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Analysis of the Possibilities for Energy Efficiency Improvement of CHP Power Plants

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Abstract

A technical and economic analysis for the possibilities of increasing the efficiency of three large CHP power plants in city of Almaty was carried out. 25 energy saving measures have been identified, as measures are prioritized based on the lowest simple payback period.
In the course of the analysis, basic and auxiliary equipment was found to be centralized and depreciated (or close to physical operational life). All power plants have a very high consumption for their own electrical and thermal energy needs. This is several times higher than the CHPs installed in central Europe, where over the past 20 years a different set of measures related with improvement of energy efficiency have been applied.
Power plants with potential for energy efficiency improvement and process automation are being explored. The implementation of the measures will minimize energy costs and increase the reliability of the Almaty power supply.
Based on a preliminary and sufficiently conservative feasibility study, the proposed saving measures make a significant contribution to lowering the price of thermal energy and electricity.
The implementation of the modernization measures of the CHP will lead to an annual decrease in the consumption of: Electricity - more than 21 636 MWh; Thermal energy - 36 326 Gcal; Natural gas with 1 755 thousand nm^3; Coal with 224 725 t.
Besides the direct reduction of energy consumption and fuels, the proposed measures for CHP-2 and CHP-3 can also lead to additional production of 375 200 MWh of electricity with a general reduction of the specific fuel consumption.

Keywords: CHP power plants, energy efficiency, technical economic analysis, fuel switch

1. Introduction

One of the most frequently used energy-efficient measures in CHPs (Combined heat and power production facilities) is the introduction of economizers for the use of exhaust gases potential. An energy analysis is presented in [1-6] and the benefits of using economizers in such systems are evaluated. Also, there are many discussions about the improved economizer system for active control of boiler running on coals.

The introduction of energy-efficient measures must be in line with current environmental standards/norms. Different aspects of technical and economic analyzes and impacts on the environment in the development of business plans related to the introduction of energy-efficient measures in CHPs are presented in [7-11].

In the present work, a feasibility study has been carried out focusing on the environmental impact when introducing energy efficiency measures in CHPs.

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2. Description of selected measures for CHP1, CHP2 and CHP3

In May and June 2018, a team of experts visited CHP-1, CHP-2 and CHP-3 to inspect the equipment, collect initial information about their condition, fuel consumption and production costs. Numerous interviews were conducted with executives, managers of Production and Technical Departments (PTD) and staff from other departments at the CHPs.

The experts did a great deal of work to finalize/determine the technical and economic indicators describing CHP-1, CHP-2 and CHP-3 equipment performance, analyze these indicators and analyze other technical data and documentation/information provided by the Beneficiary. The preliminary economic assessments were made based on data available to the experts and based on the Team's experience with similar CHP modernization projects in Eastern Europe, as well as data provided by the representatives of Almaty CHPs.

Based on the analysis of the energy efficiency potential of heat and electricity production at CHP-1, CHP-2 and CHP-3, as well as the discussion of the results of this work with Project Counterparts the following conclusions can be made:

- All CHPs have a high auxiliary consumption of electricity and heat, which significantly affects the cost of electricity and heat. The auxiliary consumption is several times higher than at CHPs with similar equipment in Eastern European countries, where in the past 20 years large investments were made in energy efficiency;
- CHP-1, CHP-2 and CHP-3 each have large potential for energy and fuel savings, and automation, which can lead to a significant reduction in the cost of electricity and heat production, and will increase the reliability of power supply to Almaty consumers;

When selecting priority measures, the representatives of the CHPs took into account the following circumstances:

- Each CHP's reconstruction plans;
- The possibility of fuel switching at CHP-2 and CHP-3 from coal to natural gas (based on the discussions related to the directive of the President of Kazakhstan);
- Plans to complete a feasibility study in 2019 for upgrading several CHPs, the results of which may affect the implementation of the individual energy efficiency measures proposed.
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Based on the simple payback period 25 energy efficiency measures (EEM) for the CHPs have been selected:

CHP1:

- EEM1: Installing additional waste-heat recovery economizers behind boilers BKZ-160 KA No. 12 and KA No. 13
- EEM2: Reconstructing boiler ash-handling pumps and ash-handling systems;
- EEM3: Adding frequency regulation to the ID fans at boilers KA No. 12 and KA No. 13 (which are currently operating in variable mode);
- EEM4: Adding frequency regulation to the FD fans at boilers KA No. 12 and KA No. 13 (which are currently operating in variable mode);
- EEM5: Fully automating the technical parameters of the power boilers KA No.12 and KA No.13 BKZ 160-100F;
- EEM6: Reducing air infiltration in the boiler room;
- EEM7: Reducing air infiltration in the turbine room
- EEM8: Restoring pumps with hydrophobic coatings.

CHP2:

- EEM1: Fully automating the main technical parameters and the fuel-pulverizing system of power boiler BKZ 420-140-7C KA No. 7;
- EEM2: Adding frequency regulation to the FD fans at the KA No. 8 boiler (which is currently operating in variable mode)
- EEM3: Adding frequency regulation to the ID fans at the KA No. 8 boiler (which is currently operating in variable mode);
- EEM4: Reconstructing the PT-80-130/13 steam turbine.
- EEM5: Improving the water treatment system of the service water supply system to prevent salt deposits on heating surfaces and in cooling towers;
- EEM6: Restoring pumps with hydrophobic coatings;

CHP3:

- EEM1: Installing an additional air heater behind the BKZ 160-100F steam generator;
- EEM2: Replacing the CHP's turbines;
- EEM3: Replacing cooling tower No. 5 with an energy efficient tower;
- EEM4: Fully automating the technical parameters of the BKZ 160-100F power boilers and the mill system
- EEM5: Replacing steam turbine seals with improved honeycomb surface seal designs;
- EEM6: Adding frequency regulation to the boiler FD fans (which are currently, operating in variable mode);
- EEM7: Adding frequency regulation to the boiler ID fans (which are currently, operating in variable mode);
- EEM8: Adding frequency regulation to the 7A and 7B network pumps;
- EEM9: Installing new feed pumps with frequency regulation in the heat network;
- EEM10: Installing an electrostatic precipitator with economizer at the BKZ 160-100F steam generator
- EEM11: Restoring pumps with hydrophobic coatings.

3. Results of the energy efficiency improvement potential

3.1 Energy efficiency potential at CHP1

Combined the proposed energy savings measures reduce energy and fuel use by an estimated:

- Electricity: more than 4,845,000 kWh/year;
- Heat: 17,247 Gcal per year;
- Natural gas: 1,755,000 m^3/year.

Implementing the proposed energy saving measures will also reduce the carbon dioxide emissions by 12,304 tons per year. The information about savings achieved and distributed by measures are presented in table 1.

Table 1. Energy and fuel savings and SOx emission reduction (in physical terms) (CHP1)

EEM	Electricity kWh/yr	Heat Gcal/yr	Fuel thousands m^3/yr	Fuel due to heat savings, thousands m^3/yr	Total savings thousands m^3/yr	Payback yr
1	-88,000	16,608		2,487	2,487	1.20
2	1,938,000					0.75
3	735,600					14.22
4	2,220,000					9.58
5			1,755		1,755	4.46
6		354		43	43	9.19
7		244		30	30	9.97
8	40,110					1.79

According to these preliminary estimates, and based on the average equipment prices in Eastern Europe, seven of the eight proposed CHP energy efficiency measures have a payback period of 0.75 to 9.97 years and three measures have a payback period of up to 1.79 years.

It should be noted that CHP-1 staff suggested that hydrophobic coatings should be considered for only the clarified water pumps. However, CHP-1 has a large fleet of other pumps (network pumps, feed pumps, etc.), and applying hydrophobic coatings to all pumps could save up to 400 - 500 MWh of electricity per year.

In addition, due to the short payback period for installing an additional economizer and waste-heat recovery boiler, it is advisable to install such equipment on all boilers that operate for more than 2,000 hours per year.

Fig. 1 presents information on the expected energy savings from the introduction of the measures. It can be seen that the biggest share of energy savings is measures 1 and 5.

Fig. 2 is a representation, in percentage, of the expected energy savings achieved as a result of energy efficiency measure implementation.

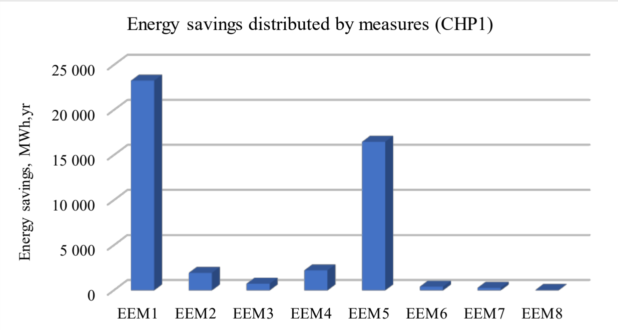

Fig 1. Estimated energy savings distributed by measures

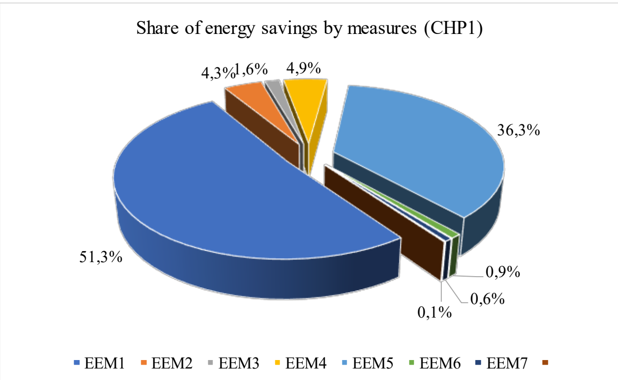

Fig 2. Share of energy savings by measures

3.2 Energy efficiency potential at CHP2

In total, if implemented, the proposed energy-saving measures would reduce the CHP's annual consumption by:

- Electricity by 8,502,000 kWh;
- Coal by about 60,000 tons.

In addition, reconstructing the PT-80-130/13 steam turbine would also provide additional electricity generation of an estimated 65,000,000 kWh per year while reducing fuel consumption.

Information about achieved and distributed savings by measures are presented in table 2.

Based on the preliminary estimates, the proposed energy efficiency measures for CHP-2 have a payback period of 1.50 to 7.86 years. Three measures have a payback period of less than 4 years.

Fig. 3 presents information on the expected energy savings from the introduction of the measures. It can be seen that the biggest share of energy savings is measures 1, 4 and 5.

Fig. 4 is a representation, in percentage, the expected energy savings achieved as a results of energy efficiency measure implementation.

Table 2. Energy and fuel savings and SOx emission reduction (in physical terms) (CHP2)

EEM	Electricity kWh/yr	Heat Gcal/yr	Fuel thousands m^3/yr	Fuel due to heat savings, thousands m^3/yr	Total savings thousands m^3/yr	Payback yr
1	1,148,619		6,426		6,426	3.76
2	2,000,000					7.86
3	5,000,000					6.23
4			8,659		8,659	7.15
5			44,721		44,721	1.50
6	352,996					2.03

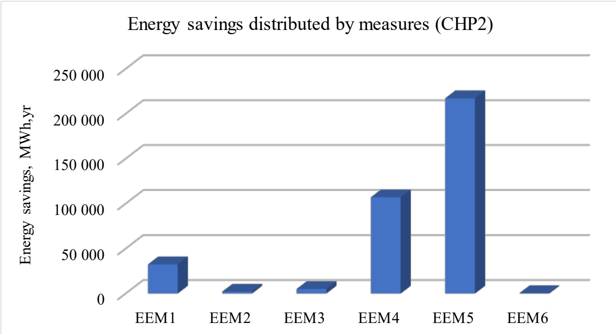

Fig 3. Estimated energy savings distributed by measures

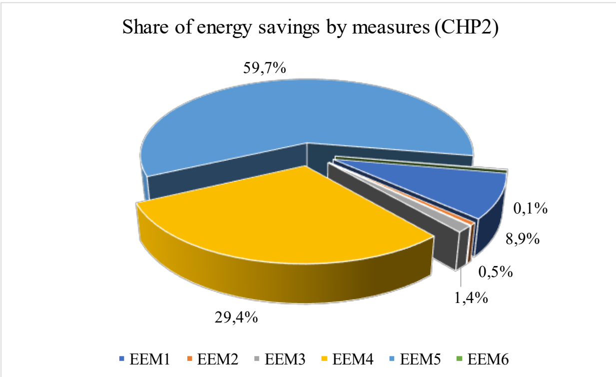

Fig 4. Share of energy savings by measures

3.3 Energy efficiency potential at CHP3

In total, the proposed energy-saving measures are estimated to reduce annual consumption of:

- Electricity by 8,289,000 kWh;
- Heat by 19,079 Gcal;
- Coal by 164,640 tons.

Additionally, replacing the turbines (with the possibility of increasing their capacity from 50 to 57 MW) and the reconstruction of cooling tower No. 5 would lead to an increase in electricity production by 310,200,000 kWh per year while reducing total fuel consumption.

Information about achieved and distributed savings by measures are presented in table 3.

Based on the preliminary estimates, the proposed energy efficiency measures for CHP-3 have a payback period of 0.47 to 12.57 years. Four measures have a payback period of less than 4 years.

Table 4. Energy and fuel savings and SOx emission reduction (in physical terms) (CHP3)

EEM	Electricity kWh/yr	Heat Gcal/yr	Fuel thousands m^3/yr	Fuel due to heat savings, thousands m^3/yr	Total savings thousands m^3/yr	Payback yr
1			3,648		3,648	3.40
2			140,395		140,395	12.57
3	3,767,040		4,824		4,824	2.11
4	771,600		3,417		3,417	6.28
5			12,356		12,356	0.47
6	1,156,400					5.11
7	2,480,000					7.48
8	168,800					7.98
9	86,300					8.48
10	-284,500	19,079		5,145	5,145	17.61
11	143,335					2.84

Fig. 5 presents information on the expected energy savings from the introduction of the measures. It can be seen that the biggest share of energy savings is measures 2, 3 and 5.

Fig. 6 shows, in percentage, the expected energy savings achieved as a results of the implemented energy efficiency measure.

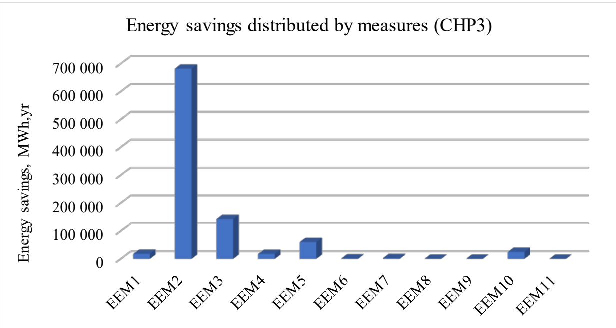

Fig 5. Estimated energy savings distributed by measures

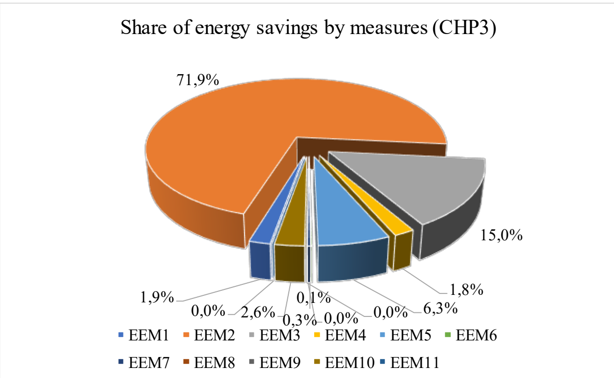

Fig 6. Share of energy savings by measures

3.4 Total energy efficiency potential at CHP1, CH2 and CHP3

From the presented preliminary analyzes, it is clear that the entire package of proposed energy-efficient measures is cost-effective. A summary of the results assessed for three CHPs is shown below.

Fig. 7 presents information on the expected energy savings from the introduction of the measures at each CHP.

Fig. 8 is a representation, in percentage, of the expected energy savings achieved as a results of energy efficiency measure implementation at each CHP.

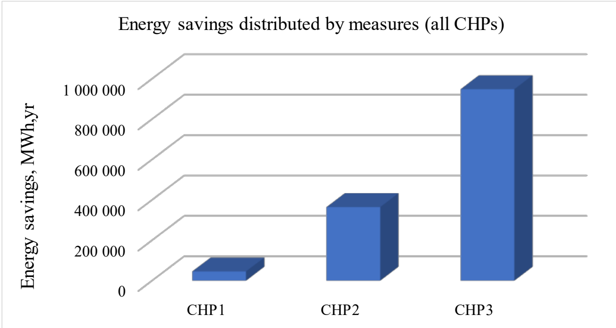

Fig 7. Estimated energy savings distributed by CHPs

4. Environmental impact assessment

When assessing and planning construction projects at facilities used for business activities, special attention must be paid to the possible impact on the environment and human health, which requires the appropriate type of environmental impact assessment (EIA).

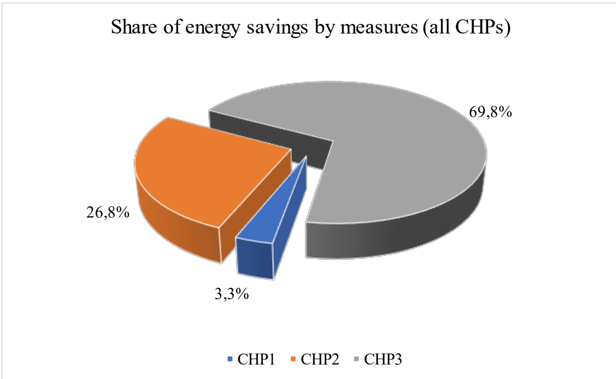

Fig 8. Share of energy savings by measures for all CHPs

In accordance with Article 36 of the Environmental Code of the Republic of Kazakhstan (with amendments and additions as of 01/01/2019), "it is prohibited to develop and implement business projects and other projects that affect the environment without an assessment of the environmental impact. The results of the impact assessment are an integral part of the pre-planning, planning, pre-design and design documentation". Moreover, thermal power plants and other thermal structures with a thermal capacity of 300 MW or more are included in the list of facilities and activities for which a detailed impact assessment is recommended.

Under the National Environmental Policy Act (NEPA) of the United States, there are three main determinations about the potential environmental impact of the project:

- Categorical Exclusion
- Negative Determination with Conditions
- Positive Determination

Summarizing the above analysis of the regulatory situation, we can conclude that, in accordance with the legislation of the Republic of Kazakhstan and in accordance with the US federal regulatory framework, there is no need to develop detailed environmental documentation (Pre-EIA, Environmental Assessment) at this stage of the project. However, should the decision be made to implement the proposed measures, such documentation will have to be developed as part of the pre-feasibility or full feasibility study.

Positive environmental, sanitary-epidemiological and social effects of the implementation of the proposed energy efficiency measures for the Almaty CHPs are indicated below. The project's main environmental effect is likely to be the significant reduction in emissions of carbon dioxide, sulfur oxides and other pollutants into the atmosphere. To facilitate the analysis and assessment of future environmental impacts, the Project experts carried out preliminary estimates of emission reductions for each of the proposed measures. Results for carbon dioxide are shown in Table 5.

Table 5. Carbon and sulfur emissions reduction

EEM	CO_2 emissions reduction t/yr	SOx emissions reduction t/yr
CHP1		
1	5,588	
2	1,012	
3	384	
4	1,159	
5	3,975	
6	98	
7	67	
8	21	
CHP2		
1	11,269	90
2	1,044	
3	2,610	
4	14,378	121
5	74,254	626
6	184	
CHP3		
1	6,058	51
2	233,112	1,966
3	9,976	68
4	6,076	48
5	20,516	173
6	604	
7	1,295	
8	88	
9	45	
10	8,543	72
11	75	

Fig. 9 presents information on the expected carbon and sulfur emission after the implementation of the EEM at each CHP.

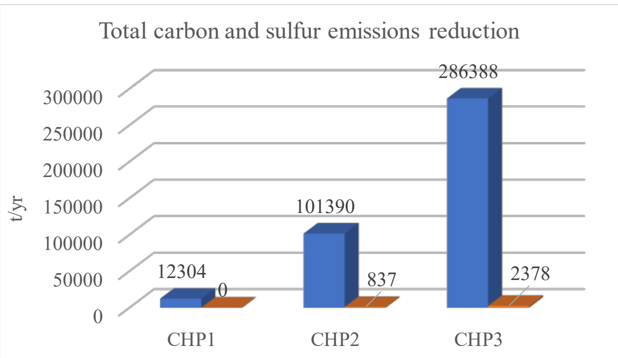

Fig 9. Total carbon and sulfur emissions reduction at each CHP

5. Conclusion

The assessment of the energy efficiency potential at CHP-1, CHP-2 and CHP-3 showed that:

- Both the CHPs main equipment (boilers, turbines, generators), and auxiliary equipment are old and depreciated (and physical deteriorated)
- All CHPs have very limited and typically outdated systems for automating the plant's technical processes (except for a few exceptions, such as KA No. 8 at CHP-2)
- All CHPs have very high auxiliary consumption of electricity and heat, which significantly affects the cost of electricity and heat production. Indicators of auxiliary consumption of energy are several times higher than those of CHPs with similar technological equipment in countries in Eastern Europe, where in the last 20 years significant investments were made in energy savings and energy efficiency
- CHP-1, CHP-2 and CHP-3 each have enormous potential for improving their energy efficiency and automating technical processes, which will lead to a significant reduction in the cost of electricity and heat production and will increase the reliability of power supply to Almaty consumers
- Based on preliminary and rather conservative technical and economic assumptions and analysis, 25 energy efficiency measures are proposed. They would make a significant contribution to reducing the cost of producing electricity and heat and modernize all three CHP plants. The measures would result in an expected reduction in the consumption of:

- Electricity by more than 21,636,000 kWh/year;
- Heat by 36,326 Gcal/year;
- Natural gas by 1,755,000 m^3/year;
- Coal by 224,725 tons/year.

- Implementing the proposed energy saving measures will lead, in particular, to the reduction of emissions:

- Sulfur oxide by 3,215 tons/year;
- Carbon dioxide by 402,431 tons/year.

- The proposed energy efficiency measures include 25 investment proposals, 12 of which have a payback period of 0.47 to 5.11 years. Moreover, the energy efficiency measures can be implemented in a period of few months. The measures are recommended by the Project experts for further in-depth technical and economic analysis with the goal of being implemented.

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