MODULE 1

CHAPTER 4_MAPPING H&C DEMAND AND RES POTENTIAL

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Abbreviations

CAPEX: Capital Expenditure
CBA: Cost-Benefit Analysis
CHP: Combined Heat and Power
DH: District Heating
DHC: District Heating and Cooling
DLT: Distributed Ledger Technologies
ESCO: Energy Service Company
EU: European Union
GHG: Greenhouse Gas
GM: General Manager
HU: Heat Upgrade
IEC: Integrated Energy Contracting
ICT: Information and communications technology
KPI: Key Performance Indicator
LCOH: Levelized Cost of Heat
OPEX: Operating Expense
R&D: Research and Development
RES: Renewable Energy Sources
REII: Renewable Energy Intensive Industries
SME: Small and Medium Enterprises
TES: Thermal Energy Storage
UI: User Interface
UX: User experience
WH/C, WH/WC: Waste Heat/Cold
WHTC: Waste Heat to Cold
WHTH: Waste Heat to Heat
WHR: Waste Heat Recovery
WHP: Waste to Power

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SHORT SUMMARY

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1 Introduction to Mapping

Georeferenced data are an important tool for city- and district-level energy planning since they allow matching the energy demand (heating & cooling, electricity, etc.) with the potential supply from renewable or sustainable sources in a specific area. Specifically, it is worth highlighting that they are useful for high-level planning since they allow identifying areas with a good potential for intervention but additional evaluations are needed to preliminarily design systems and plants to be installed.

This chapter focuses on the methodology that the SO WHAT tool adopts to determine the geographical distribution of both the heating and cooling demand and the potential for energy production from renewable energy sources. In the context of the SO WHAT tool, whose main focus is on the valorisation of excess heat and cold from industrial sites, mapping these two distributions is important in order to evaluate the possibility of feeding the recovered heat to residential/tertiary buildings through district heating/cooling networks, possibly coupled with heat or electricity produced from a renewable source.

The following two sections focus respectively on mapping the heating and cooling demand and the potential for energy production from renewables.

2 Mapping Heating & Cooling Demand

As mentioned above, in order to enable new business cases for waste heat/cold recovery, it is of paramount importance to analyse and identify the location and the magnitude of Heating/Cooling (H/C) demand in the area surrounding the industrial sites in which Waste Heat/Cool (WH/C) is available.

The methodology adopted in the SO WHAT project for mapping H&C (and DHW) demand is linked to the work made in the previous PLANHEAT project, whose mapping module combines QGIS and a customized software to carry out energy-related computations. The PLANHEAT tool as developed in the project is completely open-source, so such algorithms could be used as relevant starting point for SO WHAT tool too. It is acknowledged that the mapping methodologies hereby presented have been developed by PLANHEAT consortium, in particular by RINA-C and VITO (Top Down approach) and TECNALIA and VITO (Bottom-up Approach).

In order to map H&C and DHW demand, two main approaches can be identified according to the availability of input data, and specifically:

- **Top-Down approach** (pixel level), aimed at mapping the current annual H&C-DHW useful energy demand, provided that aggregated (at city or district scale) input data are available; starting from annual data about final energy consumption aggregated at a certain level (from district up to city aggregation), the algorithm disaggregates them at the desired resolution; the monthly and daily distribution of the annual demand can then be calculated based on the number of Heating and Cooling Degree Days at specific location;
- **Bottom-Up approach** (building level), aimed at calculating and mapping hourly and annual profile of H&C-DHW useful energy demand, provided that input data at building level are available; starting from detailed information at building level the algorithm estimates hourly profiles of H&C demand for each building for which input information is provided.

Due to the high-level target of the tool, whose objective is to quantify H&C-DHW demand in order to identify potential “clients” for WH/C recovered from industries, following methodologies developed

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in the previous PLANHEAT project, the most suitable approach for the SO WHAT tool is the simplified version of the bottom-up approach.

2.1 Top-Down Approach

The top-down approach developed in PLANHEAT WP2 under VITO and RINA-C supervision allocates the heating, cooling and DHW demand of the city based on final energy consumption data inserted by the user and spatial indicators describing the building stock and activities in the city.

The results of the analysis are presented in form of georeferenced maps and also in spreadsheets and tables, describing the demand at city level or at level of other spatial subdivisions of interest to the user. The spatial resolution can be varied by the user, usually in the range between 50 m and 1 km, depending on the size of the city, whereas the time resolution is one year.

The first step of the analysis foresees the conversion of final energy consumption data into useful demand numbers for the residential and the tertiary sector, with breakdown among the following categories:

- space heating at high temperature (>70°C);
- space heating at medium temperature (40-70°C);
- space heating at low temperature (< 40°C);
- domestic hot water;
- space cooling.

Each of the above categories of H&C demand is then spatially distributed according to a "weighted distribution" algorithm based on the most suitable spatial indicators available for the specific location. Examples of such spatial indicators are the spatial distribution of the floor area of the residential buildings within the city (if available from the local cadaster), the footprint of buildings in the city, the employment maps or the spatial distribution of population density. If specific data at local scale are not available, default GIS datasets at European scale can be used (e.g. Corine Land Cover, PVGIS, etc.).

Inputs Needed in the Top-Down Approach

The baseline scenario is assessed in terms of useful energy demand for heating, cooling and DHW for selected areas of the city. The assessment is therefore based on the following input data:

- Final energy consumption of the area of interest;
- Information or assumptions about technologies installed in the area of interest.

Specifically, it is required to provide the breakdown of final energy consumption by:

- **Sector**: Residential and Tertiary;
- **Type of system**: Single Building Solution or District Heating and Cooling Network;
- **Energy end-use**: Heating, Domestic Hot Water and Cooling (the share between heating and domestic hot water is required if the user has available final energy consumption combining heating and DHW);
- **Energy source**: for heating and DHW: natural gas, electricity, fuel oil, other fossil fuels, geothermal, solar, biomass, waste heat; for cooling: natural gas, electricity, waste heat and geothermal.

Information about technologies for each energy source are also required, including:

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- **Technology type** (boilers, combined heat and power generators, compression and absorption heat pumps, electrical heaters, heat exchangers, solar thermal panels);
- **Efficiency** and, for CHP only, utilization factor;
- **Share of technology** type (in terms of share of devices installed for each technology or share of end users supplied).

In case of lack of input data, default values coming from EU databases can be adopted. For instance, data aggregated at national level can be used and downscaled according to the population of the city of interest. In this framework, relevant databases are:

- Heat RoadMap Europe – Data set for Heating and Cooling Demand **Invalid source specified.**;
- European Building Stock Database**Invalid source specified.**;
- European Settlement Map 2015 –release 2019 (2-10m spatial resolution) **Invalid source specified.**;
- Corine Land Cover 2018 map **Invalid source specified.**.

Output of the Top-Down Approach

The outputs resulting from the application of the top-down approach are listed below:

- Residential/Tertiary sector - Single building solution:
  - Useful energy demand per energy source – Heating [MWh/year],
  - Useful energy demand per energy source – DHW [MWh/year],
  - Useful energy demand per energy source – Cooling [MWh/year];
- Residential/Tertiary sector – DHCN solution:
  - Useful energy demand per energy source – Heating + DHW [MWh/year],
  - Useful energy demand per energy source – Cooling [MWh/year];
- Residential/Tertiary sector – Single building solution + DHCN solution:
  - Total useful energy demand per energy source (all temperature levels) [MWh/year],
  - Total useful energy demand per energy source heat supply >70°C [MWh/year],
  - Total useful energy demand per energy source heat supply 40 -70 °C [MWh/year],
  - Total useful energy demand per energy source heat supply <40°C [MWh/year],
  - Total useful energy demand per energy source DHW [MWh/year],
  - Total useful energy demand per energy source Cooling [MWh/year],
  - Share of useful energy demand covered by each energy source [%];
- Raster maps (with resolution defined by the user) with spatial distribution of current useful energy demand for:
  - Residential – space heating high temperature,
  - Residential – space heating medium temperature,
  - Residential – space heating low temperature,
  - Residential – domestic hot water,
  - Residential – space cooling,
  - Tertiary – space heating high temperature,
  - Tertiary – space heating medium temperature,
  - Tertiary – space heating low temperature,
  - Tertiary – domestic hot water,
  - Tertiary – space cooling;

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- Summary of the raster maps in a bar chart and table, subdivided by district or other spatial subdivisions of interest to the user.

Examples of outputs from the top-down approach are presented in Figure 1.

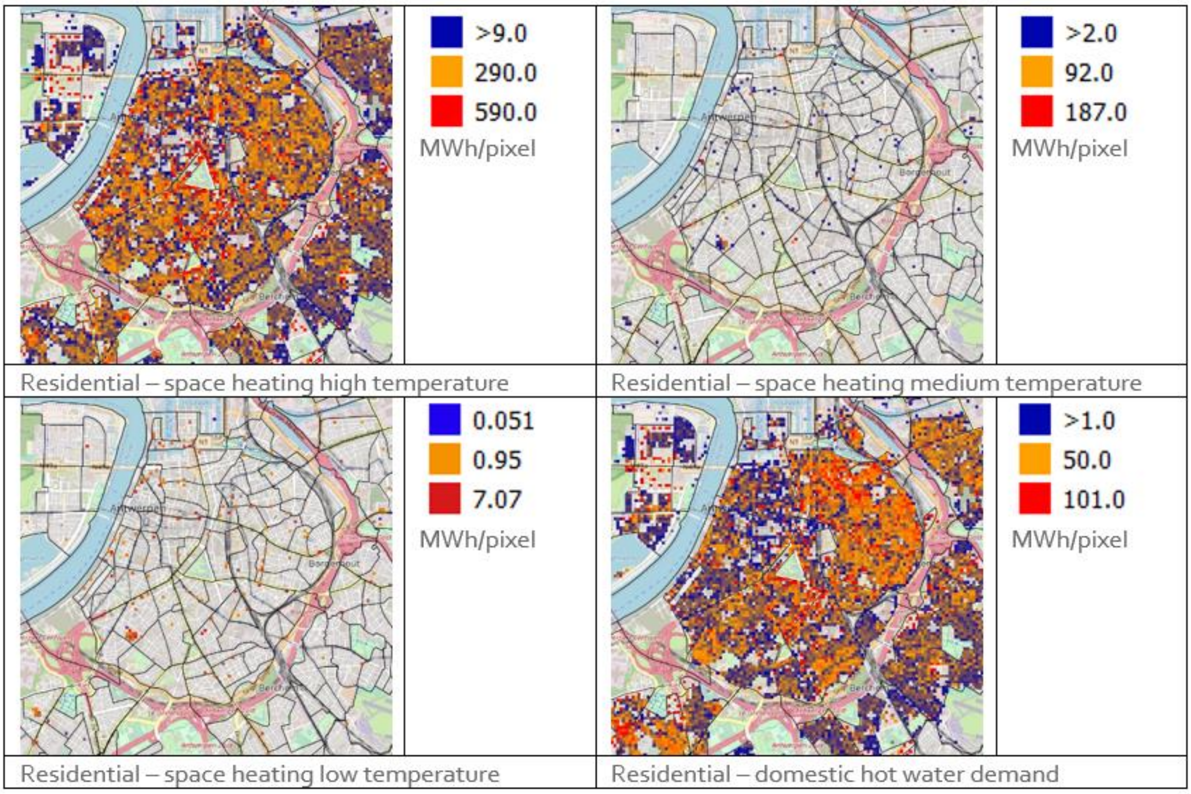

Figure 1: Example of Outputs of Top-Down H&C Demand Mapping Approach – Map View

2.2 Bottom-Up Approach

Developed in PLANHEAT WP2 under VITO and TECNALIA supervision, the Bottom-Up approach is aimed at quantifying and mapping the georeferenced thermal energy (heating, cooling and DHW) demand for each building at district scale.

It starts from different information available for the buildings of the selected area and calculates the useful hourly energy demand, aggregating results at the desired level (per building or per district, per building category in terms of use and/or construction period).

This approach can be implemented, as done in the District Mapping Module of the PLANHEAT project, through a QGIS plugin, which has the benefit to be an open-source GIS cross-platform application.

Inputs Needed in the Bottom-Up Approach

The inputs needed for the bottom-up approach are mainly related to the physical characteristics of the buildings in the area. This information is generally available for local authorities and municipalities, which use it for urban planning and public works, as well as for taxation of urban properties through the cadaster database. A cadaster is available in all EU Member States, although no homogeneous model is available and sometimes data are present only in paper form.

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The bottom-up approach is developed with the aim of basing most of the assessment only on the cadaster information. Based on the level of detail of the information available for the specific municipality, two approaches can be identified: a complete and a simplified one. In addition to cadaster information, only two further types of data may be required: information on building heights (if it is not available from the cadaster, from LiDAR for example) and air temperature data (only for the complete approach).

It is highlighted that the accuracy of the results provided by the bottom-up approach depends on the availability, accuracy and level of detail of data. When the cadastral data is not available or is outdated, an alternative solution is to base the assessment on information from OpenStreetMap**Invalid source specified.** that provides building geometries and attributes based on an open source and active collaborative framework.

Independently from the type of input data source used, a pre-processing phase is always needed. Indeed, the following issues related to data format and availability were identified:

- the information may be not included in a single layer;
- different layers can have different coordinate reference systems;
- different sources do not use the same ID for the same information;
- geometry of buildings might be too complex and need to be simplified;
- the available information is not complete for all buildings;
- data may be inconsistent.

As introduced above, when the height of the buildings is not available in the cadaster, backup information can be taken from LiDAR, which is a system generating a cloud of point covering the ground surface by means of an airborne laser scanner. From LIDAR data, a Digital Surface Model (DSM) and a Digital Terrain Model (DTM) can be derived, the former representing the elevation of the natural and built environment above the earth surface and the latter the elevation of the earth surface.

To conclude, the third type of information for the assessment is the heating and cooling degree days for the specific location, which can be gathered from many online weather services like degreedays.net.

After the pre-processing step, a shapefile is created which includes a unique geometry for each building and the set of information presented in Table 1: building ID, building geometry, footprint area, year of construction, use and building height.

Table 1: Bottom-Up Approach - Inputs to be provided by the End-User

Parameter	Mandatory or Optional	Source	Assessment approach
Building ID	Mandatory	SHP of the District	Complete (C) and Simplified (S)
Project ID	Mandatory	User input	C + S
Study area name	Mandatory	User input	C + S
Country	Mandatory	User input	C + S
Building Geometry	Mandatory	SHP of the District	C + S
Footprint area	Mandatory	SHP of the District	C + S

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Parameter	Mandatory or Optional	Source	Assessment approach
Height	Mandatory	SHP of the District or LiDAR *If the end user does not provide the information about "number of floors"	C + S
Height	Optional	SHP of the District or LiDAR *If the end user provides the information about "number of floors"	C + S
Number of floors	Mandatory	SHP of the District *If the end user does not provide the information about the "height"	C + S
Number of floors	Optional	SHP of the District *If the end user provides the information about "height"	C + S
Hourly outside air temperature	Mandatory	weather webserver	C
Year of construction	Mandatory	SHP of the District	C
Building Use	Mandatory	SHP of the District	C
Gross floor area	Optional	SHP of the District	C
Roof area	Optional	SHP of the District	C

Output of the Bottom-Up Approach

The bottom-up approach provides results at building level and at district level.

At building level, it provides two different results:

- georeferenced generic and energy-related information per building (as shown in Table 2);
- hourly heating, cooling and DHW demand data per each building of the area.

The results will be available in CSV and SHP format, to allow analysis at quantitative and at georeferenced level. The two files contain for each building of the area under analysis the information listed in Table 2.

Examples of outputs from the bottom-up approach are presented in Figure 2 and Table 1.

Table 2: Bottom-Up Approach - Outputs at Building Level

Parameter		Unit	Assessment approach (Complete / Simplified)
Project Generic Data			
	Project ID	Name	Both
	Study area name	Name	Both
	Country	Name	Both
Building Generic Data			
	Building ID	-	Both
	Centroid of the building	Coordinates	Both

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Parameter		Unit	Assessment approach (Complete / Simplified)
	Use	-	Complete
	Footprint area	m^2	Both
	Height	m	Both
	Number of floors	-	Both
	Gross floor area	m^2	Both
	External opaque facade area	m^2	Complete
	Roof area	m^2	Complete
	Window area	m^2	Complete
	Volume	m^3	Complete
	Year of construction	-	Complete
Building Energy Data			
	Annual heating demand	kWh/y	Both
	Annual cooling demand	kWh/y	Both
	Annual DHW demand	kWh/y	Both
	Annual heating demand per square meter	kWh/m²/y	Both
	Annual cooling demand per square meter	kWh/m²/y	Both
	Annual DHW demand per square meter	kWh/m²/y	Both
	Peak heating demand	kW	Both
	Peak cooling demand	kW	Both
	Peak DHW demand	kW	Both

Figure 2: Example of Output of Bottom-Up H&C Demand Mapping Approach – Map View at Building Level

Table 3: Example of Output of Bottom-Up H&C Demand Mapping Approach – Table View at District Level

Use	Construction Period	Number of Buildings	GFA (m²)	Heating Demand (kWh/year)	Cooling Demand (kWh/year)	DHW Demand (kWh/year)
Residential	Pre-1945	534	279,772	20,346,771	473,960	3,888,831
Residential	1945-1969	71	59,463	4,000,259	86,496	826,536

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Use	Construction Period	Number of Buildings	GFA (m²)	Heating Demand (kWh/year)	Cooling Demand (kWh/year)	DHW Demand (kWh/year)
Residen tial	1970-1979	32	29,70 3	1,689,811	71,039	412,872
Residen tial	1980-1989	97	61,73 4	3,760,774	218,466	858,103
Residen tial	1990-1999	52	87,44 1	3,499,476	259,553	1,215,430
Residen tial	2000-2010	34	37,48 7	951,556	138,860	521,069
Residen tial	Post-2010	14	19,67 7	500,967	67,495	273,510

3 Mapping Renewable Energy Sources Potential

In this section, focus is placed on the mapping of the potential for energy production from renewable sources, useful to identify the opportunities for integration of renewable electricity and heat in the energy systems of the plant under analysis.

The following paragraphs have the objective to provide information on the algorithms that can be used to geo-reference on a map renewable sources for heat supply (solar thermal, geothermal and biomass) and electricity generation (photovoltaic and wind energy). SO WHAT tool is provided with the functionalities of displaying on a geo-referenced map, different potentials of the mentioned sources in order to be useful to different type of end-user at different planning level.

Introduction to RES Potential

Four types of renewable sources potentials have been identified. For each of them, a map can be developed, specifying the annual energy potential in MWh. In addition, for the sources having a significant variation in time (wind and solar), a higher granularity can be achieved and also hourly values can be determined. In particular, hourly profiles can be useful for the modules of the SO WHAT tool that need to analyze the energy performance of the systems hour by hour.

The above-mentioned source potential defined are:

1) **Physical potential:** it represents the maximum amount available for the considered source. It depends on weather conditions (e.g. presence of wind, absence of clouds, etc.) and on type of territory (e.g. suitability for biomass growing). A typical example is the energy coming from solar irradiation on a surface or the energy that is contained in the forestry biomass of a hectare of forest.
2) **Geographical potential:** it represents the amount of energy that is available to be effectively exploited and that is less than the physical potential since it depends from different constraints that can limit its exploitation such as availability of surface for technology installation or limitation of biomass extraction from a forest. Also for this case, the geographical potential is expressed in MWh/y.
3) **Technical potential:** it represents the energy that is provided by an energy source after the application of a technology, therefore the thermal energy that is transferred to an intermediate medium to heat up or cool down the air of an internal space or the electricity that is produced to cover a demand. The process of transferring and transforming energy is always subject to an efficiency and part of the initial energy is lost. To consider this aspect, to each geographical potential for each source a transformation efficiency will be applied through the selection of a

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technology form the SO WHAT tool library. In order to represent the technical potential on a map, an annual value will be produced for each source after the selection of the appropriate technology. In this case, an average or seasonal efficiency will be used to provide an estimation of the technical potential that is possible to obtain from a source. In the Manufacturing and Community modules of SO WHAT tool, a more precise calculation at hourly level of technology efficiency will be done to provide more accurate results about the utilization of local sources.

4) **Local potential:** it represents local potential demand and will be evaluated in the section dedicated to the calculation of the energy demand at building level of the different modules.

In the following paragraphs, the algorithms proposed for the SO WHAT tool for the geo referenced evaluation of the annual physical, geographical and technical potentials of different local sources are described. These algorithms are implemented in the different modules of the SO WHAT tool to be used by the end-user as a support for the evaluation of the energetical potential of the territory under investigation.

Inputs for Mapping RES Potential

In the SO WHAT tool all the georeferenced information that are needed to provide the annual amount of local energy sources come from existing databases that represent the basis for the calculations of the three levels of potential that are the object of this paragraph (physical, geographical and technical).

In Table 4, for each local source considered, the external databases that can be used are mentioned. For some of them (e.g. those related to solar thermal) the information provided already represents the physical potential, for the others, various pieces of information are required to evaluate the physical, the geographical and the technical potentials.

Table 4: Databases to identify SO WHAT tool resources

Energy source's type	External database to provide default values for RES resources
Solar thermal energy (solar thermal heat and photovoltaic)	• PVGIS database. Hourly radiation data by location. Spatial resolution of 6 km. (http://re.jrc.ec.europa.eu/PVGIS5-release.html); • MERRA-2 RE-ANALYSIS. Hourly radiation data by location. Spatial resolution approx. of 50 km (http://www.soda-pro.com/fr/web-services/meteo-data/merra). • HELIOCLIM-3 REAL-TIME AND FORECAST. Hourly radiation data by location. Spatial resolution approx. of 100 m (http://www.soda-pro.com/fr/web-services/radiation/helioclim-3-real-time-and-forecast). • GLOBAL SOLAR ATLAS (https://globalsolaratlas.info/map). Daily and yearly radiation and potential values. Spatial resolution approx. of 250m.
Biomass	• Corine Land Cover suitable forest and agricultural areas [m^2] (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018). • Forest type [m^2] (https://land.copernicus.eu/pan-european/high-resolution-layers/forests/forest-type-1/status-maps/2015).
Geothermal (shallow and deep)	• Geothermal Heat (https://heatroadmap.eu/peta4/). Temperatures at different depths. • Shallow geothermal potential in W/mK (http://www.hotmaps.eu/)

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Wind	• https://globalwindatlas.info/ Wind resource mapping at 250 m horizontal grid spacing. Wind resource mapping at 10, 50, 100, 150 and 200 m above ground/sea level.
Industrial Excess Heat	• E-PRTR (European Pollutant Release and Transfer Register) database (https://prtr.eea.europa.eu/#/home)

In addition to these databases, specific local data are needed, such as cadaster data of the city with footprint of buildings. To this aim, the layer Buildings of OpenStreetMap (http://www.openstreetmap.org) can serve as an open data alternative. Moreover, EES-Natura200 areas database (https://www.eea.europa.eu/data-and-maps/data/natura-9/natura-2000-spatial-data/natura-2000-shapefile-1) can be useful to check the presence of constraints that may obstacle the realization of plants in a given area.

A summary of the technical information required from the end-user of the SO WHAT tool are provided in Table 5. For each parameter, a default value will be presented for calculation, but the related field of input opens to be edited.

Table 5: default efficiencies related to different technologies for the technical potential mapping

Source		Technology	Default for efficiency
	Thermal RES		
Solar thermal energy	Solar thermal energy	Flat plate solar collectors	50% th.
	Solar thermal energy	Evacuated tube solar collectors	70% th.
	Solar thermal energy	Concentrating collectors	80% th.
Forestry biomass	Forestry biomass	Hot water boiler	85% th.
	Forestry biomass	Steam boilers	85% th.
	Forestry biomass	Gasifiers (cogeneration)	70% th – 20% el.
	Forestry biomass	ORCs (cogeneration)	65% th. – 18% el.
Agricultural biomass	Agricultural biomass	Hot water boilers	80% th.
Deep geothermal	Deep geothermal	Heat exchanger	90% th.
	Deep geothermal	HRSG (cogeneration)	45% el. – 40% th.
	Deep geothermal	ORC (cogeneration)	40% el. – 40% th
Shallow geothermal	Shallow geothermal	Compression heat pump	300%
	Shallow geothermal	Absorption heat pump	150%
	Electrical RES		
Photovoltaic energy	Photovoltaic energy	Polycrystalline	17% el.
	Photovoltaic energy	Monocrystalline	15% el.
	Photovoltaic energy	Amorphous	13% el.
	Photovoltaic energy	Thin film	10% el.
Wind energy	Wind energy	Horizontal axis	30% el.
	Wind energy	Vertical axis	45% el.

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Mapping Thermal RES Potential

The thermal RES considered in SO WHAT tool are solar thermal, biomass (from forestry and agriculture) and geothermal (shallow and deep), being the most widely available and mature. Table 6 summarizes the algorithms and the databases used to evaluate the potential for these sources.

Table 6 : Thermal RES Potential – Algorithms and Reference Sources

Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input

Solar thermal energy $E_{pot,solar}$	$E_{pot,solar} = Ir \times Technical\ suita \times Efficiency \times Available\ Area$ [MWh/yr]	• Ir =Total solar irradiance under flat plane angle [kWh/m²]
		• *Technical suitability* [-]: assumed 40% (1);
		• *Efficiency* [-]: assumed 75% (2);
		• *Available area*=
		  ○ Footprint of buildings [m²],
		  ○ Other suitable area [m²].
			• Ir [kWh/m²]: PVGIS database (https://re.jrc.ec.europa.eu/pvg_tools/it/tools.html#MR);
			• *Footprint of buildings* [m²]: cadaster database or OpenStreetMap (http://www.openstreetmap.org) as an open data alternative;
			• *Other suitable area* [m²]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

Biomass energy from forestry PE_{FT}	$PE_{FT} = FA \times NAI_{reg} \times PE$ [MWh/yr]	• FA = Forest area of specific forest type:
		  ○ Forest cover [ha],
		  ○ Protected areas or other spatial constrains [ha],
		  ○ Global ecological zones [ha];
		• NAI_{reg} = Average stem-wood net annual increment per region [$tonnes_{DM}$/(ha yr)]: GEZ – Temperate forests:
		  - Coniferous: 3.0
		  - Broadleaf: 4.0
		  - Mixed C-B: 4.0
		GEZ – Boreal forests:
		  - Coniferous: 2.5
		  - Broadleaf: 1.5
		  - Mixed C-B: 1.5
		GEZ – Subtropical forests:
			• Forest cover [ha]: Corine Land cover (2018) (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018);
			• Protected areas or other spatial constrains [ha]: Natura2000 areas (2016) (http://ftp.eea.europa.eu/www/natura2000/Natura2000_end2016_Shapefile.zip);
			• Global ecological zones [ha]: Global ecological zones (2010) (http://www.fao.org/g

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
		- Coniferous: 0.9 - Broadleaf: 0.9 - Mixed C-B: 0.9 • PE = Primary energy production for every type of forest [MWh/ton$_{DM}$]: - Coniferous: 19.2 - Broadleaf: 19.0 - Mixed C-B: 19.1	eonetwork/srv/en/main.home?uuid=2fb209d0-fd34-4e5e-a3d8-a13c241eb61b); • NAI_{reg} [tonnes$_{DM}$/(ha yr)]: IPCC database (based on global ecological zones); • PE [MWh/ton$_{DM}$]: IPCC database.
Biomass energy from agriculture PE_{AG}	$PE_{AG} = Straw\ Yield \times Technical\ avaib \times Energy\ Content \times Available\ Area$ [MWh/yr] $StrawYield = CropYield \times 0.769 - 0.129 \times arctan[(CropYi - 6.7)/1.5]$ [ton/ha]	• Straw yield [ton/ha]; • Technical availability [-]: assumed 50%; • Energy content [MWh/ton]; • Available area [ha]; • Crop Yield [ton/ha].	• Straw yield [ton/ha]: equation in the BEE Best practices and methods handbook; • Energy content [MWh/ton]: BEE Best practices and methods handbook; • Available area [ha]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018); • Crop Yield [ton/ha]: NUTS Crop production from Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?daset=apro_cpnh1&lang=en); • Annual area with production of specific crops: NUTS database on Crop production from Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?daset=apro cpnh1&lang=en).
Deep geothermal energy $H_{tech,heat,x\ km}$	$P_{tech,heat,x\ km} = \frac{T_{x\ km} - T_r}{T_{7km} - T_r} P_{tech,l}$	• $T_{x\ km}$ = Rocks' temperature at a specific depth [°C];	• Spatial constrains: EES-Natura200 areas (http://ftp.eea.europa.eu/www/natura2000

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
(150m-7km)	[W] $H_{tech,heat,x\ km} = P_{t}$ $\times\ lifetime$ [J]	• $T_{7\ km}$ = Rocks' temperature at 7 km of depth [°C]; • T_r = Temperature of reinjected water [°C]; • *Lifetime*: assumed 8760 hours a year;	/Natura2000_end2016_Shapefile.zip); • Technical potential deep geothermal energy: database from https://www.thermogis.nl/en/map-viewer; • https://map.mbfsz.gov.hu/geo_DH/ • $T_{x\ km}$, $T_{7\ km}$ [°C]: database from https://www.thermogis.nl/en/map-viewer.
Shallow geothermal energy E (15m-150m)	$E = \rho \times V \times C \times \Delta T$ [kWh]	• ρ = Density of rocks [kg/m3]: average value equal to 1750kg/m^3; • V = Volume of rocks [m3]; • C = Specific heat of rocks [J/(kg)]: average value equal to 1500J/(kg K); • ΔT = Difference between water inlet and outlet [°C].	• ρ [kg/m3] and C [J/(kg K)]: JRC – soil type map (http://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km); • Spatial constrains: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

Mapping Electrical RES Potential

The electrical RES considered in SO WHAT tool are solar (photovoltaic) and wind: **Errore. L'origine riferimento non è stata trovata.** summarizes the algorithms and the databases used to evaluate the potential for these sources.

Table 7 : Electrical RES Potential – Algorithms and Reference Sources

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input

Photovoltaic energy $E_{pot,ph}$	$E_{pot,ph} = Ir \times Technical\ suitabilit \times Panel\ Efficiency \times Electrical\ Efficien \times Available\ Area$
	
	[kWh/yr]
		• Ir =Total solar irradiance under flat plane angle [kWh/m²]
		• *Technical suitability* [-]: assumed equal to 40% (1);
		• *Panel Efficiency* [-]: assumed equal to 30% **Invalid source specified.**;
		• $Electrical\ Efficien$ [-]: assumed to be equal to 17%
		• *Available area*=
		  ○ Footprint of buildings [m²],
		  ○ Other suitable area [m²].
			• Ir [kWh/m²]: PVGIS database (http://re.jrc.ec.europa.eu/PVGIS5-release.html);
			• *Footprint of buildings* [m²]: cadaster database or OpenStreetMap (http://www.openstreetmap.org) as an open data alternative;
			• *Other suitable area* [m²]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

Wind energy at a specific height h E_h	$E_h = 8760\ \eta_m\ \eta_{el}\ \eta_{aux} \sum_{w=w_{low}}^{w_{high}} P_h(w) f(w$ [kWh/yr] $f(w) = \left(\frac{\beta}{\eta}\right)\left(\frac{w}{\eta}\right)^{\beta-1} e^{-\left(\frac{w}{\eta}\right)^{\beta}}$ [-]	• 8760 yearly operative hours of the aerogenerator [h]; • ρ = air density [kg/m³]; • A = area of the aerogenerator that is orthogonal to wind's direction [m²]; • w = wind speed [m/s]; • C_p = power coefficient [-]; • $f(w)$ = Weibull distribution [-]; • β = shape parameter [-]; • η = scale parameter [-].	• β and η [-]: CENER database (https://globalwindatlas.info/) • Spatial constrains: EES-Natura200 areas (https://www.eea.europa.eu/data-and-maps/data/natura-9/natura-2000-spatial-data/natura-2000-shapefile-1).

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
		• Height at which the wind turbine is placed; • η_m mechanical efficiency of the device [-]; • η_{el} electrical efficiency of the device [-]; • η_{aux} auxiliaries' efficiency [-].	

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