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D5.11 – RESTORE Replication Strategy V2

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DELIVERABLE INFORMATION SHEET	
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Related Task	Task 5.5 (Replication Strategy via Stakeholders additional Cases)
Lead Beneficiary	SIMTECH (SIM) / PROSPEX Institute (PI)
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Summary

This document provides information about the RESTORE project's EU-wide replication strategy from task T5.5 on "Replication Strategy via Stakeholders additional Cases", led by SIMTECH and PI. Results of task T5.5 were initially reported in the WP5 deliverable D5.10 (V1), in month M26 [11], and also in the current deliverable D5.11 (V2), in M48.

Deliverable D5.11 was produced by SIMTECH, and reports the result of the complete work carried out in T5.5 during the period of M9 to M48 of the project, from the description of the specified replication strategy to motivate RESTORE's stakeholders to create additional cases and trials during and after the project lifetime, using the RESTORE Virtual Tool powered by the IPSE GO simulation web-platform. The creation of stakeholders' additional test-cases were encouraged to be based on the six RESTORE virtual use-cases [1], developed in WP5 task T5.4 (Implementation, Optimization, Management & Validation of RESTORE Use-Cases using the Simulation Web Platform) [12].

The information provided in this document builds upon collaboration between SIMTECH and PROSPEX Institute (PI), with contributions from other RESTORE partners, considering inputs from WP1, WP6, and WP7: [2], [3]; [4]; [5]; [6], among others.

As part of RESTORE project's participation in the "Open Research Data Pilot", Deliverable D5.11, 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.

Table of Contents

1. Introduction

This document (D5.11) reports the work carried out in Task T5.5 “Replication Strategy via Stakeholders additional Cases” of WP5 (RESTORE EU-wide Replication in Virtual Representation on Real Use-Cases). It describes the specified RESTORE replication strategy to motivate stakeholders to create additional cases and trials during and after the project lifetime, using the “RESTORE Virtual Tool” powered by the IPSE GO simulation web-platform.

The RESTORE replication strategy, also reported in [11], focused on the creation of stakeholders’ additional test-cases, based on the six defined virtual use-cases for RESTORE [1] and worked-out in WP5 task T5.4 (Implementation, Optimization, Management & Validation of RESTORE Use-Cases using the Simulation Web Platform) [12].

The replication strategy, defined and worked out in WP5-T5.5, for the use of RESTORE’s Virtual Tool by interested stakeholders for test-cases, considered inputs from WP1, WP5, WP6 and WP7 (D1.1 [2]; D1.4 [3]; D6.6 [4]; D6.9 [5]; D7.9 [6]; D5.10 [11]; D5.4.0 [12]; D5.4.0 [12]; D5.4 [13]; D5.5 [14]; D5.6 [15]; D5.7 [16]; D5.8 [17]; and D5.9 [18]). Moreover, task T5.5 collected relevant inter-dependencies, information and input based on technical development from almost all other WPs, concerning not only the exploitable project results and their applications, but also stakeholders’ community building and communities of practice relevant to the project. Hence, the replication strategy embedded inputs about: the overall concept RESTORE requirements and specification; the interfaces of RESTORE system with DHC and energy sources; the specification of RESTORE numerical models and virtual use-cases for simulation; the TCES dedicated models for the reactor simulation; the dedicated models for the thermodynamic cycle and the dynamic behavior of RESTORE system; the modelling of the RESTORE system individual components; the techno-economic modelling of the RESTORE integrated systems; the web-platform adaptation for RESTORE dynamic and techno-economic modelling to represent the use-cases; the implementation, optimization, management and validation of RESTORE use-cases; the technology watch and market evaluation within the project’s exploitation of results and business development; the exploitation and stakeholders group management; and about the stakeholders’ ecosystem community building.

The work carried out in task T5.5 was planned to have the following phases:

- M9-M17 – Preliminary strategy specifications for the replication of use-cases in stakeholders additional test-cases. Inputs from involved relevant tasks, concerning stakeholders identification. Collaboration meetings (SIMTECH, PI).
- M17-M18 – Compilation of the work done in task T5.5 for contributing to the 1st RESTORE Periodic Report.
- M16-M24 – Refinements on the preliminary strategy. Activities plan involving stakeholders. Inputs from involved relevant tasks & interaction with tasks-leaders. Further specifications and collaboration meetings (SIMTECH, PI, CENER).
- M25-M26 – 1st Virtual Stakeholders Workshop. Compilation of the requirements and specifications for the preliminary replication strategy for the production of the D5.10(V1).
- M30-M48 – Stakeholders‘ ecosystem community building and engagement with the RESTORE Virtual Tool, via the replication of proprietary test-cases based on the Use-Cases implemented for the project. Production of D5.11(V2) in M48.

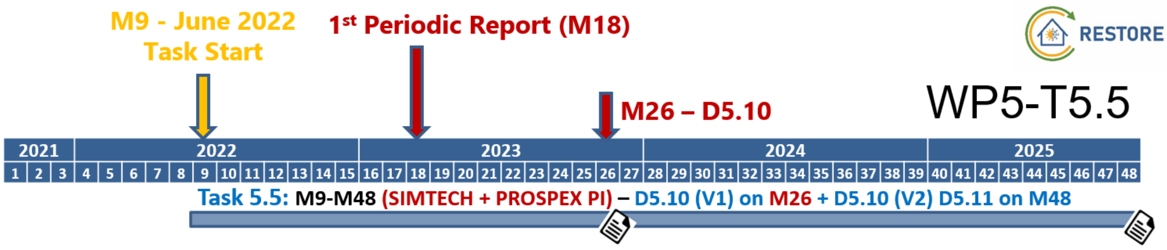

Figure 1: Task T5.5 Work Phases Timeline.

During all the period of task T5.5, several meetings were organized between SIMTECH and PI, also including other partners whenever needed. The meetings-topics varied from the definition of the CoPs (Community of Practices), and Stakeholders engagement within the replication strategy, to the RESTORE Virtual Tool usage and promotion. Most of the meetings were recorded for further post-processing.

D5.11 is structured in the following way:

- The Introduction chapter (1) includes a brief recap about the use of simulation tools in RESTORE, considering the simulation tools IPSEpro, the IPSE GO web-platform, and focusing on the description of the "RESTORE Virtual Tool" and its simulated process models and use-cases. The 6 use-cases are summarized in the Annexes.
- Chapter (2) describes the relevant aspects of the specification of the Test-Cases Replication Strategy for RESTORE, focusing on two particular phases and the main steps to be taken in each of them. In (2), also challenges to be faced on the replication strategy phases 1 and 2 are identified.
- Chapter (3) describes the activities related to the replication strategy.
- Chapter (4) presents the creation of the "Use-Cases Demo Web-pages" to serve as a multiplier element of the replication strategy for stakeholders.
- Chapter (5) draws some concluding remarks about the work carried out in T5.5.
- Chapter (6) lists the references upon which the work done was based.
- Annex I and Annex II show illustrations of the RESTORE Virtual Tool powered by IPSE GO.
- Annex III and Annex IV show the RESTORE available process models within IPSE GO. The TCES Charging Model is shown in Annex III, and the RESTORE TCES Discharging Model in Annex IV.
- Annex V shows the RESTORE Library of Components (RESTORE_Lib).
- Annex VI presents the summary of RESTORE Use-Case I.
- Annex VII presents the summary of RESTORE Use-Case II.
- Annex VIII presents the summary of RESTORE Use-Case III.
- Annex IX presents the summary of RESTORE Use-Case IV.
- Annex X presents the summary of RESTORE Use-Case V.
- Annex XI presents the summary of RESTORE Use-Case VI.
- Annex XII shows details of the Use-Cases Demo Web-pages.

1.1. The use of the Simulation Tools in RESTORE

The overall goal of the simulation within RESTORE 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, so that their evaluation and implementation within real-data virtual use-case scenarios can be validated.

The RESTORE concept has been validated both in lab-scale, and also via virtually represented applications with district heating and cooling networks. At a first stage, the consistency of the specific component models was checked and validated with the partners' experience largely obtained from the experimental activities within the project. Then, those component models were used for building the virtual demonstrations. Those virtual demonstrations represented showcases of real use-cases allowing the simulation of the project concept in scaled-up scenarios. For this to happen, the overall RESTORE system was 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. Refer to D1.4 [3] for a detailed description of the simulation tools (IPSEpro, IPSEpro-MDK, IPSEpro-PSE, and IPSE GO) used in RESTORE, and refer to [12], [13], [14], [15], [16], [17], and [18], for the explanation of how the six Use-Cases representations have been implemented and made publicly available online.

For the sake of powering the RESTORE Virtual Tool, the cloud-based simulation platform IPSE GO (https://about.ipsego.app/) uses the capabilities of the process simulation system IPSEpro via the web, and was designed to run in all internet browsers, from any device you may wish to work with (computers, mobile devices, etc.). In addition, the RESTORE Virtual Tool is based on an intuitive user interface that can handle the complexity of the industrial level within a user-friendly way. A strong advantage of using IPSE GO is the "effortless collaboration" aspect that it offers to all its users.

1.2. The RESTORE-Virtual Tool

The RESTORE Virtual Tool enables the showcase of RESTORE's 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, enabling external stakeholders to build additional test cases.

As a result, the RESTORE project was able to profit from a more interactive ecosystem community building with more stakeholder 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 allows end-users to adjust the Use-Cases according to their requirements, using the platform via web browsers. Additionally, the platform users are able to investigate new testing cases, multiplying the impact of the project's concept validation.

Figure 2: RESTORE Virtual Tool powered by IPSE GO.

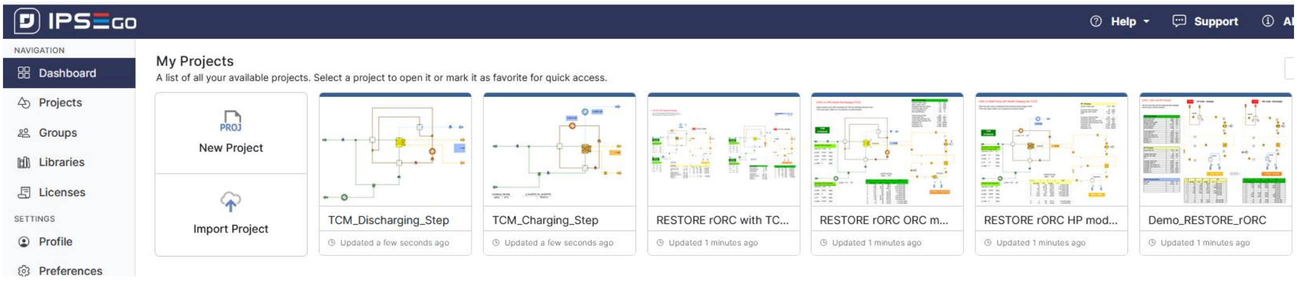

Figure 3: RESTORE Virtual Tool showing some RESTORE process models.

In Annex I. RESTORE Virtual Tool powered by IPSE GO, and in Annex II. RESTORE Virtual Tool – Projects Page, you find larger illustrations of the RESTORE Virtual Tool and the available process models that appear in Figure 2 and in Figure 3.

The implementation of the RESTORE process models using the simulation tool IPSE GO follow the specifications and requirements of relevant aspects like feasible computational effort, object-oriented philosophy, compatibility between models, and adaptability to the web-platform, modularity and flexibility, which align with the defintions in WP1-T1.4. Hence, the RESTORE Virtual Tool presents the following characteristics: Usability; System Robustness; as well as Sharing, Portability, Compatibility, and Security related to collaborating Project-Files.

1.2.1. RESTORE Simulated Models

The final versions of the process models available in the RESTORE Virtual Tool include the Thermo-chemical Storage (TCES) Charging Model, and the TCES Discharging Model (see D1.4 [3] for more details). In Annex III and in Annex IV you find illustrations of both RESTORE TCES charging and discharging process models.

The process models have been designed with customized component models from the project library RESTORE_Lib. These RESTORE component models have been implemented and fine-tuned within WP5-T5.1 with input from WP1, WP2 and WP3. Extensions and updates of both RESTORE_Lib and process models have been created throughout the project. Annex V shows the final list of RESTORE_Lib Units**,** with 87 component models.

As the RESTORE Virtual Tool has been made available online for stakeholders, the use cases implemented processed can be used as templates to simulate modified cases interactively by anyone interested in the technology. Additionally, stakeholders are able to create their own testing cases, such that the number of different application examples can grow continuously.

1.3. The Use-Cases simulated in RESTORE Virtual Tool

The RESTORE Virtual Tool hosts and showcases the RESTORE virtual Use-Cases. The overall RESTORE concept has been virtually implemented and optimized for six DHC Use-Cases with real data from the Use-Case providers.

The six Virtual Use-Cases 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 summarized in Figure 4.

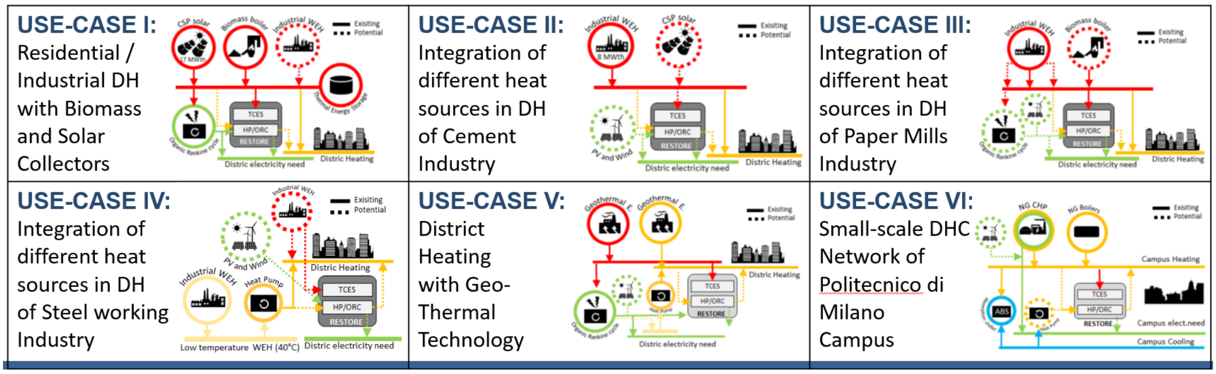

Figure 4: RESTORE Use-Cases.

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. Finally, **Use-Case VI** deals with the small-scale DHC network of POLIMI University Campus in Italy. See Annexes VI to XI for a more detailed description of the RESTORE Use-cases.

In the RESTORE deliverable D1.4 [3], you find the specification of the high-level modelling data and requirements for implementing the RESTORE Use-Cases, considering the boundary conditions imposed by each specific use-case application. In this context, D1.4 provided a general basis for the project process modelling and Use-Cases implementation. In general terms, the calculation of the use-cases' models required the following inputs to be implemented using IPSE GO: (a) User Input 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. (b) User Input for the Discharging Mode going to District Heating (DH): Supply Temperature to DH; Return Temperature from DH, Max. And Min. of Q_DH in operation. Internal Input and main outputs can be observed in Figure 5, about the Use-Cases Models' Basic Information [3].

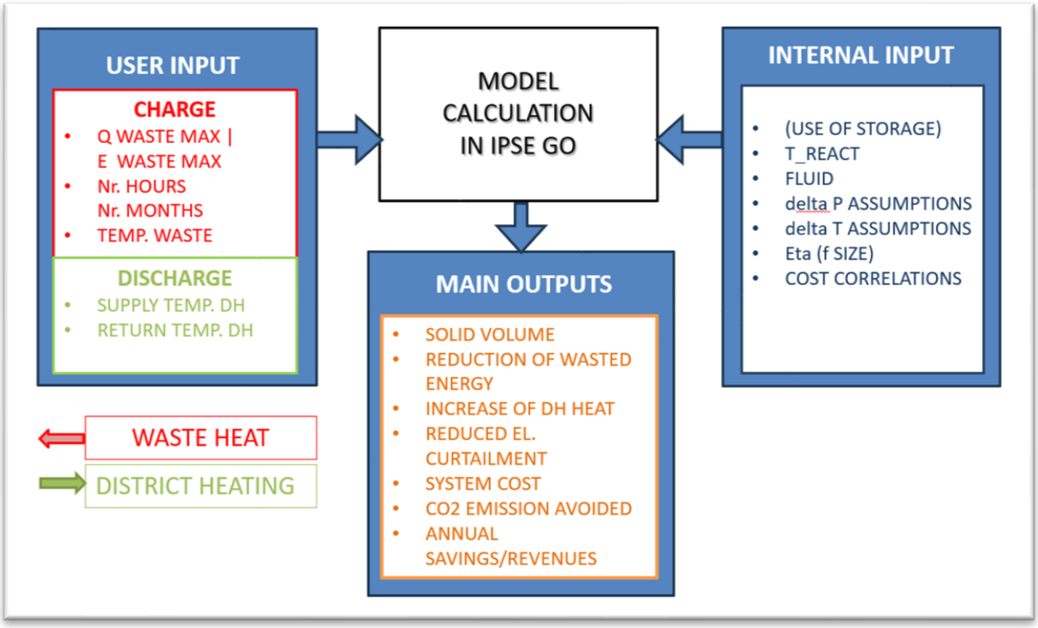

Figure 5: Use-Cases Models' Basic Information (from RESTORE WP1-T1.4-D1.4).

From the information identified in Figure 5, a template has been 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. See Annex XII for further details of the six implemented Use-Cases.

2. The Replication Strategy

2.1. RESTORE Replication Specification

The RESTORE replication specification planned in [1] has been developed and put in practice within WP5 task T5.5. As illustrated in Figure 6, the lab-scale validation and prototyping of the RESTORE system took place first, following the design of small scale and large scale DHC commercial units, to the implementation of the virtual use-cases and the possibility of testing additional stakeholder's cases.

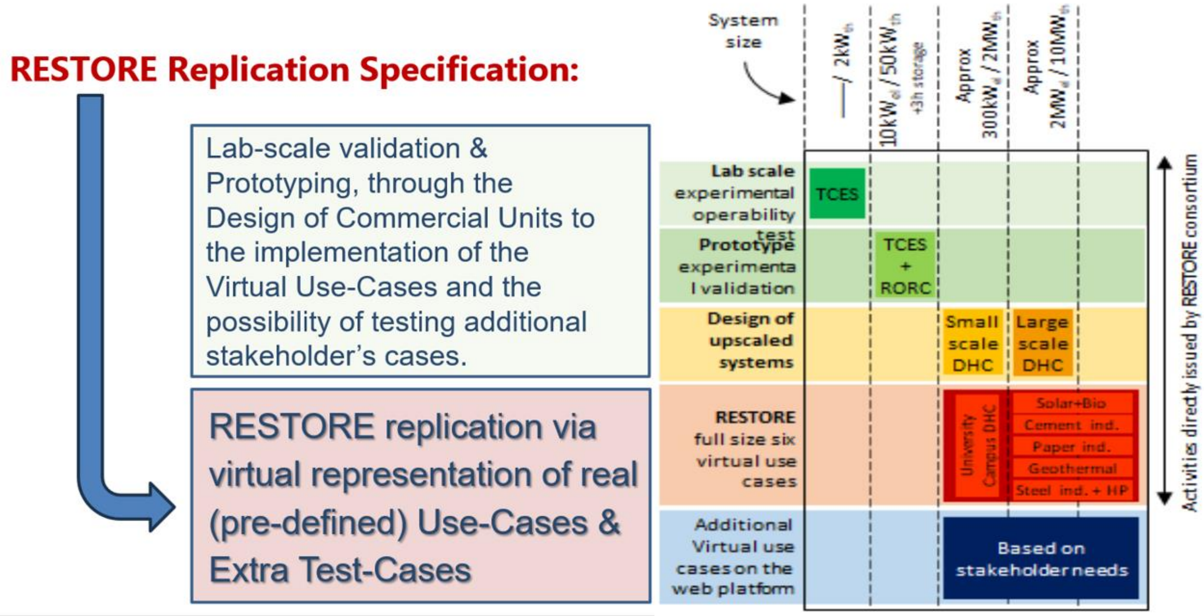

Figure 6: RESTORE Replication Specification.

Although the Test-Cases Replication Strategy for RESTORE stakeholders have been encouraged to be implemented, after the conclusion of the Use-Cases implementation, they have not been made available during the project lifetime, as planned in Figure 6. This did not compromise the achievements of the project during its lifetime, as the additional virtual cases based on stakeholders needs for test-cases, were meant to be an expected activity for the exploitation phase of the project, for after the project ends (M48 and beyond). This means that the RESTORE Virtual Tool will continue to be up and available online as a showcase and testing tool beyond the project lifetime.

Apart from the long-term availability of the web-based RESTORE Virtual Tool, powered by IPSE GO, SIMTECH also implemented the RESTORE Use-Cases Demo Web-pages that will also be maintained online beyond the project lifetime (see Chapter 4 of this document).

Important outcomes supported be WP5 task T5.5 developments:

- The use of the web-platform for virtual use-cases as showcase for the additional Cases of other Stakeholders and potential End-users.
- The definition of the replication strategy for the RESTORE testing cases, based on the use-cases selected for the project.

- Interactions with WP6 & WP7, and engagement with the project's dissemination and exploitation activities.
- Aligning and engaging with the "User-Community building around the RESTORE Virtual Tool", via WP7 task T7.4 [M3-M48].
- Implementation and online publication of the RESTORE Use-Cases Demo Web-pages, embedding the Use-Cases process models simulated in IPSE GO.

2.2. Replication Strategy Development

2.2.1. Stakeholders Identification

- Within T7.4 – PI carried on the identification of the "*User-Community building around the RESTORE Virtual Tool*" and conducted a stakeholder mapping based on the relevant identified categories (see D7.10 [20]).

- In addition, SIMTECH identified Stakeholders Identification via:
  - RESTORE ESAB Members.
  - Communities of practice (CoP) groups.
  - SIMTECH's Customers (Clients & Contacts).
  - IPSEpro's & IPSE GO Users.
  - Partner's and Use-Case Providers' Networks.
  - Contacts resulting from RESTORE Dissemination & Exploitation Network.
  - Contacts resulting from RESTORE stakeholders' engagement process.

2.2.2. Replication Strategy Dependencies

The success of the use-cases simulation within the RESTORE Virtual Tool has been taken as the key factor to propagate the easy-of-use approach of the IPSE GO simulation web-platform for test-cases to other stakeholders with similar applications. Moreover, the use-cases providers, once convinced of the usefulness of the simulated demonstrations for showcasing their virtual pilot installations of the RESTORE developed system integrated in their scenario-facilities, are expected to act as multipliers ambassadors of the RESTORE use-cases. This has been expected to accelerate decision-making within the exploitation roadmap of the project, concerning: (1) being early adopters themselves of the RESTORE technology via piloting the project solution in their real installations/plants; and (2) positively influencing other stakeholders within related application areas to try out the web-based RESTORE Virtual Tool for testing the project solution on customized test-cases based on the simulated use-cases. More details on the engagement strategy can be seen in deliverable D.7.9 [6].

Figure 7: RESTORE Replication Strategy Dependency.

Following this reasoning, the replication strategy adopted by the RESTORE project was strongly dependent on the successful implementation of the simulated use-cases. Notwithstanding, the achievement of a high number of extra test-cases using the RESTORE Virtual Tool and the RESTORE models and simulated use-cases as templates, does not only depend on the successful technical implementation of the project. It is also dependent on the appropriate alignment of the replication strategy with the project's exploitation strategic plans, within the identified communities of practice of the project.

As reported in [12], [13], [14], [15], [16], [17], and [18], concerning the technical details of how the six Use-Cases representations have been implemented and made publicly available online, we can conclude that all simulated cases were successfully implemented and that their providers were satisfied with their key-results (see Annex XII).

Task T5.5 Replication Strategy for Test-Cases was defined aligned with:

- RESTORE's dissemination and exploitation (DEC) strategic plans, so that T5.5 could profit from engagements with WP6 & WP7 planned activities.
- WP7 Task T7.4, engaging with the identified "User-Community around the RESTORE Virtual Tool".

Moreover, T5.5 Replication Strategy was strongly dependent on the RESTORE Virtual Use-Cases, so that other identified stakeholders could be encouraged to try out the RESTORE modelled solution with their own cases.

2.3. Phases of the Replication Strategy

The RESTORE replication strategy considered two distinct phases, as shown in Figure 7, namely: *Phase 1* that was planned to cover the period from M9 up to ~ M30, before the RESTORE virtual use-cases are modelled; as well as the initial stage of stakeholder engagement is currently taking place. and *Phase 2* that involved the period after M30, already counting with preliminary results of the implementation of the virtual use-cases demonstrations using the RESTORE Virtual Tool, powered by IPSE GO. This plan, however, did not happen as initially defined, due to delays on the implementation of the Use-Cases, which caused Phase 2 only to start on month M41 of the project, when most of the Use-Cases process models were made publicy available in IPSE GO. Figure 8 illustrates the actual Phases followed by the Replication Strategy.

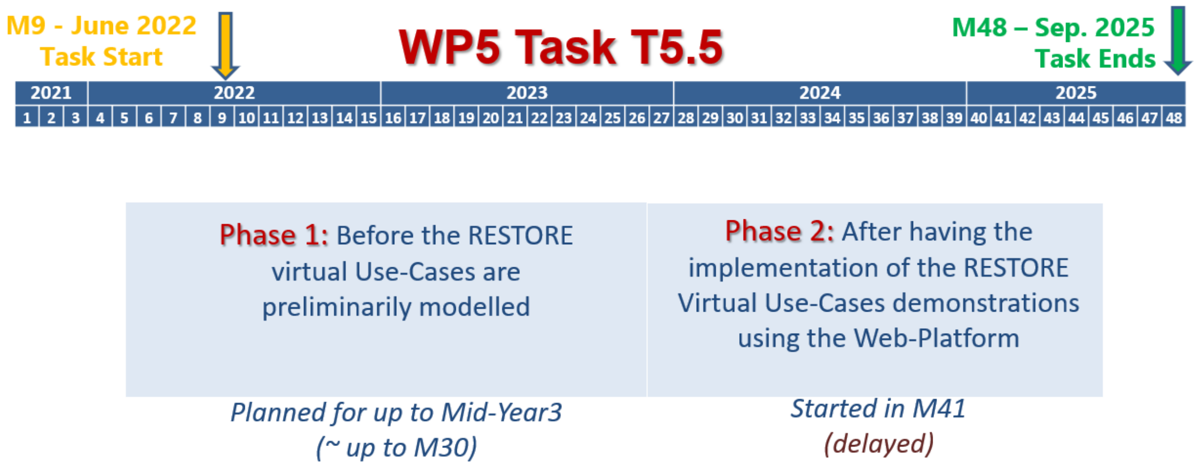

Figure 8: Replication Strategy Phases 1 & 2, during project lifetime.

Replication Strategy - Phase 1: This phase was planned to happen before the RESTORE Virtual Use-Cases were modelled and made available *(planned to happen up to Mid-Year3 – ~M30, was extended up to M41).* Phase 1 made use of the following supporting features and activities:

- Use of Conceptual Information about the project for awareness making among identified stakeholders.
- Identification of stakeholders with potential use of RESTORE solution on their own installations (confidential report done using SIMTECH's clients (IPSEpro and IPSE GO users, categorized via application areas).
- Use of the available information about RESTORE's Use-Cases to promote the interest among stakeholders on creating extra test-cases (this was also implemented with the RESTORE LinkedIn Stakeholders closed group created by PI).
- Use of SIMTECH's Training and Promotion Material of the Web-Platform (see Annex I and II), to motivate identified stakeholders to use the RESTORE Virtual Tool with the Use-Cases modelled, when available.

Replication Strategy - Phase 2: This phase was planned to happen after having the implementation of the RESTORE Virtual Use-Cases demonstrations using the Web-Platform *(initially planned to start happening in ~ M30, delayed to happen from M41 to M48).* Phase 2 made use of the following supporting features and activities:

- Use of the representation of RESTORE overall Process Model to reinforce the initial interest of selected / identified stakeholders and to gain the interest of new ones.
- Exploration of the virtual representation of the 6 RESTORE's Use-Cases to promote specific interest among stakeholders on creating extra test-cases on related areas of application. (This was implemented with the RESTORE LinkedIn Stakeholders closed

group created by PI, and with some of SIMTECH's clients, users of IPSEpro and IPSE GO).

- Use of available guidance and training on the use of the Web-Platform to the selected/identified stakeholders, supporting the creation of extra virtual test-cases for RESTORE (see Annex I and II).
- Use of the RESTORE Use-Cases Demo website created and maintained by SIMTECH (link: https://usecases.restore-dhc.eu/), to promote specific interest among end-users and targeted stakeholders on creating extra test-cases using IPSE GO.

2.4. Steps defining the Replication Strategy

As illustrated in Figure 9, the Test-Cases Replication Strategy for RESTORE was defined to follow 7 main steps, within phases 1 and 2, with the group of stakeholders already identified. Steps 1, 2 and 3 are part of Phase 1, while Phase 2 takes care of Steps 4 to 7.

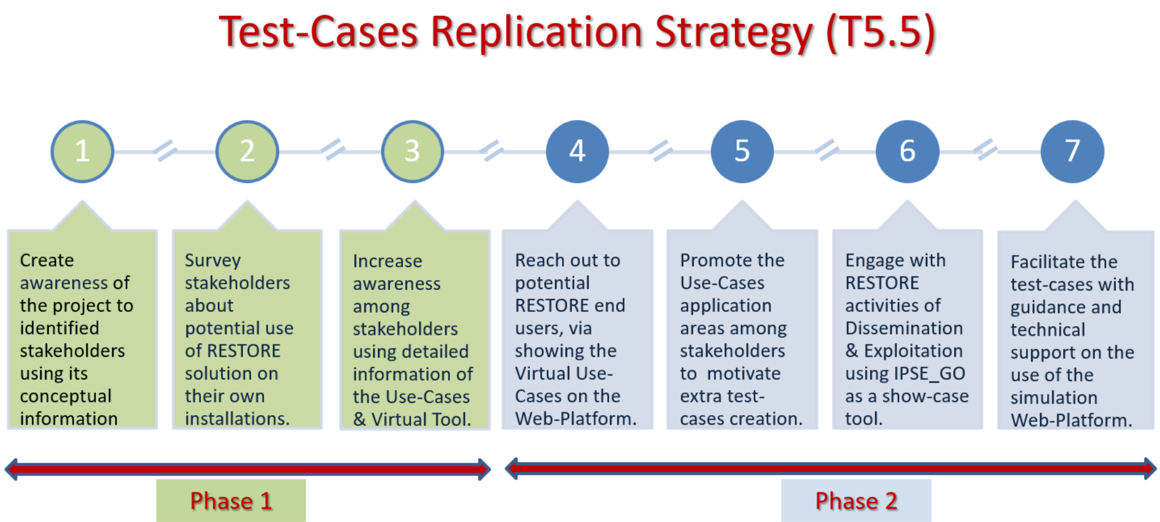

Figure 9: Important Steps of the Test-Cases Replication Strategy.

The strategy steps shown in Figure 9 were not meant to be executed sequentially. More precisely, it was not the case that once a step concludes, the subsequent one would start. In the project implementation, some steps overlap each other on their execution. For instance, steps 1, 2 and 3 are overlapping on their execution during some months of phase 1, Steps 2 and 3 start in phase 1 and are also present in the first half of phase 2. Steps 4, 5, and 6 were executed concurrently after the Use-Cases process models were made available. Step 7 is due to continue happening during the exploitation of the project, beyond the project lifetime, due to the delays of the use-cases implementation.

Figure 10 illustrates the initially planned execution schedule of the replication strategy steps within a timeline chart, as reported in D5.10 [11].

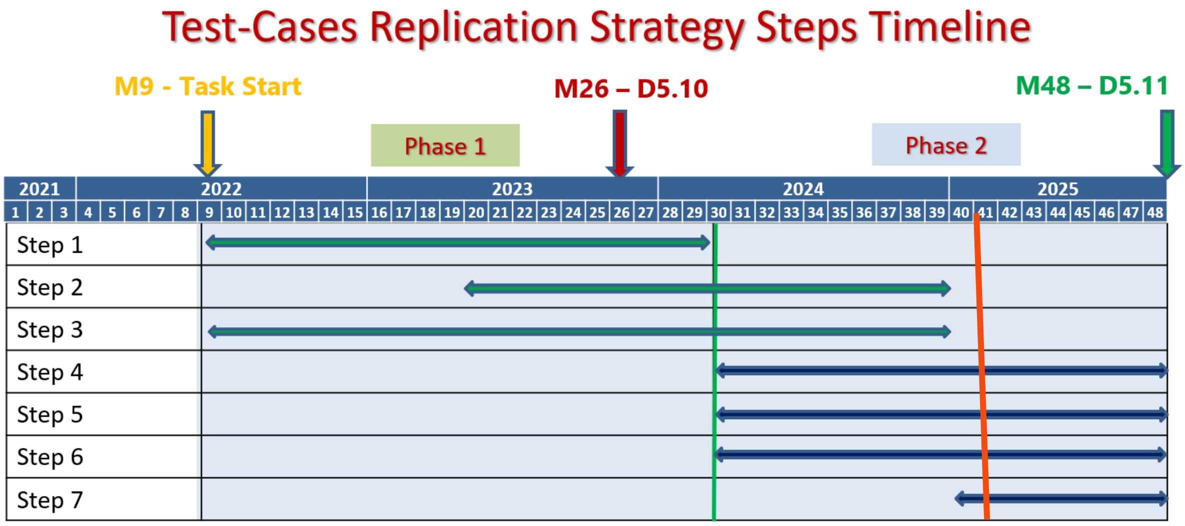

Figure 10: Execution Timeline planned for the Replication Strategy Steps. Phase 2 was delayed, and actually started in M41 (shown in red).

Step 1: The awareness-creation about the project, using its conceptual information and the information about its use-cases, towards identified stakeholders is a crucial step within the replication strategy. In this respect, the RESTORE Consortium altogether has actively and continuously disseminated the results of the project in various conferences, exhibitions and other events (see [10]).

Step 2: Survey stakeholders about potential use of the RESTORE solution on their own installations. This was a way to get some feedback from selected stakeholders about their initial impressions of their needs and preparedness for testing the project's technology using the simulated use-cases as process-model-templates in the future. Such a step was planned to be performed in phases 1 and 2. (PI promoted "Stakeholders Engagement" internal seminars to prepare the Consortium in the direction of this step. SIMTECH implemented the survey with selected IPSEpro and IPSE GO users).

Step 3: Increase awareness among stakeholders using detailed information of the Use-Cases & Virtual Tool. SIMTECH has continuously promoted, within the stakeholders of the Consortium and also externally, the information about the use-cases and about IPSE GO used as RESTORE Virtual Tool, including its available process models. Among other events, SIMTECH took part in a Stakeholders Workshop of the Horizon Europe project NET-Fuels, as well as in relevant conferences and exhibitions, presenting the RESTORE Virtual Tool for simulating the project's Use-Cases.

Step 4: Reach out to potential RESTORE end users, via showing the Virtual Use-Cases on the Web-Platform. This is an effective approach, for which various activities (webinars, online workshops, face-to-face presentations, etc.) were planned and organized. Step 4 belonged to Phase 2 of the Replication Strategy. SIMTECH and PI have already co-organized the online workshop "Introduction to the RESTORE Virtual Tool" for selected stakeholders, and users of IPSEpro / IPSE GO. In this workshop, the participants were given the opportunity to experience more details about IPSE GO and to discuss with SIMTECH and other RESTORE partners their own impressions of the RESTORE Virtual Tool in an interactive manner.

Step 5: Promote the Use-Cases application areas among stakeholders to motivate extra test-cases creation. This was a very important step taken in Phase 2 of the Replication Strategy, as soon as the preliminary process models simulated for the use-cases could be showcased in the RESTORE Virtual Tool. The simulated use-cases were validated and made available as process-model-templates for other stakeholders' test-cases (between M41-M48).

Step 6: Engage with RESTORE activities of Dissemination & Exploitation using IPSE_GO as a show-case tool. This step was vital for the alignment of the replication strategy with the DEC strategic plans, aiming at the successful result for the implementation of T5.5. In Chapter (3), some panned activities were listed in collaboration with WP6 and WP7.

Step 7: Facilitate the test-cases with guidance and technical support on the use of the simulation Web-Platform. To implement this step, SIMTECH guided the stakeholders with training material made available via recorded videos and/ or via direct technical support, whenever possible. This step was performed during the last year of the project.

Internally for RESTORE Consortium, SIMTECH performed an online training for its simulation tools (with recordings), including the following sessions: (1) "Introduction & Getting Started: overview, building a simple Organic Rankine Cycle"; (2) "Basics of Process Simulation with Interaction via the cloud platform IPSE GO"; (3) "Advanced Simulation: how IPSEpro-PSE works" (including modelling off-design, especially part-load turbomachinery and heat exchangers; advanced mechanisms; and model library development with IPSEpro-MDK). The material of this training can also be used to guide other external stakeholders with their test-cases implementation.

Following the defined strategy, it is expected that stakeholders will be able to create their own testing cases, such that the number of different application examples will grow continuously.

The platform with the collection of virtual use cases will remain online after the project to stimulate a new technological direction and the emergence of an European innovation ecosystem around the RESTORE paradigm.

2.5. Test-Cases Replication Strategy Challenges

Both Phases 1 and 2 of the Replication Strategy face identified some challenges, as shown on the Tables to follow. Those challenges have been tackled during project development. On the sequel, we present together with the challenges identifications, some mitigation measures that were sketched and used, so that the challenges could be monitored through the implementation of task T5.5, to avoid risks on the RESTORE Test-Cases implementation.

Table 1: Replication Strategy - Phase 1 Challenges.

Phase 1	Challenges to be faced
P1.1	Compilation and attraction of selected stakeholders among all identified sources. (Identify if stakeholders have interest on the project and need to make a virtua test-case using RESTORE's solution when it is ready.)

P1.2	Lack of specific examples and representations of the Use-Cases to promote interest among stakeholders to create extra test-cases.
P1.3	Lack of information on the needed modelling skills and technical abilities from the side of the stakeholders. (Identify if stakeholders have experience using simulation tools and/or experience on interacting technically with online platforms.)

Table 2: Replication Strategy - Phase 2 Challenges.

Phase 2	Challenges to be faced
P2.1	Compilation of selected stakeholders matching the specific areas of the 6 RESTORE Use-Cases to facilitate potential extra Test-Cases‘ creation.
P2.2	Identification among the selected stakeholders, the groups of different levels of technical support-needs, so that appropriate guidance and/or training can be offered for the use of the web-based simulation platform IPSE GO, to model theTest-Cases using the RESTORE process model solution.
P2.3	Supply insightful tutorials about the use of IPSE GO for RESTORE and keep technical skills needed at low and simple levels, so that they do not create a barrier for the stakeholders to try out extra Test-Cases.

The work carried out in task T5.5 monitored the challenges identified above, so that mitigation measures could be taken well in advance to prevent the risk of failing a successful replication of test cases for the project in its exploitation phase.

For preventing that the identified challenges, relative to the replication strategy, entail risks to the project implementation, some mitigation measures were implemented, as presented in Tables 3 and 4, with their estimated levels of the probability for them to happen and the respective impact severity on the replication strategy performance.

Table 3: Phase 1 Challenges – Mitigation Measures (Probability and Severity Levels: Low / Medium / High).

Phase 1 Challenge	Probability	Severity	Planned Mitigation Measures
P1.1	Low	High	Challenge P1.1 has very low probability to become a risk to the replication of test-cases, since steps 1, 2, 3 and 4 have specific targeted efforts, involving from partners members involved in WP1, WP5, WP6 and WP7, to attract appropriate groups of stakeholders interested on the project’s results. As mitigation measures, the following was planned to avoid the high severity impact of this challenge: - In WP5-T5.5, a continuous monitoring has been performed for the identification of the

			selected stakeholders' needs to make virtual test-cases using RESTORE's solution. - The use of the RESTORE Virtual Tool, powered by IPSE GO, counts with a user-interface that is friendly and self-explanatory and easy to attract the stakeholders to try out. - Several workshops and webinars were planned and organized within WP5, WP6 and WP7, to cope with specific trainings involving stakeholders.
P1.2	Low	Medium	Challenge P1.2 was very unlikely to become a risk to RESTORE replication strategy, as there were several specific examples to be explored by the project with the stakeholders and potential end-users, given that the project counts with 6 Use-Cases in different application areas. The mitigation measures performed built up on the ones of P1.1, and they are: - Promote interest among the stakeholders to create extra Test-Cases, using the examples of each of the six Use-Cases application areas to serve as basis for their own cases. - To continuously identify new examples for potential test-cases to offer as examples to the selected stakeholders.
P1.3	Low	Medium	Challenge P1.3 has low probability to become a risk, by the same reasons identified for P1.1, added to the fact that during the interactions between RESTORE activities (trainings, seminars, surveys, etc.), it is always a requisite to ask the stakeholders/participants about their level of technical skills in process modelling about their abilities and experience with simulation tools and online platforms. The mitigation measures performed were: - Integrate individual forms to be filled in by the stakeholders previous to the workshops and webinars, with specific questions about their experiences and abilities in relation to process modelling, simulation tools and online platforms.

			- Provide the proper technical assistance needed for the stakeholders with lack of modelling skills, during the workshops. - Ask for feedback after the organized workshops, so that the next event can be better tailored for the stakeholders / participants needs.

Table 4: Phase 2 Challenges – Mitigation Measures (Probability and Severity Levels: Low / Medium / High).

Phase 2 Challenge	Probability	Severity	Mitigation Measures
P2.1	Low	Medium	Challenge P2.1 has very low probability to become a risk to the replication of test-cases, for the same reasons given in Table 3 for Challenge P1.1, added to the fact that it is even easier to identify stakeholders matching the specific areas of the RESTORE Use-Cases, since there are six of them in different application areas. Apart from the mitigation measures used for Challenge P1.1, the following other ones were taken into account by the WP5-T5-5 monitoring procedure: - Group stakeholders in relation to the Use-Cases application areas, in order to deal with specific examples with them, to facilitate potential extra Test-Cases' creation. - Identify in a continuous way new examples for potential test-cases, within the specific matching area of Use-Case application, to offer to the selected stakeholders, encouraging them to try out their own Test-Cases using the RESTORE Virtual Tool. - Encourage the stakeholders to follow-up in an active and interactive way the developments of their matching Use-Cases (allowing for Q&A, etc).
P2.2	Low	Medium	Challenge P2.2 relates very much to the Challenge P1.3, and as such it was also unlikely to become a risk to the replication strategy. The mitigation measures performed built up on the ones of P1.3 and on the activities planned for the strategy steps 4, 5, 6 and 5, including:

			- Integrate individual forms to be filled in by the stakeholders previous to the workshops and webinars, so that the groups of different levels of technical support needs could be identified via the workshops, trainings and webinars promoted by RESTORE, and the respective appropriate guidance was offered for the use of the simulation platform and the modelling work. - Make sure that a feedback form is organized for the workshops, with specific questions about the „high“ and „low“ experiences the stakeholders had, so that the next event can be better tailored for their needs. - Offer several group or individual technical support hands-on seminars about the use of the web-based simulation platform IPSE GO, to facilitate the modelling of the Test-Cases using the RESTORE process model solution.
P2.3	Low	Low	Challenge P2.3 has very low probability to become a risk to the replication of test-cases, since SIMTECH, as developer of the IPSE GO web-based platform, and the RESTORE Virtual Tool. With the work packages WP5, WP6, and WP7, promote and organize several means of support (via recorded tutorials, training courses, workshops, webinars, etc.) to cater for the minimum skills that the stakeholders need to be able to create their own Test-Cases using the RESTORE Virtual Tool and the project’s technology. The planned mitigations measures to avoid that Challenge P2.3 becomes a risk are the following: - Produce specific specific and insightful tutorials about the use of IPSE GO to the selected stakeholders, focusing on the use of the RESTORE process model solution. - Provide specialized, but simplified models for usage on the web platform with the Test-Cases. - Make sure that the technical skills needed in the tutorials were at simple levels, using simple models to build up more complex ones if needed. This avoids the creation of

			barriers for the stakeholders to try out extra Test-Cases. - Provide guidance and reviewing support of the Test-Cases initiated by the stakeholders, so that eventual errors could be identified at an early stage of their work with the RESTORE Virtual Tool.

When a defined risk was identified during the execution of WP5 Task 5.5, it was informed to the project Coordinator to update the Risks list built within the context of WP1 - *Task 1.5 Key Performance Indicators (KPIs) for RESTORE development, validation & Risks Analysis*.

3. Planned Activities of the Replication Strategy

The activities listed in this section, reproduced from D6.9 [5] and from D7.5 [19], were organized within RESTORE project, aligned with the interests of WP1, WP5, WP6, and WP7.

Table 5: ESAB related Technical Events & Use-Cases/Test-Cases Events.

Event	Description	Event Date
Event ESAB-1	**Advice for the upscaled solutions** *(During this meeting, the preliminary results of the project were presented by the project consortium, with a particular focus on the progress and experience obtained during the design of the prototypes. EAB members and other stakeholders provided their feedback oriented to considerations for the upscaled solutions.)*	M31 of the project or later
Event ESAB-2	**Advice for maximizing impact and final overall concept definition** *(This event took place after the preparation of the 1st RESTORE assessment document reported in D1.6 and in D1.8. The feedback received from stakeholders was useful for improving the definition of the final overall concept re-defined in the second phase of Task 1.1.)*	Project M38 or later
Event 1-UseCase	**Analysis of the preliminary models of the use cases** *(This event was estimated to take place after 9 months of initiating the 6 sub-tasks involved in T5.4 for the implementation, optimization, management and validation of RESTORE Use-Cases. In this period, the first mature version of the modelling of the use-cases were made available. The partners have also presented to the DPG members and other stakeholders, the results of the implemented models. Feedback was used to improve the models and the accuracy of their results.)*	M38 of the project or later
Event 2-UseCase	**Analysis of first results and impact on the use cases** *(This event was expected to be held after developing the advanced version of the models of the use-cases and deeply testing them. The final feedback from the DPG was collected in order to fine-tune the last details of the models and the assessment and improve the final results as well as the associated deliverables in WP5 T5.4.)*	M42 of the project or later
Test-Cases related Events	**Events related to the Replicability of Test Cases** *(Such events were organized online, and sometimes with one-to-one contacts, counting with the co-organization of the involved partners of WP5, WP6, and WP7, and stakeholders. All members of RESTORE Consortium supported the meetings and indicated stakeholders from the Communities of Practices to participate on the events planned and organized within the specific task T7.4, with support from the use of the RESTORE Virtual Tool powered by IPSE GO web-platform.)*	Period of [M40-M48] of the project

As listed in Table 5, the events related to the Replicability of Test Cases were planned and organized within tasks T5.5 and T7.4, by SIMTECH and PI, with support from the use of the RESTORE Virtual Tool powered by IPSE GO web-platform.

The main objectives of the events related to the Test Cases cover the following aspects:

- Showcase and Validation of the Use-Cases modelled with RESTORE solution (T5.4);
- Stakeholders Engagement and Ecosystem Community Building (Task T7.4);
- Validation of the Replication Strategy for Stakeholders Additional Cases (Task T5.5);
- Support on the Elaboration of the Roadmap for RESTORE Key Exploitable Results (Task T6.2).

The activities related to the Public Webinars about the use-cases, in Table 6 below reproduced from D7.5 [19], were delivered in order to show the RESTORE Tool and the advances of the use-cases' development, with their organization supported by SOLITES (WP7). The participation in the public webinars were open to all kind of stakeholders, including all Communities of Practice (CoP). Training webinars were restricted to members of the RESTORE User Community (maintained by PI as part of WP7) within the CoP's. A final presential workshop took place in Vienna as a hybrid event, in which other European projects related to thermal energy storage were also presented.

Table 6: Public Webinars related to the Use-Cases

Date	Type	Title	Partici-pants	Link to recording (views)
19/03/2024	Public Webinar	RESTORE Overall Concept, Thermochemical Energy Storage (TCES) and the reversible Organic Rankine Cycle (rORC)	43	https://www.youtube.com/watch?v=ce1ybNy72qU&t=3s (119 views)
19/09/2024	Public Webinar	RESTORE Virtual Tool and modelling of Use-Cases	27	https://www.youtube.com/watch?v=pJ9jJyI6aIo&t=1s (32 views)
28/04/2025	Training webinar	1st Training webinar on RESTORE Virtual Tool	24	https://www.youtube.com/watch?v=2diYx3r2H0g (14 views)
04/06/2025	Training webinar	2nd Training webinar on Modelling of Virtual Use-Cases	22	https://www.youtube.com/watch?v=aU5n_rtcLc0 (5 views)
15/07/2025	Public webinar	RESTORE Insights: Applications, Sustainability Assessments and further Development	22	https://www.youtube.com/watch?v=9UlR_-01KAI (41 views)
12/09/2025	Final Workshop	Final Workshop of the H2020 RESTORE project	31 on-site + 6 online	n.a.

4. Use-Cases Demo Web-pages

The RESTORE Virtual Tool (under https://ipsego.app/) has been made available for both project partners and end-users (during the project lifetime and beyond), assisting all project phases (design, development, testing, replication cases, and exploitation), and demonstrating the project's Use-Cases and interacting with the RESTORE stakeholder ecosystem for exploitation purposes. It hosts the simulated use cases and will remain online after the project ends, to stimulate a new technological direction and the emergence of a European innovation ecosystem around the RESTORE paradigm. (See Annex I, Annex II, Annex III, and Annex IV for illustrations of the RESTORE Virtual Tool powered by IPSE GO, and the available RESTORE process models).

As a major outcome of WP5, supporting Task T5.5, SIMTECH also provided online, on a dedicated website for the use-cases results, compact description of the six RESTORE Use-Cases developed in the project, including their embedded models from the IPSE GO platform. This information is publicly accessible via the link https://usecases.restore-dhc.eu/, as shown in Figure 11.

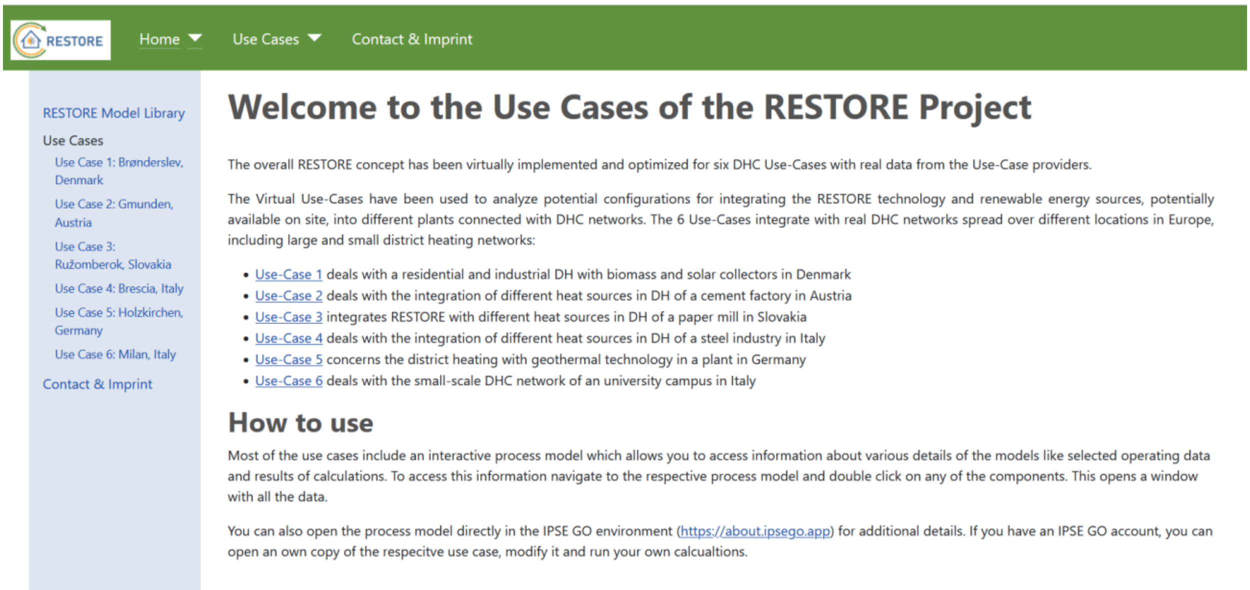

Figure 11: RESTORE Use-Cases Demo Web-site (https://usecases.restore-dhc.eu/).

The "RESTORE Use-Cases Demo Web-Pages" consolidates the efforts of the use-cases implementation for the eyes of the end-users and interested stakeholders, and is seen as the overarching development in support of the RESTORE Replication Strategy proposed in task T5.5, as it summarizes the applications virtual representations and opens the possibility for the stakeholders to test the process models directly in IPSE GO, via the embedded Use-Case Final Process Models. The figures that follow illustrate the RESTORE Demo Web-Pages for Use-Case I, and Annex XII shows all Use-Cases Demo Web-pages.

Figures 12 and 13 that follow shows the pages related to resulting information available of the implementation of Use-Case I. Full description of this use-case can be found in https://usecases.restore-dhc.eu/use-cases/use-case-1-bronderslev-denmark.

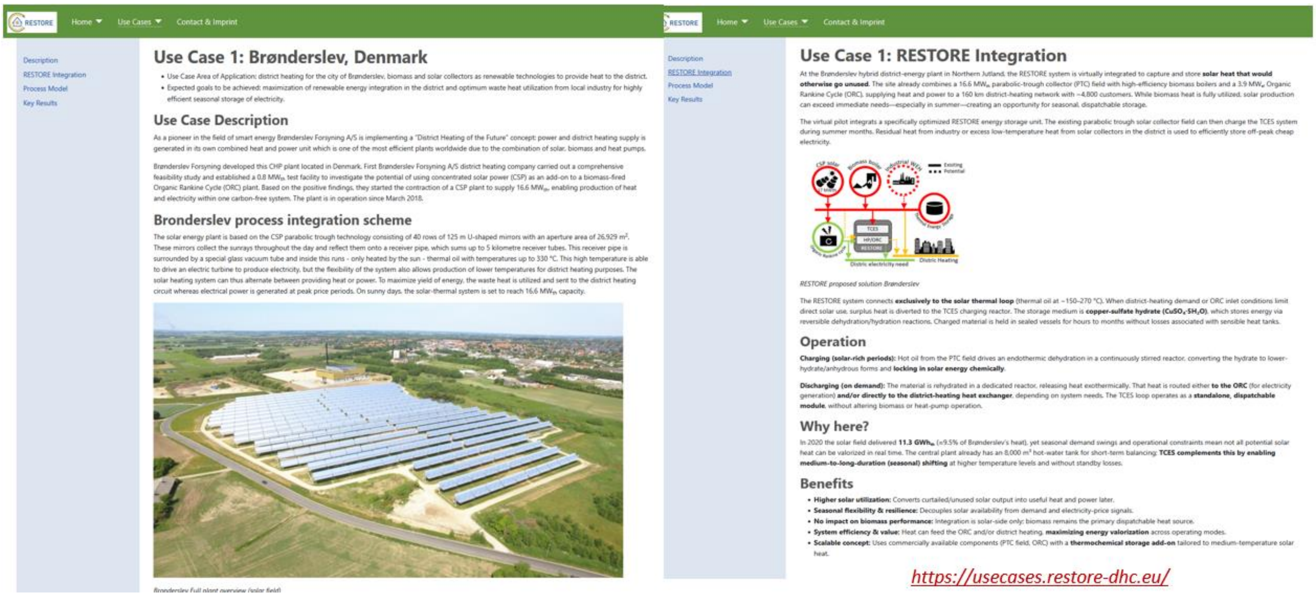

Figure 12: RESTORE Use-Case I Demo Pages (Description and RESTORE Integration).

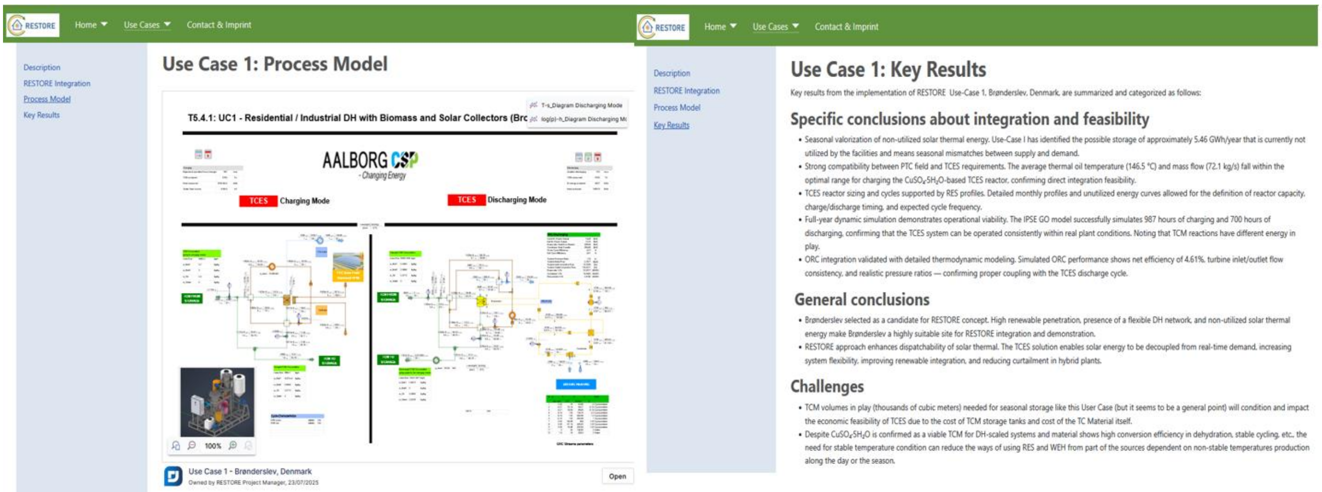

Figure 13: RESTORE Use-Case I Demo Pages (Process Model and Key Results).

In the sequel, Figures 14, 15 and 16 show the Use-Case I Process Model Pages in the RESTORE Use-Cases Demo Website (link: https://usecases.restore-dhc.eu/use-cases/use-case-1-bronderslev-denmark/process-model) and the Use-Case I Process Model in the RESTORE Virtual Tool within IPSE GO (in read-only mode, as shown in Figure 16), highlighting the detail of how one can interact with the embedded process model in the Demo Web-site and “open” the implemented Use-Case in IPSE GO, with only one click (see Figure 15). This feature allows end-users with registered accounts in the RESTORE Virtual Tool, to try out the respective Use-Case model and to use as a base reference for their own test-cases models.

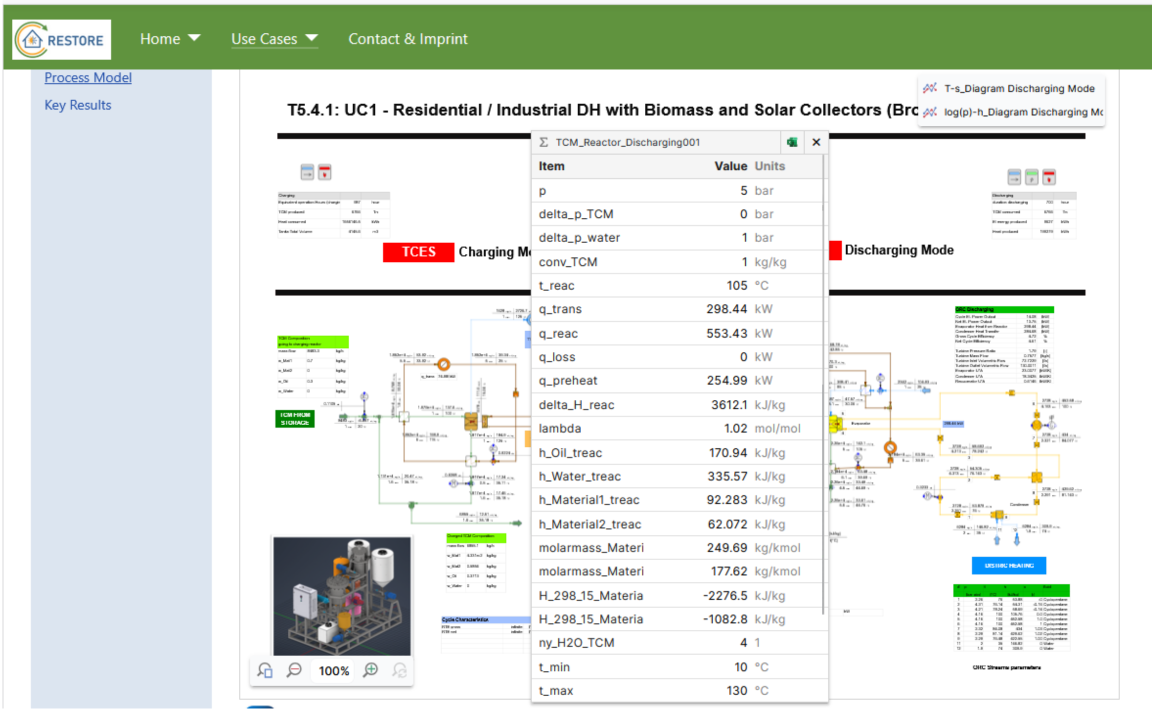

Figure 14: RESTORE Use-Case I – Process Model embedded in the Demo Website.

Figure 14 shows the Use-Case I Process Model in the RESTORE Use-Cases Demo Website, highlighting the interaction that end-users can have with the embedded model. In Figure 14, one can see the parameters' values defined or assigned for the TCM-Reactor used in the Discharging Mode of the system. This feature can be checked for each component model used in the represented process model.

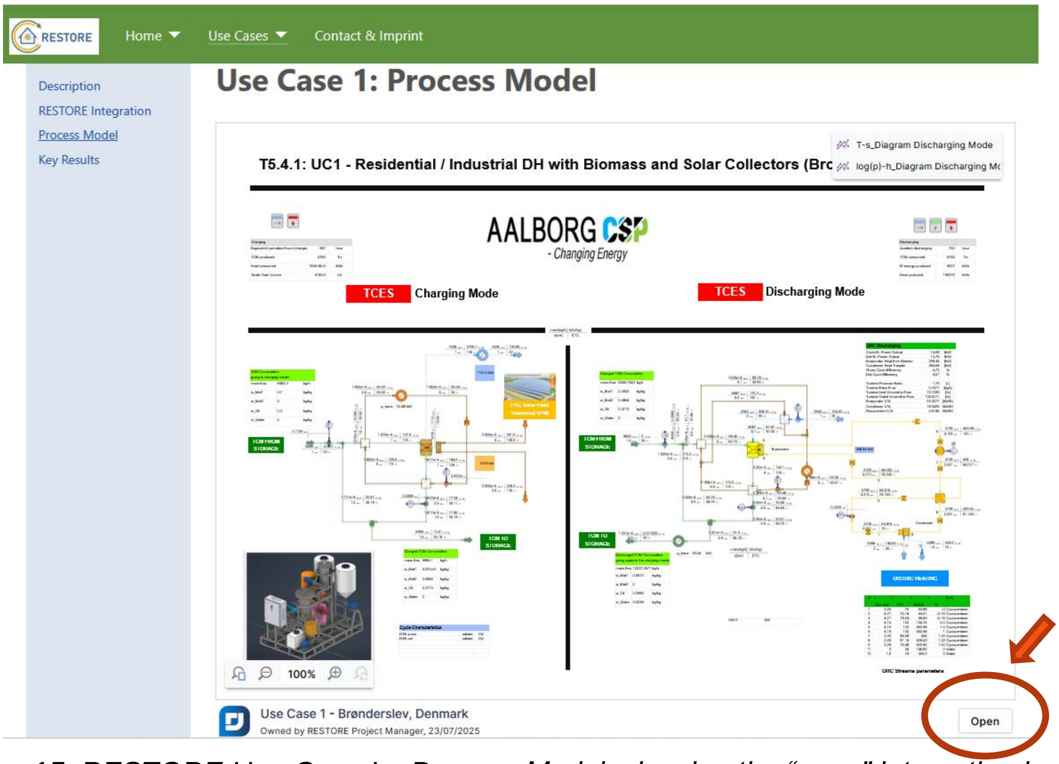

Figure 15: RESTORE Use-Case I – Process Model, showing the "open" interaction button with the IPSE GO Platform.

If the end-users, checking the Use-Cases Process Models in the RESTORE Use-Cases Demo Website, wish to go further and check more details about them directly in the RESTORE Virtual Tool within IPSE GO, all that they have to do is to click on the “open” button indicated in Figure 15, in order to open the same process model in IPSE GO, as shown in Figure 16.

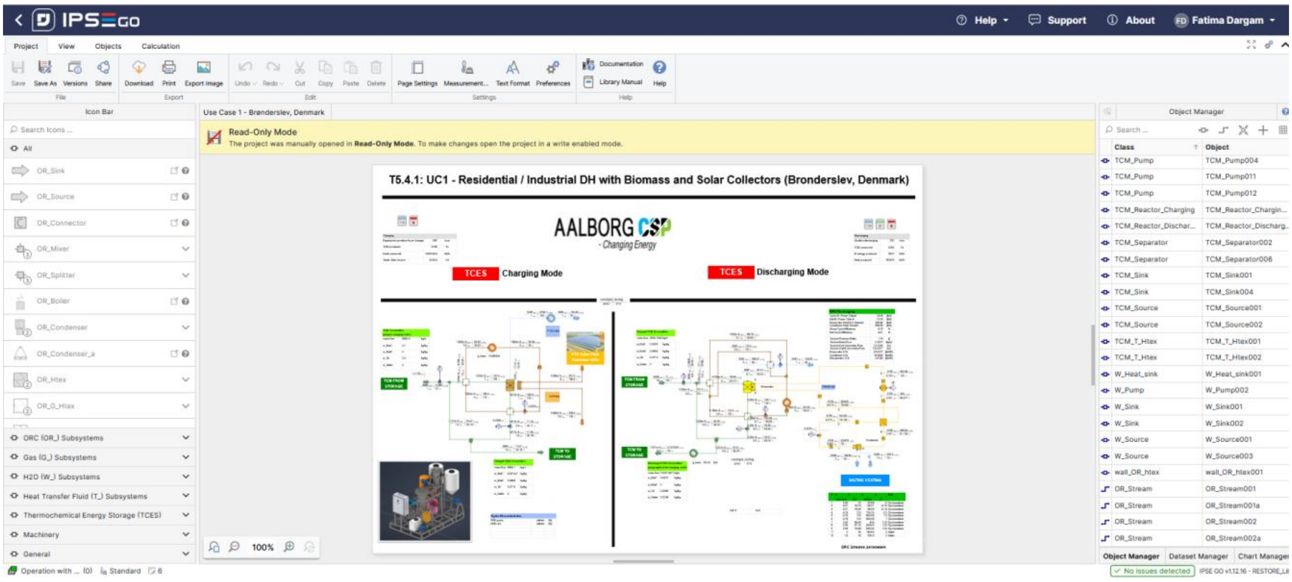

Figure 16: RESTORE Use-Case I – Process Model opened in IPSE GO.

5. Conclusion

The current deliverable D5.11 reported about the project's EU-wide replication strategy from task T5.5 on "Replication Strategy via Stakeholders additional Cases", led by SIMTECH and PI, covering the period of M9 to M48 of the project. This report mainly described the replication strategy specified for RESTORE, to allow and motivate interested stakeholders to create additional cases and trials based on the RESTORE 6 virtual use-cases, using the RESTORE virtual tool powered by the IPSE GO simulation web-platform.

The simulation environments used in the project were briefly described, 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. D5.11 updates the specification of the Test-Cases Replication Strategy for RESTORE published in D5.10 [11], focusing on the two particular phases and the main steps to be taken in each of them, as well as the challenges to be faced on the replication strategy Phases 1 and 2. A list of planned activities was presented, considering technical events related to the ESAB, events related to the use-cases testing, and related to the replication strategy test-cases, mainly in cooperation with the work done in WP5, WP6 and WP7.

The RESTORE Use-Cases Demo website created and maintained by SIMTECH, was described as a major outcome of WP5 task T5.5, including the use-cases results, compact description of the six RESTORE Use-Cases developed in the project, and their embedded models from the IPSE GO platform. All this information was publicly accessible via the link https://usecases.restore-dhc.eu/.

Following the defined Replication Strategy, it is expected that stakeholders will be able to create their own testing cases, such that the number of different application examples will grow continuously within and beyond the project lifetime. It is worth noting that the RESTORE Virtual Tool 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. It will host the simulated use cases and will remain online after the project ends, to stimulate a new technological direction and the emergence of a European innovation ecosystem around the RESTORE paradigm.

Main webinars organized within the project to promote the usage of the RESTORE Virtual Tool, supporting the T5.5 Replication Strategy, included: Workshop for RESTORE Partners, about the "Use-Cases Modelling in IPSE GO" (hosted by SIMTECH); Public Webinar about the RESTORE Overall Concept, Thermochemical Energy Storage (TCES) and the reversible Organic Rankine Cycle (rORC); Stakeholders Training Webinars about the RESTORE Virtual Tool and modelling of Use-Cases, dedicated to the CoP community members (hosted by PI and SOLITES, supported by SIMTECH and RESTORE Use-Cases Providers). Figure 17 illustrates one of these webinars and Table 6 presents all their details.

This way, task T5.5 promoted support for interested stakeholders to use the web-platform for modelling their own cases. Outcomes from tasks T5.5 and T7.4 (RESTORE User-Community building) have maximized the impact of the dissemination as well as of the exploitation of the project, during and beyond its lifetime.

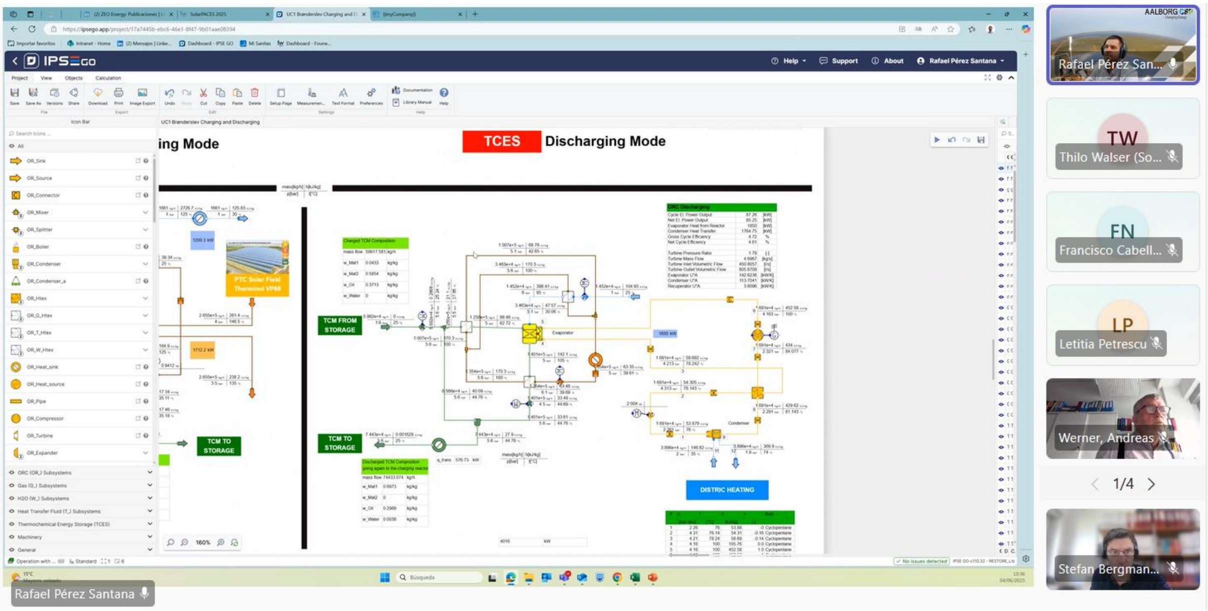

Figure 17: Screenshot of one of the webinars promoting the RESTORE Virtual Tool.

The information provided in this document was built upon collaboration between SIMTECH and PROSPEX Institute (PI), with contributions from SOLITES and other RESTORE partners.

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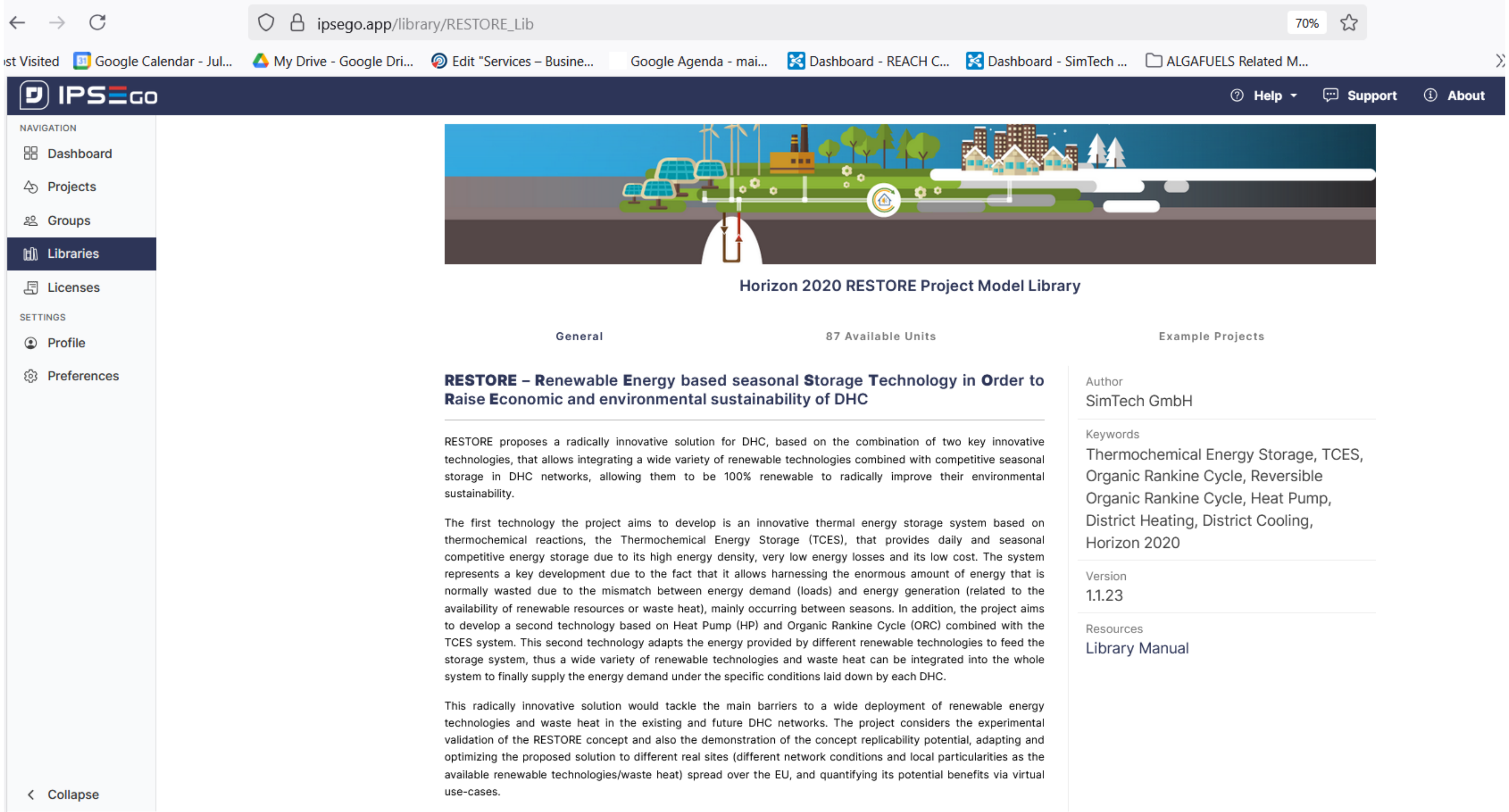
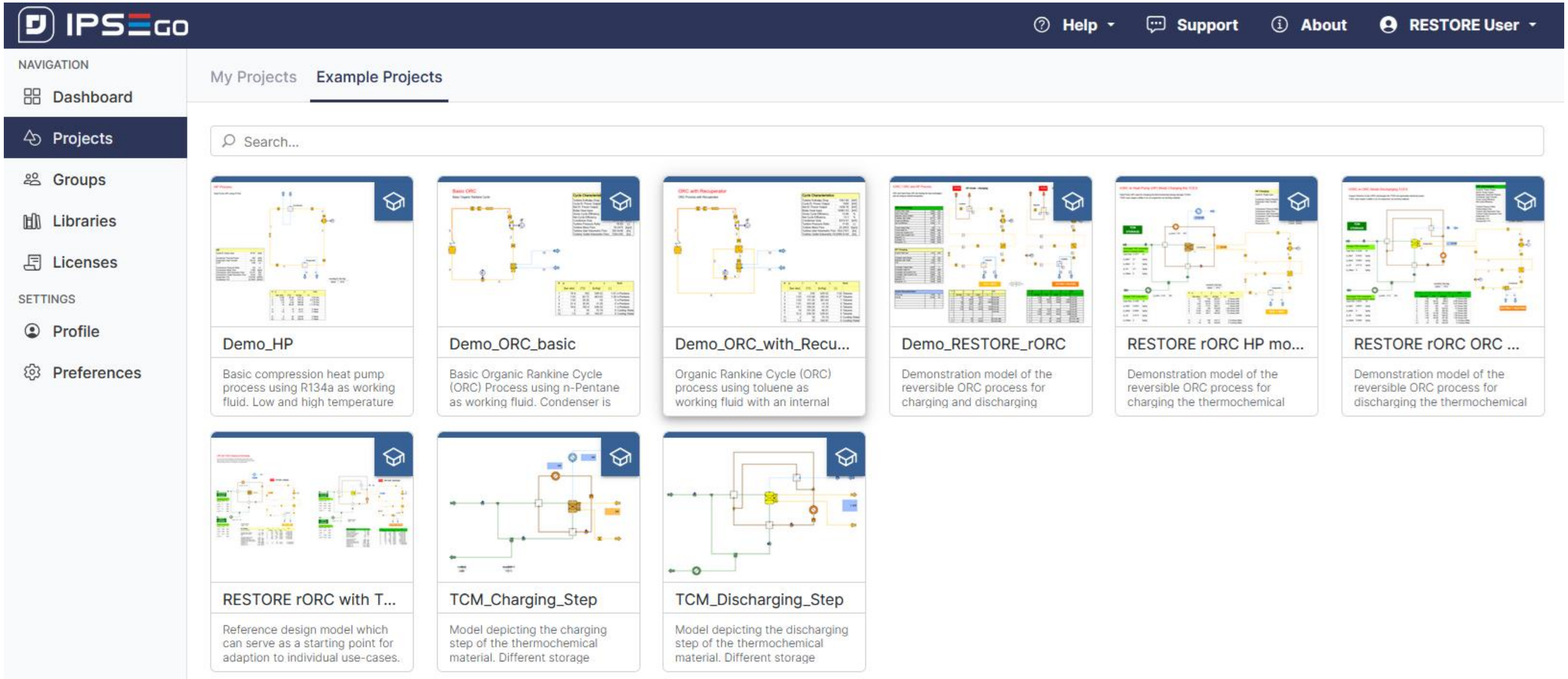
Annex I. RESTORE Virtual Tool powered by IPSE GO

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.

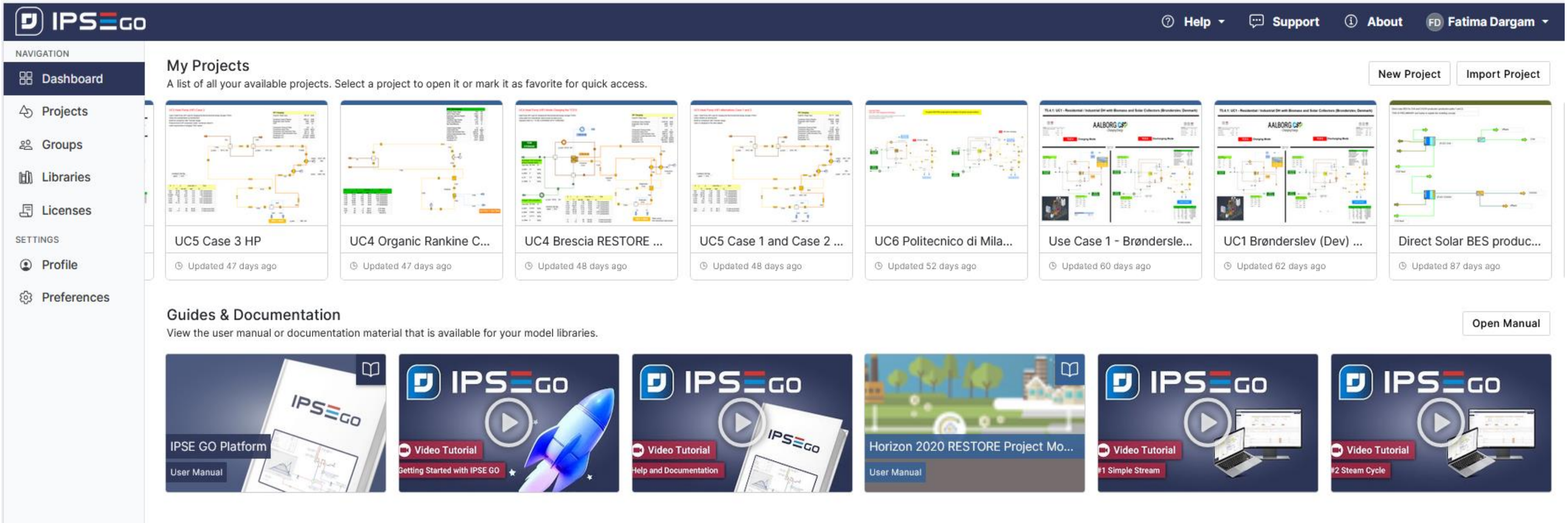


Annex II. RESTORE Virtual Tool – Projects Pages

Images of the RESTORE Virtual Tool powered by IPSE GO, showing some available RESTORE process models, the Projects and User-Guide Documentation for a registered user.

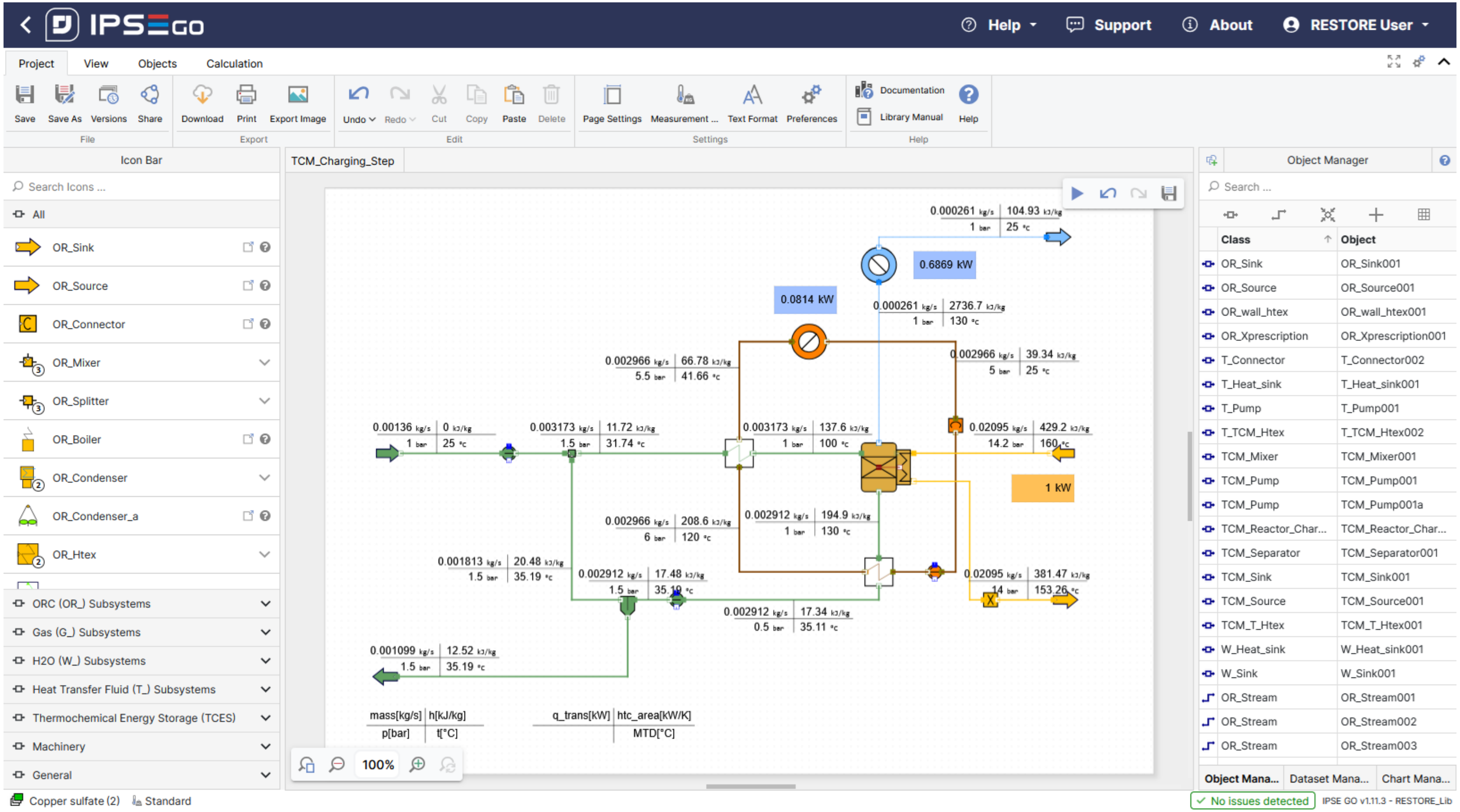



IPSE GO
Help
Support
About
Fatima Dargam
NAVIGATION
Dashboard
Projects
Groups
Libraries
Licenses
SETTINGS
Profile
Preferences
My Projects
A list of all your available projects. Select a project to open it or mark it as favorite for quick access.
New Project
Import Project
New Project
Import Project
TCM_Discharging_Step
Updated a few seconds ago
TCM_Charging_Step
Updated a few seconds ago
RESTORE rORC with TC...
Updated 1 minutes ago
RESTORE rORC ORC m...
Updated 1 minutes ago
RESTORE rORC HP mod...
Updated 1 minutes ago
Demo_RESTORE_rORC
Updated 1 minutes ago
UC6 Politecnico di ...
Project opened by Ruben Garay


IPSE GO
Help
Support
About
Fatima Dargam
NAVIGATION
Dashboard
Projects
Groups
Libraries
Licenses
SETTINGS
Profile
Preferences
My Projects
A list of all your available projects. Select a project to open it or mark it as favorite for quick access.
New Project
Import Project
UC5 Case 3 HP
Updated 47 days ago
UC4 Organic Rankine C...
Updated 47 days ago
UC4 Brescia RESTORE ...
Updated 48 days ago
UC5 Case 1 and Case 2 ...
Updated 48 days ago
UC6 Politecnico di Mila...
Updated 52 days ago
Use Case 1 - Brøndersle...
Updated 60 days ago
UC1 Brønderslev (Dev) ...
Updated 62 days ago
Direct Solar BES produc...
Updated 87 days ago
Guides & Documentation
View the user manual or documentation material that is available for your model libraries.
Open Manual
IPSE GO Platform
User Manual
Video Tutorial
Getting Started with IPSE GO
Video Tutorial
Help and Documentation
Horizon 2020 RESTORE Project Mo...
User Manual
Video Tutorial
#1 Simple Stream
Video Tutorial
#2 Steam Cycle

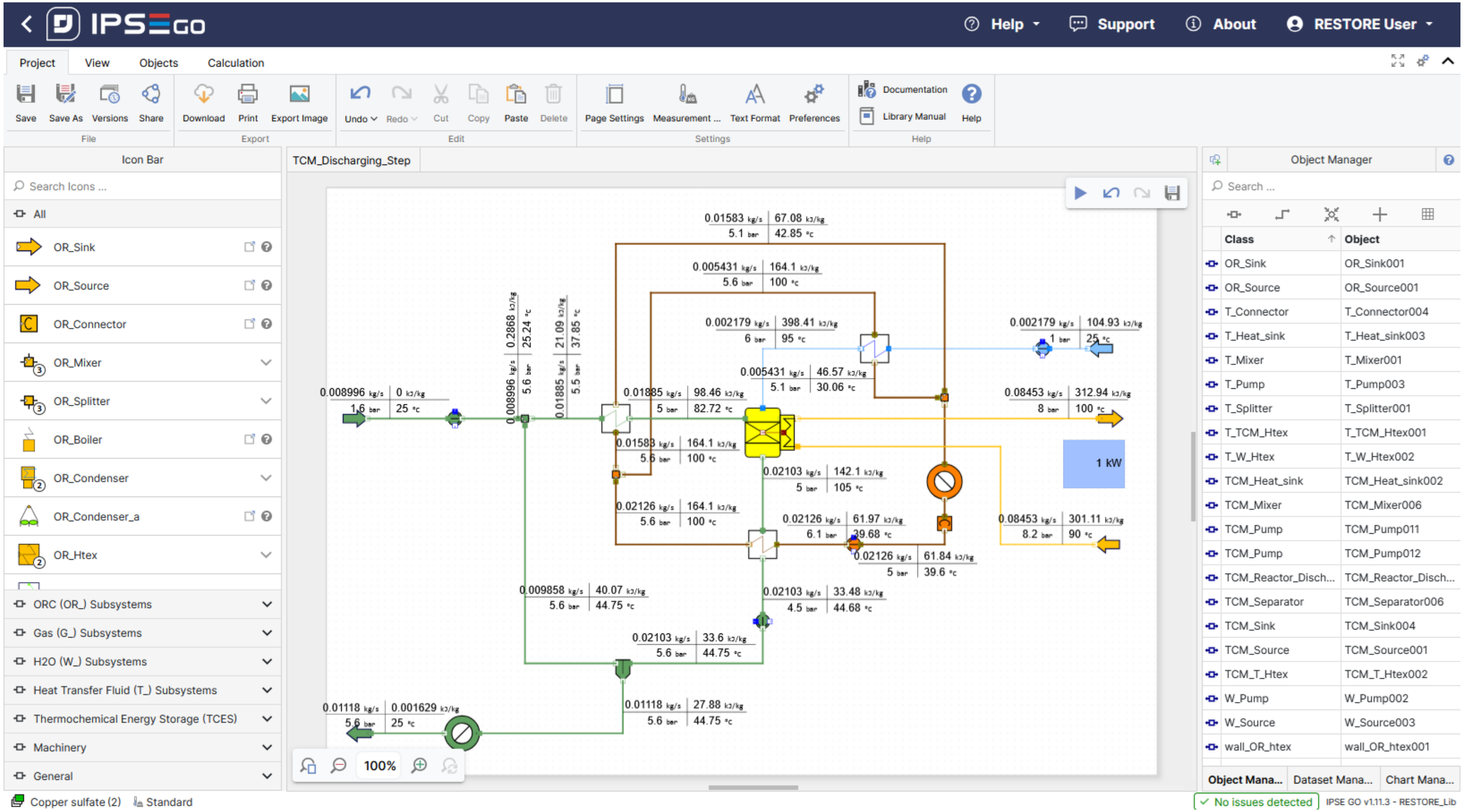
Annex III. RESTORE TCES Charging Model

RESTORE TCES Charging Model within IPSE GO (Final Version).



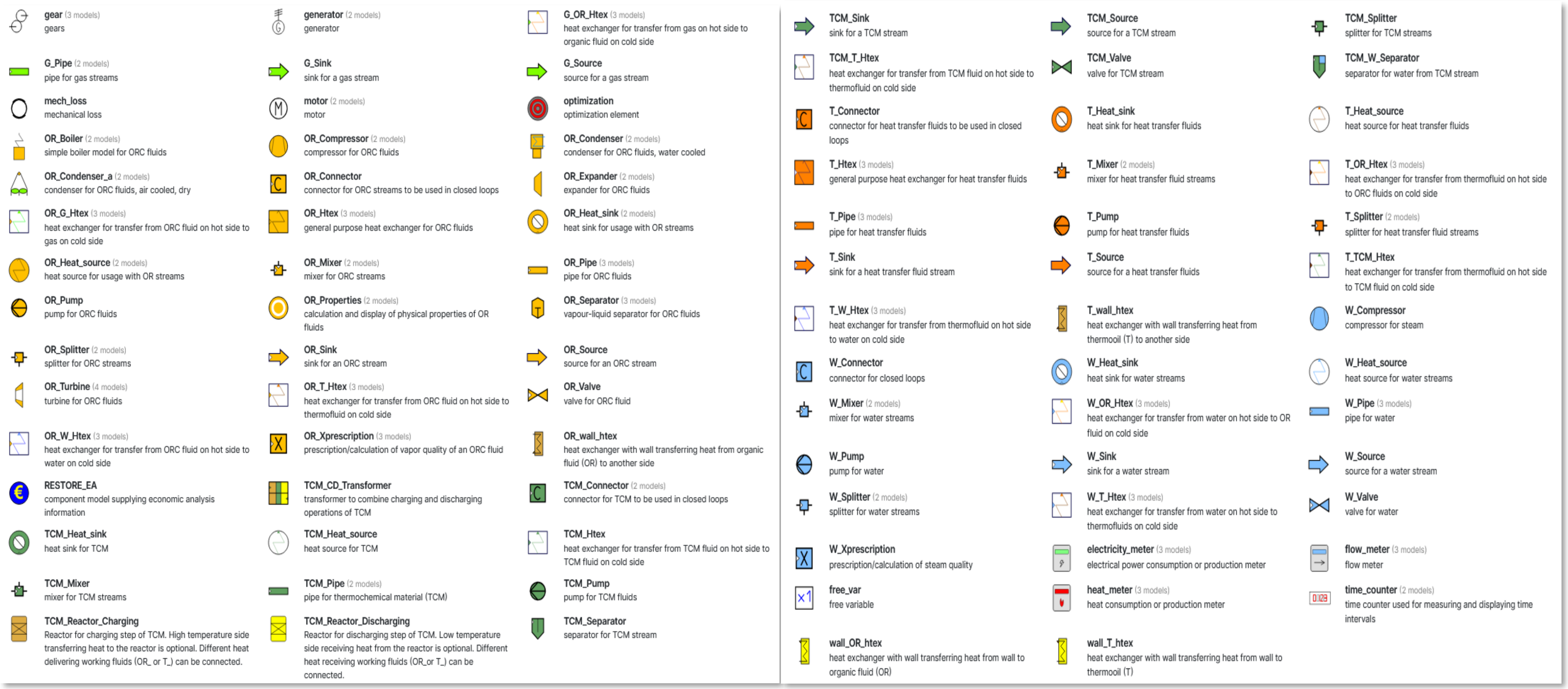
Annex IV. RESTORE TCES Discharging Model

RESTORE TCES Discharging Model within IPSE GO (Final Version).



Annex V. RESTORE_Lib Components

RESTORE_Lib Component Models (Final Version of Sept.2025) produced by TUWIEN with SIMTECH support. RESTORE_Lib was built using IPSEpro-MDK (Model Development Kit) and can be used with both IPSEpro and IPSE GO.



Annex VI. RESTORE Use-Case I - Summary

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: 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.

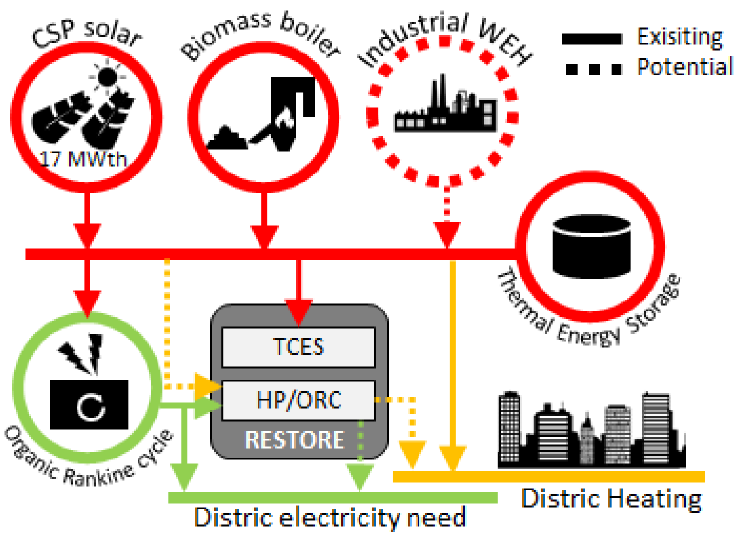


Figure 18: RESTORE proposed solution in Use-Case I.

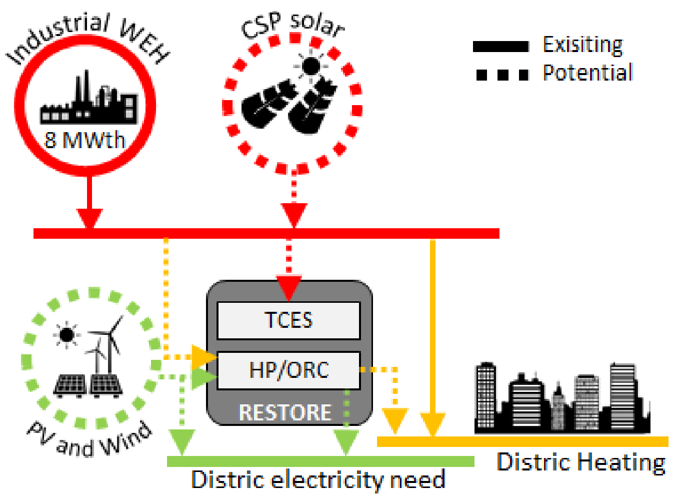
Use-Case I - RESTORE proposed solution: The virtual pilot will be based on the energy system described above, integrating a specifically optimized RESTORE energy storage unit. The existing parabolic trough solar collector field can then charge the TCES system during summer months, i.e. solar heat is 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.

Annex VII. RESTORE Use-Case II - Summary

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.



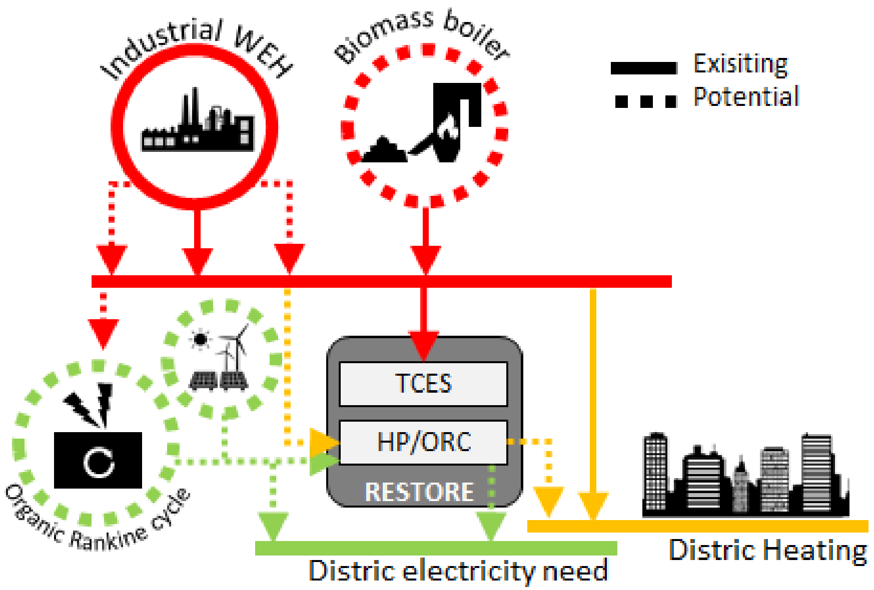
Use-Case II - RESTORE proposed solution: Within the RESTORE project, the virtual pilot will simulate the integration of the developed concept within the industrial plant in order to maximize WEH utilization and RES integration for seasonal storage of heat using cheap off-peak electricity. RESTORE concept 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.

Figure 19: RESTORE proposed solution in Use-Case II.

Annex VIII. RESTORE Use-Case III - Summary

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.



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.

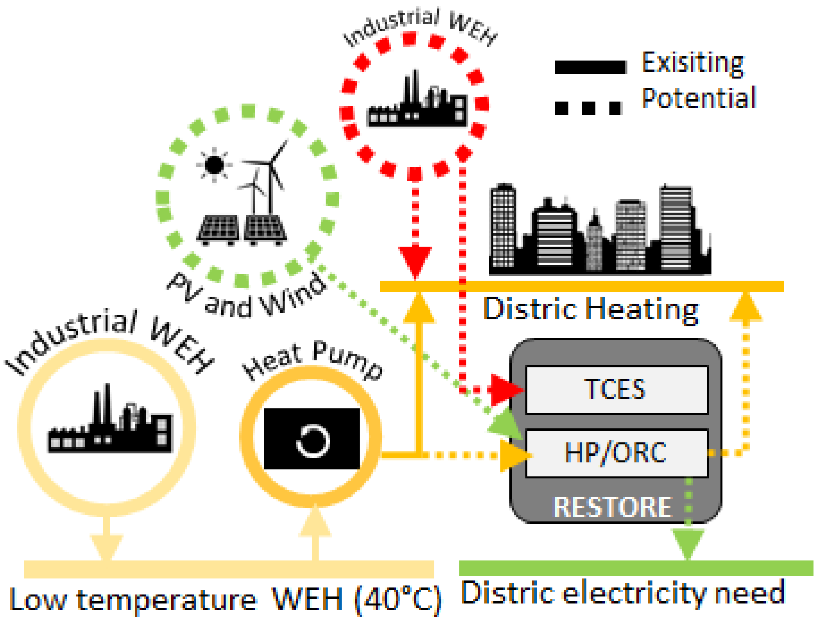
Figure 20: RESTORE proposed solution in Use-Case III.

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.

Annex IX. RESTORE Use-Case IV - Summary

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.



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.

Figure 21: RESTORE proposed solution in Use-Case IV.

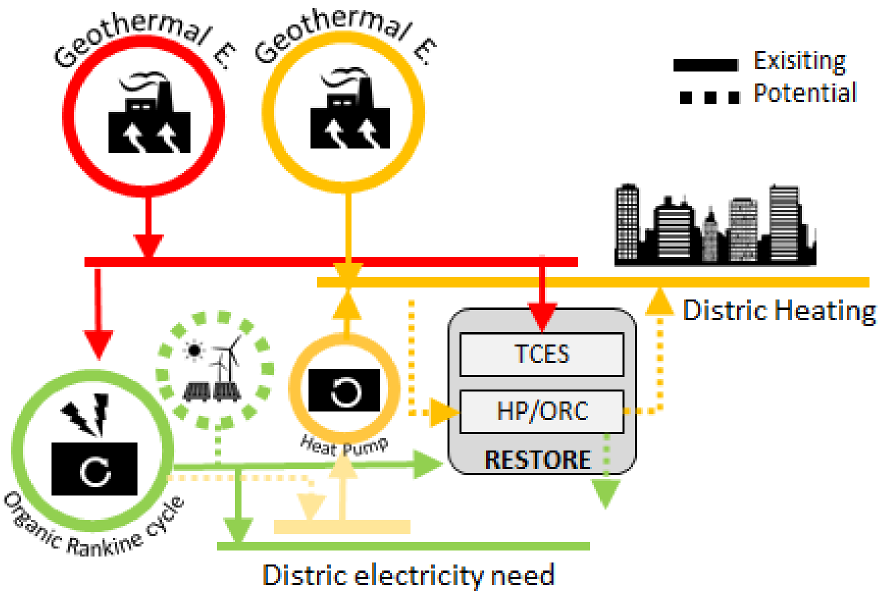
Use-Case IV - RESTORE proposed solution: RESTORE technology can dramatically increase the utilization of existing equipment and WEH utilization during summer months when heat is not required by DH and so the HPs are not working. With RESTORE heat released by EAF is upgraded to High Temperature all year 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.

Annex X. RESTORE Use-Case V - Summary

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.



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 RES will be investigated.

Figure 22: RESTORE proposed solution in Use-Case V.

Annex XI. RESTORE Use-Case VI - Summary

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.

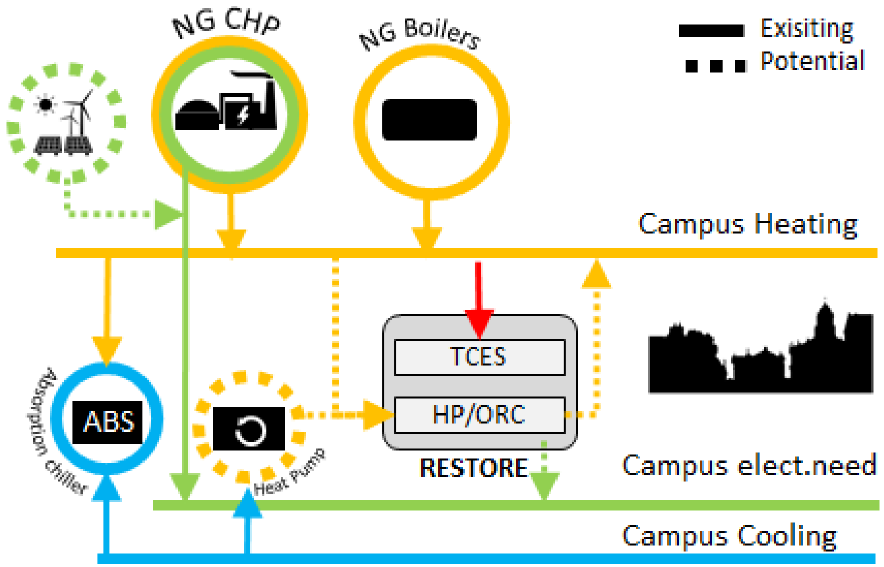
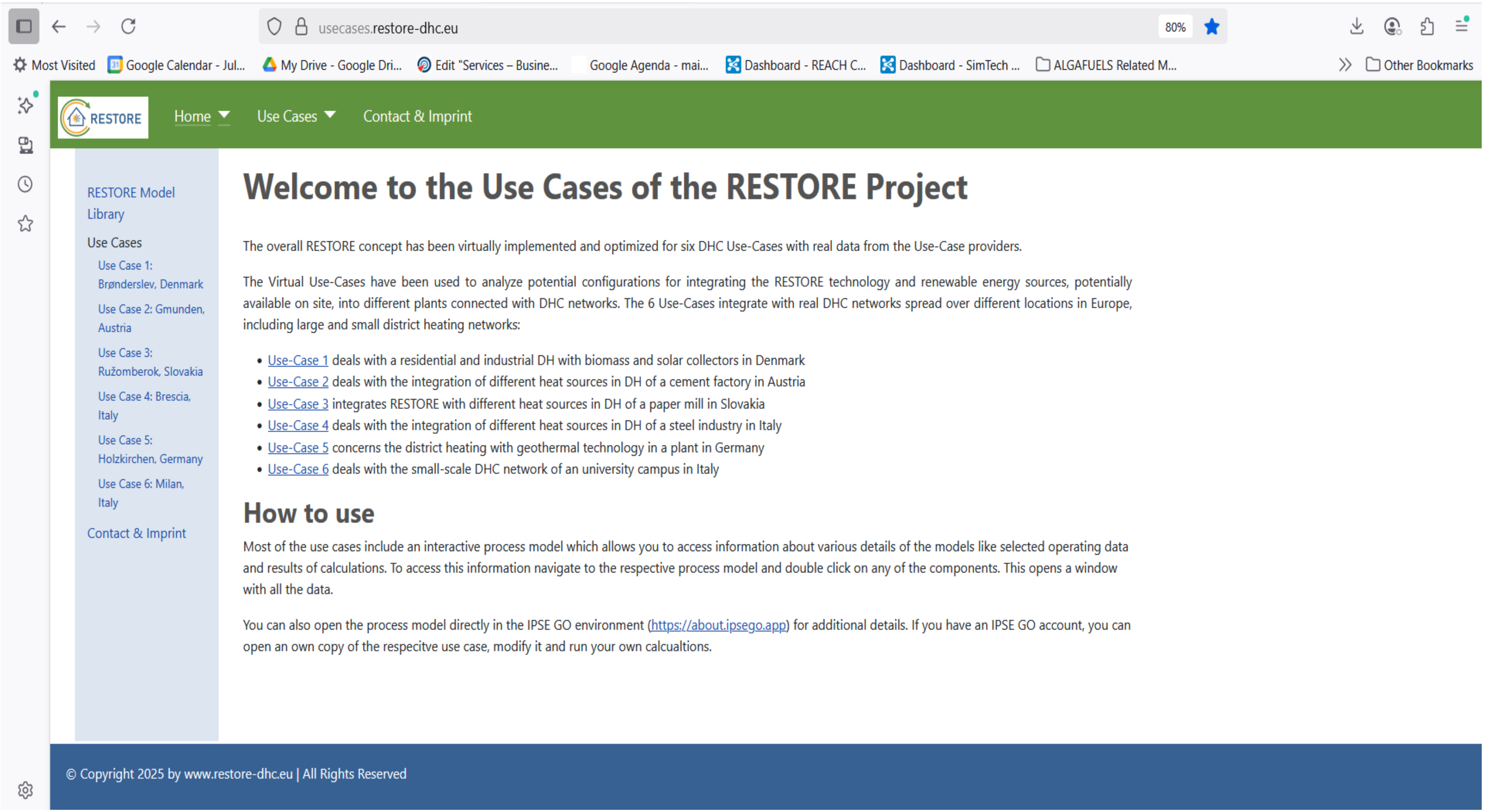


Figure 23: RESTORE proposed solution in Use-Case VI.

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.

Annex XII. Use-Cases Demo Web-pages (https://usecases.restore-dhc.eu/)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RESTORE Model Library
Use Cases
Use Case 1: Brønderslev, Denmark
Use Case 2: Gmunden, Austria
Use Case 3: Ružomberok, Slovakia
Use Case 4: Brescia, Italy
Use Case 5: Holzkirchen, Germany
Use Case 6: Milan, Italy
Contact & Imprint

Welcome to the Use Cases of the RESTORE Project

The overall RESTORE concept has been virtually implemented and optimized for six DHC Use-Cases with real data from the Use-Case providers.

The Virtual Use-Cases have been used to analyze potential configurations for integrating the RESTORE technology and renewable energy sources, potentially available on site, into different plants connected with DHC networks. The 6 Use-Cases integrate with real DHC networks spread over different locations in Europe, including large and small district heating networks:

- Use-Case 1 deals with a residential and industrial DH with biomass and solar collectors in Denmark
- Use-Case 2 deals with the integration of different heat sources in DH of a cement factory in Austria
- Use-Case 3 integrates RESTORE with different heat sources in DH of a paper mill in Slovakia
- Use-Case 4 deals with the integration of different heat sources in DH of a steel industry in Italy
- Use-Case 5 concerns the district heating with geothermal technology in a plant in Germany
- Use-Case 6 deals with the small-scale DHC network of an university campus in Italy

How to use

Most of the use cases include an interactive process model which allows you to access information about various details of the models like selected operating data and results of calculations. To access this information navigate to the respective process model and double click on any of the components. This opens a window with all the data.

You can also open the process model directly in the IPSE GO environment (https://about.ipsego.app) for additional details. If you have an IPSE GO account, you can open an own copy of the respecitve use case, modify it and run your own calcualtions.

Home Use Cases Contact & Imprint

Description
RESTORE Integration
Process Model
Key Results

Use Case 1: Brønderslev, Denmark

- Use Case Area of Application: district heating for the city of Brønderslev, 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 is implementing a "District Heating of the Future" concept: power and district heating supply is 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 heat pumps.

Brønderslev Forsyning developed this CHP plant located in Denmark. First Brønderslev Forsyning A/S district heating company carried out a comprehensive feasibility study and established a 0.8 MW_{th} test facility to investigate the potential of using concentrated solar power (CSP) as an add-on to a biomass-fired Organic Rankine Cycle (ORC) plant. Based on the positive findings, they started the contraction of a CSP plant to supply 16.6 MW_{th}, enabling production of heat and electricity within one carbon-free system. The plant is in operation since March 2018.

Bronderslev process integration scheme

The solar energy plant is based on the CSP parabolic trough technology consisting of 40 rows of 125 m U-shaped mirrors with an aperture area of 26,929 m^2. These mirrors collect the sunrays throughout the day and reflect them onto a receiver pipe, which sums up to 5 kilometre receiver tubes. This receiver pipe is surrounded by a special glass vacuum tube and inside this runs - only heated by the sun - thermal oil with temperatures up to 330 °C. This high temperature is able to drive an electric turbine to produce electricity, but the flexibility of the system also allows production of lower temperatures for district heating purposes. The solar heating system can thus alternate between providing heat or power. To maximize yield of energy, the waste heat is utilized and sent to the district heating circuit whereas electrical power is generated at peak price periods. On sunny days, the solar-thermal system is set to reach 16.6 MW_{th} capacity.

Bronderslev Full plant overview (solar field)

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Description
RESTORE Integration
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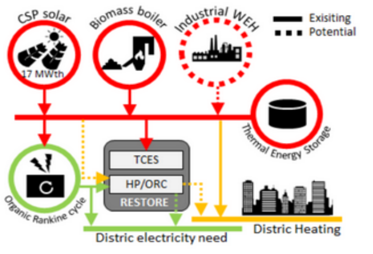
Key Results

Use Case 1: RESTORE Integration

At the Brønderslev hybrid district-energy plant in Northern Jutland, the RESTORE system is virtually integrated to capture and store **solar heat that would otherwise go unused**. The site already combines a 16.6 MW_{th} parabolic-trough collector (PTC) field with high-efficiency biomass boilers and a 3.9 MW_{el} Organic Rankine Cycle (ORC), supplying heat and power to a 160 km district-heating network with ~4,800 customers. While biomass heat is fully utilized, solar production can exceed immediate needs—especially in summer—creating an opportunity for seasonal, dispatchable storage.

The virtual pilot integrats a specifically optimized RESTORE energy storage unit. The existing parabolic trough solar collector field can then charge the TCES system during summer months. Residual heat from industry or excess low-temperature heat from solar collectors in the district is used to efficiently store off-peak cheap electricity.



RESTORE proposed solution Brønderslev

The RESTORE system connects **exclusively to the solar thermal loop** (thermal oil at ~150–270 °C). When district-heating demand or ORC inlet conditions limit direct solar use, surplus heat is diverted to the TCES charging reactor. The storage medium is **copper-sulfate hydrate ($CuSO_4 \cdot 5H_2O$)**, which stores energy via reversible dehydration/hydration reactions. Charged material is held in sealed vessels for hours to months without losses associated with sensible heat tanks.

Operation

Charging (solar-rich periods): Hot oil from the PTC field drives an endothermic dehydration in a continuously stirred reactor, converting the hydrate to lower-hydrate/anhydrous forms and **locking in solar energy chemically**.

Discharging (on demand): The material is rehydrated in a dedicated reactor, releasing heat exothermically. That heat is routed either **to the ORC** (for electricity generation) **and/or directly to the district-heating heat exchanger**, depending on system needs. The TCES loop operates as a **standalone, dispatchable module**, without altering biomass or heat-pump operation.

Why here?

In 2020 the solar field delivered **11.3 GWh_{th}** (≈9.5% of Brønderslev's heat), yet seasonal demand swings and operational constraints mean not all potential solar heat can be valorized in real time. The central plant already has an 8,000 m^3 hot-water tank for short-term balancing; **TCES complements this by enabling medium-to-long-duration (seasonal) shifting** at higher temperature levels and without standby losses.

Benefits

- **Higher solar utilization:** Converts curtailed/unused solar output into useful heat and power later.
- **Seasonal flexibility & resilience:** Decouples solar availability from demand and electricity-price signals.
- **No impact on biomass performance:** Integration is solar-side only; biomass remains the primary dispatchable heat source.
- **System efficiency & value:** Heat can feed the ORC and/or district heating, **maximizing energy valorization** across operating modes.
- **Scalable concept:** Uses commercially available components (PTC field, ORC) with a **thermochemical storage add-on** tailored to medium-temperature solar heat.

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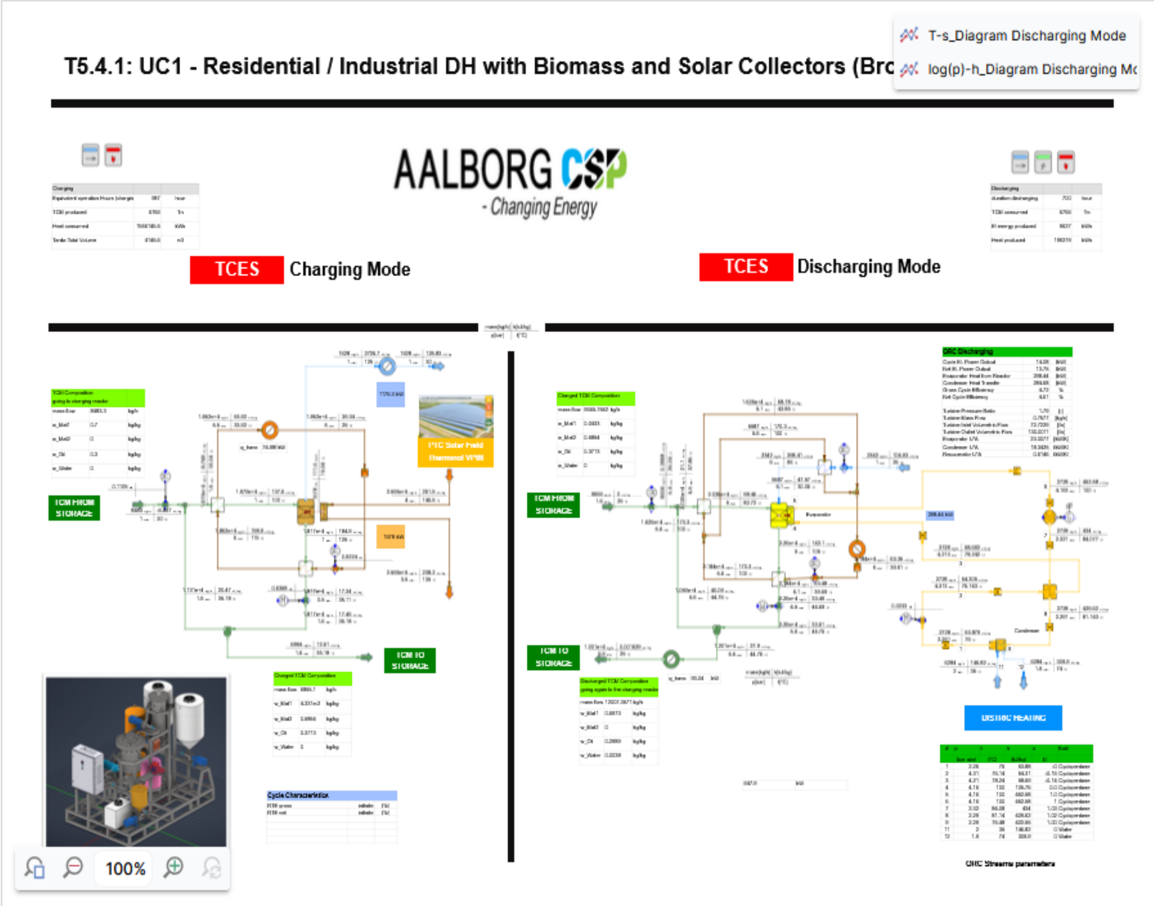
- Description
- RESTORE Integration
- Process Model
- Key Results

Use Case 1: Process Model



Use Case 1 - Brønderslev, Denmark
Owned by RESTORE Project Manager, 23/07/2025
Open

RESTORE | Home | Use Cases | Contact & Imprint

Key Results

Specific conclusions about integration and feasibility

- Seasonal valorization of non-utilized solar thermal energy. Use-Case I has identified the possible storage of approximately 5.46 GWh/year that is currently not utilized by the facilities and means seasonal mismatches between supply and demand.
- Strong compatibility between PTC field and TCES requirements. The average thermal oil temperature (146.5 °C) and mass flow (72.1 kg/s) fall within the optimal range for charging the $CuSO_4{\cdot}5H_2O$-based TCES reactor, confirming direct integration feasibility.
- TCES reactor sizing and cycles supported by RES profiles. Detailed monthly profiles and unutilized energy curves allowed for the definition of reactor capacity, charge/discharge timing, and expected cycle frequency.
- Full-year dynamic simulation demonstrates operational viability. The IPSE GO model successfully simulates 987 hours of charging and 700 hours of discharging, confirming that the TCES system can be operated consistently within real plant conditions. Noting that TCM reactions have different energy in play.
- ORC integration validated with detailed thermodynamic modeling. Simulated ORC performance shows net efficiency of 4.61%, turbine inlet/outlet flow consistency, and realistic pressure ratios — confirming proper coupling with the TCES discharge cycle.

General conclusions

- Brønderslev selected as a candidate for RESTORE concept. High renewable penetration, presence of a flexible DH network, and non-utilized solar thermal energy make Brønderslev a highly suitable site for RESTORE integration and demonstration.
- RESTORE approach enhances dispatchability of solar thermal. The TCES solution enables solar energy to be decoupled from real-time demand, increasing system flexibility, improving renewable integration, and reducing curtailment in hybrid plants.

Challenges

- TCM volumes in play (thousands of cubic meters) needed for seasonal storage like this User Case (but it seems to be a general point) will condition and impact the economic feasibility of TCES due to the cost of TCM storage tanks and cost of the TC Material itself.
- Despite $CuSO_4{\cdot}5H_2O$ is confirmed as a viable TCM for DH-scaled systems and material shows high conversion efficiency in dehydration, stable cycling, etc., the need for stable temperature condition can reduce the ways of using RES and WEH from part of the sources dependent on non-stable temperatures production along the day or the season.

RESTORE Home Use Cases Contact & Imprint

Description
RESTORE Integration
Process Model
Key Results

Use Case 2: Gmunden, Austria

- 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 RD group has currently the capacity of around 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, 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 where no space heating is required.

Gmunden cement factory overview

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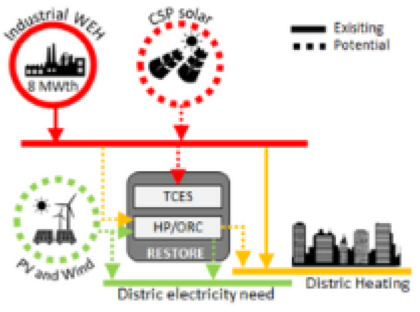
Description
RESTORE Integration
Process Model
Key Results

Use Case 2: RESTORE proposed solution

The Gmunden (Austria) cement plant of the Rohrdorfer Group supplies clinker (~1,900 t/day) and is already connected to the local district heating (DH) network. It operates roughly 10 months per year with a planned two-month shutdown (December–January) plus short unplanned stoppages, creating a clear need to decouple heat availability from DH demand.

The virtual use case integrates of the RESTORE 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 proposed solution Gmunden Community addressed: The Austrian cement industry incorporates nine integrated cement plants and two grinding mills spread across the country, including the Gmunder Zement's Hatschek plant. The communities involved are the core stakeholders in the site of Gmunden, like adjacent industrial companies, municipalities and regional authorities. Apart from the regional expected impact, RESTORE Use Case II will be a relevant reference on a wider sense, at national and European scales for the cement industry.



The RESTORE concept integrates thermochemical energy storage (TCES) to capture process waste heat and release it on demand to DH. The TCES uses copper-sulfate dehydration/hydration as the storage chemistry.

Main waste-heat sources identified are: A) ~10 MWth dust-laden flue gas at ~400 °C (preferred for charging), B) ~28.6 MWth flue gas at ~130 °C, and C) ~3 MWth around ~100 °C (cement mill). For planning, plant behaviour from 2018 is assumed; DH discharge is targeted mainly during shutdown nights (12 h/day), totaling ~798 h per year.

Operation

Charging (during production): A high-temperature intermediate Rankine loop (cyclopentane) couples the ~400 °C stream to the rest of the system, both protecting downstream components and co-producing power/heat while charging. A large heat pump (cyclopentane, with reheating) then upgrades the intermediate loop's heat to the TCES reactor at ~125 °C, charging it at ~500 kWth. Simulated performance shows ~6,326 h of annual charging, ~3,163 MWh stored in TCES, ~38,712 MWh delivered to DH during charging, and ~5,521 MWh electricity produced by the intermediate cycle (typical cycle output ≈ 1 MW). Heat-pump COP is ~4 with ~124 kW electrical input for the 500 kWth charge duty.

Discharging (during shutdowns/nights): During hydration, the reactor releases heat at ~105 °C. An ORC (cyclopentane, reheated) conditions this heat and delivers DH supply at ~55/35 °C while generating a modest ~29 kW net electric output. With a discharge setpoint of 500 kWth, the model supplies ~5,259 MWh of heat and ~22.9 MWh of electricity over ~798 h of annual discharge.

Benefits

The configuration reliably covers DH needs during shutdowns, stabilizes heat supply against production variability, and exploits high-grade waste heat more effectively. Storage capacity (TCM inventory) is the main limiter, not heat availability—favouring TCES even for shorter charge–discharge cycles. The existing DH interconnection and the IPSE GO validation indicate strong technical feasibility and replicability.

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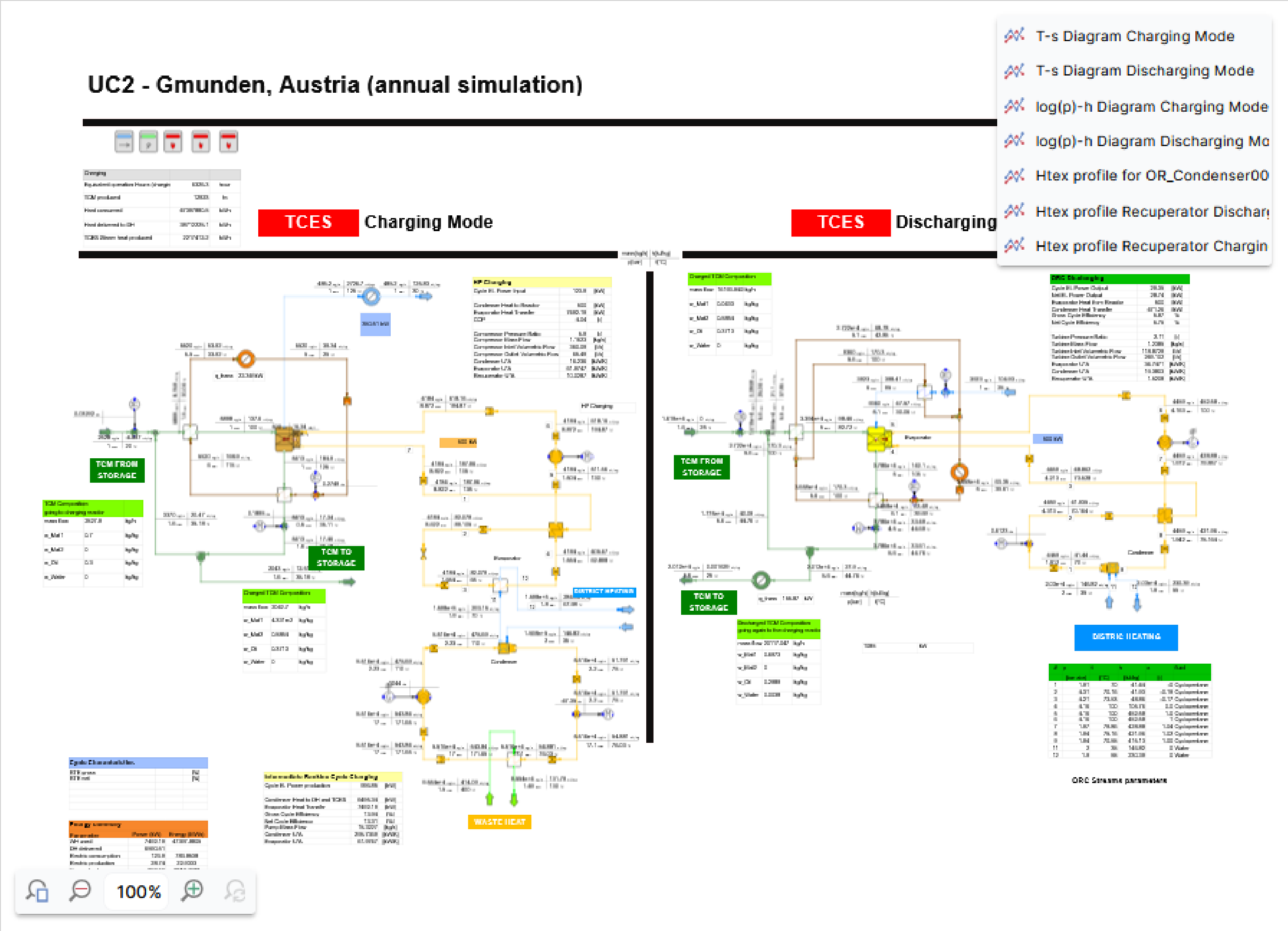
Use Case 2: Process Model



Use Case 2 – Gmunden, Austria

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Use Case 2: Key Results

Key conclusions from the implementation of RESTORE Use-Case 2, Gmunden, Austria, are summarized and categorized as follows:

Specific conclusions about integration and feasibility

- Non-used thermal energy sources identification (waste heat). The Use Case has identified the possible storage of approximately 300 GWh/year that is currently not utilized by the facilities and dissipated into the ambient environment in the form of flue gas or cement mill.
- The high temperature of the waste heat gases (~400 °C) technological challenge. This issue has been successfully addressed through the implementation of an intermediate cycle, which significantly improves the overall utilization of waste heat by enabling the co-production of electricity and the supply of energy to the district heating network, even during the charging phase of the TCES.
- Favourable operating conditions for TCES in cement production. The cement industry, due to its stable and continuous production process, offers favourable conditions for the optimal sizing of the equipment required for TCES integration. Furthermore, this operational stability simplifies the charging process of the storage system, as it ideally receives a steady flow of heat throughout the charging phase.
- Full-year simulation demonstrates operational viability. The IPSE Go model successfully simulates 6326.3 hours of charging and 798 hours of discharging, confirming that the TCES system can be operated consistently within real plant conditions.
- ORC integration validated with detailed thermodynamic modeling. Simulated ORC performance shows net efficiency of 5.75%, turbine inlet/outlet flow consistency, and realistic pressure ratios - confirming proper coupling with the TCES discharge cycle. Although the electricity generation and efficiency of the ORC cycle installed at the discharge are limited, the cycle plays an important role by adapting the heat conditions coming from the TCES to the temperatures and requirements suitable for the district heating network.
- The presence of an existing connection to the district heating network. This further facilitates the integration of the RESTORE solution in this specific use case. This infrastructure significantly reduces the complexity and cost associated with establishing the necessary distribution system for thermal energy
- Storage capacity as the limiting factor in TCES waste heat utilization. The utilization of waste heat is primarily limited by the storage capacity of the thermochemical material (TCM), rather than by the availability of energy itself. This fact has a direct and positive impact on the viability of thermochemical storage (TCES) projects, particularly those involving shorter charge-discharge cycles. In such cases, a greater share of the available waste heat can be effectively harnessed.

General conclusions

- Gmunden Cement Plant as a suitable site for RESTORE Implementation. The analysis conducted confirms the Gmunden Cement Plant as a highly suitable site for the implementation of waste heat recovery and TCES technologies. The combination of stable industrial processes, significant amounts of unused waste heat, and compatibility with district heating demands makes the plant an ideal candidate for the RESTORE use case. These findings validate its potential for supporting efficient, sustainable energy solutions through TCES integration.
- $CuSO_4 \cdot 5H_2O$ confirmed as a viable TCM for DH-scaled systems. The material shows high conversion efficiency in dehydration, stable cycling, and significant temperature lift (>60°C), making it suitable for seasonal storage applications.
- RESTORE Solution for waste heat recovery and district heating support. The solution proposed and adapted to the use case described, successfully takes advantage of an energetically intensive industry waste heat, storing it form of chemical energy, and releasing it when needed into a district heating. The solution fully satisfies the energetic necessities of the district heating during the cement plant-shutdown coinciding with the discharging period.

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Use Case 3: Ružomberok, 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.

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, through local heat exchangers and is flowing back to the steam/water heat exchanger station to gain heat again.

Mondi SCP Plant overview (Source: https://www.profisteelholding.sk/en/reference/mondi-scp-2/)

Community addressed

Paper has been produced in Ružomberok for over 300 years. The abundance of the raw materials like wood, water, and energy has had a favourable influence on the development of the mill. In early years, the mill was far away from residential areas, but in the course of urban development, the city has spread and the mill is now in the heart of the Ružomberok area, which embeds 49,035 km2 with 40.84% of forest land and a population of ~5.4 million. The main industries of the region are: automobile, chemical, iron ore processing, and pulp and paper.

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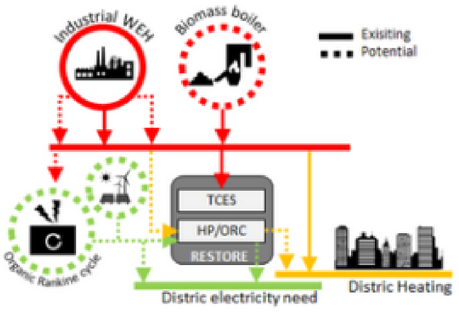
Use Case 3: RESTORE Integration

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) waste steam in case of reduced heat demand in district heating; (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. Expected outcome: huge reduction of the GHG through a high increment in the RES share and the waste heat capacity factor.



RESTORE proposed solution (Mondi)

General

This use case examines integrating a Thermo-Chemical Energy Storage (TCES) system into the MONDI SCP pulp and paper mill in Ružomberok, Slovakia. The mill also feeds the city's district-heating (DH) network with 5-bar steam that is condensed in a heat-exchange station to produce hot water for the network. The goal is to shift heat from low-value hours to periods with higher DH demand or higher electricity prices, improving the use of renewable and waste/excess heat and reducing reliance on gas-fired peaking boilers.

Integration Concept

TCES taps surplus 5-bar steam upstream of the existing DH condenser via a controlled branch to a steam-to-thermal-oil HX. That HX lifts an oil loop to ~140 °C, which is the plant-side heat carrier to and from the TCES reactor. On the low-temperature side, TCES ties back into the DH station as an additional oil-to-water HX that preheats DH return (typically ~60 °C) and, together with the existing DH condenser, brings it to forward temperature. A small water storage vessel and a steam/condensate handling line are included to manage the vapor produced/consumed by the TCES reactions without disturbing the mill's condensate system.

Operation

Charging: When mill steam and/or DH demand create a surplus at 5 bar, the diverted steam heats the thermal-oil loop. The reactor is dehydrated at ≥~125 °C ($CuSO_4$ example under ambient pressure), while the steam released in the reactor is condensed in a dedicated condenser, with the condensate stored for later hydration. The heat of that condensation—and of any upstream preheating step—can assist DH-return preheat so the existing DH condenser sees a lower load. This allows more of the main 5-bar steam to be routed to the condensing turbine when it is economically attractive, without sacrificing DH supply.

Discharging: When DH demand or electricity price is high, stored material is rehydrated. Water is pumped from the small tank to the reactor; reaction heat is removed via an internal coil, returned by the oil loop to the new oil-to-water HX, and used to lift DH-return toward the forward setpoint. In this layout, the TCES line is prioritized for direct DH heating; any optional power cycle attached to TCES faces a low condenser temperature (~35 °C) that is not well matched to DH-return preheat, so it is typically not the primary path for district-heating service.

Benefits

The site operates with strong daily/seasonal swings: DH heat exported ranges from roughly 5,000 GJ/month in summer to ~30,000 GJ/month in winter, and digester operation intermittently reduces on-site power. Integration is therefore control-driven: (i) open the 5-bar branch to charge when DH demand is low and/or electricity prices are low; (ii) throttle charging and favor turbine flow when power prices rise; (iii) discharge TCES to cover DH peaks so the condensing turbine can keep accepting steam; and (iv) respect plant rules that all condensates are reused internally (>~50 °C) and peak gas boilers run only in the coldest months.

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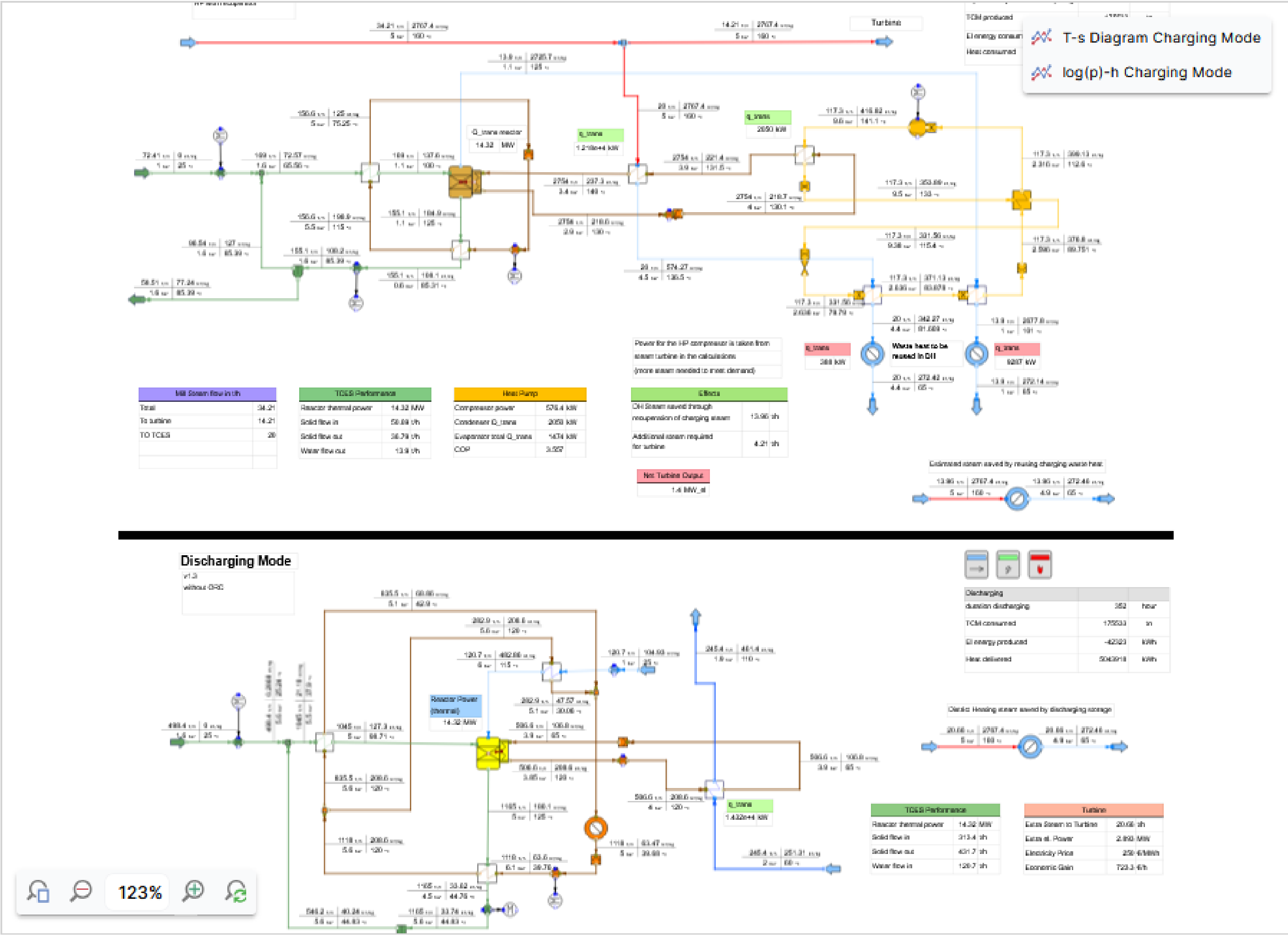
Use Case 3: Process Model



Use Case 3 - Ružomberok, Slovakia

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Use Case 3: Key Results

Key results from the implementation of RESTORE Use-Case 3, Ružomberok, Slovakia, are summarized and categorized as follows:

A case of application has been defined, where in the first approach the thermal power of the reactor was set to P_{R_th}=14.32 MW. This assumption was made to use all the steam, which can be generated, when the biomass boiler is under full load operation. In total, this assumption leads to a steam flow of 34.21 t/h, where 20 t/h are fed to the thermochemical reactor, whereas the rest (14.21 t/h) is spent to the steam turbine, producing an electric power of 1.4 MW. This case leads for charging to a very high mass flow of TCES, fed to the TCES-reactor (50,69 t/h), while 36.79 t/h are extracted. Both values are pure solid flows, not considering the oil, which is suspending the solid material.

In case of discharging at a thermal power of P_{R_th}=14.32 MW, the process was assumed to be operated without ORC-cycle. The reason for, is the relatively low condensation temperature of the ORC-process, which prevents from using the heat of condensation for heating up the return water of the district heating network. To operate the TCES-reactor at 14.32 MW causes high mass flows of solid matter to and from the reactor (feed: 313.4 t/h, extract: 431.7 t/h).

As an alternative and for comparison the discharging case, including ORC for electricity production, for a thermal power of the TCES-reactor of P_{R_th}=1 MW was analysed. Solids flow to the reactor is therefore reduced to 21.88 t/h; solids flow out to 30.15 t/h (due to the added water at hydration). At a heat input to the ORC-cycle of 646.5 kW an electric power of 46.07 kW is produced and a waste heat flow to the ambient of 521.1 kW occurs, which can't be used in the current plant configuration.

Summarized, the findings presented in this report show:

- that the TCES-system can be used for supporting the DH-network sufficiently, only if the system is used without the ORC-cycle at discharging. To overcome this problem the condensation pressure of the ORC should be enhanced (to allow higher temperatures for heat release) or the temperature of the DH-network changes, e. g. to allow for using a heat pump.
- that the described case, using a TCES-reator with a thermal power of P_{R_th}=14.32 MW, (chosen to calculate the resulting operating parameters) leads to inappropriate high values concerning solid mass flows, reactor size and volume of storage vessels, especially for long term storage.
- that, considering a realistic upscaled TCES-reactor with a thermal power of P_{R_th}=1-2 MW, could be a reliable possibility for the paper mill to supply for certain demand in future.

Overall, the findings presented in this report reinforce the suitability of the integration of the RESTORE proposed solution to paper mill plants, as virtually demonstrated in Use-Case III.

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Use Case 4: Brescia, Italy

- 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.

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 1950's. It soon became a benchmark in the industry and the construction sector at a time of rapid social and economic growth. The installation of a continuous casting system and heavy investments in new technology allowed the company to step up the production capacity in both the steel mill and rolling mill.

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.

In recent years, the Alfa Acciai group became one of Europe's leading producers of reinforcing steel for the construction industry. The community of Brescia profit directly from the continuous growth of the company and its innovations.

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 waste heat 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.

Alfa Acciai plant overview

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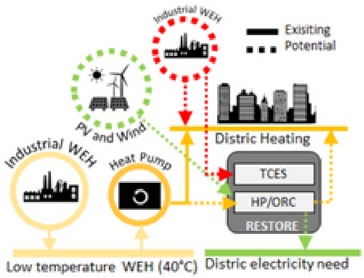
Use Case 4: Brescia, Italy

General

Alfa Acciai operates one of Italy's largest electric-arc-furnace (EAF) steel plants in Brescia. High-temperature process stages generate substantial waste heat in the flue-gas path. After primary recovery and filtration, a significant share of this energy is still carried back through the dust-collection (cassa polveri) return lines by a cooling-water circuit. Measurements on the EAF1 circuit (segments F5–F12 and F13 to the lateral dust-box panels) showed return-water temperatures around ~80 °C with thermal-power peaks of ~36–38 MW and sustained averages near ~23 MW—an attractive, but uneven, low-grade source.

Integration Concept



RESTORE proposed solution (Brescia)

To turn this residual heat into useful energy, the RESTORE configuration couples a large heat pump (LHP) to a Thermochemical Energy Storage (TCES) reactor. The LHP extracts heat from the 80 °C water loop and upgrades it to charge the TCES when waste heat is available and electricity prices are favorable. A deliberate sizing choice balances economics and operability: rather than oversizing to rare peaks, the LHP is set at ~12 MW_t, which captures >93% of recoverable heat for >96% of operating hours. Flow control on the source loop allows a higher inlet temperature at the heat-pump evaporator, improving COP without compromising overall recovery.

Operation

Charging mode: using cyclopentane as the working fluid, the LHP transfers upgraded heat to the TCES reactor. The reactor stores energy through a reversible thermochemical reaction, effectively decoupling when heat is harvested from when it is needed. Because the source is abundant, the system modulates automatically to maintain stable operating setpoints and match real-time charge demand.

Discharging mode: when heat or power is valuable—e.g., during district-heating (DH) peaks or high electricity prices—the stored energy is released. An Organic Rankine Cycle (ORC), also using cyclopentane and interfacing through the same tank and heat exchanger, converts the reactor's high-temperature output into electricity. Depending on system conditions, the ORC condenser can either supply the Brescia DH network (raising return water toward the forward setpoint) or reject heat to ambient when electrical output is the priority. The symmetric design of the charge/discharge interfaces supports predictable cycle durations and simplified control.

Benefits

System value: this integration upgrades otherwise lost industrial heat into reliable, dispatchable energy for both power and heat. It reduces gas-fired peak generation, cuts CO_2 emissions, and improves overall plant efficiency—while providing flexibility to follow market signals. In short, the Alfa Acciai TCES use case demonstrates how smart sizing, high-COP heat pumping, and thermochemical storage transform variable EAF waste heat into a continuous, green energy asset for Brescia's district heating and the grid.

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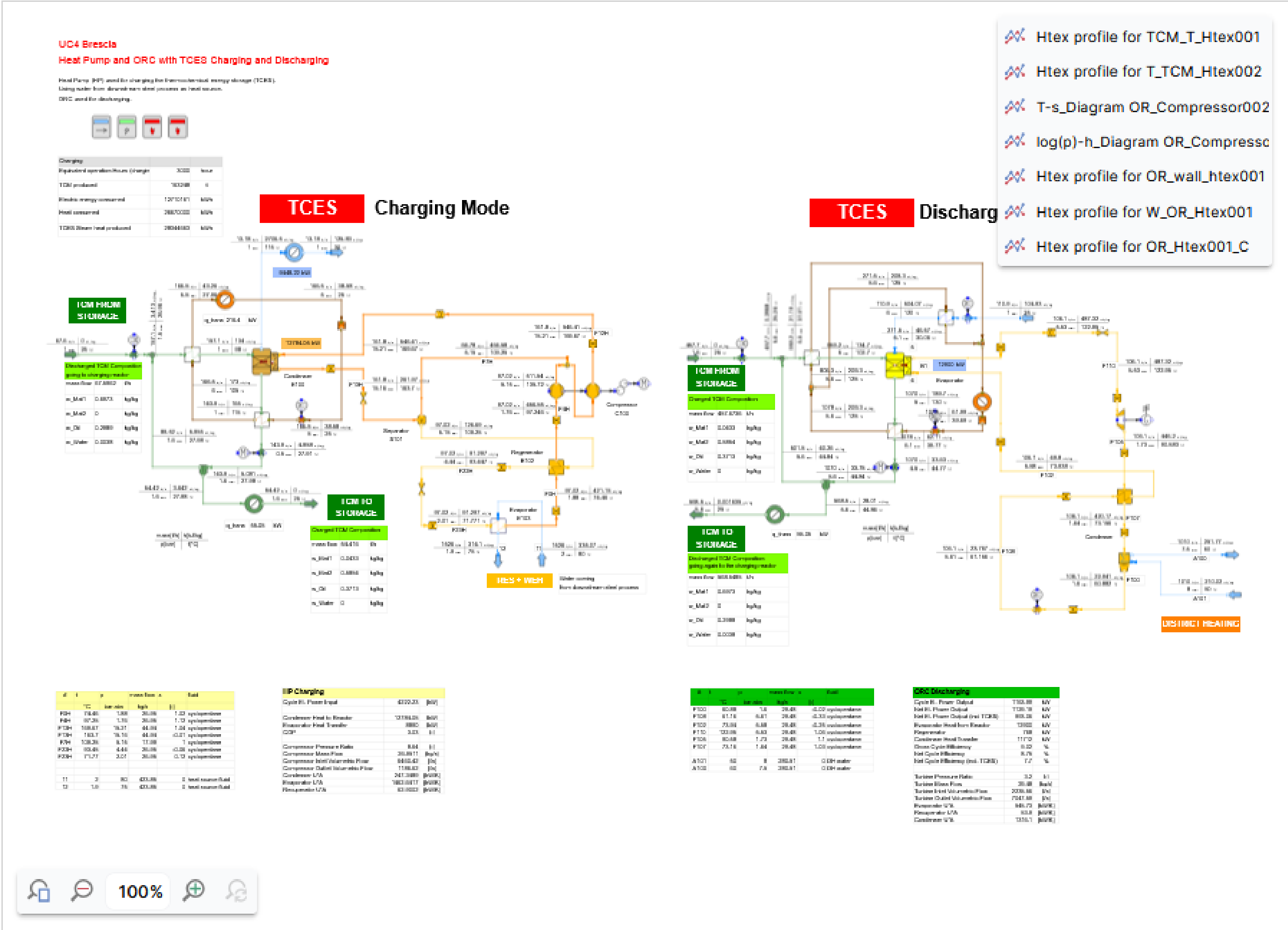
Use Case 4: Process Model



Use Case 4 - Brescia, Italy

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Use Case 4: Key Results

The RESTORE solution proposed and adapted to Use-Case IV has been thoroughly described in this document. This deliverable presents the design, simulation, and performance evaluation of the TCES (Thermo-Chemical Energy Storage) configuration developed by TURBODEN with support from SIMTECH.

The system demonstrates an annual energy storage capacity of approximately 28 GWh. One of the most critical challenges in scaling up to such large capacities is the quantity of thermochemical material required. Storing this level of energy demands a significant volume of active material capable of reversible reactions with high energy density and long-term stability. In this case, copper sulfate pentahydrate is used. Despite its favorable reaction enthalpies, the mass and volume needed to store tens of gigawatt-hours become substantial.

Therefore, while the thermodynamic performance is promising, the scalability of the storage medium remains a key area for further research and development—especially for industrial or grid-scale deployment.
It is important to note that the performance figures presented here assume an ideal scenario in which the reactor does not need to release any steam streams, as is currently required. Maintaining all stored heat becomes increasingly important at these large scales, and it is believed that future developments—driven by the experience gained through this project—will enable full heat retention.

As shown in the analysis of Figure 45, assuming this Scenario (A) the Carnot battery system achieves a round-trip electrical efficiency of approximately 20%, while its thermal round-trip efficiency exceeds 100%. Although direct comparison between thermal and electrical energy is not entirely appropriate due to their differing qualities and applications, it is worth emphasizing that if the electricity used to power the heat pump during charging comes from surplus renewable sources, its cost is effectively zero. In such cases, the low electrical round-trip efficiency becomes less relevant, as the system is primarily converting otherwise unused renewable energy into storable and dispatchable thermal and electrical outputs.

Scenario A: 2100 Hours of Discharging

Over the course of a year, with 2100 hours of operation in discharging, the system produces, assuming average load factor of 0.8:

- 1680 MWh of net electricity, generating €84,000 in revenue.
- 24,570 MWh of thermal energy, generating €1,228,500 in revenue.
- A total annual revenue of €1,312,500.

In terms of environmental impact, the system avoids approximately 672 tonnes of CO_2 emissions annually, assuming an average grid emission factor of 0.4 kg CO_2 per kWh.

Scenario B: 357 Hours of Discharging

- 285.6 MWh of net electricity.
- 4,176.9 MWh of thermal energy.
- CO_2 emissions avoided: ~1.79 tonnes

In this alternative scenario, the TCES system is designed to directly utilize the steam stream produced during the discharge phase for district heating in the city of Brescia. This is particularly advantageous because the temperature of the steam—approximately 106°C—is perfectly aligned with the requirements of Brescia's existing district heating infrastructure. This compatibility allows for seamless integration without the need for additional heat exchangers or temperature adjustments, maximizing system efficiency.

The steam generated from the thermochemical reaction is routed directly to the district heating network, where it is used to supply residential and commercial buildings with heating and domestic hot water. This approach not only enhances the overall energy utilization of the TCES system but also ensures that the stored thermal energy is delivered in a form that is immediately usable by the end consumers.

Importantly, this configuration remains effective even during the summer months. While space heating demand drops significantly in warmer seasons, the need for domestic hot water persists year-round. The system continues to operate by supplying hot water for sanitary use, maintaining its relevance and utility across all seasons. This year-round operation improves the economic viability of the system and contributes to a more stable and predictable revenue stream.

Moreover, this direct-use strategy supports the broader goals of decarbonization and energy efficiency in urban environments, as it leverages renewable energy stored in the TCES system to replace fossil-fuel-based heating sources.

The reduced discharge duration in this scenario—357 hours annually—reflects a more targeted operational strategy, focusing on periods of peak thermal demand or when renewable electricity is most abundant. Despite the shorter operating time, the system still delivers substantial thermal energy and contributes meaningfully to CO_2 emissions reduction.

In summary, the direct use of steam for district heating in Brescia represents a highly efficient and contextually optimized application of the TCES technology. It demonstrates how thermochemical storage can be tailored to local energy needs, offering both environmental and economic benefits, and paving the way for future large-scale deployments where full heat retention and utilization will be achievable.

Overall, the findings presented in this report reinforce the suitability of the integration of the RESTORE proposed solution to the as virtually demonstrated in Use-Case 4.

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Use Case 5: Holzkirchen, 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.

The Holzkirchen community works have provided the market with water and energy for more than a century. Since 1894 the company has developed into a modern, medium-sized service provider company. It has successfully faced numerous challenges, the growing population, technical progress and economic necessities. Since 1985, the business areas have expanded by supplying the community with natural gas and in 1992 with district heating.

An ORC from Turboden 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. Differently from the conventional geothermal steam turbines, the ORC process uses low-to-high enthalpy geothermal fluid to preheat and vaporize a suitable organic working fluid within a closed loop:

- The organic fluid vapor rotates the turbine, which is coupled to the electric generator.
- The exhaust vapor flows through the regenerator and condenser, which is cooled by air or water.
- The organic working fluid is then pumped again, thus completing the closed-cycle operation.

In such way the ORC turbine is not in contact with the geothermal fluid, which remains enclosed in the heat exchangers, allowing a full reinjection of all the brine and steam condensate with zero emissions to the ambient. In order to increase the geothermal heat exploitation Turboden will study a large HP in order to achieve higher flexibility in terms of heat and power production as well as increased geothermal utilisation. The energy contained in a shallow aquifer at low temperature can be used to feed a LHP and supply heat to a district energy network at higher temperature

Geothermie Holzkirchen GmbH plant overview

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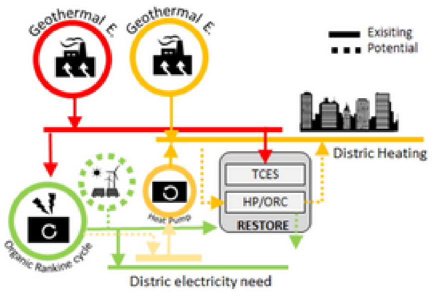
Use Case 5: Holzkirchen, Germany

General

The Holzkirchen geothermal plant in Bavaria uses a Turboden Organic Rankine Cycle (ORC) to convert ~140 °C reservoir heat from ~4,800 m depth into electricity and district heat. The ORC is a closed loop with an organic working fluid and offers 3.6 MW electrical capacity, wide part-load flexibility (10–110%), and >98% availability. Use-Case V aims to smooth year-round thermal withdrawal by optimizing how available heat is partitioned among power production, storage, and district heating—maximizing well productivity while protecting system stability and reservoir sustainability.

Three temperature levels exist: high (~140 °C) currently serving the ORC and some district heating; medium (~60 °C) downstream of the ORC; and low (~14 °C) that is presently underutilized. Indicative flows are ~95 kg/s on the medium stream (typical constant geothermal flow) and an estimated ~100 kg/s for the low stream (no meter installed). Heat demand is strongly seasonal: in January the district-heating (DH) load averages ~2 MW with daily swings; by June it falls to a fraction of a megawatt and is nearly negligible in July. Today, diverting high-grade geothermal heat to DH in winter reduces thermal input to the ORC and thus electrical output—despite cold ambient conditions that would otherwise favor ORC efficiency. In summer, with low DH demand, more geothermal heat reaches the ORC, so electrical output rises.



RESTORE proposed solution (Holzkirchen)

Integration Concept

To address this exergetic mismatch, the plant will couple a large heat pump (LHP, working fluid: cyclopentane) with a thermochemical energy storage (TCES) reactor.

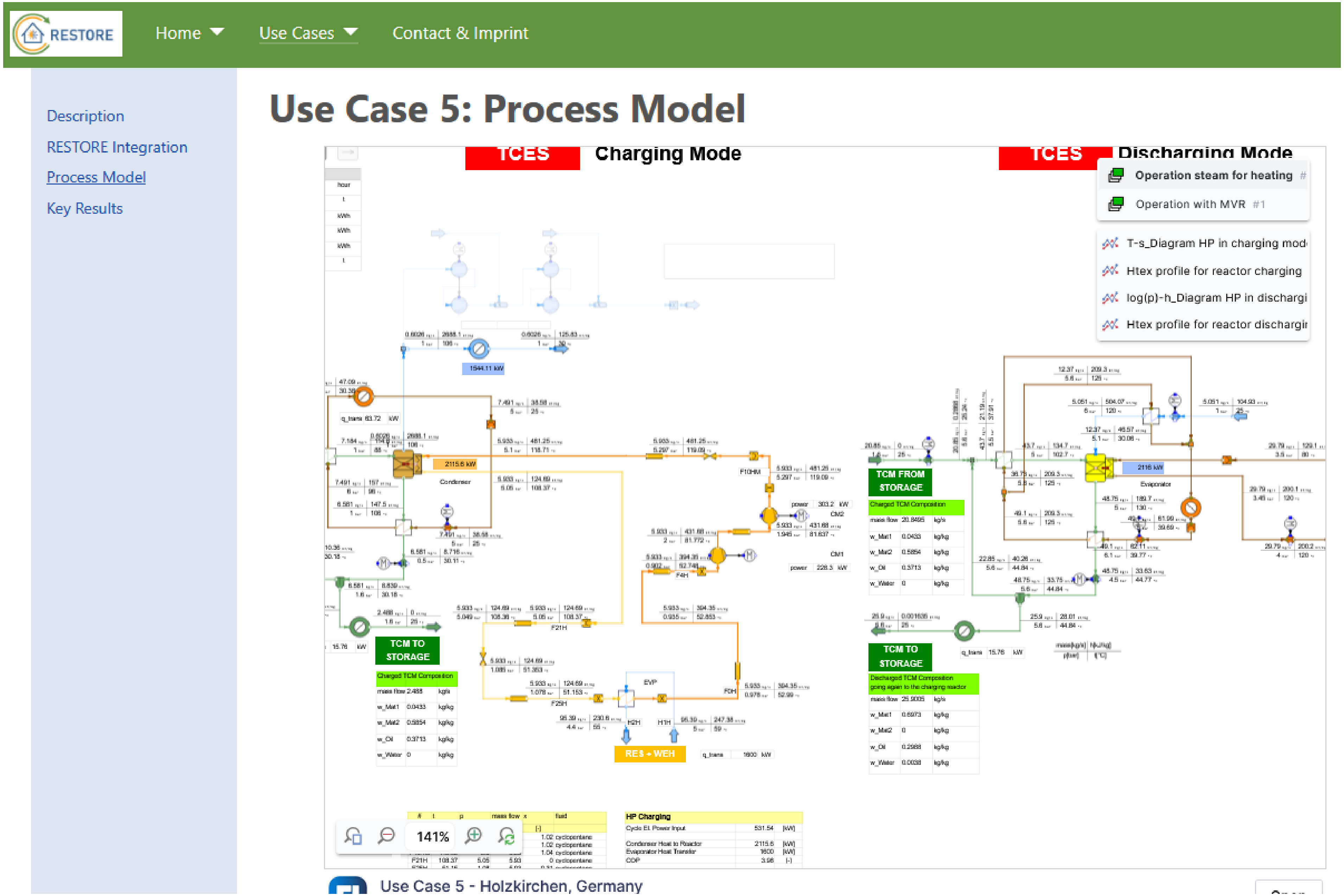
Operation

Charging (summer/low DH demand): the LHP lifts heat from the medium (~60 °C) and low (~14 °C) sources and delivers it to the TCES at elevated temperature, storing high-grade heat (endothermic step). Charging is prioritized when surplus/low-carbon grid electricity is available, using residual ORC heat without increasing geothermal extraction. The LHP starts via an external signal and modulates to maintain a stable charging setpoint as source temperatures/flows vary; integrated controls match output to the reactor's demand.

Discharging (winter/high DH demand): the TCES releases heat (exothermic step) directly to the DH network at ~85 °C with an ~10 °C exchanger drop (no intermediate power conversion) so response is fast and governed by DH return temperature and flow.

Benefit

Seasonal charging/discharging shifts summer surplus into winter demand, stabilizes geothermal heat withdrawal, raises overall exergy efficiency, and lets essentially the full geothermal thermal output feed the ORC in winter to maximize electricity production when the grid is tighter.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TCES
Charging Mode
TCES
Discharging Mode
Operation steam for heating
Operation with MVR #1
T-s_Diagram HP in charging mod
Htex profile for reactor charging
log(p)-h_Diagram HP in dischargi
Htex profile for reactor dischargir
TCM TO STORAGE
TCM FROM STORAGE
TCM TO STORAGE
RES + WEH
Condenser
Evaporator
HP Charging
141%
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Use Case 5: Key Results

The RESTORE solution proposed and adapted to Use-Case V has been thoroughly described in this document. This deliverable presents the design, simulation, and performance evaluation of the TCES (Thermo-Chemical Energy Storage) configuration integrated in a geothermal plant, developed by TURBODEN with support from SIMTECH.

Thanks to the integration of the thermochemical reactor, the system can support the district heating network for approximately 358 hours per year, allowing the entire geothermal thermal output to be directed to the ORC. This results in an estimated increase of 500 kW in electrical output during this period.

- Additional electricity produced annually: 179,000 kWh
- Equivalent CO_2 savings: 71.6 tonnes of CO_2 per year (Based on a grid emission factor of 0.4 kg CO_2/kWh)

In summary, the above results demonstrate the environmental and energetic benefit of decoupling heat supply from geothermal extraction during peak heating demand, while enhancing the electrical output when renewable electricity is less available.

Overall, the findings presented in this report reinforce the suitability of the integration of the RESTORE proposed solution to District heating with Geothermal Technology, as virtually demonstrated in Use-Case 5.

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Use Case 6: Milan, Italy

- 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.

Aerial view of Politecnico di Milano Campus Leonardo and the DH/DHC Plant

Community addressed

Politecnico di Milano is composed of seven campuses distributed in the cities of Milano (Leonardo and Bovisa campuses), Como, Lecco, Cremona, Mantova and Piacenza. Use Case VI considers the DHC network that serves the Leonardo and Bovisa Campuses in Milan which is an example of an independent network in a city largely served by a centralized district heating.

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Use Case 6: RESTORE Integration

General

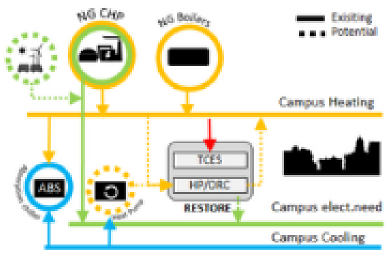
Politecnico di Milano's Leonardo campus operates PoliGrid, a 23 kV microgrid interconnecting 25+ buildings with on-site generation and a 2-km district heating (DH) loop. Core assets are a 2 MW$_e$ natural-gas CHP (overall efficiency > 82%) and summertime trigeneration via a 1.4 MW absorption chiller; rooftop PV totals ~1 MW and is planned to expand. When campus demand exceeds self-generation, electricity is imported from the grid. Annual consumption is ~14 GWh electricity and 11 GWh thermal, with ~3.3 million Sm³ of natural gas. Thermal demand peaks in Jan–Feb–Dec, drops near zero in Apr–May (and again in Oct), and rises in summer due to chilled-water needs; electrical demand is steadier, peaking in July. All key flows are metered hourly and accessible via an online platform.

The CHP unit is a Jenbacher JMS 612 GS-N.L. (2,000 kW$_e$). Heat is recovered from oil, jacket water, and exhaust, which is cooled from ~350 °C to 120 °C. A diverter valve modulates recovered heat. For the baseline model, the CHP runs continuously hour-by-hour (no start-stop), and cannot go below its minimum load.

Despite optimized dispatch (with PV and electricity sales), more than half of recoverable heat is wasted due to low thermal demand in many periods: of 18.36 GWh recoverable heat, only 8 GWh is used (≈56% discarded, mostly via the CHP diverter). Storing electricity (e.g., BESS) is not favored: excess thermal energy (5.4 GWh), and diverting exports would forfeit revenue critical to low operating cost. The integration goal is therefore to cut gas use, first by offsetting boiler operation, while preserving the economic benefits of current CHP scheduling. Seasonality underpins the case: heat is surplus in hot months and scarce in cold months.

RESTORE proposed solution

This Use Case aims to investigate 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 assess the environmental and economic sustainability of seasonal thermal storage.



RESTORE proposed solution (POLIMI CAMPUS)

Integration Concept

A thermochemical energy storage (TCES) using copper sulfate is adopted. Charging setpoint is 130 °C; discharging is 125 °C. Because hydration needs steam, an extra conversion penalty is modeled (≈72.5%). For the preliminary assessment, constant performance is assumed: HP COP = 5.5, TCES thermal efficiency = 0.725, heat-engine efficiency = 0.1, yielding a round-trip ≈0.4 (no design-specific constraints; storage cannot reschedule the CHP, so this is inherently sub-optimal).

Operation

Charging Mode: When CHP heat exceeds demand, the heat pump upgrades the otherwise-wasted low-temperature heat and stores it in TCES at high temperature (raising useful energy instead of dumping to ambient). If the store is full, the system idles.

Discharging Mode: Two operating modes exist:

- **Cover boiler load:** when demand exceeds CHP output and state-of-charge (SoC) allows, the **boiler is turned off** and TCES supplies the DH load; any associated ORC power generation is accounted for.
- **Cover total demand:** in hot periods (to avoid saturation), both CHP and boiler are stopped, and **TCES alone** meets thermal demand, activated only when CHP performance (PES) is below a threshold and SoC is sufficient. Initial and final SoC are aligned on a yearly basis.

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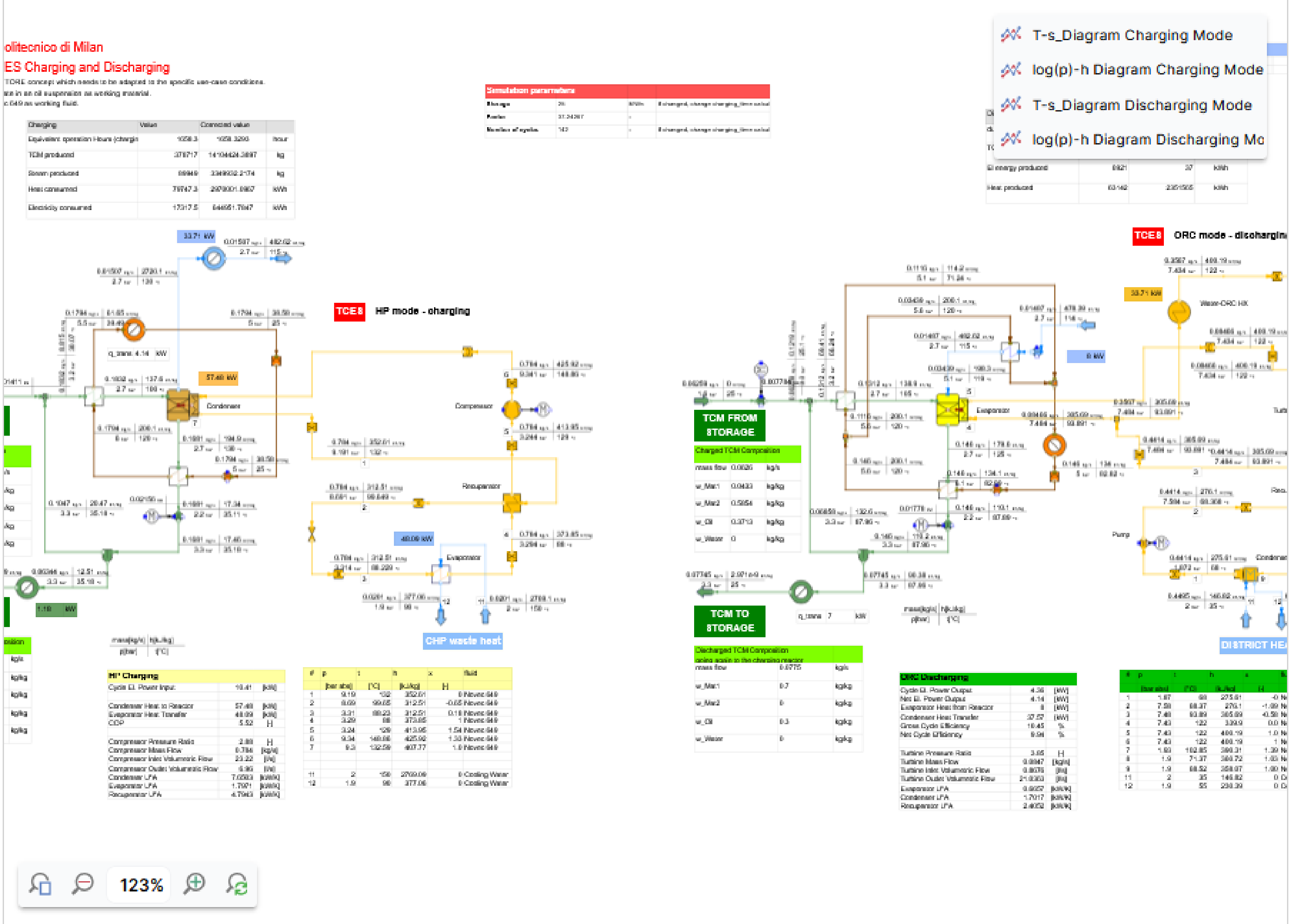

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Use Case 6: Key Results

The RESTORE solution proposed and adapted to the Use-Case VI was comprehensively described. The deliverable has presented the design, simulation, and performance assessment of the Use Case 6 TCES storage configuration developed by POLIMI and SIMTECH within the RESTORE project. The TCES system is based on the hydration/dehydration cycle of $CuSO_4$, which is charged using waste heat from the POLIMI Leonardo campus Combined Heat and Power plant. The discharging phase enables the combined production of electricity and thermal power for district heating through an ORC module.

The design of the system is carried out in the most critical scenario where the heat pump is dimensioned to absorb the entire rejected heat from the CHP plant (equal to 1791 kW), thus ensuring the system is properly sized to manage the full thermal surplus. The system configuration includes a continuously stirred tank reactor for charging and discharging the thermochemical material, coiled tubes heat exchangers for coupling with both the HP condenser (charging) and ORC evaporator (discharging), a vapor compression heat pump for the charging phase, an ORC module for electricity generation during discharging, and dedicated pumps and control valves to circulate the fluids and ensure stable operation across the daily cycle.

The heat pump designed for this use case employs Novec649 as working fluid and achieves a COP of 5.5, providing over 2 MW of heat to drive the charging reaction. The chemical conversion of the TCM features a 95% efficiency and it results in a mass reduction of approximately 19%, corresponding to the release of hydration water. In the discharging phase, the ORC module supplies 1.4 MW of thermal energy to the district heating network, while also generating around 154 kW of net electricity.

Overall, the results demonstrate that the TCES system can effectively valorize otherwise unused low-grade heat, providing flexible thermal and electrical outputs. The modularity and compactness of the daily storage solution, requiring a storage volume of only about 31 m^3, make it particularly suitable for an urban context like the POLIMI Leonardo campus energy grid.