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PREDICTING THE AMOUNT OF POLLUTANTS EMITTED OF WOOD BURNED FOR FISH SMOKING

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Abstract

The process of smoking fish uses heat resulting from burning biomass fuel, which is a source of greenhouse gas emissions. There are many ovens that use electricity and firewood as a source for energy. The study aimed to calculate the amount of emissions resulting from burning wood, such as nitrogen oxides, sulphur dioxide, particulate matter, volatile organic compounds, carbon monoxide, carbon dioxide, and carbon dioxide equivalents, and to determine the carbon footprint of fish smoking factories to reduce the negative effects of greenhouse gas emissions. The results showed that the amount of Nitrogen oxides gas produced from the factory per year was 0.007 ton NOx, Sulphur dioxide was 0.0009 ton SO_2, Particulate Matter was 0.0438 ton PM, Volatile Organic Compounds was 0.0876 ton VOCs, Carbon Monoxide was 0.613 ton CO, Carbon dioxide was 6.92 ton CO_2, the emissions from the amount of fuel used was 788 ton CO_2-eq, the emissions of electricity use was equal to 38.3 ton CO_2-eq. In the end, the total amount of emissions produced from the factory is 99.5 ton of CO_2-eq yr^{-1}.

Key words: *salmon, carbon footprint, Sulphur dioxide, Nitrogen oxides, Particulate Matter, Volatile Organic Compounds, Carbon Monoxide, Carbon dioxide and carbon dioxide equivalent*

INTRODUCTION

Preliminary forecasts for 2023 show an expected total harvest of 511,000 tonnes of Pacific salmon in the Russian Federation, double compared to 2022, but well below the projected total harvest of 322,000 tonnes. In addition, landings of 375,000 tonnes of pink salmon, 91,000 tonnes of chum salmon, 35,000 tonnes of sockeye salmon, and 9,000 tonnes of coho salmon are expected [5].

Fish has a significant role in the diet of humans. The amount consumed of it globally is steadily rising. Millions of people in Africa depend heavily on fish as a diet, and low-income households use it as a primary source of animal protein. After capture, it is a perishable commodity though. This results in significant post-catch losses and a revenue shortfall for fishermen. Under these circumstances, processing turns becomes a must for maintaining fish quality. To preserve fish, a variety of conventional methods are used, including frying, fermenting, salting, drying, and smoking [16, 6].

A substantial contributor to food security and nutrition, smoked fish accounts for two thirds of the fishery products consumed in the Ivory Coast, and it is still produced using antiquated, traditional smoking techniques. Even if the nation has enhanced ovens known as FTT ovens (FAO-Thiaroye Processing Technique), these methods do not give much thought to the health of the populace or the preservation of the environment [17].

The main processes involved in making smoked fish include brining (either by injecting or bathing in liquid or dry salt combination), chilling, packing (either modified or air/vacuum), and storing. One of the earliest methods of preservation, smoking combines the benefits of heating, drying, salting, and smoking. Fish is usually smoked at 28 to 32°C or at 70 to 80°C. Because cold smoking does not cook the meat, coagulate the proteins, deactivate the enzymes that cause food spoiling, or get rid of food pathogens, the meal must be stored in a refrigerator until it is consumed [1].

Salmon undergoes physicochemical and sensory alterations when it is treated with smoke flavoring. The finished product's qualities may resemble those obtained through the conventional cold smoking process, depending on the makeup of these flavorings. There are several benefits to smoking fish. Fish that has been smoked has a longer shelf life, tastes better, and may be used in more soups and sauces. When there are bumper catches, it minimizes waste and allows for storage during the lean season. It improves people's year-round access to protein and facilitates the packing, transportation, and marketing of fish, particularly in remote areas [13].

One source of polycyclic aromatic hydrocarbons (PAHs) is food. PAHs are produced during the smoking, roasting, barbecuing, or grilling of food, especially meat, meat products, and fish, since the organic elements do not completely burn or decompose thermally. PAH are produced when the fats in the meat or fish undergo pyrolysis and are deposited on the meat or fish. Cooking over charcoal (grilling, barbecuing) produces different amounts of PAH depending on how much fat is in the meat or fish and how close it is to the heat source. Many investigations of typical food products that have been roasted or grilled over charcoal have demonstrated the presence of PAHs like indeno [1, 2, 3-c, d] pyrene, benzo[α]pyrene, anthracene, chrysene, and benzo[α]anthracene [12].

The total amount of greenhouse gases (GHGs) emitted was 30, 279.08 MT CO_2, 131.79 MT CH_4 and 0.91 MT N_2O. The average emissions of GHGs from fish smoking were significantly higher than the usual household biomass cookstoves emission. The findings also show that fish smokers prefer specific fuelwood types to enhance the aesthetics of the fish after smoking, the ability of the fuelwood to last longer in fire, the availability of the fuelwood in the locality and other important factors [4].

Fish has been smoked in traditional smoking ovens for many years, but they have changed over time. These ovens consist of the metal cylinder oven, the metal rectangular mud oven, the metal square oven, and the more modern chorkor smoker. Along the way, more advanced fish smokers have been released, including the FTT-Thiaroye, Abuesi gas fish smoker, and Ahotor Oven. Using incompletely burned wood smoke; fish that has already been salted are treated using traditional fish smoking techniques. The main reason people eat fish is because the process of smoking it, which also requires high temperatures, denatures the proteins in the fish [2].

Determining how smoke-drying temperatures impact the nutritional qualities of the final product is crucial since very high smoking temperatures have the potential to reduce the nutritional value of smoke-dried fish. High concentrations of polycyclic aromatic hydrocarbons (PAHs) have also been seen to be introduced into the final product when fish come into direct contact with combustion fumes [7].

Following harvest, fish losses are classified as follows: physical loss (damage to body parts), quality loss (unacceptability or spoiling), and market force loss (financial). A number of factors, including inadequate road infrastructure, seasonal variations, and inappropriate packing and storage, contribute to the yearly post-harvest losses of landed fish weight, which are estimated to be between 35 and 40 percent locally and 25 percent worldwide. The species, size, and state of cleanliness all affect these losses differently. People were able to overcome the obstacles as a result by creating creative solutions. For instance, it has become more popular to hang fish over a fire to dry, and the smoke enhances the flavor over time. As a result, smoking fish became a common way to preserve fish [11].

Scientists have discovered that a variety of natural phenomena, including shifts in biotic processes, variations in Earth's orbit, variations in solar radiation received by the planet, oceanic, volcanic eruptions, and orogenic changes brought on by plate tectonics, all contribute to the planet's constantly changing climate. Moreover, it has been determined that human activity is the primary cause of the ongoing climate change, also referred to as global warming [14].

A person's contribution to global warming in terms of greenhouse gas emissions is measured and expressed as their "carbon footprint," which is measured in units of carbon dioxide equivalent. It consists of two segments in total: The term "direct footprint," also known as "primary footprint," refers to the amount of carbon dioxide (CO_2) equivalent emissions that result from using fossil fuels at home, in vehicles, on airplanes, and from other activities. The indirect carbon dioxide (CO_2) equivalent emissions from the whole life cycle of the goods and services we use, including those related to their production and ultimate breakdown, are measured by what is known as the "indirect" or "secondary" footprint [10].

The term "carbon dioxide equivalent" (or "CO_2-eq") is used to describe several greenhouse gases in terms of one unit. The amount of CO_2 that, in any quantity and for any sort of greenhouse gas, will have an equivalent greenhouse effect is known as CO_2-eq. The quantity of greenhouse gases can be expressed as CO_2-eq by multiplying it by the potential for global warming. For instance, 25 kilos of carbon dioxide are produced for every kilogram of methane released (1 kg CH_4 * 25 = 25 kg CO_2 equivalent). "CO_2-eq" is an extremely helpful phrase for a number of reasons. It makes it possible to state a "package" of greenhouse gases as a single number and to compare different packages of greenhouse gases easily (in terms of the overall effect of global warming) [3].

Four main steps can be included in the processing of cold-smoked salmon: filleting, salting, drying, and smoking. The drying and smoking processes should be carried out between 20 and 30 degrees Celsius. Filleting can be done mechanically using a machine or by hand. The method and properties of the raw material have an impact on the product yields. When Atlantic salmon is manually trimmed and filed by machine, the overall weight losses fall between 30 and 45 percent [15].

Around 0.49% of greenhouse gas emissions caused by human activity came from aquaculture worldwide in 2017. In order to prevent the worst effects of climate change, the IPCC advises that global greenhouse gas emissions be cut by 45% by roughly 2030 and attain net zero emissions by 2050. But in order to meet these long-term targets, emissions must be drastically reduced over the next several decades, especially in the transportation sector, where emissions are predicted to rise sharply by 2050. The idea of carbon footprinting was created in order to accomplish the objectives. The entire amount of greenhouse gasses, including carbon dioxide (CO_2), released during the production process, from feed preparation to waste disposal, is known as the aquaculture industry's carbon footprint [9].

Fish processing still uses smoking, one of the earliest ways of food preservation. Smoking has antibacterial and antioxidant properties, but it can also produce specific organoleptic traits (taste, color, and scent), as well as texture. A few variables that may affect the quality of smoked fish are the kind of wood used, the temperature, and the length of the smoking process. It should be mentioned that certain carcinogenic substances, like polycyclic aromatic hydrocarbons (PAHs), are present in wood smoke [18].

Since fish meal is an inexpensive source of protein, it is regarded as one of the most significant traditional ingredients in Egyptian cuisine. Fish keeping, recreational fishing, and angling are all significant aspects of fisheries, but fish as food, the fishing business, aquaculture, and fish farming are all commercially significant. When compared to other animal protein sources, fish meals represent a significant and cost-effective supply of protein. In developing nations, fish makes up more than 30% of the total animal protein consumed per person [19].

The aim study was predicted the amount Nitrogen oxides, Sulphur dioxide, Particulate matter, Volatile organic compounds, carbon monoxide, carbon dioxide and carbon dioxide equivalent also determining the carbon footprint of fish smoking factories.

MATERIALS AND METHODS

The experiment was implemented during the year 2024 in one of the fish smoking factories in 10th of Ramadan City, Sharkia Governorate, Egypt. To estimated carbon footprint and other greenhouse gas (GHG) emissions from fish smoking ovens.

The work was carried out in a salmon

smoking plant consisting of: 1) a receiving area of 100-150 square meters which includes an inspection table: 2m x 1m and a cold storage area: 10m x 10m for storing raw fish, with temperature control. 2) Preparation area including washing station: 5m x 2m, including basins and drains. Cutting tables: each table is approximately 3m x 1m. Boning station: 2m x 1m per station. 3) Salting area including salting tanks: each tank is approximately 2m x 1m, with space for multiple tanks. Drainage system: integrated within the salting area to efficiently remove liquids. 4) Smoking rooms consisting of smoke generators: the generator area is typically 1m x 0.5m, the smoking room is 1.90m x 2.15m x 2.80m and accommodates shelves. 5) Cooling area approx. 50-70 square meters. 6) Packaging area approx. 80-120 square meters. Packaging machines: Each machine approx. 2m x 1.5m. Final storage in freezing rooms approx. 100-150 square meters.

A set of mathematical equations was used to calculate the amount of emissions generated from fish smoking factories such as Nitrogen oxides, Sulphur dioxide, Particulate matter, Volatile organic compounds, carbon monoxide, carbon dioxide and carbon dioxide equivalent, according to Inventories (2006) [8].

-Nitrogen oxides (NOx) Emissions:

$$NO_X\ Emissions = \text{Mass of wood} \times \text{EF}_{NO_x}$$

where:

NOx Emissions = Measured in (ton NOx), It is Nitrogen oxides NOx emissions from burning wood.

EF $_{(NOx)}$ = Measured in (1.6 g NOx/ kg of wood), It is emission factor of NOx.

-Sulphur dioxide (SO_2) Emissions:

$$SO_2\ Emissions = \text{Mass of wood} \times \text{EF}_{SO_2}$$

where:

SO_2 Emissions = Measured in (ton SO_2), It is Sulphur dioxide (SO_2) emissions from burning wood.

EF $_{(SO2)}$ = Measured in (0.2 g SO_2/ kg of wood), It is emission factor of SO_2

-Particulate Matter (PM) Emissions:

$$PM\ Emissions = \text{Mass of wood} \times \text{EF}_{\text{PM}}$$

where:

PM Emissions = Measured in (ton PM), It is Particulate Matter PM emissions from burning wood.

EF $_{(PM)}$ = Measured in (10 g PM / kg of wood), It is emission factor of PM

- Volatile Organic Compounds (VOCs) Emissions:

$$VOC_S\ Emissions = \text{Mass of wood} \times \text{EF}_{VOC_S}$$

where:

VOCs Emissions = Measured in (ton VOCs), It is Volatile Organic Compounds (VOCs) emissions from burning wood.

EF $_{(VOCs)}$ = Measured in (20 g VOCs / kg of wood), It is emission factor of VOCs

- Carbon Monoxide (CO)Emissions:

$$CO\ Emissions = \text{Mass of wood} \times \text{EF}_{\text{CO}}$$

where:

CO Emissions = Measured in (ton CO), It is Carbon Monoxide (CO) emissions from burning wood.

EF $_{(CO)}$ = Measured in (140 g CO/ kg of wood), It is emission factor of CO

- Carbon Dioxide (CO_2) Emissions:

$$CO_2\ Emissions = \text{Mass of wood} \times \text{EF}_{CO_2}$$

where:

CO_2 Emissions = Measured in (ton CO_2), It is Carbon Dioxide CO_2 emissions from burning wood.

EF $_{(CO2)}$ = Measured in (1580 g CO_2/ kg of wood), It is emission factor of CO_2

- The emissions from the amount of fuel used

$$\text{E} = \text{FC} \times \text{EF}$$

where:

E = Measured in (ton CO_2-eq), it is the total emissions released.

FC = Measured in (liters), it is the amount of fuel used

EF = Measured in (1.8 kg CO_2-eq per kg of wood burned), it is the amount of pollutants emitted per unit of fuel.

- The emissions from the Electricity used

$$\text{E} = \text{EC} \times \text{EF}$$

where:

E = Measured in (ton CO_2-eq), it is the total emissions released.

EC = Measured in (KWh), it is the amount of electricity used
EF = Measured in (0.45 kg CO_2-eq /KWh), it is the amount of CO_2 emitted per KWh of electricity consumed.

- Carbon dioxide equivalent (CO_2eq):

$$\mathrm{KgCO_2e = Kg\ NO_X \times 0.2 + Kg\ CO_2 + E_{fuel} + E_{electricity}}$$

RESULTS AND DISCUSSIONS

NOx emissions from fish smoking factories by (ton NOx yr^{-1})

Figure 1 depicts the Nitrogen oxides emissions, calculated from fish smoking factories, and estimated at 0.0058 ton of Nitrogen oxides per year for 10 kg burning wood and thus the amount of Nitrogen oxides emitted from fish smoking factory is equal to 0.007 ton of NOx yr^{-1}. The relationship between amount of wood burned and Nitrogen oxides gas emission can be expressed by regression equation as:

y = 0.0006x $R^2 = 1$

NOx emissions from fish smoking factories by (ton CO_2-eq yr^{-1})

Figure 2 depicts the Nitrogen oxides emissions, calculated from fish smoking factories, and estimated at 0.0012 ton of Carbon dioxide equivalent per year for 10 kg burning wood and thus the amount of Nitrogen oxides emitted from fish smoking factory is equal to 0.0236 ton of CO_2eq yr^{-1}. The relationship between amount of wood burned and Nitrogen oxides gas emission can be expressed by regression equation as:

y = 0.0001x-4E-18 $R^2 = 1$

SO_2 emissions from fish smoking factories by (ton SO_2 yr^{-1})

Figure 3 depicts the Sulphur dioxide emissions calculated from fish smoking factories, and estimated at 0.0007 ton of Sulphur dioxide per year for 10 kg burning wood and thus the amount of Sulphur dioxide emitted from fish smoking factory is equal to 0.0009 ton of SO_2 yr^{-1}. The relationship between amount of wood burned and Sulphur dioxide gas emission can be expressed by regression equation as:

y = 7E - 0.5x $R^2 = 1$

PM emissions from fish smoking factories by (ton PM yr^{-1})

Figure 4 depicts the Particulate Matter emissions calculated from fish smoking factories, and estimated at 0.0365 ton of Particulate Matter per year for 10 kg burning wood and thus the amount of Particulate Matter emitted from fish smoking factory is equal to 0.0438 ton of PM yr^{-1}. The relationship between amount of wood burned and Particulate Matter gas emission can be expressed by regression equation as:

y = 0.0037x $R^2 = 1$

VOCs emissions from fish smoking factories by (ton VOCs yr^{-1})

Figure 5 depicts the Volatile Organic Compounds emissions calculated from fish smoking factories, and estimated at 0.073 ton of Volatile Organic Compounds per year for 10 kg burning wood and thus the amount of Volatile Organic Compounds emitted from fish smoking factory is equal to 0.0876 ton of VOCs yr^{-1}. The relationship between amount of wood burned and Volatile Organic Compounds gas emission can be expressed by regression equation as:

y = 0.0073x $R^2 = 1$

CO emissions from fish smoking factories by (ton CO yr^{-1})

Figure 6 depicts the Carbon Monoxide emissions, calculated from fish smoking factories, and estimated at 0.511 ton of Carbon Monoxide per year for 10 kg burning wood and thus the amount of Carbon Monoxide emitted from fish smoking factory is equal to 0.613 ton of CO yr^{-1}. The relationship between amount of wood burned and Carbon Monoxide gas emission can be expressed by regression equation as:

y = 0.0511x $R^2 = 1$

CO_2 emissions from fish smoking factories by (ton CO_2 yr^{-1})

Figure 7 depicts the Carbon Dioxide emissions, calculated from fish smoking factories, and estimated at 5.76 ton of Carbon dioxide per year for 10 kg burning wood and thus the amount of Carbon dioxide emitted from fish smoking factory is equal to 6.92 ton of CO_2 yr^{-1}. The relationship between amount of wood burned and Carbon dioxide gas emission can be expressed by regression equation as:

$y = 0.5767x - 2E\text{-}14$ $\quad R^2 = 1$

Fuel emissions from fish smoking factories (ton CO_2-eq yr^{-1})

Figure 8 shows the emissions of use burning wood from the smoke generators in factory and which were estimated at 65.7 ton CO_2-eq for 10 kg burning wood. Thus, the amount of burning wood emissions from the factory is equal to 788 ton CO_2-eq. The relationship between amount of wood burned and Fuel emissions can be expressed by regression equation as:

$y = 6.57x$ $\quad R^2 = 1$

Electricity emissions from fish smoking factories (ton CO_2-eq yr^{-1})

Figure 9 shows the emissions of electricity use from the amount of electricity used in fish smoking factories, it was estimated at 6.6 ton of **CO_2-eq yr^{-1}** for 40 kWh electricity used and thus the amount of electricity used emitted from fish smoking factory is equal to 38.3 ton of CO_2 yr^{-1}.The relationship between amount of electricity used and electricity emission can be expressed by regression equation as:

$y = 0.1643x - 2E\text{-}14$ $\quad R^2 = 1$

Total CO_2-eq Emissions from fish smoking factories (ton CO_2-eq yr^{-1})

Figure 10 depicts Total CO_2-eq emissions were calculated from fish smoking factories, and it was estimated at 78.5ton CO_2-eq for 10 kg burning wood. thus, the amount of Carbon dioxide equivalent emitted from fish smoking factory is equal to 99.5 ton of CO_2-eq yr^{-1}. The relationship between amount of wood burned and Carbon dioxide equivalent gas emission can be expressed by regression equation as:

$y = 7.7918x + 5.9885$ $\quad R^2 = 0.9999$

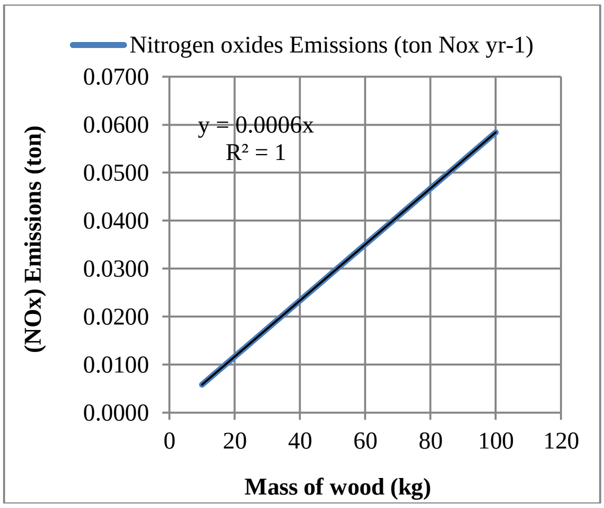

Fig. 1. NO_x emissions from fish smoking factories (ton NOx yr^{-1}) for burning wood.
Source: Author's determination.

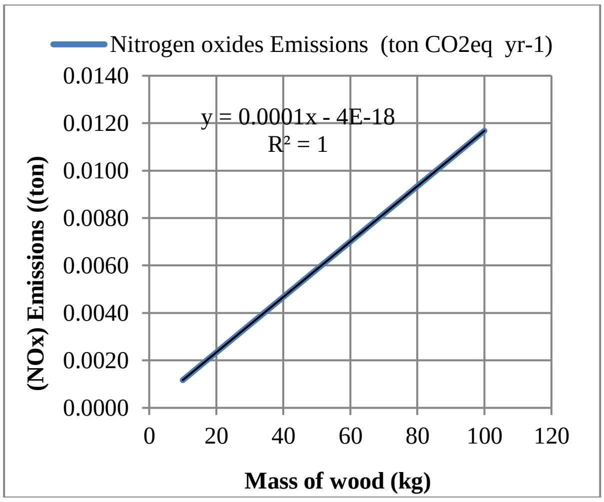

Fig. 2. NO_x emissions from fish smoking factories (ton CO_2-eq yr^{-1}) for burning wood.
Source: Author's determination.

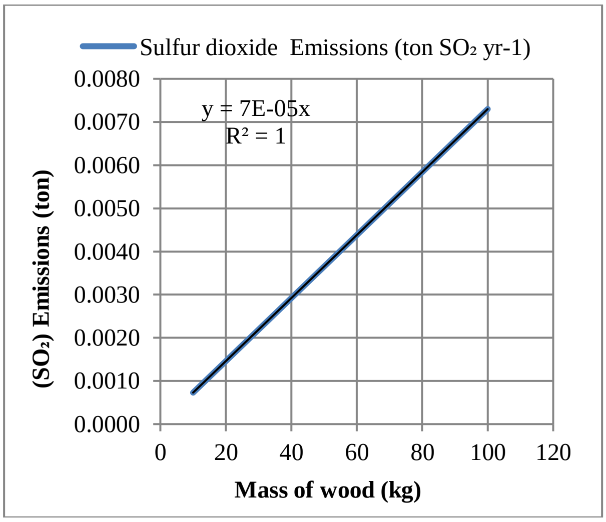

Fig. 3. SO_2 emissions from fish smoking factories (ton SO_2 yr^{-1}) for burning wood.
Source: Author's determination.

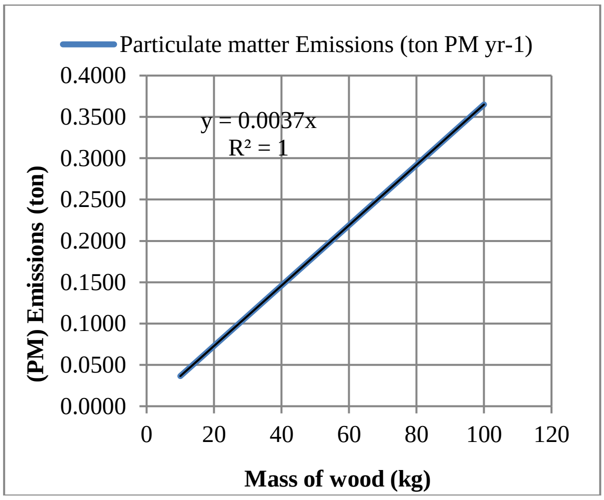

Fig. 4. PM emissions from fish smoking factories (ton PM yr^{-1}) for burning wood.
Source: Author's determination.

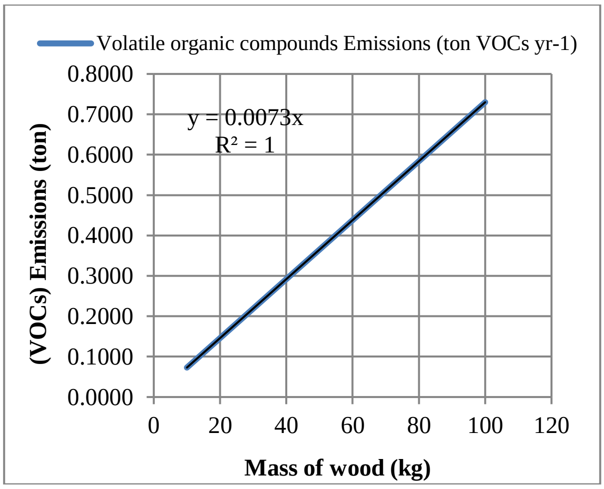

Fig. 5. VOCs emissions from fish smoking factories (ton VOCs yr^{-1}) for burning wood.
Source: Author's determination.

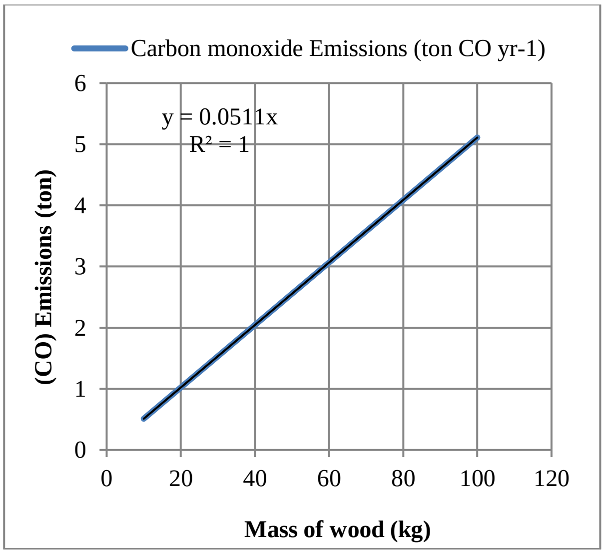

Fig. 6. CO emissions from fish smoking factories (ton CO yr^{-1}) for burning wood.
Source: Author's determination.

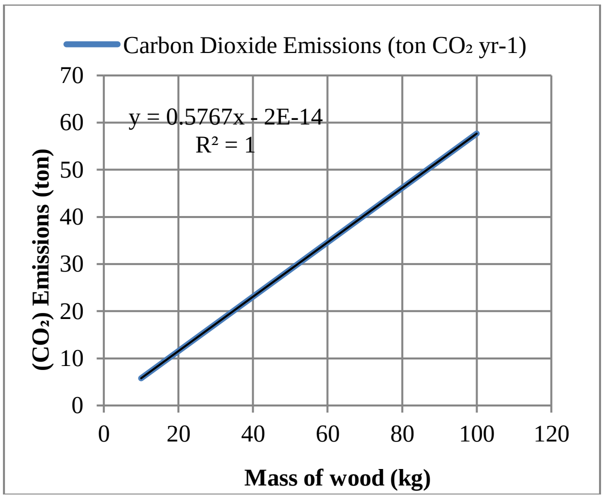

Fig. 7. CO_2 emissions from fish smoking factories (ton CO_2 yr^{-1}) for burning wood.
Source: Author's determination.

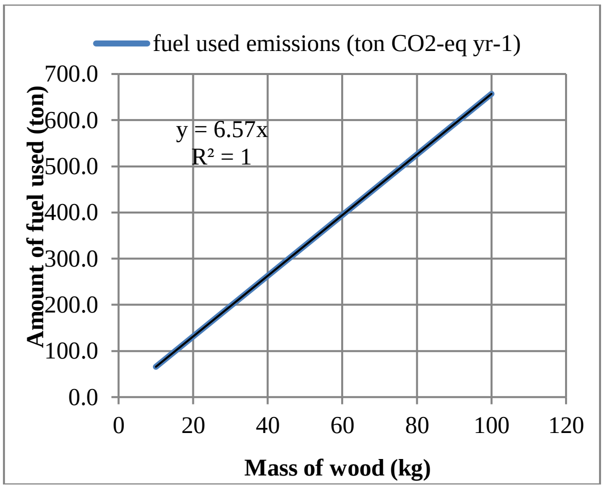

Fig. 8. Fuel emissions from fish smoking factories (ton CO_2-eq yr^{-1}) for burning wood.
Source: Author's determination.

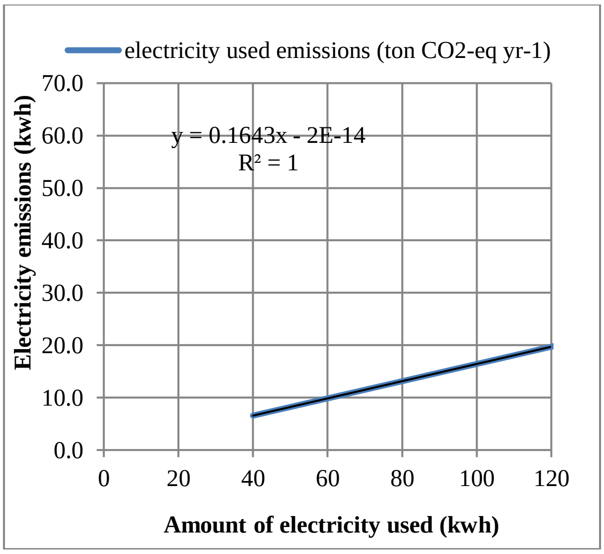

Fig. 9. Electricity emissions from fish smoking factories (ton CO_2-eq yr^{-1}) for burning wood.
Source: Author's determination.

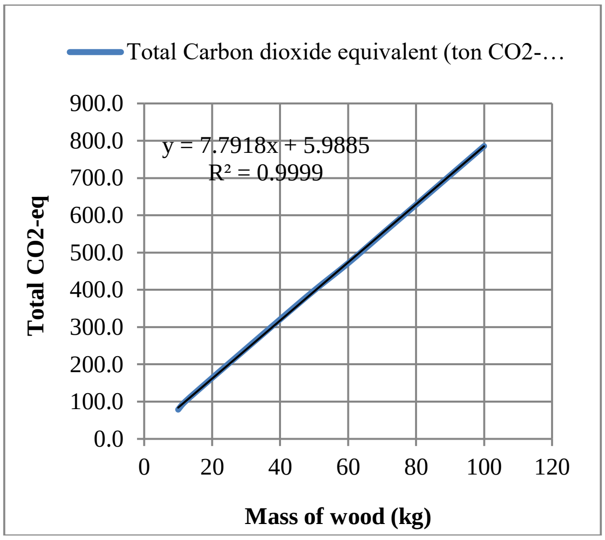

Fig. 10. Total CO_2-eq emissions from fish smoking factories (ton CO_2-eq) for burning wood
Source: Author's determination.

CONCLUSIONS

During the process of salmon smoking, the factory generated the following amounts of pollutants: Nitrogen oxides 0.007 ton NOx, Sulphur dioxide 0.0009 ton SO_2, Particulate Matter 0.0438 ton PM, Volatile Organic Compounds 0.0876 ton VOCs, Carbon Monoxide 0.613 ton CO, Carbon dioxide 6.92 ton CO_2, the emissions from the amount of fuel used was 788 ton CO_2-eq, the emissions of electricity use was equal to 38.3 ton CO_2-eq. In the end, the total amount of emissions produced from the factory is 99.5 ton of CO_2-eq yr^{-1}.

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