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DERLEME / REVIEW

Combining Different Fossil Fuel Types Used in Cement Industry With Rdf as Alternative Fuel and Analyzing the Environmental and Economic Impact

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Abstract

In Macedonia, the recycling rate is extremely low, representing only 1% of the total generated waste, leading to large amounts of waste being landfilled. A solution in line with the waste management hierarchy regarding waste disposal is waste recovery represented through energy valorization by utilizing the remaining valuable components of waste. In order to avoid throwing waste into landfills, there is a possibility to use it as an energy source for clinker production. In the paper, the energy potential of different fossil fuels is analyzed and the environmental aspect from pairing fossil fuels with refuse-derived fuel (RDF) in the cement production process. According to the national legal framework, the cement industry is permitted to use different waste types as alternative fuels, including RDF. The considered cement industry can implement alternative fuels in the production process with amounts up to 30,000 - 35,000 tons per year. The calculations regarding CO2 emissions were performed for 5 different scenarios with various shares of alternative fuels in the fuel mix composition, starting with 0%, continuing with 25%, 50%, 75%, and 100%. Also, an economic effect achieved due to the replaced thermal energy source was calculated, expressed as mass saving of fossil fuel and financial saving derived. The performed calculations showed when RDF is used in the fuel mix with 75% the CO2 emission reduction is 2.9% when used with coal, 7.3% when combined with lignite, and around 2% when combusted with petrol coke. Economic benefits are generated from the mass reduction of fossil fuels by their substitution with RDF. The maximal, theoretical substitution rate was 100% RDF where the financial savings from the reduced coal consumption were calculated to be above 12 million euro, from heavy fuel oil (HFO) saved were below 23,5 million euro, from reduced lignite usage were above 37 million, and from petrol coke saved were 15,4 million euro.

Keywords: Cement Industry, Coal, Co_2 Emissions, Fuel Oil, Lignite, Petrol Coke, RDF.

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INTRODUCTION

In the city of Skopje in the Republic of North Macedonia, there is one cement plant producing cement and cement materials with maximal annual production capacity of 1,750,000 tons. Different fossil fuel types can be used as primary fuel in the burners, including petrol coke, coal, lignite, fuel oil []. The process of excavation, transport, and combustion of fossil fuels is related with negative environmental impact [,]. In order to mitigate the influence on the environment the cement company started implementing alternative fuels in the year 2018 []. According to the national legal framework, the cement industry is permitted to use different waste types as alternative fuels, including biomass, wood, textile, refuse-derived fuel (RDF), plastics, paper, and packaging waste. The considered cement industry can implement alternative fuels in the production process with amounts up to 30,000 - 35,000 tons per year for each waste type []. This paper analyzes how substitution of different fossil fuels with RDF impacts the environment expressed through CO_2 emissions []. The fossil fuels included in the calculations are coal, petrol coke, lignite, and heavy fuel oil (HFO). The calculations regarding CO_2 emissions were performed for 5 different scenarios with various shares of RDF in the fuel mix composition, starting with 0%, then 25%, 50%, 75% and finally 100%. 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. The RDF quantities used were calculated based on the amount of municipal solid waste (MSW) landfilled at Drisla landfill. The Public utility Drisla – Skopje DOO is a public company and is the only legal landfill in the country. 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. According to the analysis done by Dong, around 50% of the combustible MSW can be used to produce RDF. However, due to the high moisture content in the MSW in Drisla the adopted conversion rate from MSW to RDF in this paper is 40% [] and the amount of RDF generated from the total amount of MSW landfilled in Drisla in 2021 presents 103,483 tons.

Table 1. Municipal waste landfilled in Drisla []

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**

Analysis of the composition of municipal waste landfilled in Drisla together with the calculated amounts of waste generated on annual level are given in Table 2 below. According to the table, organic waste represents around 2% of the total municipal waste landfilled, textile represents 5.8%, plastics are around 12.4%, paper is included with 15.3% and packaging waste represents 2% from the total municipal waste landfilled. However, apart from the quantity, additional parameters important for defining the thermal potential of waste for use as alternative fuel in cement production plant are heating value (energy content) and waste composition, such as moisture and volatile contents.

Table 2. Percentual representation of waste types in total municipal waste []

Waste type	Content [% by weight]	Quantity [tons/ year]
Municipal waste		258,770
Mixed food residues	15.2	3,933
Organic waste	2.0	518
Glass	5.5	1,423
Plastics	12.4	3,209
Paper/ Carton	15.3	3,959
Packaging waste	2.0	518
Metal	1.2	311
Textile	5.8	1,501
Electronic waste	0.2	52
Other	11.9	3,079
Material smaller than 40x50 mm	28.5	7,375

METHODOLOGY

Waste is delivered to the cement plant from factories throughout the country that perform different business activities. The waste is placed in a designated area for waste storage and preparation. The process of RDF preparation is described further. First the waste is inserted into the shredder Lindner Komet with power of 2 x 160 kW, which is shown in Figures 1 and 2. The cutting system is a single-shaft system with screwed knife rows with rotor speed of 355 min^{-1} and two rows of stator knives. The drive is an electromagnetic belt drive []. The particle sizes at the outlet are around 10-90 mm as shown in Figure 3. As such, samples can be taken for laboratory analysis for defining heating value, elementary and technical analysis.

Figure 1. Front view of Lindner Komet waste shredder

Figure 2. Back view of Lindner Komet waste shredder

Figure 3. Shredded waste

The prepared RDF is ready to be inserted in the burner. The burner is produced by Unitherm Cemcon. It has four inlets, each for different input material, including: fossil fuels, alternative fuels, primary air, and fuel oil for auxiliary ignition. Figure 4 shows the inlet pipes to the burner and Figure 5 the cross-section of the burner. The multifuel mono airduct system (M.A.S.) enables the complete primary air flow to be brought using one single channel which is directly guided into the required swirl. The swirl is adjustable offering maximum flame control and accuracy in flame setting [].

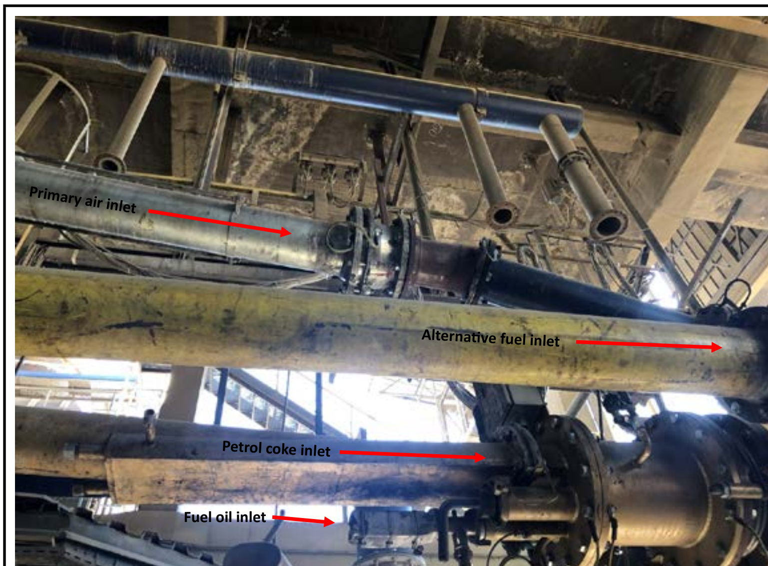


Figure 4. Inlet pipes to the burner

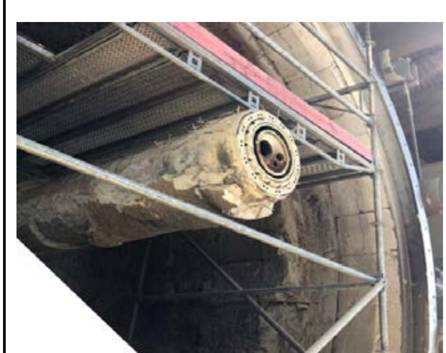


Figure 5. Multifuel M.A.S. burner

Five different scenarios were analyzed to investigate how implementing RDF as substitution for fossil fuel in the cement kiln will affect the final amount of CO_2 emitted. All calculations described below were performed based on the thermal energy necessary for annual clinker production. The average annual clinker production from two rotary cement kilns (for the last three years) is 770,000 ton/year. The annual necessary thermal energy equals 2,675,750 x 10^3 GJ. The share of energy in different scenarios coming from conventional fuels and RDF is given in Table 3. There numbers for the fuel mix will be used further in the presentation of the results.

Table 3. Fuel mix composition data

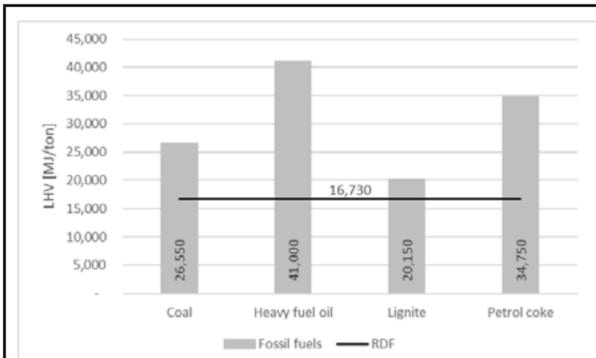
Fuel mix	1	2	3	4	5
Fossil fuel	100%	75%	50%	25%	0%
RDF	0%	25%	50%	75%	100%

The quantity of fuel necessary for achieving the heat input is given in Table 4.

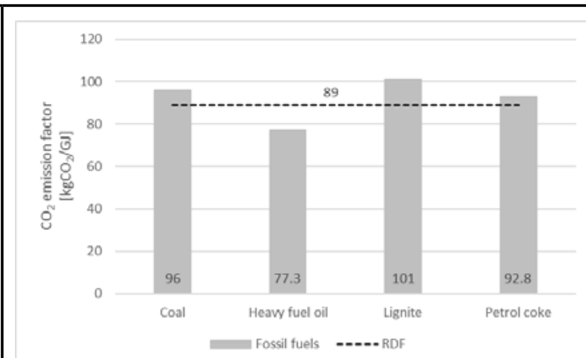
Table 4. Necessary fuel quantity for achieving thermal input

Fuel mix	Coal [t/y]	Heavy fuel oil [t/y]	Lignite [t/y]	Petrol coke [t/y]
1	100,782	65,262	132,792	77,000
2	75,586	48,947	99,594	57,750
3	50,391	32,631	66,396	38,500
4	25,195	16,316	33,198	19,250
5	0	0	0	0

The fuel quantity was calculated based on the lower heating values (LHV) of each fuel and the required thermal energy for cement production. The LHVs of all fossil fuels and RDF used for the calculations are given in Graph 1. The CO_2 emissions factors of the same fuels which represent a basis for the calculations are presented in Graph 2. The parameters regarding fossil fuels are given as stacked columns with gray color, whereas with black line are shown the values for RDF for easier comparison. The parameters of the fossil fuels and RDF considered in the calculations were not changed.



Graph 1. Lower heating values of fossil fuels and RDF



Graph 2. CO_2 emissions factors of fossil fuels and RDF

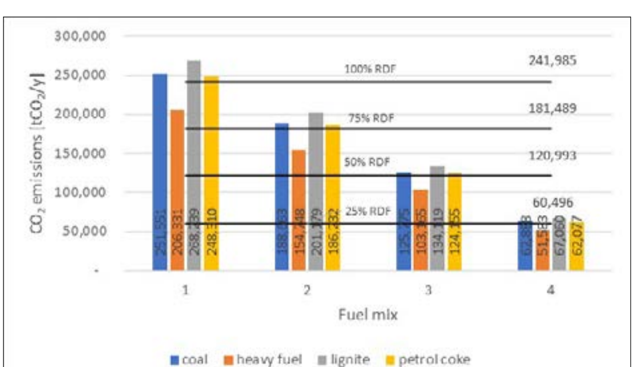
The highest calorific value of all fossil fuels has heavy fuel oil, followed by petrol coke, then coal and ending with lignite. Compared to fossil fuels, RDF has the lowest heating value with 16,730 MJ/ton. Meaning that greater quantities of RDF will be needed for achieving the necessary thermal energy for clinker production compared to the other fossil fuels.

The total CO_2 emissions from co-combustion of coal, petrol coke, heavy fuel oil or lignite with RDF, represented as in [$tonCO_2$/year] are calculated as a product between the CO_2 emission factor for different fuel in [$kgCO_2$/GJ] and the thermal input with different fuel in [GJ/year]. The CO_2 emission factors of all considered fuels are given in Graph 2. The highest emission factor has lignite, followed by coal, then petrol coke and heavy fuel oil. Heavy fuel oil has the lowest CO_2 emissions factor from all fuels, including RDF. Whereas, the emissions factor of RDF is lower compared to coal, petrol coke and lignite. The quantity of fuel saved due to replacement with RDF, expressed as in [ton/year], is delivered as quotient between the thermal input with fossil fuel in [GJ/year] and the lower heating value of fossil fuel in [GJ/ton].

The quantity of saved fuel on annual level is obtained by dividing the energy input with fossil fuel depending on the fuel mix with the LHV of respective fossil fuel. The fuel savings are calculated and expressed as financial savings taking into consideration the current fossil fuel prices. The financial savings from fossil fuel saved in [euro/year] are calculated by dividing the mass fossil fuel saving due to replacement with alternative fuel in [ton/year] with the price of fossil fuels in [euro/ton] [, ,].

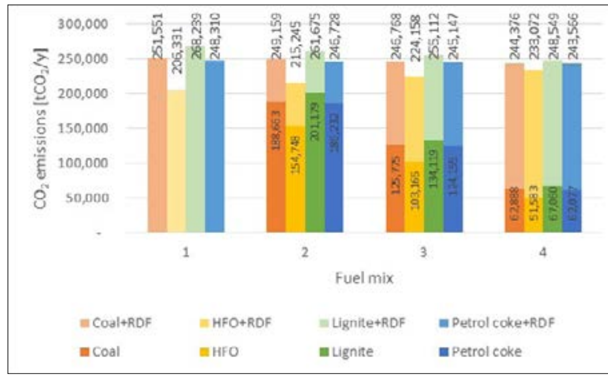
FINDINGS

The results from the calculations are given in Graph 3 and Graph 4. Graph 3 presents the CO_2 emissions from each fossil fuel compared with RDF. When no RDF is used in the combustion process the CO_2 emissions from the conventional fuels are highest for lignite with 268,239 tCO_2/y, followed by coal with 251,551 tCO_2/y, then petrol coke with 248,310 tCO_2/y, and lowest for heavy fuel oil with 206,331 tCO_2/y. The most polluting fuel regarding CO_2 emissions is lignite, and the least is heavy fuel oil. When RDF is used for total substitution of the fossil fuel in the cement kiln the CO_2 emissions are 241,985 tCO_2/y. This leads to the conclusion that the emissions from RDF combusted in cement kilns are lower compared to lignite, coal, and petrol coke. The same trend applies for the rest of the fuel mixes, with 75% RDF, 50% RDF and 25% RDF. The difference in the CO_2 emissions between 50% RDF and 50% lignite is around 13,000 tCO_2/y, 50% RDF and 50% coal is bit above 4,700 tCO_2/y, 50% RDF and 50% petrol coke is somewhere above 3,100 tCO_2/y. The differences in the CO_2 emissions are greater as the substitution rate is greater. Heavy fuel oil has lower emissions than RDF when used with 25%, 50%, 75% and 100% fuel in the burner. However, considering that using RDF as fuel in the cement production process leads to lower MWS being landfilled and methane emissions saved, it can be considered that the impact is less environmentally harmful compared to heavy fuel oil.



Graph 3. CO2 emissions from fossil fuels compared with RDF

Graph 4 presents the total CO_2 emissions from different fuel ratios when conventional and alternative fuels are mixed. It can be noted that when RDF is used in the fuel mix with 75% the CO_2 emission reduction is 2.9% when used with coal, 7.3% when combined with lignite, and around 2% when combusted with petrol coke.



Graph 4. Total CO2 emissions form fossil fuels and RDF

The mass savings of fossil fuels achieved due to their partial replacement with RDF are presented in Table 5. By replacing 25% of the heat generated from fossil fuels with RDF the saved fuel quantities are highest for lignite with 33,198 t/y, followed by coal with 25,195 t/y, then petrol coke with 19,250 t/y and heavy fuel oil with 16,316 t/y. The maximal amount of fossil fuel saved is when RDF is the only fuel in the burners, where the biggest saving with 132,792 t/y is for lignite, 100,782 t/y for coal, 77,000 t/y for petrol coke and 65,262 t/y for heavy fuel oil. The amount of fuel saved does not reflect proportionally the cost savings for the company due to the price difference of the fossil fuels. The greatest financial saving derived from the fuel saved and the price of the fuel is from lignite with above 37 million euro, followed by heavy fuel with almost 23,5 million euro, then petrol coke with 15,4 million euro and coal with around 12 million euro per year. However, realistically feasible is to replace 25% of the thermal input with RDF instead of fossil fuel. This substitution rate will also have financial benefits for the cement company considering that the costs for RDF are taken to be zero. The waste producers do not pay to hand over the waste to the cement plant. Considering that there are no CO_2 emission fees in Macedonia there are no financial benefits for the company for reducing CO_2 emissions.

Table 5. Mass and financial savings from substituting fossil fuels with RDF

Share of heat from RDF	25%	50%	75%	100%
Coal				
Fuel saved [t/y]	25,195	50,391	75,586	100,782
Cost savings [keuro/y]	3,023	6,047	9,070	12,094
Heavy fuel oil				
Fuel saved [t/y]	16,316	32,631	48,947	65,262
Cost savings [keuro/y]	5,874	11,747	17,621	23,494
Lignite				
Fuel saved [t/y]	33,198	66,396	99,594	132,792
Cost savings [keuro/y]	9,295	18,591	27,886	37,182
Petrol coke				
Petrol coke saved [t/y]	19,250	38,500	57,750	77,000
Cost savings [keuro/y]	3,850	7,700	11,550	15,400

DISSCUSIONS

In this paper it is analyzed how using RDF in the cement production process will impact the environment and the financial status of the cement company. The conclusions are that implementing RDF as substitution for fossil fuels in the cement kilns leads to CO_2 emissions reduction, thus positive environmental impact. The only deviation from this trend is for heavy fuel oil, because according to the CO_2 emissions factor, it has lower emissions compared to RDF. However, considering the production process of heavy fuel oil and the methane emissions saved from the reduced amount of MSW landfilled, it can be assumed that using RDF as fuel instead of heavy fuel oil does not lead to negative environmental impact. Regarding CO_2 emissions, the most environmentally friendly is to use heavy fuel oil instead of coal, petrol coke or lignite, combined with RDF in any in any ratio. Apart from the CO_2 emissions reduction this option leads to big financial savings for the cement company. Whereas, considering the solid fuels which are more commonly used in the cement industry, environmental benefits will be generated by using petrol coke and coal combined with RDF. The least environmentally beneficial is using lignite where apart from the high CO_2 emissions it has a high price. One ton of lignite is more expensive than a ton of coal or petrol coke. However, due to the price and amount of lignite saved if it is substituted by RDF will lead to the biggest financial benefits for the cement company. According to the analyses made it can be concluded that the type of fuel used for cement production and the substitution rate with RDF depends on the longtime goals of the company.

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