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List of abbreviations / Nomenclature

Abbreviation	Definition
API	Application Programming Interface
DHC	District Heating and Cooling
DHCRO	District Heating and Cooling Route Optimizer
DHW	Domestic Hot Water
GDAL	Geospatial Data Abstraction Library
GIS	Geographical Information System
H&C	Heating & Cooling
HD	Heating Demand
CD	Cooling Demand
OSM	Open Street Map
CMM	City Mapping Module
SMM	Supply Mapping Module
DMM	District Mapping Module
CPM	City Planning Module
DPM	District Planning Module



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Introduction

The present document represents deliverable “D4.1 PLANHEAT integrated tool” developed under the responsibility of ARTELYS in the framework of WP4 and task “T4.1 PLANHEAT integrated tool development”.

The implementation of the PLANHEAT integrated tool has been achieved in accordance with the information presented in deliverable “D1.4 Common IT framework specifications” and in “D1.5 Report and presentation on PLANHEAT integrated tool functionalities”. Specifically, bi-weekly conference calls and bilateral meetings facilitated the collaboration among partners during implementation, making possible to reach the achievements hereinafter presented as well as several physical technical meetings (the most recent held in Copenhagen in M36 – September 2019). The PLANHEAT integrated tool includes the Mapping module (developed in the framework of WP2) and the Planning and Simulation modules (developed in the framework of WP3).

The objective of this document is to present the final version of the PLANHEAT integrated tool. It includes a description of the interface embedded in a QGIS plugin and the main features available to the end-user.

Chapter 1 describes the main characteristics of the PLANHEAT integrated tool. The PLANHEAT database is presented in section 2 among with its external usage through a Python package. The PLANHEAT scenario handling system is presented in details in chapter 3 and Chapter 4 contains a step by step installation guide using the dedicated PLANHEAT tool installer.

The report has been updated in January 2020 in order to include further development and enhancement activities performed in the project duration extension period M36-M40.

1 Description of the PLANHEAT integrated tool

This section describes both the functional and technical characteristics of this first version of the PLANHEAT integrated tool in accordance with deliverable “D1.4 Common IT framework specifications” developed under the responsibility of ARTELYS and delivered at M9.

1.1 Functional description

This section regroups the functional description of the PLANHEAT integrated tool which is a global overview of the tool in terms of functionalities. The information presented in this section is available in more details in the deliverables dedicated to each module.

1.1.1 Integration of the modules in the PLANHEAT tool

The main objective of PLANHEAT is to develop and validate through real use-cases an integrated geo-referenced tool for the mapping, planning and simulation of heating and cooling systems at local level towards the identification of future low carbon and economically viable supply scenarios matching the forecasted demand. This tool is therefore divided in three modules: the mapping, the planning and the simulation modules.

1.1.1.1 The mapping module

The Mapping module aims at providing a software for mapping:

- Yearly and hourly heating, cooling and Domestic Hot Water (DHW) demand and consumption from different typologies of end-users;
- Energy potential for heating and cooling supply from renewable sources and waste energy sources available at urban and industrial level. The input data for the mapping module depends on the mapping algorithm that is used and is typically a combination of satellite-derived data, geographical data (GIS), key figures and statistical information. The mapping algorithms can deal with different levels of data availability. Top down and bottom up algorithms are available.

The PLANHEAT mapping module is composed of three functional parts:

- The GUI for configuring the structure of the sectors demanding heating/cooling and the technologies or sources for producing heating/cooling are created.
- A library with mapping algorithms for bottom-up or top-down allocation, mapping and geographical explicit estimation of the heating, cooling, DHW production, demand, consumption for the various point/diffuse producers/consumers at the chosen level of detail.
- A functionality to configure the structure of the sectors/technologies and to execute the corresponding hierarchical computations at different levels of aggregation.

1.1.1.2 The planning module

The Planning modules functional objectives are:

- Enable the identification of sustainable and feasible H&C scenarios according to energy planning criteria;
- Guide the end-users to the generation of several scenarios for heating and cooling and explore the possibility of developing DHC networks;
- Provide the optimal scenario for new district and cooling networks or expansion of existing ones and provide optimized design for pipe routes;
- Visualize at a global level main KPIs that are estimated before simulation.

1.1.1.3 The simulation module

The Simulation module objectives are to:

- Hourly balance H&C demand and supply (sources and technologies) for each future scenario and related baseline defined at district level;
- Calculate KPI in different domains to compare baseline and future scenarios;
- Provide information about the transport sector;
- Visualize KPI on a dashboard;
- Produce a final report summarizing all the information associated to the simulated scenario.

The PLANHEAT tool ensures the integration of the module functionalities while keeping in mind that a coherent user interface must be defined as each module requires a graphical interface.

1.1.2 Managing data inside and outside of the PLANHEAT tool

Several functionalities are present in the PLANHEAT integrated tool regarding geographical and non-geographical data management. The PLANHEAT tool handles both raster and vector data. Vector data represents the world using point, lines and polygons. Vector models are useful for storing data that has discrete boundaries, such as country borders, land parcels, and streets. On the other hand, raster data represents the world as a surface divided into a regular grid of cells. Raster models are useful for storing data that varies continuously, as in an aerial photograph, a satellite image, a surface of chemical concentration, or an elevation surface. Both of those data formats are available through the PLANHEAT database presented in section 2.

Additionally, getting and sharing data outside of the PLANHEAT project is a crucial requirement. The PLANHEAT user has the possibility to import public data from the internet. It completes the local data the cities already have available for their studies. The user should be able to share data and models with other city employees to facilitate their work, this functionality is available through the scenario handling system presented in section 3.

1.1.3 Choosing an Open source license

As aforementioned, a requirement for the PLANHEAT project is to provide an open source tool. An open source license is defined by its permissions, conditions and limitations. Open source licenses grant permission to everyone to use, modify, and share licensed software for any purpose, subject to conditions preserving the provenance and openness of the software.

The PLANHEAT integrated tool needs several permissions to allow the cities to use it internally but also allow commercial use for future versions:

Permission type	Definition	Status
Commercial use	This software and derivatives may be used for commercial purposes.	Yes
Distribution	You may distribute this software	Yes
Modification	This software may be modified.	Yes
Patent use	This license provides an express grant of patent rights from the contributor to the recipient.	-
Private use	You may use and modify the software without distributing it.	Yes

Some conditions were set regarding the distribution of the software:

Conditions type	Definition	Status
Disclosure source	Source code must be made available when distributing the software.	Yes
License and Copyright notice	Include a copy of the license and copyright notice with the code.	Yes
Network use is distribution	Users who interact with the software via network are given the right to receive a copy of the corresponding source code.	Not applicable
Same License	Modifications must be released under the same license when distributing the software. In some cases, a similar or related license may be used.	Yes
State change	Indicate changes made to the code.	-

Last but not least, some limitations are necessary to ensure that the software author cannot be held liable for damages:

Limitation type	Definition	Status
Hold liable	Software is provided without warranty and the software author/license owner cannot be held liable for damages.	Yes
Trademark use	This license explicitly states that it does NOT grant you trademark rights, even though licenses without such a statement probably do not grant you any implicit trademark rights.	-

According to the permissions, conditions and limitations described above, the **MIT License** has been chosen for the PLANHEAT integrated tool. The MIT License is a short and simple permissive license with conditions only requiring preservation of copyright and license notices. Licensed works, modifications, and larger works may be distributed under different terms and without source code. This license therefore allows a first open source version without closing the door on future commercial software after the end of the PLANHEAT project.

1.2 Technical description

This section regroups the technical choices made for the platform architectures to meet the requirements coming from both the end-users and the integrated modules.

1.2.1 The global architecture

The architecture selected for the PLANHEAT integrated tool is presented below:

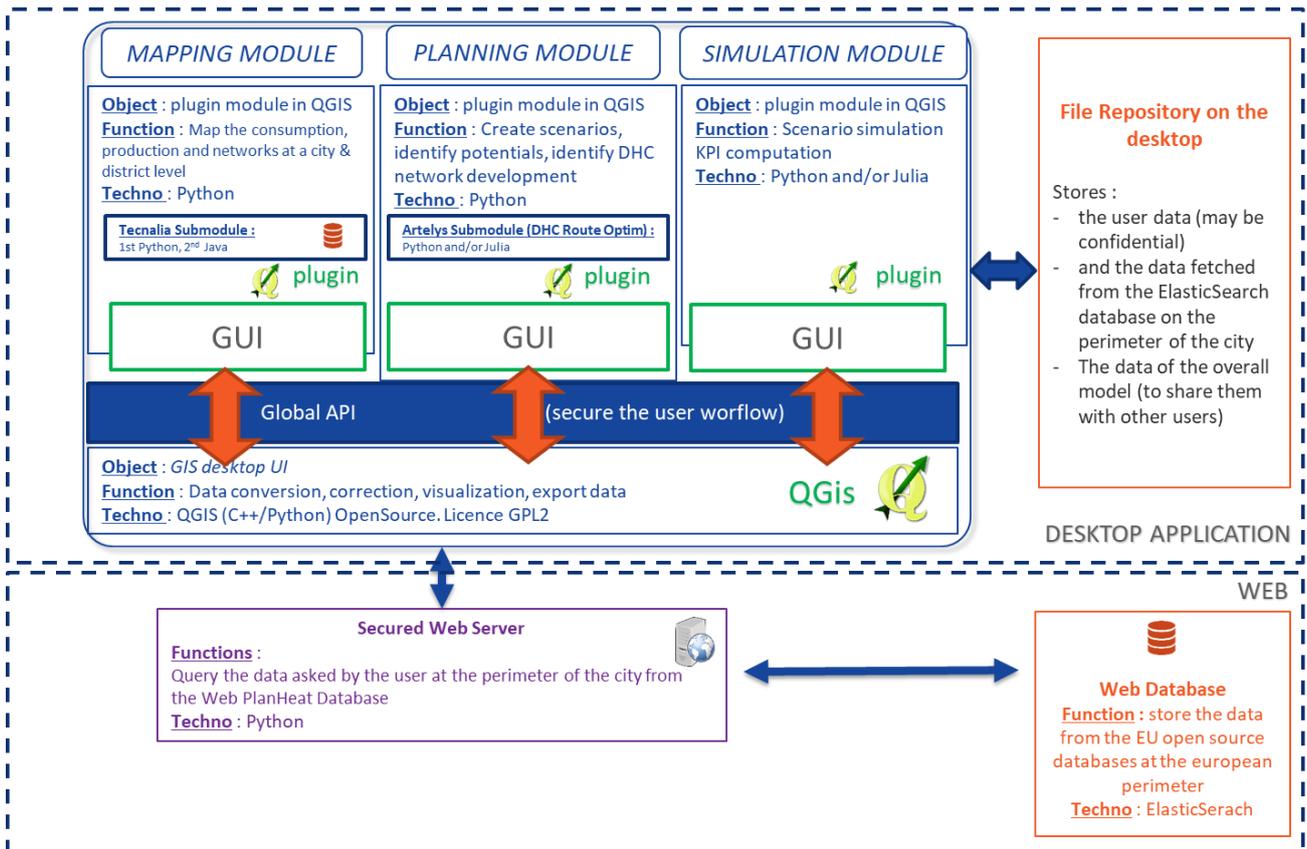


Figure 1: The PLANHEAT tool architecture

The PLANHEAT architecture is composed of both:

- A desktop application
- A web service making available European data

The desktop application is a QGIS based desktop application. The three PLANHEAT modules are implemented as QGIS plugins embedded in the QGIS client. A web database based on ElasticSearch allows the end-user to access open source European data.

1.2.2 Definition of the data exchange protocol using flat files

As mentioned in the requirements, the PLANHEAT modules have to exchange data. The PLANHEAT scenario handling system which will be further detailed in section 3 present in details the common framework and user interface implemented to exchange data among the modules.

To ensure an easy data exchange between the modules, the data is shared using a flat files database. A flat file database is a database which is stored on its host computer system as an ordinary unstructured file called a "flat file". To access the structure of the data and manipulate it, the file must be read entirely. Upon completion of the database operations, the file is again written out in its entirety to the host's file system. In this stored mode, the database is said to be "flat", meaning that it has no structure for indexing and there are usually no structural relationships between the records.

A flat files database has several advantages:

- Easy to understand
- Easy to implement
- It requires less hardware and software
- Less skills are required to hand flat database system
- Easy internal sharing among municipalities, the working files just need to be present on a shared repository

The web database presented in section 2 comes as a complement for the end-user, storing European data and drastically decreasing the size of the flat files database. QGIS handles a wide range of data formats hence an easy data sharing using flat files.

Last but not least, the use of a flat files database hosted on the computer strictly ensures the data confidentiality. The PLANHEAT tool does not share data on any public repository, every working files are present on the user computer. For cities having several users working together on a study, the flat file database could be hosted on an internal server/intranet to allow several people to share the files. However, the PLANHEAT tool does not allow simultaneous edition and does not provide any locking system preventing the users from editing the same file concurrently.

1.2.3 The PLANHEAT tool dependencies

Many technical requirements also arise from the technical choices already made for the PLANHEAT modules in the previous deliverables. These dependencies are embedded in the PLANHEAT integrated tool to facilitate as much as possible the installation process presented in section 4.

The PLANHEAT mapping module combines QGIS and custom-made software to handle the energy related computations. Via QGIS, the custom-made mapping module software components are activated. As it is envisioned at this moment, most graphical aspects (user interfaces of dialogues and the presentation of resulting maps) are handled by QGIS.

Since the mapping module uses QGIS, which is written in C++ and Python, these two languages are the major languages used for the mapping module. The sub-module from TECNALIA included in the mapping module is separated in two parts: one developed in JAVA included in the module or hosted on a distant web server, and one developed in Python.

The default building layers required by the mapping module is provided by the PLANHEAT database through a call to Open Street Map using the [OSMnx](#) Python package. In addition to the [NetworkX](#) package its dependencies consist of several geographical Python packages presented in section 2.

Both the District Heating and Cooling Route Optimizer and the the simulation module optimization engines developed respectively by Artelys and UNIZAG are implemented in the Julia language. Julia is a high-level, high-performance dynamic programming language for numerical computing. Julia's Base library, largely written in Julia itself, also integrates mature, best-of-breed open source



C and Fortran libraries for linear algebra, random number generation, signal processing, and string processing. In addition, the Julia developer community is contributing a number of external packages through Julia's built-in package manager at a rapid pace. The simulation module also relies on SCIP to solve its optimization problem. SCIP is a non-commercial solver for mixed integer programming (MIP) and mixed integer nonlinear programming (MINLP).

The Planning Module (which embeds the DHC Route Optimizer) also requires the GeoNetworkX Open Source Python package developed by Artelys in the framework of the PLANHEAT project. This package mainly relies on the [OSMnx](#) and [NetworkX](#) packages to handle spatial optimization on graphs.

2 Relying on the PLANHEAT database

Gathering data is a tedious and difficult task. For that reason, the PLANHEAT project offers access to a database which contains a wide range of European data. This European data comes in addition to the one provided by the end-user to either substitute missing data with default European values or simply complete an existing set of data. The PLANHEAT Client API's is a Python package that allows to easily exploit all the data available on the PLANHEAT database. The PLANHEAT modules are directly connected to the PLANHEAT database and does not require any extra step to be used. Whenever the information cannot be provided by the end-user, the PLANHEAT integrated tool automatically connects to the database.

The detailed list of the data uploaded on the PLANHEAT Webserver is available at the following address: <https://PLANHEAT.artelys.com/list>. Each dataset can be filtered using its specific properties. To that end, the properties of each dataset can be easily retrieved at a dedicated address using the dataset name (cf the list of uploaded data). For example, the following [url](#) displays the properties of the natura_2000 dataset.

See the [detailed documentation](#) for further information.

2.1.1 List of available data on the PLANHEAT database

This section presents an overview of all the data (both geographical and statistical) available on the PLANHEAT client.

- default-population: population for each European country.
- final-energy-consumption: final energy consumption by energy type and country.
- technologies_distribution: technology distribution by country, fuel and category.
- production_volume: production volume by country, energy and fuel.
- electricity-emission-factor: emission factor per country of several pollutants for electricity.
- resources-emission-factor: emission factor of several pollutants by fuel type.
- heat-emission-factor: emission factor per country of several pollutants for heating.
- primary-energy-factor: primary energy factor per country for electricity and heating.
- agricultural-statistics: average yield per crop type per country.
- technology-database: technical and financial information on available technologies.
- fuel-costs: fuel costs per country and consumer type.
- forestry-energy-production-factor: energy production factor map forestry, based on the 2010 Global Ecological Zones.
- map-with-eu-countries: map of European countries which corresponds to the NUTS 1 classification.
- industry-e-prtr-facilities: E-PRTR facilities, based on the European Pollutant Release and Transfer Register (PRTR).
- excess-industry-heat: excess heat from large industries, based on the European Pollutant Release and Transfer Register (PRTR).
- excess-heat-uwtp: excess heat from unconventional sources based on Wastewater Treatment Plants (WWTP).
- natura_2000: natura 2000 is a network of nature protection areas in the territory of the European Union. The network includes both terrestrial and marine sites.
- deep-geothermy (1km, 1_2km, 2_3km, 3_4km, 4_5km, 5_7km): deep geothermy potential based on the GEOELEC maps.

- corine_land_cover_2012_agr: this dataset is a subset of the CORINE Land Cover (CLC) produced in 2012. It consists of an inventory of several land cover for agriculture areas.
- corine_land_cover_2012_blf: this dataset is a subset of the CORINE Land Cover (CLC) produced in 2012. It consists of an inventory of land cover for broad-leaved forest.
- corine_land_cover_2012_conf: this dataset is a subset of the CORINE Land Cover (CLC) produced in 2012. It consists of an inventory of land cover for coniferous forest.
- corine_land_cover_2012_mixf: this dataset is a subset of the CORINE Land Cover (CLC) produced in 2012. It consists of an inventory of land cover for mixed forest.
- corine_land_cover_2012_ind_comm: this dataset is a subset of the CORINE Land Cover (CLC) produced in 2012. It consists of an inventory of land cover for industrial or commercial units and public facilities.
- cooling-degrees: This dataset contains cooling demand for several cities across Europe.
- cooling-degree-hours: this dataset contains cooling degree hours for several cities across Europe.
- heating-degrees-155: this dataset contains heating demand for several cities across Europe. Baseline temperature of 15.5 degrees.
- Celsius.heating-degrees-18: this dataset contains heating demand for several cities across Europe. Baseline temperature of 18 degrees Celsius
- heating-degree-hours-155: this dataset contains heating degree hours for several cities across Europe. Baseline temperature of 15.5 degrees Celsius
- heating-degree-hours-18: this dataset contains heating degree hours for several cities across Europe. Baseline temperature of 18 degrees Celsius
- solar-radiation: this dataset contains a subset of solar radiation from the PVGIS database.
- ghs-population-grid-2015: this dataset contains a subset of the Global Human Settlement (GHS) map restricted to Europe. The Global Human Settlement framework produces global spatial information about the human presence on the planet.
- estmap_storage: this dataset contains data related to reservoirs for energy storage. To obtain further information about this dataset, check this [link](#).

2.1.2 Using the PLANHEAT database outside of the PLANHEAT tool

The PLANHEAT Client API is available as a Python package. Python packages can be easily installed using the pip command which can download and install 3rd-party libraries with a single command as follows:

```
pip install --extra-index-url https://PLANHEAT.artelys.com PLANHEATclient
```

The PLANHEAT client includes features that make easier requests with OpenStreetMap server. These features require python dependencies. On Windows, you must have these dependencies (GDAL, Fiona, Shapely and Rtree). On Windows, all the required dependencies are available with Anaconda distribution. Without Anaconda, these three dependencies have to be installed with this order from the WHL files:

- 1) GDAL
- 2) Fiona
- 3) Shapely
- 4) Rtree

Corresponding WHL files are available [here](#).

Example : pip install path_to_file/GDAL_2.4.1_cp36_cp36m_win_amd64.whl

2.1.3 Examples of the PLANHEAT database use

The PLANHEAT database enables the user with both statistical and geographical data (including OpenStreetMap building layers).

Example with basic Geographical data:

```
from planheatclient import PlanHeatClient

results = PlanHeatClient("https://planheat.artelys.com")
    .geo_query("natura_2000")
    .filter("properties.SITENAME", "limagne")
    .within_circle([2.861478, 45.396834], "80km")
    .send()

print(results)
```

Figure 2: Example of geographical data retrieval

Example with statistical data:

```
from planheatclient import PlanHeatClient

results = PlanHeatClient("https://planheat.artelys.com")
    .data_query("default-population")
    .filter("Country", "Austria")
    .send()

print(results)
# {'Country':['Austria'], 'Population':[8814680]}
```

Figure 3: Example of statistical data retrieval

Example with the OpenStreetMap building layer:

```
from planheatclient import PlanHeatClient

results = PlanHeatClient()
    .osm_query("building")
    .within_bounding_box(north=45.2009, south=45.1734, east=5.6970, west=5.7643)

print(results)
```

Figure 4: Example of Open Street Map building layer retrieval

3 PLANHEAT scenario handling

When opening the PLANHEAT tool in the QGIS environment, the main window opens allowing the user to handle all of his scenarios.

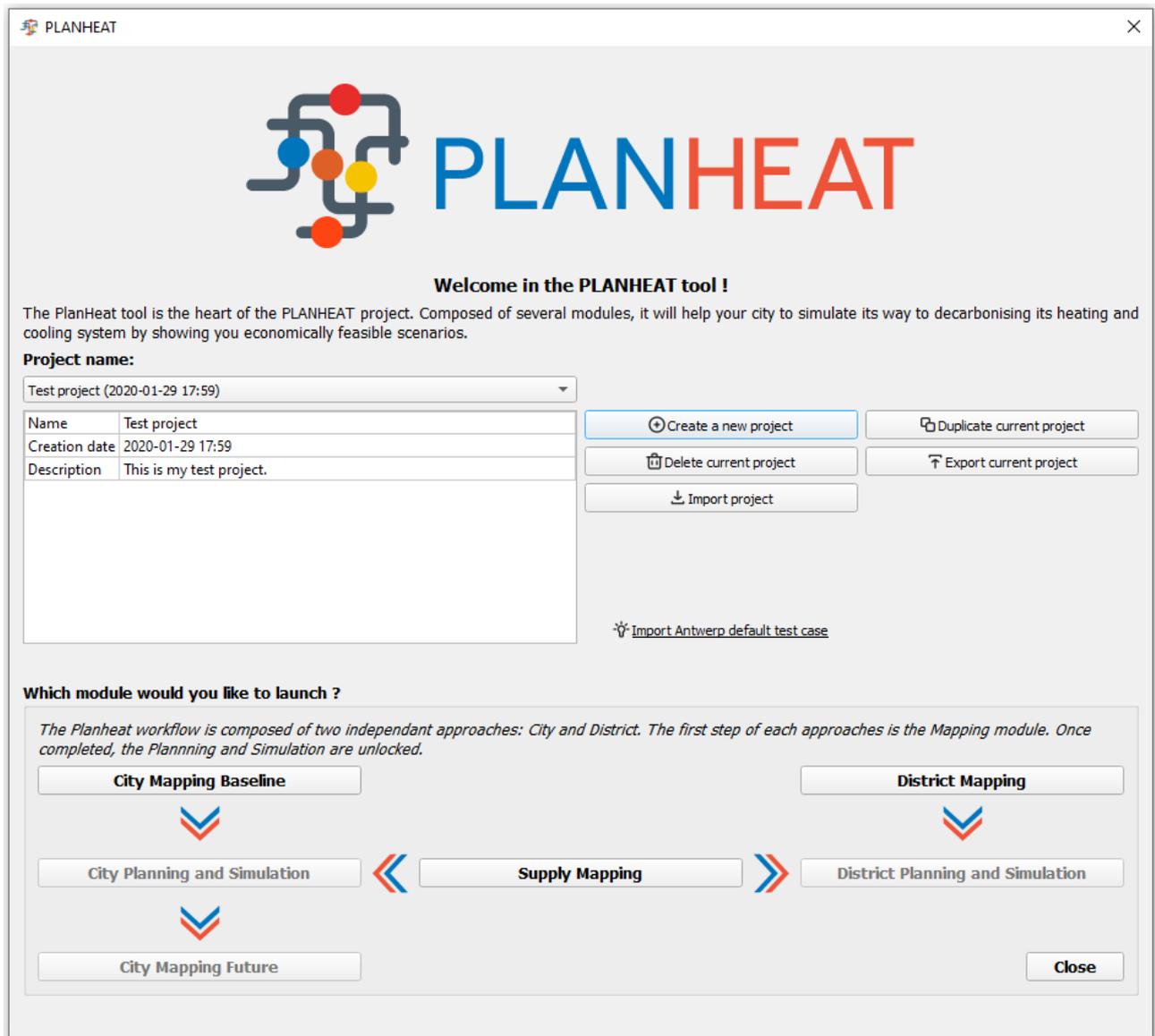


Figure 5: The PLANHEAT tool main window

Several features are available to the end-user to facilitate as much as possible the sharing of the PLANHEAT scenarios. It includes:

- Creation/Deletion to provide a common scenario handling among the modules
- Import/Export for easy scenario sharing
- Duplication to facilitate the comparison of several similar scenarios

Each scenario contains several information to ease the identification and scenario handling. When creating a scenario, the user has the possibility to had an additional description. The creation data allow to keep tracks of the scenario creation.

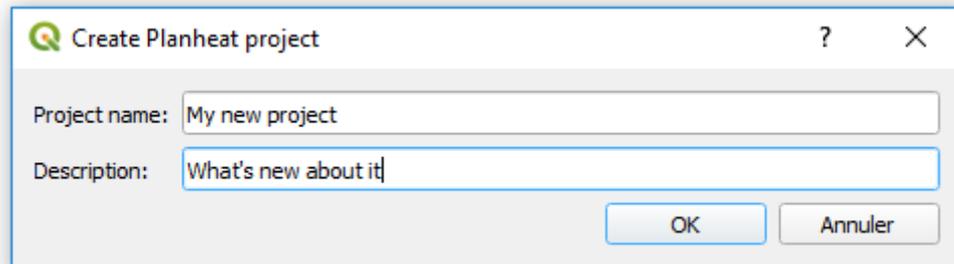


Figure 6: Scenario creation window

The import and export features allow the browsing/writing of the scenario folder among the user computer. Once selected for import, the scenario is automatically copied in your PLANHEAT directory and saved with the corresponding results.

A scenario contains both the input data and the results of the computations. The results stored in the scenario is invalidated if any change is applied to the input data. This behaviour is also applied to all the results obtained in the workflow upcoming modules. i.e. modifying input data in the Mapping modules also invalidate all the results of the Planning and Simulation modules.

The scenarios are common for all three modules (Mapping, Planning and Simulation). As several features of the modules (or submodules) may require output of other modules, a scenario checking has been implemented to only allow the start of a module if all the required files from previous modules are detected. For example, the District Planning module cannot be launched if the District Mapping module and the Supply Mapping module have not been used. The scenario folder is scanned to make sure that all their necessary output files are indeed present and available for the District Planning module.

4 Installing the PLANHEAT integrated tool

This section is dedicated to the installation guide of the PLANHEAT integrated tool. The installation process is handled by a dedicated installer executable which has to be run as administrator to be able to configure the tool effectively.

When launching the installer, the user is prompted to accept the PLANHEAT license agreement which relies on the MIT license as stated in section 1.

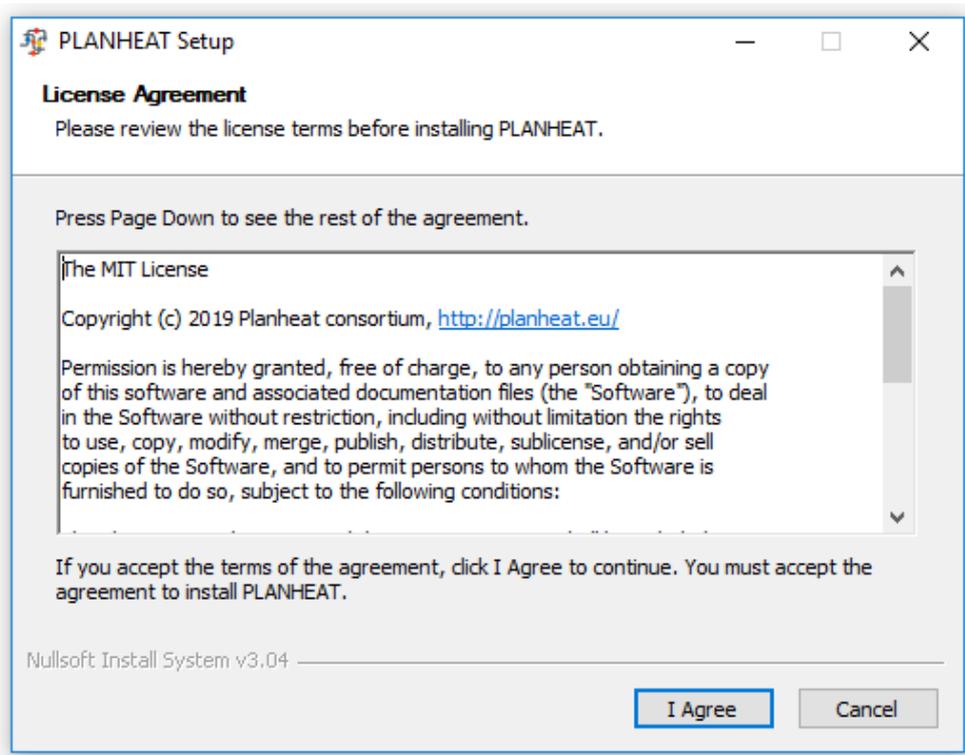


Figure 7: Installer license agreement acceptance

Content of the MIT license agreement:

The MIT License

Copyright (c) 2019 PLANHEAT consortium, <http://PLANHEAT.eu/>

Permission is hereby granted, free of charge, to any person obtaining a copy of this software and associated documentation files (the "Software"), to deal in the Software without restriction, including without limitation the rights to use, copy, modify, merge, publish, distribute, sublicense, and/or sell copies of the Software, and to permit persons to whom the Software is furnished to do so, subject to the following conditions:

The above copyright notice and this permission notice shall be included in all copies or substantial portions of the Software.

THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER DEALINGS IN THE SOFTWARE.

Once agreed, the user has to select one of the QGIS compatible installation already present on his computer (among QGIS 3.2, 3.4 or 3.6) to integrate the PLANHEAT tool into it. If no QGIS version is present, the user has the possibility to install a compatible version from [here](#).

The selected QGIS version should be closed before clicking the install button.

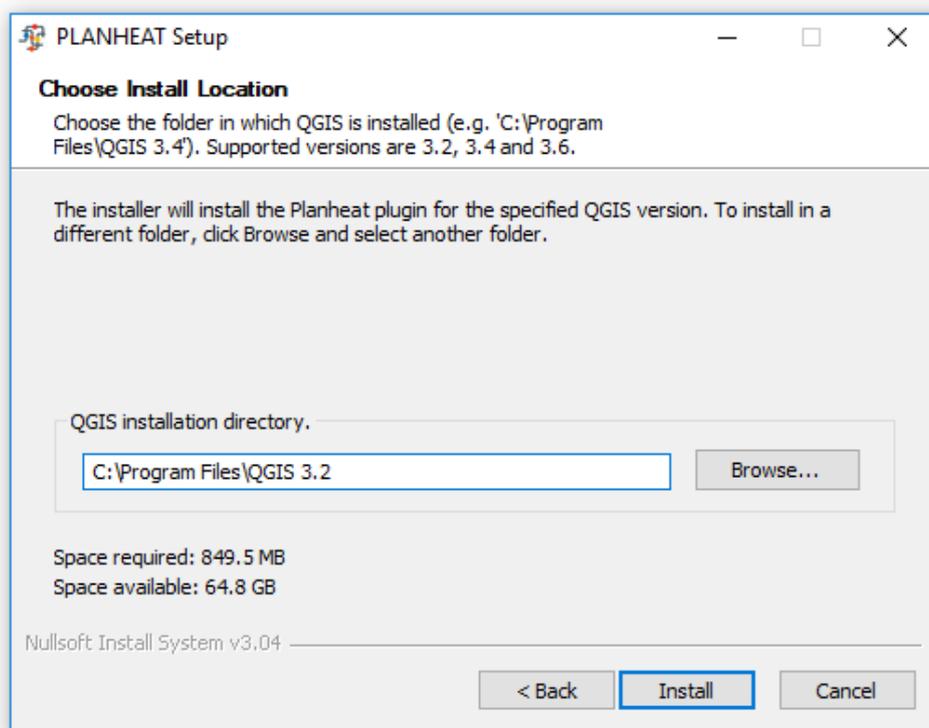


Figure 8: QGIS version selection

After selecting a valid QGIS version, the installation process starts:

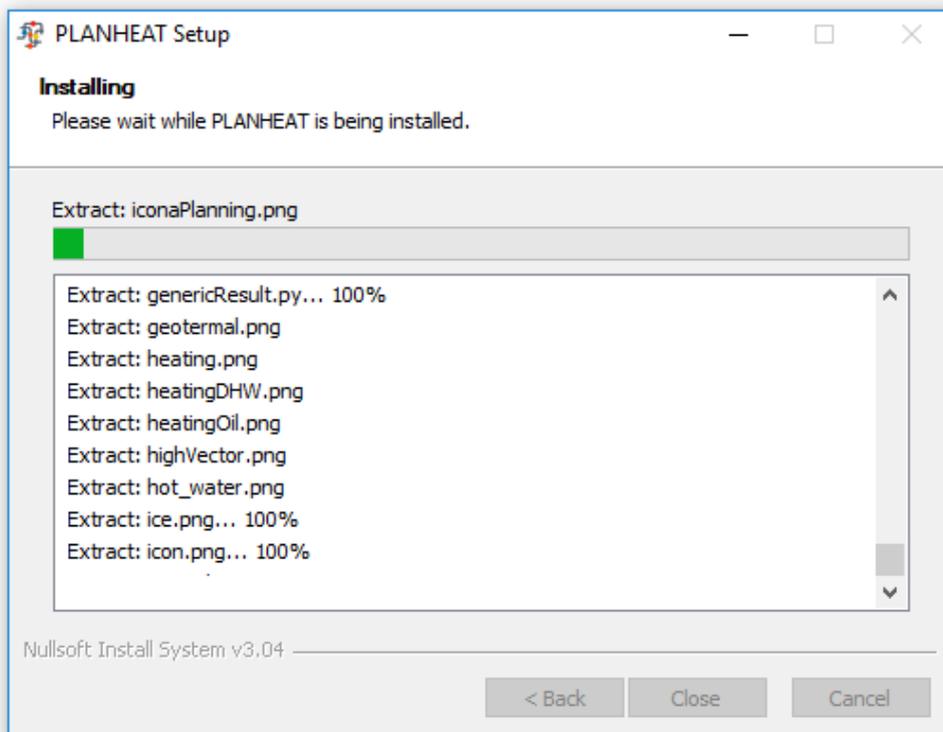


Figure 9: Ongoing installation process

When the installation is complete, the user is able to check if everything went as expected and validate the installation process by closing the installer:

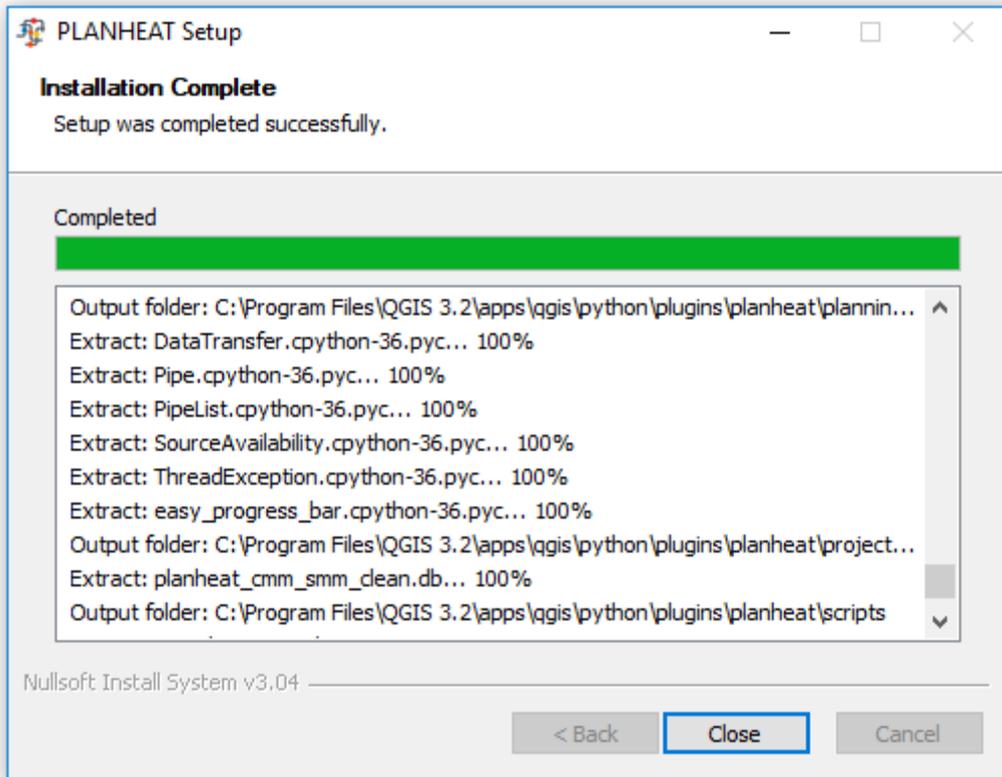


Figure 10: Successful installation process

After the installation, the PLANHEAT tool should be directly available in the QGIS interface:

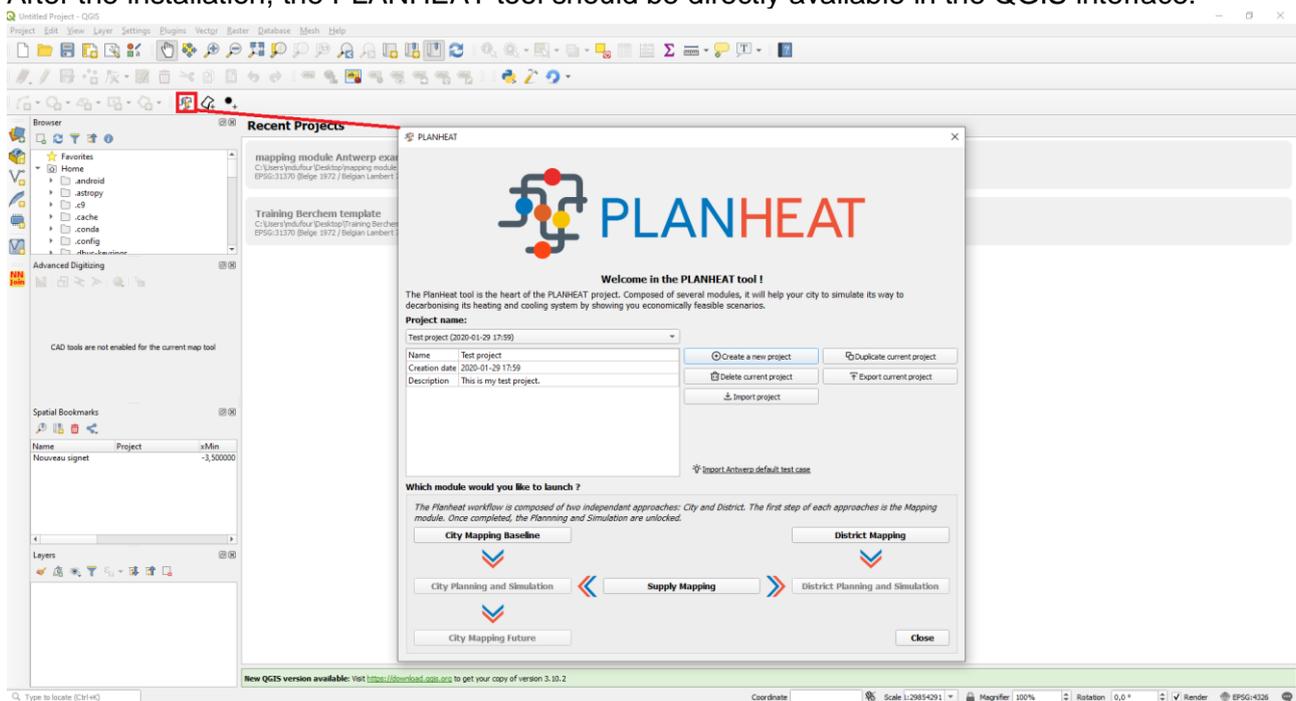


Figure 11: Opening the PLANHEAT tool

It can happen that the PLANHEAT button does not appear, in such cases the plugin has to be activated manually similarly to other QGIS plugins. To do so, the user has to go to the “Plugins – Manage and Install plugins” section and then manually check the PLANHEAT project bunding box as presented below:

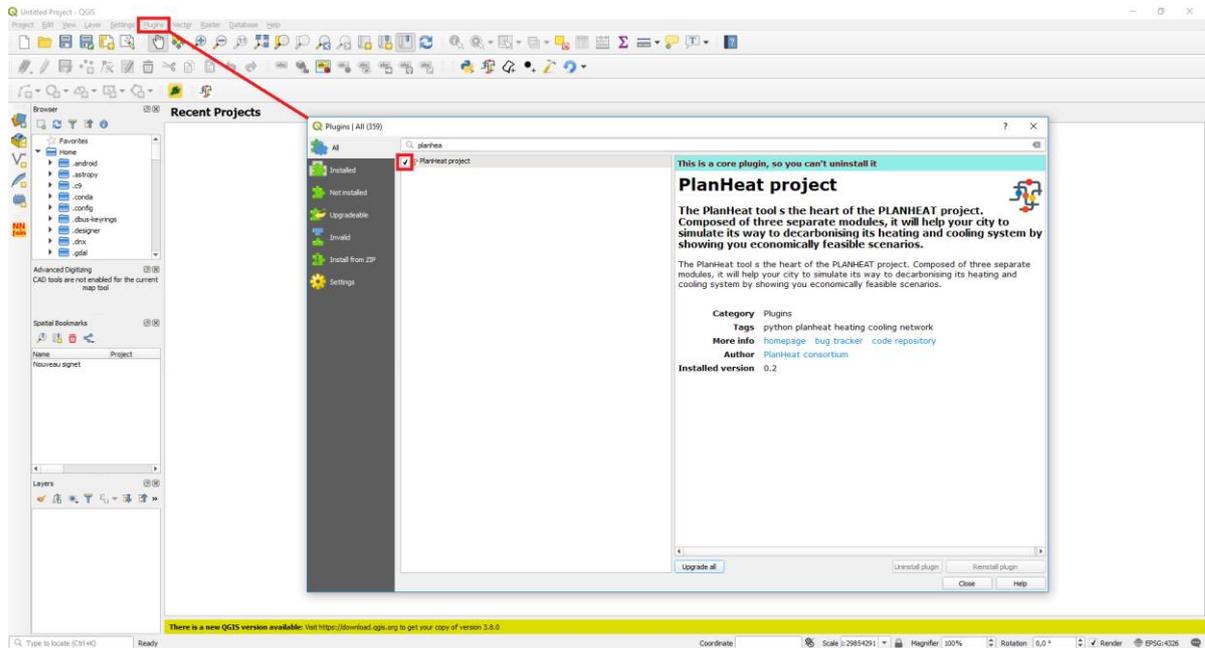


Figure 12: Manually activate the PLANHEAT project

After the plugin is activated, the PLANHEAT main window opens as presented in section 3 and the user now has access to the full potential of the PLANHEAT tool!

5 Conclusions and next steps

The present document represents deliverable “D4.1 PLANHEAT integrated tool” developed under the responsibility of ARTELYS in the framework of WP4 and task “T4.1 PLANHEAT integrated tool development”. This document is delivered together with the final version of the PLANHEAT integrated tool.

A description of functional and technical characteristics of the PLANHEAT integrated tool has been presented. The tool is delivered as a stand-alone application with an easy setup using a dedicated installer. All the required module dependencies are embedded within the tool.

From a scenario handling point of view, a dedicated interface enables the user with easy scenario manipulation. It includes several must have features such as creation, deletion, duplication or export of scenarios. These features ease the use of the tool and the sharing of results both at internal and public levels.

Several external libraries such as the PLANHEAT database and the GeoNetworkX Python package have been presented and implemented in the framework of the PLANHEAT project and are now available even for an external use of the PLANHEAT tool facilitating the usage of geographical data both on the gathering and processing levels.

Following the first version of the tool released in June 2019, several updates have been performed to improve the tool user friendliness and integrate updated versions of the mapping, planning and simulation modules including the last features and bug fixes following PLANHEAT end users’ feedback.

This report includes (in its version 2 here reported) description of such updates that are related to an enhanced usability of the tool, enhanced integration of the modules, enhanced tool functionalities.