DELIVERABLE D.7.1

OPEN ACCESS DECISION SUPPORT TOOL FOR OPTIMAL USAGE OF GEOTHERMAL ENERGY

WP7: ECONOMIC AND ENVIRONMENTAL ASSESSMENT FOR EGS INTEGRATION INTO ENERGY SYSTEMS

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1 EXECUTIVE SUMMARY

1.1 DESCRIPTION OF THE DELIVERABLE CONTENT AND PURPOSE

Commercial exploitation of energy from medium and low-temperature geothermal sources and economy of associated investment projects is very questionable at the moment. In order to help investors that are interested to these specific locations and also to boost later deliverables, namely D4.5, D7.2, D7.3 and D7.4. in scope of MEET project, it is crucial to develop satisfactory level of support that can be used for every site of interest and for different ways of geothermal energy exploitation that is mainly driven by features of available geothermal brine from one side and also needs for thermal energy and proximity of both heating and power consumption on the other hand.

In the framework of the WP7 of the H2020 MEET project, entitled "*Economic and environmental assessment for EGS integration into energy systems*", and Task 7.1: "*Development of Decision-Making Support Tool for Optimal Usage of Geothermal Energy*" first deliverable (D7.1) is Open Access Decision Support Tool for Optimal Usage of Geothermal Energy, that combines technical, economic, environmental and social aspects of geothermal projects and therefore provides background for a comprehensive assessment of EGS projects. It is designed in such a way that should enable investors to compare different approaches of geothermal energy usage and choose that with the best performance by integrating EGS into the electric and/or heat systems.

Decision making support tool (DMT) can be used for obtaining economic criteria like IRR (Internal Rate of Return), LCOE (Levelized Cost of Energy) and NPV (Net Present Value). Most of the input parameters that can be exactly monetarized have an option, either by default values or user specified, for associated costs input. Other parameters that are hard to monetarized, such as social acceptance, environmental aspects and others are taken into account in last stage of grading of specific EGS project using multiple-criteria decision-making (MCDM) approach that enables comparison between several approaches and/or different sites. MCDM also allows user specific attitudes (subjective goals) by putting different weights to specific influencing factors.

The preparation, organization and structure of MEET project and associated partner consortium have allowed to switch focus from modelling and exploring the geothermal potential in different locations (that will be provided from different partners from other WPs and deliverables) to modelling above surface phenomena. In this way, a better approach to an asses energy transfer from its geothermal source to final users is allowed. There is still incorporated special module within DMT that can provide rough estimates on geothermal potential (based on results from 6th Research and Development framework of the European Union project - ENGINE) for those future users that do not possess those data or do not have better means of approximation.

The main part of D7.1 is the tool itself that is modelled in MATLAB and is provided without any constrictions to the public (especially research community). The other important part of D7.1 is this report that provides necessary explanations of used approaches, assumptions and description of applications and functions modelled and incorporated within DMT. This report will also provide manual, both for 'only users' of DMT and also 're-users' or scientific public interested in further development and analysis of provided DMT model. Main steps and GUI interface features are intensively elaborated within the text. It is also important to mention that all functions in MATLAB are provided with basic explanations within lines of code, in order to help future researchers to better cope with code - standard knowledge transfer in scientific community.

1.2 DESCRIPTION OF THE USER MANUAL DELIVERABLE CONTENT AND PURPOSE

This report provides information for using and understanding the Decision-Making Support Tool for Optimal Usage of Geothermal Energy (DMS-TOUGE). DMS-TOUGE is used for conducting techno-economic analysis, alongside with environmental and social impacts of enhanced geothermal system (EGS) projects. Based on the input data provided by the user and pre-defined default values, DMS-TOUGE allows evaluation of different scenarios and estimates costs related to generating electrical power, producing heating energy or both, i.e. combined heat and power production (CHP). The projected costs throughout the project's lifetime and annual power sales are used to interpret one of the main economic outputs, the levelized cost of energy (LCOE).

The DMS-TOUGE is developed and modelled as part of Horizon 2020 MEET project (*Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials*). The purpose behind DMS-TOUGE's development is to support decision-making process in order to help potential investors and developers to invest in EGS technology in various geological settings.

The DMS-TOUGE User Manual provides a comprehensive overview of this MATLAB-based tool, how to use it, its limitations, and how to interpret the obtained results. It designates the parameters that can be inputted manually (by the user), as well as those that are pre-defined as fixed default values or automatically imported from external data bases. Moreover, since the tool itself is a user-friendly application, the manual lists and describes the main application, as much as all the sub-applications that are needed to obtain optimal results for desired scenario. Description of the application and sub-applications consist of introductory part, their purposes, and how to use them. By defining different set of input parameters, the user creates different scenarios of end-application of geothermal energy at the chosen site and geological setting. Furthermore, after gathering all the input parameters and conducting techno-economic analysis, the user is additionally provided with multi-criteria decision-making (MCDM) analysis. The MCDM as a subprocess of the DMS-TOUGE will enable a comprehensive understanding of the interaction between economic, geological, social, and technical uncertainty.

1.3 BRIEF DESCRIPTION OF THE STATE OF THE ART AND THE INNOVATION BREAKTHROUGHS

In comparison to most widely applied RES techniques, namely onshore wind and solar photovoltaic, geothermal energy had a significantly lower contribution to final energy consumption. From the year 2005. till the year 2013. onshore wind production had growth rate of 8%, solar photovoltaic 65% and geothermal was quite steady with growth rate of 1% [5] [Geothermal energy has several strong advantages over wind and solar power. It is not the main intermittent source of energy, it has high capacity factor (around 90%) and it takes significantly less area to be implemented and therefore has a lower environmental impact [6].

At the moment, the geothermal power industry does not have quality economic data indicators that it can rely on, that is one of the reasons for its slow progress. It is therefore of greatest importance to provide both policymakers and investors with more detailed economic data in order to make their energy decisions easier. Levelized cost of electricity/energy (LCOE) is a common metric used when considering energy solutions but due to site-specific features it is difficult to estimate the cost of a new project [7].

LCOE takes into account: capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs and other. The importance of these factors varies among the technologies. According to [7] average LCOE cost for geothermal projects in the U.S. energy market was $39.5/ MWh (2016.). The same source claims LCOE for Wind (onshore) of $50.9/ MWh and solar PV at $58.2, making geothermal overall most attractive RES source. According to [8]in 2012 LCOE for geothermal power plants varied from EUR 50-90 MWh for high-temperature plants and EUR 100- 200/MWh for low-temperature plants. The LCOE for Enhanced Geothermal System power plants was between EUR 200-300/MWh. It is important to stress that presented values can vary significantly from case to case and from site to site in the case of geothermal energy, therefore imposing a significant risk for investors, especially in early project stages (measurements, drilling etc.).

Besides electricity generation, MEET project also considers uses of geothermal energy for heating purposes such as space heating/conditioning, agriculture and aquaculture, process water for industrial purposes if there is a certain industrial facility in proximity. It is therefore important also to investigate LCOH (Levelized cost of heat) for EGS projects.

In these circumstances, certain decision-making help by software tools is more than welcomed, especially due to many site-specific affecting factors. Decision tool that is not open access and requires certain pre-processing provide a pure economic analysis of defined solution for a project is available in [10]. It is not focused solely on geothermal energy but has more general approach. A more advanced excel based tool made in the scope of FP6 project: Enhanced Geothermal Innovative Network for Europe, ENGINE [9] has incorporated geothermal reservoir model but with that approach only simple techno-economic performance estimation can be given that is not able to predict near correct LCOE of specific EGS project. There are also studies that have focused either on economic assessment [10], [11] or environmental assessment based on the life cycle environmental impact of geothermal power generation as studied in [12], [13]. A review paper [14] presents existing software packages for estimating and simulating costs of EGS facilities. The review is mainly focused on the European software EURONAUT and the US software GEOPHIRES. EURONAUT, that is developed based on the studies from the EGS plant in Soultz-sous-Forêts, provides economic estimations via discontinuous cash flows. Various interfaces are possible to be used in order to integrate calculations from separated modules. GEOPHIRES software incorporates reservoir, wellbore, and power plant models with capital and operating costs, correlations and financial levelized cost model to assess the technical and economic performance of EGS. The Geothermal Energy Technology Evaluation Model (GETEM) [15] and Hot Dry Rock economic model (HDRec) [16], are another examples of models that can be used to evaluate the performance of the EGS plant. Most of these models are either focused on solely electricity or heat production but do not permit the assessment of combined heat and power production. In this sense, already mentioned GEOPHIRES software is exception due to the fact that it considers both electricity and heat provision. On the other hand, GEOPHIRES is not focused only to binary EGS power plants but considers also single or double flash geothermal plants that are essentially different production technologies related to rather high temperatures of extracted geothermal brine.

When developing DMT, besides MEET project partners suggestions, some approaches are based on an appropriate literature review. For example, some guidelines and suggestions for deeper analyses of pre-feasibility study for geothermal projects can be found in [17] and [18].

Decision making support tool (DMT) that is developed as D7.1. a MEET project utilizes comprehensive and detailed techno-economic analysis and is significantly more holistic in nature compared to existing models and approaches. In that sense, besides technical and economic aspects it takes into account also the most relevant environmental and societal aspects and risks.

DMT is not intended for analysis of yet unexplored geothermal areas. Instead, it is designed for those sites that have good enough approximations or measurements of available geothermal potential such as existing pilot sites or oil fields that are in plan to transform to g plants in near future. A deeper analysis of such sites with DMT will provide valuable results in terms of suggestions for further site investigation on those sites that will promise good results, and also outputs for investors to choose sites for pre-investment studies that are more detailed but also requires additional costs. On the other hand, DMT is capable of more precise and comprehensive evaluation that will exclude falsely promising sites due to specific techno-economic constraints such as large distance from existing connecting infrastructures and demand. Within its applications and functions DMT incorporates expertise from economy, thermodynamic and power system fields with possibility of consideration of fine details such as different kind of subsidies for EGS (RES source), influence of power losses and grid connection costs that are not taken into account in other models but can have devastating influence on success of EGS project.

In terms of electricity production, DMT is ORC based and focused on low and medium geothermal fluid/brine temperatures and, therefore is more specified and applicable for in-depth exploration of low-temperature wells. Production and efficiencies functions are based on data from ORC developer partner that has detailed ORC model (commercial). In ORC binary geothermal plants there are several decision factors that largely affects net efficiency like subcritical, critical or supercritical conditions of working fluid and of course choosing appropriate working fluid and ORC components optimization. In this project it is possible to utilize already existing and developed ORC model. From that reason higher level of confidence to results are expected and relying upon too many assumptions is avoided.

Developed DMT and its structure are in alignment with final project deliverables that highly depend on D7.1. - evaluation and reports on different kind of geothermal sites, mapping of different resolution layers and web-based tool development that would not be possible using existing models. DMT also represents great foundation for later 'oil to water' conversion on existing oil fields with already acquired data on water flow and temperatures.

MCDM module of DMT covers most influencing EGS project factors and therefore allows a user to pick overall best site among those with similar economic parameters. Already published journal paper on this topic shows scientific community recognition of potential for successful application of proposed approach.

Development of DMT in MATLAB software has also allowed (among other important features) provision of user-friendly and straight forward graphical user interface (GUI) that most of available models lack.

2 DECISION-MAKING SUPPORT TOOL FOR OPTIMAL USAGE OF GEOTHERMAL ENERGY (DMS-TOUGE)

2.1 BACKGROUND

Delayed penetration of EGS to energy market is mainly caused by technical, economic and societal bottlenecks related to EGS, but mitigating these bottlenecks will enable the EGS to become one of the most promising solutions for heat and power production in a near future. To increase the market penetration of geothermal power in Europe, MEET main goal is to demonstrate the viability of EGS with electric and thermal power generation in all main kinds of geological settings (crystalline, sedimentary, metamorphic, volcanic). Therefore, a decision-making tool, considering the type of energy that could be produced (heat or/and power), the geological context, the local energy supply and demand, the environmental impact, and societal aspect, is one of the vital needs.

The main objective is to enable investors to conduct comparative analyses of different energy technologies and choose one with the highest yield for the specific site to successfully determine usage of geothermal energy and integrate EGS into the electric and heat systems. Moreover, the objective is to develop the approach and associated open access decision-making support tool (software) with user friendly interface for available geothermal energy usage which accounts for different possible scenarios and accordingly uses forecasted data which can occur over the operation lifetime of EGS technology on specific site.

2.2 TOOL DESCRIPTION

DMS-TOUGE is MATLAB-based tool and open-access application that estimates different important economic indices for a defined geothermal scenario, provides MCDM analysis and facilitates the decision-making process. Among other outputs, the economic outputs are system's levelized cost of energy (sLCOE), net present value (NPV) and internal rate of return (IRR) that are usually used to evaluate the potential energy production related projects. The available end-use options are electricity generation, direct-use heating power production, and combined heat and power (CHP). Evaluations are made for EGS resources with temperatures from 50-150 °C, and either for an air-cooled or water-cooled binary power plant.

The tool is modular, meaning that each sub-application is used as a separate module to pre-calculate, stimulate or prepare data for different group of parameters, i.e. influencing factors. These separate sub-applications are however joined together via main interface (main application).

The root of the tool is economic estimation based on the discontinuous cash flows (DFC). The present value of costs and revenues are determined at start-up using specified nominal discount rate, which can be default (calculated from discount rate and inflation rate) or user defined. Parameters used for the economic estimations are collected from each sub-application and mathematical operations are conducted on them to obtain relevant results.

Costs related to each phase of the project can either be inserted manually (user defined inputs) or pre-defined default cost-correlations are used to calculate costs of every segment. Default cost correlations use unit size parameters calculated from input parameters. Each obtained default cost is based on a specific year and is adjusted to the year for which the project is being evaluated using the Chemical Engineering (CE) Indexes.

The estimates of electric power and/or heating power generation over the lifetime of the project are by default based on the premise that the resource temperature declines with time, while the geothermal brine flow rate remains constant (default). Makeup drilling, as much as the makeup costs are at this stage of the model development not included. Temperature drawdown is defined with annual percentage drop. However, user itself is enabled to insert the values of resource temperature drawdown, as much as geothermal brine flow for each year of the project's lifetime. Thereby, the default settings could be changed, i.e. both resource temperature and geothermal brine can either be constant or vary during the project's lifetime.

Power sales are defined as the amount of electricity delivered to the power gird for sale. The magnitude of the power sales is the net plant output less the geothermal brine pumping power and the plant-specific parasitic power requirements to operate fans, pumps, and other power consumptions within the power plant.

$$Power\ Sales = \ Plant\ power_{net} - Parasitic\ power_{plant} - Pumping\ power_{geo-brine}$$

All input parameters are in SI units, calculations are made in SI units and the results are provided in Si units. Every input parameter related to the costs is expressed in €.

Two different approach are used to describe the energy extracted from the reservoir and later used for end-user applications (only electricity production, only heating power production or CHP). First approach includes more detailed input parameters that are available to the user. This approach is mostly used in cases of already existing production infrastructure, history and available historical data regarding geothermal brine flow, ambient conditions, available end-user application details, etc. Second approach is based on the proportion of energy extracted from the energy stored in the reservoir, i.e. the volumetric approach (already used and demonstrated in ENGINE project). This approach follows the assumption that the energy produced each year by the power plant at the surface is part of the whole available energy stored in the reservoir. The assumption for this approach is that the number of years for the complete use of the energy stored which gives the maximum power plant capacity at the surface is fixed. i.e. is equal to the project lifetime. This second approach is used when the preliminary geological data is available, and no history of production is known for the chosen site. Second approach is described in more details in APPENDIX B2.

Resulting data from DMT are available as raw data and charts and in a form of suggestions for decision-makers and investors. A separate module within DMT - multiple-criteria decision-making (MCDM) matrix has a role to process raw data into a decision. MCDM subprocess is performed by using the weighted decision matrix (WDM). For proper MCDM function it is necessary to define appropriate criterions that will allow comparison of different EGS options on specific site and comparison of different sites for application of specific EGS option. Relative importance for each criterion can be altered by decision-maker based on preferred aspects of planned investment.

Currently, there are twelve criterions defined within MCDM that include:

1. Installed ORC power capacity;
2. Equivalent brine heat flow;
3. Theoretical maximum efficiency for power production;
4. Geothermal gradient;
5. Brine temperature at the wellhead;
6. Global efficiency;
7. Corrosion and scaling hazard;
8. Distance from power/heating grid;
9. Load factor;
10. LCOE;
11. Societal impact;
12. Environmental impact.

More detailed description of the MCDM matrix and analysis can be found in [1].

Standard modelling approach was followed when modelling DMT as shown in flowchart diagram in Figure 1.

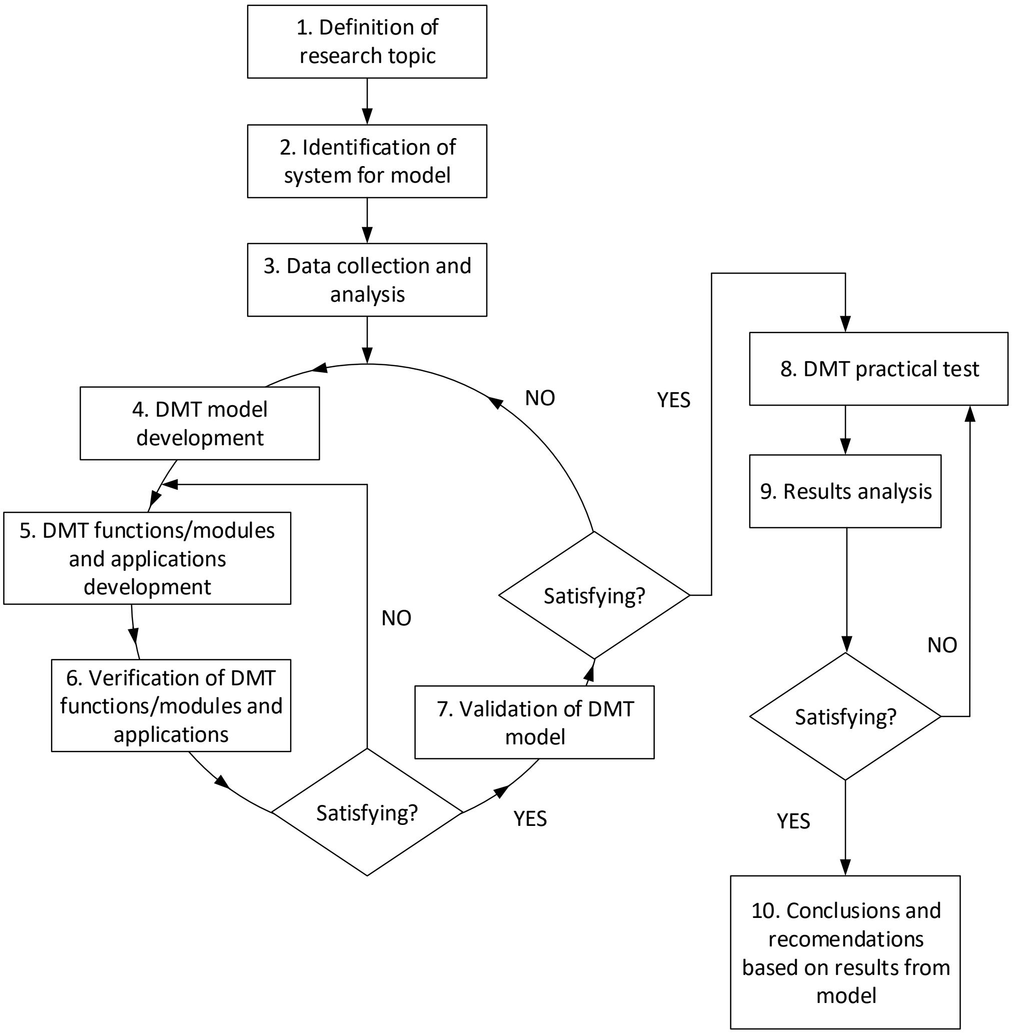

Figure 1: Flowchart of DMT modelling approach

2.2.1 Geothermal project depiction

In DMS-TOUGE, the project development occurs in the following phases (Figure 2), with unique duration of each phase:

1. Permitting
2. Exploration
3. Drilling
4. Power plant construction
5. Operation phase

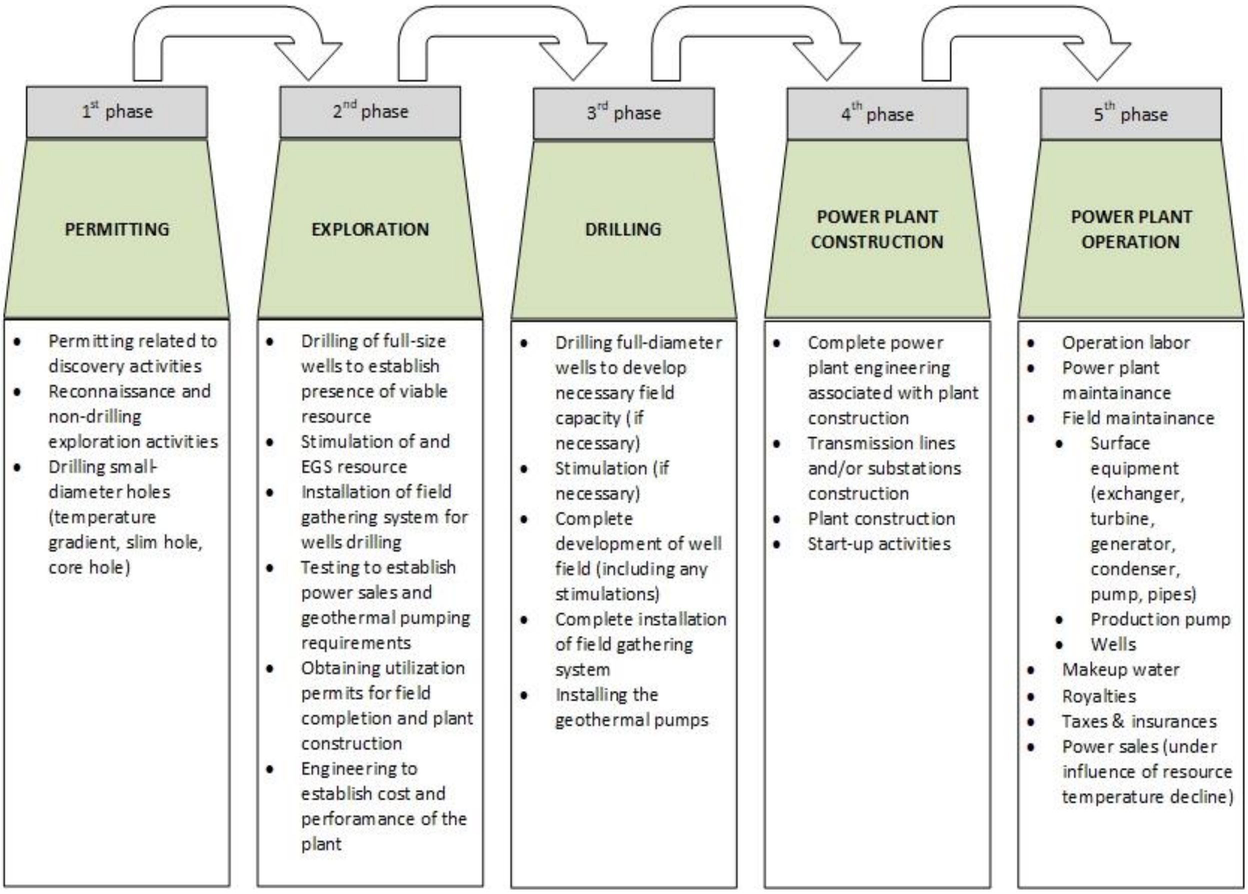

Figure 2. Geothermal project development phases and description of activities in each one

Each phase includes activities and elements that incur different related costs, which in DMS TOUGE can be estimated or inputted by a decision maker. These costs, along with the estimated electricity and/or heating power generation over a project's lifetime, are the basis for the sLCOE, NPC and IRR calculation for a defined scenario. The number of the activities in each phase, and consequently the capital and operating and maintenance (O&M) costs of the project, depend also on the state of the project, i.e. is it a greenfield project representing a new EGS site or a brownfield project representing an existing EGS site with possible upgrade, or co-production and/or conversion of mature or abandoned oil fields [1].

2.2.2 Approach

All the input parameters can be grouped into:

- Subsurface parameters $\begin{cases} \text{geothermal fluid properties} \\ \text{site geological features} \end{cases}$
- Surface technical parameters $\begin{cases} \text{end-user option} \\ \text{power plant equipment} \\ \text{gathering system} \end{cases}$
- Financial parameters

- Economic parameters { capital costs; OM costs; incentives and subsidies }
- Environmental parameters

A project evaluation is based on the installed capacity, i.e. electricity and/or heating power sales in each year. Once the project size is determined, the capital and O&M cost are either entered by the user or estimated via default cost-correlations.

2.2.2.1 Project sizing

The basic approach used to size a project is based on the resource type, resource temperature, geothermal brine flow, ambient conditions, power plant type, and end-user option characteristics. Size of the project is determined by installed capacity and sequentially produced electrical and/or heating power, i.e. power and/or heat sales.

2.2.2.2 Capital costs

Capital costs are either calculated based on the implemented default cost correlations, as in case of surface equipment costs, or directly inputted by the user (permitting, exploring, drilling phase). Each phase represents part of the total capital costs that occur in different years of project's lifetime. All capital costs that are included in determination of the sLCOE and other economic indices (NPV and IRR) are depicted in Figure 3. User can revise all capital costs whether they are default or calculated by DMS-TOUGE, however, user cannot alter how DMS-TOUGE estimates costs in default mode. Contingency is applied to all capital costs in the sLCOE determination and the level of contingency is an input parameter with default value of 15%, but is can be revised by the user.

DMS-TOUGE can be used to estimate either Greenfield or Brownfield projects. In case of Brownfield projects, exploration and perhaps drilling phase could be omitted, thereby reducing the potential capital costs specific to those phases of project development. As for Greenfield projects, the exploration phase is indispensable. Namely, to find a commercial resource, it may be necessary to evaluate and drill multiple prospects. Therefore, the exploration phase could consist of multiple sites that are initially evaluated, with some of those sites having drilling activities for production/injection wells later in the drilling phase. Due to this specificity of each project, capital costs are divided into the development phases of the project itself.

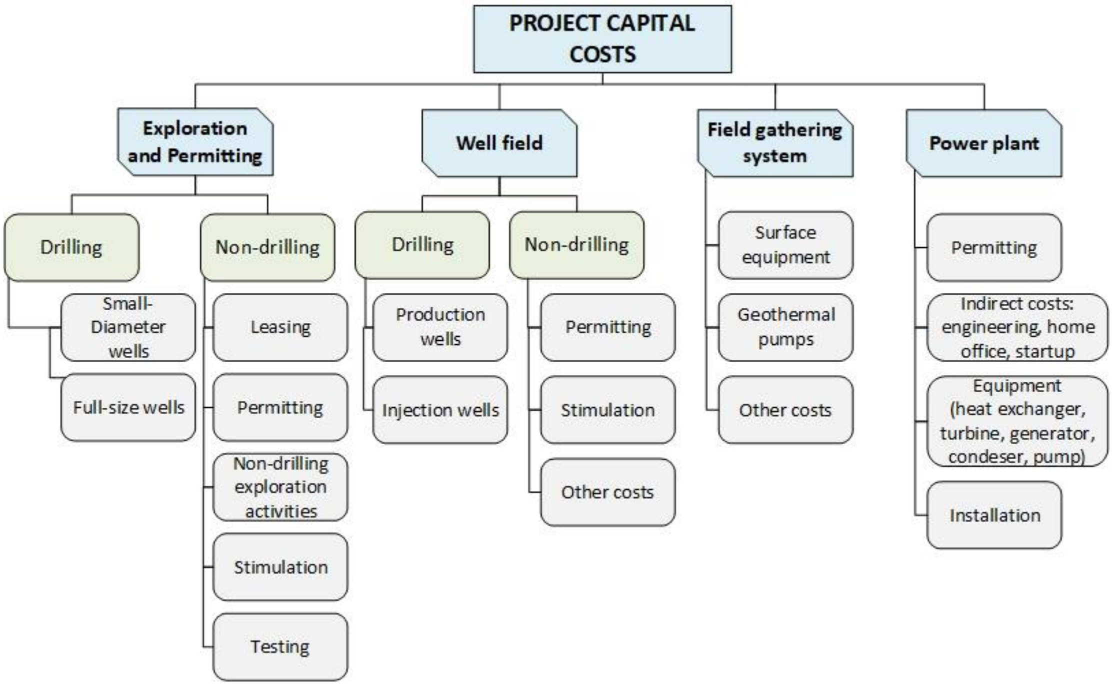

Figure 3. Project capital costs - included in economic analysis

Once the project size is determined, meaning the user selected the output net power, capital costs of the power plant, gathering system, and grid connection are estimated. Based on the size of the project, the capital cost of each component of the power plant is calculated using cost correlations. However, should the user possess more detailed and precise costs of each power plant segment, it is possible to revise the default values, i.e., the user can enter exact cost values. Grid connection costs are calculated in case of only electricity production and CHP. They are based on the distance between potential/existing power plant and existing power grid, on the type of the transmission line/cable used, on the specific costs of specified cable type, and voltage level of the grid where the power plant should be connected. Namely, when the voltage level of the purchased ORC and existing power grid are of different level, additional substation must be built and included in the grid connection costs.

2.2.2.3 Operating & Maintenance Costs (O&M)

Operating and maintenance costs are defined on an annual basis and include operating labour costs, well field maintenance costs and power plant maintenance costs. Production and/or injection replacement costs are included in capital (investment) costs with specified replacement frequency, which is by default set at each 6 years, but could be revised by the user. O&M costs are for now user inputted parameters and no default correlations are included.

Further discussion and detailed explanation of DMS-TOUGE determination of both capital and O&M costs is listed in APPENDIX B1.

2.3 APPLICATION LAYOUT

DMS-TOUGE is an application with user friendly interface. Main window of the DMS-TOUGE is shown in Figure 4. Several tabs are included in the main window of the application and are used to either open the interface for other sub-applications or to analyse the obtained results. and conduct MCDM analysis. The tabs are described in the Table ITable I. DMS-TOUGE tabs and their

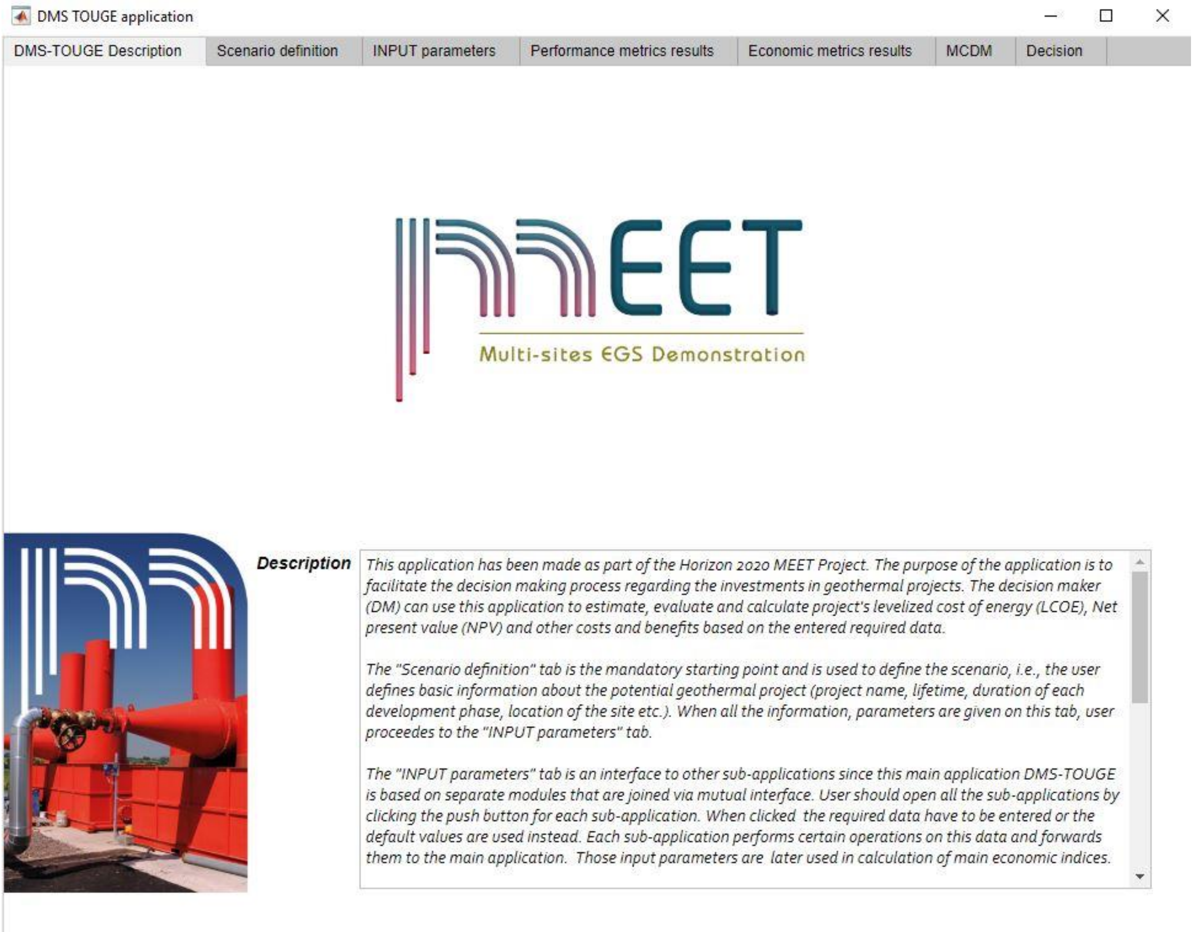

Figure 4. DMS-TOUGE application - main window

purposes.

2.3.1 Defining a Scenario for evaluation of the project

Basic information of the scenario to be evaluated is defined in the *Scenario definition* tab. These is the mandatory starting point where the user defines basic information about the desired geothermal project. Required input parameters are grouped in the *Project description* panel as:

- Name of the project – mandatory; this input is later valuable for the MCDM analysis.
- Description of the project – optionally; short textual description of the project.

- Lifetime of the geothermal project – mandatory; this includes all project development phases. This parameter is measured in years.
- Project site area – optionally; parameter used to modify grid connection investment costs (urban, suburban, rural).
- Project site terrain – optionally; parameter used to modify grid connection investment costs (flat, hilly, mountainous).
- Country – mandatory; parameter used to define country specific (geography, legislative, market specific) default values.
- Price scenario – optionally; parameter used when the electricity and/or heat market prices are forecasted with default forecasting model; by default, this parameter is set to *average.* This parameter can be altered to see how the market prices influence project economic evaluation.
- Time resolution – mandatory; defines the time step of the input data (yearly or monthly), this parameter is used to define some of the input data format, and by default it is set to *yearly*.
- Start of the project – mandatory; this parameter defines the starting date of the project (first day, including all development phases not only operational phase) and is used in financial and economic analysis of the project. User must choose every **first day of the month**, month and the year that indicates the start of the project.

Table I. DMS-TOUGE tabs and their purposes

Tab	Description
DMS-TOUGE Description	General description of the tool
Scenario definition	Basic information on project and scenario
INPUT parameters	Interface to the sub-applications
Performance metrics results	Visualisation of power plant performance
Economic metrics results	Economic results – LCOE, NPV, IRR, etc.
MCDM	Multi-criteria decision-making table for MCDM analysis conduction
Decision	Chosen decision and belonging outputs

- Duration of phases – mandatory; as mentioned in Section 2.2.1 project is divided into 5 different phases with unique duration of each of them. Duration is defined separately for each development phase. By default, duration of phases is set as follows: permitting phase – 2 years, exploration phase – 2 years, drilling phase – 2 years, construction of power plant – 2 years. Only operation phase is calculated as the difference between defined lifetime of the project and sum of first four phases. User can define duration of the first four phases and the last operation phase is then calculated as in the case of default duration values.

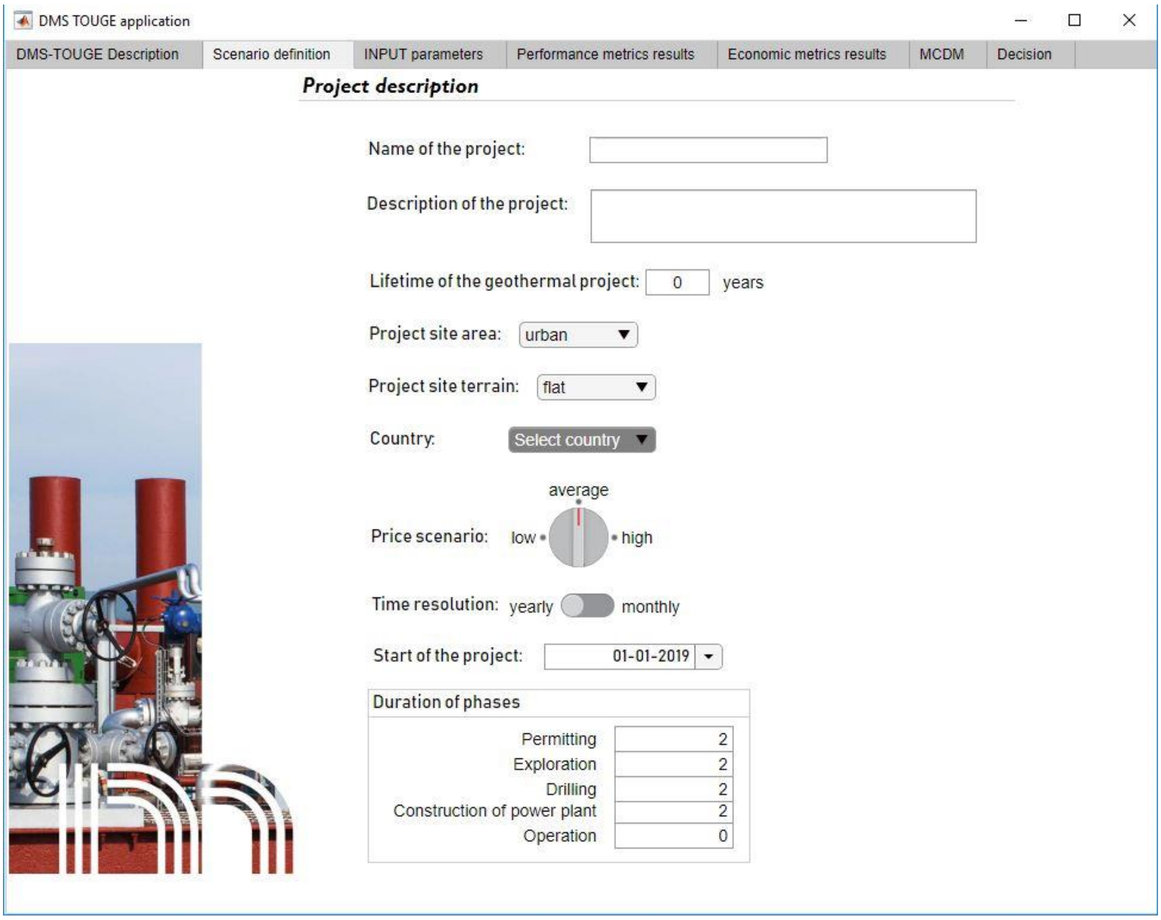

Figure 5. Screenshot of the *Scenario definition* tab

All defined parameters in *Scenario definition* tab and the screenshot of the tab are shown inFigure 5.

When all parameters on afore-described tab are inserted, the user proceeds to the *INPUT parameters* tab.

2.3.2 Gathering all relevant input parameters via sub-applications

INPUT parameters tab (Figure 6) is basically an interface to all the sub-applications where specific input parameters from different groups (as defined in Section 2.2.2) of parameters are entered. Not only do the sub-applications serve as input parameters gathering tool, but also as pre-calculating mechanism for each group of the input parameters specific to each sub-application.

As seen in Figure 6. the user should follow the order when inputting the parameters in each sub-application. The sub-applications are opened by clicking the button of each one. However, it is paramount to follow the right order of input data entry. Therefore, the order is marked with grey arrows. When all the sub-applications are opened, and the data is inputted, and corresponding pre-calculations are conducted the user pushes **Prepare data and forecast** button (red oval). Afterwards, the **Financial Analysis** button (green oval) can be pushed to obtain the economic metrics results.

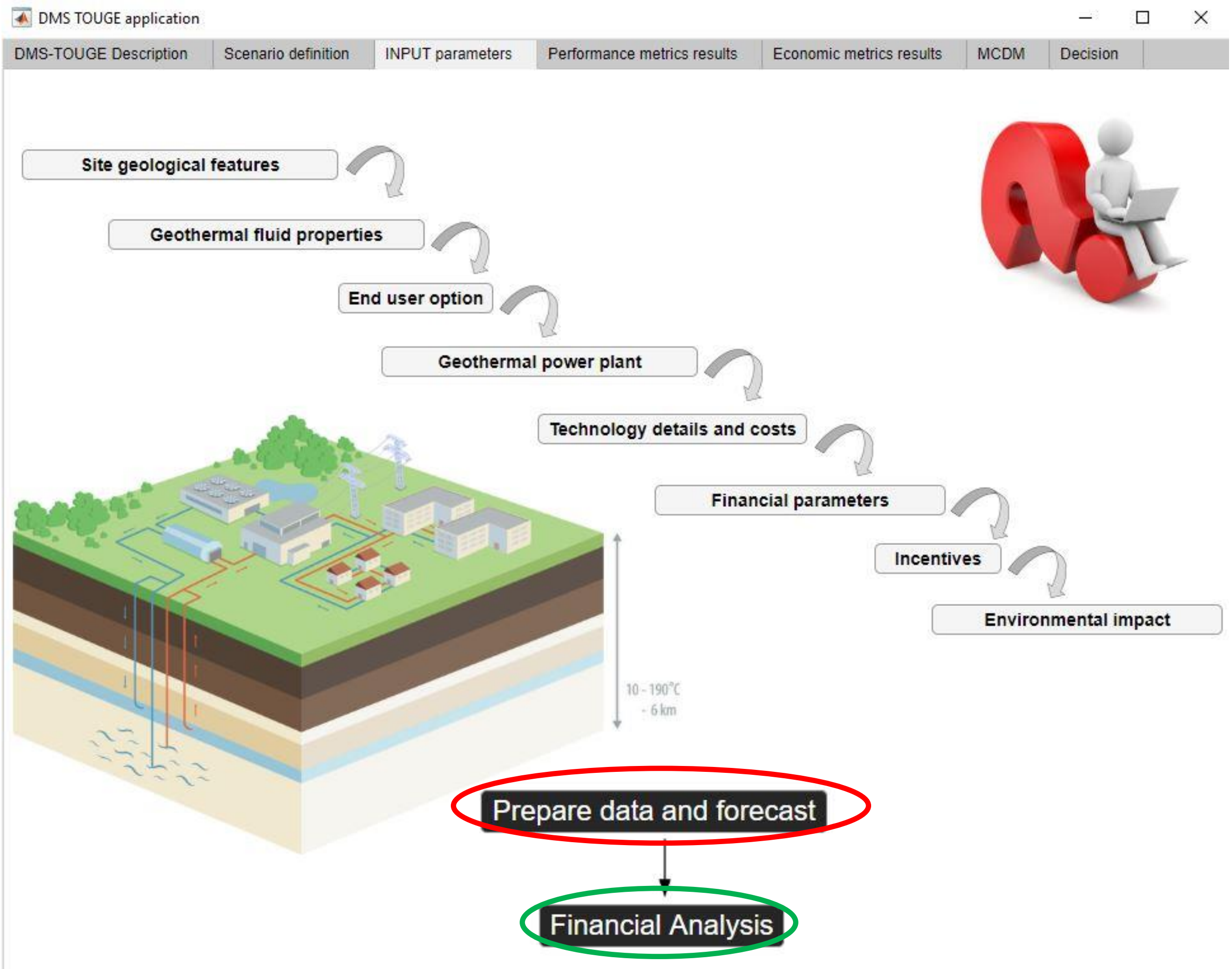

Figure 6. Screenshot of the INPUT parameters tab

In following sections, from 2.3.2.1 to 2.3.2.8 every sub-application is thoroughly described. Moreover, for each sub-application list of associated input parameters is given as much as their purpose, input format, and later use in the main application. After entering all required input parameters and after performing the pre-calculations, user must click the **Update** button at the bottom of each sub-application. By clicking this push button, all entered data is stored and forwarded to the main application.

2.3.2.1 Site geological features

Site geological features sub-application is used to gather all input parameters related to geological features of specific site. It also calculates and prepares the reservoir temperature evolution throughout the lifetime of the project. Some of the parameters are already predefined as default values, however, these values can be changed by choosing the **Exact values** insertion mode. Namely, at start-up the **Default values** mode is chosen, and the default values are already inserted and shown. But, if **Exact values** mode is chosen, user can change these default values by inserting the new ones.

Input parameters required in this sub-application are as shown in Table II:

Table II. Input parameters in the *Site geological features* sub-applications

Input parameter	Input mode	The need to fill in	Description	Unit
Reservoir temperature	exact value	mandatory	By moving the slider user sets the initial reservoir temperature (present). In the edit field on the right user can see the exact set value of the temperature. Range of the reservoir temperature is defined between 50-150°C.	°C
Thermal gradient	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	°C/100m
Specific heat of the rocks	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	J/kgK
Density of the rocks	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	kg/m^3
Total area of the fracture	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed	km^2

			capacity and power and/or heating production.	
Aperture of the fracture	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	m
Porosity of the reservoir	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	-
Average temperature at the surface	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	°C
Recovery factor	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	%
Reservoir capacity factor	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	%
Number of doublets	default or exact value	optionally; volumetric method	Used if the volumetric method for calculating the available thermal energy and consequently the potential installed capacity and power and/or heating production.	-
Well depth	exact value	optionally	This parameter will be used for default cost-correlations regarding well drilling costs estimations.	m
Annual temperature drawdown	default or exact value	mandatory	Used to calculate temperature evolution throughout the project lifetime. By default, first 10 years are associated with slight temperature drawdown (0.05%) and rest of the period with somehow bigger drawdown (0.5%). However, user can choose to insert exact values in [%] for such designed default function of	%

			temperature drawdown, or even import annual values of reservoir temperature in specified format as defined in APENDIX A1.	

When the annual temperature drawdown percentage values are inserted, or annual temperature evolution is imported, the **Calculate thermal drawdown** button must be pushed (marked with red arrow). After the button is pushed, the calculated or imported reservoir temperature evolution is visually presented in the graph (marked with yellow rectangle).

The **Use volumetric method in calculations** button should be pushed in cases when no historical production data is available, as much as other more detailed data. This is explained in Section 2.2 and the volumetric method itself in APPENDIX B2. However, this option will be enabled in the later version of the tool, in the current version this is not enabled.

When finished with this sub-application the **Update** button should be pushed so that these input parameters are forwarded to the main application and stored in the data base.

The screenshot of the described sub-application and input parameters is shown in Figure 7:

Figure 7. Screenshot of the *Site geological features* sub-application

2.3.2.2 Geothermal fluid properties

Geothermal fluid properties sub-application is used to gather all input parameters related to properties of the geothermal fluid. Some of the parameters are already predefined as default values, however, these values can be changed by choosing the **Exact values** insertion mode. Namely, at start-up the **Default values** mode is chosen, and the default values are already inserted and shown. But, if **Exact values** mode is chosen, user can change these default values by inserting the new ones.

Input parameters required in this sub-application are as shown in Table III:

Table III. Input parameters in *Geothermal fluid properties* sub-application

Input parameter	Input mode	The need to fill in	Description	Unit
Flow rate	exact: varying or constant	mandatory	This parameter can be inserted as constant value or varying value (Figure 8, red arrow). If constant value option is chosen, this flow rate is applied for all the years of the project lifetime and should be inputted in the edit field (Figure 8, yellow oval). If varying flow option is chosen user should import (Figure 8, red arrow) the flow rate values on monthly (12 months of one year) or yearly basis as described in APENDIX A2.	m^3/s
Fluid density	default or exact value	optionally	Together with the inserted flow rate this parameter is used to calculate the geothermal brine mass flow for each year or month of the project lifetime.	kg/m^3
Specific heat capacity	default or exact value	optionally	Used in calculations of possible installed capacity and production (of electricity and/or heating power)	J/kgK
LSI	exact value	mandatory	Langelier Saturation Index (LSI) is generally used for the evaluation of the corrosive or scaling tendency of the geothermal site. Used in MCDM analysis. By default, this value is set to 0.	
Pressure	default or exact value	optionally	Geothermal brine pressure will be used later in upgrades of the DMS-TOUGE tool.	MPa

When the geothermal fluid flow rate is inserted or imported, the values (yearly or monthly) are visually presented in a graph. After all the input parameters are inserted, the **Update** button should be pushed.

The screenshot of the described sub-application and input parameters is shown in Figure 8:

Figure 8. Screenshot of the *Geothermal fluid properties* sub-application

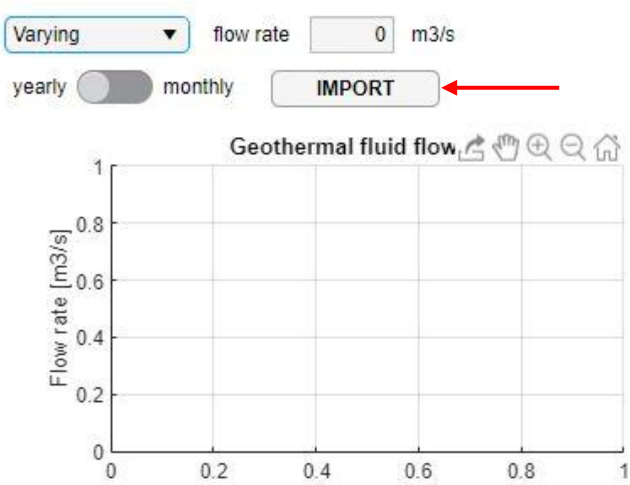

Figure 9. Screenshot of the varying option for geothermal fluid flow rate

2.3.2.3 End user option

End user option sub-application is used to gather all input parameters related to the desired end-user application. Namely, as mentioned, DMS-TOUGE can stimulate and evaluate 3 different end-user options: only electricity production, only heating power production and CHP. Parameters from this sub-application are later used in some other sub-applications as much as in the main application.

Firstly, user chooses the end-user application (Figure 10, red arrows are main applications and yellow bracket the heat production end options):

- Only heat production $\begin{cases} \text{space heating} \\ \text{agriculture} \\ \text{greenhouse} \\ \text{tourism} \\ \text{other} \end{cases}$
- Only electricity production
- CHP (combined heat and power)

Depending on the chosen option, the distance to heating network and/or power grid should be inserted. If the chosen option is only heat production, the user should move the slider of the distance to heating network (Figure 10, arrow green) and if the chosen option is only electricity generation, the user should move the slider of the distance to power grid (Figure 10, blue arrow) and in case of water-cooling condenser type insert the distance to the nearest water source (Figure 10, yellow oval). In case of CHP option both distances should be inserted, i.e. user moves both sliders to obtain these distances.

Chosen end-user application: **Only heat production**

User must check the *Only heat production* check-box and then one of the options under this main application (*space heating, agriculture, greenhouse, tourism* or *other*). In this case the data under **Heating network characteristics** panel must be entered and imported. Inserted data are parameters related to the heat demand side. Imported mass flow of heat demand side, as much as supply and return temperature in heating network are visually represented in graphs (Figure 10, blue ovals). Data entry under *Power grid characteristics* panel is in this case disabled. Distance to the heating network should be inserted.

Chosen end-user application: **Only electricity generation**

User must check the *Only electricity generation* check-box. In this case data under **Power grid characteristics** panel should be entered, i.e. the voltage level of existing power grid should be chosen (Figure 10, green oval). Data entry under *Heating network characteristics* panel is in this case disabled, and no data should be entered there. Distance to the power grid should be inserted, and in case of water-cooling condenser type (cooling tower) the distance to the nearest water source should be entered too.

Chosen end-user application: **CHP**

User must check the *CHP* check-box. In this case data under **Heating network characteristics** panel and under **Power grid characteristics** panel should be entered, imported or chosen. Heat demand side parameters are shown in graphs. Both distances to the heating network and power grid should be inserted (via sliders).

Input parameters required in this sub-application are shown in Table IV:

Table IV. Input parameters in *End user option* sub-application

Input parameter	Input mode	The need to fill in	Description	Unit
End-user application	exact selection	mandatory	Selection between main end-user applications: **only heat production, only electricity generation** and **CHP**. If the only heat production option is chosen, additional exact application must be chosen.	-
Period	Inserted in Scenario definition	Inserted in Scenario definition	Information about the lifetime of the project.	years
Distance to	exact value	mandatory	Distance to: **nearest water** – in case of electricity generation and water-cooling condenser type; **heating network** – in case of only heat production and CHP; **power grid** – in case of only electricity generation and CHP. The distance is measured as the length between the project site and the nearest connection point to the corresponding grid. Later used for grid connection costs calculations.	km
Heating network characteristics				
Tsupply	imported	mandatory	Supply temperature of the heat demand side. This is the temperature that the end-user demands. Import format is explained in detail in APENDIX A3.	°C
Treturn	imported	mandatory	Return temperature of the heat demand side. This is the temperature of the secondary fluid that returns from the end-user and enters the heat exchanger in power plant. Import format is explained in detail in APENDIX A3.	°C
Time resolution	default or exact selection	mandatory	By changing the time resolution between yearly and monthly user defines the import format of the heat demand side mass flow. In case of **yearly** option, the user must import yearly values of mass flow for "Period" number of years. In case of **monthly** values, user imports monthly changes on a one-year basis, 12 months,	years or months

			that are repeated each year for a specific month.	
Mass flow	imported	mandatory	Mass flow of the heat demand side. The input format is explained in detail in APENDIX A4. Value changes are shown in graph.	kg/s
Fluid pressure	exact	optionally	Potential use in some calculations.	MPa
Specific heat capacity	default or exact value	mandatory	Specific heat capacity of the secondary fluid. Used in calculations of possible installed capacity and production (of heating power and/or CHP).	J/kgK
Power grid characteristics				
Voltage level	exact selection	mandatory	Voltage level of the grid. Used in the grid connection costs calculations. Value can be chosen from the drop-down menu or inserted exactly if the voltage level is not mentioned in the menu.	kV

After all the input parameters are inserted, the **Update** button should be pushed.

The screenshot of the described sub-application and input parameters is shown in Figure 10.

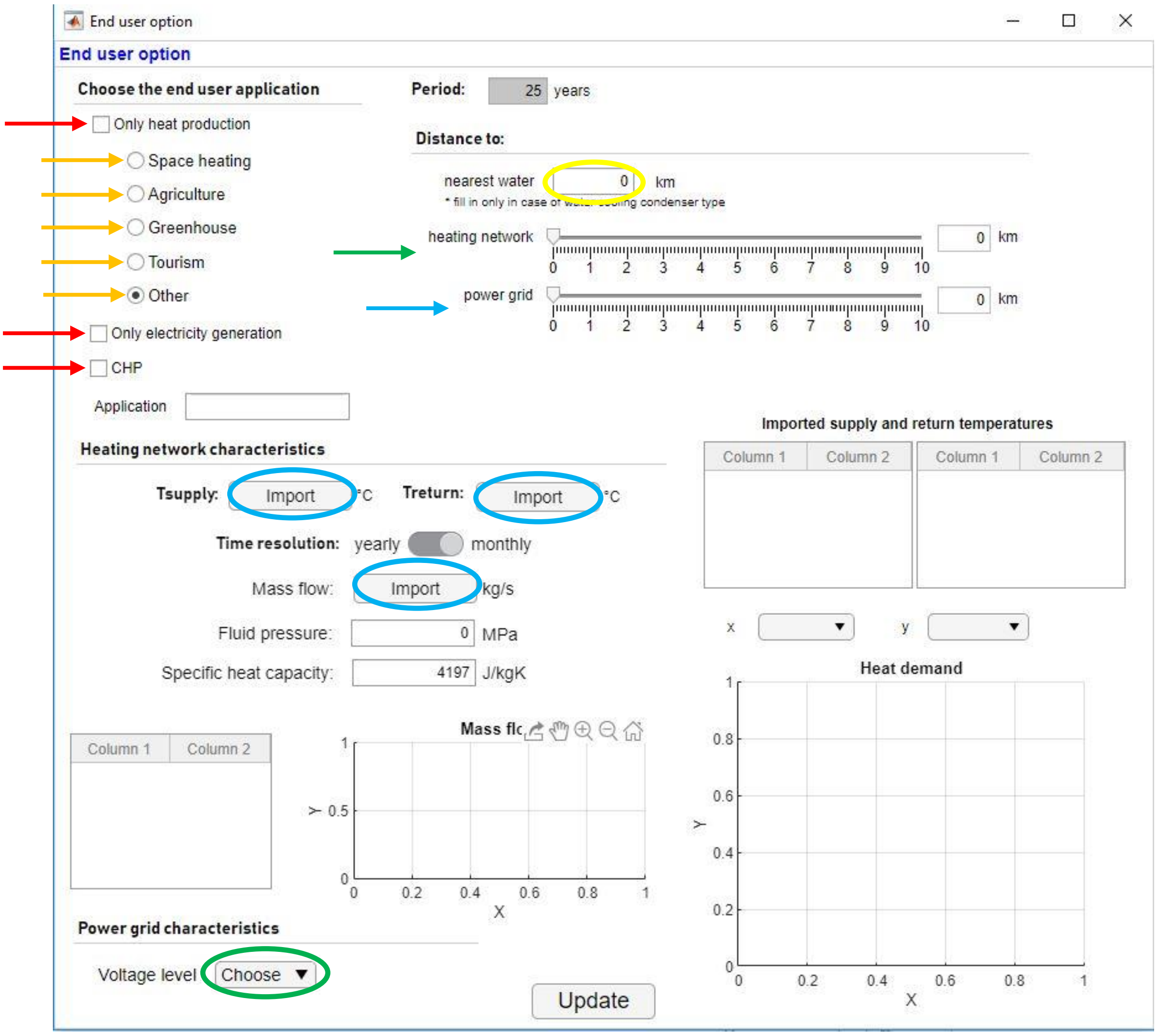

Figure 10. Screenshot of the *End user option* sub-application

2.3.2.4 Geothermal power plant

Geothermal power plant sub-application is used to gather all input parameters related to the power plant design. Namely, as mentioned, DMS-TOUGE can stimulate and evaluate different modes of geothermal energy utilization: only electricity production, only heating power production and CHP. Moreover, CHP can be derived in 2 different configurations, series and parallel configuration, respectively. Based on the end-user application chosen in the *End user option* sub-application the type of the power plant to be installed is defined.

After defining and inserting the required data the installed capacity and monthly production based on the chosen installed capacity are calculated and visually represented in a graph.

Selected power plant type: **Non CHP unit, Only heat production**

In this case (Figure 11), it is assumed that all the extracted geothermal energy is used for heating purposes (various options). Different heat demands require different heating parameters, such as supply temperature and thermal power. The energy stored in geothermal brine is transferred in the heat exchanger to the secondary (colder) loop, i.e. heat demand side loop and transported via heating network to the final costumers. Based on the characteristics of the heat demand side, as much as the hot loop characteristics (brine temperature, brine mass flow, specific heat capacity, etc.), the monthly potentially unsatisfied heat demand is calculated. Moreover, the maximum thermal power of the HEX and heat transfer area are calculated. This information will later be used to calculate the related costs if the default cost-correlation function is used.

Once the DeltaT and safe margin are defined, the **dead state temperature** is set to be equal to or smaller than the smallest value of imported return temperature (yellow oval), and the overall **heat transfer coefficient** is inserted (red underline), the user pushes the **CALCULATE** button (red arrow) in the **Heat only** panel. When pushing this button, the tool calculates the HEX area, HEX heat transfer efficiency, HEX max installed power, and monthly capacity factor of the plant as described in APPENDIX B3. Served heat demand is visually represented in a graph, and the mean plant capacity factor is shown in *Mean plant capacity factor* edit field.

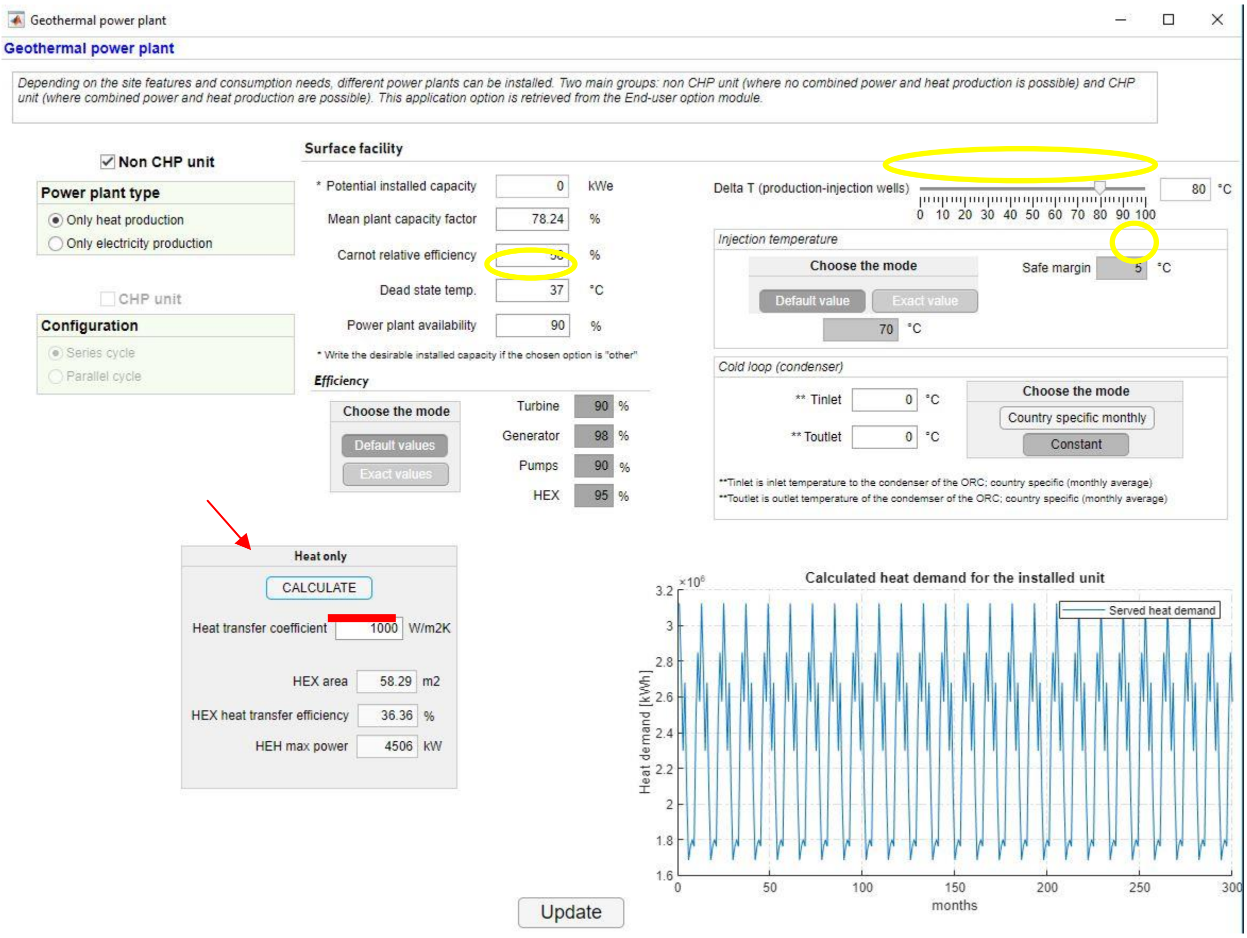

Figure 11. Screenshot of the "only heat production" mode and required input parameters

Selected power plant type: **Non CHP unit, Only electricity production**

In this case (Figure 12), it is assumed that all the extracted geothermal energy is used for power system demand exclusively. The energy stored in geothermal brine is transferred to the secondary fluid of the ORC unit and consequently the electricity is produced as described in APPENDIX B3. This production mode is affected by plenty influencing factors, such as brine temperature and brine mass flow, difference between inlet and outlet brine temperature through heat exchanger, ORC working fluid characteristics, temperature of the cooling medium, parasitic loads of ORC pump, condensing equipment, etc. For example, larger brine temperature and mass flow allow for larger net ORC output power. Increased difference of inlet and outlet brine temperature through heat exchanger will also increase net ORC output power but will decrease overall efficiency (lower average brine temperature through heat exchanger). Cooling water or air temperature also influences efficiency of ORC loop and therefore in case of using available ambient temperature larger temperatures of coolant during the summer season will decrease net efficiency while colder coolant during winter months will have opposite effect. All above-mentioned influencing factors are modelled by means of different input parameters in this sub-application. Each input parameter and its use are described in TABLE.

Once the DeltaT and safe margin are defined (yellow ovals), and the cold loop temperatures (blue arrow) are imported (*country specific monthly* – air-cooled condenser type) or defined (*constant* – water-cooled condenser type), user pushes the **CALCULATE** button in the **Electricity only** panel (red arrow). After the calculations are finished, a message box appears with the information about possible installed capacity: minimum, maximum or average power. Moreover, the monthly values of the outlet temperature of the HEX is printed out (for the whole lifetime of the project). After clicking the OK button, the user choses the nominal installed power in a drop-down menu (red oval). Possible options are calculated minimum, maximum, and average values. However, if the user choses to insert some other value the option *other* should be chosen. If option *other* is chosen, the user inserts the desired installed power in the edit field *Potential installed capacity.* Afterwards, when the chosen power is shown in the *Chosen power* edit field, the user should click the **CALCULATE PRODUCTION** button (green arrow). By clicking this button, the function described in APPENDIX B4. calculates monthly electricity production, monthly values of the efficiency of conversion, monthly values of capacity factor of the ORC power plant and monthly values of brine outlet temperature of the ORC HEX. The calculated monthly production is visually represented in a graph, and mean efficiency of conversion for such ORC is shown in *Mean efficiency of ORC* edit field. Moreover, calculated plant capacity factor, i.e. its mean value for all months of the lifetime, is shown in the *Mean plant capacity factor* edit field.

Figure 12. Screenshot of "only electricity production" mode and required input data

Selected power plant type: **CHP unit, Series configuration**

In this case, it is assumed that the extracted geothermal energy is firstly used to produce electricity via ORC loop and the remaining geothermal energy stored in the brine is used for heating energy production. This CHP configuration is widely used and is considered as the most common method of cogeneration. However, the maximum possible electrical installed power can in this case be lower since the remaining energy must be enough to satisfy the heat demand, i.e. the temperature leaving the first HEX (part of the ORC) must be high enough for the heat transfer in the second HEX (heating power production), which also depends on the supply temperature of the heat demand side loop. If this configuration of CHP is now possible for the inserted input parameters, i.e. hot and cold loop characteristics, user is advised to change the configuration into parallel.

User defines the DeltaT, safe margin and cold loop (condenser of the ORC unit) temperatures. Moreover, the overall heat transfer coefficient must be inserted, and the **dead state temperature** must be set to be equal to or smaller than the smallest value of imported return temperature. Once, those input parameters are all inserted/imported, the **CALCULATE** button should be pushed. By pushing the button, the calculations begin. Firstly, the ORC part of the CHP is calculated, the user is asked to choose the desired electrical installed power of the ORC unit (red oval) (Figure 13) After the installed power is selected the monthly electricity production is calculated, as much as the HEX outlet temperature of the brine. With this remaining brine temperature begins the calculation for heating power production. At the end, the user is provided with basic recommendations regarding heat exchanger maximum power and surface area. In the message box, that appears when the calculations are finished, the monthly conversion efficiencies of the ORC part, heating power production part and the CHP unit are listed. The histogram of mentioned efficiencies is shown, and monthly electricity production and heat demand served are shown in a graph (Figure 14). The chosen and calculated parameters are shown in edit fields (Figure 15) (red arrows). Should the temperature of the brine at some point decline too much (to be unsatisfactory for the second heat exchange for heating power production) the user is alerted via message box. In this case the user should change the parameters related to the ORC unit and electricity production and run the calculations again by pushing the CALCULATE button. If this configuration and inserted parameters are not satisfactory for this type of the power plant, user is advised to try the parallel configuration.

It must be noted that this mode will not be suitable for heat demand requiring larger heating temperatures due to brine temperature decrease through ORC heat exchanger and the fact that same mass flow of geothermal brine is going through ORC and heat demand heat exchangers.

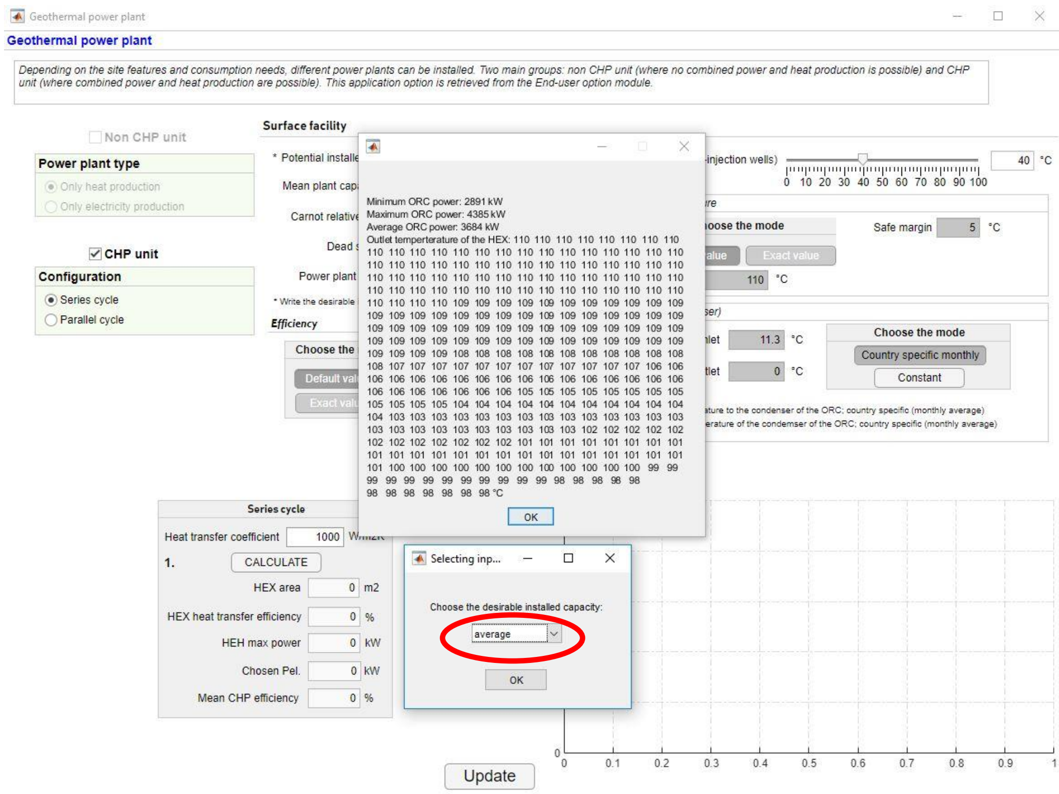

Figure 13. Screenshot of the "CHP series configuration" - choice of the installed power

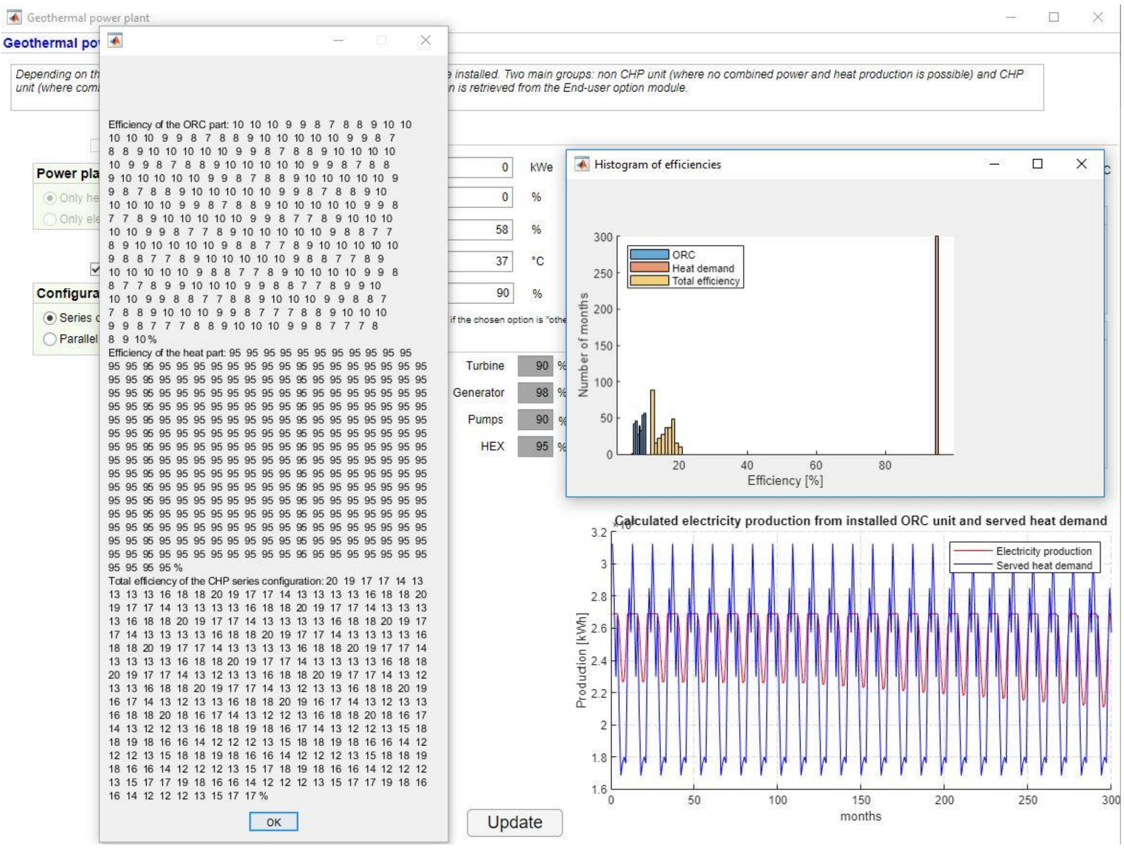

Figure 14. Obtained results of the monthly electricity production, served heat demand, monthly efficiencies of ORC part, heating power production part and CHP power plant

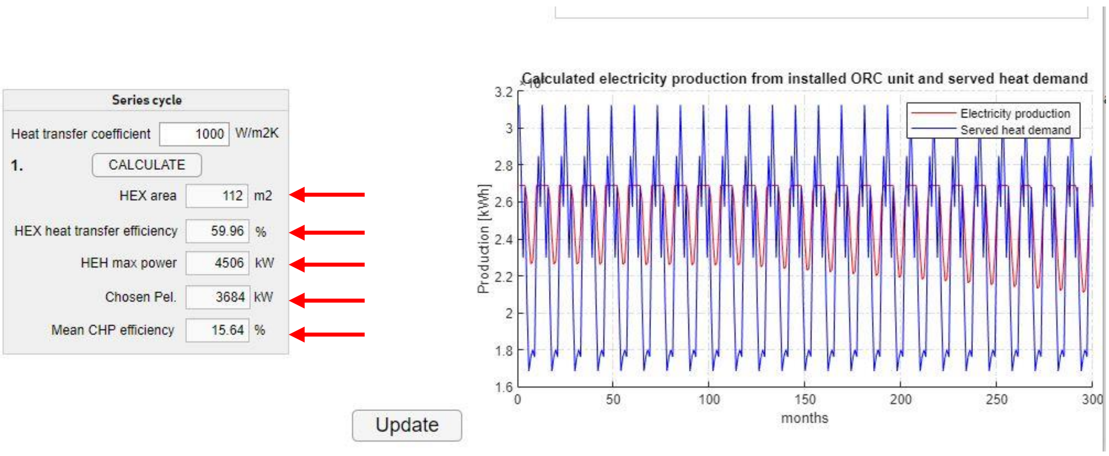

Figure 15. Screenshot of chosen electric installed capacity and calculated HEX parameters, as much as CHP mean efficiency

Selected power plant type: **CHP unit, Parallel configuration**

In this case, it is assumed that the extracted geothermal energy stored in the geothermal brine is divided into two separate hot loops used to produce electricity via ORC loop and heating energy via secondary heat demand side loop. In other words, heat is delivered to both the heat demand system and the ORC at a high temperature but at a lower flow rate. In contrast to CHP in series production mode this mode will be suitable for heat demand requiring larger heating temperatures due to fact that parts of injection geothermal brine mass flow with same temperature are directed both to ORC heat exchanger and heat demand heat exchangers.

User defines the DeltaT, safe margin and cold loop (condenser of the ORC unit) temperatures. Moreover, the overall heat transfer coefficient must be inserted, and the **dead state temperature** must be set to be equal to or smaller than the smallest value of imported return temperature. Once, those input parameters are all inserted/imported, the **CALCULATE** button should be pushed. By pushing the button, the calculations begin. This production mode can be also labelled as 'heat demand preferring production mode', since the flow rate available for the ORC loop is defined depending on the required flow rate for the heating power production loop. Basically, the calculations are made in the way that the brine flow rate for the ORC part of the CHP is calculated after the heat demand is satisfied in each point of the lifetime period. After the heating power production part of the parallel configuration is calculated, parameters of the ORC unit should be chosen. After the installed power is selected the monthly electricity production is calculated. At the end, the user is provided with basic recommendations regarding heat exchanger maximum power and surface area. In the message box, that appears when the calculations are finished, the monthly conversion efficiencies of the ORC part, heating power production part and the CHP unit are listed. The histogram of mentioned efficiencies is shown, and monthly electricity production and heat demand served are shown in a graph (Figure 16). The chosen and calculated parameters are shown in edit fields (Figure 17) (red arrows).

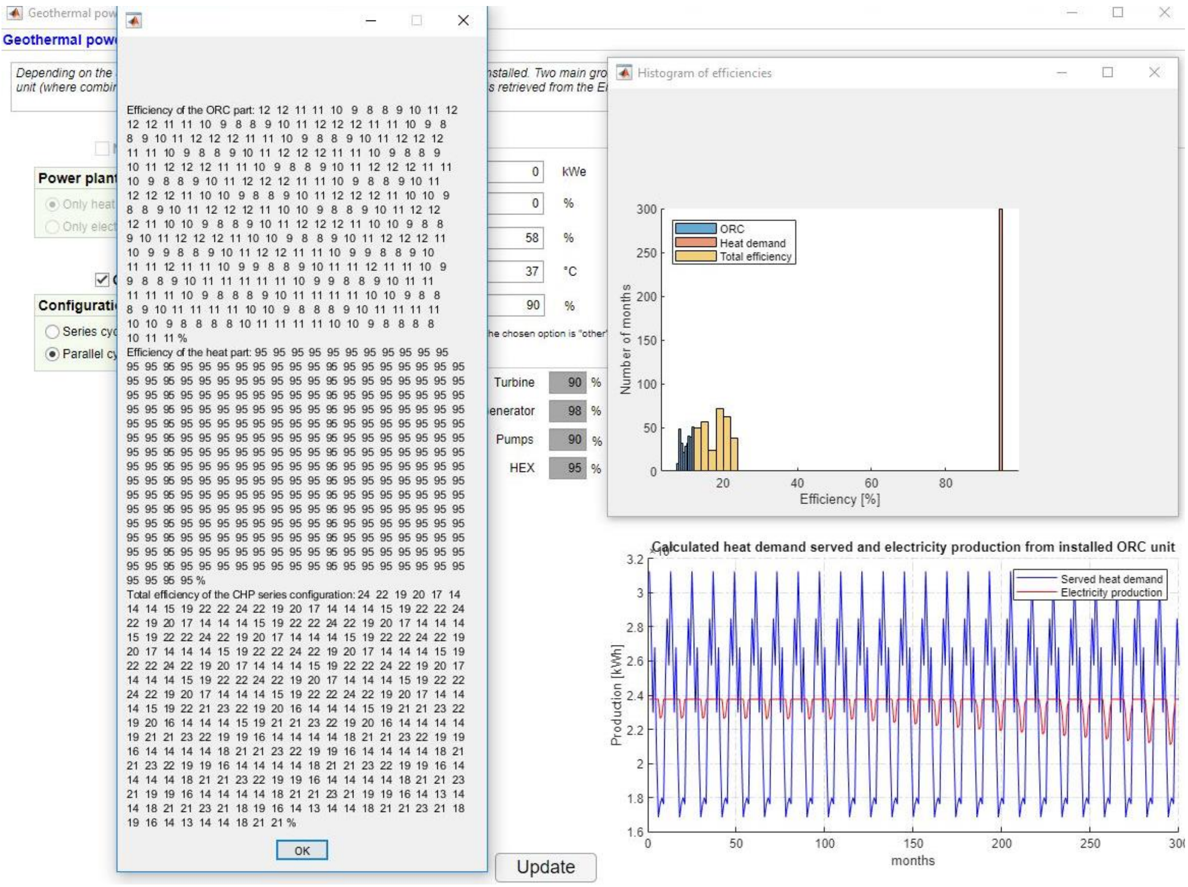

Figure 16. Screenshot of the monthly electricity production, heating power production and efficiencies, histogram of efficiencies

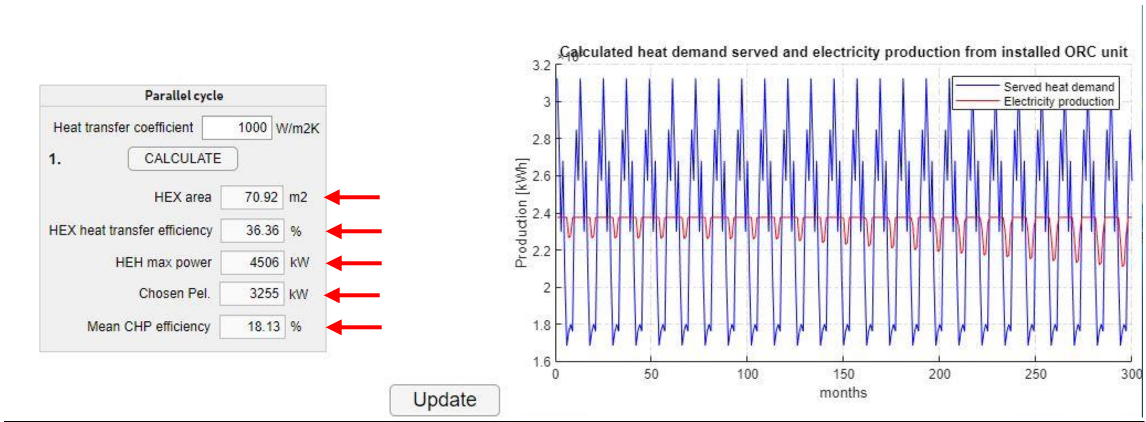

Figure 17. Screenshot of the chosen and calculated parameters

Input parameters required in this sub-application are shown in Table V:

Table V. Input parameters in *Geothermal power plant* sub-application.

Input parameter	Input mode	The need to fill in	Description	Unit
Power plant type	default	unnecessary (input from End user option sub-application)	Type of the power plant: **Non CHP** or **CHP**. This parameter is checked by default based on the previous inputs. It is later used as an indicator.	-
Configuration	default or exact selection	optionally (input from End user option sub-application)	In case of Non CHP plant the options are **only electricity production** and **only heat production**. In case of CHP plant, the options are **series** and **parallel** configuration. CHP configurations are explained in detail in APPENDIX B5.	-
Surface facility				
Potential installed capacity	exact value	optionally	Input parameter only in the case for only electricity production when the user wants some other value than minimum, maximum or average value.	kW_e
Mean plant capacity factor	calculated	calculated	This parameter shows calculated mean capacity factor of the power plant throughout the lifetime period.	%
Carnot relative efficiency	default or exact value	optionally	This value is used only in the case of calculations with volumetric method. Otherwise it is not used.	%
Dead state temp.	default or exact value	optionally	Used as the constraint of the possible production. In case of heat production, it should always be equal to or higher than the lowest return temperature.	°C
Power plant availability	default or exact value	optionally	Parameter used in the economic calculations. It describes how much time during the year a power plant is available for operation. Default value is set to 90%, meaning 10% of the year it is out of the operation due to maintenance, etc.	%
Delta T	default or exact selection	mandatory	Represents the difference in temperatures between: a) Production and injection well brine temperature (only heat production, only electricity	°C

			production and CHP parallel configuration) b) Production well brine temperature and the brine temperature after the HEX of the ORC part (CHP series configuration)	
Injection temperature	default or exact value	optionally	By adjusting the Delta T parameter, this parameter is adjusted automatically. Therefore, user can either change the injection temperature, and the Delta T will change accordingly, or the Delta T can be changed, and the injection temperature will change accordingly.	°C
Safe margin	default or exact value	optionally	Certain temperature that is equal to the difference between brine HEX inlet temperature and heat demand side medium HEX outlet temperature.	°C
Cold loop (condenser)				
Tinlet	calculated or exact constant	mandatory	It can be country specific (a) or constant (b). (a) This parameter represents mean value of imported monthly (12 months) coolant HEX inlet temperature (air-cooled condenser). Import format is explained in APENDIX A5. (b) Constant value is inserted directly, and in this case the water-cooled condenser is modelled.	°C
Toutlet	calculated	unnecessary	This parameter represents mean HEX outlet temperature of the coolant.	°C
Efficiency panel				
Turbine	default or exact value	optionally	Value for the turbine efficiency. Used later in other calculations. Here it is only as an input parameter.	%
Generator	default or exact value	optionally	Value for the generator efficiency. Used later in other calculations. Here it is only as an input parameter.	%

Pumps	default or exact value	optionally	Value for the ORC (centrifugal) pumps efficiency. Used later in other calculations. Here it is only as an input parameter.	%
HEX	default or exact value	optionally	Value for the heat exchanger efficiency. Used later in other calculations. Here it is only as an input parameter.	%
HEAT ONLY panel				
Heat transfer coefficient	exact value	mandatory	Overall heat transfer coefficient used in calculations of heat exchanger area and max installed power.	W/m^2K
ELECTRICITY ONLY panel				
Choose nominal power	selected value	mandatory	Input parameter where the user chooses the installed power. With chosen installed power the calculations continue, and the monthly electricity production is calculated.	kW
SERIES CYCLE panel and PARALLEL CYCLE panel				
Heat transfer coefficient	exact value	mandatory	Overall heat transfer coefficient used in calculations of heat exchanger area and max installed power.	W/m^2K
Choose the desirable installed capacity	drop down selection	mandatory (message box)	Selection of the desired installed capacity for electricity production. Options: min, max, average or other. If other is chosen, additional message box appears, and the user inserts the desired value. It is advised that the inserted value is in the range between min and max values.	kW

In the Table VI. the output parameters and their description are shown.

Table VI. Output parameters that are shown for each power plant type scenario

Output parameter	Description	Unit
ONLY HEAT PRODUCTION panel		
HEX area	This parameter is calculated with all relevant input parameters. Details on function are described in APPENDIX B3. This	m^2

	parameter is later used in the surface equipment cost calculations if the default cost correlations are used.	
HEX heat transfer efficiency	Maximum required heat transfer efficiency to satisfy the desired heat transfer and heating power production. Details on function are described in APPENDIX B3.	%
HEX max power	Calculated HEX power of heat exchanger to satisfy the desired heat demand. Details on function are described in APPENDIX B3.	kW
ONLY ELECTRICTY PRODUCTION panel		
Paverage	Calculated possible average installed power of the power plant.	kW
Chosen power	Chosen installed power of the plant (minimum or maximum or average or other).	kW
Mean efficiency of ORC	Calculated mean efficiency of the conversion in the ORC unit. Average of all calculated monthly efficiency values.	%
SERIES CYCLE panel and PARALLEL CYCLE panel		
HEX area	This parameter is calculated with all relevant input parameters. This parameter is later used in the surface equipment cost calculations if the default cost correlations are used.	m^2
HEX heat transfer efficiency	Maximum required heat transfer efficiency to satisfy the desired heat transfer and heating power production.	%
HEX max power	Calculated HEX power of heat exchanger to satisfy the desired heat demand.	kW
Chosen Pel.	Chosen installed power of the plant (minimum or maximum or average or other).	kW
Mean CHP efficiency	Calculated mean efficiency of the conversion in the CHP unit. Average of all calculated monthly efficiency values.	%

2.3.2.5 Technology details and costs

Technology details and costs sub-application is used to gather all input parameters related to the investment and O&M costs that occur in different development phases of the project. Moreover, it is used to gather input parameters related to the power loss due to the operation of different segments of the power plant (e.g. submersible pumps) and, in the case when the electricity is produced, to calculate the grid connection costs and transmission losses. Basically, input parameters are defined for each development phase as already show in Figure 3.

For the first three phases (permitting, exploration and drilling phase) the user can define the number of sites included in each phase. Namely, as seen in literature and other similar evaluation tools and models, it is not unusual to have multiple sites with exploration activities prior to discovery of the site that will eventually be developed. Permitting costs include costs for pre-drilling activities, for explorational-drilling and early drilling activities and cost for utilization permit. Exploration costs can include pre-drilling activities costs, multiple site drilling costs and any other additional costs related to finding the viable site or stimulating the existing wells. Drilling cost under exploration phase include well testing costs for undeveloped sites where full-size wells are drilled. Those testing and exploration full size wells that successfully drilled contribute to the required production and injection capacity. Costs in the drilling phase include the production and/or injection wells drilling to cover the remaining well field capacity. This phase also includes costs related to the stimulation of already existing wells or successful wells drilled in this phase. The drilling success rate is not specified in this version of the tool, i.e. the number that the user inserts under the *Number of sites* parameter is assumed to be the number of successful sites.

Default values and cost correlations for Permitting, Exploration and Drilling phase are in this version of the tool not anticipated. It is expected that the later version will also include this type of default values.

Under the **Equipment investment costs** panel, the *Plant equipment* costs can be set as default values or exact values that are inputted by the user. If the default values mode is chosen, all the *Plant equipment* costs are calculated according to the cost correlations defined in the APPENDIX B1.

Grid connection costs are calculated in the case of electricity production (only electricity production and CHP). The calculations are made based on the inputted cable length, cable material and cable specific costs. Moreover, based on the comparison between grid voltage and the voltage of the purchased ORC unit, the decision on possible substation construction is made.

Gathering system costs include costs of production and/or injection pumps (if needed). Those costs are also used as replacement costs included in the economic calculations each 6 years (default value – can be changed). Default pump costs are assumed to be incorporated in the later version of the tool.

Operating and Maintenance costs are at this stage anticipated as the exact annual value input parameters. O&M costs consist of **annual labour costs**, **annual well field maintenance costs** and **annual plant maintenance costs**. The user should input the estimated O&M costs.

Input parameters related to the parasitic *power loss* consist of the power required for the working fluid cooling (in the case of the existence of the ORC unit/s and air-cooled condenser type with the fan), pumping of centrifugal pumps (in the case of the existence of the ORC unit/s) and the submersible pumps. This input parameters are latter used to calculate the actual power and or/heat sales.

EQUIPMENT COSTS:

Default values for plant equipment costs:

When the sub-application starts, insertion mode for these costs is set as exact values. If the user wants to use the default cost correlation functions the **Default values** mode must be chosen (red arrow). Before pushing the **Default values** button, the user should insert the Chemical Engineering Plant Cost Index (CEPCI) used to bring the costs up-to-date (Figure 18, red arrow). If the CEPCI index remains 0, the default value for September 2018. is used. When chosen, a message box with the drop-down menu appears. In this drop-down menu, the user must choose the *cooling system type* (i.e. condenser type) (Figure 18, red rectangle). Two different option of condenser type can be chosen: *WCT – water-cooling tower* and the *ACC – air-cooling condenser*.

If WTC condenser type is chosen, new message box appears, and the user must insert the water flow value (Figure 19). If the water flow is smaller than the flows for which the cost-correlations are made for, the user should insert the exact value of the condenser. Moreover, too calculate the centrifugal pump cost the power of the pumping **must be inputted** (Figure 18, orange circle). When the calculations are finished, the estimated costs of each segment of the plant equipment are printed in belonging edit fields (Figure 20, green brackets). Additional costs for auxiliary heat exchangers must be inserted as exact value (red arrow, Figure 20). Moreover, the specific costs for the piping should be inserted as exact value (red arrow, Figure 20).

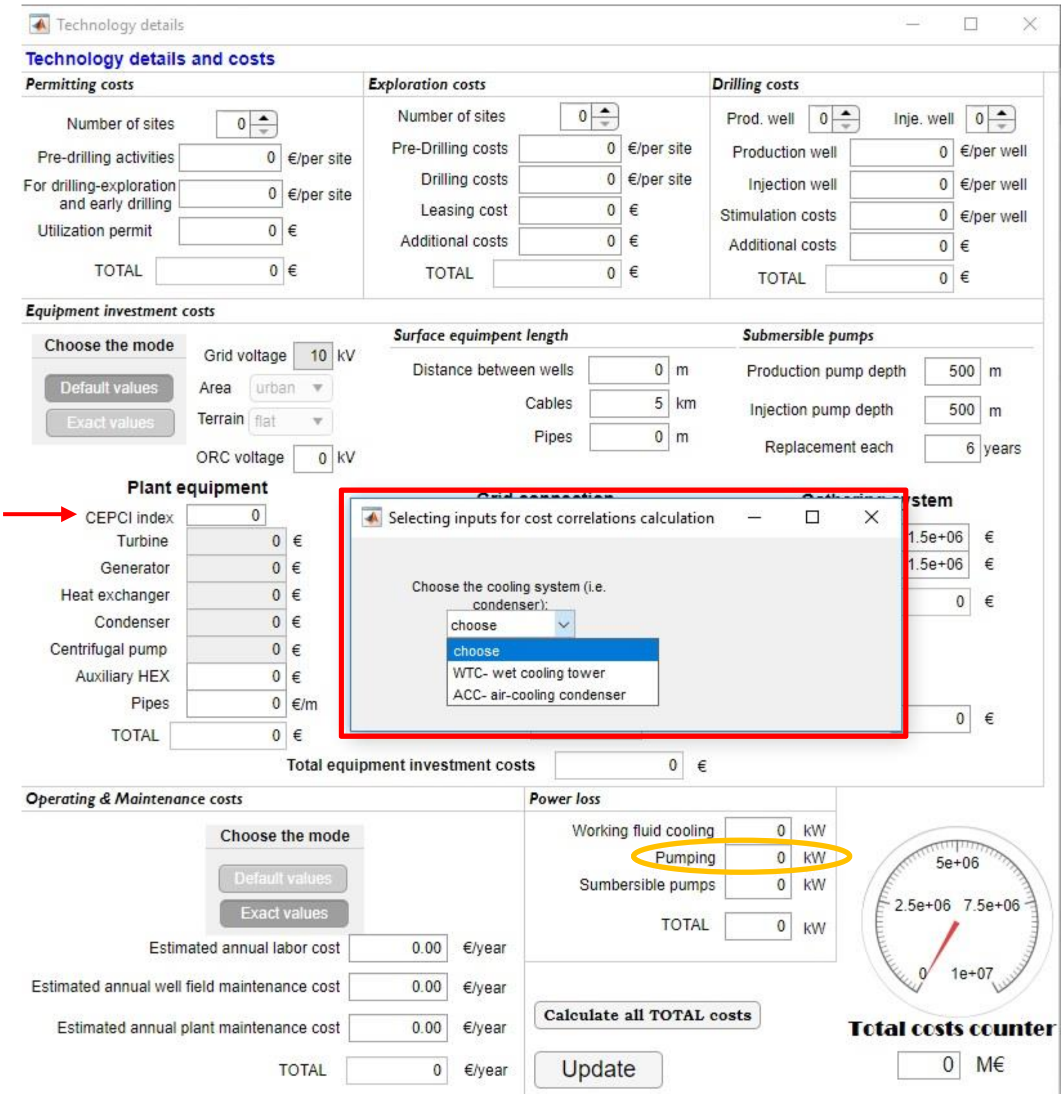

Figure 18. Message box for choosing the cooling system, i.e. the condenser type (in cases where the ORC unit must be installed)

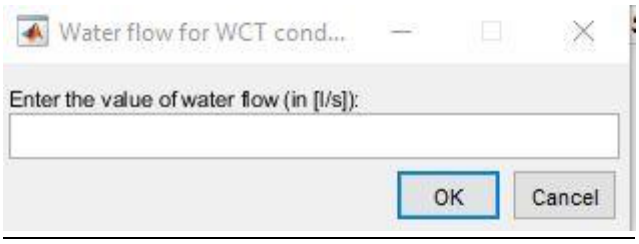

Figure 19. WCT condenser type - message box to insert the water flow (coolant)

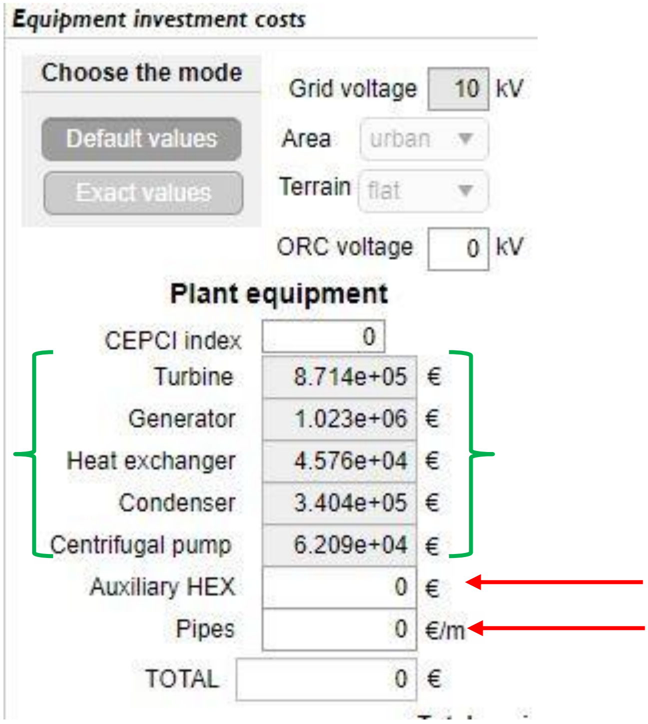

Figure 20. Calculated estimated costs for each segment of the plant

If the ACC condenser type is chosen, new message boxes appear, and the user must insert the ACC fan power (Figure 21) and the ACC area (Figure 22).

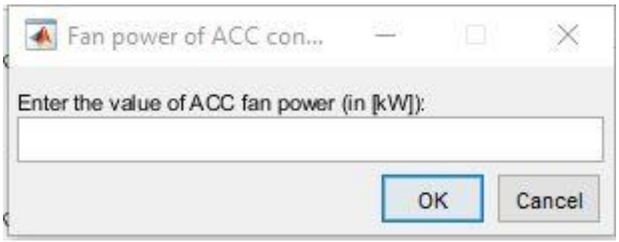

Figure 21. ACC condenser type - message box to insert the ACC fan power [kW]

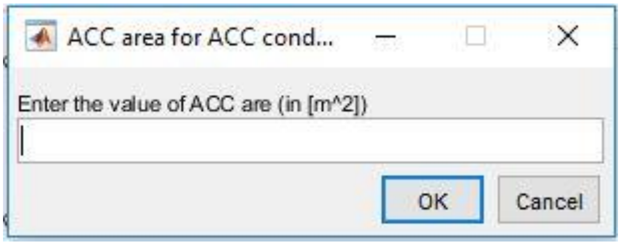

Figure 22. ACC condenser type - message box to input the ACC area [m^2]

GRID CONNECTION COSTS:

In case of the only electricity production and CHP power plant, user must enter the voltage for which the purchased ORC unit is constructed for (Figure 23, red arrow). The grid voltage is automatically inserted according to the value chosen in the *End user option* sub-application. When the grid construction actions take place, it is of significant important where the works are done. In other words, the costs of constructions are also influenced by the **area** and the **terrain**. Therefore, additional multipliers are anticipated and the approach from the GETEM model was taken. By default, the area is set to urban and the terrain to flat (Figure 23, blue bracket). Possible area and terrain options and belonging multipliers are shown in Table VII:

Table VII. Grid connection costs multipliers for chosen area and terrain type

Area type	Multiplier	Terrain type	Multiplier
urban	1.5	flat	1
suburban	1.2	hilly	1.2
rural	1	mountainous	1.5

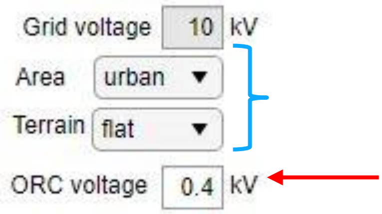

Figure 23. Grid connection setting - grid and ORC voltage; area and terrain parameters

Furthermore, the costs of transmission cable depend on the used material. The user choses the **cable material**, which can be aluminium (Al) or copper (Cu). Than the specific cable costs per kilometre must be inserted. For the substation costs (Figure 24, yellow oval), they are either calculated (based on the grid voltage and the ORC unit voltage) or if the user knows the exact costs, they should be inserted, and, in this case, they are not calculated. The length of the cables is automatically inserted based on the information on the distance from the *End user option* sub-application. After all the data have been inputted the button **Calculate costs** must be pushed (Figure 24, red arrow). The calculated estimated costs appear in TOTAL edit fields afterwards.

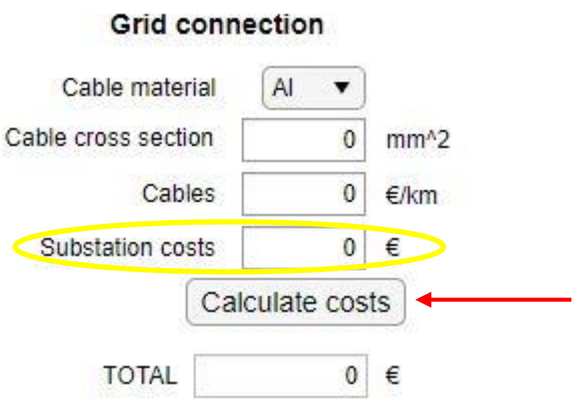

Figure 24. Grid connection parameters

When all the data is inputted and pre-calculated, user must push the **Calculate all TOTAL costs** button (Figure 25, red arrow). At the end user must push **Update** button to save and forwarded all the acquired input parameters in this sub-application.

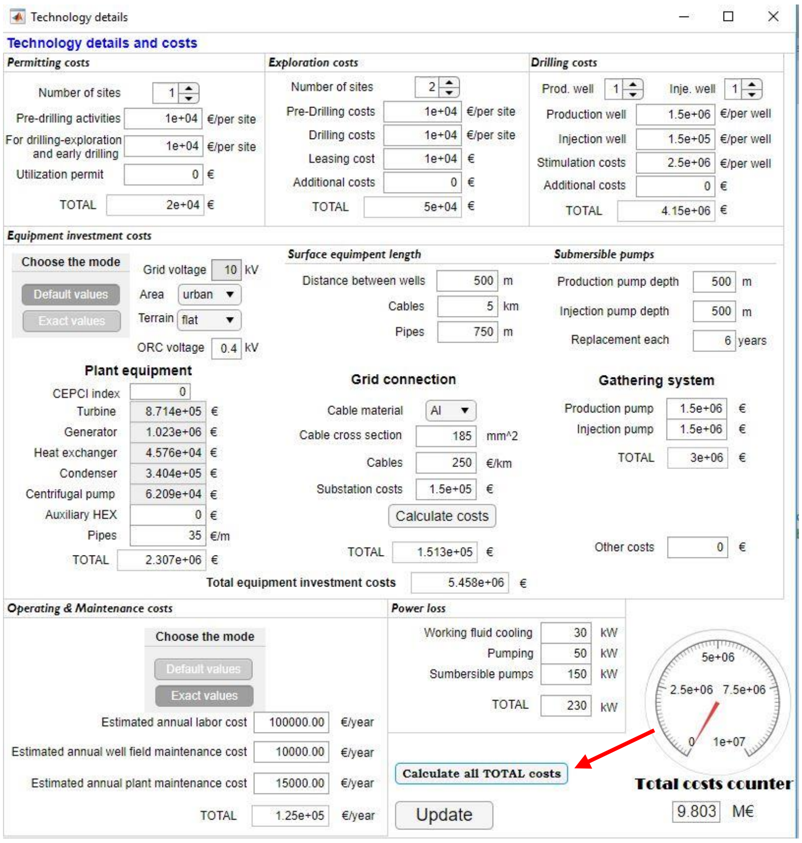

Figure 25. Calculated all total costs of the project

Input parameters required in this sub-application are shown in Table VIII:

Table VIII. Input parameters in the *Technology details and costs* sub-application

Input parameter	Input mode	The need to fill in	Description	Unit
Permitting costs				
Number of sites	exact value	mandatory (if this phase exists)	Number of sites under permitting conditions.	-
Pre-drilling activities	exact value	mandatory (if this phase exists)	Permitting costs for pre-drilling activities. Multiplied with the number of sites.	€/per site
For drilling-exploration and early drilling	exact value	mandatory (if this phase exists)	Permitting costs for drilling-exploration & early drilling. Multiplied with the number of sites.	€/per site
Utilization permit	exact value	mandatory (if this phase exists)	Costs related to the field utilization permits.	€
Exploration costs				
Number of sites	exact value	mandatory (if this phase exists)	Number of sites where the exploration drillings take place. Can differ from the actual successful drilled wells in drilling phase.	-
Pre-drilling costs	exact value	mandatory (if this phase exists)	Costs for locations that are under evaluation before the exploration drilling begin. Multiplied with the number of sites	€/per site
Drilling costs	exact value	mandatory (if this phase exists)	Drilling costs of drilled exploration wells – full-size. Multiplied with the number of sites.	€/per site
Leasing cost	exact value	mandatory (if this phase exists)	Costs related to the lease.	€
Additional costs	exact value	mandatory (if this phase exists)	Any additional costs that may occur in this development phase.	€
Drilling costs				
Prod. well	exact value	mandatory (if this phase exists)	Number of production wells drilled to obtain the desired flow rate.	-

Inje. well	exact value	mandatory (if this phase exists)	Number of injection wells drilled to obtain the desired flow rate.	-
Production well	exact value	mandatory (if this phase exists)	Costs of each drilled production well. Later it will be multiplied with number of prod. Well.	€/per well
Injection well	exact value	mandatory (if this phase exists)	Costs of each drilled injection well. Later it will be multiplied with number of prod. Well.	€/per well
Stimulation costs	exact value	mandatory (if this phase exists)	Cost of the stimulation of the EGS source.	€/per well
Additional costs	exact value	mandatory (if this phase exists)	Any additional costs that may occur in this development phase.	€
Equipment investment costs				
		Plant equipment		
Mode of input	selection	mandatory	Mode of the cost input can be either **default** or **exact values**. If default values are chosen, the cost-correlations are used to estimate costs of each segment. If exact values are chosen, the user must input exact values of cost of each segment.	-
CEPCI Index	exact value	optionally	Chemical Engineering Plant Cost Index used to get the present value of the costs. If no CEPCI index is inserted, the CEPCI index for September 2018. is used in the cost-correlations.	-
Turbine	exact value or calculated	mandatory	Turbine cost. Either inserted as exact value or calculated with cost-correlation function based on the power output,	€

			explained in detail in APPENDIX B1.	
Generator	exact value or calculated	mandatory	Generator cost. Either inserted as exact value or calculated with cost-correlation function based on the power output, explained in detail in APPENDIX B1.	€
Heat exchanger	exact value or calculated	mandatory	HEX cost. Either inserted as exact value or calculated with cost-correlation function based on the pre-calculated HEX area, explained in detail in APPENDIX B1.	€
Condenser	exact value or calculated	mandatory	Condenser cost. Either inserted as exact value or calculated with cost-correlation function based on the water flow (for WCT) or area and fan power (for ACC), explained in detail in APPENDIX B1.	€
Centrifugal pump	exact value or calculated	mandatory	Centrifugal pump cost. Either inserted as exact value or calculated with cost-correlation function based on the inserted power, explained in detail in APPENDIX B1.	€
Auxiliary HEX	exact value	mandatory	Inserted costs of additional auxiliary heat exchanger/s.	€
Pipes	exact value	mandatory	Specific piping cost per m.	€/m
		Grid connection		
Grid voltage	imported from other sub-application	unnecessary	Voltage level of the existing grid. Inputted in the *End user option* sub-application.	kV

Area	default value or selection	optionally	The area where the construction takes place. Three options are available: **urban, suburban, rural**.	-
Terrain	default value or selection	optionally	The terrain where the construction takes place. Three options are available: **flat, hilly, mountainous.**	-
ORC voltage	exact value	optionally	Voltage for which the purchased ORC unit is constructed for. Should this parameter be different from the Grid voltage, the substation construction is necessary.	kV
Distance between wells	exact value	mandatory	This distance is used to calculate piping costs.	m
Cables	imported from other sub-application	mandatory	The length of the cables is assumed to be the inserted distance to the power grid from the *End user option* application.	km
Pipes	calculated	unnecessary	The length of the piping that should be installed. It is calculated as the distance between well multiplied by 1.1 (10% more)	m
Gathering system				
Production pump depth	default or exact value	optionally	The depth where the production pump is installed. This value will be used in the cost estimations of submersible pump (later version of the tool). Default value is 500m.	m
Injection pump depth	default or exact value	optionally	The depth where the injection pump is installed. This value will be	m

			used in the cost estimations of submersible pump (later version of the tool). Default value is 500m.	
Replacement each	default or exact value	mandatory	The frequency of the submersible pump replacement. By default, it is set at each 6 years.	years
Production pump	default or exact value	mandatory (if one is used)	Cost of the production pump/s if they are used. This value is also used as the value of replacement costs.	€
Injection pump	default or exact value	mandatory (if one is used)	Cost of the production pump/s if they are used.	€
Other costs	exact value	optionally	Any other costs that have not been covered by the named input parameters.	€
Operating and Maintenance Costs				
Estimated annual labour costs	exact value	mandatory	Annual labour costs. In later version a default cost-correlations will also be available.	€/year
Estimated annual well field maintenance cost	exact value	mandatory	Annual well field maintenance cost. In later version a default cost-correlations will also be available.	€/year
Estimated annual plant maintenance cost	exact value	mandatory	Annual plant maintenance cost. In later version a default cost-correlations will also be available.	€/year
Power loss				
Working fluid cooling	exact value	mandatory	Power for cooling the working fluid. Either ACC fan or WCT water pump.	kW
Pumping	exact value	mandatory	Used to estimate the centrifugal pump costs. It must be inserted before	kW

			the Default values button is pushed.	
Submersible pumps	exact value	mandatory	If submersible pumps are used the power consumption of them must be inserted.	kW

All main output parameters in the Technology details and costs are shown in the Table IX:

Table IX. Main output parameters shown in the *Technology details and costs* sub-application

Output parameter	Description	Unit
TOTAL (Permitting costs)	The calculated total costs that occur in the permitting phase. If the phase lasts longer than one year, the total costs are equally divided for all years.	€
TOTAL (Exploration costs)	The calculated total costs that occur in the exploration phase. If the phase lasts longer than one year, the total costs are equally divided for all years.	€
TOTAL (Drilling costs)	The calculated total costs that occur in the exploration phase. If the phase lasts longer than one year, the total costs are equally divided for all years.	€
TOTAL (Plant equipment)	Sum of all the equipment costs.	€
TOTAL (Grid connection)	Calculated grid connection costs.	€
TOTAL (Gathering system)	Sum of all the gathering system costs.	€
Total equipment investment costs	Sum of total plant equipment costs, total grid connection costs, total gathering system costs.	€
TOTAL (O&M costs)	Total annual O&M costs.	€
TOTAL (Power loss)	Total parasitic power loss calculated as sum of all parasitic loads.	kW

2.3.2.6 Financial parameters

Financial parameters sub-application is used to gather input parameters related to the financial parameters such as discount rate, tax rate, financing option, electricity and heat market prices, etc.

Possible sources of financing the project are private capital, community assistance, national public contribution and other resources. Financing option private capital can be modelled that part of the net capital costs is financed from the loan; i.e. dept-equity ratio is defined. Community assistance includes financing from the EU grant on local, regional or central level, national public contribution includes grants or capital subsidies at central, regional and local government level and other resources.

Main financial parameters used later in the DCF calculations can either be default values or exact values inputted by the user (Figure 26, yellow rectangle). Sources of financing should be inputted by the user, specifying the cash inflow for each year separately (Figure 26, green under lines). Selling prices can either be market prices obtained from the default forecasting function or imported from the Excel file. If the end user application option is only electricity production or CHP, the electricity prices should be imported or forecasted with default function (Figure 26, red arrow). Should the end user application option be only heat production or CHP, the heat selling prices should be imported or forecasted with default function.

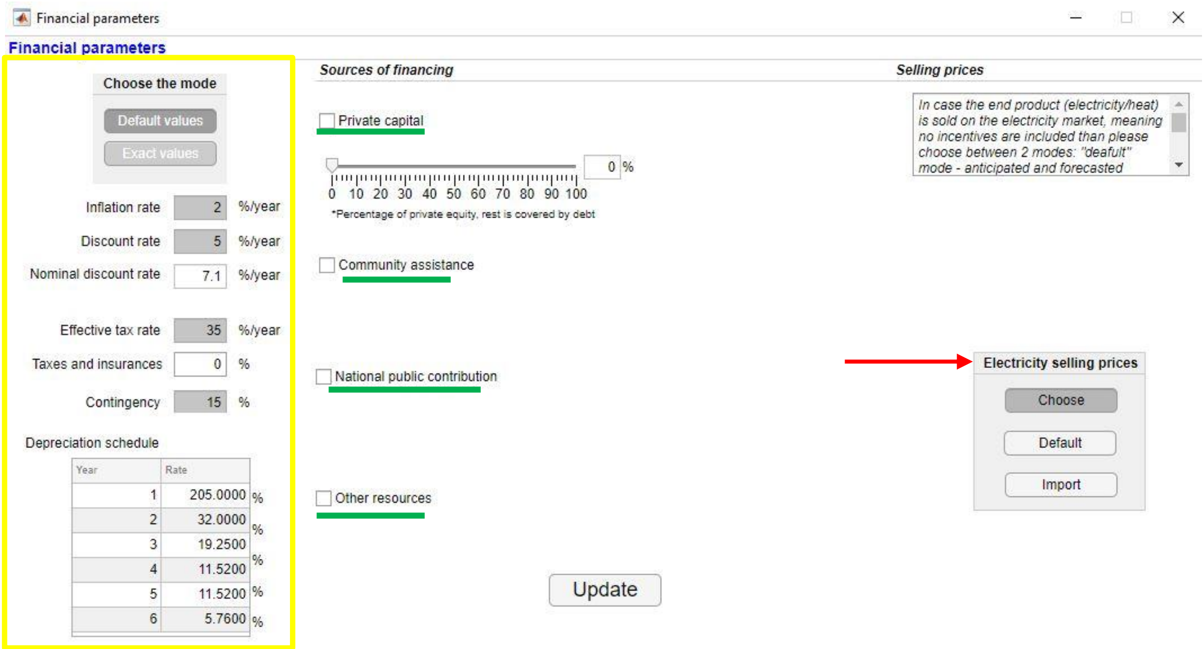

Figure 26. Financial parameters - importing or default forecasting of the electricity selling prices

When one option of the financing source is checked (Figure 27, yellow circles), a table appears on the right side of the checked source (blue arrows). The table consists of 2 columns labelled *Year* and *Amount*. In the column *Year,* the user should write the year (Figure 27, red circle) in which the financing source appears and, and in the column, *Amount* the amount of the financing in that year (Figure 27, green rectangle). Each new year of financing should be written in the same manner but separately in a new row. For the source of financing that are not checked, the table is invisible.

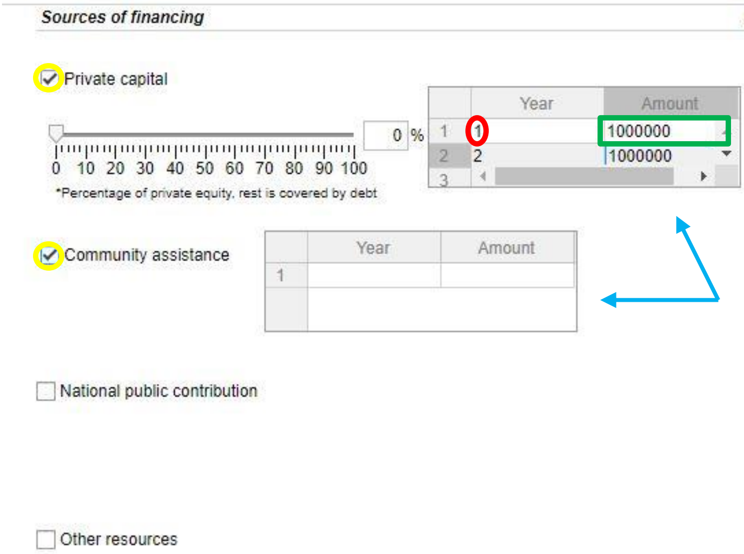

Figure 27. Sources of financing input parameters insertion

All the input parameters in the *Financial parameters* sub-application are listed in Table X:

Table X. Input parameters in the *Financial parameters* sub-application

Input parameter	Input mode	The need to fill in	Description	Unit
Choose the mode	default or exact selection	optionally	This option serves that the user choses between default values for the financial parameters or exact (other) values for these parameters.	-
Inflation rate	default or exact value	optionally	The inflation rate is used to calculate the nominal discount rate. By default, it is set to be 2%.	%/year
Discount rate	default or exact value	optionally	The discount rate, alongside with the inflation rate is used to calculate the nominal discount rate which is later used in the DCF calculations. By default, it is set to be 5%.	%/year
Nominal discount rate	calculated	unnecessary	Used in the DCF calculations.	%/year
Effective tax rate	default or exact value	optionally	Used for taxation calculations. It is the annual income tax	%/year

			rate that is applied to taxable income. Taxable income includes all incomes (from energy sales) and from any incentive marked as taxable in the *Incentives* sub-application.	
Taxes and insurances	exact value	unnecessary	Insurance rate are annual insurance payments as part of the annual operating costs. This option will be enables in the later version of the tool.	%
Contingency	default or exact value	optionally	Percentage of the power plant costs to account for expected uncertainties in direct cost estimates. Contingency is not used in the current version of the tool but is anticipated to be used in the later version. It will be applied to all capital costs. The default value is 15%.	%
Depreciation schedule	default or exact value	optionally	The depreciation inputs represent the decrease in value of project assets over the analysis period. Depreciation reduces taxable income. By default, the 5-year MACRS (modified accelerated cost recovery) depreciation scheduled is used [3]. Not used in current version of the tool.	%
Sources of financing panel				
Private capital	exact value	optionally (only if it is a source of fin.)	Private equity under PPP. The percentage slider defines the amount of the debt financing, i.e. the shown percentage is the percentage of the private equity, the rest is covered by debt.	%
Private capital table	exact value/s	optionally (only if it is a source of fin.)	If *Private capital* check-box is checked, the table appears. The user should insert the	€/year

			financing amount for each year where the financing appears. This option is in current version not used.	
Community assistance table	exact value/s	optionally (only if it is a source of fin.)	I.e. the EU grant (on local, regional or central level). If *Community assistance* capital check-box is checked, the table appears. The user should insert the financing amount for each year where the financing appears.	€/year
National public contribution	exact value/s	optionally (only if it is a source of fin.)	I.e. grants or capital subsidies at central, regional and local government level. If *National private contribution* capital check-box is checked, the table appears. The user should insert the financing amount for each year where the financing appears.	€/year
Other	exact value/s	optionally (only if it is a source of fin.)	Any other source of financing the project. The user should insert the financing amount for each year where the financing appears.	€/year
Selling prices				
Heat selling prices	default or imported values	mandatory (in case of only heat production and CHP)	The yearly or monthly heating power selling prices. Either default values obtained by the default forecasting function, for specified country, or exact imported monthly or yearly values. The import format is described in APPENDIX A6.	€/MWh
Electricity selling prices	default or imported values	mandatory (in case of only electricity production and CHP)	The yearly or monthly electricity selling prices. Either default values obtained by the default forecasting function, for specified country, or exact imported monthly or yearly	€/MWh

			values. The import format is described in APPENDIX A6.	

2.3.2.7 Incentives

Incentives sub-application is used to define the input parameters for different kind of tax credits and cash incentives.

A tax credit incentive is an amount that is deducted from the project's income tax. Following tax-credit incentives are available (Figure 28, red rectangle):

- Investment tax credit (ITC)
- Production tax credit (PTC)

A cash incentive is an amount paid to the project that contributes to the project's annual cash flow. Following cash incentives are available (Figure 28, green rectangle):

- Investment-based incentive (IBI)
- Capacity-based incentive (CBI)
- Production-based incentive (PBI)

All cash incentives can also be taxable amounts (Figure 28, yellow circles), meaning that if the incentive is checked as taxable, this incentive is qualified as income for tax purposes. By default, no incentive is qualified as taxable incentive.

Tax credit incentives are in current version modelled as input parameters, but their use will be modelled in the later version of the tool.

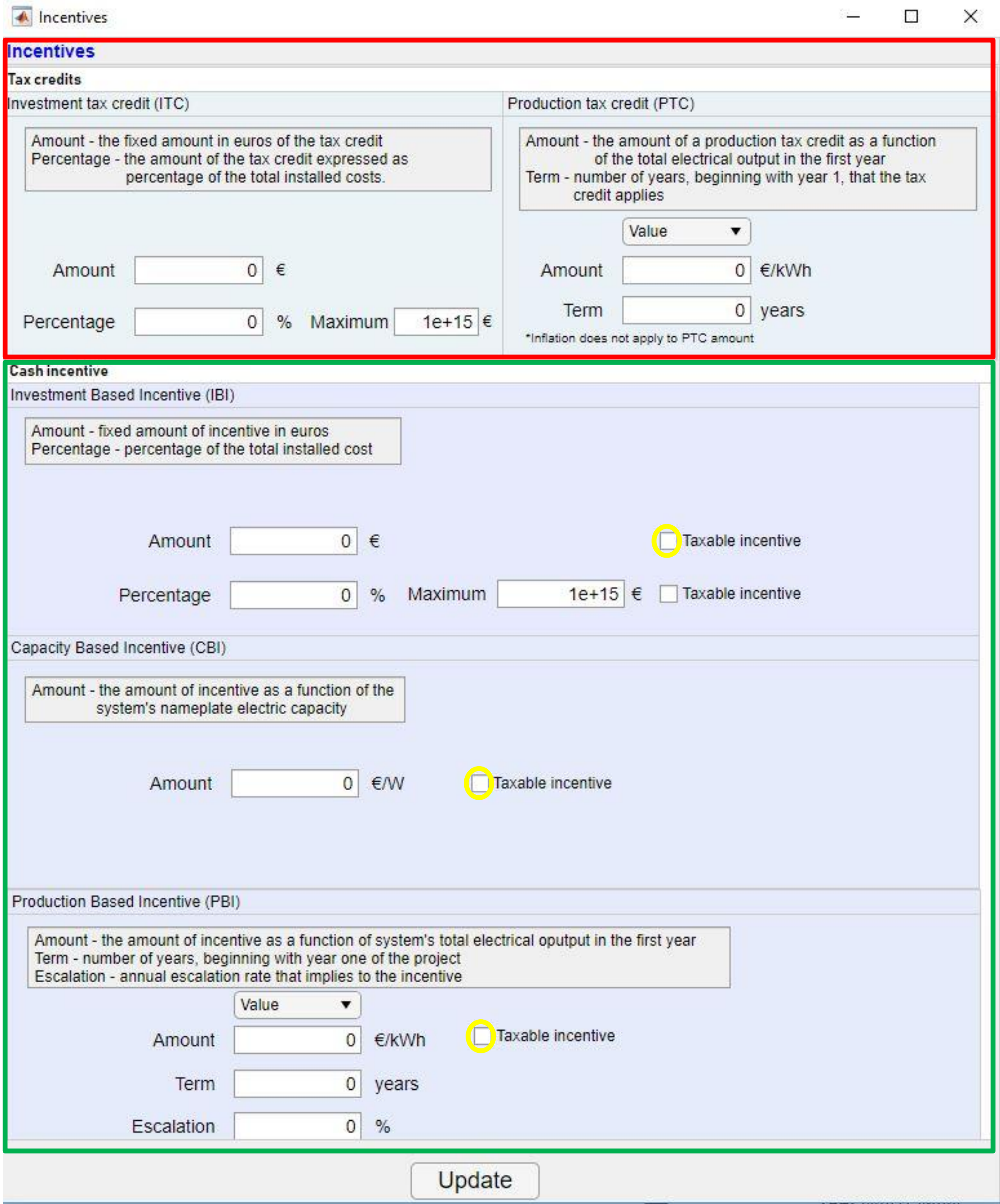

Figure 28. Screenshot of the *Incentives* sub-application

All the input parameters in the *Incentives* sub-application are listed in Table XI:

Table XI. Input parameters in the Incentives sub-application

Input parameter	Input mode	The need to fill in	Description	Unit
Tax credits				

Investment tax credit – amount/percentage	exact value	optionally (if this type of incentive is used)	The fixed amount in euros of the tax credit. Reduces the project's annual tax liability in the first year that the project is operational. ITC is expressed either as fixed amount or as a percentage of the project's total installed costs with a maximum limit. This option is in current version not used.	€ or %
Production tax credit - amount	exact value or imported yearly values	optionally (if this type of incentive is used)	Reduces project's annual tax liability in Year One of the cash flow and subsequent years up to and including the year specified in the Term variable. The PTC is a dollar amount per kilowatt-hour of annual electric output. It can be specified as either single value that applies to all the years or assign different value to each year using the *Import option*. This option is in current version not used.	€/kWh
Production tax credit - term	exact value	optionally (if this type of incentive is used)	The number of years, beginning with the year 1 of the project cash flow that the tax credit incentive applies. This option is in current version not used.	years
Cash incentives				
Investment based incentive – amount or percentage	exact value	optionally (if this type of incentive is used)	Cash payment to the project in 1 year of the project cash flow. It is either expressed as fixed amount or as a percentage of the project's total installed cost with maximum limit.	€ or %
Capacity based incentive – amount	exact value	optionally (if this type of incentive is used)	It is a payment to the project in 1 year of the project cash flow. It is expressed as function of the system's rated capacity in watts.	€/W
Production based incentive - amount	exact value	optionally (if this type of incentive is used)	It is a cash payment to the project specified as euro amount per kilowatt-hour of annual electric/heating output. The PBI can either be specified as single	€/kWh

			value that applies to all years for the specified term variable, or user can import the values for each year. However, the import option is in current version of the tool not used.	
Production based incentive – term	exact value	optionally (if this type of incentive is used)	The number of years that the incentives are applied to.	years
Production based incentive – escalation	exact value	optionally (if this type of incentive is used)	The annual escalation rate that applies to the incentives. For example, for an incentive with a ten-year term and two percent escalation rate, the incentive in year two would be two percent greater than in Year One, and in year three, two percent greater than in year two, and so on. This is not enabled in the current version of the tool.	%

2.3.2.8 Environmental impact

Environmental impact sub-application is used to gather the input parameters related to the evaluation of the environmental impact of the defined project. This input parameters are later used for other calculations (e.g. global efficiency) as much as the parameters which define some of the criteria in the MCDM analysis.

Some of the input parameters are pre-defined with default values (e.g. noise), but most of them should be inputted by the user since they are highly site-specific parameters. By default, some of the values are set to be zero, if no changes are made, they are equal to zero. The user should input the estimate of lifecycle GHG emission, the annual subsidence, land use intensity, total dissolved solids (TDS) amount in the geothermal brine and the pH of the geothermal brine, the non-condensable gases (NCG) percentage and the estimated noise level (Figure 29, red arrows). Moreover, the user should choose (Figure 29, blue arrows) from the drop-down menus the peak ground velocity (Figure 30) and peak ground acceleration (Figure 31), and the rock type (Figure 32)

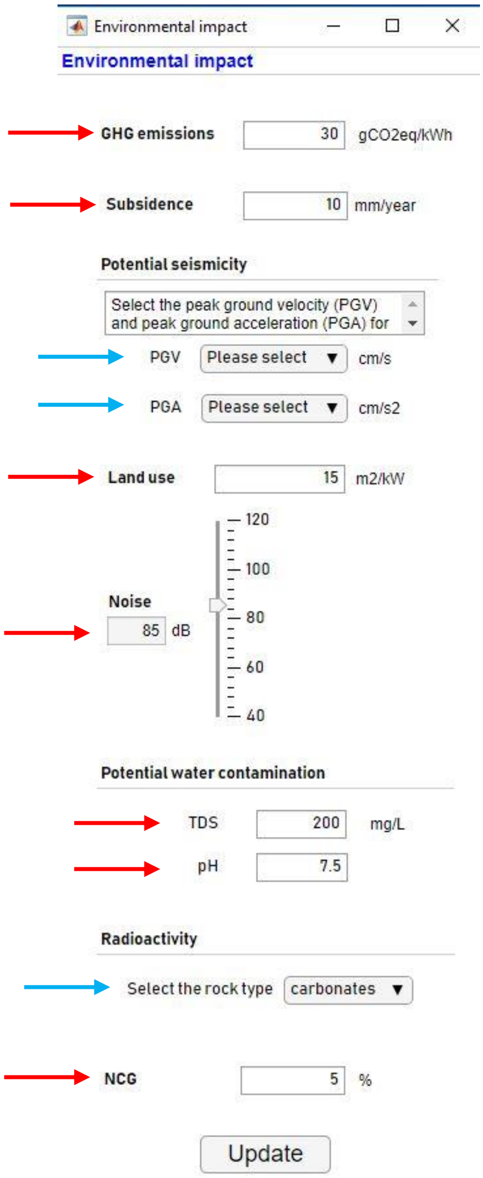

Figure 29. Screenshot of the *Environmental impact* sub-application

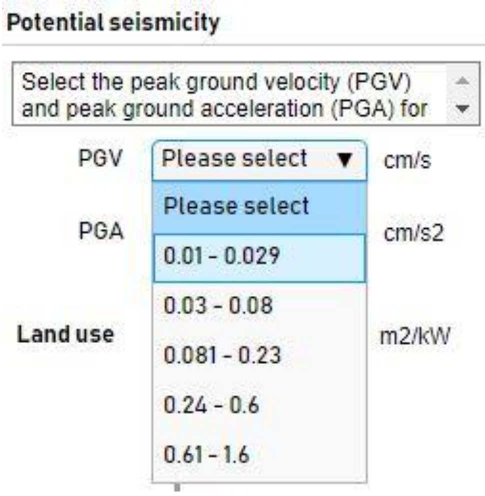

Figure 30. PGV drop-down menu

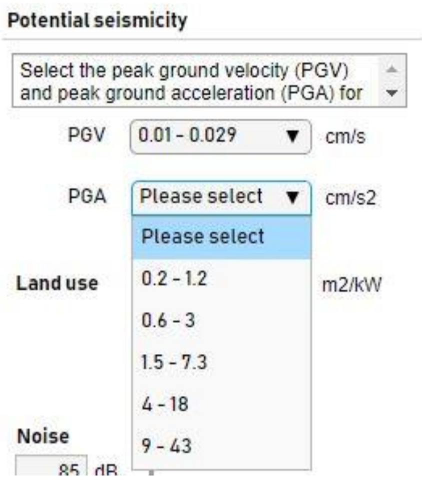

Figure 31. PGA drop-down menu

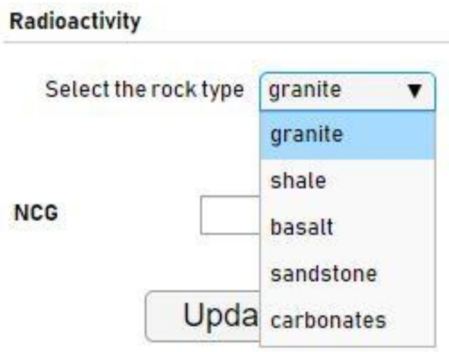

Figure 32. Rock type drop-down menu

All the input parameters in the *Environmental impact* sub-application are listed in Table XII:

Table XII. Input parameters in the *Environmental impact* sub-application

Input parameter	Input mode	The need to fill in	Description	Unit
CO_2 emissions	exact value	optionally (if existing)	The estimate of life cycle GHG emissions in grams of carbon dioxide equivalent per kilowatt-hour generated	$gCO2_{eq}/kWh$
Subsidence	exact value	mandatory	The fluid extraction could cause subsidence because of reservoir pressure decline. This is measured in mm/year of soil decay.	mm/year
Potential seismicity panel				
PGV	exact selection	mandatory	Moreover, the pore pressure reduction in production and increase in reinjection operations have been associated with increased induced seismicity. Peak ground velocity is used to determine the estimated potential seismicity impact of the project.	cm/s
PGA	exact selection	mandatory	Peak ground acceleration is used to determine the estimated potential seismicity impact of the project.	cm/m^2
Land use	exact value	mandatory	The impact on the landscape is measured as land use intensity (LUI).	m^2/kW
Noise	default or exact value	mandatory	The noise impact during routine operation is mainly caused by cooling towers and electrical transformers. The default value is set at 85 dB.	dB
Potential water contamination				
TDS	exact value	mandatory	TDS stands for total dissolved solids. Groundwater contamination may occur if the casings in	mg/L

			reinjection wells should fail, allowing fluid to leak. This parameter is used to evaluate the potential water contamination alongside with the pH value.	
pH	exact value	mandatory	This parameter is used to evaluate the potential water contamination alongside with the TDS value.	-
Radioactivity	exact selection	mandatory	User must choose the rock type according which the radioactivity will be evaluated.	-
NCG	exact value	mandatory	The non-condensable gases (NCG) content is used to calculate the heat loss due to the NCG.	%

2.3.3 Preparing the data and executing the financial analysis of the project

Once all the sub-applications have been opened and required data inputted, the user should push the **Prepare data and forecast** button. When pushed, the tool calculates following:

- Revenues from the sold electricity and/or heating power;
- Social acceptance costs;
- Employment rate – full time and O&M jobs;
- Global efficiency of the power plant;

It also visually represents calculated performance metrics results on the graphs in the **Performance metrics results** tab, described in the Section 2.3.3.1.

When the necessary data is prepared and calculated the **Financial analysis** button must be pushed. This action triggers the calculation of all the economic metrics (APPENDIX B6):

- Systems levelized cost of energy (sLCOE) – for only heat production the levelized cost of heat (LCOH) is calculated, for only electricity production the levelized cost of electricity (LCOE) is calculated and for CHP the user can choose to consider either LCOE or LCOH;
- Net present value (NPV) – financial net present value on the investment (NPV(C)) and financial net present value on capital (NPV(K)) are calculated. To gain the contribution from the Funds (EU) the NPV(C) should be negative.
- Internal rate of return (IRR) – internal rate of return on investment (IRR(C)) and internal rate of return on capital (IRR(K)) are calculated. The project that can gain the

contribution from the Funds should have lower IRR(C) than the discount rate used for the analysis.

The main economic metrics are shown in the **Economic metrics results** tab which is described in in detail in Section 2.3.3.2.

2.3.3.1 Performance metrics results

This tab is used to visually represent the obtained calculated results considering the performance of the modelled system and scenario. Presented graphs are as shown in Figure 33:

- Full-time (FT) employment – the red dot marks the installed power of the power plant and the related full-time jobs shown on the FT employment curve.
- Construction and Manufacturing (CM) employment rate – the red dot marks the installed power and associated CM jobs shown on the CM employment rate curve.
- Social acceptance costs – calculated social acceptance costs based on the installed capacity and shown on the social acceptance costs curve.
- Energy production – monthly values; either only electricity or only heating power, or both in case of CHP.
- Efficiency of the conversion process – monthly values.
- Energy loss due to the electricity transmission – monthly values.

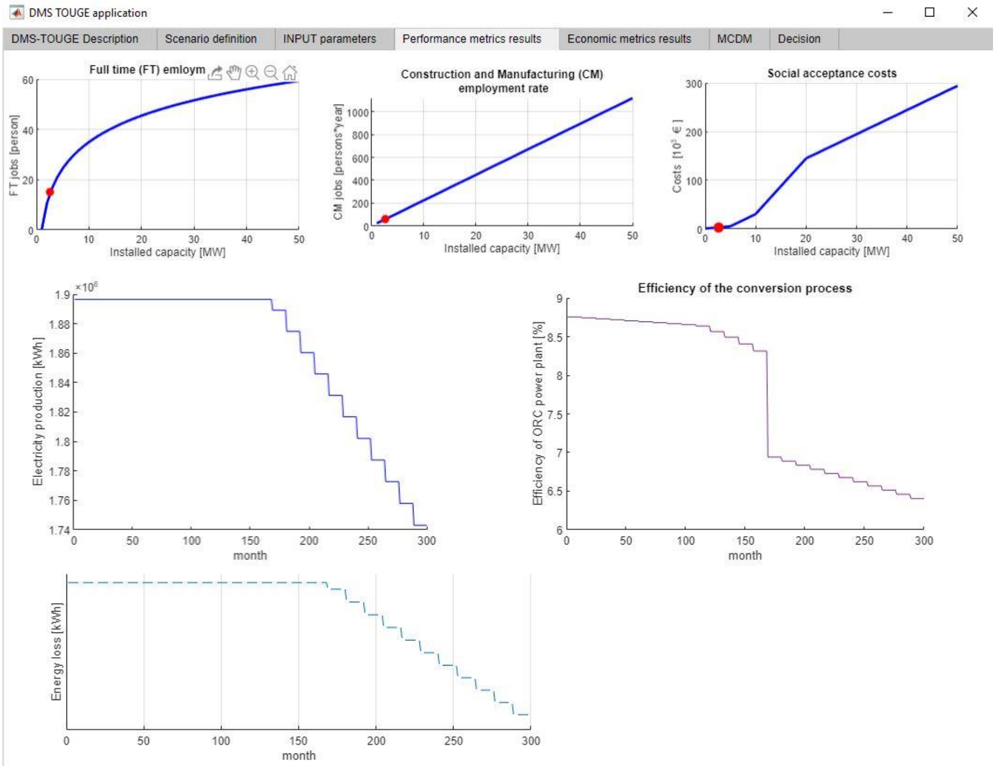

Figure 33. Performance metrics results - for only electricity production mode (water-cooled condenser type)

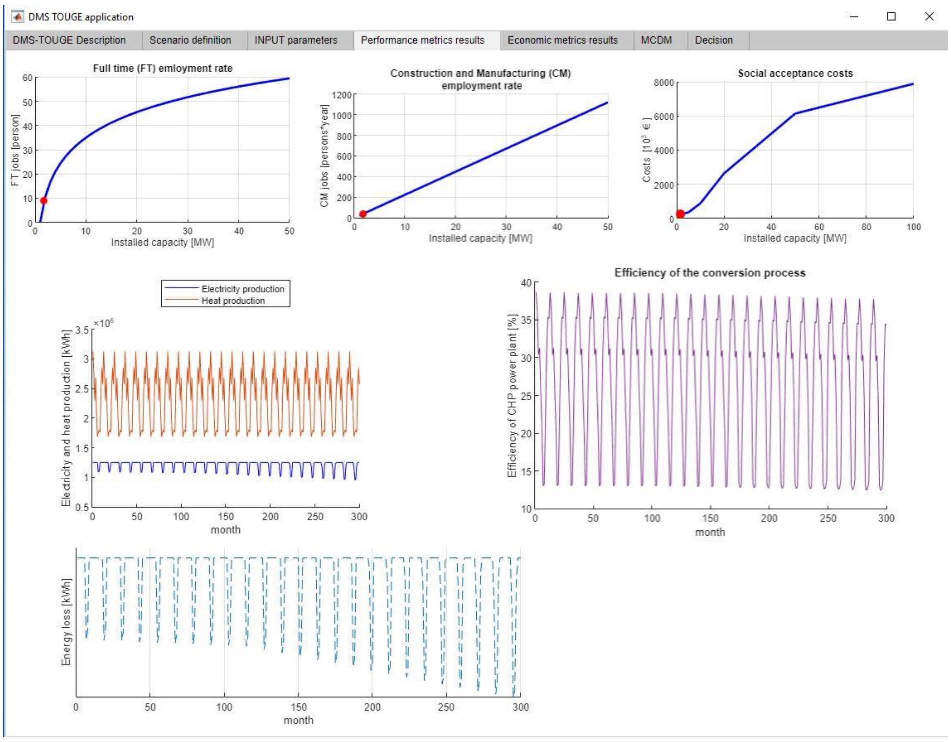

Figure 34. Performance metrics results - for CHP option (air-cooled condenser type in ORC unit)

2.3.3.2 Economic metrics results

This tab is used to display the calculated obtained calculated results of economic indices. Presented values and graphs as shown in Figure 35. are:

- Electricity prices (red arrow) – monthly or yearly values. In case of only electricity production and CHP;
- Heat prices (green arrow) – monthly or yearly values. In case of only heat production and CHP;
- Project cash flow thorough all development phases (red rectangle);
- Total structure of the costs – investment (capital costs), operation and maintenance costs (O&M) and financing cost (e.g. loan payments) (green rectangle);
- Investment cost structure – fixed assets costs and star-up costs (orange rectangle);
- Percentage of each investment costs – cost related to each phase of the project development (blue rectangle);
- LCOE – levelized cost of electricity for only electricity production case and CHP if the electrify is the main product (blue underline).
- LCOH – levelized cost of heat for only heat production case and CHP if the heating power is the main product (orange underline).
- NPV(C) – net capital value of investment. If this is negative, the project can receive financing from the Funds. The financial net present value of investment (FNPV(C)) and the financial rate of return of the investment (FRR(C)) compare investment costs to net revenues and measure the extent to which the project net revenues are able to

repay the investment, regardless of the sources or methods of financing. (yellow underline)

- IRR(C) – internar rate of rerun of investment. If this is lower than the used discount rate in the DCF calculations the porject can recieve finaning from the Funds. (red underline)
- NPV(K) – net present value of capital. It is the sum of the net discounted cash flows that accrue to the national beneficiaries (public and private combined) due to the implementation of the project. (green underline) The corresponding financial rate of return on capital, FRR(K), of these flows determines the return in percentage points. When computing FNPV(K) and FRR(K), all sources of financing are taken into account.
- IRR(K) – internal rate of return on capital. The return on national capital is calculated considering as outflows: the operating costs; the national (public and private) capital contributions to the project; the financial resources from loans at the time in which they are reimbursed; the related interest on loans. (black underline)

Figure 35. Screenshot of the Economic metrics results - for only electricity production scenario

2.3.4 Multiple-criteria decision making (MCDM) analysis

The MCDM matrix has been developed for the MCDM analysis and is a subprocess in the DMS-TOUGE used for preliminary evaluation of different geothermal sites (EGS sites) and technologies for electricity and/or heat production. After the MCDM analysis is carried out, the user is

The description of the MCDM analysis and MCDM matrix is described in [1].

The MCDM matrix consists of technological, economic and geological criteria extended with the evaluated social and environmental impact, giving the comprehensive assessment of the EGS project. In the all the criterions are listed.

Table XIII. WDM matrix for the MCDM analysis

Criterion	Description	Unit
$x_{i,1}$	Installed capacity	p.u.
$x_{i,2}$	Equivalent heat flow	m^2/h°C
$x_{i,3}$	Theoretical maximum efficiency	%
$x_{i,4}$	Geothermal gradient	°C/100m
$x_{i,5}$	Fluid temperature at the wellhead	°C
$x_{i,6}$	Corrosion and scaling	-
$x_{i,7}$	Distance from the grid	km
$x_{i,8}$	Load factor	-
$x_{i,9}$	Environmental impact	Average of all sub-criterions
$x_{i,10}$	Social impact	Average of all sub-criterions
$x_{i,11}$	sLCOE	p.u.
$x_{i,12}$	Global efficiency	%

The *MCDM tab* consist of the table (Figure 36) in which the columns represent the options from 1 to 10, i.e. different scenarios. In other words, user can evaluate and compare to 10 different scenarios. The rows represent 12 different criterions (Figure 36, red rectangle). The table in the yellow rectangle represents the weights for each criterion and the user can chose from 1 to 10 for each criterion. In some way the user models the final decision since its preferences are reflected in the weight selection. In other words, the weights of each criterion reflect the relative importance between criterions from the perspective of the DMT user.

After the evaluation of the first project, i.e. scenario if finished, to evaluate a new scenario the user must return to the *Scenario definition* tab and change the **Name of the project** variable. When this input parameter is changed, a new evaluation begins, and user can change all other input parameters in the sub-applications, following again the procedure described in Section from 2.3.1 to 2.3.4. After the input parameters are entered, and the buttons **Prepare data and forecast,** and **Financial analysis** are pushed, the user can again conduct the MCDM analysis by selectin new or same weights for each criterion. The newest scenario evaluation and its grades appear in the column under 'Option 2'. Each new scenario i.e. project with new name is printed out under next column as 'Option x'. If the user wants to see the explanation of each criterion, the **Criteria description** button should be pushed (Figure 36, blue arrow).

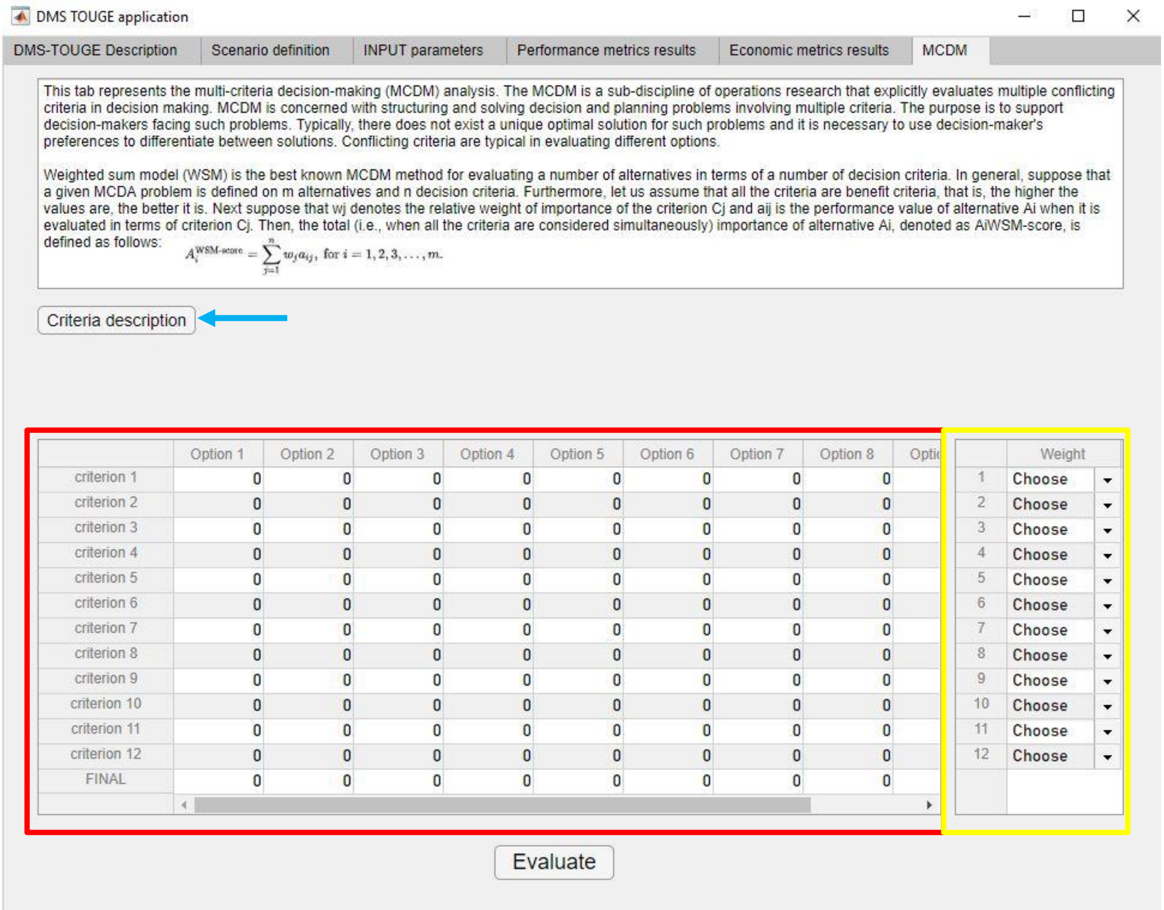

Figure 36. Screenshot of the MCDM tab

3 CONCLUSION

3.1.1 Objectives

This Deliverable Report provides comprehensive description of Decision-Making Tool, DMT, regarding its development approach, structure and both mathematical and physical model that is executed in MATLAB programming tool. All DMT modules are described, where all basic assumptions are stated and elaborated and most of modeled functions key parts are stated in form of equations. For each DMT module all input, and output parameters are listed and defined. All DMT application restrictions are also stated. DMT is modeled as holistic tool taking into account economical, technical, environmental and societal parameters that can affect EGS project feasibility. Major UNIZG-FER staff contributions to DMT development are also explained.

Besides this textual part of report, a MATLAB based model and application is also provided as part of deliverable 7.1. DMT provides nice user-friendly GUI that is also comprehensively explained in separate APPENDIX (APPENDIX 1) of this report with purpose to help DMT users to get familiar with DMT applicability and understanding both input and output parameters for DMT.

3.1.2 Perspectives

DMT as deliverable D7.1 is developed in order to help investors that are interested in EGS project development on specific locations. In the scope of MEET project D7.1. is crucial for achievement of later deliverables, namely D4.5 Methodology and tool for an economic evaluation of end-of-field life conversation, D7.2 Geothermal energy potential development in different geological conditions, D7.3 Upscaling of already existing geothermal provinces and co-produced oil fields and D7.4 Optimal usage of geothermal potential on already existing geothermal pilot sites in scope of MEET project. In this regard DMT provides support that can be used for every site of interest and for different ways of geothermal energy exploitation such as electricity only, heat only or combined heat and electricity production (CHP). Current DMT version will be continuously upgraded and updated in coordination with other MEET consortium partners especially with ENOGIA and Vermilion. Therefore, it is expected that evolved version (in comparison to current version) of DMT will be available near the end of MEET project.

ABBREVIATIONS

ACC	Air-cooled condenser
CEPCI	Chemical Engineering Plant Cost Index
CHP	Combined Heat and Power plant
CM	Constriction and manufacturing (jobs)
DCF	Discounted cash flow
EGS	Enhanced Geothermal System
FT	Full-time (jobs)
DM	Decision Maker
DMS-TOUGE	Decision-Making Support Tool for Optimal Usage of Geothermal Energy
GHG	Greenhouse Gases
HEX	Heat Exchanger
IRR(C)	Internal Rate of Return of Investment
IRR(K)	Internal Rate of Return of Capital
LCOE	Levelized Cost of Electricity
sLCOE	System Levelized Cost of Energy
LCOH	Levelized Cost of Heat
MACRS	Modified accelerated cost recovery
MCDM	Multi Criteria Decision Making
NCG	Non-condensable gases
NPV(C)	Net Present Value of Investment
NPV(K)	Net Present Value of Capital
ORC	Organic Rankine Cycle
O&M	Operating and Maintenance
PGA	Peak ground acceleration
PGV	Peak ground velocity
pH	Potential of hydrogen
TDS	Total dissolved solids
WCT	Water-cooling tower
WSM	Weighted Sum Model

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Appendix A

DMS-TOUGE Data import formats

1 APPENDIX A – DATA IMPORT FORMATS

A1. TEMPERATURE DRAWDOWN

DMS-TOUGE does not model the performance of the reservoir, but it rather models the impact of the reservoir performance on the power sales and the economic indices consequently. Based on the reviewed literature and the historical operation of existing geothermal facilities, an expectation exists, that, over time, the productivity of the reservoir will decline. This decline in productivity can be manifested as a decreasing temperature, pressure, and/or flow rate. DMS-TOUGE characterizes the decline in productivity by declining resource temperature, i.e. temperature drawdown of the resource.

As seen in literature, the usual temperature decline rates for binary power plants typically approach the 0,5 % per year.

If **Default values** mode is chosen, the values of the resource temperature are decreasing 0,05% during the first 10 years and afterwards 0,5% annually. User can change this mode to **Exact values**, and in that case change the annual percentage decline for the first 10 years and the rest of the project lifetime. For these two modes, after the evaluated annual resource temperature decline in percentage is defined, the user must push the **Calculate thermal drawdown** button (Figure 37, red arrow). When pushed the resource temperature is visually represented in the graph.

In the case if **Import** mode is chosen, the user imports prepared annual resource temperatures in a ***.xlsx** format. The prepared Excel document should contain *2 columns*. The first column contains years for the duration of the period (project lifetime) in the *Scenario definition* tab and the second column temperature for each year expressed in degrees Celsius (°C) as depicted inFigure 38. For this mode, the Calculate thermal drawdown must not be pushed.

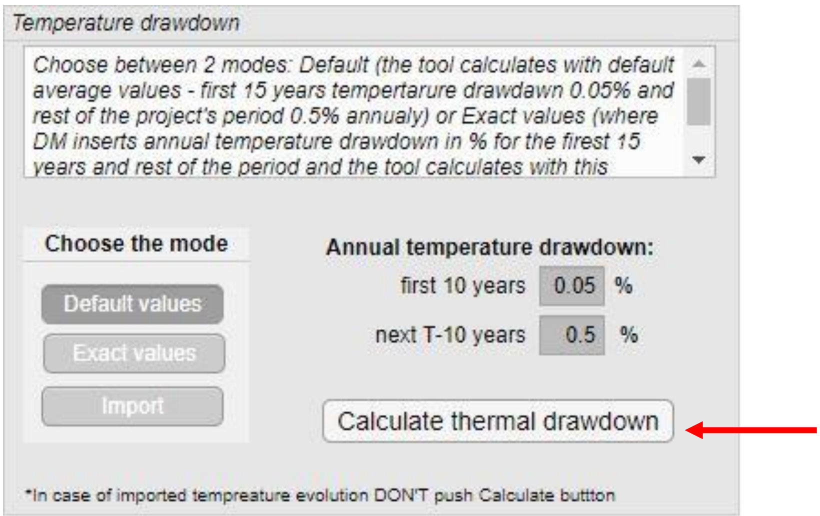

Figure 37. Screenshot of the *Temperature drawdown* panel

	A	B
1	Year	Temperature
2	2019	110
3	2020	109.5
4	2021	109
5	2022	108.5
6	2023	108
7	2024	107.5
8	2025	107
9	2026	106.5
10	2027	106
11	2028	105.5
12	2029	105
13	2030	104.5
14	2031	104
15	2032	103.5
16	2033	103
17	2034	102.5
18	2035	102
19	2036	101.5
20	2037	101
21	2038	100.5
22	2039	100
23		

Figure 38. Import format for temperature drawdown (for lifetime period of 21 years)

Tab: *INPUT sheet*

Sub-application: *Site geological features*

Panel: *Temperature drawdown*

Parameter 1: *Year*

Number format: *yyyy*

Number format: *General*

Parameter 2: Temperature (°C)

Number format: *General*

Document format: *.xlsx*

A2. IMPORTING GEOTHERMAL BRINE FLOW RATE

In the *Geothermal fluid properties* sub-application, the user must import **flow rate** of the **geothermal brine**.

The geothermal brine flow rate can be inputted with 2 different options (Figure 39, red rectangle). When the **Varying** option is chosen, importing data is required. Imported data could be entered in the time resolution of month or year (Figure 40, blue ovals). When the time resolution is chosen, the **IMPORT** button must be pushed. The prepared document must be Excel document (.xlsx format) and should contain sheets where the brine flow is expressed in m^3/s. The sheet should be named according to the selected time resolution, i.e. **yearly** if the yearly values are inputted or **monthly** if the monthly values are inputted. Moreover, for *yearly* option, the columns should be named **Year** and **FlowRate** as shown inFigure 41. As for *monthly* option the columns should be named **Month** and **FlowRate** as shown inFigure 41.

If the *Constant* mode is selected, the end-user should enter the annual flow rate expressed in m^3/s and this value is considered to be equal throughout the whole lifetime period.

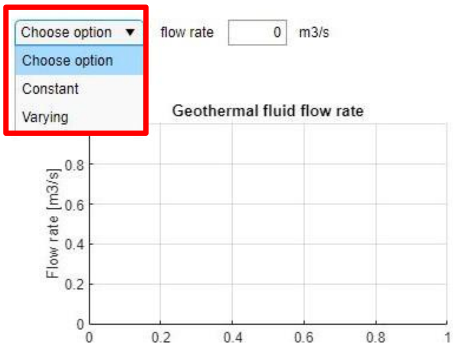

Figure 39. Options for geothermal brine input option

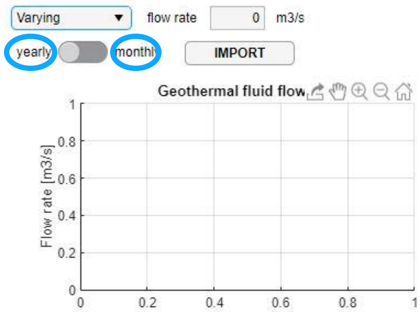

Figure 40. Varying option input

	A	B
1	Year	FlowRate
2	2019	0.99
3	2020	0.99
4	2021	0.99
5	2022	0.99
6	2023	0.99
7	2024	0.99
8	2025	0.99
9	2026	0.99
10	2027	0.99
11	2028	0.99
12	2029	0.99
13	2030	0.99
14	2031	0.96
15	2032	0.948
16	2033	0.948
17	2034	0.948
18	2035	0.948
19	2036	0.948
20	2037	0.948
21	2038	0.948
22	2039	0.948
23	2040	0.948
24	2041	0.948
25	2042	0.948
26	2043	0.948
27		

	A	B
1	Month	FlowRate
2	1	0.0825
3	2	0.0825
4	3	0.0825
5	4	0.0825
6	5	0.0825
7	6	0.0825
8	7	0.0825
9	8	0.0825
10	9	0.0825
11	10	0.0825
12	11	0.0825
13	12	0.0825
14		

Figure 41. Brine flow rate sheet input formats

Tab: *INPUT sheet*

Sub-application: *Geothermal fluid properties*

Panel: *Geothermal fluid properties*

Parameter 1: *Time (Year* or *Month)*

Resolution: *yearly/monthly*

Number format: *yyyy* or *m*

Parameter 2: *FlowRate*

Number format: *General*

Document format: **.xlsx*

A3. HEAT DEMAND SIDE SUPPLY AND RETURN TEMPERATURE

In the *End user option* sub-application, in the **Heating network characteristics** panel, the user must import supply and return temperature of the heat demand side, i.e. characteristic temperatures of the heating network, by pushing the **Import** button for each temperature. The monthly (12 months of the year) temperatures should be prepared in a ***.csv** file. Supply temperatures are higher temperatures of the secondary (heating network) medium which is going from the plant to the end-user and return temperatures are the lower temperatures of the secondary (heating network) medium that returns to the power plant. By importing monthly values of these temperature, the seasonality of the heat demand has been modelled. The temperatures must be expressed in the degree Celsius [°C].

	A	B
1	Month	Temperature
2	1	74
3	2	70
4	3	70
5	4	72
6	5	67
7	6	65
8	7	66
9	8	66
10	9	65
11	10	65
12	11	70
13	12	67

Figure 42. Example of T_{supply} input data

Tab: *INPUT sheet*

Sub-application: *End use option*

Panel: *Heating network characteristics*

Parameter 1: *Month*

Resolution: *monthly (12 months)*

Number format: *mm*

Number format: *General*

Parameter 2: *Temperature (°C)*

Number format: *General*

Document format: **.csv*

	A	B
1	Month	Temperature
2	1	40
3	2	40
4	3	40
5	4	37
6	5	40
7	6	43
8	7	43
9	8	42.5
10	9	42
11	10	38
12	11	39
13	12	39

Figure 43. Example of T_{return} input data

Tab: *INPUT sheet*

Sub-application: *End use option*

Panel: *Heating network characteristics*

Parameter 1: *Month*

Resolution: *monthly (12 months)*

Number format: *mm*

Number format: *General*

Parameter 2: *Temperature (°C)*

Number format: *General*

Document format: **.csv*

A4. MASS FLOW FOR THE HEAT DEMAND

In the *End user option* sub-application, in the **Heating network characteristics** panel, the user must import **mass flow rate** of the **secondary fluid** (medium of the heating network).

The mass flow of the district heating system demand is expressed in [kg/s]. The required file format is as ***.xlsx**, and the Excel file should contain two columns, depending on the selected time resolution. Namely, this input parameter can be expressed either on monthly or yearly basis (Figure 44, blue oval). When *monthly* time resolution is chosen, the heat demand mass flow file must contain the sheet named **monthly** and it should consist of 2 columns: the column **Month**, where 12 months (of one year; it is repeated for all years throughout the lifetime period) data is inputted, and the column **MassFlow** where the mass flow values of each month are entered (Figure 45). When *yearly* time resolution is chosen, the heat demand mass flow file must contain the sheet named **yearly** and it should consist of 2 columns: the column **Year**, with data for all the years of predicted lifetime period (inputted in the *Scenario definition* tab), and the column **MassFlow** where the yearly data for the het demand side mass flow are entered (Figure 46).

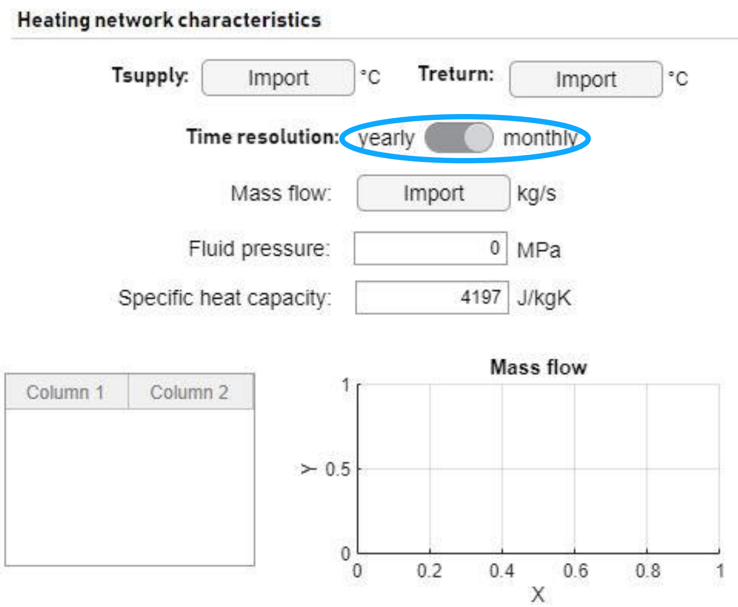

Figure 44. Screenshot of the Heating network characteristics panel

	A	B
1	Month	MassFlow
2	1	30
3	2	30
4	3	25
5	4	25
6	5	25
7	6	25
8	7	25
9	8	25
10	9	25
11	10	30
12	11	30
13	12	30

monthly

Figure 45. Example of heat demand side mass flow (monthly)

Tab: *INPUT sheet*

Sub-application: *End user option*

Panel: *Heating network characteristics*

Parameter 1: *Time*

Resolution: *monthly*

Number format: *mm*

Number format: *General*

Parameter 2: *MassFlow (kg/s)*

Number format: *General*

Document format: *.xlsx*

2	2019	325
3	2020	324
4	2021	323
5	2022	322
6	2023	321
7	2024	320
8	2025	319
9	2026	318
10	2027	320
11	2028	321
12	2029	321
13	2030	314
14	2031	313
15	2032	308
16	2033	304
17	2034	300
18	2035	296
19	2036	292
20	2037	288
21	2038	284

yearly

Figure 46. Example of heat demand side mass flow (yearly data) for lifetime period of 20 years

Tab: *INPUT sheet*

Sub-application: *End user option*

Panel: *Heating network characteristics*

Parameter 1: *Time*

Resolution: *yearly*

Number format: *yyyy*

Number format: *General*

Parameter 2: *MassFlow (kg/s)*

Number format: *General*

Document format: *.xlsx*

A5. COUNTRY SPECIFIC OUTSIDE TEMPERATURE DATA

In the *Geothermal power plant* sub-application, in the **Cold loop (condenser)** panel, the T_{inlet} and temperature is imported according to the outside **country specific monthly average** temperatures. The country specific data is imported based on the selected input parameter **Country** on the *Scenario definition* tab.

Cold loop inlet (inlet to the HEX) temperature can be imported as the monthly average temperatures or as constant value (Figure 47, blue arrows). By inserting the monthly (12 months basis) values, the air-cooled condenser type is modelled, and this parameter represent the geographic position of the geothermal site (Figure 48). By inserting the constant value, which is than applied to all the months, the water-cooled condenser type is modelled. When *constant mode* option is chosen, the user inserts the value in the $\mathbf{T_{inlet}}$ edit field, and when the *country specific monthly mode* option is chosen, the mean temperature of the inserted 12 months is shown in the T_{inlet} edit field.

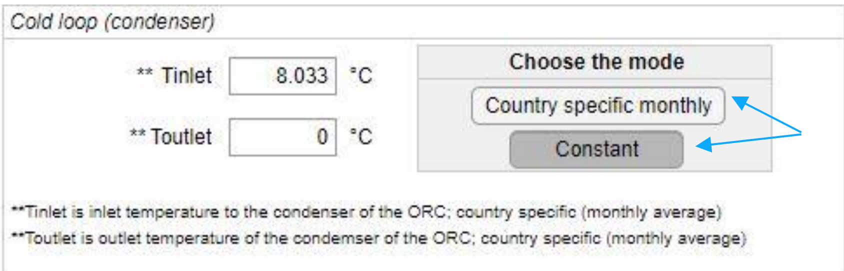

Figure 47. Screenshot of the cold loop HEX inlet temperature

According to the selected country, the application enters the already prepared country specific average temperatures as presented in table in Figure 48.

	A	B	C	D
1	Month	Average_temp	Avg_high_temp	Avg_low_temp
2	Jan	4	7.3	1.3
3	Feb	4.7	8.5	1.5
4	Mar	7.5	12.1	3.5
5	Apr	9.9	14.9	5.6
6	May	13.6	18.7	9.1
7	Jun	16.9	22.1	12.2
8	Jul	19.2	24.6	14.3
9	Aug	19	24.4	14.1
10	Sep	16.3	21.4	11.7
11	Oct	12.2	16.6	8.5
12	Nov	7.5	11.1	4.6
13	Dec	4.8	7.9	2.3

Figure 48. Example of default, country specific coolant (air) temperatures (for France)

Tab: *INPUT sheet*

Sub-application: *Geothermal power plant*

Panel: *Cold loop (condenser)*

Parameter 1: *Time*

Resolution: *Monthly*

Number format: *Jan - Dec*

Parameter 2: *Average_temp*

Number format: *General*

Document format: **.csv*

A6. IMPORTING ELECTRICITY AND/OR HEAT PRICES

In the *Financial parameters* sub-application, in the **Selling prices** panel, the user chooses between default values or imported values (Figure 49).

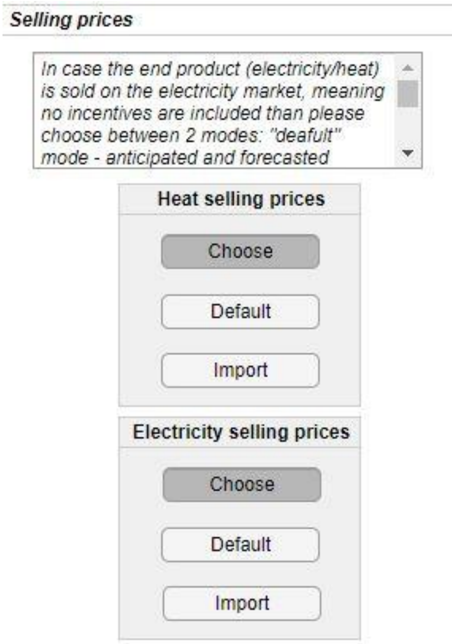

Figure 49. Selling prices panel

When **default** option is chosen, the forecasting calculates forecasted electricity and/or heat prices on a *monthly* or *yearly* basis – depending on the time resolution chosen in the *Scenario definition* tab. Calculated forecasted prices are stored in the variables and could later be visually represented in the *Financial metrics* tab.

When **import** option is chosen, the user should import forecasted prices prepared in a Comma separated **(*.csv)** file. When importing the user's forecasted prices for the period of project's lifetime, following Excel Comma separated template should be used: first column should be named ***Time*** and second column ***Price***. Time column should be in the date format and depending on the time resolution selected in the *Scenario definition* tab it should contain either monthly or yearly data for the whole lifetime period. If the selected time resolution is monthly, ***Time*** column should contain dates of every first day in the month for the whole desired/predicted lifetime of the project. The used date format should be *dd/mm/yyyy* (Figure 50). If the selected time resolution is yearly, ***Time*** column should contain dates of every first day of each year for the whole desired/predicted lifetime of the project (Figure 51).

Prices are expressed in **€/MWh**.

	A	B
1	Time	Price
2	01/01/2015	41.33
3	01/02/2015	50.15
4	01/03/2015	43.78
5	01/04/2015	39.54
6	01/05/2015	26.48
7	01/06/2015	32.1
8	01/07/2015	37.95
9	01/08/2015	32.16
10	01/09/2015	37.45
11	01/10/2015	45.2
12	01/11/2015	41.7
13	01/12/2015	35.13
14	01/01/2016	33.6
15	01/02/2016	25.53
16	01/03/2016	27.08
17	01/04/2016	25.48
18	01/05/2016	24.27
19	01/06/2016	28.01
20	01/07/2016	30.11
21	01/08/2016	29.69
22	01/09/2016	37.19
23	01/10/2016	54.59
24	01/11/2016	64.52
25	01/12/2016	59.26
26	01/01/2017	78
27	01/02/2017	51.16
28	01/03/2017	35.41
29	01/04/2017	34.77
30	01/05/2017	33.85
31	01/06/2017	32.71
32	01/07/2017	34.49
33	01/08/2017	31.74
34	01/09/2017	36.88
35	01/10/2017	50.16
36	01/11/2017	63.93
37	01/12/2017	56.77

Figure 50. Example - monthly data for forecasted electricity prices

Tab: *INPUT sheet*

Sub-application: *Financial parameters*

Panel: *Selling prices*

Parameter 1: *Date*

Resolution: *yearly/monthly*

Number format: *dd/mm/yyyy (every first day of each month/year)*

Parameter 2: *Price*

Number format: *General*

Parameter 2 unit: *€/MWh*

Document format: *.csv

	A	B
1	Time	Price
2	01/01/2015	41.33
3	01/01/2016	50.15
4	01/01/2017	43.78
5	01/01/2018	39.54
6	01/01/2019	26.48
7	01/01/2020	32.1
8	01/01/2021	37.95
9	01/01/2022	32.16
10	01/01/2023	37.45
11	01/01/2024	45.2
12	01/01/2025	41.7
13	01/01/2026	35.13
14	01/01/2027	33.6
15	01/01/2028	25.53
16	01/01/2029	27.08
17	01/01/2030	25.48
18	01/01/2031	24.27
19	01/01/2032	28.01
20	01/01/2033	30.11
21	01/01/2034	29.69
22	01/01/2035	37.19
23	01/01/2036	54.59
24	01/01/2037	64.52
25	01/01/2038	59.26
26	01/01/2039	78

Figure 51. Example - yearly data for forecasted electricity prices

Tab: *INPUT sheet*

Sub-application: *Financial parameters*

Panel: *Selling prices*

Parameter 1: *Date*

Resolution: *yearly/monthly*

Number format: *dd/mm/yyyy (every first day of each month/year)*

Parameter 2: *Price*

Number format: *General*

Parameter 2 unit: *€/MWh*

Document format: *.csv*

APPENDIX B

Used approaches and functions

2 APPENDIX B – USED APPROACHES AND FUNCTIONS

B1. EQUIPMENT COST CORRELATIONS

DMT module 'Equipment_cost_correlations', calculates plant equipment costs based on the cost approximations from literature [4], [5], [6], [7].

Calculating the turbine cost based on the (desired) installed capacity is achieved by Equations (1) and (2):

$$Ce_{Turbine} = 10^{\left(2.6259+1.4398 \cdot log_{10} P_{ORC} - 0.1798 \cdot log_{10}\left(P_{ORC}{}^{2}\right)\right)} \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_c}\right), \quad 70\ kW \leq P_{ORC} \leq 100\ kW \tag{1}$$

$$Ce_{Turbine} = \left(-14000 + 1900 \cdot (P_{ORC})^{0.75}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_b}\right), \quad 100\ kW < P_{ORC} \leq 20000\ kW \tag{2}$$

It must be noted that for ORC power less than 70 kW and greater than 20 MW related turbine costs must be directly inserted.

Calculating the generator cost based on the (desired) installed capacity is achieved by Equation (74):

$$Ce_{Generator} = 1850000 \cdot \left(\frac{1.1 \cdot P_{ORC}}{11800}\right)^{0.94} \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_d}\right) \tag{3}$$

Calculating the Heat exchanger (shell & tube with single shell pass, counter-flow cost based on the (desired) installed capacity for only heat production mode is achieved by Equations (75) and (76):

$$Ce_{HEX} = \left(2.8 \cdot 10^{4} + 54 \cdot (HEX_{Area})^{1.2}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_b}\right), \quad 10\ m^{2} \leq HEX_{Area} < 80\ m^{2} \tag{4}$$

$$Ce_{HEX} = \left(3.28 \cdot 10^{4} \cdot \left(\frac{HEX_{Area}}{80}\right)^{0.68}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_a}\right), \quad 80\ m^{2} \leq HEX_{Area} \leq 4000\ m^{2} \tag{5}$$

It must be noted that for HEX area less than 10 m^2 and greater than 4000 m^2 related HEX costs must be directly inserted.

In case of only electricity mode and CHP mode ORC HEX costs are calculated using Equation (6):

$$Ce_{HEXORC} = 16.75 \cdot P_{ORC} + 2250. \tag{6}$$

Calculating the pump costs based on the (desired) installed capacity for is achieved by Equation (7):

$$Ce_{Pumpcent} = \left(9.84 \cdot 10^3 \cdot \left(\frac{P_{Pump}}{4}\right)^{0.55}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_a}\right), \quad 4\ kW \leq P_{Pump} \leq 700\ kW \tag{7}$$

It must be noted that for pump power less than 4 kW and greater than 700 kW related pump costs must be directly inserted.

Calculating the wet cooling tower (WCT) costs based on the (desired) installed capacity is achieved by Equation (8):

$$Ce_{WCT} = \left(1.7 \cdot 10^5 \cdot 1500 \cdot \left(Cool_{flow}\right)^{0.9}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_b}\right), \quad 100\ l/s \leq Cool_{flow} \leq 10000\ l/s \tag{8}$$

It must be noted that for WTC flows less than 100 l/s and greater than 10000 l/s related WTC costs must be directly inserted.

Calculating the air-cooling condenser (ACCfan) costs, with fan, based on the (desired) installed capacity is achieved by Equation (9):

$$Ce_{ACCfan} = \left(1.23 \cdot 10^4 \cdot \left(\frac{Cool_{Power}}{50}\right)^{0.76}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_a}\right), \quad 50\ kW \leq Cool_{Power} \leq 200\ kW \tag{9}$$

It must be noted that for ACCfan power less than 50 kW and greater than 200 kW related ACC costs must be directly inserted.

Calculating the air-cooling condenser (ACC) without fan related costs based on the (desired) installed capacity is achieved by Equation (10):

$$Ce_{ACC} = \left(Ce_{ACC} = 1.56 \cdot 10^5 \cdot \left(\frac{Cool_{Area}}{200}\right)^{0.89}\right) \cdot 0.91 \cdot \left(\frac{INDEX2\_EQ}{INDEX1\_EQ\_a}\right), \quad 200\ m^2 \leq HEX_{Area} \leq 2000\ m^2 \tag{10}$$

It must be noted that for ACC area less than 200 m^2 and greater than 2000 m^2 related ACC costs must be directly inserted.

Where:

- P_{ORC} represents installed capacity of the ORC power plant in [kW],
- P_{Pump} represents power of the centrifugal pump that drives the working fluid [kW],
- HEX_{Area} represents area of the heat exchanger (U-tube shell & tube) [m^2],
- $Cool_{flow}$ represents flow of the cooling water in case of wet cooling tower (WCT) as condenser [l/s],
- $Cool_{Power}$ represents power of the cooling fan in case of air-cooling condenser (ACC) [kW],
- $Cool_{Area}$ represents area of the ACC condenser (excl. fan) [m^2],
- $INDEX1\_EQ\_a$ is equal to 435.8,
- $INDEX1\_EQ\_b$ is equal to 532.9,
- $INDEX1\_EQ\_c$ is equal to 397,
- $INDEX1\_EQ\_d$ is equal to 359.2 and
- $INDEX2\_EQ$ is equal to 753.3 or user defined.

B2. VOLUMETRIC METHOD APPROACH

The volumetric approach is a methodology for geothermal reserves assessment. It belongs to a group of methods that are not depending on the production history of the field and can therefore be used to estimate the reserves before the exploitation. The volumetric approach has been well established in geothermal industry and according to the authors in [8], the volumetric method is favourable above other methods as it is giving the most complete and reliable description of the accessible resource base.

This method uses estimates of subsurface temperature, volume, specific heat and density to calculate the accessible resource base and by multiplying this theoretically available thermal energy in the reservoir with recovery factor, the thermal energy that can be extracted at the wellhead can be estimated.

In the current version of the tool this approach has been modelled but is not used. The modelled approach will undergo upgrades and it is expected to be enabled in the later version of the tool.

B2.1. Capacity_sizing module description (the volumetric approach)

This module calculates the maximum installed capacity in the fixed years. This approach has been slightly modified from the approach used in the ENGINE tool [9]. This model follows the assumption that the energy produced each year by the power plant at surface is a part of the whole energy available in the reservoir. Based on this assumption, two main strategies can be developed, either to fix the number of years for the complete use of the energy stored which gives the maximum installed power plant capacity, or to fix the power plant capacity which then gives the maximum number of years that the reservoir can be used before its complete depletion.

First the stored thermal energy is calculated as:

$$W_{stored} = c_{res} \cdot V_{res} \cdot \rho_{res} \cdot (\overline{T_{surfout}} - T_{surface}), \tag{11}$$

$$c_{res} = c_R \cdot (1 - \phi) + c_F \cdot \phi, \tag{12}$$

$$\rho_{res} = \rho_R \cdot (1 - \phi) + \rho_F \cdot \phi, \tag{13}$$

$$V_{res} = A \cdot H\ , \tag{14}$$

where the c_{res} and ρ_{res} represent the specific heat and the density of the reservoir, which is basically a balance between the rocks, (c_R and ρ_R), and fluid (c_F and ρ_F), driven by the porosity ϕ. The V_{res} is the volume of the rocks, calculated as the product of A, reservoir area and H, thickness of the reservoir. The $\overline{T_{surfout}}$ is the average resource temperature at the wellhead (surface), and $T_{surface}$ is the average surface (ambient) temperature.

The energy which can then be recovered from the stored thermal energy is:

$$W_{rec} = r_{res} \cdot W_{stored}\ , \tag{15}$$

where the r_{res} represents the heat recovery factor.

When the stored thermal energy is calculated, the surface, i.e. plant parameters can be determined. For first strategy, which is implemented in this module, the maximum installed plant capacity is calculated. Firstly, the thermal efficiency of conversion is calculated. For electricity generating power plants, the efficiency of the binary power plant is calculated following [10] and is partitioned in a relative Carnot efficiency and the maximum theoretical Carnot efficiency:

$$\eta_{cycle} = \eta_{rel,carnot} \cdot \frac{T_{surfout} - T_{surface}}{(T_{surfout} + 273.15) + (T_{surface} + 273.15)} \tag{16}$$

For the heating power production, the conversion efficiency is assumed to be 90%. Now, the maximum installed plant capacity can be calculated:

$$P_{max\_ins\_cap} = \frac{W_{rec} \cdot \eta_{cycle}}{f_p \cdot f_r \cdot T \cdot tyts}\ , \tag{17}$$

where, f_p is the plant capacity factor (for geothermal plants is usually very high), f_r is reservoir capacity factor, T is fixed number of years and $tyts$ is time conversion factor:

$$tyts = 365 \cdot 24 \cdot 3600 \quad (18)$$

B3. HEAT CALCULATION

This DMT module is used for calculation and comparison available geothermal heat and required head demand. It is used both for 'Only heat' and 'CHP production in series - topping' production modes that are already described. Figure 52. depict the basic details and parameters that are relevant for this module:

- U_{HEX} - overall heat transfer coefficient of heat exchanger, in [W/m^{2}K],
- c_{HD} - heat demand fluid specific heat, in [J/kg K],
- c_b - geothermal brine specific heat, in [J/kg K],
- m_{HD} - heat demand fluid stream mass flow, in [kg/s],
- m_b - geothermal brine stream mass flow, in [kg/s],
- T_{inb} - geothermal brine temperature at inlet of HD heat exchanger, in [°C],
- T_{outb} - geothermal brine temperature at outlet of HD heat exchanger, in [°C],
- T_{inHD} - heating fluid temperature at inlet of HD heat exchanger, in [°C],
- T_{outHD} - heating fluid temperature at outlet of HD heat exchanger, in [°C],
- ETA_HEX - heat exchanger heat loss coefficient, in [%] and
- T_0 - dead state temperature in [°C].

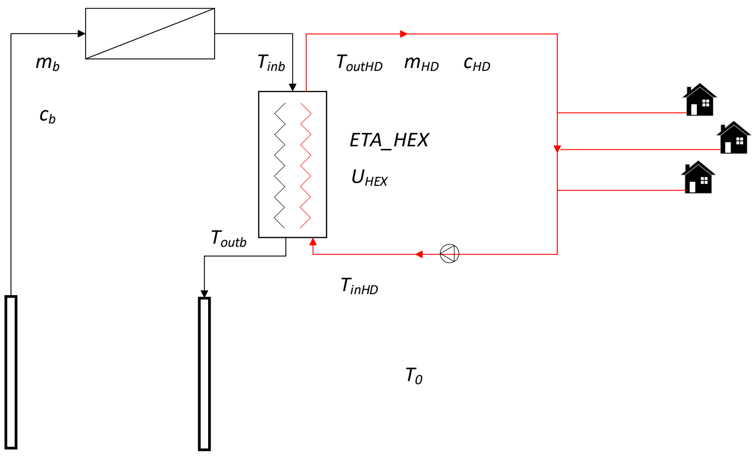

Figure 52: HEAT_CALCULATION module graphical description

This module will alarm error in following impossible cases:

- in case that T_{inHD} is lower than T_0 and
- in case that T_{inb} is lower than T_{outHD}.

Only in theory, considering perfect heat exchanger, T_{inb} could be equal to T_{outHD}. That is never the case in practice. Therefore, there certain temperature safe margin (*TSM*) should be set (by end-user) that is equal to the difference between T_{inb} and T_{outHD}. In scope of DMT approach it is assumed that Difference between T_{inb} and T_{outHD} and between T_{outb} and T_{inHD} are the same.

Geothermal brine temperature at the outlet of HD heat exchanger is calculated using Equation (19):

$$T_{outb} = T_{inb} - \frac{\frac{m_{HD} \cdot (T_{outHD} - T_{inHD}) \cdot c_{HD}}{ETA\_HEX}}{m_b \cdot c_b}. \tag{19}$$

Heat demand ($HD_S(i)$) that can be satisfied for each of *T* time steps (*i*) is calculated in [kWh] using Equation (20):

$$HD_S(i) = \frac{(T_{inb}(i) - T_{outb}(i)) \cdot m_b(i) \cdot c_b \cdot ETA\_HEX}{1000}. \tag{20}$$

It must be noted that in the case when time step is one month, such as in current DMT version, heat demand that can be satisfied from Equation (20) should be multiplied by 730 (average monthly number of hours).

Heat fluid mass flow ($m_{HDS}(i)$) that can be satisfied for each of *T* time steps (*i*) is calculated in [kg/s] using Equation (21):

$$m_{HDS}(i) = \frac{(T_{inb}(i) - T_{outb}(i)) \cdot m_b(i) \cdot c_b \cdot ETA\_HEX}{(T_{outHD}(i) - T_{inHD}(i)) \cdot c_{HD}}. \tag{21}$$

In cases when required mass flow of heating fluid ($m_{HD}(i)$) is lower than heat fluid mass flow that can be satisfied $m_{HDS}(i)$ warning message will be issued to inform end-user appropriately.

This DMT module also activates and incorporates the previously described module 'HEX_AREA_CALCULACTION'. This function is used for suggestions on heat exchanger dimensioning regarding precalculated heat demand and geothermal fluid parameters in the scope of 'HEAT_CALCULATION' module. End-user is informed on following suggested heat exchanger parameters:

- *HEX_AREA* - Heat exchanger heat transfer area [m^2],
- *HEX_epsilon* - Heat exchanger heat transfer efficiency [%] and
- *P_HEXHD* - Heat exchanger power for heat transfer [kW].

Finally, this module also calculates efficiency, in [%], (*ETA_HD(i)*) for 'Only heat' production mode for each of *T* time steps (*i*) using Equation (22):

$$ETA\_HD(i) = \frac{HD_S(i) \cdot 100 \cdot 1000}{(T_{inb}(i) - T_{outb}(i)) \cdot m_b(i) \cdot c_b}. \tag{22}$$

It must be noted that in the case when time step is one month, such as in current DMT version, efficiency for 'Only heat' production mode from Equation (22) should be divided by 730 (average monthly number of hours).

B4. ELECTRICITY PRODUCTION – ORC

B4.1. Electricity production

This DMT module is used for evaluation of ORC power plant net electricity production for each of *T* time steps. ORC type of binary geothermal power plants requires deep thermodynamic expertise in the field of thermodynamics that is beyond UNIZG-FER scope of expertise. Therefore, as planned in the project proposal, ENOGIA partner in MEET consortium contributed greatly to development of this DMT module. Namely there are numerous, more or less complex conceptual models of ORC power plant operation available in literature [11], [12], [13], [14]. There are different approaches in ORC heat exchanger construction (with or without preheating of working fluid), working fluid utilization and others. Regarding ENOGIA's partner expertise, especially in practical terms, and their ORC models that are tested in real applications, empirical approach was undertaken while creating this DMT module. Regarding restrictions on ENOGIA models that are used for commercial purposes and proprietary rights, UNIZG-FER was provided with excel files filled with significant number of discrete operational points of ORC power plant that was precalculated from their models. With known geothermal mass flow, m_b, and extraction temperature T_{1b}. Following parameters are necessary in order to evaluate net ORC power plant production:

- *DT* - difference of temperature on primary (geothermal brine loop) side of ORC dedicated heat exchanger. This parameter is defined by end-user.
- $ETA_{ORC}(T_{1b}, DT)$ - net ORC power plant efficiency as function of geothermal brine extraction temperature and *DT* and
- $F_{COOL}(T_{1b}, DT)$ - net ORC power plant efficiency correction factor that takes into account different temperatures of ORC cycle coolant as function of geothermal brine extraction temperature and *DT*.

As it can be observed, both ETA_{ORC} and F_{COOL} are functions of two variables. In addition, there was limited number of ORC operating points available from ENOGIA. For that reason, 'MATLAB Curve Fitting Tool' was used to approximate these three-dimensional relationships. Polynomial approximation including third degree was performed.

Regarding this excellent fitting parameters, it was decided that chosen approximation for three-dimensional relationships between net ORC power plant efficiency, brine extraction temperature and *DT* is applicable for utilization in DMT.

Regarding this excellent fitting parameters, it was decided that chosen approximation for three-dimensional relationships between net ORC power plant efficiency correction factor, ORC cycle coolant temperature and *DT* is applicable for utilization in DMT.

B4.2. Installed power

This DMT module is used for evaluation of ORC power plant parameters regarding possible installed capacities. It provides end-user with several values regarding site-specific available installed ORC power plant capacity. It uses similar approach as 'ORC_POWER_PRODUCTION' module. Namely, this module is used to check and calculate available ORC power for each time step *i*, using equation (23):

$$Pow_{ORC}(\mathrm{i}) = m_b(\mathrm{i}) \cdot c_b \cdot DT(i) \cdot ETA_{ORC}(\mathrm{i}) \cdot F_{COOL}(\mathrm{i}), \qquad (23)$$

In this module parameter *DT(i)* is set by end-user and in cases that it is constrained by dead state temperature (T_0) its value is adjusted and used for calculation.

This module provides end-user with following values that can be used as directives for selection of appropriate ORC power plant installed capacity:

- *MAX_ORC_POWER* - maximum value of available ORC power plant production over each of *T* time steps,
- *MIN_ORC_POWER* - minimum value of available ORC power plant production over each of *T* time steps and
- *AVG_ORC_POWER* - average value of available ORC power plant production over each of *T* time steps.

Parameter *MAX_ORC_POWER* is obtained by equation (24):

$$MAX\_ORC\_POWER = max\big(Pow_{ORC}(\mathrm{i})\big), \;\; i \in (1, T). \qquad (24)$$

Parameter *MIN_ORC_POWER* is obtained by equation (25):

$$MIN\_ORC\_POWER = min\big(Pow_{ORC}(\mathrm{i})\big), \;\; i \in (1, T). \qquad (25)$$

Parameter *AVG_ORC_POWER* is obtained by equation (26):

$$AVG\_ORC\_POWER = avg\big(Pow_{ORC}(\mathrm{i})\big),\ \ i \in (1, T). \quad (26)$$

The user interface is developed in such manner that end-user can pick any value for ORC power plant installed capacity in range from *MIN_ORC_POWER* to *MAX_ORC_POWER* in [kW].

B5. CHP CONFIGURATIONS

B5.1. CHP production in series - topping

According to [15] there are two main types of cogeneration cycle: a topping cycle and a bottoming cycle and the topping cycle is considered as the only economic cycle of the two due to fact that the bottoming cycle is not very efficient.

Topping CHP production mode assumes that fuel (geothermal energy) is firstly used to produce electricity via ORC loop. Remaining geothermal energy in brine is used to produce thermal energy. Topping CHP production is widely used and is considered as the most common method of cogeneration.

On the other hand, in a bottoming CHP production cycle, fuel (geothermal energy) is firstly used to produce industrial, usually very high high-temperature heat. Residual heat is used to generate power via ORC loop. Bottoming CHP production cycle facilities are less common when compared to topping CHP production cycle facilities. Bottoming cycles utilize high-enthalpy heat is used directly for process needs (e.g., cement, steel, ceramic, gas and petrochemical industries), and low-enthalpy waste heat is used to generate electricity. Considering low (60°C-90°C) to medium (90°C-150°C) geothermal wells as targets for MEET project bottoming CHP cycles might be integrated into DMT in the further development stages [16].

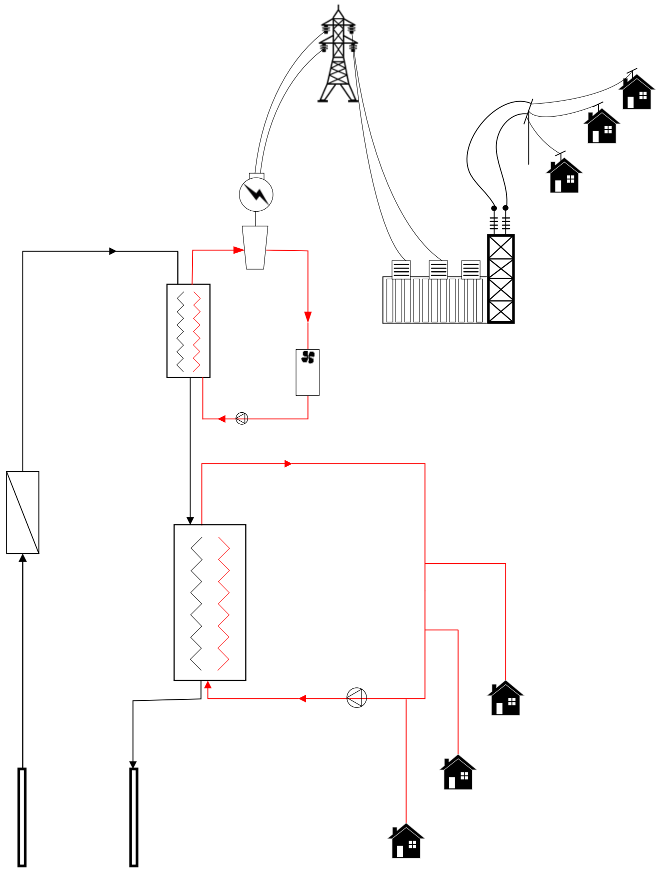

Figure 53: CHP production in series - topping production mode

Combined heat and power (electricity) or CHP in series - topping cycle production mode of final energy assumes that geothermal energy extracted from the geothermal reservoir and brought by geothermal brine is used for both power system demand and heating purposes.

Same as in only heat production mode different heat demands require different heat parameters and same as in only electricity production mode electricity produced via ORC loop it is standardized product ready to be delivered to the power system.

This production mode is more complex in comparison to the previous two described modes. It consists of three circulating loops as shown in Figure 53. Hot circulating loop is represented by geothermal fluid loop that flows through pipelines from well to the heat exchanger (left part on Figure 53). In ORC heat exchanger heat is transferred to colder organic working fluid that transforms thermal energy to electricity in turbine using Rankine cycle procedure. Condensed and cooled working ORC fluid re-enters ORC heat exchanger where it is preheated and evaporated using heat from geothermal brine. Remaining heat in geothermal brine that is exiting ORC heat exchanger is forwarded to heat exchanger for heat demand in which geothermal energy is transferred to colder circulating loop used for delivery of transferred heat to final heat consumers.

Due to the fact that geothermal brine exiting from ORC heat exchanger brings low-enthalpy brine to the heat exchanger intended for the heat demand apart from the production well brine, this mode can be also named as 'electricity preferring production mode'. Therefore, this mode is suitable for sites where the higher brine temperature is needed compared to the sites where only heat production mode is necessary when ORC technology can achieve sustainable efficiency and there are appropriate conditions for both, connection to the power grid and satisfaction of demand from heat consumers in a reachable area.

It must be noted that this mode will not be suitable for heat demand requiring larger heating temperatures due to brine temperature decrease through ORC heat exchanger and the fact that same mass flow of geothermal brine is going through ORC and heat demand heat exchangers. For this reason, this mode is called CHP in series. Same as for only electricity mode this mode also requires availability of economically and technically feasible connection to power grid.

Main costs in this production mode (apart from drilling costs) are costs related to ORC loop technology (heat exchanger usually included into the package), heat exchanger for heat demand and also construction of connection to power grid. Same as in only electricity mode loses in connection lines additional impose negative effects on feasibility of EGS project considering this specific production mode.

Based on inputs on heat demand, available brine temperature, brine mass flow and difference of inlet and outlet brine temperature through ORC heat exchanger user will be provided by results that give information on potentially available output power from generator in ORC loop and consequently information on potentially unsatisfied heat demand and basic recommendations regarding heat exchanger for heat demand dimensioning. By changing the difference of inlet and outlet brine temperature through ORC heat exchanger, as dimensioning parameter, user can try to find most satisfying solution and make balance between electricity and heat production. Lowering this temperature difference will surely decrease available net ORC output power but will simultaneously provide geothermal energy for heat demand with higher temperature. Decreasing temperature difference will have opposite effects.

B5.2. CHP production in parallel

Combined heat and power (electricity) or CHP in parallel production mode of final energy, assumes that geothermal energy extracted from geothermal reservoir and brought by geothermal brine is used for both power system demand and heating purposes.

Same as in previously presented CHP production mode in series, different heat demands require different heat parameters and electricity produced via ORC loop which is standardized product ready to be delivered to power system.

This production mode is also more complex in comparison to only heat or only electricity modes but somewhat equally complex as CHP production mode in series. In comparison to CHP production mode in series, this production mode actually consists of four circulating loops as shown in Figure 8. Two separate (parallel) hot circulating loops are represented by geothermal fluid loops that flow through pipelines from well to ORC heat exchanger in one loop and to heat exchanger for heat demand in another loop (left part on the Figure 54.). In ORC heat exchanger part of geothermal heat is transferred to colder organic working fluid that transforms thermal energy to electricity in turbine using Rankine cycle procedure. Condensed and cooled working ORC fluid re-enters ORC heat exchanger where it is preheated and evaporated using heat from geothermal brine. The other part of geothermal heat (with the same temperature as for ORC loop) in geothermal brine is forwarded to heat exchanger for heat demand in which geothermal energy is transferred to colder circulating loop used for delivery of transferred heat to final heat consumers.

In comparison to CHP production mode in series, where temperature of the geothermal fluid entering heat exchanger for heat demand is lower than brine temperature from injection well. In this production mode part of injection geothermal brine is used for heat demand and other part, with same temperature but different mass flow is used for electricity production via ORC loop. Therefore, this production mode can be also labelled as 'heat demand preferring production mode'. This mode is also suitable for sites with higher available brine temperature compared to only heat production mode when ORC technology can achieve sustainable efficiency and there are appropriate conditions for both connection to power grid and satisfaction of demand from heat consumers in reachable area.

In contrast to CHP in series production mode this mode will be suitable for heat demand requiring larger heating temperatures due to fact that parts of injection geothermal brine mass flow with same temperature are directed both to ORC heat exchanger and heat demand heat exchangers. For this reason, this mode is called CHP in parallel. Same as for only electricity mode this mode also requires availability of economically and technically feasible connection to power grid.

Again, main costs in this production mode (apart from drilling costs) are costs related to ORC loop related technology (heat exchanger usually included into the package), heat exchanger for heat demand and also construction of connection to power grid. Same as in only electricity mode loses in connection lines additionally impose negative effects on feasibility of EGS project considering this specific production mode.

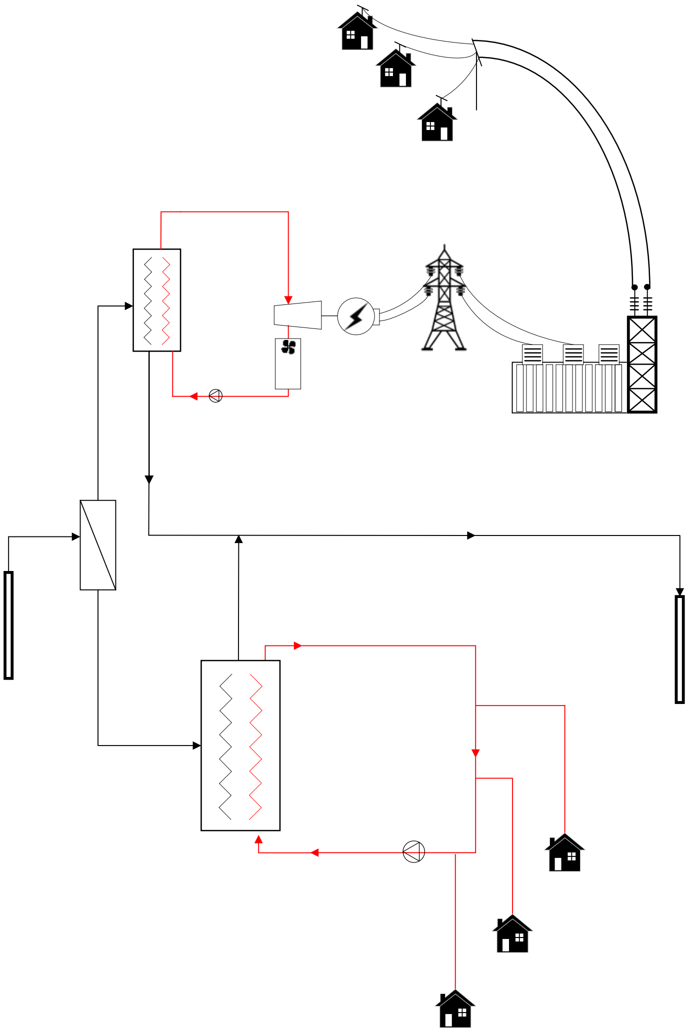

Figure 54. CHP production in parallel

Based on inputs on heat demand, available brine temperature, brine mass flow and difference of inlet and outlet brine temperature through ORC heat exchanger user will be provided by results that give information on potentially unsatisfied heat demand and basic recommendations regarding heat exchanger for heat demand dimensioning and consequently information on potentially available output power from generator in ORC loop. This production mode is very sensitive to potentional seasonal character of heat demand. If, for example, there is large heat demand for district heating during the winter season and low or neglectable heat demand for district heating during summer season available brine mass flow and thermal energy for ORC loop will be also different based on seasonal character. In this case user will be able to decide on final ORC installed capacity based on pre-calculation with results on minimum, maximum and average available ORC loop power. If ORC nominal power is based on maximum available power (in summer season) capacity utilization factor of ORC power plant will be expectably low and therefore expected LCOE will be relatively high. On the other hand, if ORC nominal power is based on minimum available power (that in winter season) capacity utilization factor of ORC power plant will be almost 100%, but in this case, there is potentially too much thermal energy thrown away. In these situations, DMT user can check several options for nominal installed capacity of ORC power plant and decide on that with best overall economic and other indicators.

B6. FINANCIAL ANALYSIS

Before building a new power plant or taking on a new project, prudent managers conduct a cost-benefit analysis (CBA) to evaluate all the potential costs and revenues that a company might generate from the project. The outcome of the analysis will determine whether the project is financially feasible or if the company should pursue another project.

CBA is an analytical tool for judging the economic advantages or disadvantages of an investment decision by assessing its costs and benefits in order to assess the welfare change attributable to it. Moreover, a CBA involves measurable financial metrics such as revenue earned, or costs saved as a result of the decision to pursue a project. In other words, financial analysis is one of the essential steps in the project appraisal. According to [17], financial analysis is carried out to:

- assess the consolidated project profitability,
- assess the project profitability for the project owner and some key stakeholders,
- verify the project financial sustainability, a key feasibility condition for any typology of project, and
- outline the cash flows which underpin the calculation of the socio-economic costs and benefits.

The financial analysis methodology used in the DMS-TOUGE is the **Discounted Cash Flow (DCF) method**. Only **cash inflows** and **outflows** are considered in this financial analysis, i.e. depreciation, price and technical contingencies and other accounting items which do not correspond to the actual flows are disregarded. Moreover, financial analysis should be, as a general rule, carried out from the point of view of the infrastructure owner (investor). An appropriate **nominal discount rate** is adopted (default or user defined and calculated based on the discount rate and inflation rate) in order to calculate the present value of the future cash flows. Both purchase costs and revenues from sales are included as **net of VAT**. Direct taxes (on capital, income or other) are considered only for the financial sustainability verification and not for the calculation of the financial profitability, which is calculated before such tax deductions. The rationale is to avoid capital income tax rules complexity and variability across time and countries. Financial analysis in the DMS-TOUGE is carried out in 3 main steps:

1. calculating the Net present value on investment (NPV(C)) and Internal rate of return on investment (IRR(C)),
2. calculating the financial sustainability, and
3. calculating the Net present value on capital (NPV(K)) and Internal rate of return on capital (IRR(K)).

The structure of the financial analysis and input data included in each step is depicted in Figure 55.

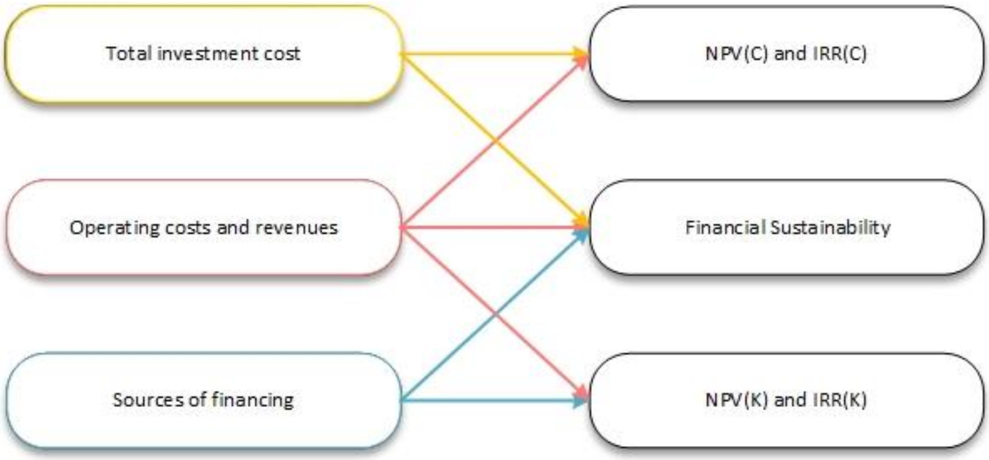

Figure 55. Structure of financial analysis

B6.1. NPR and IRR calculation

Determined investment costs, operating and maintenance cost and revenues, and sources of financing enable the assessment of the project profitability, which is measured by two key indicators:

- net present value– NPV(C) - and internal rate of return– IRR(C) - **on investment**;
- net present value– NPV (K) - and internal rate of return - IRR (K) - on **national capital**.

The NPV(C) is defined as the sum that results when the expected investment and operating costs of the project (discounted) are deducted from the discounted value of the expected revenues:

$$NPV(C) = \sum_{t=0}^{T} a_t \cdot S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_T}{(1+i)^T}, \quad (27)$$

where the S_t is the balance of cash flow (inflows minus outflows) at the time t, a_t is the financial discount factor chosen for discount at the time t, and i is the nominal discount factor.

The IRR(C) on investment is defined as the discount rate that produces a zero NPV, i.e. it is calculated with the following equation 28:

$$0 = \sum_{t=0}^{T} \frac{S_t}{(1+IRR)^t} \quad (28)$$

The NPV(C) is expressed in the money terms [€], and the IRR(C) is expressed in percentage. When the IRR(C) is lower than the applied discount rate or the NPV(C) is negative, the generated revenues will not cover the costs and the project needs assistance (mainly EU).

As mentioned, net present value and return on investment is calculated considering only **investment costs** and **operating costs** as **outflows**, and **revenues** and **residual value** as **inflows**. Thus, the costs of financing are not included in these calculations.

The return on national capital is calculated considering as **outflows**: the **operating costs**, the **national (public and private) capital contributions** to the project, the **other financial resources** from loans at the time in which they are reimbursed, and the related interest on loans. The **inflows** are the **operating revenues** only (if any) and the **residual value**.

The financial net present value of capital, NPV(K), in this case, is the sum of the net discounted cash flows that accrue to the national beneficiaries (public and private combined) due to the implementation of the project. The corresponding financial rate of return on capital, IRR(K), of these flows determines the return in percentage points.