers is the season of the year. The mean values of clothing, activity, air speed indoors and other parameters are modified by the majority of the people depending if it is summer or winter. In other words: a cold day in summer and a warm day in winter could present the same curve of temperature, but the behaviour of the citizens would be quite different in both cases. In an extreme case it would force the dwellers to connect the cooling in winter or the heating in summer in the same situation.

The way to model this is through the means of a displacement of the temperatures, especially the comfort range, as it can be noticed in the tables used to calculate comfort. For example, these could be typical values during summer and winter respectively:

Table 4 Typical values of temperature comfort ranges for winter and summer

Season	T heat. base	T heat. comfort	T cool. comfort	T cooling base
Winter	17°C	20°C	24°C	27°C
Summer	19°C	22°C	26°C	29°C

The bases have been calculated with a 50% of humidity and using the curves from [8], and the bases have been assumed proportionally to the ones given by the EUROSTAT value proposal.

It is noticed that the comfort range has been extended in both cases 1°C over the mean case of EUROSTAT, but the most important detail is the displacement of 2°C between both cases, that could reflect the variation of the activity in winter, the seasoning of the dwellers to hot/cold, and the change in clothing. These situations can be instantiated as more realistic, and can make effectively change the final results, especially in areas of moderate/mild weather where the temperatures are around comfort values during most of the year.

The second most important consideration is the mean value for a given country or region. As we have commented, the values given initially for the temperature parameters are directly a mean value for the whole set of European countries. The consequence is that the best way to increase the accuracy of the calculation of energy demand is to search for mean regional or even local values. This is, by far, the most difficult element to assume and requires making strong assumptions in terms of users’ behaviour, schedules, age, gender and social distribution, mobility and some others that cannot be properly calculated, only with advanced analysis of statistics that could or could not be available. Some parameters like humidity, clothing and others related to comfort shall not be directly considered. Nevertheless, those cultural particularities would be indirectly referred and grouped in the regional features considered in the next chapter, concretely in the usage of data from Tabula/Episcope or in the Building Stock Observatory.

As a side note, and considering the temperature ranges in Europe, the first interesting document can be found in (Brelih, 2013), where the differences between the temperature (and other parameters) values from different EU countries are represented together. Considering both single cases of summer and winter values, there is an important variation in the comfort setups, as it can be clearly seen in the comparative graphics. This corroborates the previous statement for the cultural, weather and constructive differences between countries, expressed in their global mean values. In the corresponding sections, the results and precedence of this table will be defined for each demo site. Anyway, the typical values of temperature comfort ranges for winter and summer could be used por all the countries without losing too much accuracy.

12.2.2 Data input: geometry calculation and building characterisation

The precise definition and characterisation of the building is crucial for the attainment of reliable calculation results. In this line, there are three main questions to be answered:

1. Where is the building located and what are its dimensions? > **Geometry calculation and location definition**
2. How is the building built? What are the thermal parameters that characterise it? What are its technical characteristics? > **Building characterisation**
3. What buildings share the same characteristics? > **Assigning building characterisation parameters to their geometry**

12.2.2.1 Geometry calculation and location definition

The singular element that must be completely evaluated and serves as basic unit for the calculations is the building.

The **geometry** is needed to quantify the elements integrating each of the specific buildings considered, that is, the envelope surfaces (façade, roof, floors, windows…), which will be then combined with the materials of the building considering its typology explained in the next section (building characterisation). The considerations about geometry for the buildings will only go as far as the data make it possible; in some cases, only the ground perimeter would be solely considered.

The **location** indicates the position of the building, where it is located so the effects of weather and the proximity of other buildings can be considered in the equation, and also, we could have an energy map as a result, with all the visual consequences, and the possibility of making data processing based on this location through GIS tools.

The main question about geometry and location information is how to obtain data with values as near as the real ones as possible, that would be accessible and open. Most countries have cadastre institution or its equivalent, but those data are not usually available online, or require some legal permits or even pay for the delivery. This means that given a country where the cadastre data would be available, the method of calling country cadastre APIs looking for data would be optimal.

Anyway, considering that the ideal approach is not possible in most of the countries, the solution found has been to use Open Street Maps [9]. Data is open-source open, free and OSM is independent, non-profit and is created by and for independent users. There are some negative issues, like the lack of homogeneity and quantity of data depending on the region, if the zone selected has not been intensively edited with new data, but the issue can be partially solved as long as the data editors (online and offline) are easy to handle so part of the missing data can be added. For more information about OSM, please consult the corresponding Annex I: Handling data from OSM sources of this document, where the basic details of usage are explained.

12.2.2.2 Building characterisation

The two main data sources used to characterise buildings were TABULA (mainly used for residential buildings due to its level of detail) and the Building Stock Observatory (to cover non-residential buildings). From these two sources it was possible to obtain the following parameters:

- Building characteristics
- Building elements
- Building energy systems

The list of values initially proposed to be calculated for each type of building was the following:

- U value per 1m^2 of roof
- U value per 1m^2 of wall
- U value for 1m2 of window
- Mean height per floor
- Mean number of windows per 1m^2 of wall (window-wall-ratio)
- Mean surface of each window in m^2
- Mean number of total floors of the building.
- Mean surface of dwellings and number of stores per dwelling.

All the previous values, except for the last one, are calculated in the standard way and give a simple numeric value for the correspondent typology. The U values are done taking the materials used for the element with its corresponding thickness and calculating the sum of all its components.

The floor height, number of floors per buildings and number of windows are obtained by direct analysis of the building typology.

The last parameter is a bi-dimensional array of data, a list of bi-dimensional elements with a relation like

[square meters for a x stores building, x number of stores]

as long as in some cases if the dwelling has more or less stores, the mean surface of every store might differ. For example: [[30,1], [20,2]] -> this represents a case where the typology, if it has 1 store, will occupy 30 m^2, meanwhile if it had 2 stores, the total surface will be distributed in 2 stores of 20 m^2 each, for a total of 40 m^2. By default, there would be only one value, like [[80,1]] that indicates a typical apartment that occupies 80 square meters in a distribution of one single floor.

With the previous steps, we could have both the types of building with its main features.

The real deployment of data ended up being a bit different, in order to simplify the calculations and avoid making assumptions for the building features, centered in the data that could be gathered via OSM: as it will be explained, concrete values of geometry, year of construction and typology of building will be crossed with feature lists in order to obtain the values necessary to make the energy calculations as accurate as possible.

12.2.2.3 Assigning building characterisation parameters to their geometry

There are some parameters corresponding to the kind of buildings that are considered on each case that are necessary to generate the energy data associated to each building.

Starting from the proposal that the typology of the building is well known (see corresponding table), the next step is to recover the general data and values for this specific type of building.

Table 5 Hierarchy order of selection of values

Hierarchy order of selection	Selection procedure	Kind of building selected
1	Consult OSM label	Deducted by the value of the label/labels
2	Position of the polygon centroid of the building surface	Type corresponding to the zone where the building is located
3	Global default value	Typology by default

The types of building must be obtained from TABULA for the country being considered. For the case of more general procedure, this had to be done for each typology of building and each country, but it would be possible to generate groups considering similar constructive features between countries in determined climatic zones. Besides, for non-residential buildings information from Building stock Observatory (BSO) is used, considering the country for extracting the corresponding values of the parameters.

OSM contains information about the use of the building. This information could be found in different tags from the OSM. The tags analysed for the categorization of the buildings are the following: building, aerialway, aeroway, amenity, barrier, boundary, craft, emergency, geological, highway, historic, landuse, leisure, man_made, military, office, place, power, public_transport, railway, route, shop, sport, telecom, tourism and waterway.

Considering these tags the buildings are organized in three main groups: residential, non-residential and discard. The “discard” group include the buildings that are not conditioned and not have energy demand. The energy calculation will ignore these buildings in the next phase. Besides, if there are enough information the residential group is divided in other groups with more information for the cataloguing in the different typologies. The groups are: Apartment buildings, Single Family Houses, Multi Family Houses and Terrace Houses.

The equivalence of the tags for the typologies of TABULA and BSO can be seen in table 6.

Table 6 TABULA and BSO typology tags overview

Key	Value	type	typology_TABULA	typology_BSO
building	apartments	Residential	Residential_AB	Residential
building	bungalow	Residential	Residential_SFH	Residential
building	cabin	Residential	Residential_SFH	Residential
building	detached	Residential	Residential_SFH	Residential
building	dormitory	Residential	Residential_AB	Residential
building	farm	Residential	Residential_SFH	Residential
building	ger	Residential	Residential_SFH	Residential
building	hotel	Residential	Residential_AB	Residential
building	house	Residential	Residential_MFH	Residential
building	houseboat	Residential	Residential_SFH	Residential
building	residential	Residential	Residential_MFH	Residential
building	semidetached_house	Residential	Residential_TH	Residential
building	static_caravan	Residential	Residential_SFH	Residential

building	terrace	Residential	Residential_TH	Residential
building	commercial	Non-residential	no_correspondence	Non-residential
building	industrial	Non-residential	no_correspondence	Non-residential
building	kiosk	Non-residential	no_correspondence	Non-residential
building	office	Non-residential	no_correspondence	Non-residential
building	retail	Non-residential	no_correspondence	Non-residential
building	supermarket	Non-residential	no_correspondence	Non-residential
building	warehouse	Discard	no_correspondence	no_correspondence
building	cathedral	Non-residential	Residential_MFH	Non-residential
building	chapel	Non-residential	Residential_MFH	Non-residential
building	church	Non-residential	Residential_MFH	Non-residential
building	mosque	Non-residential	Residential_MFH	Non-residential
building	religious	Non-residential	Residential_MFH	Non-residential
building	shrine	Non-residential	Residential_MFH	Non-residential
building	synagogue	Non-residential	Residential_MFH	Non-residential
building	temple	Non-residential	Residential_MFH	Non-residential
building	bakehouse	Non-residential	no_correspondence	Non-residential
building	civic	Non-residential	no_correspondence	Non-residential
building	fire_station	Non-residential	no_correspondence	Non-residential
building	government	Non-residential	no_correspondence	Non-residential
building	hospital	Non-residential	no_correspondence	Non-residential
building	kindergarten	Non-residential	no_correspondence	Non-residential
building	public	Non-residential	no_correspondence	Non-residential
building	school	Non-residential	no_correspondence	Non-residential
building	toilets	Discard	no_correspondence	Non-residential
building	train_station	Non-residential	no_correspondence	Non-residential
building	transportation	Non-residential	no_correspondence	Non-residential
building	university	Non-residential	no_correspondence	Non-residential
building	barn	Discard	no_correspondence	no_correspondence
building	conservatory	Discard	no_correspondence	no_correspondence
building	cowshed	Discard	no_correspondence	no_correspondence
building	farm_auxiliary	Discard	no_correspondence	no_correspondence
building	greenhouse	Discard	no_correspondence	no_correspondence
building	stable	Discard	no_correspondence	no_correspondence
building	sty	Discard	no_correspondence	no_correspondence
building	grandstand	Non-residential	no_correspondence	Non-residential
building	pavilion	Non-residential	no_correspondence	Non-residential
building	riding_hall	Non-residential	no_correspondence	Non-residential
building	sports_hall	Non-residential	no_correspondence	Non-residential
building	stadium	Non-residential	no_correspondence	Non-residential
building	hangar	Discard	no_correspondence	no_correspondence
building	hut	Discard	no_correspondence	no_correspondence
building	shed	Discard	no_correspondence	no_correspondence
building	carport	Discard	no_correspondence	no_correspondence
building	garage	Discard	no_correspondence	no_correspondence
building	garages	Discard	no_correspondence	no_correspondence
building	parking	Discard	no_correspondence	no_correspondence
building	digester	Discard	no_correspondence	no_correspondence
building	service	Discard	no_correspondence	no_correspondence
building	transformer_tower	Discard	no_correspondence	no_correspondence
building	water_tower	Discard	no_correspondence	no_correspondence
building	bunker	Discard	no_correspondence	no_correspondence
building	bridge	Discard	no_correspondence	no_correspondence
building	construction	Discard	no_correspondence	no_correspondence
building	roof	Discard	no_correspondence	no_correspondence
building	ruins	Discard	no_correspondence	no_correspondence
building	tree_house	Residential	Residential_SFH	Residential
building	yes	Residential	Residential_Default	Residential

building	user defined	Residential	Residential_MFH	Residential
aerialway		Discard	no_correspondence	no_correspondence
aeroway		Discard	no_correspondence	no_correspondence
amenity		Non-residential	no_correspondence	Non-residential
barrier		Discard	no_correspondence	no_correspondence
boundary		Discard	no_correspondence	no_correspondence
craft		Non-residential	no_correspondence	Non-residential
emergency		Discard	no_correspondence	no_correspondence
geological		Discard	no_correspondence	no_correspondence
highway		Discard	no_correspondence	no_correspondence
historic		Non-residential	Residential_MFH	Non-residential
landuse		Discard	no_correspondence	no_correspondence
leisure		Non-residential	no_correspondence	Non-residential
man_made		Discard	no_correspondence	no_correspondence
military		Discard	no_correspondence	no_correspondence
office		Non-residential	no_correspondence	Non-residential
place		Discard	no_correspondence	no_correspondence
power		Discard	no_correspondence	no_correspondence
public_transport		Discard	no_correspondence	no_correspondence
railway		Discard	no_correspondence	no_correspondence
route		Discard	no_correspondence	no_correspondence
shop		Non-residential	no_correspondence	Non-residential
sport		Non-residential	no_correspondence	Non-residential
telecom		Discard	no_correspondence	no_correspondence
tourism		Residential	Residential_AB	Residential
waterway		Discard	no_correspondence	no_correspondence

12.2.3 Calculations: energy calculations

The objective of the tools is the calculation of the following parameters for each building:

- Cooling demand
- Heating demand
- Hot water
- Heating consumption per vector
- Hot water Consumption per vector

An additional objective is the calculation of the hourly hot water, cooling and heating demand for the municipality in one year (i.e., 8760 values for each parameter)

So, for the next explanation it would be considered that the calculation will be don for each building, and those at the municipality level will be done using the sum of all the buildings.

12.2.3.1 Heating demand

For calculating the heating demand, the following formula is used:

Calculation of the heating demand: $Q_{heat} = P_{specific} * HDD / 1000$,

where HDD is the Heating Degree days for the entire interval.

The $P_{specific} = U * \text{Surface of the building}$.

In our case this $P_{specific}$ is calculated for each type of surface, specifically:

$P_{specific} = Uvalue_{walls} * Area_{walls} + Uvalue_{roof} * Area_{roof} + Uvalue_{windows} * Area_{windows}$

12.2.3.2 Cooling demand

For calculating the cooling demand, the following formula is used:

Calculation of the heating demand: $Q_{cool} = P_{specific} * CDD / 1000$,

where CDD is the Cooling Degree days for the entire interval.

The $P_{specific}$ is the same that those calculated for the heating demand

12.2.3.3 Hot water

For the hot water demand values, parameters about the hot demand per m² are used following the simple formula:

$Q_{hotwater} = Q_{hotwater/m^2} * GrossAreaFloor$

This $Q_{hotwater}$/m² is taken differently if the building is residential or non-residential. For the non-residential buildings information from Building Stock Observatory is used, and it is different for each country and for each interval of year of construction. In the case of the residential building, TABULA data are used and the parameters are different for each country but also for each type of typology defined (for type of building and for each interval of year of construction).

12.2.3.4 Heating consumption per vector

In the case of the consumption of the heating demand per vector the approach is also slightly different for residential or non-residential buildings.

The different vectors that are considered are those provided by TABULA (that is the more complete source data used by the tool) are the following: Gas, Oil, Coal, Biomass, Electricity and District Heating.

In the case of the residential buildings, the energy systems considered in the corresponding typology of the building (up to three systems per typology) are taken into account with their efficiencies. Also, distribution and storage losses are considered. Besides auxiliary energy to uses these systems (usually electricity) is calculated. All this information is extracted from TABULA and the calculation are carried out following the methodology proposed by TABULA.

For the case of the non-residential building a simpler methodology is used. In this case the values of the energy consumption per vector and per m² are used (but differently per country). The values are extracted from Building Stock Observatory (BSO) and there is only information for four vectors: Gas, Oil, Coal and Electricity. In the no-residential case, it is considered that each building has the four vectors in the proportion indicated by the BSO data.

12.2.3.5 Hot water consumption per vector

In the case of the hot water demand the procedure is the same that the followed in the previous section: TABULA for residential buildings and BSO for those non-residential one, with the same methodology explained before.

12.2.3.6 Hourly domestic hot water, cooling and heating demand for the municipality

In this case the objective is to calculate the hourly demand for domestic hot water, cooling and heating demand for the complete municipality. The way to do that is the same for the cooling and heating demand but different for the hot water demand

For heating and cooling calculation, demands of all the buildings are summed and after that, this is distributed using the hourly HDD and CDD. In this way we have the following formulas:

Heating demand $_{\text{hour i}}$ =Energy demand $_{\text{total}}$* HDD $_{\text{hour i}}$/ HDD

Cooling demand $_{\text{hour i}}$ =Energy demand $_{\text{total}}$* CDD $_{\text{hour i}}$/ CDD

In the case of the domestic hot water demand calculation, it has been assumed that the demand is constant over the year but excluding the night periods. Specifically, it has been distributed evenly from 6:00 to 24:00 for every day.

Then, the result is three vectors of each 8760 values.

12.2.4 Outputs and mapping

The calculations are done at building level and the results are stored in the same dataset that comes from the OSM, so the results are mapped.

In the mapping phase the objective is using this dataset to create a grid of 100m x 100m squares with the heating and hot water demand corresponding to each square. The steps are the following:

1. Using GIS procedures, split the OSM map into 100m x 100m squares. Then, associate each building through its centroid to each square.
2. Sum up each building heating and hot water demand value with the others belonging to the same square location.
3. Creating a raster file (tiff) with this information

This raster fil can be visualized and used for feeding other tools.

12.3 Future works, possibilities and recommendations

The concept is to add new scripts and integrate other related data in order to offer a better approach (a more realistic one at least) of results.

- Usage of the information about if the buildings are attaches to other buildings. The concept behind is the fact that grouped buildings help to reduce the energy requirements. The fact of having another building attached to a wall reduce substantially the heat losses from that wall.
- Another evolution is the “zonification” of the urban centres. The idea is to make divisions where the types of buildings are clearly different from the rest of the building set considered.
- One interesting element to consider inside the homes is the inclusion of the efficiency factors from the heating and cooling equipment, in order to obtain both demand and consumption numbers.

- Next is the factor of occupation for the buildings: not all of them are occupied and should not add anything to the result. The way to add this effect is to use a factor created through the information gathered via Eurostat.
- Finally, and similar to the previous variation, the usage of the occupancy factor, but not in absolute terms (unoccupied homes) but considering daily usage of the dwelling, simulating the standard behaviour of the users.

12.4 Annex II References

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