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Energy Potential from the Municipal Solid Waste in the Skopje Region

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The increasing living standard and technology development on a global level affect the waste management of the Western Balkan region, including the Republic of North Macedonia. This improvement in the living conditions in the country led to increased municipal waste generation throughout the years reaching a value of 452 kg per person in 2021. However, a growing challenge to the waste sector is the insufficient and inadequate infrastructure, as well as lack of awareness of the population regarding recycling. Considering that the percentage of recycled municipal waste is below 1 %, the most applied method of waste disposal is landfilling, although it presents the least desired option regarding the waste management hierarchy. Drisla Landfill is the only controlled landfill in the country registered for processing and disposal of hazardous and non-hazardous waste. This paper analyses the impact of replacement raw fossil fuels with refuse-derived fuel in the cement industry by conducting simulations on the energy produced, emission reductions, and financial saving. The adopted conversion rate from municipal solid waste to refuse derived fuel is 40 %. The amount of refuse-derived fuel generated from the total amount of municipal solid waste landfilled in Drisla presents 103,483 tons. The conclusions are that the benefits from the pairing between the landfill and cement plant are numerous, reducing waste being landfilled to half, lowering CO2 emission, replacing fossil fuels in cement kilns lowering the impact on biodiversity from excavation contributing to circular economy.

1. Introduction

The city of Skopje is the largest city in R. North Macedonia representing country's capital. The city is positioned on the upper course of the Vardar River and is located on a major north-south Balkan route between Belgrade and Athens. Skopje is the largest and fastest growing city in Macedonia with a population of 544,086 inhabitants. Currently, the population density is four times the average, having in mind that 25.1 % of the total population in the country lives in the capital. According to the National Energy Efficiency Action Plan, the indicative target for 2025 is to reduce the final energy consumption in Macedonia by at least 10 % until 2025 relative to reference consumption. The conditions in this area are far from satisfactory and far from sustainable. Waste management and air pollution are the biggest environmental problems of the city of Skopje, considering the poor urban waste handling conditions and rapid construction expansion. The Public utility Drisla – Skopje DOO is a public company and is the only legal landfill in the country. It was built and opened by the city of Skopje in 1994 and is located in the south-eastern part of the city at a distance of 14 km from the city centre. It covers an area of 76 ha, with a design capacity of 26,000,000 m3 for depositing municipal waste. According to the project documentation the estimated time period for filling the landfill capacity was 30 years. However, after 16 years of operation it was filled up to 33 % of the total capacity. Drisla Landfill is registered for collection, processing, and disposal of non-hazardous and hazardous waste. Additional activities realized at the plant are treatment (crushing and sterilization) and incineration of medical waste, and disposal of asbestos waste. The amount of disposed municipal waste on the landfill is continuously growing and the numbers for the last 10 years are presented in Table 1 below.

Table 1: Quantities of municipal waste landfilled in Drisla (Ministry of Environmental and Physical Planning, 2022)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Municipal waste [tons/year]	151,791	155,732	167,639	172,679	196,003	227,236	219,699	226,187	233,686	258,770	1,980,000

The considered cement industry can implement alternative fuels (AF) in the production process with amounts up to 30,000 - 35,000 tons per year for each waste type, or maximum 35 % substitution rate (Ministry of Environmental and Physical Planning, 2020). The adopted conversion rate from MSW (municipal solid waste) to RDF (refuse derived fuel) is 40 % and the amount of RDF generated from the total amount of MSW landfilled in Drisla presents 103,483 tons. This means the amount of RDF produced annually is enough to completely replace fossil fuels (FF). This paper analyses the impact of replacement raw fossil fuels with RDF in the cement industry by conducting simulations on the energy produced, emission reductions, and financial saving. The main aim of this paper is how substituting fossil fuels with RDF affects the environment by calculating the CO2 emissions from combustion of fossil fuels and RDF in cement kilns. The calculations were conducted for 8 different scenarios with various shares of RDF in the fuel mix composition, starting with 0 %, continuing with 5 %, 10 %, 15 %, 20 %, 25 %, 30 % and the maximum allowed of 35 %. Also, an economic effect achieved due to the replaced thermal energy source was calculated, expressed as mass saving of fossil fuel and financial savings derived.

2. Materials and methods

Waste comes in the form of bales and is placed in a designated area for waste storage and preparation. Figure 1 shows the waste storage location at the cement factory.

Figure 1: Waste storage location

For accepting and storing alternative fuels is used Schenck Process Walking Floor Containers which is shown in Figure 2a. The RDF is supplied into the bulk semitrailers which are sealed using an inflatable sealing system in order to keep the material inside the trailer. The RDF is transported using screw extractor floor into the chain conveyor that follows (Rupp and Faber, 2010). The chain conveyor transports the fuel into Schenck Process MultiFlex Weighfeeder presented in Figure 2b. It is used for weighting and feeding bulk alternative fuels into the burner of the cement kiln (Schenck Process, 2013).

Figure 2a: Schenck Process Walking Floor Containers

Figure 2b: Schenck Process MultiFlex Weighfeeder

The burner is a multifuel mono airduct system (M.A.S.) kiln burner from Unitherm Cemcon with four inlets for: fossil fuels, alternative fuels, primary air, and fuel oil for auxiliary ignition. The inlet pipes are presented in Figure 3 and the cross-section of the burner in Figure 4. The complete primary air flow is brought using one single channel which is directly guided into the required swirl which is adjustable offering maximum flame control and accuracy in flame setting (Unitherm Cemcon, n.d.).

Figure 3: Burner inlets

Figure 4: Unitherm Cemcon multifuel M.A.S. burner

The calculations were performed based on the thermal energy necessary for annual clinker production and the CO2 emission factor of RDF. The CO2 emission factors of petrol coke, natural gas and RDF are given in Figure 5. In the CO2 emission factors are addressed the direct and indirect sources of CO2 emissions related to the cement manufacturing process. The direct sources of CO2 emissions are calcination of carbonates, combustion of organic carbon contained in raw materials, combustion of conventional fossil fuels and alternative fossil fuels. The indirect sources of CO2 emissions are external production of electricity consumed by cement producers, production of clinker bought from other producers and combined with own production, production and processing of conventional and alternative fuels by third parties, transport of inputs (raw materials, fuels) and outputs (cement, clinker) by third parties.
For the purpose of this work the following input parameters were taken into account:

- The annual clinker production from two rotary cement kilns (taken as average from the last three years) is 770,000 ton/year,
- For the annual production of 770,000 tons clinker per year the necessary amount of fuel is 77,000 tons petrol coke per year and 53,515 tons natural gas per year,
- The annual entered thermal energy with petrol coke equals 2,675,75 x 103 GJ, and is calculated using the following formula:

$$Q_{total} = m_{petrol\ coke} \cdot LHV_{petrol\ coke} \quad (1)$$

Where:
Q_{total} - annual entered thermal energy with petrol coke [GJ/year]
$m_{petrol\ coke}$ – annual petrol coke consumption [ton/year]
$LHV_{petrol\ coke}$ – lower heating value of petrol coke [GJ/ton]

- The fuel mix was combusted only in the main burner,
- The quality parameters of the fossil fuels considered are not changed during the calculations. The LHV of petrol coke is 34,750 MJ/ton and of natural gas is 51,250 MJ/ton,
- The quality parameters of RDF considered are not changed during the calculations,
- The share of energy coming from conventional fuels and RDF is given in Table 2,
- The price of petrol coke is 350 euro/ton and natural gas is 1,300 euro/ton.

Eight different scenarios were analyzed to investigate how the quality parameters of RDF affect the final amount of CO_2 emission.

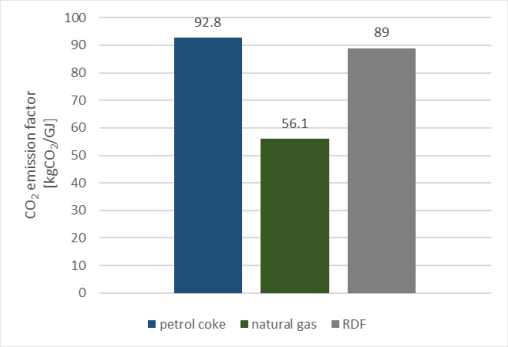


Figure 5: CO_2 emissions factors of petrol coke, natural gas and RDF

Table 2: Fuel mix composition data

Fuel mix	1	2	3	4	5	6	7	8
Fossil fuel	100%	95%	90%	85%	80%	75%	70%	65%
RDF	0%	5%	10%	15%	20%	25%	30%	35%

The total CO_2 emissions from co-combustion of petrol coke and RDF in the cement kiln are calculated using the following formula:

$$E_{CO_2,fuel} = EF_{CO_2} \cdot Q_{fuel\ input} \quad (2)$$

Where:
$E_{CO_2,fuel}$ – total CO_2 emissions from fuel combustion [tonCO_2/year]
EF_{CO_2} – CO_2 emission factor for different fuel [kgCO_2/GJ]
$Q_{fuel\ input}$ – thermal input with different fuel [GJ/year]

The mass fuel savings are calculated using the equation:

$$m_{FF,saved} = {}^{Q_{FF}}/_{LHV_{FF}} \quad (3)$$

Where:
$m_{FF,saved}$ – mass fossil fuel saving due to replacement with RDF [ton/year]
Q_{FF} – thermal input with fossil fuel [GJ/year]
$LHV_{fossil\ fuel}$ – lower heating value of fossil fuel [GJ/ton]

Dividing the energy input with fossil fuel depending on the fuel mix with the lower heating value of respective fossil fuel gives the quantity of saved fuel on annual level. The fuel savings are calculated and expressed as financial savings taking into consideration the current petrol coke prices (The Coal Hub, 2023) and natural gas prices for non-household consumers in Macedonia, defined by the Energy and Water services Regulatory Commission (State Statistical Office, 2022).

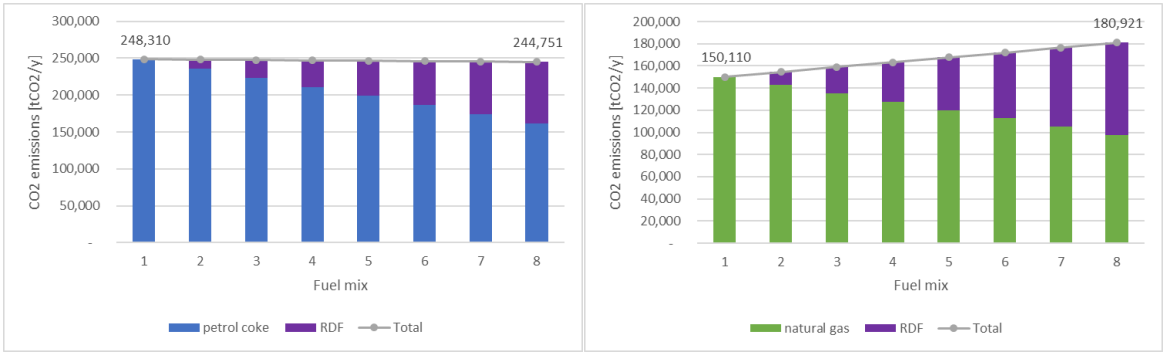
The financial savings are calculated using the following formula:

$$FS = m_{FF,saved} \cdot P_{FF} \quad (4)$$

Where:
FS – financial savings from fossil fuel saved [euro/year]
$m_{FF,saved}$ – mass fossil fuel saving due to replacement with RDF [ton/year]
P_{FF} – price of fossil fuels [euro/ton]

3. Results and discussions

The results are presented in Figure 6, and they show different CO_2 emission trends depending on the fuel mix and RDF used in the mix. When no RDF is used, the total CO_2 emissions from combustion petrol coke in cement kilns are 248,310 tons per year. Considering that RDF is entered in the fuel mix, the consumption of petrol coke and natural gas decreases, and the CO_2 emissions also decrease. The amount of saved fossil fuel increases as the percentage of substitution of the fuel increases. When analyzing the maximal substitution rate of 35% RDF in the fuel mix with petrol coke RDF delivers reduction of total CO_2 emissions by 3,559 tons per year.



a) *b)*

Figure 6: CO_2 emissions trend from combustion RDF with a) petrol coke, b) natural gas

When no RDF is used, the total CO2 emissions from combustion natural gas are 150,110 tons per year. Substituting natural gas with RDF leads to an increase in total CO2 emissions. The reason is found in the CO2 emissions factors of RDF compared to natural gas, having greater value than natural gas. In this study, the mass savings of petrol coke and natural gas achieved due to their partial replacement with RDF are presented in Table 3. The financial savings resulting from the fuel saved are given in Table 4. Based on the results, it can be estimated that the maximal substitution of petrol coke with RDF will lead to financial savings of more than 9 million euro per year. Whereas replacing natural gas with RDF leads to even greater financial savings due to the high price of natural gas nowadays. The maximal substitution rate of 35 % RDF leads to around 24 million euro per year financial gain for the company from reduced natural gas consumption. It should be noted that the costs for RDF delivered to the cement plant are taken to be zero. Considering that there are no CO2 emission fees in Macedonia there are no financial benefits for the company for reducing CO2 emissions. The cost for landfill disposal of 1 ton of MSW at Drisla Landfill is 10 euro per ton (PU Landfill Drisla Skopje, 2020). By replacing fossil fuels with RDF the MSW landfilled is reduced leading to cost reductions. The financial savings from reuse of MSW as RDF in the cement factory are presented in Table 5.

Table 3: Fuel savings from substituting fossil fuels with RDF

Share of heat from AF	5 %	10 %	15 %	20 %	25 %	30 %	35 %

Petrol coke saved [t/y]	3,850	7,700	11,550	15,400	19,250	23,100		26,950
Natural gas saved [t/y]	2,610	5,221	7,831	10,442	13,052	15,663		18,273

Table 4: Financial savings from substituting fossil fuels with RDF

Share of heat from AF	5 %	10 %	15 %	20 %	25 %	30 %	35 %
Cost savings from petrol coke [kilo euro/y]	385	770	1,155	1,540	1,925	2,310	2,695
Cost savings from natural gas [kilo euro/y]	313	627	940	1,253	1,566	1,880	2,193

Table 5: Financial savings from reduced MSW landfilled

Share of heat from AF	5 %	10 %	15 %	20 %	25 %	30 %	35 %
Reduced MSW landfilled [t/y]	11,196	22,391	33,587	44,782	55,978	67,174	78,369
Cost savings from reduced MWS landfilled [kilo euro/y]	112	224	336	448	560	672	784

4. Conclusion

This study discusses several issues of using RDF in clinker burning systems, including energy potential, environmental impact and financial aspect. The performed calculations showed that implementing RDF as alternative fuel for petrol coke led to CO2 emissions reduction. As the substitution percentage of RDF increases the CO2 emissions reduction also increases. The possibility of increasing the replacement rate of RDF should be considered by the cement production company. Most environmentally friendly fuel is natural gas but has high cost price. Due to that reason, it is not financially viable for the company to use natural gas to cover all necessary thermal input. Substituting natural gas with RDF leads to financial benefits, starting from around 3.4 million euro to above 23.7 million euro per year, for a substitution rate of 5 % RDF to 35 %. Economic advantages can be observed from reduction of petrol coke combusted in the kilns in the limits of around 1.3 million euro to 9.4 million euro by inserting 5 % RDF up to 35 %. Further research is needed to analyze how co-combusting alternative fuels affects the parameters in the cement kiln, the flame characteristics and product quality. The contribution from the analyses done in this paper is directly related to the cement company considering that no such calculations have been done for the plant based on real-life data. This article presents the environmental and financial benefits for the firm considering the thermal parameters of the plant. Next stadium would be to simulate the combustion process in the rotary kiln with the prescribed substitution rates of fossil fuel with RDF and see how it affects the parameters in the cement kiln, the flame characteristics and product quality.

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