Status of the ClaRa Library: Detailed Transient Simulation of Complex Energy Systems

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Abstract

This paper presents the current state of the open-source Modelica library ClaRa, which provides its users with the capability to proficiently tackle tasks in the disciplines of thermal hydraulics, instrumentation and control pertaining to power plants and other kind of energy systems. We provide a comprehensive overview of how the library has successfully broadened its scope over the years of its development, transcending the original focus on conventional power plants to encompass renewable power plants, waste heat utilization, general process plants, refrigeration cycles, heat pumps and beyond. The new version, ClaRa 1.8.1, brings an exciting addition to the already impressive suite of features - support for the utilization of various artificial intelligence models in Modelica simulation tools. Furthermore, the authors unveil ClaRa's ambition to serve as a potential publication platform for third-party models from a steadily growing community of ClaRa users. This is underscored by several application models. Finally, we also describe the funding scheme for maintenance of open source ClaRa by an extended commercial version, ClaRa-Plus.

Keywords: Energy system, ClaRa library, TransiEnt library, Thermal Separation library, Artificial Intelligence, Waste heat, Concentrating solar, Refrigeration cycle, Heat Pump

1 Introduction

1.1 Context of Paper

Climate change is an ongoing and pressing issue, and governments worldwide are taking measures to promote the use of renewable energy sources. However, as the transition to renewable energy takes time, fossil fuels like coal and gas will continue to play a critical role in the world's energy mix for the foreseeable future. Despite this, the proportion of renewable energy sources is growing significantly, underscoring the need for accurate and reliable simulation tools to capture the effects of this transition. Simulation tools enable stakeholders to evaluate the impact of different renewable energy options and assess the feasibility of transitioning to a more sustainable energy system. By leveraging simulation tools capturing the dynamics of the energy system, we can develop efficient and effective strategies that balance the practicality of fossil fuels with the long-term benefits of renewable energy.

Numerous simulation programs are being used in industry today depending on the field, application and desired type of simulation. In the Modelica community, there are several open source libraries available for investigating energy systems in detail, particularly power plant transients such as start-up, shut down, and load change: The ThermoPower (ThermoPower 2023) library, being the first power plant library written in Modelica, the ThermoSysPro (ThermoSysPro 2023) library having a strong industry background, the TRANSFORM (TRANSFORM 2023) focusing on nuclear power plants and the ClaRa (ClaRa 2023) library. ClaRa was developed by a German research collaboration (DYNCAP/DYNSTART 2011-2019)[1] of Hamburg University of Technology, TLK-Thermo GmbH and XRG Simulation GmbH. Its first official release of version 1.0.0 dates from March 2015 (see (Brunnemann, Gottelt, et al. 2012; Gottelt, Wellner, et al. 2012; Gottelt, Hoppe, and L. Nielsen 2017) for an introduction to ClaRa and a control-related application). The aim of ClaRa's Development team was to create a library that is suitable for both beginners and advanced researchers in the field of Modelica simulation. This paper serves as a companion to the ClaRa paper from 2012 (Brunnemann, Gottelt, et al. 2012), introducing several of the most recent enhancements that have been integrated.

1.2 Outline of Paper

This manuscript is organised as follows: Section 2 summarises the scope and structure of the library. In Section 3, we present two novel features of the recent release of ClaRa 1.8.1. The first feature enables the integration of different artificial intelligence models in Modelica simulation tools. The second feature includes new models for investigating generalized thermodynamic cycles, e.g. for refrigeration and heat pumps. The introduction of these new models in ClaRa library expands the range of possible applications, particularly in the area of refrigeration and heat pumps in industries such as automotive, aerospace, and buildings. In Section 4, we introduce the new ClaRa Open Development Repository intended for fast publishing third-party models prior to full ClaRa integration. Two example model, a waste heat in-

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cinerator and parabolic solar receivers, are shown. Section 5 describes the integration of ClaRa with other Modelica libraries, specifically TransiEnt for simulating coupled energy networks (TransiEnt 2023) and ThermsSeparation (ThermalSeparation 2023) for process engineering. This coupling presents a promising approach to address contemporary energy challenges. Section 6 presents the ClaRa funding scheme of and introduces supplementary content offered in the commercial variant, ClaRaPlus. Finally, the Summary & Outlook can be found section 7.

2 Overview of the Library ClaRa

2.1 Scope of Library

The ClaRa is used for a broad scope of applications and can support all project phases with dynamic simulations: from the evaluation of concept variants to component design, optimization of control technology, virtual commissioning and optimization during operation. The ClaRa is flexible and user friendly and also provides efficient means for simplified steady state analysis (via `ClaRa.StaticCycles` models which one integrates into a dynamic model) for the calculation of consistent initial values for states to smooth the initialisation of complex thermodynamic cycles. The library follows well defined model design principles including level of detail, level of insight, naming conventions, limited inheritance depth in comparison to the Modelica Standard library (MSL 2023), comprehensive documentation, and more (Brunnemann, Gottelt, et al. 2012). For detailed information, please refer to the ClaRa documentation (ClaRa-documentation 2023).

The initial goal of the ClaRa library was to provide models for the analysis of complex conventional power plants with CO_2 capture in both static and dynamic operation mode (DYNCAP/DYNSTART 2011-2019). Consequently, ClaRa has been effectively utilized in multiple projects where a number of digital twin models were created for several lignite-fired power plants, incorporating the complete water-steam cycle, flue gas and air path, coal mills, and a virtual representation of the control technology (H.Prausse et al. 2021), (Marcel Richter 2018), (Brunnemann, Gottelt, et al. 2012), (Gottelt, Wellner, et al. 2012), (Gottelt, Hoppe, and L. Nielsen 2017). In addition to its applications in coal power plants, ClaRa has also been utilized in several commercial projects involving combined-power plants as well as captive power plants with bubbling fluidized bed boilers, and more. Based on the experience gained, it is evident that the established design principles have been effective. As a result, we are now extending the accessibility of ClaRa to the community via (ClaRa-openDevelopment 2023).

The scope of ClaRa's applications extends today far beyond conventional steam power plants towards renewable power plants, waste heat utilization, process plants, generalized thermodynamic cycles, and more. Following the 2012 ClaRa paper (Brunnemann, Gottelt, et al. 2012) that provided an overview of the ClaRa library's status, many new models have been introduced together with improved numerical robustness, initialisation and functionality of the library. For comprehensive details, see the Revisions in ClaRa documentation (ClaRa-documentation 2023).

Regarding the applications from ClaRa community, various references are available. For instance, users have leveraged ClaRa in the design of supercritical CO_2 cycles as a power cycle (Vojacek, Melichar, and al. 2019), heat removal in nuclear power plants (sCO_2-4-NPP 2023), effective bulk energy storage (Kriz, Vlcek, and Frybort 2023), the design of experimental loops for the development of gas-cooled reactors, and small modular reactors cooled with molten salt (Krivsky 2020),(ClaRa User Meeting 2019), and beyond. ClaRa's further noteworthy reference is its role in the Future Energy Solution (FES) storage system, utilizing volcanic rock to store electricity generated from renewable energy, where ClaRa played a crucial role in modelling and analysing its performance, see (Heyde, Schmitz, and Brunnemann 2021). Additional applications of ClaRa are explicated in section 4.

2.2 Structure of Library

ClaRa library comes in a bundle (Table 1) of three libraries, ClaRa (Core), TILMedia (Thermo-physical properties) and SMArtIInt (AI).

Table 2 gives an overview of the top level content of the ClaRa library covering a diverse range of physics with well-structured and user-friendly architecture. The library adopts a functional approach to its structure, organizing components based on their functionality rather than the specific medium being modeled. As an illustration, a pipe model for vapor-liquid equilibrium can be found within the same package, `Components.VolumesValvesFittings.Pipes`, alongside models for gas pipes.

Table 1. ClaRa bundle

	TILMedia	Thermo-physical properties of incompressible liquids, ideal gases as well as real fluids containing a vapor liquid equilibrium.
	ClaRa	"The core" of the bundle supplying models within the fields of thermal hydraulics and instrumentation and control
	SMArtIInt	Support SMArtIInt (SMArtIInt 2023) for usage of (trained) TensorFlow (TensorFlow 2023) models from within Modelica.

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Table 2. ClaRa library structure

ClaRa	
UsersGuide	Information on basic modelling concepts, revisions, contact, license
Examples	Introducing examples showing different levels of complexity and library capabilities.
Basics	Basic models providing fundamentals to all models contained in ClaRa.
Components	Models for turbo machines and electrical machines, connection pipings, heat exchanger, mass storage and steam separation, valves, coal grinding, furnace, flue gas cleaning, and sensors, i.e. "the core of the library"
SubSystems	Conceptual package containing models of increasing complexity which are based on each other
Visualisation	Elements for displaying and plotting of dynamic simulation data.
StaticCycles	Static models for the calculation of consistent initial guess values or conceptual design purposes
SimCenter	A top level model which is mandatory for every complex ClaRa simulation. It provides global settings such as the media models etc.

3 Latest Features of ClaRa

3.1 ClaRaDelay now Open Source

Since its first release the ClaRa library comes with ClaRaDelay (ClaRaDelay 2023), an extended version of the Modelica delay operator `ModelicaReference.Operators.delay()`. The latter can be used in order to read past values of an expression from a buffer during simulation. While the original Modelica implementation only allows reading of a single past time value per buffer, ClaRaDelay takes a vector of past times as input and gives a vector of the according past values as output. This is particularly useful for numerical evaluation of convolution integrals during simulation, a feature that is used in ClaRa's implementation of a transmission line pipe `PipeFlowVLE_L1_TML`. In order to foster application and discussion with the Modelica community ClaRaDelay is now available open source.

3.2 Support for Hybrid Modelling

With the ongoing advances of machine learning and the availability of operational data there is a growing user interest in using trained neural networks from within Modelica and ClaRa. Combining data driven and a physics based model parts in a system model results in what is called a 'hybrid model': internally both parts exchange data through an internal communication interface ('com' see figure 1) and share the overall model parameters and outside connectors. This combination offers new perspectives for system simulation that go beyond 'traditional' characteristic fields (feed forward neural networks) or response surfaces (recurrent neural networks): complex correlations inside data can be directly derived from the data and encoded by the network parameters. Especially for high dimensional data fields this can be much more memory efficient than by using conventional interpolation methods (Chahrour and Wells 2022). Moreover neural networks can be applied in order to increase the level of detail offered by system models at low performance costs, e.g. spatially resolved temperature profiles or velocity distributions.

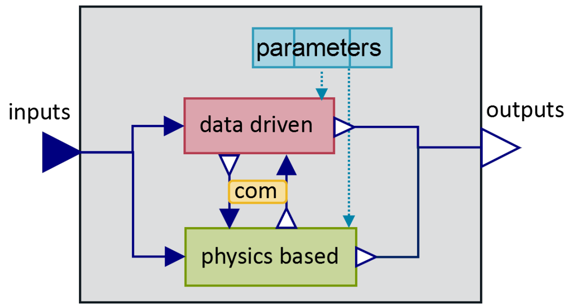

Figure 1. Hybrid Modeling

The Modelica library SMArtIInt (SMArtIInt 2023) addresses this issue and ships with ClaRa from version 1.8.1. Currently it supports tensorFlow (TensorFlow 2023) models for both feed forward and recurrent neural networks (RNN, stateful and stateless), using ClaRaDelay (ClaRaDelay 2023). Being open source the intention is to further develop SMArtIInt to support more network formats, architectures and Modelica tools by means of the user community. The library was created within the DIZPROVI (2021 - 2024) research project [2].

SMArtIInt allows the import of pre-trained neural networks into Modelica using external C-functions inside a Modelica block, similarly to the tables blocks available in the Modelica standard library. Figure 3 shows an example for a super heater boiler section of a conventional coal fired power plant taken from (Brunnemann, Kolter-

[2] funded by the German Federal Ministry of Education and Research under reference number FKZ 03WIR0105E

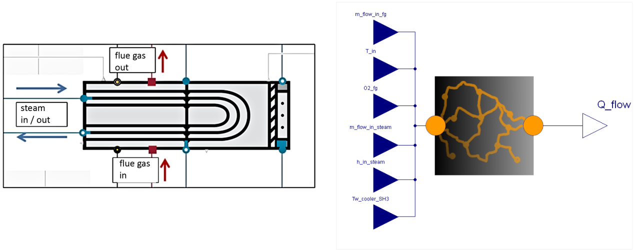

Figure 2. Usage of SMArtIInt: Left: physics based model of a super heater. Right: diagram of the build in data based heat transfer correlation.

mann, et al. 2022). The heat transfer Q_{flow} between hot flue gas and the water steam side is computed by a neural network that was trained on measurement data. It takes inputs from the surrounding physics based system model. Figure 3 shows a comparison of obtained heat flow rates from a physics based correlation ($Q_{flow,sim}$) and the data driven $Q_{flow,sim,AI}$ to the measurement $Q_{flow,meas}$ during a load change of the plant.

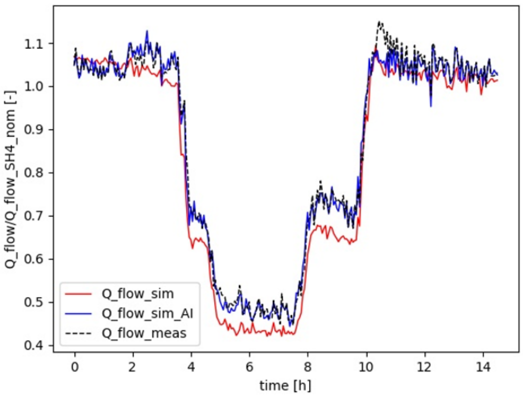

Figure 3. Hybrid Modeling from (Brunnemann, Koltermann, et al. 2022)

Hybrid models certainly offer exciting new perspectives for system simulation. However identifying the optimal combination of physics based and data driven model part (see Figure 1) can be a challenging trade-off between measurement data from the real plant and abstracted model assumptions. Special care has to be taken in consistent validity range of data driven models build into physics based system models: firstly, the inputs may be driven outside the trained ranges by the system dynamics, e.g. when it comes to non-standard operation or control feedback loops. Secondly solvers with variable time steps can may ask for a step that takes the inputs outside their range, possibly causing time steps to be accepted that would be rejected for the true correlation encoded in the data driven model.

Additionally stateful RNNs need to be sampled at the time interval they have bee trained with. This is undesirable, as it would slow down simulations using variable time step solvers. SMArtIInt addresses this issue by evolving the RNN inside a container in the external C-code, hidden from the solver. If the Modelica solver proposes a time step larger than the trained step size of the RNN, then inside the container the RNN is evolved with input values that are equidistantly interpolated between the current time step and the proposed time step with the time step compatible to the RNN.

The functionalities of SMArtIInt are currently under active testing and research and we invite the ClaRa community to experiment with it.

3.3 Generalized Application of Thermodynamic Cycles

The recent release of ClaRa, which includes models for commonly designed condensers and evaporators (a flat tube finned HX and plate HX), enables Clara users to model and analyse different thermodynamic cycles such as refrigeration cycles and heat pumps.

To showcase the capabilities of ClaRa, a simple refrigeration cycle was modelled, consisting of a compressor, a flat tube finned plate air-cooled condenser, separator, expansion valve, and water-heated plate evaporator/chiller [3]. The results are visualized in Figure 4. Regarding numerical performance, the ClaRa model is much similar to other Modelica libraries in the field such as AirConditioning (2023) or TIL (2023). These initial findings and experiences demonstrate that ClaRa is capable of delivering accurate and reliable results. This positions ClaRa as a viable alternative for modelling refrigeration cycles, alongside other Modelica libraries in that field. We invite the community to test such applications.

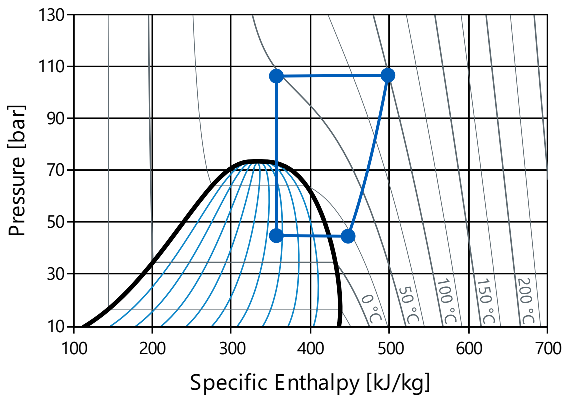

Figure 4. Refrigeration cycle with CO_2 modelled in ClaRa.

4 ClaRa Open Development Repository

The ClaRa Development team has set a new objective to establish the ClaRa library as a potential publication platform for third-party models originating from the

[3] Similar model can be found in `ClaRa.Examples.VapourCycle_01`

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ever-expanding ClaRa users' community. To achieve this, there is now a dedicated Git repository (ClaRa-openDevelopment 2023), intended for model publication prior to full integration into the official ClaRa library. To ensure optimal usability, there are some minimum requirements to these new models: they should contain introductory functional examples, declarative comments, well structured parameter dialogues and model diagrams as well as a self-explanatory and consistent nomenclature, good source code transparency and at least basic documentation. Following a comprehensive quality check by the ClaRa development team, models and their corresponding documentation can be considered for integration into the official ClaRa release if there is sufficient user interest.

To make sure everyone is protected and ClaRa can keep growing, all contributors must sign a Contributor License Agreement (CLA 2022). Basically, it means that contributors give the ClaRa Development team (CDT) permission to publish their work in the ClaRa library, currently under 3-clause-BSD License. In return, the CDT assures to always make the contributions available as open source in ClaRa. A few models have already been included in the official release of ClaRa, thanks to contributions from different individuals. Specifically, there are models from (FVTR 2021) sponsored by LEAG (LEAG 2021), as well as from the Future Energy Solution (FES) storage system project (Heyde, Schmitz, and Brunnemann 2021).

In this chapter, we further demonstrate our objective through the presentation of various application models that are vital for sustainable energy solutions. The first model focuses on waste heat incineration, highlighting its effectiveness in harnessing valuable energy resources while minimizing environmental impact. The second model demonstrates the use of renewable sources, such as solar energy, which plays a crucial role in achieving an environmentally friendly energy mix and driving the transition towards a cleaner and more sustainable future. All of the models shown in Section 4, as well as their basic equations, can be found on the ClaRa Open Development Repository (ClaRa-openDevelopment 2023).

4.1 Waste Heat Incinerator

A part of the ClaRa Open Development Repository is the model of a grate combustion system, which was developed as part of a master's thesis (Gulba 2019). Such grate combustion systems find application in the incineration of biomass and waste materials. The combustion process within such a grate combustion system can be conceptually divided into four stages. Initially, the untreated fuel undergoes a heating process that leads to evaporation of its water content during the drying phase. Temperatures exceeding 300 °C result in the release of volatile components and chemical transformations of certain fuel constituents (pyrolysis). The ensuing gases subsequently react with oxygen present in the flue gas. Following the pyrolysis stage, solid carbon (coke) reacts with oxygen, leading to the formation of CO and CO2. The remaining inert components, such as ash and slag undergo cooling through interaction with the flow of cooler incoming air.

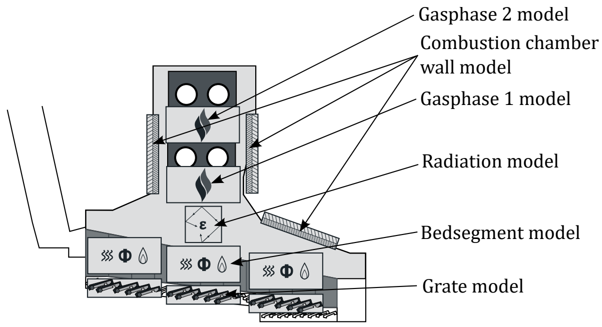

Figure 5. Modeling of the combustion chamber - representation and spatial assignment of all submodels

The in Figure 5 shown combustion chamber is divided into the components of grate, fuel bed, combustion chamber volume, chamber walls, and radiation model. The grate and fuel bed are discretized, consisting of multiple individual elements that are interconnected. Figure 6 provides a schematic representation of the processes occurring within the fuel bed segment. In this illustration, dark red arrows symbolize heat transfer exclusively, while all other arrows represent mass transfer as well as the associated energy transfer.

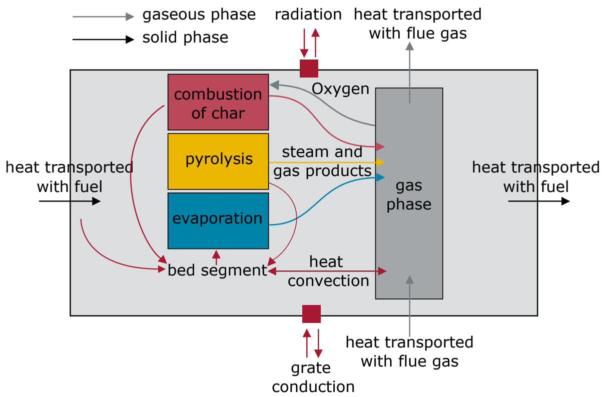

Figure 6. Schematic representation of the bed segment model with heat and material flows

The processes of evaporation and pyrolysis are endothermic processes that require energy to occur. This required energy is extracted from the fuel bed, as indicated by the representation of dark red arrows. On the other hand, residual coke combustion is an exothermic process that releases energy. It takes place in the presence of oxygen, which must be supplied from the gas phase. During evaporation and pyrolysis, there is no requirement for material transport from the gas phase to the solid phase. Instead, gaseous products generated in these processes directly transition into the gas phase. Additionally, the material flows transport energy in the form of heat from one phase to another. The drying and pyrolysis models employed in the fuel bed segment model are based on (R. J.

Nielsen et al. 2018). On the other hand, the coke combustion model and the gas phase model were developed within the scope of the master's thesis (Gulba 2019). Furthermore, the radiation model utilized in the combustion chamber model is based on the approach of (R. J. Nielsen et al. 2018). The fuel model, grate model, and model of the combustion chamber walls all consist of components of the ClaRa library. The combustion chamber model expands Nielsen's model by incorporating temperature-dependent reaction rates for both residual coke combustion and pyrolysis gas combustion. This allows for the consideration of activation energies for the different reactions.

For this combustion chamber model, two different cases are considered below. First, a start-up process and second, a change of state in steady-state operation. For the investigation of these scenarios, both the bed and the grate model are discretized into 10 segments. All of these segments are connected to the gas phase 1, allowing for gas exchange between the fuel bed and the gas phase. The gas phase 1 is also connected to gas phase 2, where additional secondary combustion air is supplied.

The startup process of the system shows that initially, the vaporization of the fuel primarily occurs in the three rear segments (8, 9, 10) (Fig. 7). This is due to the external heat supply from an auxiliary burner in these segments. Despite the externally added heat, temperatures and thus reaction rates remain low due to necessary drying of the initially wet fuel in these segments. The temperature pro-

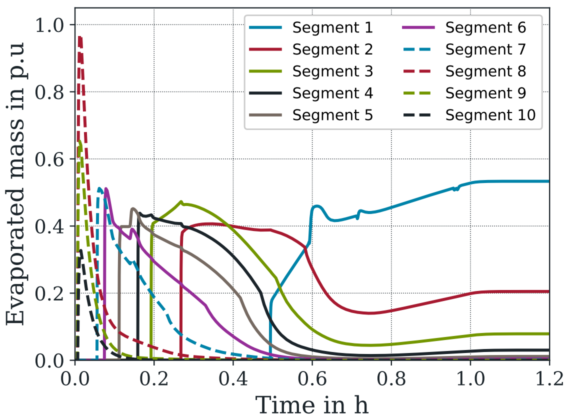

Figure 7. Amount of water evaporated from the fuel in the individual segments

file in Figure 8 demonstrates that combustion of the dried fuel starts in segment 10. As heat generation increases, the drying of the fuel and therefore the coke combustion shifts to preceding segments. Steady state is reached after more than one hour, with fuel drying in the first four segments and the substantial combustion occurring in segments 5 and 6. In the second scenario, the primary air (grate air) is reduced after 2.5 hours, followed by a reduction in secondary air in the gas phase after 3 hours. These changes initially affect the gas phase 1. Due to the lack

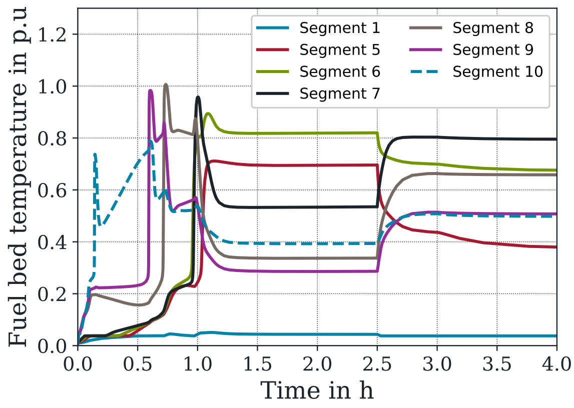

Figure 8. Fuel bed temperature in the individual segments

of air, there is insufficient oxygen to convert all volatile components (H2, CH4, CO). As a result, less energy is released in gas phase 1. Meanwhile, more energy is released in gas phase 2 as the secondary air reacts with the volatile components (Fig. 9). However, with the reduction of secondary air, the energy released in gas phase 2 also decreases. These changes in reaction energetics affect the gas phase temperatures and the heat transferred to the segments through radiation (Fig. 10). The reduced heat

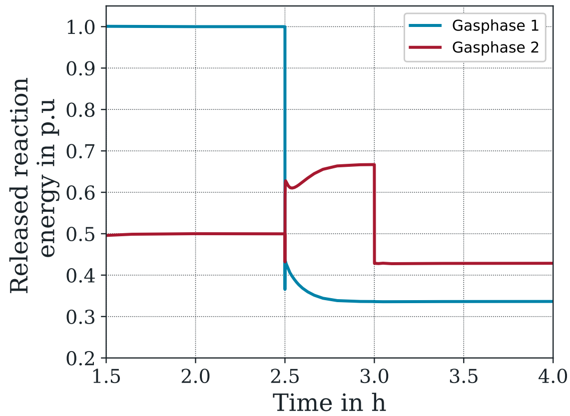

Figure 9. Energy released during the reaction in the gas phase

transfer to the front segments causes a shift in the drying and pyrolysis process to later segments. Consequently, the coke combustion in the bed segment is also shifted from segments 5 and 6 to segments 6, 7, and 8. This shift is evident in both temperature profiles and heat radiation in the figures 8 and 10. Prior to the state change, segments 5 and 6 released heat to the gas phase. However, after the adjustment in the air supply, segment 5 absorbs heat from the gas phase, while segment 6 releases significantly less heat. Conversely, segments 7 and 8 initially absorb heat and then release the heat generated during combustion after the change in air supply.

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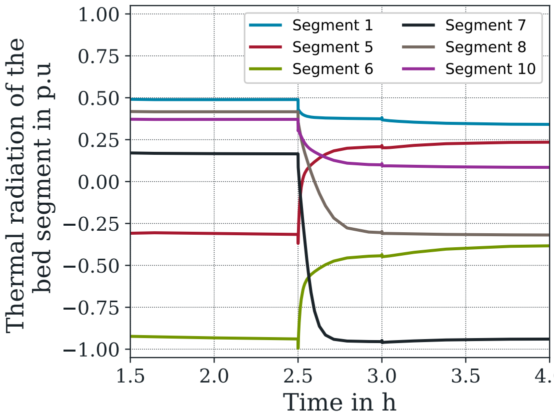

Figure 10. Thermal radiation between the individual segments and the gas phase

4.2 Concentrating Solar Thermal (CST) Power Plants

The Concentrating Solar Thermal (CST) power plants are an important part of the ClaRa Open Development Repository. Concentrated solar power (CSP) technologies utilize concentrated solar radiation to heat a fluid, which drives a heat engine to generate electricity through a generator. The CST power plant models integrated into the ClaRa Open Development Repository are currently based on the principle of the directly evaporating parabolic trough power plant. The collector model combines a tube and a tube wall model from the ClaRa library with a parabolic mirror model that was developed as part of a master's thesis (Hoppe 2013). A collector model realized in this way is shown in Figure 11.

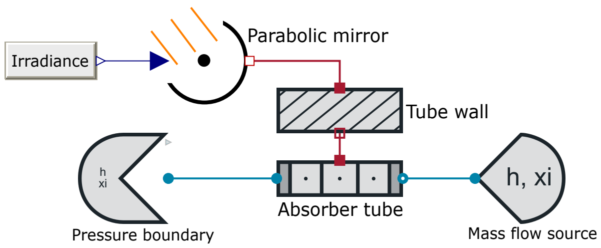

Figure 11. Collector model

The parabolic mirror model calculates a heat flux to be passed to the pipe wall from a given irradiance. Two different parabolic mirror models exist: a simplified and a detailed model. The simplified model disregards the position of the sun and the orientation of the collector. It is used to investigate short-term disturbance situations where no fundamental changes in sun position occur. The detailed parabolic mirror model considers sun position and the orientation of the collector in its heat flux calculation and can be used to investigate whole day operation cycles.

The collector models can be used in combination with ClaRa's water-steam cycle components to simulate complete parabolic trough power plants such as shown in figure 12. The model of this solar thermal power plant op-

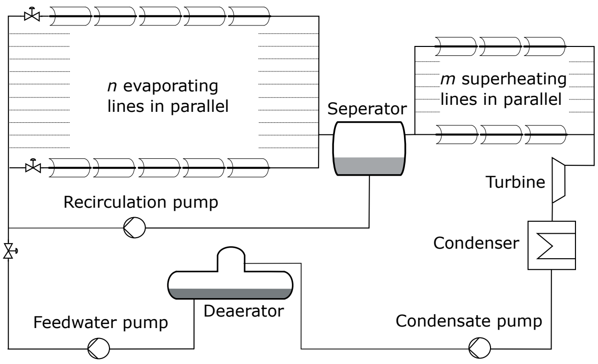

Figure 12. Schematic CST power plant

erates according to the principle of direct evaporation and uses water as a heat transfer medium. The collector field consists of 6 parallel evaporator rows and 3 parallel superheater rows. Two different operation scenarios are investigated for the model described above.

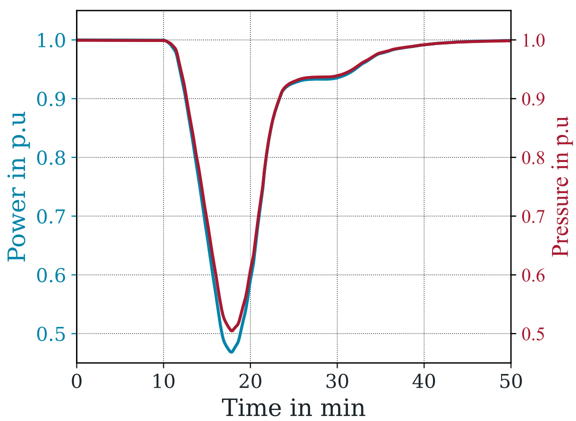

Figure 13. Turbine power and steam pressure at turbine inlet

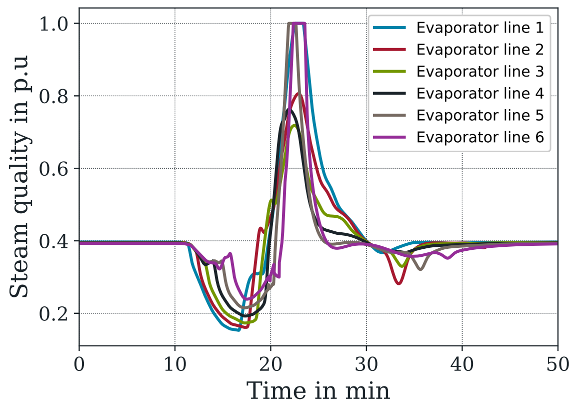

Figure 14. Tube steam quality outlet

In the first scenario, a cloud front passes over the collector field after 10 minutes, resulting in a decrease in solar irradiation on each individual collector. This causes a pressure drop at the turbine inlet, leading to a reduction in the mechanical power output of the turbine (as shown in Figure 13). Figure 14 illustrates the steam quality at the outlet of each evaporator line. Initially, the steam quality decreases due to the reduced irradiation. Consequently, the power plant reduces the mass flow rate through the individual evaporator lines, which causes the steam quality to rise again. Once the disruption ends after 20 minutes, the water-steam cycle's inertia leads to a sharp increase in the steam quality before reaching a steady-state level once again.

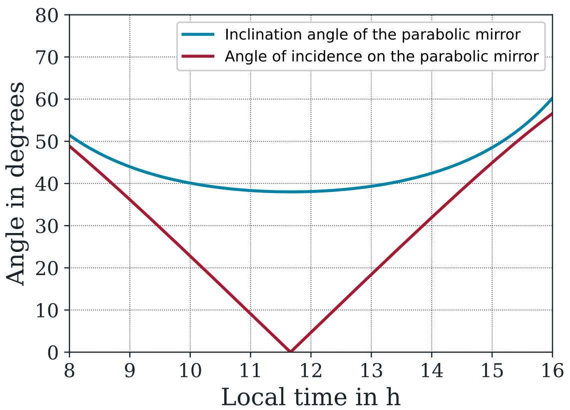

Figure 15. Angle of inclination of the parabolic mirror and angle of incidence on parabolic mirror

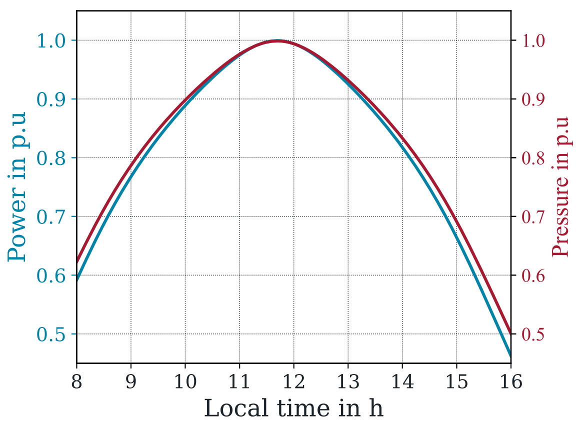

Figure 16. Turbine power and steam pressure at turbine inlet

The second scenario examines how the daily cycle of the sun affects the CST power plant. Figure 15 illustrates the behavior of the parabolic mirrors. The collector field is oriented parallel to the east-west axis, leading to an incidence angle of 0° when the sun is in the south. The parabolic mirrors are then tilted in complement to the sun's elevation angle. Figure 16 displays the resulting inlet pressure and the mechanical power output of the turbine. The detailed model is capable of simulating various locations, seasons, and orientations of the collector field, making it possible to support analyses of expected yield.

5 Combining ClaRa with other Modelica Libraries

Beside adapters to fluid components of the Modelica Standard library (MSL 2023) and the ThermoPower library (ThermoPower 2023) ClaRa's range of applicability is further broadened by its integration with other Modelica libraries.

5.1 TransiEnt Library

The TransiEnt Modelica library (TransiEnt 2023) aims at studying complex sector coupled energy systems on a scale from single settlements (Schindhelm et al. 2021), city districts (Benthin et al. 2019) or entire geographic regions (Senkel et al. 2022) and was awarded as one of the best submitted Modelica libraries at the previous Modelica conference (Senkel et al. 2021).

ClaRa models provide the foundation of the TransiEnt packages for heating and gas grid through code inheritance in basic components such as connectors, control volumes or components such as pipes, fans or sensors. Moreover TransiEnt's global model settings (SimCenter) as well as ModelStatistics inherit code from the according ClaRa componets. Hence TransiEnt user models contain also code from ClaRa and there is a deep interconnection between the two libraries. Consequently TransiEnt ships in a bundle with ClaRa.

5.2 Thermal Separation Library

The Thermal Separation library (ThermalSeparation 2023) is an open-source Modelica library designed for simulating thermal separation processes, including rectification and absorption processes. The library primarily focuses on simulating amine scrubbing processes, which are utilized for capturing CO_2 from flue gases emitted by various sources such as biogas or thermal power plants.

Models of the Thermal Separation library can be coupled to ClaRa-library. Adapters for linking both libraries can be provided upon request. This enables the ClaRa users to simulate coupled combustion + carbon capture processes in order to understand the dynamic behaviour or test suitable control schemes or evaluate the potential of carbon capture and storage (CCS) strategies.

Detailed results of the coupled operation of a coal fired power plant with post-combustion carbon capture can be found in (Wellner, Marx-Schubach, and Schmitz 2016) and (Marx-Schubach and Schmitz 2019).

6 The ClaRa Funding Scheme: Sustaining Open-Source Development

ClaRa has been and will be an open source project with regular updates and releases. In order to make its ongoing development financially sustainable it comes with an

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an extended commercial companion version called ClaRaPlus (ClaRaPlus 2023) since 2017.

ClaRaPlus offers access to a wider variety of models and components that enable more advanced simulation capabilities, such as instrumentation and control very close to modern power plants, in the ClaRa_DCS module, as well as modelling interactions between power plants and electric grids using the ClaRa_Grid module. Additionally, ClaRaPlus provides advanced pump and fan models (defined in all operational modes - 4 Quadrant), which enable the investigation of detailed start-up and shut-down as well as abnormal operations such as pump trip, pressure shocks, and beyond. ClaRa (ClaRaPlus 2023) provides a detailed comparison between the two libraries and highlights the differences in features and capabilities offered by ClaRa and ClaRaPlus.

Additionally, ClaRaPlus offers technical support and maintenance services, which can be valuable for users who require assistance with the implementation and use of the library. Ultimately, the choice between ClaRa and ClaRaPlus will depend on the specific needs and requirements of each user or organization. The ClaRaPlus is available at (LTX Simulation GmbH 2023) and alongside Dymola via (Dassault Systèmes 2023).

Also sponsorship (models or money) is warmly welcomed and greatly appreciated, as it plays a vital role in ensuring the long-term viability of the open-source ClaRa initiative.

7 Summary & Outlook

We are pleased to announce the latest functionalities in ClaRa, the open-source Modelica library that continues to push the boundaries of simulation technology.

With the recent release, users of ClaRa can now seamlessly integrate AI models which opens up a world of possibilities in the realm of energy system analysis, enabling users to harness the power of machine learning, deep learning, and other AI techniques to gain deeper insights into complex systems. Further, the introduction of new models in the ClaRa Open Development Repository such as waste heat incinerator, parabolic solar receiver, evaporators/condensers for refrigeration cycles and heat pumps, expands the range of possible applications.

We look forward to seeing new community contributions and sponsorships in the third-party ClaRa Open Developemnt Repository that unlocks new possibilities. We are excited to continue supporting our users in their quest for innovation across a wide range of industries, including renewable energy, process engineering, building management, and many others.

Currently, Dymola remains the primary development environment for the ClaRa library. However, we are committed to ensuring its compatibility with OpenModelica (OpenModelica 2023) and have made significant progress in this regard thanks to the OpenModelica development team. More than half of the examples can now run in OpenModelica (OM-ClaRa-Suport 2023). At the moment, OpenModelica and Dymola handle symbolic manipulations differently. The current approach used in OpenModelica leads to numerically unstable models, as seen in cases such as discretized pipe models. We will continue our efforts to expand this compatibility further.

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