

Status of the TransiEnt Library: Transient Simulation of Complex Integrated Energy Systems

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Abstract

The TransiEnt Library is an open-source Modelica Library originally developed at the Hamburg University of Technology. It is a flexible framework for modelling and analysing the dynamic behaviour of coupled energy systems under current and future scenarios. With the addition of three new members to the TransiEnt Library consortium, namely Fraunhofer UMSICHT, Gas- und Wärme-Institut Essen e.V. and XRG Simulation GmbH, the TransiEnt Library has expanded its portfolio of models and methods for investigating the challenges in energy systems. Building upon the previous status report, this article presents the latest developments in the TransiEnt library, highlighting its extended capabilities to model and simulate large, complex energy systems. The recent developments include the automatic generation of aggregated models at district and regional levels, as well as the modelling of medium- and low-voltage electrical distribution networks. In addition, new concepts for the representation of large-scale heating networks have been developed and are presented alongside illustrative use cases.

Keywords: District Heating Network, Large-scale Simulation, Modelica, Sector coupling

1 Introduction

Due to climate change, energy systems are in the midst of a transformation from using fossil fuels to a sustainable energy production. Large, centralized plants are being replaced by many small, decentralized ones. As energy production becomes predominantly renewable, various energy systems formerly based on heat or gas are increasingly electrified, resulting in enhanced interconnectivity and rising electricity demand through power to x technologies. In addition to the growing demand for elec-

tricity, the decentralized and small-scale systems in the electricity grid are leading to bi-directional power flows, which are putting a particular strain on the distribution grids (Greve et al. 2021). The intermittent nature of renewable energy generation from wind and solar on hourly and seasonal time scales leads to a growing need for short-term and long-term storage with different capacity and performance requirements. The digitalization of energy systems also makes it possible to control generation and consumption in real time.

This transformation process is leading to significantly more complex and interconnected energy systems that need to be assessed in terms of economic efficiency, sustainability, reliability and resilience. The economic design of storage systems, the investigation of flexibility through increased interconnection, and the resilience of grids require the investigation of dynamic processes.

The modelling language Modelica is ideally suited for simulating the dynamic behaviour of multi-domain systems. There are several open-source Modelica libraries that specialize in different areas of energy system modelling (Modelica Association 2025). The AixLib (Maier et al. 2024) and the buildings library (Wetter et al. 2014), for example, are two very comprehensive libraries that focus on the modeling of building energy systems at different levels of detail, from individual buildings to district level. The DisHeatLib library (Leitner et al. 2019) is a useful tool for simulating heating networks. However, to the authors' knowledge, no large-scale heating networks have been simulated with it yet. The library also does not take coupled networks into account. The ClaRa library (Vojacek et al. 2023) enables the analysis of power plant processes. Nevertheless, owing to its level of detail, it is not appropriate for simulating large networks. However, the TransiEnt library is designed for analyzing large-scale, coupled energy systems. Building upon the previous status paper (Senkel, Bode, Heckel, et al. 2021), this paper

focuses on simulations of large-scale energy networks. In the following, the context of the library, its scope and structure are described, before three more detailed considerations of larger energy systems are given, that are enabled by the new models in the library. At first, the modeling of large energy systems at regional level using the superstructure model is explained. Then, the modeling of large medium and low voltage distribution grids is presented. Finally, the modeling of large district heating networks is discussed. The paper concludes with a summary and an outlook on future developments.

2 Overview of Library

2.1 Context of TransiEnt Library

Experience from the development of the libraries *HKSim* (Wischhusen, Lüdemann, and Schmitz 2003) and *ACLib* (Pfafferott and Schmitz 2003) as well as a research focus on climate-friendly energy and environmental technology at the Hamburg University of Technology (TUHH) led to the idea of a Modelica library for the simulation of integrated energy systems, which resulted in the research project TransiEnt.EE from 2013 to 2017. First results and the relevance of dynamic consideration of integrated energy systems in the calculation of CO₂ emissions for different conversion paths were presented at the Modelica conference in 2015 (Andresen, Dubucq, et al. 2015) and led to the first release (version 1.0.0) of the Transient Library in 2017. The main focus was on the analysis of costs and CO₂ emissions of energy systems, facilitating the evaluation of efficiency measures.

The library was further developed in the follow-up project ResiliEntEE from 2017 to 2021. The focus here was on applying the Transient Library for large-scale simulations through numerically efficient modelling and evaluating the resilience of energy systems. As a new partner, the Institute of Electrical Power and Energy Technology at the TUHH made a significant contribution to the development of electrical power systems and grids (Heckel and Becker 2019). The resulting changes to the library were presented at the Modelica conference in 2021 (Senkel, Bode, Heckel, et al. 2021).

At the same time, the TransiEnt Library was also used and further developed outside the TUHH, in particular in the IntegraNet project (2016 - 2019). The project partners Fraunhofer UMSICHT, Gas- und Wärme-Institut Essen e.V. investigated sector coupling at the distribution system level, supported by XRG Simulation GmbH. Consequently, new models for gas and heating networks were developed, as well as the GridConstructor for complex district modelling (Benthin, Heyer, et al. 2019).

The follow-up project IntegraNet II (2019-2023) has led to new developments, including the introduction of an electric vehicle model to represent electromobility in local energy systems. Moreover, the coupling of the electricity and transport sectors has been facilitated, and heating network models have been revised to reduce computation

time.

Due to many years of cooperation and parallel development of the TransiEnt library, a consortium was formed with TUHH and the Integranet project partners in April 2021 to combine their activities and support further developments. Together they released version 2.0.0 with extensions in the domains of large-scale simulations and resilience at the transport system level, in addition to novel models for the underlying distribution system level. After the alliance was founded, the development of the library was moved to GitHub in favor of better access and community collaboration (TransiEnt-official/transient-lib).

Components of the TransiEnt library have also been used in the project CyEntEE (2021 – 2024) to develop novel dynamic integrated low and medium voltage grid models with the goal to optimize flexibility and develop congestion management strategies. Additionally, the ongoing EffiziEntEE project (2022 - 2025) further utilizes and enhanced those models. Furthermore in EffiziEntEE heat models, which enable the numerically efficient simulation of large-scale district heating networks, were developed. The models from CyEntEE and EffiziEntEE are part of the release for this publication. The new release also contains the latest improvements in the automation of model creation at district and regional level. The next chapter provides a detailed insight into the improvements and innovations of the TransiEnt library.

2.2 Scope of TransiEnt Library

The TransiEnt Library serves as a comprehensive Modelica library specifically designed for the dynamic modeling of integrated energy systems with a high share of renewable energy (RE). It facilitates the representation of interactions among the domains of electricity, heat, and gas, thereby addressing the complexities inherent in present and future energy systems.

The primary objective of the TransiEnt Library is to provide a versatile framework that can be applied across various areas of energy research and analysis. Through documentation and the provision of check models, the library aims to ensure accessibility for researchers and engineers engaged in the dynamic modeling of integrated energy systems.

The applications of the TransiEnt library extend from district-level analysis to regional investigations, comprising industrial, commercial and residential sectors. This integration facilitates the interactions between producers (power plants and decentralized units), consumers, storage systems, and the infrastructures of the gas, heat, and electricity sectors.

The existing models of the TransiEnt library allow the modeling and simulation of complex integrated energy systems and can therefore be used to study the effects and opportunities of increased integration of electricity, heat and gas from RE into existing structures, such as the deployment planning of combined heat and power plants (cf. Peniche and Kather 2015) or the use of conven-

tional power plants per se (cf. Dubucq and Ackermann 2015). The library also ensures the investigation of the potential and integration of green hydrogen in industry (cf. Andresen and Schmitz 2016; Andresen, Bode, and Schmitz 2018) or the volatile nature of RE on the stability of the electricity grid and possible flexibility options (cf. Dubucq and Ackermann 2017; Heckel, Möws, and Becker 2022). By providing models for the interconnection of the sectors, i.e. power-to-heat (PtH) and power-to-gas (PtG) technologies, issues related to flexibility between the individual sectors, such as the use of surplus electricity in PtH units (Bode and Schmitz 2019) or voltage stability in coupled grids (cf. Heckel and Becker 2020; Heckel, Steffen, and Becker 2022), can be investigated. In particular, the introduction of a resilience index in coupled grids (Senkel, Bode, and Schmitz 2021; Heckel and Becker 2019) can be used to assess the resilience of energy grids to disturbances (cf. Bode, Senkel, and Schmitz 2020; Heckel, Senkel, et al. 2022). Furthermore, uncertainties regarding the economic evaluation of future investments in building energy systems can be addressed through real options analysis using simulated energy flows (Glombik and Fromme 2024).

Moreover, the TransiEnt Library offers aggregation models, such as `GridConstructor` and `Superstructure`. These models empower users to model entire districts or large energy systems at the transport grid level with simple parameterizations. For instance, the `GridConstructor` can be used to analyze the physical impact of vehicle-to-grid communication attacks on low-voltage grids (Zhdanova et al. 2022).

While the TransiEnt Library offers robust modeling capabilities and ensures large-scale simulations, it is important to note its inherent limitations. The optimization of energy systems cannot be performed with the models in Dymola itself, but must be implemented via interfaces such as Matlab or Python. Furthermore, the library is not designed as a high-level designing tool; rather, it allows dynamic simulations of given system designs to analyze their impacts on the energy system.

2.3 Structure of TransiEnt Library

The TransiEnt Library provides models for components of gas, heat and electrical systems (generators, storage facilities, infrastructure, consumers) as well as various system models. Some basic models, particularly in the area of heat and gas, as well as basic modeling principles have been adopted from the ClaRa Library. This freely available model library was developed by TLK-Thermo GmbH and XRG Simulation GmbH and contains models of power plant components for the simulation of power plant systems.

As shown in Figure 1, the current version of the TransiEnt library consists of eight top level packages. Since the last status paper, the package `SystemGeneration`

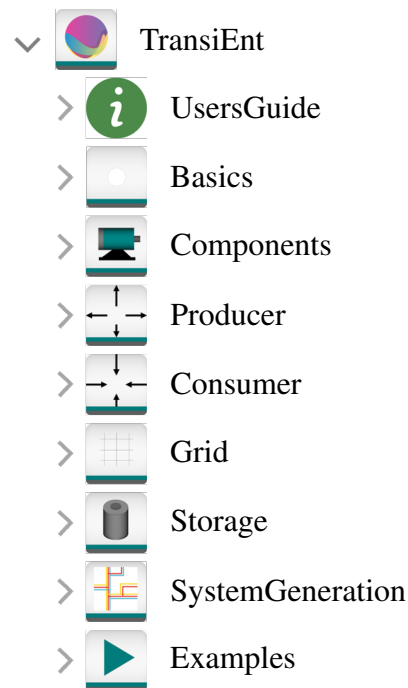


Figure 1. Icons of the relevant top level packages inside the TransiEnt Library

has been added, which supports the automated generation of energy systems on a city and regional level: `GridConstructor` and `Superstructure`. Please refer to Benthin, Heyer, et al. (2019) for information on how the `GridConstructor` works. The modeling of regional energy systems with the `Superstructure` is presented in subsection 3.1.

3 Exemplary Developments and application examples

The focus of this chapter is to present the most important developments in the TransiEnt library. First, the automated model creation through the `Superstructure` model is presented. Second, the developments in modeling medium and low voltage networks are explained. Finally, two modeling approaches for large heating networks are introduced.

3.1 Cellular Energy Systems with the Superstructure

Modeling of large energy systems can include large structural data sets and may require a substantial amount of manual work and is error prone. Script based automated model generation can be a solution. However, generating Modelica code for detailed energy systems from scratch can become very complex, as completeness of the equation system in the generated code needs to be ensured. The superstructure model of the TransiEnt Library enables the

user to create checkable models of energy systems at the scale of coupled regions or more generally, coupled energy cells by choosing available technologies and setting (structural) parameters.

As shown on the left of Figure 2, the superstructure contains for each cell (region) subsystems for (1) the heating Grid including thermal storages, (2) electrical storages of different types, (3) gas storages, (4) power to gas, (5) CO₂ capture and storage, (6) available power plants of different types, (7) local renewable power generation and (8) local demand. The technologies available in each of these subsystems can be specified by the user with a replaceable package called technology portfolio. Here all technologies available in the TransiEnt Library as well as user specific models may be added by extending the existing base package.

All subsystems and their sub components are connected to the sectors they involve (electricity, heat, gas), e.g. power to gas is connected to electricity and gas. For the electric and gas sector, each cell provides a connector to the outside as well as three bus connectors for input, control and output signals. At present there is no outside connector for the district heating network (DHN). It is assumed that each DHN is located entirely inside its cell. The technical reason behind this is the lack of an automated DHN model generation, entirely from structural parameters, similarly to the electric grid connector in Figure 3. This may change in the near future, since the new modeling approach of section 3.3 offers more flexibility for model initialization and simulation performance.

In order to resolve larger spatial scales, an array of cells (regions) can be used consisting of `nRegions` cells. This is done in the so called portfolio mask model (Figure 2, center). For each of the `nRegions` cells (regions), its local energy system can be specified through structural parameter records: instance records can be used to disable technologies through conditional components in order to adapt the energy cell model to a specific configuration, for example, to set up the available generation technologies. Enabled technologies can be further specified by parameter records, by setting e.g. the total power of each individual renewable generation technology or storage capacities of a given energy cell. For each technology an individual number of plants in a cell with their specific properties may be specified.

By construction the portfolio mask model provides an array of `nRegions` gas and electric grid connectors as well as a collection of all cell-buses in a master bus.

In order to model a scenario (Figure 2, right), the different cells of the portfolio mask model need to be connected by an electric and gas grid. Furthermore a control algorithm for the system has to be provided.

For constructing a simple electric grid model just from parameters, the `GridConnector` model can be used. There, as shown in Figure 3, an incident matrix specifies how many lines exist between two given regions.

Each line can be individually parametrized with respect

to its voltage level, cable type, length and cross sectional area. For the gas grid a lumped model is used by default, however more detailed models may be provided by the user.

By using the masterBus, the control of the overall system is separated from the physics based cell models: all status information of the different cell components ("measurements") are aggregated towards the controller and the controller signals are propagated down to the individual cell component.

3.2 Integrated Electric Distribution Grids

The ongoing electrification of consumers in the electrical grid is one of the central consequences of the energy transition. This particularly affects consumers and producers in the distribution grid at medium- and low-voltage level, i.e. electric heat pumps (EHP), battery electric vehicles (BEV) and battery energy storage systems (BESS) as consumers and photovoltaic generators (PVG) as producers. These electrified components represent not only large additional loads or generators, but can also provide flexibility for the operation of the electrical grid, if according control and communication strategies are implemented. As these components couple the sectors, slower dynamics from the heat and mobility sectors are integrated into the electricity grid. To represent those dynamic effects of interest in grid simulations at system level, the library was expanded by several components. In order to be able to carry out simulations at system level, a scenario generator was developed that maps consistent development scenarios by parameterizing different low- and medium-voltage grid models on the basis of the SimBench data sets topologies (Meinecke et al. 2020; Wiegel et al. 2023). With the help of the scenario generator, a set of 17 pre-configured exemplaric grid models, 15 low voltage and 2 medium voltage, were implemented and added to the library. For the electric grid the RMS simulation approach was chosen. For all underlying novel component models, numerical efficiency was considered so that simulations of large non-aggregated grid models are feasible. The most important developments are briefly described below.

Building Heating System Building heating systems are increasingly being electrified by replacing gas or oil heating systems with heat pumps. The electrical energy demand of heat pumps is primarily dependent on the heat flow required to maintain a defined room temperature and for the provision of hot water. For this purpose, a building model was created in accordance with the enveloping surface method of DIN EN 12831, which calculates the heat flows occurring through walls, windows, floor and ceiling. The heat transfer coefficients required for this were taken from the current design standards for buildings. In addition to conductive heat transfer, the mass-bonded enthalpy exchange through room ventilation is also taken into account.

In order to perform system simulations using the developed model, numerical efficiency competes with model

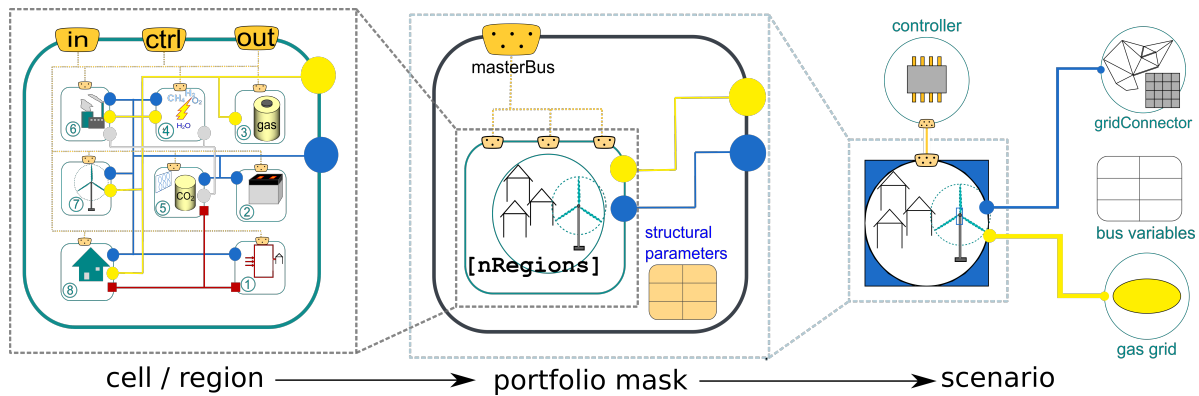


Figure 2. Workflow with superStructure model. Left: individual cell, center: array of cells, right scenario model with spatial resolution given by cell array and grid models. Color code: electric sector (blue connectors), heat sector (red connectors), gas sector (yellow connectors). Additionally the CO₂ cycle (gray connectors).

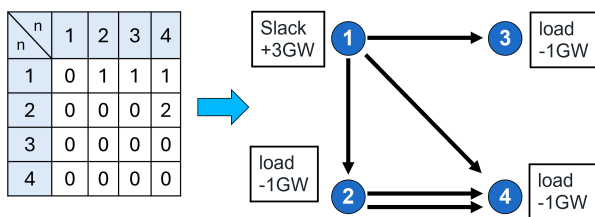


Figure 3. Using the GridConnector to model a simple electric grid, linking electric connectors of $n_{\text{Regions}} = 4$ different cells/regions: the lines of the grid are specified by an incidence matrix and line parameters.

accuracy. Fluid dynamic simulations are therefore not useful at the system level for modeling of larger systems of decentralized heating units. Therefore, the behavior of the EHP in the system is mapped by a gray-box controller model. The basic structure of the model consists of a PID controller, a power splitter, and various components that represent the operating state under real-world conditions. The controller parameters were measured and validated on a real test facility as part of the European ERIGrid 2.0 project at the SYSLAB of the Technical University of Denmark (DTU). Part of the measurements are steady state operation and dynamic state changes. In addition to system simulation under regular operation, the behavior under external influence, for example by the grid operator when the load is reduced or limited, can be investigated using these models. Another use case is aggregators that use the flexibility of the components for energy trading on the electricity exchange.

Battery Electric Vehicles BEVs are characterized by two main aspects from the perspective of the electrical grid: availability according to the charging behavior and the electrical properties of the on-board charger. An empirical profile generator was therefore developed as part of the scenario generator, which maps the presence and driving behavior of individual owners. The electrical behavior of the on-board charger was investigated as part of the ERIGrid 2.0 project. This mainly affects the efficiency

of the charger and the reactive power behavior. Moreover, the grid voltage dependency of the parameters and the dynamics of operating point shifts were analyzed and derived into the newly developed models (Steffen et al. 2024).

Battery Electric Storage System BESSs are usually controlled in such a way that self-consumption is maximized. This is achieved by measuring the load at the grid connection point and setting the operating point of the BESS according to the available power. Measurement takes place via a smart meter, which also takes measurement uncertainties into account.

Grid-level simulations The scenario generator developed allows system configurations to be created on the basis of parameters derived from the TYNDP scenarios to estimate future developments (Wiegel et al. 2023). These are automatically converted into an executable Modelica model using a Python script. The modular structure allows the parameters to be adapted to the users individual needs. The electric grid simulation is based on a complex root mean square approach, since the fast electromagnetic transient effects are not in the scope of this modelling approach. The dynamic effects included originate from the models described above.

Use Case With the previously introduced component models, large distribution grid scenarios can be modelled and simulated. An example, a medium voltage ring based on the urban distribution grid model, named MV-urban-6, from the benchmark topology *1-MV-urban-6-no-sw* published by SimBench (Meinecke et al. 2020) is simulated. The medium voltage ring consists of in total 18 low voltage grid models, whereby 12 are different semiurban and 6 are urban low voltage grid topologies, in a future scenario. In total, over seven thousand individual component models contribute to this simulation.

Table 1 shows the share of included components. For the simulation the C-variable-coefficient ordinary differential equation solver (CVODE) with fixed integration step size of 60 seconds and tolerance of $10e-4$ was used. 7 days of winter weather data for the location Berlin in

Table 1. Overview of grid components and their number in different topologies

Component	LV-semiurb-4	LV-semiurb-5	LV-urban-6	MV-urban-2
Transformers	1	1	1	19
Lines	42	109	57	1583
Nodes	43	110	58	1601
Households	41	104	111	1851
Battery Electric Vehicle (BEV)	16	48	48	832
Building Heating System (BHS)	20	47	49	831
Battery Energy Storage System (BESS)	1	4	4	69
Photovoltaic Generator (PVG)	5	15	18	278

January 2024 where chosen as input data sources. The data was acquired by the German Weather Service (DWD) (Reinert et al. 2025). The simulation time is close to 17 hours on an Intel I9 13900k CPU. The results are given in figure 4 and show the maximum loaded cables, node deviations and the power consumption of the low voltage grids connected to the medium voltage ring as well as the maximum cable load from the medium voltage grid. One can see, that the medium voltage grid in terms of line load is usually less loaded than the low voltage grid. The daily rising loads and falling voltages can be justified by the increased probability of BEV arriving in the late afternoon of a day. Additionally the influence of the electric heating within the BHS is noticeable with a slower dynamic due to the falling temperatures in the middle of the simulated week.

3.3 Simulation of large-scale district heating networks

In the following section, the developments of the heat components in the TransiEnt Library are described. There are two main use cases for the heat models of the TransiEnt library:

- the simulation of dwelling heating systems and
- the simulation of district heating networks (DHN).

Modelica is a suitable modeling language for DHN simulations because of its acausal character allowing physical modeling and easy model adaption. Moreover, it enables dynamic simulation, which allows the investigation of thermal inertia.

Until now, large-scale simulations using the TransiEnt Library have only been performed for electricity and gas grids. In contrast, the simulation of heating grids has been limited to a few components. This absence of large-scale examples has also been mentioned in literature (e.g. Schweiger et al. 2017). For this reason, the emphasis of recent developments has been on the simulation of large-scale DHN. Therefore, new modeling concepts for the simulation of DHN have been developed. Within the TransiEnt library two different approaches regarding the consideration of thermal dynamics in DHN are available - Euler and Lagrange. The Euler approach focuses on fixed

locations inside a fluid field while the Lagrange approach is about tracking an individual fluid particle inside a fluid field. Both approaches are valid and have their flaws and assets.

The first one is described by (Westphal, Brunnemann, and Speerforck 2025) and is based on the discretization of the balance equations of momentum, mass, and energy. The presented modeling concept can be categorized as shown in Figure 5. DHN simulations are often categorized with regard to simulation type, calculation method, loop method, software environment, and control strategy. The modeling concepts consider thermal dynamics but neglect the hydraulic dynamics inside the network.

To achieve an efficient simulation performance and scalability for larger models, three key points were discovered and implemented in the component models using the Euler approach:

1. Avoidance of implicit non-linear systems of equations through a suitable consumer model and the strategic use of mass flow states, which is partly based on Zimmer (2020).
2. Discretization of only the energy balance to enable the use of a sparse solver.
3. Avoidance of unnecessary equations and function calls by assuming constant or fitted curves for the fluid properties.

The new models have been presented by (Westphal, Brunnemann, and Speerforck 2025) and used by (Vieth, Westphal, and Speerforck 2025). Further explanations regarding the modeling concept and how to achieve an efficient simulation can be found in (Westphal, Brunnemann, and Speerforck 2025).

The second concept is based on a plug flow Lagrangian approach and is used in the models `SinglePipe_LX` and `DoublePipePair_LX`. The same approach is used in the IBPSA library, which is, for instance, integrated into the Buildings library (Heijde et al. 2017). For the TransiEnt library, the model was adapted within the project IntegraNet (Benthin, Hagemeyer, et al. 2020) based on the work of (Hägg 2016) and (Heijde et al. 2017) to enable usage within the TransiEnt framework. The model `SinglePipe_LX` comprises submodules for heat loss,

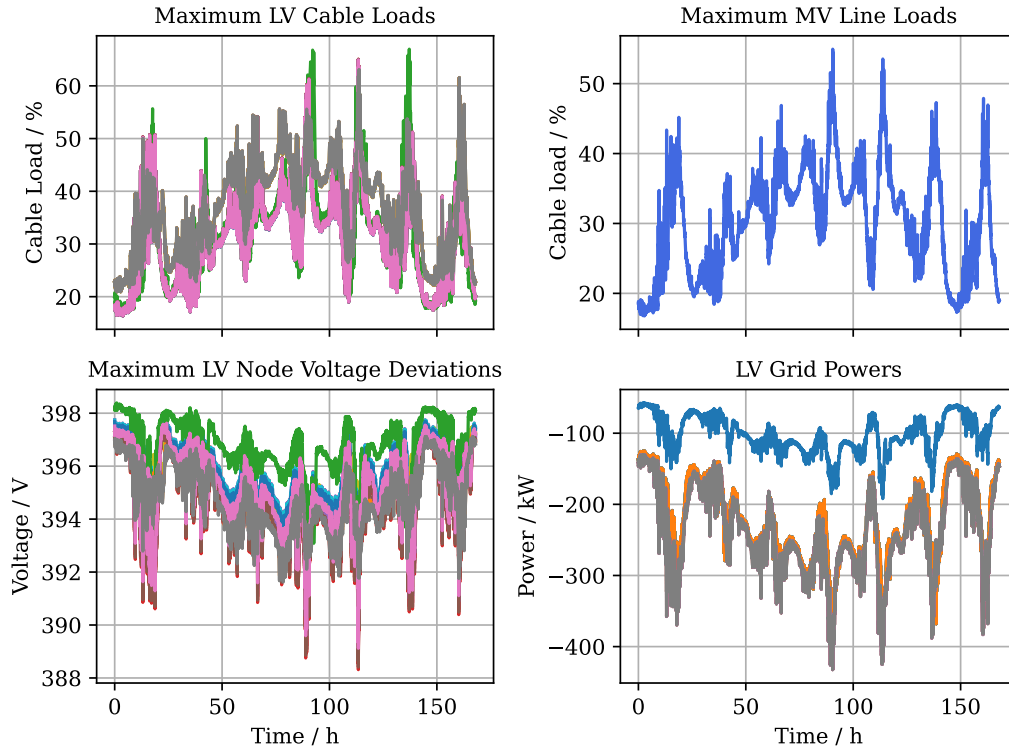


Figure 4. Illustration of the most loaded lines and nodes as well as the power consumption of the low voltage grids within the medium voltage ring simulation.

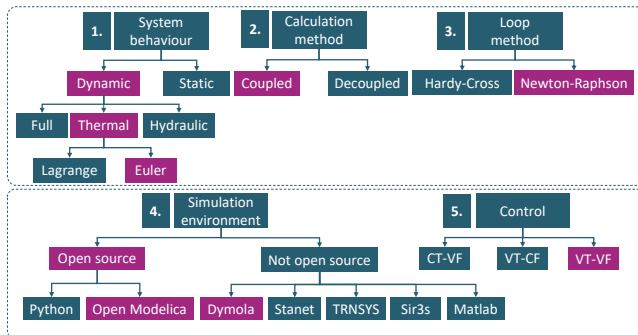


Figure 5. Categorization of modeling concepts for district heating networks based on the literature review of Kuntuarova et al. (2024)

residence time, pressure drop, and volume. It contains two heat loss components, one for the nominal flow and one for the reverse flow. Each of them implements the plug flow approach in a different flow direction. In the plug flow approach, thermophysical properties are evaluated solely at the pipe inlet and outlet, significantly reducing numerical complexity.

The heat loss rate $\dot{Q}$ is calculated as a function of the mass flow $\dot{m}$, the heat capacity of the medium c_p and difference of the inlet temperature T_i and the outlet tempera-

ture T_e :

$$\dot{Q} = \dot{m} \cdot c_p \cdot (T_e - T_i). \quad (1)$$

The outlet temperature T_e is calculated as shown in Equation 2 as a function of the residence time τ , the inlet temperature T_i , the ambient temperature T_a , the thermal resistance R , and the heat capacity of the heat carrier per meter C :

$$T_e = T_a + (T_i - T_a) \cdot e^{-\frac{\tau}{RC}}. \quad (2)$$

A key feature of the model is the physically consistent representation of the residence time, which is essential for capturing transient thermal effects in pipe systems. The residence time required for the heat loss calculation is determined in the residence time component using the `spatialDistribution()` function as described in (Heijde et al. 2017). The pressure drop across the pipe is computed using the Darcy-Weisbach equation, linearized for small mass flows.

The plug flow approach facilitates initialization by allowing initial values for physical parameters such as temperatures to be less precise. The approach itself does not account for delays in temperature changes due to the carrier pipe. Therefore, an optional volume component is added (Benonysson 1991; Hägg 2016; Heijde et al. 2017). Another module, `Pipe-Parameter`, provides a centralized interface for setting initial conditions and defining the geometric parameters of the pipe.

3.3.1 Use case: Using the piping network as a short-term storage

To prove the applicability of the component models, a dynamic simulation of a large-scale DHN with 2167 substations and a network length of 140 km is performed. The scope of the simulation is to use the piping network as a short-term storage to reduce peak heat production. This can be done by adapting the supply temperature of the network shortly before peak loads appear.

In Westphal, Brunnemann, and Speerforck (2025) the DHN topology used for this study has been introduced. Heat is generated by one large-scale heat producer, and the network is configured in a meshed topology. The main topology is derived from Frederiksen and Werner (2013) who classified different DHN based on the position of the heat producers. Distribution topologies have been based upon the work of Benthin, Hagemeyer, et al. (2020) and designed with assumed heat fluxes. By combining the suggested main topology with the designed distribution topologies, a realistic heating network is created (see Figure 6). The mass flows are calculated by the consumer models with the use of a P-Controller, whose output depends on the room temperature.

To prove a decrease of peak heat production the heat flows required by the consumers are increased manually over a time span of four hours. In Figure 7, the generated heat flows can be seen for two scenarios. The blue graph describes the reference scenario where the supply temperature is held constant during the whole simulation. Therefore, the generated heat increases simultaneously with the heat load. The orange graph describes a scenario where the supply temperature was increased shortly before the peak load. It can be seen that the produced heat is increased when the supply temperature is raised. However, after a while, the produced heat starts to decrease again. The reason for this is that the increased temperature starts to reach the consumers with a time delay. Because of the higher supply temperature, the consumers need less mass flow and the generated heat flow starts to decrease. As a result, heat generation is decoupled from the heat load.

It can be concluded that the maximum peak generation is decreased due to the supply temperature adaptation. Therefore, peak generation can be avoided by using an advanced control strategy for the supply temperature and thus using the piping network as a short-term storage. This could, for example, be used for DHN operators to avoid costly peak generations like gas boilers and use more base load generation like combined heat and power plants (CHP).

3.3.2 Use case: Analysing future developments of a district heating network

The pipe models using the plug flow approach were used within the project IQDortmund (Gas- und Wärme-Institut Essen e.V et al. 2023) to simulate and analyze the district heating network of the city of Dortmund. This includes the assessment of the current state, as well as expansion

and transformation scenarios for the period up to 2045. Using detailed simulations in combination with GIS-based modelling, several neighborhoods were evaluated in terms of future heating infrastructure development. A detailed model of the heating network with approximately 56 km of pipeline was created for simulating dynamic network behavior and future scenarios. To ensure robust initialization and improve numerical convergence in such a large-scale simulation, a node model is inserted between pipe segments. This model dampens rapid transients and decouples adjacent sections by introducing a time constant in the mass flow and energy balance equations.

The overall system model enables the investigation of changes in the system infrastructure like different heat sources or an expansion of the district heating network and their effects on the loading of the pipe infrastructure and resulting pressure losses. In the current state of the district heating network evaluated, a CHP plant serves as the primary heat source. In a future scenario, waste heat from a source located in the northern area becomes the main supply. Natural gas boiler plants are replaced by hydrogen boiler plants and a biomass heating plant. For larger potential waste heat sources, two heat pumps are installed. The shift in the primary heat generator results in a changed pressure distribution within the network (as shown in Figure 8), leading to increased loads of specific pipeline sections. Due to the intensified use of waste heat, a significant portion of the thermal energy has to be transported from the northern area to the rest of the network. As illustrated in Figure 8, this causes increased loading on two pipelines that are critical for connecting the northern section to the remaining network. For more details and further analyses on the district heating in Dortmund please refer to the final report (Gas- und Wärme-Institut Essen e.V et al. 2023).

4 Summary and Outlook

The transformation of energy networks and their requirements for economic efficiency, sustainability, reliability and resilience require dynamic simulations of energy systems with a large number of components at different levels. With the `GridConstructor` and the `Superstructure` two models are available in the TransiEnt library, which can be used to **easily** create aggregated energy systems at city or regional level. The focus of the `GridConstructor` is on simulating coupled energy grids at the district level. On the other hand, the `Superstructure` is used for simple modeling of coupled energy systems at the regional and supra-regional levels. While in recent years the focus of electrical modeling has been on extra-high voltage networks, new models are now available in the TransiEnt library, such as electrical prosumers, which are an integral part of medium and low voltage distribution grid. These models are capable of integrating the dynamic effects associated with the residential heating and mobility sector into electric grid simulations. In the specific use case, the utilization of a medium voltage network

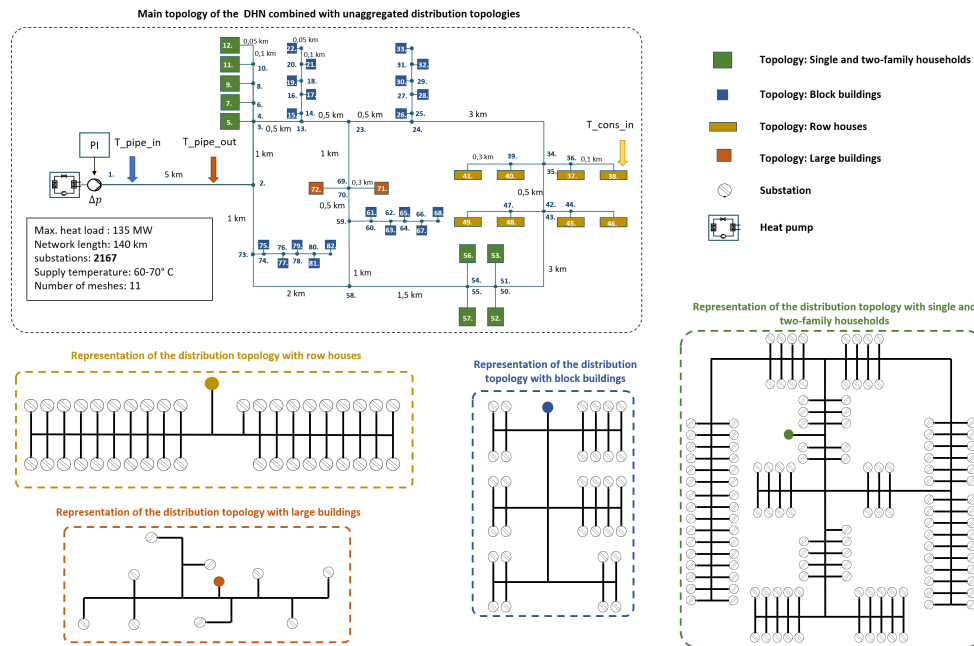


Figure 6. Topology of the investigated DHN from (Westphal, Brunnemann, and Speerforck 2025)

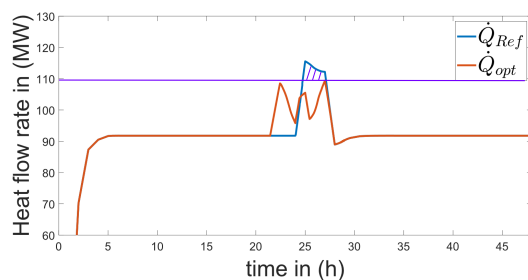


Figure 7. Heat flows of the producer for the reference scenario (blue) and the scenario with an adapted supply temperature (orange)

with over 7000 components is investigated. Until now, the TransiEnt library has shown weaknesses in the simulation of large heating networks. With the two presented models, based on conservation equations on the one hand and the plug-flow approach on the other hand, large heating networks with e.g. over 2000 transfer stations and a network length of over 140 km can be simulated.

In addition to the standard extension of models, the future development of TransiEnt will also focus on enabling the use of the library with the OpenModelica platform. Furthermore, the documentation of the models is to be improved, access to the library simplified through tutorials and the exchange with the user community strengthened. In addition, hybrid models from Modelica and AI are to be given greater consideration.

The current version and Release 2.1.0 can be downloaded from the GitHub repository at <https://github.com/TransiEnt-official/>

transient-lib. It is freely available under the terms of 3-clause BSD license. Further information about the library can also be found on the website <https://www.tuhh.de/transient-ee>.

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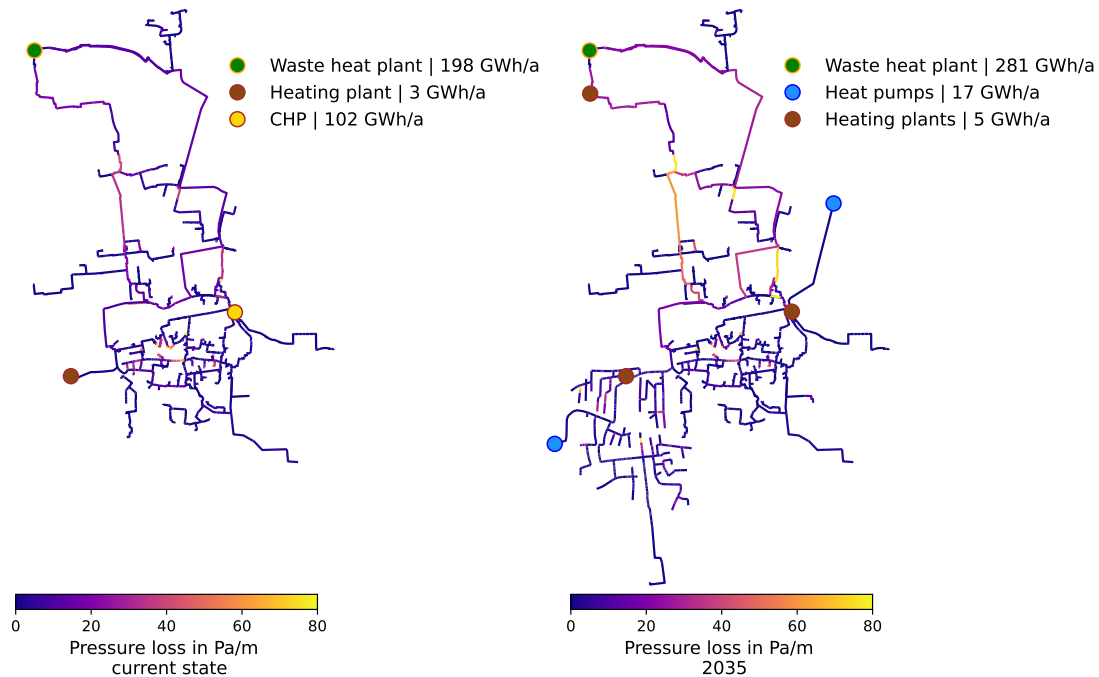


Figure 8. Average pressure loss of the network area in the current state and in the 2035 scenario based on (Gas- und Wärme-Institut Essen e.V et al. 2023).

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