03.08.2021

O3.2: Methodology for strategies to implement LTDH

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Abbreviations

CHP- cogeneration heating plant

COP- coefficient of performance (used mainly for heat pumps)

DH – District Heating

LTDH- Low Temperature District Heating

RES- renewable energy sources

Introduction

District heating (DH) systems are designed to be adapted to reduced energy needs which have been or are accomplished in the past years by innovative heating technologies and energy efficient buildings. Thus, DH systems and technologies must be further improved and adapted to decrease grid losses, exploit synergies and thereby increase the efficiencies of low-temperature production units in the system. The successful implementation of these techniques shall be pointed out, discussed and promoted within though the installation of a low-temperature grid within the involvement of the key stakeholders in fact including the expertise (e.g. DH operators, heat suppliers, energy planner, energy agency) and the public bodies with an emphasis at the municipality level.

The implementation of low temperature District Heating (LTDH) systems needs to be embedded in an overall energy strategy, which investigates and displays the possibilities on how to apply such a system. These energy strategies need to take into consideration both most common framework conditions of particular region or district (such as climate conditions, building heat consumption, available energy sources etc.) and innovative solutions for efficient heat production.

This methodology describes the main steps to create transferable energy strategies and their application at municipal level in fact providing guidelines for efficient district heating system implementation with lower temperature in the distribution networks. The proposed methodology provides specific working steps for energy planners in municipalities on how to compile an energy strategy. This includes area analysis, stocks evaluations (i.e. buildings, density, supply, energy demand), potentials for increasing energy efficiency and diminishing consumption, resolving the technical preconditions and requirements of district heating, profitability assessment etc.

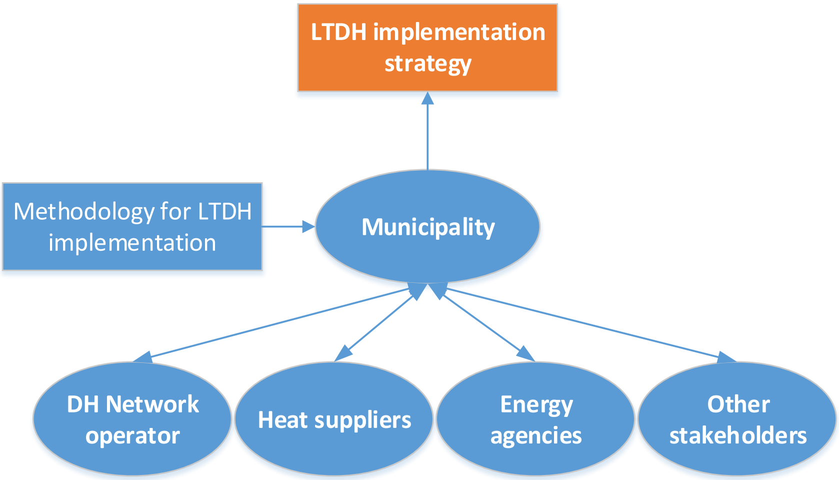

Figure 1. Main target groups of the methodology

The DH development strategy should be developed in close cooperation with the municipality and relevant stakeholders (see figure 1) as there are steps that cannot be implemented without the support of heat supplier or DH network operator. Nevertheless, municipality has an important role in transformation process as it has necessary tools to ensure legislative framework, identify long term goals for particular area and ensure communication between heat supplier, developers, consumers and other interested parties.

1. Transformation process dynamics

The necessity of changing the operational conditions of DH system arises because of rapid decrease of residential building heat consumption due to renovation process as well as for the adoption of energy efficiency measures/strategies and (re)construction works. Therefore, newly built buildings have an higher energy efficiency performance therefore heat density in newly built areas decreases. This situation leads to the necessity to change the operating conditions of DH system and thus shift the focus on how more consistently use of renewable energy sources in order to ensure both a feasible heat production meantime reducing the overall environmental impact (Rämä & Sipilä, 2017).

One of the lately discussed solutions for DH companies to adapt to the new conditions is oriented towards the reduction of the supply water temperature. The low temperature DH (LTDH) system concept provides innovative solutions in all three DH system components – heat source, heating network and heat consumer (Schmidt et.al, 2017). There is no single solution for all DH systems to lower the heat carrier temperature and raise the overall operational efficiency. Hence, it requires a careful strategic planning process toward the sustainable development of new generation type DH system.

The development of DH system should be consistently framed within the municipal energy planning process. Municipalities have an important role to shape the transformation process and set the strategic long-term goals toward an efficient and CO2 neutral heat supply (Neves et.al, 2018).

For all these reasons this methodology aims to present the steps for a detailed analyses of existing DH system, future heat consumption forecasting in order to select of most suitable transformation pathways towards a more efficient heat supply by introducing LTDH concept. In the following parts the approach useful the municipal transformation management is described as a cyclical process implemented in several consequential steps. (Riechel et.al, 2017)

In each step recommendations for specific actions and/or analysis to be performed are added. However, in practice, the explained steps cannot always be clearly separated and it may happen that action are parallel or even alternated. Management generally means a concrete organizing of tasks and processes. However, the management of the transformation process is more than an assignment of responsibilities and steps. It is rather a collective process on search, experimentation and learning. Responsibilities and the involvement of specific actors as well as the operative methods or tools within the steps need to be reviewed during the process.

The model of municipal transformation management towards LTDH is characterized by an interplay between different levels and scales of optimization moving from district (or parishes) till the overall city dimension. At the city level, the focus lies on opening up for new visions of the future and the collective research for possible technical and organizational transformation paths. Therefore, solutions need to be defined to lead to the transformation of the urban heat supply system, rather than the application of ready-made solutions. This must be done on the basis of a system and stakeholder analysis.(Riechel et.al, 2017)

This methodology suggests the continuous reflection of particular steps to achieve the general transformation goals, including review, adaptation and concretization of the targets. Therefore, it can result in additional steps or skipping some of them in order to customize the strategy development process. If it becomes clear in the conceptual development of strategies and measures that technical or economic parameters are not correct or there is no interest in their implementation, alternative transformation paths should be considered. In other words, the transformation process should be open and flexible. (Riechel et.al, 2017)

In Figure 1.1 is reported the conceptual scheme of the proposed methodology to better implement transformation strategies to move towards LTDH implementation at municipal level.

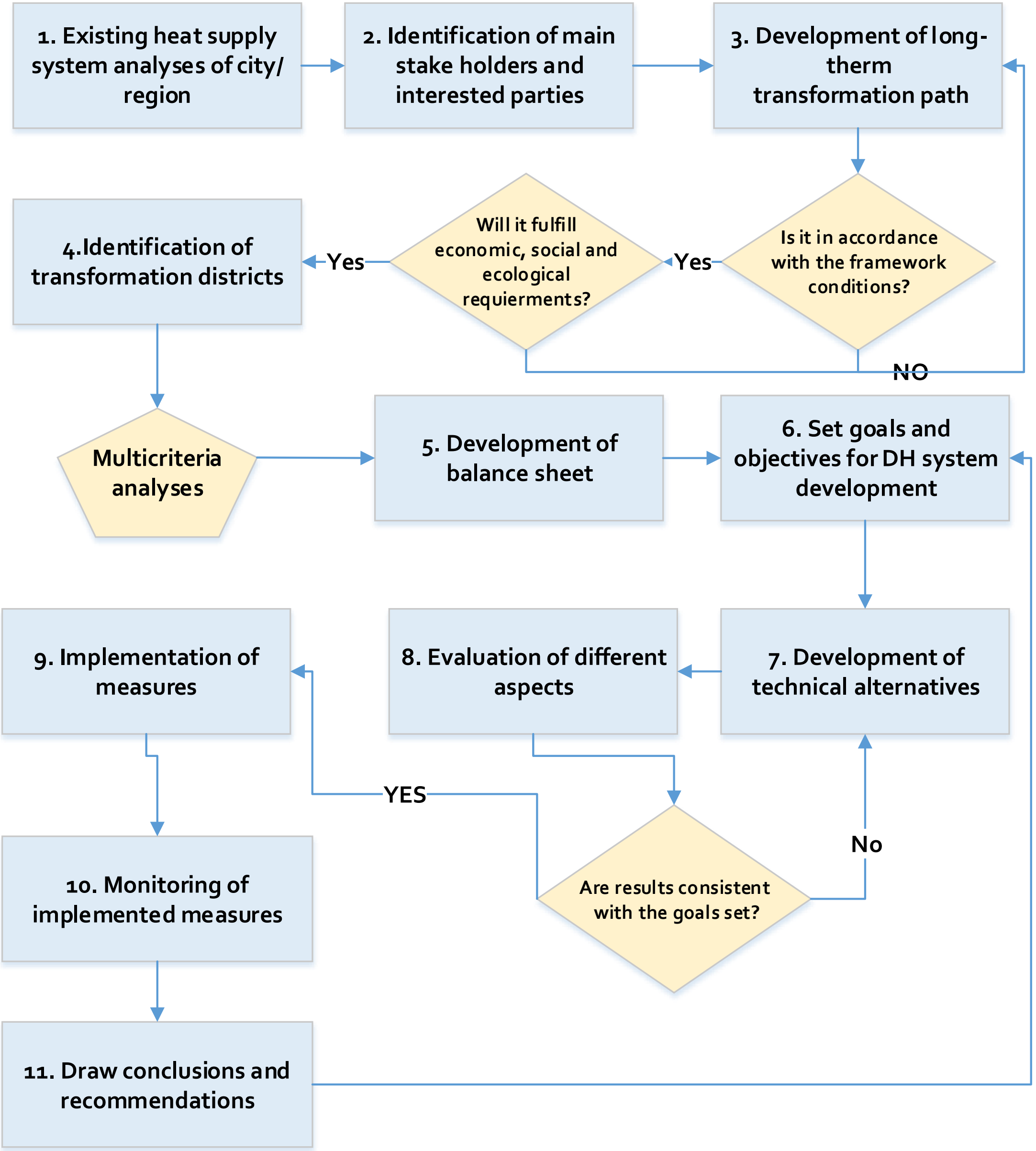

Fig.1.1. Transformation process dynamics (Riechel et.al, 2017)

2. Analyses of preconditions

Action performer: *Municipality with help of experts*
Involved stakeholders: *Heat suppliers and operators of DH networks, Utilities Companies, Building agencies, Largest industrial enterprises*
Outcome: *Report on preconditions analyses*

Within the implementation of the DH development strategy towards LTDH system it is crucial to analyse different heating supply system parameters. The whole city or region should be thus investigated by taking account regional differences and key needs. Therefore, this overview should allow identifying the aspects that has not been strengthened yet and would affect the focus of the transformation process. The evaluation of the interaction between buildings and supply systems is crucial for further strategy development to optimize the operation and extension of heat supply system. (Riechel et.al, 2017)

2.1. Analysis of existing planning documents

The DH development strategy is a tool for planning and prioritising different development and investment pathways for local heat demand and supply. Analyses of existing strategic planning documents can be useful material for further transformation process. Therefore, the values regarding energy consumption and CO2 emission levels presented in the strategic plans can be used as a benchmark for further evaluation of transformation process. It is important to evaluate the depth of existing situation analyses in the planning document (Chittum &Østergaard, 2014).

The strategic energy plan and the relied transformation pathways should be aligned with the national energy objectives and targets including long-term goals. Therefore, it is important to identify the analysed development scenarios stated in the strategic planning documents. If those goals are comprehensive, then they could be further adjusted to the LTDH planning and implementation process.

In this light, the evaluation process should also include the implementation phase aiming to control until which level the ideal plan has been fulfilled. If the goal reaching rates are low it is useful to understand the causes and problems which need to be taken into account when preparing a new strategic document (Mirakyan &De Guio, 2013).

Most of the energy planning documents contains scenario analyses of different future. The starting points for the local analyses usually are the oriented towards the identification of targets at the national levels implemented in local and regional context by local politicians (Delmastro et.al, 2017).

In fact, it is key that strategic district heating planning involves collaboration with stakeholders, within and between cities, regions and central government. If the stakeholders and interested parties have participated in the development process of strategic plan this can bring a clear view on common goals, which can be further adjusted in the low temperature DH strategy.

2.2. Technical preconditions

Locations and performance of energy generation plants

Conventionally, DH heat is generated in larger or smaller production units, which can be divided in heat-only boilers or cogeneration plants of electricity and heat (CHPs). There are technologies for heat generation such as utilization of environmental heat (i.e. solar, water air) or heat pump can be integrated in large or small DH systems.

When analysing the DH system in particular district, city or region it is important to identify all heat plants including CHP plants. The main parameters to be analysed among the others are the location of heat plant, the used energy source, the plant heat and power capacity, the boiler capacities, the depreciation of technology. To more precisely determine the overall impact from heating network lowering on the overall plant efficiency it is also important to identify if there are flue gas economizers or thermal energy storage systems used in the heat plants.

Important indicators that can be determined to compare or evaluate the heat generation are the heat plant efficiency, the capacity utilization factor, the coefficient of performance (COP) of heat pump, the specific produced electric power in CHP, the specific production costs etc. (Neves & Leal, 2010).

The changes in the heating network temperature will also reflected on the heat generation. A common way to increase the efficiency in heat plants and CHPs is to install a flue gas condenser. When flue gas condensation is present, it is beneficial to have a low return temperature, as the heat extraction is more efficient. In CHPs, electricity is generally seen as the main product. The heat extracted from this process may thus to some extent be seen as heat recovery of excess heat. In addition, CHP plants benefit from a low return temperature, because this enables an increased electrical output from the plant. (Li & Wang)

Heat distribution networks and district transfer stations

Heat distribution networks have a large impact on the overall DH system performance; therefore, it is important to evaluate the various heating network parameters. Heating network consist of insulated differently sized pipes through which the heat is transported from heat source to consumers.

The heating network is dived in primary and secondary networks by heat transfer substation in which heat exchangers are located. Nevertheless, there is DH systems were heating network is directly connected to consumers pipe system (Tol & Svendsen, 2012).

For the primary evaluation, it is important to evaluate the heating network plans, and if necessary the primary and secondary network, heat distribution and district transfer stations. Another important parameter is the connection rates of quarters or districts to the respective supply network. (Riechel et.al, 2017)

Therefore, the wastewater treatment system should also be included in the precondition analyses as sewage pipelines can be as an energy source for low temperature heat supply.

Related network analyses

When planning to introduce intermittent renewable energy sources into heat or power supply it is essential to ensure the flexibility of energy supply. In this direction, the LTDH system concept defines the heat supply system as integrated part in overall smart energy system (i.e. with integrated smart electricity, gas, fluid and thermal grids). The supply concept for future energy provides the opportunity to combine smart electricity grids as well as smart thermal and smart gas grids in order to coordinate energy flows and to identify synergies between them (Lund et.al, 2014). This allows achieving an optimal solution for each individual sector as well as for the overall energy system.

To develop such complex system, it is important to obtain detailed overview of all integrated components. Therefore, an in-depth analysis should include plans of low and medium voltage power grid and transformation stations, plan of the gas network with individual pressure stages and pressure control systems and other relevant information.

2.3. *Urban preconditions*

Regional settlement structure and heat demand densities

Heat consumers represent the main factor determining significant parameters of DH system operational conditions. Therefore, it is important to accomplish a detailed overview of the existing and potential heat demand despite the challenge of data availability and collection.

When analysing the settlement structure of the region or city it is important to mark the different types of buildings (apartment buildings, family houses, public buildings, industrial areas etc.) as they have different heating regimes and heat demand requirements. This allows identifying the areas with highest heat (and population) density, the potential waste heat sources (e.g. data centres, industrial objects, sewage plants) or buildings with heat load management potential (e.g. swimming pools) which is important for planning DH system development. (Riechel et.al, 2017)

For a detailed overview, it is also helpful to collect building age, depreciation periods and upcoming investments in the technical infrastructure and buildings (approximately at district level).

Location of potential construction and/or deconstruction residential areas

Both new and existing buildings can be connected to a LTDH. Nevertheless, it requires longer period to lower heating network temperature in existing district heating areas. In new areas with new-built low energy houses, low temperature district heating systems should always be considered. Energy efficient buildings with low temperature heating systems (under-floor heating or low temperature radiators) make LTDH system particularly suitable (Kaarup et.al, 2014). Therefore, it is essential to identify location of potential residential areas and their future heat demand requirements to plan the most sustainable heat supply for such buildings.

At the same time the reconstruction of specific areas have an important impact on the overall DH system as heat density reduces. This aspect needs to be included in the strategic development plan.

3. Stakeholder analyses

Action performer: *Municipality*

Involved stakeholders: *Energy and Public Service Companies, Housing Companies, Largest industrial enterprises, Private owners and investors, Energy agencies/planners*
Outcome: *List of stakeholders*

It is important to carry out an actor analyses that allows determining which actors are relevant in the case of a specific region or city. Different actor's types are in fact involved within transformation processes (Gustafsson et.al, 2015). The main stakeholders who have a significant influence on the direction and rapidity of the local transformation because of their decision-making powers are:

- Energy suppliers;
- Housing companies;
- Private owners, investors etc.
- Public authorities and public service companies (sewage companies, waste companies)

Actor's analyses should include also the specific focus of customized actions in order to better address resources and thus better evaluate the possible influence of specific transformation processes. Often there are key persons (alias "champion)" which could offer new impulses on promoting transformation process within innovative ideas. Other aspects should be also taken into account such as different interests, conflicts or tensions between the key players, lack of important organizational structures etc. (Riechel et.al, 2017)

There are several benefits of stakeholder participation in strategy development process. First, it is possible to include a broad range of perspectives and knowledge in the process. Secondly, it contributes to a transparent process where stakeholders can more easily follow why particular decision has been made. Moreover, it is possible to develop and come to an agreement to common goals among actors. Goal agreements can be difficult because different actors have different agendas, goals and different approaches to have a profitable business. On the other hand, it is often stated that the formulation of the common document is not the goal. The real outcome is the process where actors meet, discuss and share knowledge and perspectives with each other. For successful process implementation, the municipality needs to clarify how the different actors will benefit from participating in the processes of developing strategies. (Gustafsson et.al, 2015)

4. Institutional and organizational framework

Action performer: *Municipality with help of experts*
Involved stakeholders: Heat suppliers and operators of DH networks
Outcome: *Analyses of Institutional and organizational framework*

Another important aspect affecting transformation process is the institutional and organizational framework of the DH system. There are different companies' business areas (heat production, heat distribution or combined), ownership and regulation policies, therefore, also the transformation "pull & push" motivations are different. (Riechel et.al, 2017)

The institutional framework of DH Companies differs in each country. Private stakeholders, municipalities or other government institutions, can own it. Nevertheless, in Denmark, DH system operator is a non-profit organization. Therefore, such organization has different interests in DH system development in future.

When DH operation is embedded in a business model, it is important that the integration of LTDH or renewable energy sources can be economically beneficial. Therefore, technological solutions should either be competitive with other heat generation and distribution alternatives or municipalities should use different mechanisms to gain environmental benefit.

5. Analyses of strategy pathway for transformation

Action performer: *Municipality with help of experts*
Involved stakeholders: *Het production and distribution companies, Energy agencies, Building developers, Largest enterprises*
Outcome: *Confirmed decision on transformation pathway*

After the described detailed analyses of existing system and possible development alternatives, it is necessary to set the long term goals for city or region which can further shape the transformation path for district level. There could be various future scenarios for heat generation and distribution by taking into account the framework conditions such as changes of local heat supply, stakeholder impact, technological development, guidelines for energy planning etc. Those scenarios should be consistent with the broader scale policy planning documents and specific regional or national targets and objectives. Therefore, the most suitable transformation should be evaluated under technical, economic, ecological and social aspects in connection to local conditions and higher level planning documents.

Low temperature district heating requires innovative solutions and a comprehensive view of the current situation. Thus, the defined development scenarios should include new heat supply solutions. A scenario can be defined as a description of a possible future situation, including the path of development leading to that situation. Scenarios are not intended to represent a full description of the future, but rather to highlight central elements of a possible future and to draw attention to the key factors that will drive future developments. There should not be more than 4 to 5 development scenarios to fully to track their common and distinctive features, and to measure the benefits and losses (Kosow & Gasner, 2008).

When analysing the development of building heat supply system, in general there are two main directions for heat production: local heat supply by individual heat solutions (her after called as "*Thousand flowers*" scenario) or heat supplied by DH. The *Thousand flowers* scenario is a bottom-up approach focuses on decentralized solutions to energy problems (Barton et.al, 2018) – see Figure 5.1.

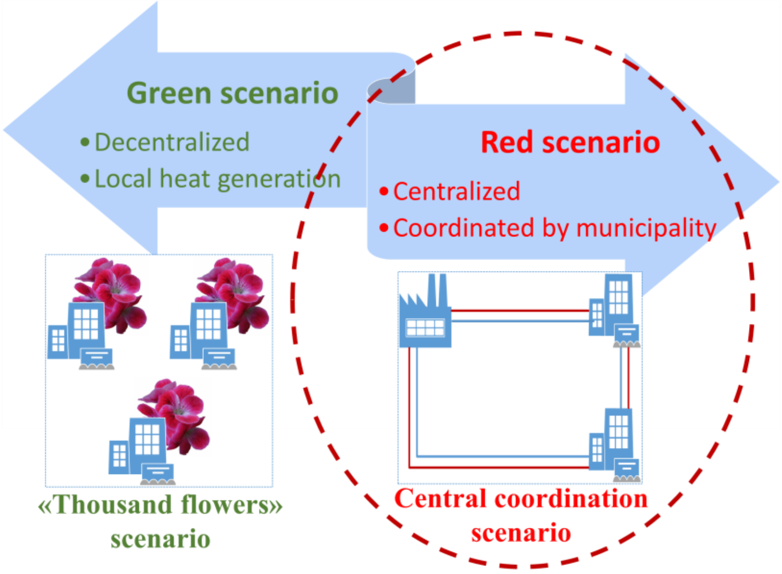

Figure 5.1. General development scenarios for DH system

In *Thousand flowers* scenario, each building chooses the most preferable heat source and heat generation technology. On the other hand, there is *Red scenario* with DH as a heat source. Therefore, large scale heat plants and heating network allows the system work more efficiently and be flexible when integrating renewable energy sources. Moreover, further concepts can be seen as a mixture of both scenarios making consumers „prosumers" with the local infeed of own heat productions and the hybrid connection between heat, power, gas and water systems.

The main aspect for choosing the DH system scenario is the heat density of particular area. If the heat density is very low, heat losses in heating network and specific operation costs become too high to compete with the individual heat solutions. The minimum heat density value for efficient DH operation depends on several aspects such as heat losses, heat costs, investments for alternative heat solutions etc. This methodology analyses the transformation from existing DH system to LTDH, which can ensure lower heat losses as well in low-density heat areas. Therefore, local heat generation in buildings is not further analysed as a solution for DH development.

Most recent development trends of energy supply systems indent to combine all energy supply systems (heat, power, transport fuel etc.) in order to reach the common goal of a CO_2 neutral economy. Therefore, building heat consumption reduction is a crucial task in order to ensure the more efficient use of energy (Ziemele et.al, 2017).

The main aim of the transformation process is the conversion and expansion of local and district heating supply in neighbourhoods towards low-temperature systems. The requirement for this is, as with all local and district heating systems, a comparatively high heat density in order to keep the development costs under feasible control. Therefore, the transformation path and relevant technological solutions will depend on the several aspects such as: building heat requirements, desirable heating network temperature level, heat source and heat generation technology etc. (Riechel et.al, 2017)

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Table 5.1. identifies the potential applicable and desirable main transformation processes for different types of buildings. First, there are limited possibilities in existing building areas with high heat requirements and high temperature space heating systems (radiators) to lower the heating network temperature. Nevertheless, it can be done to certain point by using temperature optimization programs or adjustment of the heat substations (Tunzi et.al, 2016). Consequently, the use of renewables is also limited. The most suitable CO_2 neutral energy sources would be biomass and biogas which can be easily used in CHP or heating boilers.

The heating network temperature can be lowered further if the buildings with high heat requirements are using low temperature heating systems (floor, wall heating or forced air radiators) or in mixed building areas with both renovated and non-renovated buildings. Such areas are suitable for use of energy cascades when return water flow is used as a supply flow in energy efficient buildings (Köfinger et.al, 2017) giving to renewables to become more attractive in such areas. Therefore, high potential waste heat should be evaluated as a priority if there are such energy source (Fang et.al, 2013).

The most significant reduction in heating network temperature can be reached in newly built and/or renovated efficient building areas with low heat requirements (Hesaraki & Holmberg, 2013). Reduction of heat supply temperature below 60°C allows using cost effective plastic pipes and integrating different renewables into to the DH system. Temperature can be reduced even further in the passive house areas with a very low heat consumption. However, there are several solutions that need to be used for safe domestic hot water supply when heat temperature is below 60°C. The hot water requirement remains largely constant, regardless of the energy-related modernization status of the building. Depending on the standard of modernization, it has a share of around 10% (non-modernized) to around 40% (modern building energy standard) of the heat demand of a building. In the case of passive and zero-energy houses, the share of energy demand for water heating is increasing in relation to this (Yang et.al, 2016).

On the building side, the focus lies on the existing buildings. Buildings that have being built today already have a very low energy requirement due to the requirements to accomplish the national energy consumption regulations. In the future, the energy requirements for new buildings will be further tightened, so that a separate heat supply system is not necessary. The transformation potential of existing buildings depends on the building typology and the building age. Even some types of existing buildings can be upgraded to the passive house standard. However, the level of energetic upgrading depends on historical value of the building, preservation aspects and on the budget of the owner.

In this light, further technical options in the building should be considered. In particular, the interaction of future heat supply systems with the energy needs of the buildings should be kept in mind. For example, a future lowering of the flow temperatures in local or DH systems is only possible if it meets the absolute heat requirement of the building decreases and the technical requirements in the building. Special attention should be paid to the adaptability of the buildings and their internal heat distribution system. This includes, for example, the adaptation of radiator sizes to the complete change from radiators to underfloor heating in floors or walls. If such rebuilding measures cannot be done – both financially and organizationally – also simple measures such as hydraulic balancing or more efficient pumps can make a contribution to achieving the goals.

With the participation of all relevant local players, common guiding principles for the local heat supply change can be designed. This gives a strategic orientation in technological, organizational and institutional terms. It serves as a long-term guide for joint political action and results from the joint search for a locally suitable transformation path.

When the main heat supply development scenarios have been approved, it is necessary to prepare the guiding principles for local heating system transformation. This should be done by the participation of all relevant stakeholders. Such document shapes the political action and helps in search for a locally suitable transformation path

Table 5.1. Overview of transformation paths for different types of buildings

Building area type	Heat requirements	Flow temperature	Technical solutions for heat delivery	Favourable energy sources	Conversion technology	Adjustments for SH	Adjustments for DHW	Environmental benefits	Assessment
Existing building area with HTHS	High	>70°C	Temperature optimisation Adjusted heat exchangers	Biomass Biogas Fossil fuels	CHP Heating boiler	Existing high temperature radiators	No necessary	Reduced heat losses Use of high potential waste heat	Temporary path. until building heat requirements are high
Existing building area with adjusted LTHS	High	60-70°C	+ Energy cascades Use of return flow for heat supply	High potential waste heat Solar energy Biomass Biogas Combined energy sources Fossil fuels	CHP Heating boiler Solar collectors	Adjusted low temperature radiators or underfloor heating Adjusted heat exchangers in substation		+ Increased efficiency of flue gas condensation Higher power output on CHP	
Mixed building area or renovated building area with HTHS	Medium					Existing high temperature radiators			
Newly build and renovated building area with adjusted HS	Low	<60 °C	Use of plastic heating network pipes Use of direct connection for space heating Increased pressure in heating network Adjusted heat substations Short-circuit flows Proper by-pass design	Low potential waste heat; Environmental heat (geothermal field, large bodies of water, pits. soil, water, air); Solar energy RES renewable electricity Biogas Synth. methane Hydrogen Biomass	Heat pump Power-to-heat Solar collectors Condensing system technologies CHP	Under-floor heating Low temperature radiators Forced air heating systems	Proper design of in-house DHW preparation and distribution systems Low-temperature water treatment	+ Higher coefficient of performances in heat pumps; Increased utilization of geothermal heat; Higher conversion efficiencies in central solar collector fields; Reduced heat loss in thermal storage units Greater utilization of thermal storage units	Requires strategic planning and negotiation between involved parties
Passive house area	Very low	<50°C							

5.1. Building heat requirements

Evaluation of future heat demand of buildings

The performance of buildings energy consumption depends on a number of factors such as the performance of the installed heating system and building envelope, climatic conditions, behavioural characteristics (e.g. typical indoor temperatures) and social conditions (e.g. fuel poverty meaning that not all buildings are used at maximum capacity). Despite different improvements in, for instance, heating systems, there is still a large saving potential associated with energy efficiency measures in residential buildings.

The major factor that determines progress tendencies of buildings heat consumption is the age of the structure. In the residential sector, the age of a building is likely to be strongly linked to the level of energy use for the majority of buildings that have not undergone renovation to improve energy performance (see Figure 5.2).

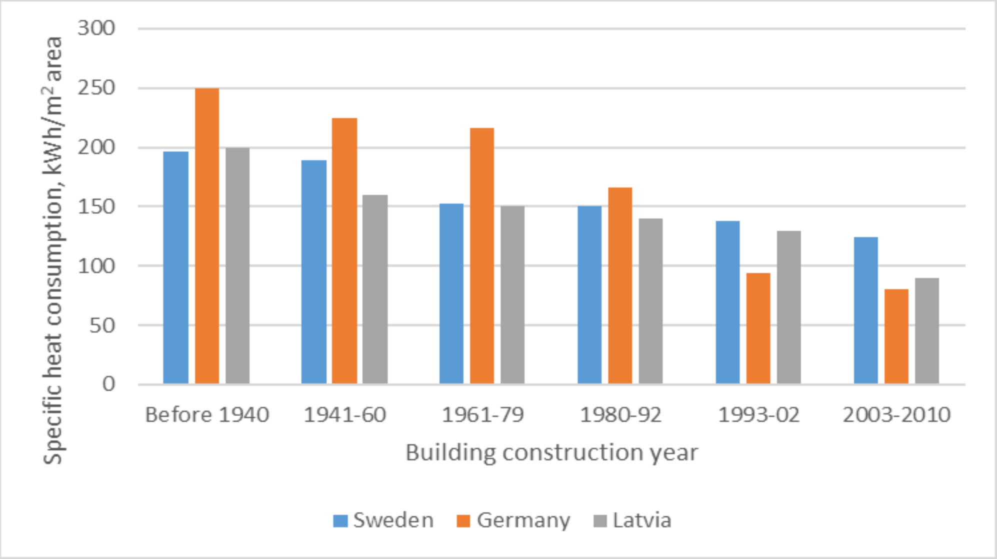

Figure 5.2. Specific heat consumption dependency of building age in different countries (Lapillonne et.al, 2012.)

Only in the nineties energy efficiency policies for buildings and energy using goods (e.g. minimum performance standards and energy labelling) were introduced at EU level. More recently, the EU has started to require that countries meet certain targets for energy efficiency and set up comprehensive overall policy packages (Lapillonne et.al, 2012.). This must be taken into account when setting up a local strategy and/or transformation path.

This factor must be considered when planning progress tendencies of heat supply systems. In next year's these buildings need to be renovated, what would noticeably reduce heat consumption and mostly demand for heat energy.

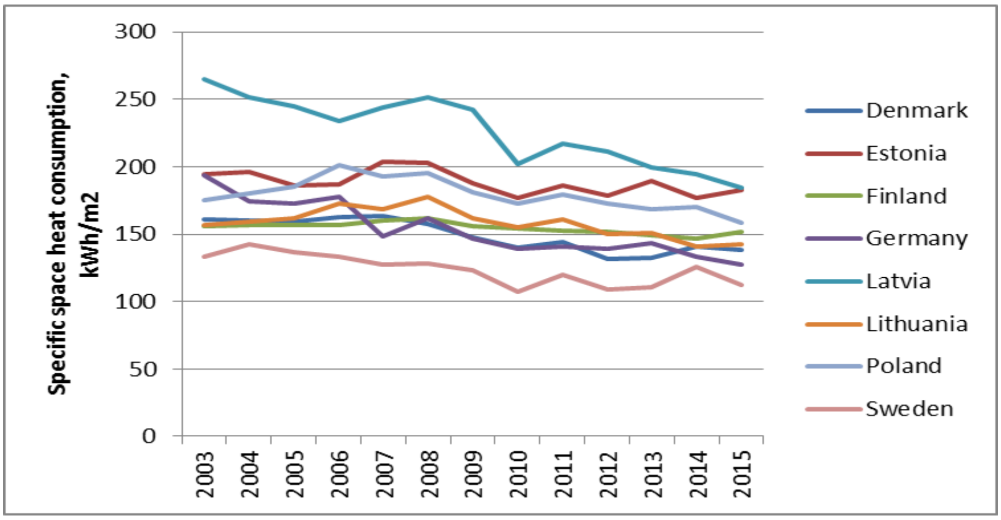

Figure 5.3. Changes in average specific space heat consumption in existing and newly built buildings in different countries (ODYSEE, 2018)

Legal heat consumption requirements

Energy efficiency requirements in buildings or energy standards for new buildings are therefore among of the most important single measures for buildings' energy efficiency. Building efficiency standards often serve as the efficiency target for refurbishment or other improvements of existing buildings.

There are different approaches for heat consumption requirements in newly build and renovated buildings in European countries. Several countries have determined the maximal allowed heat consumption for space heating in different type of buildings (for example, 70-90 kWh/m^2 in Baltic Countries) (Regulation on the Latvian Construction Standard, 2015) In Sweden, different climate zones have been identified and heat consumption regulations differs in each of zone. In addition, there are different regulations depending on heat source used for heating purposes. Lower heat consumption should be achieved in buildings with electrical space heating. In Denmark, allowed maximal heat consumption depends on building area (Lapillonne et.al, 2012).

Nevertheless, there is also a growing trend for zero energy or passive house construction. Such efficient buildings allow minimizing exploitation expenses and decrease the negative environmental impact, however costs of construction of such buildings are much higher.

The regulations of building energy efficiency can give an insight in future development trends of total heat demand as such values should be reached when planning refurbishment or energy efficiency measures in building.

Implementation of energy efficiency measures

The energy performance of a building can be improved by the implementation of a single measure, such as the insulation of the roof space of change of windows. Typically, energy savings of up to 30%

might be expected by the application of one to three low cost/easy to implement measures. In other cases, renovation might involve the wholesale replacement or upgrade of all elements that have a bearing on energy use. The reduction of the energy needs towards very low energy levels (i.e. passive house standards, below 15 kWh/m² and year) will lead to the avoidance of a traditional heating system.

Table 5.2 shows different categories of renovation and average total project costs for energy efficiency measures, expressed in €/m² floor area. The costs reflect the total installed costs of measures, i.e. materials, labour and professional fees. When estimating the potential heat reduction after building renovation it is meaningful to assume that existing heat consumption for space hating will reduce from 20 to 60% depending on renovation depth.

Therefore, another important variable that needs to be taken into account is the renovation rate, which shows how fast the renovation process takes place. There are several aspects influencing this rate such as legislative framework, available economical support, building owner structure etc. The ownership of buildings has a bearing on the rate at which renovations are undertaken and the depth of the energy savings measures that may be included in renovation projects (Economidou et. al. 2011). Arguably, the public sector should be taking the lead in 'deep renovations' and its large portfolio of buildings provides many opportunities for economies of scale. Private owners may be reluctant to act early and may require encouragement, incentives and regulations to stimulate reasonable rates and depths of renovation.

Table 5.2. Potential savings from different types of building renovation (Economidou et. al. 2011)

Renovation type	*Final energy saving (% reduction)*	*Indicative saving (for modelling purposes)*	*Average total project cost (EUR/m²)*
Minor	*0-30%*	*15%*	*60*
Moderate	*30-60%*	*45%*	*140*
Deep	*60-90%*	*75%*	*330*

The question of tenure is another key factor that influences the willingness and ability to take action on renovation measures and to improve energy performance in the residential building stock.

5.2. Energy sources

There are many different fossil and renewable heat sources and technologies for thermal energy production. The choice of most suitable energy source depends of several criteria and priorities. Nevertheless, the transformation toward LTDH allows extracting low potential heat (excess heat from industry, geothermal heat, solar thermal energy, environmental heat etc.) more efficiently. Therefore, it is important to identify low temperature heat sources, which can be recycled for DH purposes as it can bring important environmental benefits.

Figure 5.4. shows the comparison of different energy sources and corresponding technology for low or high potential heat generation. As can be seen, the waste heat from industry or other sectors

should be used as a priority. However, such heat is instable or temporary, and mainly low potential with high temperature variations (usually below 80-70°C). It can be used directly in LTDH system or converted to high potential heat (below 70-80°C) by using heat pump used in standard DH system. Therefore, waste heat fluctuation requires careful planning process and combination with more stable heat sources.

If there are no opportunities to use waste heat, it should be considered to use other renewable energy sources for heat production such as solar collectors or geothermal energy. When considering large-scale solar thermal systems one should identify available land space for collector field and accumulation system. Main challenges for use of shallow geothermal energy is the permissions necessary for use of this energy and the lack of knowledge on deep geothermal energy. Lower DH temperature allows to use environmental heat from air, water, sewage or ground more efficiently, therefore, when using heat pump technology it is important to evaluate the operation parameters as power consumption and related emissions and COP.

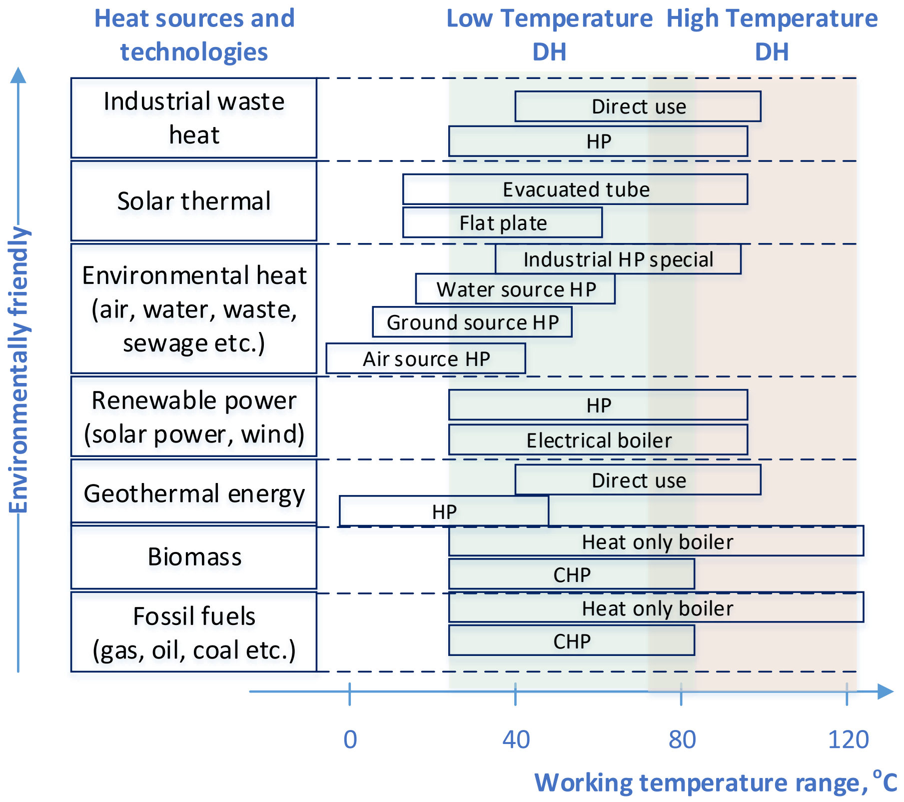

Figure 5.4. Comparison of different energy sources and heat generation technologies (Sayegh et.al. 2018)

Lately discussed solution for increased renewable energy source flexibility and cost-effectiveness when electricity price is low is the power-to-heat concept, which provides the heat generation from surplus power when electricity demand and price is low. Therefore, heat can be produced from solar or wind power via electric boilers or heat pumps.

Another important renewable energy resource widely used in Baltic countries is biomass (wood pellets, wood chips, straw etc.). The use of wood biomass as an energy source requires strategic planning for sustainable use of local resources. Both biomass boilers and CHP plants are commonly used for heat generation.

The environmental benefit from renewable energy sources presented in Figure 5.3 is indicative as it strongly depends on local parameters and particular technological aspects. Nevertheless, it is clear that transformation should be from fossil fuel use towards integration of renewable energy sources or waste heat.

6. Initial district identification

Action performer: *DH operator or Municipality with help of experts*
Involved stakeholders: *Building developers, building owners, largest enterprises*
Outcome: *Analyses on different initial district evaluation and decision on most suitable initial district identification*

In order to realize the transformation process of the DH system it is necessary to identify the suitable area for the specific measures, activities and innovative technologies. This step requires switching from the regional or the overall municipal perspective to the particular smaller pilot case/s. Several aspects and criteria needs to be taken into account in order to select the most suitable area for the transition.

One of main criteria is the energy efficiency and renewable energy integration potential. When comparing different districts one should evaluate if the building and heat consumption density is suitable for implementing heat supply network. If not, maybe it is possible, to increase the density by integrating new heat consumers or equip extra appliances within the DH. Therefore, the evaluation should also include the identification of unused renewable energies or surplus heat from industries that can be integrated into the DH system.

In priority should be the buildings, heating networks or systems that should have renovation or modernization. It is more easily to plan LTDH together with other construction works as technologies can be adjusted.

When selecting the transformation districts, the building and spatial structures, ownership structures and other framework conditions must be taken into account. Heterogeneous neighbourhoods with buildings from different construction periods and a large number of owners tend to be more involved in coordination than homogeneous quarters in owned by housing company. (Riechel et.al, 2017)

Therefore, the demographic development of city is another important aspect. For the increased population and forecasted increase in heat consumption there will be different solutions when comparing the shrinking cities and regions.

Social aspects should also been taken into account when planning the transformation project. The level of utilities payments can strongly affect the building owners to participate in measures for the transformation of the energy system. In additions, older property owners are less willing to invest into building modernization. (Riechel et.al, 2017) Therefore, public entities can often provide necessary „impulse" for initiation of transformation process.

At this step different alternatives can be selected for the identification of the DH for the initial transformation. In this light the evaluation of qualitative and quantitative parameters must be processed. The use of a multi-criteria decision analysis (MCDA) tool has been choose as a most suitable method for the initial district identification. Multi-criteria decision analysis has been widely applied for sustainable energy (Loken, 2007), (Pohekar & Ramachandran, 2004) (Wang, et al., 2009).

There are several multi-criteria analyses methods and tools from which TOPSIS method has been showed as an example in this methodology. Nevertheless, other methods can be applicable as well. The TOPSIS method is based on ranking different scenarios based on different criterion. Each criterion has been weighted depending on it`s importance. As the first step when using TOPSIS is development of matrix from analysed districts and several qualitative and quantitative analyses criterions.

Table 6.1 shows the example matrix developed for analysing 5 different districts based on several criteria. In this case 6 criterions has been identified as most important: specific heat consumption of buildings, energy efficiency at heat source, heat density of the district, heat losses, potential for RES and waste heat integration). Nevertheless, the number of analysed criterions is not limited and other aspects can be added for the analyses.

Table 6.1. Example of multi-criteria analyses matrix in first step

Criterion	Specific heat consumption of buildings, kWh/m²	Energy efficiency at heat source	Heat density, MWh/m	Heat losses	Potential for RES	Waste heat potential
Desired value	*Min*	*Min*	*Min*	*Max*	*Max*	*Max*
District 1	90	0,95	2	10%	5%	5%
District 2	120	0,85	2	15%	20%	0
District 3	200	0,65	2	12%	50%	10%
District 4	150	0,8	3	20%	10%	15%
District 5	180	0,7	1,5	11%	40%	0

The matrix further need to be normalized to obtain values in common units. It can be done by using linear normalization method (Turski, et al., 2009) by apllying following equations:

$$b_{ij} = \frac{x_{ij} - min\, x_{ij}}{max\, x_{ij} - min\, x_{ij}} \qquad (6.1)$$

$$b_{ij} = \frac{max\, x_{ij} - x_{ij}}{max\, x_{ij} - min\, x_{ij}} \qquad (6.2)$$

The choice between (6.1) and (6.2) depends on the desired value of criterion. If the optimal criterion value needs to be maximized than (6.1) can be used for the normalisation, if the criteria need to be minimized than (6.2) is used. Further, each normalized value b_{ij} needs to be multiplied by the weight of each specific criterion. The weights can be detected with the help of experts.

Table 6.2. shows the normalized values and the determined weight for each criterion. In example case, specific heat consumption in buildings, energy efficiency at heat source and heat losses have been stated as more important than other criterions. Therefore, in real case study weights can differ depending on framework conditions, expert opinion or other aspects.

Table 6.2. Example of normalized values of multi-criteria analyses

Criterion	Specific heat consumption of buildings	Energy efficiency at heat source	Heat density	Heat losses	Potential for RES	Waste heat potential
Weight	0,2	0,2	0,1	0,2	0,1	0,2
District 1	1,0	0,0	0,7	0,0	0,0	0,3
District 2	0,7	0,3	0,7	0,5	0,3	0,0
District 3	0,0	1,0	0,7	0,2	1,0	0,7
District 4	0,5	0,5	0,0	1,0	0,1	1,0
District 5	0,2	0,8	1,0	0,1	0,8	0,0

For the each normalized criterion v_{ij} maximal value S^+ and minimal S^- has been calculated according (6.3).

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_j^+ - v_{ij})^2} \tag{6.3}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_j^- - v_{ij})^2}$$

where v_j^+ and v_j^- is ideal positive and negative weighted solutions for each criterion. In the last stage the relative closeness to the ideal solution has been calculated (6.4) and the scenarios are ranked:

$$C_i^* = \frac{S_i^{k-}}{S_{ii}^{k+} + S_i^{k-}} \tag{6.4}$$

Table 6.3. Example of normalized values of multi-criteria analyses

Criterion	Specific heat consumption	Energy efficiency	Heat density	Heat losses	RES	Potential for waste heat	S+	S-	Rank
District 1	0,20	0,00	0,09	0,00	0,00	0,07	0,31	0,23	0,43
District 2	**0,15**	**0,06**	**0,09**	**0,08**	**0,04**	**0,00**	**0,18**	**0,20**	**0,53**
District 3	0,00	0,17	0,09	0,03	0,13	0,13	0,28	0,27	0,49
District 4	0,09	0,08	0,00	0,17	0,01	0,20	0,30	0,29	0,49
District 5	0,04	0,14	0,13	0,02	0,10	0,00	0,23	0,22	0,50
v_j^+	0,20	0,17	0,13	0,17	0,13	0,20			
v_j^-	0,0	0,0	0,0	0,0	0,0	0,0			

Table 6.3 shows the final steps of multi-criteria analysis for the presented example. As can be seen, by applying multi-criteria analysis it is possible to identify which of particular districts would be most suitable for LTDH implementation based on several prioritised criteria.

7. Data collection and scenario evaluation

Action performer: *Experts*
Involved stakeholders: *Municipality, DH operator, Building developers, building owners, largest enterprises*
Outcome: *Report with results on different development scenario evaluation for particular district*

There are several technological solutions to achieve LTDH in particular district. Therefore, detailed analyses for different alternatives should be carried out to obtain most beneficial solution from economic and environmental point of view. Figure 7.1. shows the general methodology for the evaluation of different alternatives.

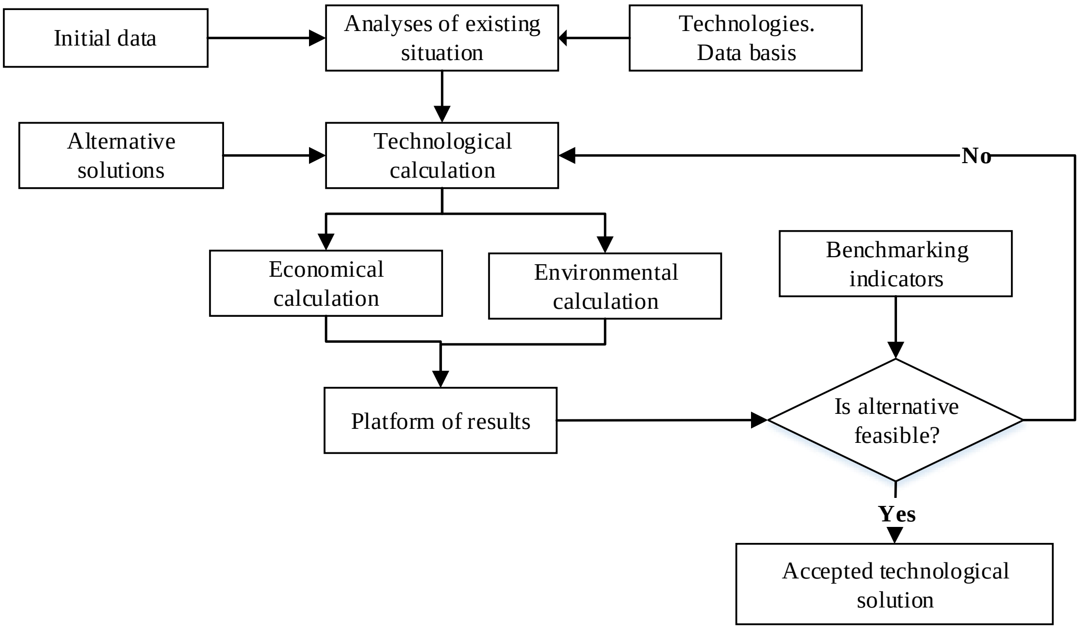

Fig.7.1. Methodology for scenario evaluation

In order to gain a deeper understanding of transformation spaces, the existing energy supply situation has to be analysed and accounted precisely. Such analyses is a basis for developing shared goals and strategies, as well as comparing different development scenarios. The analyses of existing situation involves the initial data analyses as well as evaluation of available technologies.

Operation of DH system includes many technical, economic and environmental parameters which affects the efficiency of the system. In order to evaluate different scenarios, it is necessary to obtain comparative indicators by using available input data and assumptions. Such calculations would give the necessary answers for most suitable alternatives for further development of DH system.

It is necessary to define the input parameters in order to start the scenario evaluation. The main initial data are:

- Produced heat, MWh per year

- Fuel consumption, natural units or MWh
- Fuel's lowest calorific value, MWh/natural unit
- Consumed heat energy for heating and hot water generation, MWh per year
- Heat losses in MWh per year
- Maximum temperature and return temperature, oC
- Length of the heat pipe, m
- Average diameter of the heat pipe, mm

Therefore, it is necessary to defines existing system parameters - what kind of system is generally studied (existing building, energy-efficient or passive building, refurbished buildings, etc.). This includes technological parameters, such as efficiency, energy resource parameters (calorific value), the total annual heat consumption (MWh per year) and other. Therefore, evaluation process will always include certain assumptions.

Table 7.1. shows the example for input data and technical parameters when evaluating possible alternatives for particular newly build building area. In this case study, there are different building heat requirements analysed (buildings with standard heat consumption and energy efficient buildings) as well as various heating network temperature levels compared.

Table 7.1. Example for input data and technical parameters for different scenario

DH system parameter	Standard buildings	Energy efficient buildings
Building heat consumption, MWh year	40606	27046
Heat capacity, MW	15	9
Equivalent diameter of heat network, mm	110	98
Heat losses, MWh/year		
120/70	1615	1570
90/70	1510	1473
60/30	875	851
Electricity consumption, MWh/year		
120/70	215	119
90/70	228	124
60/30	302	152
Fuel consumption, MWh/year		
120/70	5017	3401
90/70	4895	3314
60/30	4210	2831

When the methodology has been applied for all alternatives, it is possible to compare the results and identify the most beneficial solution.

7.1. Data sources and quality levels, data collection methods

In order to choose the possible alternative for DH system it is necessary to collect input data. The collecting and accounting of district data represents a more detailed level compared to the general analyses of preconditions in city or region. The data collection and analysis can cause a considerable expenditure of time and personnel.

Quantity and quality of required data as well as the depth of necessary accounting depends on the approach of process organization. For the technical approaches, detailed data are needed to create a consistent quantitative output and thus derive specific measures. Also, the implementation of test runs and pilot projects with good data quality is necessary. However, for the communication processes or estimations single local data are often sufficient. (Riechel et.al, 2017)

There are following data sources that can provide the different types and qualities of data:

- Energy providers (CO_2 emissions, type of heat supply, heat generation parameters);
- Housing companies and building owners (heat and power consumption);
- Proprietors and landlords (building parameters, state of modernization);
- Online surveys and site visits (different average parameters);
- Estimations and assumptions.

Good quality is obtained by using original consumption data. Lower level of quality is for global city data like extrapolations and summarized data of utilities.

If there are no other sources the data from regional characteristics and statistics can be used. Site inspections and optical analyses can be useful for better situation understanding. Therefore, the data transfer of the same types of buildings can be admitted. Very often, these characteristics values must be cumulated in order to prevent conclusions about individual consumers.

7.2. Development of balance sheet

One of the most important parameters describing the DH system operation is the heat load curve which shows the amount of produced thermal energy. This curve is used for all technical, economic and statistical calculations. By knowing the heat consumption, it is possible to determine the number of necessary equipment and their capacities. Heat load curve describes the capacity of base and peak loads of DH system. It gives a comprehensive overview of different energy source capacities that can be integrated into the DH system. The example of heat load curve from DH system with different energy sources is showed below.

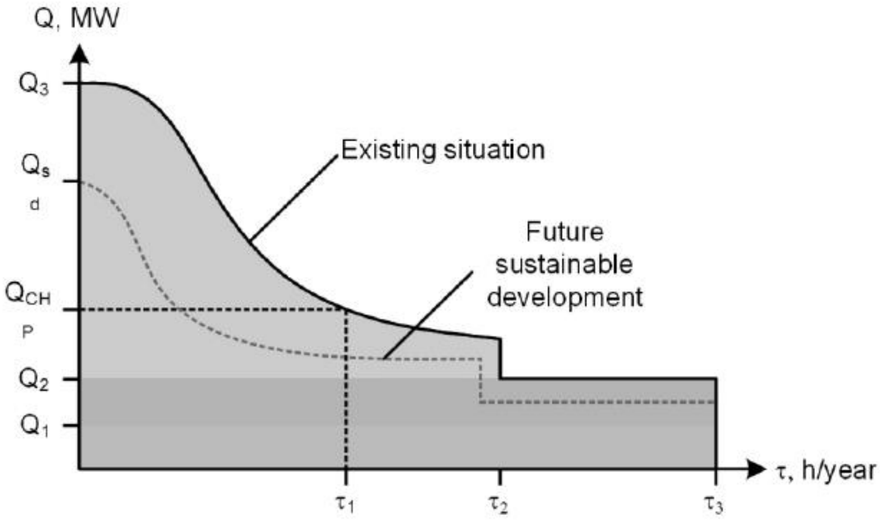

Fig. 7.2. Heat load curve example (Cirule et.al, 2016)

The method to draw up a balance sheet depends on the available data quantity and quality. It becomes more detailed with increasing project relevance. The CO_2 emissions as well as the primary and final energy demand should be considered.

When evaluating particular pilot case, also the economic and environmental aspects should be taken into account. The comparison of economic and environmental indicators gives more detailed overview of the specific alternatives. Fig.7.3. shows the results for heat tariff (economic indicator) evaluation for several alternatives with different building heat requirements and heating network temperature regime.

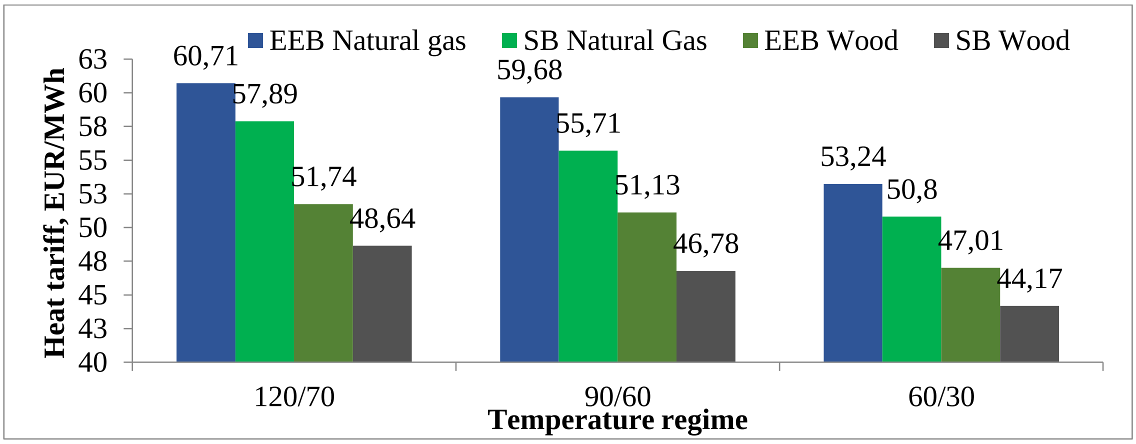

Fig.7.3. Example of heat tariff comparison results for different alternatives (EEB-energy efficient buildings, SB-standard buildings)

The methodology for calculation of different indicators is described in the Annex 1. In addition, the pilot case analyses in Latvia, Beļava parish described in Annex 2 can be used as an example of pilot case analyses.

7.3. Identification of development scenarios

Technical and structural reconfiguration of the energy supply system has been further evaluated. This step requires the concrete goals and tasks for temperature level reduction in particular DH system area. For example:

- the connection of new development areas to the return of district heating system
- identification of areas where temperature can be lowered without extensive renovations in the buildings, e.g. after energetic modernization.
- the conversion of existing heating facilities into surface heating etc.

Therefore, the clear action strategy should include the tasks and goals for the heat source in order to reach higher share of renewables. When developing action plant, the efficiency level and economies of conversion technologies, such as power-to-heat or power-to-gas and electrical and thermal storage systems should be taken into account.

Taking into account the constructional starting point in the previous step, the guiding principles for particular district are specified in this step. However, also the actor-specific and district-specific framework conditions should be taken into account such as ownership structure, modernization cycles, willingness to invest, composition of the population, spatial concentration of social problems, population fluctuation and development, rent levels, etc. Otherwise, the implementation of innovative solutions may not be supported.

8. SWOT analyses

Action performer: *Experts*
Involved stakeholders: *DH operator, Municipality*
Outcome: *SWOT analyses matrix for different alternatives*

SWOT analysis is an examination of an organization's internal strengths and weaknesses, its opportunities for growth and improvement, and the threats the external environment presents to its survival. The primary aim of strategic planning is to bring a system into balance with the external environment and to maintain that balance over time. Organizations accomplish this balance by evaluating new programs and services with the intent of maximizing organizational performance. SWOT analysis is a preliminary decision-making tool that sets the stage for this work.

When the detailed overview of technological, economic and environmental aspects has been carried out, the SWOT analyses can serve a frame for the inventory of the results. It allows to include other aspects that cannot be measured by quantitative indicators. SWOT analyses identifies the gaps in overall energy supply development plan such as problems with legislative framework, motivation of heat consumers or other stakeholders, lack of funding etc. (Ghazinoory et.al., 2011).

SWOT analysis involves the collection and evaluation of key data that has been completed in previous steps. Those data are collected and sorted into four categories: strengths, weaknesses, opportunities, and threats. Strengths and weaknesses generally stem from factors within the system, whereas opportunities and threats usually arise from external factors. Next step involves the development of a SWOT matrix for each technological alternative under consideration. The SWOT analysis should be incorporated into the decision-making process to determine which technological alternative meets the overall strategic goals.

Tables below shows the example for SWOT analyses comparing two different development alternatives for DH system. Alternative 1 is installation of Biomass heat plant and heating network temperature lowering, Alternative 2 – Natural gas heat plant with standard heating network temperature.

Table 8.1. SWOT analyses for Alternative 1

Strength	Weaknesses
Use of local and renewable heat source - biomass Lower energy source costs Lower heat losses Increased efficiency in flue gas condenser	Higher investment costs for biomass boiler Heating unit adjustment
Opportunities	**Threats**
EU and government support for alternative energy source Biomass price stability	Decrease of biomass quality Consumer unwillingness to cooperate Domestic hot water preparation

Table 8.2. SWOT analyses for Alternative 2

Strength	Weaknesses
Low investment costs Low labor costs High boiler efficiency	Use of fossil fuel High fuel costs High environmental taxes Higher heat losses
Opportunities	**Threats**
Use of existing natural gas infrastructure	Unstable fuel costs Increased energy and environmental taxes

9. Evaluation of implementation conditions and synergies

Action performer: *Municipality or DH operator with help of experts*
Involved stakeholders: *Building developers, building owners, largest enterprises*
Outcome: *Pilot cases implementation action plan with terms, responsible persons/structures and monitoring methods for the results*

New technical or organizational approaches are often tried out as examples in pilot cases. Therefore, great attention must be paid to the conditions of implementation in the district pilot case. Several available tools can be used for the implementation of the necessary changes. The most common of those are:

- planning strategical concepts;
- communicative measures;
- financial incentives;
- municipal statutes.

The planning strategical concepts should be in accordance with other plans, programs and instruments by providing necessary synergy. The concepts should include a clear recommendation for strategies and actions to be followed. These include spatially differentiated statements on priorities for the development of supply infrastructures (e.g. priority district heating), guidelines for energy efficiency and the development of renewable energies implementation.

For the successful implementation phase, it is important to clarify the responsibilities, priorities, guidelines and conflict management. The action plans should consistently outline who is responsible for the implementation of a specific action or transformation step. The assessment of the actors responsible for implementation must be obtained in the preliminary stage. Also the political decision is important for the concept commitment.

The implementation strategy is as useful document, which puts the building modernization and infrastructure redevelopment into a meaningful order. Therefore, the modernisation process can be divided in several steps for more transparent implementation process. Nevertheless, concepts should be flexible. If there are changes necessary, the actions should be revised.

The required measures can be implemented by the authorities as an actor or in the form of public enterprises. Another possibility is to attract private companies, individual owners or households for the implementation of concrete measures. This requires communication plan and new formats of public relations to arouse interest and to combine information with personalized advisory service that takes into account the specific situation of the owner. Municipality as a building owner can set high energy standards and implement innovative heat supply concepts in municipal real estates.

10. Reflection and learning

Action performer: *Municipality or DH operator with help of experts*
Involved stakeholders: *Building developers, building owners, largest enterprises*
Outcome: *Conclusions and recommendations based on pilot cases operation data analyses*

Reflection and learning are important steps because the transformation process is continuing. Only the careful monitoring of obtained results serves the bases for further analyses to determine if the goals and tasks are aligned with the chosen pathway. Therefore, it can indicate if the course correction is necessary. Furthermore, the results from pilot case can give a useful information for the transformation process application in wider scale of whole city or region.

The implementation progress is also important parameter that needs to be monitored. It provides transparency in the local heat change and acts as a steering instrument.

The development of monitoring plan can be a useful tool that regulates the key indicators and other parameters. An evaluation of the changes in consumption, supply technology, energy sources and other qualitative parameters needs to be investigated in order to see if the goal has been achieved. It must be examined whether the changes in the balances can be clearly attributed to measures in the transformation area or in the municipal energy supply system. However, changes can be also justified by nationwide developments. To ensure that local values can be compared over a long period, the accounting methodology and sources of data should be documented in a traceable way. Alternatively, evaluation and monitoring systems can be purchased, which usually enable online-based long-term observation under the same basic conditions. In the meantime, even simpler indicators such as the number of implemented measures give a first overview of the state of implementation.

There are several indicators that can be monitored to obtain clear overview of the results:

- Energy requirements for space heating and DHW (kWh)
- Specific energy consumption parameters (kWh/ inhabitant; kWh/m^2 etc.)
- Output of generation plants (kW/inhabitant),
- Storage capacity (kW)
- Efficiencies of technical installations
- Number and scope of building modernization measures
- Type and volume of energy used (kWh per year)
- CO2 emissions (ton per year)
- Heat price developments (EUR/kWh)
- Length of heat supply networks (km)
- Heat supply flow temperature (°C)

Authorship

The proposed methodology has been finalized within the group of activity 3.2 of LowTEMP project with contribution from the partners reported below:

Project Partner	Responsible persons
Riga Technical University – RTU (PP12)	Ieva Pakere Francesco Romagnoli Dagnija Blumberga
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Sustainable Business Hub – SBHub – PP7	Cecilia Thapper

In particularly the frame of the methodology was based on published manuscript of Riechel R. et al. 2017 from the LowTEMP project BTU focused on :

1. Technical transformation paths – strategic recommendations and technical options;
2. Municipal transformation management for energy supply in ten steps.

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Appendix

10.1. Annex 1. Technological analyses of pilot case

Determination of Heat Load

One of the most important parameters is the amount of thermal energy, which is consumed in buildings. This value is used for all technical, economic and statistical calculations. By knowing the heat consumption it is possible to determine the number of necessary equipment and their capacities. When designing the heating system, the amount of heat required for heating purposes is calculated by (1.1.):

$$Q_{heat,n} = Q_l - \eta_{heat} Q_{heat\ gain} \qquad (1.1.)$$

were

$Q_{heat,n}$ – energy for heating purposes, Wh;

η_{heat} – gain utilization rate

Q_l – total heat losses, Wh;

$Q_{heat,gain}$ – total heat gains, Wh.

The amount of heat required for heating Q_{heat} is determined by the following equation:

$$Q_{heat} = H_k(t_{in} - t_{out})\, t_d - \eta_{heat}\,(A_{sol}\, E_{sol} + Q_{iek}) \qquad (1.2.)$$

were

H_k – total heat loss coefficient for buildings [17]

t_{in} –indoor temperature in buildings, °C;

t_{out} –outdoor temperature, °C;

E_{sol} – solar radiation in the particular period, Wh/m^2;

A_{sol} – solar energy collecting area of building, m^2;

t_d – heating period, h.

If the analysed project is in the development stage, and the whole building construction solutions are not known, than the actual heat required are unknown. Therefore, building heat consumption can be estimated by making heating-load assessment of particular district. Assumption can be made based on the specific heat consumption of different type of buildings. The necessary heating power N_{heat} can be calculated by the following formula:

$$N_{heat} = \frac{q_{heat} S}{t_d} \qquad (1.3.)$$

where

q_{heat} – specific average heat consumption, Wh/m^2 year;

S – heating area of building, m^2;

To calculate the maximum heat load, the coldest five-day average temperature is used which differs indifferent countries. Duration of heating period is determined by the particular construction standards.

To create a heat load curve, Q_{heat} (kW) at any temperatures (for example, - 0°C) has been calculated at the beginning. The heating capacity of the system to other outdoor temperature t is defined as follows:

$$Q_t = Q_{heat} \frac{t_{in} - t_{out}}{t_{in} - t_c} \qquad (1.4.)$$

where

t_c – standard outdoor temperature, °C;

In order to determine the Q_t, temperature coefficient has been calculated:

$$K = \frac{t_{in} - t_{out}}{t_{in} - t_c} \qquad (1.5.)$$

The required amount of heat during the heating period is calculated by dividing the heating period in separate sections, depending on the outdoor temperature range, taking into account individual outdoor temperature range duration.

The total thermal energy consumption consists of three components – space heating, hot water and cooling. If cooling is provided locally, it consists only of two components-space heating and hot water. Energy demand for hot water heating is calculated as follows:

$$N_{hw} = c\, G_{hw}\, \Delta t_{hw} \qquad (1.6.)$$

where

c – specific heat of water, J/m^3 K;

G_{hw} – hot water consumption, m^3/s;

Δt_{hw} – temperature difference.

Hot water consumption is calculated by using the standards required for hot water: 50 litters per capita per day in residential and 5 litters per day for office workers.

In result the total heat capacity can be determined by following equation:

$$N = N_{heat} + N_{hw} + N_{losses} \tag{1.7}$$

where

N_{losses} –transmission heat losses, W.

The heat flow G_i (kg/s) (2.9) and pipe diameters (d_i, m) (2.10) for each network stage *i* are calculated by knowing a maximum installed capacity (N_{max}) of each building. This is determined by adding the heat capacity to cover the hot water consumption to calculated N_{heat}.

$$G_i = N_{\max} / (c \cdot \Delta t) \tag{1.8}$$

$$d_i = \sqrt{4G_i / (\pi \cdot \omega_i)} \tag{1.9}$$

where Δt is temperature difference between the supply and return flows (°C) and ω_i is heat transfer velocity at particular network stage *i* (m/s).

The optimal heat velocity rate must be in the range of 1 m/s to 3 m/s at maximum outdoor temperature. If the modelled velocity is among or below these limits, different pipe diameters should be selected.

Determination of Heat Losses

The heat loss calculations start with the determination of linear resistance R of pipes ((m K)/W):

$$R = R_p + R_{ins} + R_{cov} + R_{soil} + R_{bet} \tag{1.10}$$

where

R_p – linear resistance of pipe, m K/W;

R_{ins} – linear resistance of insulation, m K/W;

R_{cov} – linear resistance of cover, m K/W;

R_{soil} – linear resistance of soil, m K/W;

R_{bet} – linear resistance between pipes, m K/W;

Linear resistance of pipe is determined by (1.11):

$$R_c = \frac{1}{2\pi\lambda_c} \ln \frac{d_{out}}{d} \tag{1.11}$$

where

λ_c – heat transmission coefficient of pipe, W/m K;

d_{out} – outer diameter of pipe, m;

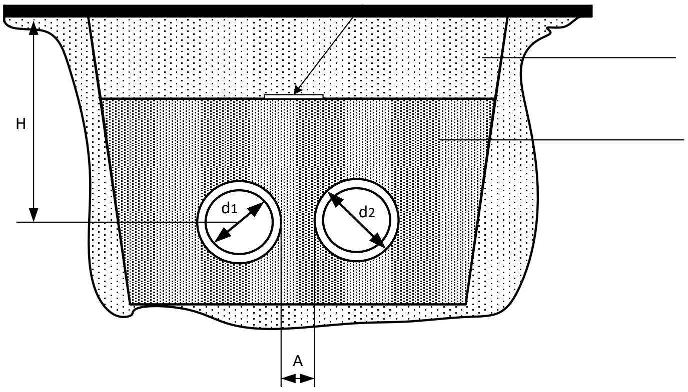

Fig. 0.1. Trench cross-section of a two-pipe system

Linear resistance of insulation is calculated by using (1.12)

$$R_{ins} = \frac{1}{2\pi\lambda_{izol}} \ln \frac{d_{izol}}{d_{ar}} \tag{1.12}$$

where

λ_{izol} – heat transfer coefficient of insulation, W/m K;

d_{izol} – outer diameter of pipe with insulation, m.

Linear resistance of cover can be calculated as:

$$R_{\text{cov}} = \frac{1}{2\pi\lambda_{\text{cov}}} \ln \frac{D_{out}}{d_{izol}} \tag{1.13}$$

where

λ_{cov} – heat transfer coefficient of pipe cover, W/m K;

D_{out} –pipe diameter with insulation and cover, m.

Heat network pipes are placed close to each other (see Fig.0.1) and there appears linear resistance between the pipes:

$$R_{bet} = \frac{1}{4\pi\lambda_s} \ln\left[1 + \frac{(2(H + 0{,}0685\lambda_s))^2}{(A + D_{out})^2}\right] \tag{1.14}$$

where

λ_s – heat transfer coefficient of soil, W/m K;

H – placing depth until the pipe centre, m;

A –length between the pipes , m.

Linear resistance of soil is calculated after (1.15).

$$R_{soil} = \frac{1}{2\pi\lambda_{gr}} \ln\left[\frac{4(H + 0{,}068\lambda_{gr})}{D_{ar}}\right] \tag{1.15}$$

After determine the total linear resistance R (1.16) linear heat transfer coefficient is calculated k_L W/m K:

$$k_L = \frac{1}{R} \tag{1.16}$$

The linear density of heat flow q_L W/m is calculated as:

$$q_L = k_L(T1 + T2 - 2t_{soil}) \tag{1.17}$$

where

T1– supply water temperature, °C;

T2 – return water temperature, °C;

t_{soil} – soil temperature, °C.

For the heat network placed in the air linear heat flow density is calculated after (2.28).

$$q_L = \frac{t_{av} - t_{out}}{\frac{1}{\alpha_1 \pi d_1} + \frac{1}{2\pi\lambda_1}\ln\frac{d_{out}}{d} + \dots + \frac{1}{2\pi\lambda_{n-1}}\ln\frac{d_n}{d_{n-1}} + \frac{1}{\alpha_2 \pi d_n}} \tag{1.18}$$

where

$\alpha_{1,2}$ – convective heat coefficient, W/m²K;

d_n – diameter of last pipe segment, m;

$\lambda_{1,n}$ – heat transfer coefficient, W/mK;

t_{av} – average temperature of supply and return temperature, °C;

Total heat losses Q_l (Wh) are determined by (1.19):

$$Q_l = q_L L_{tot} z \tag{1.19}$$

where

L – total length of heat network, m;

z – heating period, h.

Electricity Consumption for Heat Transmission

To determine the amount of electricity needed for pumping the heat carrier, the network hydraulic calculation has been done. By knowing the DH parameters for the heat consumers, the heat flow and network lengths, it is possible to calculate the pressure drop of the heating network. Calculation order is as follows:

1) calculate the main pipe - from the heat source to the consumer, where there is the smallest specific linear pressure drop (Pa/m). If the pressure drop to a number of consumers is equal-selects the most distant consumer.

2) if there is no restriction on the relief, the pressure drop is adopted proportionally to the length of the line (graphically-straight).

3) the calculation starts with the closes network stage to the source, calculate the local pressure drop and the linear pressure drop in the network stage.

To determine the water flow for the space heating and hot water loads irregularity coefficient of hot water must be taken into account (Gedrovics, 2002):
- main pipe 0.7 to 0.75 ;
- first stage branch pipe 0.8-0.9 ;
- inner courtyards networks and building leads -1.

Pressure loss of h_{1-2} consists of:

- linear losses h_L caused by the friction forces between the individual fluid particles and between particles and fluid flow restrictive walls;
- Loss of local resistance h_R. These losses cause the existing pipe bends, valves, and other resistance. Pressure drop h_{1-2} in Latvian conditions by selecting the appropriate pipe diameter is usually taken not greater than 100 Pa/m.

Pressure loss can be calculated by:

$$h_{1-2} = h_L + h_R \qquad (1.20)$$

(1.21)

The necessary capacity of pump N_1 (W) is determined as:

$$N_1 = \rho g H \qquad (1.22)$$

A power consumed by pump N (W) is greater due the effective resistance of the pump power:

$$N = \frac{N_1}{\eta} = \frac{\rho g H}{\eta} \tag{1.23}$$

where

η - pump effectiveness.

By multiplying the pump power N (W) with operating hours according the required load electricity consumption of the heat pumping is derived.

Determination of Heat Source Efficiency in case of CHP

If the heat is produced in a cogeneration plant (CHP), then switching to a lower temperature regime can increase the produced amount of electricity. Produced electric power in CHP with steam turbine (N_{el}) can be determined by (2.24).

$$\mathrm{N_{el}} = \frac{m \cdot (h_1 - h_2)}{3{,}6} \eta_t \eta_m \eta_{\text{ģ}} \tag{1.24}$$

where h_1-enthalpy in turbine inlet, h_2-enthalpy in turbine outlet, η_t-efficiency of turbine, η_m-mechanical efficiency, $\eta_{\text{ģ}}$-efficiency of generator.

According to (1.24) the amount of produced power increases with the enthalpy difference between the turbine inlet and outlet. Providing a lower DH supply water temperature can reduce the turbine outlet enthalpy h_2.

An important indicator of CHP is electrical and thermal power ratio α, which describes how much electrical power N_{el} can be produced by covering the heat capacity N_Q.

$$\alpha = \frac{N_{el}}{N_Q} \tag{1.25.}$$

Electrical and heat ratio in CHP for different temperature regimes can be seen in Table 0.1.

Table 0.1. Electrical and heat ratio in CHP for different temperature regimes

Temperature regime	120/70	90/60	60/30
Alfa value	0.21	0.25	0.33

Economical Indicators

After obtained the results of technical calculations, it is necessary to futrher investigate the economic and environmental aspects of analyzed scenarios. The most commonly used methods for economical evaluation of project is a net present value (NPV) calculation method. Each project has a net present value which allows getting a summary of investment performance level, namely the final effect in the absolute form. The NPV (1.26) is understood as the difference between the current value for the indicated net cash flows of the investment project for a period of realization and investment consumption.

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$$NPV = PV - C_o \quad (1.25)$$

where

NPV – net present value, EUR;

PV – discounted net cash flow, EUR;

C_o – investment, EUR.

The discounted net cash flow is the difference between total costs of the DH company and the profit from selling the heat.

In order to use the investment project economic evaluation methods, discount rate is determined and the discounted cash flow is developed. The discount rate reflects the "opportunity costs" of invested money, and at the same time it determines the "price of money" or project funds available to finance the costs.

Levelized cost of energy (*LCOE*) shows if generated energy can compete with other energy sources. Therefore, it can be used an indicator in particular analyses for system profitability evaluation. *LCOE* is calculated as lifetime costs divided by energy production.

Another indicator that represents the results of system operation is the payback time (*PBT*) which is division between the total costs and total annual incomes from energy saving or selling.

In addition to indicators described above, the heat tariff can be used as a comperative indicator. There are different methodologies for heat tariff calculation. Threfore, one of examples is described below.

Consumer price of heat (T) consists of three components: production (t_{prod}), transmission (distribution) (T_{trans}) and realisation (T_3) rate. The highest role of these components is for the production component, but realisation costs are relatively low. Each section is divided into two parts of costs - fixed costs and variable costs, which together makes the total cost. Fixed costs FC does not depend on the quantity of produced heat. There are included the investment costs, payment of loan, interest payments, amortization costs, taxes, rent, operating costs, insurance etc. Also the salaries for the staff belong to the fixed costs.

The variable cost changes according the produced amount of heat. Variable costs consist of costs for materials, fuel, electricity etc. The total production costs are calculated as:

$$T_{prod} = FC_{prod} + VC_{prod} \quad (1.26)$$

where

FC_{prod} – fixed production costs, Euro;

VC_{prod} – variable production costs, Euro.

In order for DH system to work effectively, it is necessary to minimize the system costs.

Environmental and Climate Indicators

Different natural resources are used for the heat production – water, air and fuel. In the fuel combustion process different emissions (SO_2, CO_2, CO, NO_x etc.) are realized in the atmosphere.

GHG emissions are emitted both in artificial and natural processes. They absorb and re-emit infrared radiation. Direct GHG emissions are carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O, perfluorocarbons PFCs, SF_6 sulphur hexafluoride, hydrofluorocarbons HFCs. Indirect GHG are nitrogen oxides NO_x, carbon monoxide CO, sulphur dioxide, SO_2, non-methane volatile organic compounds NMVOC. (Blumberga, et al., 2010)

Internationally it is recognized that GHG emissions are determined with the help of CO_2 equivalent. Equivalents of direct GHG gases are following:

- CO_2 = 1 CO_2 equivalent;
- CH_4 = 21 CO_2 equivalent;
- N_2O = 310 CO_2 equivalent.

Climate impact assessment calculations include the determination of the emission factors E_{CO_2} (t/MWh). It shows how many tons of CO_2 is formed per unit of energy consumed. Actual emissions shall be determined as follows:

$$E = \frac{E_{CO2}Q}{\eta} \tag{1.27}$$

where

E_{CO_2} – emissions, t_{CO_2};

Q-produced amount of heat, MWh;

η - efficiency coefficient of the boiler.

The emission factor differs for each type of fuel. If renewable energy sources are used, the emission factor is equal to zero.

By assuming the total exploitation time of the technology (Z_{expl}), it is possible to determine the emission intensity EE (EUR/t $_{CO_2}$ year):

$$EE=K/E*Z_{expl} \tag{1.28}$$

were

K – investments, EUR.

If the efficiency of overall heating system is increased, the primary energy consumption can be decreased. This results in decrease of emitted emissions.

10.2. Annex 2. Pilot project analyses

The chosen case study is a Belava parish located in the East part of Latvia. Due to decreasing number of inhabitants and recently accomplished energy efficiency measures in building it was necessary to redesign the existing inefficient DH system. Detailed analyses according methodology described in Chapter 5 has been applied for the particular parish (Pakere et.al, 2018). As a result, several transformation scenarios are identified. The technical solutions include replacement of boiler, heating network reconstruction, heat supply temperature lowering and solar panel installation. Further technical analyses is carried out for system development evaluation and strategy implementation.

The DH network scheme of the parish can be seen in Fig.0.2. The DH network has been redesign completely in order to increase the heat density and reduce heat loses. In order to optimize the heat pipe length, four private houses has been switched from the DH network to individual heating system. In addition, the location of boiler house has been changed and new pellet boiler house were integrated into the system.

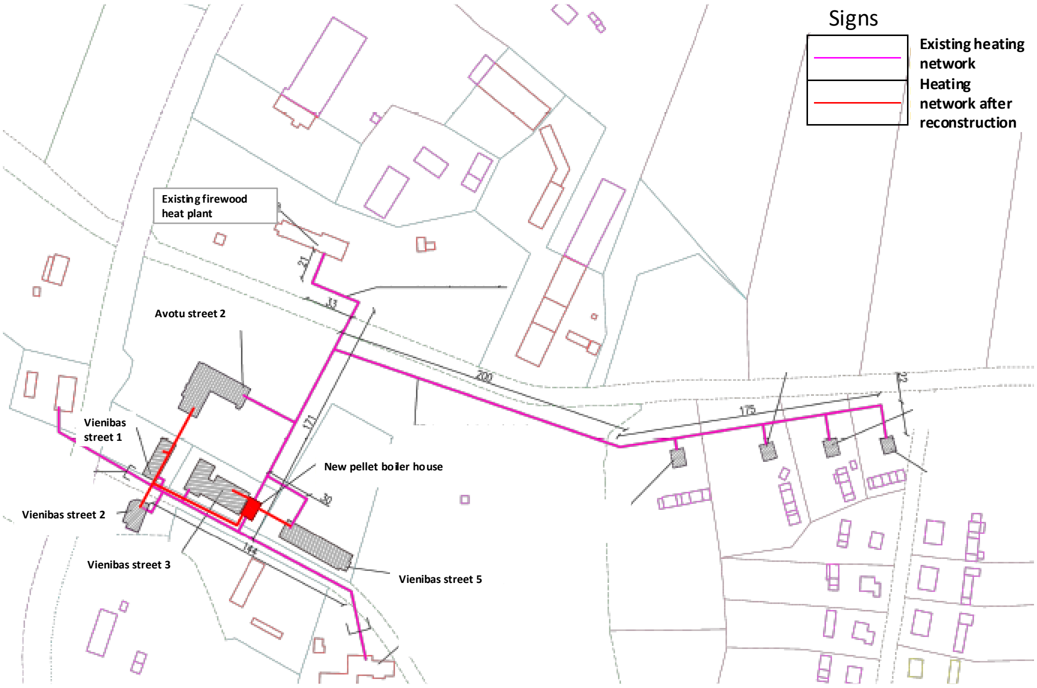

Fig.0.2. Pilot case DH network before and after reconstruction

After the DH network reconstruction only five buildings will be connected to the system. The heat density increases from 1.1 MWh/m to 2.8 MWh/m after reconstruction. Table 0.2 shows the overview of the building types, area and specific heat consumption for space heating. Most of buildings experienced energy efficiency measures recently, therefore only apartment building has high specific heat consumption compared to standard in new buildings in Latvia that is 80 kWh/m^2 per year. Therefore, two different scenarios are analyzed for further development. In Base scenario the heat consumptions remains constant. In energy efficient (EEF) scenario it is assumed that heat losses from apartment building will be reduced due to insulation works and the specific heat consumption will decrease by

60% to 80 kWh/m².

Table 0.2. Overview of buildings connected to DH system after reconstruction

Nr.	Address	Type	Insulated	Area, m²	Specific heat consumption, kWh/m²
1	Avotu street 2	Kindergarten Mail Local authority	Yes	1614	75
2	Vienibas street 2	Shop	Yes	229	88
3	Vienibas street 1	Recreational, utility room	No	277	65
4	Vienibas street 3	Cultural house	Yes	723	125
5	Vienibas street 5	Apartment building	No	1224	192

Figure 0.3 shows the heat load duration curves for both scenarios. It can be seen that heat capacity in EEF scenario reduces to 150 kW by comparing to 200 kW in Base scenario. In the particular parish heat is provided only for space heating and there is no heat load in summer period.

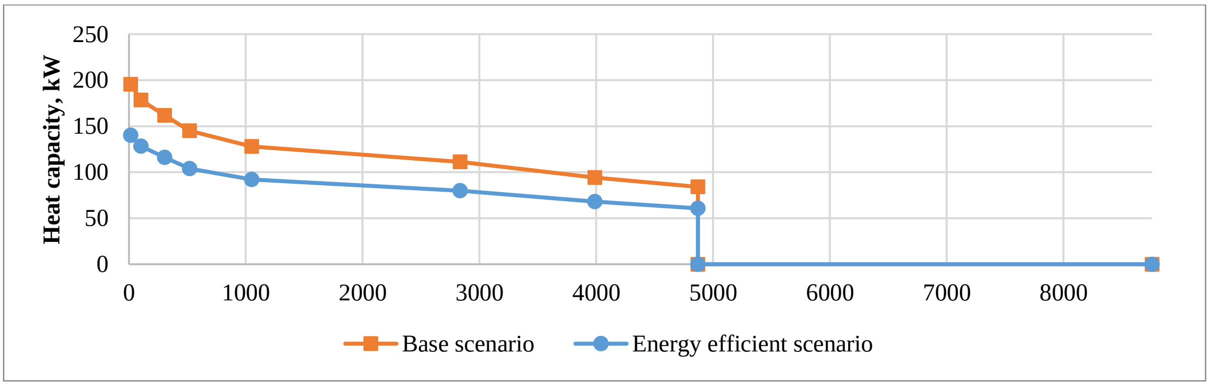

Fig.0.3. Heat load duration curve

To reduce the transmission heat losses it is considered to reduce supply and return water temperature from 90°C/60 °C to 60°C/35°C.The heating network temperature curve is shown in Figure 0.4. It has been considered that heating system in renovated buildings remains the same as before the renovation. Therefore, the surface area of installed heating elements would allow to reduce the supply water temperature without any other additional change of operational parameters. In case of appartment building in BS when no energy efficiency measures are considered, it would require to consider energy cascade or other solutions for supply temperature lowering to be possible.

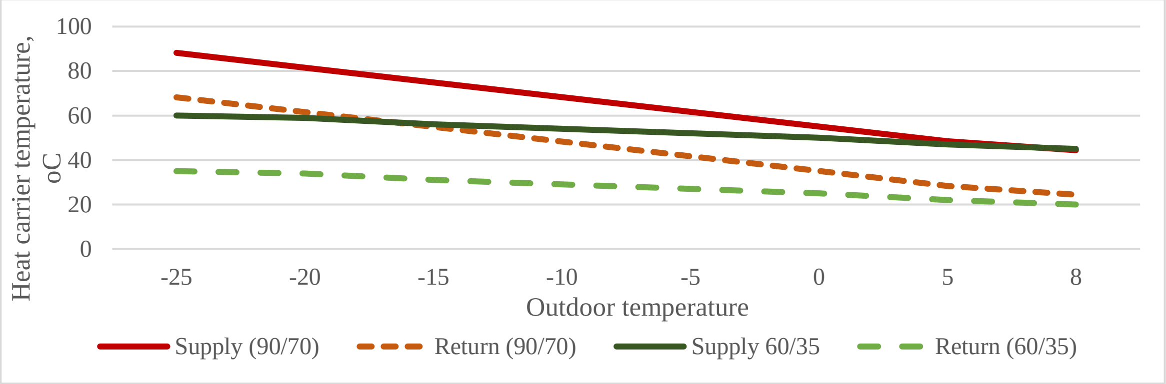

Fig.0.4. Heat carrier temperature curves for standard and low temperature system

Therefore, four different technical alternatives regarding building heat consumption and temperature levels in DH network have been identified for the further development of particular parish. In order to compare and evaluate those alternatives, the heat losses and heat density have been used as technical indicators.

In addition, it has been considered to install the PV panels for power production and building power consumption coverage. The total power consumption in buildings and boiler house is 33 MWh per year. It would require 9 kW of PV panel to cover such consumption in summer period (see Figure 0.5). The assumed PV efficiency is 15% and annual solar radiation is 973 kWh/m^2.

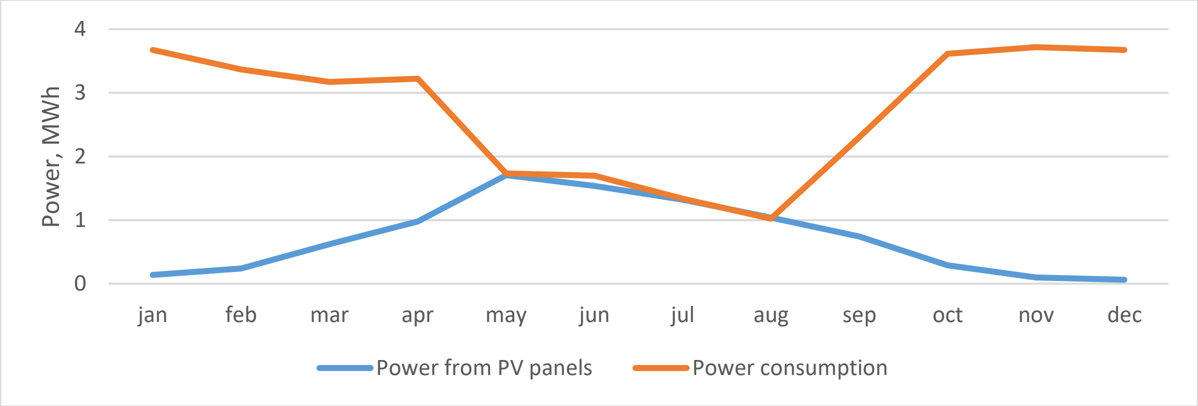

Fig.0. 5. Power consumption and solar power production duration

Table 0.3 shows the results of technical calculations. It can be seen that in EEF scenario, when energy efficiency measures are considered, the heat consumption and heat density decreases, therefore specific heat losses in heating network increases. Reduced heating network temperature is a solution for optimal operation of DH system in such conditions.

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Table 0. 3. Technical calculation for different scenarios

Scenario	Heat consumption, MWh per year	Heat density, MWh/m	Heat losses, MWh	Heat losses, %	Power consumption, MWh	Solar power, MWh	PEF	PEF Solar
BS (90/60)	491	2.8	41.3	8%	33	8.7	0.322	0.347
BS (60/35)	491	2.8	34.5	7%			0.319	0.344
EEF (90/60)	347	2	41.3	12%			0.350	0.384
EEF (60/35)	347	2	34.5	10%			0.345	0.380

In order to compare the scenarios when PV are installed for power production, the primary energy factor is calculated for all scenarios (PEF –without solar power and PEF $_{solar}$ – with solar power considered). Results shows that lowest value is for base scenario with lowered temperature regime and solar panel installation as primary energy is low and delivered energy remains high. Therefore, PEF for EEF scenarios is higher than for BS scenarios as heat consumption decreases and the specific heat losses are higher.

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