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Estimation of CO₂ Emissions Produced by Commercial Grills in Veracruz, Mexico

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Received: 1 December 2017; Accepted: 26 January 2018; Published: 9 February 2018

Abstract: In some urban areas in Mexico, the use of firewood and charcoal as fuel for meat grills in commercial establishments, has proliferated due to economic and cultural factors. Although this activity satisfies diverse human necessities, it also generates waste that impacts the environment to local and global scales. Such is the case of CO₂ emissions produced by biomass burning in grills, whose sources are not recognized in municipal inventories of greenhouse effect gases (GEG) of the State of Veracruz. A theoretical estimation was made based in a census of establishments and an emission parameter, in order to establish a baseline on the amount of gas emitted to the atmosphere by commercial grills in Boca Del Río, Ver. It was concluded that 30 operating grills emit 134.56 tons of CO₂ into the atmosphere, equivalent to the annual combustion of 59,016.43 L of gasoline. Hence, these grills must be considered as micro-fixed sources of GEG, which influence local marine acidification and global climate change. It is recommended that it should be included in municipal, state, and national inventories for subsequent professionalization and regulation.

Keywords: biomass; GEG; use of technology; grilled meats

1. Introduction

In Mexico, as it is worldwide, firewood and charcoal are traditional fuels used when preparing meals in rural and marginalized urban areas due to their low cost and availability [1]. These customs, energy qualities, and the supply of firewood without commercial value coming from degraded forest areas or forest waste [2] promoted its use as fuels in diverse businesses, among them, those that offer ready-to-eat foods.

Due to contemporary economic and social dynamics, where the polarization of wealth has generated poverty and sophistication in consuming patterns, society demands employment and new food presentations [3]. Therefore, street and established sale of grilled foods are options of income and employment, as well as a means of satisfying food demands for those people whose only option is to eat out or those who satisfy psychological and social demands, rather than biological [4].

The consumption of meats from different animal origin is considered essential in the Mexican diet, that is why the modern urban offer of meat products aims to meet its weekly demand [4]. Among these products, grilled meats in their different presentations are very popular [5], resulting in the proliferation of establishments that offer these products [6], additional to the domestic preparation and consumption option.

In addition to its economic and social implications, the environmental scopes of operating commercial grills in Mexico have not been widely studied, as well as for urban domestic grills. In both cases, there is no empirical information to visualize its operation and determine its effects in different scopes of influence. Nonetheless, these are recognized as fixed sources of atmospheric

pollutant emissions by the total or partial burning of firewood or charcoal used as fuel. These materials, when burned, emit high concentrations of toxic compounds for both humans and the environment, such as particulate matter (PM), nitrogen oxide (NO_x), carbon monoxide (CO), sulfur dioxide (SO₂), volatile organic compounds (VOCs), and carbon dioxide (CO₂), among others [7,8].

CO₂ is considered the main greenhouse effect gas (GEG), which is why its main emission sources are included in national inventories, where burning of wood, charcoal, and wood waste were integrated in the residential and commercial sectors, in accordance with international considerations on climate change [9]. In this context, due to its generality, it is impossible to identify the participation in municipal, state, and national accounts of emitting micro-sources, among them, commercial and domestic grills. These micro-sources are insignificant individually, however, in conjunction they cause important environmental effects, which is why their assessment is relevant in relation to the establishment of a baseline for inclusion in municipal inventories and the design of specific regulatory mitigation strategies, which sustain the emission registries and state and national regulatory norms.

The location of this study was established considering that Mexico in 2012 ranked eleventh in the contribution to global CO₂ emissions, with 493 million tons, while the state of Veracruz contributed 15.3 million tons (3% of the national total), occupying the fourth national place among the states with the highest emissions of this gas [10]. In 2010, 8% of CO₂ emissions of the state total were concentrated in the municipalities of Veracruz and Boca del Río [11].

The aforementioned is reflected in climatic fluctuations (temperature and rainfall) presented in the state [12], which, associated with the physiographic and socioeconomic characteristics of the same, have caused diverse affectations. Veracruz is a coastal entity with important lagoon systems and mouths of several high-flow rivers, which is why it is high vulnerable to flooding [13]. Conversely, the rise in temperature has affected seasonal crops, livestock, and fisheries [14], on which a large part of the population depends [15], since 85% of the territory has an agricultural and forestry vocation (6 million hectares, representing 3.5% of the national total).

Considering the above, the objective of the present study was to identify the different types of urban establishments that use forest biomass as fuel in the cooking of commercial meat foods as a micro-point source of GEG emissions at municipal level, by determining the total magnitude of annual CO₂ emissions produced by grills in Boca Del Río, Veracruz, through the theoretical determination of an emission factor, to establish a baseline for future research on urban emissions in micro sources of unrecognized CO₂.

2. Materials and Methods

The study area is in the municipality of Boca Del Río, Veracruz, Mexico, located in the coordinates 19°28'–17°9' N, 96°0'–98°0' W, whose area of 38.1 km² houses 138,058 inhabitants mainly dedicated to trade and service provision. It borders on the north with the municipality of Veracruz, on the south with the municipality of Alvarado, on the east with the Gulf of Mexico, and on the west with the municipalities of Medellín and Veracruz [16]. It has a warm–regular climate with an average temperature of 25 °C and average annual rainfall of 1694 mm [17].

To carry out the theoretical estimation of the amount of CO₂ produced by the burning of biofuel used in commercial grills and establish its polluting potential, a descriptive investigation was made that characterized and technologically differentiated the establishments dedicated to this activity. To achieve this, a 13-step investigation was proposed (Figure 1).

To describe the phenomenon, it was characterized as a complex five-dimensional system wherein the constructs susceptible of observation and measurement were identified, which in turn were also divided according to their aptitude for bibliographic and empirical compilation. In the end, 19 variables were identified (Table 1).

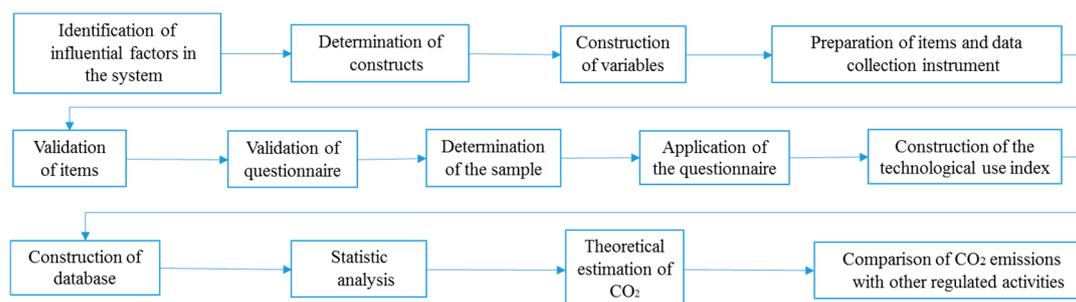


Figure 1. Design of the investigation “Estimation of CO₂ emissions produced by commercial grills in Veracruz, Mexico”.

Table 1. Variables used in the study.

Dimension	Variables
Economic	(1) Acquisition method; (2) Biomass type; (3) Type of food; (4) Use schedule; (5) Annual frequency; (6) Days per week when the service is provided; (7) Amount of weekly biomass used; (8) Biomass cost
Geographic	(9) Location of the cooking equipment.
Social	(10) Training; (11) Health condition; (12) Fiscal condition; (13) Commercial condition; (14) Seniority
Technological	(15) Filtration; (16) Ash handling; (17) Temperature measurement; (18) Extraction; (19) Type of grill/oven

The theoretical estimation of CO₂ emissions considered that the carbon content of a fuel is an intrinsic chemical property, that is, the mass of carbon atoms with respect to the total mass of the fuel [18]. Therefore, to determine the amount of CO₂ released into the environment by burning wood, the emission factor proposed by Muro [19] was selected, where it was specified that the combustion of one kilogram of firewood emits 1.83 kg of CO₂, because half of its mass is coal (C) and if the relationship between the molecular weight of CO₂ and C is 44/12, then 1 kg of firewood produces 0.5 (44/12 kg of CO₂) = 1.83 kg of CO₂. The equivalence between carbon and CO₂ is:

$$(\text{Molecular weight of CO}_2)/(\text{Molecular weight of C}) = (44 \text{ (for CO}_2\text{)})/(12 \text{ (for C)}) = 3.667.$$

So, if in each kilogram of firewood, 50% is coal (C), the ratio will be: 0.5 kg × 3.667 = 1.83 kg of CO₂/kg of firewood.

In the case of charcoal, according to the information provided by FAO [20], the carbon content is normally estimated as a “difference” of all the volatile components of water, so that they are deducted from a hundred as percentages, and what remains is the % of pure or fixed carbon that can vary from 50% to 95%, in such a way that, for the carbon calculation, an intermediate value of 72.5% was taken, that is, 0.725 kg (C × (44/12)) = 2.65 kg of CO₂/kg of carbon.

A data collection instrument with 19 items was applied, designed under the criteria of simplicity, low cost, and universal applicability referred by Alonso and colleagues [21], whose content validity was determined with different tests.

The level of concordance of 0.97 was estimated using Fleiss’ Kappa test (1971) applied to a five-point empirical scale matrix (Likert scale) that evaluated, by expert judgment, the properties of relevance, adequacy, justification, and feasibility of the items [22] (Table 2).

Likewise, the level of reliability and stability of the instrument was quantified as very high with the Cronbach’s Alpha test (1951) with a value of 0.92, in addition to a high concordance and homogeneity determined by an Average Interclass Correlation of 0.0932.

Using Torres criteria [23] the questionnaire was empirically validated with its application in a pilot test to ten grill operators in a different area to the one studied; in it, the metric scale properties, the application time, and the acceptance or refusal to answer questions were evaluated.

Table 2. Empirical criteria for evaluating the instrument.

Relevance	Ordinal Value			Nominal Value
	Adequacy	Justification	Feasibility	
Fully appropriate	Fully understandable	Fully justifiable	Fully feasible	5
Appropriate	Understandable	Justifiable	Feasible	4
Uncertain	Medium	Medium	Medium	3
Little appropriate	Little understandable	Little justifiable	Little feasible	2
Inappropriate	Incomprehensible	Unjustifiable	Not feasible	1

The target population was identified from the census data of grilled foods producers that used biomass on its process, provided by the H. City Hall of Boca del Río, Veracruz. A census was conducted from 19 May to 25 May 2016 with the 30 registered establishments. However, only 27 of them were interviewed and three non-registered establishments were incorporated to complement the sample.

The Use Technology Level (UTL) for the grills was constructed in accordance to the methodology proposed by Gich [24].

$$UTL = \sum_{n=1}^n \frac{WWM}{WWF} WWF,$$

where WWM = weighted weight of management practice; WWF = weighted weight of the factor; n = management practice.

The range of this indicator is from 0 to 100, where 100 indicated the best technological use. The factors were created based in the variables used to establish the technological dimension of the grilling system. Through expert judgement, weighted weights for the management practice were assigned according to the thermal insulation capacity of the system to monitor for process control and to the emissions management (Table 3).

Table 3. Scoring criteria of the Use Technology Level (UTL) for commercial grills.

Factor	WWM * %	Practice	WWF ** %
Types of grills and ovens	30	Professional grill with cap	30
		Artisan grill with cap	25
		Professional oven	20
		Rustic oven	15
		Professional grill without cap	10
		Artisan grill without cap	5
Temperature measurement	10	It measures	10
		It does not measure	0
Smoke filtration	50	Filters	50
		It does not filter	0
Smoke extraction	5	Extracts	5
		It does not extract	0
Ash management	5	Takes benefit	5
		Disposes	0
Sum	100		100

* WWM, weighted weight of management practice; ** WWF, weighted weight of the factor.

The numerical values of the UTL were used to set the establishment grading criteria (Table 4).

In order to process the descriptive data obtained and the CO₂ estimation, a data bank was created with Microsoft Excel 2016, whereas, to carry out the descriptive statistics analysis, SPSS Statistics

22.0 was used for the analysis of frequencies, the tests of normality (Shapiro–Wilk), and correlation of Spearman.

Table 4. Grading criteria of the Use of Technology Level.

Value Ranges (%)	Use of Technology Level
100	Optimal
80–100	Very good
60–80	Good
40–60	Bad
20–40	Very bad
0	Null

3. Results and Discussion

General Characteristics of Commercial Food Grills

We visited 30 establishments dedicated to a variety of commercial meat grills, characterized for using forest biomass as fuel and being located in the municipality of Boca del Río, Ver. Amongst these microenterprises, 70% were formalized before the Ministry of Finance and Public Credit, 93% have Notice of Operation to the Ministry of Health, and 93% have the municipal trade permit, which varies according to the type of establishment: registration and operation license and permission to sell on public streets. There is no environmental normativity that regulates the activities of these businesses.

Therefore, these establishments are characterized as chain restaurants that have all the necessary permits, restaurants or family diners that do not pay taxes, or semi-fixed or ambulatory stands that do not have any permit or registration. These are distributed within the municipal territory according to the urban context or socioeconomic stratum of their target market [25]. In general, poor quality jobs are provided, segmented by gender, schooling, routine artisanal activities, and low salaries for the employee (not for the owner), high mobility between jobs, and low access to social security [26].

In the present study, the operators of these places were mostly males (80%) in their working age. This activity is considered proper of this gender due to the physical effort required in the management of biomass and exposure to fire and the grill's high temperatures, and it has become a source of income and formal and informal employment for household heads that lost their jobs because of the decrease in the state GDP (Gross Domestic Product) of 2000–2003 [27]. However, this segregation by gender may be reduced with the recent increase in participation of female household heads and spouses in the generation of income [28] and growth in the formal and informal sector of services, particularly in the food sector, as a result of the change in consumption patterns of large cities [25]. For the informal sector, women would benefit from the absence of age, marital status, number of children, and education requirements for this activity [29]. However, the presence of a male majority among operators can respond to the fragility of female independent microenterprises and the domestic responsibility associated with women [28].

The foregoing notion is that gender is a factor related to the amount of CO₂ emissions produced by commercial grills and is explained by the logic that if there is an increase in the general unemployment rate, then there will be an increase (slightly lower due to of gender issues since women are the ones with the highest unemployment rates [30]) in the unemployed male population, who are mostly the economic support of the homes in countries such as Mexico and particularly in the state of Veracruz (in 2003, there was a male presence of 97.1% in state economic participation [30]). This favours the establishment of informal jobs with a gender focus in the service sector, which require little specialization and technology, such as the grills studied. According to Ariza [30], this logic is manifested in an inverse way; in her work, she mentions that, in Veracruz, women are the unemployed population who dedicate the most to informal jobs related to commerce, restaurants, and hotels. However, she confirms that the loss of salaried jobs affected the male population to a greater extent.

The average schooling of operators is 9.3 years, where 20% completed primary school, 50% secondary school, 23% high school, and 7% completed a bachelor's degree. While the average experience in this area is 9.29 years, with a range of 0.5 to 25 years, individuals with less experience were among 70% of the population, while the remaining 30% gathered those whose experience ranged from 10 to 25 years.

In this sector, the average schooling is higher than the national average schooling for informal establishments (70% with secondary school completed) due to the presence of 30% of people with high school and college completed, directed to work in formal grills.

Even though the school level of the group corresponds to secondary, it is still low to access formal quality jobs, making this activity a job opportunity for a population with educational limitations [31]. While the limited experience of the majority of the grill operators is associated with the insertion in the formal labour sector by recent hiring and insertion in the informality by the loss or reduction of the family income [27], the presence of informal operators (owners) with more experience exhibits a possible family tradition (activity transferred from parents to children) and a profitability that equals or exceeds the formal sector [31].

Regarding training or informal education, 17% of operators received instruction in the handling of equipment, while the rest did not.

Those trained correspond to those who work in formal establishments, since when belonging to franchise-type restaurant chains, their training program to standardized processes is included in their business plan [32].

Grills offer products from chicken (27%), beef (7%), and pork (3%), though their offer is mostly (63%) mixed.

This offer of grilled meats in Veracruz, as in the rest of the country, responds to consumer preferences, mainly influenced by the real price, in addition to the consumers' income and the prices of substitute meats [33]. The availability in the market, customs, and regional gastronomy also influence such demand [34]. According to per capita consumption, chicken meat is the most accepted (32.1%), followed by pork (18%) and beef (14.8%), which are produced in the state of Veracruz, guaranteeing its supply at competitive prices [35–37].

The acceptance of chicken meat in popular cuts or whole is due to the fact that it is the most accessible animal protein for low and medium income consumers [38]. For medium and high strata, beef has the highest consumption outside of home, associated with festive aspects and special cuts [39]. With respect to pork, the behaviour is similar to the consumption of chicken and acts as a substitute product, since the consumption of popular cuts is higher among people with low and medium income; however, only 53% of consumers buy it [40].

The fuel used for grilling is 74% firewood, 23% charcoal, and 3% mixed. The origin of the wood is unknown to 73% of the operators, while 27% of them are knowledgeable; 14% of the firewood corresponds to huisache *Acacia farnesiana*, whereas 14% of charcoal is mesquite *Prosopis glandulosa*, 9% oak *Quercus* sp., and 9% mango *Mangifera indica*. The firewood used is purchased from local suppliers by 87% and the remaining 13% is collected. In the case of charcoal, 96% is purchased and the same user produces 4%.

In tropical areas, wood used as fuel in cooking food is collected in rural areas where there is abundant dry vegetation that is detached or standing dry [41], although it is also extracted by logging or by its waste [42]. Thus, the sale of firewood is a small-scale activity performed by producers, plantation owners, or rural micro-entrepreneurs [41,43].

Another source of wood for firewood used in cooking food is post-production waste from port and industrial activity; such is the case of pallets used in the loading and unloading of various goods [44]. Even though this activity is a form of reuse, it presents a risk to final consumers and operators of the grills since the wood used in the manufacturing of pallets must be fumigated in accordance with current phytosanitary regulations [45].

The use of firewood migrated to cities as an alternative of low-cost fuel for marginal homes and specialized commercial establishments, since they only pay for the labour of the collector and the transport of the purchased cargo, besides not needing high technology for its exploitation [46]. Although its use in urban households is minimal, among grilled meat merchants, its usage, as in rural areas, is rooted in cultural issues related to the taste of food, which is the same for charcoal [47,48]. Charcoal is widely used in grills where there is a lack of abundant vegetation nearby [49].

The preferences for the type of firewood lie in its production properties of fire type, smoke emission, and humidity percentage.

In the 30 aforementioned establishments, the grills remain lit on average 8.5 h, in a range of 4 to 16 h. Working an average of 311.66 days per year, with a range of 96 to 365 days, six establishments were found in the maximum range, while five were in the minimum. The remaining 19 work between 288 and 354 days per year.

According to the working days of the grills, the consumption of grilled meats in Veracruz is constant, since 62% are open 7 days per week, 24% are open 6 days per week, and 14% are open on weekends.

Stalls and restaurants of grilled meats are a cross-cultural adaptation to the concept of fast food restaurants. In the same manner that fast food establishments offer foods with intense flavours, palatability, and ease of purchase [50], grills offer dishes prepared with traditional recipes ready to go and consume, complemented with rice, tortillas, sauces, and drinks at affordable prices, that, like other street foods, are an alternative to homemade food [6,51].

Food consumers outside their homes are divided into occasional and frequent, who buy prepared foods up to ten times a month and prefer to eat traditional dishes, including grilled meats [5].

Current grilled meats consumers are modern economic actors who evolved by adapting to changes in contemporary lifestyle characterized by a wide range of products, hedonic satisfaction for consumption itself, health aspects associated with food, insertion of women in working life, the economic situation of the country, and socio-economic demographic aspects, among others [52].

The proliferation of formal and informal establishments that sell grilled meats offers a service to people who are on their way home. They respond to the economy of mobility by minimizing energy and economic expenditure in the activities of buying and selling food, by locating in highly populated areas of different socio-economic strata. The itinerant offer is concentrated in mobile and semi-fixed stalls in popular areas, while the established offer focuses on popular restaurants or luxury chain restaurants located in medium or high stratum areas [25].

The technological equipment was characterized by the presence of extraction and filtration devices, the temperature measurement of the grill, the type of grill or oven used in the grilling, and the handling of residual ashes.

In 80% of the grills, there are chimneys for the extraction of gases, but they do not confine them inside the equipment, nor do they have ventilation to direct them towards an exit duct, causing that part of them to remain inside the establishments and be inhaled by the employees. In the remaining 20%, there is no extraction of any type, since they operate in the open. As for the filters in the chimneys, their presence was not identified in any establishment. The temperature of the grills was measured in 13% of the establishments.

To identify the type of grilling equipment, a previous empirical classification of the existing equipment in the local market was made; the isolation characteristics of the process, construction materials, the extraction of their emissions, and their design bases in function of its application were considered (Table 5).

Considering the previous classification, it was identified that professional grills without a cap are the most common (61%) and professional ovens and grills with a cap are the least used (3%). However, all types of grills operate in the municipality: semi-professionals without a cap (13%), semi-professional with a cap (13%), and rustic oven (7%).

Table 5. Empirical classification of existing equipment in the market.

Type	Name	Characteristics
1	Professional grill without cap	Grill manufactured under construction and operational specifications; weather resistant; made with steel coated with porcelain, or with bricks and concrete; covered with thermal insulation that confines and allows better control of heat; has removable ashtray or gate for the extraction of ash; includes a space for the deposit of charcoal or firewood, which should allow a uniform distribution and motility at free demand; in addition, a grill with adjustable height for a variety of meats in the grill, or a height between 25 cm and 35 cm for when its destined to a single type of grilled meat; and includes the following elements: thermometer, channel for fat draining, and wheels.
2	Professional grill with cap	Grill manufactured under construction and operational specifications; weather resistant; made with steel coated with porcelain, or with bricks and concrete; covered with thermal insulation that confines and allows better heat control; has removable ashtray or gate for the extraction of ash; has a space for the deposit of coal or firewood, which allows a uniform distribution and motility at free demand; has a grill with adjustable height for a variety of meats in the grill, or a height between 25 cm and 35 cm when it is destined to a single type of grilled meat; includes a cap that allows the confinement of the heat and the smoke of the grilling area; and includes the following elements: thermometer and a channel for fat draining.
3	Artisan grill without cap	Grill manufactured with materials other than those specified for this purpose, does not have design or operational specifications, and does not have a cap.
4	Artisan grill with cap	Grill manufactured with materials other than those specified for this purpose, does not have design or operating specifications, includes a cap, and is generally known as "chulengo".
5	Rustic oven	Built without constructive nor operative specifications, with materials not suitable for high temperatures, does not retain heat efficiently, does not allow an optimal performance in energy consumption and heat retention, may include base, door, chimney, and thermometer.
6	Professional oven	Built under constructive and operative specifications, with refractory material for high temperatures (1350 °C maximum) with a minimum heat retention of 24 h, with a low inferior vault between 31 cm and 41 cm that allows an optimal performance in energy consumption and heat retention, includes base, door, chimney, and thermometer.

Regarding the handling of ashes, it was identified that the majority of establishments (83%) dispose of it as waste without prior treatment, and 17% use it as compost.

Most of the grill equipment (73%) is confined in spaces with exclusive access by operative personnel, and 27% are out in the open.

Around the world, there are diverse types of grills in accordance with the socio-economic development of the country or region where they are occupied. As in the study area, grills vary according to the socio-economic level of their location, but can be typified by agreement with common characteristics. Grills are classified according to the design, the construction material, the type of fuel to be used, and portability [53].

Most grills observed are inefficient to conserve heat and achieve energy efficiency, are unsafe, and produce emissions harmful to health and the environment [53].

4. Use of Technology

The previous technological variables were integrated into the Use of Technology Level (UTL) variable to show the level of technical excellence of this sector. The group of establishments obtained an average score of 5.9 points from a base 10 scales, being placed in a bad UTL due to the presence of 73% of establishments with zero technology level, 20% very bad, and 7% bad, where the use of filters and ash management obtained the lowest scores (0.0 and 0.25). The highest score was obtained in the type of grill used (3.70), which, although it was the best qualified, its value is still low in relation to the optimum (Table 6).

Table 6. Grading of Use of Technology Level for the group of grills in Boca Del Río, Veracruz, Mexico.

Index	Variables					
	Smoke Extraction	Smoke Filtration	Ash Handling	Temperature Measurement	Type of Grill/Oven	Total
Use of Technology Level						
Optimum	5.00	50.00	5.00	10.00	30.00	100.00
Group	1.15	0.00	0.25	0.80	3.70	5.90
Average	0.04	0.00	0.01	0.03	0.12	0.20

The UTL showed a direct association ($r = 0.400$; significant at level 0.05 (bilateral)) with the variable years of experience, which evidenced that those establishments that have been working for more years have adapted their equipment to improve their performance, so this sector presents an empirical technological development.

No specific information was found on the evaluation of the technological level of the commercial grills, so this categorization serves as a baseline for future research. However, regarding the subject, some authors mention that, in Mexico, the equipment used in semi-fixed or mobile grills are of rustic manufacturing, and the fixed grills include more technological elements, such as ventilation openings, fat traps, or air filters [54,55].

It is also mentioned that the design, technology, and construction materials of the grilling devices, as well as the utensils used for the process influence its efficiency to transfer heat, which, in turn, is related to the amount of wood consumed [53]. Likewise, this technology influences the nutritional and health quality of the meats offered to the consumers, and even in the quantity and quality of the emissions derived by the cooking process [51].

5. Estimation of Emissions

Through the theoretical model of quantification of CO₂ production, it was determined that the group of 30 grills emits 33,639.37 kg of CO₂ per week into the atmosphere (Table 7), where the amount of emissions varies considerably according to the establishment and the type of biomass used. However, six sites (10, 11, 15, 16, 17, and 18) stand out due to the CO₂ emission higher than 2000 kg per week (Figure 2).

Table 7. CO₂ production by biomass type.

Type of Biomass	Number of Grills	CO ₂ Emissions (kg) Per Week				
		Total (kg)	Percentage Participation (%)	Average (kg)	Minimum (kg)	Maximum (kg)
Charcoal	22	21,059.34	63	957.24	33.55	4026.00
Firewood	7	8874.28	26	1267.75	549.00	2745.00
Mixed	1	3705.75	11	3705.75	DNA *	DNA *
Total	30	33,639.37	100	1121.31	33.55	4026.00

* Does Not Apply.

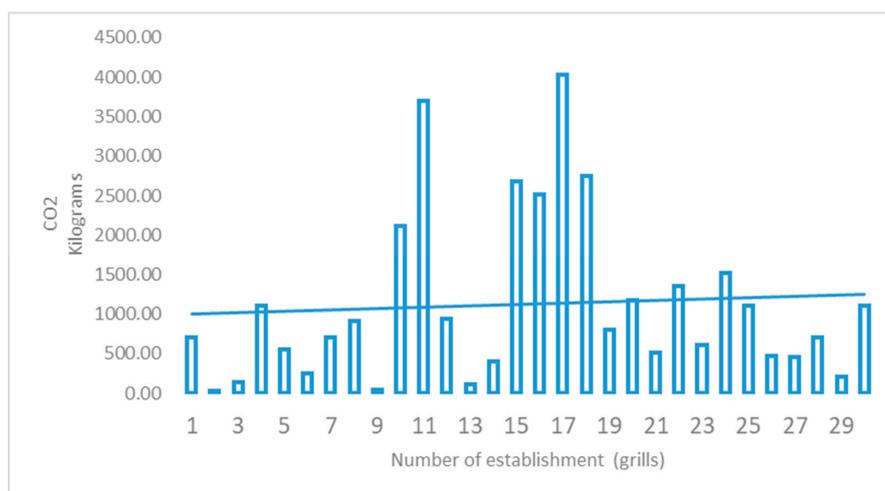


Figure 2. CO₂ emissions emitted per week by establishments (grills) in Boca Del Río, Ver.

This variation in the amount of emission per establishment agrees with that affirmed by McDonald et al. [56] in their study on charcoal and grilled meat emissions, where they mention that the emissions vary according to the type of grill, meat, amount of fat, and meat preparation.

According to the average emission, the biomass that produces the highest CO₂ emission is the mixed one (mixture of charcoal and firewood), followed by firewood, then charcoal. It is pertinent to note that although only one establishment uses this mixture, by itself it produces 11% of the total emissions, being 6% higher than the average per unit (5%). Therefore, special attention should be given to discouraging the use of this type of fuel.

In 12 of the 30 establishments, 75% of the total of emissions were concentrated, representing 25,155.53 kg of CO₂ per week. For this group, Type 1 grilling equipment is the most used (50%), while the meat grilled the most is the mixed type. On average, these establishments operate 354 days per year for 5.9 days per week, and the grills remain afire for 9.13 h per day.

The amount of weekly emission was directly associated with the amount of firewood and charcoal consumed in the process ($r = 0.36$, $r = 0.43$; significant at level 0.05 (bilateral)), as well as economic issues related to the number of days worked per week and the hours of daily operation of the establishments ($r = 0.69$ y $r = 0.59$; significant at level 0.05 (bilateral)). The technological aspects are reflected in the emissions through the height of the chimneys of the establishments ($r = 0.53$; significant at level 0.05 (bilateral)).

The emissions associated with the economic variables indicated an energy and economic expenditure that could depend on bad management practices derived from the scarce training among the population. According to the statistical evidence, we cannot affirm that the emissions depend directly on the technological level of the establishments, nevertheless, the design and suitable materials of construction, the use of filters, the height of the chimneys, and the use of equipment that contain and monitor the cooking temperature could influence a significant reduction of emissions due to the increase in heat transfer efficiency and the corresponding fuel reduction.

In accordance with the number of weeks worked per year, it was estimated that the annual production of CO₂ released into the atmosphere by the group of grills is 134.56 tons. This production is equivalent to the annual combustion of 59,016.43 L of gasoline (1 L = 0.47 kg = 2.28 kg/CO₂) or 87,946.05 of ethanol (1 L = 0.80 kg = 1.53 kg/CO₂) [57].

If the annual CO₂ production estimated for the group under study becomes the CO₂ emission produced by a vehicle, 1,130,734.96 km would have been covered (the gasoline needed to travel 1.00 km emits 119.0 g of CO₂ according to the optimal level of combustion of a vehicle) [57].

Considering the proportion of grills by number of inhabitants of the municipality of Boca del Río (0.021%), it was estimated that in the Veracruz–Boca del Río–Medellin conurbation, up to 175 grills could be found whose collective CO₂ production would be greater than 783 thousand tons/year. With this information, it is established that the amount of grill emissions in the urban zone is equivalent to the CO₂ emissions of a vehicular fleet of 527 private units (on average, a vehicle travels 12,487.00 km/year and produces 1485.95 tons of CO₂/year) [58].

The above estimates support the claim that the emissions produced by commercial meat grills are important micro-fixed sources of greenhouse gases, which impact globally on climate change and locally on the acidification of the sea, since the CO₂ concentration varies according to the topography and meteorological factors of the region and the behaviour of long-stay gases [59].

This thesis has been shared by authors from different countries since the end of last century, and first identified air pollutants (particulate matter, aerosol, organic carbon, volatile organic compounds, carbonyl compounds, polycyclic aromatic hydrocarbons, etc.) and their effects on health [60–63] to later include CO₂ as an atmospheric pollutant because it is a greenhouse gas with contribution to current climate change [64–66].

Different meat presentations, preparation methods, cooking devices, and fuels were evaluated, charcoal being the most studied due to its abundant use worldwide [56]. The measurements have been made using different techniques and evaluation standards, whose results were used to build national inventories of emissions and national standards related to the production of pollutants considered a risk to health and the environment [67], where the equipment destined to the trade of grilled

foods, fuels used, and the maximum permissible concentration of the pollutants emitted by these are regulated [68].

Particularly, in China, the acceptable CO₂ standard is a concentration of 10 mg/m³, however there are variations from 0.16 mg/m³ to 0.80 mg/m³ in the concentration of emissions from typical restaurants in the country where charcoal briquettes are used as fuel [64]. Korean barbecued meats prepared inside the establishments obtained an average CO₂ emission of 1648 ppm in a range from 136 to 1868 ppm, and meat prepared outdoors obtained an average of 512 ppm in a range of 461 to 609 ppm. The first are above the established ranges for air quality, this being 1000 ppm (8 h average). The high concentration of CO₂ was associated with inadequate ventilation [65]. The emissions of Chinese restaurants have been compared with the emissions produced by automobiles, such as in the case of the work of Ho et al. [66], which measured the production of carbonyls produced by different types of restaurants that included meat grills.

While in Mexico, Watson and Chow [69] characterized the smokes produced by the burning of charcoal in the cooking of meat, fats, and charred meats in different hours of service of commercial grills; the results showed a chemical profile of 48 components, with the highest concentration (PM10) being the organic carbon (OC) and water-soluble non-organic compounds such as chlorine (Cl, Cl⁻) and potassium (K, K⁺). In this burn, the concentration of the total mass of OC was 58 ± 7.5% to 72 ± 4%, slightly higher than that produced by plant burning (including domestic firewood, agricultural waste, and domestic garbage), whose concentration was 56 ± 15%; the concentration by burning charcoal was higher than that emitted by automotive combustion (45 ± 18%).

The CO₂ emitted by the burning of charcoal in the grilling of beef and chicken has also been monitored with devices calibrated in the range of 0% to 20%, where measurements were reported from 0.73% to 1.30%, which at that time were considered reasonable, nevertheless they were associated with the emissions by the burning of charcoal. This study mentions that the use of meshes placed in the chimneys function as emission control devices [63].

6. Conclusions

Commercial food grills as fast-food outlets are important micro-fixed sources of pollutants due to the great variety of organic and inorganic compounds they produce, whose presence in the atmosphere impacts the health of people and the planet. The use of firewood and charcoal as fuel, cooking practices (temperature and time), meats and their ingredients, and the equipment used influence the amount of emissions. The main sources of CO₂ emissions are the incomplete combustion of biomass or the use of biomass with low energy efficiency. There are technological devices in the market and adequate food cooking practices that can control emissions when incorporated in the operations of the grills, a situation that is unknown or ignored by the owners of the establishments and the government. There are no environmental regulations or emission standards that regulate this activity, so its inclusion in municipal, state, and national inventories is recommended for further professionalization and regulation.

Acknowledgments: We thank to the Consejo Nacional de Ciencia y Tecnología (CONACYT) for the postgraduate scholarship awarded, No. 669521. To the Tecnológico Nacional de México/Instituto Tecnológico de Boca del Río (ITBOCA) for the funding granted to the present investigation. To the Programa para el Desarrollo Profesional Docente, para el Tipo Superior/Secretaría de Educación Pública (PROMEP/SEP) for the postdoctoral stay scholarship. Last but not least, to the program of Master's Degree in Environmental Engineering of the ITBOCA for the support in publishing this article.

Author Contributions: Veronica Lango-Reynoso, Jonathan López-Spiegel, Fabiola Lango-Reynoso, and María del Refugio Castañeda-Chávez conceived and designed the experiments; Jonathan López-Spiegel performed the experiments; Jonathan López-Spiegel, Veronica Lango-Reynoso, and Jesús Montoya-Mendoza analyzed the data; Fabiola Lango-Reynoso and María del Refugio Castañeda-Chávez contributed with reagents/materials/analysis tools; Veronica Lango-Reynoso wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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