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Research Article

Environmental and economic analysis of animal feed production from food waste

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ABSTRACT

Nowadays, food waste is disposed of in various ways considering the environmental impacts. The energy consumption for each of these methods can have environmental impacts. In this paper, the amount of pollution caused by the conversion of food waste into animal feed has been investigated. For this purpose, a reverse flow food waste dryer had been specifically constructed. Restaurant food waste was collected. Using a power analyzer, amount of kilowatt-hours consumed by the dryer at various operating levels was measured to estimate the quantities of CO_2, SO_2, and NO_x emitted during the generation of electricity required to dry the waste using three steam power plants, a gas turbine, and a combined cycle system. The emission rates were calculated at temperatures of 55, 62.5, and 70 °C and durations of 90, 150, and 210 minutes, based on conversion factors. Among the different power plants, the steam power plant exhibited the highest environmental pollution due to its elevated production of SO_2 and CO_2. In contrast, the combined cycle system proved to be the most favorable option, generating the lowest levels of pollution. The least harmful method for converting food waste into animal feed involved producing energy with natural gas in a gas turbine power plant over a 150-minute drying period. Environmental and economic analyses revealed that operating at a temperature of 55 °C for 150 minutes resulted in the lowest environmental and economic impacts. Policymakers can use the results of economic and environmental analyses to gain a more accurate understanding of the environmental impacts of different waste management methods.

1. Introduction

Data show that the world emitted about 50 billion tons of greenhouse gases (CO_2, N_2O, CH_4) in 2021. Of that 3.4% is from food waste. This includes consumer food waste and waste from the food supply cycle, but not waste from production and harvesting. Certainly, the final amount will be higher if we include waste from production and harvesting [1]. But food waste will be the third largest emitter of greenhouse gases after the U.S. and China if we consider it nationally [2].

Ceria and ceria-based materials have excellent oxygen According to European research, nine different food waste sources contribute 186 million tonnes of CO_2 and 1.7 million tonnes of SO_2. This study only looks at a small part of the 88 million tonnes of food waste created in the EU each year. It is 15 to 16% of the total impact of the entire food supply chain [3]. One-third of the world's food is lost or wasted. This causes almost 1.3 billion tons of food waste each year [4]. Australian research found that food waste uses 9% of total water and causes 6% of GHG emissions, or 57,507 Gg of CO_2 [5]. Bangladesh's households produce 4.87 million tons of waste a year. Food and vegetables make up 67.65% of this. This amount of waste creates 2.19 × 106 tons of CO_2 every year [6]. Food waste is also linked to South Korea, China, and Japan. South Korea produces 6.24 million tonnes per year. China produces 92.4 million tons. Japan produces roughly 21 million tons [7,8,9]. According to studies, the United Kingdom (UK) has the greatest FW output in Europe, with over 14 million tons produced in 2013 [10].

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Life cycle assessment (LCA) is an environmental management methodology that recognized to assess different production systems. As an analytical technique, it is used for the identification, quantification, and evaluation of environmental impacts and the specification of potential pathways to improve environmental quality [11]. Masuda, (2016) calculated the values of global warming potential and eutrophication potential in wheat production based on the data from the Ministry of Agriculture, Forestry and Fisheries of Japan. The author compared the two growing conditions in paddy farms with inferior drainage performance (crop rotations of rice, wheat, and soybean) and upland farms (crop rotations of sugar beet, pulses, potato, and wheat) in two regions: Hokkaido and Tofuken. It was noted that the values of the global warming potential in the Hokkaido and Tofuken regions of paddy fields (3305 and 2545 kg CO_2 eq ha-1, respectively) were higher than those of upland farms (2896 and 2410 kg CO_2 eq ha-1, respectively) due to lower yield. This trend was observed for eutrophication in paddy fields (7.0 kg PO4 eq ha-1) and upland farms (5.6 kg PO4 eq ha-1) in the Tofuken region, but the reverse trend was observed for the Hokkaido region (20.7 kg PO4 eq ha-1 for paddy and 26.6 kg PO4 eq ha-1 for upland farms).

According to the above description, combining silica and cerium could be a promising candidate for catalyst support in CO oxidation reactions. Since no systematic survey has been done on the study of the composition of cerium and various silica structures as a support for the CO oxidation reaction, in this paper, we have tried to achieve the best structure of silica-cerium composite for this reaction. After that, different active metals were embedded in the optimum support, and the catalytic performance of the manufactured specimens was evaluated.

Using the LCA from the bottom up, some researchers assessed the effects of carbon and water on total avoidable food waste in UK homes. They found that it was 6% and 3% of the total water and carbon effects of UK households, respectively. It has to do with food waste that may have been avoided [13]. According to findings from 2021, over a quarter of the food consumed in the UK is wasted. It happens around half in the consuming phase and 28% in the initial manufacturing phase. In terms of global warming potential, trash accounts for 5.9% of national greenhouse gas emissions and 3.7 percent of primary energy consumption [14]. Venkat estimated that avoidable food waste accounts for 2% of total national greenhouse gas emissions in the United States, whereas Heller and Koleh Olian discovered that greenhouse gas emissions from food waste in the United States are 40% greater than Venkat anticipated [15,16]. Some researchers estimated the carbon impact of avoidable household waste in Sweden to be between 0.8 and 1.4 tonnes of CO_2 per tonnes of food waste, while others found that the average carbon impact of food waste in supermarkets in Sweden is 1.6 tons of CO_2 per ton of food waste [17,18]. Brancoli et al (2017) conducted a similar investigation, determining the effect of 2800-3100 kg CO_2-eq per tonne.

With a top-down approach to the environmental impact of household food in China, Song et al., (2015) estimated the impact of 2,500 kg of CO_2-eq per ton of food waste. The impact of food waste on the Irish food supply chain, according to Oldfield et al (2016), is roughly 5,600 kg CO_2-eq per tonne. Martinez-Sanchez et al. (2016) found that food waste from Danish households caused about 1200 kg CO_2-eq per tonne. They focused on the indirect effects of waste reduction in Denmark. Food chain food waste costs in South Africa are estimated to be around 2.1 percent of annual GDP by Nahman, Anton, and Willem de Lange [19]. The US estimates that 85 billion euros of food is wasted each year. This includes € 40 billion in Europe and about € 17 billion in the UK (WRAP, 2015) [9,20,21].

Food waste harms the ecosystem. It causes groundwater pollution, greenhouse gas emissions, and soil erosion. It also causes atrophy, acidification, and photochemical oxidation [22]. These wastes have the potential to harm countries' economies and the environment [23]. As a result, many waste management methods have been developed over time. They include landfilling, incineration, anaerobic digestion, aerobic composting, bioethanol fermentation, animal feed production, and converting waste into valuable products.

In scientific circles, waste management methods are usually categorized using several qualitative parameters. Animal feed production from waste is one of the desirable methods that has not been quantitatively studied. This research simultaneously examines the environmental and economic impacts of animal feed production from food waste. This research is relevant due to the need for food waste in animal feed production and various waste management systems. The gases of interest are CO_2, SO_2 and NOx. Different combined cycles, gas and steam turbines, and the similarities between them are examined.

In general, the paper consists of the following sections: Materials and Methods After introducing the system of governing equations in environmental and economic assessment, the calculation is made. In the results section, the data obtained are first presented, followed by the results of the analysis of variance. The analysis of the amount of pollution produced and the economic assessment are presented next. In the conclusion section, the operational strategy and the importance of the research in the progressive approach to food waste management are stated.

2. Materials and methods

A return flow dryer was created at Gorgan University of Agricultural Sciences and Natural Resources in Iran. It turns food waste into animal feed. The dryer has six main parts. They are: a tank (made of galvanized sheet), a heater (with 6 thermal elements with model U), a fan (centrifuge type, with KAIJIELI model engine), an electric motor (1 hp, moto-gene model), a gearbox (Isfahan Toranj), and electrical switch-boards.

2.1 Calculating the power of the thermal heater

The device's heater is made up of six heating components, each with a power of 750 W. The heater, with a rated output of 4.5 kWh has a three-phase circuit since both heating components are driven by a single phase linked. A power analyzer (Lutheron brand, model DW-6090A) was utilized to calculate the wattage consumed during heat treatment. This device was mounted on one phase of the heater. The power consumption for three phases was found by multiplying the one-phase kW hours by three. Figure 1 shows the power circuit of the analyzer.

$$P_H = PR \times 3 \quad (1)$$

2.2 Calculating fan power

The airflow was created by a centrifugal fan. The electric motor utilized has a power of 3 hp (2.2 kW). Because the fan runs at full speed during the drying process, the power consumption was assumed to be equal to the rated power. The rated power is multiplied by the time used in the equation (2) to compute the fan's power consumption. In addition, the device's electric motor was turned on cross-sectional for 30 seconds every 30 minutes to speed up the drying process using the arm in the tank.

$$P_F = 2.2 \times t \quad (2)$$

The power consumption of the heater, fan, and electric motor are put together to calculate the device's total power usage. Eq. 3:

$$P_T = P_H + P_F + P_E \quad (3)$$

2.3 Greenhouse gas emissions and electricity consumption calculations

On average, energy producers use 3.2 percent of the electricity they generate. Also, 13.3 percent of the energy produced is wasted. This is due to the distance of power plants from industrial and urban areas. Finally, for each treatment, the necessary kW hours were determined. Then, we calculated the ratio of energy use to the mass of evaporated water. Next, we estimated the greenhouse gases produced per kilogram of water evaporated by the dryer's food waste. We used coefficients from energy-related organizations. The necessary coefficients are shown in Table 1.

2.4 Economic evaluation

According to Mishra et al. to perform an economic assessment, the annual cost (P_Y) is first calculated from Eq. 4 [25]:

$$P_Y = P_K + P_M + C_{ea} + V_s \quad (4)$$

(P_K), (P_M), (C_{ea}) and (V_s) are annual capital cost, annual maintenance cost, annual electricity cost and installment value, respectively.

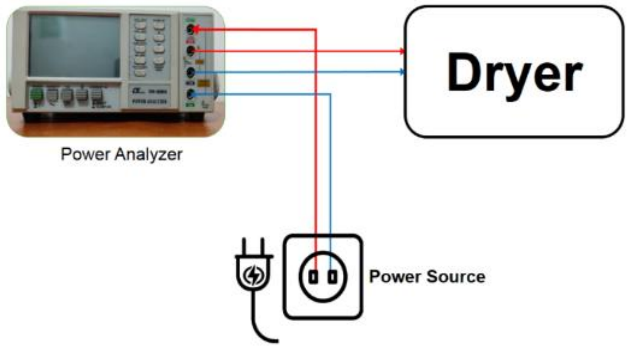

Fig. 1. Circuit for calculating the power consumption of the heater

Table 1. Amount of greenhouse gases produced per one kW of electricity generated in power plants with different fuels [24]

Power house type	Fuel type	Greenhouse gas (g kWh^{-1})		
		NOx	SO_2	CO_2
Steam	Natural gas	2.69	0	636
	Heavy oil	2.52	15.25	1025
Gas turbine	Natural gas	1.91	0	782
	Gas oil	5.79	3.84	1048
Combined cycle	Natural gas	2.95	0	450
	Gas oil	3.78	2.32	622

The annual cost of capital is obtained by using (P_{CC}) capital and capital factor coefficient (F_{cr}) in Eq. 5:

$$P_K = P_{CC} \times F_{cr} \quad (5)$$

Also, the annual electricity cost is obtained using Eq. 6, which (N), (W_r) and (P_e) are the working hours, the nominal power of the device and the cost of electricity, respectively:

$$c_{ea} = N \times W_r \times P_e \quad (6)$$

(V) and (F_v) are the value of the installments and the capital ratio of the installments. Eq. 7 calculates the value of installments:

$$V_a = V \times F_v \quad (7)$$

Capital recovery coefficients and installment value in Eq. 8 and 9 are calculated using (d) the long-term investment interest rate:

$$F_{cr} = \frac{d(1+d)^n}{(1+d)^n-1} \quad (8)$$

$$F_v = \frac{d}{(1+d)^n-1} \quad (9)$$

The cost for drying each kilogram of product (P_d) is obtained by dividing the annual cost (P_a) by the total annual output (M_a) (Eq. 10).

$$P_d = \frac{P_a}{M_a} \quad (10)$$

Using Eq. 11, the annual output of the device in kilograms is obtained:

$$m_a = \frac{m_d D}{D_b} \quad (11)$$

Where (m_d), (D), and (D_b) are the output weight of the product for each drying, the number of working days per year and the ratio of days to the number of drying cycle.

The net profit from the sale of the final product per kilogram as animal feed is calculated using Eq. 12:

$$SP_b = P_b - P_d \quad (12)$$

Finaly according to ELkhadraoui et al. [26] the payback period, which is the time required after the start of operation to obtain the initial capital cost of the annual profit, is calculated using Eq. 13. (i) In this equation, the annual inflation rate is [26].

$$P_p = \frac{\mathrm{Ln}(1-\frac{P_{CC}}{V}(d-i))}{\mathrm{Ln}(\frac{1+i}{1+d})} \quad (13)$$

2.5 Statistical plan

This research used ANOVA to compare the mean across temperatures, periods, power plants, and fuels. It aimed to find the most contaminated. With the assistance of the SAS 9.4 program, the design was totally random, and then the Excel 2013 diagrams were created.

3. Results and discussion

The purpose of this paper is to assess the environmental impacts and economic analysis of the approach to producing animal feed from food waste. Initial analysis with ANOVA analysis and then examination of the pollution produced by each method helps in selecting the optimal temperature and time levels for pollution reduction. Combining the results of environmental and economic evaluation will be effective in fully understanding the existing method.

Because the device requires more energy to raise the air temperature, raising the temperature is always followed by an increase in the device's kW hour. As seen in Figure 2, the device's consumption rises as the temperature and time increase.

Table 2 indicated the pollution generated by fossil fuels in power plants at various temperatures and periods. The lowest NOx was from a natural gas turbine at 55 °C for 90 minutes. The highest NOx was from the same plant, at the same temperature, using gas oil fuel for 210 minutes. Treatment 55-210 with a turbine power plant and gas oil had the highest CO_2 emissions. Treatment 55-90 with a combined cycle power plant and natural gas had the lowest. Natural gas fuel produced the least SO_2 in each power plant. The most SO_2 was from treatment 55-210 in a steam power plant using heavy oil fuel.

The results of the analysis of variance for fuel, temperature, power plant, and time variables were shown in Table 3. As could be seen, time had an impact on the quantity of NOx and CO_2 generated at a particular percentage level, but it had no effect on SO_2. Furthermore, there was no statistically significant difference in the average impact of temperature on the quantity of SO_2, CO_2, and NOx generated at any level.

Also, a study of average pollution in various power plants showed that, regardless of the fuel used, NOx levels were not significant. However, SO_2 and CO_2 were significant at 1% and 5%, respectively. Finally, a comparison of average CO_2 in various fuels showed that, at any level, the type of power plant was not significant. However, NOx and SO_2 levels were substantial at 1%.

3.1 Calculating the power of the thermal heater

The comparison of average CO_2 produced at various time levels was significant, according to Table 3. Figure 3 showed the contamination levels over time. They peaked at 90 minutes, then fell to the lowest at 150 minutes. The duration was 210 minutes. Also, a comparison of the average CO_2 produced by the power plants showed that the gas turbine plant had the highest value, followed by the steam plant. There was no significant difference between them. However, the combined cycle plant had the lowest amount, with a significant difference between it and the other two plants. This implied that regardless of the kind of fuel used, the combined cycle power plant produced the least CO_2 (Figure 4).

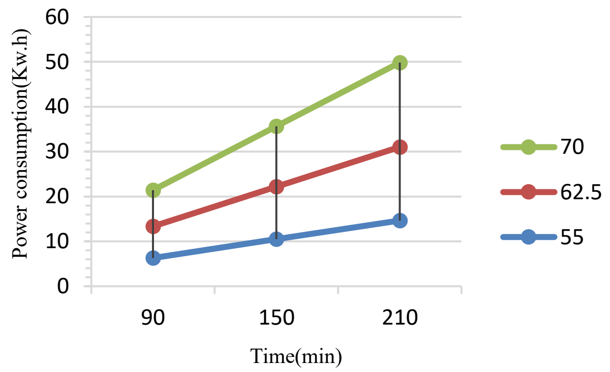

Fig. 2. Results of calculating the kW hour of device consumption

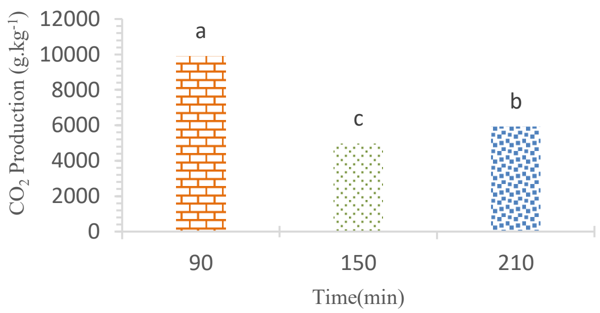

Fig. 3. Comparison of the average CO_2 produced at different times

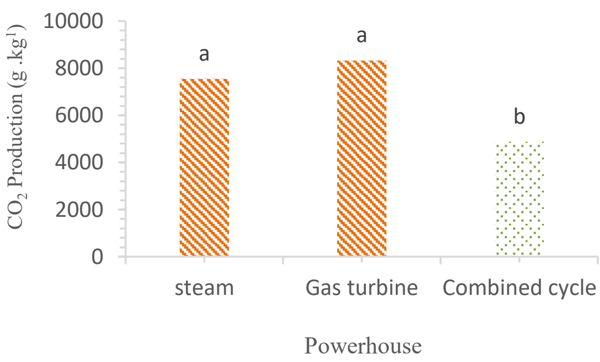

Fig. 4. Comparison of the average CO_2 produced in different power plants

Table 2. NOx, SO_2 and CO_2 at 55,62.5 and 70 and 90,150 and 210 at different power plants (g kg^{-1})

			Temperature (°C) – Time (min)								
Powerhouse	**Fuel**	**Pollutant**	**55-90**	**55-150**	**55-210**	**62.5-90**	**62.5-150**	**62.5-210**	**70-90**	**70-150**	**70-210**
Steam	Natural gas	NOx	9.886264	25.46181	47.51055	35.96632	11.33336	16.21897	16.82432	25.33325	22.31978
		SO_2	0	0	0	0	0	0	0	0	0
		CO_2	2337.421	6019.966	11232.98	8503.562	2679.56	3834.672	3977.795	5989.571	5277.093
	Heavy oil	NOx	9.261481	23.8527	44.50802	33.69336	10.61713	15.19398	15.76107	23.73226	20.90923
		SO_2	56.04666	144.3467	269.3442	203.8983	64.25046	91.94772	95.37952	143.6178	126.5341
		CO_2	3767.071	9701.99	18103.46	13704.64	4318.474	6180.092	6410.754	9653.003	8504.748
Gas turbine	Natural gas	NOx	7.019615	18.07883	33.73426	25.53743	8.047107	11.51607	11.94589	17.98755	15.84787
		SO_2	0	0	0	0	0	0	0	0	0
		CO_2	2873.999	7401.908	13811.62	10455.64	3294.679	4714.958	4890.937	7364.535	6488.501
	Gas oil	NOx	21.27936	54.80441	102.2625	77.4145	24.39411	34.90999	36.21294	54.52769	48.04146
		SO_2	14.11273	36.34697	67.82175	51.34226	16.17848	23.15274	24.01688	36.16345	31.86169
		CO_2	3851.6	9919.693	18509.69	14012.16	4415.376	6318.768	6554.605	9869.607	8695.586
Combined cycle	Natural gas	NOx	10.84181	27.9228	52.10265	39.44262	12.42878	17.78661	18.45046	27.78181	24.47708
		SO_2	0	0	0	0	0	0	0	0	0
		CO_2	1653.836	4259.41	7947.861	6016.671	1895.915	2713.211	2814.478	4237.904	3733.792
	Gas oil	NOx	13.89222	35.77905	66.76203	50.54004	15.92569	22.79098	23.64161	35.59839	31.36385
		SO_2	8.526443	21.95963	40.97564	31.01928	9.774496	13.98811	14.5102	21.84875	19.24977
		CO_2	2285.969	5887.451	10985.71	8316.377	2620.576	3750.261	3890.233	5857.725	5160.93

Table 3. Results of analysis of variance of NOx, SO_2 and CO_2 at various temperatures, times, fuels and power plants

	NOx		**SO_2**		**CO_2**	
Parameter	**Average**	**F**	**Average**	**F**	**Average**	**F**
Time	2292.006753	7.01**	5447.48767	2723.74384$^{n.s}$	123718277.2	7.62**
Temperature	492.206728	1.51$^{n.s}$	1169.84389	584.92194$^{n.s}$	26568407.1	1.64$^{n.s}$
Power planet	586.745511	1.80$^{n.s}$	37208.85578	18604.42789**	58979117.0	3.63*
Fuel	1958.285027	5.99**	94122.57441	31374.19147**	31246368.2	1.92$^{n.s}$
Error	326.74712		1402.7695		16244813	

*, **: significant at the 5% and 1% level, respectively
n.s: no significant difference

3.2 NOx Emission rate

As shown in Figure 5, the average NOx generated in various power plants differed significantly depending on the kind of fuel used. The gas turbine power plant generated the most NOx while utilizing gas oil, which was a considerable difference from other instances. Natural gas in gas turbine power plants had the lowest quantity (17.37), but there was a big difference with natural gas in combined cycle, steam, and heavy oil plants. In the combined cycle and steam, there was no discernible difference between heavy oil and natural gas. Furthermore, there was no substantial difference between these instances and the average NOx generated by gas oil in the combined cycle. However, when compared to other power plant fuels, gas oil generated the highest NOx. Figure 6 showed that the highest NOx level, 42.5844, was at 90 minutes. Furthermore, the times 150 and 210 minutes were not substantially different. This could be attributed to moisture failure after 150 minutes, which resulted in a rapid drop in product moisture. This failure reduced the energy needed to evaporate each kilogram of moisture from the trash. It lowered NOx emissions compared to the steam moisture.

3.3 SO_2 Emission rate

Due to the absence of SO_2 release, natural gas had the lowest SO_2 emissions of any power plant, as shown in Fig. 7. However, heavy oil (138.74) had the highest SO_2 emission in a steam power plant, which was a considerable difference. The greatest emission came from gas oil in gas turbine power plants, which emitted a fifth as much SO_2 as heavy oil. Finally, with a considerable difference, the same fuel in a combined cycle power plant emitted the least SO_2. Figure 8 compared the three power plants in terms of fuel type. This power plant had been using oil. In addition, there were no substantial variations in SO_2 emissions between Combined Cycle and Gas Turbine facilities.

3.4 Economic evaluation

Figure 9 shows a cost diagram for drying each kilogram of product. The cost rises with higher temperatures and longer times. At 55 °C, the lowest cost is \$0.0322 at 90 minutes. The highest cost is \$0.0470 at 210 minutes.

Table 4 shows the values obtained in different parameters in the economic evaluation.

Table 4. Parameters calculated in economic evaluation

Parameter	**Unites**	**Value**
Annual maintenance cost	$	17,304
Annual capital cost	$	132,46
Installment value	$	95,15
Return of capital	Year	5.8
Annual output	Kg	1632
Profit from sales	Kg$/	0.129

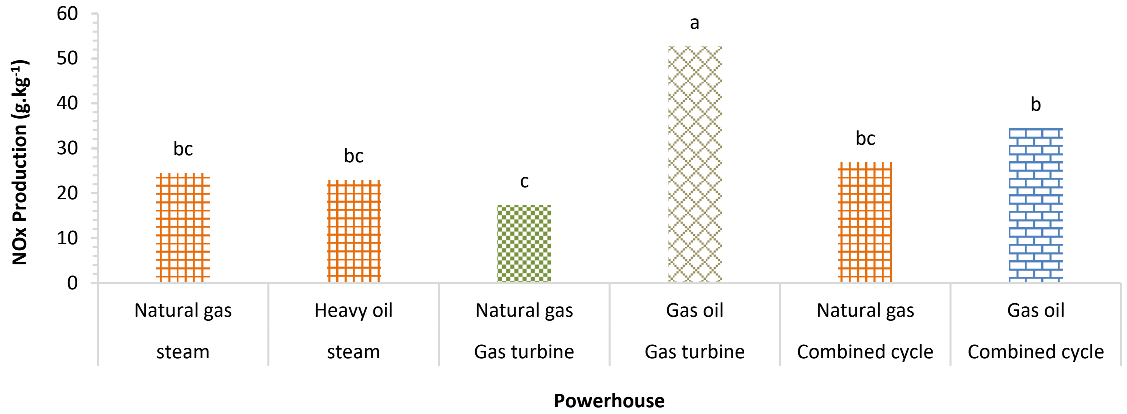

Fig. 5. Comparison of average NOx produced from different fuels

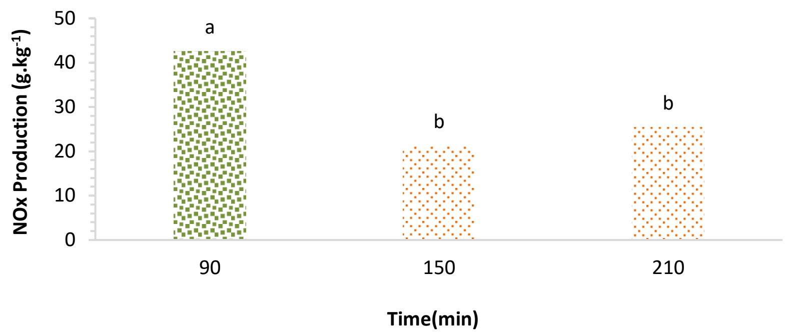

Fig. 6. Comparison of average NOx produced at different temperatures

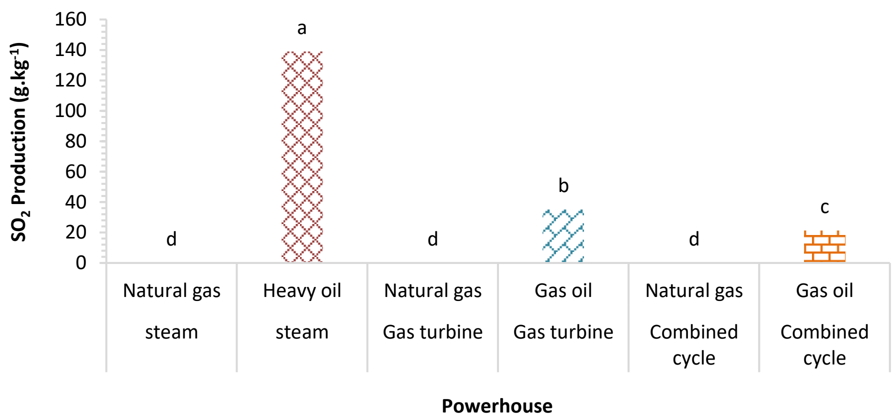

Fig. 7. Comparison of average SO_2 produced from different fuels

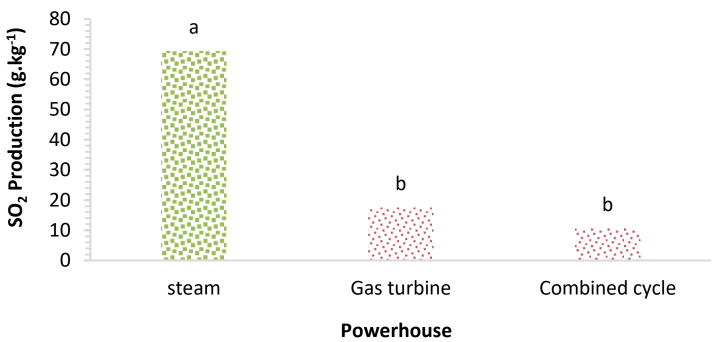

Fig. 8. Comparison of average SO_2 produced from different power plants

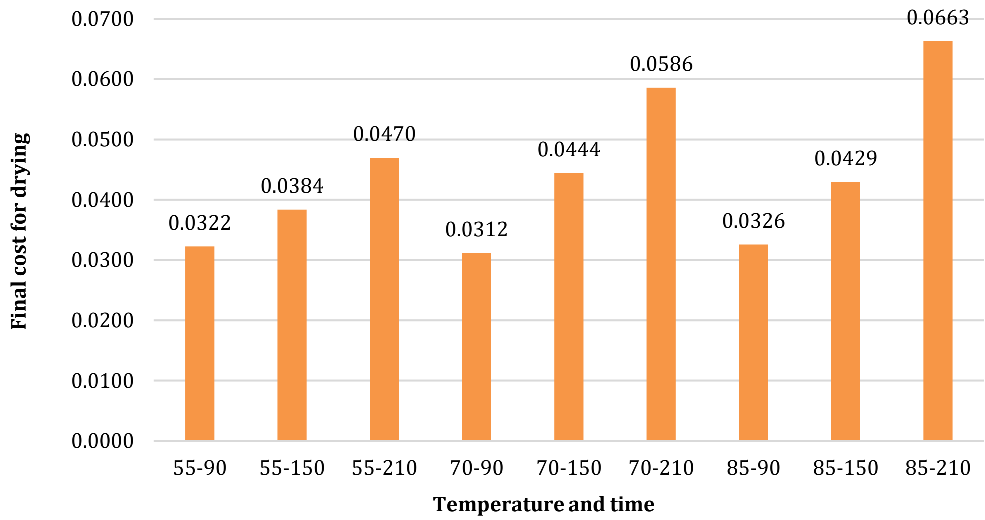

Fig. 9. Cost to dry each kilogram of waste at different temperatures and times

4. Conclusion

This research helps food waste management policy makers to make more accurate decisions about the consequences of actions. The analysis of this research from figures and tables leads to one conclusion. Total pollution (CO_2, SO_2 and NOx) is lowest at 150 minutes and highest at 90 minutes. 150 minutes at any temperature may produce the least pollution. This is because there is no relationship between temperatures. Of the many power plants, steam power plants produce the most pollution. They produce the most SO_2 and CO_2. The best choice is the combined cycle, which produces the least pollution. However, heavy oil steam power plants produce the most pollution. In contrast, gas turbine power plants using natural gas produce the least. They produce the electricity needed to dry the product. Finally, research shows that using natural gas to generate electricity in a gas turbine facility to convert food waste into animal feed in 150 minutes has the least negative environmental impact. As a result, a temperature of 55 °C in 150 minutes causes the least damage to the environment and the economy. It is recommended that governments conduct the necessary studies regarding the environmental and economic impacts of the proposed technology before introducing an approach as a suitable option for food waste management. Also, examining the effects of the entire chain of actions of each food waste management method could be a good option for future research.

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