GOCE DELCEV UNIVERSITY, STIP, NORTH MACEDONIA
FACULTY OF ELECTRICAL ENGINEERING

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PREFACE

The Faculty of Electrical Engineering at University Goce Delcev (UGD), has organized the Second International Conference ***Electrical Engineering, Informatics, Machinery and Automation - Technical Sciences applied in Economy, Education and Industry-ETIMA*****.**
ETIMA has a goal to gather the scientists, professors, experts, and professionals from the field of technical sciences in one place as a forum for exchanging the ideas, strengthening the multidisciplinary research and cooperation, and promoting the achievements of technology and its impact on every aspect of living. We hope that this conference will continue to be a venue for presenting the latest research results and developments on the field of technology.
Conference ETIMA was held as online conference. More than sixty colleagues contributed to this event, from five different countries with more than thirty papers.
We would like to express our gratitude to all the colleagues, who contributed to the success of ETIMA'23 by presenting the results of their current research and by launching the new ideas through many fruitful discussions.
We invite you and your colleague to attend ETIMA Conference in the future as well. One should believe that next time we will have opportunity to meet each other and exchange ideas, scientific knowledge and useful information as well as to involve as much as possible the young researchers into this scientific event.

The Organizing Committee of the Conference

ПРЕДГОВОР

Меѓународната конференција ***Електротехника, Технологија, Информатика, Машинство и Автоматика-технички науки во служба на економија, образование и индустрија-ЕТИМА*** е организирана од страна на Електротехничкиот факултет при Универзитетот „Гоце Делчев“.
ЕТИМА има за цел да ги собере на едно место научниците, професорите, експертите и професионалците од полето на техничките науки и да претставува форум за размена на идеи, да го зајканува мултидисциплинарното истражување и соработка и да ги промовира технолошките достигнувања и нивното влијание врз секој аспект од живеењето. Се надеваме дека оваа конференција ќе продолжи да биде настан на кој ќе се презентираат најновите резултати од истражувањата и развојот на полето на технологијата.
Конференцијата ЕТИМА се одржа online и на неа дадоа свој придонес повеќе од шеесет автори од пет различни земји со повеќе од триесет труда.
Сакаме да ја искажеме нашата благодарност до сите колеги кои придонесоа за успехот на ЕТИМА'23 со презентирање на резултати од нивните тековни истражувања и со лансирање на нови идеи преку многу плодни дискусии.

Организационен одбор на конференцијата

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COMPARATIVE ENVIRONMENTAL ANALYSIS BETWEEN CONVENTIONAL AND COGENERATION GAS-FIRED CENTRAL HEATING SYSTEMS

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Abstract

Heating power plants are the major source of hot water intended for heating of communal areas or districts, or even whole cities for any developed country on a large scale. The usual concept for conventional heating power plants is burning fuel into combustible chambers called boilers and production of heat in the form of hot water. Then, using already developed heat network consisted of pipes and pumps, the hot water is distributed to final customers. At the cogeneration power plants, the process is almost similar, with the major difference that in the boilers instead of hot water, the so-called superheated water vapor is generated which initially is used in the steam turbines for electricity generation, and later the exhausted steam is re-used using condensers for production of heat in the form of hot water for central heating purposes.

In this paper, the authors present comparative environmental analysis between two gas-fired plants used for central heating of the city of Skopje. The first one is the conventional gas-fired heating plant which has only one product, hot water for central heating purposes. The second power plant is cogeneration gas-fired power plant; thus, it simultaneously generates electricity and heat used for central heating. Since 2013, both plants use natural gas as primary fuel, which although still a fossil fuel, is less polluting and environmentally more acceptable. The obtained results of the analysis and comparison between both power plants are given in details showing that both plants are within the prescribed environmental regulations.

Key words

heating power plants, central heating, cogeneration, environment protection, pollution

Introduction

The conducted research indicates analyzed one of the most important heating plants in the main town in our country. One heating plant is intended only for central heating, while the other one is cogeneration power plant intended to generate both, the electricity and the heat, simultaneously. In this analysis, particular attention is paid to the environment impact of both power plants. Heating plants are the major source of public heat in various developing country, using primary fuel, usually coal or fuel oil burnt inside the combustible chambers/boilers at high temperature and generating heat energy. The heating plant has serious negative environmental impacts on soil, air and wastewater, and emits a large amount of CO_2 particles aggravating the surrounding environment. Various mitigation measures for the control of pollution caused by heating plants along with some new technologies have already been discussed.

The conventional heating power plant (HP) "West" treated in this analysis until 2013 used fuel oil as primary fuel. However, during 2013 a replacement of the fuel oil as primary fuel with natural gas occurred, keeping fuel oil as reserve or backup fuel in case of emergency. On other side, the cogeneration plant TE-TO, also treated for comparison in this analysis, uses only natural gas as primary fuel. Natural gas is a fossil fuel, nonetheless the global pollution emissions during its combustion, especially particles, CO_2 and NO_X emissions are much lower in comparison with fuel oil and especially coal. This fact enables us to make comparison between environmental impacts of both plants using the same primary fuel. Detailed presentation of the operation system and distribution of heat energy for both plants are presented.

Research methodology

As a basic methodology for researching the problem, elaboration, evaluation and proposing measures that can improve the process, initially we used the usual concept of an Environmental Impact Assessment (EIA) with Sustainable Development Analysis (SDA) and Sustainable Development Goals (SDGs) [1]. This methodology allows us to make comparative analysis between both generation plants and provides an easy tool for analyzing advantages and disadvantages of each of them independently. To use the proposed methodologies, a system analysis needs to be performed for the system under consideration. Speaking about the system, we follow the definition *"a system is a set of components and the connections between them"* as given in [1], or simply said, we consider all relevant parts of the system, such as, the input to the system *(e. g. material, energy, information)*, the type of transformations that will occur within the system and the output to the system that needs to be analyzed.

Case-study

General information about the companies

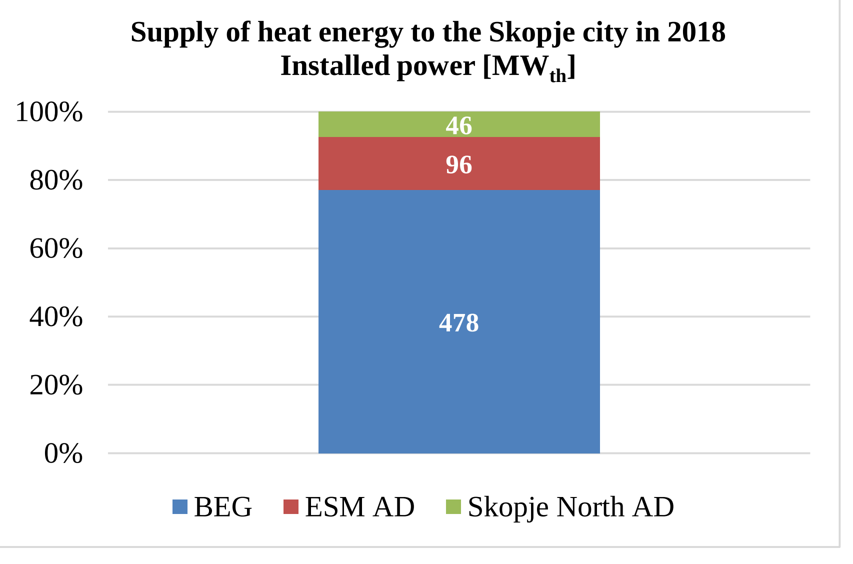

Figure 1: Participation with heat energy of the three heating systems of the Skopje city in 2018 [2]

Figure 1 shows the total required heating energy for 2018. The BEG has the largest share with an installed production capacity of 478 MW_{th}, followed by ESM AD with 96 MW_{th}, and Skopje North AD with only 46 MW_{th}, [2]. The percentage share of heating energy from BEG is approximately 75%, and it can be concluded that the importance of this company is the largest in the central heating of the city of Skopje.

The BEG company has three heating plants for heat energy production, two of which are active, with a total installed power of 470.19 MW_{th} (100%):

1. Heating plant (HP) "East", located in the eastern industrial zone of the city, installed heat power of 279.12 MW_{th} (58%), and steam power of 16.30 MW.
2. HP "West", located in the municipality Taftalidze with installed heat power of 162.82 MW_{th} (36%), and steam power of 20.09 MW, and

3. HP “11 October”, located in the Kisela Voda municipality with an installed heat power capacity of 28.25 MW_{th} (6%).

The meaning and impact on the environment of each of the heating plants is equally important, but in order to make a comparative analysis of the environmental characteristics between conventional and cogeneration gas district heating systems, a detailed presentation of the impact itself will be analyzed only on one of the BEG heating plants, the "West" heating plant. This heating plant is designed for the production of heat energy with a total capacity of 182.91 MW [3]. There is an installation of a total of:

- Four superconducting drive units,
- two combined boiler – steam units, and
- one steam propulsion unit.

Two high-flow propulsion units are connected to their own chimney, while the others are connected to a common chimney. This plant is designed in such a way that the transport of flue gases from each hot water boiler to the entrance to the chimney takes place through separate flue ducts for each boiler, but the flue ducts are also run separately even in the multicycle of each boiler. The remaining flue gases from the other boilers are removed through a common collection flue channel with a special opening on the chimney.

The plant has also additional (auxiliary) boilers:

- one boiler for combined production (steam – hot water), which can change the mode of operation in a very short time. This boiler can be used for the production of heat in the central system and for meeting one's own energy needs in the plant itself, and
- two steam boilers.

During the preparation of the application for obtaining of the unified A-type environmental permit, the old heating burners that work on fuel oil were substituted with natural gas burners. Today, natural gas is mainly used as a burning fuel, while fuel oil is used only as a backup fuel.

The other plant used for environmental comparison, the TE-TO company is a cogeneration power plant with production of electricity and heat in the so-called combined cycle and uses only natural gas as fuel. This power plant is in the eastern industrial zone of Skopje city. The installed capacity of this power plant is 220 MW_{el} electric power and 160 MW_{th} heat power.

The combined cycle involves the use of waste heat produced by the gas turbine for steam generation in the so-called heat recovery steam generator (HRSG) for driving the steam turbine and electric generator. This enables better utilization of primary fuel energy which usually exceeds 50%, significantly higher than the efficiency of conventional electricity generation power plants. Additionally, after utilization of the steam in the steam turbine for electricity generation, the heat energy that the steam still retains is used for generation of heat for heating purposes using energy conversion unit (the condenser). In that way, the total utilization factor of the primary fuels rises additionally above 75%.

This cogeneration plant is designed to work in two modes:

- **Cogeneration mode** (simultaneous production of electricity and heat energy), when the efficiency of the power plant in this mode of operation is over 75%. The produced heat is delivered as hot water to the public heating distribution system in the city of Skopje.
- **Condensation mode** (electricity production only), when energy efficiency is on average around 50%.

In addition to the improve utilization factor for the primary fuel, an additional environmental advantage of the TE-TO plant compared to conventional power plants is the use of a hybrid cooling tower instead of a conventional wet cooling tower in the water-cooling process. This concept, which is also being applied for the first time in the country, has environmental benefits due to reduced water consumption and the occurrence of fog associated with the evaporation of cooling water from the towers. Table 1 summarizes the main technical data for the TE-TO installation.

Table 1: Basic project technical data for TE-TO

	Units	Data
Electricity production capacity		
– Gross	MWel	around 220 to 240
– Net	MWel	around 214 to 234
Mode of operation		basic work with approx. 8,300 h/annual operating hours
Heating production capacity	MWth	max.160
Fuel		
– Type	-	Natural gas
– LHV	MJ/Nm^3	36
– Consumption	Nm^3/h	About 52,000
Expected emissions dry, at 15% O_2		
– NOx emissions	mg/Nm^3	< 75
– CO_2 emissions	mg/Nm^3	< 100

Source: [4]

Heat Distribution

The distribution of heat energy is carried out by a two-pipe distribution network (DN) from the point of receipt of the produced heat energy, through the main connecting lines and heating stations to the place where the heat is delivered for heating of the end consumers. The transport of natural gas as a separate part of the distribution to HP "West" takes place via the natural gas pipeline network that passes through the city of Skopje. Some main technical characteristics of the existing DN are shown in Table 2. We could notice that the length of the DN is almost 400 km with normal pressure of 16 bars.

Table 2: Technical characteristics of a distribution system

Distribution system of pipelines	**Two-pipe distribution system**
Length of the distribution network	cca 200 km (400 km pipelines)
Primary side temperature mode	110/65 °C
Nominal pressure	16 bar
Annually distributed heating energy	500 GWh

Source: [5]

During distribution, chemically prepared and diaurated water is used through the supply and return pipelines. Technical water used in the process of heat energy production and with which energy is transferred to the end users is softened by ion exchange with ion exchange resins, whereby the calcium and magnesium ions that define the hardness of the water are removed. The gases (mainly O_2 and CO_2) are then removed in a high vacuum deaeration plant. Softened and diaurated water is stored in expansion supply tanks. During the preparation of the chemical and diaurated water, there are waste particles as a residue that have a negative impact on the environment [6].

Pros & Cont analysis of fuel oil and natural gas

As previously stated, the HP "West" which is the subject of this analysis, until 2013 operated on fuel oil to produce heat energy. Then, the plant has been repowered using natural gas as an energy source, and it should be noted that all burners are adapted to burn both fuel oil and natural gas. Since 2014, due to the huge positive aspects that characterize natural gas, fuel oil has been set only as a backup fuel, while the plants continue to operate using only natural gas.

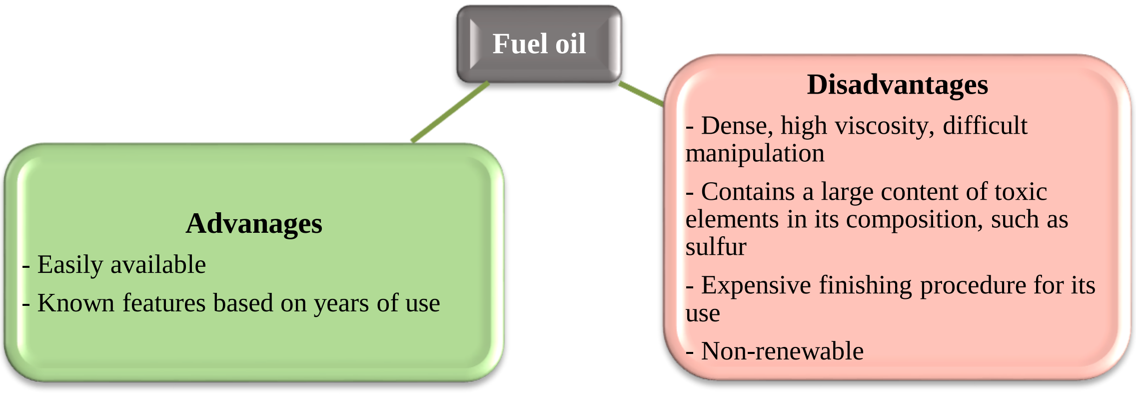

Figure 2: Advantages and disadvantages of fuel oil

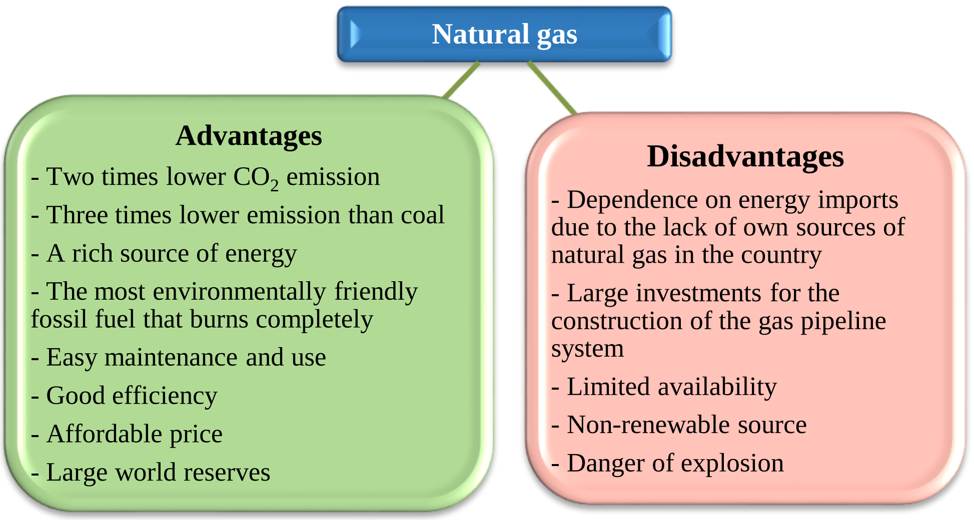

Figure 3: Advantages and disadvantages of natural gas

Figures 2 and 3 show the main advantages and disadvantages of fuel oil and natural gas. It can be concluded that natural gas has more advantages than fuel oil. Fuel oil is a fuel that has been used in the country for many years, while natural gas can be considered as a *"new"* fuel because it has been used on a large scale only in the last several years, despite the large world reserves. One of the reasons or shortcomings of this energy source is that there are no existing sources of natural gas in the territory of the Republic of North Macedonia, so the country is entirely dependent on imports.

The biggest advantage of natural gas is that it is the cleanest fossil fuel. It does not contain SO_X in its composition, so it follows that there will be no SO_2 emissions in the combustion products.

Unlike natural gas, when fuel oil is burned, there is a large amount of SO_2 in the combustion products. SO_2 in contact with hydrogen creates sulfuric acid, which is not suitable for the plant and for the heating energy production process itself, thus natural gas is much more environmentally friendly.

Research results and discussion

Analysis of NOx emissions and reduction proposals

Table 3 shows data for annually delivered heat energy and emissions of NO_X from 2014 to 2019, according to the BEG company. The reason why the emissions after 2014 were analyzed is that after 2014 only natural gas is used as primary fuel. Since NO_X emissions are significant, we recommend the installation of gas burners with ultra-low NO_X emissions with < 30 [mg/kWh]. A good example of such burners are the burners produced by the Weishaupt burner company, like WM-G10 ZM-PLN and/or WM-G20 ZM-PLN [7]. The calculations in the table were given in case the burners with NO_X emissions < 30 [mg/kWh] were installed in HP "West" from 2014 to 2019. The reduction of annual NO_X emissions could be at least 4 times lower when using gas burners with ultra-low NO_X.

Table 3: NO_X emission: real, measured values and values in case of using ultra-low NO_X burners,

	Delivered heat energy into distribution network	Emissions	
		NO_X - Measured	NO_X in case of using ulta-low NO_X burners with <30 [mg/kWh]
	[MWh]	[t/year]	[t/year]
2014	112,864	29.17	3.39
2015	109,381	23.18	3.28
2016	115,473	15.72	3.46
2017	140,233	19.09	4.21
2018	124,698	17.02	3.74
2019	108,968	13.14	3.27

Source: BEG

Emissions of CO_2

Table 4 shows annual emissions of CO_2 obtained by using different types of fuel. The values of emissions in tCO_2/MWh are taken from the Regulator for Energy Control [8]. The value of 125,526 MWh/year is the annual thermal energy production by the HP "West" in 2018 [9].

Table 4: Emissions of CO_2

Emissions of CO_2			
Fuel	tCO_2/MWh	MWh/year	tCO_2/year
Heating energy (central heating)	0.259	125,526	32,511
Individual heating with natural gas	0.202	125,526	25,356
Individual heating with fuel oil	0.279	125,526	35,022
Individual heating with electricity	0.915	125,526	114,856
Individual heating with lignite (brown coal)	0.364	125,526	45,691

Source: BEG, [8] [9]

Figure 4 shows the types of energy sources that can be used to obtain heat energy and the value of annual CO_2 emissions. It can be noted that individual use of natural gas in each household would result in the lowest possible emissions of CO_2. However, considering that there is no natural gas distribution pipeline network in the city of Skopje delivering natural gas to every household, central heating remains the best option for obtaining thermal energy. It is interesting to mention that the use of electricity enables the largest emission of CO_2. Although the emission of CO_2 is not directly hazardous for human health, it is significant because of its contribution to the greenhouse effect creation. Additionally, the emission of other harmful substances should also be analyzed, however, that was not part of our analysis.

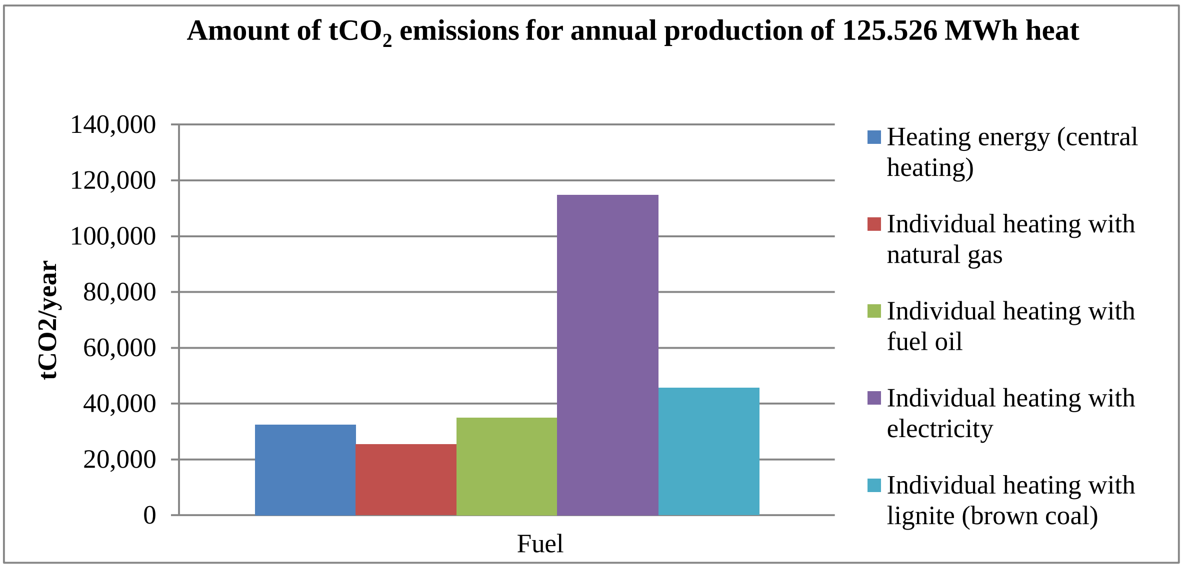

Figure 4: CO_2 emissions from different fuel sources for annual production of 125.526 MWh of heat

Source: BEG, [8] [9]

Comparison between fuel oil and natural gas

A comparison of these two energy sources, fuel oil and natural gas, in relation to emissions of pollutants such as CO_2, NO_X and SO_2 when burning 1 kg of fuel for heat generation are presented in Figure 6, where the values of the CO_2 emission of fuel oil and natural gas per kWh heat energy are 0.278 kg/kWh, and 0.202 kg/kWh, respectively [11], [12].

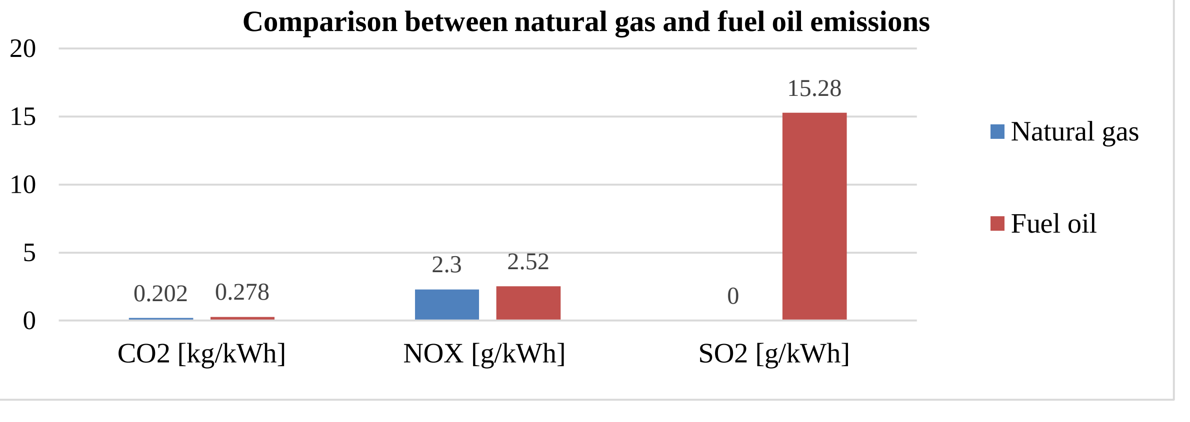

Figure 6: Comparison between natural gas and fuel oil emissions per kWh generated [11]

As shown in Figure 6, the emission of NO_X burning fuel oil is also higher compared to natural gas. Although there are no huge differences in emissions, even this small difference could be significant when it comes to environmental protection. Unlike the emission of CO_2 and NO_X, when it comes to the emission values for SO_2, there is a significantly large difference between these two fuels, that is the main reason and a decisive factor to switch primary fuel from fuel oil to natural gas. The amount of primary fuel per year before and after transformation from fuel oil to natural gas is shown in Figure 7.

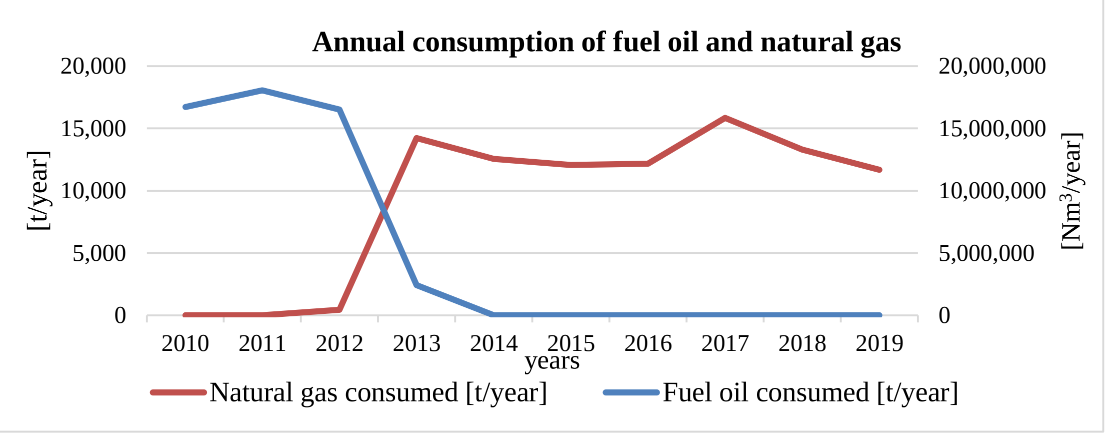

Figure 7: Annual consumption of fuel oil and natural gas from 2010 to 2019 [11]

Distribution of heat energy – Environmental impact

During the distribution of heat energy through pipelines, water, which is the carrier of the heat, is in contact with the pipelines which are buried in the ground. It is obvious that at the slightest damage to the pipeline, there is a possibility of direct contact of the water that carries heat with the soil, as well as potential underground and/or surface water.

According to BEG company, due to water losses in the DN, water is constantly replenished. In the last 4 years, i.e. after 2015, in order not to use drinking water, the DN was fed from a well within the HP “East”. According to the obtained data of BEG on the addition of water to the HP “West” DN, the amount of added water in the distribution system for different years (2010-2019) was given in Figure 5.

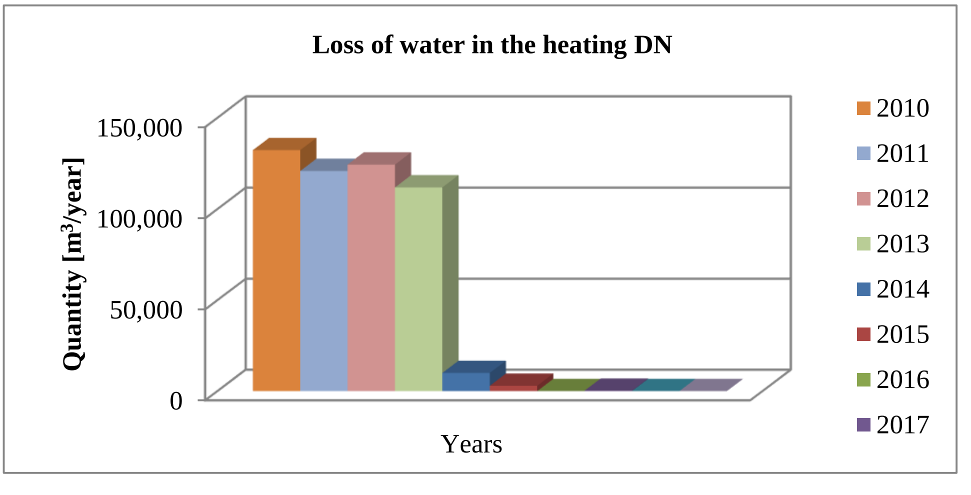

Figure 5: Loss of water during distribution of heat in the heating DN

The hot water that carries heat has a pressure higher than atmospheric at temperature of about 90°C at the exit from the plant and 70°C at the return to the plant. This, the water may contain some mechanical and chemical impurities and agents that can negatively affect the environment. Suggested measures to eliminate or reduce these pollutants could be:

- Installation of filters in the DN,
- Use of flow meters along the length of the DN to detect sinkholes, and
- Remedy of possible breakdowns in the DN

Possible impacts of waste on the environment

According to the data provided in the regulation [9], waste can be temporarily stored at the location itself until the arrival of an authorized person who will take it over. Storage takes place in accordance with all legal requirements. The conditions of waste storage depend on the type of waste itself and could be clasified as:

- Waste that must not be washed into the soil, such as:
  - scrap iron,
  - sludge from washing boilers, and
  - Stack filter deposits.
- Waste that is not allowed to be washed into the soil and with the possibility of external ciculations, such as:
  - motor oil,
  - filters, towels, etc.,
  - packaging waste, and
  - packaging wast from any raw materials.

Disposing of waste in an inappropriate place can cause negative impacts on the environment such as soil, ground water and wastewater pollutions. If there is a large amount of waste oil in this waste, it can penetrate into the soil and cause the extinction of the live in the soil. The waste must be taken to appropriate landfills after being collected by the competent companies. Waste that can be recycled is separated and selected at landfills.

Potential Achievements of the Sustainable Development Goals (SDG)

Due to their nature, both power plants under this analysis have an impact on the fulfillment of all SDGs [10]. However, the focus of the research was their impact on the HP "West" especially for the following SDG goals:

- SDG 6 – Clean water and Sanitation,
- SDG 7 – Affordable and Clean Energy,
- SDG 8 – Decent Work and Economy Growth,
- SDG 9 – Industry, Innovation and Infrastructure,
- SDG 11 – Sustainable Cities and Communities, and
- SDG 13 – Climate Action.

The impact on **SDG 6** is negative because the quality of the water used is changing. Most of the wastewater is generated when washing boilers, but this only happens when heating oil is used as fuel. Wastewater is properly treated before being discharged into the sewer system. Pollution of surface and underground water is possible. For complete water purification, mechanical, biological and chemical water purification is recommended. In this way, the water can be completely purified, which would have a good quality. Adequate protection should also be provided in the event of improper operation or failure that would lead to pollution of surface or underground water. By applying these measures, the influence of HP "West" would change from negative to positive or neutral.

The impact on **SDG 7** is positive for both power plants from an energy, social and environmental perspective. Using natural gas as a fuel means using an energy source that has a less negative impact on the environment compared to other conventional energy sources. The population has at its disposal heating energy that is produced in such a way that it has a positive and avoiding any negative impact on the environment.

The impact on **SDG 8** is considered mostly from a social aspect, thus a huge positive impact can be noticed, especially on the population living in the city of Skopje. A significant percentage of the population is employed in the heating industry, which has a positive effect on the level of employment in the city of Skopje.

The operation of the plant positively affects **SDG 9**, especially considering increasing the value of the Target 9.2: Global manufacturing value added (MVA) per capita [10].

The existence and functioning of the plant has a huge effect on the sustainability of the city, and thus has a positive impact on **SDG 11**. The existence of the plant is of particular importance for the city of Skopje, due its impact on the generation of heating energy.

The use of natural gas enables reduction of pollution that would occur if another energy source were used to obtain the necessary heat energy, such as coal or fuel oil that was used previously. A positive effect according to **SDG 13** was done only because changing of primary fuel from fuel oil to natural gas was possible and enabled.

Conclusions

Central heating is used in many cities in developed countries, and often in developing countries as well. Natural gas, as a fuel in central heating systems is a frequently used fuel due to a number of advantages it has compared to other used fuels. On the other hand, the fuel oil which was once used in one of the analyzed heating plants and is still used often as an reserved fuel, has numerous environmental disadvantages. According to the results obtained from the made analyzes, it can be concluded that, overall, the impact of this heating plant on the environment is positive for both plants mostly due to recent replacement of primary fuel for the HP "West" from fuel oil to natural gas.

The energy significance of the heating power plants HP "West" and TE-TO Skopje for the city of Skopje is great considering that they produce a significant amount of heating energy that the city needs. If these facilities, or the entire DN for the city's central heating, did not exist, every household would be forced to use its own heating system, which in any case would have additional negative impact on the environment compared to this method of heating.

According to the analysis made from the perspective of three main pillars of sustainable development, social, economic and ecological, it was concluded that in most cases heating plants have positive impacts and effects. The operation of these facilities contributes to the better achievement of SDGs, in particularly SDG 6th , 7th , 8th , 9th , 11th and 13th.

It is obvious that the operation of heating plants results with the emission of CO_2, which negatively affects the ozone layer of the Earth. Therefore, from the analyzes carried out in relation to CO_2 emissions, it was concluded that compared to other types of fuel that would be used to obtain heating energy, the use of natural gas and fuel oil as a secondary or reserve fuel means reduced CO_2 emissions, and additionally a reduced contribution to global warming.

It is evident from the analysis that negative impacts occur only when the heat carrier – in this case hot water – is intentionally or unintentionally discharged out of the pipelines of the DN. A proposal to reduce this negative effect is the installation of filters for purifying the heat carrier, which will reduce/eliminate mechanical contamination of the soil and potentially groundwater. It is also proposed to install multiple flow meters along the length of the pipeline, to identify any water leakage along the DN and repair it quickly and promptly. This investment would be small, however, with great importance for the environment, as well as for the company itself, because the annual costs of maintaining and replenishing the water system would be considerably reduced.

Based on the analysis of the type of waste generated by these plants and the methods of storage, separation, and transportation to the appropriate landfill, in order to reduce or avoid the negative impact on the environment of the generated waste, it is suggested to minimize the generated waste, i.e., reduce it to the smallest possible extent, act appropriately and store in appropriate conditions.

According to the fact that in the past fuel oil was used for production of heat energy, and since 2013 natural gas burners have been installed, a comparison was made between these two types of energy sources. From the discussion it can be concluded that the advantage of using natural gas is huge. Pollution caused by the burning fuel oil which exceeds the permitted limits, has been reduced using natural gas. From the available data, it is evident that the emission of harmful substances into the atmosphere using natural gas instead of fuel oil is within the permissible limits. Although it is within the permissible limits, the emission of NO_X that still exists when using natural gas should not be ignored. In order to minimize NO_X emissions, the proposed measure is the installation of ultra-low NO_X burners, which are available on the market and are used in many plants. This would make the plant a minimal polluter of the environment in respect to the NO_X emissions.

Finally, by reviewing the available data related to the considered heating plants and the analyzes made, it was concluded that in most cases the effect that the conventional and the cogeneration heating plants on the environment is positive and they contribute towards bringing our country closer to the developed countries. Although there are still some negative effects, taking appropriate measures can be reduced or eliminated and thus be good example of how other similar plants should function.

List of abbreviations

BEG – Balkan Energy Group
DN – Distribution network
MOEPP – Ministry of Environment and Physical Planning
SP – Sustainable Development
SDGs – Sustainable Development Goals
HP – Heating plant
EIA – Environmental Impact Assessment

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