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# The Optimization of Chisinau District Heating System Study

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The team was led by Sandu Ghidirim (Senior Energy Specialist and Task Team Leader) and Fabrice Bertholet (Senior Financial Analyst and co-Task Team Leader), and included Pekka Salminen (Strategy and Policy Consultant), Pekka Kouri (Lead Consultant), Pasi Vesimäki (Energy Modelling Consultant), Panu Kuitunen (Hydraulic Modeling Consultant), and Alexandru Melenciuc (Technical Audit Consultant). The team would like to acknowledge contributions and valuable inputs by Termoelectrica (Chisinau District Heating Company). The team also greatly acknowledges the close cooperation and support from the Ministry of Economy and Infrastructure (MoEI) of Moldova and its Energy Policy Department, the Moldova Energy Projects Implementation Unit (MEPIU), other Moldovan stakeholders, and the development partners.

The report also benefitted from a stakeholder workshop conducted on October 11, 2019 in Chisinau, where representatives of MoE, Termoelectrica, other Moldovan stakeholders and development partners provided feedback, shared their views, and discussed the findings and recommendations of the Study. Participants in the workshop commended the Study for its unique and comprehensive approach and providing solid basis for future analytical work and investments to improve the security and efficiency of Chisinau DH system as well as domestic power generation. The Study was revised to acknowledge the feedback received during the workshop.

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## List of abbreviations

| Abbreviation | Description |
|---|---|
| DHEIP | District Heating Efficiency Improvement Project |
| WB | The World Bank |
| Lei | Currency of Moldova |
| GOM | Government of Moldova |
| ESMAP | Energy Sector Management Assistance Program |
| TF | Trust Fund |
| TE | Termoelectrica |
| PIP | Proposed Investment Program |
| ST | Short-Term |
| MT | Medium-Term |
| LT | Long-Term |
| CHP | Combined Heat and Power |
| DH | District heating |
| CHS | Central Heat Substation |
| HOB | Heat-Only-Boiler |
| NIS | Network Information System |
| VSD | Variable Speed Drive |
| LHV | Lower Heating Value |
| GT | Gas Turbine |
| CCGT | Combined Cycle Gas Turbine power plant |
| GE | Gas Engine |
| S1 | CHP Source 1 |
| S2 | CHP Source 2 |
| S3 | CHP Source 3 |
| IFI | International Financial Institution |
| EBRD | European Bank for Reconstruction and Development |
| GHG | Green House Gas |
| EPC | Engineering, Procurement, Construction |
| VAT | Value Added Tax |
| O&M | Operation and Maintenance |
| CAPEX | Capital Expenditure |
| DHW | Domestic Hot Water |
| DN | Nominal dimension (for pipes) |
| IHS | Individual Heat Substation |
| IRR | Internal Rate of Return |
| EIRR | Economic Internal rate of Return |
| FIRR | Financial Internal rate of Return |
| NPV | Net Present Value |
| PMU | Project Management Unit |
| PV | Photovoltaic |
| SH | Space Heating |

# EXECUTIVE SUMMARY

## Background

The World Bank (WB) approved on November 21, 2014 the District Heating Efficiency Improvement Project (DHEIP) in amount of USD 40.5 million with the objective to contribute to improved operational efficiency and financial viability of the new district heating company (Termoelectrica) and to improve quality and reliability of heating services delivered to the population of Chisinau.

Building on the technical, commercial and financial recovery of Termoelectrica since 2015 and on the network investments under DHEIP, the logical focus for new investments is now on the supply side infrastructure (heat and electricity production), as well as on continued investment efforts on the demand side (heat distribution and supply to consumers) for more efficient supply of heat and better and more efficient control and use of heat. Termoelectrica's heat and electricity production infrastructure is old (with poor fuel efficiency) and close to the end of its operational life. Without modernization, this could pose a threat to uninterrupted heat supply in Chisinau and for the energy security of the country. In order to address this risk, in 2018, the Government of Moldova (GoM) sought support to conduct a study on the optimization of Chisinau DH system. Following-up on its previous support to DH sector reform in Moldova, Sweden provided funding support through the ESMAP program for such a study to be carried out under WB supervision.

Chisinau District Heating (DH) system has four main district heating production plants: CHP Source 1, CHP Source 2, HOB West and HOB South. CHP Source 1, which is located in the Eastern part of Chisinau, in the Central (main) part of the DH network, is the main source of heat and electricity production during the heating season.

During the heating season, due to limitations in heat transmission capacity of the DH network, CHP Source 1 cannot provide heat to the HOB West and HOB South network areas. Therefore, during the heating season, the HOB West and HOB South network areas are operated independently (with shut-off valves separating them from the rest of the network) with the heat produced respectively by HOB West and HOB South.

Outside of the heating season, the network can be operated as a whole, with the heat provided from CHP Source 1 or CHP Source 2 supplying the entire network (Central area, HOB West area and HOB South area).

However, the minimum heat production from a single unit in CHP Source 1 is much higher than the usual total heat demand in summer. For this reason, CHP Source 2, an old CHP plant, located west from CHP Source 1, and also connected to the Central network area, is nowadays usually operated in summer to cover the summer heat load (Domestic Hot Water heating). This mode of operation may be somewhat preferable to using Heat-only-Boilers but is neither satisfactory nor sustainable. First, CHP Source 2 is very inefficient as an electric power generation source. Second, it will have to be decommissioned within a few years, since there are no plausible justifications for engaging significant rehabilitation expenditures to maintain an obsolete facility dating from the 1950's in operation.

In this context, in order to identify the optimum investment scenario to reduce overall heat and electricity production costs, the analysis had to cover two critical parameters:

- assess the best strategy to address the hydraulic network constraints (during the heating season),
- provide an efficient alternative to CHP Source 2 for Domestic Hot Water supply (outside of heating season).

For this purpose, the study consisted of the following tasks:

- Task 1: Technical audit of the DH system and its components
- Task 2: Assessment of General hydraulic model of Termoelectrica's (TE) DH network
- Task 3: Energy modelling of main generation sources
- Task 4: Assets development and financing plan

**Proposed Investment Program ("PIP")**

Since the CHP Source 1 units have reached or are about to reach their operational and licenced/normed lifetime, the study recommends rehabilitating two units in order to extend their lifetime and also bring some upgrades in capacity and efficiency. For the third unit, which could remain as back-up, more limited expenditures in a major overhaul are recommended.

In addition to the rehabilitation of CHP Source 1, this study recommends installing new gas engines for a total capacity of 55 MW electricity (net) and 43 Gcal/h district heat, respectively. The new capacity is recommended to be dimensioned based on the district heat demand in summertime, allowing its operation at baseload through the whole year. Due to this high load factor, this new CHP capacity is expected to provide a very high return on investment. Since the heating season is rather short, dimensioning the capacity for wintertime DH demand would mean much shorter operation time and result in lower rate of returns on investments, as well as a much larger investment program.

Under the proposed scenario, the new capacity would consist of five gas engines units, with two units to be installed at the newly created CHP Source 3 (next to existing CHP Source 2 site which would be closed and benefitting from existing infrastructure to connect to electricity, natural gas and heat networks) and three units at HOB West site. Dividing the capacity into smaller units in two locations will result in a more flexible and reliable system.

**In summary, the proposed investments under PIP would be as follows:**

**Investment Components**

| | **Component** | **Total Project Cost** | **TE Own Financing** | **Loan Financing** |
|---|---|---|---|---|
| 1 | Optimization of Heat and Electricity Generation | US$98,2 million | US$12,0 million | US$86,2 million |
| *1.1* | *Rehabilitation of CHP Source 1* | | | *US$16,2 million* |
| *1.2* | *Installation of Gas Engine Combined Heat and Power Capacity* | | | *US$70,0 million* |
| 2 | Pilot Energy Efficiency investments | US$7,0 million | | US$7,0 million |
| 3 | Project Management and Technical Assistance | US$6,8 million | | US$6,8 million |
| *3.1* | *Project Management* | | | *US$2,0 million* |
| *3.2* | *Technical Assistance* | | | *US$4,8 million* |
| | **Total** | **US$112,0 million** | **US$12,0 million** | **US$100,0 million** |

**Component 1. Optimization of Heat and Electricity Generation (US$ 86,2 million):** This component will finance modernization of CHP Source 1 and installation of gas engines, including electrical connections, to increase and optimize the efficiency of heat and electricity generation by Termoelectrica. The Component will consist of two subcomponents:

**Sub-Component 1.1. Rehabilitation of CHP Source 1 (US$ 16,2 million):** This Component will finance works at CHP Source 1, including:

a. Rehabilitation of Unit 1 (ongoing investment, financed from TEs own sources US$ 12 million) and Unit 2 (US$ 12 million)
   Renovation of Unit 1 and Unit 2 at CHP Source 1 will extend the lifetime of the units by 50 000 hours (about 8 operational years), ensuring continuation of heat and electricity generation at CHP Source 1. In addition, the investment will increase electricity production capacity from 80 MW up to 98 MW per unit and it will improve the heat production efficiency by 1.5%.
b. Major overhaul of Unit 3 (US$4,2 million)
   Major Overhaul for Unit 3 at CHP Source 1 will extend the lifetime of the unit by 25 000 hours, 8 operational years.

**Sub-Component 1.2. Installation of Gas Engine Combined Heat and Power Capacity (US$ 70,0 million):** This Component will finance installation of gas engines, with a total capacity of 43 Gcal/h heat and 55 $MW_e$ electricity, including:

a. Installation of Gas Engines at CHP Source 3 (US$ 28,0 million).
b. Installation of Gas Engines at HOB West (US$ 35,7 million).

The component will also finance the facilities needed for feeding the generated electricity to the power grid, including:

c. Installation of power transformers at HOB West (US$ 2,3 million)
d. Installation of switchgear ID-110 kV at CHP Source 3 and HOB West (US$ 4,0 million).

**Estimated Benefits**

Installation of Gas Engines at CHP Source 3 and HOB West has following benefits:
Due to additional electricity sales and increased heat production in CHP mode, the operational result will increase from USD 13,7 million up to USD 31,6 million. The additional economic benefits are USD 17,9 million per year.
The direct payback time (without interest rate) of the investment will be 3,8 years (direct payback time is calculated based on formula: Investment costs divided by operational result without depreciation 2024).

a. The electricity sales will increase from USD 56,3 million up to USD 89,2 million. The additional benefits are USD 32,9 million.
b. Reliability and flexibility of heat supply to consumers will increase significantly.
c. The Investment is lowering significantly the burden of heat tariff increase

**Component 2. Pilot Energy Efficiency investments (US$ 7,0 million):** This component will finance pilot energy efficiency and conservation investments to be implemented in public and residential buildings, to maximize the energy efficiency results after installation of Individual Heat Substations (IHSs) and to give and impulse to the process of modernization of the internal distribution systems. The IHSs installed and owned by „Termoelectrica” S.A. make possible efficient and quality preparation of Domestic Hot Water (DHW) and control over energy consumption at room level, by modernization of the internal distribution systems. At the same time, in many of the buildings in Chisinau the internal DHW distribution systems are non-operational; at the level of the DH system, only circa

50% of the heat consumers have centralized DHW from DH. Often the internal heat distribution systems do not satisfy the requirements of the consumers, because of the multiple unauthorized changes and disconnections of separate apartments. These problems are more pronounced in residential buildings without IHSs, leading to inefficient heat consumption, physically distributed disproportionately.

**Thus, the proposed investments will include:**

a. Installation of 140 IHSs and associated pipes in residential buildings where there are deficiencies with the quality of internal heating systems operation and/or which do not have centralized DHW from DH.
b. Reconstruction of the internal heat and DHW distribution systems in 40 buildings, providing heat consumption control at apartment level by changing to horizontal distribution.
c. Thermal rehabilitation of 7 residential buildings which have horizontal distribution systems.

Through these investments the number of consumers who benefit from modernized and efficient heating and DHW preparation systems, as well as much better-quality services, will increase substantially.

**Component 3. Project Management and Technical Assistance (US$ 6,8 million):** This Component will finance two subcomponents, including:

**3.1 Project Management (US$ 2,0 million)** This sub-component will finance consultancy support for project implementation and supervision (US$2), including fiduciary, safeguards, and project monitoring and reporting through the existing Moldovan Energy Project Implementation Unit (MEPIU).

**3.2 Technical Assistance (US$ 4,8 million)**

This sub-component will finance:

- Technical assistance for a modern comprehensive Management Information System (US$ 3,0 million): This Component will finance a modern, comprehensive, reliable, efficient and flexible integrated Management Information System (MIS), including all necessary components, to support efficient operation and management of the company in all relevant areas. MIS will include components such as: Financial management and accounting; Salaries; Costs management; Budgeting; Supplies management; Billing and CRM; Stocks management; Fixed assets management, including network inventory and technical operations management; Human resources; Work safety; Procurements management; Legal; Dispatch; Maintenance; Investments management; Electronic documents and workflows management; Vehicles management; Reporting (including analytics and statistics); Other components, relevant for the activity of the company; and System administration module.
  This component will improve Termoelectrica's operational planning and control capabilities.

- Technical assistance for developing a modern Hydraulic System (US$ 0,3 million): This sub-component will finance a modern Hydraulic System, where simulation time required varies between couple of seconds and couple of minutes and required flow for each consumer is determined based on actual supply and return temperature.

- Technical Supervision for Sub-component 1.2 (US$ 1,5 million).
  This Component will finance Consulting Services for design and bidding documentation and technical supervision of the implementation works.

## Overall energy balance and efficiency under PIP

Installing new efficient CHP capacity increases electricity generation by around 35,6% compared with 2018 production, with less than 8% increase in gas consumption. The total $CO_2$ emissions decrease by 20%.

| | | Present | After implementation | Difference |
|---|---|---|---|---|
| DH production | 1000 Gcal/a | 1 665 | 1 665 | 0 |
| Power generation (net) | GWh/a | 621 | 983 | 363 |
| Gas consumption | 1000 Gcal/a | 2 755 | 2 979 | 224 |
| | 1000 $m^3$/a | 337 238 | 364 651 | 27 413 |
| $CO_2$ emissions[1] | t/a | 392 313 | 287 057 | -105 256 |

[1]including fuel and changes in grid electricity

## Economic results under PIP

**Based on the modelling, the summary impact of the proposed investment scenario would be:**

- Economic Internal Rate of Return (EIRR- real rate excluding inflation):23,5%;
- Financial Internal Rate of Return (FIRR- nominal): 21,2%;
- Payback time 3,8 years
- Annual Operational result, compared with 2019, increases by US$ 17,9 million

**The Technical results under PIP are:**

- The capacity of the Option covers the needed summer load (109,4% of the demand)
- Reconstruction of Unit 1 at CHP Source 1 will extend the lifetime of the Unit by 50 000 hours (about 8 operational years), ensuring heat and electricity production at CHP Source 1. In addition, the investment will increase gross electricity production capacity from 80 $MW_e$ up to 98 $MW_e$ and it will improve the global (total) efficiency of the Unit by 1%.
- Reconstruction of Unit 2 at CHP Source 1 will extend the lifetime of the Unit by 50 000 hours (about 8 Operational years), ensuring heat and electricity production at CHP Source 1. In addition, the investment will increase gross electricity production capacity from 80 $MW_e$ up to 98 $MW_e$ and it will improve the total efficiency of the Unit by 1%.
- Major Overhaul for Unit 3 at CHP Source 1 will extend the lifetime of reserve Unit 3 likely by 25 000 hours (about 8 operational years).
- The installation of Gas Engines can benefit of possibility to use existing infrastructure and connections to networks, lowering investment costs and implementation time.
- Reliability and flexibility of heat supply to consumers will increase significantly.
- The Investment is lowering significantly the burden of heat tariff increase, compared to the scenario without the investments

Installation of Gas Engines with a total capacity of 55 $MW_e$ (net) at CHP Source 3 and at HOB West has following benefits:

- Projected cumulative lifetime (2020-2035) heat energy savings due to investments financed under the project: 2 657 315 MWh
- Projected cumulative lifetime (2020-2035) reduction in $CO_2$ emissions 1 469 232 tons, value in money terms USD 38,8 million
- The Generation Capacity constructed increase 39%, from 240 $MW_e$ (gross) to 335 $MW_e$ (gross)
- The Net electricity production increase 58%, from 620 608 MWh/year to 983 166 MWh/year
- The Heat production in CHP mode increase 8,2%, from 1 254 428 Gcal/year to 1 357 242 Gcal/year
- Decrease of heat losses in the District Heating Network 35 008 Gcal/year

**Sensitivity of PIP profitability to investment cost variations**

**PIP Investment cost factor:**

| | -20% | Base case | +20% |
|---|---|---|---|
| **EIRR** | **28,7%** | **23,5%** | **19,5%** |
| **FIRR** | **26,7%** | **21,2%** | **16,8%** |

The PIP investment cost factor is not very sensitive. If the investment costs increase by 20%, the FIRR will still remain largely above the cost of financing . (presumably IBRD loan conditions consisting of Libor + small spread).

**Technical audit**

- The level of operation and maintenance practices is generally high. Termoelectrica systematically plans and performs checks, maintenance and repairs, replacement of worn out parts and equipment, as required for safe operation, keeps track of operation time of critical components.

- CHP Source 1: Main heat and electricity production plant, 3 cogeneration Units, 2 operational peak HOBs. Requires reconstruction / major overhaul of cogeneration units to extend operation life. Unit 1 currently under reconstruction.

- CHP Source 2: Old plant, planned to be closed down. Currently mainly operated to cover the summer DH load. Capable to continue operation with minimum required maintenance and repairs until planned commissioning of new Gas Engines. Available space and facilities for installation/connection of new Gas Engines.

- HOBs West and South: For operation during the next 10-year period will require investments for maintenance and repairs/overhauls, including replacement of worn out parts and equipment, other investments based on feasibility analysis (as will be identified by Termoelectrica). Available space and facilities for installation/connection of new Gas Engines.

- Pumping stations: 17 pumping stations. 6 largest pumping stations were reconstructed/renovated, and 1 new pumping station was constructed during the last 4 years. For operation during the next 10-year period other pumping stations will require investments for replacement of worn out equipment and/or reconstruction (as will be identified by Termoelectrica).

### Hydraulic modelling

HeatGraph, software presently utilized in hydraulic calculations for the district heating system of Chisinau by Termoelectrica, has several deficiencies that are mandatory when considering proper and credible simulation of the system. The most significant issues include the lack of temperature drop and heat loss calculations as well as very long period of time required for modelling (manual data entering, etc.) to perform single hydraulic calculation. The current software is not integrated with the used SCADA systems. The time required for modelling to perform a complex hydraulic calculation with present software can take 20-30 days, making the optimization of heat production, pumps configuration and supply temperature level almost impossible task to be performed in reasonable amount of time.

In addition, there are several minor issues that are caused by neglecting the heat transfer calculations. These include the utilization of simplified figures (density of cold water for both of theoretical values) while creating flow distribution of the network leading to systematic inaccuracies.

As a result, commissioning and implementing a modern hydraulic modelling software is recommended in order to resolve the issues found in present hydraulic modelling practices as well as the modelling software itself.

# 1 Introduction

## 1.1 Background

With the World Bank (WB) support, since 2009, the DH sector in Chisinau has embarked on a comprehensive institutional, corporate and financial restructuring reform, which achieved remarkable success since 2014 allowing to halt and reverse a downward spiral for DH services in Chisinau such as lack of funds for maintenance and investments resulting in poor service causing loss of clients and thus, increasing financial losses.

Success achieved in recovery process includes

- completed corporate restructuring and optimization with creation of single modern management operator Termoelectrica (TE) in 2015
- major staff downsizing
- reduction of thermal losses and electricity consumption (with WB financed investments and own investments)
- improvement of service and client-orientation (resulting in reconnections, new consumers connection and increase in volumes of sales)
- return to operating results

## 1.2 World Bank Investment Supporting DH Reform

To support the successful reform, the WB approved on November 21, 2014 the District Heating Efficiency Improvement Project (DHEIP) in amount of USD 40.5 million with the objective to contribute to improved operational efficiency and financial viability of the new district heating company and to improve quality and reliability of heating services delivered to the population of Chisinau.

The DHEIP became effective on August 14, 2015 and is supporting “no regret” emergency investments, largely demand side (heat distribution and supply to consumers), in:

(a) modernization of largest pumping stations to reduce electricity consumption and provide for efficient variable flow operation mode of the DH system;

(b) rehabilitation of selected segments of the distribution network to ensure continued secure DH service and reduction of losses of heat and hot water;

(c) replacement of old and inefficient central heat substations (CHS) with modern fully automated individual building level heat substations (IHS) for more efficient and secure heat supply to end-users; and

(d) reconnection of selected public institutions, which were earlier disconnected.

**The logical continuation is to identify least-cost investments in heat and electricity production (supply side) to increase fuel efficiency of the heat and electricity production as well as to increase electricity production.**

### 1.3 Study on optimization of Chisinau DH System

**Context:**

The ongoing DHEIP revealed a significant need in investments on the supply side infrastructure (heat and electricity production), which is closed to end of its operational life and could pose a threat to uninterrupted heat supply in Chisinau, as well as continued investment efforts on the demand side (heat distribution and supply to consumers) for more efficient and secure supply of heat and better and more efficient control and use of heat. To address that, in 2018, the GoM has asked the WB to conduct a study on the optimization of Chisinau DH system and fuel supply options with funding support by Sweden through WB's ESMAP program.

**Study's Objectives:**

- "To support Termoelectrica and the Government of Moldova to identify the optimal energy model of the District Heating sector in Chisinau that would contribute to increased operational efficiency and financial viability of Termoelectrica".
- Specific focus: identify actionable short and medium-term investment priorities to (i) secure heat and electricity production, and (ii) increase heat and electricity production efficiency.

**Technical approach**

- System optimization based on (i) hydraulic model, (ii) energy model, and (iii) economic model.
- The analysis of relevant scenarios for short-term investments considering differences regarding (i) hydraulic constraints, (ii) electricity connection and evacuation, and (iii) investment costs.
- Identification of mid and long-term investment scenarios.

The Government of Moldova (GoM) has asked the WB to carry out a study on the optimization of Chisinau DH system. The WB agreed to do so and negotiated with the Government of Sweden the allocation of financing to support the Study through a Trust Fund (TF) agreement with the ESMAP.

The proposed Optimization of Chisinau District Heating (DH) System is to analyse and recommend solutions for the DH system optimization and identify the mid- and long-term investment needs to sustain the commenced reform and further improve the efficiency and affordability of DH services.

The activity consists of Analysis of the DH sector in Chisinau and recommendations for DH system optimization and elaboration of a financing plan, specifically:

- Task 1: Technical audit of the DH system and its components;
- Task 2: Assessment of General hydraulic model of Termoelectrica's (TE) DH network;
- Task 3: Energy modelling of main generation sources; and
- Task 4: Assets development and financing plan that includes investment plans for network rehabilitation and development, as well as options for heat production and power generation (including ST/MT/LT options for maintenance and replacement of CHP Source 1)

## 2 Assumptions

The following general assumptions have been used in these calculations:

- Gas price estimated based on "World Bank Natural Gas Price forecast Europe"

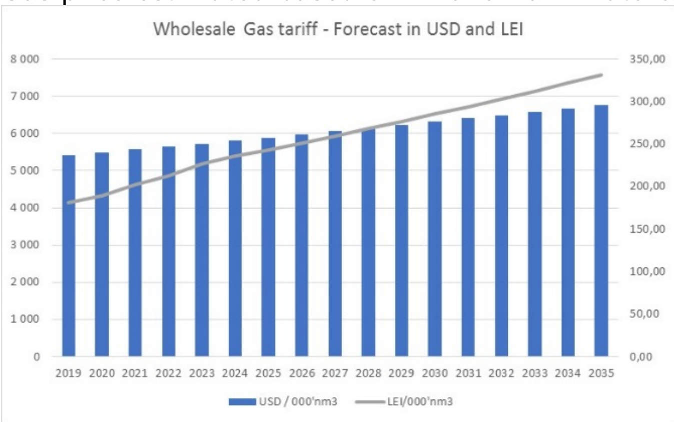


**Figure 1 Wholesale Gas tariff forecast**

- Local inflation rate (CPI) is based on the World Bank estimation

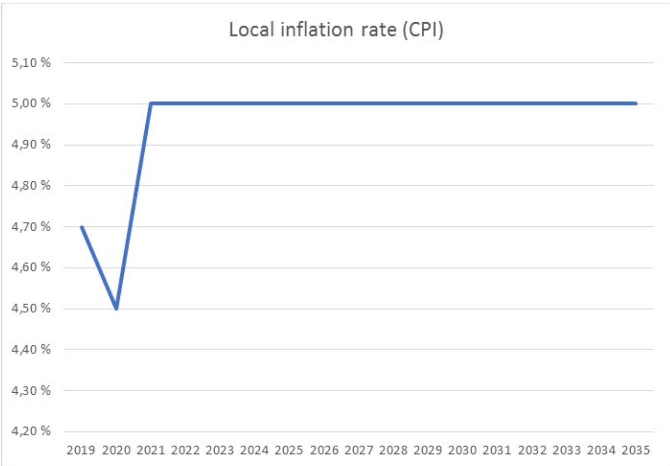


**Figure 2 Local Inflation**

- Other cost components are forecasted to grow based on local inflation
- IRR calculation: term 2019 – 2035
- NPV calculation: real interest rate 5%, term 2019 – 2035
- Investment costs: 2019 real prices of similar investment components, implemented in Ukraine, Finland and elsewhere in Europe. Investment costs are based on unit rates (USD/MW, number of units installed at the same time)
- Investment costs are without contingency.

# 3 Existing system

## 3.1 General

There are four main district heating production plants producing heat to the main DH network in the city of Chisinau:

- CHP Source 1
- CHP Source 2
- HOB West
- HOB South

The main DH network is shown in Figure 3.

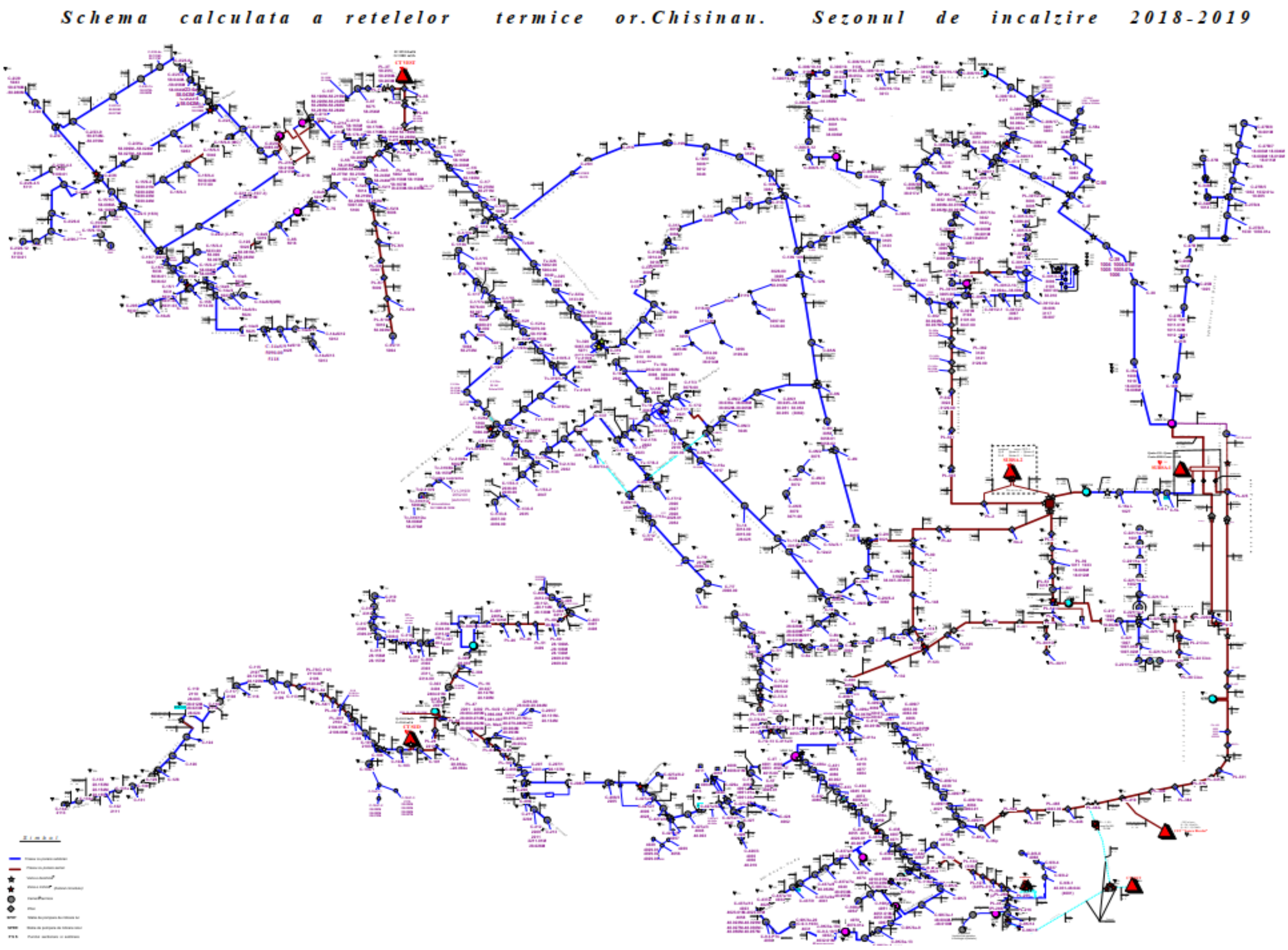


**Figure 3 The main DH network in Chisinau.**

CHP Source 1 is the main source of DH production located in the eastern part of the network operating mainly during the heating season. CHP Source 2 is an old CHP plant located west from CHP Source 1 and operated nowadays mainly only in summer providing Domestic Hot Water heating. HOB West and HOB South are operated independently during heating seasons providing heat to their own areas (shut-off valves closed separating the areas from the main part of the network). In summer the heat is provided by CHP Source 1 or CHP Source 2 also to HOB West and HOB South areas.

## 3.2 Generation assets

### 3.2.1 CHP Source 1

CHP Source 1 consists of three operational natural gas fired CHP units and five natural gas fired Heat-Only-Boilers (HOBs) of which two are operational. The CHP units have reached or are about to reach their permitted operational lifetime and therefore, they need to be reconstructed and/or overhauled in the coming two years to be kept into operation.

The CHP units are independent meaning that the boilers of different units cannot feed steam to the turbines of the other units. The main data of the CHP units as of today and after the planned reconstruction are presented in Table 1 and the main data of the HOBs in Table 3.

The DH and power production capacities of the CHP Source 1 units are shown in Table 1. Although the maximum DH capacity of one unit is 175 Gcal/h the total DH capacity of the three units is 375 Gcal/h, since the throughput capacity of the medium-low pressure part of the turbines is limited (as explained below Figure 4) and the total heat exchanger capacity for DH after the high pressure parts is 75 Gcal/h. There are 6 high pressure steam heat exchangers with a total available capacity of 75 Gcal/h, common for all units, and low pressure steam heat exchangers (two for each unit), providing 100 Gcal/h DH from each unit.

The total capacities of the units in two different operation modes are shown in Table 2.

- one unit at full load, two units at partial load
- each unit at equal load

**Table 1 Main data of CHP Source 1.**

| CHP Source 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | As of today | | | After Retrofit | |
| | | Unit 1 | Unit 2 | Unit 3 | Unit 1 | Unit 2 |
| **Turbine part** | | | | | | |
| Turbine manufacturer | | | | | | |
| Turbine type designation | | ПТ-80/100-130/13 | ПТ-80/100-130/13 | ПТ-80/100-130/13 | ПТ-80/100-130/13 | ПТ-80/100-130/13 |
| Turbine type (back-pressure/extraction-condensing) | | extraction-condensing | extraction-condensing | extraction-condensing | extraction-condensing | extraction-condensing |
| Turbine commissioning year | | 1976 | 1978 | 1980 | n.a. | n.a. |
| **Operational info** | | | | | | |
| Electric capacity (gross) | MW | 80 | 80 | 80 | 98 | 98 |
| Live Steam temperature to turbine, design | °C | 560 | 560 | 560 | 560 | 560 |
| Live Steam temperature to turbine, actual | °C | 555 | 555 | 555 | 555 | 555 |
| Live Steam pressure to turbine, design | bar | 140 | 140 | 140 | 140 | 140 |
| Live Steam pressure to turbine, actual | bar | 130 | 130 | 130 | 130 | 130 |
| DH capacity | Gcal/h | 175 | 175 | 175 | 168 | 168 |
| From turbine extraction | Gcal/h | 100 | 100 | 100 | 168 | 168 |
| Via separate heat exchangers / steam from turbine high pressure part | Gcal/h | 75 | 75 | 75 | 0 | 0 |
| Fuel consumption | Gcal/h | 297 | 297 | 297 | 269 | 269 |
| **Steam boilers** | | | | | | |
| Boiler manufacturer | | | | | | |
| Boiler type | | ТГМ-96Б | ТГМ-96Б | ТГМ-96Б | ТГМ-96Б | ТГМ-96Б |
| Boiler commissioning year | | 1976 | 1978 | 1980 | n.a. | n.a. |
| **Operational info** | | | | | | |
| Live Steam temperature, design | °C | 560 | 560 | 560 | 560 | 560 |
| Live Steam temperature, actual | °C | 555 | 555 | 555 | 555 | 555 |
| Live Steam pressure, design | bar | 140 | 140 | 140 | 140 | 140 |
| Live Steam pressure, actual | bar | 130 | 130 | 130 | 130 | 130 |
| Live Steam capacity, design | t/h | 480 | 480 | 480 | | |
| Live Steam capacity, actual | t/h | 470 | 470 | 470 | 440 | 440 |
| Boiler capacity | Gcal/h | 275 | 275 | 275 | 275 | 275 |
| Minimum boiler capacity | t/h | 200 | 200 | 200 | 200 | 200 |
| Boiler efficiency | | 92,5 % | 92,5 % | 92,5 % | 93,5 % | 93,5 % |
| **Operation hours** | | | | | | |
| Annual operating hours (2016) | h/a | 5 138 | 3 106 | 3 654 | n.a. | n.a. |
| Annual operating hours (2017) | h/a | 4 841 | 3 716 | 2 279 | n.a. | n.a. |
| Annual operating hours (2018) | h/a | 4 462 | 2 735 | 4 597 | n.a. | n.a. |
| Total operation hours (accumulated from commissioning up to 31.12.2018) | h | 223 204 | 209 278 | 202 851 | n.a. | n.a. |
| **Gas connection**(* | | | | | | |
| Gas delivery pressure | barg | 3 - 6 | | | | |
| Maximum available capacity of gas | $m^3/h$ | 150 000 - 300 000 | | | | |

(*CHP + HOBs

*Source: Termoelectrica*

**Table 2 Performance data of CHP Source 1 units in two operation modes.**

| CHP Source 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | One unit at full load | | | All units at equal load | | |
| | | Unit 1 | Unit 2 | Unit 3 | Unit 1 | Unit 2 | Unit 3 |
| Power output (gross) | MW | 80 | 65 | 65 | 70 | 70 | 70 |
| DH output | Gcal/h | 175 | 100 | 100 | 125 | 125 | 125 |
| From turbine extraction | Gcal/h | 100 | 100 | 100 | 100 | 100 | 100 |
| Via separate heat exchangers / steam from turbine high pressure part | Gcal/h | 75 | 0 | 0 | 25 | 25 | 25 |
| Fuel consumption | Gcal/h | 297 | 195 | 195 | 222 | 222 | 222 |
| Live steam flow | t/h | 470 | 300 | 300 | 335 | 335 | 335 |

*Source: Termoelectrica*

**Table 3 Main data of hot water boilers at CHP Source 1.**

| CHP Source 1 (Hot Water Boilers) | | | | | | |
|---|---|---|---|---|---|---|
| | | Boiler 1 | Boiler 2 | Boiler 3 | Boiler 4 | Boiler 5 |
| Boiler type | | PTVM-100 | PTVM-100 | PTVM-100 | KVGM-180 | KVGM-180 |
| Boiler commissioning year | | 1974 | 1975 | 1982 | 1990 | 1991 |
| In operation (yes/no) | | No | Yes | Yes | No | No |
| **Operational info** | | | | | | |
| DH production capacity, design | Gcal/h | 100 | 100 | 100 | 180 | 180 |
| DH production capacity, actual | Gcal/h | 0 | 100 | 100 | 0 | 0 |
| Minimum capacity | Gcal/h | 20 | 20 | 20 | - | - |
| Boiler efficiency | | 91 % | 91 % | 91 % | 91,7 % | 91,7 % |
| Plant efficiency | | 91 % | 91 % | 91 % | 91,7 % | 91,7 % |
| **Operation hours** | | | | | | |
| Annual operating hours (2016) | h/a | 0 | 1 470 | 67 | 0 | 0 |
| Annual operating hours (2017) | h/a | 0 | 73 | 0 | 0 | 0 |
| Annual operating hours (2018) | h/a | 0 | 53 | 0 | 0 | 0 |
| Total operation hours (accumulated from commissioning up to 31.12.2018) | h | 31 664 | 23 729 | 20 366 | 3 943 | 1 819 |

*Source: Termoelectrica*

The steam extraction connections of the turbines at CHP Source 1 are presented in Figure 4.

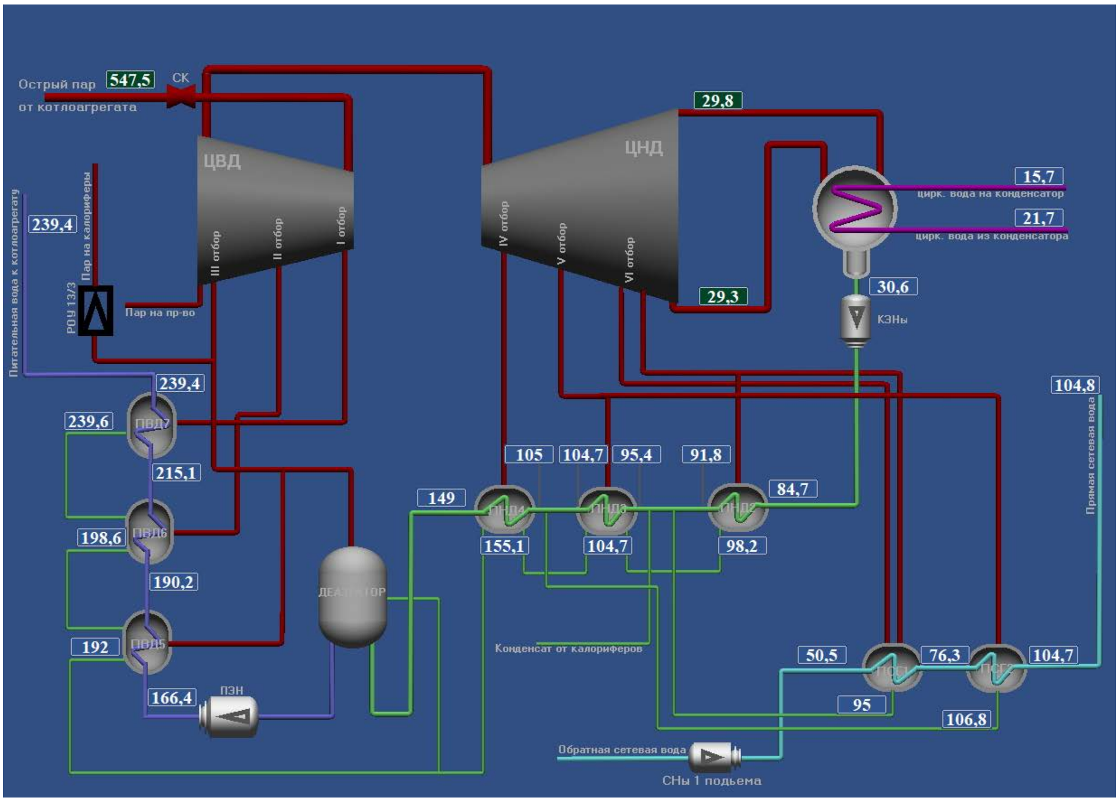

**Figure 4 Steam extraction connections of the turbines at CHP Source 1.**

*Source: Feasibility assessment for Unit No.1 turbine and boiler reconstruction / retrofit project, CHP Source 1.*

Since the medium-low pressure cylinders of the turbines at CHP Source 1 have maximum steam throughput capacity of about 270 t/h[1] (corresponding DH output 100 Gcal/h), part of the steam has to be led out from the turbine before the medium-low pressure part from extraction III as shown in Figure 4 (the common high pressure steam heat exchangers for DH are not shown).

During about half of the heating season, all the three units are needed to cover the heat demand, though without being operated at full capacity.

The calculations in the energy model are based on the revised characteristics provided by Termoelectrica (see Figure 5).

[1] Feasibility assessment for Unit No.1 turbine and boiler reconstruction / retrofit project, CHP Source 1

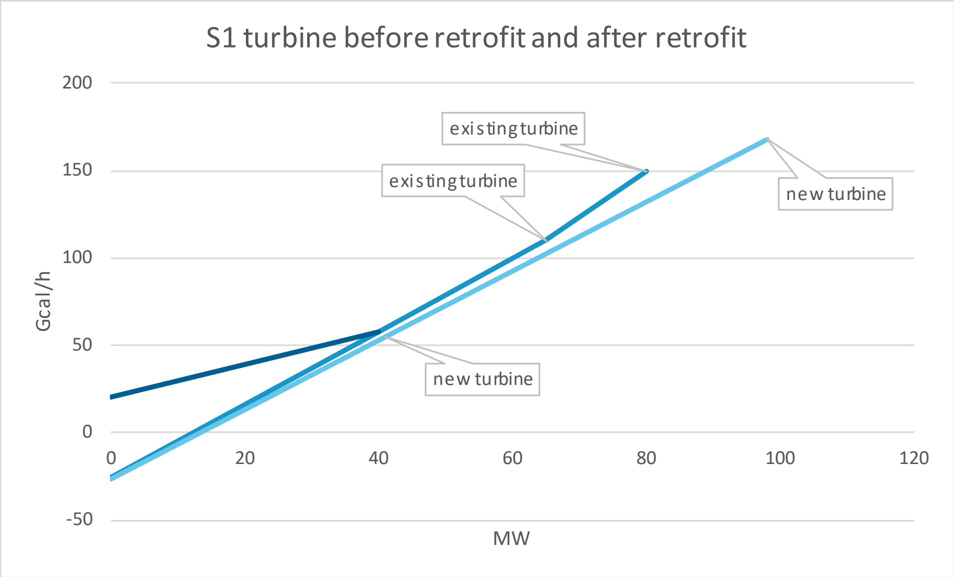


**Figure 5 Revised turbine characteristics of CHP Source 1.**

*Source: Termoelectrica.*

### 3.2.2 CHP Source 2

CHP Source 2 consists of eight natural gas fired steam boilers and five steam turbines. Four of the boilers and two of the turbines are in operation. Especially, the boilers are very old are kept in operation only for summer load. The main data of CHP Source 2 is presented in Table 4.

**Table 4 Main data of CHP Source 2.**

| CHP Source 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Turbine part** | | **Turbine 1** | **Turbine 2** | **Turbine 3** | **Turbine 4** | **Turbine 5** | | | |
| Turbine type designation | | Р-12-35-3М | ПТ-12/15-35/10М | ПР-10-35/10-1,2 | Р-27-90/1,2 | Р-5-90/37 | | | |
| Turbine type | | Back-pressure | Back-pressure | Back-pressure | Back-pressure | Back-pressure | | | |
| Turbine commissioning year | | 1994 | 2001 | 1958 | 1960 | 1961 | | | |
| In operation (yes/no) | | Yes (in summer) | Yes (in summer) | No | No | No | | | |
| **Operational info** | | | | | | | | | |
| Electric capacity (gross) | MW | 12 | 12 | 10 | 27 | 5 | | | |
| Design | MW | 12 | 12 | 10 | 27 | 5 | | | |
| Actual | MW | 12 | 12 | n.a. | n.a. | n.a. | | | |
| Live Steam temperature to turbine, design | °C | 440 | 440 | 440 | 520 | 520 | | | |
| Live Steam temperature to turbine, actual | °C | 435 | 435 | n.a. | n.a. | n.a. | | | |
| Live Steam pressure to turbine, design | bar | 40 | 40 | 40 | 90 | 90 | | | |
| Live Steam pressure to turbine, actual | bar | 35 | 35 | n.a. | n.a. | n.a. | | | |
| DH capacity, design | Gcal/h | 57 | 60 | 67 | 70 | 0 | | | |
| DH capacity, actual | Gcal/h | 57 | 45 | n.a. | n.a. | n.a. | | | |
| **Turbine operation hours** | | | | | | | | | |
| Annual operating hours (2016) | h/a | 657 | 2 124 | 0 | 1 311 | 1 954 | | | |
| Annual operating hours (2017) | h/a | 4 126 | 0 | 0 | 0 | 0 | | | |
| Annual operating hours (2018) | h/a | 4 564 | 0 | 0 | 0 | 0 | | | |
| Total operation hours (accumulated from commissioning up to 31.12.2018) | h | 36 940 | 68 697 | 318 379 | 228 204 | 135 102 | | | |
| **Boilers** | | **Boiler 1** | **Boiler 2** | **Boiler 3** | **Boiler 4** | **Boiler 5** | **Boiler 6** | **Boiler 7** | **Boiler 8** |
| Boiler type | | ГМ-50 | ГМ-50 | ГМ-50 | ГМ-50 | ГМ-50 | ГМ-50 | БКЗ-120-100Г М | БКЗ-120-100Г М |
| Boiler commissioning year | | 1951 | 1951 | 1954 | 1955 | 1958 | 1959 | 1961 | 1961 |
| Operational status | | Operated in summer | Operated in summer | Operated in summer | Operated in summer | Not in operation | Not in operation | Not in operation | Not in operation |
| **Operational info** | | | | | | | | | |
| Live Steam temperature, design | °C | 440 | 440 | 440 | 440 | 440 | 440 | 520 | 520 |
| Live Steam temperature, actual | °C | 440 | 440 | 440 | 440 | n.a. | n.a. | n.a. | n.a. |
| Live Steam pressure, design | bar | 39 | 39 | 39 | 39 | 39 | 39 | 92 | 92 |
| Live Steam pressure, actual | bar | 39 | 39 | 39 | 39 | n.a. | n.a. | n.a. | n.a. |
| Live Steam capacity, design | t/h | 50 | 50 | 50 | 50 | 50 | 50 | 120 | 120 |
| Live Steam capacity, actual | t/h | 35 | 35 | 47 | 47 | n.a. | n.a. | n.a. | n.a. |
| Boiler capacity, design | Gcal/h | 33 | 33 | 33 | 33 | 33 | 33 | 74 | 74 |
| Boiler capacity, actual | Gcal/h | 23 | 23 | 31 | 31 | n.a. | n.a. | n.a. | n.a. |
| Minimum boiler capacity | t/h | 25 | 25 | 25 | 25 | n.a. | n.a. | n.a. | n.a. |
| Boiler efficiency | | 94 % | 94 % | 94 % | 94 % | n.a. | n.a. | n.a. | n.a. |
| **Boiler operation hours** | | | | | | | | | |
| Annual operating hours (2016) | h/a | 0 | 55 | 560 | 828 | 0 | 0 | 1983 | 1282 |
| Annual operating hours (2017) | h/a | 0 | 1936 | 3189 | 2944 | 0 | 0 | 0 | 0 |
| Annual operating hours (2018) | h/a | 0 | 4450 | 4520 | 206 | 0 | 0 | 0 | 0 |
| Total operation hours (accumulated from commissioning up to 31.12.2018) | h | 254 866 | 251 007 | 232 871 | 245 573 | 208 592 | 227 685 | 196 783 | |
| **Gas connection** | | | | | | | | | |
| Gas delivery pressure | barg | 2,94 | | | | | | | |
| Maximum available capacity of gas | $m^3/h$ | 41 666 | | | | | | | |

*Source: Termoelectrica*

### 3.2.3 HOB West

HOB West Boiler consists of four PTVM-100 hot water boilers and two DKVR-6.5/13 steam boilers of which three hot water boilers and both steam boilers are in operation. The main data is presented in Table 5.

**Table 5 Main data of HOB West.**

| HOB West | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Boiler** | | **1** | **2** | **3** | **4** | **5** | **6** |
| Boiler type | | PTVM-100 | PTVM-100 | PTVM-100 | PTVM-100 | ДКВР-6,5/13 | ДКВР-6,5/13 |
| Boiler commissioning year | | 1968 | 1968 | 1979 | 1981 | 1983 | 1983 |
| Major refurbishment | | 1997 | 1998 | | 1999 | 2019 | 2008 |
| In operation (yes/no) | | Yes | Yes | No | Yes | Yes | Yes |
| **Operational info** | | | | | | | |
| DH production capacity, design | Gcal/h | 100 | 100 | 100 | 100 | 5 | 5 |
| DH production capacity, actual | Gcal/h | 54 | 54 | n.a. | 54 | 5 | 5 |
| Minimum capacity | Gcal/h | 26 | 26 | n.a. | 26 | 1,5 | 1,5 |
| Boiler efficiency | | 92 % | 92 % | n.a. | 92 % | 91 % | 91 % |
| **Operation hours** | | | | | | | |
| Annual operating hours (2016) | h/a | 1 984 | 2 788 | no info | 1 078 | 1 970 | 1 290 |
| Annual operating hours (2017) | h/a | 914 | 1 205 | no info | 3 071 | 1 484 | 46 |
| Annual operating hours (2018) | h/a | 1 494 | 2 685 | no info | 1 586 | 2 122 | 174 |
| Total operation hours (accumulated from 1995 up to 2019) | h | 31 645 | 52 694 | 7 838 | 44 888 | 48 854 | 46 128 |
| **Gas connection** | | | | | | | |
| Gas delivery pressure | barg | 3 | | | | | |
| Maximum available capacity of gas | $m^3/h$ | 54 000 | | | | | |

*Source: Termoelectrica*

Termolectrica has made significant improvements to one of the boilers to improve heat transfer and thus efficiency by installing new burners and heat surfaces to the boiler.

### 3.2.4 HOB South

HOB South consists of five hot water boilers and three steam boilers of which three hot water boilers and one steam boiler are in operation. The main data is presented in Table 6.

**Table 6 Main data of HOB South.**

| HOB South | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Boiler** | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Boiler type | | ТВГМ-30 | ТВГМ-30 | PTVM-50 | KVGM-100 | KVGM-100 | ДКВР-10/13 | ДЕ-6,5/14 | ДКВР-10/13 |
| Boiler commissioning year | | 1967 | 1967 | 1974 | 1985 | 1986 | 1966 | 2004 | 1966 |
| Major refurbishment | | | 2012 | 2018 | 2002 | | n.a. | No | n.a. |
| In operation (yes/no) | | No | Yes | Yes | Yes | No | No | Yes | No |
| **Operational info** | | | | | | | | | |
| DH production capacity, design | Gcal/h | 30 | 30 | 50 | 100 | 100 | n.a. | n.a. | n.a. |
| DH production capacity, actual | Gcal/h | n.a. | 26 | 42 | 70 | n.a. | n.a. | 2 | n.a. |
| Minimum capacity | Gcal/h | n.a. | 12 | 17 | 30 | n.a. | n.a. | 0,5 | n.a. |
| Boiler efficiency | | n.a. | 92 % | 92 % | 92 % | n.a. | n.a. | 92 % | n.a. |
| **Operation hours** | | | | | | | | | |
| Annual operating hours (2016) | h/a | 0 | 531 | 2 830 | 1 166 | 0 | 0 | 5 289 | 0 |
| Annual operating hours (2017) | h/a | 0 | 3 374 | 3 549 | 0 | 0 | 0 | 3 629 | 0 |
| Annual operating hours (2018) | h/a | 0 | 3 632 | 3 480 | 0 | 0 | 0 | 3 395 | 0 |
| Total operation hours (accumulated from commissioning up to 31.12.2018)(* | h | no info | 25 875 | 39 450 | 9 638 | 568 | 1 063 | 52 766 | 1 267 |
| **Gas connection** | | | | | | | | | |
| Gas delivery pressure | barg | 3 | | | | | | | |
| Maximum available capacity of gas | $m^3/h$ | 40 100 | | | | | | | |

(*from 2005

*Source: Termoelectrica*

### 3.3 Operation regime

The main source of district heat for the main DH network of the city of Chisinau is CHP Source 1 that produces the base load during the heating season. The minimum boiler output of one unit is 200 t/h steam leading to around 70 – 80 Gcal/h district heat production capacity, while typical summer load is around 30 – 40 Gcal/h. Therefore, in summer CHP Source 1 should be operated in condensing mode (i.e. part of the heat produced has to be thrown away in cooling towers), which is uneconomic. For this reason, CHP Source 2 has been kept operational and is being operated in summer to produce district heat for domestic hot water heating.

During heating seasons the areas of HOB West and HOB South are isolated and the plants produce all the heat to their areas, whereas in summer the shut-off valves are opened, HOB West and HOB South shut down and heat for domestic hot water purposes is produced with CHP Source 2 and/or CHP Source 1.

In the beginning of the heating season in autumn a small portion of heat can be delivered to HOB West area from the CHP Source 1/CHP Source 2 area and HOB West can be operated parallel.

### 3.4 District Heating Network

The District Heating Network is strongly deteriorated.

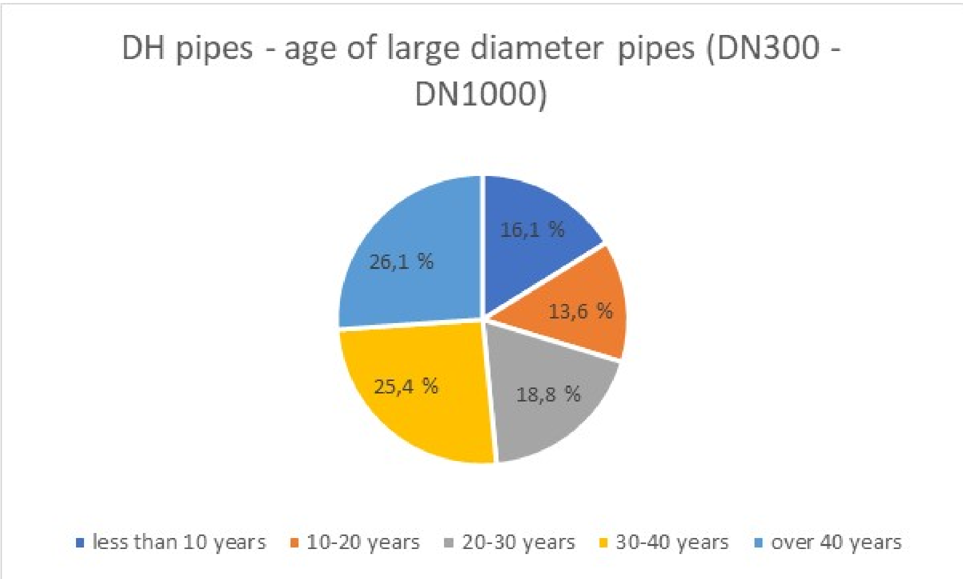


**Figure 6 Age of large diameter DH pipes.**

The estimated lifetime for installed pipes is 30 years. As of today, 51.5% of pipes have reached the end of their technical lifetime. The Short-Term, Mid-Term and Long-Term Investment strategy is to renovate systematically all pipes over 40 years.

**Table 7 Age and length of large DH pipelines**

| DN, mm | Length of pipes (large DNs only), m | | | | | Estimated specific cost of reconstruction, USD/lin. m | Total estimated cost of reconstruction of DH pipes over 40 years old mln. USD |
|---|---|---|---|---|---|---|---|
| | less than 10 years | 10-20 years | 20-30 years | 30-40 years | over 40 years | | |
| 300 | 7 321,2 | 10 064,8 | 5 471,3 | 7 498,8 | 9 413,6 | 320,2 | 3,0 |
| 400 | 5 929,0 | 8 645,6 | 5 102,7 | 8 475,0 | 12 842,2 | 375,7 | 4,8 |
| 500 | 11 456,2 | 5 181,7 | 8 829,8 | 21 448,1 | 8 802,3 | 565,3 | 5,0 |
| 600 | 6 901,1 | 4 755,0 | 3 268,4 | 4 895,6 | 2 490,1 | 620,7 | 1,5 |
| 700 | 1 378,8 | 708,2 | 7 482,2 | 3 034,0 | 7 755,0 | 799,6 | 6,2 |
| 800 | 2 704,8 | 1 704,0 | 12 391,8 | 9 729,0 | 10 481,0 | 978,4 | 10,2 |
| 900 | 889,6 | 63,0 | - | - | 438,4 | 1 157,3 | 0,5 |
| 1000 | 481,6 | - | 496,0 | 3 313,0 | 7 665,6 | 1 336,1 | 10,2 |
| Total by age | 37 062,3 | 31 122,3 | 43 042,2 | 58 393,5 | 59 887,9 | - | - |
| **Total** | **229 508,2** | | | | | | **41,6** |

Replacement of pipes older than 40 years (as of today) will reduce heat losses in District Heating network from 336 985 Gcal/year (19,7%) down to 310 689 Gcal/year (18,1%.)

After completion of district heating network rehabilitation programme (all large pipelines more than 20 years old today), the heat losses will decrease to 15,6%. (source: Termoelectrica).

Besides the large diameter pipes, Termoelectrica will continue gradual replacement of the smaller diameter DH pipes in the network, when needed.

### 3.5 Assessment of Hydraulic modelling system HeatGraph (ТеплоГраф)

The software **HeatGraph** (ТеплоГраф) primarily acts as a DH network information system (NIS) for Termoelectrica. In addition, it is equipped with limited hydraulic calculation tools. In general, HeatGraph is capable of performing both pressure loss and heat loss calculations. However, the calculation time of the software requires long time.

Key differences between Heat Graph and modern hydraulic modelling software Termis:

**Table 8 Key differences between HeatGraph and Termis**

| Feature | HeatGraph | Termis |
|---|---|---|
| **Calculation time** | Long, up to ~30 days | Short, ~5 minutes |
| **Type of simulation** | Steady-state | Dynamic |
| **Heat loss calculation** | Not included | Included |
| **Options for modelling and controlling pumping stations** | According to pump characteristics and efficiency curve as well as speed setting | According either to the curves and speed setting or many other controlling options (constant flow, constant inlet or outlet pressure, constant generated head, constant pressure difference at given point) |
| **Temperature values used for calculation** | Theoretical | Measured |
| **Properties of water used for calculation** | Fixed (due to missing heat loss calculation module) | According to simulated temperature |
| **Support for coordinate systems** | No | Yes |
| **Support for importing and exporting data** | No / limited | Yes / versatile |

In addition, current software has few functionalities, which are useful but not presently utilized by Termoelectrica. These include e.g. the model base allowing the creation of multiple simulation scenarios and thus achieving deeper understanding of the hydraulics of the system in various operational states. Currently, the hydraulic calculation has only been performed for design temperature conditions, even though performing calculations for other, more common conditions could be possible.

**Conclusions and recommendations:**

Existing hydraulic calculation software can be utilized to calculate pressure losses and determine pipelines with insufficient heat transfer capacity.

**As a result, commissioning and implementing a modern hydraulic modelling software is recommended in order to fully resolve the issues found in present hydraulic modelling practices as well as the modelling software itself.**

## 3.6 Technical audit

As part of Chisinau District Heating System Optimization Study, a Technical Audit of Termoelectrica production plants (combined heat and power plants and heat-only boiler plants) and pumping stations was performed to evaluate/define the condition of their main equipment, aiming at securing reliable operation and actions/measures needed over the next 10-year period, establishing critical components for operation over this period, supporting identification of priority investments. Review operation and maintenance history and practices.

Besides, the situation with the DH networks and consumer connections was examined.

Some general findings of the Technical Audit are presented below.

**Operation and maintenance practices, investments in assets:**

- The level of operation and maintenance practices in the company is generally high. The production plants, pumping stations and other facilities/systems have been generally well operated and maintained to ensure safe operation.
- The company systematically plans and performs regular checks, diagnostics, maintenance and repairs, including periodical major repairs/overhauls, replacement of worn out parts and certain equipment, as required for safe operation, following technical regulations, norms and guidelines. The needed current and major repairs/overhauls are identified and included in annual investment and maintenance plans.
- The company keeps track of the operation time of different equipment and parts (e.g. turbine parts, boiler heat transfer surfaces, other critical components, etc.) vs. their prescribed/normed lifetime to plan diagnostics, repairs and replacement of worn out parts.
- At the same time, an important part of the equipment/facilities and networks are over 30-40 years old. Investments in major overhauls, replacement of worn out equipment, installation of new high performance equipment and systems, reconstruction/renovation of facilities and networks – are limited by the available financial resources. For many years such investments were reduced to the minimum because of inadequate tariffs (especially before the tariffs approval function was transferred to ANRE and the launch of the World Bank assistance program).
- Besides major overhauls and replacement of worn out equipment and networks – investments necessary for safe and reliable operation, there are opportunities for investments to further increase performance – increase efficiency of facilities, quality of services, electricity production, reduce losses, operational and maintenance costs, reconnect and connect new consumers, ensure long-term sustainability.

**CHP Source 1:**

- CHP Source 1 (containing 3 cogeneration units, commissioned in 1976, 1978 and 1980 and 2 operational peak/reserve hot water boilers) has a crucial role for operation of the DH system in Chisinau and for the energy security of the country.
- The steam turbines are reaching the end of their prescribed/normed operation lifetime (220 thousand hours): turbine no.1 exhausted its operation lifetime and was stopped in April 2019; turbines no.2 and no.3 are expected to exhaust their operation lifetime in 2021 and 2023 respectively.
- To ensure operation of the plant during the next 10-year period, reconstruction/major overhaul of the turbines is required to extend their operation lifetime. Besides, major overhaul is required for the steam boilers (replacement of worn out heat transfer surfaces, burners, etc.) and overhaul/replacement of some associated equipment/systems. Thus, it is necessary to perform reconstruction/major overhaul of the cogeneration units – including turbines, boilers and associated equipment/systems. The solution for reconstruction of cogeneration units examined in the present document, besides extending operation lifetime,

includes additional changes to increase electricity production and overall performance.

- In 2019 Termoelectrica contracted works for the reconstruction of Unit no.1, including major overhaul of the steam boiler, replacement and upgrade of the burners (changing from the existing configuration with 4 burners to 8 new modern burners, including changes to the boiler), reconstruction and retrofit of the turbine (including replacement of the medium-low pressure rotor and increasing the capacity of the medium-low pressure cylinder, diagnostics and repairs of the other parts of the turbine to extend lifetime by 50 thousand hours), replacement of the deaerator, replacement of a DH heat exchanger, certain upgrades to control/automation systems, other associated works. A new feed water pump with VSD is installed. Completion of the works, testing and restarting operation of Unit no.1 is planned for the year 2020.
- Reconstruction/major overhaul of Units no.2 and no.3 will be required during the next few years to continue their operation. These are critical investments for normal operation of Chisinau DH system.
- Generally, it is necessary to continue regular checks, maintenance, repairs and replacement of worn out parts and equipment when needed, as required for safe and reliable operation. Other possible measures (based on feasibility analysis) to further increase performance and reduce operation and maintenance costs.

**CHP Source 2:**

- CHP Source 2, currently operated mainly during summer and serving as backup during winter, is planned to be closed down.
- The existing plant is capable to continue operation with minimum required maintenance and repairs for safe operation – to cover the summer load of the DH system and to serve as backup/reserve source in case units need to be stopped during winter at CHP Source 1 – until the completion of the proposed new high efficiency gas engine cogeneration units (to cover the summer heat load) and of the reconstruction/major overhaul to extend operation lifetime of CHP Source 1 units.
- On Source 2 site there are opportunities for installation of new high efficiency gas engine cogeneration units (available space, connections to the electricity grid, gas and DH system).

**Heat-only boiler plants West and South:**

- For operation during the next 10-year period, as a minimum it is necessary to continue regular checks, maintenance, repairs and replacement of worn out parts and equipment when needed (including boilers' overhaul to replace worn out heat transfer surfaces and other parts when needed), as required for safe and reliable operation. Other possible measures (based on feasibility analysis) to further increase performance and reduce operation and maintenance costs.
- On both sites there are opportunities for installation of new high efficiency gas engine cogeneration units (available space, connections to the electricity grid, gas and DH system) – to partially replace HOBs operation during winter and to cover the summer heat load. *During summer operation from HOB West site it is possible*

*to supply heat to an important part of Chisinau DH system (besides HOB West circuit).*

**Pumping stations:**

- Considering the landscape of the city, Termoelectrica operates 17 pumping stations in the DH system.
- A new pumping station was constructed during 2015-2016 and three largest pumping stations were completely reconstructed in 2016 within DHEIP. Renovations were performed in three other pumping stations during 2016-2018, including modern VSDs and electrical equipment.
- For operation during the next 10-year period other pumping stations will require investments for replacement of worn out equipment and/or reconstruction.
- It is necessary to continue regular checks, maintenance, repairs and replacement of worn out parts and equipment when needed, as required for safe and reliable operation. Other possible measures (based on feasibility analysis) to further increase performance and reduce operation and maintenance costs.

**Heat-only boiler plants in suburban areas:**

- Termoelectica has 19 boiler plants in 14 suburban areas of Chisinau, supplying separate DH systems and, in several cases, separate buildings. They include 14 boiler plants completely redesigned and reconstructed during the years 2002-2011, based on modern equipment, designed for automatic operation. Other 5 boiler plants are using original main equipment, installed mostly during 1979-1990 (non-reconstructed boiler plants).
- The 14 reconstructed boiler plants are considered to be in satisfactory/good condition. For operation during the next 10-year period, as a minimum it is necessary to continue regular checks, maintenance, repairs and replacement of worn out parts and equipment when needed, as required for safe and reliable operation. Other possible measures (based on feasibility analysis) to further increase performance and reduce operation and maintenance costs.
- In Bacioii Noi boiler plant the boilers and equipment are worn out and need to be replaced. Redesign and reconstruction of the boiler plant is required.
- For Ciorescu, Stauceni and Ghidighici boiler plants there are options to continue for some time operation of existing boilers (providing needed repairs/overhauls and upgrades) or install new more efficient boilers and associated equipment and upgrade the boiler plants for automatic operation.
- In Gratiesti, considering that consumers are concentrated in several areas in different parts of the town and lengthy DH networks from the existing boiler plant to those areas cause high heat losses (circa 40%), it is not feasible to make any significant investments in the existing boiler plant. The proposed solution is to close down the existing boiler plant and to install 3 new automated smaller boiler plants in the areas where the consumers are concentrated.
- There are opportunities to use biomass (especially where new boilers need to be installed).

- In suburban DH systems there are opportunities to install gas engine cogeneration units (based on feasibility analysis), opening possibilities to restart all-year-round operation and DHW supply to consumers, electricity production.

**DH networks and consumer connections:**

- An important part of the DH pipes are over 30-40 years old. Termoelectrica is gradually replacing the old DH pipes with modern pre-insulated pipes, focusing on problematic areas (which cause failures) and on the older pipes in the system, prioritizing the pipes of higher importance for the reliability of the system. Installation of modern pre-insulated pipes leads to reduction of losses in the system.
- There are circa 770 consumer connections with modern IHSs and circa 4510 consumer connections without modern IHSs in the city (situation as of end of year 2019). Besides, there are circa 426 consumer connections in the suburbs, all without IHSs.

# 4 Energy demand and production

## 4.1 Energy balances 2015 - 2018

The annual variations of actual DH and power production based on daily average values in 2015 - 2018 are presented in Figure 7 and Figure 8.

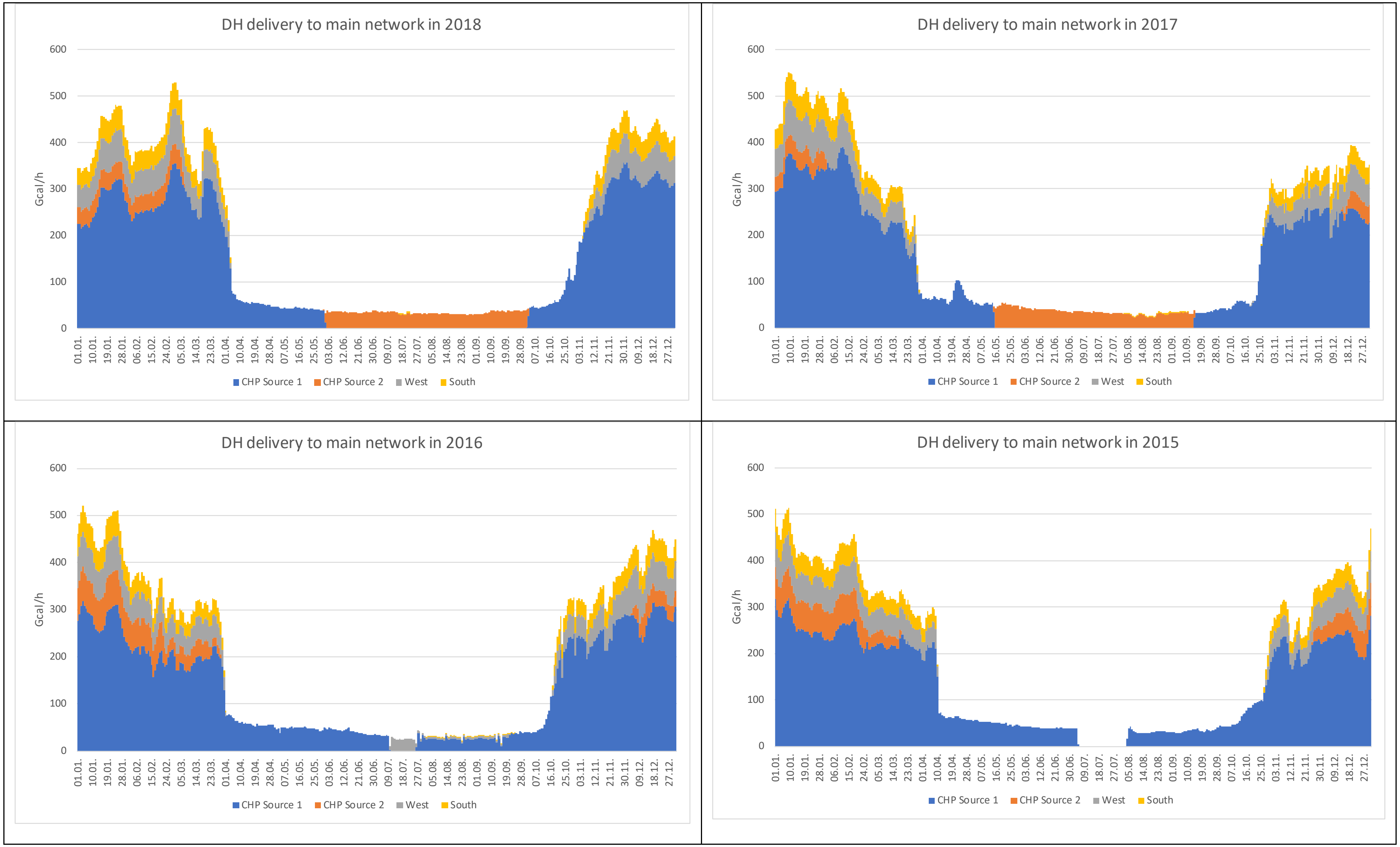


**Figure 7 DH production in 2015 – 2018.**

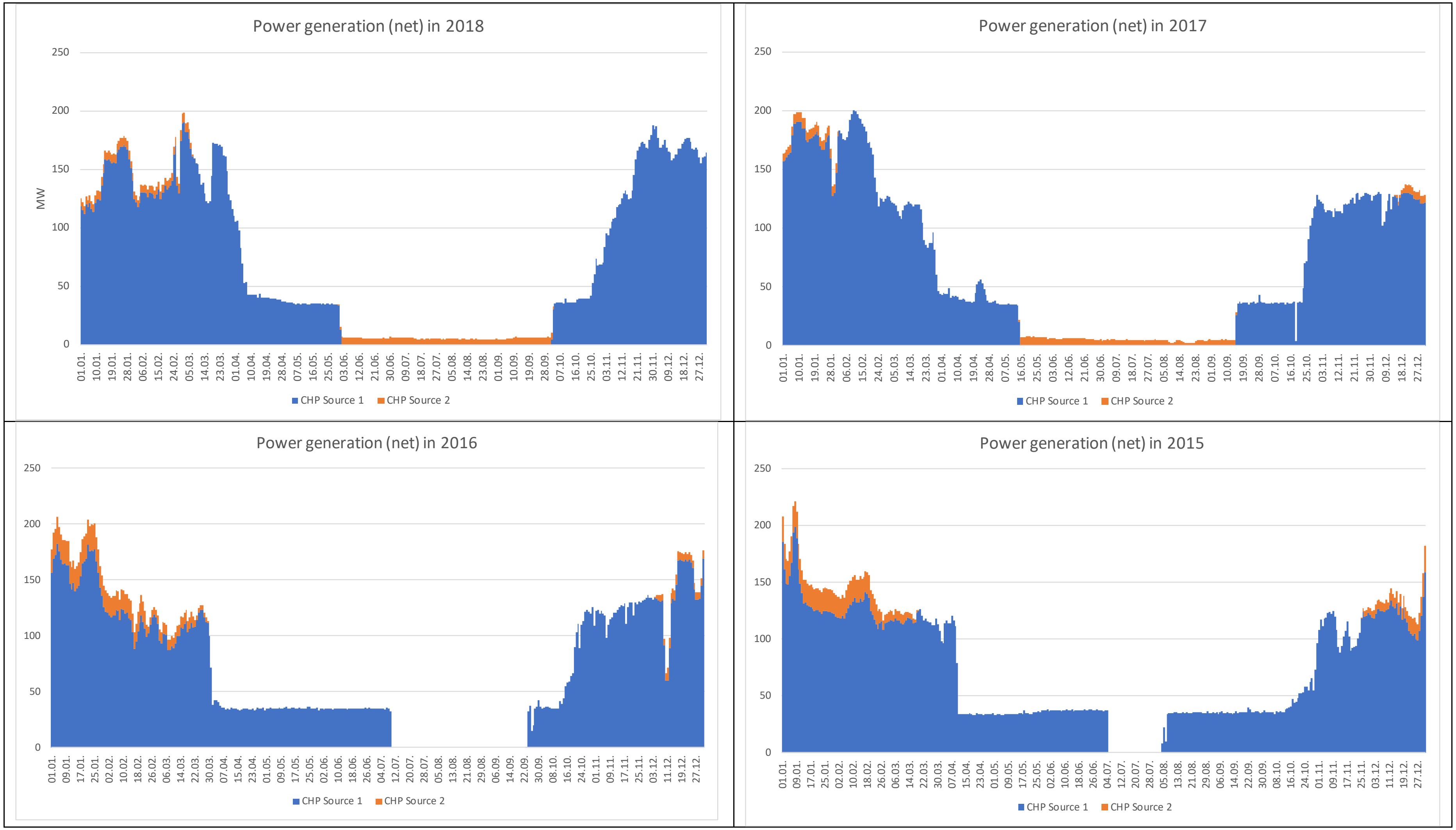


**Figure 8 Power generation in 2015 – 2018.**

As shown in the figures above, the operation periods of CHP Source 1 and CHP Source 2 have varied depending on the year. However, it is assumed in the calculations that CHP Source 1 is operated only during the heating season and CHP Source 2 is operated only in summer.

The actual DH and power generation, fuel consumption and efficiencies of the main sources are presented in Table 9.

**Table 9 Energy production, fuel consumption and efficiencies in 2015 – 2018.**

| Year | | 2018 | 2017 | 2016 | 2015 |
|---|---|---|---|---|---|
| **DH production** | | | | | |
| Source 1 | 1000 Gcal/a | 1 156 | 1 109 | 1 136 | 1 092 |
| Source 2 | 1000 Gcal/a | 161 | 147 | 132 | 136 |
| West HOB | 1000 Gcal/a | 198 | 195 | 231 | 201 |
| South HOB | 1000 Gcal/a | 150 | 144 | 155 | 145 |
| **Total** | 1000 Gcal/a | **1 665** | **1 595** | **1 654** | **1 574** |
| **Power generation** | | | | | |
| **Gross** | | | | | |
| Source 1 | GWh/a | 725 | 693 | 708 | 732 |
| Source 2 | GWh/a | 36 | 32 | 44 | 47 |
| **Gross total** | GWh/a | **761** | **725** | **752** | **779** |
| **Net** | | | | | |
| Source 1 | GWh/a | 625 | 596 | 607 | 627 |
| Source 2 | GWh/a | 27 | 24 | 36 | 39 |
| **Net total** | GWh/a | **652** | **619** | **644** | **666** |
| **Gas consumption** | | | | | |
| Source 1 | 1000 Gcal/a | 2 287 | 2 179 | 2 251 | 2 246 |
| | 1000 $m^3$/a | 279 948 | 266 765 | 275 581 | 274 872 |
| Source 2 | 1000 Gcal/a | 214 | 195 | 200 | 209 |
| | 1000 $m^3$/a | 26 139 | 23 829 | 24 531 | 25 623 |
| West HOB | 1000 Gcal/a | 215 | 210 | 248 | 217 |
| | 1000 $m^3$/a | 26 284 | 25 714 | 30 391 | 26 555 |
| South HOB | 1000 Gcal/a | 166 | 159 | 170 | 159 |
| | 1000 $m^3$/a | 20 273 | 19 438 | 20 792 | 19 475 |
| **Total** | **1000 Gcal/a** | **2 881** | **2 743** | **2 870** | **2 831** |
| | **1000 $m^3$/a** | **352 643** | **335 746** | **351 294** | **346 526** |
| **Total efficiency (net)** | | | | | |
| Source 1 | | 74 % | 74 % | 74 % | 73 % |
| Source 2 | | 86 % | 86 % | 82 % | 81 % |
| West HOB | | 92 % | 93 % | 93 % | 93 % |
| South HOB | | 91 % | 91 % | 91 % | 91 % |
| **Total** | | **77 %** | **78 %** | **77 %** | **76 %** |

*Source: Termoelectrica*

The own electricity consumption of CHP Source 1 and CHP Source 2 is taken directly from the power plant's gross generation via auxiliary transformers. In addition to this consumption, Termoelectrica purchases electricity needed at HOB West and HOB South and at the pumping stations. The consumption is shown in Table 10.

**Table 10 Electricity consumption.**

| Year | | 2018 | 2017 | 2016 |
|---|---|---|---|---|
| **Electricity consumption** | | | | |
| **HOBs** | | | | |
| West HOB | MWh | 5 685 | 5 922 | 7 106 |
| South HOB | MWh | 4 741 | 4 779 | 5 324 |
| **HOBs total** | MWh | **10 426** | **10 701** | **12 430** |
| **Pumping stations** | MWh | **19 111** | | |

*Source: Termoelectrica*

## 4.2 Energy demand

Termoelectrica has estimated that district heat consumption will slightly increase in the future. Basically, this would be resulted from connecting new buildings to the DH system. However, the increase will be partly compensated by reducing the DH network heat losses by continuing the DH network rehabilitation program.

In addition, there is a need to improve energy efficiency of the buildings and there are also programs for that. However, reaching significant reduction in energy consumption is a slow, time-consuming process.

Therefore, no substantial change in heat consumption is foreseen during the calculation period and it has been agreed that actual amount of district heat in 2018 supplied to the DH network (1 665 000 Gcal) has been used in the calculations.

# 5 Fuels

Only natural gas is assumed to be used in energy production in the city of Chisinau.

Natural gas characteristics are presented in Table 11.

**Table 11 Natural gas characteristics.**

| Natural gas characteristics | | |
|---|---|---|
| Lower heating value (LHV) | kcal/$m^3$ | 8 165 |
| Gas composition | | |
| $CH_4$ | mol-% | 96.27 % |
| $C_2H_6$ | mol-% | 2.04 % |
| $C_3H_8$ | mol-% | 0.62 % |
| $C_4H_{10}$ | mol-% | 0.18 % |
| $N_2O_2$ | mol-% | 0.69 % |
| $CO_2$ | mol-% | 0.16 % |
| Other | mol-% | 0.04 % |
| Total | mol-% | 100.00 % |

*Source: Termoelectrica*

The gas delivery pressure at the plants is about 3 bar(g). Based on the information received from Termoelectrica, there has not been any problems in gas availability. Also, gas delivery capacity is sufficient for the future production options.

Heavy oil (mazut) can be used as reserve fuel for the existing production plants including the reconstructed Unit 1 of CHP Source 1 (in emergency situations in case of unavailability of gas supply).

# 6 Future alternatives

## 6.1 General

Since the CHP Source 1 units have reached or are about to reach their operational and licenced lifetime, Termoelectrica has planned to reconstruct the units to secure heat and power production in the future and to improve the performance of the units. Termoelectrica has justified the reconstruction in two separate documents ("Feasibility assessment for Unit No.1 turbine and boiler reconstruction / retrofit project, CHP Source 1" and "Operation safety arguments for the need to reconstruct / retrofit the medium-low pressure cylinder of the turbine ПТ-80/100-130/13 No.1, Source 1 "Termoelectrica" S.A.").

Termoelectrica originally planned to reconstruct all the three units, but the Consultant suggests to reconstruct only two units, and make only a major overhaul to the third unit, since there is not enough heat load for viable operation of the third unit. The third unit would be in operation only for about one week during the heating season.

The third unit would be in reserve in case of some failures in one of the two other units. This is discussed further later in this report.

As an alternative to the reconstruction of the units, extension of lifetime of the steam turbines could be applied for by making major overhauls and inspections for the turbines. With one overhaul the lifetime could be extended with 20 000 – 25 000 hours. However, there are no guarantees that such an extension would be admitted. Also, the major overhauls would not necessarily provide a safe and reliable long-term solution for the old CHP units to be operated as base load units. Therefore, the Consultant does not recommend the major overhauls as basis for the operation of Units 1 and 2 in the future, reconstruction of the units being necessary.

Termoelectrica has started the reconstructions in 2019 with Unit 1. The following schedule for the reconstruction has been assumed in this study:

- Unit 1 in 2019-2020 (in operation 1st of April, 2020)
- Unit 2 in 2021 (in operation 1st of January, 2022)

It has been estimated that the reconstruction would provide about 50 000 hours extension to the lifetime of CHP Source 1.

In addition to the rehabilitation of CHP Source 1, this study recommends to install new efficient CHP capacity. The recommendation is to dimension the new capacity based on the district heat demand in summertime allowing operation at base load through the whole year (and therefore high load factor and very high return on investment for the new CHP capacity). Since the heating season is rather short, dimensioning the capacity for wintertime DH demand would mean much shorter operation time and result in much lower rate of returns on investments.

Since the only available fuel in practice is natural gas and the summertime DH demand is around 30 – 40 Gcal/h (up to 45 Gcal/h at the beginning and end of the summer season, average summer load is 39.3 Gcal/h), the CHP plants have been selected to be based on natural gas fired gas engines. The plant(s) would consist of several gas engines leading to a very flexible and reliable system. The gas engines are assumed to be commissioned in the beginning of 2023.

It had been agreed between the World Bank and Termoelectrica as part of DHEIP preparation that CHP Source 2 would be closed after completion of project investments removing network bottlenecks which required to operate CHP Source 2 in spite of its low electricity production efficiency. This objective has been achieved for winter operation, however, CHP Source 2 is still being operated in summer, because operating CHP Source 1 in condensing mode in summer during low heat demand is wasteful. The study demonstrates that CHP Source 2 is no longer needed in summer after the gas engine investments and could therefore be shut down reducing operating costs and freeing assets and/or land for other use.

A combined cycle power plant (CCGT) based on gas turbine(s) would be an alternative to the gas engines covering the summer time heat demand. However, gas engines have some advantages compared to a CCGT plant, such as:

- There is some uncertainty in the level of heat demand in summer:
  - Several gas engines instead of one CCGT unit would provide more flexibility in operation;
  - Performance values of the gas engines at partial load are better than the ones of a CCGT.
- The reliability of several gas engines is higher (in case of a major failure of CCGT there would be no new CHP capacity available).

Based on above, the gas engines are recommended for short-term and mid-term investments. The viability of a CCGT plant as a long-term investment is discussed below. Possible locations of the gas engines are CHP Source 1 and CHP Source 3 (site of CHP Source 2), HOB West and HOB South.

## 6.2 Gas engine plants

### 6.2.1 Background

The conditions and technical constraints for installation of gas engines at different sites are described below.

**Available space**

On the territories of HOB West and CHP Source 2 there are available areas free from piping/cables for installation of gas engine units as follows:

- at HOB West – up to 3 gas engine units on a land plot as shown in Figure 12, without affecting the oil (mazut) storage facility;
- at CHP Source 2 – up to 5 gas engine units on a land plot as shown in Figure 11.

At HOB South gas engine plant can be installed in the existing steam boiler plant building.

**Hydraulic limitations of the DH system**

- no hydraulic limitations to supply heat to the entire DH system from CHP Source 1, CHP Source 2 / CHP Source 3 during the summer period.
- HOB West: hydraulic limitations for supplying all the heat from more than three gas engine units (11 $MW_e$ each) during the summer without replacing the interconnecting line connecting HOB West circuit with the rest of the DH system (circa 2x1400 m pipes ,USD 2,8 million investment cost, currently DN600, completely replaced in 2016) with a larger diameter.
- hydraulic limitations for supplying heat to other parts of the DH system from HOB South:
  - in summer it is possible to cover South circuit plus a limited area beyond the South circuit from HOB South

  - besides interconnection capacity limitations with the rest of the system, there are also limitations related to the considerable elevation difference between South circuit and the rest of the DH system
- Because of hydraulic limitations, during the winter/cold season the DH system is separated into 3 DH circuits: CHP Source 1+CHP Source 2 circuit (supplied by CHP Source 1 operating in cogeneration), HOB West circuit and HOB South circuit (both supplied by heat only boilers (HOBs)). Although certain amount of heat is transferred from CHP Source 1 to West circuit at the beginning and end of the heating season, during most of the heating season it is not possible to transfer any significant amounts of heat from CHP Source 1 (or CHP Source 2) to HOB West and HOB South circuits without major reconstructions of the DH system, and the circuits operate isolated.

**Electricity transmission capacities / available connections**

CHP Source 1 vs. CHP Source 2:

- Considerably smaller investments in the electrical systems for connection to the grid at CHP Source 2. The existing power transformers and (with certain upgrades) ID-6/110 kV power facility can be used.
- Regarding the use of existing electrical infrastructure at CHP Source 1, the proposed generation capacity (particularly the generation capacity of each gas engine unit) is considerably lower compared to the capacities of existing cogeneration units and particularly of the power system (CHP Source 1 power facility ID-110 kV); technically it is inadmissible to operate small capacity generators in parallel with high capacity systems (power facility ID-110 kV connected to 11 interconnecting overhead power lines, including power lines to power substations Straseni 330 kV and Braila 330 kV).
- In order to install new gas engine units at CHP Source 1, it would be necessary to install a new power facility (switchgear, power transformers) ID-6(10)/110 kV (or reconstruct the existing power facility ID-110 kV), and construct two 110 kV overhead power lines with a length of circa 2 km (in case of technical possibilities for connection on the side of the power distribution company). Technical possibilities for connecting additional cogeneration units were studied by the design institute Teploelectroproiect (which developed the initial design) on Termoelectrica's request

### 6.2.2 General

The gas engine plants are sized based on the summertime DH demand to be able to operate them at base load through the whole year. Generated electricity is sold to the grid.

In this study the short-term calculations are based on gas engines with net electric capacity of 11 $MW_e$ and district heating capacity of 8.6 Gcal/h. To cover the summertime DH demand, totally four or five gas engine plants shall be installed. In case of four engines the total DH capacity of the engines is 34.4 Gcal/h and correspondingly, in case of five engines 43 Gcal/h. The gas engine capacity described above is the minimum to avoid remarkable heat production with heat-only-boilers after closing CHP Source 2.

On the market there is a number of gas engine suppliers, as e.g. Wärtsilä, Jenbacher, Caterpillar and Mitsubishi, producing engines with similar technical characteristics. If the project proceeds, the final selection of the gas engine type and supplier will be made through international competitive bidding. The exact capacity of each unit may vary to a certain extent depending on the manufacturer, ensuring the total capacity at least as required for each site (the number of units may also differ, as necessary to cover the required capacity).

Possible sites are CHP Source 1, CHP Source 3 and HOB West. The Consultant visited the possible sites at CHP Source 3 and HOB West and found them to be technically feasible. CHP Source 1 is excluded due to required high investments in power transmission facilities. Moreover, CHP Source 1 is a proposed site for the future CCGT plant.

All engines (4 or 5) can be installed at CHP Source 3. Alternatively, maximum three engines can be installed at HOB West. According to Termoelectrica, due to limitations in the heat transmission capacity the maximum number of gas engines at HOB West is limited to three. The advantage of installing gas engines at HOB West is that, besides covering a part of the summer DH load, during winter operation the gas engines will replace a part of the heat produced by HOB with heat produced in CHP mode.

To cover the average heat load of the DH system during the summer season (39.3 Gcal/h according to Termoelectrica), five engines are required.

Locating engines at both at CHP Source 3 (2 gas engines) and at HOB West (3 gas engines) would be optimal due to limitations in heat transfer capacity of the network. According to Termoelectrica heat cannot be transferred from CHP Source 1/CHP Source 2/CHP Source 3 to HOB West area in winter. However, during the summer a significant amount of heat from 3 gas engines can be transferred from the HOB West area to other parts of the network. Therefore, this arrangement would maximize CHP production decreasing the heat production of HOB West. Also, locating the engines at two sites would increase the reliability of heat delivery. The viability of different location alternatives is discussed below.

Heat cannot be delivered to the other parts of the network from HOB South or (during the heating season) to HOB South from the other parts of the network e.g. due to high elevation of the HOB South site and due to limitations in heat transfer capacity of the network. To further increase CHP production, a small gas engine plant can be installed to cover the summer heat load of the HOB South area. The viability of installing one 4 $MW_e$ gas engine with district heating capacity of 3.8 Gcal/h later (mid-term investment) has also been calculated.

On the market there is a number of gas engine suppliers producing engines with similar technical characteristics. If the project proceeds, the final selection of the gas engine type and supplier will be made through international competitive bidding. The exact capacity of the unit may vary to a certain extent depending on the manufacturer, ensuring the required capacity.

The capacity of the gas engine plant for HOB South may be updated based on the actual summer heat load of the HOB South circuit at the time of implementation.

A schematic flow diagram of a gas engine plant is presented in Figure 9.

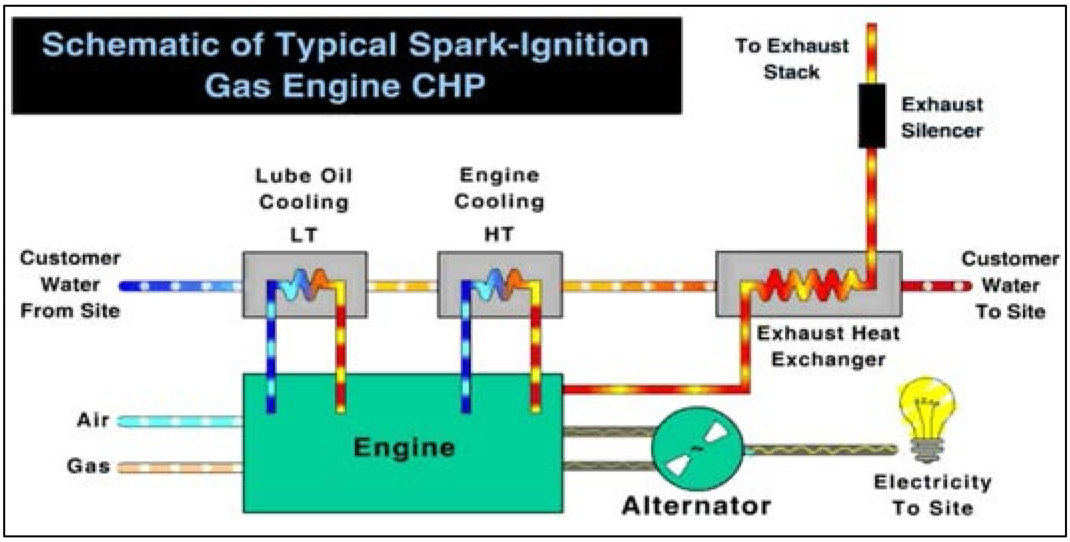


**Figure 9 Schematic flow diagram of a gas engine plant.**

*Source : http://gandras.net/en/equipment/108-gas-and-diesel-engines*

Natural gas fired engines are using otto process in most cases (spark ignited piston engine). Multi-fuel engines use diesel process (compression ignited piston engine) to be able to operate with various fuel oils, too. In the otto process the gas is pre-mixed with the combustion air to enable more lean mixtures.

In both cases the mechanical efficiency is high (>45%) thanks to high compression ratio enabled by methane gas. Heat recovery from exhaust gas, engine block cooling water, charge air cooling and lube oil cooling raises the total efficiency up to >85%.

The gas engines have long development history (1860 →) and the basic constructions used in most engines are based on long operation and maintenance history. The number of wearing parts is although high and engines are relatively maintenance intensive in base load operation.

Practically all critical parts of the gas engines are changed in the periodic maintenance overhauls. The maintenance philosophy of the engine manufacturers is a bit different from one manufacturer to another, but the general idea is the same – to replace the critical component before they brake. Natural gas fired base load engines reaches typically >60000 h overhaul (revision service) life.

### 6.2.3 Performance values

The main performance values of the gas engine plants used in the calculations are presented in Table 12. The values are based on the information for modern gas engines available on the market. The values vary between engine suppliers and will be finally fixed only during the procurement process.

**Table 12 Performance values of gas engine plants.**

| Performance values of gas engines (1 engine) | | | |
|---|---|---|---|
| **Engine** | | **Big** | **Small** |
| Power output (gross) | MW | 11,8 | 4,0 |
| Own electricity consumption | | | |
| Plant | MW | 0,2 | 0,05 |
| Gas compression (from 3 to 10 barg) | MW | 0,2 | 0,07 |
| DH pumping | MW | 0,2 | 0,09 |
| Power output (net) | MW | 11,2 | 3,8 |
| DH output | Gcal/h | 8,6 | 3,8 |
| Electrical efficiency (gross) | | 48 % | 42 % |
| Gas consumption | Gcal/h | 21,1 | 8,2 |
| | $m^3/h$ | 2 587 | 1 002 |
| Total efficiency (net) | | 86 % | 86 % |

The total availability based on the planned and unplanned maintenance shut downs is around 95% based on statistics from gas engine manufacturers.

## 6.3 Combined cycle power plant

### 6.3.1 General

As discussed above, the reconstruction of two units of CHP Source 1 provides approximately 50 000 hours ( about 8 operational years) extension for the lifetime of CHP Source 1 with rather low investments compared to an investment of a new CHP plant. Therefore, investment of a new CCGT is not profitable until CHP Source 1 has to be closed. The profitability compared to the reconstruction is discussed more below. Also, the required amount of funds would be remarkable. However, the viability of the CCGT after closing CHP Source 1 has been roughly calculated.

The CCGT plant will be dimensioned based on the DH demand during heating season. The target district heat output of the CCGT plant is around 300 Gcal/h. This output can be reached with different gas turbine setups, but in this study the calculations have been made based on two gas turbines, two Heat Recovery Steam Generators (HRSG) and one steam turbine.

The capacity is indicative and will depend on evolution of heat demand (network coverage, reconnection, new connections, energy efficiency etc.).

The power plant consists of the following main components:

- Gas turbine plant
- Heat recovery steam generator
- Back-pressure steam turbine plant
- Necessary auxiliary equipment and systems (BOP, balance-of-plant) such as mechanical auxiliaries, piping, control and instrumentation, electrification, water treatment equipment
- Related civil works

A schematic flow diagram is shown in Figure 10.

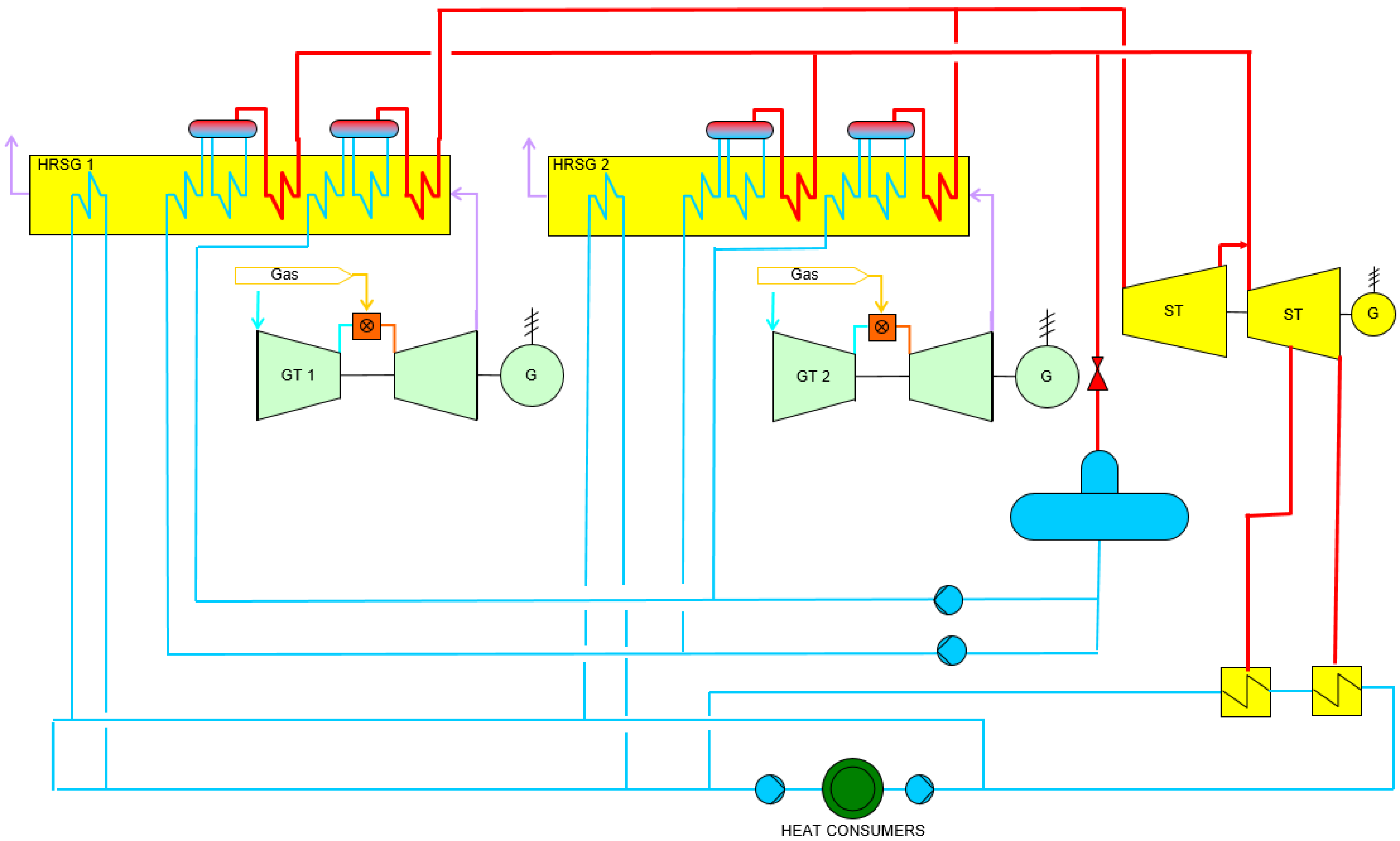


**Figure 10 Simplified main flow diagram of the combined cycle power plant.**

The main components of a gas turbine are compressor, combustion chamber and turbine. The compressor sucks air, the compressed air flows to the combustion chamber into which the fuel is fed. Hot exhaust gas expands in the turbine generating mechanical energy, which is partly used by the compressor and the rest is used to generate electricity.

The hot exhaust gases from the gas turbine are fed to the heat recovery steam generator, where the exhaust gases are used to generate steam to be fed to a back-pressure steam turbine to generate electricity. To further cool down the exhaust gases district heat is produced in the last heat exchanger of the boiler.

### 6.3.2 Performance values

The performance values are based on the Consultant's experience from previous assignments and they are presented in Table 13.

**Table 13 Performance values of CCGT plant.**

| Performance values of CCGT plant | | |
|---|---|---|
| Power output (gross) | | |
| Gas turbines | MW | 272 |
| Steam turbine | MW | 116 |
| Power output, total (gross) | MW | 388 |
| Own electricity consumption | | |
| Plant | MW | 8,0 |
| Gas compression (from 3 to 26 barg) | MW | 3,5 |
| DH pumping | MW | 6,8 |
| Power output (net) | MW | 370 |
| DH output | Gcal/h | 291 |
| Gas consumption | Gcal/h | 688 |
| | $m^3/h$ | 84 211 |
| Total efficiency (net) | | 89 % |

The availability excluding the planned shut-downs (reliability) of the CCGT plant is assumed to be 98%.

## 6.4 Summary of investment schedule

The suggested schedule for the production unit investments is as follows:

- Short-term investments
  - Totally five 11 $MW_e$ gas engines at CHP Source 3 and at HOB West in 2022 (first full operating year 2023)
- Mid-term investments
  - One 4 $MW_e$ gas engine at HOB South in 2025 (first full operating year 2026)
- Long-term investments
  - 370 $MW_e$ CCGT in 2032-2035 (first full operating year 2036)

The overall schedule of the availability of production units applied in the study is presented in Table 14.

**Table 14 Availability of production units.**

| Year | 2019 | | 2020 | | 2021 | 2022 | 2023 | 2024 | 2025 | 2026-2035 | 2036 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quarter | I | II-IV | I | II-IV | I-IV | I-IV | I-IV | I-IV | I-IV | I-IV | I-IV |
| | Short term | | | | | | | | Mid-term | | Long-term |
| **CHP Source 1** | | | | | | | | | | | |
| Unit 1 as of today | yes | no | no | no | no | no | no | no | no | no | no |
| Unit 2 as of today | yes | yes | yes | yes | no | no | no | no | no | no | no |
| Unit 3 as of today / overhauled | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | no |
| Unit 1 reconstructed | no | no | no | yes | yes | yes | yes | yes | yes | yes | no |
| Unit 2 reconstructed | no | no | no | no | no | yes | yes | yes | yes | yes | no |
| Unit 3 reconstructed | no | no | no | no | no | no | no | no | no | no | no |
| HOBs | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| **CHP Source 2** | yes | yes | yes | yes | yes | yes | no | no | no | no | no |
| **HOB West** | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| **HOB South** | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| **Gas engines** | | | | | | | | | | | |
| Gas Engines at CHP Source 3/HOB West | no | no | no | no | no | no | yes | yes | yes | yes | yes |
| Gas Engine at HOB South | no | no | no | no | no | no | no | no | no | yes | yes |
| **CCGT** | no | no | no | no | no | no | no | no | no | no | yes |

## 6.5 Operation principles

As described in more detail below, the recommended alternative is to install two 11 $MW_e$ gas engines at Source 3 and three at HOB West. The operation regimes with this alternative in different years are described below.

### 6.5.1 Operation in 2019

The following units were in operation:

- CHP Source 1
  - Unit 1: 1.1. – 31.3. (under reconstruction 1.4. - 31.12.)
  - Unit 2 and Unit 3 as of today
- CHP Source 2
- HOB West
- HOB South

The operation regime was as follows:

- CHP Source 1 was operated as base load plant during January-May and October-December.
- CHP Source 2 was operated during June-September producing all DH for the whole city.
- The hot water boilers at CHP Source 1 were used to cover the peak demand, if needed.
- HOB West and HOB South areas were isolated during heating season and the corresponding boiler plants produced all the heat needed in their areas. The boiler plants were shut-down during summer, the shut-off valves were opened and heat was produced by CHP Source 1 or CHP Source 2.

### 6.5.2 Operation in 2020

The following units are in operation:

- CHP Source 1
  - Unit 1: 1.4. – 31.12. (under reconstruction 1.1. - 31.3.)
  - Unit 2 and Unit 3 as of today
- CHP Source 2
- HOB West

- HOB South

The following operation regime is assumed:

- CHP Source 1 is operated as base load plant during January-May and October-December, but it is closed in summer.
- CHP Source 2 is operated during June-September producing all DH for the whole city.
- The hot water boilers at CHP Source 1 are used to cover the peak demand, if needed.
- HOB West and HOB South areas are isolated during heating season and the corresponding boiler plants produce all the heat needed in their areas. The boiler plants are shut-down during summer, the shut-off valves are opened and heat is produced by CHP Source 1 or CHP Source 2.

### 6.5.3 Operation in 2021

The following units are in operation:

- CHP Source 1
  - Unit 1 reconstructed
  - Unit 2 under reconstruction
  - Unit 3 as of today
- CHP Source 2
- HOB West
- HOB South

The following operation regime is assumed:

- CHP Source 1 is operated as base load plant during January-May and October-December, but it is closed in summer.
- CHP Source 2 is operated during June-September producing all DH heat for the whole city.
- The hot water boilers at CHP Source 1 are used to cover the peak demand, if needed.
- HOB West and HOB South areas are isolated during heating season and the corresponding boiler plants produce all the heat needed in their areas. The boiler plants are shut-down during summer, the shut-off valves are opened and heat is produced by CHP Source 1 or CHP Source 2.

### 6.5.4 Operation in 2022

The following units are in operation:

- CHP Source 1
  - Unit 1 and Unit 2 reconstructed
  - Unit 3 as of today
- CHP Source 2
- HOB West
- HOB South

The following operation regime is assumed:

- CHP Source 1 is operated as base load plant during January-May and October-December, but it is closed in summer.
- CHP Source 2 is operated during June-September producing all DH heat for the whole city.

- The hot water boilers at CHP Source 1 are used to cover the peak demand, if needed.
- HOB West and HOB South areas are isolated during heating season and the corresponding boiler plants produce all the heat needed in their areas. The boiler plants are shut-down during summer, the shut-off valves are opened and heat is produced by CHP Source 1 or CHP Source 2.

### 6.5.5 Operation in 2023 - 2025

The following units are in operation:

- Two 11 $MW_e$ gas engines at CHP Source 3
- Three 11 $MW_e$ gas engines at HOB West
- CHP Source 1 (two units reconstructed, one as of today as reserve)
- HOB West
- HOB South
- CHP Source 2 has been decommissioned

The following principles are applied:

- Gas engines at CHP Source 3 are operated as base load plant as first in the operation order throughout the whole year
- CHP Source 1 is after the gas engines in operation order. It is operated during the heating season and it is shut down in summer. Unit 3 of CHP Source 1 (not reconstructed) is as reserve.
- During the heating season HOB West area is isolated and the gas engines at HOB West are operated as base load plant producing heat to its area.
- In summer the gas engines at HOB West plant are operated to cover the heat demand in the HOB West area and of a part of the rest of the DH system.
- HOB South area is isolated during the heating season and the corresponding boiler plant produce all the heat needed in its area. The boiler plant is shut-down during summer, the shut-off valve is opened and heat is produced by gas engines at CHP Source 3 and/or HOB West.
- If the capacity of the gas engines is insufficient in summer, hot water boilers at CHP Source 1, HOB West or HOB South are used to cover the deficit.

### 6.5.6 Operation in 2026 - 2035

The following units are in operation:

- Two 11 $MW_e$ gas engines at CHP Source 3
- Three 11 $MW_e$ gas engines at HOB West
- One 4 $MW_e$ gas engine at HOB South (mid-term investment)
- CHP Source 1 (two units renovated, one as of today as reserve)
- HOB West
- HOB South

The following principles are applied:

- Gas engines at CHP Source 3 are operated as base load plant as first in the operation order throughout the whole year
- CHP Source 1 is after the gas engines in operation order. It is operated during the heating season and it is shut down in summer. Unit 3 of CHP Source 1 (not reconstructed) is as reserve.
- During the heating season HOB West area is isolated and the gas engines at HOB West are operated as base load plant producing heat to its area.
- In summer the gas engines at HOB West are operated to cover the heat demand in the HOB West area and of a part of the rest of the DH system.

- If the capacity of the gas engines is insufficient in summer, hot water boilers at CHP Source 1 or HOB West are used to cover the deficit.
- HOB South area is isolated the whole year. The gas engine is operated as base load plant and the rest of the heat is produced by the boiler plant.

### 6.5.7 Operation in 2036 and onwards

The following units are in operation:

- 370 $MW_e$ CCGT
- Two 11 $MW_e$ gas engines at CHP Source 3
- Three 11 $MW_e$ gas engines at HOB West
- One 4 $MW_e$ gas engine at HOB South
- HOB West
- HOB South

The following principles are applied:

- CCGT is operated as base load plant as first in the operation order during heating season
- Gas engines at CHP Source 3 are operated after the CCGT plant during heating season and as base load plant in summer
- During the heating season HOB West area is isolated and the gas engines at HOB West are operated as base load plant producing heat to its area.
- In summer the gas engines at HOB West Boiler plant are operated to cover the heat demand in the HOB West area and of a part of the rest of the DH system.
- If the capacity of the gas engines is insufficient in summer, hot water boilers at CHP Source 1 or HOB West are used to cover the deficit.
- HOB South area is isolated the whole year. The gas engine is operated as base load plant and the rest of the heat is produced by the boiler plant.

## 6.6 Sites

### 6.6.1 CHP Source 3

The preferred area at CHP Source 3 (at the site of CHP Source 2) is shown in Figure 11.

The Consultant visited the site and it was considered as the best alternative having all needed connections (gas, DH, electricity, water) nearby.

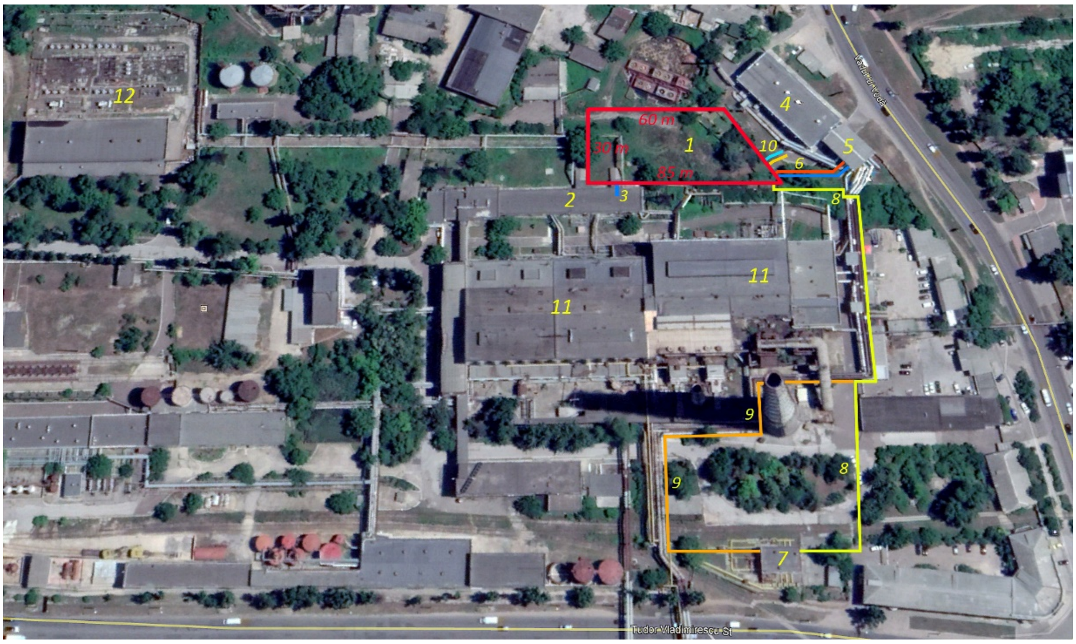


**Figure 11 Available area for the gas engine plant at CHP Source 3 area.**

Legend:

1. Proposed location/area for the new gas engines plant, size of the proposed area circa 60-85x30 m (the exact size and shape of the new gas engines plant building shall be determined during the design).
2. Existing 6 kV switchgear (ID-6kV).
3. Electricity connection of the new gas engines plant – new power cables to the existing switchgear ID-6 kV (located in immediate vicinity).
4. Existing Pumping Station no.8 (on the DN1000 interconnection line between CHP Source 1 and CHP Source 2 areas).
5. Existing DH headers.
6. Connection of the new gas engines plant to the DH system – new DH pipes to the existing DH headers.
7. Existing natural gas regulation and metering station.
8. New natural gas pipe from the existing gas regulation and metering station to the new gas engines plant.
9. Alternative route for a part of the new gas pipe from the existing gas regulation and metering station – along the existing pipe route of the main DH pipes transiting the site (the optimal pipe route shall be determined depending on the future planning for the site).
10. Connections to the water supply and sewerage networks.
11. Existing CHP Source 2 main production building.
12. Existing 6/110 kV power transformers and 110 kV switchgear (ID-110kV).

### 6.6.2 HOB West

The preferred area at HOB West is shown in Figure 12. The Consultant visited the site and it was considered as the best alternative having all needed connections (gas, DH, electricity, water) nearby.

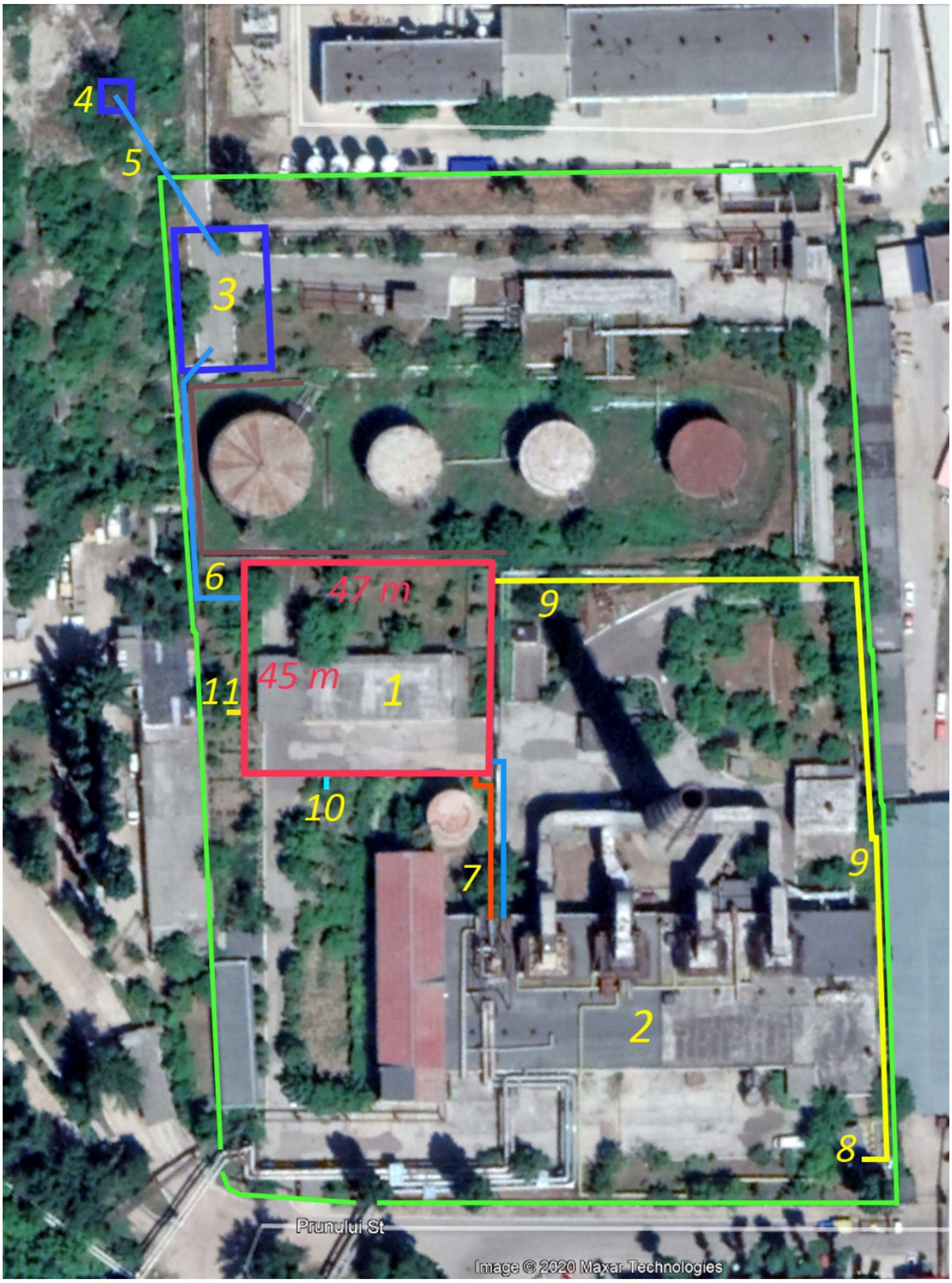


**Figure 12 Available areas for the gas engine plant at HOB West**

Legend:

1. Proposed location/area for the new gas engines plant, size of the proposed area circa 47x45 m (the exact size and shape of the new gas engines plant building shall be determined during the design).
2. Existing HOB West main production building.
3. Proposed location/area for the new 110 kV switchgear (ID-110kV) and 6(10)/110 kV power transformers (the exact size and shape of the area for

the switchgear and transformers shall be determined during the design, ensuring necessary access ways to the site).

4. Existing 110 kV overhead power line tower of the power distribution company (two 110 kV overhead power lines are available on the tower) – proposed connection point to the power system.
5. Connection(s) from the existing 110 kV overhead power line tower to the new 110 kV switchgear (ID-110kV).
6. New 6(10) kV cable lines to be installed from the new gas engines plant (from 6(10) kV switchgear to be included) to the 6(10)/110 kV power transformers (routed in space available outside mazut storage area).
7. DH connection of the new gas engines plant – new DH pipes to HOB West main production building (the new DH pipes will enter HOB West main production building in the area of the DH pumps).
8. Existing natural gas regulation and metering station.
9. New natural gas pipe from the existing gas regulation and metering station to the new gas engines plant.
10. Connection to water supply network.
11. Connection to sewerage network.

### 6.6.3 HOB South

At HOB South the engine would be located in the existing steam boiler building. The steam boilers shall be removed.

# 7 Energy balances

In order to assess costs and savings, energy balance calculations are required, since they create the basis for cost balance calculations.

The energy balances have been calculated in each situation described in Section 6.4 and they are presented in Table 15, Table 16, Table 17, Figure 14, Figure 15 and Figure 16.

The structure of the Energy Model used to calculate the energy balance is shown below.

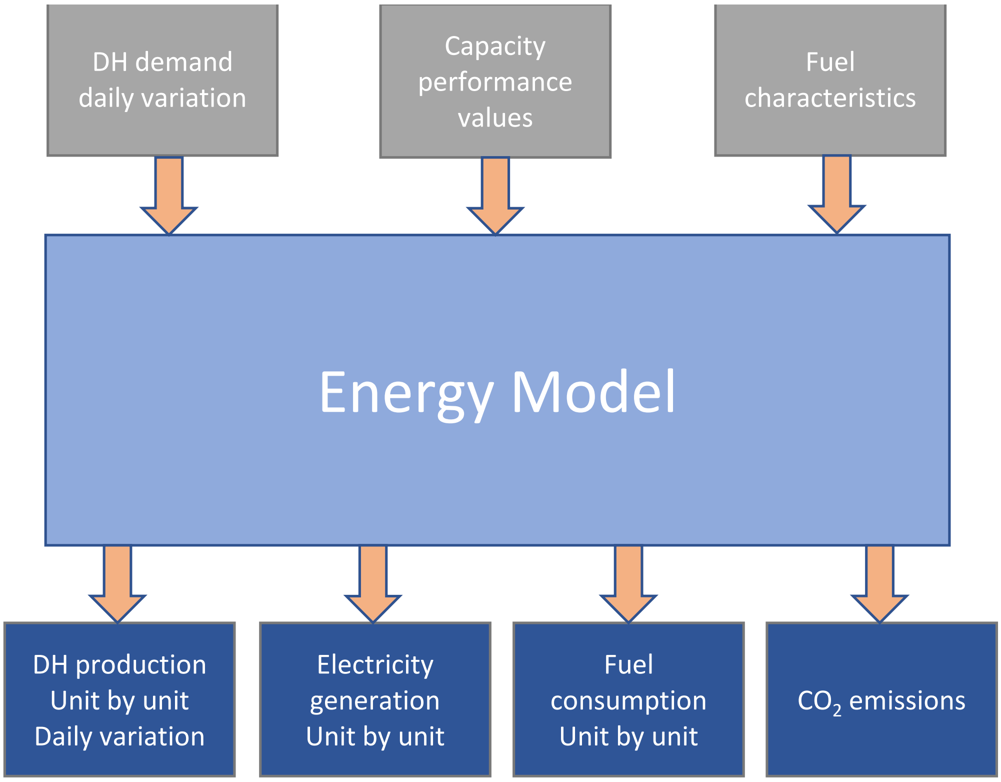


**Figure 13 Structure of Energy Model.**

**Table 15 Energy balances.**

| Year | | 2018 actual | 2019 | 2020 | 2021 | 2022 | 2023-2025 | 2026-2035 | 2036 |
|---|---|---|---|---|---|---|---|---|---|
| **Units in operation** | | | | | | | | | |
| CHP Source 1 | | | | | | | | | |
| Non-reconstructed | pcs | 3 | 3/2 | 2 | 1 | 1 | 1 | 1 | 0 |
| Reconstructed | pcs | 0 | 0 | 0/1 | 1 | 2 | 2 | 2 | 0 |
| Gas engines | | | | | | | | | |
| CHP Source 3 | pcs | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 |
| HOB West | pcs | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 |
| HOB South | pcs | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| CCGT | yes/no | no | no | no | no | no | no | no | yes |
| ***DH demand (incl. losses)*** | 1000 Gcal/a | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** |
| ***DH production*** | 1000 Gcal/a | | | | | | | | |
| **Gas engines** | | 0 | 0 | 0 | 0 | 0 | 333 | 352 | 323 |
| **CCGT** | | | | | | | | | 993 |
| **CHP Source 1** | | | | | | | | | |
| Non-reconstructed CHP units | | | 1 159 | 754 | 441 | 0 | 0 | 0 | 0 |
| Reconstructed CHP units | | 1 156 | 0 | 378 | 741 | 1 200 | 1 024 | 1 024 | 0 |
| **CHP Source 1 total (net)** | | 1 156 | 1 159 | 1 133 | 1 183 | 1 200 | 1 024 | 1 024 | |
| **CHP Source 2** | | 161 | 96 | 96 | 96 | 96 | 0 | 0 | 0 |
| **CHP Source 1 HOB** | | | 57 | 83 | 33 | 16 | 49 | 43 | 103 |
| **HOB West** | | 198 | 205 | 205 | 205 | 205 | 109 | 109 | 109 |
| **HOB South** | | 150 | 149 | 149 | 149 | 149 | 149 | 137 | 137 |
| ***Total*** | | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** | **1 665** |
| ***Power generation (net)*** | GWh/a | | | | | | | | |
| **Gas engines** | | | | | | | | | |
| Gross | | 0 | 0 | 0 | 0 | 0 | 452 | 465 | 426 |
| Own consumption | | 0 | 0 | 0 | 0 | 0 | 22 | 22 | 20 |
| Net | | 0 | 0 | 0 | 0 | 0 | 430 | 443 | 405 |
| **CCGT** | | | | | | | | | |
| Gross | | | | | | | | | 1 279 |
| Own consumption | | | | | | | | | 60 |
| Net | | | | | | | | | 1 219 |
| **CHP Source 1** | | | | | | | | | |
| Gross | | 725 | 707 | 672 | 715 | 751 | 626 | 626 | |
| Own consumption | | 100 | 101 | 89 | 90 | 87 | 73 | 73 | |
| ***Net*** | | | | | | | | | |
| Non-reconstructed CHP units | | 625 | 606 | 359 | 214 | 0 | 0 | 0 | |
| Reconstructed CHP units | | | 0 | 224 | 411 | 664 | 553 | 553 | |
| **CHP Source 1 total (net)** | | 625 | 606 | 583 | 625 | 664 | 553 | 553 | |
| **CHP Source 2** | | | | | | | | | |
| Gross | | 36 | 20 | 20 | 20 | 20 | 0 | 0 | 0 |
| Own consumption | | 9 | 5 | 5 | 5 | 5 | 0 | 0 | 0 |
| Net | | 27 | 14 | 14 | 14 | 14 | 0 | 0 | 0 |
| ***Total*** | | **652** | **621** | **598** | **640** | **678** | **983** | **996** | **1 624** |
| ***Gas consumption*** | | | | | | | | | |
| **Gas engines** | 1000 Gcal/a | 0 | 0 | 0 | 0 | 0 | 814 | 849 | 778 |
| | 1000 $m^3$/a | 0 | 0 | 0 | 0 | 0 | 99 689 | 103 934 | 95 265 |
| **CCGT** | 1000 Gcal/a | | | | | | | | 2 312 |
| | 1000 $m^3$/a | | | | | | | | 283 024 |
| **CHP Source 1** | 1000 Gcal/a | 2 287 | 2 182 | 2 077 | 2 148 | 2 161 | 1 829 | 1 829 | |
| | 1000 $m^3$/a | 279 948 | 267 050 | 254 217 | 262 880 | 264 489 | 223 890 | 223 890 | |
| **CHP Source 2** | 1000 Gcal/a | 214 | 127 | 127 | 127 | 127 | 0 | 0 | 0 |
| | 1000 $m^3$/a | 26 139 | 15 562 | 15 562 | 15 562 | 15 562 | 0 | 0 | 0 |
| **CHP Source 1 HOB** | 1000 Gcal/a | 0 | 63 | 92 | 37 | 17 | 54 | 47 | 113 |
| | 1000 $m^3$/a | 0 | 7 694 | 11 219 | 4 476 | 2 094 | 6 618 | 5 790 | 13 852 |
| **HOB West** | 1000 Gcal/a | 215 | 220 | 220 | 220 | 220 | 118 | 118 | 118 |
| | 1000 $m^3$/a | 26 284 | 26 930 | 26 930 | 26 930 | 26 930 | 14 411 | 14 411 | 14 411 |
| **HOB South** | 1000 Gcal/a | 166 | 163 | 163 | 163 | 163 | 164 | 150 | 150 |
| | 1000 $m^3$/a | 20 273 | 20 001 | 20 001 | 20 001 | 20 001 | 20 042 | 18 397 | 18 397 |
| ***Total*** | **1000 Gcal/a** | **2 881** | **2 755** | **2 679** | **2 695** | **2 689** | **2 979** | **2 994** | **3 472** |
| | **1000 $m^3$/a** | **352 643** | **337 238** | **327 930** | **329 849** | **329 076** | **364 651** | **366 422** | **424 950** |
| **Total efficiency (net)** | | **77 %** | **80 %** | **81 %** | **82 %** | **84 %** | **84 %** | **84 %** | **88 %** |

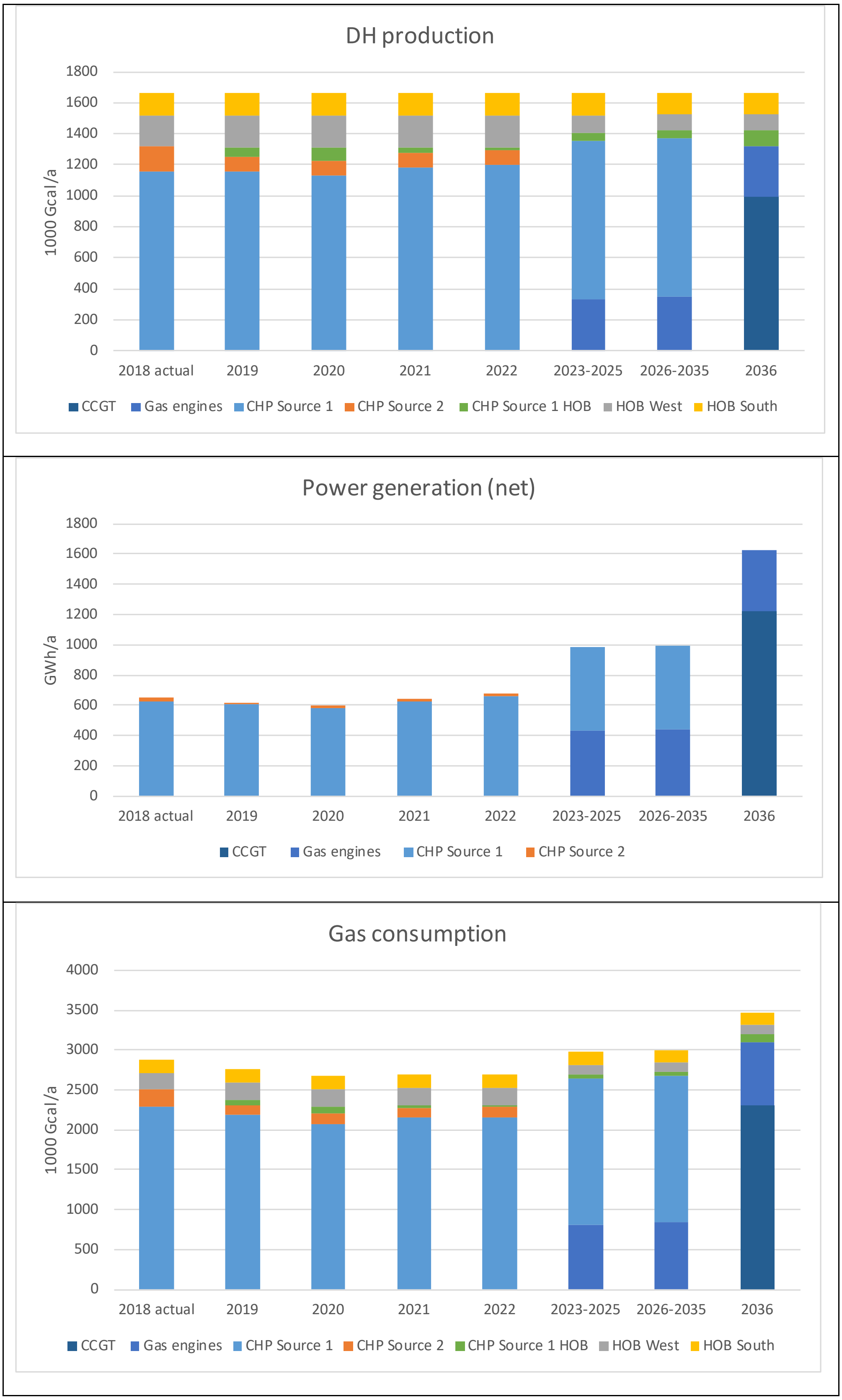


**Figure 14 DH and power production and gas consumption.**

The heat and power generation and fuel consumption of the gas engine plants at different sites are presented in Table 16.

**Table 16 Heat and power generation and fuel consumption of the gas engine plants at different sites.**

| Heat and power production and fuel consumption of gas engines | | | | | |
|---|---|---|---|---|---|
| **Year** | | **2022** | **2023-2025** | **2026-2035** | **2036** |
| **Source 3** | | | | | |
| District heat production | 1000 Gcal/a | 0 | 143 | 143 | 115 |
| Power generation | | 0 | 0 | 0 | 0 |
| Gross | GWh/a | 0 | 196 | 196 | 156 |
| Own consumption | GWh/a | 0 | 9 | 9 | 7 |
| Net | GWh/a | 0 | 187 | 187 | 149 |
| Fuel consumption | 1000 Gcal/a | 0 | 352 | 352 | 281 |
| | 1000 $m^3$/a | 0 | 43 096 | 43 096 | 34 427 |
| **West Boiler Plant** | | | | | |
| District heat production | 1000 Gcal/a | 0 | 190 | 180 | 180 |
| Power generation | | 0 | 0 | 0 | 0 |
| Gross | GWh/a | 0 | 255 | 240 | 240 |
| Own consumption | GWh/a | 0 | 12 | 11 | 11 |
| Net | GWh/a | 0 | 243 | 229 | 229 |
| Fuel consumption | 1000 Gcal/a | 0 | 462 | 436 | 436 |
| | 1000 $m^3$/a | 0 | 56 593 | 53 350 | 53 350 |
| **South Boiler Plant** | | | | | |
| District heat production | 1000 Gcal/a | 0 | 0 | 29 | 29 |
| Power generation | | 0 | 0 | 0 | 0 |
| Gross | GWh/a | 0 | 0 | 29 | 29 |
| Own consumption | GWh/a | 0 | 0 | 1 | 1 |
| Net | GWh/a | 0 | 0 | 28 | 28 |
| Fuel consumption | 1000 Gcal/a | 0 | 0 | 61 | 61 |
| | 1000 $m^3$/a | 0 | 0 | 7 488 | 7 488 |
| **Gas engines total** | | | | | |
| District heat production | 1000 Gcal/a | 0 | 333 | 352 | 323 |
| Power generation | | 0 | 0 | 0 | 0 |
| Gross | GWh/a | 0 | 452 | 465 | 426 |
| Own consumption | GWh/a | 0 | 22 | 22 | 20 |
| Net | GWh/a | 0 | 430 | 443 | 405 |
| Fuel consumption | 1000 Gcal/a | 0 | 814 | 849 | 778 |
| | 1000 $m^3$/a | 0 | 99 689 | 103 934 | 95 265 |

The electricity consumption of heat-only-boiler plants and pumping stations is presented in Table 17. Electricity consumption of pumping stations has been received from Termoelectrica and it has been assumed to stay at the same level.

**Table 17 Electricity consumption of heat-only-boiler plants and pumping stations.**

| Electricity consumption | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | | | **2019** | **2020** | **2021** | **2022** | **2023-2025** | **2026-2035** | **2036** |
| **Electricity consumption** | GWh/a | | | | | | | | |
| CHP Source 1 HOB | | | 2,2 | 3,2 | 1,3 | 0,6 | 1,9 | 1,7 | 3,9 |
| HOB West | | | 7,7 | 7,7 | 7,7 | 7,7 | 4,1 | 4,1 | 4,1 |
| HOB South | | | 7,6 | 7,6 | 7,6 | 7,6 | 7,6 | 7,0 | 7,0 |
| Pumping stations | | | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| **Total** | | | **37** | **38** | **36** | **35** | **33** | **32** | **34** |

District heat delivery to the main network and net power generation before installation of gas engines are presented graphically in Figure 15 and after installation gas engines in Figure 16. Maintenance periods and unreliability are not shown in the graphics.

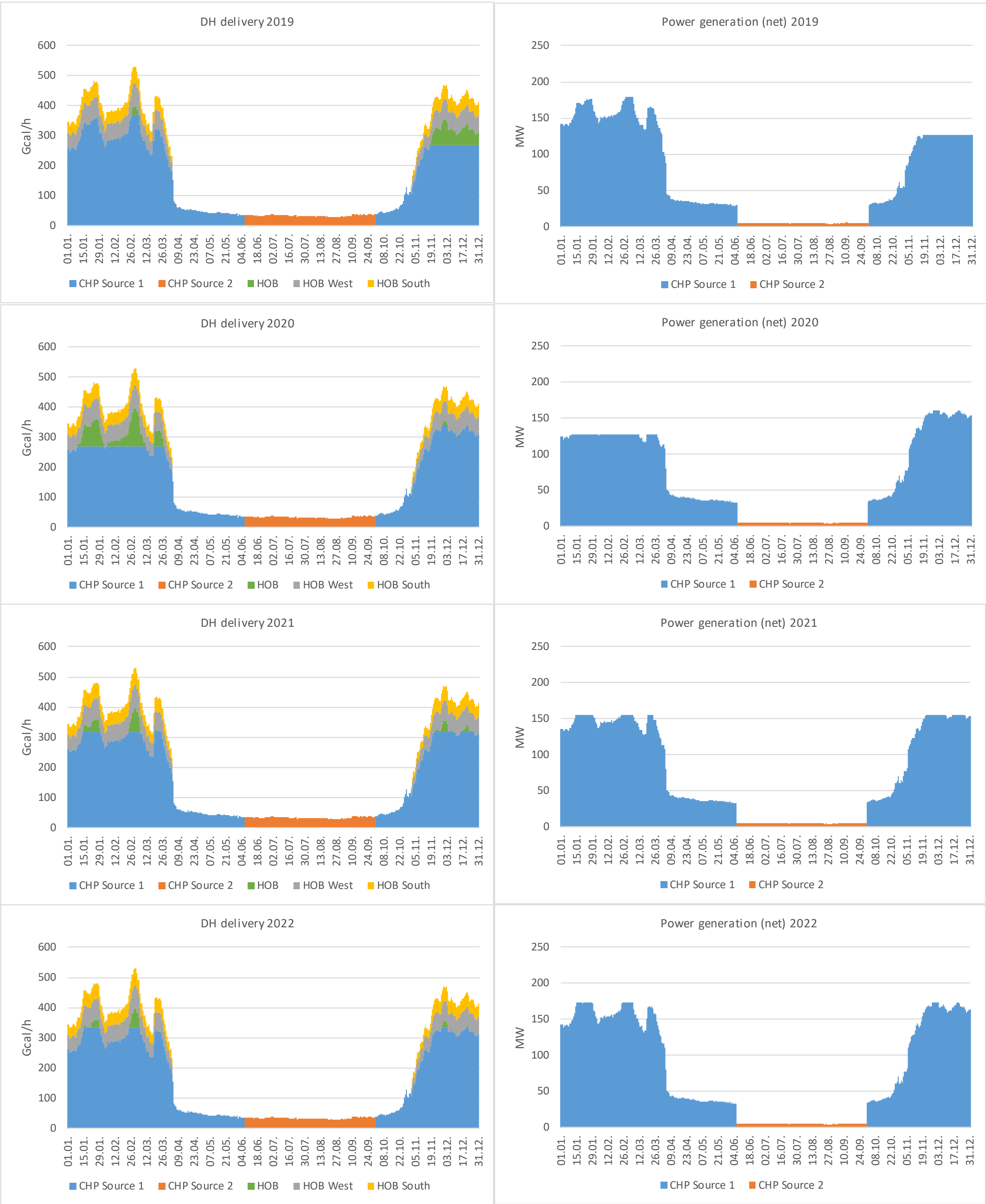


**Figure 15 District heat delivery to the main network and net power generation before installation of gas engines.**

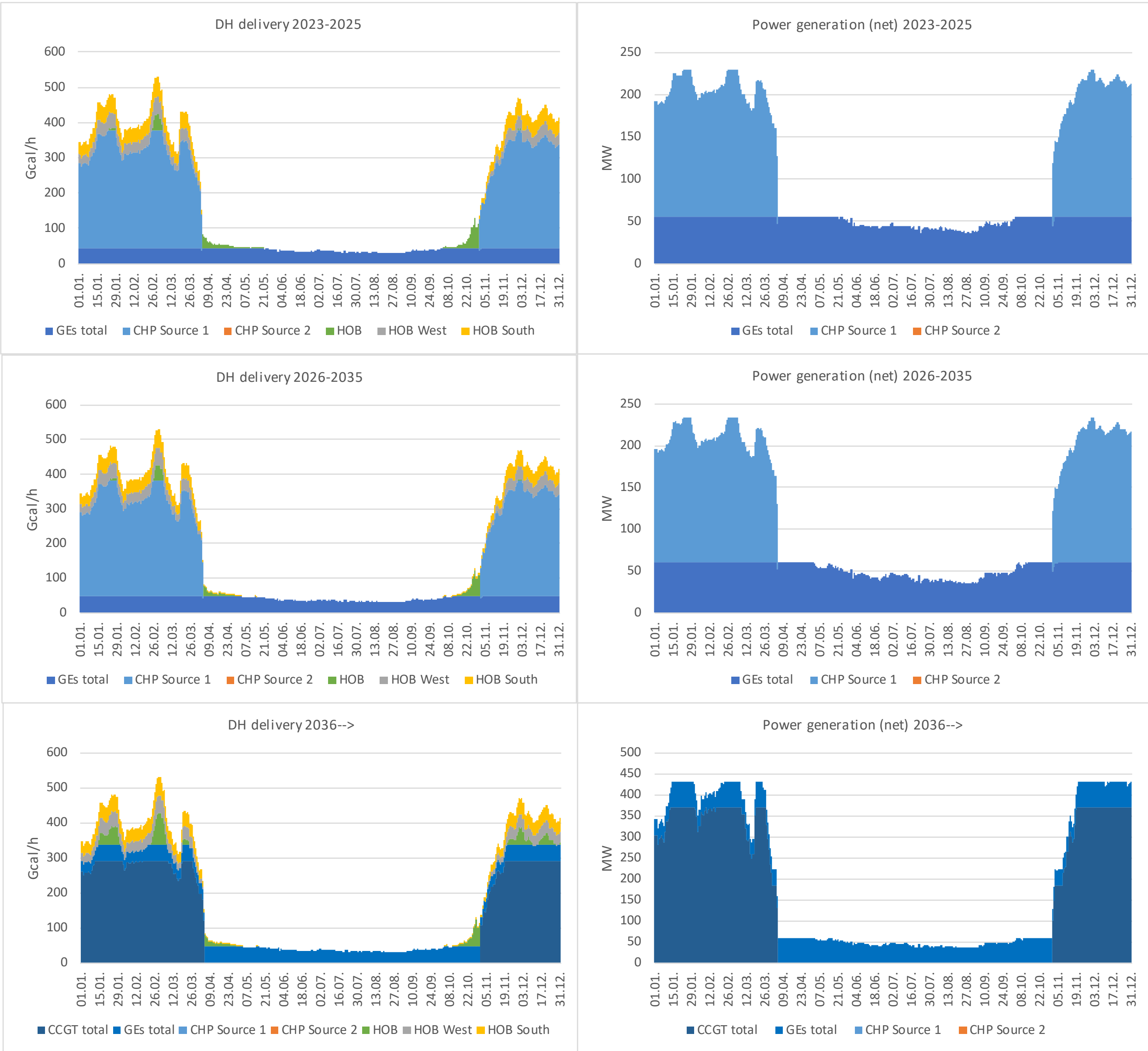


**Figure 16 District heat delivery to the main network and net power generation after installation of gas engines.**

In addition, the energy balances have been calculated in several different situations with different number of gas engines.

## 8 $CO_2$ emissions

The following emission factors have been used in this report

1. Emission factor – gas, $tCO_2/MWh_{fuel}$: 0.2008[2]
2. Emission factor –electricity, $tCO_2/MWh_{el}$: 0.43[3]

The emission factor for natural gas combustion has been calculated based on WB's methodology presented in "Calculation tool for direct emissions from stationary combustion, Version 3.0, July 2005" (https://ghgprotocol.org/sites/default/files/Stationary_Combustion_Guidance_final_1.pdf).

The emission factor for grid electricity is based on "The IFI (Interim) Dataset of Harmonized Grid Factors (Version 1.0)": Combined margin.

Emissions based on electricity describe the $CO_2$ emission changes due to electricity generation, i.e. if more electricity is produced by own power plants, less electricity needs to be purchased from the grid and the amount of emissions decreases.

Emissions based on gas describe the $CO_2$ emissions resulting directly from the gas combustion.

The $CO_2$ emissions are presented in Table 18 and in Figure 17.

**Table 18 $CO_2$ emissions.**

| $CO_2$ emissions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | | **2019** | **2020** | **2021** | **2022** | **2023-2025** | **2026-2035** | **2036** |
| **$CO_2$ emissions** | | | | | | | | |
| From fuel | t/a | 643 444 | 625 684 | 629 346 | 627 872 | 695 747 | 699 127 | 810 796 |
| From electricity savings | t/a | -251 131 | -240 771 | -259 670 | -276 689 | -408 691 | -414 670 | -683 738 |
| **Total** | **t/a** | **392 313** | **384 913** | **369 676** | **351 183** | **287 057** | **284 457** | **127 058** |
| **$CO_2$ difference to 2019** | **t/a** | **0** | **-7 400** | **-22 637** | **-41 130** | **-105 256** | **-107 855** | **-265 255** |

[2] Calculation tool for direct emissions from stationary combustion (Version 3.0, July 2005), https://ghgprotocol.org/sites/default/files/Stationary_Combustion_Guidance_final_1.pdf

[3] Source: The IFI (Interim) Dataset of Harmonized Grid Factors (Version 1.0); Combined margin

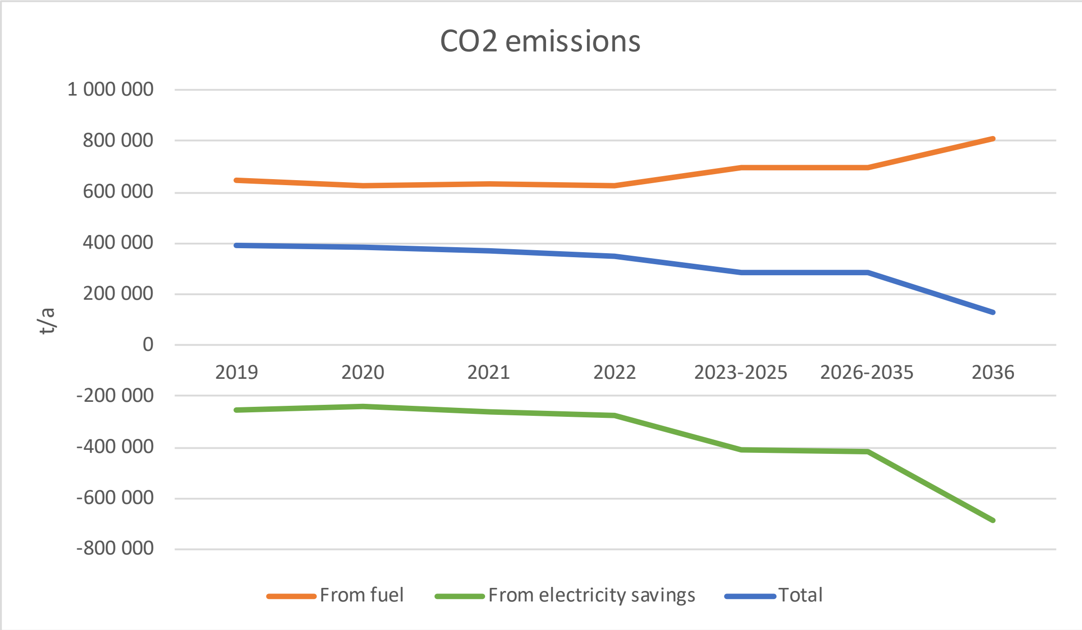


**Figure 17 $CO_2$ emissions.**

As shown above, the direct fuel-based $CO_2$ emissions will increase due to installation of new capacity, but the total emissions will decrease due to reduced demand of electricity from other sources though the grid.

# 9 Investment costs of generation assets

The investment cost estimates are based on the assumption that the new CHP plants will be built as EPC projects. The EPC prices of the gas engine plants have been estimated based on the information received from the equipment suppliers. Correspondingly, the EPC price of the CCGT plant has been estimated based on the Consultant's experience on similar projects.

The total investment costs consist of

- reconstruction of Units 1 and 2 of CHP Source 1[4]
- major overhaul of Unit 3 of CHP Source 1[5]
- new gas engine plants[6]
- power transformers at HOB West, if gas engine(s) are located there[7]
- power facility / ID-110 kV at CHP Source 3 and HOB West, if gas engine(s) are located there[8]

The investment estimate is based on present price level. Cost increases during the development and construction periods have not been applied and the prices are exclusive of VAT.

The specific investment costs (USD/MW) of gas engine plants depend strongly on the number of engines to be installed at the same site. The estimated investment costs of different number of gas engines based on information received from Wärtsilä is presented in Table 19. This information has been used, when different location alternatives have been compared (discussed below).

**Table 19 Gas engine plant investment costs.**

| Investment costs of 11 $MW_e$ gas engine plants (MUSD) | |
|---|---|
| 1 engine | 16,1 |
| 2 engines | 28,0 |
| 3 engines | 35,7 |
| 4 engines | 47,4 |
| 5 engines | 58,1 |

The summary of the investment costs of the recommended alternative is presented in Table 20.

- Reconstruction of Unit 1 and Unit 2 of CHP Source 1
- Major overhaul of Unit 3 of CHP Source 1
- Two 11 $MW_e$ gas engines at CHP Source 3
- Three 11 $MW_e$ gas engines at HOB West
- One 4 $MW_e$ gas engines at HOB South

[4] Source: Termoelectrica
[5] Source: Termoelectrica
[6] Source: equipment suppliers
[7] Source: Termoelectrica
[8] Source: Termoelectrica

**Table 20 Investment costs**

| Investment costs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Short-term | | | | Mid-term | Long-term | Year of investment |
| | | CHP Source 1 | CHP Source 3 | HOB West | Other | HOB South | | |
| **Existing units** | | | | | | | | |
| Reconstruction of Unit 1 of CHP Source 1 | MUSD | 12 | | | | | | 2019-2020 |
| Reconstruction of Unit 2 of CHP Source 1 | MUSD | 12 | | | | | | 2021 |
| Major overhaul of Unit 3 of CHP Source 1 | MUSD | 4,2 | | | | | | 2022 |
| **New CHP capacity** | | | | | | | | |
| Project management(1 | MUSD | | 2 | | | | | 2021-2022 |
| Design and Bidding documents for gas engine plants, supervision of installation(1 | MUSD | | 1,5 | | | | | |
| Power transformers | MUSD | | | 2,3 | | 0,4 | | 2021-2022 |
| Power facility/ ID-110 kV | MUSD | | 1,7 | 2,3 | | 0,4 | | 2021-2022 |
| 11 MW$_e$ gas engines plants | MUSD | | 28 | 35,7 | | | | 2021-2022 |
| 4 MW$_e$ gas engine plant | MUSD | | | | | 4,8 | | 2025 |
| CCGT plant | MUSD | | | | | | 336 | 2032-2035 |
| **Other(2** | | | | | | | | |
| Management Information System | MUSD | | | | 3 | | | 2021-2023 |
| Hydraulic model | MUSD | | | | 0,3 | | | 2020 |
| Pilot energy efficiency investments | MUSD | | | | 7 | | | 2021-2023 |
| **TOTAL** | | **28,2** | **33,2** | **40,3** | **10,3** | **5,6** | **336** | |

(1Total for CHP Source 3 and HOB West

(2Not related only to generation assets

# 10 Termoelectrica's Investment Strategy

## 10.1 General

The Short-Term, Mid-Term and Long-Term investment programme is an affordable package of activities specifically intended to:

- Improve the efficiency, flexibility and reliability of heat supply to consumers.
- Ensure the "summer operation" for Domestic Hot Water production on the cost level affordable for the consumers.
- Increase the efficiency of the heat and electricity production.
- Reduce maintenance costs, fuel, electricity and water consumption thereby reducing operating costs.
- Ensure and maximize the heat production in CHP mode, when technically and economically feasible.
- Ensure and maximize the electricity production, when technically and economically feasible.

For each of the components selected, reasonable estimates of quantities and costs based on applicable previous bidding experience in the country have been prepared. Potential cost savings upon implementation of the Project have been identified and estimated. A review of operational costs has been prepared and costs specified as either fixed or variable for each component.

## 10.2 Strategy for Consumer connections

- Convert the current open district heating network to modern closed system. It requires separation of the consumer's building level space heating system from District Heating Network via Individual Heat Substations.
- Provide possibility to the Consumers to control and regulate the use of heat.
- Provide possibility to the Consumers to benefit from own demand side Energy Efficiency Investment

At the moment circa 770 connections are via modern Individual Heat Substations (IHS) installed in buildings. Circa 4 600 connections, including 339 single-family houses, are connected via Central Heat Substations or directly with or without hydro-elevators.

The Investment Plan is to install 160 IHSs on yearly basis, starting year 2023.

# 11 Investment scenarios

Three investment scenarios have been identified:

- Scenario no 1: Rehabilitation of CHP Source 1 Unit 1 / No other investments
- Scenario no 2: Rehabilitation of CHP Source 1 Unit 1 and Unit 2
- Scenario no 3: Rehabilitation of CHP Source 1 Unit 1 and Unit 2, major overhaul for Unit no 3 and Installation of Gas Engines

The scenarios are described below.

## 11.1 Scenario 1: Rehabilitation of CHP Source 1 Unit 1 / No other investments

- No additional investment at CHP Source 1 (beyond reconstruction of Unit 1 to be completed in 2020)
- Unit 2 will be closed year 2020 and Unit no 3 in 2021.
- CHP Source 2 to be closed
- CHP Source 1 electricity production will drop by 43%, from 547 GWh to 311 GWh.
- Heat tariff impact: required increase of 14% immediately for heat.
- Risk of "death spiral": high tariffs, poor service leading to disconnections, resulting in lower volume to absorb fixed costs.

The variations of heat and electricity production are shown below.

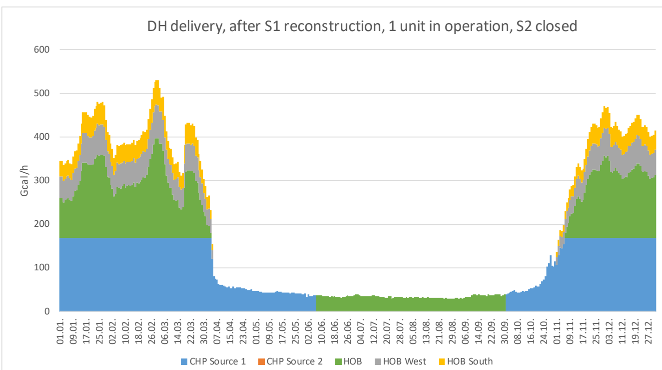


**Figure 18 DH delivery, after S1 reconstruction, 1 unit in operation, S2 closed**

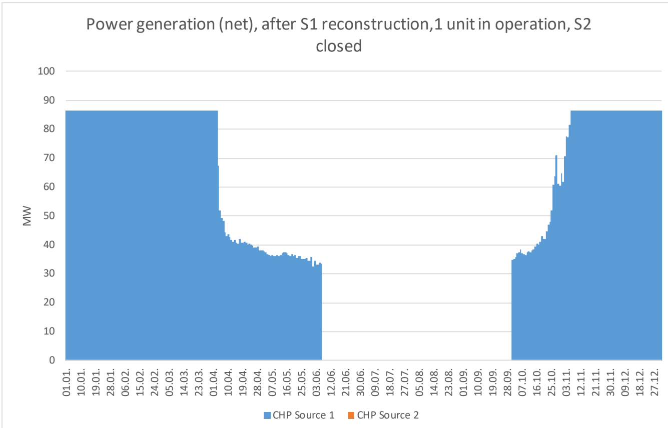


**Figure 19 Power generation, after S1 reconstruction, 1 unit in operation, S2 closed**

The advantages/disadvantages of scenario no 1 "Without the project" are:

- Doesn't improve the flexibility and reliability of heat supply to consumers.
  - Limited redundancy, reduced reliability of heat supply (particularly during coldest periods) and electricity supply, considering the aging production equipment
- Doesn't ensure the "Summer operation" for Domestic Hot Water production on the cost level affordable for the consumers.
  - Increased heat tariff – negative social and economic impact, discouraging consumers and preventing development of the company
- Doesn't increase the efficiency of the heat and electricity production.
- Doesn't reduce "summer operation" costs for Domestic Hot Water production
- Doesn't decrease $CO_2$ emissions
  - $CO_2$ emissions increase 0,7%, from 392 313 ton/year up to 395 196 ton /year
- Overall system optimization: Doesn't reduce unit costs of maintenance, fuel, electricity and water consumption thereby Doesn't reduce operating costs.
- Doesn't ensure and maximize the heat production in cogeneration mode, when technically and economically feasible.
  - Heat consumption produced in cogeneration mode decreases 40,9%, from 1 254 000 Gcal/year down to 741 000 Gcal/year.
  - Heat produced in HOB mode increases 125%, from 411 000 Gcal/year up to 924 000 Gcal/year.
  - Reduced use of cogeneration: need to use 2 available PTVM-100 HOBs at CHP Source 1 (currently operational but needing major overhaul for reliable operation).
- Doesn't ensure and maximize the electricity production, when technically and economically feasible.
  - Net electricity production decreases 33,7%, from 621 000 MWh/year down to 411 000 MWh/year.
  - Considerably reduced available electricity production capacity in the country – increased risks for energy security of the country

**Conclusion:**

**Scenario no 1: Rehabilitation of CHP Source no 1 Unit 1, no other investments Scenario, doesn't meet any of Investment strategy targets.**

The alternative will lead to Risk of "death spiral": high tariffs, poor service leading to disconnections, resulting in lower volume to absorb fixed costs**.**

**In Summary: Scenario no 1 is not a feasible OPTION**

## 11.2 Scenario 2: "Rehabilitation of CHP Source no1 Unit 1 and Unit 2"

- Reconstruction of Unit no 1 to be completed in 2020
- Reconstruction of Unit no 2
- Overhaul of Unit no 3
- CHP Source 2 to be closed

The variations of heat and electricity production are shown below.

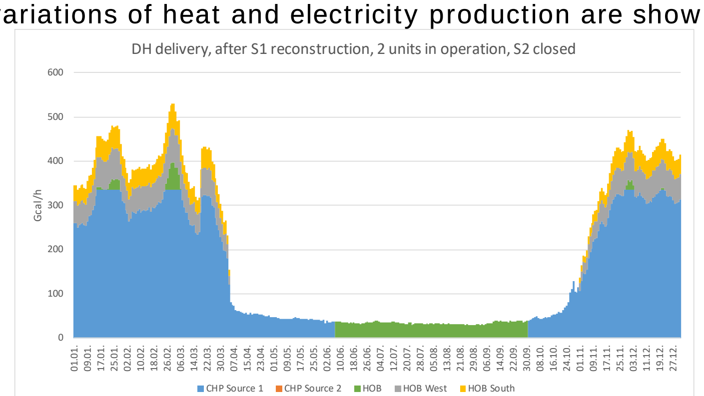


**Figure 20 DH delivery, after S1 reconstruction, 2 units in operation, S2 closed**

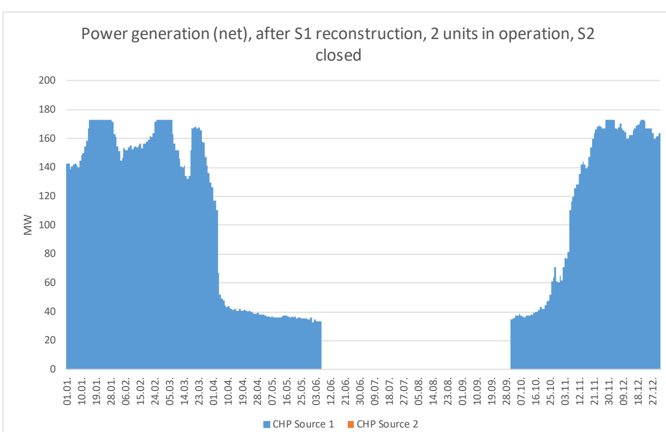


**Figure 21 Power generation, after S1 reconstruction, 2 units in operation, S2 closed**

The advantages/disadvantages of alternative no 2 “Rehabilitation of CHP Source no1 Unit 1 and Unit 2 Scenario” are:

- Doesn’t improve the flexibility and reliability of heat supply to consumers.
    - Limited redundancy, reduced reliability of heat supply (particularly during coldest periods) and electricity supply, considering the aging production equipment
- Doesn’t ensure the “Summer operation” for Domestic Hot Water production on the cost level affordable for the consumers.
    - Increased heat tariff – negative social and economic impact, discouraging consumers and preventing development of the company
- Doesn’t increase the efficiency of the heat and electricity production.
- Doesn’t reduce “summer operation” costs for Domestic Hot Water production
- Doesn’t change $CO_2$ emissions
    - CO2 emissions decreases 9,8%, from 392 313 ton/year up to 353 878 ton /year
- Overall system optimization: Doesn’t reduce unit costs of maintenance, fuel, electricity and water consumption thereby Doesn’t reduce operating costs.
    - Heat produced in HOB mode increases 13,1%, from 411 000 Gcal/year up to 465 000 Gcal/year.
- Doesn’t ensure and maximize the heat production in cogeneration mode, when technically and economically feasible.
    - Heat consumption produced in cogeneration mode decreases 4,3%, from 1 254 000 Gcal/year down to 1 200 000 Gcal/year.
- Doesn’t ensure and maximize the electricity production, when technically and economically feasible.
    - Net electricity production increases 6,9%, from 621 000 MWh/year up to 664 000 MWh/year.

**Conclusion**

**Scenario no 2: “Rehabilitation of CHP Source no1 Unit 1 and Unit 2 Scenario, doesn’t meet Investment strategy targets.**

The alternative will lead to Risk of “death spiral”: high tariffs, poor service leading to disconnections, resulting in lower volume to absorb fixed costs.

**In Summary: Scenario no 2 is not feasible OPTION**

## 11.3 Scenario 3: “Rehabilitation of CHP Source 1 Unit 1 and Unit 2 and Installation of Gas Engines”

- Reconstruction of Unit 1 to be completed in 2020
- Reconstruction of Unit 2
- Major Overhaul of Unit 3
- Installation of Gas Engines
- CHP Source 2 to be closed

**Background:**

In order to identify an optimal solution/option for installation of new gas engine cogeneration units at Termoelectrica facilities, technical aspects were analyzed for installing/placing the new units on the territory of existing generation sources/plants, sized for the summer heat load of the DH system.

The following criteria were used for analyzing the installation options for new gas engine units:

- Total investment cost;
- Impact on the amount of heat produced in cogeneration;
- Impact on the amount of produced electricity;
- Impact on the flexibility and reliability of heat supply to consumers (heat sales);
- Extent to which the gas engine units will cover the summer/warm season heat load;
- Opportunities of using electrical and other infrastructure.

The selection of options for further analysis was based on e.g. local conditions and technical constraints at different sites identified by Termoelectrica, such as

- available space for the new units
- hydraulic limitations of the DH system
- electricity transmission capacities / available connections
- amount electricity and cogeneration heat production
- reliability

**The variations of heat and electricity production are shown below.**

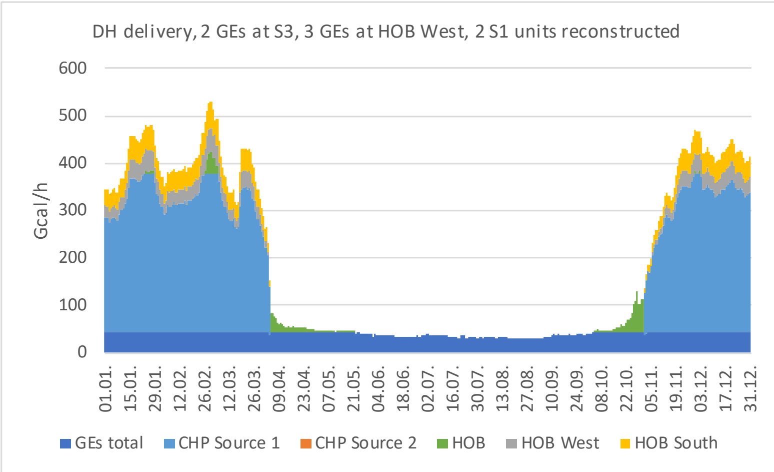


**Figure 22 DH delivery, 2 GEs at S3, 3 GEs at HOB West, 2 S1 units reconstructed**

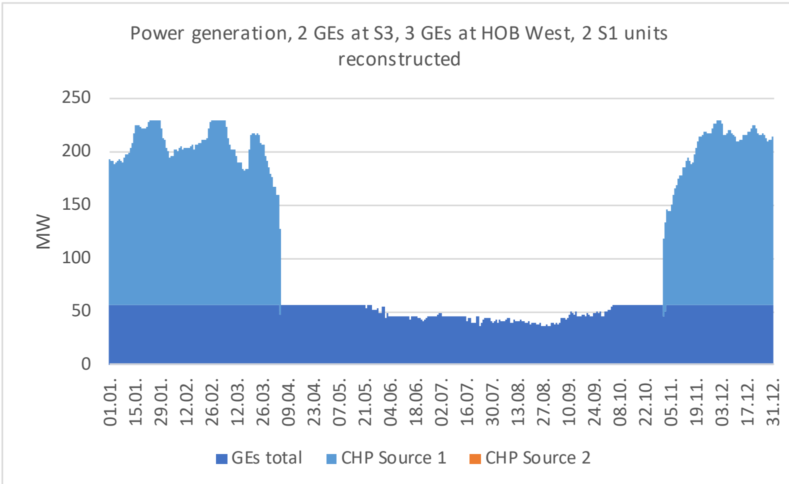


**Figure 23 Power generation, 2 GEs at S3, 3 GEs at HOB West, 2 S1 units reconstructed**

The advantages/disadvantages of alternative no 3 ""Rehabilitation of CHP Source 1 Unit 1 and Unit 2 and installation of Gas Engines Scenario" are:

- o Scenario no 3 improves the flexibility and reliability of heat supply to consumers.
  - Improves reliability of heat supply (particularly during summer period) and electricity supply
- o Ensures the "Summer operation" for Domestic Hot Water production on the cost level affordable for the consumers.
  - Decreased heat tariff – positive social and economic impact
- o Increases the efficiency of the heat and electricity production.
- o Reduces "summer operation" costs for Domestic Hot Water production
- o Increases fuel efficiency of the heat and electricity production
- o Decreases $CO_2$ emissions
  - $CO_2$ emissions decrease 26,8%, from 392 313 ton/year down to 287 057 ton /year
- o Overall system optimization: Reduces unit costs of maintenance, fuel, electricity and water consumption thereby reduces operating costs.
  - Heat produced in HOB mode decreases 25,0%, from 411 000 Gcal/year down to 308 000 Gcal/year
- o Ensures and maximizes the heat production in cogeneration mode, when technically and economically feasible.
  - Heat consumption produced in cogeneration mode increases 8,2%, from 1 254 000 Gcal/year up to 1 357 000 Gcal/year.
- o Ensures and maximizes the electricity production.
  - Net electricity production increases 58,4%, from 621 000 MWh/year up to 983 000 MWh/year.
  - Considerably increases available electricity production capacity in the country – decreased risks for energy security of the country

**Conclusion:**

| |
|---|
| **Scenario no 3: "Rehabilitation of CHP Source 1 Unit 1 and Unit 2, Major Overhaul for Unit 3 and Installation of 2 Gas Engines at CHP Source 3 and 3 Gas Engines at HOB West" Scenario, meets all of Investment strategy targets.**<br><br>**In Summary: Scenario no 3 is a feasible OPTION** |

# 12 Investment Plan (2019 – 2035)

## 12.1 Short-Term Investment Plan (2019 – 2023)

The Short-Term Investment Plan based on the selected alternative as described above includes the following components:

- Implementation of new modern Hydraulic Model system for District Heating Network simulation and optimization of operation.
- Reconstruction of Units no 1 and no 2 at CHP Source 1
- Major Overhaul for Turbine no 3 and Boiler no 3 at CHP Source no 1
- Construction of new CHP units (Gas Engines), total capacity 55 $MW_e$ and 43 Gcal/h heat.
- Installation of power transformers at HOB West and Installation of switchgear ID-110 kV at CHP Source 3 and HOB West
- Pilot Energy Efficiency investment programme
- Technical assistance for a modern comprehensive Management Information System
- Continuation of programme to replace systematically outdated District Heating pipelines (Dual pipe 3,4 km per year), starting year 2023.
- Continuation of programme to install Individual Heat Substations for all consumers (160 units per year), starting year 2023.

**Table 21 Short-Term Investment Plan**

| No. | Component / Contract | mln USD | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| | | | Short - Term Investment needs | | | | |
| | | | Estimated Cost, MUSD | | | | |
| **1** | Hydraulic Modelling of the District Heating Network, delivering the Model and training of the Client | 0,3 | | 0,30 | | | |
| 2 | Reconstruction of CHP Source 1, Unit 1 | 12,0 | 2,22 | 2,88 | 2,88 | 2,88 | 1,14 |
| 3 | Reconstruction of CHP Source 1, Unit 2 | 12,0 | | 1,20 | 8,40 | 2,40 | |
| 4 | Major Overhaul of CHP Source 1, Turbine 3 and Boiler 3 | 4,2 | | | | 4,20 | |
| 5 | Construction of new CHP units (Gas Engines), total capacity 55 $MW_e$ and 43 Gcal/h heat | 63,7 | | 6,37 | 50,96 | 6,37 | |
| 6 | Installation of power transformers at HOB West and Installation of switchgear ID-110 kV at CHP Source 3 and HOB West | 6,3 | | | 0,63 | 5,04 | 0,63 |
| 7 | Pilot Energy Efficiency investment programme | 7,0 | | | 0,70 | 2,80 | 3,50 |
| 8 | Project Management | 2,0 | | | 0,40 | 1,20 | 0,40 |
| 9 | Technical assistance for a modern comprehensive Management Information System | 3,0 | | | 0,60 | 1,80 | 0,60 |
| 10 | Technical Supervision for Sub-components | 1,5 | | 0,15 | 0,60 | 0,60 | 0,15 |
| 11 | Rehabilitation of District Heating Network 3,4 km (dual pipe). | 4,7 | | | | | 4,7 |
| 12 | Installation of Individual Heat Substations in buildings, 160 units | 2,9 | | | | | 2,9 |
| | **TOTAL** | **119,6** | **2,22** | **10,90** | **65,17** | **27,29** | **14,02** |

The estimated investment needs for 2019 – 2023 years are **USD 119,6** million.

## 12.2 Mid-Term Investment Plan (2024 – 2030)

The Mid-Term Investment Plan includes following components:

- Major Overhaul for Turbine no 3 at CHP Source 1. It has been assumed that Major Overhaul shall be revised always after 25 000 operation hours.
- Construction of new CHP unit (Gas Engine) for HOB South area, total capacity 4.6 $MW_e$ and 4.5 Gcal/h heat.
- Continuation of programme to replace systematically outdated District Heating pipelines 23,0 km (dual pipe)
- Continuation of programme to install Individual Heat Substations for all consumers (1120 units)

**Table 22 Mid-term Investment Plan**

| No. | Component / Contract | mln USD | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mid - Term Investment needs | | | | | | |
| | | | Estimated Cost, MUSD | | | | | | |
| 1 | Construction of new Gas Engine at HOB South | 4,8 | | 4,8 | | | | | |
| 2 | Rehabilitation of District Heating Network, 23,0 km (dual pipe) | 31,4 | 4,7 | 4,7 | 4,7 | 4,7 | 4,2 | 4,2 | 4,2 |
| 3 | Installation of Individual Heat Substations in buildings, 1120 units | 20,3 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 |
| | **TOTAL** | **60,7** | **7,6** | **12,4** | **7,6** | **11,8** | **7,1** | **7,1** | **7,1** |

The estimated investment needs for 2024 – 2030 years are **USD 60,7** million.

## 12.3 Long-Term Investment Plan (2031 – 2035)

The Long-Term Investment Plan includes the following components:

- Investment of a new CCGT after closure of CHP Source 1
- Continuation of programme to replace systematically outdated District Heating pipelines 14,0 km (dual pipe)
- Continuation of programme to install Individual Heat Substations for all consumers (800 units)

**Table 23 Long Term Investment Plan**

| No. | Component / Contract | mln USD | 2031 | 2032 | 2033 | 2034 | 2035 |
|---|---|---|---|---|---|---|---|
| | | | Long -Term Investment needs | | | | |
| | | | Estimated Cost, MUSD | | | | |
| 1 | Rehabilitation of District Heating Network 14,0 km (dual pipe) | 18,4 | 4,2 | 4,2 | 3,3 | 3,3 | 3,3 |
| 2 | Installation of Individual Heat Substations in buildings, 800 units | 14,5 | 2,9 | 2,9 | 2,9 | 2,9 | 2,9 |
| 3 | Construction of New CCGT CHP Plant, gross 388 $MW_e$, net 370 $MW_e$, Heat output 291 Gcal/h | 336,0 | | 84,0 | 84,0 | 84,0 | 84,0 |
| | **TOTAL** | **368,9** | **7,1** | **91,1** | **90,2** | **90,2** | **90,2** |

The estimated investment needs for 2031 – 2035 years are **USD 368,9** million.

**In Summary, the Investment needs for 2019 to 2035 are heavy, totally USD 549,2 million.**

# 13 Economic analysis

## 13.1Economic – Technical Model

The structure of the Economic and Technical Model is shown below.

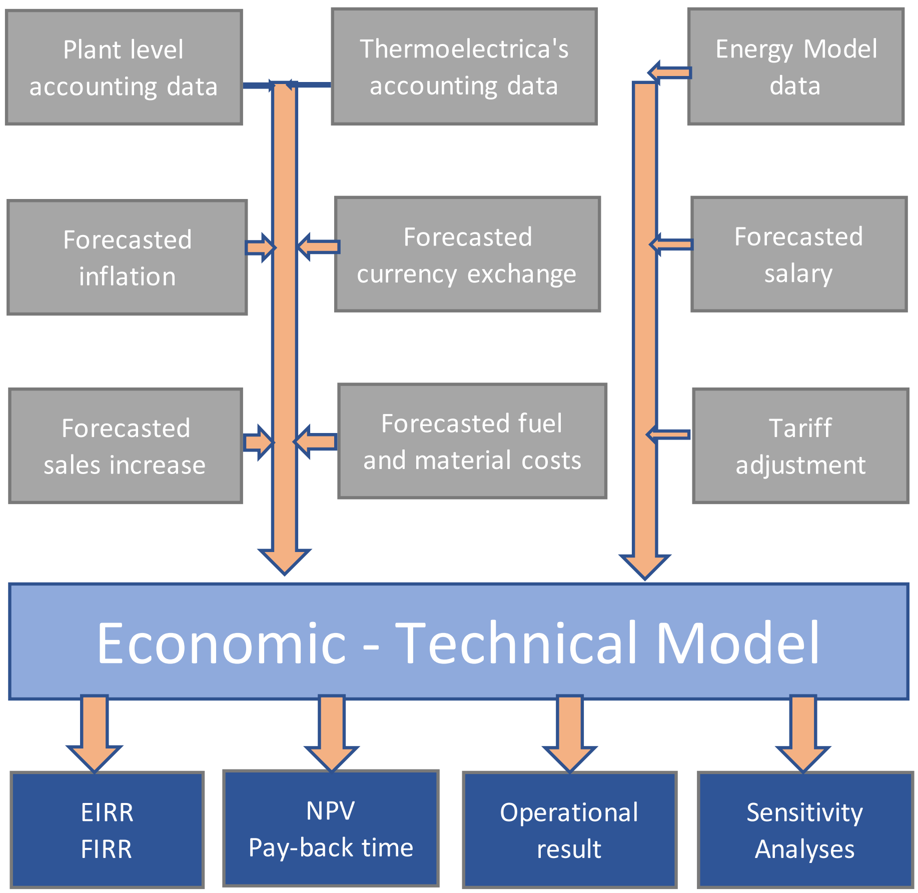


**Figure 24 Structure of Economic – Technical model**

## 13.2 General

The Consultant has selected below presented options for future evaluation in cooperation with Termoelectrica. The selected options meet the criteria of the Company's Energy strategy.

- Option: Unit 1 and Unit 2 at CHP Source 1 are reconstructed, two Gas Engines at CHP Source 3, three Gas Engines at HOB West
- Option: Unit 1 and Unit 2 at CHP Source 1 are reconstructed, five Gas Engines at CHP Source 3
- Option: Unit 1 and Unit 2 at CHP Source 1 are reconstructed, four Gas Engines at CHP Source 3, one Gas Engine at HOB West

Summary findings are presented in this chapter.

## 13.3 Investment costs of different options

**Table 24 Investment costs of Options without consulting services**

| Option | Cost in mln. USD | CHP Source 1 | CHP Source 3 | Gas Engines at HOB West | Gas Engine at HOB South |
|---|---|---|---|---|---|
| "Option: 2 Gas Engines at Source 3, 3 Gas Engines at HOB West" | **98,2** | 28,2 | 29,7 | 40,3 | 0,0 |
| "Option: 5 Gas Engines at Source 3, no Gas Engine at HOB West and no Gas Engine at HOB South" | **88,0** | 28,2 | 59,8 | 0,0 | 0,0 |
| "Option: 4 Gas Engines at Source 3, 1 Gas Engine at HOB West and no Gas Engine at HOB South" | **98,0** | 28,2 | 49,1 | 20,7 | 0,0 |

## 13.4 Operation and maintenance costs

The operating and maintenance (O&M) costs used in this study are based on the actual costs of similar types of power plants with similar operation structure. The costs include e.g. the following items:

- Materials, replacement parts
- Lubricants
- Purchased services
- Insurances
- Reserve for replacement investments

The costs are divided into variable and fixed costs. Based on the Consultant’s experience the average variable O&M costs during the lifetime (including also major overhauls) of the new plants are as presented in Table 25.

**Table 25 Variable operation and maintenance costs.**

| Plant type | | Cost |
|---|---|---|
| Gas boilers | $USD/Gcal_{fuel}$ | 0.6 |
| Gas engines | $USD/MWh_e$ | 7.8 |
| Combined cycle power plants | | |
| GT | $USD/MWh_e$ | 5.0 |
| Other | $USD/Gcal_{fuel}$ | 0.6 |

The cost levels of gas engine and gas turbine plant maintenance are based on the Consultant’s experience on the cost level of maintenance contracts with engine and gas turbine suppliers.

The fixed annual O&M costs for the new equipment are estimated to be 1.2% of the investment.

## 13.5 Economic and financial IRR of investment options

The analyses of IRR, NPV and Payback time have been made as shown in the table below.

**Table 26 IRR, NPV and Payback**

| Option | Economic | | | Financial | | |
|---|---|---|---|---|---|---|
| | IRR (%) | NPV (MUSD) | Payback time (years) | IRR (%) | NPV (MUSD) | Payback time (years) |
| "Option: 2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West" | 23,5% | 126,3 | 3,8 | 21,2% | 97,6 | 3,6 |
| "Option: 5 Gas Engines at Source 3, no Gas Engine at HOB West and no Gas Engine at HOB South" | 22,6% | 107,9 | 4,0 | 19,1% | 72,3 | 3,7 |
| "Option: 4 Gas Engines at CHP Source 3, 1 Gas Engine at HOB West and no Gas Engine at HOB South" | 21,2% | 108,2 | 4,2 | 18,0% | 73,6 | 3,9 |

Based on the Analyses, the best case is **Option (2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West"),** achieving the following results:

- **Economic IRR 23,5%**
- **Financial IRR 21,2 %**

## 13.6 Annual operational results (Total revenues – total operational costs including depreciation)

**Table 27 Annual operational results of Options**

| Option | Unit | Before investments | After investments | Difference | Difference % |
|---|---|---|---|---|---|
| **"Option: 2 Gas Engines at Source 3, 3 Gas Engines at HOB West"** | **USD million** | **13,7** | **31,6** | **17,9** | **130,7 %** |
| "Option: 5 Gas Engines at CHP Source 3, no Gas Engine at HOB West and no Gas Engine at HOB South" | USD million | **13,7** | **28,8** | **15,1** | **110,2 %** |
| "Option: 4 Gas Engines at Source 3, 1 Gas Engine at HOB West and no Gas Engine at HOB South" | USD million | **13,7** | **29,2** | **15,5** | **113,1 %** |

Based on the Analyses, the best case is Option with 2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West"**,** achieving operational result increase of 130,7%.

## 13.7 Net electricity production of investment options

**Table 28 Net Electricity production of Options**

| Option | Unit | Mode | Net electricity sold to the Grid before investments | Net electricity sold to the Grid after investments | Difference | Difference % |
|---|---|---|---|---|---|---|
| **"Option: 2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West"** | **GWh/a** | **CHPs + GE** | **620,6** | **983,2** | **362,6** | **58,4 %** |
| "Option: 5 Gas Engines at Source 3, no Gas Engine at HOB West and no Gas Engine at HOB South" | GWh/a | CHPs + GE | 620,6 | 947,1 | 327,0 | 52,6 % |
| "Option: 4 Gas Engines at CHP Source 3, 1 Gas Engine at HOB West and no Gas Engine at HOB South" | GWh/a | CHPs + GE | 620,6 | 959,5 | 339,4 | 54,6 % |

Based on the Analyses, the best case is Option with 2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West"**,** achieving the target to increase substantially electricity sales: net electricity production will increase 362 558 MWh (58.4%)

## 13.8 Heat production of investment options

**Table 29 Heat production in CHP and HOB mode**

| Option | Unit | Mode | Heat produced before investments | Heat produced after investments | Difference | Difference % |
|---|---|---|---|---|---|---|
| **"Option: 2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West"** | **000' Gcal/a** | **HOB mode** | **410,6** | **307,8** | **-102,8** | **-25,0%** |
| | **000' Gcal/a** | **CHP mode** | **1 254,4** | **1357,2** | **102,8** | **8,2%** |
| "Option: 5 Gas Engines at CHP Source 3, no Gas Engine at HOB West and no Gas Engine at HOB South" | 000' Gcal/a | HOB mode | 410,6 | 398,3 | -12,3 | -3,0% |
| | 000' Gcal/a | CHP mode | 1 254,4 | 1266,7 | 12,3 | 1,0% |
| "Option: 4 Gas Engines at CHP Source 3, 1 Gas Engine at HOB West and no Gas Engine at HOB South" | 000' Gcal/a | HOB mode | 410,6 | 367,5 | -43,1 | -10,5% |
| | 000' Gcal/a | CHP mode | 1 254,4 | 1297,5 | 43,1 | 3,4% |

Based on the Analyses, the best case is Option with 2 Gas Engines at CHP Source 3, 3 Gas Engines at HOB West", achieving following results:

- Heat production in HOB mode will decrease 25,0% and respectively in CHP mode increase 8,2%

## 13.9 Production costs of heat

In Summary, the impact of investments has insignificant influence on the heat production cost. The key issue is the selected method, how the gas is divided between heat and electricity production.

In this Study the Gas consumption at CHP Source 1, CHP Source 2 and at Gas Engine Plants has been divided between electricity and heat production using three different allocation method:

### a) Fuel Allocation Method no 1: (DRAFT) METODOLOGY for calculation, approval and applying regulated prices and tariffs for heat and electricity production, and for heat distribution and supply services

In case of energy production at urban CHPs, considering that cogeneration represents simultaneous production, within the same process, of electricity and heat within the same facility/plant, the present Methodology provides allocation of the used fuel cost between the produced electricity and heat, so that the fuel saving, compared to separate production of electricity and heat, to be distributed in a non-discriminatory manner between the two forms of energy produced simultaneously.

The fuel saving is determined according to the formula:

$$\Delta Q_{CHP_j} = (Q_{TPP_j} + Q_{HOB_j}) - Q_{CHP_j} = \left(\frac{E_j}{\eta_{TPP}} + \frac{H_j}{\eta_{HOB}}\right) - \frac{E_j + H_j}{\eta_{CHP_j}} \quad (7)$$

where:

$\Delta Q_{CHPj}$ – fuel saving, GJ;

$Q_{TPPj}$ – amount of fuel needed for separate production of the amount of electricity $E_j$ at an efficient (condensation) thermal power plant (TPP), GJ;

$Q_{HOBj}$ – amount of fuel needed for separate production of the amount of heat $H_j$ at a heat-only boiler plant (HOB), GJ;

$Q_{CHPj}$ – amount of fuel used by the CHP in the year, j" for simultaneous production of the amount of electricity $E_j$ and heat $H_j$;

$E_j$ – amount of electricity produced by the CHP in the year, j", GJ;

$H_j$ – amount of heat produced by the CHP in the year, j", GJ;

$\eta_{TPP}$ – reference efficiency of an efficient (condensation) steam-turbine thermal power plant (without combined cycle). According to the present methodology $\eta_{TPP}=0,35$;

$\eta_{HOB}$ – reference efficiency of the most efficient heat-only boiler plant in the country (with capacity comparable to heat capacity of CHP). According to the present methodology $\eta_{HOB}=0,92$;

$\eta_{CHPj}$ – global (total) electricity and heat production efficiency of the CHP in the year ,,*j*". When adjusting the tariffs, the global (total) efficiency to be used is established not lower than its average value during the previous 5 years.

Amount of fuel allocated to the electricity produced at the CHP is determined according to the formula:

$$Q_{E_j} = Q_{TPP_j} - \Delta Q_{CHP_j} \times \left(\frac{Q_{TPP_j}}{Q_{TPP_j} + Q_{HOB_j}}\right) \quad (8)$$

Amount of fuel allocated to the heat produced at the CHP is determined according to the formula:

$$Q_{H_j} = Q_{HOB_j} - \Delta Q_{CHP_j} \times \left(\frac{Q_{HOB_j}}{Q_{TPP_j} + Q_{HOB_j}}\right) \quad (9)$$

**Table 28 Example of fuel allocation - January 2017 - according to new draft ANRE methodology**

| Item | Unit | CHP Source 1 | | | CHP Source 2 | | |
|---|---|---|---|---|---|---|---|
| | | electricity | heat | total | electricity | heat | total |
| Reference TPP and HOB efficiency according to methodology | | **0,35** | **0,92** | | **0,35** | **0,92** | |
| Produced energy | MW, Gcal | **210,80** | | 590,80 | **31,00** | | 101,00 |
| Supplied energy | MW, Gcal | 185,90 | 380,00 | | 24,60 | 70,00 | |
| Actual fuel consumption | thousand $m^3$ | | | 85,50 | | | 13,40 |
| Actual fuel consumption | thousand tons coal equivalent | | | 100,16 | | | 15,70 |
| Actual amount of fuel | Gcal | | | 701,10 | | | 109,88 |
| Fuel amount for TPP and HOB | Gcal | 517,97 | 413,04 | 931,01 | 76,17 | 76,09 | 152,26 |
| Saved fuel | Gcal | | | 229,91 | | | 42,38 |
| Saved fuel for electricity and heat | Gcal | 127,91 | 102,00 | | 21,20 | 21,18 | |
| Actual amount of fuel allocated for electricity and heat | Gcal | 390,06 | 311,04 | | 54,97 | 54,91 | |
| Fuel consumption | thousand tons coal equivalent | 55,72 | 44,43 | 100,16 | 7,85 | 7,84 | 15,70 |
| Specific fuel consumption | g c.eq./kWh, kg c.eq./Gcal | **299,74** | **116,93** | | **319,22** | **112,06** | |

- **Fuel Allocation Method no 2: Heat production-based method**

  The Methodology provides allocation of the used fuel cost between the produced electricity and heat, so that fuel for heat production is calculated based on formula:

  *Produced heat / 92% production efficiency.*

  The fuel for electricity production is calculated based on formula: Total fuel consumption – fuel allocated for heat production.

- **Fuel Allocation Method no 3: Produced Energy based method**

  The Methodology provides allocation of the used fuel cost between the produced electricity and heat, so that fuel for heat production is calculated based on formula:

  *Produced heat (MWh)/ ((produced electricity (MWh) + produced heat (MWh)) * total fuel consumption.*

  The fuel for electricity production is calculated based on formula:

  *Produced electricity (MWh)/ ((produced electricity (MWh) + produced heat (MWh)) * total fuel consumption.*

**Summary impact of different fuel allocation methods**

In Summary, the impact of different fuel allocation methods has significant influence on the heat production cost. Using ANRE method, the heat production cost of 1 Gcal to the network is 535,4 lei, using Heat based method 692,7 lei and correspondingly using Energy based method 742,2 lei.

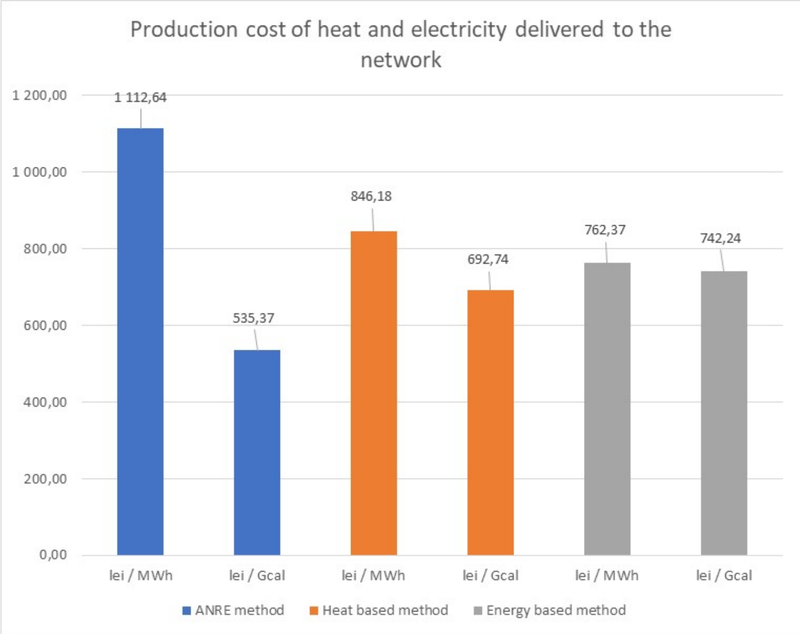


**Figure 25 Production costs of heat and electricity delivered to the network**

## 13.10 Summary of Analyses

**In conclusion:** Installation of 55 $MW_e$ gas engines units distributed between HOB West and CHP Source 3 and installation of 4.0 $MW_e$ gas engine at HOB South, is the most feasible solution, covering the average heat load of the DH system during the summer season and operated as base load plants throughout the whole year. However, installation of gas engine at HOB South is not urgent investment and has been scheduled to be installed in 2026.

**In summary, the most feasible solution for investment needs is Option, including:**

- Reconstruction of Unit 1 at CHP Source 1 (contract ongoing)
- Reconstruction of Unit 2 at CHP Source 1
- Major Overhaul for Unit 3 at CHP Source 1
- Installation of two 11 $MW_e$ Gas Engines at CHP Source 3
- Installation of three 11 $MW_e$ Gas Engines at HOB West

**Benefits of proposed investment package are:**

- Reconstruction of Unit 1 at CHP Source 1 will extend the lifetime of the Unit by 50 000 hours, ensuring heat and electricity production at CHP Source 1. In addition, the investment will increase electricity production capacity from 80 $MW_e$ up to 98 $MW_e$ and it will improve the heat production efficiency by 1,5%.

- Reconstruction of Unit no 2 at CHP Source 1 will extend the lifetime of the Unit by 50 000 hours, ensuring heat and electricity production at CHP Source 1. In addition, the investment will increase electricity production capacity from 80 $MW_e$ up to 98 $MW_e$ and it will improve the heat production efficiency by 1,5%.

- Major Overhaul for Unit 3 at CHP Source 1 will extend the lifetime of reserve Unit 3 likely by 25 000 hours.

- Installation of two 11 $MW_e$ Gas Engines at CHP Source 3 and three 11 $MW_e$ Gas Engines at HOB West has following benefits:

    - Due to additional electricity sales and increased heat production in CHP mode, the profitability of operation will increase from USD 13,7 million up to USD 31,6 million. The additional benefits are USD 17,9 million.

    - The direct simple payback time (without interest rate) of investment will be high 3,8 years (simple payback time is calculated based on formula: Investment costs divided by operational result excluding depreciation (year 2024).

    - The additional net electricity produced will be 362 558 $MWh_e$/year increasing 58,6% from today's production level

    - The additional sold heat produced in CHP mode will increase 102 800 Gcal/year, respectively 8,2%. The reduction in heat produced in HOB mode decrease 25,0%.

    - Reliability and flexibility of heat supply to consumers will increase significantly.

    - The Option can cover fully the average heat load of the DH system during the summer season

    - The Investment can utilize existing electrical and other infrastructure, lowering investment costs and implementation time

    - The Investment is lowering significantly the burden of heat tariff increase

## 14 IRR sensitivity of proposed Short-term Investment Option

For the sensitivity analysis, the Consultant has compared the effect on the Internal Rate of Return for the factors:

**Priority Investment costs (PIP)**

For the PIP Investment Cost factor, the effect of a 20% decrease as well as 20% increase in investment costs has been calculated.

**PIP Investment cost factor:**

| | -20% | Base case | +20% |
|---|---|---|---|
| EIRR | 28,7% | 23,5% | 19,5% |
| FIRR | 26,7% | 21,2% | 16,8% |

**Summary:** The PIP investment cost factor is not very sensitive. If the investment costs increase by 20%, %, the FIRR will still remain largely above the cost of financing (presumably IBRD loan conditions consisting of Libor + small spread).

**Impact of Gas Tariff increase**

For the Gas tariff factor, the effect of a 10% increase in Gas Price has been calculated.

**Gas Tariff factor:**

| | Base case | +10% increase in Gas tariff | +10% increase in Gas and Heat tariff |
|---|---|---|---|
| EIRR | 23,5% | 7,8% | 21,4% |
| FIRR | 21,2% | -5,4% | 18,4% |

**Summary:** The PIP Gas tariff factor is very sensitive. If the Gas Tariff increases by 10%, the EIRR decreases to level 7,8% and FIRR to -5,4%. However, it is assumed that if Gas Price increases, the Heat Tariff will be increased respectively. The incorporated impact provides EIRR 21,4% and FIRR 18,4%.

## 15 Cash Flow Analyses

| Cash Flow Statement million USD. | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2030 | 2035 |
|---|---|---|---|---|---|---|---|---|---|
| Total Revenue | 148,9 | 146,8 | 150,6 | 154,1 | 183,4 | 183,4 | 183,4 | 183,4 | 183,4 |
| Total Expenditures | 135,2 | 134,4 | 134,9 | 137,2 | 151,8 | 151,8 | 151,8 | 151,8 | 151,8 |
| **Operating Margin** | **13,7** | **12,4** | **15,7** | **16,9** | **31,6** | **31,6** | **31,6** | **31,6** | **31,6** |
| Interest on External Debt and Finance Charges | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Interest on cash | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Net Interest Expenses | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Depreciation and Amortization | 5,5 | 7,0 | 7,0 | 9,2 | 12,3 | 12,3 | 12,3 | 12,3 | 12,3 |
| **Cash flow Before Taxes** | **19,1** | **19,3** | **22,6** | **26,1** | **43,9** | **43,9** | **43,9** | **43,9** | **43,9** |
| Taxes paid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Operating Cash Flow** | **19,1** | **19,3** | **22,6** | **26,1** | **43,9** | **43,9** | **43,9** | **43,9** | **43,9** |
| **Component 3.2.(ii)** / Component Capital investments / Consultir | 0,00 | -0,15 | -0,60 | -0,60 | -0,15 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Basic Component** / Capital investments / Source 1, Unit 1 | -2,22 | -2,88 | -2,88 | -2,88 | -1,14 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 1.1 (i)** / Capital investments / Source 1, Unit 2 | 0,00 | -1,20 | -8,40 | -2,40 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 1.1 (ii)** / Capital investments / Source 1, Unit 3 | 0,00 | 0,00 | 0,00 | -4,20 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 1.2 (i)** / Capital investments / Source 3 GE's | 0,00 | 0,00 | -2,80 | -22,40 | -2,80 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 1.2 (i)** / Capital investments / Source West Boiler Pla | 0,00 | 0,00 | -3,57 | -28,56 | -3,57 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 1.2 (i)** / Capital investments / Power transformers a | 0,00 | 0,00 | -0,63 | -5,04 | -0,63 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 2** / Capital investments / Pilot Energy Efficiency Inve | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 3.1 /** Consultancy support for project implementati | 0,00 | 0,00 | -0,40 | -1,20 | -0,40 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 3.2 (i) /** Modern Management Information System | 0,00 | 0,00 | -0,60 | -1,80 | -0,60 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Component 3.2 (ii) /** Modern Hydraulic Calculation Model | 0,00 | 0,00 | -0,30 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Working Capital Additions** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Capital investments / Replacement of DH network pipes | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Capital investments / Installation of Individual Heat Substations | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Cash Flow Before Financing** | **16,9** | **15,1** | **2,5** | **-43,0** | **34,6** | **43,9** | **43,9** | **43,9** | **43,9** |
| External Debt Borrowings / Consulting Services | 0,00 | 0,15 | 0,60 | 0,60 | 0,15 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Source 1, Unit 1 | 2,22 | 2,88 | 2,88 | 2,88 | 1,14 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Source 1, Unit 2 | 0,00 | 1,20 | 8,40 | 2,40 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Source 1, Unit 3 | 0,00 | 0,00 | 0,00 | 4,20 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Source 3 GE's | 0,00 | 0,00 | 2,80 | 22,40 | 2,80 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / West Boiler Plant GE's | 0,00 | 0,00 | 3,57 | 28,56 | 3,57 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Power transformers and power facili | 0,00 | 0,00 | 0,63 | 5,04 | 0,63 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Pilot Energy Efficiency Investments | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Consultancy support for project impl | 0,00 | 0,00 | 0,40 | 1,20 | 0,40 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Modern Management Information Sy | 0,00 | 0,00 | 0,60 | 1,80 | 0,60 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Modern Hydraulic Calculation Model | 0,00 | 0,00 | 0,30 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Replacement of DH network pipes | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| External Debt Borrowings / Installation of Individual Heat Substa | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| **Cash Flow After Financing** | **19,1** | **19,3** | **22,6** | **26,1** | **43,9** | **43,9** | **43,9** | **43,9** | **43,9** |
| External Debt Repayments / Consulting Services | 0 | 0 | 0 | 0 | -0,1 | -0,1 | -0,1 | -0,1 | -0,1 |
| External Debt Repayments / Source 1, Unit 1 | -2,22 | -2,88 | -2,88 | -2,88 | -1,14 | 0 | 0 | 0 | 0 |
| External Debt Repayments / Source 1, Unit 2 | 0 | 0 | 0 | 0 | -0,9 | -0,9 | -0,9 | -0,9 | -0,9 |
| External Debt Repayments / Source 1, Unit 3 | 0 | 0 | 0 | 0 | -0,3 | -0,3 | -0,3 | -0,3 | -0,3 |
| External Debt Repayments / Source 3 GE's | 0 | 0 | 0 | 0 | -2,2 | -2,2 | -2,2 | -2,2 | -2,2 |
| External Debt Repayments / West Boiler Plant GE's | 0 | 0 | 0 | 0 | -2,7 | -2,7 | -2,7 | -2,7 | -2,7 |
| External Debt Repayments / Power transformers and power facil | 0 | 0 | 0 | 0 | -0,5 | -0,5 | -0,5 | -0,5 | -0,5 |
| External Debt Repayments / Pilot Energy Efficiency Investments | 0 | 0 | 0 | 0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| External Debt Repayments / Consultancy support for project imp | 0 | 0 | 0 | 0 | -0,2 | -0,2 | -0,2 | -0,2 | -0,2 |
| External Debt Repayments / Modern Management Information S | 0 | 0 | 0 | 0 | -0,2 | -0,2 | -0,2 | -0,2 | -0,2 |
| External Debt Repayments / Modern Hydraulic Calculation Mode | 0 | 0 | 0 | 0 | -0,02 | -0,02 | -0,02 | -0,02 | -0,02 |
| Investment financed from Cash funds / Replacement of DH netw | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Investment financed from Cash funds / Installation of Individual I | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Equity Contributions | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grant | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Front-end Fee | 0 | -0,2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Commitment Charge | 0,0 | -0,2 | -0,2 | -0,2 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| Interest rate | 0,0 | 0,0 | -0,2 | -0,8 | -0,9 | -0,8 | -0,7 | -0,4 | 0,0 |
| **Cash Flow Available for Dividends and Reserves** | **16,9** | **16,0** | **19,3** | **22,2** | **34,7** | **35,9** | **36,0** | **36,3** | **36,7** |

**Summary:** Based on Cash Flow analyses Termoelectrica's cash flow will be positive despite of Loan costs and investments (DH pipes and Individual Heat Substations) to be financed from own funds.

## 16 Recommendation

Based on technical and economic analysis the recommended energy production option is:

| |
|---|
| Reconstruction of Units 1 and 2 of CHP Source 1 |
| Major overhaul of the Unit 3 turbine at CHP Source 1 |
| Installation of gas engine capacity of around 55 $MW_e$/43 Gcal/heat at CHP Source 3 and HOB West |
| Installation of power transformers at HOB West and Installation of switchgear ID-110 kV at CHP Source 3 and HOB West |
| Hydraulic Modelling of the District Heating Network, delivering the Model and training of the Client |
| Implementation of Pilot Energy Efficiency investment programme |
| Continuation of network rehabilitation programme |
| Continuation of IHSs programme |
| Implementation of a modern comprehensive Management Information System |
| Creation of Project Management Unit and Technical Supervision Team for project implementation |