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Greenhouse Gas Emissions in Commercial Grills in the Metropolitan Area of the City of Veracruz, Mexico

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Abstract — The present work is an effort to determine the generation of greenhouse gases, including carbon dioxide, methane and nitrous oxide, from the cooking process that is developed for chickens, meats, ribs, hamburgers and pizzas, using firewood and coal as a source of thermal energy in the commercial grills of the metropolitan area of the City of Veracruz, which is made up of the municipalities of Veracruz, Boca del Río, Medellín de Bravo, Jamapa and Manlio Fabio Altamirano, at Veracruz State, Mexico which as a whole They have a population of 882,011 inhabitants, where they exist of 430 commercial establishments of this type exists, making 275 visits to carry out interviews and surveys, showing that 74.18 % use charcoal and 25.81 % use firewood. Using emission factors and caloric indices, it was determined that a total of 2,739.99 tons/year of carbon dioxide equivalent is generated by consumption of firewood and 8,872.66 tons/year of carbon dioxide equivalent by consumption of coal and with a total of 11,612.65 tons/year of carbon dioxide equivalent for all commercial grills facilities, which are involved in constant climate change and the effects that this causes in this metropolitan area on the central coast of the Gulf of Mexico and that must be included in both regulations municipal and in the climate change agenda.¹

Keywords: commercial grills; emissions, greenhouse gases.

Resumen — El presente trabajo tiene como objetivo determinar la generación de gases de efecto invernadero, específicamente dióxido de carbono, metano y óxido nítrico, derivada del proceso de cocción empleado en asaderos comerciales de la zona metropolitana

de la Ciudad de Veracruz. Este proceso incluye la preparación de alimentos como pollos, carnes, costillas, hamburguesas y pizzas, utilizando leña y carbón como fuentes de energía térmica. La zona metropolitana de la Ciudad de Veracruz está conformada por los municipios de Veracruz, Boca del Río, Medellín de Bravo, Jamapa y Manlio Fabio Altamirano, en el Estado de Veracruz, México, con una población conjunta de 882,011 habitantes. En esta región, se identificaron 430 establecimientos comerciales de este tipo. Para el estudio, se realizaron 275 visitas, en las cuales se llevaron a cabo entrevistas y encuestas. Los resultados indican que el 74.18 % de los establecimientos utilizan carbón como combustible, mientras que el 25.81 % emplean leña. Mediante factores de emisión e índices calóricos se determinó que se genera un total de 2,739.99 toneladas/año de dióxido de carbono equivalente por consumo de leña y 8,872.66 toneladas/año de dióxido de carbono equivalente por consumo de carbón y con un total de 11,612.65 toneladas/año de dióxido de carbono equivalente para la totalidad de los asaderos comerciales los cuales son partícipes del constante cambio climático y los efectos que esto ocasiona a esta zona metropolitana en la costa central del Golfo de México y que deben estar incluidos tanto en reglamentación municipal y en la agenda de cambio climático.

Palabras Clave: asaderos comerciales, emisiones, Gases de Efecto Invernadero.

I. INTRODUCTION

GLOBAL temperatures have increased over the last 50 years, not only due to carbon dioxide emissions (CO₂), but also due to other types of greenhouse gases (GHG) as methane and nitrous oxide [1], Since the intensive use of energy based on the burning of fuels of origin fossil (such as oil, coal and gas) has been one of the main sources of energy, especially in developing countries; the global average combined surface and ocean temperature is estimated to show an increase, in a range of 0.8 to 1.2 °C, during the period 1880-2012 compared to the pre-industrial era [2].

Since 1992, Mexico has signed the United Nations Framework Convention on Climate Change (UNFCCC), with this it committed to comply with the guidelines established in that instrument, among which is the development and updating of a national GHG inventory [2]. This is why in 2012 the General Law on Climate Change was decreed and in 2013 the state law of mitigation and adaptation to the effects of climate change for the state of Veracruz, where the guidelines are established for the regulation of Greenhouse Gas emissions and the obligation to have inventories with estimates of anthropogenic emissions [3],[4].

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Firewood is a fuel widely used for cooking in Mexico, with a consumption pattern that reveals implications for climate change, since by 2022 it was estimated that a total of 31.3 million Mexicans, which represents close to 26 % of the population, will total of the country [5], and according to the National Institute of Statistics, in 2018, 11 % of the national population consumes firewood and charcoal in Mexican homes. [6]. This fuel is obtained from various sources, including forests, scrub areas [7], and waste from the construction industry and tree pruning. The use of this fuel has a great impact due to its combustion power, apart from the social and symbolic importance since cooking and preparing food is an activity that is carried out every day [8]. The quality of the wood is the most important factor for use as firewood, since these affect properties such as heating value, ash content and humidity content, among other attributes [9].

Exposure to pollutants generated by the consumption of firewood in the United States has had a great impact on the increase in respiratory diseases, including infections, cancer, asthma and cardiovascular diseases, among others, as well as the deterioration of cognitive functioning in older people [10]. The WHO estimates that 3.8 million deaths occur each year due to air pollution, where the use of firewood takes first place, where women and children are the most affected [11], the use of firewood in commercial grills represents 26 % of total final energy consumption where it is estimated that 2.6 billion people, mainly low and middle income, use traditional biomass (firewood, charcoal, crop residues, livestock manure) to meet your cooking energy needs [12].

The consumption of this type of solid biofuels is an issue of environmental concern, because it arises from the unsustainable production and use of firewood, exerting pressure on the regional and global environment. The unsustainable extraction of firewood has caused deforestation, soil erosion and loss of biodiversity. Traditional biomass, when produced and used from controlled and sustainable sources, represents a reliable and accessible source of energy because it supplies energy in places where access to conventional fuels and technologies is null or limited. Thanks to proposed strategies such as forest codes and certification programs, it has been possible to achieve sustainable production and use of firewood. And now, biofuels and clean cooking technologies are the new alternatives to traditional cooking with biomass. For example: biogas, pellets and briquettes, as well as improved wood stoves [13].

It is important to mention that the use of firewood and charcoal represents a substantial generation of Greenhouse Gases; only the United States Environmental Protection Agency has reported since 1998 that the generation of Carbon Dioxide has been 1,032 and 1,979 grams for each kilogram of Firewood and Coal used as fuel, while for methane it was 4.2 and 7.9 and 0.35 and 0.51 for nitrogen dioxide [14].

The first attempt to determine the emission of greenhouse gases from commercial grills in the metropolitan area of the City of Veracruz was carried out by Lango-Reynoso et al., in 2018, which calculated the CO₂ emissions produced by burning different fuels in grills. commercials, but it is restricted to the City of Boca del Rio, which only represents 16 % of the metropolitan area, concluding that 30 grills in operation emit a total of 134.56 tons/year of CO₂ [15], Diaz-Nigueda et al., in 2022,

the calculation of Emissions generated by the consumption of firewood and charcoal in the preparation of roasted chickens in the city of Tuxtla Gutiérrez, Chiapas, Mexico is carried out through the application of emission factors (EF), where they were categorized from establishments based on their production and the infrastructure used for the activity to determine the fuel consumed annually, the results of which indicate that carbon dioxide emissions as a greenhouse gas is 5312.12 tons/year [16].

II. MATERIAL AND METHODS

A. The Metropolitan Area of City of Veracruz, Mexico

The Metropolitan area of City of Veracruz is located in the central part of the State of Veracruz, in the Sotavento Region on the coast of the Gulf of Mexico, it has 1061.9 km² (0.3 % of the state territory) and 882,011 inhabitants which represents 7.5 % of the state total and with the municipalities of Boca del Rio, Medellin Jamapa and Manlio Fabio Altamirano form as a whole the most metropolitan area in the state populated metropolitan area in the State of Veracruz [17] (Fig. 1).



Fig. 1. Metropolitan Area of City of Veracruz, Veracruz State, Mexico.

B. identification and location of commercial grills

To account for the commercial grills, an in-person visit was made to the most populated neighborhoods in the month of June 2024 in the municipalities of Veracruz and Boca del Rio because they were the most populated, going street by street, especially the main avenues where Strategy and location Most of the grills are located there. In this tour, a total count and structured interviews were carried out with the owners, managers and employees of these establishments.

Surveys were applied with questions related to establishment data, type of fuel used, fuel consumed (kg), daily production,

days and hours of service. The establishments were classified into three categories with based on its production and infrastructure; identifying national franchises, as well as establishments established on the banks of streets and avenues. The number of establishments surveyed was calculated by [16] (Eq. 1):

$$n_i = \frac{N_i \sigma^2 Z^2}{(N_i - 1)e^2 + \sigma^2 Z^2} \quad (1)$$

Where:

i = category.

n_i = sample size in category i,

N_i = number of establishments in category i,

Z = value of 1.96 for a level of 95 % confidence

σ = population variance in study (0.5).

e = absolute precision level (9 %).

This equation has been used to determine the number of samples that must be taken to be representative with a finite universe, in research carried out for this type of research [16]:

C. Greenhouse gas emission calculation

To calculate pollutants, the annual production of CO_2 , CH_4 , N_2O (greenhouse gases) was quantified. This was done using the equation [16] (Eq. 2):

$$E_{ij} = (CA_i)(FE_j) \frac{1 \text{ Ton}}{10^6 \text{ g}} \quad (2)$$

Where:

i = category.

j = pollutant.

E_{ij} = annual emission of pollutant j in category i (t year⁻¹).

CA_i = annual fuel consumption in category i (kg year⁻¹).

FE_j = factor of emission of pollutant j by type of fuel (g kg⁻¹).

D. Calculation of the volume of Methane, Carbon Dioxide and Nitrous Oxide from the consumption of firewood and Coal in commercial grills

The emission factors of the greenhouse gases Carbon Dioxide, Methane and Nitrogen Dioxide for charcoal and firewood were obtained from the values tabulated by Díaz-Nigenda and co-authors in 2022, which on average are presented in Table 1 [16].

TABLE 1
GREENHOUSE GAS EMISSION FACTORS

Emission factors (firewood) (g kg ⁻¹)		
CO_2	CH_4	N_2O
1569.5 (± 104.25)	5.47 (± 2.25)	0.06 (± 0.01)
Emission factors (carbon) (g kg ⁻¹)		
CO_2	CH_4	N_2O
2 424.26 (± 353.37)	5.62 (± 1.55)	0.20 (± 0.13)

E. Calculation of the Tons of Methane and Nitrous Oxide in Tons of CO_2 equivalent

To calculate the tons of Methane and Nitrous Oxide equivalent to Tons of Carbon Dioxide, the formulas proposed by the Institute of Ecology and Climate Change of Mexico in 2020 were used, [18] which establishes (Eq. 3):

$$\text{CH}_4 \text{ em in CO}_2 \text{ eq} = (\text{CH}_4 \text{ em})(\text{PCGCH}_4) \quad (3)$$

Where $\text{CH}_4 \text{ em}$ is the total Methane emissions during the reporting year and PCGCH_4 is a Global warming potential of methane (Eq. 4).

$$\text{N}_2\text{O em in CO}_2 \text{ eq} = (\text{N}_2\text{O em})(\text{PCGN}_2\text{O}) \quad (4)$$

Where $\text{N}_2\text{O em}$ is the total Nitrous Oxide emissions during the reporting year and PCGN_2O is a Global warming potential of Nitrous Oxide.

Considering the global warming potential of methane at 28 and nitrous oxide at 265 [19].

F. Calculation of the emission of total tons of Carbon Dioxide equivalent of Greenhouse Gases

To calculate the emission of Greenhouse Gases expressed in total tons of Carbon Dioxide equivalent, the following equations are established for the use of coal and firewood. Finally, the total emission results from the sum of the results of both equations (Eq. 5, 6, 7).

$$\text{CO}_2 \text{ eq as Coal} = E_{ij} + \text{CH}_4 \text{ em in CO}_2 \text{ eq} + \text{N}_2\text{O em in CO}_2 \text{ eq} \quad (5)$$

$$\text{CO}_2 \text{ eq as Firewood} = E_{ij} + \text{CH}_4 \text{ em in CO}_2 \text{ eq} + \text{N}_2\text{O em in CO}_2 \text{ eq} \quad (6)$$

$$\text{Total CO}_2 \text{ eq} = \text{CO}_2 \text{ eq as Coal} + \text{CO}_2 \text{ eq as Firewood} \quad (7)$$

III. RESULTS AND DISCUSSION

To determine the number of commercial grills in the metropolitan area of Veracruz, the commerce directors of the municipalities of Veracruz, Boca del Rio and Medellin were interviewed, who provided the number of commercial grills registered in their respective municipalities, giving a total of 430 establishments of this type, (Table 2).

TABLE 2
TOTAL OF COMMERCIAL GRILLS
IN THE METROPOLITAN AREA OF HE CITY OF VERACRUZ

Municipality	Use of Firewood	Use of Coal
Veracruz	60	201
Boca del Rio	15	90
Medellin	36	28
Total	111	319

As can be seen in table 2, commercial grills predominantly use coal, since it is used mainly in cooking chicken and meat,

which is more common in the municipalities of Veracruz and Boca del Rio. However, the number of commercial grills that use firewood increases considerably in the Municipality of Medellín de Bravo, this is because in this area there is a gastronomic culture that influences the use of this fuel, especially in the communities of El Tejar and Rancho del Padre, since, as in South American countries, firewood is considered a fuel for cooking [20]. Although the municipalities of Jamapa and Manlio Fabio Altamirano are considered part of the metropolitan area of the city of Veracruz, both municipalities are completely rural and are not part of the urban conglomerate, so the decision was made not to include them in this study.

To determine the number of surveys and interviews necessary for the sample to be representative, equation No. 1 was used for a total population of 430 commercial grills with a confidence level of 95 %, a population variance in study of 0.5 and an absolute precision level of 9 %, resulting in the need to carry out a total of 144 surveys or interviews, 57.58 for commercial grills with the use of firewood and 86.63 for the use of charcoal, these values were adjusted given the complexity of the metropolitan area, for which it was determined that 131 surveys or interviews would be representative of the total number of commercial grills, and that 48 were carried out for those commercial grills that use firewood and 83 for those that use charcoal.

In this study, the consumption of charcoal was separated from that of firewood, since commercial grills do not use both fuels, this is due to the type of food preparation denominated in Spanish A LA LEÑA or LEÑERO y AL CARBÓN. An important point why the number of commercial grills has increased is the change in the stereotypes of traditional Mexican food that considers A LAS BRASAS and AL HUMO as a more gourmet style, where commercial grills offer different gastronomic experiences than the traditional roast chicken, meat, ribs, pizzas and burgers.

The interviews and surveys were carried out through tours of the metropolitan area of the city of Veracruz, from north to south, starting in the municipality of Veracruz from 10:00 a.m. to 2:00 p.m. in the period from Tuesday, 04 June to Sunday, June 9, 2024. It was found that there are commercial grills with restaurant service, in pizzerias, hamburger restaurants and self-service stores, in some of these places they did not have service in the same place, but it was exclusively to go.

For a better understanding of the product of commercial grills and the type of fuel they require, they were divided into Chicken, Beef, Meat, Pizzas and Hamburgers and the use of firewood or charcoal Table 3.

TABLE 3
TOTAL NUMBER OF COMMERCIAL GRILLERS,
SURVEYED OR INTERVIEWED BY FOOD CATEGORY

Food Category	Use of Firewood	Use of Coal
Chicken	34	60
Meat	3	6
Ribs	6	9
Hamburgers	2	8
Pizza	3	
Total	48	83

With the information in Table 3, it was possible to identify that the majority of commercial grills in the municipalities of Veracruz, Boca del Rio and Medellín de Bravo are roast chicken grills; and that these consume 70 % of the firewood and 72 % of the charcoal used as fuel, since the state of Veracruz, Veracruz is the main producer of chicken nationwide, and is also the largest consumer of this product. [21]. Meat grills, ribs and hamburgers represent 6.87 %, 11.45 % and 7.63 % respectively, in both cases the use of firewood and charcoal is very similar and there is no considerable difference between them, however in pizzas the use of charcoal is not used. charcoal, because only firewood is used for this food, when we refer to meat, we are considering cuts such as sirloin, bisteck, flank steak, t-bone, longaniza, chistorra, suckling pig

As a result of the surveys and field interviews, it was found that on average commercial chicken grills consume 45 kilograms of firewood per day, this is due to the fact that they are large local chains with restaurants, since this type of preparation is known as firewood chicken. In the case of meat and ribs grills, these are restaurants, they are also wood-fired preparations with less firewood consumption, which on average is 30 kilograms per day. Finally, there are commercial grills that have wood-burning ovens where they prepare pizza and consume on average 20 kilograms of firewood per day and for wood-fired hamburgers on average 15 kilograms of firewood per day are consumed in each commercial grill (Table 4).

TABLE 4
FIREWOOD CONSUMPTION BY COMMERCIAL GRILLS

Food category	Average daily firewood consumption (kg/day)	Total daily firewood consumption (tons/day)
Chicken	45	3.500
Meat	30	0.208
Ribs	30	0.416
Hamburgers	20	0.092
Pizza	15	0.104
Total		4.320

The total consumption of firewood per food category was obtained by multiplying the average daily consumption by the number of commercial units.

As can be seen in table 4, chicken roasters represent the highest consumption of firewood with an average of 1.5 kilograms per chicken, a value that is much less than the 1.85 kilograms of firewood per chicken reported in 2022 for the city of Tuxtla. Gutierrez Chiapas [16], this variation can also be determined given the sensory effects of roasting chickens over wood due to the wood used for cooking and its cost or availability [22].

In the case of commercial grills that use charcoal, the result of field surveys and interviews found that the average consumption in the case of chicken is 30 kilograms of charcoal per day; In this case, we must consider that charcoal grilling occurs both in commercial chains and in small mobile grills in family businesses. An important aspect is that no grill was found that used charcoal to prepare pizzas and the values for

consumption in the case of meat, ribs and hamburgers are presented in Table 5.

TABLE 5
COAL CONSUMPTION BY COMMERCIAL GRILLS
AT METROPOLITAN AREA OF VERACRUZ CITY

Food category	Average daily coal consumption (kg/day)	Total daily coal consumption (tons/day)
Chicken	30	6.89
Meat	25	0.570
Ribs	35	1.215
Hamburgers	18	0.552
Pizza	0	0
Total:		9.227

According to table 5, commercial chicken roasters represent the highest consumption of charcoal with an average of 1 kilogram per chicken. It was not possible to determine the amount of charcoal used for meat, ribs and hamburgers, since this depends on the type of commercial grill, however, it can be seen that for meat and ribs the amount of charcoal increases compared to firewood, if compared in tables 6 and 7. However, studies presented by Melo in 2022 show that beef steak is the meat that emits the most greenhouse gases in its production, with almost 130 kilograms of CO₂ equivalent per kilogram [23], there is a difference in the consumption of firewood and charcoal in commercial grills, this is fundamentally due to the fact that the amount of heat they produce is substantially lower in the case of firewood and greater in the case of firewood. case of charcoal, which allows the cooking time to be shorter and therefore its consumption to be lower.

To determine the annual emission for each of the pollutants (carbon dioxide, methane and nitrogen oxide), equation number 2 was used, for the two categories of firewood and coal, considering the annual consumption per category (which results from the multiplication of the daily emission for 365 days/year) and the emission factors for firewood and coal from table 1, obtaining the values shown in table 6.

TABLE 6
TOTAL GREENHOUSE GAS EMISSIONS
FROM COMMERCIAL GRILLS IN THE METROPOLITAN
AREA OF THE CITY OF VERACRUZ

Category	CA _i Annual consumption (kg/year)	Emission E _{ij} (tons/year)		
		CO ₂	CH ₄	N ₂ O
Firewood	1,576,800	2,474.78	8.62	0.09
Coal	3,367,855	8,164.55	18.92	0.67
Total		10,639.33	27.54	0.76

From the data in table 8 we can see that the emission of Carbon Dioxide by commercial grills that use charcoal is 337% greater than what is emitted in grills that use firewood, this is because. The value of the carbon dioxide emission factor of

coal is 54 % higher than that of firewood, in the case of Methane the emission values are similar because their emission factor is similar.

Finally using equations 5 and 6 and the values of the global warming potential of methane established by the Institute of Ecology and Climate Change of the Secretariat of Environment and Natural Resources of Mexico [18] and reported by Susunaga-Miranda et al., in 2023 [19] it is obtained that the total equivalent carbon dioxide emitted by the consumption of firewood by commercial grills in the metropolitan area of the city of Veracruz is 2,739.99 tons/year and in the case of the equivalent carbon dioxide by consumption of coal is 8,872.66 tons/year, and with the help of equation number 7, we have that the total amount of equivalent Carbon Dioxide emitted by commercial grills, both firewood and charcoal, for the year 2024 is 11,612.65 tons/year.

Commercial grills facilities contribute substantially to climate change due to the generation of greenhouse gases, since it is known that due to the increase in the amount of Greenhouse Gases in the local atmosphere and given the proximity to the reef zone on the coast of the Gulf of Mexico, contributes to the increase in sea temperature and thus to the bleaching of corals in the Veracruz Reef System National Park due to global warming [19], [24]. In addition, the estimates that have been made by various investigations consider a rise in sea level of between 19 to 58 cm by the year 2100; Other calculations predict a rise of 0.9 to 1.3 meters for the same period, it should not be ruled out that these variations are not the same in all regions, since some coastal scenarios will present flooding up to the current levels of 10 and 5 meters above sea level, and 5 meters on the coasts. of the municipalities of Veracruz, Boca del Rio, in the low areas of the municipality of Medellin, affecting the habitability conditions of the metropolitan area of the city of Veracruz [25].

V. CONCLUSION

After having carried out the field work, visits, surveys and interviews, it is concluded that in the metropolitan area of the city of Veracruz there are a significant number of commercial grills. The above is due to the ease of acquiring firewood and charcoal as fuel and the little environmental regulation and/or little commercial regulation, which is why the majority of commercial grills use the take-out service, they do not have the infrastructure to provide the service. of restaurants.

Although commercial grills that use firewood or charcoal specialize in chicken, meat, ribs, hamburgers and pizzas, there are other types of restaurants that use these fuels in various preparations of Mexican or international gastronomy and cannot be considered commercial grills, in addition that some supermarkets offer the roasting service with the purchase of products such as meats and vegetables.

Due to the geographical characteristics of the metropolitan area of Veracruz, it is evident that the use of charcoal in commercial grills exceeds those that use firewood, due to the conditions of the territory, firewood is scarce and its cost is much higher than that of charcoal. and due to its dimensions, transporting it presents exponential risk and handling difficul-

ties. For this reason, the consumers of this raw material as fuel for commercial grills predominate those who use charcoal. It is important that city councils do not make isolated efforts to control Greenhouse Gases, since in their respective regulations the subject of regulation is very varied and does not contribute to the metropolitan decrease in the emission of these pollutants.

Although the caloric index of methane and nitrous oxide are very high due to the small proportion present in these fuels, these pollutants do not represent a substantial variation in the tons of carbon equivalent, for which the largest proportion is represented by carbon dioxide.

It can be determined that by making some changes in the cooking of different types of food in commercial grills with the help of renewable energy, implementing solar ovens in these establishments. Through this change, the use of firewood and coal could be reduced, which would therefore result in a decrease in the generation of greenhouse gases, which would be a considerable amount per year, not leaving aside efficiency and heating power. This for the benefit of our environment, thanks to alternatives that can already be implemented.

As final results, there are fundamental characteristics of these fuels (firewood and coal) that determine their performance. On the one hand, charcoal heats up faster, providing higher and more uniform temperatures compared to firewood, which takes longer to reach high temperatures, being more difficult to control, producing more smoke.

The results of this research must be included in the Municipal Climate Change Agendas for the municipalities of Veracruz, Boca del Rio and Medellín de Bravo so that legal provisions are generated to carry out actions that help combat Climate Change, and thus regulate commercial barbecue activities so that they contribute to the reduction of Greenhouse Gases (GHG) and allow adaptation and reduction of the vulnerability of the area to the effects of climate change to its population and territory and thus comply with the provisions of the General Law on Climate Change in the scope of jurisdiction of the municipalities

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