D2.6 – REWARDHeat predesign tool

Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks

REWARDHeat

Project Title: Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks

Project Acronym: REWARDHeat

Deliverable Title: REWARDHeat predesign tool

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1 Summary

This deliverable (D2.6) reports the main outcome of REWARDHeat Task 2.4 focused on the development of an open source, GIS-based tool for the predesign of District Heating and Cooling Networks (DHCNs) under neutral-temperature design and operation premises promoted by the project.

The document presents the status of development of the tool by M30 with detailed descriptions of the tool interfaces and main capabilities already defined in D2.4.

Moreover, the structure of the development activities as well as the most relevant aspects of the ongoing works are presented. These currently focus on the backend development of the software both addressing the definition of the database structure and the improvement of the different calculation modules.

The development of the predesign tool will continue up to M42, when first release of the validation report will be included in the deliverable D2.7.

2 Introduction

The main and final purpose of REWARDHeat WP2 activity on the design of district heating and cooling networks (DHCNs) with multiple energy sources is the development of an open-source, GIS-based tool for the predesign of such networks, focusing on supporting the increased integration of low-temperature renewable (RE) and waste heat (WH) sources at urban level into thermal grids conceived under the neutral-temperature design and operation premises developed by the project.

Related to this main objective, several tools have been (or currently are) developed to support planning and design of district heating networks (e.g. PLANHEAT [1], THERMOS [2], Hotmaps [3], City Energy Analyst [4], SimStadt [5], INDIGO [6])

The development of REWARDHeat predesign tool takes benefit from the available background knowledge and fundamental modules offered by these existing software applications and linked open EU research in order to provide a dedicated, complete tool oriented to the specific challenge addressed by the project. In these sense, unique features under development are focused on:

- Preliminary techno-economic evaluation of neutral-temperature bidirectional networks based on yearly calculations with hourly resolution accounting for the impact of network temperature levels. Specific network topologies, centralised and distributed energy assets, design guidelines and operational constraints for these networks are considered.
- Mapping of energy resource potential from low-temperature RE/WH sources in cities
- Combination of GIS-based information for energy demand and resource estimation together with the above-mentioned dedicated modelling approach

In addition, it should be remarked that the predesign tool development is fed by the outcomes of the different WP2 tasks, thus integrating the generated knowledge and collected inputs from:

- T2.1 – structured database with available information from best practice examples on neutral-temperature DHCNs
- T2.2 – GIS-based assessment of low-temperature RES and waste heat sources at urban level
- T2.3 – Design requirements collected from DHC experts and potential end users of the tool

Within this context, the present deliverable will first describe the REWARDHeat predesign tool general concept and detailed interface mock-ups that constitute the ongoing developments to enable the interaction with the user as well as the actual (predesign) calculation workflows. Then, a brief update on the current development status is provided, and finally, the next steps and expected timelines are referred.

3 Predesign tool concept and interface mock-ups

The general concept of the REWARDHeat predesign tool was already presented and described in more detail in REWARDHeat D2.4, Section 8.2 [7]. Figure 1 shows the general software architecture distributed into 3 main layers: (i) Data layer; (ii) Business Logic Layer; and (iii) Application Layer. The first two layers comprise the tool backend, while the Application Layer represents the tool frontend or Graphical User Interface (GUI).

- The Data Layer contains the data repositories where the general project information, GIS data of the target urban areas (buildings, sources, roads, etc.), technology data and other contextual information (e.g. weather data, economic and environmental reference indicators, etc.) will be stored.
- The Business Logic Layer connects the data layer to the application layer and controls the overall functionality of the tool by performing the main calculations and data processing. Different scripts will implement the core services/modules dedicated to energy demand calculation, network route design and network energy modelling and simulation.
- The Application Layer acts as the point of interaction between the REWARDHeat predesign tool and the user. It will be used for data insertion and results visualization, including the supporting warnings and guidance to the user across the tool workflow.

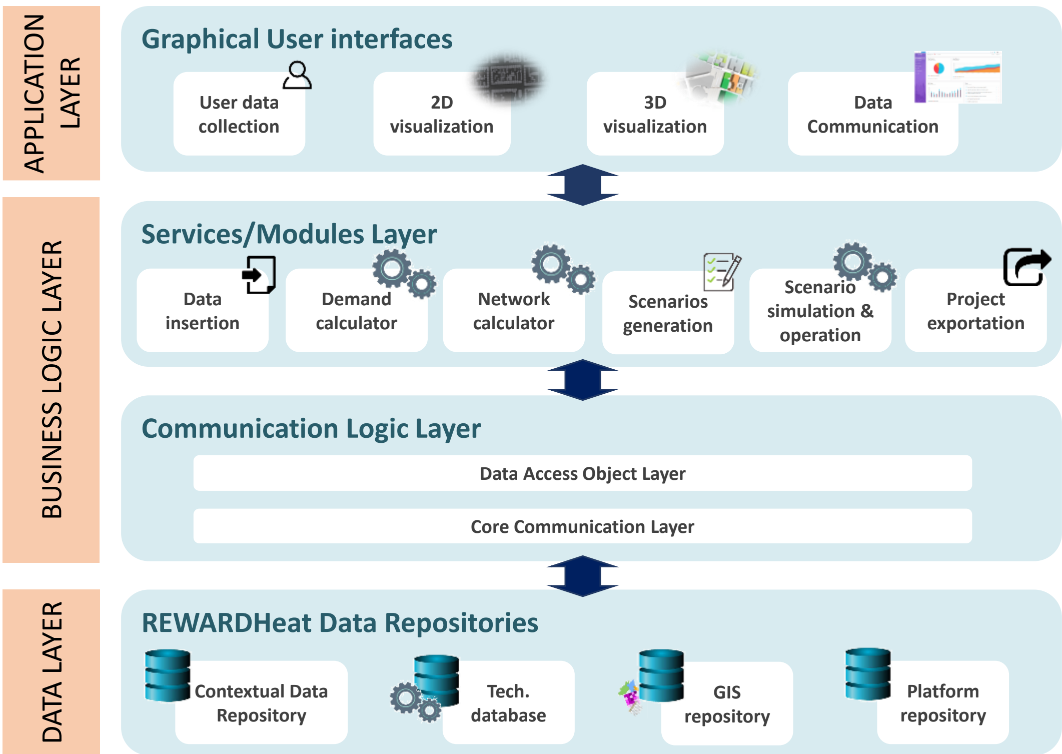


Figure 1 - General architecture of the REWARDHeat Predesign Tool.

In order to provide a clear vision of the tool capabilities, the interaction with the user (comprising input and output data definitions) as well as the overall information management and calculation workflows, a set of interface mock-ups have been already devised. These mock-ups are presented in Figure 2 to Figure 17, including relevant descriptions of each step. Nevertheless, it should be noted that most mock-ups are preliminary and currently under development, so slight modifications might take place during the development process.

Figure 2 shows a tentative design for the REWARDHeat tool main webpage with a brief description of the project and tool objectives while enabling the registration (creation of a new user account) or login process through the corresponding username and password information.

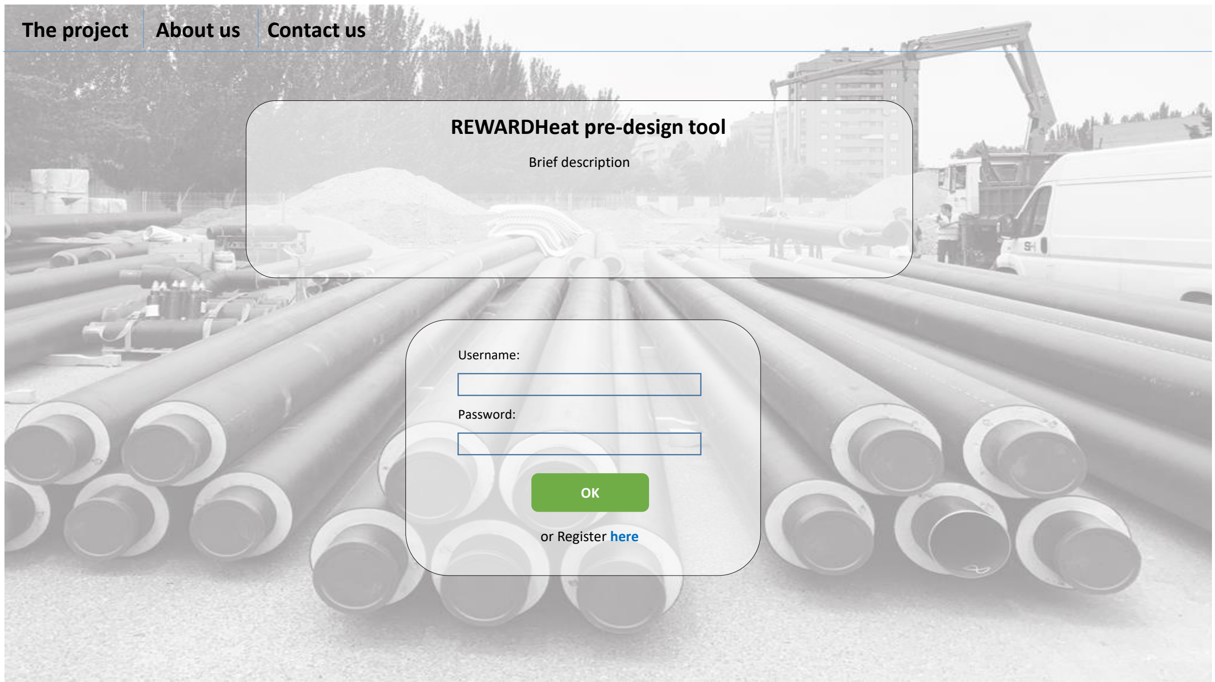


Figure 2 - Home page of the REWARDHeat Predesign Tool

Once the user has logged in, Figure 3 shows the general appearance of the User area. It will be possible to create new projects (to start the predesign process of a new DHC project) and/or access already existing projects (previously created by the user).

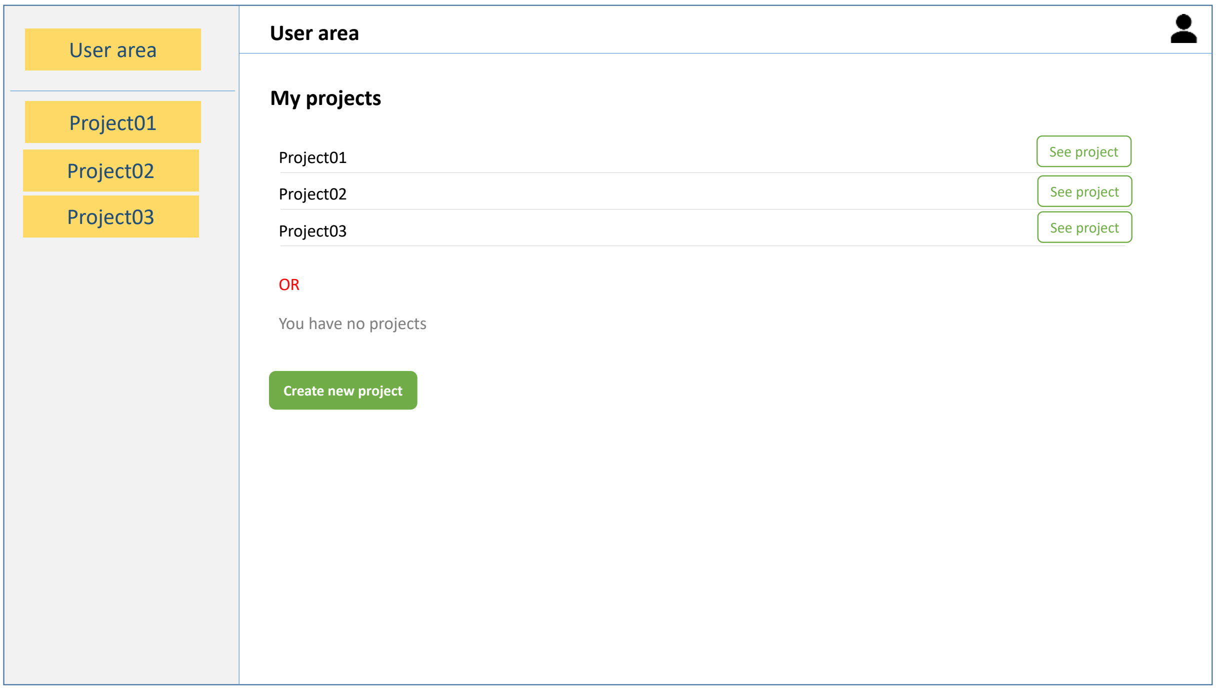


Figure 3 - User area of the REWARDHeat Predesign Tool

The definition of a new project starts with the selection of the GIS information source and the Area of Interest (see Figure 4). Two main options will be provided so that the user can select the main (GIS) source of information: (i) using data available in OpenStreetMap, or (ii) upload a user's own shapefile with more detailed and/or accurate information (e.g. building attributes such as building use, year of construction, height, etc.). A brief guide will be provided to support the user with the shapefile uploading, in case of not selecting OpenStreetMap source. The shapefile must comply with a set of mandatory and optional attributes.

Moreover, offline enrichment of OpenStreeMap files for selected locations in Europe are intended to be developed also within the project, so that a third option -not reflected in the picture- can be provided to the user: selecting an enriched shapefile previously uploaded and available into the tool GIS database.

Once the GIS source file is selected, the user will be asked to draw the Area of Interest (AoI) where the project should be developed. The AOI must contain those buildings whose energy demand will be targeted by the addressed DHC project.

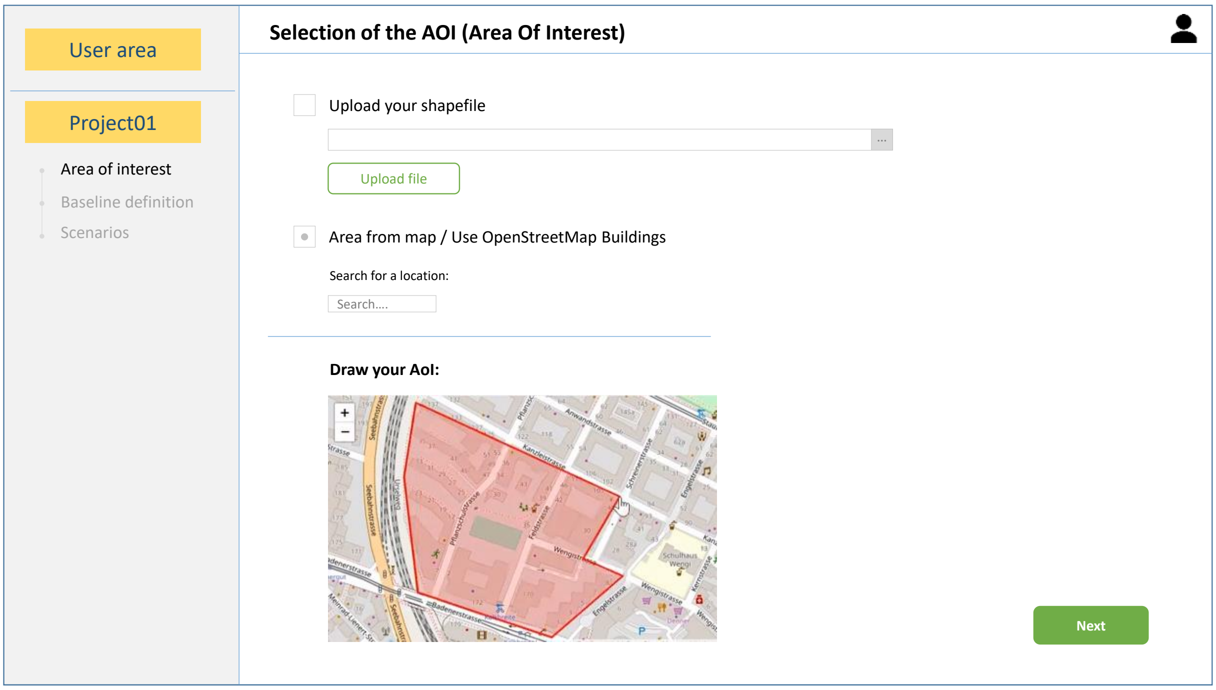


Figure 4 - Selection of the AOI page of the REWARDHeat Predesign Tool

Figure 5 to Figure 7 represent the interface provided to define and/or complete the definition of the baseline scenario. It should be noted that depending on the level of detail of the source file, some of the building attributes for one, several or all the buildings within the AOI may be empty or inaccurate (so that the user can modify their values if more reliable information is available)

Therefore, an interactive framework will allow the user to work with the buildings contained in the Area of Interest in order to select one or several of them (from the list or directly on the map). For the selected buildings, if their energy demand is not known and needs to be calculated, the building use, year of construction and height must be provided (Figure 6, Option 1). Moreover, for a baseline calculation of the buildings' energy consumption and other related energy and environmental indicators, the type of energy system in place must be defined.

Alternatively, if the user has got more reliable information on the energy demand of the target buildings, he/she will be allowed to directly provide aggregated annual demand values and/or hourly load profiles for the whole year (Figure 7, Option 2)

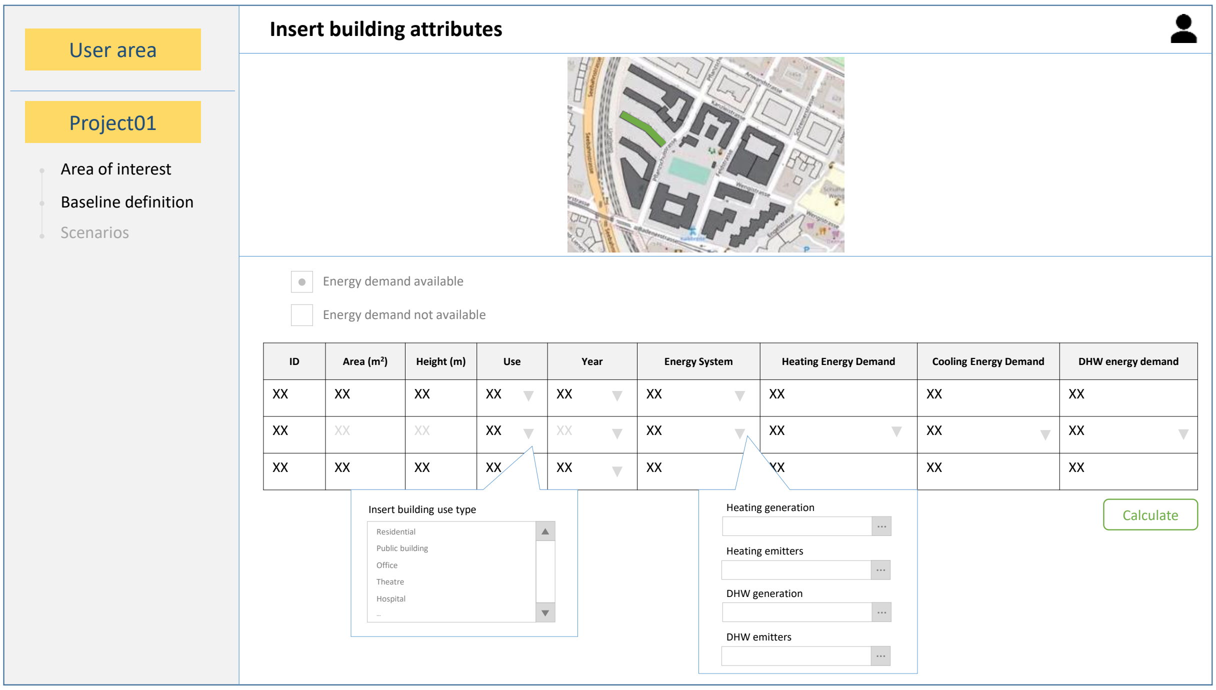


Figure 5 - Insert building attributes of the REWARDHeat Predesign Tool

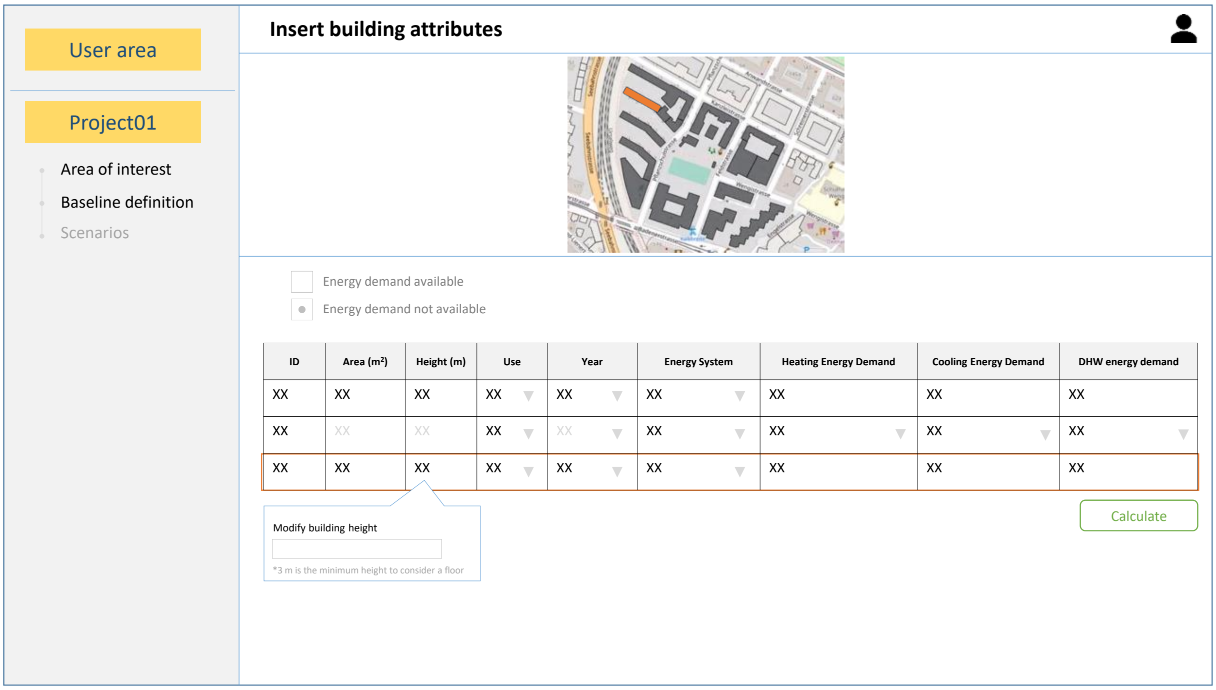


Figure 6 - Insert building attributes. Option 1: energy demand not available.

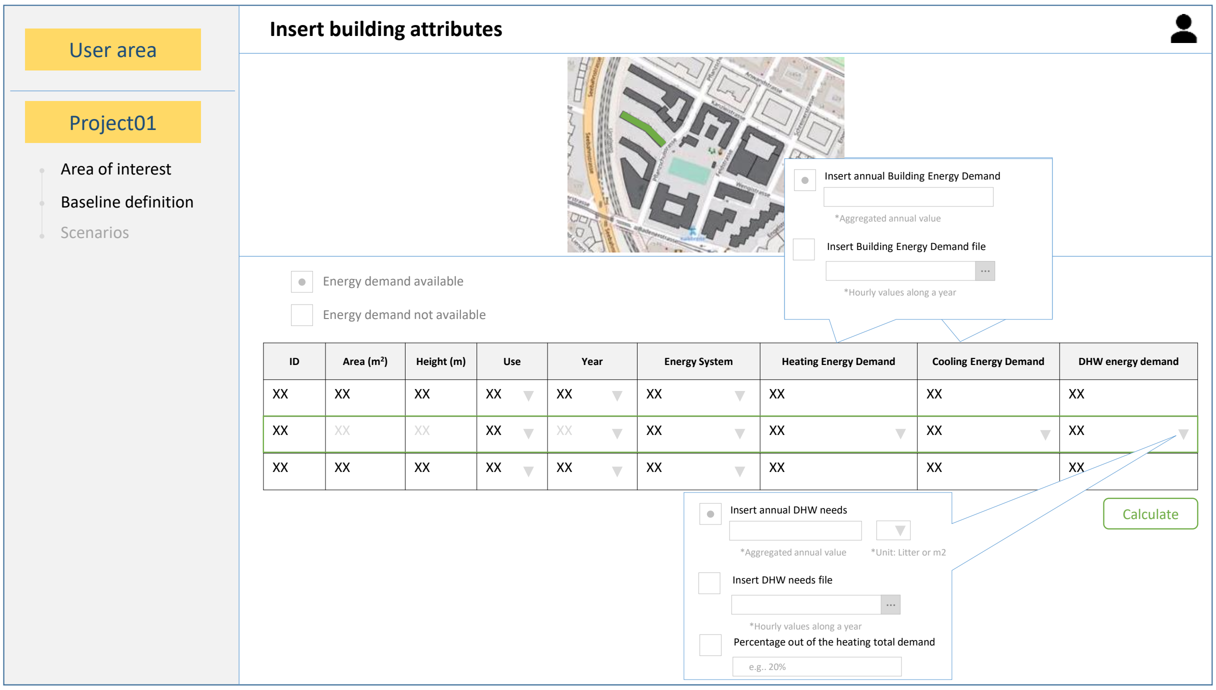


Figure 7 - Insert building attributes. Option 2: energy demand available.

Once all the building attributes are correctly defined, the baseline calculation can be executed. Results deriving from this calculation can be visualized in dedicated graphs showing the most relevant energy indicators (see Figure 8).

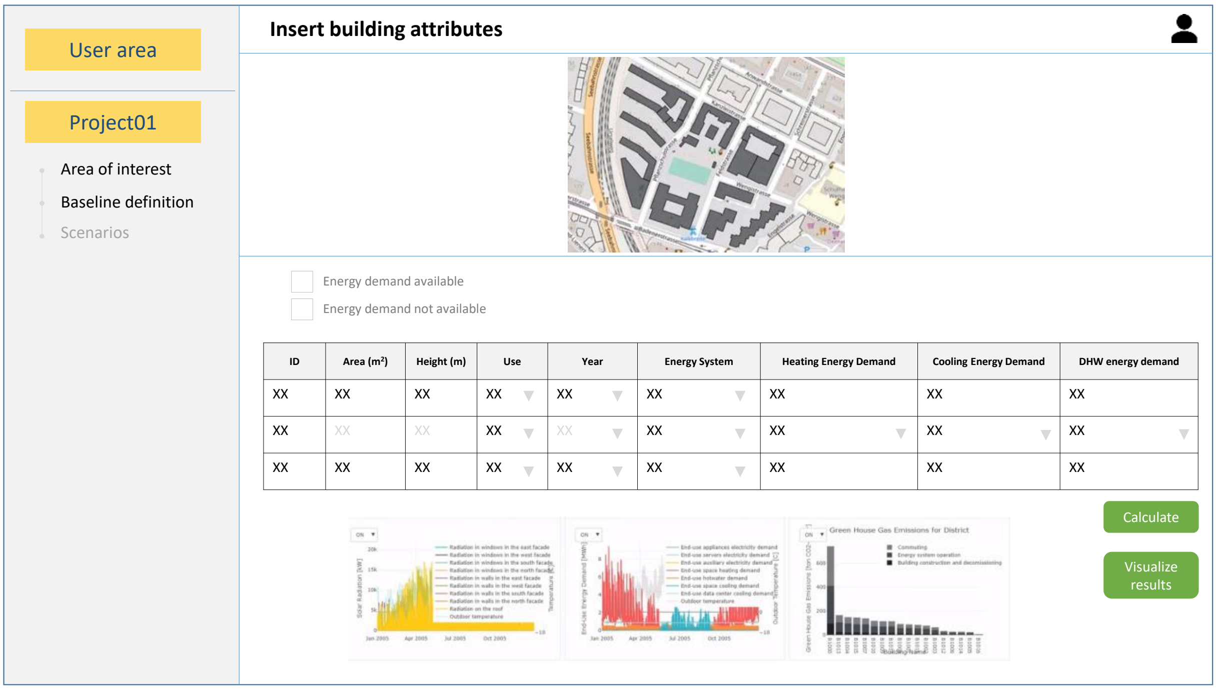


Figure 8 - Results of the baseline calculation of the REWARDHeat Predesign Tool

Figure 9 shows the next step of the DHC predesign project, which consists of creating the different scenarios to be analysed. A dedicated interface will allow the user to create new scenarios and/or explore the characteristics of those ones already defined within the selected project. A visualization option to directly compare two different scenarios could be also provided.

It is important to remark that scenarios are defined inside a specific project (then they are referred to the same AOI). Moreover, each scenario is characterized by a set of design constraints, in terms of energy, economic or environmental indicators, and a set of energy sources and storage components to be considered in the DHC network design.

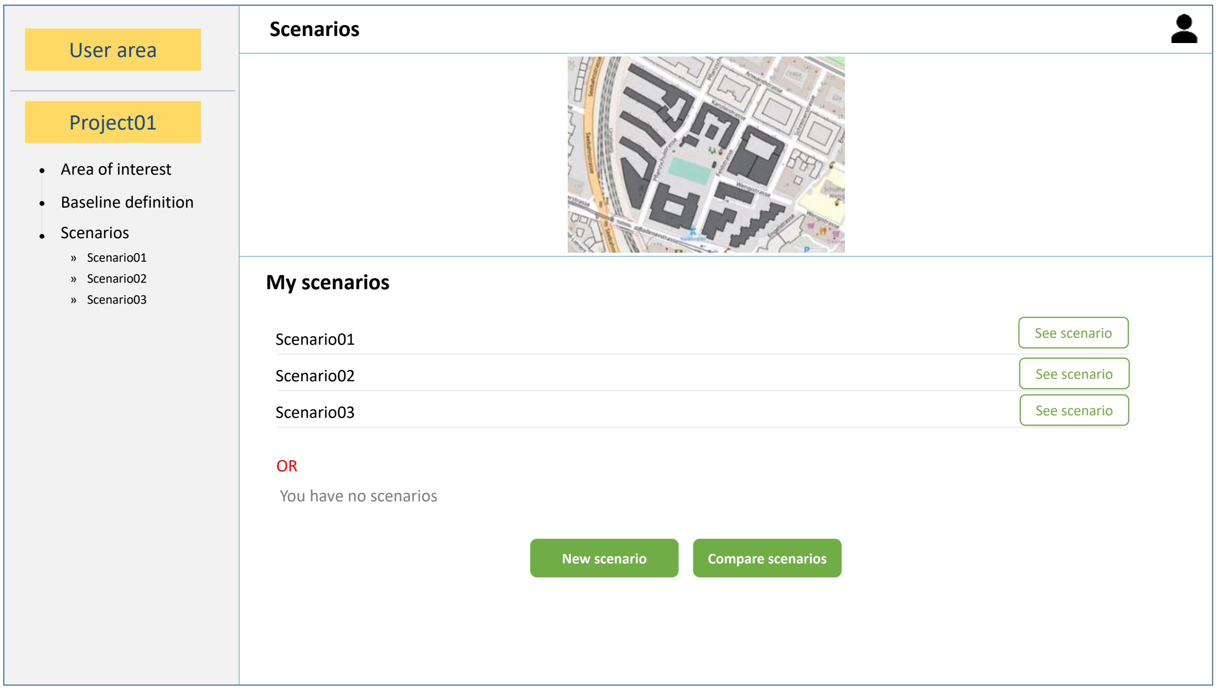


Figure 9 - List of scenarios associated to the same project of the REWARDHeat Predesign Tool

Figure 10 shows the interface where the energy resources and other network components to be considered in a particular scenario are defined.

The ambition is that the tool will show the energy resources available within the close surroundings of the AOI and the user will select those to be considered in the analysis by directly clicking on the map of the interface. The same procedure will apply to define the location of specific centralised thermal plants (e.g. Heat-Only-Boiler, large centralised Heat Pump, CHP plant, etc.), storage systems and connections to existing larger DHC systems.

In addition, at this stage each building block within the AOI will be assigned to one end-use substation. The user will be allowed to remove/add/merge substations (e.g. if a common connection point to the thermal network is desired for several blocks).

Once the energy resources and network components are selected, the scenario is ready for the network route calculation. This will be accessible through a dedicated button in this interface.

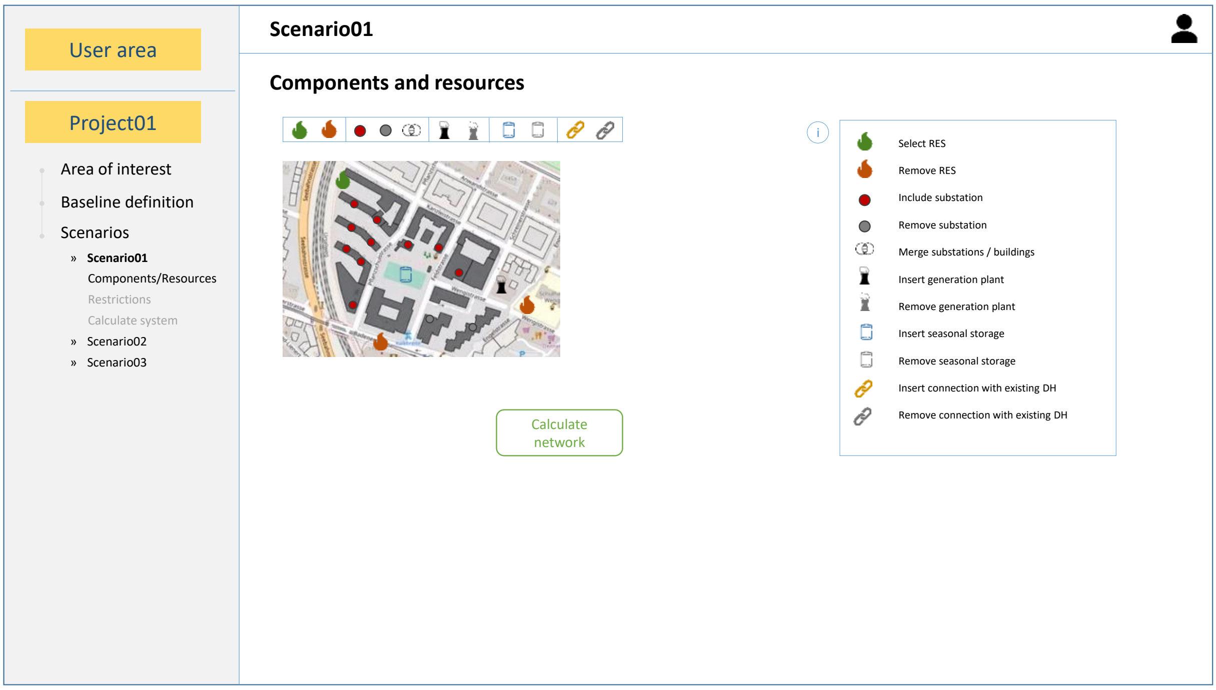


Figure 10 - Selection page of components and resources of the REWARDHeat Predesign Tool

Figure 11 shows a representative screenshot of the completed network calculation process. The result of such calculation (with the thermal network connecting energy sources and end-use substations after an optimization process) will be shown in the map.

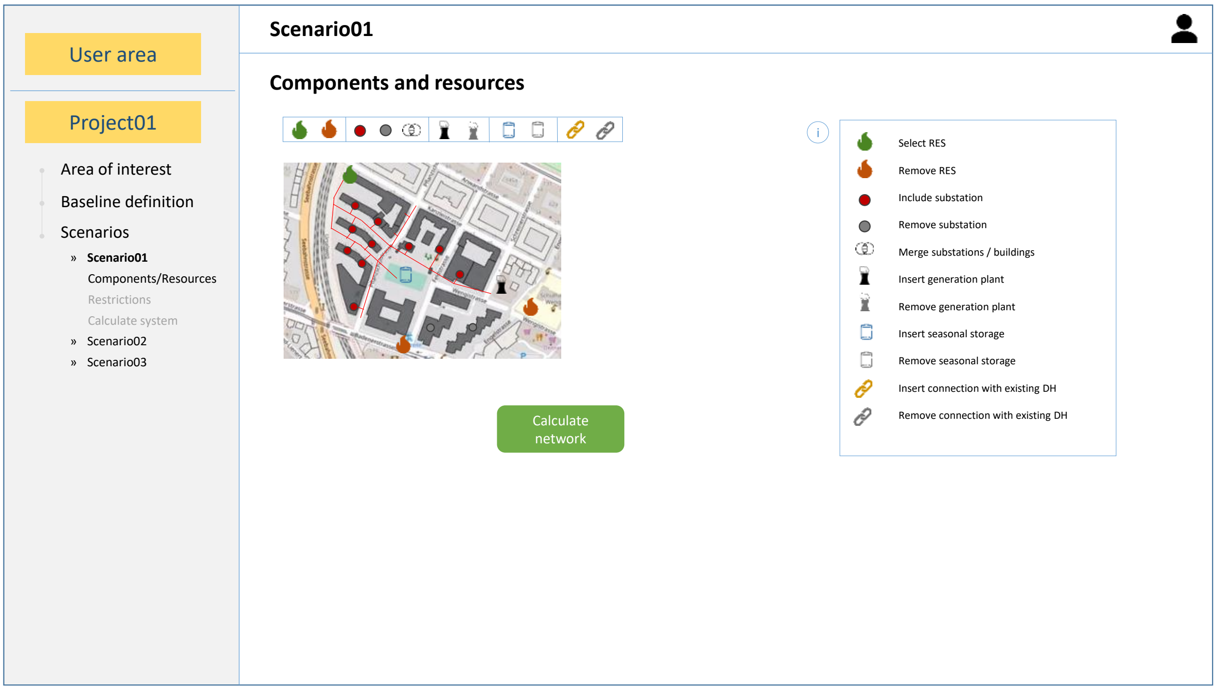


Figure 11 - View of the network route after calculation process of the REWARDHeat Predesign Tool

The second key aspect to define when specifying the characteristics of a new scenario is the design constraints/restrictions. Figure 12 shows a dedicated interface for this purpose. The detailed definition of this stage is still under elaboration. Generally, restrictions will be mainly included under ‘Economic’ and ‘Environmental’ categories (other additional categories may be added if needed). Within each category a set of restriction types (e.g. maximum CAPEX, maximum Levelized Cost of Heat, minimum GHG emission savings, etc.) will be provided in a drop-down list, also allowing the user to define the threshold value for the selected constraint.

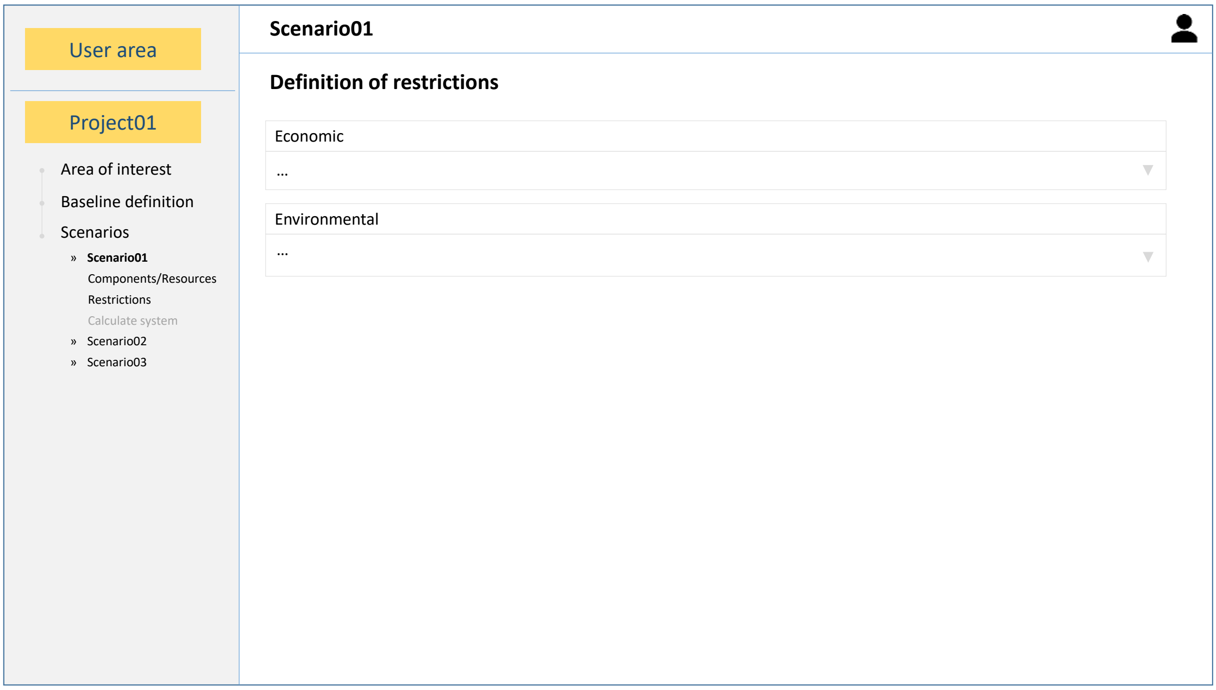


Figure 12 - Page for user introduction of restrictions to the scenario of the REWARDHeat Predesign Tool

After this stage the predesign scenario is completely defined; however, many network solutions with completely different energy/economic/environmental performances would be able to meet the targeted energy demand and make use of the selected energy sources and network assets; even several of them would be able to get this respecting the performance limits required by the scenario restrictions. Indeed, this is exactly the nature of the predesign problem addressed by the tool, which gives rise to its main objective: to be capable of providing approximate (but reliable) comparison of how different network designs (‘options’) can perform under a given scenario, and supporting the user on selecting the most convenient one. The existence of this type of restrictions should be further discussed in order to define the impact in the design calculation of the network.

Figure 13 presents a specific interface (inside the definition of a particular scenario) where different network/system configurations can be specified and prepared for evaluation. Such network designs or configurations are referred as ‘Options’. Again, the tool will allow to create new ones and/or access to read or modify the characteristic information of any of them.

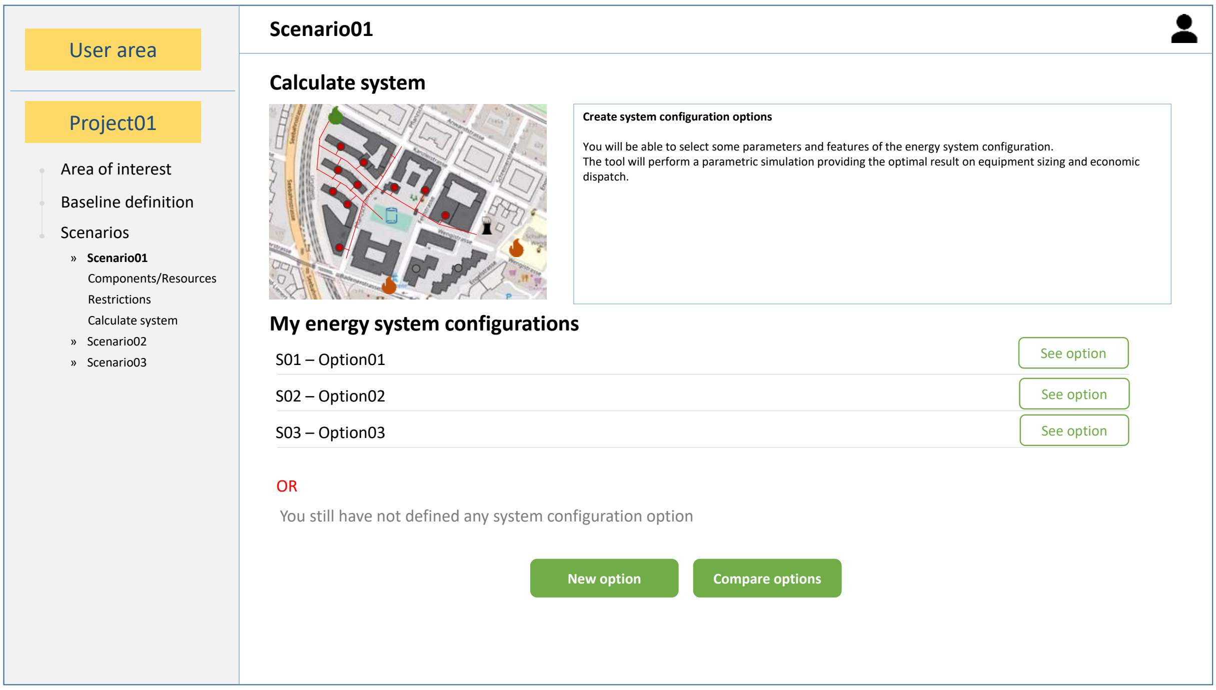


Figure 13 - List of energy system configuration options for a given scenario of the REWARDHeat Predesign Tool

Figure 14 and Figure 15 show a tentative interface to enable the definition of an 'Option' (i.e. network/system configuration) within a given scenario. The final appearance of these windows is closely linked to the details of the network modelling approach, which is currently under development; however, the general concept of the information required at this stage and the tool capabilities that have to be accessible from this interface are as follows:

The main characteristic parameter of each option will be the reference network temperature, which will be required to the user. In addition, so far, only the location of energy sources and network assets (e.g. storage systems) have been provided. At this stage, technical specifications for them need to be defined.

The same problematic affects the type and characteristics of building substations. Depending on the network temperature levels and the targeted temperature of use which is linked to the existing building energy systems (terminal units), heat exchanger- or heat pump- based substations may be needed).

From the network temperature and the information already available in the project related to the targeted energy demand and energy potential of the selected sources (both in terms of energy volumes and temperatures), the tool will provide default specifications for the majority of energy equipment involved in the system. However, the user will be allowed to modify this information in order to address specific evaluations. In that case, the tool will trigger warning messages if inconsistent system definitions are intended and/or if the limits for the defined solutions to be simulated are exceeded.

Finally, for what particularly concerns individual centralised thermal plants and connections to existing DHC grids, again type and characteristics (e.g. thermal power) need to be defined at this point (see Figure 15).

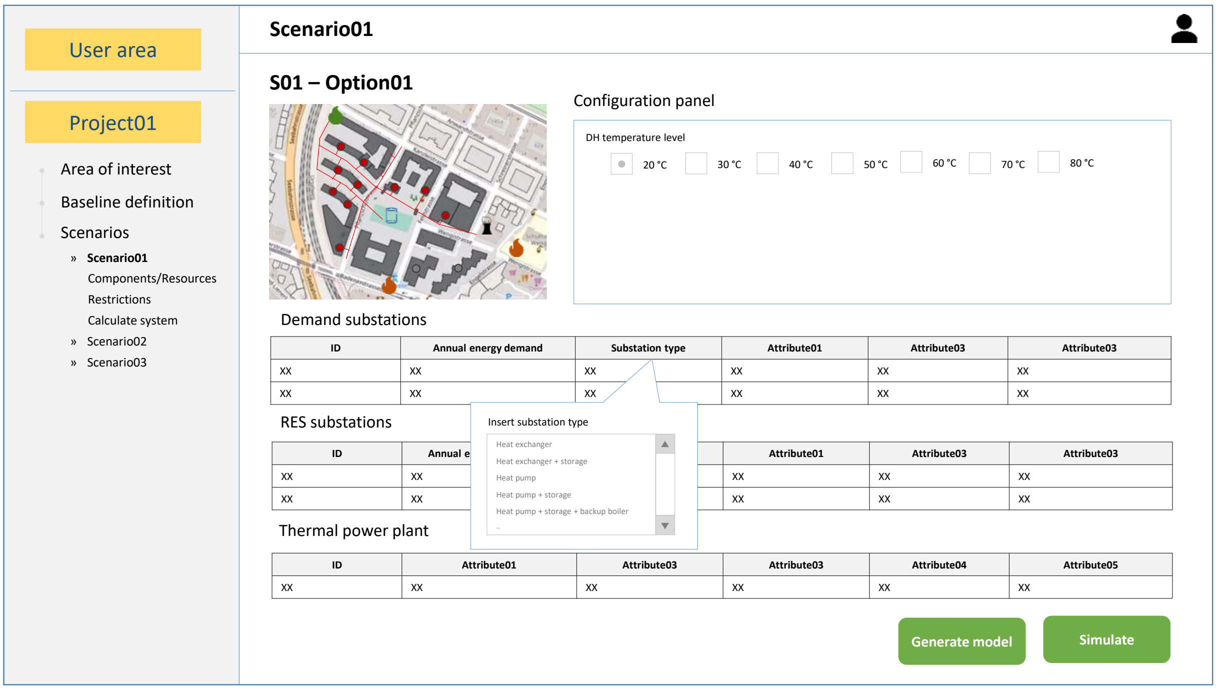


Figure 14 - Parameters definition of the energy system configuration I

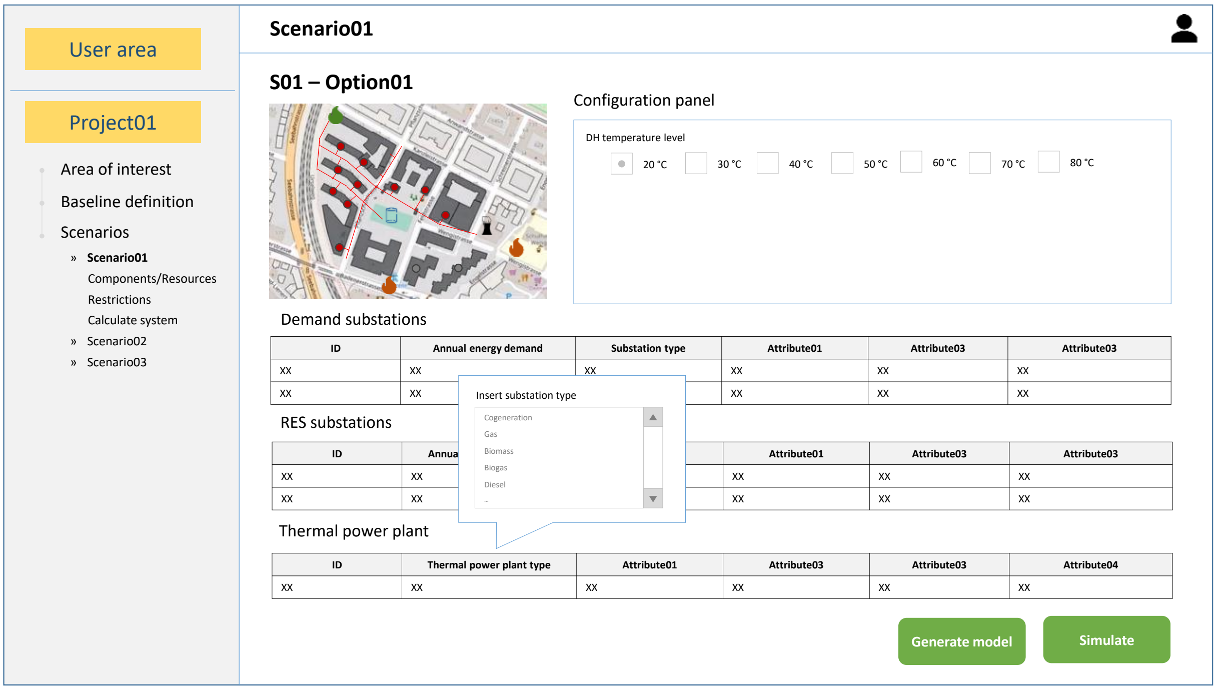


Figure 15 - Parameters definition of the energy system configuration II

The problem definition workflow presented so far should be followed in the abovementioned sequence when a project is defined and accessed for the first time. Later stages of the definition process cannot be accessed if the first ones are not fulfilled. However, once the creation of scenarios is reached the user will be allowed to navigate back and forth through a given project.

Figure 16 shows the appearance of the main tool window corresponding to the summary of a given scenario when some options have been already defined and calculated inside. The general scenario information on sources, network route and assets, is presented directly on the map. The list of restrictions is also accessible, and finally, the list of defined options is also included in the summary. These options can be accessed and may be compared through dedicated graphs that can be launched from this interface.

Finally, the possibility to duplicate a given scenario is provided.

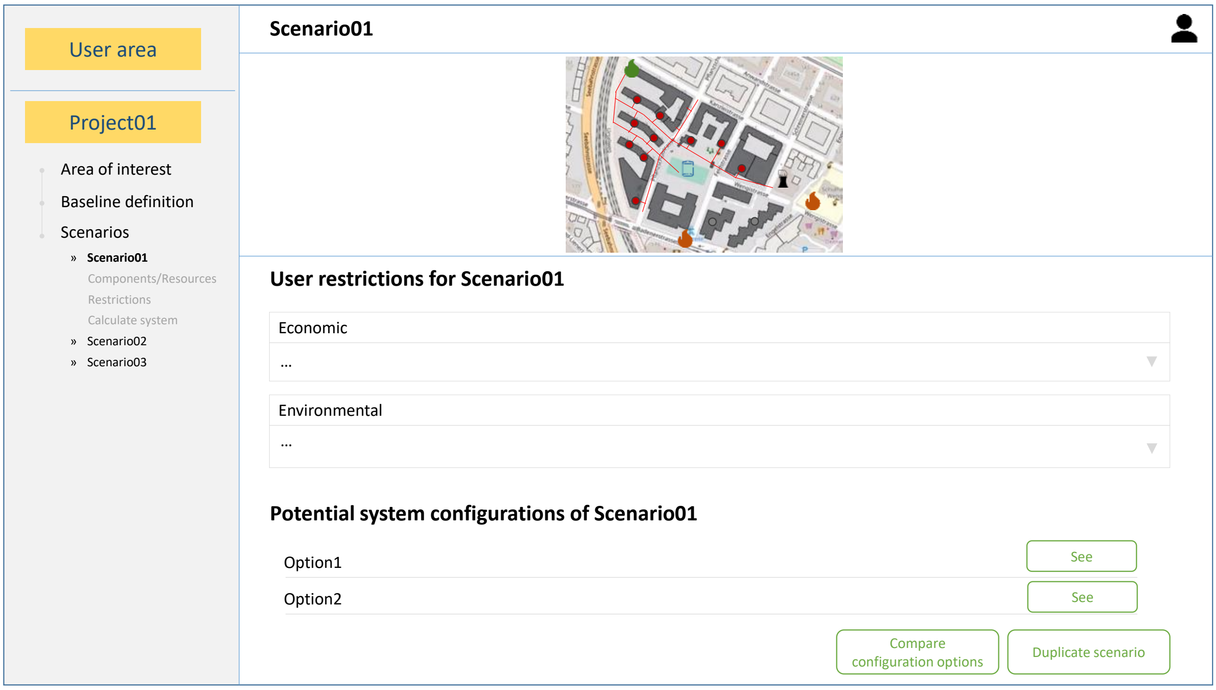


Figure 16 - Summary of a scenario of the REWARDHeat Predesign Tool

Similarly, Figure 17 shows the proposed appearance of the main tool window corresponding to the summary of a given project when the baseline scenario has been already calculated and one or several scenarios have been defined inside. This window will provide access to baseline calculation results/graphs and to the specification of the different scenarios (including the possibility to define new ones).

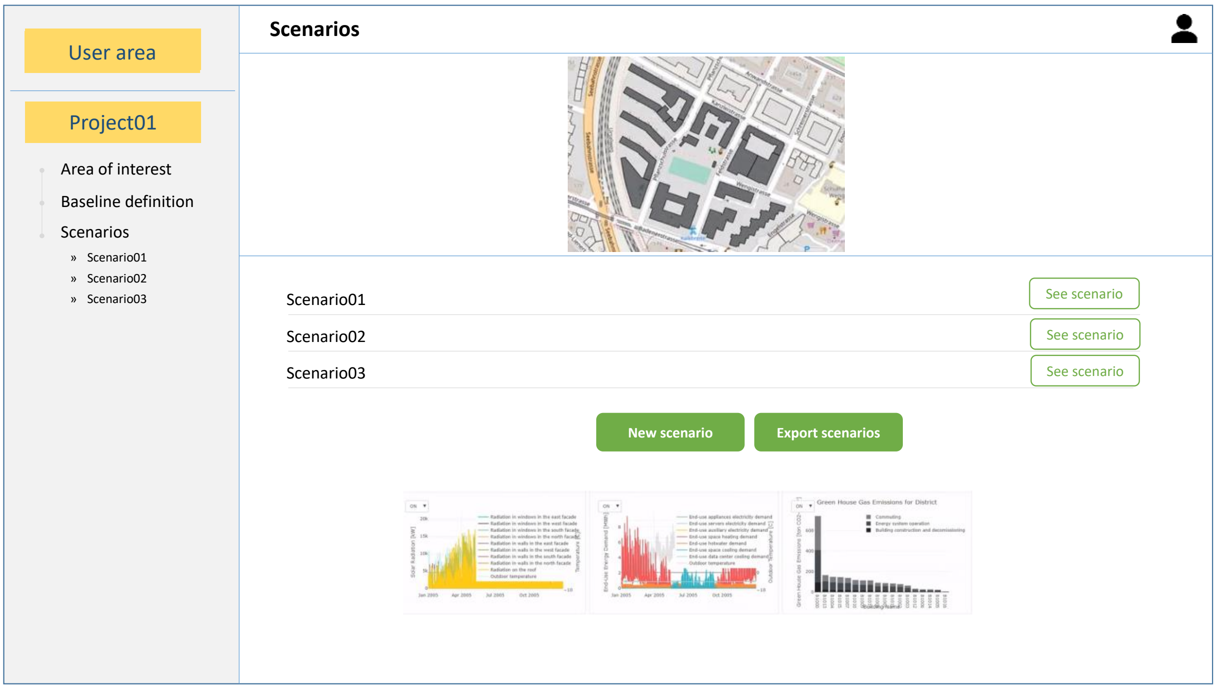


Figure 17 - Summary of the scenarios and results associated to the same project of the REWARDHeat Predesign Tool

4 Development status

The development of the REWARDHeat tool has been started in February 2021 once the tool requirements and functionalities were defined and translated into the specific use cases that must be covered. For further details, please refer to REWARDHeat deliverable D2.4 [7].

4.1 Organization of the development process

The development process has been organized into the following topics:

- Enriched input shapefiles – Activities to generate input shapefiles of selected locations around Europe that are relevant for the project, and for which more detailed and/or accurate GIS information than in OpenStreetMap database can be provided. This affects buildings information as well as energy sources and other relevant infrastructures within the urban environment (e.g. roads, existing DHC networks, etc.) and will be dealt with in T2.2. Estimation algorithms for low temperature waste heat potentials at urban level are being developed and available information from other relevant sources coming from PLANHEAT will be recovered.
- Energy demand estimations – REWARDHeat tool will build on the energy demand estimation algorithms already developed within the framework of previous projects, particularly PLANHEAT. However, the adaptation of the corresponding modules to be integrated into the whole web-based tool is being addressed, including specific improvements on the collection of input data for the demand calculation equations (an example of this is further explained later in this document).
- Network router – REWARDHeat tool will also build on existing tools for what concerns the network router. Particularly, the optimization algorithm implemented in PLANHEAT will be recovered.
- Network overall energy modelling – This is the core part of the tool calculation engine. Based on the literature review and the tool specifications reported in D2.4 [7] a general model approach is being defined to account for the impact of different network temperature levels and different system configurations for neutral-temperature bidirectional thermal grids including appropriate capture of the effects produced by thermal energy storage systems and different sizing of central and decentral production units.
- Database structure and contents – As already mentioned, the REWARDHeat tool will rely on a specific Data Layer with several databases dedicatedly defined to deal with all the information derived from the required inputs, interim internal calculations and produced outputs. This mainly includes general project information, GIS data, technical data for the different involved technologies, as well as other contextual data.
- Backend connections – The Communication Logic Layer (represented in Figure 1) is a hidden, but fundamental, part of the development. The software integration of the tool databases, the calculation engine and the Graphical User Interface (GUI) will be dealt with in a parallel development thread.
- GUI / frontend development – This comprises the creation of the visual interfaces represented by the aforementioned mock-ups particularly including those required input/output interactions between the tool and their users.

These topics can be classified into 4 separate groups: (i) “Inputs and calculation engine”, (ii) “Software backend”, (iii) database design and development, and (iv) “Frontend development”.

In this sense, the development of the first three groups has been prioritized in order to work in parallel on the different services/modules of the calculation engine, as well as on the enrichment of input information, while the supporting database structure and communication features are created. This is being addressed in an iterative development process where different development threads feed each other as the definition of the calculation modules evolve.

Afterwards, the development of the GUI will be initiated. Frontend modifications are more challenging; this is why it has been decided to undertake the full development of the GUI once the first consolidated versions of the backend are ready.

4.2 Tool frontend developments

The pre-design tool is built under client-server architecture to provide user the functionality of implement their own analysis without installing some applications and software. All the developments cover the initial architectural design described with the pre-design tool mock-ups. The alpha version of the tool includes the following interfaces:

- Main page
- Project management area
- Selection of an Area of Interest (AOI)
- Baseline definition

These interfaces including the main functions and functionalities of each step will be described below considering the user interaction in each interface. The first developed interface corresponds to the main page of the tool. *Figure 18* shows the design of the REWARDHeat pre-design tool main webpage with a brief description of the project and tool objectives while enabling the user registration (creation of a new user account) or login process through the corresponding username and password information. These two options (Figure 19) for user interaction are included with two buttons. The scroll-down function in this main page gives user the opportunity to find more information about REWARDHeat project.

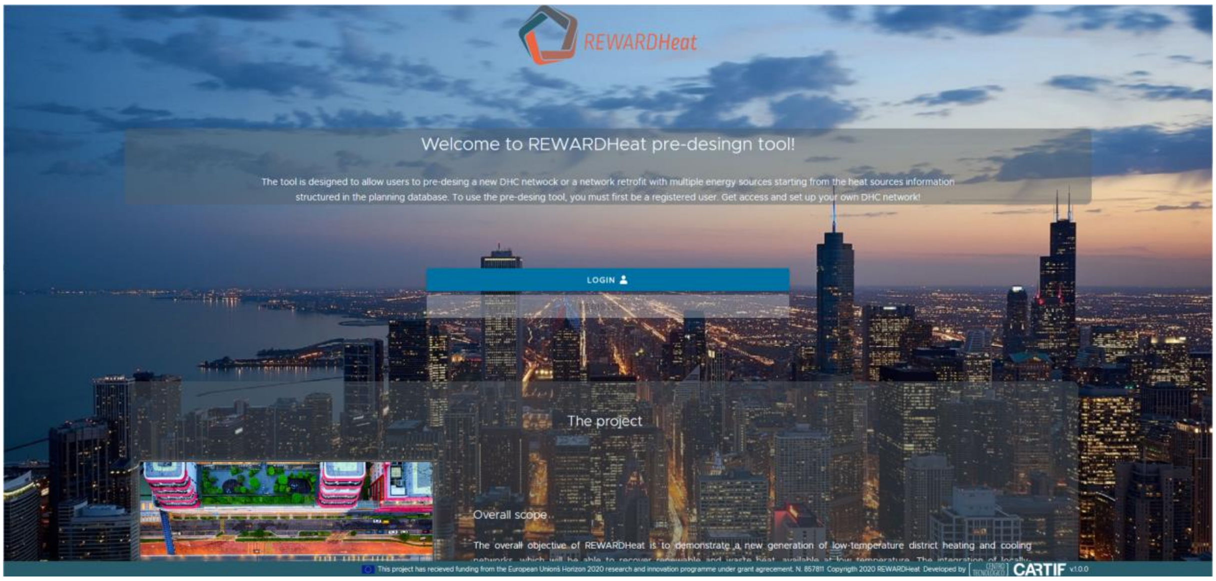


Figure 18 - Home page of the REWARDHeat pre-design tool

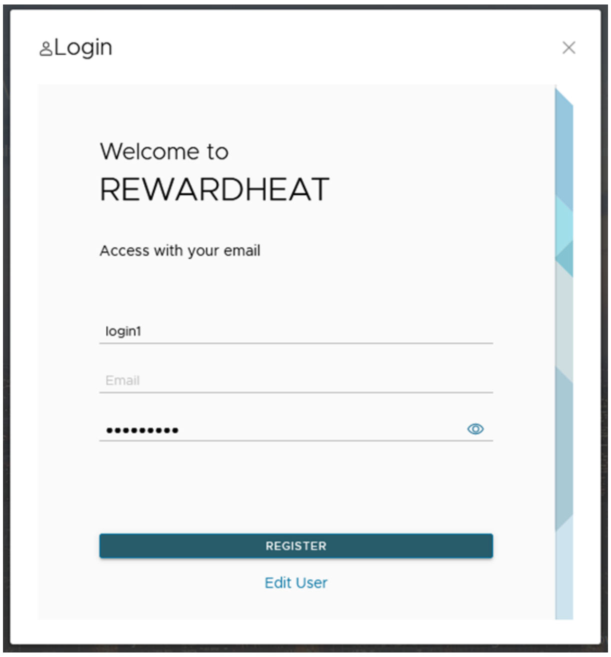


Figure 19 - Application form for the login (left) and register (right) in the pre-design tool

The second developed interface provides users the opportunity to create and manage new projects (Figure 20). Once the user is registered as a tool user and logged in the tool, users need to create a new project to start using the calculation algorithms for district heating design. For this a project name and a description will be provided (Figure 21).

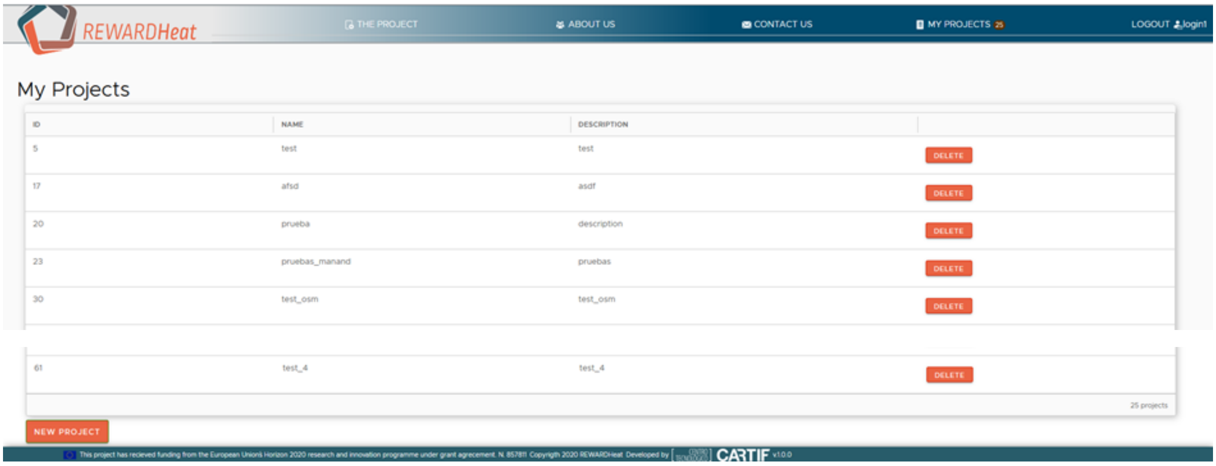


Figure 20 - List of projects in the project management area of the REWARDHeat pre-design tool

Figure 21 - Application form for the definition of a new project using the pre-design tool

The third interface that is now included in the tool is the selection of an Area of Interest (AOI) (Figure 22). This interface provides user the following functions and functionalities: (i) upload your own shapefile, (ii) use OpenStreetMap buildings and (iii) select building geometries from a demosite. Each functionality is explained below.

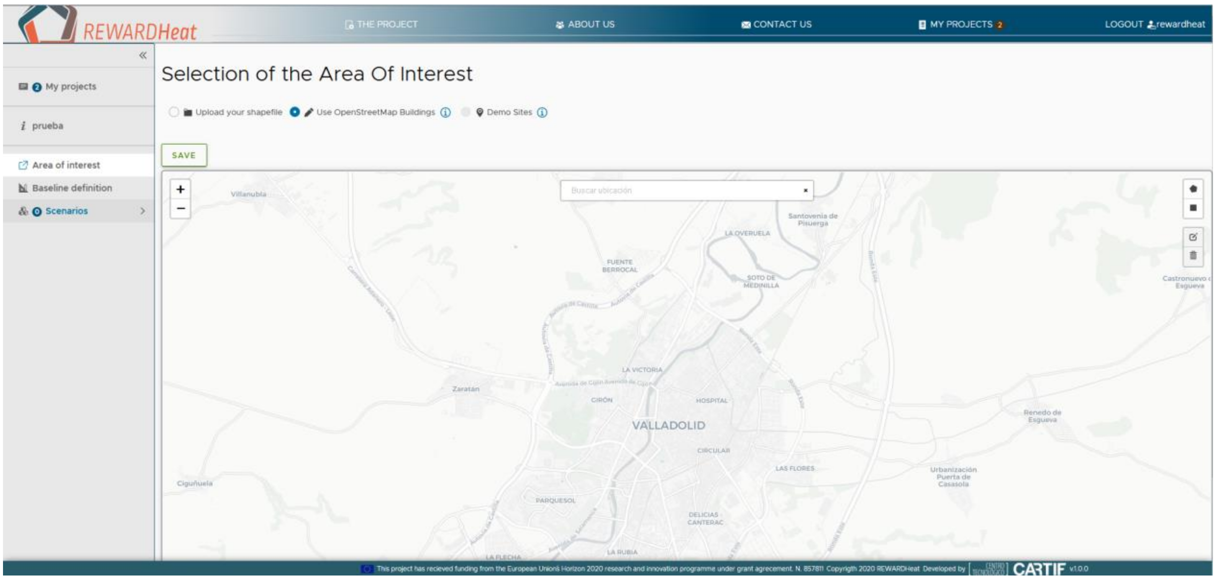


Figure 22 - Area of interest (AOI) interface included in the pre-design tool.

- Upload your own shapefile: this function gives user the opportunity to upload a shapefile of the building as starting point for baseline definition. The shapefile will be uploaded using a zip file in which all the files required in a shapefile are stored. At least .shp, .dbf, .prj are included in the zip file. The shapefile needs to include these attributes: year of construction (year), building height (height), building area (area), building use (use) and a numerical identifier (id) for each building (Figure 23). If a shapefile is provided, the attributes of each building parameter will be provided. Otherwise, the tool will estimate it as detailed in the use of OSM or will allow the user to edit the attributes of his building to choose the most appropriate. Otherwise, the tool will estimate it as detailed in the use of OSM or will allow the user to edit the attributes of his building to choose the most appropriate
- Otherwise, the tool will estimate them as is detailed in the use of OpenStreetMap buildings or will allow the user to edit the attributes of each building or a group of buildings to choose the most appropriate value of each attribute.

	year	height	area	use	id
1	1964	14,0	1864,698	education	11
2	1965	21,0	149,649	residential	12
3	1973	25,1	530,128	residential	13
4	1900	11,9	3697,870	education	14
5	1971	20,5	644,680	residential	15
6	1971	24,1	352,309	residential	16
7	1977	20,5	391,935	residential	17
8	1976	19,0	739,808	residential	18
9	1980	7,1	1858,845	education	19

Figure 23 - Example of building attributes.

- OpenStreetMap buildings: this function uses the API service of OpenStreetMaps (OSM) to collect the building geometries and attributes that are collected by this initiative. The tool provides two different alternatives to collect the data: build a polygon or a polyline to call the OSM database (Figure 24) and collect the required data for the project (Figure 25). Some of the attributes are empty in OSM and default functions were developed to give a value based on estimations as height-area ratio, residential as default value for building use or 1980 as default value for the year of construction. The building area is calculated by the tool backend. As explained before, the tool will allow the user to edit the attributes of each building or a group of buildings to choose the most appropriate value of each attribute.

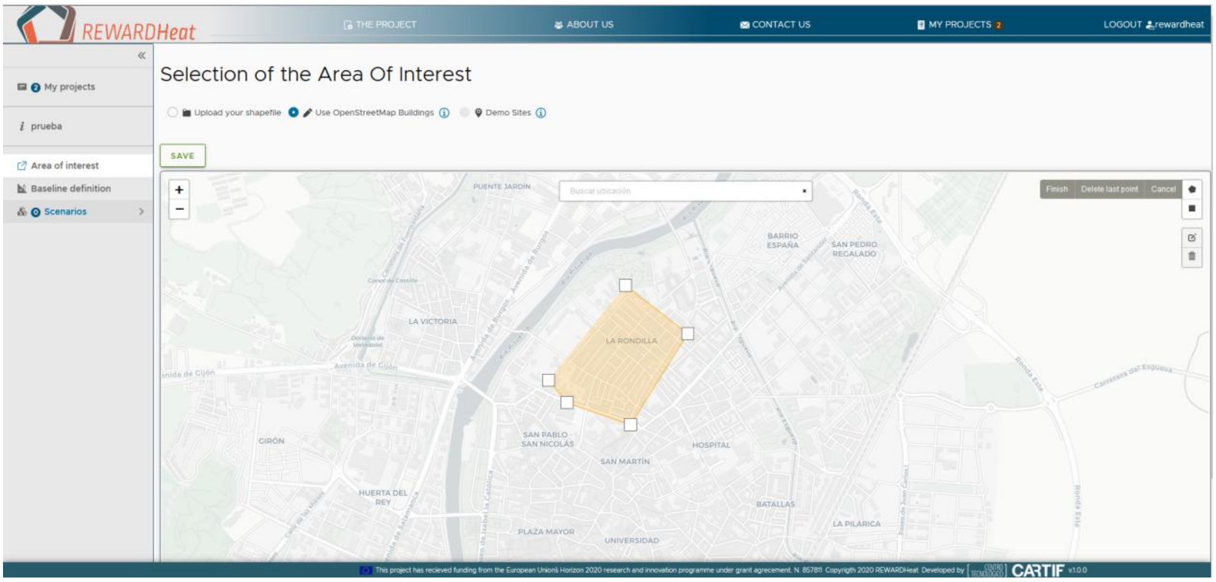


Figure 24 - Selection of an Area of Interest to collect data from OpenStreetMaps

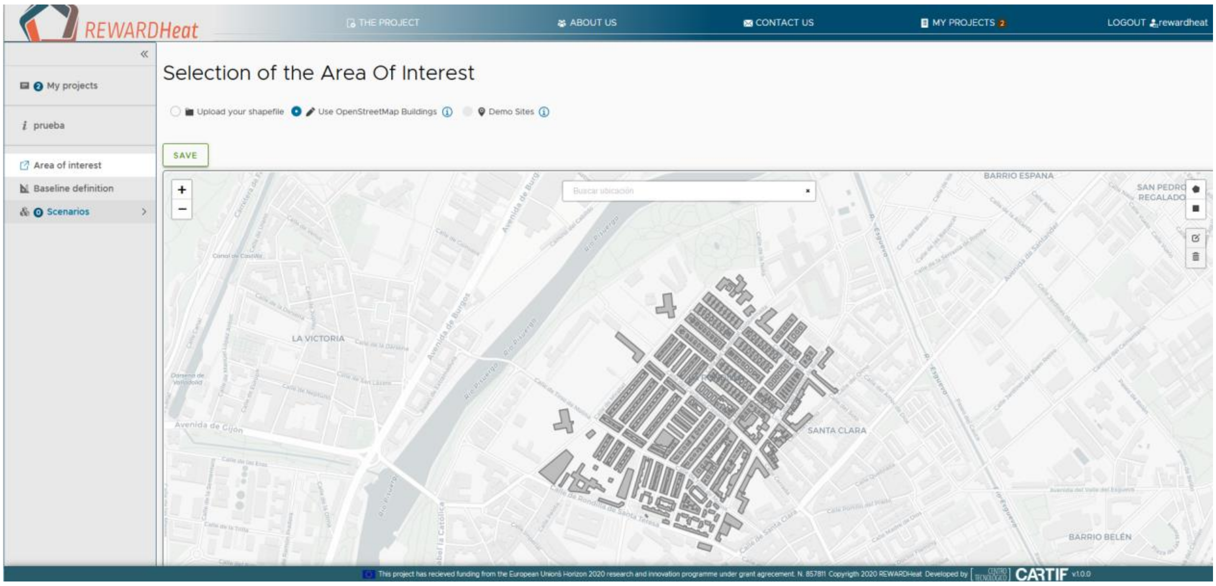


Figure 25 - Data collected from OpenStreetMaps using the defined Area of Interest

- Select shapefile from a demo site. This option to work with real data (buildings and their attributes) will be included in the tool once data from demosites will be available.

Once the buildings are collected or updated in the tool, the tool will select the final buildings with which the user intends to work and save them so that they can be stored in the database being available during the project baseline definition.

The fourth developed interface covers the project baseline definition (Figure 26). At the end, this use case will provide as outputs the energy demand calculation (heating, cooling and domestic hot water), the primary energy to cover this demand, the cost and the associated emissions. To obtain these results, the user has four different alternatives for calculation: (i) demand algorithm, (ii) monthly demand disaggregation, (iii) yearly demand disaggregation and (iv) upload your own demand file. Below we will explain the process to obtain the demand of each building.

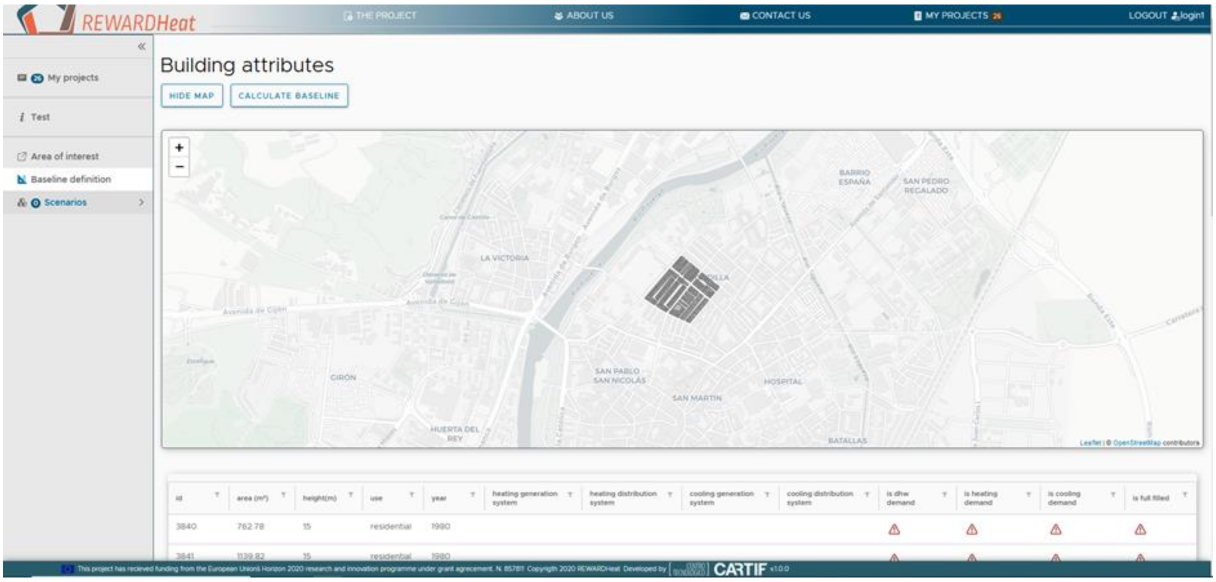


Figure 26 - Main interface of project baseline definition.

The first item for the energy demand calculation is to evaluate if all buildings have filled the required attributes (id, area, height, use and year) to set up the process. The user has the opportunity to modify building attributes by selecting and editing each building or a group of them. After editing the user need to save to upload the data in the project database (Figure 27). For primary energy calculation, cost and emissions, the user needs to select for each building the heating and cooling generation system as well as the heating and cooling distribution system. If this data were not provided, a default value will be included considering the year of construction of each building and the typology. If all required data were provided a green validation element will be included in the “is fulfilled” attribute. In addition, when a building is selected the tool includes an option to upload your own energy demand profile (hourly, monthly or yearly) based on real measured data (Figure 28). If this data is provided in one or more buildings, the tool backend excludes them for the complete energy demand calculation selecting the disaggregation methods or in a simpler way, storing the hourly data profile.

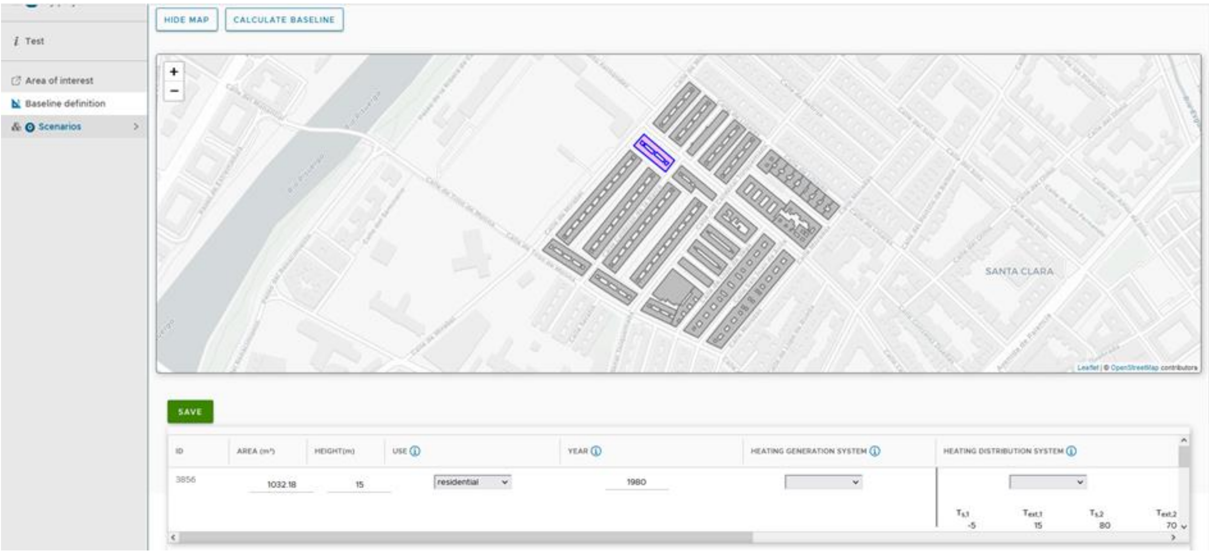


Figure 27 - Building selection to modify attributes.

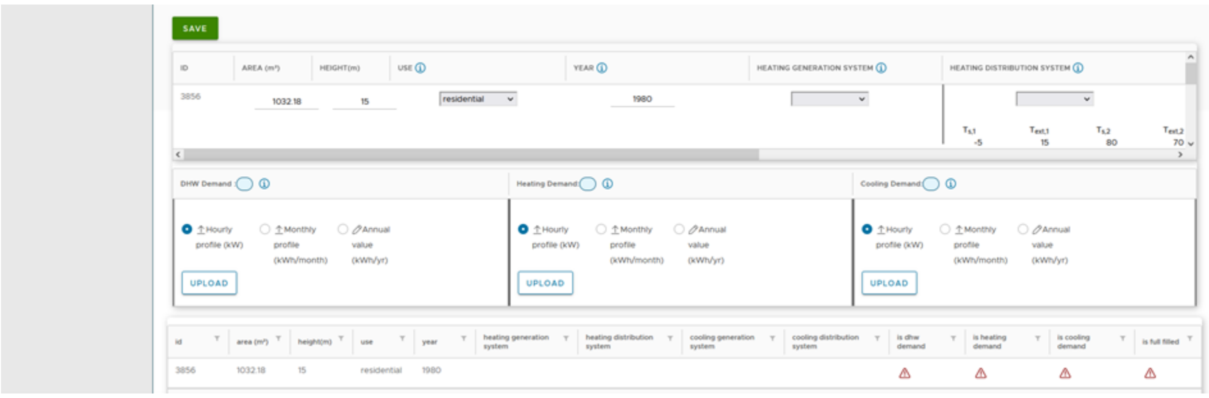


Figure 28 - Building selected to upload energy demand data.

Once the user has completed all the building attributes that allow the calculation of the energy demand, the user can activate the "calculate baseline" button to start the execution of the energy demand calculation algorithm and the primary energy transformation algorithm. A progress bar will appear showing the user the progress of the calculation and an estimation of the remaining processes for its completion. When the calculation is finished, a new button will appear to see the results graphically for each of the evaluated buildings (Figure 29). The graph library used by the tool gives users the opportunity to evaluate the results in a yearly, monthly and hourly basis for each evaluated building. In the graph visualization, three different alternatives are provided: demand, primary energy and costs-emissions.

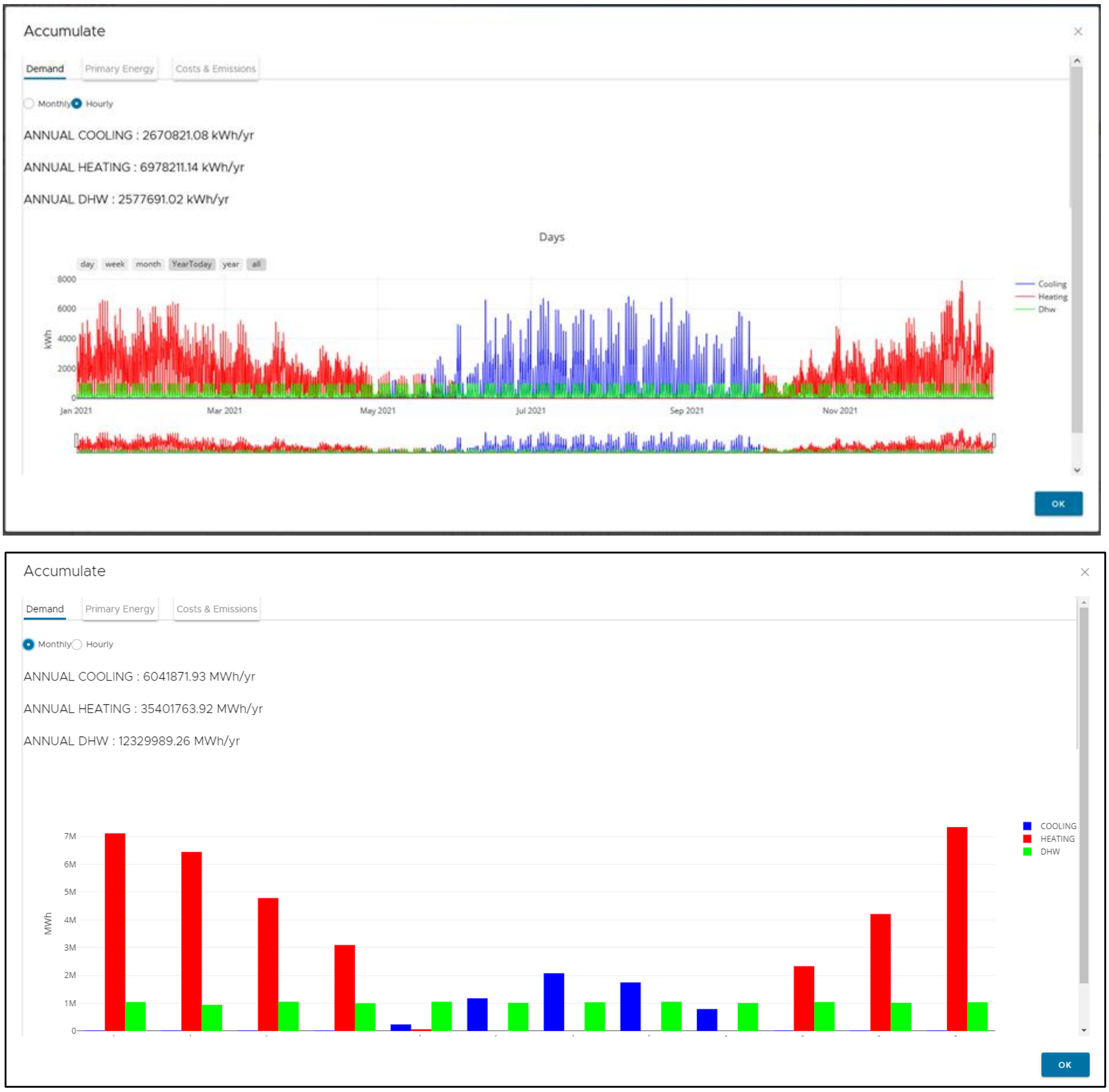


Figure 29 - Graph visualization of the energy demand calculation in yearly and monthly basis.

4.3 Database, computation modules and backend integration

This section includes a description of the tool database (architecture and stored data), the different computation modules developed during the tool implementation and a brief description of how the database and the modules are connected to be functional in the tool.

4.3.1 Pre-design tool database

First activities of the pre-design tool development have focused on the definition of a suitable structure of databases capable of storing and serving all the information required at each step of the predesign tool workflow. Figure 30 presents a preliminary structure of tables linking the information to be contained in the .dbf file (i.e. the attributes table of the source shapefile) with static information required for the demand calculations according to the reference databases already available from PLANHEAT.

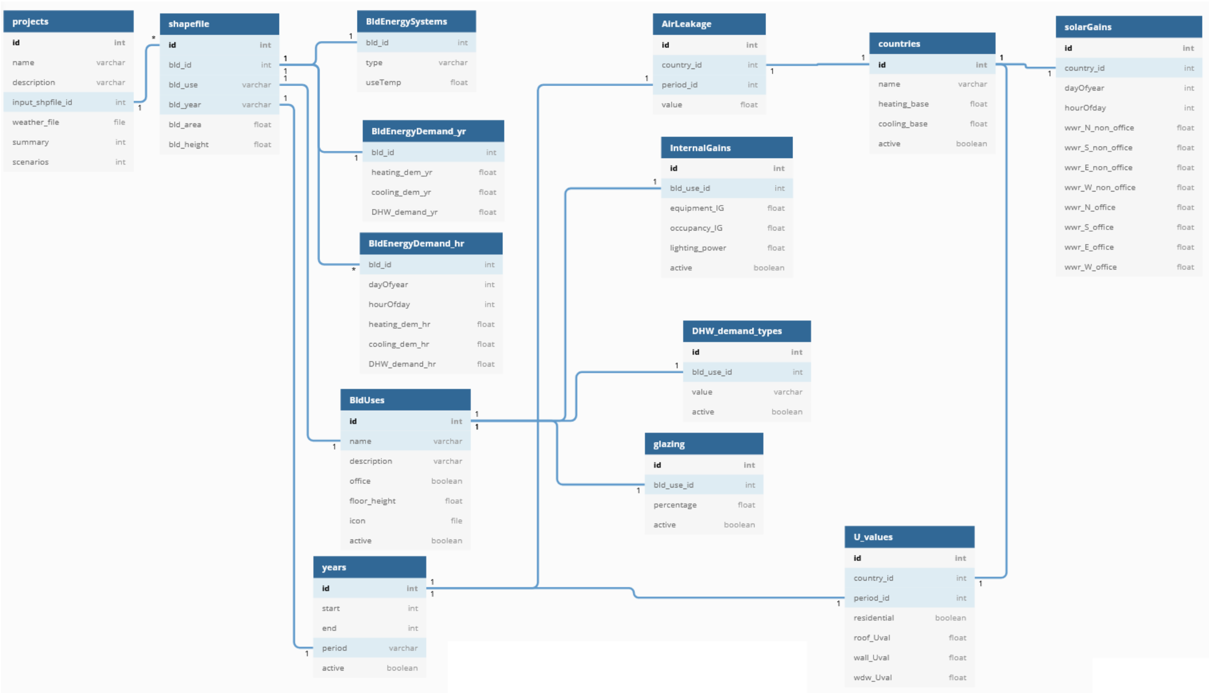


Figure 30 – Preliminary table structure of relational databases proposed for storing building information.

The most recent version of the database includes new tables that allow storing new data generated by the calculation scripts, such as energy based on demand calculations or the network generated by the optimal route calculation script, as well as data stores such as the project temperature and radiation data or the energy distribution points (see Figure 31).

The database is an open task throughout the development of the tool that will incorporate data according to the needs established by the different calculation algorithms. It is feasible that the implementation of data on new energy sources as well as the energy model associated with the network will establish additional needs and as consequence it will be necessary to create new tables and relate them to the existing ones.

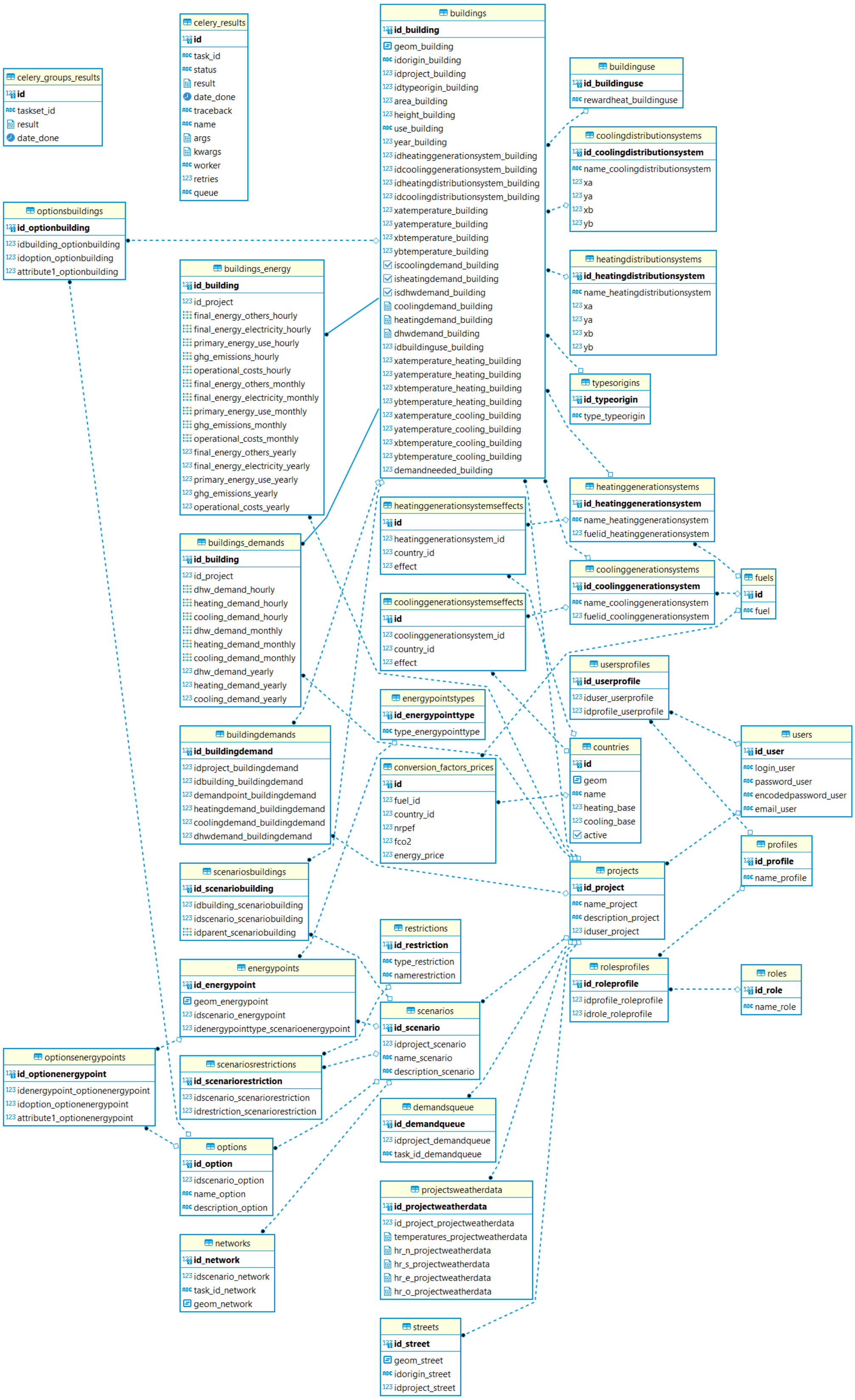


Figure 31 – Current REWARDHeat database

4.3.2 Energy demand calculation

Energy demand estimation algorithm is one of the first and core calculations to be solved, initial focus is on addressing how to manage the information required in this phase.

It should be reminded that REWARDHeat will build on PLANHEAT's Demand Mapping Module (DMM) approach to conduct the demand calculations. This DMM is built as a QGIS plugin, which is quite different from the requirements needed for implementation within the REWARDHeat predesign tool following a client-server architecture. The hypotheses and main considerations within the reference method can be consulted in [8] and are summarized below.

In order to simplify the assessment, static equations are used to determine hourly demands following the Energy Performance of Buildings Directive (see equation 1, 2 and 3). The static calculation is considered suitable and preferable for a pre-design tool in the early stages of a DHC project conception. Full dynamic modelling would be used for advanced stages of design when a big amount of input data and higher levels of detail and accuracy on the technical analyses are required.

The wall heat transfer hourly loads for each building is determined multiplying the number of heating/cooling degree hours (HDH/CDH) at the particular location, the heat transfer coefficient (U) of the envelope areas (A) and the heating schedule of each hour. The annual heating and cooling demand results are obtained as the sum of their corresponding hourly values. In order to calculate the HDH and CDH values, reference heating set point of 21ºC and cooling set point of 25ºC respectively are considered. Night setback effects can be accounted for by the corresponding schedules. Losses through the ground are neglected, but might have an impact on the overall heating demand. Different internal gains related to occupancy, lighting, appliances and solar gains are included. Finally, ventilation heating/cooling loads (calculated for the different base temperatures for heating-h or cooling-c) are assumed. If a mechanical ventilation system with heat recovery is installed, ventilation heating/cooling loads are reduced by the heat recovery system efficiency (nHR).

The hourly domestic hot water demand is determined by multiplying the annual DWH demand per square meter, the gross floor area of the building and the normalized utilization factor of the DHW (see equation 3).

$$AHD_k = \sum_{i,j=1}^{8760} \left(HDH_{i,j} \times A_k \times U_k - Gains_{i,j} + hventilation\ losses_{i,j} \times (1 - n_{HR}) \right) \cdot heating\ schedule_{i,j}$$

(Eq.1)

$$ACD_k = \sum_{i,j=1}^{8760} \left(CDH_{i,j} \times A_k \times U_k + Gains_{i,j} + cventilation\ gains_{i,j} \times (1 - n_{HR}) \right) \cdot cooling\ schedule_{i,j}$$

(Eq.2)

$$DHWD_k = \sum_{i,j=1}^{8760} DHW\ demand_k \times GFA_k \times \frac{Hourly\ usage\ factor_{DHW_{i,j}}}{\sum_{i,j=1}^{8760} Hourly\ usage\ factor_{DHW_{i,j}}}$$

(Eq.3)

These equations require an important amount of input data related to building geometries and constructive characteristics, weather conditions along the year, as well as to static information dependant on the specific building use. The used data will be explained below.

The energy demand calculation engine that is implemented in the tool includes weather (hourly temperature and hourly solar radiation) data from two different alternatives: The first one is the PVGIS initiative [9] which is connected to the tool by means of an API, collecting temperature and solar radiation in four orientations (N, S, E, W) using a slope of 90 degrees (vertical wall). Both datasets are in an hourly basis. The second alternative is only available if PVGIS API is not working. This alternative uses Copernicus C3S datasets [10] to obtain hourly temperature and hourly radiation data in each project location. Solar radiation data (global component) are transformed in the four orientations following distribution patterns built with downloaded PVGIS data. Static information or static data was collected from PLANHEAT database in order to cover the required data for heating, cooling and domestic hot water demand calculation considering the specific use of each building.

The first collected values are the heat transfer coefficients or thermal transmittances (U-values) that are used to measure how effective elements of a building's fabric are as insulators. These values are used to estimate how effective the different building elements are at preventing heat from transmitting between the inside and the outside of a building. Calculation also requires air leakage data per building use considering it year of construction. The database includes values covering the 27 European countries and 3 non-European countries. An example of this data is presented in Table 1.

Table 1 – Example of the U-value data (roof, wall and window)) of PLANHEAT for Spain by different types of buildings and period of construction.

Country	Period	Type	Roof	Wall	Window	Air leakage
Spain	<1945	Residential	1.8	2.5	5.7	1.2
Spain	1945-1969	Residential	1.4	2.1	5.7	1.2
Spain	1970-1979	Residential	1.4	2.1	5.7	0.9
Spain	1980-1989	Residential	1	1.6	3.3	0.9
Spain	1990-1999	Residential	1	1.6	3.3	0.9
Spain	2000-2010	Residential	0.5	0.8	3.1	0.9
Spain	>2010	Residential	0.5	0.8	3.1	0.6
Spain	<1945	Others	1.4	2.5	5.8	1.2
Spain	1945-1969	Others	1.4	2.2	5.8	1.2
Spain	1970-1979	Others	1.4	2.2	6.1	0.9
Spain	1980-1989	Others	1	1.8	3.3	0.9
Spain	1990-1999	Others	0.9	1.7	3.3	0.9
Spain	2000-2010	Others	0.6	0.9	2.8	0.9
Spain	>2010	Others	0.6	0.9	2.8	0.6

Other relevant data for energy demand calculation, are the equipment internal gains, internal gains that are related with the developed activities in the building and the gains due to lighting. Our calculation approach works with different values and schedule per building use (Table 2 and Table 3) but differences at country level in both parameters are not provided. This is a very interested approach that could be included in future releases of the tool is we found data to configure different schedule profiles at country level.

Table 2 – Equipment internal gains, occupancy internal gains, lighting gains and glazing values by different building use collected from PLANHEAT database.

id	Building use	Equipment internal gains	Occupancy internal gains	Lighting gains	Glazing
1	Residential	4.4	1.755	6.46	0.27
2	Office	11.77	70.485	15	0.50
3	Education	4.7	298.242	10.66	0.28
4	Health care	3.58	7.329	13.02	0.23
5	Commerce	5.2	8.183	15.07	0.20
6	Hotel	0.945	4.72	10.76	0.17
7	Public	5.48	5.94	9.69	0.50
8	Restaurant	18.88	11	9.69	0.30
9	Sport	16.02	25.5	10.76	0.20

Table 3 – Hourly building schedule for residential buildings in the day one of the year.

id	Day of year	Hour of day	Season	Building use	Heating	Cooling	Lighting	Equipment	Occupancy	DHW
1	1	0	W	Residential	0	0	0.1	0.1	1	0.25
2	1	1	W	Residential	0	0	0.1	0.1	1	0.1
3	1	2	W	Residential	0	0	0.1	0.1	1	0.1
4	1	3	W	Residential	0	0	0.1	0.1	1	0.1
5	1	4	W	Residential	0	0	0.1	0.1	1	0.1
6	1	5	W	Residential	0	0	0.1	0.1	1	0.1
7	1	6	W	Residential	0	0	0.1	0.1	1	1
8	1	7	W	Residential	1	0	0.3	0.3	0	0.5
9	1	8	W	Residential	1	0	0.3	0.3	0	0.25
10	1	9	W	Residential	1	0	0.3	0.3	0	0.25
11	1	10	W	Residential	1	0	0.3	0.3	0	0.25
12	1	11	W	Residential	1	0	0.3	0.3	0	0.25
13	1	12	W	Residential	1	0	0.3	0.3	0	0.25
14	1	13	W	Residential	1	0	0.3	0.3	0	0.25
15	1	14	W	Residential	1	0	0.3	0.3	0	0.25
16	1	15	W	Residential	1	0	0.3	0.3	0	0.5
17	1	16	W	Residential	1	0	0.3	0.3	0	0.5
18	1	17	W	Residential	1	0	0.3	0.3	0	0.5
19	1	18	W	Residential	1	0	0.5	0.5	0	0.5
20	1	19	W	Residential	1	0	1	1	0	0.5
21	1	20	W	Residential	1	0	1	1	0	0.5
22	1	21	W	Residential	1	0	1	1	0	0.5
23	1	22	W	Residential	1	0	1	1	0	0.5
24	1	23	W	Residential	0	0	0.5	0.5	1	1

Finally, we collect data for each building type on domestic hot water demand by building use per unit area (Table 4). These data are distributed to determine the hourly DHW demand.

Table 4 – Domestic hot water demand by building use per unit area.

id	Building use	DHW demand
1	Residential	13.9
2	Office	3.2
3	Education	57.2
4	Health care	133.4
5	Commerce	3.2
6	Hotel	126.4
7	Public administration	3.2
8	Restaurant	35.3
9	Sport	256

In order to calculate the energy demand adequately, it is necessary to have the height of the buildings being able to quantify their envelope and area exposed to the different weather conditions. Height can be obtained using LiDAR data or calculating them be using the number of floors in that are stored as part of the building attributes in the national cadasters. But this height attribute is not always available, as is the case with OSM or the geometries generated by the user himself. To cover this lack of data, we developed an analysis of more than 150,000 building using Copernicus Urban Atlas [11] and building boundaries. to evaluate the relationship between building height and area. The obtained results are presented in Figure 32. For Hotel and Sport buildings a pattern similar to Office and Education respectively is assumed.

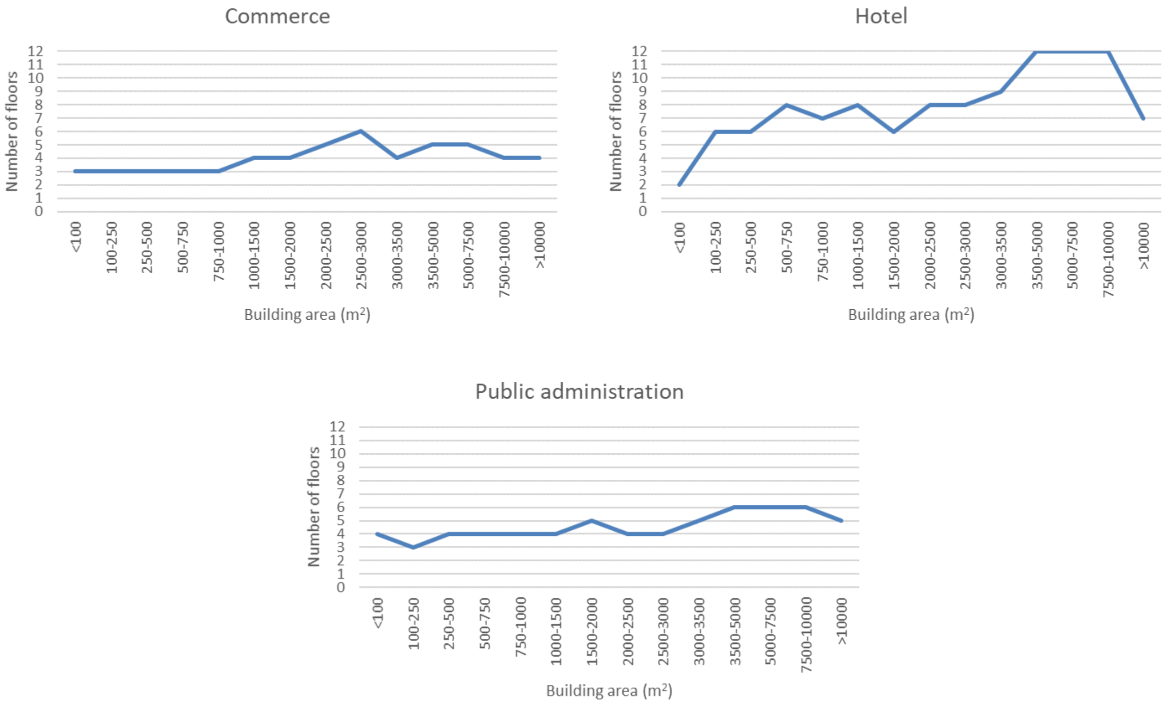
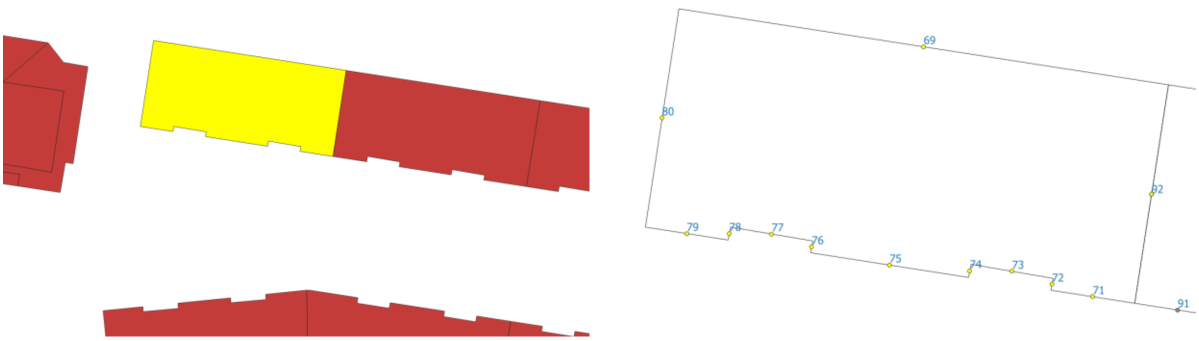


Figure 32 – Building height-area analysis that is integrated in the tool for energy demand calculation.

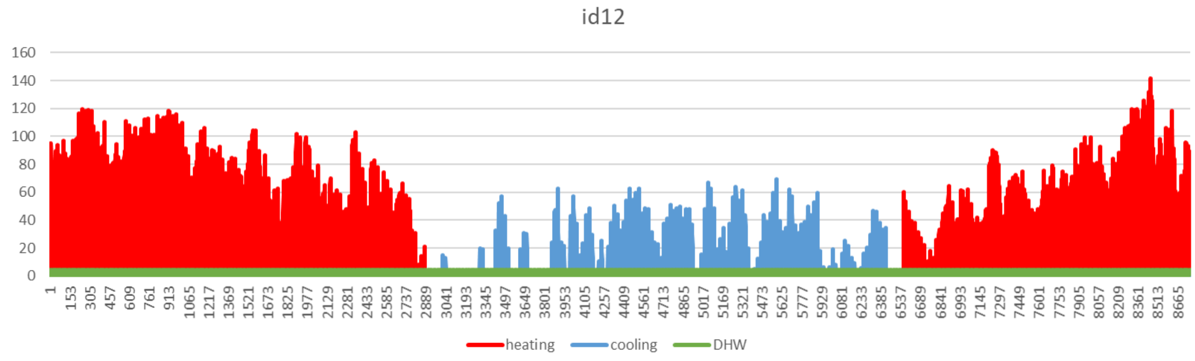
Finally, as referred before in this document, some modifications to the PLANHEAT calculation algorithms are required for proper integration into the whole REWARDHeat tool concept, but also, they are being addressed to facilitate and improve the data extraction from data sources (such as the buildings geometries contained in the shapefile or the hourly values from representative weather files). In particular, Figure 33 shows the definition and results of a dedicated GIS process developed in Python created to extract representative building envelope areas for each of the four main orientations (N, S, E and W). These will be used later to apply the corresponding hourly radiation values and thus, properly consider solar gains into the balance equation excluding adjacent walls. The process decomposes the building envelope into its constituent walls and determines if they correspond to external (free) walls and assign its main orientation based on the wall azimuth. The accuracy of the calculation can be improved by predefining a larger set of main orientations, better calculation of glazing values per building type or the application of more specific glazing transmittance values. It is necessary to consider that the approach requires a selection of the constituent buildings for and accurate calculation of the solar gains due to the exclusion of constituent wall and the calculation only with free walls.



fid	cat	gml_id	Function	Year	AREA	Height	Azimut	Azimut1	Length	X	Y	Aspect	Free_Wall
69	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	9	9	21,4474034	354932,341	4610937,8	N	Yes
70	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	99	99	9,5733506	354942,207	4610931,42	E	No
71	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	189	189	3,6749979	354939,662	4610926,98	S	Yes
72	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	-79	281	0,5197847	354937,897	4610927,52	O	Yes
73	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	190	190	3,6128855	354936,166	4610928,08	S	Yes
74	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	100	100	0,578787	354934,336	4610928,1	E	Yes
75	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	189	189	6,9241621	354930,866	4610928,35	S	Yes
76	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	-79	281	0,5197847	354927,496	4610929,14	O	Yes
77	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	190	190	3,6205795	354925,761	4610929,69	S	Yes
78	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	100	100	0,5689387	354923,926	4610929,71	E	Yes
79	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	189	189	3,6240451	354922,086	4610929,71	S	Yes
80	7	ES,SDGC,BU,5111102UM5151A_part1	1010	1960	201,185	16,036	-81	279	9,5619437	354921,021	4610934,72	O	Yes
92	8	ES,SDGC,BU,5111103UM5151A_part1	1010	1960	202,399	15,408	-81	279	9,5733506	354942,207	4610931,42	O	No

Figure 33 - Dealing with building attributes and orientations. Example application for internal algorithms.

The demand calculation includes other two algorithms that are useful if the user has real data of buildings in the case study. Following a similar approach than the DHW demand calculation, these algorithms work with the yearly or monthly value disaggregating them by means of the HDH and CDH values. The algorithm makes possible to obtain a daily profile but potential improvements could be necessary in order to ensure the accuracy of the obtained results. The results of the energy demand calculation using both scripts are presented in Figure 34.



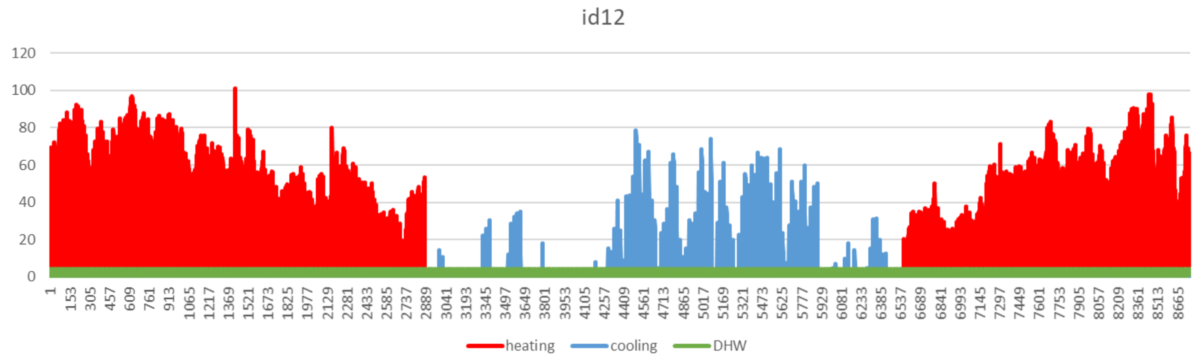


Figure 34 – Visualization of the energy demand calculation results with both approaches. Complete calculation at the top and disaggregated approach at the bottom.

4.3.3 Primary energy, final energy, GHG and Cost estimations calculation

Former to calculate an estimation of the final energy, primary energy, GHG and cost estimations, some operational parameters should be assigned to each generation system depending on the country and kind of energy source. Thus, some tables identifying the country, where the building is installed, the type of heating and cooling generation system of the building and the fuel used by them has been defined (Table 5 to Table 6).

Table 5 - Country IDs used by REWARDHEAT predesign tool.

id	country	id	country	id	country
1	Austria	11	Germany	21	Poland
2	Belgium	12	Greece	22	Portugal
3	Bulgaria	13	Hungary	23	Romania
4	Croatia	14	Ireland	24	Serbia
5	Cyprus	15	Italy	25	Slovakia
6	Czech Rep.	16	Latvia	26	Slovenia
7	Denmark	17	Lithuania	27	Spain
8	Estonia	18	Luxembourg	28	Sweden
9	Finland	19	Malta	29	UK
10	France	20	Netherlands	30	Norway

Table 6 - Heating and Cooling Generation systems and fuel IDs used by REWARDHEAT predesign tool.

id	HGS
1	Biomass boiler
2	Gas boiler
3	Oil boiler
4	WWHP
5	AWHP
6	Electric Boiler
7	District Heating
8	None

id	CGS
1	None
2	WC-chiller
3	AC-chiller
4	GF-ABS-chiller
5	SF-ABS-chiller

id	Fuel
1	Wood
2	Gas
3	Oil
4	Elect
5	DH
6	Sun

Then, taking into account the combination of the types of generation systems and countries, an additional table defining an estimation of the performance of the generation system has been created. At the moment, the value of the performance does not depend on the country (Table 7), but the system is prepared to introduce different values for each country in the future.

Table 7 - Heating and cooling performances used by REWARDHeat predesign tool.

HGS_id	HGS	country_id	HGS_eff
1	Biomass boiler	1	0.85
2	Gas boiler	1	0.9
3	Oil boiler	1	0.8
4	WWHP	1	4.5
5	AWHP	1	3.5
6	Electric Boiler	1	1
7	District Heating	1	0.93
8	None	1	1

CGS_id	CGS	country_id	CGS_eff
1	None	1	3
2	WC-chiller	1	4
3	AC-chiller	1	3
4	GF-ABS-chiller	1	0.8
5	SF-ABS-chiller	1	0.8

Similar to the table shown above, the conversion factors to calculate the non-renewable primary energy, green-house gases emissions and operative costs are defined depending on the fuel and the country. At the moment, the value of the conversion factors does not depend on the country (Table 8), but the system is prepared to introduce different values for each country in the future.

Table 8 - Conversion factors used by REWARDHeat predesign tool

fuel_id	fuel	nrPEF [$kWh_{primary}$/kWh]	fCO2 [gCO2/kWh]	EnerPrice [€/kWh]
1	wood	0.1	20	0.05
2	gas	1.1	210	0.04
3	oil	1.15	260	0.06
4	elect	2.5	300	0.15
5	DH	1.6	150	0.1
6	sun	0	0	0

Finally, for each building, the factors indicated in the tables are applied to the corresponding energy demand and accumulated in monthly and annual basis.

4.3.4 Route optimizer

The building of the network route is based on a minimum distance optimization algorithm based on graph theory. The configured algorithm works with the selected buildings as energy consumers, the energy producers (waste heat from industries, supermarkets, datacentres, substations, storage or sources inserted by the user) and the streets (collected from OSM) as an axis for the route layout. The developed algorithm uses the DHNx library for geometry managing before the network optimization. A graph example of the algorithm implementation is presented in Figure 35.

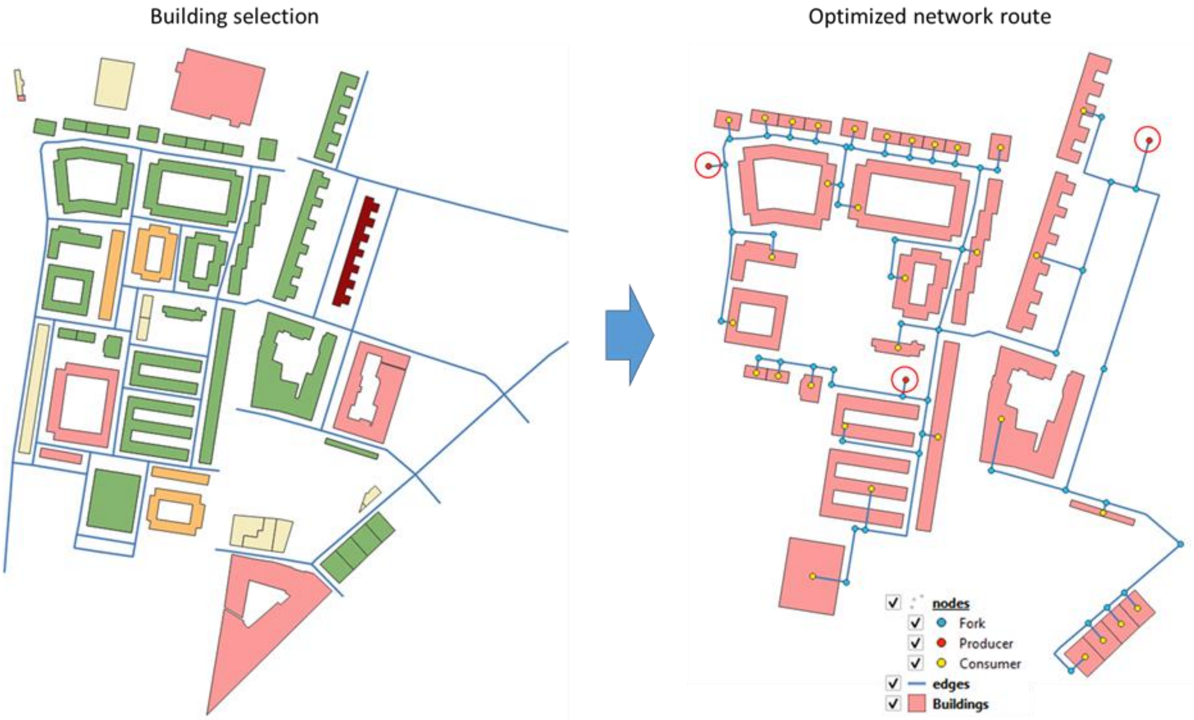


Figure 35 - Example of the inputs and results from the network route optimizer.

This part of the tool is under development and will be available in the following months. The user will have the opportunity to select buildings and energy sources, delete streets to extract them from the algorithm implementation or to insert new energy sources including storage. Once all the required data are selected, the user will run the algorithm obtaining the minimum distance optimised network. One of the bottlenecks in data management for the algorithm implementation is the projection management being necessary to transform projections so that all data sources are in the same reference system.

4.3.5 Architecture and backend development and integration

Figure 36 shows the general architecture of the REWARDHeat platform. As shown in the figure, there are two main blocks, the frontend or user interface and the backend. For the development of the frontend, the Angular web development platform has been used. In the case of the backend, and given its complexity, different technologies have been used to adapt in the best possible way to the different needs of the platform development.

The platform API enables the communication between the frontend and the database, which uses Spring Boot technology (based on Java) both for authentication and authorization, as well as for the CRUD operations with the different tables of the database.

The database is based on Postgres/Postgis. The main reason to work with this object-relational database is the power of its geometric/geographic functions, which greatly facilitate common tasks in platform development.

For the calculation and communication of the scripts, used to obtain the demand, the energy or the optimal route, different technologies have been used, with the aim of allowing the user of the platform to work on different projects, while waiting for the completion of the calculations required during the different steps. A small API has been developed in Flask, which allows communication with the main API of the platform, responsible for queuing the different calculation tasks, adding them to a table in Redis memory, and managing the different calculations through Celery.

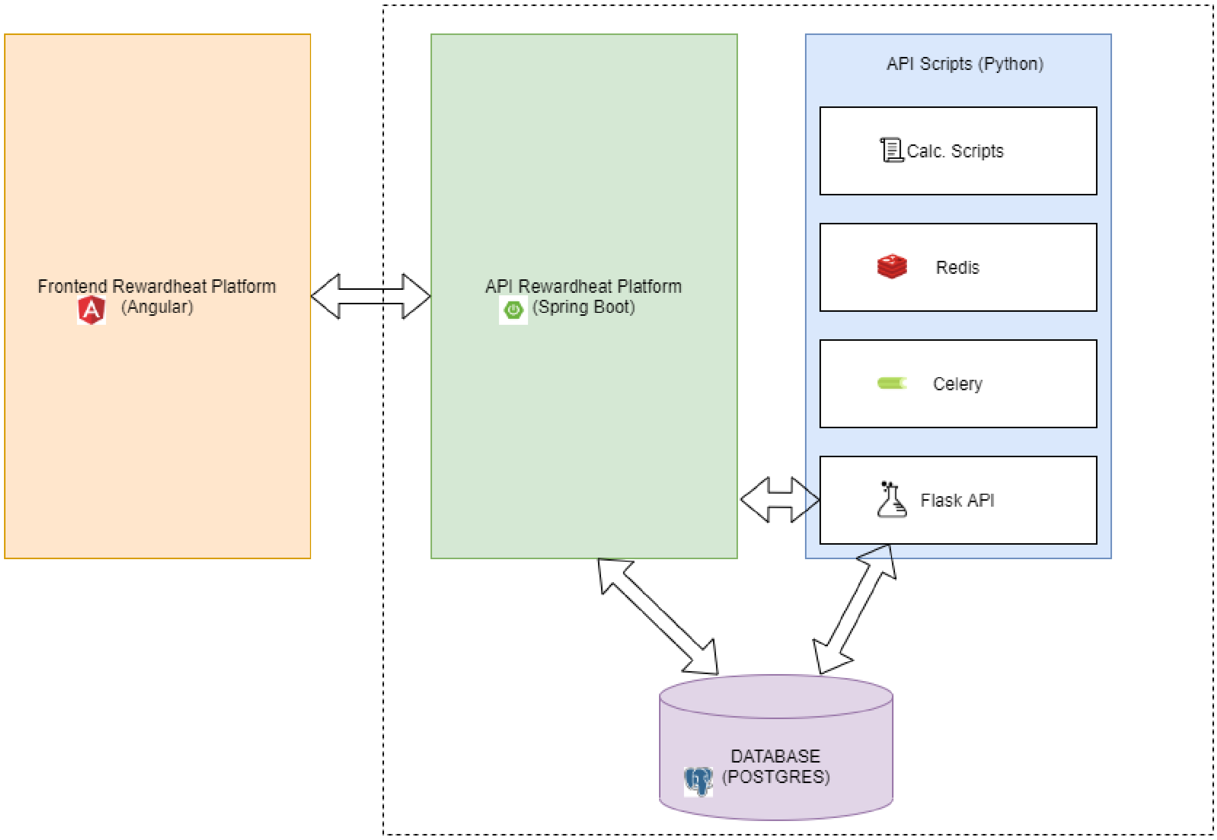


Figure 36 – REWARDHeat Predesign Tool backend architecture

4.4 Ongoing developments

Since the version presented in this report is an alpha-version, continuous improvements and partial implementations of new features will be deployed progressively to allow developers tracking errors and debugging them in parallel to finally get the complete version of the predesign tool.

The features to be improved and/or implemented within the project are:

- Modifications in GUI and corrections of errors in a continuous way.
- Improvement of internal calculation time.

- Validation of calculation of energy demand, primary energy, GHG and costs depending on the type of building, fuel and system generation.
- Definition of default generation systems of a building in case no more specific information is available depending on the construction year and area of the building.
- Possibility for the user to merge/add/remove buildings in order to define the scenarios (according to mock-up presented in Figure 10).
- Possibility for the user to introduce the location of energy sources and network assets (energy storage, RES, central generation plants, connections to existing DH). The characteristics of each element should be further discussed balancing the calculation simplicity and the introduction of representative data to have specific results.
- Possibility for the user to include exclusion areas to avoid the network passing through some street in case some specific restriction is present (e.g. the network cannot pass through the streets where there are metro railways in the underground)
- Implementation of the route optimizer calculation script and representation in the GUI (according to mock-up presented in Figure 11).

New features have been identified to be implemented most likely after the project for further improvement of the tool, since they are not critical parts:

- Include an "acceptance factor" for the adoption of the DHC network emulating that not all the inhabitants of the selected building may want to switch their existing system generation for a new one. This feature may be simulated generating a reduction in the energy demand of some buildings selected randomly.
- Include the possibility for the user to exclude streets from the scenarios depending on the tag information assigned by Open Street Maps.

4.5 Tool deployment and access to the first release version

The REWARDHeat predesign tool Access Release has been deployed in a web-based application allocated in the servers of CARTIF which will be accessible, in a first step, by the WP2 partners. Parallel to the debug of the version and the implementation of new features, the tool will be available progressively to other relevant stakeholders such as demo site owners or DHN operators.

The URL to access the REWARDHeat predesign tool Access Release is:

https://tools.cartif.es/rewardheat/#/Projects

For this version, there is only one predefined user accessible using the following login information:

- Login: rewardheat
- Password: #xk16BV%B

It should be noted that the tool, at this stage of development, presents some limitations:

- 200 buildings are allowed to be included in the project. This number should be sufficient to allow the user to have relevant information about a possible DHN

- Since the deployment of this version is temporal, the computational resources assigned to this task are not as relevant as it could be. As an estimation for the user about time need to execute the demand calculation, a project including about 20 buildings, takes approximately 30 minutes.

5 Conclusions and next steps

The development of the REWARDHeat predesign tool alpha version has been launched according to the expected plan once its main functionalities and workflows were defined (see REWARDHeat D2.4 [7]) accounting for the needs and expectations expressed by expert partners and potential tool users, which were collected during the first year of the project in Task 2.3.

A complete definition of the tool capabilities included in the alpha version and their integration with a dedicated design of interface mock-ups have been presented in this report. This will enable a proper interaction with the user and the operative execution of the tool workflows.

Moreover, the planned development process has been described identifying the core threads that can be parallelized comprising both frontend and backend components. Initial activities already undertaken are also reported. They have been focused on the definition of the required databases and the adaptation of useful existing energy demand calculation algorithms.

Finally, next steps and expected timelines to conclude the task and produce the first complete release of the tool in one year are depicted below within a planned Gantt chart.

Table 9. Development next steps and time planning

Activities	2022									2023		
	A	M	J	J	A	S	O	N	D	E	F	M
	31	32	33	34	35	36	37	38	39	40	41	42
Database structure and contents												
Backend connections												
GUI development												
Overall network energy model												
Input shapefiles enrichment												
Network route optimizer script												
Buildings/streets modifications												
Component and system validation												

The validation of the tool will be carried out in parallel to the deployment of each feature to assure the functionalities. Besides, an Access Release version of the tool including all the characteristics described in this report will be available for WP2 project partner. The project partners will act as testers and they will be encouraged to gather information of any problem, bug or improvement idea they find.

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