RESTORE

Renewable Energy based seasonal Storage Technology in Order to Raise Economic and environmental sustainability of DHC

# D1.4 - Report on Specifications of Use-Cases and Models

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# Summary

This document provides information about the requirements and specifications of the Use-Cases and Models of the different innovative components presented in the RESTORE solution (the thermochemical storage system and the thermodynamic cycles).

Deliverable D1.4 is the result of the work carried out in Task 1.4 “Specifications of RESTORE Numerical Models and Virtual Use-Cases for Simulation” of WP1 (RESTORE Requirements Definition, Specifications and Analysis). The main purpose of this report is to describe the relevant specifications for the numerical models developed within RESTORE Project, giving emphasis to the models that are used in the six defined virtual use-cases for RESTORE. For this, D1.4 gathers specifications, such as feasible computational effort, compatibility between models, adaptability to the web-platform, modularity and flexibility.

The information provided in this document builds up on the general guideline of Deliverable D1.1 of the RESTORE overall concept, and focuses on its modelling, emphasizing the simulation concept of the project and the adaption of the simulation tools for the design of each use-case in an ad-hoc solution, considering the boundary conditions imposed by each specific application. In this context, the document provides the general basis to be considered as a guide during the project process modelling and use-cases implementation.

To highlight the importance of specifying the numerical models and virtual use-cases for simulation in the project, we provide here the various inter-dependencies that RESTORE T1.4 task has within the overall development. It delivers results to, and receives inputs from, the following tasks: WP2-T2.5 (led byTUW) - about the TCES dedicated models for the reactor simulation; WP3-T3.4 (led by POL) – about the off-design performance quantification of RESTORE system; WP3-T3.5 (led by POL) - about the dedicated models for the thermodynamic cycle and the dynamic behavior of RESTORE system; WP5-T5.1 (led by SIM) - about modelling the individual components of the overall RESTORE system; WP5-T5.2 (led by CENER) - about the techno-economic modelling of the RESTORE integrated systems; WP5-T5.3 (led by SIM) - about the Web-Platform adaptation for RESTORE dynamic and techno-economic modelling to represent the Use-Cases; task WP5-T5.4 (led by SIM) - about Implementation, Optimization, Management & Validation of RESTORE Use-Cases using the Simulation Web Platform; WP5-T5.5 (led by SIM + PI) – about the replication strategy of the simulated process models via the opportunity of other stakeholders build additional test cases; and WP7-T7.4 (led by PI) about stakeholders engagement & ecosystem community building.

Deliverable D1.4 production was led by SIMTECH, in collaboration with POLIMI and CENER (leader of WP1).

# Table of Contents

# 1. Introduction

This document (D1.4) focuses on the specifications of RESTORE Use-Cases and Models, as a result of the work carried out in Task 1.4 “Specifications of RESTORE Numerical Models and Virtual Use-Cases for Simulation” of WP1 (RESTORE Requirements Definition, Specifications and Analysis). D1.4’s main purpose is to define the relevant specifications for the numerical models developed within the RESTORE Project, with emphasis on the models that are used in the six defined virtual use-cases for RESTORE, ensuring important aspects like: feasible computational effort, compatibility, and adaptability to the web-platform for the use-cases, as well as the feasibility of the RESTORE numerical models and of the Virtual Use-Cases platform.

The specifications gathered in this report highlights the important inter-dependencies that task T1.4 has within the overall RESTORE project development. T1.4’s outcomes will be beneficial to the following tasks: WP2-T2.5 (led byTUW) - about the TCES dedicated models for the reactor simulation; WP3-T3.4 (led by POL) – about the off-design performance quantification of RESTORE system; WP3-T3.5 (led by POL) - about the dedicated models for the thermodynamic cycle and the dynamic behavior of RESTORE system; WP5-T5.1 (led by SIM) - about modelling the individual components of the overall RESTORE system; WP5-T5.2 (led by CENER) - about the techno-economic modelling of the RESTORE integrated systems; WP5-T5.3 (led by SIM) - about the Web-Platform adaptation for RESTORE dynamic and techno-economic modelling to represent the Use-Cases; task WP5-T5.4 (led by SIM) - about Implementation, Optimization, Management & Validation of RESTORE Use-Cases using the Simulation Web Platform; WP5-T5.5 (led by SIM + PI) – about the replication strategy of the simulated process models via the opportunity of other stakeholders build additional test cases; and WP7-T7.4 (led by PI) about stakeholders engagement & ecosystem community building.

The work carried out in task T1.4 followed the phases described below in relation to four periods of time from M3 to M24, up to Deliverable D1.4‘s submission (M24 - Sept. 2023).

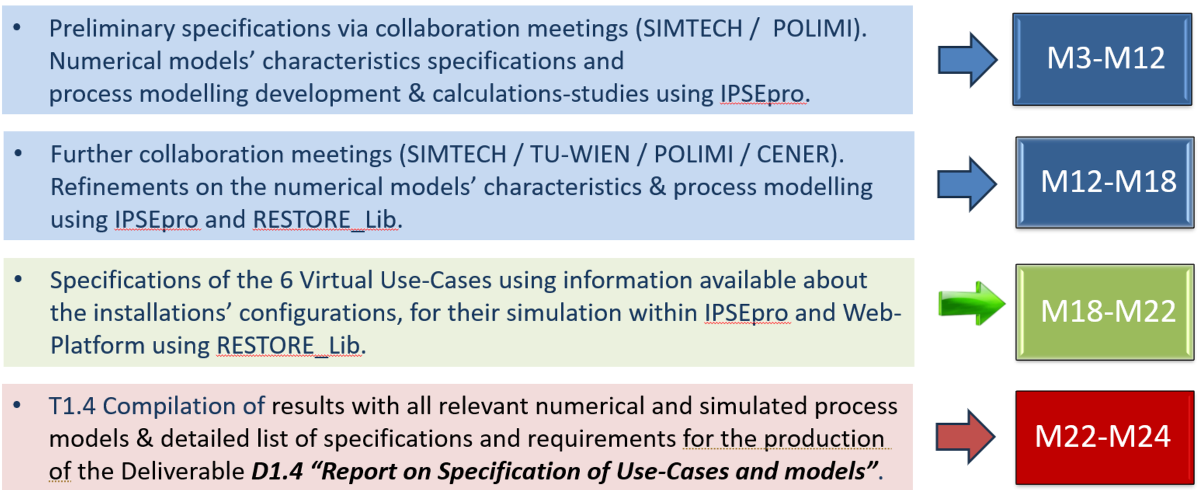



*Figure 1: Task T1.4 Work Phases.*

D1.4 is structured in the following way: The Introduction chapter (1) includes a brief description of how the simulation is considered in the concept of RESTORE; and presents an overview about the IPSEpro simulation environment and the IPSE GO web-platform, which serves as the "RESTORE Virtual Tool". Section (2) describes the relevant aspects of the specifications and requirements for the implementation of the process models. Section (3) presents the RESTORE current models already available in the IPSE GO environment, and the overall goals of the simulation procedure. Section (4) introduces the RESTORE library and the models included in it. Section (5) presents an overview of the six RESTORE Use-Cases. Section (6) summarizes the data required for the use-cases implementation. Section (7) draws some concluding remarks about the work carried out in task T1.4 and its impact within the RESTORE project. Section (8) lists the references upon which the work done was based. Finally, six annexes (Annex I – Annex VI) show illustrations in large format of the RESTORE Virtual Tool and its available process models and components library (RESTORE_Lib).

## 1.1. Simulation within RESTORE

The RESTORE concept will be not only validated in lab-scale, but it will also be virtually represented into applications with district heating and cooling networks. The virtual demonstration of the real use-cases will fully showcase the capability of the project concept in scaled-up scenarios. For this to happen, the overall RESTORE system will be virtually implemented and optimized using SIMTECH's simulation tools (IPSEpro and IPSE GO), and incorporated in the six specific Use-Cases defined for the project.

### 1.1.1. The IPSEpro Simulation Environment

**IPSEpro** is an open modelling framework, which handles components' mathematical representations and physical property methods apart from its solver module. Hence, application specific information is maintained in model libraries, completely separate from the core software (see Figure 2), bringing a high degree of flexibility and sustainability to both projects and system maintenance.

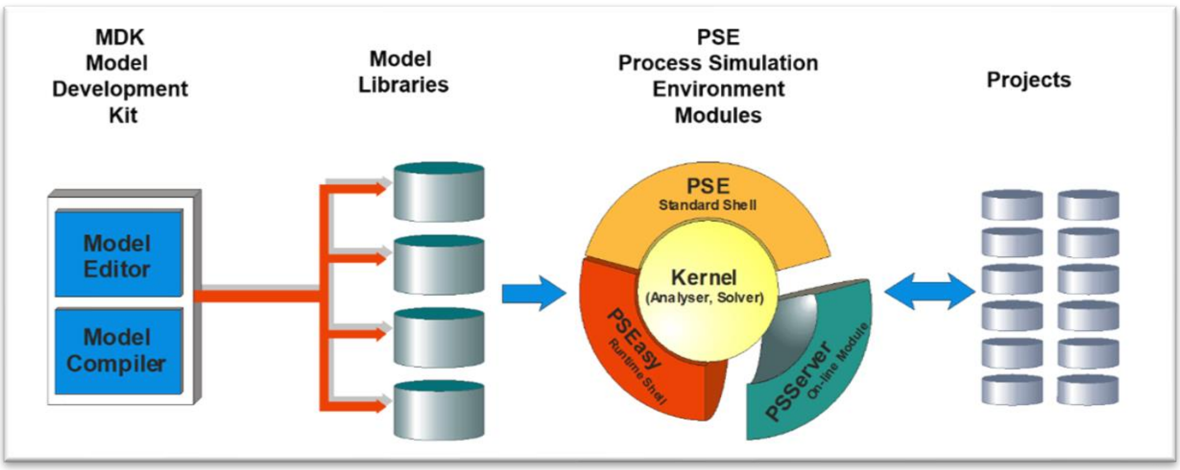



*Figure 2: IPSEpro Core System (incl. MDK, PSE, and other IPSEpro Modules - [https://www.simtechnology.com/cms/ipsepro/program-modules](https://www.simtechnology.com/cms/ipsepro/program-modules)).*

**PSEpro-MDK:** Using MDK, one can create and modify Model Libraries, and new component-models of existing equipment to populate the Model Library of components that will be used in modelling processes to simulate a scenario or plant configuration.

For using MDK to create component models for a library, information about the parameters and behaviour of the physical components (e.g.: turbines, heat-exchangers, pumps, etc.) are needed, and a user-friendly interface is provided with a built-in intuitive equations-oriented model development language (MDL) and a graphics editor for designing the graphic representation (icon) of the defined component.

**IPSEpro-PSE:** Using PSE, the end-user can build process models of the needed plant configuration to be simulated, using the flowsheet environment available in PSE and a Model Library available (or created in a customized way) for his/her project within the chosen/specified application area.

### 1.1.2. The IPSE GO Web-Platform

**IPSE GO** (https://about.ipsego.app/) is a cloud-based simulation platform, which can be interpreted as an online version of IPSEpro-PSE. The web-based platform IPSE GO[1] uses the capabilities of the process simulation system IPSEpro via the web. IPSE GO was designed to run in all internet browsers, from any device you may wish to work with (computers, mobile devices, etc.) with and intuitive user interface that can handle the complexity of the industrial level within a user-friendly way. IPSE GO offers a highly flexible modelling environment with numerous components from available Model Libraries that allow you to calculate almost any application area in process simulation. A strong advantage of using IPSE GO is the "effortless collaboration" aspect that it offers to all its users. In this respect, sharing IPSE GO projects with coworkers, project partners or students, happens in a fast and easy way within a simple click.

In RESTORE, the final 6 Use-Cases representations will be made publicly available online via SIMTECH's web-platform IPSE GO, based on SIMTECH's process simulation environment IPSEpro. The IPSE GO web-based simulation platform has been customized for the RESTORE project (WP5-T5.3) to demonstrate the capabilities of the overall project concept, allowing for an optimized virtual implementation and performance of the overall RESTORE process model and use-cases. This process involves the following steps that have been carried out within RESTORE by SIMTECH and the involved collaboration partners: (a) definition of the required individual component models that then can be arranged and interconnected as required to represent the system process model (WP5-T5.1); (b) creation of a dedicated component model library for RESTORE (RESTORE_Lib) and simulation of the technology integrated system (WP5- T5.1 & T5.2); as well as (c) set up of the Use-Cases on the basis of the pre-defined customized component models within RESTORE_Lib (WP5-T5.4).

[1] Initial implementation of IPSE GO, named as the IPSEpro Online Framework, was partially developed in the EU project MIDES No. 685793, was evaluated by the European Commission Innovation Radar and acknowledged as "Excellent Innovation" with "High" market creation potential in June 2020.

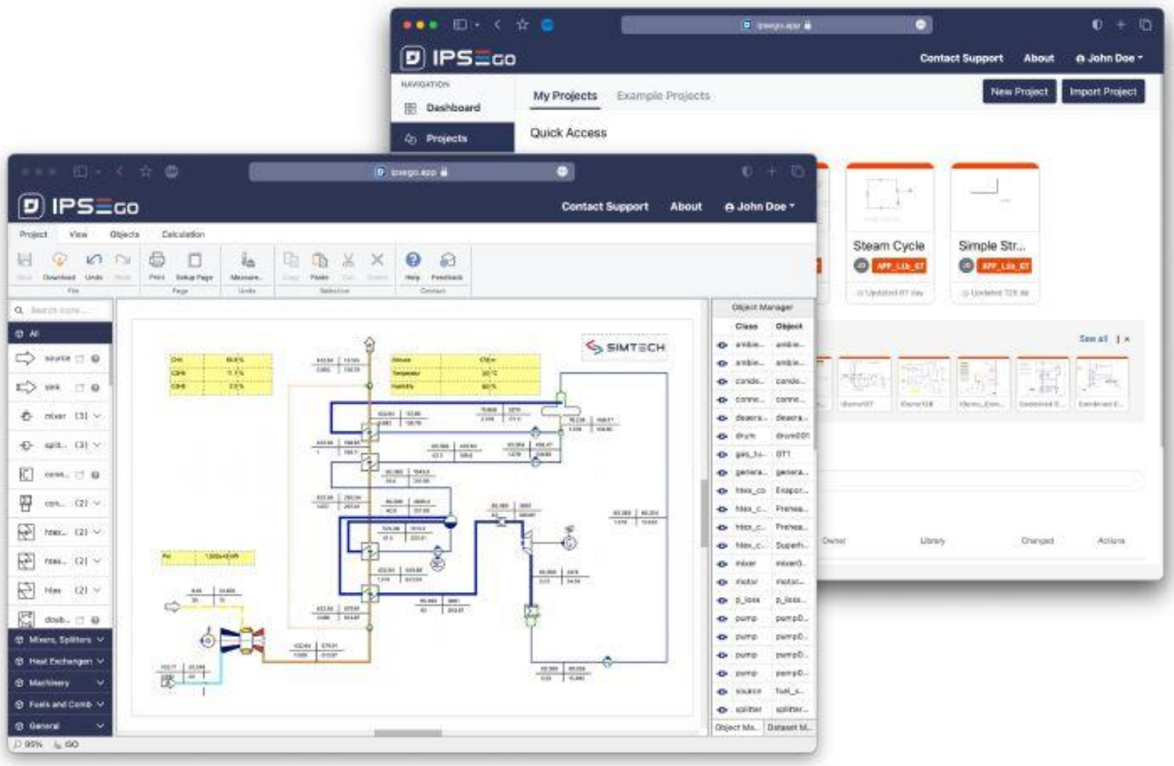



*Figure 3: IPSE GO Web-based Platform ([https://about.ipsego.app/](https://about.ipsego.app/)).*

Thus, IPSE GO offers the appropriate simulation environment, providing an excellent basis for the fulfillment of the requirements of the virtual use-cases and thus the objectives of the project.

The modular approach of the component models, interconnected for building simulation projects, guarantees high modularity of the processes simulated in this environment. In addition, this characteristic allows for partial modification of a section or sub-system of the project to adapt it to further users' demands, guaranteeing a high degree of flexibility.

Finally, the graphic interface of its flowsheet, where the different components are represented by small icons and their connections, includes the all technical information needed in the model and helps the users to have an overview of the simulated process at a glance. This is quite adequate for showcasing the virtual use-cases and much more attractive and representative than other software, for which models are not graphically represented, but with lines of code.

### 1.1.3. RESTORE-Virtual Tool powered by IPSE GO

The adapted usage of IPSE GO web-based platform for RESTORE (called the "RESTORE Virtual Tool) will enable the showcase of its overall process model solution, the performance evaluation of the Use-Cases interactively; making the results available to a wider audience of end-users, stakeholders related to the defined virtual Use-Cases segments. This leads to valuable impact with the project stakeholders, aggregated via RESTORE's exploitation replication strategy (WP5-T5.5), which enables that other stakeholders rather than the ones involved in the project as use-cases' providers, to build additional test cases.

As a result, RESTORE project will be able to profit from a more interactive ecosystem community building with more stakeholders engagement (WP7-T7.4), via the experimentation of the RESTORE simulated process models online via their internet browsers, without the need for any software installation. The RESTORE Virtual Tool will allow end-users to adjust the Use-Cases according to their requirements, using the platform via web browsers. Additionally, the platform users will be able to investigate new testing cases, multiplying the impact of the project’s concept validation.

Figure 4 shows the *Landing Page* of the “RESTORE Virtual Tool” within IPSE GO, showing the *Navigation Tabs* for: Project **Overview**; RESTORE_Lib **Available Units** (currently with 52 components); and RESTORE **Example Projects**.


Figure 4: RESTORE Virtual Tool powered by IPSE GO (see Annex I for more detail).

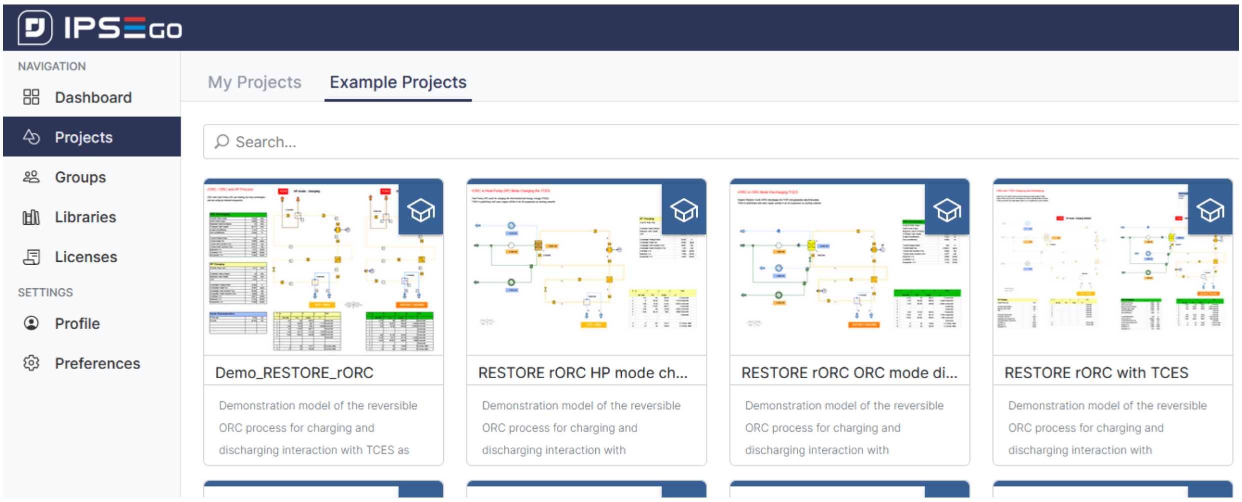



Figure 5: RESTORE Virtual Tool powered by IPSE GO showing some RESTORE process models (see Annex II for more detail).

Figure 5 shows details of the page that opens if the RESTORE Example Projects option is selected from the landing page.

In *Annex I. RESTORE Virtual Tool powered by IPSE GO,* and in *Annex II. RESTORE Virtual Tool – Projects Page*, you find larger graphic detail of both Figure 4 and Figure 5.

# 2. Models Specifications & Requirements

This section describes the relevant aspects of the specifications and requirements for the implementation of the RESTORE process models, including for instance: feasible computational effort, compatibility between models, and adaptability to the web-platform, modularity and flexibility.

The first step in T1.4 was to define the application framework of the specifications and requirements to be applied to the models developed within the RESTORE project which must be implemented in the simulation platform, in order to ensure the compatibility between both. Complex models developed in the frame of the project whose first aim is to support detailed results for the precise design of the prototypes (such as those based on Computational Fluid Dynamics - CFD) are not in the application framework of the result of the task due to their present high computational effort and a long time of simulation.

The requirements identified and defined within the development of task T1.4 include:

- **Comprehensive simulation time**: Reduced simulation duration, as maximum in terms of minutes.
- **Modularity:** The Models of components to be developed in the RESTORE should be programmed following an object-oriented philosophy, making them able to be connected to other component models.
- **Validation:** Models must be validated with experimental results, external bibliography or other validated complex models.
- **Comprehensive computational effort:** The models must be able to be simulated in a normal user computer (RAM 8G, CPU i3) and on the servers for the web-based platform.
- **Description:** Models should include a brief description and, if applied, mention the calculation hypothesis.
- In addition, the **simulation platform must include a user-friendly** interface, making it easy to use and understand by all potential users.

All the models developed/planned to be developed have been/will be tested in order to ensure the fulfillment of these requirements. All the above listed aspects can be fulfilled by the RESTORE Virtual Tool powered by IPSE GO, which adaptation to the project’s requirements enforced improvements on its:

- **Usability:** via user-friendly functions, and enhancements on the graphical usability of the flowsheet, following an intuitive and logical user-based approach.

- **System Design & Robustness:** via Architectural design improvements; More robustness on the standard browser-based flowsheet editor for entering data and displaying results of the simulation; Framework Management revised and improved; Optimization of the Data / User / Session Management feature; and Enhanced calculations response time, carried out on library hosts.

- **Sharing / Portability / Compatibility / Security:** via Full-Capability to Exchange Projects with IPSEpro (desktop simulation environment version), so that projects can be further worked online and vice-versa. Easy and fast sharing of process and component models among project partners, as projects are stored on web servers. Enhanced overall security within the platform for data, user and projects / sessions management.

Initial tests with the RESTORE Virtual Tool, were made in collaboration with POLIMI and TU-WIEN, and the RESTORE sub-systems, with the Thermo-Chemical Energy Storage TCES and the reversible Organic Rankine Cycle rORC technologies were modelled using a preliminary version of the customized RESTORE_Lib model library created via WP5-T5.1. Figure 6 shows the simulation experiment of the 1st rORC process for the TCES charging and discharging modes for RESTORE. These initial tests were made according to TCES parameters considered at the very early phase of the RESTORE project.

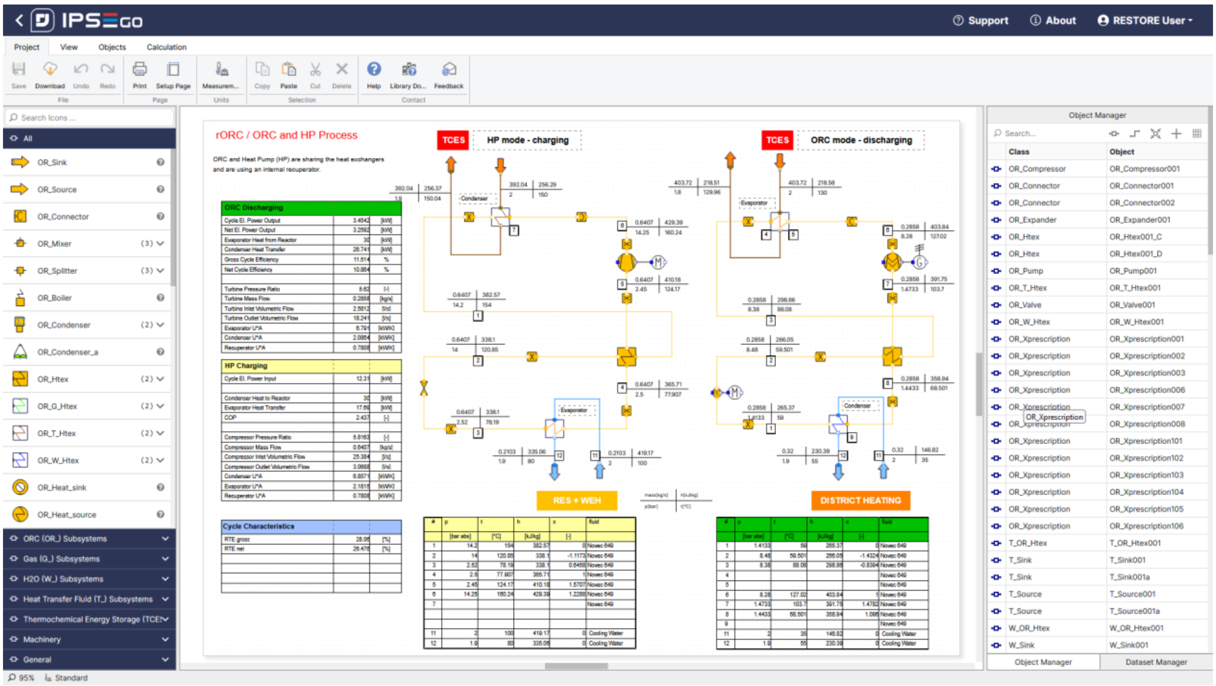



*Figure 6: rORC / ORC and Heat Pump Processes.*

The modelling of the rORC core components and processes (ORC and heat pump operation) is illustrated in the following Figure 7, Figure 8,

Figure 9, and Figure 10.

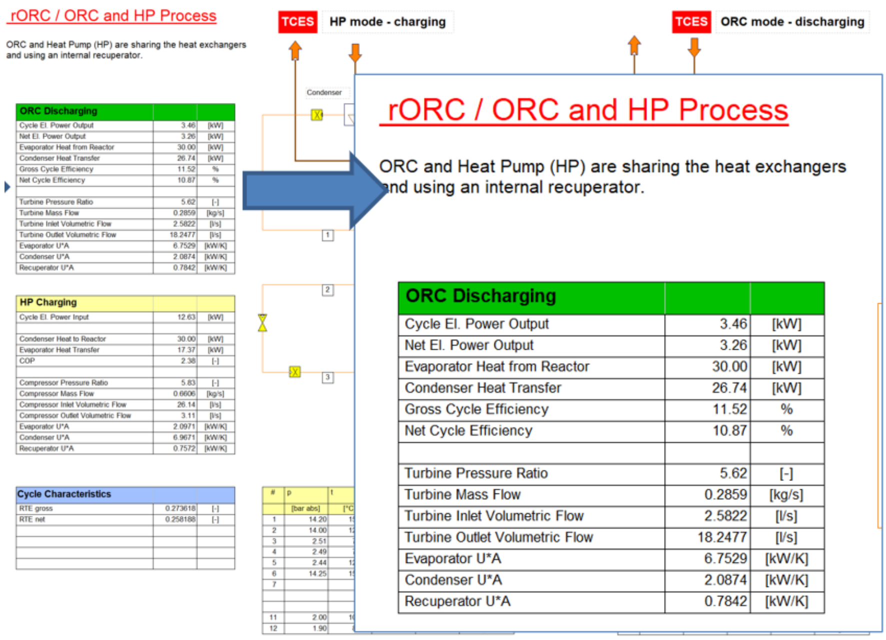



*Figure 7: Modelling of the rORC preliminary process for RESTORE, with TCES charging and discharging modes, using rORC core components: ORC and heat pump operation (Detail 1).*

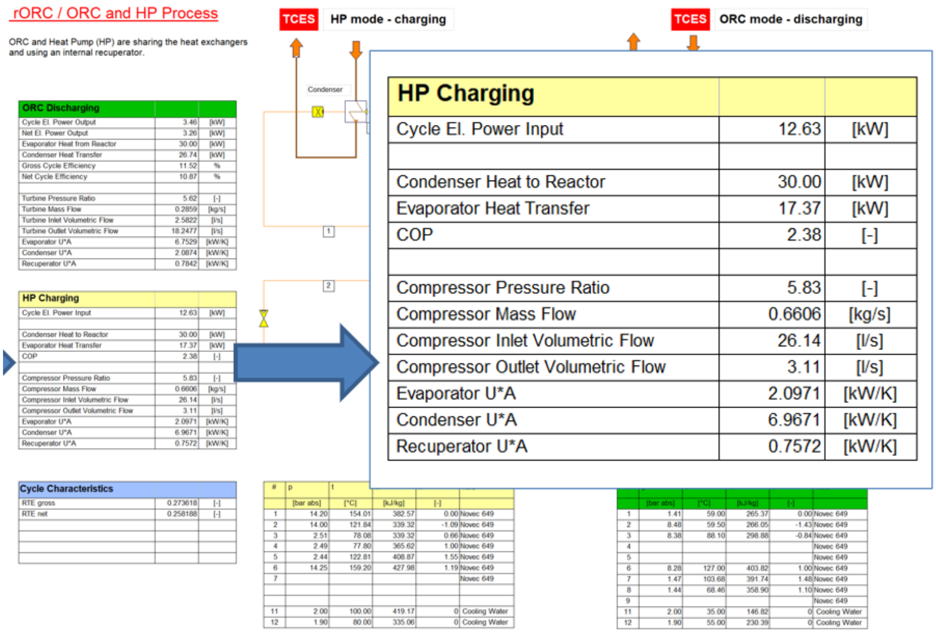



*Figure 8: Modelling of the rORC preliminary process for RESTORE, with TCES charging and discharging modes, using rORC core components: ORC and heat pump operation (Detail 2).*

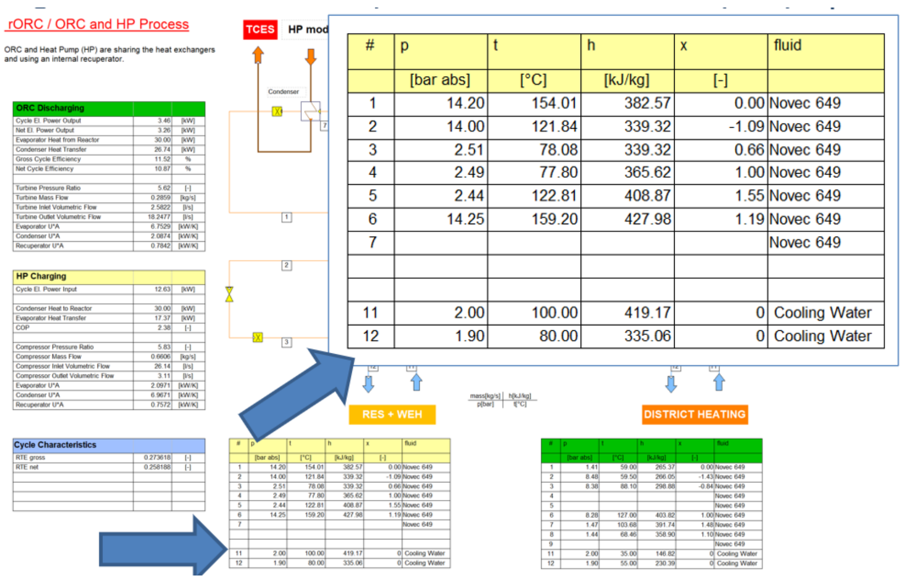



*Figure 9: Modelling of the rORC preliminary process for RESTORE, with TCES charging and discharging modes, using rORC core components: ORC and heat pump operation (Detail 3).*

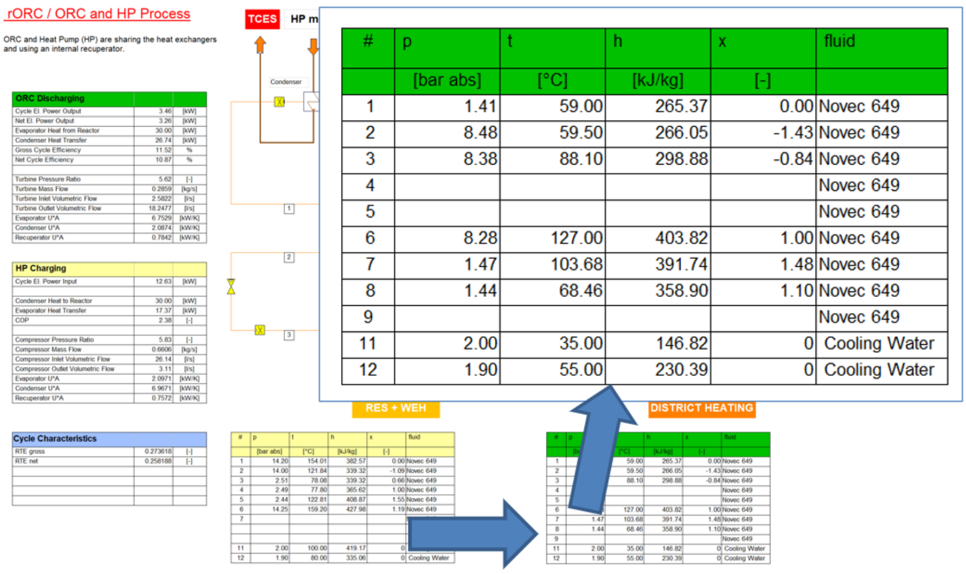



*Figure 10: Modelling of the rORC preliminary process for RESTORE, with TCES charging and discharging modes, using rORC core components: ORC and heat pump operation (Detail 4).*

Moreover, the IPSE GO features described and illustrated in the sequel ensure that the basic defined requirements are achieved. The features are: (1) Integration between IPSEpro and IPSE GO projects (Figure 11) ; (2) Multi-platform Modern Editor (Figure 12); (3) Collaboration & Sharing Feature (Figure 13); as well as features relative to (4) Access Rights and Security (Figure 14).

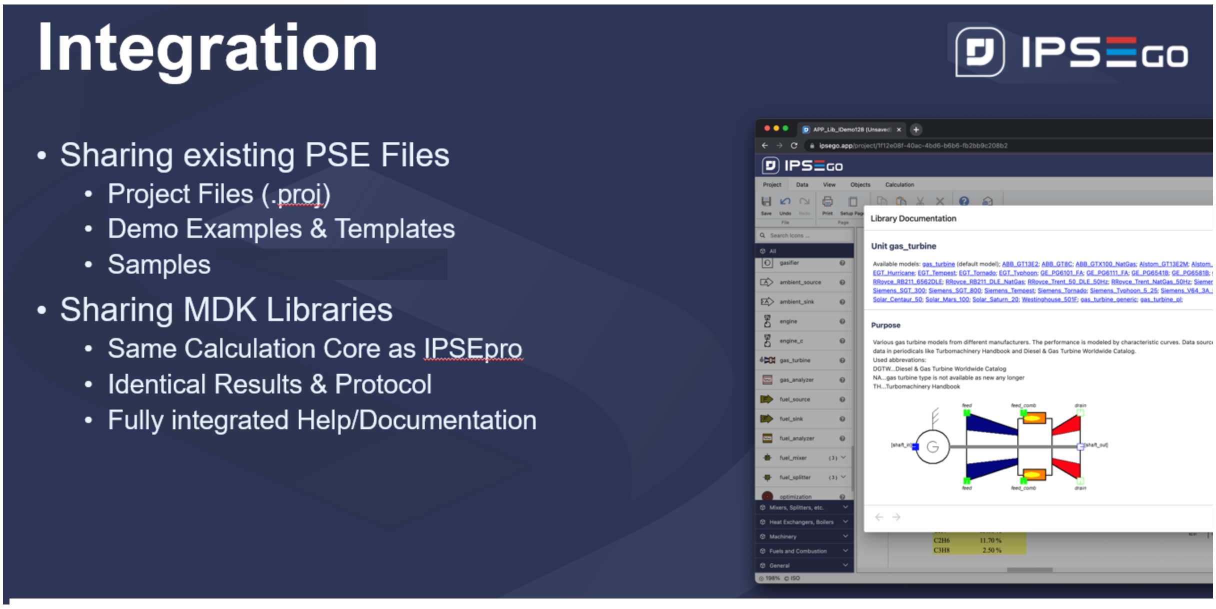



*Figure 11: IPSE GO Integration Feature.*

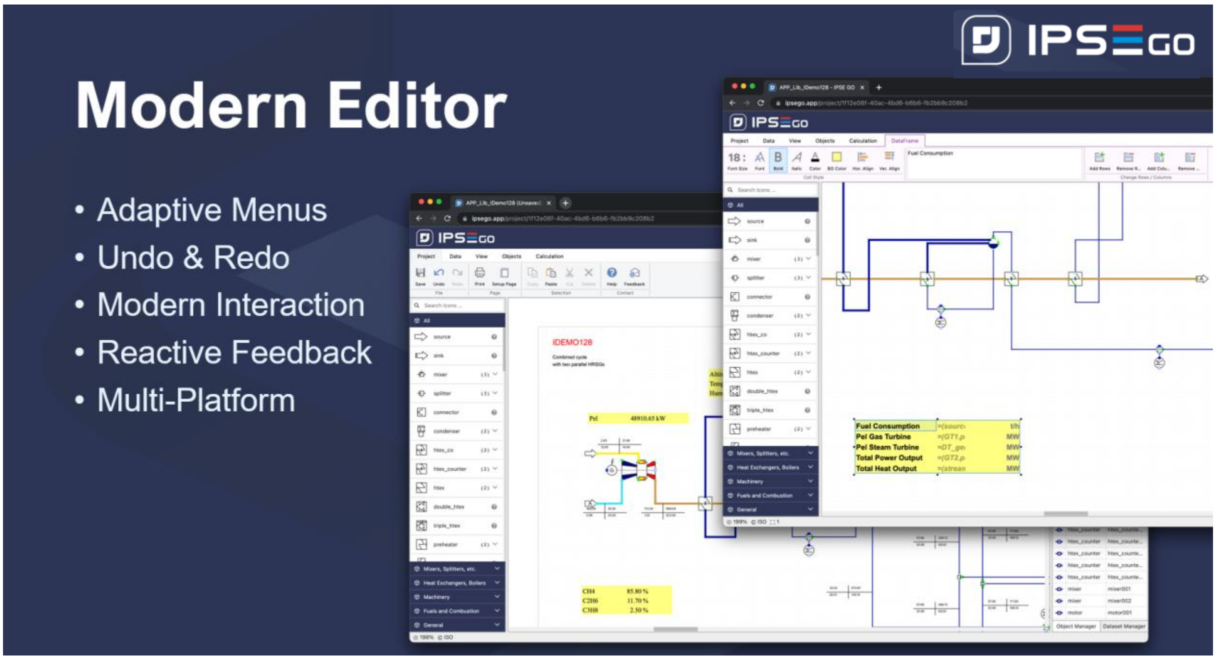



*Figure 12: IPSE GO Modern Editor Feature.*

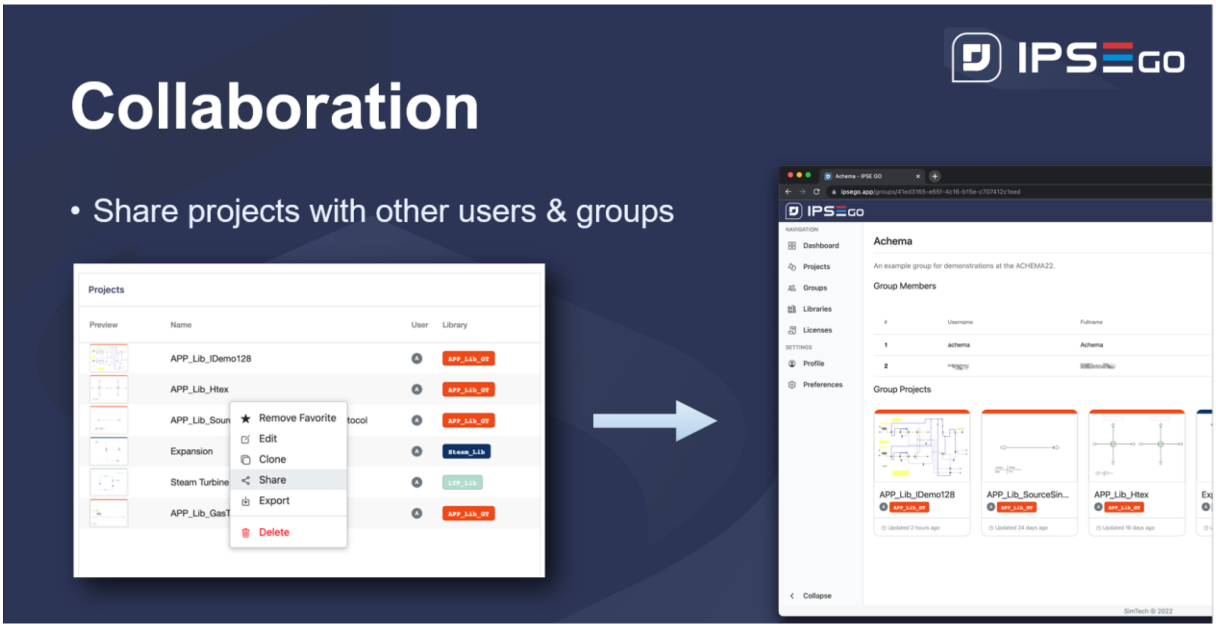



*Figure 13: IPSE GO Collaboration Feature.*

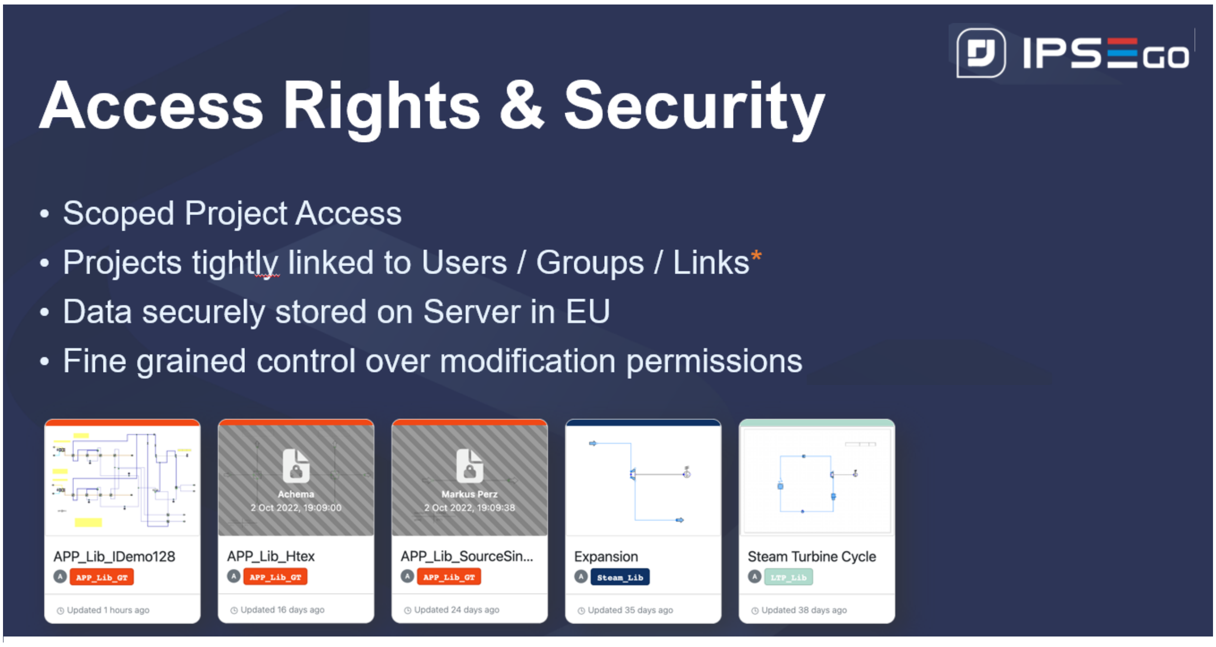



*Figure 14: Access Rights & Security Feature.*

# 3. RESTORE Models available in IPSE GO

The current process models available in the IPSE GO environment are the ones shown in Figure 15 (RESTORE TCES Charging Model); Figure 16 (RESTORE TCES Discharging Model); and Figure 17 (RESTORE rORC with TCES Charging and Discharging Model). These models have been developed following the same basis concerning interconnections in order to ensure full compatibility between them.

So far, all available projects are preliminary process models, still being further developed by TU-WIEN with support from SIMTECH, within the work being carried out in WP2 (RESTORE High Energy-density Thermo-chemical Storage for daily and seasonal Energy Storage in DHC, led by TU-WIEN), and in WP3 (RESTORE Thermodynamic Cycle Development for smart integration of a wide variety of renewable sources and technologies in DHC, led by POLIMI).

In *Annex III. RESTORE Preliminary rORC with TCES Process Model, (rORC – reverse organic rankine cycle)*; in *Annex IV. RESTORE Preliminary TCES Charging Model*; and in *Annex V. RESTORE Preliminary TCES Discharging Model*, larger graphic details of Figure 17, Figure 15, and Figure 16 are respectively shown.

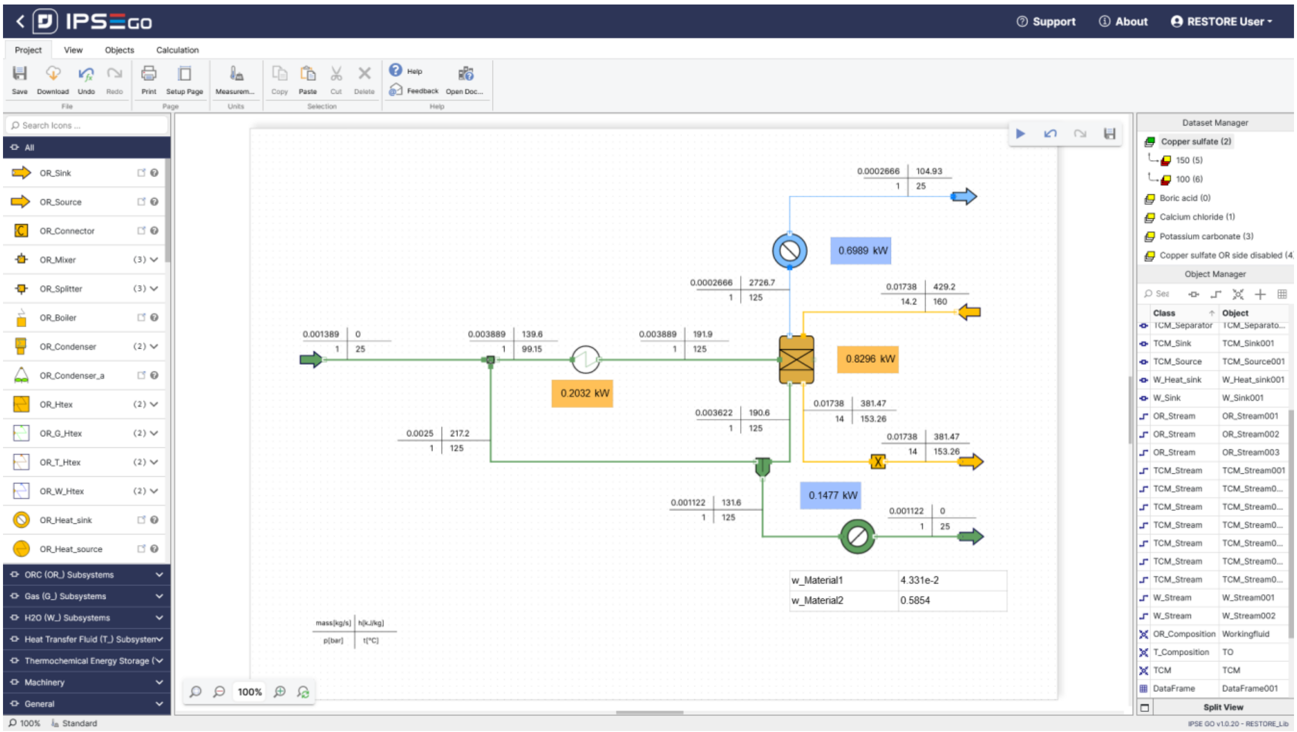



Figure 15: Preliminary RESTORE TCES Charging Model within IPSE GO.

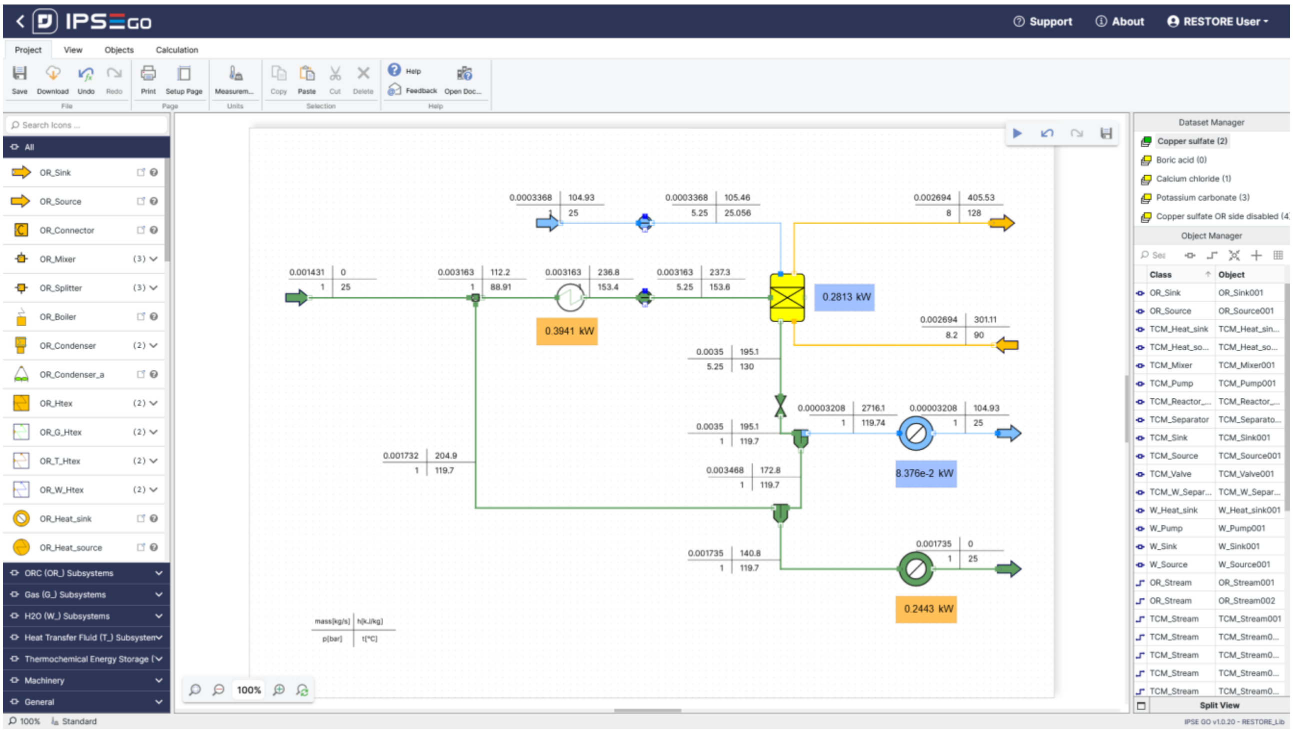



Figure 16: Preliminary RESTORE TCES Discharging Model within IPSE GO.

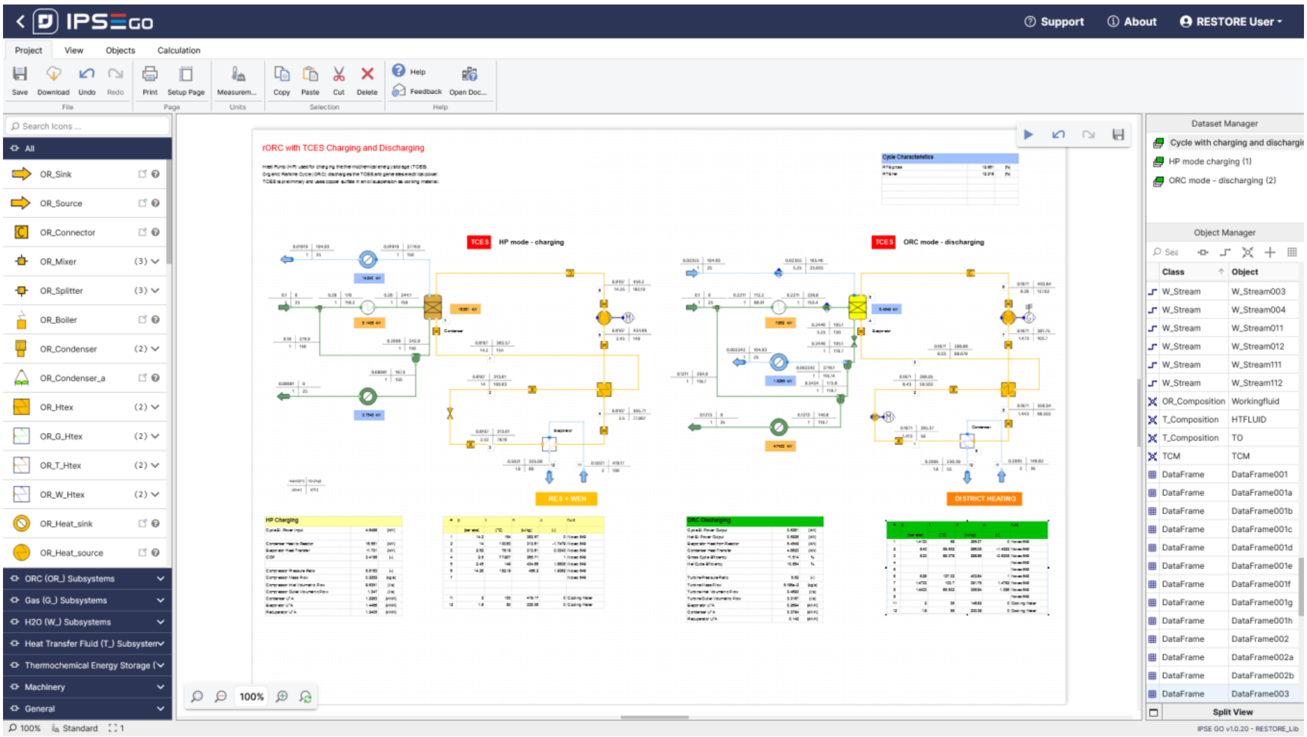



Figure 17: Preliminary RESTORE rORC with TCES Charging and Discharging Model within IPSE GO (see Appendix I for details of the model).

## 3.1. Goals of the Simulation

The overall goal of the simulation within RESTORE system development includes the precise behavioural and numerical representation of the involved components and process models, at a high accuracy level in relation to the real data provided / acquired, so that their evaluation and implementation within real-data virtual use-case scenarios can be validated. This entails that feasible further piloting stages of the system can take place with low implementation risks.

It is worth noting that in RESTORE, SIMTECH's Web-based Process Simulation Platform will be available for both project partners and end-users (during the project lifetime) to assist all project phases (design, development and testing), as well as to demonstrate the project's Use-Cases interacting with the RESTORE Stakeholder ecosystem for exploitation purposes.

Once RESTORE Virtual Tool is made available online for stakeholders, the use cases can be simulated interactively by anyone interested in the technology. Additionally, stakeholders will be able to create their own testing cases, such that the number of different application examples will grow continuously.

Before M13, a preliminary version of the RESTORE_Lib was made available for the project Consortium Members in IPSEpro and also on the IPSE GO web platform, when the modelling online training sessions guided by SIMTECH were given to participants from POLIMI, CENER and TU Wien. Since then, IPSE GO has been also made available to be tested and used by Consortium Members, with evolving RESTORE process models of the TCES and rORC technologies. Extensions and updates of both RESTORE_Lib and process models will continue to follow throughout the project.

# 4. RESTORE Models

For the implementation of the process models presented in Section 3, novel and required RESTORE component models had to be implemented and are still being fine-tuned and updated (work being carried out WP5-T5.1) with input from WP1, WP2 and WP3. Examples of such customized models for the RESTORE solution, more precisely for the thermochemical energy storage system (TCES) and the thermodynamic cycles, are the ones shown in Figure 18, among others (Heat sink for thermochemical Material (TCM); Heat source for TCM; Mixer for TCM Streams; Pump for TCM Fluids; Reactor for Charging of TCM; Reactor for Discharging of TCM). All component models used for the implementation of the overall RESTORE system are stored within the RESTORE_Lib.

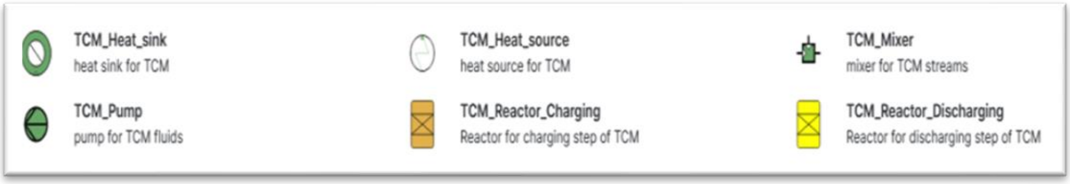



*Figure 18: Some customized component models to implement the RESTORE system.*

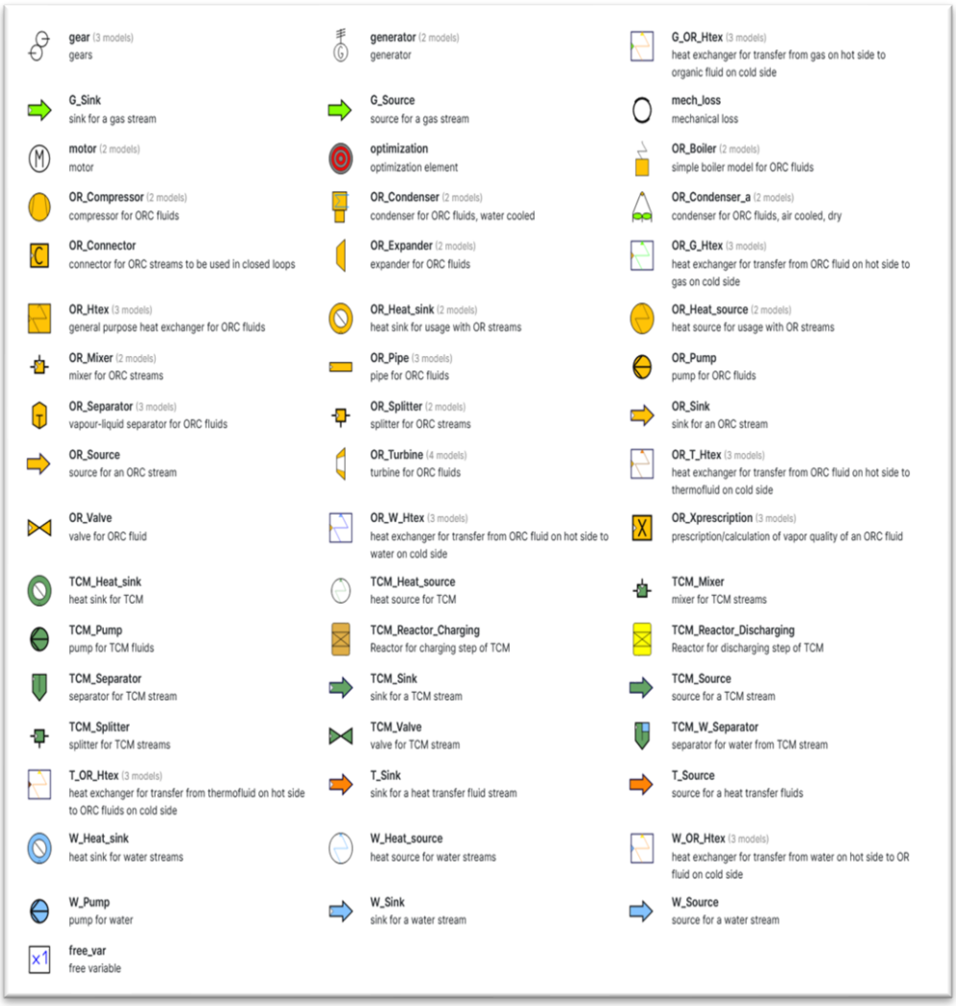



Figure 19: RESTORE Library of Component Models – RESTORE_Lib
(see Annex VI for more detail)

## 4.1. RESTORE_Lib

The RESTORE_Lib is the Library of Component Models that has been created and is currently being updated within the work done in WP5, in collaboration with the involved development partners (TU-WIEN in WP2, POLIMI in WP3, among others).

RESTORE_Lib comprises the basic models already existing with the simulation tool for the implementation of general thermodynamic and rORC process models, added by specific component models customized for RESTORE solution, concerning the required elements to model the thermochemical storage system and the thermodynamic cycles.

RESTORE_Lib Component Models for TCES were defined and implemented by TUWIEN in cooperation with SIMTECH. RESTORE_Lib was created using IPSEpro-MDK and is used in both IPSEpro and IPSE GO. *Figure 19 shows the list of models so far available in RESTORE_Lib.*

# 5. Summary of the RESTORE Use-Cases

The overall RESTORE concept will be virtually implemented and optimized for six DHC Use-Cases with real data from the Use-Case providers. The use cases will be made publicly available via the RESTORE Virtual Tool powered by IPSE GO, and will remain available online after the project lifetime to stimulate a new technological direction and the emergence of a European innovation ecosystem around the RESTORE paradigm.

The six Virtual Use-Cases will analyze potential configurations for integrating the RESTORE technology and RES, potentially available on site, into different plants connected with DHC networks. They integrate with real DHC networks spread over different locations in Europe, including large and small district heating networks, as illustrated in Figure 20.

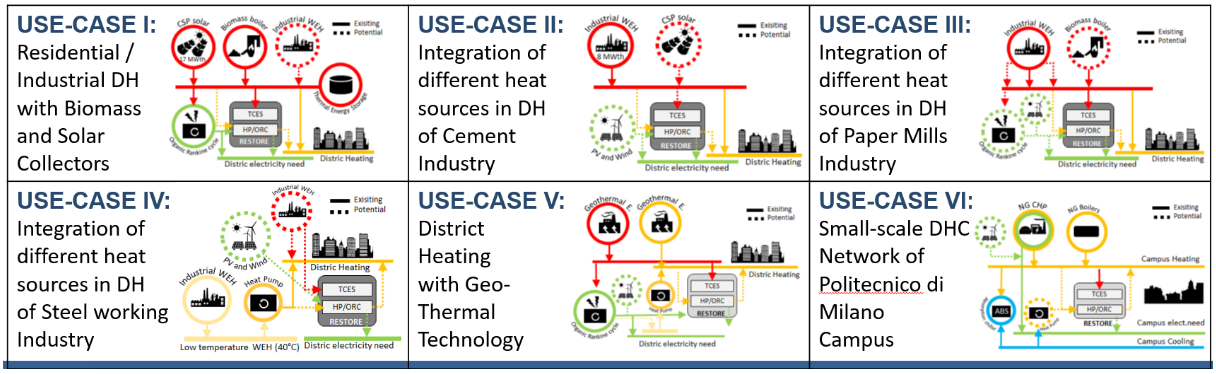



*Figure 20: RESTORE Use-Cases.*

***Use-Case I*** *deals with a residential and industrial DH with biomass and solar collectors in Denmark.* ***Use-Case II*** *deals with the integration of different heat sources in DH of a cement factory in Austria.* ***Use-Case III*** *integrates RESTORE with different heat sources in DH of a paper mill in Slovakia.* ***Use-Case IV*** *deals with the integration of different heat sources in DH of a steel industry in Italy.* ***Use-Case V*** *concerns the district heating with geothermal technology in a plant in Germany.* ***Use-Case VI*** *deals with the small-scale DHC network of POLIMI University Campus in Italy.*

## 5.1. Use Case I

**USE-CASE I: Residential / Industrial DHC with Biomass and Solar Collectors and industrial WEH -** Location: BRONDERSLEV PLANT (CSP INTEGRATED WITH BIOMASS-ORC) – Denmark.

● **Use-Case provider:** Aalborg CSP, based on detailed engineering data and integration experience.

● **Use-Case Area of Application:** District heating for the city of Bronderslev, Biomass and Solar collectors as renewable technologies to provide heat to the District.

● **Expected goals to be achieved:** Maximization of renewable energy integration in the district, and optimum waste heat utilization from local industry for highly efficient seasonal storage of electricity.

**Use-Case Description:** As a pioneer in the field of smart energy Brønderslev Forsyning A/S has implemented a District Heating concept: power and district heating supply are generated in its own combined heat and power unit which is one of the most efficient plants worldwide due to the combination of solar, biomass and HPs. After a comprehensive feasibility study and 0.8MWth test facility campaign Brønderslev Forsyning A/S started the contraction of a CSP plant to supply 16.6 MWth which has been in operation since March 2018. The solar energy plant is based on the parabolic trough technology consisting of 40 rows of 125m U-shaped mirrors with an aperture area of 27,000 m² and glass vacuum tube receiver. Thermal oil is used as heat transfer fluid with a maximum temperature of 330°C. The system was designed and constructed by project partner AAL. Collected energy can be stored in a thermal energy storage unit based on pressurized water tanks that are connected to an existing biomass-fired ORC power plant or directly provide heat to the local district heating system adapting its operation temperature according to the specific needs of the district's energy system. Similarly, the biomass boiler provides heat to the ORC or the district. The ORC (40 CHPRS SPLIT) is manufactured by project partner TURBODEN and has a power output of about 3.8 MWe and was originally fed by thermal oil coming both from the 2 biomass boilers. Overall system represents an advanced DH solution based on non-conventional hybrid solar-biomass ORC plant able to provide sustainable heat and electricity. District heating return and supply water temperature are 50°C and 72ºC respectively.

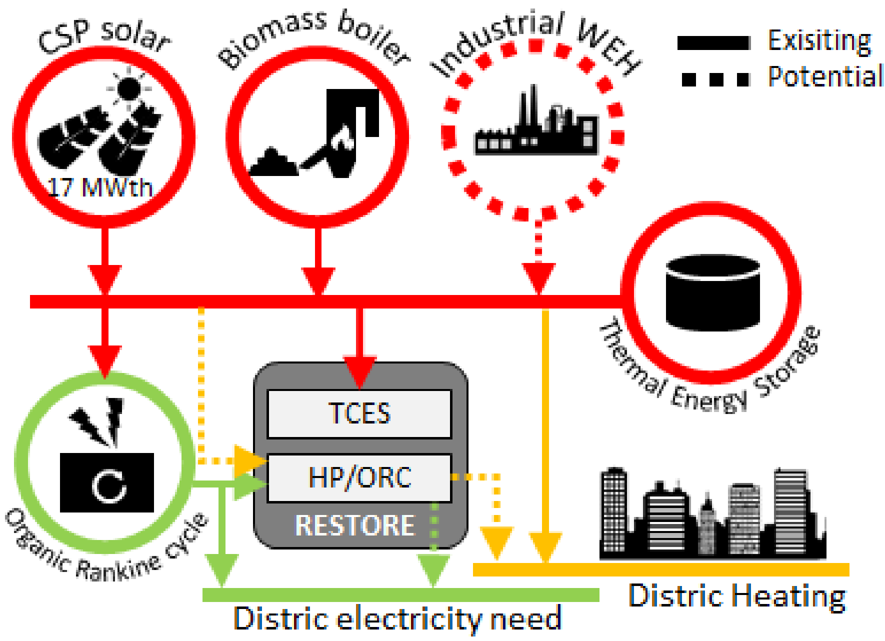



*Figure 21: RESTORE proposed solution in Use-Case I.*

**Use-Case I - RESTORE proposed solution:** In the RESTORE project, the virtual pilot will be based on the energy system described above, integrating a specifically optimized RESTORE energy storage unit. The existing parabolic trough solar collector field can then charge the TCES system during summer months, i.e. solar heat is stored for heating in winter. Additionally, residual heat from industry or excess low-temperature heat from solar collectors in the district is used to efficiently store off-peak cheap electricity.

## 5.2. Use Case II

**USE-CASE II: Integration of different Cement Industry heat sources in DHC -** Location: GMUNDEN CEMENT FACTORY - Gmunden, Austria.

● **Use-Case provider:** CENER & TU-WIEN based on detailed engineering data and integration experience from the owner ROHR of the Gmunden cement plant.

● **Use-Case Area of Application:** Analysis of potential configurations of integrating the RESTORE technology into the Cement production plant and its relation to the neighbouring heat consumers.

● **Expected goals to be achieved:** Maximization of renewable energy integration and optimum WEH utilization from the factory for highly efficient seasonal storage of electricity using RESTORE.

**Use-Case Description:** The Gmunden site cement plant of Rohrdorfer group has currently the capacity of ~1.900 ton/day of cement clinker, with a district heating connection (capacity of ~8 MWth). The clinker process offers multiple options of heat integration with district heating and cooling, either via the WEH coming from air cooled clinker coolers, or from the off gas from cyclone tower. In the case of a waste heat steam cycle plant such as in the Rohrdorf site, also, or from extraction steam from a steam turbine can be used which itself is fed by steam from the waste heat recovery steam generator. The installation of a waste heat steam generator is under consideration in the frame of a national research project. The state-of-the-art cement factory in Gmunden produces huge amounts of WEH that cannot be used by the cement production process itself. Its recent connection to a local district heating network allowed 8 MW thermal power to be provided covering the heat demand for roughly 1,000 homes. Additional excess heat is available, especially during summer months when no space heating is required.

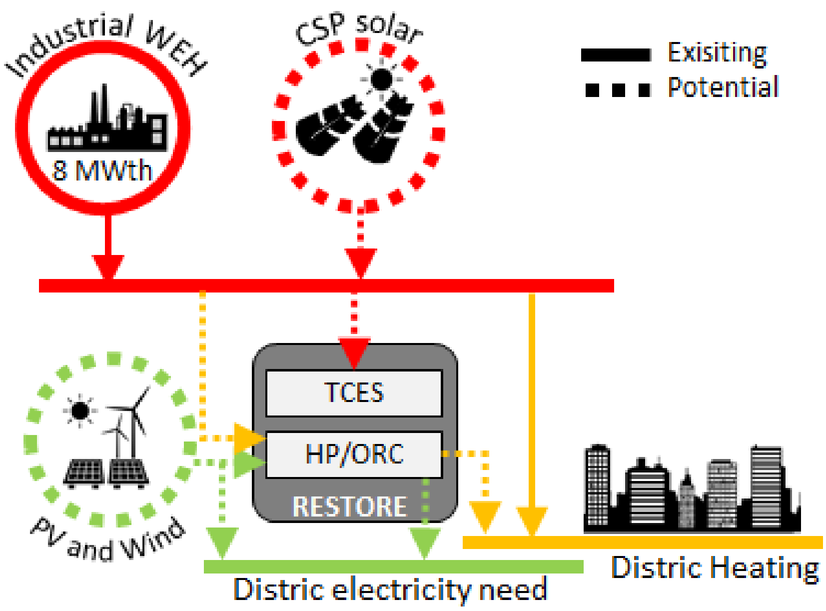



*Figure 22: RESTORE proposed solution in Use-Case II.*

**Use-Case II - RESTORE proposed solution:** Within the RESTORE project, the virtual pilot will simulate the integration of the developed concept within the industrial plant in order to maximize WEH utilization and RES integration for seasonal storage of heat using cheap off-peak electricity. RESTORE concept allows to transfer excess heat from the summer to the winter, when cement plants are typically shutting down for at least 6 weeks thus continuously providing DH with carbon free heat. In this virtual pilot, the integration of additional RES will be studied. The RESTORE project counts with the support of the owner of the plant (member of the ESAB), being actively involved in configuring the virtual pilot and in supplying the needed technical data as well as important considerations for the system as final user of the RESTORE system.

## 5.3. Use Case III

**USE-CASE III: Integration of different heat sources in DHC of Paper Mills Industry -** Location: MONDI SCP PLANT - Ružomberok, Slovakia

● **Use-Case provider:** ANDRITZ (AND), based on detailed engineering data and integration experience from its customer MONDI SCP in Slovakia.

● **Use-Case Area of Application:** Analysis of potential configurations for integrating the RESTORE technology into plants of the Pulp and Paper Industry connected to DH and RES.

● **Expected goals to be achieved:** Maximize the renewable energy integration and optimize WEH utilization from the factory for highly efficient seasonal heat storage.

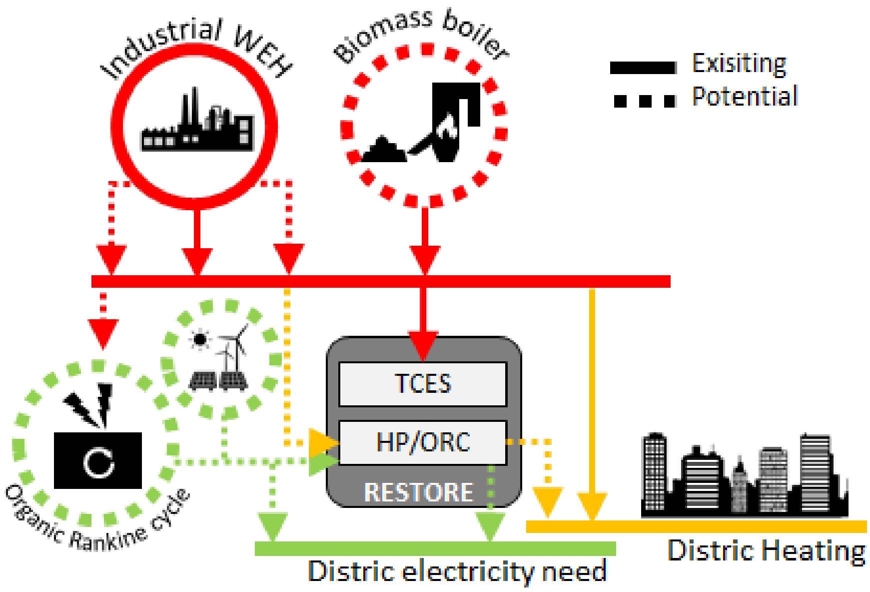



*Figure 23: RESTORE proposed solution in Use-Case III.*

**Use-Case Description:** Mondi SCP in Ružomberok is one of Mondi's largest plants and is the biggest integrated mill producing paper and pulp in the Slovak Republic, with a production capacity of 560,000 tonnes of uncoated fine paper, 66,000 tonnes of packaging paper and 100,000 tonnes of market pulp. After its latest investment into a new recovery boiler, the mill is 100% energy self-sufficient with over 94% of its energy coming from renewable resources. The wood comes from certified, well-managed forests. The production continuously decreases footprint on the environment. Part of the heat produced by the Mondi mill is used for the district heating system in the form of 5 bar steam. Steam enters a heat exchanger station, where heat exchangers transfer heat into water. Hot water is pumped via a distribution network into the city, local heat exchangers and flowing back to the steam/ water heat exchanger station to gain heat again.

**Use-Case III - RESTORE proposed solution:** The utilization of the following energy sources will be explored and integrated in RESTORE concept and use to store heat on seasonal base: (i) utilisation of waste steam in case of reduced heat demand in district heating (e.g. summer time), (ii) flue gas recovery from boilers at LT which is not used so far, (iii) hot water streams available at site which may be used for water preheating or HP energy input. Moreover, synergies with thermal and electrical based energy sources will be investigated considering also adding new RES sources in order to limit additional fossil fuel consumption. The expected outcome is a huge reduction of the GHG through a high increment in the RES share and the waste heat capacity factor.

## 5.4. Use Case IV

**USE-CASE IV: Integration of different heat sources in DHC of Steel-working industry -** Location: BRESCIA – Italy.

● **Use-Case provider:** TURBODEN based on detailed engineering data and integration experience from the potential final user and Use-Case provider Alfa Acciai, from Brescia.

● **Use-Case Area of Application:** The use case will apply the RESTORE concept to a DHC network linked to one of the largest Electric Arc Furnace steel mills in Italy

● **Expected goals to be achieved:** Achieve higher efficiency of Alfa Acciai production process, improve HP utilization during summer season and increase share on local DH.

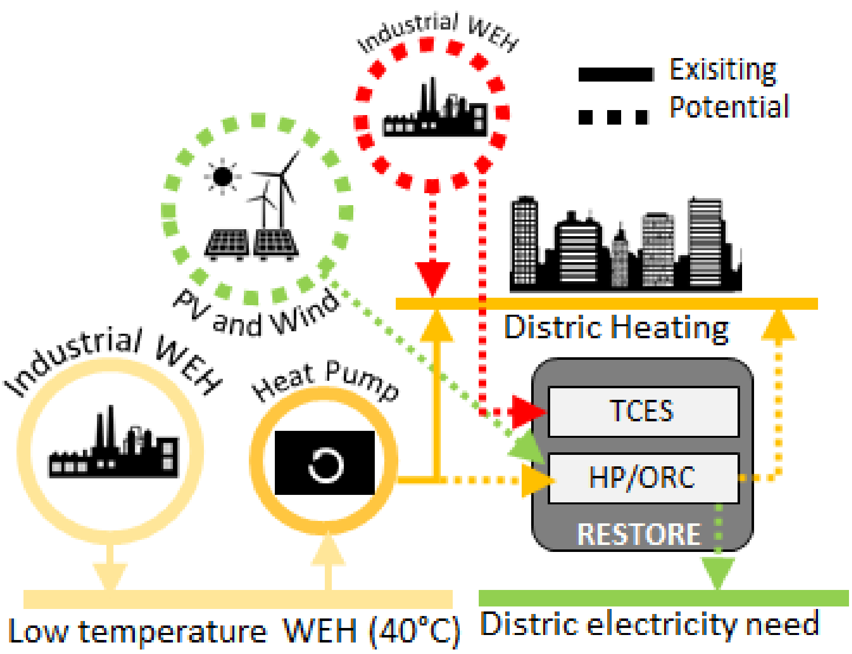



*Figure 24: RESTORE proposed solution in Use-Case IV.*

**Use-Case Description:** Alfa Acciai is one of the largest Electric Arc Furnace Steel Mill in Italy. It started producing steel in Brescia in the mid-1950s. The Alfa Acciai Group has been increasingly oriented towards customer service, by focusing on the production of steel for the reinforcement of concrete, while respecting the environment and the worker health and safety in the workplace. Alfa Acciai site in Brescia is composed by 2 Electric Arc Furnace units and 3 rolling mills. Current strategy for waste heat recovery system based on a large HP able to recover WEH from the cooling system of the “pipe to pipe” circuit of the furnaces. The temperature of available heat is in the range of 30°-40°C and can be upgraded up to 90°C through the HP and used for district heating instead of being wasted. The recovered upgraded thermal energy will be used and integrated in the local district heating of municipality of Brescia and distributed to the final users in order to satisfy the heat demand in a smart and green way.

**Use-Case IV - RESTORE proposed solution:** RESTORE technology can dramatically increase the utilization of existing equipment and WEH utilization during summer months when heat is not required by DH and so the HPs are not working. With RESTORE heat released by EAF is upgraded to High Temperature all year long: during winter heat is directly used by DH while during summer heat is exploited by RESTORE HP and allows storing energy for the winter season. Integrated solution with renewable energies and synergies with other industry subsystems will be investigated. The expected impact is a strong increase of HP capacity factor and a final energy provided to the DH network nearly double of the current state of the art.

## 5.5. Use Case V

**USE-CASE V: District heating with Geothermal Technology -** Location: Geothermie Holzkirchen Plant, Holzkirchen- Germany.

● **Use-Case provider:** TURBODEN based on detailed engineering data and integration experience from its Use-Case provider Geothermie Holzkirchen GmbH from Holzkirchen in Germany.

● **Use-Case Area of Application:** The use case will apply the RESTORE concept to a DHC network (local utility of Holzkirchen) with Geothermal Technology.

● **Expected goals to be achieved:** Maximization of the geothermal heat exploitation and optimum WEH utilization for highly efficient seasonal storage of heat.

**Use-Case Description:** Geothermie Holzkirchen GmbH is a wholly owned subsidiary of the local utility of Holzkirchen, a town located in the south of Munich, Germany. The existing conditions for developing geothermal energy are particularly favourable in the southern German Molasse basin, as there is particularly hot water at the appropriate depth (500 meters). Heat can be used as direct supply to district heating and, from a temperature of around 120 degrees Celsius, electricity production is possible. It is estimated that in the long term up to 80 percent of Holzkirchen's district heating network demand can be covered with geothermal energy equivalent to around 10,000 tons of climate-damaging carbon dioxide avoided every year. An ORC from TUR is already installed on site to exploit geothermal hot water during the summer from a temperature of 140°C, producing a power output of 2.8 MWel and contributing to the amortization of the project due to the feed-in tariff. Moreover, in order to increase the geothermal heat exploitation TUR will study a large HP in order to achieve higher flexibility in terms of heat and power production as well as increased geothermal utilisation.

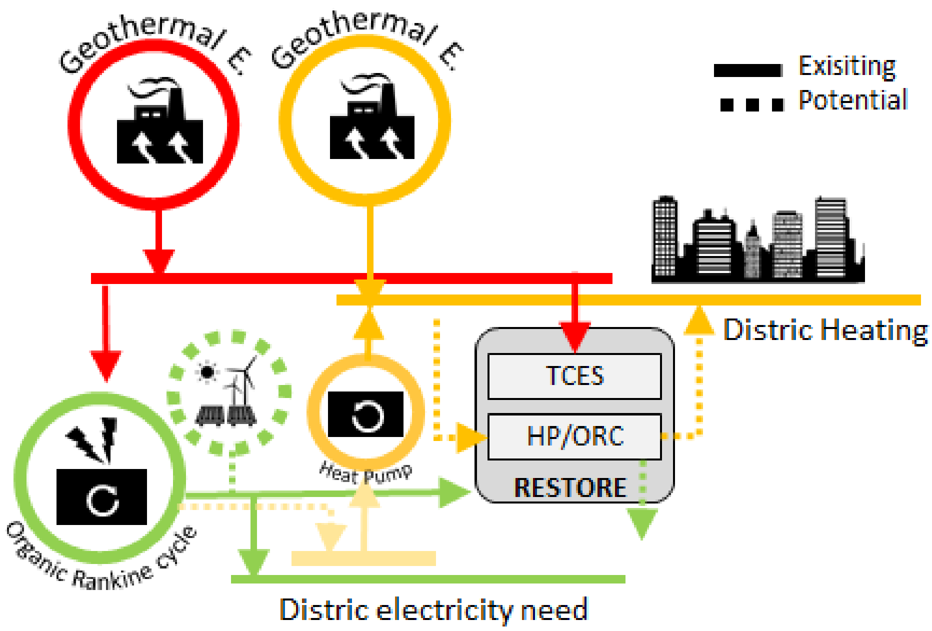



*Figure 25: RESTORE proposed solution in Use-Case V.*

**Use-Case V - RESTORE proposed solution:** RESTORE technology can be integrated with geothermal energy exploiting it during summer to store heat for the cold season. From this point of view RESTORE is a competitive solution against ORC and this Use-Case provides a unique possibility to evaluate and compare the economic feasibility of both solutions. The integration of additional RES technologies due to RESTORE technology will be investigated. Expected impact are a dramatic increase of energy to the DH and a marked reduction of GHG emission. Availability of HP during summer and other RES will be investigated.

## 5.6. Use Case VI

**USE-CASE VI: Small scale DHC network of Politecnico di Milano campus -** Location: POLIMI CAMPUS, Milan - Italy.

● **Use-Case provider:** POLIMI, based on detailed engineering data and integration experience from its small DHC network.

● **Use-Case Area of Application:** This use case aims to exploit RESTORE in small-scale DHC networks.

● **Expected goals to be achieved:** Apply the RESTORE concept to a small DHC network available at Politecnico di Milano campus and representative of small size decentralized solutions.

**Use-Case Description:** Politecnico di Milano adopts a small DH network to provide electricity and heat to a relevant fraction of campus offices, classrooms and laboratories serving approximately 120.000 mq. Moreover, cooling is also provided to some buildings during the summer season. Maximum thermal power request is around 15 MWth and thermal plant of the

DHC encompasses three natural gas boilers of 6 MWth each and one natural gas internal combustion engine in CHP configuration able to provide 2 MWel plus 1.8 MWth. Cooling power 1.25 MW is generated by one absorption chiller (LiBr) exploiting CHP unit waste heat. The CHP unit is operated in thermal load following and most of electrical energy (80%) is for internal consumption while the remaining (20%) is sold to the grid. Annual hours of operations of the CHP unit thanks to the integration with the cooling network is around 5000 h. In addition to the DHC network, the Energy Department of Politecnico di Milano located in Bovisa Campus can also provide accurate information on the availability of solar PV energy thanks to the availability of PV panels of different technologies for a total 75 kWel and a storage system constituted by 70kWh Lithium-ion Samsung battery. All the quantities related to DHC network, the thermal plant operation and the PV fields are continuously monitored and detailed dataset are available for the last years of operation.

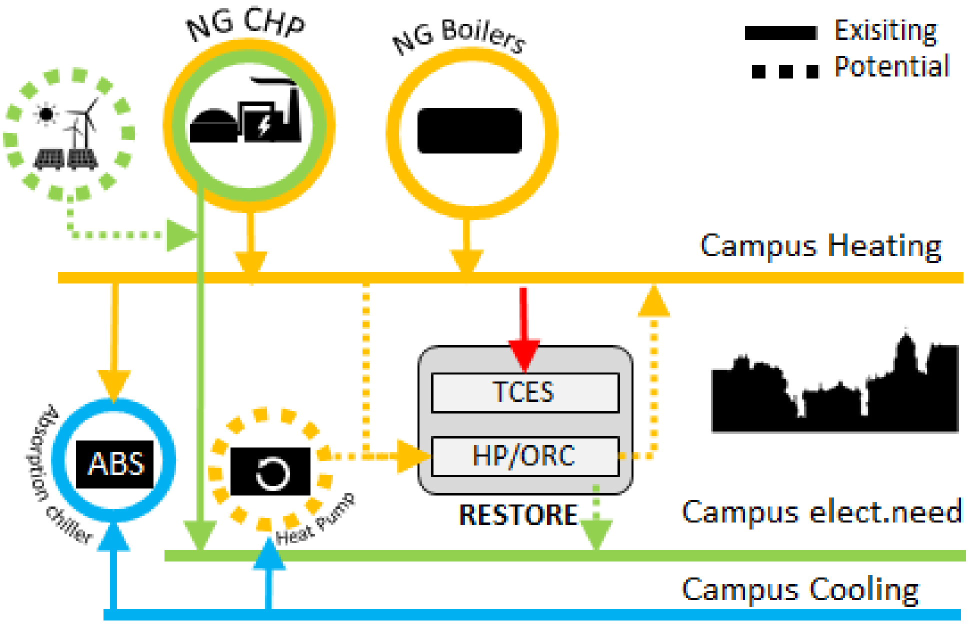



*Figure 26: RESTORE proposed solution in Use-Case VI.*

**Use-Case VI - RESTORE proposed solution:** The POLIMI Campus Use-Case aims to understand the role of RESTORE technology in small decentralized DHC networks and to understand the constraints in terms of space in urban contexts. First, an evaluation of fuel shifting from natural gas to biogas will be investigated, then the RESTORE concept is implemented understanding the synergies with district cooling operation and RES integration. Final results would assess the environmental and economic sustainability of seasonal thermal storage.

# 6. Data required for the Use-Cases

The RESTORE Virtual Tool will host and showcase the 6 RESTORE virtual use-cases, ensuring the feasibility of the RESTORE numerical models and catering for suitable adaptations to the made for the different Use-Cases framework conditions (renewable technologies involved, demand loads, network conditions, etc.). Figure 27 illustrates the RESTORE concept, including the possible sources of electricity and heat, as well as the supply output as RES electricity, and District Heating and Cooling (DHC).

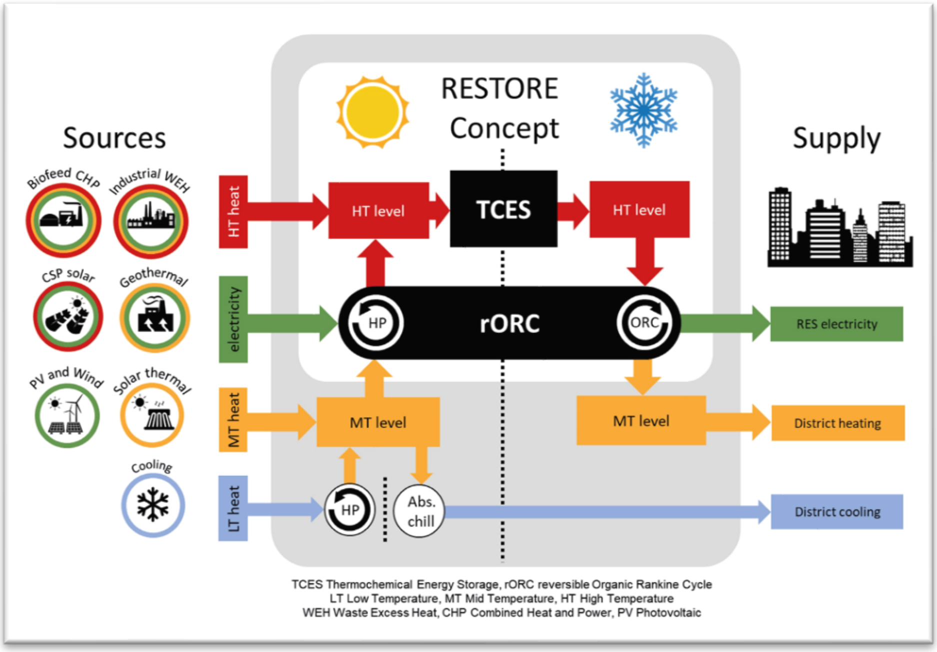



*Figure 27: High-level Overview of the RESTORE Project Concept.*

Figure 28 illustrates a simplified overview of the elements involved in the RESTORE project concept, in which “sources” are systems that can be connected to the RESTORE solution to provide green energy to it (upwards), while “sinks” are systems that receive the energy stored in RESTORE (downwards). In our case, the considered sinks the DHC / District Heating and Cooling networks. For detailed technical and non-technical issues of how to integrate DHC networks with the RESTORE concept, refer to [2], the RESTORE Deliverable D1.1 (Report on Requirements and Specifications of the Overall Concept-V1).

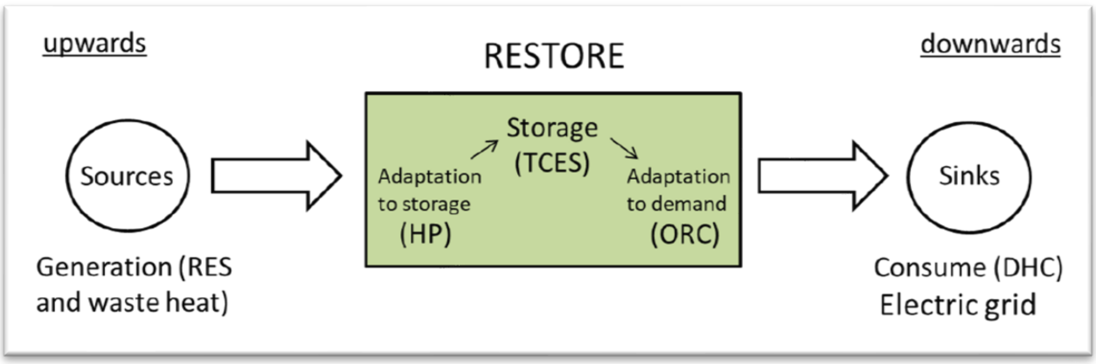



*Figure 28: General RESTORE Elements Scheme (reproduced from D1.1 [2]).*

Regarding the Data required for implementing the Use-Cases, T1.4 focused on their general high-level modelling, emphasizing the simulation concept of the RESTORE project and the adaption of the simulation tools for the design of each use-case in an ad-hoc solution, considering the boundary conditions imposed by each specific application. In this context, this document provides a general basis to be considered as a guide during the project process modelling and use-cases implementation.

## 6.1. Basic Requirements

- End-users / Use-Case Providers should be required to provide specific and needed data about the inputs of their installation processes, to match the desired outputs. The used Renewable Energy Sources (RES) mix is also required (see limits in Figure 29).

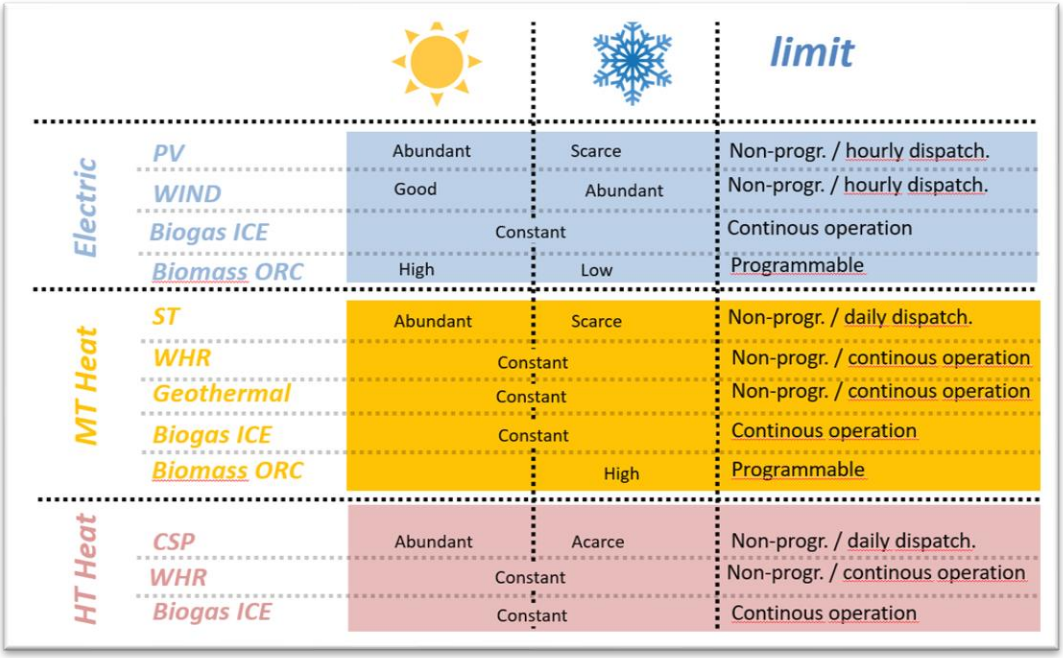



*Figure 29: General RES usage limits.*

- A general request about the Use-Cases configurations will be made to the Use-Case Providers. (In the case that an end-user supplies detailed information about their installation plants, this will be taken into account for the Use-Case simulation process model.)

- **Data to be collected (from Use-Cases Providers):**
  For all Use-Cases, the main needed parameters to be requested from end-users include:
  - Waste Heat – Q_waste / Number of hours / load profile
  - Temperature levels of the available waste heat
  - Amount of waste heat to be collected and stored
  - Is the amount of electricity from the grid limited?
  - What is the excess power? (The system will be considered “green” if we use the excess power (wasted) from the process.)

- Basic scheme of the system connection with the district heating network, in terms of exchange of energy, mass flows, the composition of the different streams and temperature (see Figure 30).

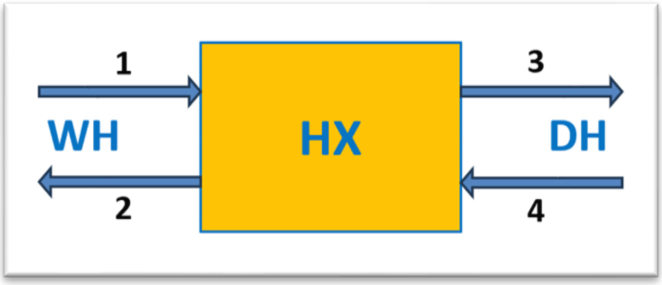



*Figure 30: Basic Scheme of the Connection with the DH.*

Figure 30 illustrates, in a very general way, the exchange of energy system (via the Heat Exchanger HX box) with the key mass flow streams for waste heat (WH) and district heating (DH) represented by (1) &(2), and (3) & (4) respectively.

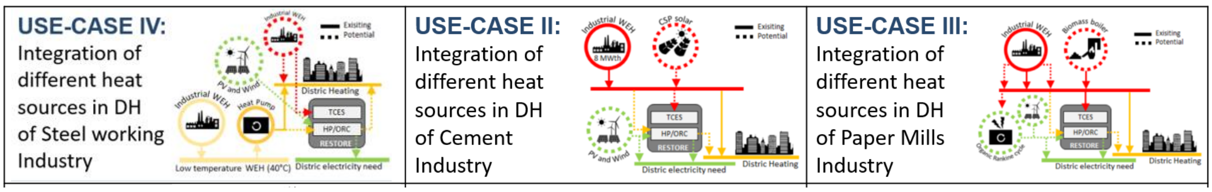
- **Information to be provided:**

  The following shall be clearly provided to the end-users (from SIMTECH):
  - Guidance on the registration for usage of IPSE GO.
  - Basic information about what is required to simulate the Use-Cases using the RESTORE-Virtual tool powered by IPSE GO.

## 6.2. Specific Requirements per Use-Case

The specific requirements for the Use-Cases will be dependent on their connections upwards: connections to waste heat recovery systems, connections to the used RES input; their connections to the DHC network, as illustrated in Figure 28. To simplify the required data from the use-cases providers, we will focus on the simple scheme of required data exemplified in Figure 30. Following this, we classified the six use-cases into two groups, according to similar characteristics, and we exemplify in the sequel some specific aspects required for both groups. The information shall be given via the defined template, illustrated in Figure 31.

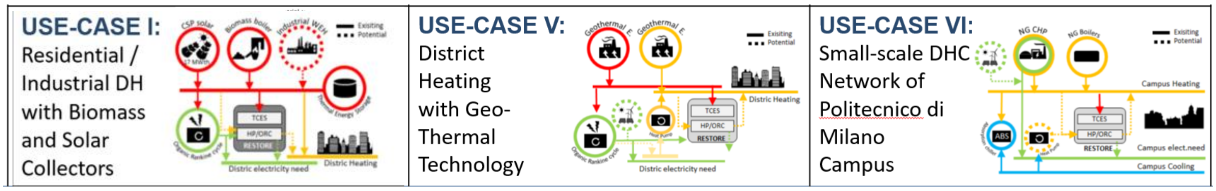
**Requirements for Use-Cases IV (Brescia IT), II (Rohrdorf AT), and III (Mondi SK):**




Considering the basic scheme of the connection with DH (Figure 30), the required data for this group of use-cases would be: the fluid and hourly data for temperature, pressure, , mass flow and composition of the key streams (1), (2), (3) and (4) for: (a) Ideally: 1 Year; or (b) Simplified

Case: Representative days of operation (1 day in summer; and 1 day in winter). In the case of the „Year Case“, it is required to collect data in „Hours/ Day“ of operation of the plant (industrial process), and the number of days that they were operating the DH connection. In addition to the basic scheme of the connection, a general overview of the process that provides the waste heat would help to implement further details to represent more information on the specific plant/sector.

**Requirements for Use-Cases I (Bronderslev DK), V (Holzkirchen DE), and VI (POLIM IT):**




Considering the basic scheme of the DH connection of Figure 30, and the connection between generation and other systems, namely: ORC, TCES, Cooling system if it applies, as well as DHC (see Figure 27), the required data for this group of use-cases would be: the fluid and hourly data of temperature, pressure, mass flow and composition of the key streams (1), (2), (3) and (4) for: (a) Ideally: 1 Year; or (b) Simplified Case: Representative days of operation (1 day in summer; and 1 day in winter).

## 6.3. Use-Cases‘ Models Basic Information

This section summarizes the basic information of the use cases to be modelled using the RESTORE Virtual Tool powered by IPSE GO. For this, a template concept was devised within the requirements definition of Task T1.4, illustrated in **Error! Reference source not found.**.

The use cases’ models calculation will require the following inputs to be implemented using IPSE GO:

- **User Input: (a) For the Charging Mode coming from Waste Heat:** Maximum of Q_Waste / Maximum of E_Waste; Number of Hours; Number of Months; Temperature of Waste Heat.
- **User Input: (b) For the Discharging Mode going to District Heating (DH):** Supply Temperature to DH; Return Temperature from DH.
- **Internal Input:** Use of Storage; T_React; Fluid; Assumptions for ΔP and ΔT; f size; Cost correlations.

After the models' calculations, the main outputs that will be delivered are related to the following information about the use-cases.

- **Main Outputs:** Solid Volume; Reduction of Wasted Energy; Increase of DH Heat; Reduced EL. Curtailment; System estimated Cost; CO2 Emission Avoided; Annual Savings, Revenues. In addition, for each use-case, the optimized parameters used in the TCES, HP and ORC models will be illustrated in the specification tables of these systems. (Example of specification tables can be found in Deliverable 1.1).

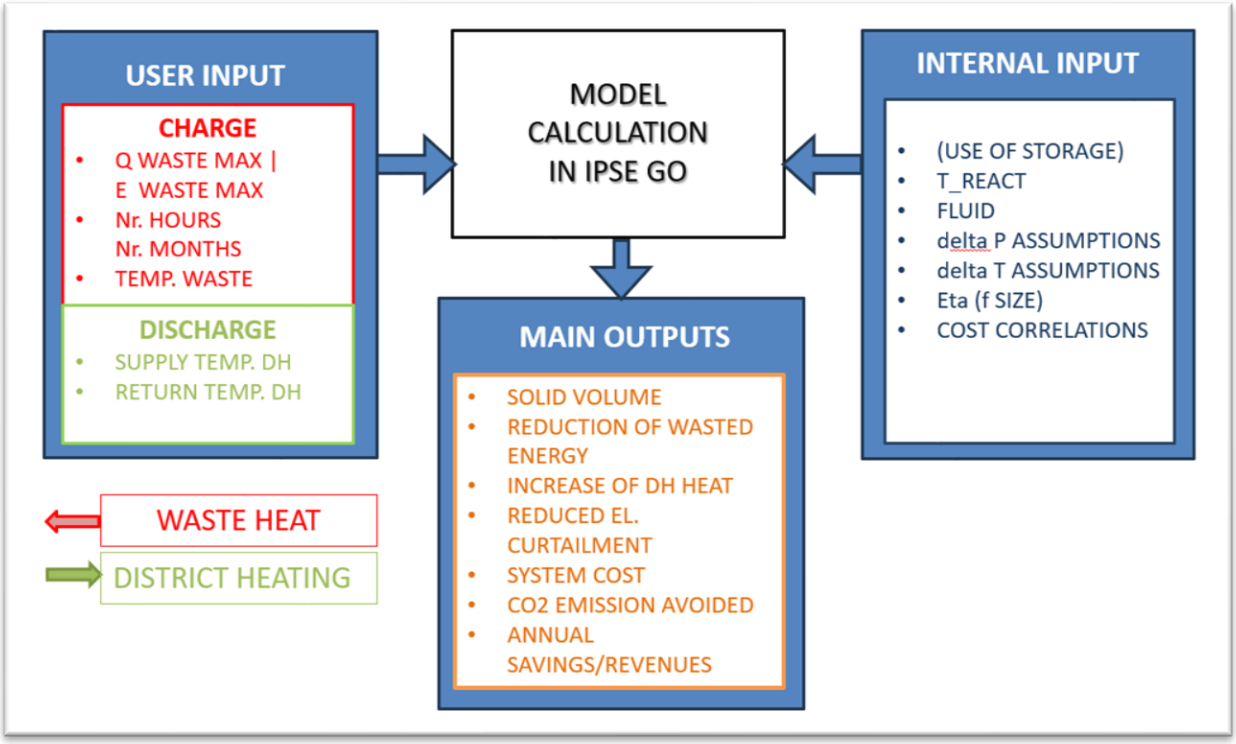



*Figure 31: Use-Cases Models' Basic Information.*

From the information identified in Figure 31, a template will be produced within WP5-Task T5.4 to adapt the required input data and the expected outputs for each of the six use-cases in RESTORE project.

# 7. Conclusion

Deliverable D1.4 reported the specifications of RESTORE numerical models and virtual use-cases for their simulation and showcase within the “RESTORE Virtual” tool, powered by the web-platform IPSE GO. Relevant specifications for the numerical models developed within the project were described, with emphasis on the way that the models for the RESTORE system as a whole, and for the defined virtual use-cases will be implemented. A summary of all 6 use-cases was presented and important aspects were discussed for their simulation. This led to the basic specification and requirements, such as: feasible computational effort, compatibility between models, adaptability to the web-platform, modularity and flexibility of the simulation tool and the process models, among others.

The simulation environment IPSEpro, as well as the RESTORE-Virtual Tool, powered by SIMTECH’s web-platform IPSE GO were briefly described, with focus on practical aspects related to: How the users are expected to use the tool; The goals of the simulations that will be implemented concerning the process models of the overall RESTORE seasonal storage technology, and the Use-Cases process models; The kind of data, input, and requirements that need to be provided for implementing new required component models (innovative elements, special equipment, TCES, renewable sources systems, etc.); as well as the showcase outcome and valuable impact with the project stakeholders that the online RESTORE-Virtual Tool will be able to aggregate via its exploitation replication strategy. A template for the collection of the Use-Cases required information was devised and shall be used by the use-cases’ providers as input contribution within WP5-T5.4.

Deliverable D1.4 established the importance of the outcomes of task T1.4 “Specifications of RESTORE Numerical Models and Virtual Use-Cases for Simulation” (led by SIM in collaboration with POL) of WP1 (RESTORE Requirements Definition, Specifications and Analysis), with its inter-dependencies with other WPs and Tasks, namely: with WP2-T2.5 (led byTUW) - about the TCES dedicated models for the reactor simulation; with WP3-T3.4 (led by POL) – about the off-design performance quantification of RESTORE system; WP3-T3.5 (led by POL) - about the dedicated models for the thermodynamic cycle and the dynamic behavior of RESTORE system; with WP5-T5.1 (led by SIM) - about modelling the individual components of the overall RESTORE system; with WP5-T5.2 (led by CENER) - about the techno-economic modelling of the RESTORE integrated systems; with WP5-T5.3 (led by SIM) - about the Web-Platform adaptation for RESTORE dynamic and techno-economic modelling to represent the Use-Cases; with task WP5-T5.4 (led by SIM) - about Implementation, Optimization, Management & Validation of RESTORE Use-Cases using the Simulation Web Platform; with WP5-T5.5 (led by SIM + PI) – about the replication strategy of the simulated process models via the opportunity of other stakeholders build additional test cases; and with WP7-T7.4 (led by PI) about stakeholders engagement & ecosystem community building for experimenting with the RESTORE simulated process models.

As part of RESTORE project’s participation in the “Open Research Data Pilot”, Deliverable D1.4, as a public dissemination-level document, will be made available in the RESTORE open-access research data repository within the Zenodo RESTORE Community (https://zenodo.org/communities/101036766/?page=1&size=20), for further reference and dissemination.

# 8. References

[1] European Commission, Horizon 2020 Project RESTORE "Renewable Energy based seasonal Storage Technology in Order to Raise Environmental sustainability of DHC", https://cordis.europa.eu/project/id/101036766,Grant Agreement GA Nr.101036766, August 207th, 2021.

[2] European Commission, RESTORE Horizon 2020 Project GA Nr.101036766. Deliverable D1.1 - Report on Requirements and Specifications of the Overall Concept (V1), ed.: Francisco Cabello (CENER), March 31st, 2023.

[3] European Commission, "An EU strategy on heating and cooling," *J. Chem. Inf. Model.*, vol. 53, pp. 1689–1699, 2016.

[4] SIMTECH GmbH, "The Process Simulation Environment IPSEpro", https://www.simtechnology.com/cms/ipsepro/process-simulation-and-heat-balance-software, © 2023 SimTech GmbH.

[5] SIMTECH GmbH, "IPSE GO: The Future of Simulation", https://about.ipsego.app/, © 2023 SimTech GmbH.

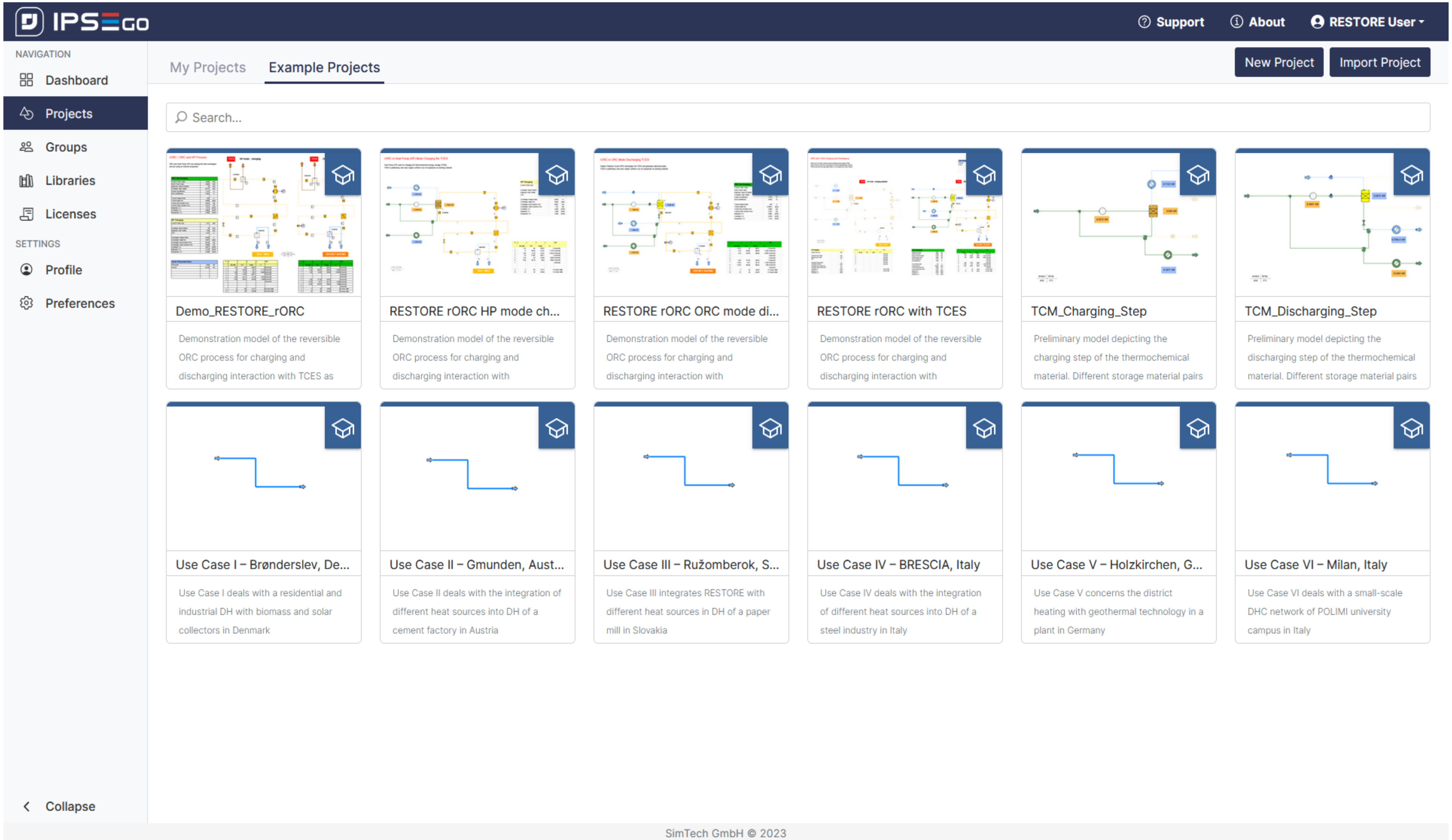
[6] SIMTECH GmbH, "IPSEpro & IPSE GO - Powerful Process and Heat Balance Simulation Solutions", https://www.linkedin.com/pulse/ipsepro-ipse-go-powerful-process-heat-balance-simulation/, © 2023 SimTech GmbH.

# Annex I. RESTORE Virtual Tool powered by IPSE GO

Landing Page of the RESTORE Virtual Tool powered by IPSE GO, showing the navigation Tabs for: Project Overview; RESTORE_Lib Available Units; and RESTORE Example Projects.

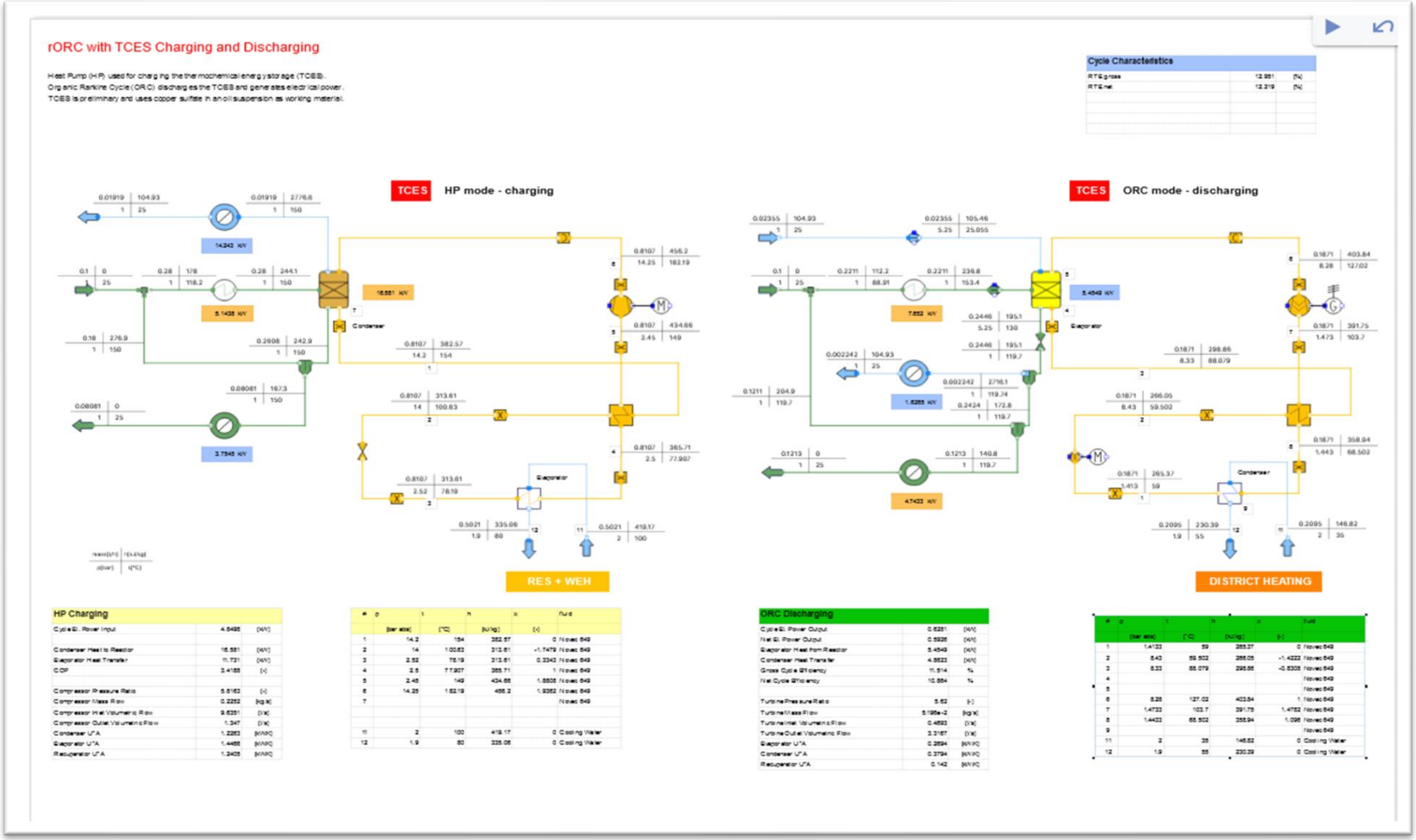
# Annex II. RESTORE Virtual Tool – Projects Page

RESTORE Virtual Tool powered by IPSE GO, showing the available RESTORE process models.



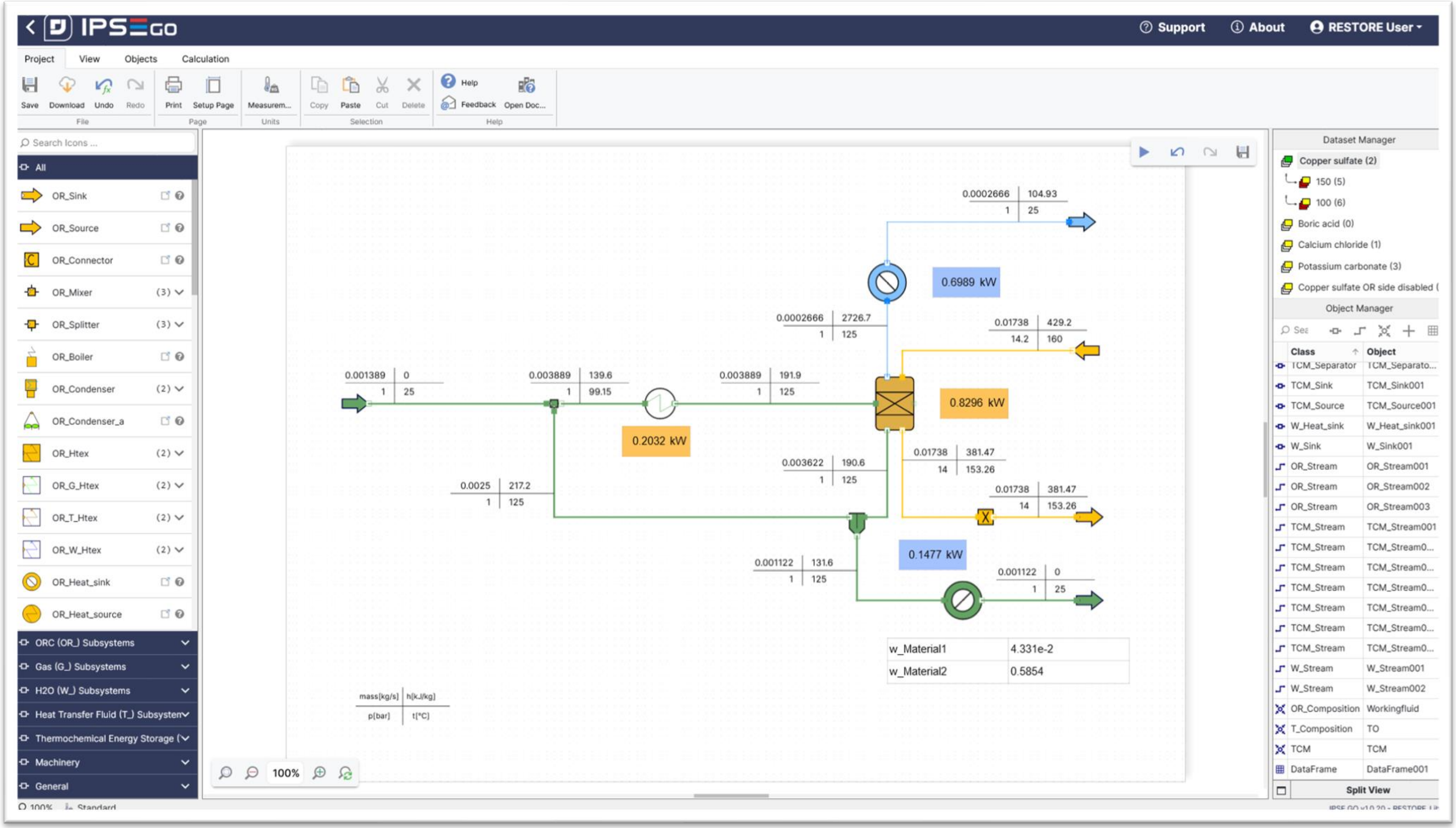
# Annex III. RESTORE Preliminary rORC with TCES Process Model

RESTORE Preliminary rORC with TCES Charging and Discharging Model (as of September 2023) produced by TUWIEN with SIMTECH support.



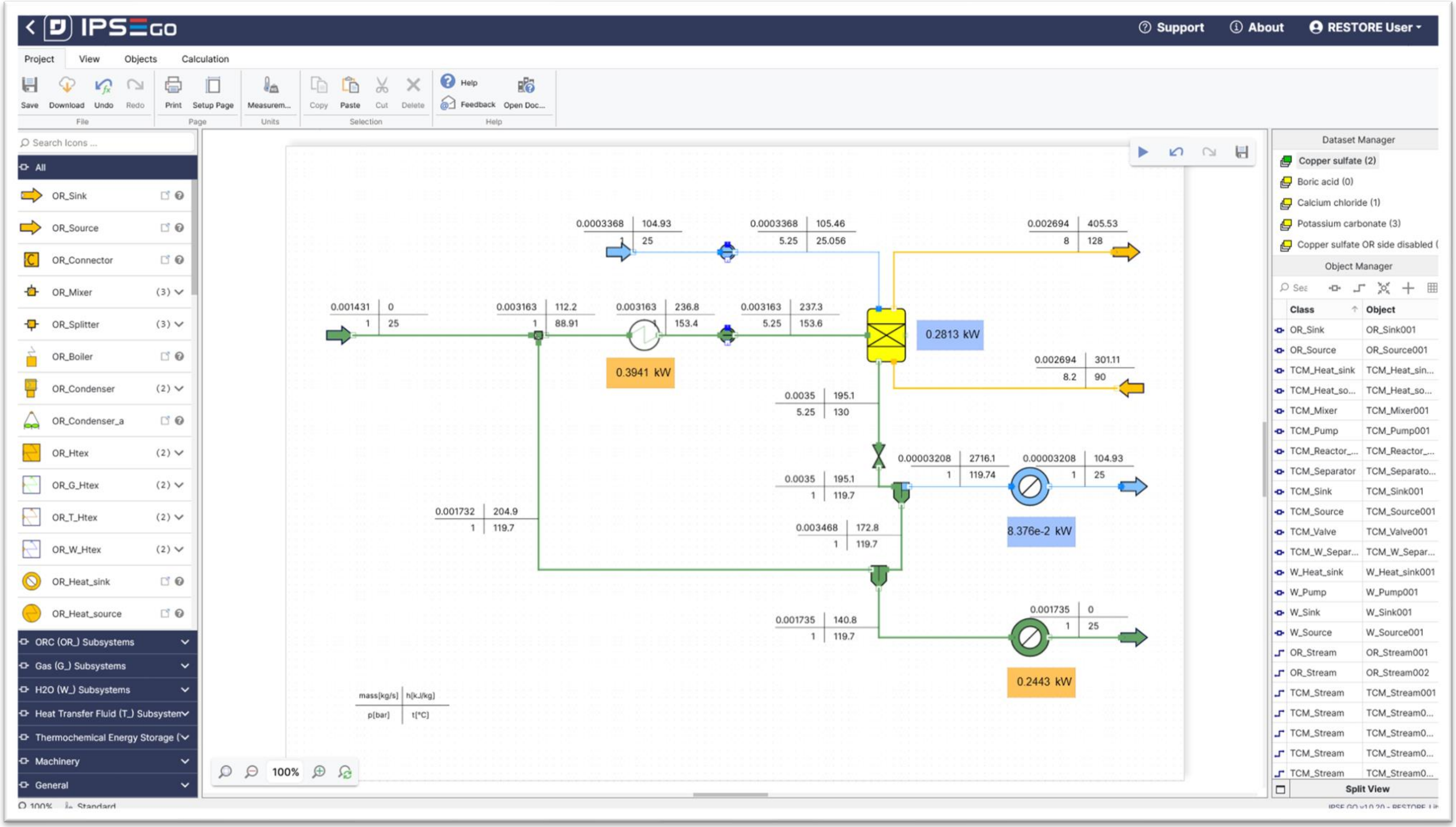
# Annex IV. RESTORE Preliminary TCES Charging Model

RESTORE Preliminary TCES Charging Model within IPSE GO (as of September 2023).



# Annex V. RESTORE Preliminary TCES Discharging Model

RESTORE Preliminary TCES Discharging Model within IPSE GO (as of September 2023).



# Annex VI. RESTORE_Lib Components

RESTORE_Lib Component Models (as of September 2023) produced by TUWIEN with SIMTECH support. RESTORE_Lib was produced using IPSEpro-MDK and is used in both IPSEpro and IPSE GO.