**Summary**

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Prefeasibility Study on Interconnection of the District Heating System of the City of Belgrade

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LIST OF ABBREVIATIONS

BE – Beogradske elektrane
DU – Dunav
NB – Novi Beograd
KO – Konjarnik
HP – Heating plant
ZE – Zemun
1 INTRODUCTION

The heat distribution system in Belgrade currently operates through 14 independent units, i.e. each heating plant in the system of the company “Beogradske elektrane” has its own, independent distribution network. Although heat source redundancy is established at the level of each heating plant, a major malfunction within the heating plant or distribution network could jeopardize secure supply of heat to users. Effective mitigation of this risk is possible by interconnecting heat sources. Namely, the interconnection creates an opportunity to supply certain urban area with heat coming from several heat sources. In addition to increasing the security of supply, interconnection enables successive inclusion/exclusion of certain heat sources according to the required quantity of thermal energy, but also according to the price or environmental acceptability of heat from individual sources. If the price of heat was taken as a key factor in determining which heat sources (and energy generating products) would be used as the basic ones and which as the peak ones, this would incur significantly lower operating costs and ensure higher efficiency of the entire system. Selecting environmental acceptability as a key factor for selecting a heat source (and energy generating product) could appear as a very strong incentive for using renewable energy sources. Of course, a combined approach is possible. Furthermore, the heat distribution pipeline to be built for the purpose of interconnection could be used as a heat storage system when the consumption is smaller than the amount of energy produced, all in order to reduce the need for peak production during certain intervals within the heating season.

Heat source interconnection is very important for achieving the full utilization of capacity of the potential heat distribution pipeline from TENT-A to HP Novi Beograd. Without interconnection, the significance of this project refers only to the heating area of the heating plant Novi Beograd, and using the full capacity of the heat distribution pipeline is possible only for a few days during the heating season. However, during the process of establishing interconnection in Belgrade, terrain configuration must be taken into account. It is difficult to execute an interconnection in a ring system, which all heat sources would be connected to, due to significant differences in altitude of heat sources. Such a connection would require very high pressure values within the ring in order to supply heat to consumers at higher altitudes.

Therefore, this study focuses on interconnections which are practically feasible and which would ensure optimal utilization of the capacity of the heat distribution pipeline from TENT-A to HP Novi Beograd. Namely, the connection of HP Novi Beograd heating area with the neighboring heating areas - Zemun, Dunav and Konjarnik was considered. Even if the project of the heat distribution pipeline is not implemented, the interconnection of the above mentioned heating areas would ensure a secure supply to the heating areas Dunav and Konjarnik, through the existing capacity of HP Novi Beograd. In this way, the need for building new heat sources would be eliminated in order to cover the shortage of capacity for HP Konjarnik, while the missing capacity of the heat source for HP Dunav would be significantly smaller1.

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1 According to the projections of future heat needs taken from the Development Strategy of “Beogradske elektrane” for the period 2015 – 2025, with the projection until 2035.
2 TECHNICAL DESCRIPTION OF THE MEASURES

2.1 Interconnection of subnets, hydraulic analysis

The objective of the study is to determine the optimal configuration of 4 of the major networks in Belgrade, i.e. Novi Beograd, Dunav, Konjarnik, Zemun, currently constituting separate systems.

Also, it is foreseen that new, greener and cheaper sources may be leveraged upon in the future. Specifically, waste heat may be recovered from a thermal plant (TENT A) and an incinerator. The former will supposedly be connected to the existing plant in Novi Beograd, whilst the latter will expand the capacity in Konjarnik. Furthermore, more customers are expected to be connected to the network, with a capacity close to 88 MWth, located mostly on the Eastern bank of river Sava – dismissing the currently operating isolated boiler houses – and also in Zemun.

The study leverages on previous analyses by Beogradske Elektrane (BE), which had previously highlighted the main potential strategies to plan the network expansion, taking into account the technical and economic framework.

Therefore, the study considers two main areas of intervention:

- Connection of Novi Beograd (NB) and Zemun (ZE) networks, allowing for the dismissal of the heat plant in the latter system;
- Connection of Novi Beograd, Dunav (DU) and Konjarnik (KO), defining in which way these networks have to be linked taking into account the future hydraulic balance of a newly refurbished network.

Figure 1: Focus areas of the study

Building on substantial previous work from BE, that had been investigation several scenarios, the current study takes the challenge of managing the complexity of the issue at hand leveraging on an advanced tool for DHC network development optimization developed by Optit srl (Italian spinoff of the University
of Bologna), that, embedding a sophisticated hydraulic model, allows for experimentation of all potential scenarios, providing the basis to investigate a wide range of strategies and provide technical and economic insights of benefits and drawbacks of each.

Therefore, the key challenge is to identify the optimal new network configuration, analyzing the technical and economic impacts of:

- Different interconnection layout;
- Different piping sizing;
- Integration of new heat sources.

The goal is to strike a balance between a series of complex issues:

- Technical and operational drivers, e.g. evaluating if fewer and bigger connections are better than multiple smaller links;
- Resource allocation, e.g. defining when to lay new piping and when to refurbish existing assets;
- Reference load to dimension, e.g. analyzing the network behaviour in both high and low load conditions.

The methodology involves a three-step approach:

- Calibration of the hydraulic model, i.e. simulation of the current network configuration in Optit’s tool and benchmark with the actual field data, in order to endure the proper representation of the current status of the system;
- Simulation of future network development scenarios, i.e. representation of the impacts of potential future configurations, also providing the values of minimum pressure regimes ensuring the customers’ supply;
- Technical and economic analysis of the most promising scenarios, i.e. cartographic representation of the results and cash flow sheets of the investment.

2.1.1 Key general assumptions

The analyses focus on design and investment scenarios, thus considering a “static” snapshot of the network (where users are assumed to have nominal load) and then providing projected economic evaluations based on some equivalent yearly hours at peak capacity.

Also, the systems are assumed to be operated at design values for operational constraints (e.g. differential temperature between supply and return equal to 55°C).

In the study the new sources are represented as additional capacity at the existing plants’ premises, thus not including the topological connection to the actual geographic location. The costs of connecting the new sources are not considered as well, as of BE’s indications.

Furthermore, all tracks and diameters of new planned piping considered in the scenarios have been set as of BE indications, leveraging on antecedent analyses. Yet, if said prior studies were not available, Optit’s tool could have introduced optimization elements, i.e. piping sizing optimization and/or piping layout optimization.
2.1.2 Hydraulic model set up and calibration

The 4 networks previously mentioned have been set up into Optit’s tool, verifying the cartographic data integrity and consistency with the actual state. Then the results of the simulation have been benchmarked with field data from SCADA, in order to ensure that the network behavior is properly represented into the software.

The items that have been object of verification are the following:

- Coherence of flows in the various branches, in terms of directions and quantity;
- Pressure regime at the plant, taking into account specific technical constraints;
- Identification of the most critical areas of the network, in terms of differential pressure between supply and return, e.g. the most disadvantaged customers;
- Distribution of head losses in the various branches.

In particular, differential pressure at the plant and some select customers, indicated by BE based on the experience, represents the main indicator of the simulation accuracy, within reasonable tolerance.

It should be noted that, once calibrated, the benchmark has shown a very close alignment between simulated behavior and SCADA data, with the maximum deviation just under 0.3 bar. In the context of a very extensive and complex system, with numerical challenges due to the sheer dimension, it is quite a good mark, also taking into account that the computational times have amounted to about 15 minutes for the analysis on the entirety of the 4 grids.

At the same time, the model has been also validated against a top-level commercial thermal-hydraulic simulation software (TERMIS). The comparison has highlighted that the results of the two models are very much alike.

2.1.3 Results of identified scenarios

2.1.3.1 Novi Beograd – Zemun Connection

The scenario involves the network served by the backbones from M1 to M5 of Novi Beograd plant and the network in Zemun. Each backbone in Novi Beograd is an independent branch, with the plant as common starting point.

The objective is to leverage on the new capacity of TENT A (300 MWth may be delivered to this system) to serve Zemun, thus shutting off the local gas-fueled boiler house. Novi Beograd system features many pipes which are currently closed, but may be opened to form loops between different backbones. Among those, one may operate the connection to Zemun. Yet, it is possible that further interconnections between different branches may bring unexplored benefits.

Therefore, extensive effort has been put into analyzing the impacts of all possible opening combinations, in order to assess the optimal strategy. It resulted that only selected pipes are actually beneficial to be reinstated, in particular certain links between backbones M1 and M2.
Due to technical constraints, the perspective hydraulic regime in the network has to reflect as much as possible the current state, e.g. at NB plant’s site:

- approx. 10 bar maximum on the supply line;
- approx. 2 bar minimum on the return line;
- approx. 8 bar differential pressure between supply and return.

Also some general constraints are to be applied:

- Minimum pressure in any point of the network (supply/return line): 1.5 bar;
- Maximum pressure in any point of the network: 16 bar;
- Minimum differential pressure at the users’ substations: 1.0 bar.

Moreover, BE plans to install pumping stations on M1 and M2, as well as lay a new DN 350 backbone in Zemun, forming a parallel link to the feed from Novi Beograd. The design of the pumping station has been object of further analyses, in terms of required extra pressure ensured, indicating that 4.8 bar on the supply line and 3.1 bar on the return line has to be considered, in order to comply with the technical constraints above. A new 10 MWth customer is assumed to be connected also, located in the northern part of Zemun.
Lastly, a temperature-based regulation is to be assumed due to the hydraulic constraints above mentioned, thus configuring a scenario with nominal loads (with respect to the user’s capacity), considering a design ΔT of 55 °C.

In the framework above described, the results of the hydraulic simulation show that the pressure regimes may remain within the current levels also in the new configuration. The table below reports a benchmark between the Baseline, i.e. the current status of the network, and the analyzed scenario.

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Simulated Scenario</th>
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<tbody>
<tr>
<td>Zemun flow (kg/s)</td>
<td>246</td>
<td>0</td>
</tr>
<tr>
<td>Novi Beograd M1 flow (kg/s)</td>
<td>613</td>
<td>769</td>
</tr>
<tr>
<td>Novi Beograd M2 flow (kg/s)</td>
<td>643</td>
<td>800</td>
</tr>
<tr>
<td>Novi Beograd M3 flow (kg/s)</td>
<td>729</td>
<td>729</td>
</tr>
<tr>
<td>Novi Beograd M4 flow (kg/s)</td>
<td>638</td>
<td>638</td>
</tr>
<tr>
<td>Novi Beograd M5 flow (kg/s)</td>
<td>601</td>
<td>601</td>
</tr>
<tr>
<td>p supply (bar)</td>
<td>9.89</td>
<td>10.09</td>
</tr>
<tr>
<td>p return (bar)</td>
<td>1.90</td>
<td>2.05</td>
</tr>
<tr>
<td>Δp (bar)</td>
<td>7.99</td>
<td>8.04</td>
</tr>
</tbody>
</table>

Table 1: Flows and pressures at the plant in the Baseline and in the analyzed Scenario

Since in the scenario Zemun plant has been dismissed, the flow at NB plant increases, in order to supply the customers in Zemun. Also, since M1 and M2 are now interconnected, only these backbones see a variation in the supplied flow.
Below is shown a thematic map of the “before” and “after” situation, highlighting the distribution of differential pressure in the branches.

![Thematic Map](image)

**Figure 4: Distribution of Δp in the current status and in the simulated scenario**

The new configuration of the network presents less extensive critical areas (in terms of low Δp), as well as a slight shift of the location of some critical points, as highlighted in figure 5 below.

![Thematic Map](image)

**Figure 5: Examples of different hydraulic status compared with the current situation**
Quite different is also the distribution of the supply pressure in the areas served by NB M1 and M2, because of the additional flow that has to be carried up to Zemun and the newly formed loop between the two pipelines (see figure 6 below).

![Figure 6: Distribution of supply pressure in the network compared to the current status](image)

Analyzing the distribution of flow speed in the various branches (figure 7), it can be seen that it is mostly consistent across the two scenarios, since interventions involve only M1 and M2.

Yet, it can be noted in figure 8 that the conditions along said backbones are a bit different, with higher flow speed in the perspective scenarios. That is due to:

- The need to carry additional flow to meet Zemun’s demand;
- The interconnection between the two pipelines, which alters the conditions with respect to the current status;
- The installation of the new pumping stations in the highlighted locations, which increases the local flow speed, yet are necessary to ensure the overall hydraulic feasibility under the technical constraints.
Figure 7: Distribution of flow speed in the network in both scenarios

Figure 8: Examples of flow speed profiles in the current status and in the perspective scenario
All in all, the simulation of the new network configuration highlights that the most important prerequisites are satisfied:

- The hydraulic regimes in the various branches comply with the technical constraints provided and are adherent to the current conditions, thus ensuring the operational feasibility;
- The load in Zemun may be absorbed by the newly expanded Novi Beograd plant, thus allowing the current local plant to be dismissed, leading to reduced operating costs;
- The connection of the new 10 MW user does not introduce significant complexity issues, in terms of overall hydraulic balance, thus constituting a feasible network expansion opportunity.

2.1.3.2 Novi Beograd – Dunav – Konjarnik Connection

The “Eastern part” of the system presents some more challenges, given the ample possibility to investigate numerous control variables (e.g. pumping design, opening of loops, etc.).

Preliminary extensive analyses have outlined the impacts of some potential high-level strategies, yielding some interesting insights. Firstly, some hypothesized interventions (such as a long “ring” piping linking Gazela bridge directly to Dunav plant, as shown in figure 9) have been discarded, because the investment cost / operational benefit ratio was just not favorable enough.

Secondly, the direct connection of the entire network of Konjarnik with the others would not be convenient, given the altitude difference of the area. Several simulations highlighted how the connection between NB M6 and KO M1 would require significantly higher supply pressure in Novi Beograd without significant premiums with respect to other scenarios. Moreover, many simulations highlighted that the newly highly-connected system would yield some hydraulic imbalances, e.g. excessive differential pressure between supply and return at the users’ substations or excessive flow speed in some piping segments. These insights have led to the conclusion that some key backbone refurbishment is to be implemented in the most critical areas, as well as the installation of new backbones, as shown in figures 10-12 below.
Figure 10: Infrastructural investment considered in the final scenarios (part 1: Gazela bridge)

Figure 11: Infrastructural investment considered in the final scenarios (part 2: NB-DU connection)
Lastly, an operational range of the new pumping stations at the Gazela bridge has been assessed, defining the design differential pressure to be expected by the pumps.
In light of these first take-aways, the focus has then slightly shifted towards the integration of Novi Beograd and Dunav, yet considering a partial connection with Konjarnik.

Therefore, the final scenarios are the following:

1. **Connection NB-DU-KO (100% flow – high load conditions):**
   - Dunav plant is still operational and feeds its backbones M1, M2A and part of M2, while the rest of M2 is served by the incoming NB M6;
   - The backbone M2 is cut-off in order to ensure different hydraulic regimes in the parts served by Dunav and Novi Beograd (figure 15);
o One of the new customers (a 48 MW_th Clinical Center served by NB M6) is considered not to be connected;
o Konjarnik is connected to NB M6 through its backbones M1 and M3, yet considering some pipe partitions, in order to separate hydraulically the “Eastern” side of KO network (located at higher altitude with respect to the rest of the system), as of figure 16;

![Figure 16: Partition of the segment of KO M1-M3 served by NB M6](image)

o The planned PPS at Gazela bridge is designed to provide extra pressure (2 bar) on the line directed to Dunav and Konjarnik (3 bar);

2. **Connection NB-DU (100% flow – high load conditions):**
o Dunav plant is still operational and feeds its backbones M1, M2A and part of M2, while the rest of M2 is served by the incoming NB M6;
o The backbone M2 is cut-off in order to ensure different hydraulic regimes in the areas served by the plants in Dunav and Novi Beograd, yet in a different node of the backbone with respect to the previous scenario, as shown in figure 17;
Figure 17: Partition points of Dunav M2 for Scenario 1-2

- The 48 MW Clinical Center is considered not to be connected;
- Konjarnik network is kept separate, opening the planned new piping connecting NB M6 and KO M1, as in the figure 18;

Figure 18: Separation of Konjarnik from other networks

- The planned PPS at Gazela bridge is designed to provide extra pressure (4 bar) on the line directed to Dunav, while it remains inactive in the line towards Konjarnik;
3. Connection NB-DU-KO (50% flow – low load conditions):
   o Dunav plant is still operational and feeds its backbones M2A and part of M1, while the rest of M1 and M2 are served by the incoming NB M6 (figure 19);

![Figure 19: Supply dispatching for Dunav sub-grid](image)

   o The users served by DU and KO plants are supplied with nominal flow (therefore assuming a temperature-based regulation), while the customers served by NB plant are supplied with 50% flow (therefore assuming a flow-based regulation);
   o The 48 MW în Clinical Center is connected to the network;
   o Konjarnik network is connected as described for the first scenario (see fig. 16)
   o The planned PPS at Gazela bridge is designed to provide extra pressure (4 bar) on the line directed to Dunav, and +2 bar on the line towards Konjarnik;

The description of the scenarios highlights that major emphasis has been put on maximizing the capacity that may be supplied from NB M6, within the technical constraints. The rationale is to keep pressures as low as possible, yet investigating potential leverages of flexibility, constituted by the capability of “shaping” the network connection however needed (e.g. if some boundary condition may change).

The figures reported above have all been consolidated after extensive sensitivity analyses, e.g. evaluating the effect of different pumping figures on the overall hydraulic balance, as well as different cut off points delimiting the areas served by the plant in Novi Beograd.

It is also to be noted, that the configurations of said scenarios involve mostly simulation, rather than optimization, since in a certain scenario all hydraulic sub-grids are rigidly defined by the closed-down pipes aforementioned and served by a single plant. This means that there is no leverage to optimize the heat supply dispatching from the various plants, because it is actually not the focus of the study itself.

Finally, there are some boundary conditions which have shaped how the scenarios are constituted. These constraints, provided by BE’s experience, hold true for all the scenarios above:
- Minimum pressure in any point of the network (supply/return line): 1.5 bar;
- Maximum pressure in any point of the network: 25 bar;
- Minimum differential pressure at the users’ substations: 1.0 bar;
- Maximum flow on M6 across Gazela bridge: 4,500 m^3/h (approx. 1,250 kg/s) (thus limiting the amount of heat which may be potentially supplied by TENT A);
- Maximum differential pressure at every substation: 8.0 bar.

Below is shown a thematic map highlighting the distribution of differential pressure in the branches for the current status and the two variants of perspective scenario (with 100% flow).

![Thematic map showing differential pressure distribution](image)

**Figure 20: Distribution of Δp in the current status and in the simulated scenarios with 100% flow**

The overall hydraulic balance seems to be fairly similar at a system's level. Yet, there are similarities as well as differences.

Firstly, it can be noted that there is consistency about the most critical area (in terms of differential pressure), located at the end of DU M1 (see figure 21). The reason is that in all the scenarios above, said backbones has not changed feed-in point or other features, being served still by Dunav plant entirely.
Nevertheless, it is shown that some currently critical areas may improve their conditions, with increased overall Δp. In particular, in figure 22 is provided an example of such sorts, in which the Eastern part of NB M6 area sees greater differential pressure in the two scenarios, especially in Scenario 2, where Konjarnik is not being connected in any form.

At the same time, there are some instances in which the opposite happens, for example in the area around the connection NB-DU on DU M2 (as shown in figure 23).
In the figure 24 below it is also shown the distribution of supply pressure in the current network configuration and in the perspective scenarios.

The map shows an overall consistency in terms of broad range of pressures, yet it may be seen some differences, due to the various network configurations, as show in figure 25.

Figure 24: Distribution of supply pressure for scenarios with 100% flow
Another interesting point is how the perspective network would behave in low-load conditions, in which the dispatching logic is mostly impacted by the possibility of fully leverage on the new sources, i.e. TENT A in Novi Beograd and the WTE unit in Konjarnik. As described above, there are several changes with respect to the scenarios with 100% flow, in terms of network layout and, consequently, hydraulic profiles, as shown in figure 26.
This may be seen (figure 27) across DU M2A and the terminal part of DU M1, served by Dunav plant, even though the regulation in these branches is temperature-based, so that the flow is still equal to the nominal value. Yet, assigning part of M1 load to the supply from NB, allow for a significant reduction in differential pressure, up to Dunav plant.

Also, the supply of DU M2 via the new planned piping through „Belgrade on Water“ yield greater differential pressure in the whole area, yet not changing the fact that the critical area highlighted in figure 21 stays as such.
The table below reports a benchmark between the Baseline, i.e. the current status of the network, and the analyzed scenarios, in terms of flows (Table 2) and pressures (Table 3) at the plants.

<table>
<thead>
<tr>
<th>flow (kg/s)</th>
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<th>s 2.2</th>
<th>s 2.3</th>
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<tr>
<td>Dunav M1</td>
<td>1 010</td>
<td>1 010</td>
<td>1 010</td>
<td>333</td>
</tr>
<tr>
<td>Dunav M2</td>
<td>750</td>
<td>307</td>
<td>103</td>
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</tr>
<tr>
<td>Dunav M2A</td>
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<td>168</td>
<td>168</td>
<td>168</td>
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<td>Konjarnik M1</td>
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<td>Novi Beograd M6</td>
<td>456</td>
<td>1 250</td>
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**Table 2: Comparison of flow distribution across the backbones from the plants**

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>s 100% Flow (1)</th>
<th>s 100% Flow (2)</th>
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</tr>
</tbody>
</table>

**Table 3: Comparison of pressure regimes at the plants for the scenarios considered**
The tables highlight some key points:

- The distribution of flows follow the load dispatching strategies defined in each scenario, in order to maximize the supply from the new sources, which are saturated within capacity and technical constraints;
- Pressures in Dunav plant remain identical in 100% load scenarios, whilst decrease decisively in 50% load conditions, also because of the partition in backbone M1 eliminating a substantial share of the overall load of the sub-grid;
- Pressures in Konjarnik depend on whether part of KO M1-M3 are served by NB M6 or not and in the former case the supply and differential pressure decrease up to 0.5 bar;
- Although the load connected is greatly superior with respect to the current status, pressures in Novi Beograd do not drastically increase, yet taking into account that additional pumping is ensured at the Gazela bridge.

All in all, the results of these scenarios may be recapped as the following:

- The interconnection of Novi Beograd-Dunav-Konjarnik is feasible and may be achieved in at least a couple of different manners (Scenario 1 and 2), thus allowing for operational flexibility in case of boundary conditions variations;
- After a thorough sensitivity analysis on numerous variables, the variants presented as final scenarios have different features and potential benefits/drawbacks, yet the overall hydraulic balance of the network is ensured in either case and the high-level technical KPIs (e.g. pressures at the plants) are quite similar;
- Refurbishment of long segments of existing pipeline is necessary in order to comply with the technical constraints and avoid impactful bottlenecks (which have been pointed out in the course of the various scenario iterations);
- Flow speed does not exceed the critical treshold value (3 m/s) in any of the analyzed scenario, after that extensive refurbishment has been taken into account;
- Scenario 2 seems to present less extensive critical areas, yet the difference is not astounding, while, at the same time, a complete interconnection of the 3 major networks is achieved;
- In low-load conditions the new sources may be fully leveraged upon, allowing to fully saturate their capacity within the technical constraints;

In low load conditions many areas may be switched from being served by the gas-fueled Dunav and Konjarnik plants onto TENT A in Novi Beograd, also decreasing the differential pressure required at the former plants.

2.2 \textbf{Financial analysis of interconnection scenarios}

In general, interconnection results in various positive effects in district heating systems. In the technical sense, it enables optimization of heating capacities, provides opportunities for fuel mix optimization, enables reducing consumption of raw materials, materials and energy, enables releasing heating capacities for further expansion of the district heating system, and has other positive effects.
These technical improvements, consequently, result in improving financial status in companies which manage district heating systems, primarily through increased profits and liquidity. In 2019, PUC “Beogradske elektrane” generated net profit of RSD 3,720,165 thousand (approximately EUR 32 million). It can be expected that the implementation of considered scenarios, regardless of whether they are implemented together or if just one of them is implemented, will result in an improvement of financial operations of PUC “Beogradske elektrane”. Financial operations of PUC “Beogradske elektrane” should be further improved due to the connection of the district heating system to TENT-A, and creating opportunities for the purchase of significantly cheaper thermal energy compared to current production costs of PUC “Beogradske elektrane”.

A financial analysis was performed to assess financial feasibility of the implementation of considered scenarios. Financial feasibility of the considered scenarios is assessed against three basic financial indicators, net present value (NPV), internal rate of return (IRR) and payback period.

Cash flow projections for each of the considered scenarios for the following 20 years are taken as the basis for the calculation of these financial indicators. Cash flow projections are made based on the investment costs of implementation of the considered scenarios, and expected income and operating costs. Furthermore, a 7% discount rate was used in the financial analysis. The financial analysis was performed according to the available data and possible estimates during the preparation of the Study. Detailed calculations, which would provide more details and data, need to be performed prior to the project implementation.

### 2.2.1 Investment costs

Investment costs include costs of designing interconnection lines, costs of construction works, costs of pipe procurement and installation, and costs of installing pump stations. An overview of financial investments required for the implementation of considered scenarios is provided in the table below.

**Table 4: Overview of required financial investments**

<table>
<thead>
<tr>
<th>Item</th>
<th>Scenario 1 Amount (RSD)</th>
<th>Scenario 2 Amount (RSD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design works</td>
<td>71,376,239</td>
<td>205,218,688</td>
</tr>
<tr>
<td>Construction works</td>
<td>24,556,835</td>
<td>510,969,449</td>
</tr>
<tr>
<td>Pipes</td>
<td>88,843,476</td>
<td>2,271,436,391</td>
</tr>
<tr>
<td>Pump stations</td>
<td>1,116,748,750</td>
<td>1,116,748,750</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,301,525,300</strong></td>
<td><strong>4,104,373,278</strong></td>
</tr>
</tbody>
</table>

The implementation of the Scenario 1 requires an investment of RSD 1,301 million (approximately EUR 11 million), whereas the implementation of the Scenario 2 requires an investment of RSD 4,104 million (approximately EUR 35 million). The financial analysis was performed based on the assumption that the implementation of investments in Scenario 1 would take place in the period 2020 - 2021, and in Scenario 2 in the period 2020 - 2029.
2.2.2 Operating costs

Operating costs include costs of fuel, costs of electricity, tangible and intangible costs, costs of production services, and costs of staff salaries and compensations. These costs are calculated based on the following assumptions:

- **Costs of fuel** in the Scenario 1 include costs of gas, heating oil (medium), gas oil (extra light) as well as costs of procuring thermal energy from TENT A, whereas costs of fuel in the Scenario 2 additionally include costs of compressed natural gas. Prices of these fuels are taken from the Business Programme of PUC “Beogradske elektrane” for 2020, except for the price of thermal energy from TENT Obrenovac, which is assumed to amount to RSD 1,646 (EUR 14). The quantities of the above mentioned energy generating products are obtained as a result of a technical analysis of scenarios and are as follows:
  - Gas - Scenario 1 - 31 mil. m³/year on average, Scenario 2 - 73 mil. m³/year on average;
  - Heating oil (medium) - Scenario 1 - 2.7 mil. l/year on average, Scenario 2 - 8.7 mil. l/year on average;
  - Gas oil (extra light) - Scenario 1 - 0.5 mil. l/year on average, Scenario 2 - 1.5 mil. l/year on average;
  - Thermal energy from TENT A - Scenario 1 - 0.913 mil. MWh/year on average, Scenario 2 - 1.63 mil. MWh/year on average
  - Compressed natural gas - Scenario 2 - 8.2 mil. m³/year on average.

- **Costs of electricity** – Quantity of electric power is also a result of technical analysis of the considered scenarios and amounts to 27 GWh/year on average in the Scenario 1 and 55 GWh/year on average in the Scenario 2;

- **Costs of materials** - Estimated based on the Business Programme of PUC “Beogradske elektrane” for 2020, and amount to RSD 136 million per year on average in the Scenario 1, i.e. RSD 221 million per year on average in the Scenario 2;

- **Intangible costs** - Estimated based on the Business Programme of PUC “Beogradske elektrane” for 2020, and amount to RSD 231 million per year on average in the Scenario 1, i.e. RSD 375 million per year on average in the Scenario 2;

- **Costs of production services** - Estimated based on the Business Program of the Business Programme of PUC “Beogradske elektrane” for 2020, and amount to RSD 602 million per year on average in the Scenario 1, i.e. RSD 977 million per year on average in the Scenario 2;

- **Costs of staff salaries and compensations** - Estimated based on the Business Programme of PUC “Beogradske elektrane” for 2020, and amount to RSD 1.23 billion per year on average in the Scenario 1, i.e. RSD 2 billion per year on average in the Scenario 2.

2.2.3 Revenue

Revenue in both observed scenarios includes revenues from heat sales. Revenue is calculated under the assumption that PUC “Beogradske elektrane” will charge for heat supply services in accordance with the consumption-based billing method, using the methodology of PUC “Beogradske elektrane” for the calculation of costs of these services. Revenue projection is performed in accordance with the following input parameters:
- Heat supplied to end customers - Result of the technical analysis of considered scenarios and amounts to 790 million kWh/year on average in the Scenario 1 and 1.6 billion kWh/year on average in the Scenario 2;
- Heated surface - Result of the technical analysis of considered scenarios and amounts to 8,557,100 m² in the Scenario 1 and 16,222,900 m² in the Scenario 2;
- Expansion of heated area - The foreseen expansion of the heated area amounts to 8 thousand m²/year in the period 2020-2024 according to the Scenario 1, i.e. 52 m²/year in the period 2020-2030 according to the Scenario 2;
- It is assumed that heat needs of heated surfaces amount to 80 w/m² in both scenarios;
- The price of heating service amounts to 8.39 RSD/kWh for the delivered thermal energy, i.e. 3,240.67 RSD/kw of rated power.

### 2.2.4 Direct financial effects of interconnection for observed scenarios

The above analysis is a financial analysis of operations of PUC “Beogradske elektrane” in the areas where the interconnection would be executed according to the Scenario 1 and Scenario 2. As such, it provides a broader picture of feasibility of the following steps in the process of interconnection (preparation of detailed studies, conceptual designs, main designs, etc.), required by PUC “Beogradske elektrane” and potential project financiers (international financial institutions, etc.).

However, if observed as a separate project without being placed in the context of business operations of PUC “Beogradske elektrane”, interconnection has its direct financial and other effects. Most of interconnection effects are difficult to quantify without detailed analyses. In this case, the most significant financial effect of the interconnection is ensuring the use of cheaper thermal energy from TENT A in the major part of the City of Belgrade and thus reducing operating costs of the district heating system.

If the interconnection is not executed according to one of considered scenarios, the energy obtained from TENT A will be used only in the area of Novi Beograd (716 thousand MWh/year on average).

The interconnection according to the Scenario 1 will result in a possibility of using additional quantities of energy obtained from TENT A (23 thousand MWh/year on average) which would be distributed in the area of Zemun, due to which the total distributed quantity of thermal energy obtained from TENT A would amount to 739 thousand MWh/year on average. The possibility of using additional energy obtained from TENT A, as a result of interconnection according to the Scenario 1, would generate savings in costs of fuel in the amount of RSD 96 million per year (EUR 813 thousand/year), which for the observed period of 20 years amounts to RSD 1.9 billion (EUR 16 million). An overview of the calculation of fuel cost savings due to the interconnection according to the Scenario 1 is given in the table below.

#### Table 5: Fuel cost savings due to interconnection implemented according to the Scenario 1

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Without interconnection (quantity/year)</th>
<th>With interconnection (quantity/year)</th>
<th>Price (RSD/quantity)</th>
<th>Costs without interconnection (RSD/year)</th>
<th>Costs with interconnection (RSD/year)</th>
<th>Difference (RSD/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas (Sm³)</td>
<td>30,156,970</td>
<td>30,777,793</td>
<td>41.67</td>
<td>1,256,640,921</td>
<td>1,282,510,634</td>
<td>-25,869,713</td>
</tr>
<tr>
<td>Heating oil – medium (kg)</td>
<td>6,540,291</td>
<td>2,707,094</td>
<td>41.38</td>
<td>270,637,259</td>
<td>112,019,531</td>
<td>158,617,728</td>
</tr>
<tr>
<td>Gas oil - extra</td>
<td>499,653</td>
<td>499,653</td>
<td>121</td>
<td>60,458,012</td>
<td>60,458,012</td>
<td>0</td>
</tr>
</tbody>
</table>
The interconnection according to the Scenario 2 will also result in a possibility of using additional quantities of energy obtained from TENT A compared to the situation without the interconnection (604 thousand MWh/year on average) which would be distributed in the areas of Dunav and Konjarnik, due to which the total distributed quantity of thermal energy obtained from TENT A would amount to 1.32 million MWh/year on average. The possibility of using additional energy obtained from TENT A, as a result of interconnection according to the Scenario 2, would generate savings in costs of fuel in the amount of RSD 1.86 billion per year (EUR 15.8 million/year), which for the observed period of 20 years amounts to RSD 37.3 billion (EUR 317.2 million). An overview of the calculation of fuel cost savings due to the interconnection according to the Scenario 2 is given in the table below.

**Table 6: Fuel cost savings due to interconnection implemented according to the Scenario 2**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Without interconnection (quantity/year)</th>
<th>With interconnection (quantity/year)</th>
<th>Price (RSD/quantity)</th>
<th>Costs without interconnection (RSD/year)</th>
<th>Costs with interconnection (RSD/year)</th>
<th>Difference (RSD/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas (Sm³)</td>
<td>141,057,291</td>
<td>72,472,728</td>
<td>41,67</td>
<td>5,877,857,307</td>
<td>3,019,938,571</td>
<td>2,857,918,736</td>
</tr>
<tr>
<td>Compressed natural gas (Sm³)</td>
<td>8,207,646</td>
<td>8,207,646</td>
<td>54,24</td>
<td>445,182,719</td>
<td>445,182,719</td>
<td>0</td>
</tr>
<tr>
<td>Heating oil – medium (kg)</td>
<td>8,731,474</td>
<td>8,731,474</td>
<td>41,38</td>
<td>361,308,396</td>
<td>361,308,396</td>
<td>0</td>
</tr>
<tr>
<td>Gas oil – extra light (l)</td>
<td>1,500,653</td>
<td>1,500,653</td>
<td>121</td>
<td>181,579,054</td>
<td>181,579,054</td>
<td>0</td>
</tr>
<tr>
<td>TENT-A Obrenovac (MWh)</td>
<td>715,909</td>
<td>1,319,586</td>
<td>1645,735</td>
<td>1,178,196,399</td>
<td>2,171,689,073</td>
<td>-993,492,674</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>8,044,123,876</td>
<td>6,179,697,814</td>
<td>1,864,426,062</td>
</tr>
</tbody>
</table>

In addition to the aforementioned direct financial savings, expected positive effects refer to the following:

- ensuring security of heat supply;
- construction of a stable district heating system;
- improving performance, and facilitating control and monitoring of district heating system operations.

Direct financial effects of the interconnection for considered scenarios are calculated according to the available data and estimates, and can be used only to show advantages and benefits which can be obtained by implementing the interconnection project. It is important to mention that it is necessary to
perform detailed analyses and calculations prior to the project implementation to ensure greater reliability of the presented results.

2.3 Conclusions of the analysis of possible interconnection scenarios

A summary of key conclusions of the Study is given hereinafter:

- In the scenario of NB-Zemun connection, the perspective hydraulic regime complies with the technical constraints provided and is adherent to the current status, thus ensuring the operational feasibility of the new network configuration;

- The interconnection of Novi Beograd-Dunav-Konjarnik may be achieved through different piping loops, which are feasible from a technical standpoint and provide operational flexibility in case of boundary conditions variations (e.g. different load distribution across the various areas with respect to design conditions);

- The connection to the main system of the new customers allows to turn off various gas-fired local boiler houses, whilst it does not impact negatively on the overall hydraulic balance;

- Thorough sensitivity analyses on numerous variables have been carried out, exploring the potential impact from a technical and economic standpoint, allowing for the incremental process of defining final scenarios which satisfy the requirements suggested by BE’s experience;

- Refurbishment of long segments of existing pipeline and installation of new backbones is necessary, yet the effort is expected to resolve impactful bottlenecks in the new system;

- The installation of additional pumping stations is planned, since they are instrumental in managing the pressure regimes at the plants and ensuring the feasibility with respect to all constraints;

- Flow speed in the piping does not exceed the critical threshold value (3 m/s) in any of the final scenario, being a focal point in diagnosing the status of the network;

- Considering the NB-DU-KO connection scenarios, pressure regimes across the system do differ from the current status (i.e. isolated networks), yet the overall balance and distribution is mostly consistent with the current operating conditions (e.g. supply pressure and Δp at the plant are fairly similar across the board, considering that the layout of the network is quite different);

- In the scenario of NB-DU-KO connection with low-load conditions, the new sources may be saturated, without negative impact on the hydraulics of the systems, and allowing to ease the requirement at the plants in Dunav and Konjarnik.