

Evaluation of HUHA 2 WtE Plant in the District Heating Supply of Budapest

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Abstract—Urban waste management is an important task of every major city. However, solutions can be very different and international regulations show the way to the most environmentally friendly solution. As it is impossible to reduce municipal solid waste production to zero with reuse, calorific valorisation of urban waste provides the next possible alternative. The economic evaluation of a second waste to energy plant is presented in this paper which would reduce the waste disposal of the Hungarian capital as currently less than 2/3 of the 680000-700000 t/a MSW is recycled or used for energetic purposes with one plant operating. The HUHA 2 plant would provide partially renewable fuel for the district heating system of Budapest and reduce energy supply dependency of the currently heavily natural gas based system. As for all energy-related investments, a thorough economic investigation has to be carried out to facilitate the decision-making. In the current study the feasibility of HUHA 2 is investigated reflecting annuity, fix and operational costs, CO₂ quota and the specific costs of heat and electricity generation. The thermal output connection has been evaluated for various supply zone alternatives.

Keywords—Waste management, waste incineration, economic analysis, district heating, green energy

Nomenclature

Sign	Description	Unit
A _{total}	total annuity	Euro
A _{loan}	annuity of the loan taken	Euro
A _{self-funded}	annuity of the self-funded part	Euro
APR	annual percentage rate of bank loans	1
C _{20years}	Installation cost projected to the end of the life cycle	Euro
C ₀	Installation cost projected at the start	Euro
C _{CO2}	Cost of CO ₂ quota	Euro
C _{fix}	fix costs of operation	Euro
C _{operational}	changing cost of operation	Euro
d	duration of the loan period	years
E _{heat,sold}	heat energy sold in a year by HUHA 2	MWh
E _{electricity,sold}	electricity sold in a year by HUHA 2	MWh

p	unit price of electricity	Euro/kWh
i	nominal interest rate	1
I _{net}	net yearly profit	Euro
F	low heating value of MSW	MJ/kg
FV	future value of investment	Euro
f _{MSW,weight}	specific CO ₂ emissions based on weight unit	kg(CO ₂)/kg (MSW)
f	specific cost of energy	Euro/kWh
f _{heat}	specific cost of heat	Euro/kWh
f _{electricity}	specific cost of electricity	Euro/kWh
n	years of operation	1
NPV	net present value	Euro
m _{MSW}	specific CO ₂ emissions of MSW firing	
PV	present value of investment	Euro
p _{CO2}	price of the CO ₂ quota	Euro/tonne
P _{heat}	heat power of HUHA 2	MW
P _{electricity}	electricity power of HUHA 2	MW
r	inflation rate	1
α	climate neutrality ratio	1
η _{MSW,cogen.}	system efficiency of HUHA 2	1
η _{heat}	efficiency of heat output of HUHA 2	1
η _{electricity}	efficiency of electricity output of HUHA 2	1
Abbreviations		
APR	Annual percentage rate	
CEEGEX	Central Eastern European Gas Exchange	
DH	District heating	
GWP	Global Warming Potential	
HUPX	Hungarian Power Exchange	
HUHA 2	a second planned waste incineration plant in Budapest	

MSW	municipal solid waste
RDF	refuse derived fuel
SRF	solid recovered fuel
WtE	waste to energy

I. INTRODUCTION AND CONTEXT OF STUDY

Globally, 1.3 trillion tonnes of municipal solid waste are generated each year, equivalent to 180 kg per person per year. This is expected to rise to 2.2 trillion tonnes by 2025. In developed countries such as members of the European Union and the USA, this figure is significantly higher. Waste management is therefore regulated on European level and action plans have been set to optimise the treatment of waste. According to the EU regulatory framework, the most efficient waste management methods are prevention, recycling and energy recovery. To avoid is landfilling of municipal solid waste due to space requirements, the release of unused methane from decomposition into the atmosphere and further aesthetic and environmental impacts. The GWP of methane is twenty-five times that of CO₂, making it a significantly bigger problem for global warming. In addition to environmental impacts, reducing energy dependency has recently become a major concern for European countries due to the Russian-Ukrainian war, which has led to severe gas price increases and security of supply problems. European countries have put substantial efforts and investments to improve their management efficiency of energy from waste and align to CE. Gatto [1] developed a composite indicator to calculate European countries' achievements in this regard. A set of statistical techniques is employed to analyse a large panel dataset of 17 countries and 14 energy efficiency variables for 15 years. Denmark, the Netherlands, Austria, the UK and Germany get positive outcomes. Conversely, the remaining 12 European countries get negative performances at the global level. In Budapest, Hungary significant improvement could be reached with the construction of a second waste-to-energy power plant, as currently less than 2/3 of the 680000-700000 t/a MSW is recycled or used for energetic purposes with one plant operating.

II. CONTEXT OF STUDY AND STATE OF ART

In this paper, an economic analysis of the establishment of a second incineration plant (HUHA 2) in Budapest is presented, taking into account the evolution of international gas prices. This study is the first step of an extensive research on the improvement WtE share in the district heating system of Budapest. A preliminary study was made in 2017 which primarily targeted the siting optimisation of HUHA 2. The current study goes into deeper details of the economic assessment, actualised for the economic situation of 2024. Further chapters of the research are a logistical optimisation of waste transportation into the HUHA 2 plant, a thermo-energetic assessment of the integration of HUHA 2 into the district heating system of Budapest, as well as a machine learning based DH demand forecasting for optimal operation of the HUHA 2 plant.

The site for HUHA 2 has already defined by the time of this study in south-east Budapest based on a previous siting study. [2] The plant to be installed was compared with three natural gas based power plants: *Kelenföld*, *Kispesti* and *Csepel*, which currently supply the targeted district heating networks. Fig. 1 shows that although the total amount of MSW produced in Hungary is decreasing, there is still a significant

amount of waste going to landfill. The plant has an annual incineration capacity of 230 000 t MSW, which can be further increased by the installation of a pre-sorting plant. For separation, a pre-sorter was assumed in the power plant that converts the MSW into RDF or SRF, greatly increasing its calorific value. The calorific value of MSW ranges from 7.5 to 10.5 MJ/kg, whereas the calorific value of SRF/RDF ranges from 19 to 21 MJ/kg. [3]

HUHA 2 could connect to the district heating network of Budapest in four alternatives:

- To the *Kelenföld* subsystem
- To the *Csepel-Pesterzsébet* subsystem
- To the *Kispest-Kőbánya* subsystem or
- To the unified district heating system of Budapest.

In the current study, first it is assumed that by the realisation of HUHA 2, the now independent DH subsystems will be interconnected (a target of Budapest DH provider company) and the new plant can be connected to the unified Budapest DH network. In this state, the plant would operate as a base-load heat and power plant with a thermal output of 55 MW and an associated electrical output of 14.6 MW for most of the year. At the end of this work, the supply of the individual DH supply zones will be evaluated.

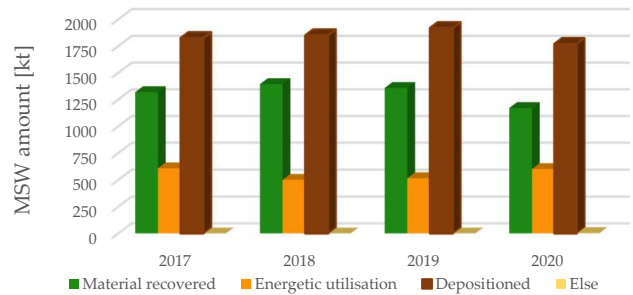


Fig. 1. MSW amount charactzerised by processign methods [3]

For comparison, the waste-to-energy plant *Spittelau* in Vienna, Austria is capable to treat 250 000 t/a MSW, produces 60 GWh/a electricity and 500 GWh/a heat.

III. METHODOLOGY

As a first step, the investment costs were determined. Original investment costs estimated in 2017 by an individual bid have been actualised by the rate of inflation (57.9 %) to make investment cost assumptions for 2024, as it can be seen in TABLE I. [5] TABLE I.

TABLE I. ADJUSTED INSTALLATION COSTS

	Investment costs [million Euros]	
	2017	2024
Waste pre-separator	3.38	5.33
Plant installation	211.98	334.72
DH connection	27.79	43.88
Total	243.15	383.94

A. Annuity

Once the investment costs have been determined, the annuity for the investment has to be calculated, which allows the determination of the projected costs for each year of

operation. For the annuity calculation the inflation rate was set at 7%, while the nominal interest rate to be 5%. The investment was split into a co-financed and a loan-backed part, which was then adjusted for inflation over the 20-year period. The future values were calculated first following the logic above:

$$FV = C_0 * (1 + i)^n \quad (1)$$

The present value of the annuities can be determined using the following formula:

$$PV = FV * \frac{1 - \frac{1}{(1 + r)^n}}{r} \quad (2)$$

Using the present value the capital value of the investment can be calculated at the end of the investment time period, in our case 20 years. The annual economic returns can be derived from the data made available by the previous step.

$$A = C_{20yrs} \frac{i - r}{(1 + i)^n - (1 + r)^n} \quad (3)$$

The resulting annual return, adjusted for inflation, was determined for each year of operation. The same steps were carried out for the self-funded part of the investment contribution (excluding, of course, the interest on the loan), and the resulting values were summed for each year to obtain its total yearly annuity.

$$A_{total} = A_{loan} + A_{self\ funded} \quad (4)$$

B. Fix and operational costs

For the fixed costs, a similar logic has been followed as for the investment cost, adjusting most costs for inflation, such as maintenance, labour, etc. The variable costs specification is more challenging to acquire as energy prices could not be determined on the same basis as presented above. Transport costs were calculated based on the change in fuel prices recorded by the Hungarian National Tax- and Customs Office (NAV), and for electricity revenues the Hungarian Power Exchanges (HUPX) track record data have been utilised for the current European market prices, which at the time of writing the study was 78,2 €/MWh. This value was obtained by aggregating and averaging the quarter hourly electricity prices in 2024 up to the date of the study. [6][7][8] Similarly, the international gas price was determined using the Central Eastern European Gas Exchanges (CEEGEX) data, which is 24,6 €/MWh.

C. Cost of CO₂ Quota

As MSW incineration plants benefit from a 50 % renewable status by the Hungarian regulations, the CO₂ quota price can significantly influence the operational cost edge these power plants can provide compared to other, fossil fuel based ones.

$$C_{CO2} = \frac{(E_{heat,sold.} + E_{heat,sold.}) * \frac{\dot{m}_{MSW}}{10^6}}{\eta_{MSW,cogeneration}} * p_{CO2} \quad (5)$$

To determine the cost of the quota, we first need to know what the specific emissions of MSW firing are.

$$\dot{m}_{MSW} = \frac{(1 - \alpha) * f_{MSW,weight}}{F} \quad (6)$$

The value of the climate neutrality ratio is $\alpha = 0.5$ according to the Hungarian regulations. α indicates that the part of the energy produced by the power plant is considered to be renewable energy and thus exempt from CO₂ quota prices and emissions.

The specific mass fraction of CO₂ emissions based on the CEWEP report is $f_{MSW,weight} = 0.9$ ton (CO₂)/kg(MSW). [9] Assuming a calorific value of 8 MJ/kg for MSW, the specific CO₂ emissions were calculated as $\dot{m}_{MSW} = 202.5$ g/kWh. [10] From this the previously required CO₂ quota costs can be calculated. The quota price is currently 56.37 Euro/ton(CO₂). [11] This value is much higher than in 2017 (12.98 Euro) and though it has been in a downward trend for a couple of months the costs associated with it can still be of formidable size. The cost of quotas for the MSW has become 2.1 million Euros per year. The coupled efficiency of HUHA 2 is 80.9% based on the projected electricity and heat output performances, with 63.9% for heat and 16.9% for electricity. The CO₂ quota cost of natural gas-fired power plants can be obtained following the same logic, the combined efficiency of gas turbine power plants is assumed to be 0.8.

The specific CO₂ emissions of natural gas was calculated using a stoichiometric equation and the specific heat value:



$$16 \frac{g}{mol} + 2 * 32 \frac{g}{mol} \rightarrow 44 \frac{g}{mol} + 2 * 18 \frac{g}{mol} \quad (8)$$

$$16g\ CO_2 \rightarrow 44g\ CO_2 \quad (9)$$

$$\frac{m_{CO2}}{m_{CH4}} = 2,75 \quad (10)$$

The specific emissions of natural gas were calculated to be 198 g/kWh. The CO₂ emissions from HUHA 2 would be higher than from gas turbine power plants, even with the 50% reduction of the climate neutrality ratio with a difference of more than 20 000 tons per year. Even though the incineration emissions are higher the CO₂ emissions from the incineration of MSW would be reduced if the amount of landfill methane and CO₂ gas released during landfilling were included, but this is not addressed in this study.

D. Net Present Value

Based on the data calculated earlier, the net present value (NPV) of the investment were determined in two cases: in the first case the investment would be self-financed, and in the second case the investment would be financed with 129.87 million Euro of subsidies and loans in addition to own contribution. The calculation method is as follows:

$$NPV = \sum_n \frac{I_{net}}{(1 + r)^n} - C_0 \quad (11)$$

If NPV = 0 then the payback period can be determined. In the case of the loan, the NPV of the annual repayments has to be subtracted from the profits, calculated as follows:

$$NPV_{loan} = \sum_n \frac{\frac{C_{loan}}{d} * (1 + APR)^n}{(1 + r)^n} \quad (12)$$

From the credit-adjusted subsidised NPV, the present value of the loan repayments over the life of the loan should also be deducted.

$$NPV = \sum_n \frac{I_{net}}{(1+r)^n} - C_0 - NPV_{loan} \quad (13)$$

For the calculations a loan term of 15 years and an APR of 0.053 was used based on the values at the time of writing the study. Since the investment cost used is only an estimate and does not include the recent increase in raw material and labour costs, the changes in the investment cost were determined to a $\pm 30\%$ level and then used these to make the return calculations. The results are shown in Fig. 2:

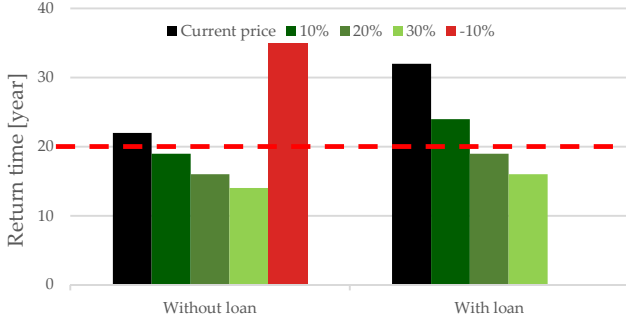


Fig. 2. Evolution of payback periods with changes in investment cost

The diagram shows the payback periods of the project as a function of the change in the price of natural gas with and without loan. It can be observed that with the natural gas price in 2024, the payback period is slightly above the red dashed line indicating the lifetime, which is not appropriate from an investment point of view. With the increase in natural gas prices, the payback could be reduced to 14 years if self-financing is used to take into account the opportunity cost, but a further decrease in gas prices would make the investment virtually impossible to realise. The necessity if a loan also severely hinders the installation of the system, the negative natural gas price changes have not been marked on the diagram for this very reason.

E. Determining specific costs

One of the main indicators of the operation and economics of power plants is the specific cost, which is the amount of money invested to produce 1 kWh of energy. These indicators can be determined for both heat and electricity supply. The annuity values calculated earlier are used again here, because these subtotals will give us the annual cost of building the power plant with the loans. After separating the fixed and variable costs an aggregate unit cost can be calculated, which does not yet take into account heat and electricity.

$$f = \frac{(A + C_{fix} + C_{operational})}{E_{heat,sold} + E_{electric,sold}} \quad (14)$$

The variable heat costs were determined by taking into account the efficiency values and power outputs as follows:

$$p_{heat} = p_{oper.} \left(1 - \frac{P_{electricity}}{P_{heat}} \right) \left(1 - \frac{\eta_{electricity}}{\eta_{heat}} \right) \quad (15)$$

To obtain the variable electricity cost one only needs to subtract the variable cost and the previously calculated variable heat cost.

$$p_{electricity} = p_{operational} - p_{heat} \quad (16)$$

To calculate the specific heat costs the annuity costs, the fixed costs and the variable costs calculated above have been taken into account. For a better accuracy the investment costs

have been allocated in proportion to the energy produced, so that the actual cost of production is more apparent.

$$f_{heat} = \frac{(A + C_{fix}) * \left(1 - \frac{P_{electricity}}{P_{heat} + P_{electricity}} \right) + p_{heat}}{E_{heat,sold}} \quad (17)$$

Specific electricity costs are determined using the same methodology.

$$f_{electricity} = \frac{(A + C_{fix}) * \frac{P_{electricity}}{P_{heat} + P_{electricity}} + p_{electricity}}{E_{electricity,sold}} \quad (18)$$

IV. RESULTS AND DISCUSSION

Due to the instability of the gas market the natural gas prices have been calculated within a range of $\pm 30\%$ of the current case. Fig. 3 illustrates the dependence of the specific heat and electricity costs on the gas price and the specific costs of the incineration plant as a function of the life year. To avoid overcrowding the diagram only the values for the extreme gas price variation of $\pm 30\%$ alongside the current "original" costs were shown. The diagram shows a break in the functions at year 5, because taking into account the averaged installation time and the investment costs of the three gas plants over an assumed 20-year period, this depreciation period would end 5 years after the construction of HUHA 2, after which the investment costs would no longer increase the specific costs.

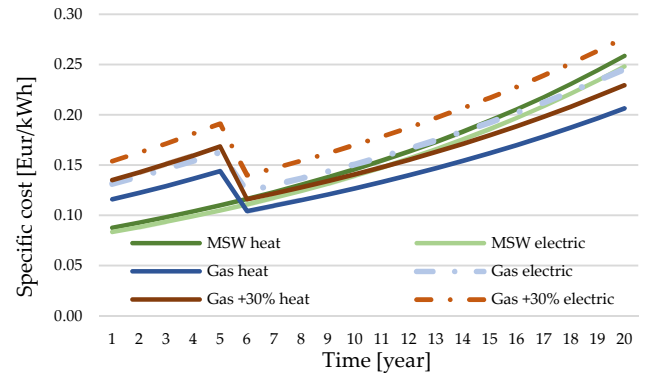


Fig. 3. Specific cost of electricity and heat generation in the case of the HUHA 2 and the gas powered plants

The net profit of HUHA 2 from the state's point of view is positively correlated with the evolution of the gas price, and the diagram below illustrates how much profit the plant could make per year depending on the gas price.

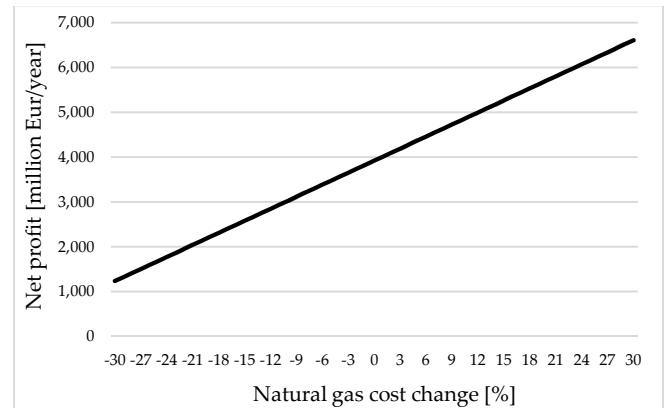


Fig. 4. Net profit realised by the HUHA 2 as a function of gas price modulations

Fig. 4 is a simple linear function designed to give a better understanding of the potential net profits generated by the HUHA 2 WtE plant. It can be concluded that in the current natural gas and elevated construction cost environment, the installation of such a power plant would not be economically beneficial. Even though this conclusion can be drawn in our current state, the analysis of the previous years can give useful insight for the future, where the fossil fuel prices are destined to rise significantly.

A. Real-life based analysis of Waste to Energy in Budapest

The paper up to this point presented the overarching economic analysis of the HUHA 2 waste to energy (WtE) power plant's potential installation in the southern border of Budapest. This analysis was based on the assumption of the WtE plant being connected to a Budapest-wide district heating distribution system, which unfortunately at the time of this study has not been built due to the immense economic and logistical strain it would put on the city's administration.

For this reason in the last part of this study an alternative solution is proposed to combat this issue. Instead of connecting the power plant to the city wide system it is supplying the three southernmost district heating zones of the city: *Kelenföld*, *Csepel* and *Kispest* respectively. The company responsible for all district heating related activity in Budapest has provided hourly district heating consumption data for all three of these zones from 2019 up to 2022. The utilisation of this real life data allowed for an accurate, detailed analysis of the accumulated losses occurring from 2017 (the latest proposal of the HUHA 2 installation) to 2024 (the time of the publication) due to it not being built. During this time more than 80% of the entire city's district need had to be met using natural gas fuelled power plants, causing enormous costs compared to a hypothetical WtE plant. While this comparison can shed a light on the possible past management mistakes in retrospect, it also enables us to predict the possible future benefits of the installation. Though this comparison underperforms in terms of system efficiency and peak load hour compared to the city-wide construction presented above, it balances these shortcomings with a more realistic connection network proposal to enable the district heating supply and a real life, accurate dataset consisting of more than 35 000 data points for each data type and district heating zone.

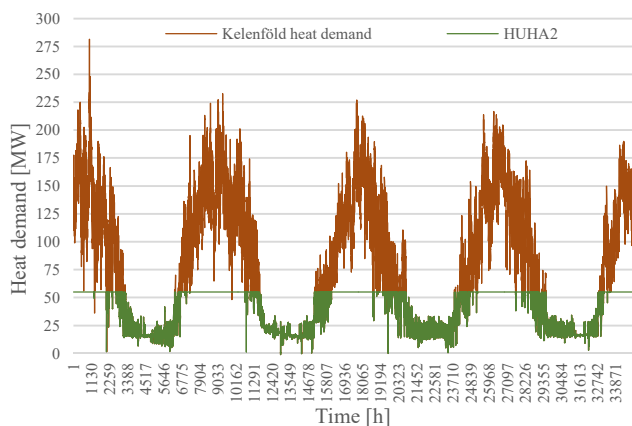


Fig. 5. Heat Demand of Kelenföld District Heating Zone and the Capacity of HUHA 2 over the Four Years

In this diagram the district heating needs of the *Kelenföld* zone can be seen in brown in addition to the demand that can be supplied from the HUHA 2 represented in green. The output of HUHA 2 is calculated with the inner power plant efficiency and the heat losses experienced on the entire pipe network at any given instance in hourly resolution taken into account. The heat losses vary depending on the connected zone due to their differing physical location. This diagram gives an illustration to the general system of the connections and calculations as the same method was used in all three zones.

It can clearly be seen that even though the WtE plant can supply the whole district during the warm months of the year, it's maximum output – 55 MW – is reached during nearly the entirety of the winter period, further requiring assistance from the already present gas powered power plants. This proves the need of either fully gas powered or combined operation between MSW and gas utilization.

In Fig. 5 we can observe the total heat energy consumption of each zone, *Kelenföld* being the biggest with the colour green. The graph also illustrates the percentage or the heating needs covered by HUHA 2 marked with the coloured line graphs. Each district heating zone has a distinct colour, which links them with their respective line graph. It is important to note that this graph is based on the real life data provided by *Főtáv*, the district heating company of Budapest.

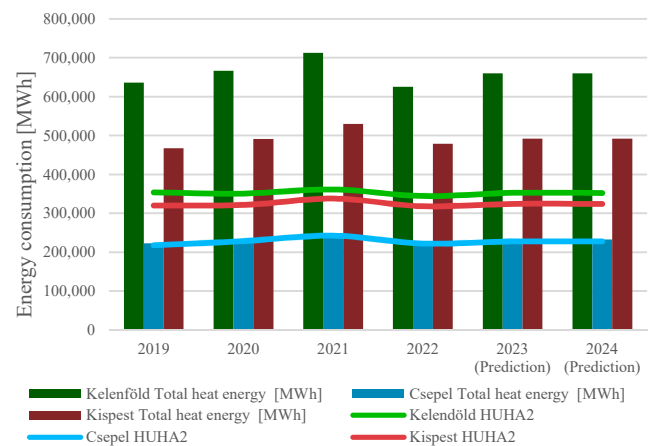


Fig. 6. Cumulated District Heating Needs and the Potential Supply of the HUHA 2

The graph illustrates the previously mentioned statement regarding the WtE plant's supply capacity. Since it is limited to a maximum of 55 MW heat power output it is only able to meet roughly half of all demand in the *Kelenföld* zone, but can almost completely cover the needs of the significantly smaller *Csepel* zone. The results from the three-zone comparison are presented on the following graph. The pillar graphs represent the total cost of yearly operation of the fully gas powered district heating system (brown) currently in place, and of the WtE – gas combined operation (green). The varying cost of MSW fuel prices can be attributed to the changing fuel prices during the examined timeframe. Using the official monthly fuel price data available in Hungary the yearly average prices were calculated, then subsequently utilised in the calculations to provide a more accurate representation of the costs. 2022 was observed as being the highest with the diesel fuel price in Hungary reaching a 1.96 €/l average price during the entirety of the year. [8]

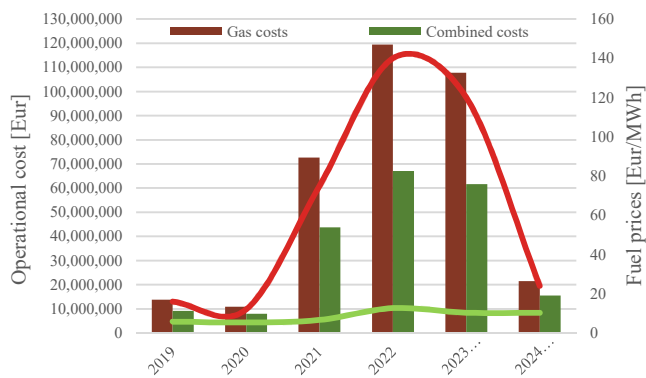


Fig. 7. Gas vs. MSW powered plant operational costs and fuel prices [6][7]

It can be noted, that the combined system provides drastically cheaper operational costs. The saving volume can be associated with the gas and the MSW prices displayed as line graphs (red and light green respectively), a strong correlation can be observed between the gas price boom of the 2021 – 2023 period resulting in a more than 52 million Euro net difference in 2022. The total cost reduction of the MSW fuelled HUHA 2 power plant could have been 140.84 million Euros, which could have covered almost half of its installation cost. As the gas prices began to consolidate during late 2023 up to the current time in 2024 the benefits of the MSW firing slowly diminishes, though it still can be regarded as a superior form of fuel both economically, geopolitically and strategically due to the steadily available local fuel source, unlike with the case of natural gas.

V. SUMMARY

In the light of the results presented, it can be concluded that although MSW combustion has its negative aspects, mainly in terms of the complexity of meeting the requirements, the use of poor quality fuel and the corrosion problems it causes, it can nevertheless offer significant economic advantages over gas-fired power plants and many environmental benefits, which are also reflected in EU regulations. In addition to these statements, it is important to note the experience that the payback characteristics and overall applicability of waste-to-energy plants depend to a large extent on the prices set by the international natural gas market and the CO₂ quota prices. In the present case, the low natural gas prices would not make the establishment of HUHA 2 economically viable, but the economic feasibility of the project as described earlier in Fig. 7 can be clearly demonstrated that, with values similar to the high natural gas

prices of recent years, it will be highly profitable to have a WtE plant.

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