MINISTRY OF FOREIGN AFFAIRS OF DENMARK

Mykolaiv

# Assistance to the Development of the Mykolaiv Masterplan

## Annex No. 1 to the Roadmap, Energy Detailed Vision, Report
## Final

February 2024

COWI

ADDRESS COWI A/S
Parallelvej 2
2800 Kongens Lyngby
Denmark

TEL +45 56 40 00 00
FAX +45 56 40 99 99
WWW cowi.com

# Assistance to the Development of the Mykolaiv Masterplan

## Annex No. 1 to the Roadmap, Energy Detailed Vision, Report Final

| Project No. | Document No. |
|---|---|
| A246262 | Annex 1 to the Roadmap_Energy_F1 |

| Version | Date Of Issue | Description | Prepared | Checked | Approved |
|---|---|---|---|---|---|
| 4 | 02-28-2024 | Detailed Vision | ALGD, LUUR | ADFR, PB, AS | JKP |

# Contents

# List of Figures



# List of Tables

# List of Abbreviations

| | |
|---|---|
| BAT | Best Available Technology |
| BH | Boiler House |
| CAPEX | Capital Expenditure |
| CBA | Cost benefit analysis |
| CHP | Combined Heat and Power |
| CRM | Customer Relationship Management |
| DC | District Cooling |
| DH | District Heating |
| DIC | Discounted Investment Cost |
| DSO | Distribution System Operator |
| EIB | European Investment Bank |
| ESAP | Environmental and Social Action Plan |
| EUR | Euro |
| E5P | Eastern Europe Energy Efficiency and Environment Partnership Fund |
| FB | Final Beneficiary |
| FNPV | Financial Net Present Values |
| FPI | Financial Performance Indicators |
| FRoR | Financial Rate of Return on the Investment |
| FS | Feasibility Study |
| HH | Household |
| DHW | Domestic Hot Water |
| IHS | Individual Heating Substations |
| IRR | Internal Rate of Return |
| LFO | Light Fuel Oil |
| LTIP | Strategic Long-term Investment Plan |
| MCTIDU | Ministry for Communities, Territories, and Infrastructure Development of Ukraine |
| MCHPP | Mykolaiv Combined Heat and Power Plant, Private Joint Stock Company |
| MD | Micro-district (residential area) |
| MoF | Ministry of Finance |
| MOTE | Mykolayivoblteploenergo, a Municipally Owned Heat Supply Company |
| MOE | Mykolayivoblenergo, Joint Stock Company |
| NG | Natural Gas |
| NPV | Net Present Value |
| OPEX | Operational Expenditure |

# 1 Introduction

This report has been developed within the framework of the project “Mykolaiv - Denmark partnership – Technical support unit” financed by the Danish Ministry of Foreign Affairs (MFA). The project, which has been entrusted COWI, is a framework contract, which, among others, includes assistance to the Mykolaiv City Administration (MCA) in developing the Mykolaiv Masterplan in close cooperation with an Italian company, One Works.

*COWI's contribution to Mykolaiv Masterplan in a nutshell*

Mykolaiv Masterplan, which has been requested by the Mayor of Mykolaiv City, has a time horizon till 2050. It provides a compass for actions to be taken by the Mykolaiv City to ensure that it will develop into a thriving city attractive to its citizens and business community.

COWI and One Works assist Mykolaiv City Administration in developing the masterplan. In this work, COWI focuses on three sectors:

- Water and wastewater
- Energy, including power, district heating and renewable energy sources
- Solid waste management.

Mykolaiv City Administration meets every week with COWI and One Works to ensure proper coordination.

COWI has established a project organization consisting of a project management team and three sector teams of professionals, each headed by a Discipline Leader. Three sectoral Focal Points are responsible for monitoring cross-cutting activities, ensuring coordination between the parties and maintaining consistency in the deliverables.

To enhance transparency in the development of the Mykolaiv Masterplan, given its significant public interest and exposure, COWI has established three sector-specific Sounding Boards inviting all potentially interested parties to take part in these.

The principal audience for this report comprises the Mykolaiv City Administration (MCA) and One Works, given their central roles in the realization of this vision.

This report presents a detailed vision and strategy for development of the energy sector in Mykolaiv city and oblast, defining the goals and major steps to reach these goals. It is intended to serve as a communication tool articulating the rationale and strategy to follow to achieve the set goals in the most cost efficient and environmentally prudent way.

# 2 Mykolaiv Energy Sector Development Strategy until 2050

The strategy should identify the most crucial elements of the energy system requiring immediate reconstruction and provide directions for the development of the Energy Sector, so that Mykolaiv can become a modern, sustainable, and green city offering high quality living conditions for its residents.

## 2.1 Main assumptions

The development strategy for Mykolaiv Energy Sector consists of a carefully crafted set of activities and measures to be implemented on short and longer term:

1. Short-term

   The fastest possible reconstruction of the existing city's energy infrastructure to enable residents to return to normal life while accelerating the city's development in a country recovering from war which can be achieved by:

   - preserving the basic functionalities of the system,
   - reduction of heat losses by switching to lower temperature regimes,
   - reduction of technological water losses by means of pipeline sectioning, introducing IT based asset management.

2. Long-term

   The construction of a modern, sustainable urban energy system that relies on renewable energy sources. This system, with its advantages, will be able to attract residents and, in the long run, investors who can conduct their activities using affordable and reliable electricity, heating and cooling technologies. This can be achieved by:

   - decentralization of production providing flexibility, resilience and independence (Decentralization and diversification of heat sources, RES and waste heat to leverage (cost) benefits of different energy sources at any given time. System flexibility/resilience and more reliable heat energy supply),
   - new sources of production ensuring an optimal heat price (establishing new work regimes that enable the wide application of RES and its integration into existing systems),
   - heat storage,
   - interconnecting islanded heating networks to enable optimal utilisation of cheap renewable heat sources,
   - reconstruction of the distribution network (e.g., sectioning of pipelines, replacement and repair of pipelines based on age and needs), and identification of delivery points for thermal energy (heating substations, buildings, etc.).

Reconstruction of both the electrical and district heating infrastructure should incorporate the highest standards achievable today. The process of planning the reconstruction of the electrical power network should consider the current locations of key consumers in order to meet the present demand and facilitate the development of industrial and service areas. During the planning stage, it is also essential to consider the potential future local sources of electrical energy so that local transformer stations and other critical infrastructure elements can fully fulfil their roles.

In the next steps, the transformation of electric grid in line with the Smart and Green Cities concepts should be considered. These transformations are intended to lead to the achievement of the net-zero future goals, which means a complete reduction of greenhouse gas emissions.

The reconstruction of the district heating network - piping, as well as existing heat sources, should consider the need to provide domestic hot water to residents, public utility buildings, as well as commercial recipients, both industrial and in the service sector.

The next stage in the development of District Energy should involve the supply of cooling, which should initially be received by large, significant consumers, such as city-owned facilities or potentially major industrial consumers. The use of heat pumps for generation of cooling should be thoroughly analysed. An optimal solution for cooling generation by means of heat pumps would be to utilize waste heat from the cooling process for heating.

Given the current situation, a major opportunity for the development of Mykolaiv's energy system is the construction of a combined waste and biomass incineration plant. Both the waste designated for incineration and biomass - municipal and agricultural - should originate from Mykolaiv and its immediate vicinity. Due to year-round production and the lack of heat demand during the summer, as currently observed in Mykolaiv, it is necessary to consider the construction of a combined heat and power generation unit that will primarily produce electricity during the summer in the coming years. Excess heat during the summer should be utilized for the preparation of domestic tap water or cooling, with the share of utilization expected to increase in the following years due to connecting new recipients.

Such a unit can serve as the core of the energy system, which will be supplemented in the coming years by gas units, serving as a transitional solution, as well as electric generation units such as heat pumps and electrode boilers powered by renewable energy sources. Along with the development of the district heating network, which will be associated with an increase in the demand for domestic tap water and cooling, in the following years, geothermal and innovative hydrogen technologies may find applications in achieving a sustainable, zero-emission system free from fossil fuels.

All the assumptions mentioned above are further detailed in the next subsection. To verify their feasibility, a detailed analysis of current data, legal requirements, and verification of limitations in access to fuels and energy sources is needed.

## 2.2 Actions: 2030, 2040, 2050

The vision, along with the expanded Masterplan, considers the year 2050 as the final time horizon for analysis, with 2030 and 2040 serving as intermediate points where specific steps toward achieving the final goal will be outlined.

The starting point for further analysis is estimates of the future population of the Mykolaiv city. The ongoing war has led to some changes in population of Mykolaiv city. Since the outbreak of the war, approx. 250,000 people left the city, while approx. 200,000 refugees from Kherson have moved to Mykolaiv. Predictions are that once the war concludes, native citizens will gradually return to the city, while some of the refugees may leave and some may stay. Three different scenarios were developed to describe possible changes in city's population – see Figure 2-1. However, for further detailed analysis, "Neither-Nor" variant was considered.

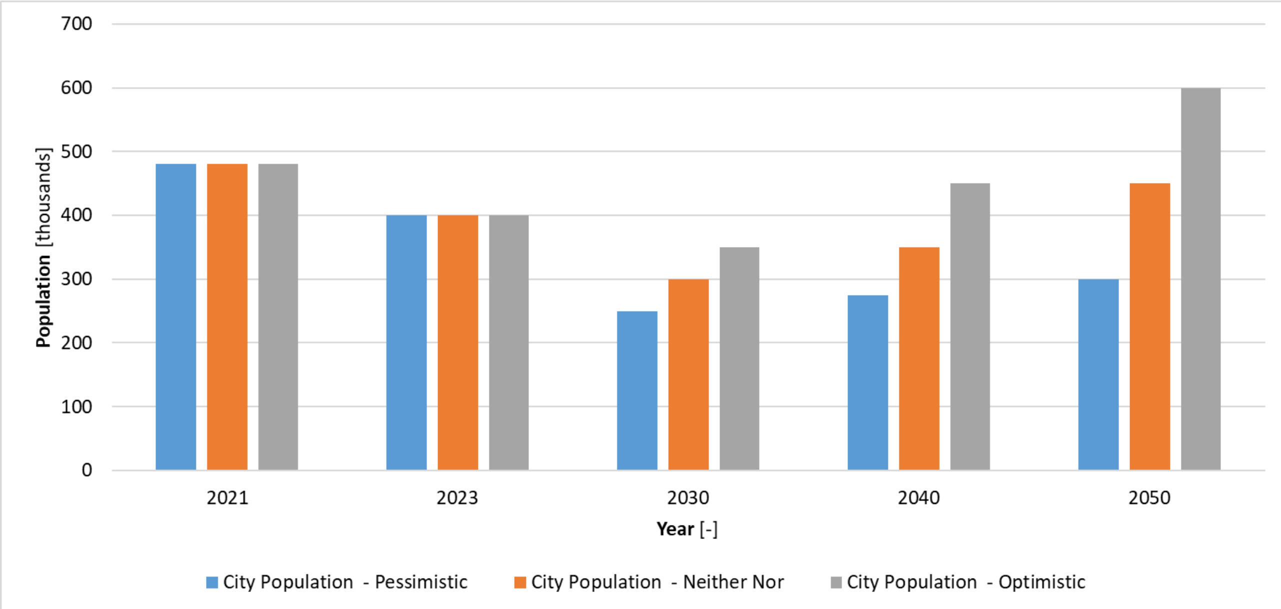


*Figure 2-1 Predicted changes in Mykolaiv population, across various projection scenarios*

## 2.3 District Heating Network

This section describes the development plan for the District Heating Network from now up to 2050. It presents the system transition in terms of energy efficiency, production units and operating temperatures over time. Graphical presentation of this potential development is presented on Figure 2-2.

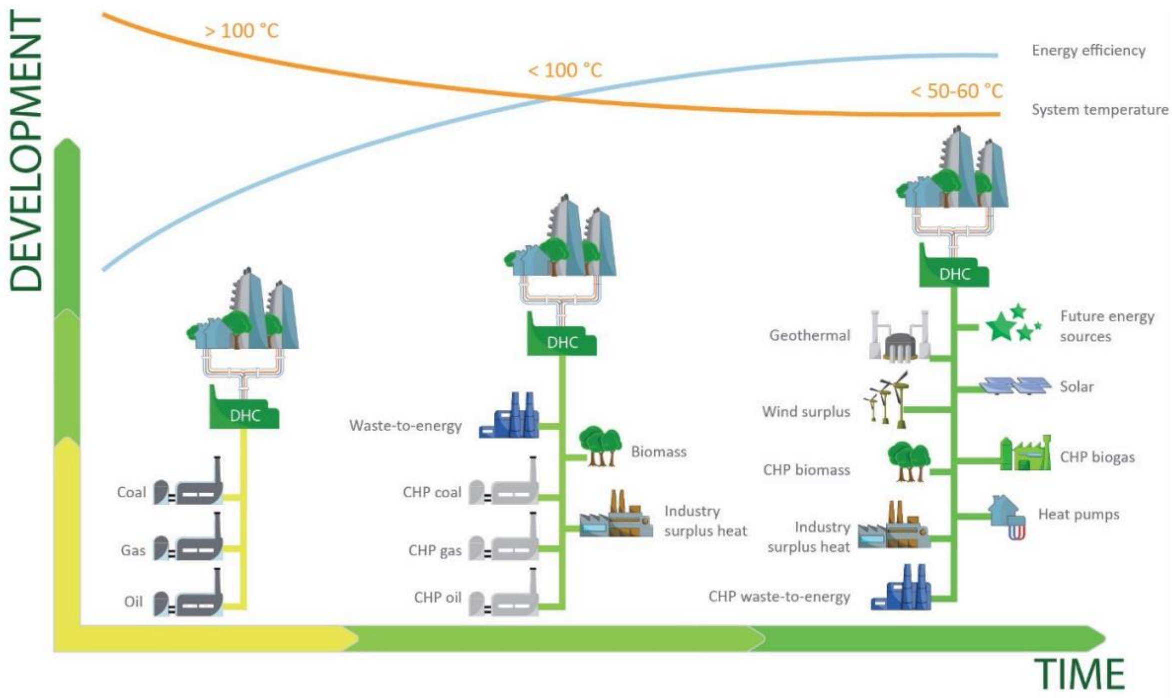


*Figure 2-2 Example of development of DH-system with time[1]*

[1] Euroheat&Power

The district heating system constitutes the three main elements: consumption, distribution, and production.

The steps that need to be undertaken in each of those three fields to reach a goal of building liveable, green city in 2050 are described below.

### 2.3.1 Production

In terms of the heat production, the focus is on the green transition – by 2050, the combustion of fossil fuels will need to be phased out completely, with other energy sources substituting for natural gas. The heat production mix for the period from 2021 to 2050, which is presented later in this section, has been developed with this goal in mind.

Firstly, the existing and future maximal heat loads have been assessed. The existing heat load was calculated based on the data of existing heat consumption from 2021, which is approximately 640 000 MWh. This figure, in conjunction with the known heat losses in the system (received from MOTE and MCHPP), which are approximately 18% of total production, results in an estimated 780 000 MWh of total heat production in 2021. The future heat load was estimated by accounting for changes in the city's population, the expansion of the district heating network, the inclusion of domestic hot water needs in the future, and an overall decrease in system heat losses (encompassing both reductions of heat losses from the piping system and the buildings). It was also assumed that length of the heating season will remain consistent at approximately 160 days, based on the data received from the city.

The predicted level of max heat load in relation to the city population is presented in Figure 2-3.

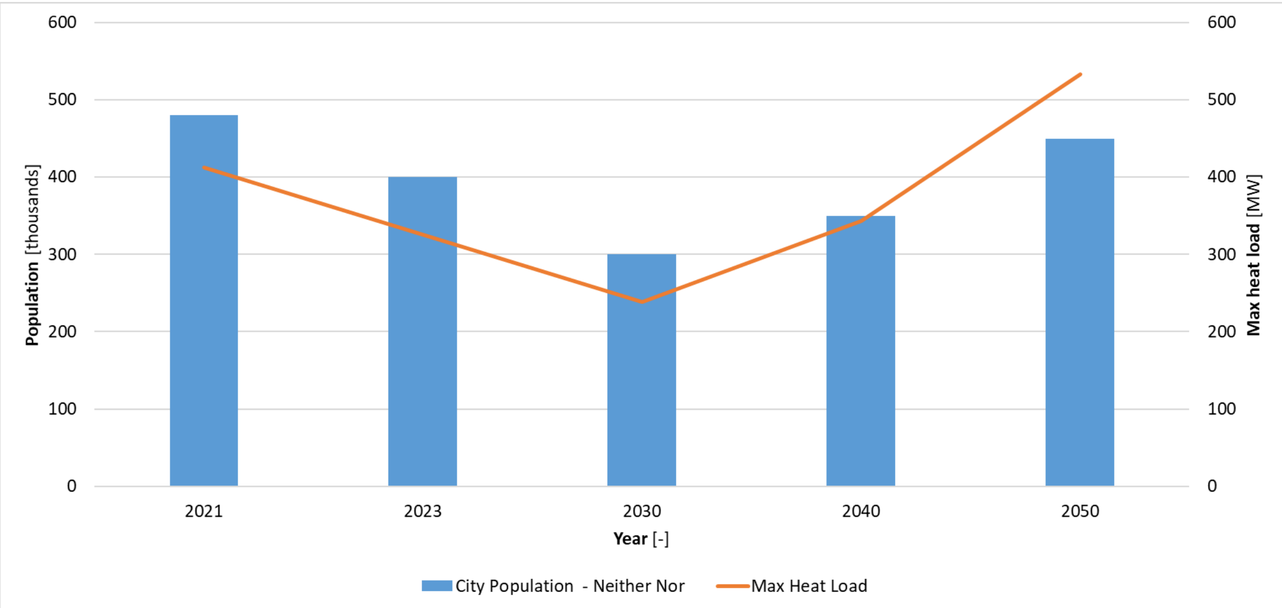


*Figure 2-3 Population of Mykolaiv city in years 2021-2050 with estimated Max Heat Load*

This has enabled the outlining of the general vision for the heat production mix (with the share of specific heat production units) from now up to 2050. The development of the production mix is presented in **Error! Reference source not found.**.

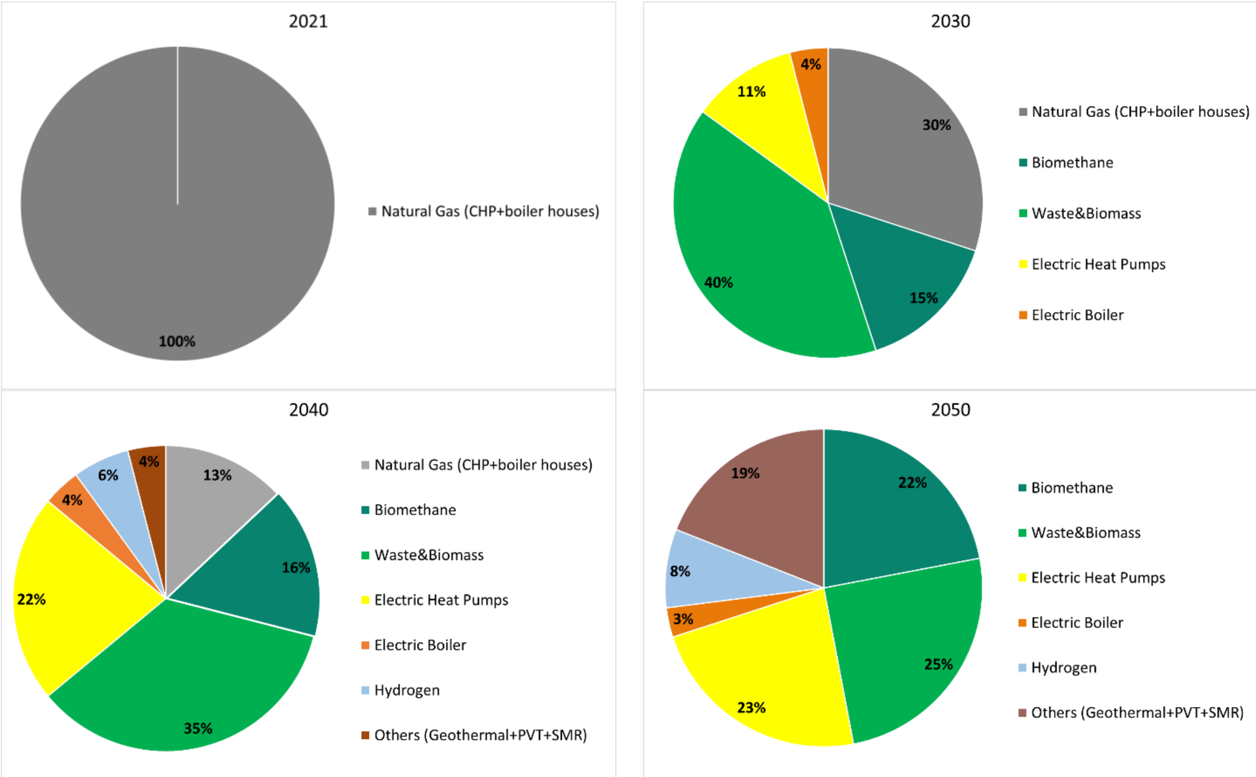


*Figure 2-4 Projected share of different heat production units in the overall heat production mix*

In 2030 the share of natural gas in total heat production will have dropped from almost 100% to 30%. It will be substituted mostly with biomass and waste incineration plant (40%), gas engines fuelled by biomethane (15%), heat pumps (11%) and electric boilers (4%). In 2030, the first heat storage is anticipated to be operational, contributing up to 5% of the total heat distributed.

In 2040 the share of natural gas may drop even more, to 13%. The share of biomass and waste in total heat production may be slightly lower than in 2030 (35%). Biomethane may cover 16%, the share of heat produced by heat pumps may grow up to 22%. It includes heat pumps utilizing air, river water, sewage water and heat from low temperature excess heat sources. It may be also possible to utilize excess heat generated during electrolysis and synthesis of hydrogen to ammonia or methanol. Additionally, co-firing hydrogen and compounds synthesized from hydrogen in gas engines or fuel cells. The share of generated heat out of processes related with hydrogen is predicted to be approx. 6%. Finally, other sources may appear, which could be either solar hybrid photovoltaics (PVT), geothermal or small modular reactors (SMRs), and these could constitute approximately 4% of total heat production. Those three sources are not that certain. Therefore, their combination is presented on the assumption that at least one will be developed. By this time additional heat storage facility may appear, which could cover up to 10% of the total delivered heat.

In order to reach the main goal, in 2050 the District Heating shall become completely sustainable and carbon-neutral. There will be no heat production based on fossil fuels and natural gas will be totally substituted by other heat sources. Share of biomass and waste will drop to 25%, while the shares of other sources will increase, such as biomethane up to 22%, heat pumps 23%, electric boilers 3%, hydrogen 8% and others (like geothermal+ PVT+SMR) constituting up to 19%. This comprehensive transition will aid in creating modern and efficient 4th Generation District Heating Network.

*Table 2-1 Projected heat production unit shares in the overall heat production mix (2023-2050)*

| Heat source | 2021 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| **Natural Gas (CHP+boiler houses)** | 100% | 100% | 30% | 13% | 0% |
| **Biomethane** | 0% | 0% | 15% | 16% | 22% |
| **Biomass&Waste** | 0% | 0% | 40% | 35% | 25% |
| **Electric Heat Pumps** | 0% | 0% | 11% | 22% | 23% |
| **Electric Boiler** | 0% | 0% | 4% | 4% | 3% |
| **Hydrogen** | 0 | 0 | 0 | 6% | 8% |
| **Others (Geothermal+PVT+SMR)** | 0 | 0 | 0 | 4% | 19% |
| **TOTAL** | 100% | 100% | 100% | 100% | 100% |
| **Heat Storage** | 0% | 0% | 5% | 10% | 10% |

Duration curves were created based on the projected production mix to illustrate how each suggested heat source contributes to the total heat production. See figures from Figure 2-5 to Figure 2-11.

- 2021

In the existing DH system of Mykolaiv city, natural gas is the dominant fuel used for heat production. A minor part of heat is also produced in coal fired boilers, but this accounts for less than 1% of total heat production. The fuel usage proportions are expected to stay approximately the same until 2025.

Estimated heat load curve for 2021 is presented in Figure 2-5, while Figure 2-6 shows an hourly heat load curve for 2021 generated based on typical weather conditions and heat load variations.

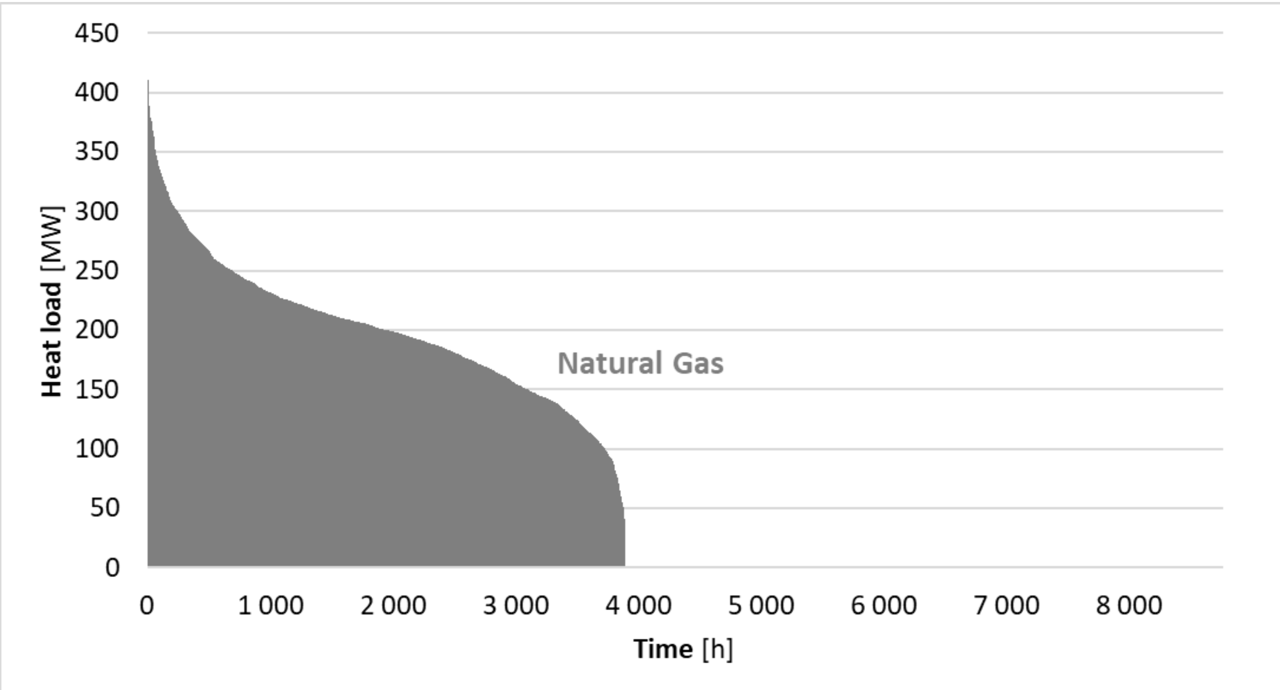


*Figure 2-5 Duration curve for heat load, 2021*

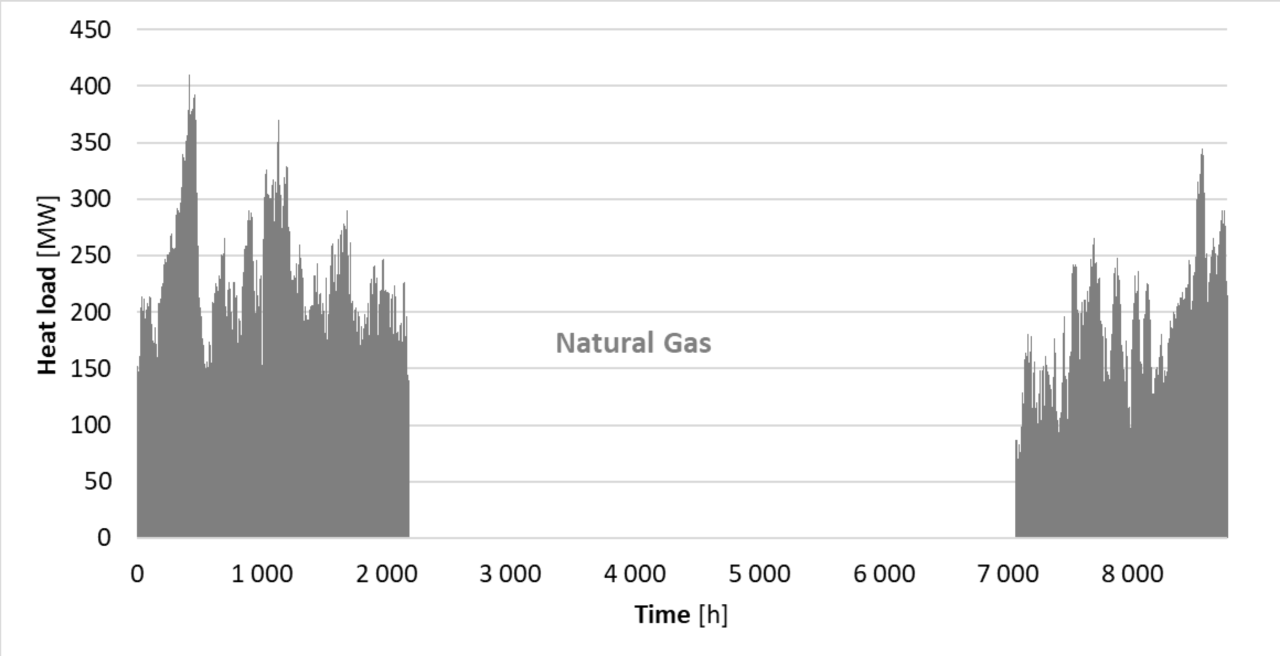


*Figure 2-6 Estimated hourly heat load curve, 2021*

- 2030

In 2030, it is assumed that a biomass-waste CHP plant will be established together with biomethane or natural gas engines, heat pumps, electric boilers, and a heat storage tank.

**Biomass-waste CHP**: The new CHP will burn a mix of biomass and municipal waste and will be operated as a base load unit. It shall be located in a suburban industrial zone separated from residential areas, making the city more liveable. The location shall also consider easy biomass transportation. The new biomass-waste CHP would supply heat directly to the large, interconnected supply area of the existing CHP plant by a set of newly placed interconnecting pipelines.

The CHP shall be able to work in flexible modes, with variable heat and power outputs throughout the year. In general, priority will be given to heat production during winter, and to electricity production during summer. However, the heat output during summer will gradually increase with time, as more and more consumers will be supplied with domestic hot water, this simultaneous result in lower power production during summer.

In the first period of operation of the new biomass-waste CHP, from 2030-2040, the load required for domestic hot water (summer heat load) might be much lower than its nominal heat capacity, as it is assumed that most of the consumers installation might not be ready for domestic hot water supply.

The option for summer months in this transition period might be to switch CHP into high electricity production, since electricity demand during summer months will be substantial due to high demand coming from e.g. of individual air conditioners (as cooling network will not have been developed yet). Excess heat (over the summer load) might be redirected to the cooling tower.

An alternative option could be to intensify the work on constructing consumer installations for domestic hot water supply to reach high summer load from the first period of operation of the new

CHP. To do this, some of the existing consumer installations that were in place before 2018 could be restored.

However, the document later describes the first option in detail, with the summer load increasing gradually.

**Biomethane:** The vision assumes a significant reduction of the total number of boiler houses in the network. Some of the 94 existing, old gas boiler houses can be replaced by a smaller number of large gas engines for combined heat and power production or large gas boilers, and their existing supply areas can be interconnected. However, the final number of the units, as well as their chosen locations and capacities will be determined through a separate, detailed analysis, which is described in section **Error! Reference source not found.**. New installations could possibly run on different g as fuels (biomethane or hydrogen in the future).

This project requires the construction of a biomethane plant for the production of biomethane fuel, which should be completed before 2030. What is more, one of the existing gas boilers (possibly situated at 71 Bila street) after renovation could take part in Pilot Project, with delivery of domestic hot water to the vicinity of Bila street.

**Heat pump (Flue gas recovery heat pump)**: The proposal here is to install heat pumps that would recover heat from the flue gas system in the newly built biomass CHP. Such heat pump (or possibly few heat pumps connected parallelly for higher capacity) may be installed on the inlet to CHP, preheating water entering the incineration lines. The water may be further reheated by incineration lines depending on the required supply pipe temperature in the interconnecting pipelines. In case of low temperature operation inside interconnecting pipelines, heat pumps might supply directly to the grid.

**River water heat pump:** It is considered to install heat pumps utilizing heat coming from Buh River. Further investigation shall be done for finding optimal location for the installation. Heat pumps may have the capacity to operate in a cycle that allows them to produce heat during the winter months and to provide cooling during the summer.

**Electric boiler:** Electric boilers, together with biomethane engines may partly replace existing boiler houses, reducing reliance on natural gas. On short term, they could substitute those boiler houses, which require rehabilitation. Together with the heat storage tank, electric boilers could work as an element of a virtual battery, giving more flexibility to the system. Their operation would be controlled by the prices of electricity and heat.

**Heat storage:** It could be considered to install a heat storage tank (either non-pressurized or pressurized), that would be able to be loaded/unloaded in daily cycles. Preferably it shall be located nearby the base load unit, (the biomass-waste CHP). This could help optimizing the heat and electricity production based on current energy price fluctuations.

The estimated heat load curve for 2030 is presented in Figure 2-7, while Figure 2-8 shows an estimated hourly heat load curve for 2030.

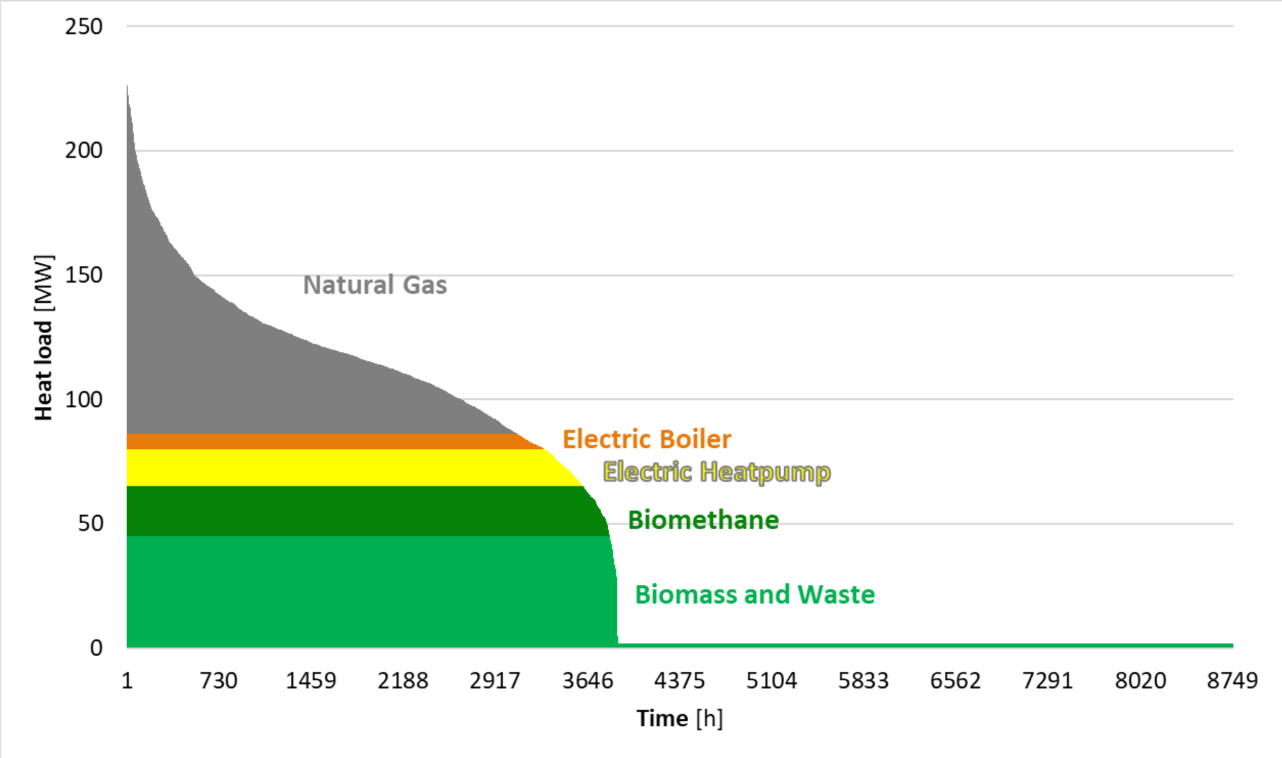


*Figure 2-7 Estimated heat load curve, 2030.*

As can be seen, there is an expected small summer load corresponding to approximately 1-2 MW, as projected for the year 2030.

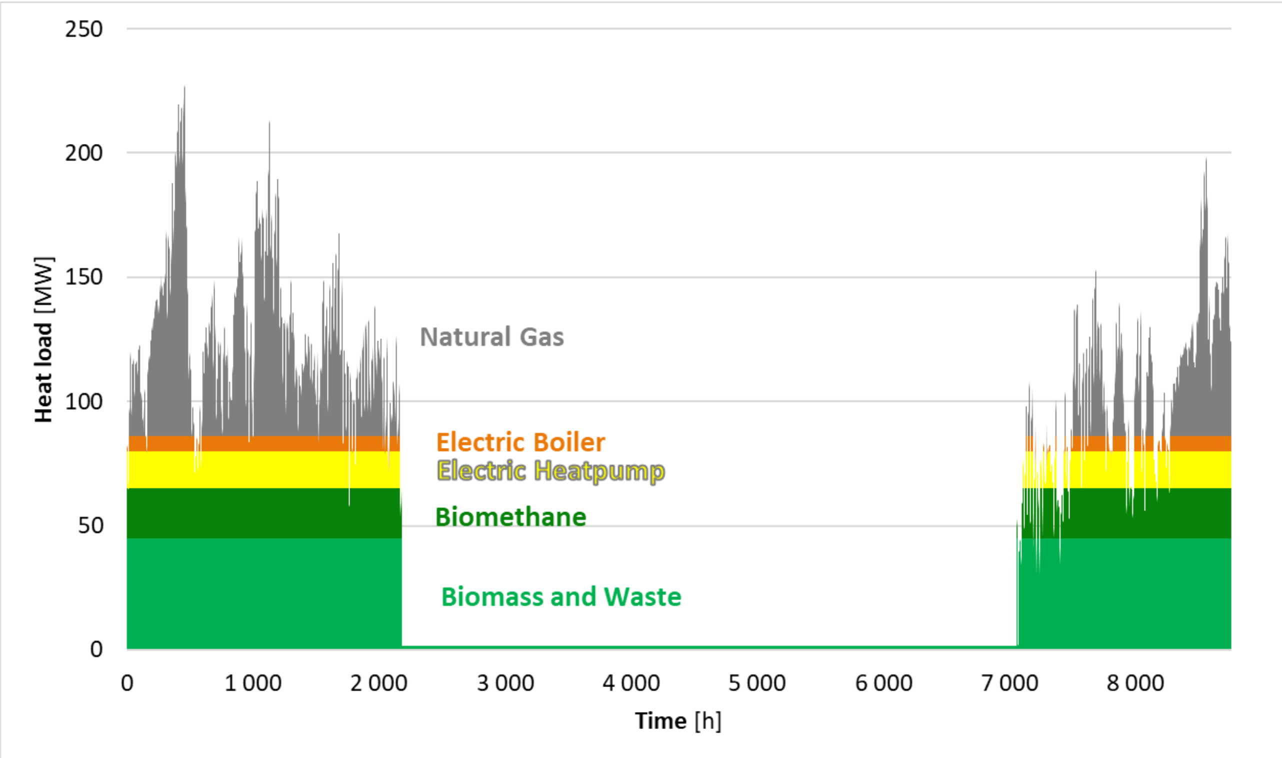


*Figure 2-8 Estimated hourly heat load curve, 2030*

- 2040

In 2040, it is assumed that heat will be produced by the biomass-waste CHP, heat pumps, electric boilers, and hydrogen/ hydrogen compounds fuel cells and engines, supported by heat storage tanks.

**Biomass-waste CHP**: The installation will continue its operation with previously designed load.

**Biomethane:** Additional existing gas boiler houses could be eliminated/replaced by highly efficient, bigger gas engines, possibly running on biomethane or hydrogen in the future.

**Air to water heat pump:** Air to water heat pumps could potentially be installed in the same locations as existing boilers houses. Such heat pumps could preheat the water, which could be then reheated to desired temperature at the boiler house. There are few advantages of such connection. Firstly, as long as gas boilers are in operation, they can heat up the water to desired temperature. Secondly, after they will be demolished, heat pumps can work independently, delivering low temperature heat to the distribution network. Thirdly, pipe network close to an existing boiler house is generally designed for higher capacity (having higher dimension), allowing for easy distribution of the produced heat. Lastly, it may be easier to establish the heat pump within the boiler house premises than in a new location.

**River water heat pump:** More heat pumps on Buh River are expected to be installed.

**Sewage water heat pump:** It is assumed that by 2040 first sewage water heat pumps will appear. One of the considered locations for a sewage water heat pump could be the wastewater treatment plant. To enhance the operation of the heat pumps it shall be considered to install a heat storage facility nearby. The reason for that is that the usual peak production out of sewage water heat pumps occur after the morning and evening peak consumption, meaning that production and consumption do not occur simultaneously. A heat storage facility can help to balance the production and consumption.

**Electric boilers**: It is anticipated that by 2040 more electric boilers will appear.

**Use of excess heat**: It is predicted that by this time part of the heat may be recovered from e.g. data centres or heavy industry, replacing internal cooling systems. Depending on the temperature level of the available heat, it can be either supplied directly to the network or supported by a heat pump to reach the desired temperature.

**Hydrogen**: By 2040 it is assumed that hydrogen may be available in Mykolaiv. The hydrogen may be utilized for heating purposes in two different ways:
1) Utilizing excess heat generated during the synthesis of hydrogen to ammonia or methanol; 2) co-firing hydrogen and compounds synthesized from hydrogen in gas engines.
For electricity production hydrogen and compounds synthesized from hydrogen might be utilized in fuel cells (dependent on technological advancements).

**Others (Geothermal+PVT):** It is expected that one of the selected sources, either geothermal energy or solar hybrid photovoltaics (PVT), is expected to appear by 2040.

**Heat storage**: As suggested above, additional heat storage tanks may appear, preferably next to sewage water heat pumps, working in daily cycles.

Estimated heat load curve for 2040 is presented in Figure 2-9 while Figure 2-10 illustrates an hourly heat load for 2040.

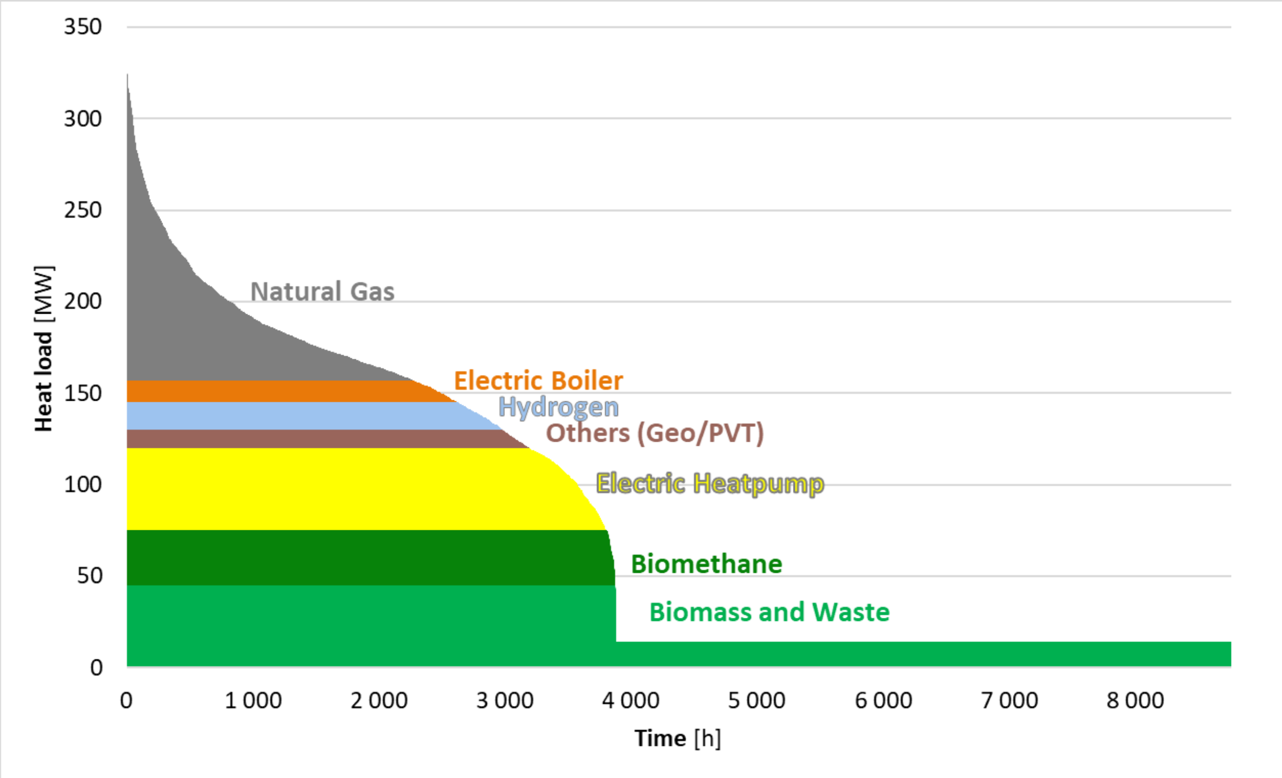


*Figure 2-9 Estimated heat load curve, 2040*

Increased demand in domestic hot water results in summer load corresponding to approximately 10 MW.

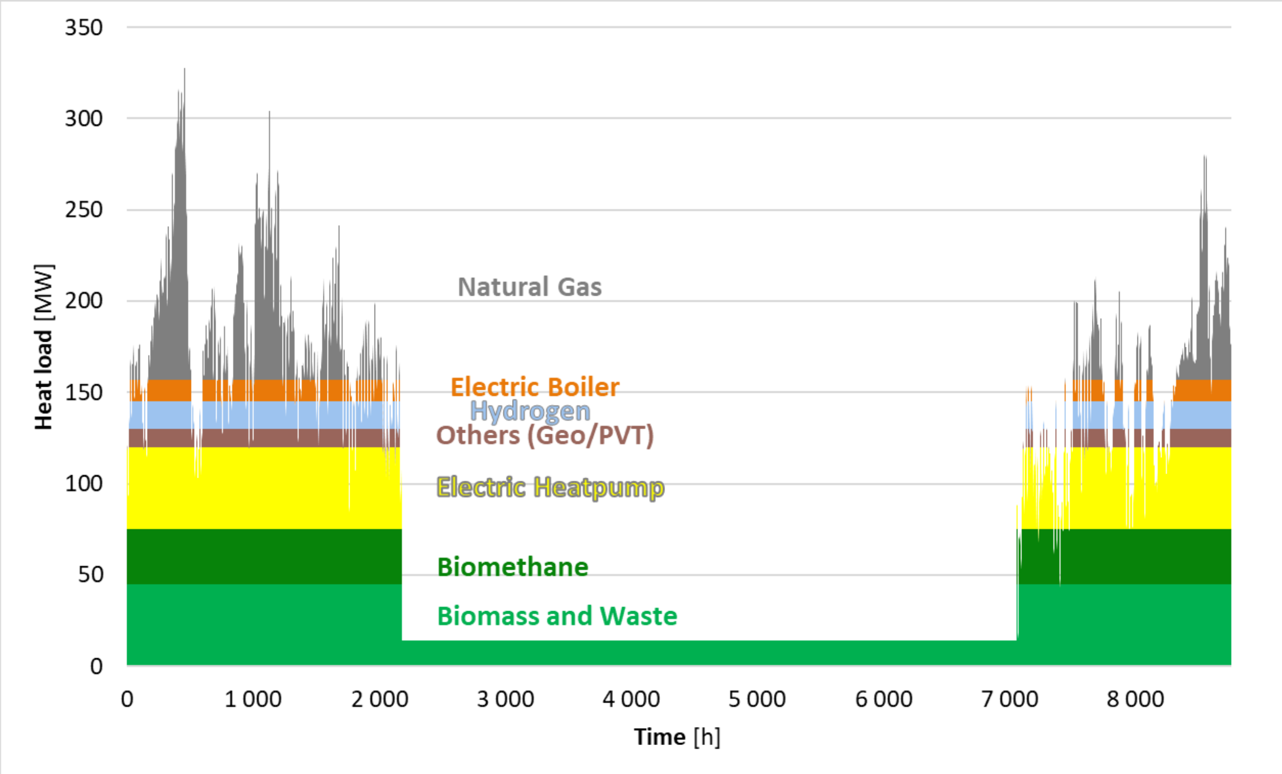


*Figure 2-10 Estimated chronological heat load curve, 2040*

- 2050

In 2050, it is assumed that heat will be generated by the biomass-waste CHP plant, heat pumps, electric boilers, excess heat, hydrogen, and geothermal plant, supported with heat storage solutions. Fossil fuels will have been totally phased out.

Furthermore, the first prosumers capable of both consuming and delivering heat to the network, such as supermarkets, commercial and industrial buildings, public buildings, etc., are expected to join the network by this time.

**Waste-biomass CHP**: The plant will continue its operation with previously designed load. However, it should be noted that from 2050 CHP will deliver full designed heat load throughout the year (approx. 50 MW), which will reduce the power output during summer operation compared to the situation with less heat load.

**Biomethane:** More existing gas boiler houses could be replaced by highly efficient gas engines, possibly running on biomethane or hydrogen in the future.

**River water heat pumps:** More heat pumps on Buh River will appear.

**Sewage water heat pumps:** More sewage water heat pumps will appear.

**Air to water heat pumps:** Part of the remaining boiler houses may be replaced with air to water heat pumps. By 2050, significantly lower temperatures in the distribution network are expected. This reduction will create an opportunity for heat pumps to directly supply heat to the network.

**Use of excess heat**: More excess heat sources may be interconnected with the district heating network.

**Electric boilers:** In 2050 total installed capacity of electric boilers will significantly increase and they may serve as peak load units once natural gas is totally replaced.

**Hydrogen:** In 2050 a significant growth of heat based on hydrogen is expected, constituting a significant share in the overall heat production mix.

**Geothermal:** It is anticipated that by this time some part of heat may come from geothermal source, however its availability shall be confirmed with further investigations. First estimates point to temperatures reaching up to 75°C, which should be sufficient for direct supply to the distribution network without use of heat pumps. The most feasible locations for such plants will need to be determined based on future surveys.

**Solar hybrid Photovoltaics (PVT):** Hybrid solar panels combining thermal and photovoltaic technologies in a single module are expected to be widely introduced in 2050, mounted on roofs of industrial buildings or placed on fields.

**Small Modular Reactors (SMR):** SMRs, either for combined power and heat generation or heat only, are likely to be commercially available before 2050. SMRs may become a part of Mykolaiv's energy system by 2050 and cover a considerable part of the heat demand. It is, however, considered only as an option. Alternatively, the share of heat produced in SMR could be covered either by PVT or geothermal sources.

**Heat storage**: No more heat storage tanks are planned to be constructed at this stage.

Estimated heat load curve for 2050 is presented in Figure 2-10 while Figure 2-11 shows a chronological heat load curve for 2050.

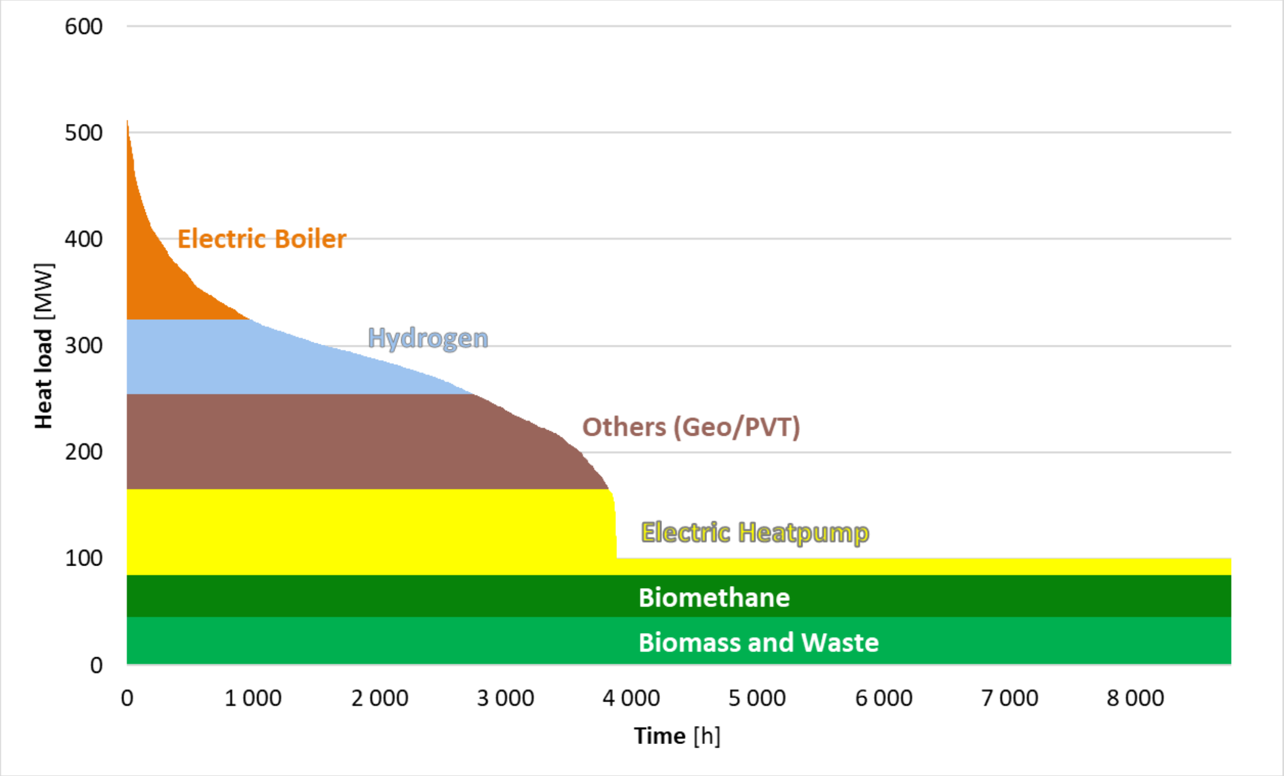


*Figure 2-11 Estimated load curve, 2050*

An additional increase in summer heat demand is expected. The summer load for 2050 is projected to be 100 MW.

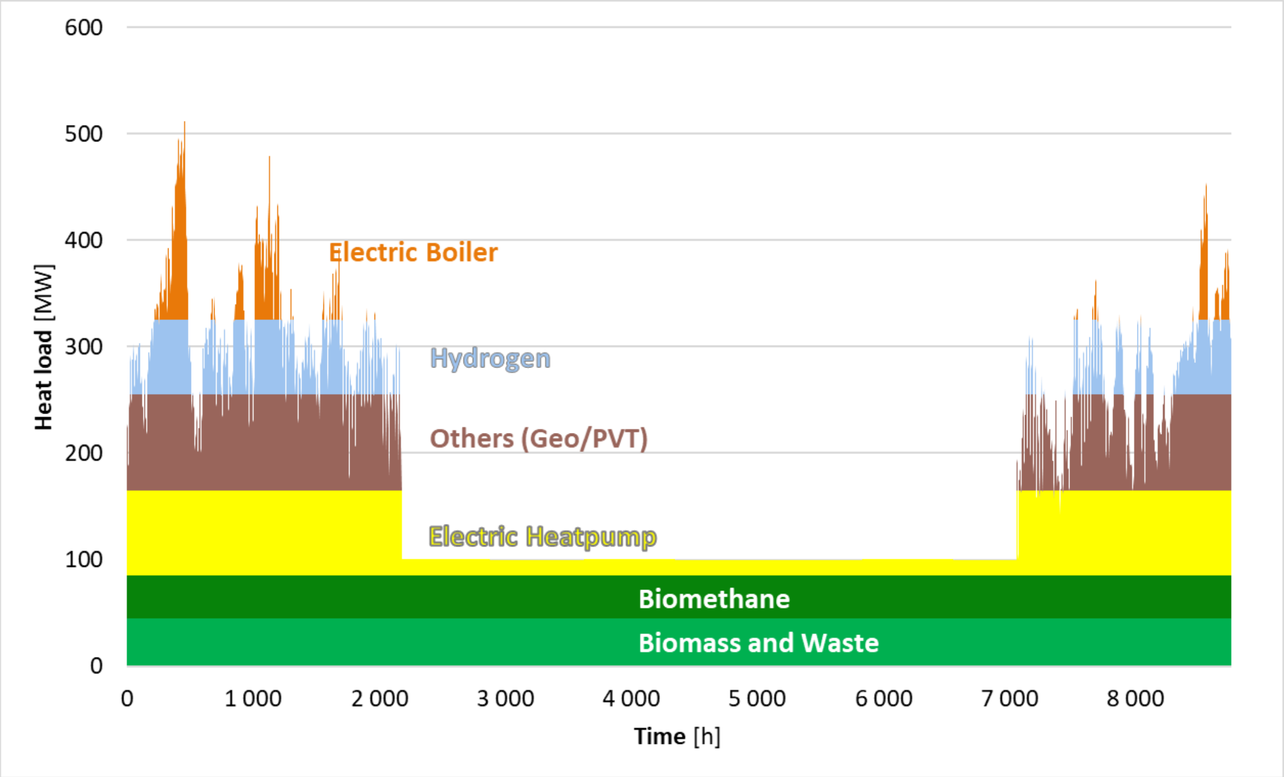


*Figure 2-12 Estimated hourly load curve,2050*

The first assessment of the required installed heat generation capacities from different heat sources is gathered in Table 2-2. Once the DH network is fully interconnected and all the production units deliver heat to the entire network, the total installed capacity shall be close to or only slightly higher than the maximum heat demand in the entire network which is presented in Table 2-2 and Figure 2-13.

*Table 2-2 Compilation of heat sources based on installed capacity up to 2050*

| Heat source | 2021 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| | Installed capacity | Installed capacity | Installed capacity | Installed capacity | Installed capacity |
| | MW | MW | MW | MW | MW |
| **Natural Gas (CHP)** | 477 | 477 | 477 | 0 | 0 |
| **Natural Gas (boiler houses)** | 515 | 515 | 258 | 232 | 26 |
| **Biomethane** | 0 | 0 | 20 | 30 | 40 |
| **Hard Coal** | 1 | 1 | 0 | 0 | 0 |
| **Waste&Biomass** | 0 | 0 | 45 | 45 | 45 |
| **Air to Water Heat Pump** | 0 | 0 | 0 | 5 | 10 |
| **River Water Heat Pump** | 0 | 0 | 10 | 20 | 30 |
| **Sewage Water Heat Pump** | 0 | 0 | 0 | 10 | 20 |
| **Excess heat + Heat Pump** | 0 | 0 | 5 | 10 | 20 |
| **Electric Boiler** | 0 | 0 | 6 | 12 | 208 |
| **Hydrogen** | 0 | 0 | 0 | 15 | 70 |
| **Others (Geothermal)** | 0 | 0 | 0 | 0 | 30 |
| **Others (PVT)** | 0 | 0 | 0 | 10 | 10 |
| **Others (SMR)** | 0 | 0 | 0 | 0 | 50 |
| **TOTAL** | 993 | 993 | 821 | 389 | 559 |
| ***Peak demand*** | *412* | *325* | *238* | *343* | *533* |

Electric boilers are considered to cover peak demand and their combined capacity is assessed together with the capacity of heat storage(s).

The vision assumes a gradual decrease in the total installed heat capacity of gas units over time, which is graphically presented on Figure 2-14 and Figure 2-15.

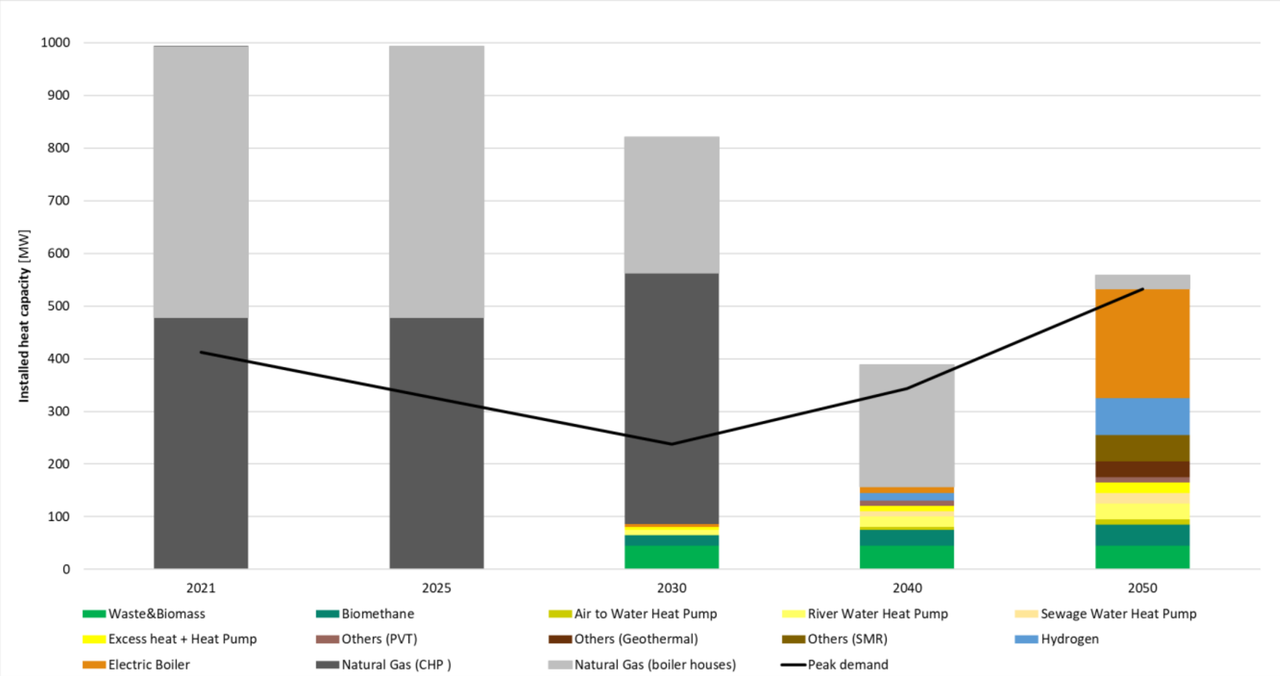


*Figure 2-13 Heat sources installed heat capacities in relation to peak load*

Figure 2-14 illustrates the concept of the potential reduction in gas units' installed capacities (in MW), and Figure 2-15 compares the extent of this reduction to their current capacities (in %).
One of the assumptions is that existing CHP may be decommissioned by 2040. In 2050, some of the most efficient boiler houses may remain as backup sources to operate in emergency situations.

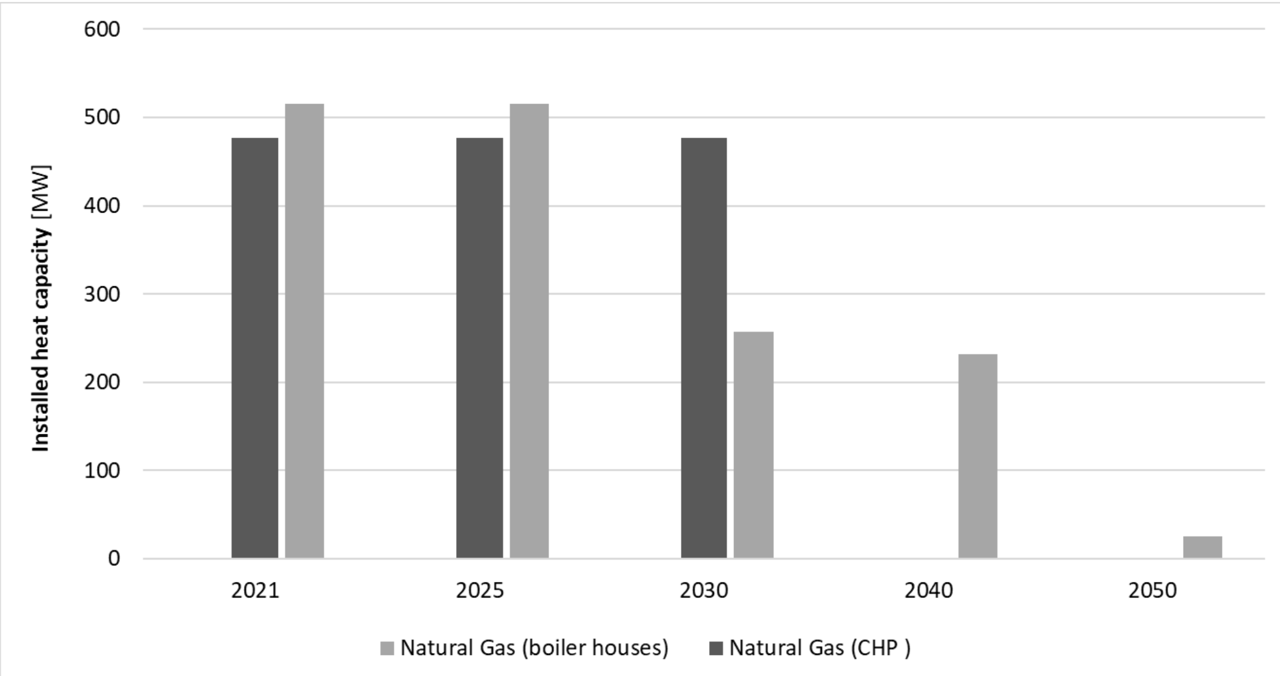


*Figure 2-14 Reduction of total installed heat capacity in existing CHP and boiler houses*

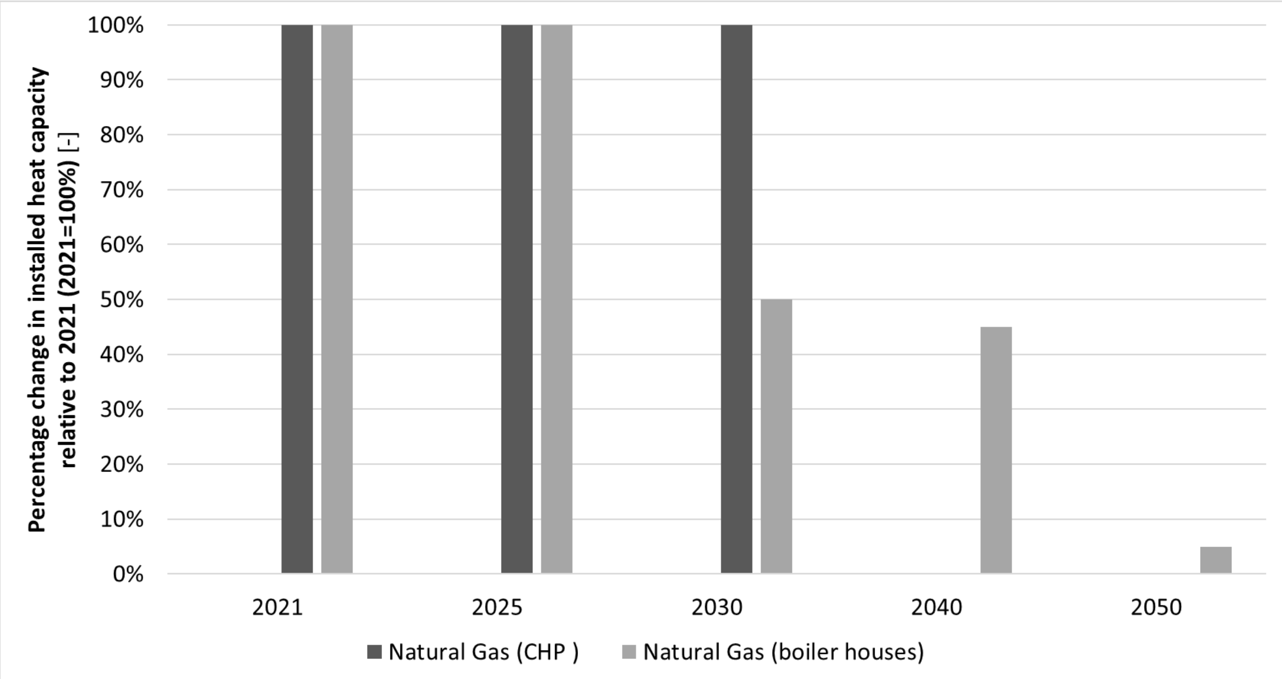


*Figure 2-15 Change in installed heat capacity in natural gas-fuelled heat sources relative to the year 2021*

**Verification of the possible size of biomass CHP based on availability of biomass fuel.**

To verify the feasibility of installing a biomass-based CHP, the Renewable Energy Agency of Ukraine has assessed potential bioenergy sources for use in the District Heating (DH) and Power Sector of the city of Mykolaiv. The assessment describes the bioenergy potential as of 2021 (just before the onset of the war) as well as initial predictions for the future, targeting the year 2050. Future potential assessments are based on UABIO's (Ukrainian Association of Renewable Energy) general approach to evaluating Ukraine's bioenergy potential by 2050.

Results show high economic potential of biomass available for energy, both regarding solid biomass and biomethane. Main parts of the solid biomass potential are straw of cereals, by-products of sunflower production, sunflower husk, and energy crops. The biggest amount of biomethane can be produced from cover crops.

The assessment of available biomass resources in the Mykolaiv region showcases a trend of increasing availability. These findings are detailed in **Error! Reference source not found.**. It is i mportant to note that the figures represent the total biomass potential, including portions consumed in other sectors.

*Table 2-3 Assessment of available biomass resources in Mykolaiv region*

| | | 2021 | 2050 |
|---|---|---|---|
| **Total amount of solid biomass available for energy (including also needs for other sectors)** | kt/year | 1860 | 2363 |
| **Total amount of biomethane available for energy (including also needs for other sectors)** | mln $m^3$/year | 375 | 433 |

Based on biomass resources assessed for 2021, available information on the existing consumption of biomass, distances between Mykolaiv city and centres of other cities (which is important for solid biomass transportation) and expert estimation, the potential of biomass that can be used in DH and power sector was estimated and gathered in **Error! Reference source not found.**.

However, since the future biomass consumption (for 2050) in other sectors is hard to predict as it might be influenced by various factors, further calculations assume the amounts of available biomass for DH and power sector will remain constant during the planning period.

*Table 2-4 Assessment of biomass in the Mykolaiv region available for the DH and Power Sector*

| | | 2021 | 2050 |
|---|---|---|---|
| **Assessment of available biomass for DH and Power Sector, 2021** | kt/year | 851,5 | 851,5 |
| **Array assessment of available biomethane for DH and Power Sector, 2021** | mln $m^3$/year | 333 | 333 |

Based on existing biomass availability for DH and Power Sector (2021), the maximum capacity of a biomass-based CHP plant, utilizing all available biomass and biomethane has been assessed. Assumptions regarding heating value and estimated efficiencies are gathered in Table 2-5 together with calculated total available thermal capacity.

*Table 2-5 Assessment of available thermal capacity in solid biomass and biomethane*

| **Solid biomass** | | |
|---|---|---|
| Amount available | t/year | 851 500 |
| Heating value | MJ/t | 17 000 |
| **Available thermal capacity (in solid biomass)** | MW | **468** |
| **Biomethane** | | |
| Amount available | mln $m^3$/year | 333 |
| Heating value | MJ/$m^3$ | 34 |
| **Available thermal capacity (in biomethane)** | MW | **366** |
| **TOTAL available thermal capacity solid biomass+ biomethane** | **MW** | **833** |

Table 2-5 shows that available thermal capacity in solid biomass is 468 MW, while in biomethane is 366 MW. To calculate if this amount is sufficient for determined sizes of biomass and biomethane co-generation units, it is important to assess their power capacities. The share between heat and power may be different depending on chosen turbine. Technologies that are coupled with DH usually has bigger share of produced heat than of produced power. First estimates of the power capacity (in relation to heat capacity) are presented in Table 2-1.

*Table 2-6 Estimates on required thermal capacity of biofuel units*

| | Installed heat capacity | Installed power capacity | Efficiency | Required thermal capacity (in fuel) |
|---|---|---|---|---|
| | MW | MW | % | MW |
| **Biomethane** | 40 | 40 | 90 | 89 |
| **Biomass&waste** | 45 | 14 | 80 | 73 |

Analysis shows that availability of biomass in Mykolaiv region significantly exceeds what is required.

### 2.3.2 Distribution

The existing District Heating Network in Mykolaiv City, operated by MOTE, is currently divided into many isolated, independent networks supplied by boiler houses, whereas the part operated by MCHPP consists of one large system supplied from the CHP.

According to the vision, it is assumed that by 2050 the majority of islanded networks will be progressively integrated with a larger network, currently supplied from existing CHP, through a series of newly constructed interconnecting pipelines. This will enable the establishment of a system comprising interconnecting pipelines and distribution pipelines, with the possibility of maintaining different operating temperatures on each side of the network.

Major production units may supply directly to the interconnecting pipelines, while some of the smaller production units may be connected directly into the distribution system.

One of the possible benefits of having one large interconnected system is that it does not need to be oversized in terms of installed production capacity for emergency and back-up. In the event of a shutdown of one of the heat production units due to various reasons it can be easily replaced by other heat sources which deliver heat to the same network, which is not possible in the case of isolated networks with a single supply source.

A graphical example of how the network could develop in the future can be found in Figure 2-16. Location of new production units and interconnecting pipelines are only examples and are not based on a detailed investigation. The idea is to locate heat production units further from the city centre and other attractive locations like, for example, the vicinity of the Buh River.

The graphical visualization also shows how distributed DH systems will develop to create one integrated network. Green circles refer to areas with district heating only, while purple circles refer to areas where there will be both district heating and domestic hot water in the future. Overlapping of the circles means that they are interconnected.

The areas coloured with green in the, Figure 2-16, are distributed DH Networks that delivers only district heating to end consumers. Networks where both district heating and domestic hot water is delivered are marked with purple colour. Yellow colour describes new interconnecting pipelines that will merge existing distributed systems. Also changes in domestic hot water supply are indicated in left top corners of each year scenario. It is presented as a share of consumers connected to DHN and supplied with domestic hot water.

The presented, possible expansion of the DH network requires a significant number of new pipes (intereconnecting, distribution and service) due to connecting new areas and in order to interconnect existing distributed networks.

The total length of the new distribution and service pipelines (in km) was assessed based on scaling total length of existing pipelines in regard to new consumers that will be connected in the future. It was assumed that growth in connecting new households will go in parallel with connecting public buildings, service and industry consumers. As mentioned before, connecting new areas will start after 2030 and continue to grow gradually. Based on those assumptions, approx. total length of distribution and service pipelines can grow from 285 km in 2021 (MOTE + MCHPP) to approx. 400 km in 2050.

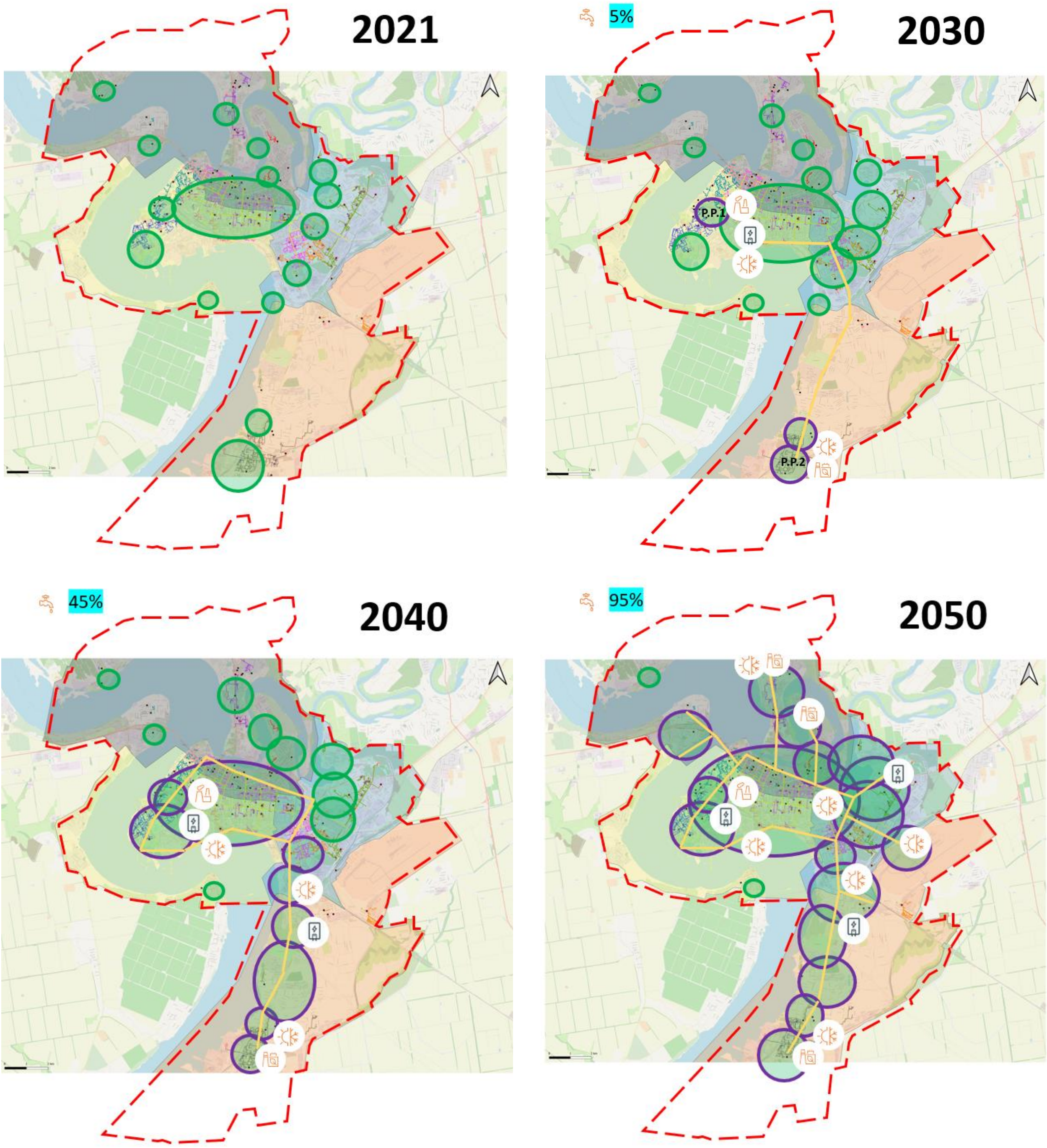


*Figure 2-16 Visualization of the development directions of the DH Network in the city of Mykolaiv from 2021 to 2050*

New interconnecting pipes aim to integrate existing distributed DH networks. It is assumed that construction of interconnecting pipes will start before 2030 and continue at a steady pace up to 2050. The total length of new interconnecting pipelines has been estimated by measuring the distances along proposed routes for potential new pipelines. The total length of new transmission pipelines can reach up to approximately 60 km in 2050.

Furthermore, existing pipes require thermal modernization due to the poor quality of insulation and high heat losses; therefore, replacing the existing pipes is necessary. New pipes replacing existing ones will be designed with sufficient capacity for future peak loads and low temperature operation.

It is assumed that up to 2050 all the 285 km existing pipelines will have to be replaced. This constitutes the biggest share of total new pipelines to be constructed or replaced before 2050.

According to questionnaires filled by MOTE and MCHP, the existing DH piping system in Mykolaiv is characterized by heat losses reaching in average 18% of total heat production (11% for MOTE system and 26% for MCHPP system, which have similar share of installed heat production capacity, however, with higher share of pipe networks on MOTE's side).

However, as mentioned above, existing pipelines will be gradually exchanged leading to overall decrease in network heat losses. The aim is that, up to 2050, all currently existing pipelines will be replaced with highly efficient pre-insulated pipes, designed for low temperature operation. Each part of the gradually renewed or newly installed network will be designed for low temperature operation and will feature excellent insulation. Apart from totally new network, also existing pipelines will be upgraded. Considering all above, the anticipated share of heat losses in the total heat production is expected to decrease from approximately 18% (as it is today) to 12% in 2050. Detailed data regarding the share of heat losses in the total heat production throughout the planning period is presented in Figure 2-17.

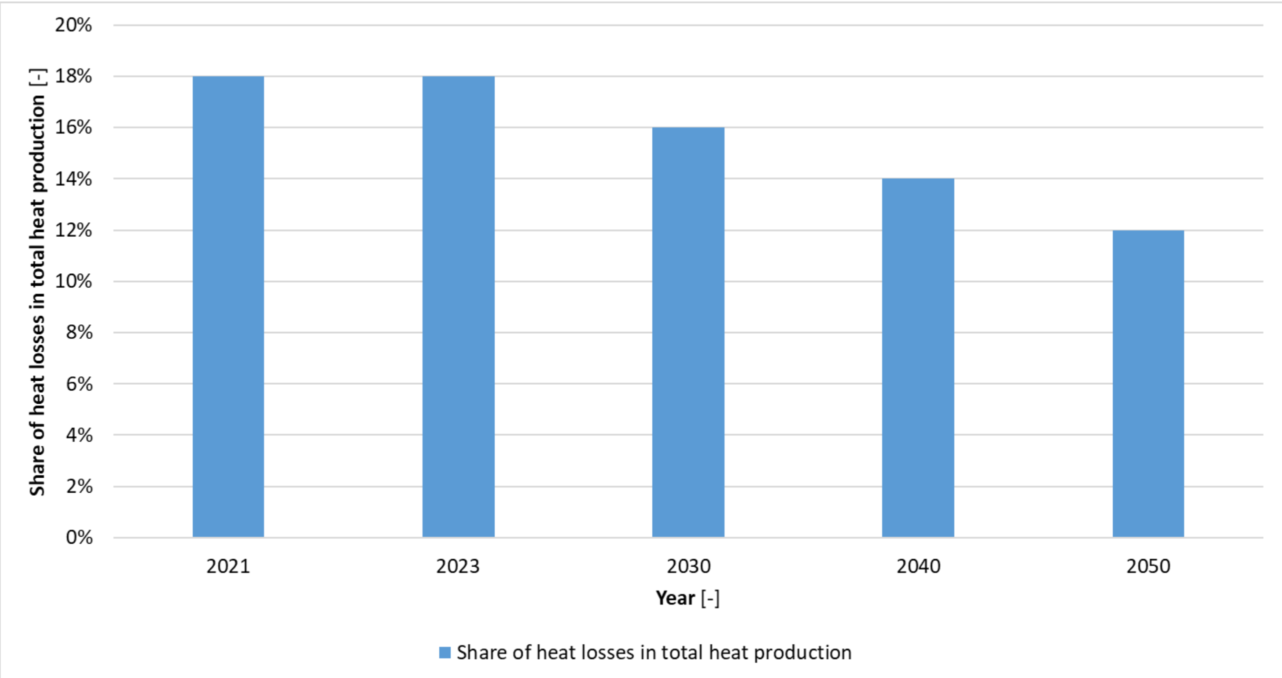


*Figure 2-17  Expected share of heat losses in total heat production*

In the whole process of building new and replacing existing pipelines, focus shall be put to firstly reinforce existing network to enable stable and highly efficient heat delivery. It would mean start (from approx. 2025) replacing existing pipelines, first the ones with the highest frequency of accidents and leaks, and thereafter the ones with highest heat and pressures losses. It could go in parallel with interconnecting the system, by building first interconnecting pipelines. Finally, less prioritized would be connecting more consumers, which could start after 2030.

Predicted lengths of pipes are presented in Figure 2-18 and Figure 2-19.

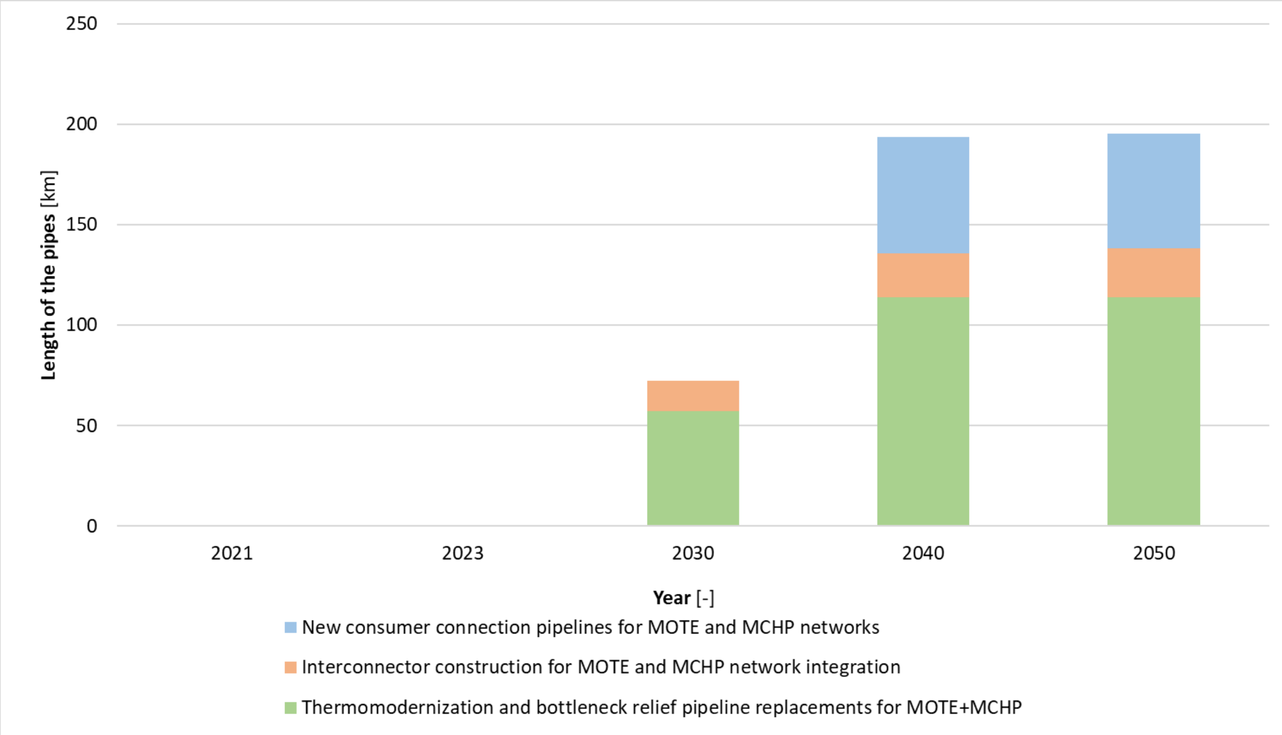


*Figure 2-18 Pipelines scheduled for construction to meet the 2050 network modernization goals*

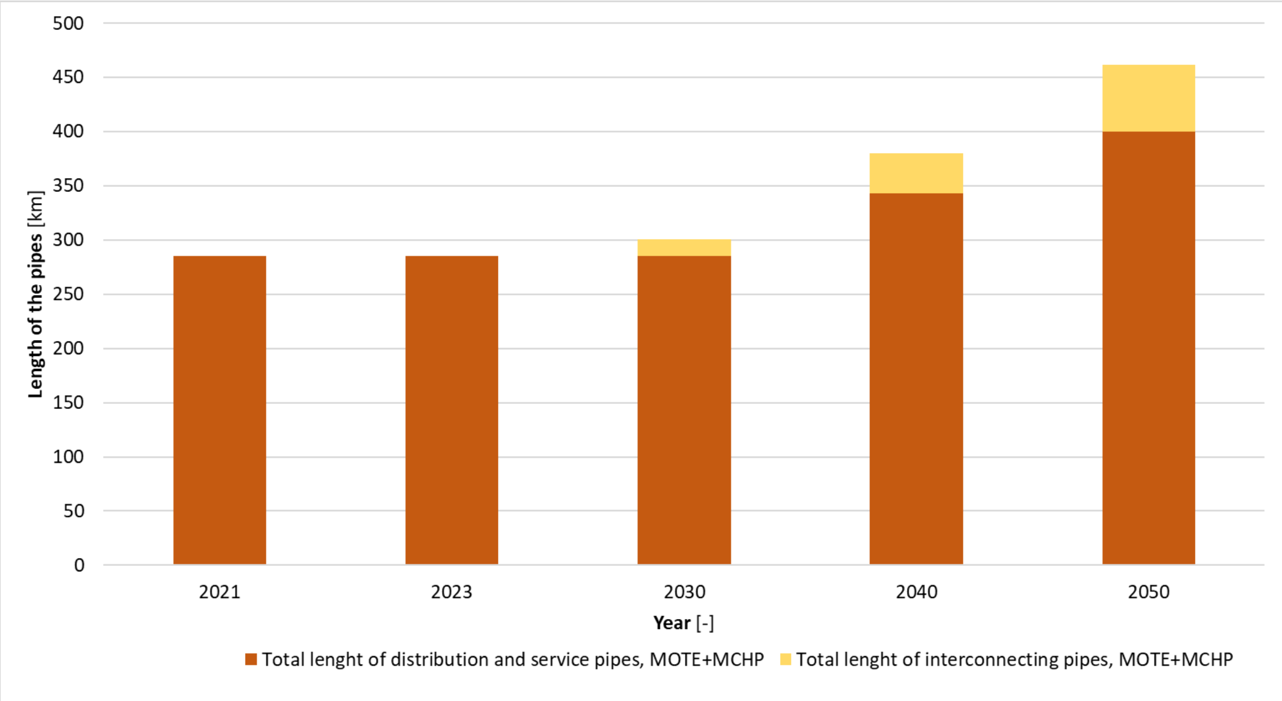


*Figure 2-19 Total length of the pipelines in corresponding years*

As seen in Figure 2-18, the suggested network renovation and reinforcements would require enormous amounts of new pipes to appear in considerably short time – approximately 70 km of new pipes up to 2030, and on average 19 km per year from 2030 to 2050. Based on experience from Danish and Polish markets, a DH company builds or reconstructs on average approx. 6 km each year. The limiting factors are here: financial issues, like obtaining loans, capacity for manufacturing of required components and capacity of contractors in the market (labour and machinery).

The estimated approx. length of pipelines to be built or reconstructed in Mykolaiv city is more than 3 times higher (19 km per year) during the period from 2030 to 2050 and approx. 2 times higher between 2025 and 2030 (14 km per year). This would mean that in order to meet this goal Mykolaiv city would have to have access to good financing, as well as contractors with sufficient capacity in terms of labour and machinery. Since Mykolaiv city will not be the only city requiring substantial reconstruction in Ukraine at this time, this aim may be difficult to reach, however, not impossible.

A crucial factor for the future network design is the choice of operating temperature regimes. This will have significant influence on pipe dimensions and overall costs of investment. Having these in mind, two possibilities are considered.

First one assumes keeping low supply temperature everywhere in the network, which would correspond to approx. 70°C/40°C in supply and return (this temperature level is presently aimed in most Danish DH systems). This approach would enable applying low temperature solutions like heat pumps directly to the network.

The second one assumes keeping higher supply temperature out of the major production units and in the primary interconnecting pipelines between production units and distribution network, while distribution pipelines reaching residential and industrial zones would be supplied with lower temperature, decreased in shunting stations or heat exchangers. Such shunting stations/heat exchangers separates high temperature primary network from low temperature distribution networks. This approach is well recognized in some Danish systems, like e.g. in DIN Forsyning DH network (Esbjerg city). It opens for smaller dimension for primary pipelines because it allows for a higher temperature difference between supply and return pipe. For each major production unit, the optimal solution should be chosen based on a thorough Feasibility Study.

Those two approaches differ with operating temperature in the interconnecting pipelines, however, regardless of chosen one, the aim is that all the consumers connected to Mykolaiv DH network will gradually be converted to receiving low temperature heat during the planning period up to 2050.

### 2.3.3 Consumption

Before the war, approximately 55% of the population was connected to the DH network. It was calculated based on known number of connected households and the assumption that one household comprise approx. 3 people. The vision anticipates that, in 2030, this number will remain unchanged. By 2040, the proportion of the city's population connected to the heating network is anticipated to rise to 75%. Furthermore, by 2050, it is estimated that this connected share could potentially increase to 95%.

The existing DH network currently provides only space heating during the heating season lasting approximately 160 days, with no distribution of domestic hot water (DHW). Domestic hot water was provided to consumers in the past, but ended in 2018, leading to reliance on individual electric boilers in apartments. These boilers are preferred for their lower cost and quality, influenced by the disparity in electricity pricing for residents and industries. The engineering infrastructure inside buildings has likely deteriorated due to disuse.

However, the future vision assumes the delivery of DHW together with space heating, extending the future operational periods of new production units and potentially accelerating the return on investment. Regarding DHW, the ultimate aim is (similarly like with space heating) to supply 95% of citizens in 2050. It may start slowly before 2030, while the more rapid change is expected after 2030.

The development in the expected city population, as well as the anticipated shares of consumers supplied with space heating and domestic hot water, are presented in Figure 2-20.

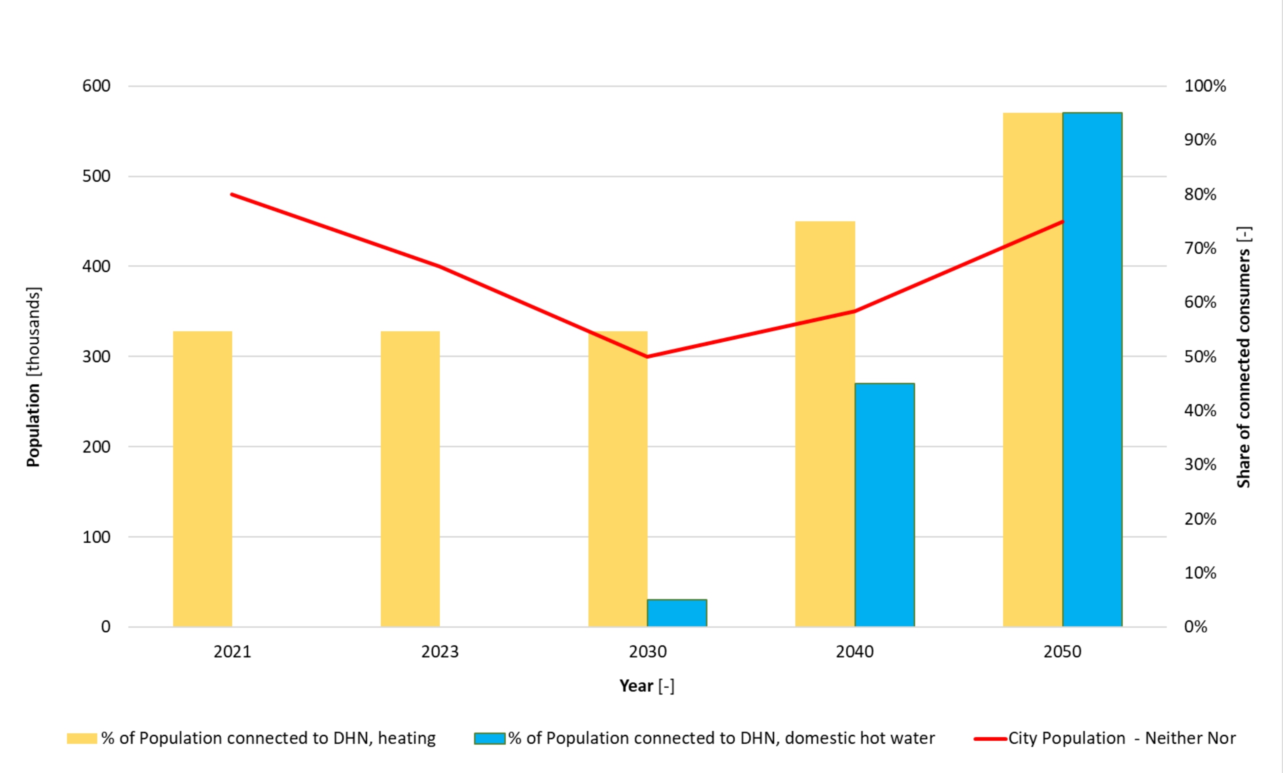


*Figure 2-20 Population of Mykolaiv city in years 2021-2050 with percentage of population connected to DH Network*

Connecting more consumers to the DH network will be reflected in more households connected, as well as service, industrial and public buildings. See Figure 2-21 and Figure 2-22. The growth of the consumer base will go in line with growth of city population connected to DH network (Figure 2-20, red line).

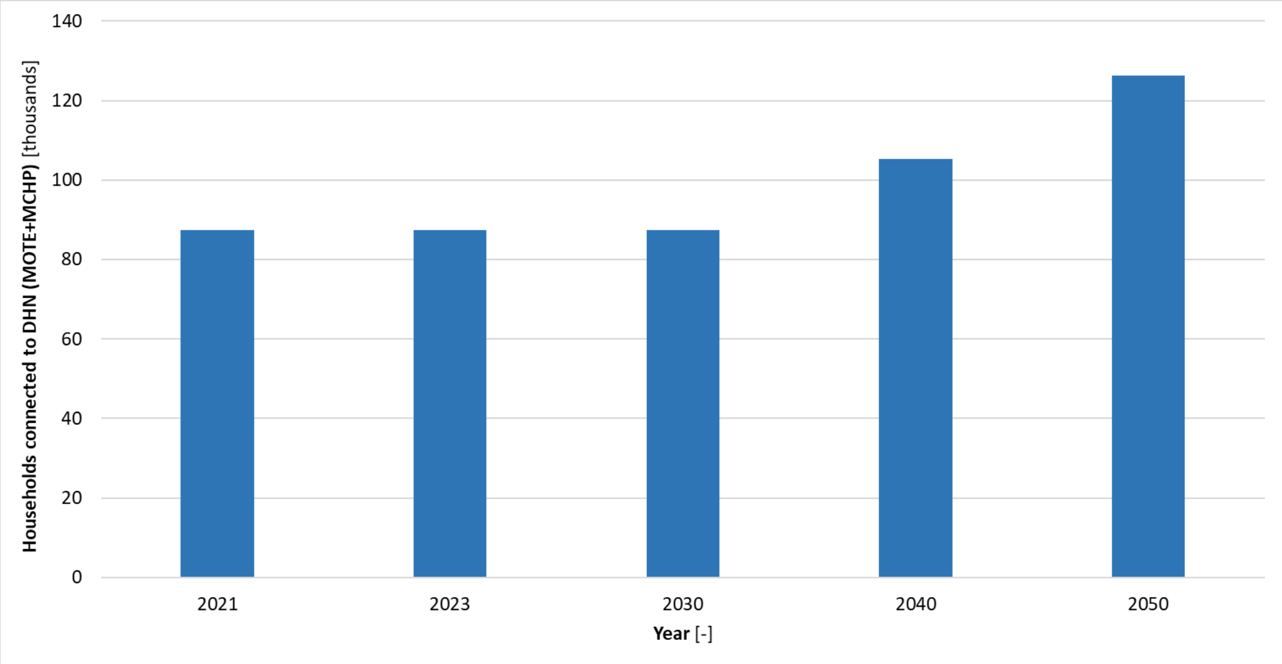


*Figure 2-21 Predicted number of households connected to DH network in selected years*

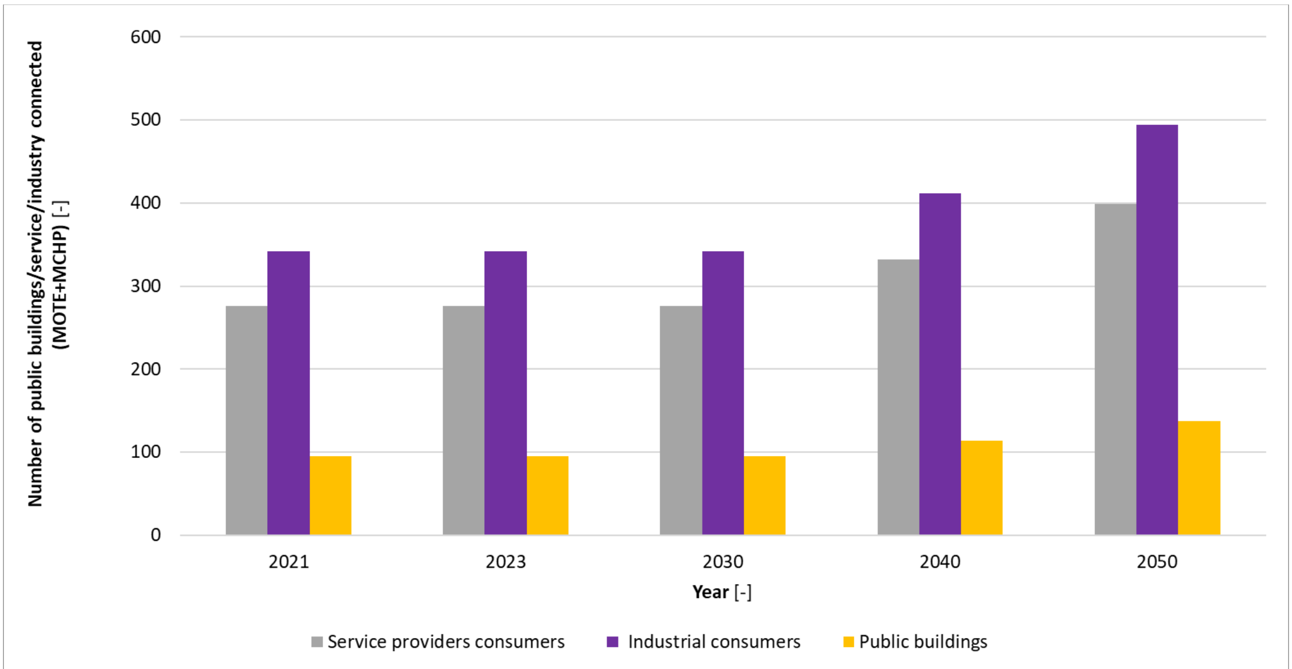


*Figure 2-22 Predicted number of service providers, industry and public buildings connected to DH network in selected years*

As can be seen in Figure 2-20-Figure 2-22 there are no plans to connect new consumers to the DH Network before 2030, however preparation works for the connection may start sooner. Up to this time focus will be on securing stable delivery of heat to existing consumers, that will hopefully come back to their home city. However, before 2030 initial steps will be undertaken to deliver DHW to some of the existing consumers.

This would require building new or renovating old installations for DHW at each substation, meaning heat exchangers and pipe networks. It is important to emphasize that the planned introduction of low temperature operation will require that all the existing space heating installations shall be modified accordingly. These two investments (DHW and space heating) may be conducted simultaneously. A graphical presentation of how that process could be organized time wise is presented in Figure 2-23. It covers both existing and future consumers.

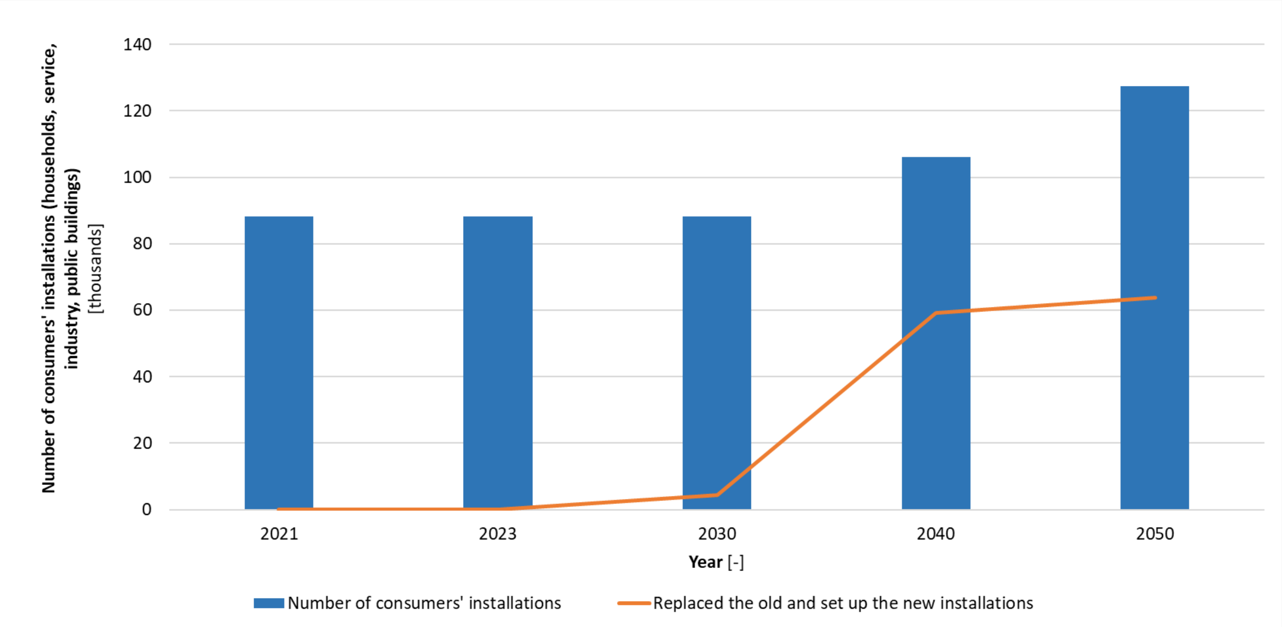


*Figure 2-23 Summarized annual installations in relation to total consumer installations*

By the end of 2050, all consumer installations are expected to be adapted for low-temperature operation.

It is considered to carry out two pilot projects, covering two different areas of the city, where domestic hot water could be distributed in the first period (before 2030). These areas were proposed by the city as places where installation of IHS could be executed in a short-term period, as well as where boiler houses could be rehabilitated. These are:

1. Vicinity of Bila street
2. Vicinity of Samoilovicha street

The proposed roll out of connecting DHW to consumers is as presented in Figure 2-16. The priority for the roll out of domestic hot water shall be given to consumers situated closest to the base load unit. This will allow to take more remote parts of the network without DHW supply out of operation during summer and thereby ensure the lowest heat losses in the network.

**Types of Individual Heat Substations for connection of individual buildings to the DH network**

There are generally two main connection types between distribution network and consumer, which can be further considered in Mykolaiv: direct or indirect.

In direct connection, water from primary grid flows directly through the consumer space heating installation, while domestic hot water circuit is separated through the heat exchanger. In this kind of installation, it shall be considered that static pressure at the plant needs to be high enough to secure flow reaching highest floors in multi-story residential buildings, which limits hydraulic capacity out of the plant. Alternative to this can be locally installed pump at the substation controlling pressure at the consumer side. Main drawbacks of direct systems are high temperatures inside consumers installation and issues in the event of leakage. An example of such connection is presented on Figure 2-24. However, this kind of system is not used in Ukraine.

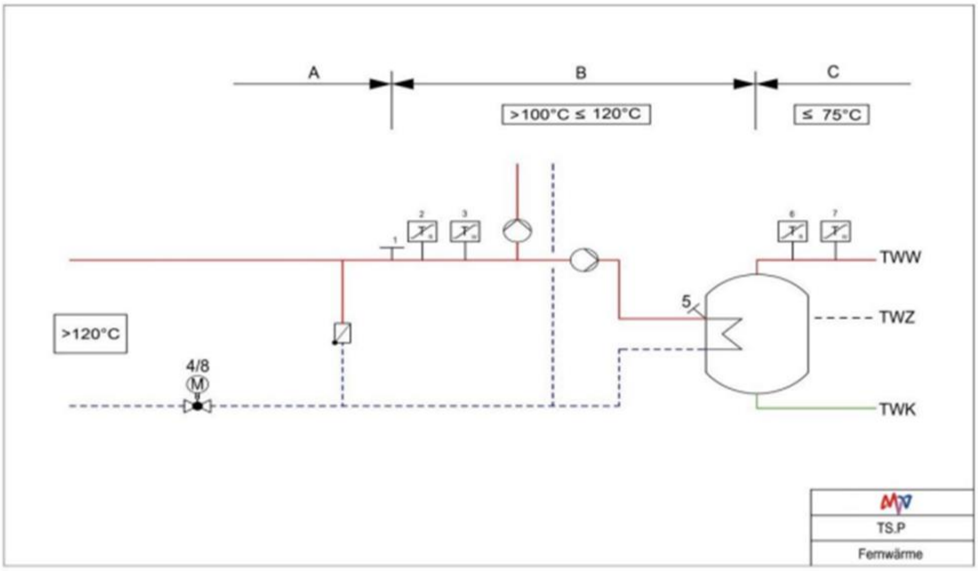


*Figure 2-24 Example of the scheme of direct connection.*[2]

In indirect connection, primary network is separated from consumers' installation by heat exchanger (separate for space heating and domestic hot water). This is the common approach in modern DH systems, because it enables a better control of water quality and helps to eliminate water losses due to leakages internally in the buildings supplied by DH.

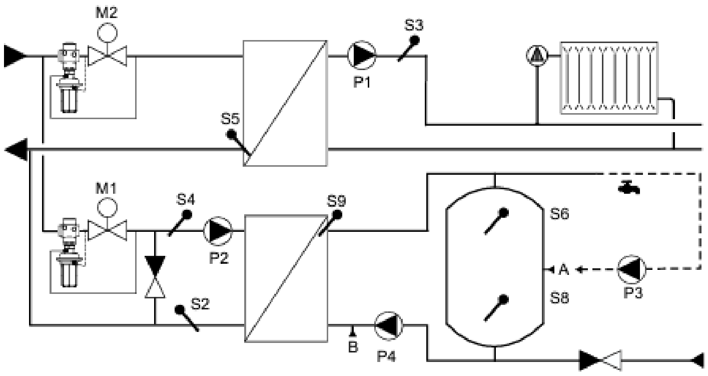


*Figure 2-25 Example of typical scheme in Ukraine, indirect connection*[3].

It is also possible to install a substation when district heating and cooling is integrated. The example of such substation, with the use of heat from local source (5GDH integrated DH/DC) is presented on Figure 2-26.

[2] www.upgrade-dh.eu, MVV Netze, 2015
[3] Danfoss, scheme delivered by the company

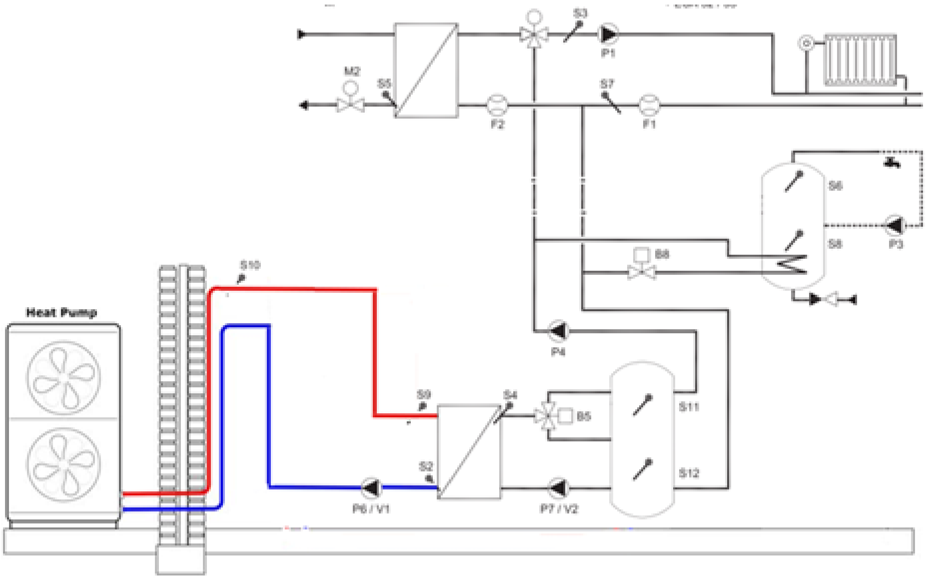


*Figure 2-26 LTDH Substations with using heat from a local source (5GDH integrated DH/DC), indirect connection.*[4]

In both cases, the DHW installation is separated by a heat exchanger from primary grid. It is normally designed as a side branch from the space heating installation at the individual substation.

Change to variable flow and introduction of Individual Heat SubstationsIt is standard in Ukraine to use open dependent heating systems in which the heat sources, the distribution system and the consumer are one circuit. Such systems are regulated in a qualitative way where the flow rate of the heating agent remains constant while the supply pipe temperature of the heating agent is regulated according to weather conditions.

To be able to operate the DH system with input from two or more heat sources, and at the same time ensure a smooth and highly efficient operation of the DH system, the flow regime must be changed from constant to variable flow by controlling the heat circulation pumps according to the differential pressure at critical consumer (the consumer in the network with lowest differential pressure between supply and return pipe). In some cases, it may be necessary to allow pump speed control according to differential pressure at more than one critical consumer, because variations in the share of heat produced by different heat sources will lead to fluctuations in the flow distribution and therefore in the differential pressures throughout the networks.

The change to variable flow will also require installation of Individual Heat Substations (IHS) at each connection point between the DH network and individual consumers, enabling continuous and precise control of heat supply in accordance with demand. The full benefits of the conversion to variable flow cannot be obtained until all consumers within an interconnected supply area have been provided with an IHS.

Finally, in order to reduce thermal losses and thereby increase efficiency of the heat consumption, thermal modernization of the buildings together with introduction of the regulatory systems for temperature control must be considered. It is assessed that this process will start before 2030 and

[4] Danfoss, scheme delivered by the company

up to 2050 all the buildings connected to DH will have proper insulation and regulatory systems. This will have significant impact on the decrease in overall heat consumption for existing consumers.

According to Danfoss, absolute losses, which consist of relative losses in the network and buildings (including due to low automation) in Ukraine can reach large values and amount to more than 50%. It is assessed that by minimizing heat losses in the buildings, overall heat consumption for existing consumers may decrease by approx. 30 %.

Figure 2-27 shows prediction of the behaviour of the future heat consumption in relation to growth in thermal modernization of the households as well as implementing of the regulatory systems for temperature control.

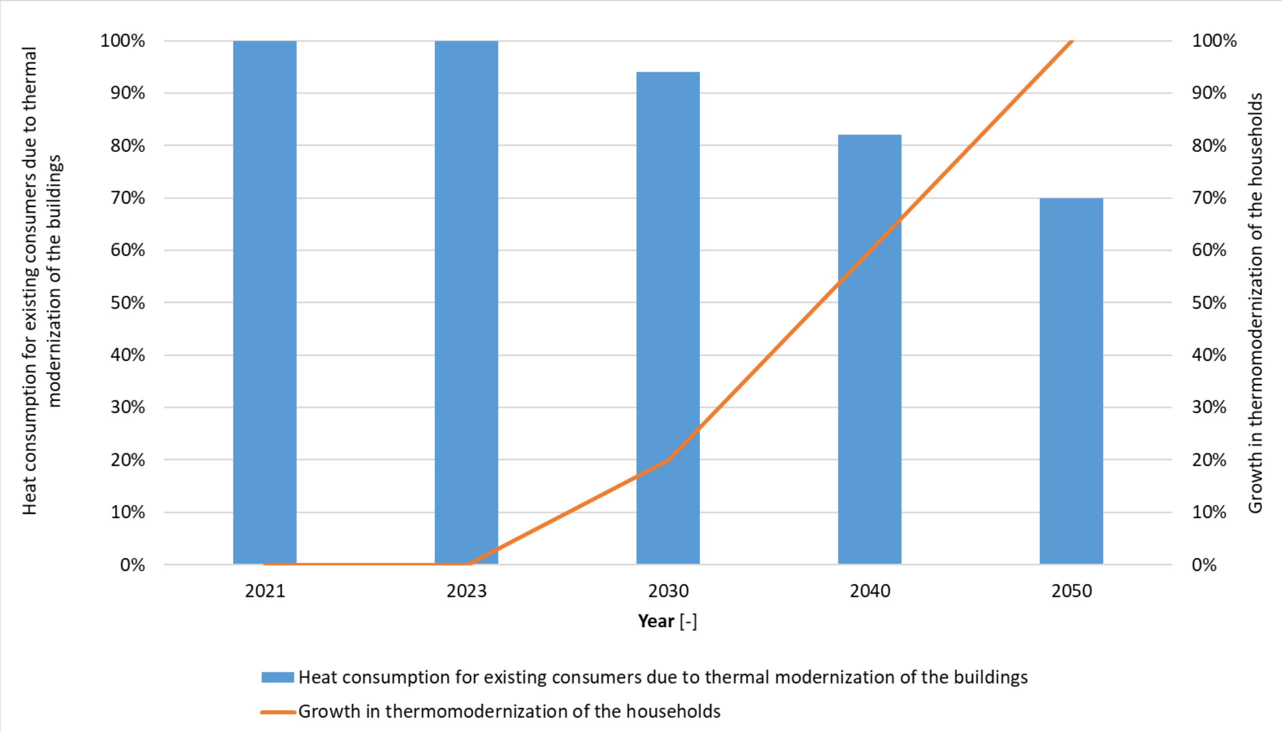


*Figure 2-27 Growth in household thermal modernization leading to reduced heat consumption by 2050*

## 2.4 District Cooling Network

The initial growth of district cooling (DC) would be limited due to the absence of an existing cooling network in Mykolaiv. As a first step, a DC network should be established, connecting public utility buildings, such as healthcare facilities, educational institutions, cultural and sports facilities, and public administration buildings. Depending on the location of the central cooling source, the DC system could be extended to include other facilities, such as religious buildings, shopping centres, and components of public transportation infrastructure, including railway and bus stations, as well as transportation hubs.

Subsequently, the development of the cooling network should advance toward the most densely populated areas of the city. This strategic progression aims to significantly increase the number of cooling recipients while keeping network expansion costs relatively low. Similar to the development of the DH network, a priority for connecting cooling consumers should be given to those located closest to the DC production unit. In later stages, DC can be extended to cover more remote areas, either by expanding the centralized DC network or by establishing local DC systems.

The primary source of cooling should be a trigeneration unit, which additionally has the capability to utilize waste heat. This feature allows for efficient and economically effective cooling generation. Cool produced in trigeneration plant could be transferred towards different parts of the network.

An additional option to be considered is to utilize Buh river water for cooling and heating buildings, mirroring the approach proved in Geneva. This could be a valuable source of cooling and heating for areas in the close vicinity of the Buh river. In the same way as the UN building and the airport in Geneva benefited from this system, buildings in Mykolaiv, such as commercial centres and offices, can also leverage the advantages of using river water for thermal regulation.

The principal layout of the system is as follows: River water is extracted at a predetermined depth where the water maintains a relatively constant temperature, and directed into an underground reservoir on land. From there, the water enters a system of pipes for distribution throughout the district. River water is separated from the water circuit in the DH/DC network by means of heat exchangers. The same network is used for DC during summer and DH during winter.

During the summer months, the river water is used directly for cooling purposes.

During winter, the river water is used for heating purposes, and heat energy is extracted from the river water by means of a heat pump. See Figure 2-28 for the visualization of the suggested solution.

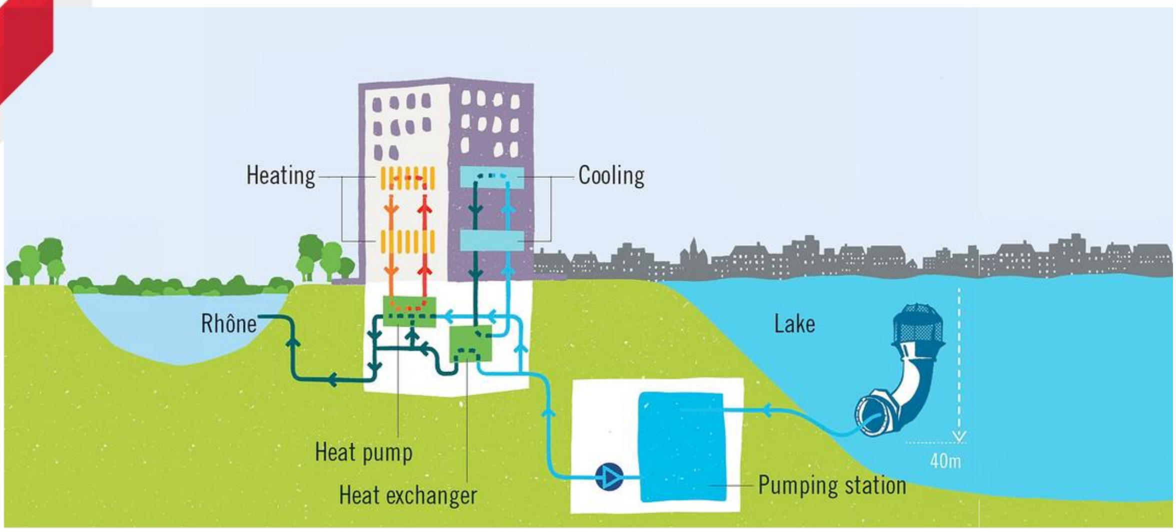


*Figure 2-28 The Geneva hydrothermal project* [5]

This closed-loop system using the Buh river water for cooling and heating offers an efficient and sustainable solution for maintaining comfortable temperature levels within buildings. By leveraging the characteristics of the river water and employing heat exchange and heat pump technologies, the system minimizes energy consumption and decreases reliance on traditional heating and cooling systems.

Furthermore, by 2050, prosumers may emerge in the DH and DC Network, capable of both supplying and consuming heat and cool. This development represents a significant shift in the dynamics of the network, introducing more flexibility and potential for mutual energy exchange.

[5] https://www.swisscommunity.org/en/news-media/swiss-review/article/lakes-set-to-cool-and-heat-an-increasing-proportion-of-our-buildingslakes-set-to-cool-and-heat-an-increasing-proportion-of-our-buildings

To fully assess the potential for achieving synergy through the collaboration of the DH and DC system, a detailed analysis would be needed. This analysis will enable the estimation of the cooling system's development potential. Any potential investment actions should be initiated during the expansion and reconstruction phases of the DH system. This approach minimizes associated costs and streamlines the integration of both systems for optimal efficiency.

## 2.5 Urban Electrical Power System[6,7]

The planning of urban electrical power system development is hindered by the fact that a significant portion of the transmission and distribution infrastructure is owned by national operators and energy producers. In many cases, professional energy management is not fully developed and controlled at the state or local government levels. Consequently, the majority of projects related to plans for the urban electrical power system will be limited to the utilization of relatively small, local sources of electric energy, energy consumption reduction efforts, or increasing the share of electric energy consumption. This includes initiatives such as the electrification of transportation.

In considering actions and achievable goals for the modernization and development of the urban electrical power system, they can be divided into several areas:

1. **Renewable Energy Integration**

   There is a growing focus on increasing the share of renewable energy sources, such as solar, wind, and hydropower, in the energy mix of cities and municipalities. Governments and local authorities are promoting policies to encourage the adoption of renewable energy technologies.

   The integration of renewable energy into urban areas is not only crucial for the present but also represents a pivotal step toward ensuring a sustainable future. The embrace of renewable energy technologies, notably solar and wind power, is not merely altering the skyline of cities; it is fundamentally reshaping their structure and design. This transformative process is leading to the development of energy-efficient buildings, marking a significant reduction in overall energy consumption and the establishment of urban spaces that prioritize environmental sustainability.

   Beyond the environmental benefits, policies aimed at promoting renewable energy adoption within cities serve as catalysts for job creation and the generation of new economic opportunities. A sustained commitment to investing in research and development for renewable energy holds immense potential. This commitment can act as a driving force behind innovation, elevating the efficiency of energy systems, and ultimately lowering associated costs.

   The advent of smart grid solutions stands as a revolutionary force in the seamless integration of renewable energy within urban landscapes. These intelligent networks not only optimize energy usage through analytics and automation but also contribute to the creation of a more sustainable and effective energy infrastructure. Cities, recognizing their role as drivers of change, can make a substantial impact by concentrating efforts on three pivotal areas: advocating for the

[6] EU Reference Scenario 2020, Energy, Transport and GHG emissions – Trends to 2050, July 2021

[7] Global Energy Transformation, A Road Map to 2050; IRENA 2018

widespread adoption of renewable energy in buildings, providing sustainable alternatives for transportation, and crafting comprehensive urban energy systems.

Through the strategic adoption of renewable energy policies, cities have the potential to redefine their trajectory. This transformation involves a simultaneous reduction in their ecological footprint and an enhancement of the overall well-being of their inhabitants. By championing sustainability in energy practices, cities not only contribute to a greener environment but also create spaces that prioritize the health, prosperity, and resilience of their communities.

## 2. Smart Grids and Energy Storage

The implementation of smart grid technologies and energy storage solutions is gaining importance. Smart grids enable more efficient energy distribution, reduce losses, and enhance the integration of renewable energy sources. Energy storage systems help in managing intermittent renewable sources and ensuring a reliable power supply.

The commitment to energy efficiency and conservation within cities and municipalities is growing, as they recognize the imperative to reduce overall energy consumption for a sustainable future. This commitment extends to a range of initiatives aimed at fostering more responsible and efficient energy practices.

One notable facet of this effort involves the promotion of energy-efficient buildings. Cities are investing in innovative architectural designs, sustainable materials, and cutting-edge technologies to construct structures that not only meet the demands of modern urban living but also significantly minimize energy requirements. The integration of smart technologies within buildings, such as automated climate control systems and energy-efficient appliances, further enhances overall energy performance.

Another key focus area is the implementation of LED street lighting. Cities are transitioning from traditional lighting systems to energy-efficient LED alternatives, which not only contribute to significant energy savings but also offer longer lifespans and reduced maintenance costs. The adoption of LED technology not only enhances visibility and safety in urban spaces but also aligns with the broader goal of reducing environmental impact.

Furthermore, cities are embracing smart city planning strategies to optimize energy use across various sectors. This involves the integration of data-driven technologies and urban analytics to enhance the efficiency of public services, transportation systems, and infrastructure. By leveraging real-time data, city planners can make informed decisions that minimize energy waste, reduce carbon emissions, and create more sustainable urban environments.

In essence, the multifaceted approach to energy efficiency and conservation in cities involves not only the adoption of advanced technologies but also a shift in the overall mindset towards sustainability. By investing in these initiatives, cities and municipalities are not only reducing their environmental footprint but also setting the stage for resilient, resource-efficient urban spaces that prioritize the well-being of both residents and the planet.

## 3. Energy Efficiency and Conservation

Cities and municipalities are increasingly investing in energy efficiency measures to reduce overall energy consumption. This includes initiatives such as energy-efficient buildings, LED street lighting, and smart city planning to optimize energy use.

The utilization of energy-efficient building materials, advanced LED lighting systems, effective air conditioning units, and the incorporation of energy management systems constitutes a strategic approach to significantly curbing energy consumption in urban environments. This involves a comprehensive strategy that encompasses sustainable architectural practices, efficient lighting solutions, and innovative technologies to optimize energy utilization within urban structures.

The promotion of sustainable transportation alternatives, such as the widespread adoption of electric vehicles, the enhancement of public transit infrastructure, and the development of cycling networks, emerges as a crucial avenue for reducing emissions and energy consumption in urban settings. Barcelona serves as an exemplary model, having successfully decreased its $CO_2$ emissions by 30% in recent years. This achievement is attributed to a multifaceted approach, integrating energy-efficient practices in both buildings and transportation systems. By prioritizing sustainable modes of travel and investing in eco-friendly transportation initiatives, cities can make substantial strides in mitigating the environmental impact of urban mobility.

The integration of energy storage technologies, particularly advanced battery systems, plays a pivotal role in managing the intermittency of renewable energy sources, addressing grid instability, and ensuring a consistent and resilient power supply in urban areas. The implementation of energy storage solutions represents a forward-looking strategy to harness the potential of renewable energy while maintaining grid stability. This proactive approach safeguards against fluctuations in energy production, offering a reliable and sustainable energy supply for urban communities. Through strategic investment in energy storage infrastructure, cities can fortify their resilience to energy challenges and contribute to the long-term sustainability of their power systems.

## 4. Decentralization and Distributed Energy Resources (DERs)

The trend towards decentralization involves the use of distributed energy resources like rooftop solar panels, small-scale wind turbines, and local energy storage. This approach can enhance energy resilience and reduce dependence on centralized power plants.

The adoption of decentralization and distributed energy resources (DERs) holds significant potential in the development of modern and sustainable cities. DERs encompass small-scale power generation systems like solar panels and wind turbines, strategically positioned near the point of consumption. Decentralization entails the dispersal of power generation and management to localized systems, departing from dependence on a centralized power grid.

Embracing DERs and decentralization allows cities to attain increased energy independence, minimize transmission losses, and enhance grid resilience. Additionally, DERs contribute to lowering the carbon footprint of cities, fostering environmentally sustainable energy practices.

Cities can take proactive measures to encourage DERs and decentralization, including incentivizing the installation of solar panels and wind turbines, supporting community-driven energy projects, and investing in smart grid infrastructure.

In summary, the integration of decentralization and DERs empowers cities to achieve heightened energy independence, decrease transmission losses, and advocate for sustainable energy practices. Through the adoption of these technologies, cities can chart a course toward a more environmentally friendly and sustainable future for their communities.

## 5. Electrification of Transportation

The shift toward electric vehicles (EVs) is impacting the power sector. Cities are developing charging infrastructure, and municipalities are exploring ways to integrate EVs into their overall energy and transportation plans.

In contemporary urban planning, a significant focus lies on the electrification of transportation to curb emissions, reduce energy consumption, and diminish reliance on fossil fuels. With urban populations steadily increasing, the demand for sustainable transportation solutions is growing. Cities are actively incorporating electric buses and light rail systems to address issues of noise and pollution. Notably, some urban areas are committed to converting their entire bus fleets to electric within a specified timeframe. Efforts are underway to encourage widespread adoption of electric vehicles through policy implementation and infrastructure development. Ambitious targets, such as having a predetermined number of electric vehicles on the roads by a specific year, showcase the commitment of certain regions, like California.

Creating a robust charging infrastructure is imperative to support the escalating number of electric vehicles. This involves the establishment of fast-charging stations and the integration of smart grid technologies. Additionally, urban areas are directing attention towards electrifying goods movement, aiming to reduce emissions and enhance efficiency in vehicles such as forklifts, delivery trucks, and port equipment. Electric bicycles and scooters are gaining popularity as a sustainable and convenient mode of transportation in urban settings. Moreover, the promotion of electric vehicles in car-sharing and ride-hailing services at a reasonable cost further encourages their adoption.

By emphasizing the electrification of transportation in urban planning, cities can foster environments that are more sustainable.

## 6. Digitalization and Data Analytics

The integration of digital technologies and data analytics plays a role in optimizing energy systems. Advanced metering infrastructure, data analytics, and predictive maintenance can enhance the efficiency and reliability of energy infrastructure.

In today's urban landscape, the integration of digitalization and data analytics is crucial for shaping smart and efficient cities. These technologies play a key role in various aspects:

- Digitalization facilitates the development of smart city services, utilizing big data analysis and ICT solutions to address public issues and enhance urban livability and efficiency.
- Data analytics in urban planning and management optimizes mobility, minimizes congestion, and provides real-time updates on transportation systems. It supports improved traffic flow, energy usage, waste management, and the development of intelligent infrastructure.

- Equitable development is promoted through data analytics, enabling cities to measure environmental outcomes, reduce pollution, and ensure sustainable growth for more environmentally friendly urban planning.

Digitalization enhances community engagement by tapping into the insights of residents and visitors. This fosters smarter decision-making and establishes networks among governments, businesses, nonprofits, and community groups to better serve residents.

Leveraging data-based insights significantly impacts the efficiency and quality of life in urban environments. This is crucial for informed decision-making, increased resilience, and an overall enhancement of residents' quality of life.

Embracing digitalization and data analytics offers cities the opportunity to improve urban planning, enhance efficiency, and create more liveable and sustainable environments for their residents.

Considering the above assumptions and directions of actions in respective areas, proposed actions have been suggested to be undertaken in the near, mid and long-term. Similar to the goals for the DH and DC systems, suggested actions for the Urban Electrical Power System have been presented for the horizons of 2030, 2040, and 2050.

2030:

- Tap into the strong synergies between energy efficiency and renewable energy by combining energy efficiency and renewable energy measures, such as integrating renewable technologies in the renovation of public buildings.
- Set targets for the replacement of conventional fossil fuel-based technologies by electric vehicles, heat pump systems, and electric stoves and boilers.
- Facilitate sector coupling between power and end-use sectors to integrate variable renewables in the power sector.
- Increase flexible electricity demand through demand side management, smart charging, vehicle-to-grid for electric vehicles, flexible heat pump heating and cooling, and thermal storage fed by electricity.
- Use information communication technology and digitalization, along with demand side management, to reduce peak electricity demand, lower the need to invest in power capacity, and reduce operational costs.

2040:

- Continue implementing the actions mentioned for 2030.
- Continue to increase the share of renewables in power generation.
- Increase the use of electricity in transport, buildings, and industry to unlock substantial efficiency gains and reduce air pollution.
- Increase the deployment of other renewable solutions, including modern bioenergy, solar thermal, and geothermal, in sectors where electrification is not possible.
- Foster system-wide innovation, including the development of new technologies and their full life-cycle.

2050:

- Continue implementing the actions mentioned for 2030 and 2040.
- Align socio-economic structures and investment with the transition.
- Ensure that transition costs and benefits are fairly distributed.
- Encourage and support changes in behaviour through digitalization, education, and regulation.
- Design incentive schemes to permit consumers to become net clean energy producers.

In line with the above assumptions, a comprehensive reconstruction of the power distribution system will be necessary, allowing for the distribution of the increasing amounts of electricity and integration of renewable heat sources. Energy networks that have not been adapted to transmit locally generated electric power by prosumers will limit the development of such electric power sources. Therefore, focused efforts on the appropriate modernization of the existing power systems are necessary, preceded by a detailed analysis to identify bottlenecks that should be eliminated as a priority.

In addition to renewable energy sources, cogeneration units will also have a direct impact on supplying electric power to Mykolaiv. Taking into account the construction of cogeneration units and other power sources, such as photovoltaics, wind turbines, sources utilizing biomass, biomethane and hydrogen, additional power generation capacities will appear in the power system of Mykolaiv. Expected changes in installed electric power generation capacity resulting from the operation of cogeneration units in the years 2030, 2040, and 2050 are presented below.

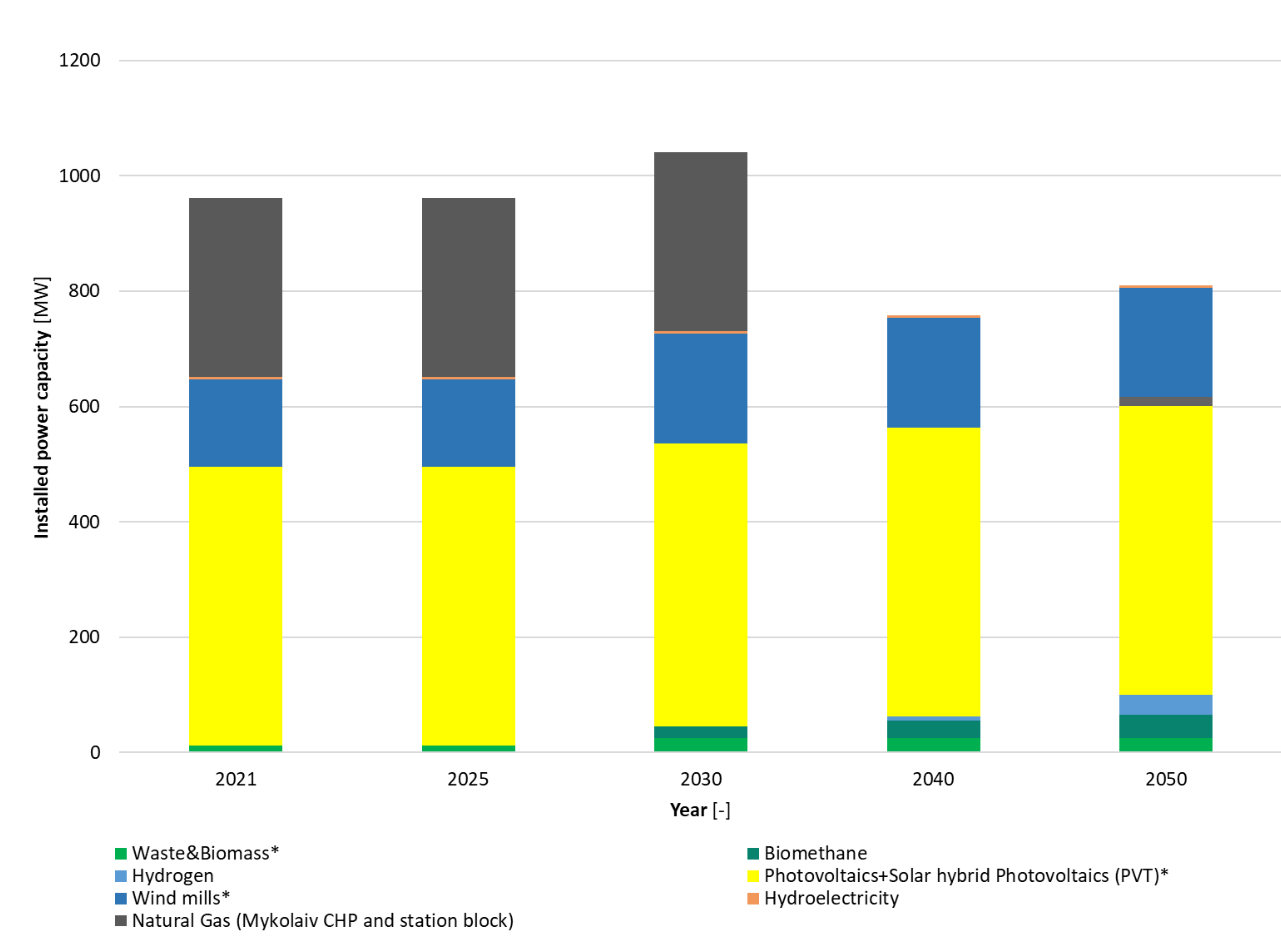


*Figure 2-29 Installed electrical capacity broken down by various generation sources within Mykolaiv region and connected to the networks of Mykolayivoblenergo*

In addition to that the power generation capacities shown in Figure 2-27, other power plants located in the vicinity of Mykolaiv deliver electricity to the main grid and cover part of the city's power consumption. These are: South Ukrainian Nuclear Power Plant (3 000 MW), Oleksandrivska Hydroelectric Power Plant (9,8 MW) and Tashlytska Hydro Power Plant (906 MW).

# 3 Modern Urban Energy System

## 3.1 Combined district heating, cooling and power generation[8]

By combining district heating and cooling in 4th Generation DH&C system it is possible to obtain considerable energy savings resulting in a reduced need for fuel combustion and reduced greenhouse gas emissions. Particularly, the utilization of cold in urban buildings can contribute to improving the energy balance. The location of Mykolaiv furthermore enables the use of river water for district cooling which offers the opportunity for further energy savings.

Building 4th Generation DH&C system opens for wide utilization of heat pumps which can produce both heating and cooling. Heat pumps can make use of certain ambient energy sources, such as groundwater or wastewater, which can serve as heat sources for heating during the winter and as cooling sources for cooling during the summer. To some degree, interconnected groundwater wells or shallow soil volumes can store ambient cold and warm energy between seasons.

The benefits of centralization of cold production and combining it with heat production are evident. Some key issues worth mentioning are:

**Energy Efficiency**

CDH&C systems utilize waste heat from cooling processes for heating and vice versa, maximizing energy efficiency and reducing overall energy consumption. What is more, district cooling networks and chilled water tanks benefit from economy of scale and can replace costly and ineffective chillers installed at the individual building level.

**Energy Flexibility**

These systems can adapt to changing energy demand and supply by balancing heating and cooling needs, increasing their resilience and reliability. What is more, chilled water tanks can help in stabilizing consumption and enabling the efficient operation of chillers based on fluctuating electricity prices.

**Efficient Load Management**

CDH&C systems can efficiently manage energy loads by shifting energy between heating and cooling modes based on demand, contributing to grid stability.

**Enhanced Urban Planning**

These systems support sustainable urban planning by providing efficient and environmentally friendly solutions for heating and cooling in densely populated areas.

**Improved Comfort**

CDHC systems can provide consistent indoor comfort year-round, which is especially valuable in regions with varying climate conditions.

[8] Hot&Cool Magazine, No.2, 2023

## 3.2 Energy Efficiency[9,10]

According to IEA Energy efficiency is often referred to as the primary driver in the transition to clean energy, as it offers some of the fastest and most cost-effective methods for reducing $CO_2$ emissions. Simultaneously, it helps lower energy expenses and enhances energy security. Together with electrification, behavioural shifts, and digitalization, energy efficiency plays a pivotal role in shaping global energy intensity, which measures the amount of energy needed to generate a unit of GDP, a crucial indicator of a nation's economic energy efficiency.

In the Net Zero Emissions by 2050 Scenario, energy efficiency stands out as the most significant measure to curb energy demand. Additionally, most energy efficiency initiatives lead to cost savings for consumers, reducing energy bills and mitigating the impact of unexpected price fluctuations, such as those triggered by events like Russia's invasion of Ukraine.

Although investments in energy efficiency have recently increased and reached record levels, the pace of global energy intensity improvement had slowed significantly in the latter half of the previous decade and nearly ground to a halt during the first two years of the Covid-19 pandemic. Accelerating the global rate of progress in energy efficiency over this decade is a critical step toward achieving net-zero emissions.

Energy efficiency is a cornerstone of modern sustainable energy systems, including district heating and cooling networks. These systems are designed to maximize the utilization of energy resources while minimizing waste and environmental impact. Energy efficiency in such systems involves various measures, including optimizing heat and cooling generation, distribution, and consumption processes.

Efficient district heating and cooling systems are essential for reducing greenhouse gas emissions and achieving climate goals. By using energy-efficient technologies and practices, these systems can significantly decrease energy consumption, lower operating costs, and enhance overall sustainability. Energy-efficient buildings and infrastructure, combined with effective energy management, play a vital role in reducing energy demand and, consequently, the carbon footprint of cities and regions.

Moreover, energy efficiency not only contributes to environmental sustainability but also has economic and social benefits. It leads to reduced energy bills for consumers, promotes local job creation, and enhances energy security. Therefore, investing in energy efficiency remains a central strategy in the transition to clean and sustainable energy systems and plays a pivotal role in achieving net-zero emissions objectives.

At the forefront of the list of the most energy-efficient cities, presented by gb&d magazine[11], Scandinavian capitals, such as Copenhagen, Oslo and Reykjavik are leading by applying best practices in sustainability and energy efficiency. Several cities worldwide are setting remarkable examples in terms of sustainability and energy efficiency through innovative practices:

1. **Copenhagen**: Known for its bike-friendly infrastructure and green initiatives, Copenhagen has removed over a third of fossil-fuel-reliant transportation since 2019, significantly reducing

---

[9] Energy Efficiency - Energy System - IEA
[10] Energy Efficiency Watch (energy-efficiency-watch.org)
[11] 10 Sustainable Cities Inspiring Green Action (gbdmagazine.com)

greenhouse gas emissions. Mandatory green roof policies, extensive bike-sharing programs, and a focus on renewable energy sources contribute to the city's goal of carbon neutrality in

- Notable Project: UN17 Village, a mixed-use community designed to address all 17 United Nations Global Goals, emphasizing renewable energy and energy efficiency.

2. **Oslo**: The Norwegian capital welcomes 10,000 new residents annually, prompting green building mandates for zero-emission, energy-plus buildings. Oslo aims for climate neutrality by 2030, tracking citywide emissions, investing in green projects, and aspiring to a car-free city centre.

   - Notable Project: The Vulkan Area, a sustainable neighbourhood with energy-efficient buildings, geothermal heating, and recycling energy systems.

3. **Amsterdam**: Amsterdam prioritizes cycling with extensive bike paths and aims to reduce $CO_2$ emissions by 55% by 2030. The city also strives for circularity, where all products are reused, repurposed, or recycled, minimizing waste.

   - Notable Project: Schoonschip Amsterdam, a self-sustaining floating village using solar panels, blockchain for energy sharing, and efficient water and waste management.
   - Notable Project: HAUT, the tallest mass timber building in the Netherlands, featuring sustainable design elements like solar panels, rainwater collection, and energy-efficient windows.

4. **Reykjavik:** Reykjavik stands out as one of the few cities primarily powered by renewable energy, predominantly geothermal and hydropower. The city is committed to becoming carbon-neutral by 2040 and fossil-fuel-free by 2050, with measures like reducing gas stations and promoting pedestrian infrastructure.

   - Notable Project: FABRIC, an eco-friendly project with geothermal energy, cross-laminated timber construction, and a "Green Ribbon" for gardening and geothermal ducts.
   - Notable Project: Living Landscape, set to become Iceland's largest wooden building, focusing on carbon reduction through CLT construction and sustainable practices.

These cities demonstrate that sustainable urban development, energy-efficient buildings, renewable energy integration, and green transportation solutions are key to achieving ambitious environmental goals and improving the quality of life for residents. Their innovative approaches serve as inspirations for cities around the world striving to create more sustainable, energy-efficient urban environments.

## 3.3 Smart Energy Grids (and Demand Response)

In the face of the urgent need to modernize and sustain energy systems, Smart Energy Grids emerge as an indispensable solution. These grids transcend mere technological advancements; they represent a pivotal shift towards a cleaner and more customer-centric energy ecosystem, essential for modern cities.

- Advanced Metering Infrastructure (AMI)

Advanced Metering Infrastructure (AMI) represents a groundbreaking innovation that is revolutionizing energy consumption monitoring and management within the energy sector, encompassing both the electricity grid and district heating and cooling systems. At its core, AMI involves the strategic deployment of smart meters at customer locations, a pivotal shift in the landscape of data collection. These smart meters provide real-time insights into energy consumption, significantly surpassing the precision of traditional meters.

Real-time data collection is a fundamental hallmark of AMI, with smart meters continuously capturing and transmitting consumption data. This real-time data accessibility benefits both customers and energy companies, offering immediate insights into consumption patterns, peak demand periods, and emerging trends. The convenience of remote data access through a secure network eliminates the necessity for manual meter readings and facilitates instantaneous access to consumption data.

AMI extends beyond technological advancement; it empowers customers to take control of their energy usage. Customers can vigilantly monitor their consumption patterns, identify areas for energy conservation, and adapt their behaviour accordingly. Moreover, the utilization of real-time data from smart meters ensures precise billing based on actual consumption, thus reducing disputes and fostering trust between customers and energy providers.

Proactive issue detection is another substantial advantage intrinsic to AMI. It enables early identification of anomalies or irregularities in consumption patterns, potentially indicative of equipment malfunctions or leaks, thereby prompting timely interventions. Additionally, AMI's analytical capabilities can decipher consumption data, shedding light on peak demand periods and aiding in the formulation of load management strategies designed to optimize energy distribution.

The wealth of data furnished by AMI serves as an invaluable asset to energy companies, enhancing their comprehension of consumption patterns. This, in turn, facilitates more accurate forecasting, resource planning, and infrastructure investments. Moreover, AMI streamlines the process of remote service activation and deactivation, diminishing the need for physical visits to customer premises.

AMI ardently supports sustainability goals by empowering customers with insights into their energy usage, consequently promoting energy-saving behaviours that contribute to the overarching objectives of environmental sustainability. It is of paramount importance to prioritize data security and privacy in the implementation of AMI, safeguarding both customer information and the integrity of the energy grid.

In summary, Advanced Metering Infrastructure is poised to transform the landscape of customer interaction and energy distribution within the electricity grid and district heating and cooling systems. Through the prism of real-time data collection and customer empowerment, AMI plays a pivotal role in bolstering energy efficiency, ensuring accurate billing, and catalysing the development of a more robust and sustainable energy infrastructure.

- Demand Side Response (DSR)

Demand Side Response (DSR) represents a pivotal strategy in the optimization of energy consumption that is applicable not only to district heating and cooling systems but also to the broader energy sector, encompassing the electricity grid. It pertains to the dynamic adjustment of heat consumption by consumers in response to market signals, energy prices, and the evolving requirements of the energy system.

Within the realm of district heating and cooling systems, DSR encompasses a multifaceted approach:

- Shifted Consumption Schedule: Customers wield the flexibility to reschedule heat-dependent operations, such as industrial processes or home heating, to circumvent peak demand periods, thereby actively contributing to load balancing.

- Heat-Driven Cooling: In specialized contexts such as data centers, the heat emanating from the heating system can be ingeniously repurposed for cooling purposes, thus optimizing energy utilization.

- Heat Load Shifting: Consumers are afforded the liberty to migrate heat-reliant activities to time slots characterized by lower energy demand, thereby reducing strain during peak hours.

- Response to Price Signals: Customers can adeptly fine-tune their behaviour in response to prevailing energy prices, intelligently utilizing heat energy during off-peak times or embracing more economically viable alternatives.

The overarching objective of DSR is the enhancement of system efficiency, the minimization of losses, and the reduction of operational costs through the nimble adaptation of heat energy consumption to the fluid dynamics of market and operational conditions. This adaptability extends its purview to the broader energy sector, ensuring optimal resource allocation and grid stability within the electricity grid.

- Data Analytics and AI

The integration of Data Analytics and Artificial Intelligence (AI) constitutes a paradigm shift in the handling of extensive datasets within the energy sector, encompassing both the electricity grid and district heating and cooling systems. This integration harnesses advanced analytics and AI algorithms to meticulously scrutinize voluminous datasets, predict trends in energy consumption, optimize grid operations, and elevate the efficacy of decision-making processes.

The journey commences with data collection and preparation, involving the extraction of data from diverse sources, including smart meters, sensors, and operational systems. This data undergoes rigorous cleansing, organization, and structuring to unearth profound insights.

Predictive analytics assumes a central role, empowering data analytics and AI to forecast energy consumption patterns by leveraging historical data. This facilitates proactive management of energy supply, an indispensable capability in the realms of both electricity grids and heating and cooling systems.

Grid optimization stands as another vital facet of this integration. Data analytics and AI algorithms work diligently to process real-time data, fine-tuning grid operations that encompass load balancing, energy distribution, and adaptive management in response to ever-changing conditions. This optimization heralds superior grid stability and efficiency, benefiting both the electricity grid and district heating and cooling networks.

AI systems shine brightly in their capacity to promptly identify anomalies or deviations from expected behavior in real time, thus facilitating rapid fault detection that averts disruptions and curtails downtime. This capability assumes critical importance in ensuring the reliability of both electricity grids and heating and cooling systems.

Energy efficiency insights unearthed through data analytics and AI proffer the opportunity to optimize energy usage, thereby reducing waste and aligning seamlessly with sustainability objectives across both sectors. Predictive maintenance, a linchpin of AI, underpins scheduled maintenance, thereby mitigating the specter of unplanned downtime and augmenting the reliability of indispensable infrastructure.

Customer insights, another hallmark of this integration, facilitate the analysis of customer behavior and preferences. This aids in the tailoring of services, optimization of pricing models, and augmentation of customer engagement. This manifests as a mutual benefit to both the electricity grid and district heating and cooling providers.

Continuous learning epitomizes AI systems as they adapt and enhance their models over time through the incorporation of new data inputs, thereby ensuring improved accuracy. Scalability and automation are intrinsic to this integration, enabling data analytics and AI to handle escalating data volumes, execute intricate tasks, and liberate human resources for strategic initiatives.

In summation, the amalgamation of Data Analytics and AI empowers not only the electricity grid but also district heating and cooling systems with a data-driven modus operandi for operations and decision-making. This bequeaths the ability to optimize energy usage, refine grid efficiency, and adeptly navigate the ever-evolving energy landscape.

- Integration with IoT Devices

The judicious exploitation of the capabilities conferred by Internet of Things (IoT) devices heralds a transformative boon to operational efficiency and responsiveness, extending its benefits to both the electricity grid and district heating and cooling systems.

IoT devices, equipped with an array of sensors, perpetually amass real-time data from diverse equipment pieces such as boilers, pumps, and valves. This data is seamlessly transmitted to centralized systems, effecting continuous monitoring without necessitating on-site personnel. This perpetual vigilance not only bolsters the reliability but also amplifies the performance of equipment within both sectors.

Predictive maintenance constitutes the cornerstone of IoT devices, as they meticulously analyse data to craft models that predict equipment failures rooted in performance trends. This foresight is instrumental in instituting scheduled maintenance, consequently mitigating the spectre of unanticipated downtime and fortifying the reliability of mission-critical infrastructure within both the electricity grid and heating and cooling systems.

IoT sensors are exceptionally adept at expeditiously flagging anomalies in equipment behaviour, thereby sounding alerts that expedite timely responses and forestall larger-scale breakdowns or system failures. This rapid fault detection assumes pivotal importance in preserving uninterrupted operations within both sectors.

The ability to remotely control IoT-enabled devices facilitates immediate intervention when necessitated, assuring the safety and reliability of equipment within the electricity grid and heating and cooling systems.

IoT sensors, through their acumen, unfurl valuable insights into energy consumption patterns, thus illuminating avenues for energy usage optimization and the curtailment of operational expenditures.

This dovetails neatly with the objectives of economic savings and environmental sustainability, aligning seamlessly with the goals of both sectors.

The reservoir of data amassed by IoT devices represents a treasure trove of insights, serving to unveil patterns, trends, and performance metrics that underpin informed decisions regarding equipment upgrades, replacements, and operational strategies within both the electricity grid and heating and cooling systems.

Enhanced safety measures are an unequivocal benefit of IoT devices, as they vigilantly monitor parameters critical to safety, such as temperature and pressure. Any deviations from safe thresholds serve as triggers for alerts, engendering the prompt resolution of potentially precarious situations.

The scalability and adaptability intrinsic to IoT solutions facilitate their expansion to encompass a diverse spectrum of equipment and geographical areas. This scalability, in turn, empowers district heating companies to broaden their monitoring purview in accordance with evolving requirements.

Furthermore, the integration of IoT data with other enterprise systems, such as maintenance management or fieldwork management software, serves to ensure that the insights gleaned from IoT devices are judiciously leveraged within the ambit of decision-making processes.

Remote troubleshooting, a potent capability rooted in IoT data analysis, leads to expedited issue resolution, thus curtailing downtime and minimizing the necessity for on-site interventions.

In summative reflection, the integration of IoT devices into the operational tapestry of district heating systems ushers forth an innovative approach, one that engenders augmented efficiency, curtailed downtime, and an elevated standard of system performance. By harnessing real-time data and predictive analytics, companies are poised to optimize their maintenance strategies and respond with alacrity to nascent challenges.

Implementation of smart grids enable efficient energy flow between producers and consumers, allowing for optimization of consumption and increased efficiency. In a modern energy company, the concept of Smart Energy Grids is a crucial element that encompasses advanced technologies and strategies for more efficient, reliable, and sustainable energy distribution. The integration of Smart Energy Grids transforms an energy company into an agile, sustainable, and customer-centric entity, contributing to a cleaner environment and more reliable energy services.

### 3.3.1 iGRID[12]

The fundamental idea of the iGRID system is to lower the temperature in district heating grids, in ade-centralised manner, to be able to significantly reduce heat losses and provide DH Companies with a short return on investments. By lowering the temperature, DH companies get the following benefits:

- **Significantly reduced heat losses** due to lower supply temperatures
- **Facilitate the energy transition** to renewable energy sources, which require lower temperatures
- **Increased production efficiency**, by reducing the return temperatures

[12] Grundfos – technology description delivered by the company

- **Increased asset lifetime**, due to lower temperatures and pressures

As a result of the above, the district heating companies will:

- **Significantly reduce the carbon footprint***,* to meet carbon emission targets and get a green profile
- **Significantly increase the operational capacity**, which can be used to extend the grid and get more customers

**iGRID consists of many elements**

To reach maximum impact iGRID utilises both products, intelligent control, services and digital optimisation.

**iGRID Temperature Zone** is a prefabricated mixing loop with pumps and advanced controls for incorporation in a new or existing district heating network. The solution enables controlled recirculation from the return pipe to the supply pipe in order to reduce and adapt the supply temperature and flow to the exact needs.

**iGRID Pressure Zone** is a prefabricated pumping station for incorporation in a new or existing district heating network where pressure boosting and optimisation of the circulated district heating water is desired.

To facilitate operation of these pumping stations the iGRID concept also consists of a portfolio of IoT devices for obtaining critical data inputs from the DH grid. These data are available through the proprietary cloud solution´s web portal or directly through SCADA integration. The intelligent use of data unlocks new knowledge of the grid and provides an important insight for further optimizations.

## 3.4 Monitoring and Management

In modern, sustainable urban energy sectors and district heating and cooling systems, advanced monitoring and management systems are of paramount importance. These systems ensure tight control over energy consumption, emergency response, and system optimization. They play a crucial role in efficiently managing operations, monitoring systems, and providing reliable thermal energy to customers. Here are key components:

- SCADA (Supervisory Control and Data Acquisition): SCADA systems offer real-time monitoring, centralized control, data collection and analysis, alarm management, failure prediction, and energy efficiency optimization. They integrate with other systems and provide remote access for swift emergency responses.

- Centralized Database: Centralized databases streamline data access, enable holistic analysis, identify trends, support reporting and visualization, enhance data integrity and security, optimize operations, and scale with company growth.

- Energy Management Systems (EMS): EMS systems collect and integrate data, analyze and forecast energy consumption, automate and control energy-consuming devices, optimize energy production and distribution, offer remote monitoring, generate reports, support sustainability goals, and integrate with other systems.

- Simulation and Optimization Software: These tools allow for simulation, modeling, optimization, data analysis, and forecasting, aiding in efficient network planning, maintenance, and decision-making.

- Cloud Computing: Cloud computing offers scalability, optimization of computations, data management, simulations, and modeling, collaboration, data security, and expedited decision-making.

- Cybersecurity: Robust cybersecurity measures, including firewall protection, intrusion detection systems, regular security audits, and security training for personnel, are vital to safeguard IT infrastructure.

- Emission Monitoring Systems: These systems monitor emissions, support regulatory compliance, avoid penalties, ensure transparency, aid data-driven decision-making, utilize various technologies, and align with sustainability goals.

- Geographic Information Systems (GIS): GIS technology aids in infrastructure mapping, spatial analysis, asset management, network planning and design, emergency response, data integration, environmental impact assessment, regulatory compliance, customer engagement, renewable energy integration, and informed decision-making.

- Field Work Management Systems: Field work management systems offer efficient task planning, real-time tracking and monitoring, enhanced resource utilization, maintenance and repairs management, infrastructure modernization, data-driven insights, customer satisfaction, integration with other systems, and operational efficiency.

- Mobile Applications: Mobile apps for field personnel enable rapid issue reporting, on-site access to information, real-time communication and monitoring, GPS navigation, enhanced data accuracy, and digital documentation, improving field operations.

In summary, the application of these monitoring and management systems is crucial in modern, sustainable urban energy sectors and district heating and cooling systems. They enhance efficiency, responsiveness, data accuracy, and decision-making, contributing to the overall success and sustainability of these operations.