Advanced Simulation and Control Methods for Operation, Planning and Control of District Heating Networks

A Dynamic Simulation Approach

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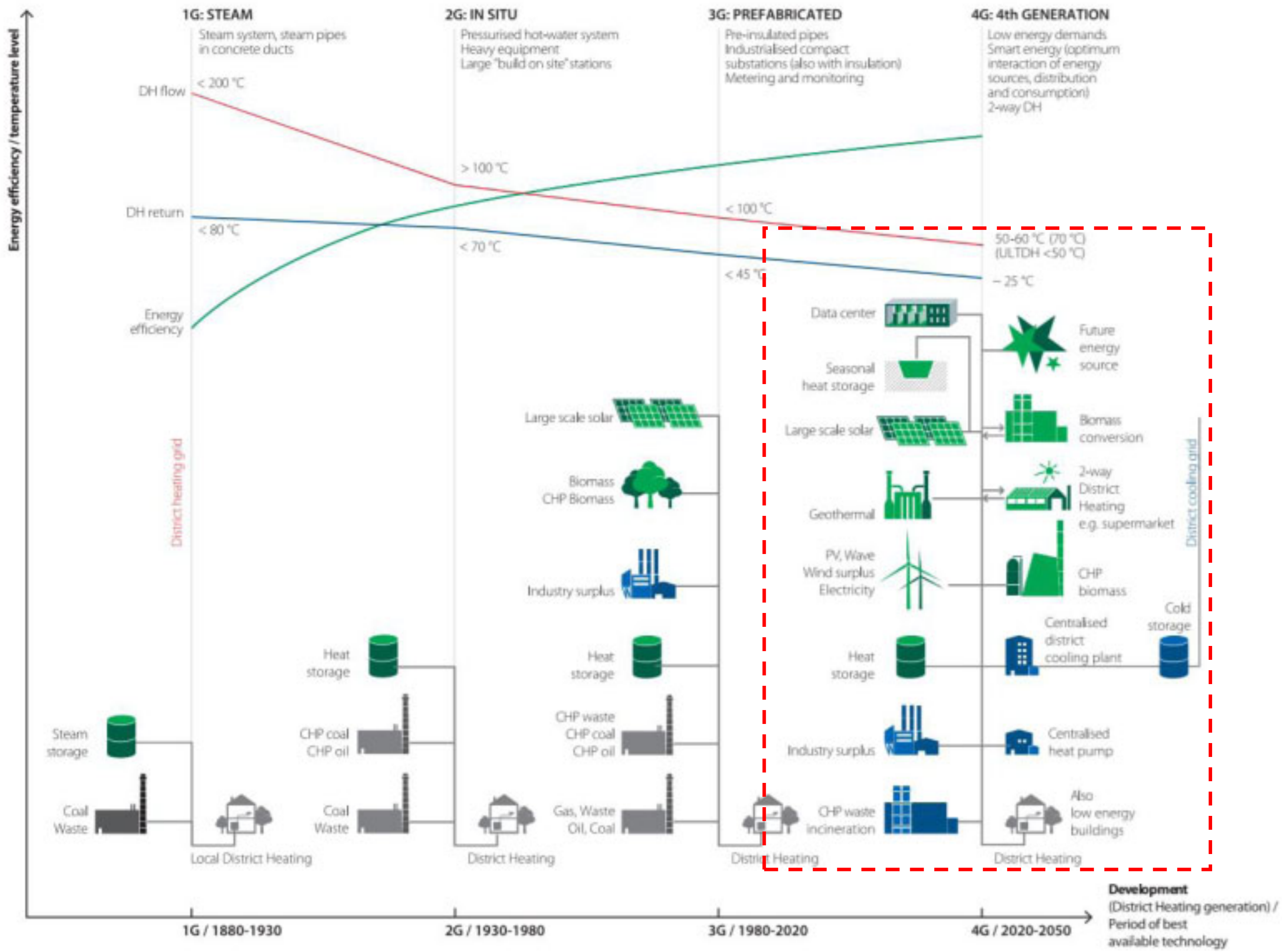
4th Generation of District Heating



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How to handle such requirements? Simulation Tools Available

In order to design, operate and control future networks, **sophisticated dynamic modelling and simulation tools** are necessary.

TRNSYS 18

Dymola

EQUA

STANET Network Analysis

MATLAB SIMULINK

Dymola- Modelica Strengths and Weaknesses

Strengths

Detailed representation of complex systems and their dynamic behavior

Wide range of available libraries in development for energy systems

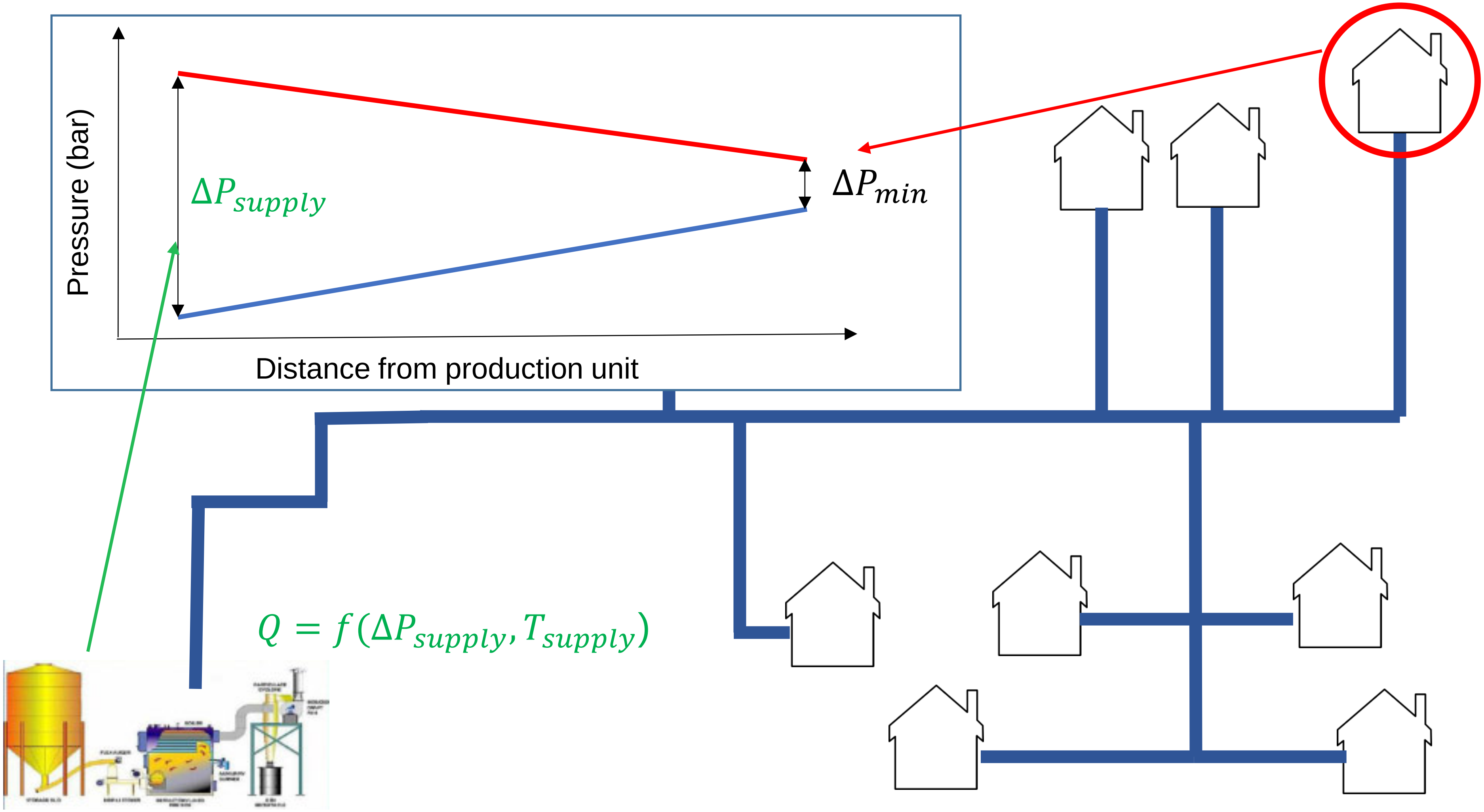
Suitable platform for Dynamic Optimisation tasks

Weaknesses

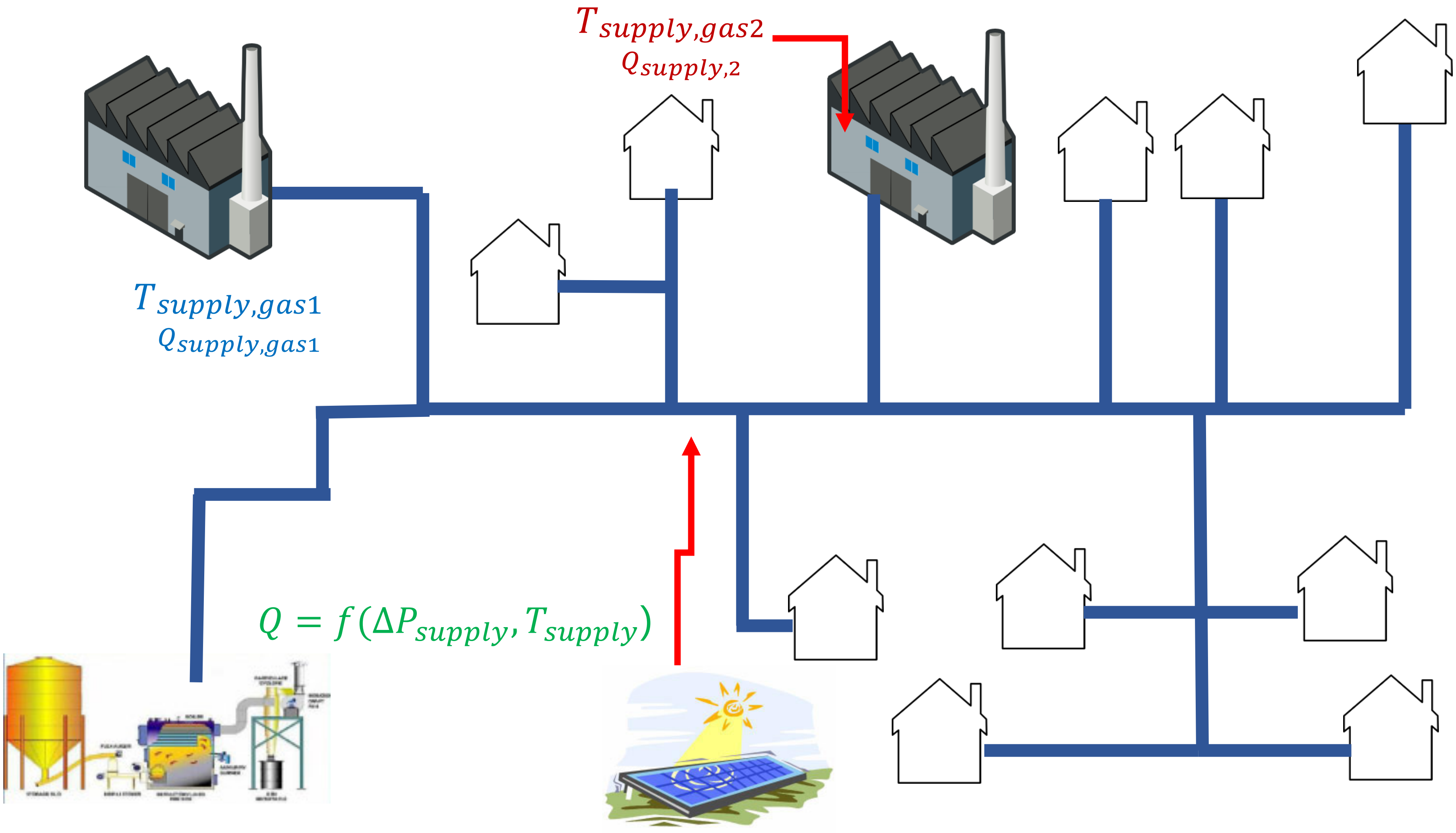
Dynamic models have their limitations due to high computational effort

Not feasible for simulation of very large networks

DH Network Control and Operation



DH Network Control and Operation



Network Operation– How to optimize for more efficient DH operation?

- Objective function $$F = \sum_{i=1}^{n} f_i(P_i)$$

Total number of thermal units

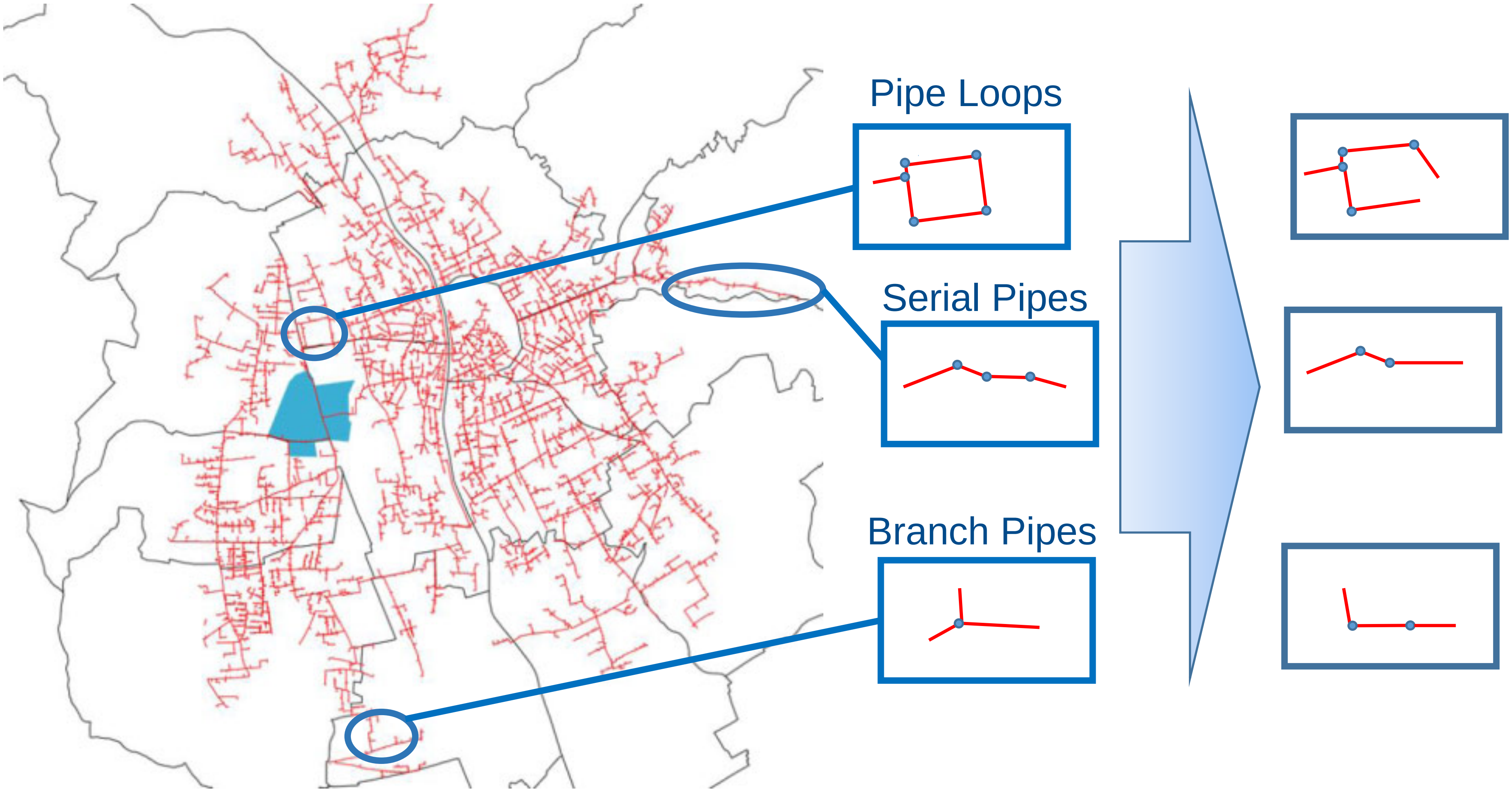
Cost function of thermal unit i

Power output of thermal unit i

- Constraints:
  - Total generation to meet total demand
  - Max/Min outputs of production units
  - Max/Min ramp up/ramp down rates of production units

- **Supply temperature optimization** is often used to minimize the objective function. Dynamic simulations are needed to account for delay times in temperature propagation across the network

How to simplify a network's Topology?



Source: Energie Graz

Network Aggregation

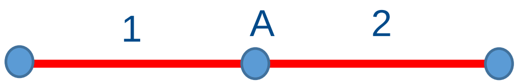
- Done in accordance with the thermo-hydraulic laws to conserve **as best as possible**:
  - Total fluid volume in network
  - Overall heat losses
  - Sum of mass and heat flows to all consumers
  - Temperures at remaining nodes
  - Delay times at remaining nodes

- Error is unavoidable and scales proportionally to how much the networks is simplified from the original. This level of simplification is defined as the aggregation depth ϕ:

$$\phi = 1 - \frac{Number\ of\ consumers\ in\ aggregated\ network}{Number\ of\ consumers\ in\ original\ network}$$

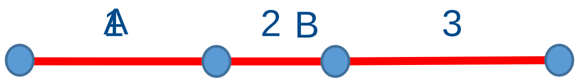
Network Aggregation – Comparison of Two Methods

German Method



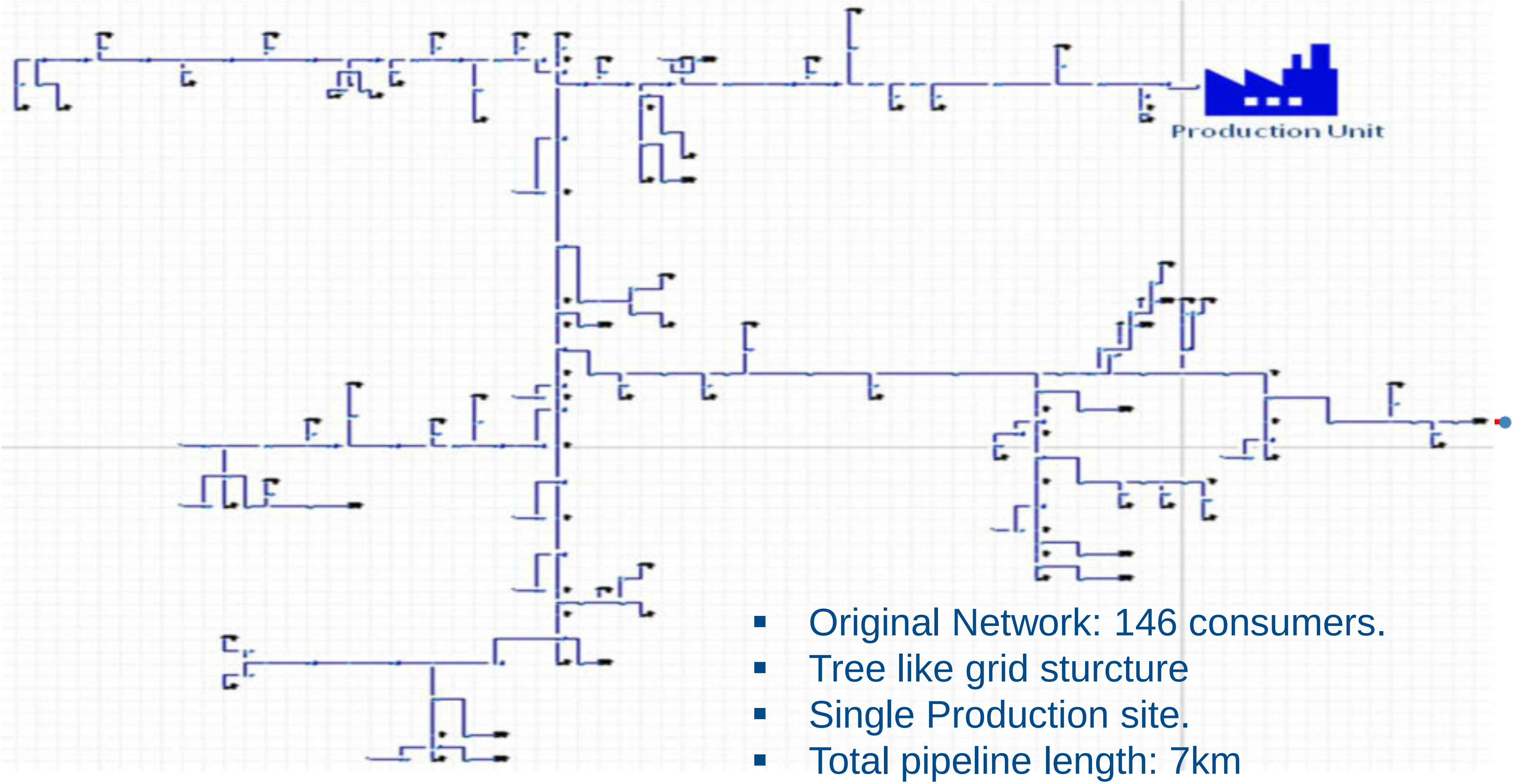
- Supports loop structures
- Temperatures in all nodes are conserved
- Pressure drops in pipes considered
- Heat loss coefficients are adjusted and can be negative

Danish Method



- Does not support loop structures
- Temperatures nodes are not conserved
- Pressure drops in pipes are not considered
- Heat loss coefficients are independant of temperatures

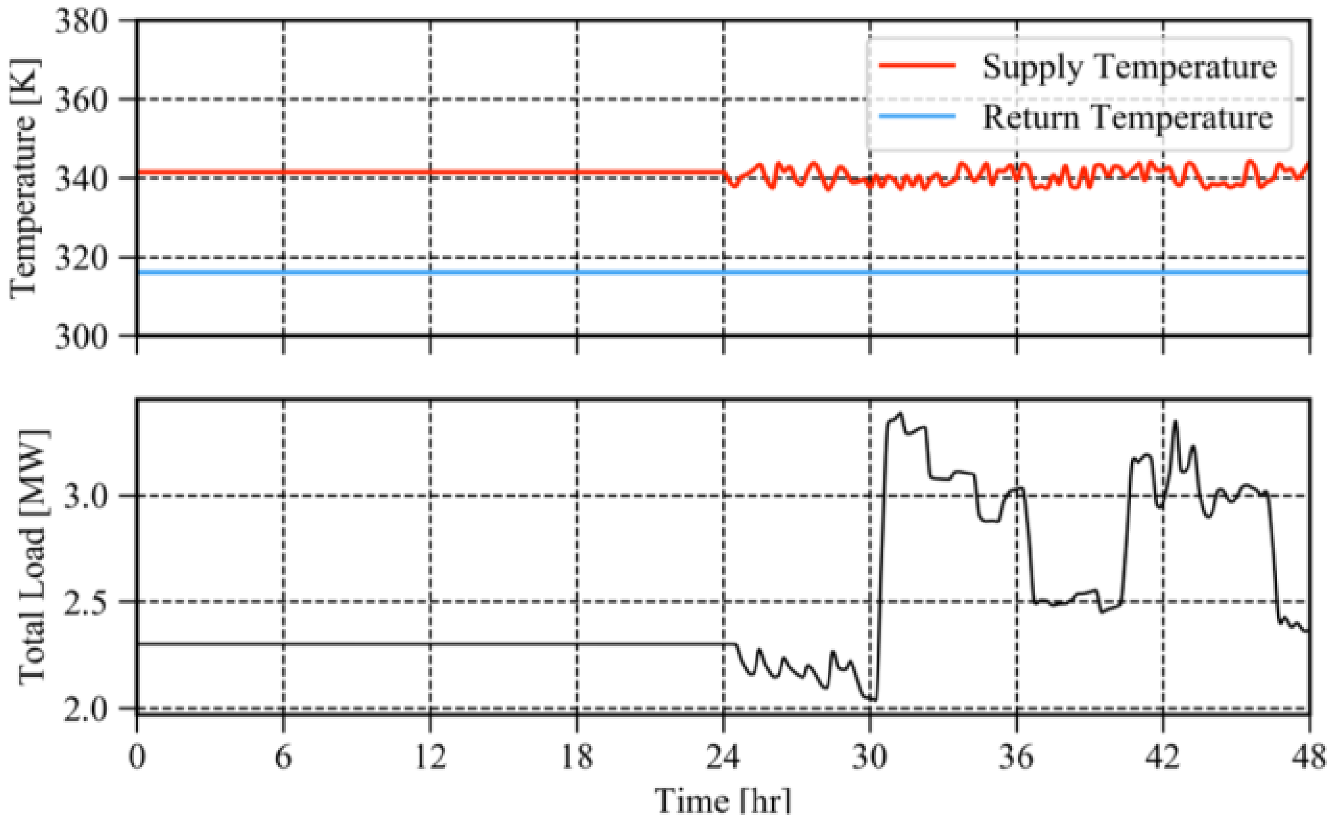
Network Aggregation – Case Study



- Original Network: 146 consumers.
- Tree like grid sturcture
- Single Production site.
- Total pipeline length: 7km
- Capacity 2.5MW

Case Study Setup

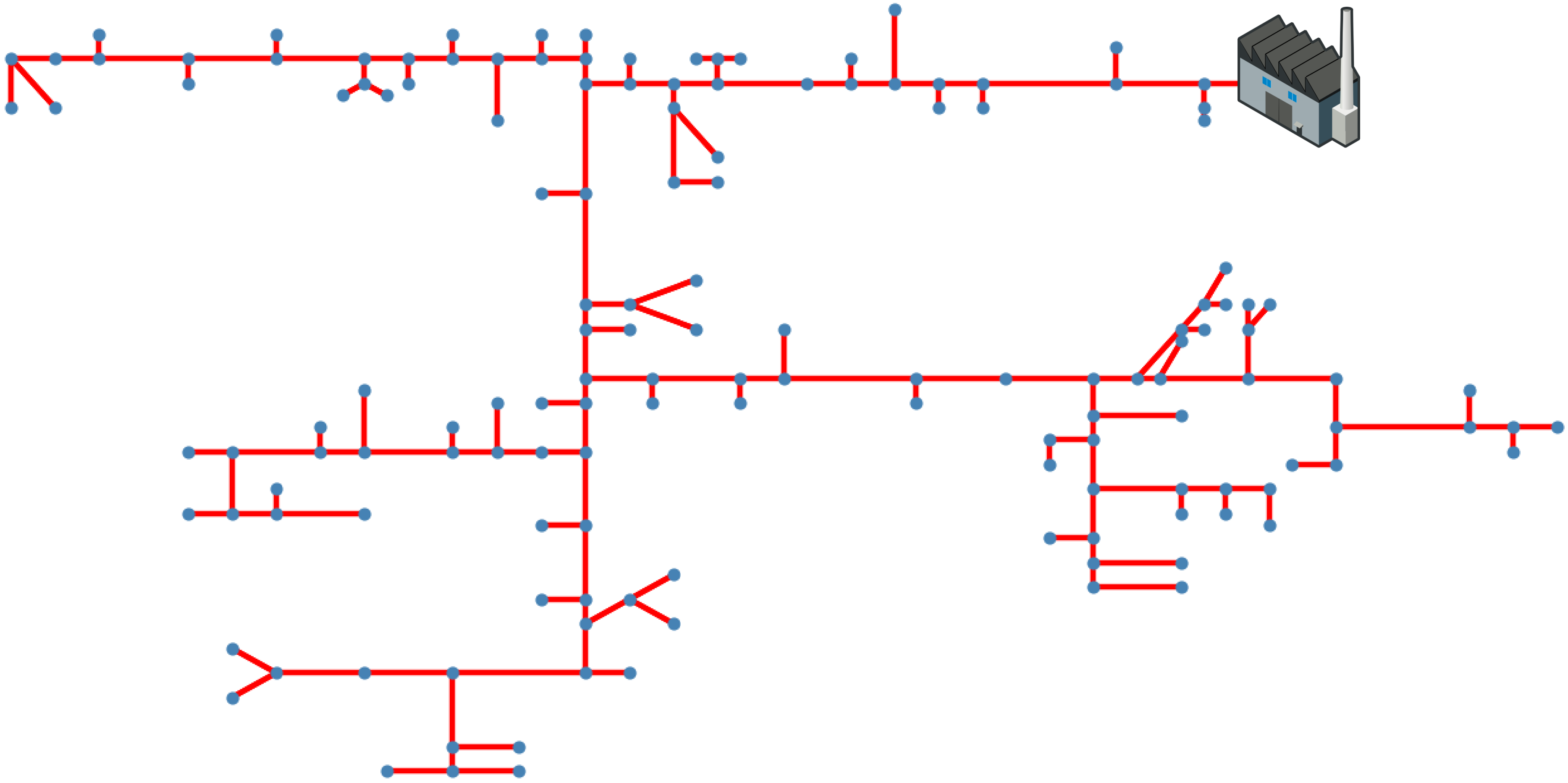
- The aggregated networks were compared with the original network over a 48 hour timeframe with the following profile at the production site:



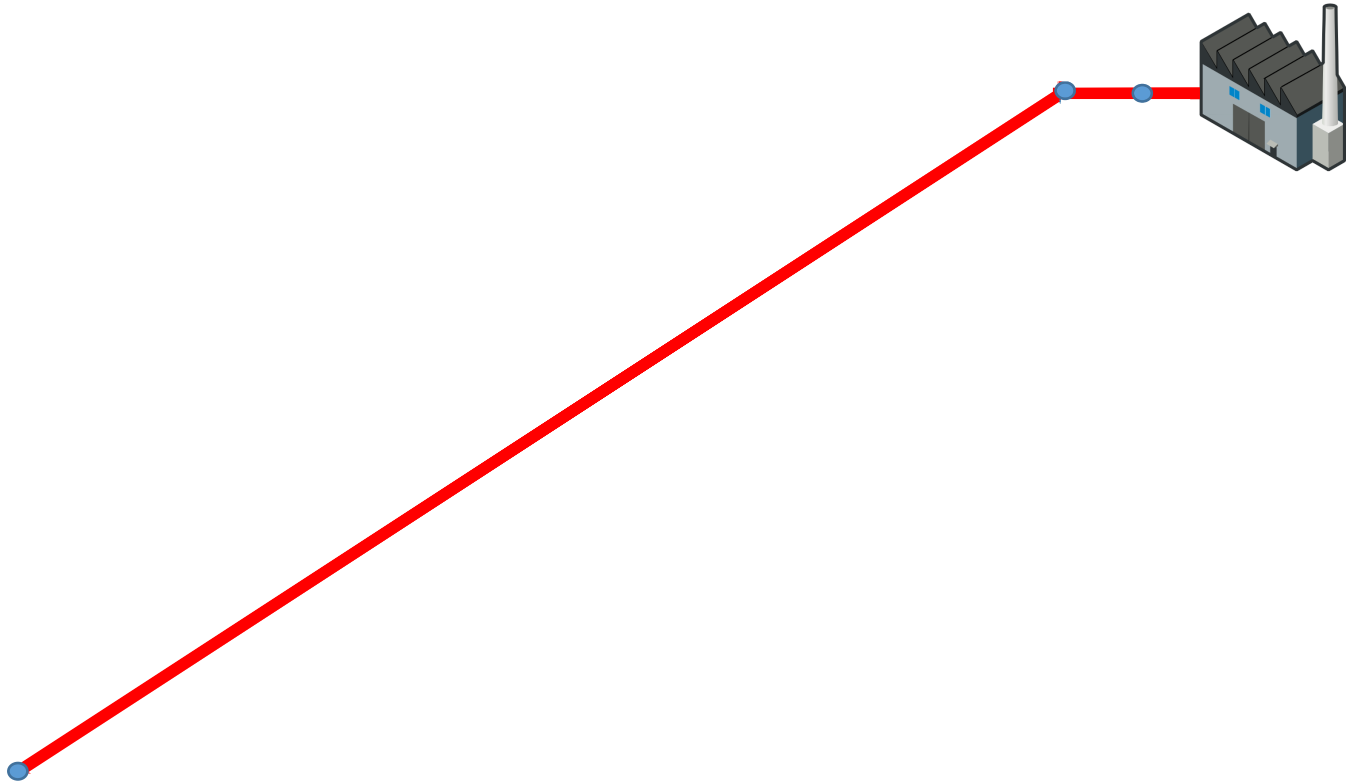
Case Study Setup

- Both German and Danish Aggregation methods were carried out on the network to assess the impact on:
  - Mass flow rates at the producer
  - Heat flow rates at the producer
  - Heat losses
  - Delay times
  - Simulation time

Network Aggregation- Case Study 98% Aggregation Depth

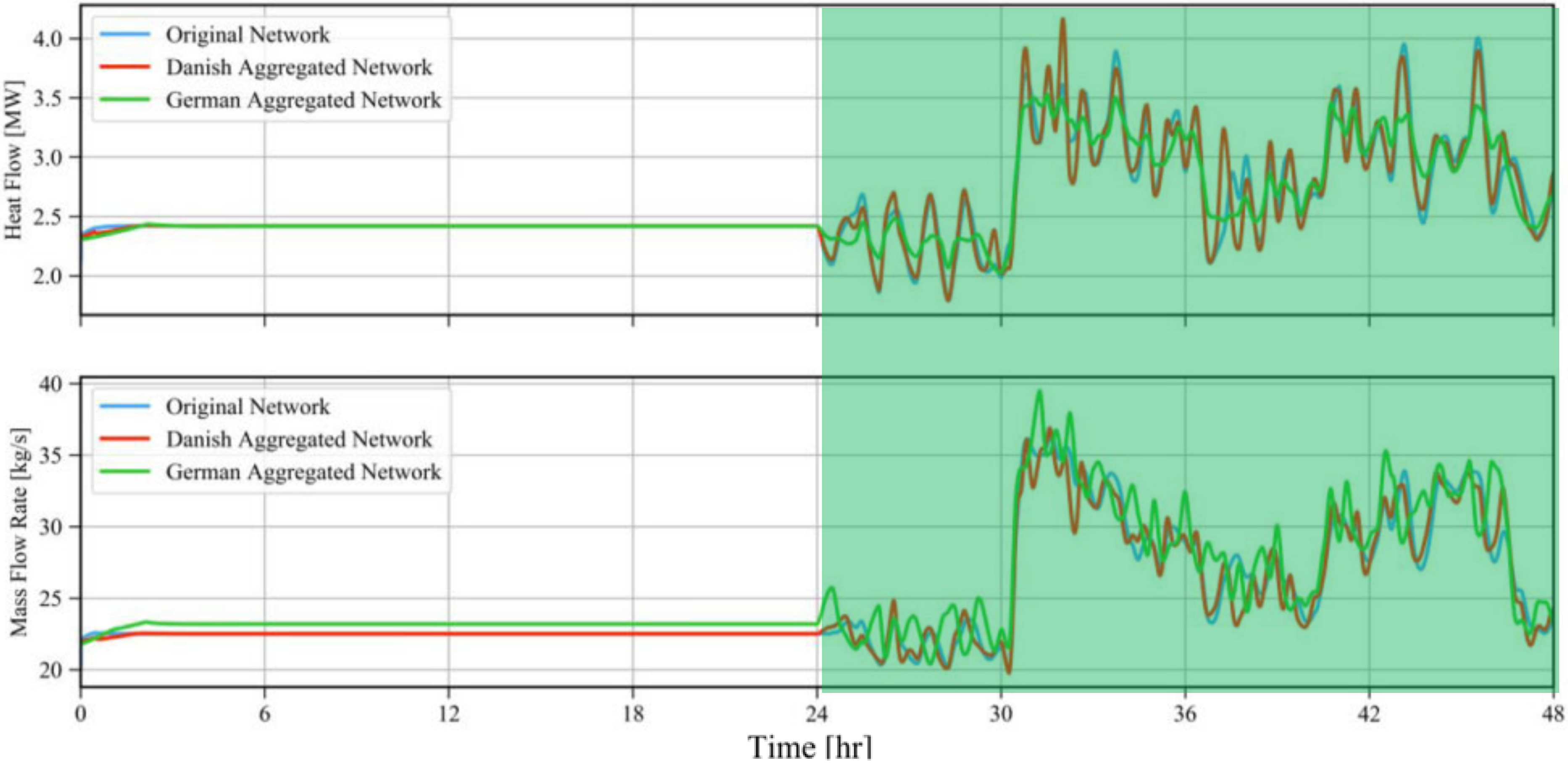


Network Aggregation – Case-Study 98% Aggregation Depth



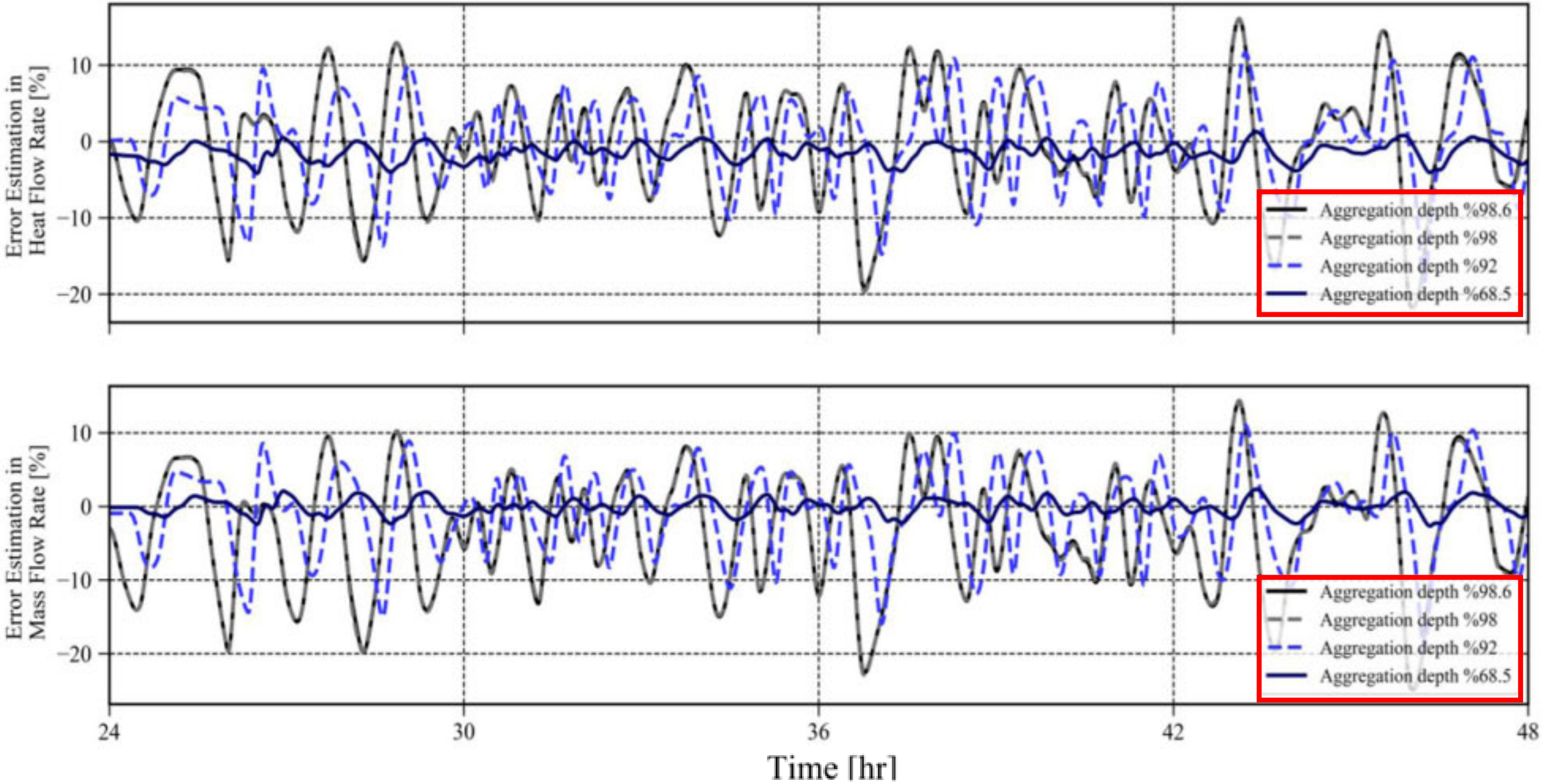
Case Study Results Aggregation

- Comparison of Heat and Mass Flows at producer for both German and Danish aggregation methods at 98% aggregation depths



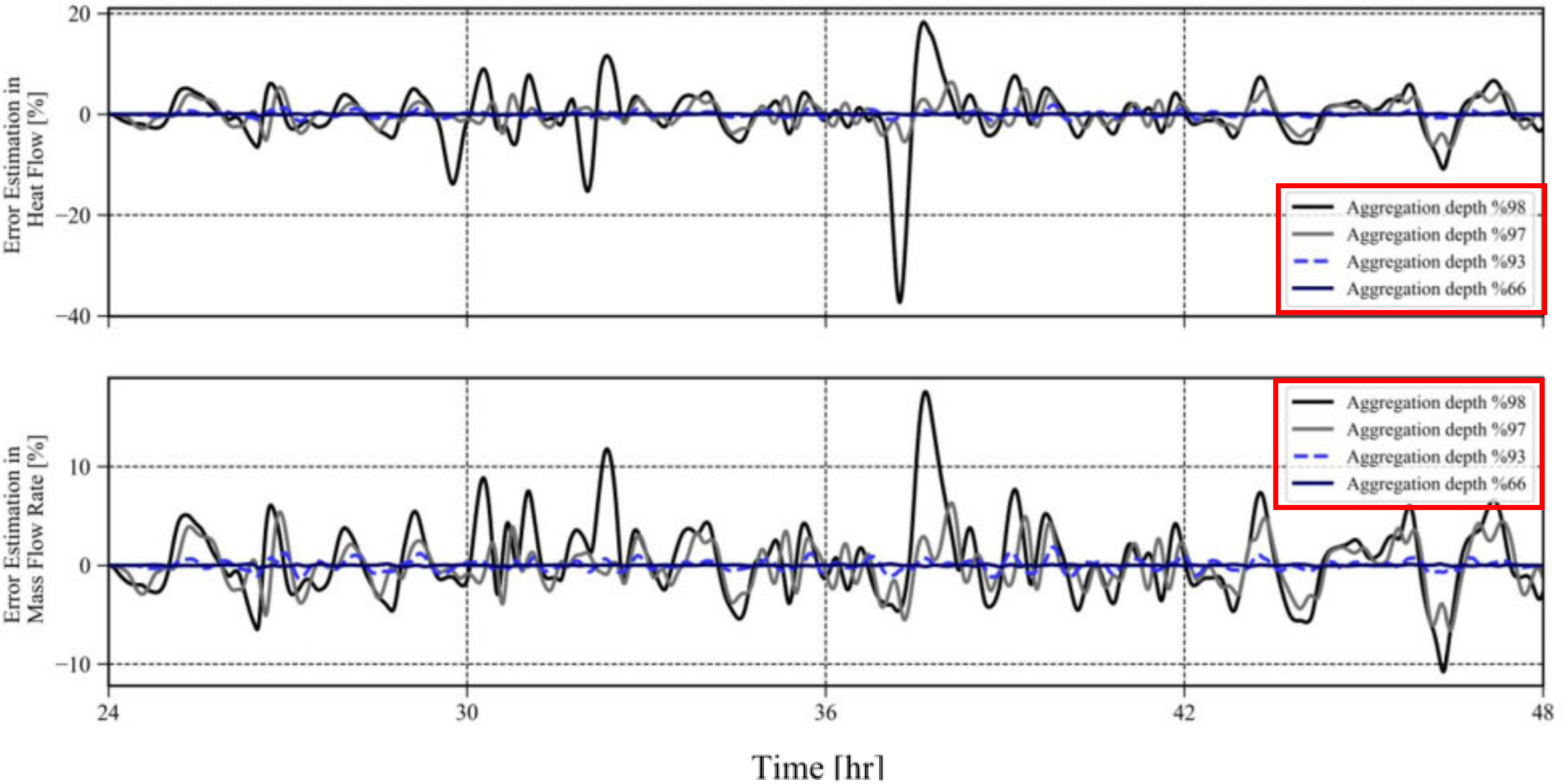
Case Study Results Aggregation

- Error comparison for German Method

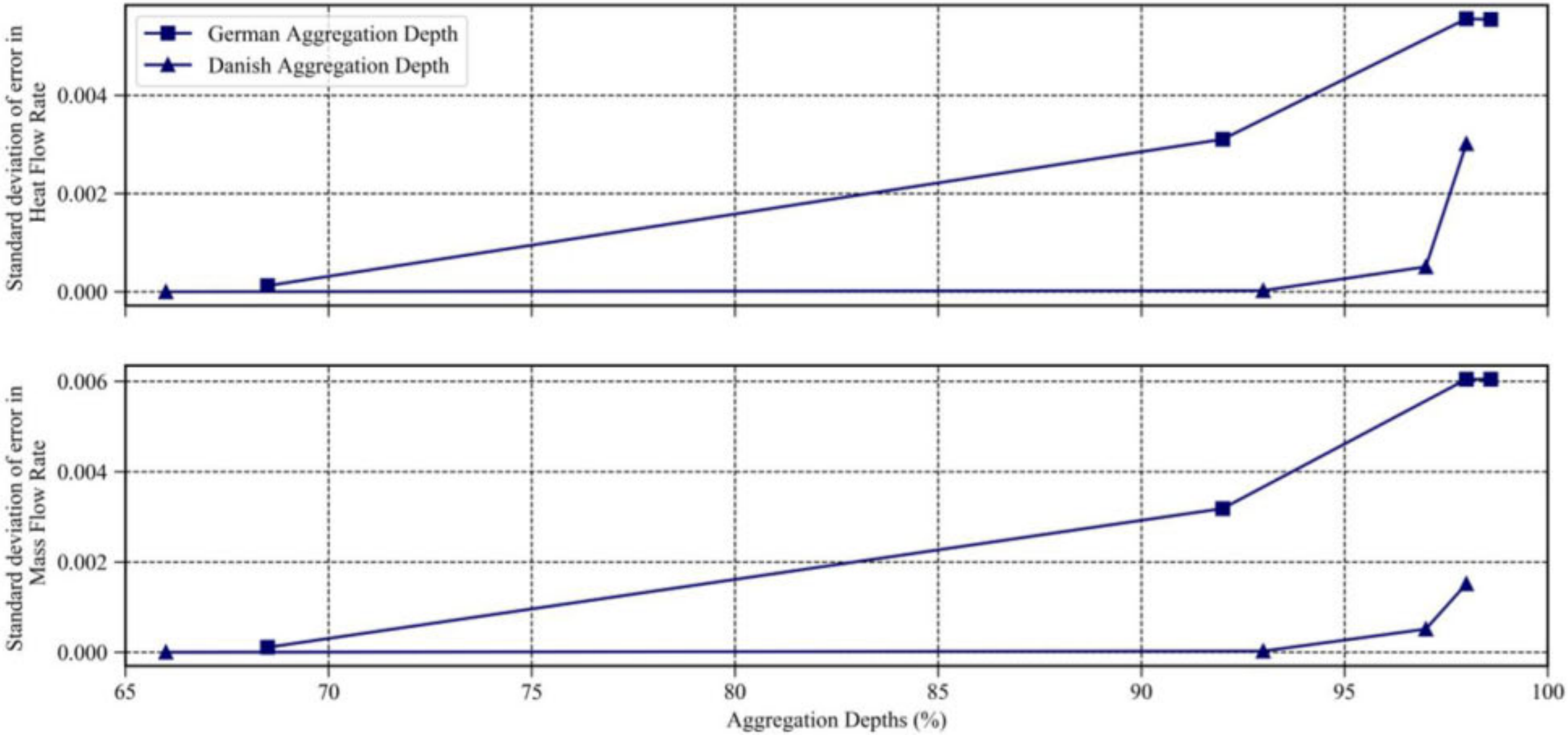


Case Study Results Aggregation

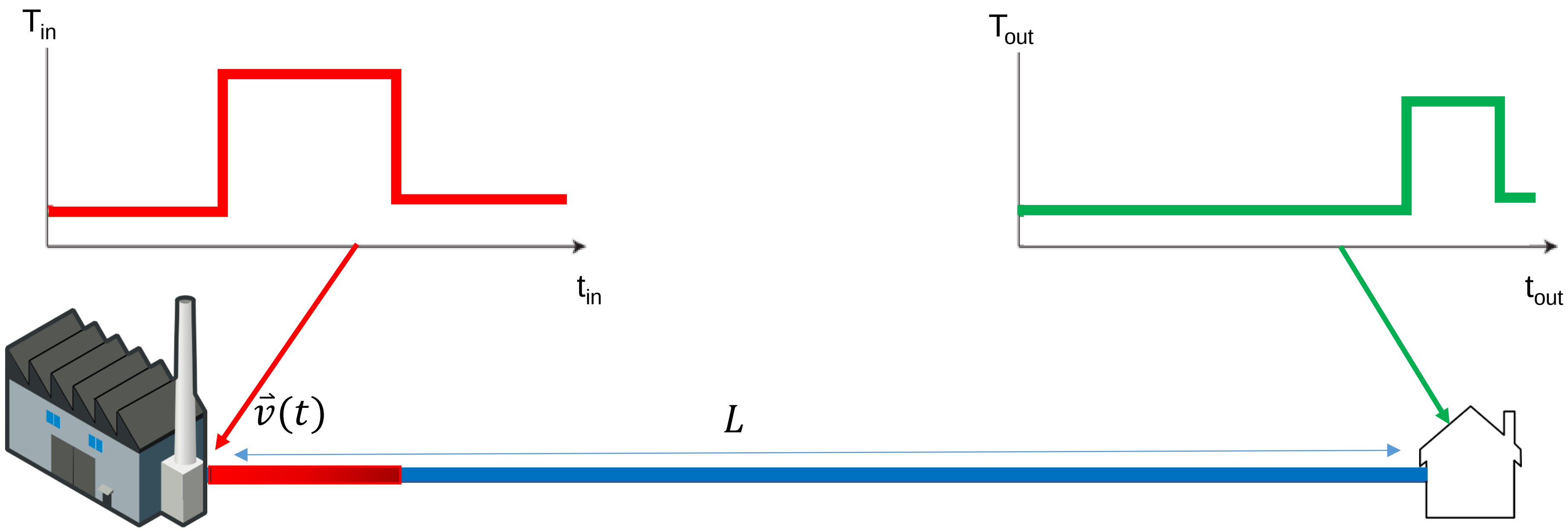
- Error comparison for Danish Method



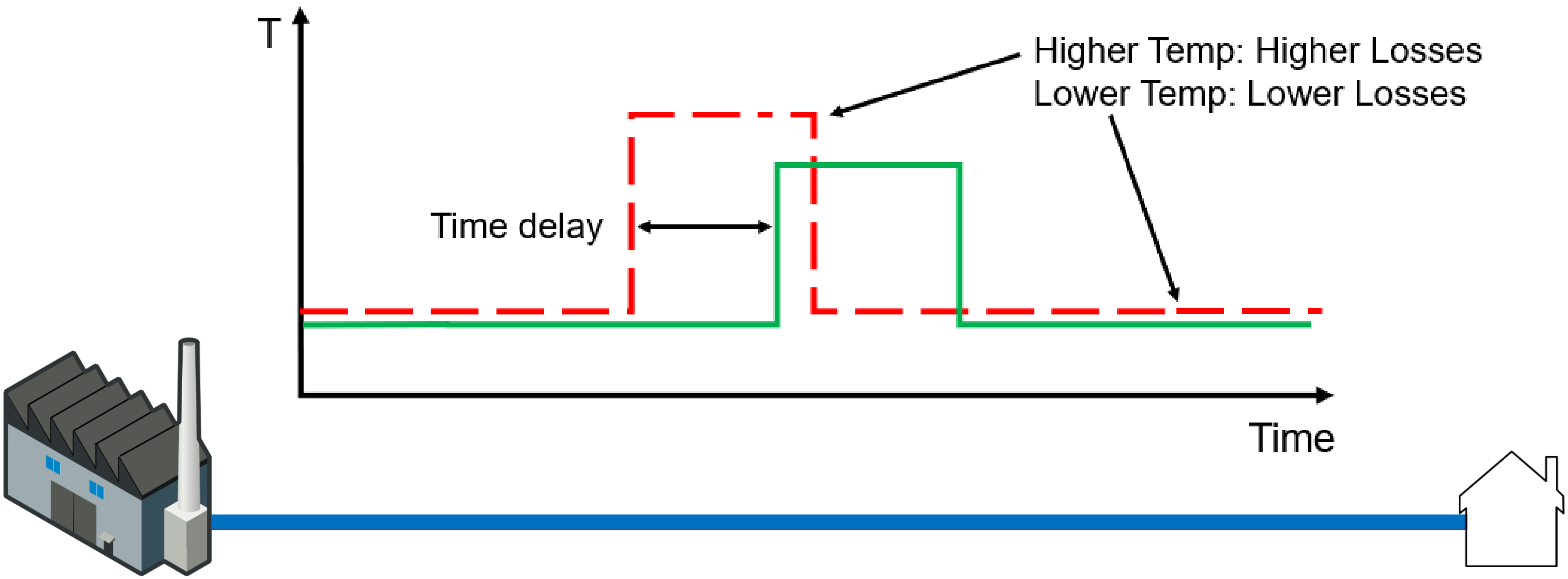
Standard Deviation Comparison



Dynamic Phenomena: Temperature Wave Propagation



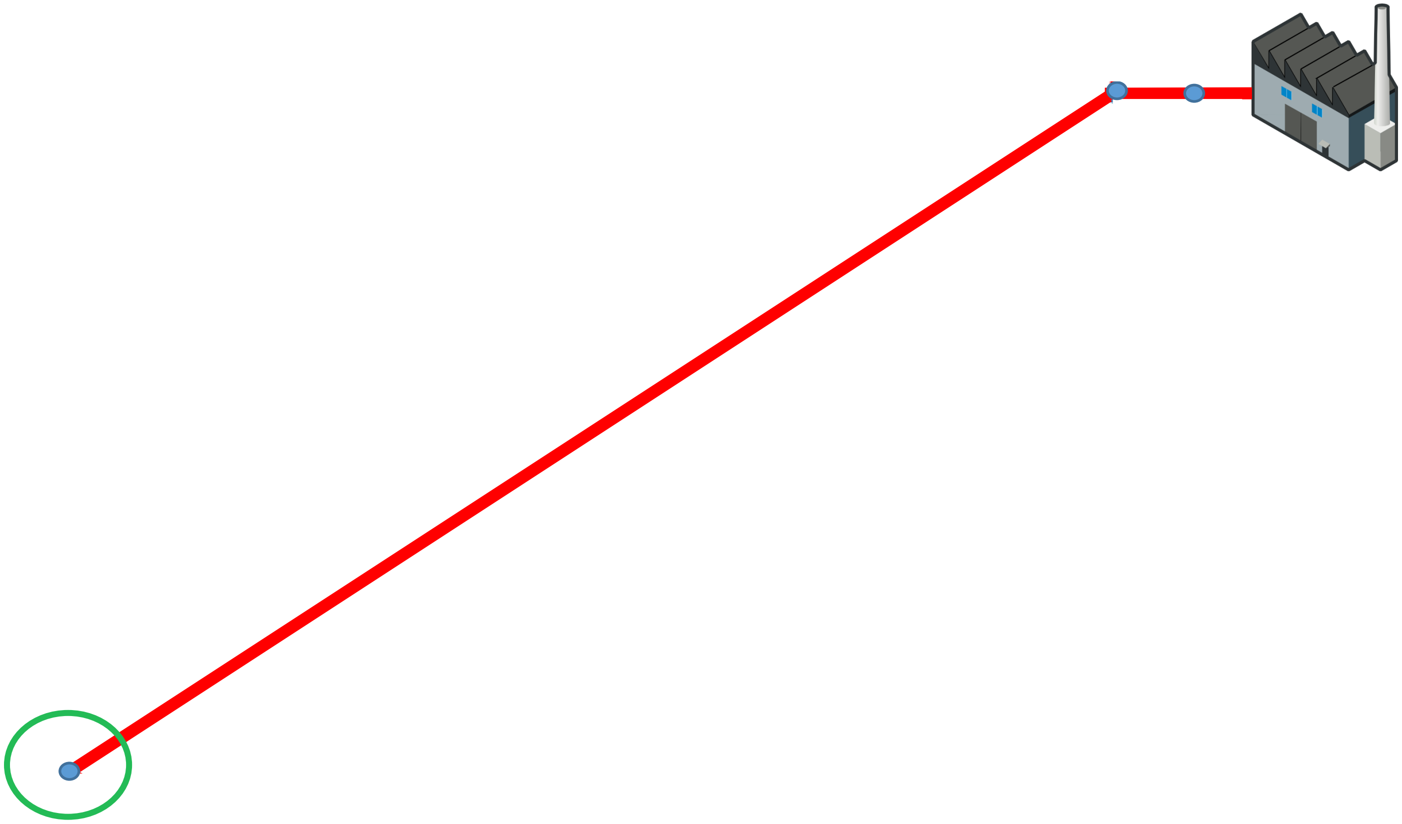
Delay Time Present



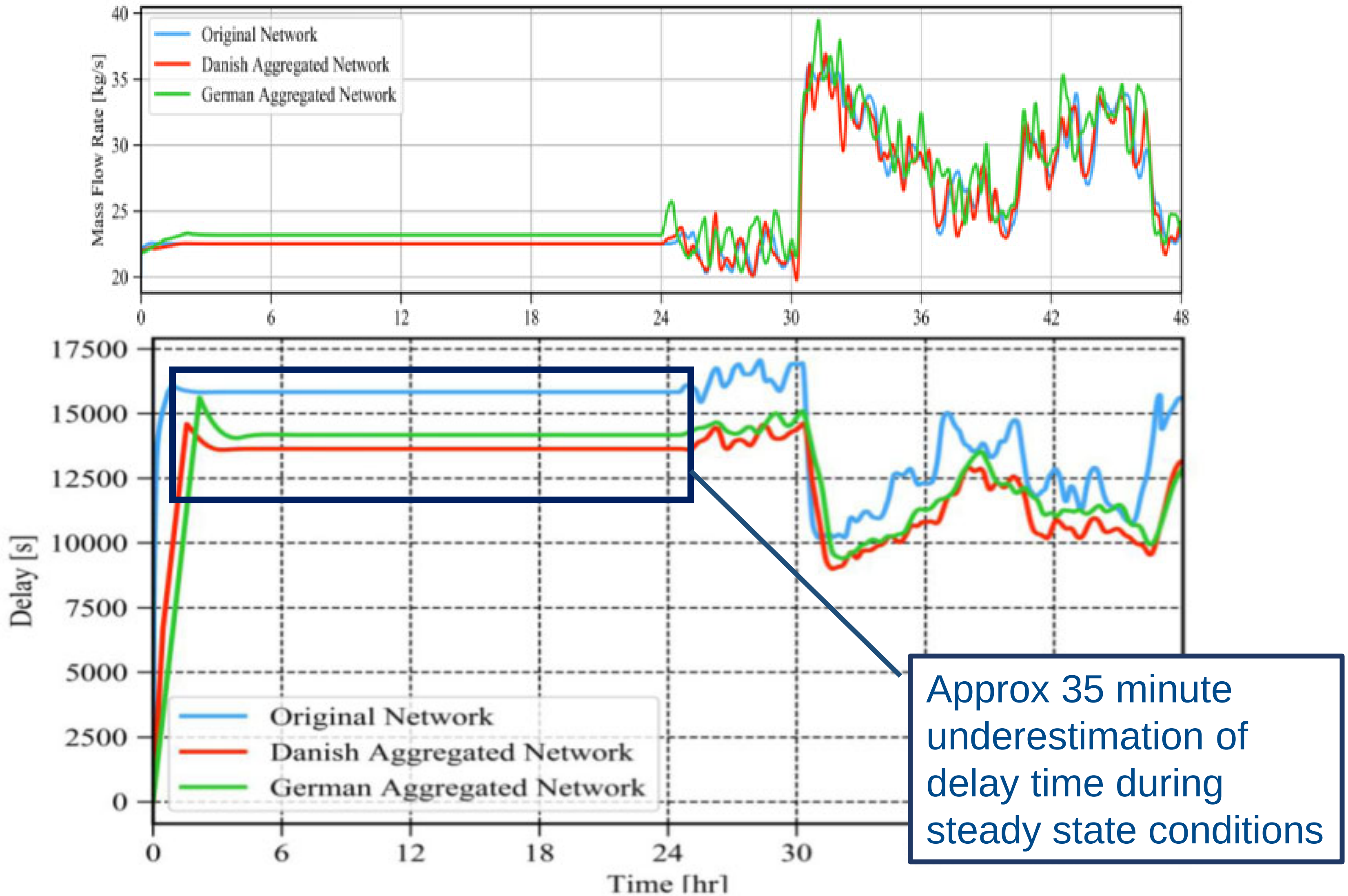
- Temperature wave propagates along pipeline with a significant delay at the consumer

- Heat Losses/temperatures are functions of time t and x position on pipeline – dynamic pipe models necessary calculate!

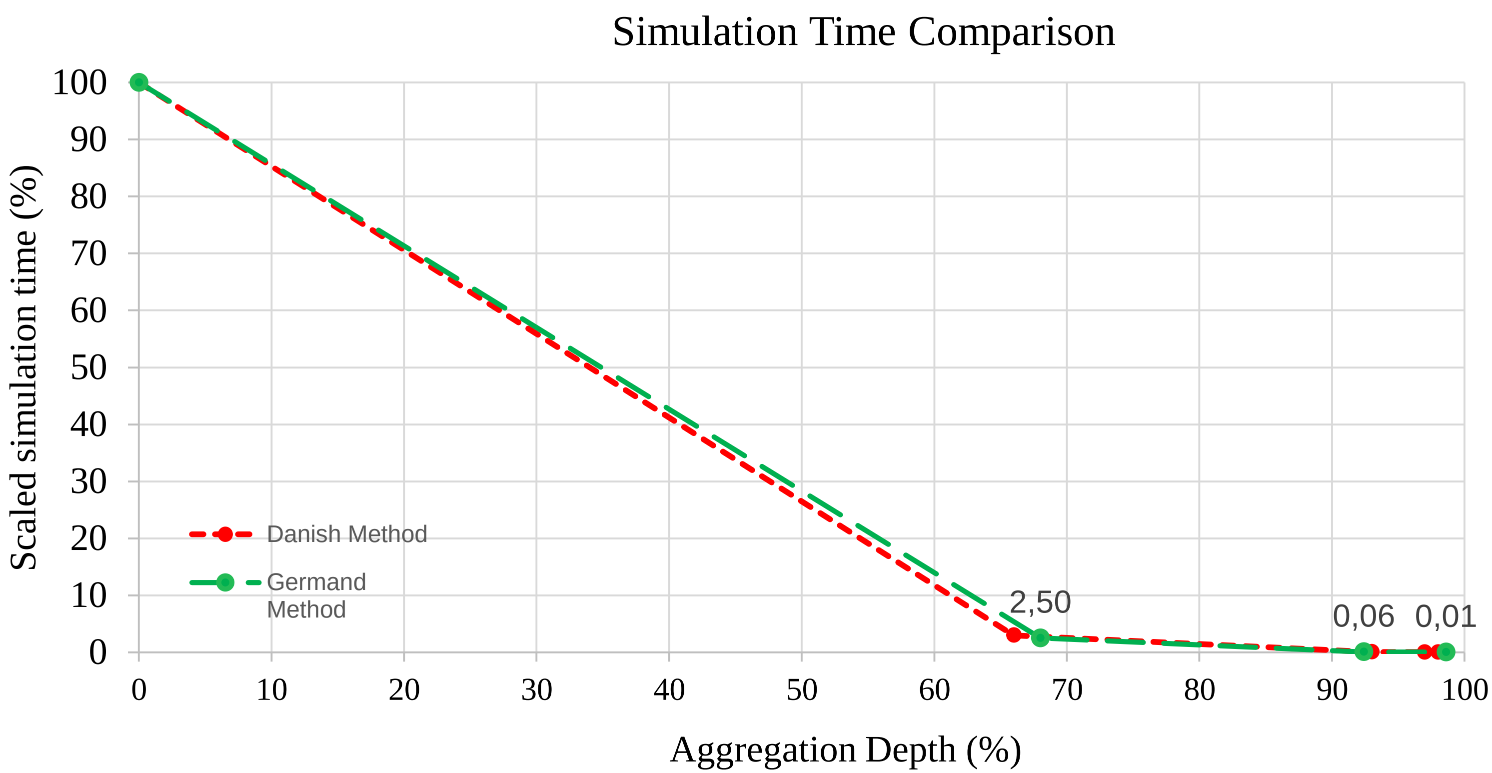
Time Delay at furthest consumer



Case Study Results – Time Delay Tracking
Aggregation depth of 98% to furthest consumer



Reduction in Simulation Time for different depths of aggregation



- Simulation time reduced to approx. 0.01% of the original network simulation when aggregated from 146 down to 2 consumers.

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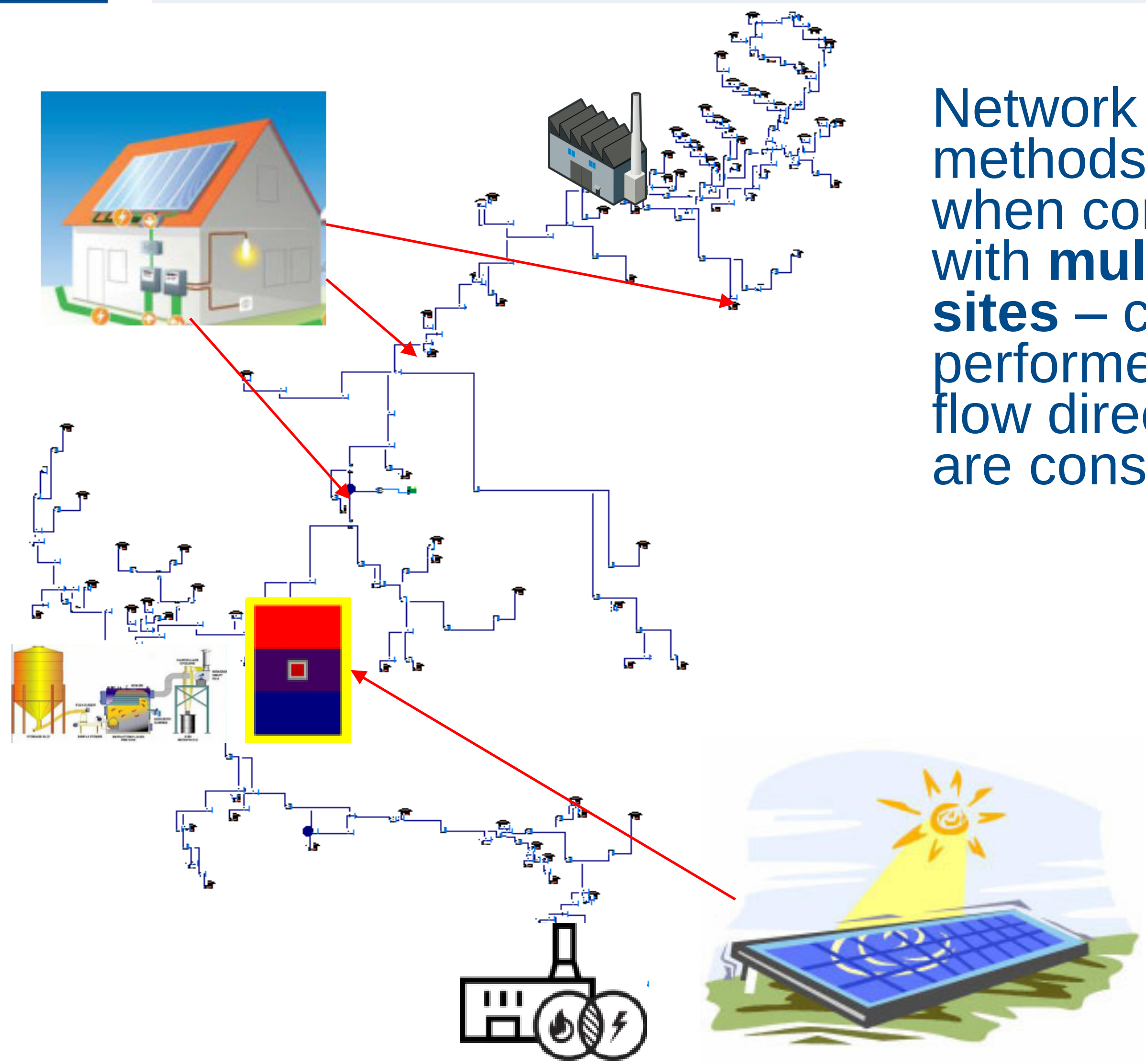
Summary of results

- Both Danish and German Methods are effective at preserving dynamic mass flow and heat flow rates with the Danish method giving the best representation of the original network.

- Both aggregated network significantly **underestimate time delays** from the original the network – error can be expected to be higher for larger networks. Can be improved by through further tweaking of pipe parameters.

- Despite discrepancies in delay time conservation, simulation time could be reduced down to 0.01% of the original time at 98% aggregation of the consumers.

The next big challenge!



Network aggregation methods are highly limited when considering networks with **multiple production sites** – can only be performed when we assume flow directions in pipelines are constant.

Thank you
for your Attention