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The Importance of Asset Management of District Heating Pipes for the Implementation of Climate Goals in Europe

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Abstract. The aim of the asset management of district heating pipes is to create a financial framework for a reliable, affordable and ecological heat supply in a district heating system. Today, estimates based on available statistical data suggest that over 19,000 heating networks with a total pipeline route length of over 199,000 kilometres supply heat to over 80 million inhabitants in the European Union (EU). With the 'European Green Deal' and the EU 'Fit-for-55' legislative package, the EU has described its climate goals and established the political framework for achieving them through the 'Renewable Energy Directive' (RED III), the 'Energy Performance of Buildings Directive' (EPBD) and 'Energy Efficiency Directive' (EED). Existing district heating systems, their transformation and expansion as well as building new district heating systems are essential for the achievement of the European climate goals. To this end, network operators require reliable asset management tools for implementing the EU climate goals. This paper presents the factors influencing the service life of different pipe systems and approaches for improving asset management simulations based on ongoing national and international research.

Keywords: District Heating Pipes, Asset Management, Climate Goals

1. District heating pipes in European District Heating Systems

In district heating (DH) systems, the quality and security of supply depend directly on the functionality of the heating network [1]. In Europe today, approximately 19,000 district heating networks with a total route length of approximately 199,000 kilometres (km) supply heat to around 80 million inhabitants [2]. These heating networks have developed as infrastructure in urban areas under various technical, ecological and economic conditions. As a result, every heating network in Europe has its own individual characteristics, which is reflected in the network structure with the corresponding heat generation plants, the technical operating parameters (e.g. temperature and pressure) and the pipe systems installed. Figure 1 shows, by way of example, the percentage shares of pipe systems used in 14 heating networks in Germany. The total length of these 14 heating networks is 5,100 km, and the average age of the pipes is

21.6 years. In summary, 51 % of the 5,100 km of pipelines are pre-fabricated DH pipes, 20 % are DH pipes laid in concrete duct systems, and 16 % are basement-laid pipes.

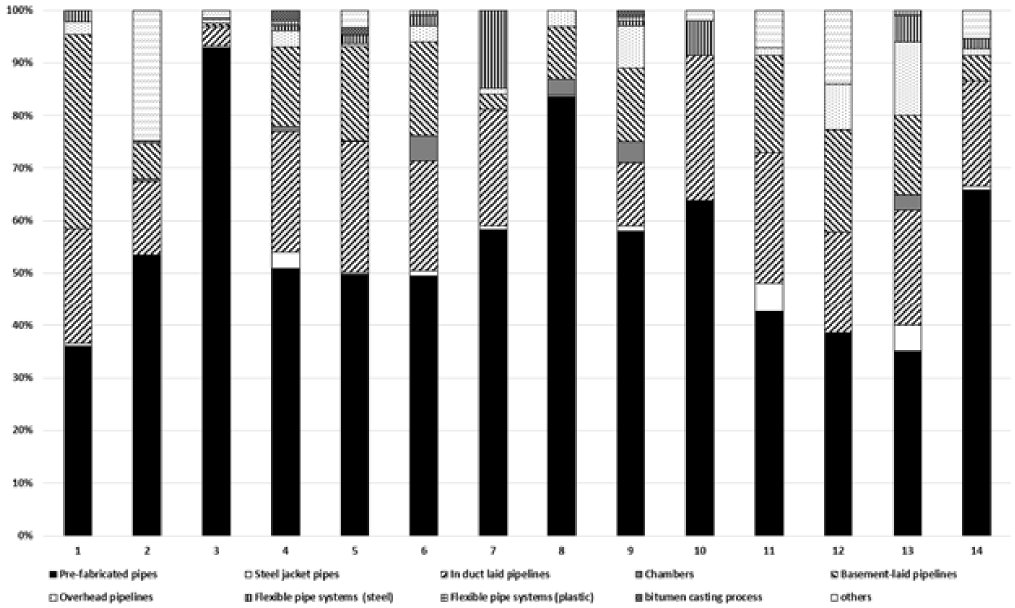

Figure 1. *Percentage shares of different pipe systems in 14 heating networks in Germany, source: AGFW 2024*

Table 1 shows examples for pipe systems used in DH related to the service pipes and the operational temperature range. The categorisation refers to the European Standardisation Committee TC 107 [3]. Additionally, the related standards as well as the minimum service life for the several pipes systems are given in Table 1. The examples of pipe systems described in table 1 are focused on metallic service pipes systems with a high share in existing DH systems with a design temperature above 90 °C and plastic service pipe systems used in DH systems with lower design temperature.

The minimum service life of pipe systems specified in Table 1 is based on accelerated aging procedures described in the respective standards. According to these a minimum service life can be calculated. In [4], the Continuous Calculated Operation Temperature Test (CCOT test) was deleted in the 2018 revision of the standard because this method does not take into account other in situ aging mechanisms and can therefore lead to deviations in the service life. However, practical experience to date shows that the use of CCOT in the past has led to quality assurance measures for the prefabricated DH pipes. For this reason, the minimum service life of these pipe systems continues to be specified in [4] as a minimum service life of 30 years at a continuous operating temperature of 120 °C.

For DH systems, [5] describe the development paths of district heating based on four generations and their technical characteristics. Essentially, the four generations are classified by their design and operating temperatures: the first uses steam (up to 200 °C), the second hot water (>100 °C), the third warm water (<100 °C), and the fourth low-temperature distribution (30–70 °C). In 2024 the IEA DHC Executive Committee provides a simplified definition of the different generations of district heating networks in line with [5]. The members of the IEA DHC Executive Committee classify what is described in science as the 5th generation of heating networks (operating temperatures < 50°C) as a subclass of the fourth generation [6].

Table 1. *Pipe systems used in DH systems based on the temperature range categorisation of the standardisation committee TC 107 [3]*

Service pipe	**Temperature range**	**Specific pipe system**	**According to Standard**	**Min. Service life [a]**	**Remarks regarding min. service life**
Metallic service pipes systems for DH	> 120 °C	Steel jacket pipes	[7]	30	Based on experiences [8]
		In duct laid pipelines	No European standard	30	Based on experiences [8]
	< 140 °C and ≤ 120 °C	Pre-fabricated pipes	[4], [9]	30	Based on CCOT at 120 °C
		Flexible pipe systems	[10]	30	Based on CCOT at 120 °C
		Overhead pipelines	[11]	50	Based on experiences [8]
		Basement-laid pipelines	[11]	50	Based on experiences [8]
Plastic reinforced service pipe for DH	≤115 °C		No European standard	30	Based on CCOT at 85 °C
Plastic service pipe systems for DH	≤ 95 °C	Flexible pipe systems	[10]	30	Based on CCOT at 80°C
Plastic service pipe systems for DH with lower temperature profile	≤ 80 °C	Flexible pipe systems	[12]	30	Based on CCOT at 70°C

2. EU Policy and Climate Goals for District Heating

The European Union's 'Green Deal' sets the overarching goal to achieve full climate neutrality and net-zero greenhouse gas emissions within the EU by 2050 [13]. As part of the Green Deal, the EU's 'Fit for 55' legislative package aims to reduce greenhouse gas emissions by at least 55% in 2030 compared to 1990 levels [14]. For existing and new district heating systems, the legislative framework was changed within 'Fit for 55'; central EU directives for the heating sector were revised. The EU directives EED [15], REDIII [16], and EPBD [17] contain key targets for future heat generation and performance of district heating systems, as well as for reducing the final energy consumption of buildings supplied by district heating.

The revised 'Energy Efficiency Directive' [15] introduces binding energy efficiency requirements for primary and end energy at Member State as well as company level. Art. 26(1) EED contains the definition of an 'efficient district heating and cooling system', central for the sector. It represents the EU institutions' decarbonisation pathway for district heating by 2050. A DHC system is efficient within EED if it meets certain minimum percentage shares of heat from renewable energy, waste heat or (high-efficiency) cogenerated heat or a combination of such energies. Currently, until 31 December 2027, a system using at least 50 % renewable energy, 50 % waste heat, 75 % cogenerated heat or 50 % of a combination of such energy and heat is efficient. Every 5 to 10 years, the share of renewable heat and waste heat must be increased, for a system to remain 'efficient' by definition. From 2050 onwards, DHC systems using exclusively renewable heat or waste heat, will count as 'efficient'. Therefore, existing and new DHC systems are encouraged to continuously invest and decarbonise their heat generation infrastructure. A DHC system is still allowed to operate without being efficient. However, non-conformity with EED leads to severe penalties in other EU heat legislation, such as RED and EPBD (see below) [15]. Moreover, EU state aid rules only permit public funding for DHC networks that are efficient or become efficient within three years. Further, only efficient DHC systems are aligned with the EU-Taxonomy.

The amended ‘Renewable Energy Directive’ [16] sets Member State and sectoral targets for promoting the expansion of renewable energies in the EU. For the district heating sector, Art. 24(4) RED mandates an average annual increase of 2.2 percentage points in the share of renewable energies or waste heat in district heating for all EU Member States between 2021 and 2030. Following Art. 24(2) RED, customers of non-efficient DHC systems have the right to terminate or modify their existing contract in order to produce heating or cooling from renewable sources themselves. Non-efficient networks with low shares of renewable heat or waste heat therefore face the risk of losing their existing customers. Instead, DHC operators are encouraged to decarbonise their network. One of RED’s key focuses is “Third Party Access” (TPA) of renewable energy or waste heat to DHC networks. The EU takes a clear position on TPA in Art. 24(4b) RED: There is no obligation to introduce third-party access regulations for district heating for Member States. Instead, Member States shall ensure that DHC systems above 25 MW thermal capacity are encouraged to connect third party suppliers of renewable heat/ or waste heat to their networks under certain conditions [16].

The revised ‘Energy Performance of Buildings Directive (EPBD) contains ambitious renovation requirements for the existing building stock and introduces the new EU building standard for the so-called ‘Zero-Emission Buildings’ (ZEB) in Art. 11 EPBD. All new buildings from 2030 onwards must be ZEBs; the entire EU buildings stock should be transformed to ZEBs until 2050. As central condition, no CO_2 emissions from fossil fuels are permitted at the building site. This largely corresponds to a ‘100% renewable energy rule’ for new buildings and prohibits any individual boilers using fossil fuels. Moreover, ZEBs’ energy demand must comply with a national maximum primary energy threshold. Most importantly, ZEBs must only be supplied with energy from specific technologies according to Art. 11(7) EPBD. These technologies include among others ‘*energy from renewable sources generated on-site or nearby*’ (e.g. heat pumps, biomass boilers), and ‘*energy from an efficient DHC system according to Art. 26(1) EED*’. Positively, the EPBD recognises all DHC networks that comply with EED as eligible to supply new buildings with energy. Again, this reinforces the need for DHC operators to decarbonise their systems to be able to connect new customers [17].

The EU directives strongly focus on the heat generation side. There are no EU expansion targets for DHC market share or network length. Instead, studies by relevant EU heat actors need to be analysed. The latest “Heat Roadmap Europe 5“ study by Mathiesen et al. 2025 from Aalborg University estimates a market share of 55 % for district heating grids (currently 13 %) for the EU27 for 2050 [18]. The authors recommend transitioning existing and new DH networks to low temperature 4th generation district heating. For the grid expansion and transition measures, an estimate of 1,16 trillion € in investments is needed until 2050. Assuming a service life of 40 years for the pipe systems, the maintenance requirements for existing pipe systems are included in the total investment requirements at €190 billion [18]. The European DHC Association ‘Euroheat & Power’ has similar projections in their yearly Market Outlook. In the latest 2025 EHP Market Outlook, they expect “significant expansion of DH grid length” from currently around 199.900 km, due to the implementation of the EU Fit-for-55 package [2]. In [19], the effects of implementing European and national climate goals for the district heating sector in Germany are forecast. In addition to the decarbonization of heat generation, it is assumed that the length of pipelines in Germany will increase from around 35,000 kilometres [20] to 73,000 kilometres in 2045. The investment required for the transformation of Germany's heating networks is estimated at €117.9 billion. Out of this, €60.4 billion, or slightly more than 50%, will be spent on the expansion, new construction, and repair of existing heating networks [19].

3. Asset Management of Pipes in District Heating Systems

3.1 Status quo

The term asset management refers to coordinated activities within an organization that serve to create and maintain value with its assets, e.g., operating resources such as pipelines, and to achieve the organization's objectives [21]. In the field of district heating pipelines, this means in particular maintaining the security and quality of the heat supply and ensuring the functionality of the corresponding operating resources. The asset management of district heating pipelines must be adapted to the individual operating resources and operating conditions of the district heating system in question. The various pipe and laying systems are partly made of different materials, whose material degradation is influenced by different, sometimes combined stresses and the resulting aging processes. Therefore, comprehensive and as complete as possible inventory and damage data as well as operating data of the district heating system are required for the asset management of pipelines to implement measures to meet the targets for security of supply and economic efficiency using suitable maintenance strategies [22, 23].

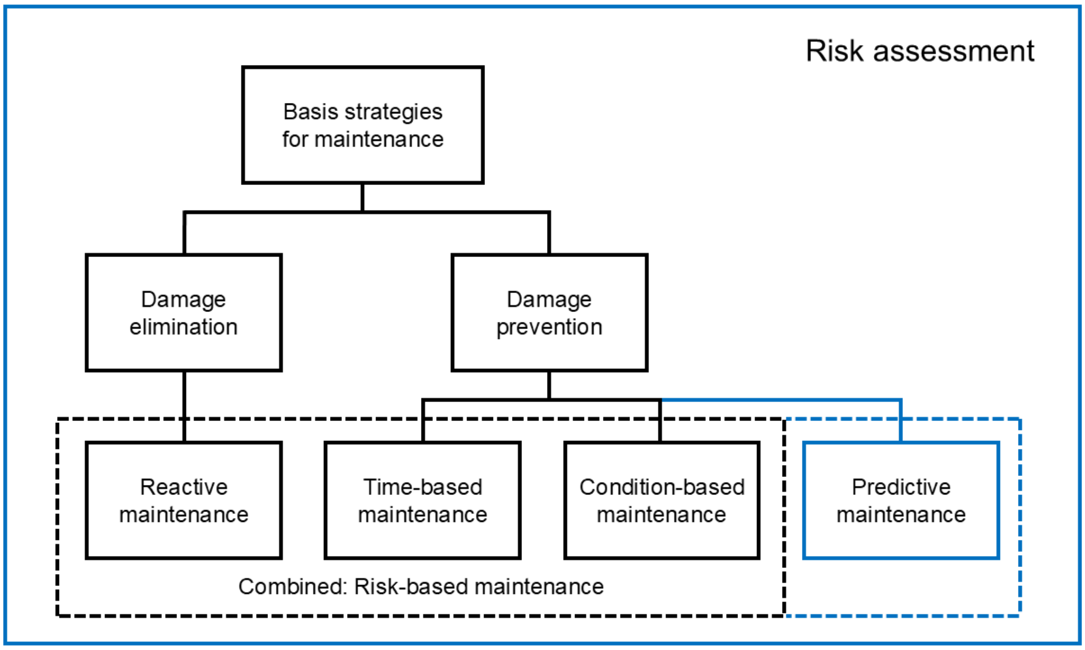

Figure 2. *Basic maintenance strategies from [8], expanded to include risk-oriented maintenance and predictive maintenance, source: own illustration*

The basic strategies of maintenance (see Figure 2, in black) are divided into reactive (damage elimination) and proactive (damage prevention) approaches [8]. While time- and condition-based strategies serve to prevent damage, reactive maintenance strategies respond to damage events and restore the functionality of the equipment [22]. Risk-oriented strategies assess the condition and importance of the equipment in terms of the security and quality of supply of the heating network to carry out reactive or proactive maintenance depending on the assessment result. However, in addition to thermo-hydraulic calculations to assess the importance of a section of pipeline for security of supply, this also requires condition assessments and evaluations as well as estimates of the (residual) service life. Another combination of existing basic types of maintenance that can be classified as damage-preventive maintenance is predictive maintenance (see Figure 2, in blue). In addition to the information already presented and supplementing risk-oriented maintenance, additional measured values are incorporated into the condition assessment of the operating equipment, which can be used in conjunction with defined limit values to forecast the service life and predict a damage event.

Figure 2 therefore shows predictive maintenance as a link between condition-based and risk-based maintenance in the basic maintenance strategies for district heating networks in accordance with [8]. Previous studies by the authors for district heating supply companies in Germany and exchanges with international partners in the IEA DHC Task Shared 6 project [24] show that the data basis of DH companies with regard to inventory, operating, and damage data is incomplete and does not meet the requirements of asset management for reliable forecasts of service life [25]. Consequently, result-based maintenance strategies on the one hand and condition-based maintenance strategies on the other have been widely used in the district heating sector to date.

3.2 Development Caused by Research Activities, Technological Improvements and EU Climate Goals

Further developments to increase the reliability of forecasts made by existing asset management software tools are the subject of national and international research activities. For example, the SAM-FW research project [26] focuses on approaches to filling existing data gaps (e.g. [22]), the development and installation of suitable measurement technology for recording the condition of various pipe systems in existing and future heating networks, and the improvement of status assessment for DH pipes aged in operation using material-based service life models.

Overall, it can be assumed that in the asset management of heating networks, the increase in data volume, e.g., through the implementation of remotely readable heat meters to record customer consumption data or through the installation of measurement technology in existing heating networks (e.g., temperature or flow measurements or recording environmental conditions in DH pipes laid in concrete duct systems), in conjunction with improvements in data evaluation to increase data quality, the reliability of forecasts made by existing asset simulation programs can be increased in the future. Predictive maintenance approaches and artificial intelligence (AI) based evaluations are also considered promising for the asset management of district heating pipes, based on the proven potential of other sectors such as oil and gas pipelines [27, 28, 29]. However, in the current result-oriented, analogue approach to district heating pipeline asset management, these require considerable measures to digitize existing data, information, and processes. In addition, reliable aging and prediction models for pipe systems form the basis for the introduction of predictive maintenance in the district heating sector, which also requires the development and application of appropriate algorithms in utility companies.

Considering the political goals of the European Union, which stipulate the transformation of existing district heating networks into efficient, climate-neutral heat supply systems, further requirements will also arise for the asset management of district heating networks. While the targets set by the EED [15] and RED III [16] describe decarbonization, individual adjustments to the network structure and operational management (target network planning) must be made on this basis, and corresponding transformation measures in the heating network must be developed. These range from network expansion and network conversion to the evaluation of future operational management over the service life of the existing pipelines. Similarly, solutions and measures for implementing the European climate goals must be evaluated in terms of economic efficiency, sustainability, and security of supply. As shown in [18] a massive change is expected to increase the flexibility of district heating systems in connection with high investments in corresponding infrastructure adjustments [18]. To accomplish these tasks, utility companies need reliable asset management simulations to minimize the risks of upcoming investment decisions. Sufficient data bases and condition assessments and evaluations are essential for this purpose.

4. Status Assessment and Lifetime Prediction of District Heating Pipes

Fundamentally, the service life of a pipe system is influenced by the quality of the materials and the properties of the product manufactured in the factory, the quality of the workmanship in the construction of the pipes, and the stresses acting during operation, some of which are additionally caused by local boundary conditions such as traffic loads. The relationships shown in Figure 3 can be applied to pipe systems (e.g., from Table 1).

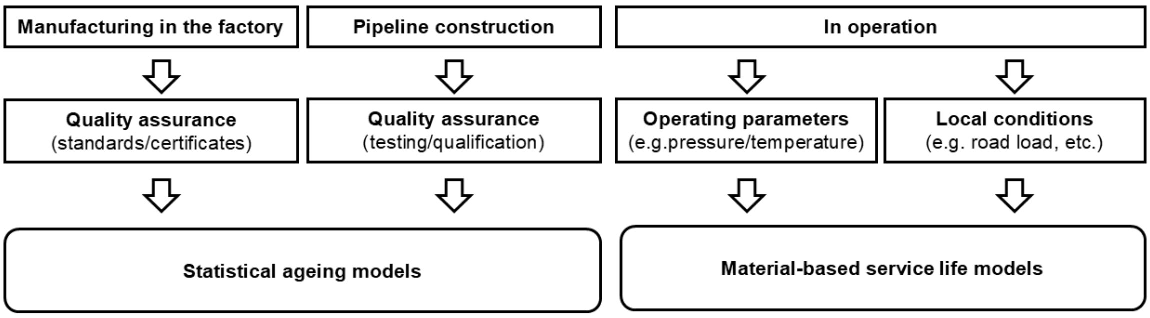

Figure 3. *Key factors influencing the service life of district heating pipes, source: own illustration*

If the average age of the pipes in the heating network is below the minimum service life of the pipe systems (usually 30 years) and the utility company complies with the normative quality standards for planning, construction, and operational management, the frequency of damage is low. As the service life increases and the pipes are subjected to corresponding stress, the risk of damage occurring rises. For reliable service life estimations in a certain district heating grid, it is crucial to identify the critical ageing mechanism and their impact on materials used based on the local boundary conditions.

The following sections outline how these general principles apply to the three main types of district heating pipe systems.

4.1 Influences on the Service Life of Prefabricated District Heating Pipes

Prefabricated buried DH pipes according [4] are widely used in district heating networks in Europe. The basic structure of the pipe system consists of a steel service pipe, a rigid polyurethane (PU) foam thermal insulation, and a polyethylene (PE) casing. In district heating pipeline construction, straight pipes, fittings (such as valves, branches, elbows), and compensation elements (such as compensators, expansion pads) are available to construct the district heating route in accordance with the requirements of the utility company. When dimensioning a district heating route, evidence must be provided against impermissible stresses on the steel medium pipe as a result of primary and secondary effects. In [30] relevant influences on the service life of pipe systems and current methods for determining the remaining service life are presented.

So far, most investigations on the remaining service life of pre-insulated bonded pipes concluded [31 - 34] that the deterioration of the polyurethan foam is limiting the service life. Scientific investigations in [24] agreed that the deterioration of the polyurethane foam is mostly caused by thermal load, permeation of cell gases, thermo-oxidative ageing, and mechanical load. Until now, a reliable method for the evaluation of the remaining service life of a DH pipe aged in operation is still missing. Approaches using methods to describe the change in the chemical structure of the PU-foam are promising to end up with a reliable service life estimation [35]. Investigations evaluating the remaining service life of DH pipes aged in operation figured out that based on the results of scientific methods, a service life longer than 60 years can be expected [31, 34].

4.2 Influences on the Service Life of District Heating Pipes Laid in Concrete Duct Systems

District heating pipes installed in inaccessible concrete duct usually consist of a steel service pipe, thermal insulation made of mineral wool and a casing, as well as bearings and compensation elements made of steel and the concrete duct structure. Assessing the condition of such systems requires evaluating both the pipe system - including bearings and components- and the structural integrity of the concrete duct, including the seals between duct covers. Camera inspections have been and continue to be carried out in practice [36]. In many cases, the inspection of inaccessible concrete duct system is heavily dependent on design-related constraints. In concrete duct systems, corrosion processes and structural degradation of the duct are the dominant ageing mechanisms determining service life. Depending on the design of the system, this can mean that it is not possible to carry out an inspection to assess its condition. The use of drones is considered a promising means of improving visual assessment of the status of DH pipes laid in inaccessible concrete duct, but this technology is still in its infancy.

Experience from utility companies shows that these pipe systems can achieve service lives of more than 60 years if the water chemistry of the district heating water meets the relevant requirements for preventing corrosion. Ultrasonic measurements can be carried out using inspection devices that move through the medium pipe to assess the condition of the steel medium pipe. Corrosive environmental conditions in the duct system can reduce the service life of bearing structures and thus also the pipe system. In addition to ventilating duct systems, measurement technology is increasingly being used to monitor environmental conditions in the duct system. Furthermore, acoustic measuring systems can be used to determine the average steel pipe wall thickness of the medium pipe [37]. In summary, due to the lack of standardization of the systems and components inaccessible duct systems require individual assessment. In addition, the demands on asset managers are increasing, as the condition of the structure must also be recorded and evaluated in addition to the pipe system. Since access to duct systems is often limited, suitable methods for visual condition assessment and the installation of suitable measurement technology for long-term measurement of operating and environmental conditions are currently the focus of activities by researchers and utility companies.

4.3 Influences on the Service Life of Flexible District Heating Pipe Systems with Plastic Service Pipe

Flexible district heating pipes with plastic medium pipes differ mainly in terms of the plastic used (e. g. thermoplastic polybutene or cross-linked polyethylene) and the thermal insulation (e. g. polyurethane foam or closed-cell, cross-linked polyethylene foam). This report focuses on systems with plastic medium pipes and PUR, which constitute a composite system. The first systems were developed in the early 1980s and were mainly used for smaller networks in rural areas. The hydrostatic long-term strength (creep strength) according to [38] is the basis for predicting the service life of polymer pipes. Recording operating data (temperature/pressure) during the service life forms the essential basis for calculating the service life and predicting the remaining service life, as both the aging processes of the medium pipe and the thermal insulation are influenced by thermal aging processes. Since PU thermal insulation has a higher temperature resistance than the materials of the medium pipe at the permissible operating temperatures of the pipe system, the thermal aging processes of the medium pipe are the critical path for the service life of flexible pipe systems with plastic medium pipes [39]. For flexible plastic pipe systems, the dominant ageing mechanism is the thermal degradation of the plastic service pipe, which primarily determines the overall service life of the system. For residual service life estimation forecasts are based on Miner's rule and the temperature history. Flexible polymeric DH pipes acc. [10] are designed for a minimum service life of 30 years at 80°C. Practical experiences and long-term tests show much longer service life exceeding 50 years, if service temperatures can be kept below 80°C. Examples in [10] of various operation conditions in temperature and operation time show service life increasing up to 100 years.

5. Improved Asset Management as a key for the Implementation of Climate Goals?

The implementation of the European climate goals places new demands on the asset management of district heating pipelines, both in terms of developing target networks and planning measures. However, it also presents a wide range of opportunities to further develop existing approaches and tools. At the same time foundations for the use of future predictive maintenance approaches in the transformation of the entire district heating system can be initiated. Similarly, due to the high investment costs in resilient and climate-neutral district heating systems, there is also a need to demonstrate the necessity of additional investments and the use of human resources in improving asset management tools. In [40] the perspective of a Swedish DH company in the field of asset management is presented. From the DH operator's perspective, it is necessary to replace the right pipe at the right time [40]. This is particularly important in connection with the high investments required for the transformation of existing heating networks, the high demands on supply security as existing networks age, and the affordability of heat supply. Targeted status assessment, knowledge building within the utility company on asset management of pipelines in district heating networks, and the further development of asset management tools can reduce the entrepreneurial risk involved in developing an individual transformation strategy. Based on the authors' work to date, the following approaches for improving asset management have emerged in connection with the development of resilient, climate-neutral district heating systems.

5.1 Target Networks and Pipe Systems

In order to adapt existing heating networks to the requirements of the ‘Fit for 55’ program, utility companies are carrying out planning processes in which, among other things, the development of heat demand, available heat sources, the capacity of existing and future heat generation plants, and the operating parameters of the heating network are determined for various target years up to 2050. This process is referred to as target network planning and forms the basis for the development of an individual transformation strategy for each district heating system. The utility company's target network planning and transformation strategy determine the future operating parameters (e.g., temperature and pressure), operating modes (e.g., temperature profiles), and network structures in the supply area. Based on this, the requirements for the pipe systems of the heating network can be derived in the specified expansion stages (e.g., in the target year 2035 or 2050). As described in this paper, many different pipe systems, some of which are made of different materials, are used in district heating networks that have grown historically. This fact must be examined in connection with the possibilities for status assessment and service life predictions of the pipe systems, the results of target network planning, and the experience of the utility company.

5.2 Data Management

Asset management has certain requirements in terms of data and information. Much of this data and information, most of which is historical, is no longer available or only available in incomplete form in utility companies. In some cases, it is documented in paper form or can only be accessed through the expertise of staff. To develop a transformation strategy for existing district heating networks based on European climate legislation, a wide range of company data must be collected and evaluated. In some cases, analogue data and information will be digitized. This process is currently running parallel to a wide range of technical developments in utility companies, which can be summarized under the heading of *digitalisation*. In this context, it makes sense to implement a data management system in the utility company in which relevant asset management information is also contained and accessible for the corresponding asset simulations. New construction of heating networks opportunity to document assets and relevant information and start the corresponding data model with the construction of the heating network.

5.3 Damage Assessment, Status Assessment and Evaluation

Discussions with network operators in the IEA DHC TS6 Project and in Germany show that, in case of a damage, the utility company's focus is on repairing the damage. Investigating the cause of the damage is of secondary importance. In this context, it has also become apparent that companies use different definitions for a damaging event and that events are often only assessed if the supply must be interrupted to repair the damage. However, to use predictive maintenance approaches in the future, it is important to record all events, assign them to components or materials, and evaluate them if they restrict the functions and operability of the equipment [8]. Only with reliable information and training data for damage detection can AI-based algorithms be created that increase the reliability of predictive maintenance forecasts. Further, associated with the function ability end of life criteria must be defined in terms of mathematical values - in order to allow calculation for forecast.

The condition assessment and evaluation of the pipe systems used in heating networks forms the basis for maintaining security of supply while implementing climate goals during ongoing operations. Suitable methods for status assessment and evaluation must be adapted to the requirements and capabilities of the used pipe systems. The expansion and conversion of existing networks provide an opportunity to generate additional asset information when working on the pipelines of the heating network (e.g., when increasing the number of connections). In addition, documentation should be improved when constructing new assets.

5.4 Key Performance Indicators and Target Values in the Asset Management of District Heating Pipe Systems

Key performance indicators that take technical, economic, environmental, and social aspects into account in the decision-making process are already being used in asset management today. In [29], 11 key performance indicators were proposed on the basis of a literature review for asset management of district heating pipelines (see figure 4). Discussions with DH companies revealed that, in addition to the data required to determine the indicators, target values or empirical values are also needed in order to use these or similar indicators in practice.

KPIs	Category				Type		Target value / target range
	Technical	Economic	Ecological	Social	Informative / Evaluation	Complexity	
Pipe length acc. to installation system	X				Informative	low	-
Age structure / average age	X				Informative	low	-
Service life	X	X	X		Evaluation	medium -high	Ongoing research work
Substance value	X	X	X		Evaluation	low	40% - 60%
(Age-specific) Failure rate	X	X	X		Evaluation	low	To be defined DVGW values possibly too high
Heat losses	X	X	X		Evaluation	high	To be defined 10-15% in survey
Water losses	X	X	X		Evaluation	high	1 Network's volume (AGFW)
Supply reliability	X			X	Evaluation	high	To be defined
CO_2			X		Evaluation	high	To be defined
OPEX (operational and maintenance costs)		X		X	Evaluation	low	To be defined
CAPEX (investment costs)		X		X	Evaluation	low	To be defined
(Temperature level)	X				Informative		-

Figure 4. *KPI list developed in the research projects SAM-FW & IEA DHC TS6, source: 3S Consult*

Until now, security of supply, quality of supply, and economic efficiency have been the main factors influencing asset management decisions. As shown in Figure 4, target values or target ranges for the developed KPI´s are missing. The implementation of legal requirements for sustainability in connection with the European Green Deal, such as the Circular Economy Act [41] or the Corporate Sustainability Reporting Directive [42] and Corporate Sustainability Due Diligence Directive [43], are increasing the importance of sustainability in the evaluation of asset decisions. Suitable criteria must also be developed for this purpose.

All in all, the exchange between utility companies and academia is considered necessary for the implementation and use of indicators.

6. Conclusions

Existing district heating (DH) systems, their transformation and expansion, as well as newly build systems are essential for achieving European climate goals. Asset management of DH pipes provides the financial framework for a reliable, affordable and ecological heat supply. Existing district heating systems have individual characteristics that are reflected, among other things, in the technical operating parameters (e.g., temperature and pressure) and the pipe systems used. Assessing and evaluating the status and residual service life of the respective pipe systems in the asset management of DH companies is a challenging task due to the multitude of factors involved. This paper presents general facts and various influences on the service life of individual pipe systems. Using a practical example of 14 heating networks in Germany, it was shown that the average network age of the pipelines is below the normative minimum service life of the pipe systems. Furthermore, it was emphasized that pipe systems in operation can significantly exceed the minimum service life if the known European and national standards for the construction and operation of heating networks are complied with. As a result, the asset information available today allows simulation models to predict maintenance requirements with sufficient accuracy. As the pipe systems age, the need for targeted maintenance measures for the pipe systems used will also increase.

To implement the European climate neutrality goals, the requirements regarding security of supply and the service life of existing heating networks form essential planning principles on which a resilient, climate-neutral, and cost-efficient heat supply can be built. In addition, changes in operating conditions due to the integration of available renewable energies and waste heat, as well as the implementation of the EBPD in existing buildings, will also affect the operation of heating networks. Both the approaches in [18] and in [19] predict that these changes will result in far-reaching, investment-intensive measures in heating networks. Even though the effects of implementing climate goals on heating networks are challenging, appropriate processes must be developed in the design of European framework conditions due to the increasing service life, high investments, and consistent requirements for security of supply when implementing climate goals during ongoing operations.

Finally, this article has shown that DH operators require reliable asset management tools to implement the European climate goals. The increasing demands on the reliability of forecasts in asset management simulations are keeping pace with technological progress. The two research projects IEA DHC TS6 and SAM-FW are working to pool existing knowledge at the international level and identify improvements in the asset management of pipe systems. However, in addition to the contributions of researchers, implementation and practical experience from utility companies are also necessary to further develop existing asset management approaches for designing resilient, climate-neutral, and affordable heat supply systems.

Author contributions

Stefan Hay: Conceptualization, Investigation, Methodology, Writing – original draft, Validation. **Raphael Schenkel:** Writing – review & editing. **Christian Engel:** Writing – review & editing. **Anna Marie Cadenbach:** Writing – review & editing. **Andreas Leuteritz:** Writing – review & editing. **Pakdad Langroudi:** Writing – review & editing. **Ingo Kropp:** Writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

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