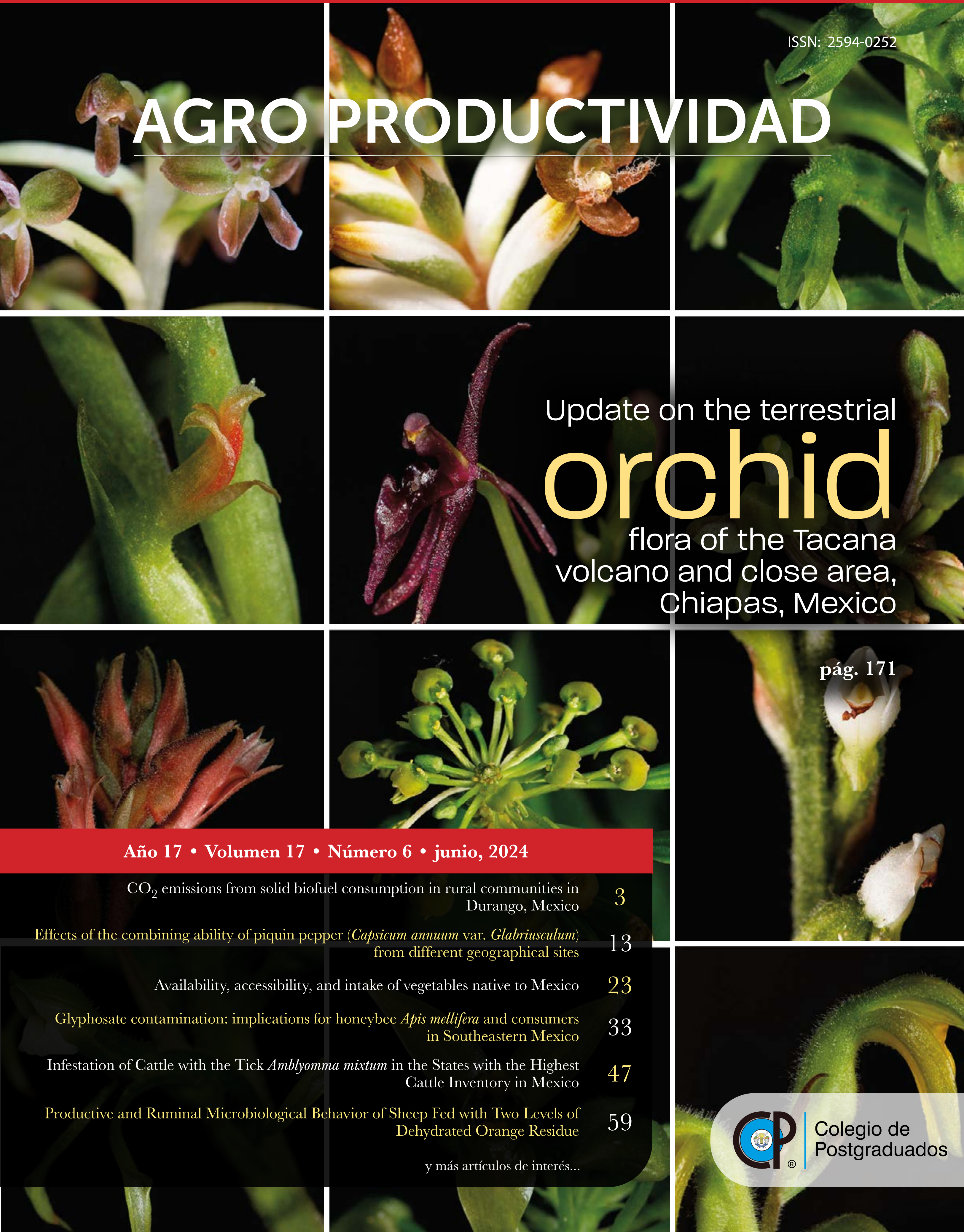

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CO_2 emissions from solid biofuel consumption in rural communities in Durango, Mexico

Briceño-Contreras, Edwin A.[1,2]; **Valenzuela-Núñez, Luis M.**[3*]; **García-De La Peña, Cristina**[3]; **Martínez-Sifuentes Aldo R.**[4]; **Hernández-Herrera, José A.**[5]; **Navarrete-Molina, Cayetano**[5]

1 Universidad Tecnológica de Rodeo. Departamento de Agricultura Sustentable y Protegida; carretera Federal Panamericana km 159.4, Colonia ETA. Rodeo, Durango, México. C.P. 35760.
2 Universidad Para El Bienestar Benito Juárez García. Departamento de Procesos Agroalimentarios. Ejido Hidalgo s/n., Francisco I. Madero, Coahuila, México; C.P. 27911.
3 Universidad Juárez del Estado de Durango. Laboratorio de Biología y Ecología Forestal. Facultad de Ciencias Biológicas. Avenida Universidad s/n Fraccionamiento Filadelfia. Gómez Palacio, Durango, México. C.P. 35010.
4 Centro Nacional de Investigación Disciplinaria en la Relación Agua Suelo Planta Atmósfera. Margen Derecha Canal de Sacramento km 6.5, Gómez Palacio, Durango, México; C.P. 35140.
5 Universidad Autónoma Agraria Antonio Narro. Departamento de Recursos Naturales. Calzada Antonio Narro 1923, Colonia Buenavista. Saltillo, Coahuila, México. C.P. 25315.
* Correspondence: luisvn70@hotmail.com

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ABSTRACT
Objective: the objective of this study was to calculate the amount, in kilotons per year (kt a^{-1}), of CO_2 emissions from firewood consumption in rural communities of Durango in managed areas (UMAFOR - Forest Management Units) and at the municipality scale.
Design/Methodology/Approach: the firewood consumption was determined for each of the UMAFOR areas and the 39 municipalities into which the state of Durango is divided. Greenhouse Inventory Software® was used to determine CO_2 emissions.
Results: the annual CO_2 balance due to firewood consumption in Durango was 268.05 kt of CO_2. These emissions in relation to the national scale represent 1.52% per year. Those UMAFOR and the municipalities that are geographically located in the semi-arid zone of the state of Durango were those with the higher CO_2 emissions.
Findings/Conclusions: it is necessary to couple the consumption of firewood with eco-technologies that favor its efficient consumption, thus mitigating CO_2 emissions.

Keywords: firewood, greenhouse gases, rural localities, climate change.

INTRODUCTION

Air pollution affects all areas of the planet, and is defined by the effects on people's health as a result of their exposure to high concentrations of pollutants [1]; among other implications pertaining GHG emissions which generate changes in the global climate

Image by Andreas Lischka at Pixabay

[2]. Air pollutants are emitted by many sources that modify the quality of breathing air in a specific region [3]. The volume of CO_2 emissions from fuelwood consumption in developing countries is 825 million (Megagrams) Mg of CO_2 per year, and high CO_2 content has an environmental impact and consequences on human health [7].

In 2008, Mexico's National Emissions Inventory (INEM) included in its inventory estimates of pollutant emissions by source, state, and municipality [4]. However, INEM [5] mentioned that those published data are not comparable with previous inventories, since the methodologies implemented underwent some changes in order to improve the quality of accurate information. Therefore, it is necessary to recalculate previous inventories in order to make them comparable. Mexico has implemented three national GHG inventories, based on the methodology of the 1996 revised guidance of the Intergovernmental Panel on Climate Change (IPCC) [6].

Firewood is a primary source of energy for around 2.6 million people in rural communities in developing countries to meet the needs of cooking food, purifying drinking water, providing heat to households; as well as the production of clay products and the production of bread and other foods [8] The widespread use of this type of fuel is the leading cause of premature death for approximately 2.5 million people each year from inhaling large amounts of smoke [9].

CO_2 is a gas of natural origin, which is a by-product of combustion along with other gases, it is considered a greenhouse gas that affects climate change worldwide, affecting the natural balance of the planet [10]. In adequate quantities, CO_2 contributes to global habitable temperature, since without the presence of CO_2 global climatic conditions would be different. The importance of CO_2 is not due to be the most dangerous gas in terms of toxicity or permanence in the atmosphere, but in the concentration at which it is found. This is, 1000 times higher than any other product of industrial origin. Emissions of this gas are 50% of the greenhouse effect produced by human activity that forms part of global warming. CO_2 is a product of the combustion of fuels in automobiles and industrial heating, thermal power plants, residential chimneys, forest fires and the combustion of natural gas [11].

The origin of CO_2 emissions through anthropogenic activities varies by region. In the U.S., most of this gas originates from transportation. In China, by industries and thermal power plants [12]; in oil-producing countries by oil power plants; and in countries with lower human development indices, by the burning of firewood and other plant biomass fuels [13].

Mexico emits around 3.70 Mg of CO_2 *per capita*, a figure that is 4.02 Mg below the global average for emissions. Two-thirds of this volume corresponds to the various combustion processes in the energy, industrial, transports, and services sectors. The rest, about one third, originates from deforestation, land-use change, and wood burning [14, 16].

Nowadays, both developed and developing countries are adopting clean energy to mitigate global warming from GHG emissions. An example regarding the consumption of firewood in rural communities is the application of sustainable technologies such as solar stoves or ecological stoves [14]. Therefore, with the period 2021-2022 as a reference, the objective of this study was to calculate the amount, in kilotons per year (kt a^{-1}), of CO_2

emissions from firewood consumption in rural communities of Durango in managed areas (UMAFOR - Forest Management Units) and at the municipality scale.

MATERIALS AND METHODS

Study zone

This study was conducted in Durango, located in the Central-Northwest region of Mexico; at coordinates 26° 48' and 22° 19' N and 102° 28' and 107° 11' W. The bordering states are Chihuahua to the North, Coahuila and Zacatecas to the East, Sinaloa to the West, and Nayarit to the South (Figure 1).

Determination of total fuelwood consumption in Forest Management Units (UMAFOR) and at the municipal scale

The firewood consumption was determined in each of the UMAFOR and the 39 municipalities into which the state of Durango is divided. UMAFORs are areas defined according to the boundaries of watersheds, sub-watersheds or micro-watersheds, and are the basis for planning the efficient management of forest resources. Based on the above and within the framework of Mexico's General Law on Sustainable Forestry Development, CONAFOR-SEMARNAT, in coordination with the states, delimited 218 UMAFORs at the national scale, of which 13 are located in Durango (Figure 2). Also within the state administration framework, the consumption of firewood in the rural localities was determined, for the 39 municipalities composing the state of Durango (Figure 3).

The number of localities in each of the municipalities and the UMAFOR of Durango were identified and reclassified by parameters, leaving only the localities that met the established parameter, a human population between 100 and 2500 inhabitants [6].

Firewood consumption was estimated with the application of a survey in 100 randomly selected communities that included questions about the amounts used by the inhabitants

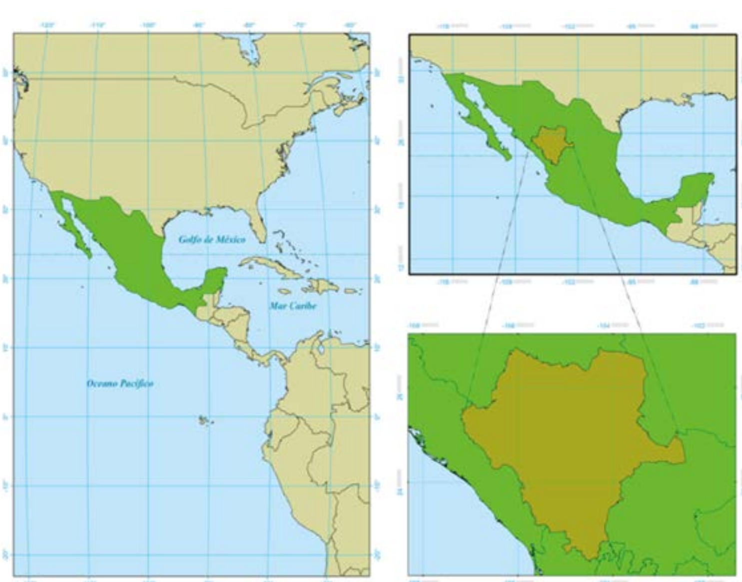

Figure 1. Geolocation of the state of Durango.

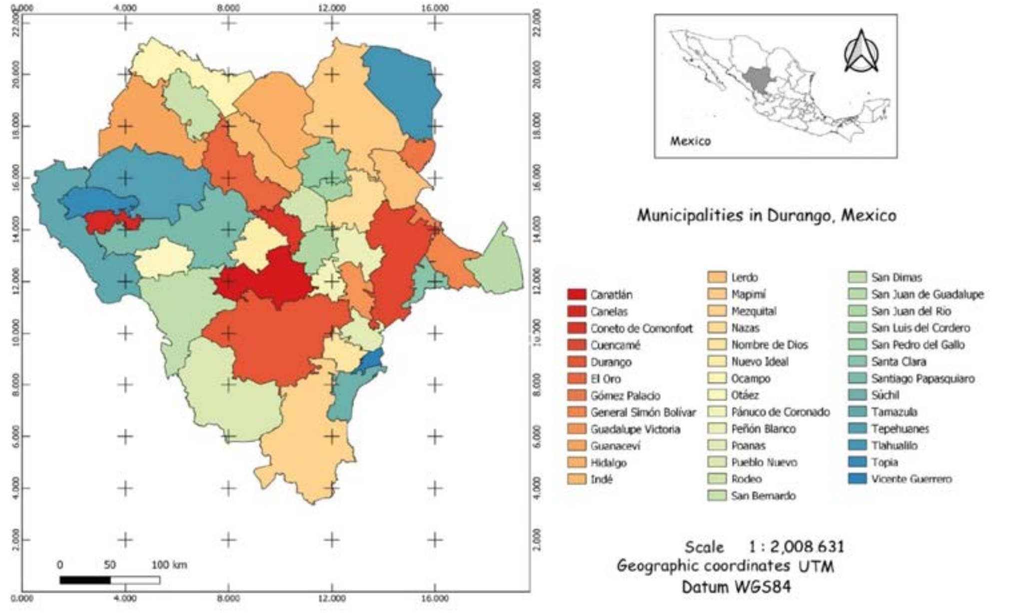

Figure 2. Geographical division by UMAFORs (Forest Management Units) in the state of Durango, Mexico. Graphics elaborated by the authors.

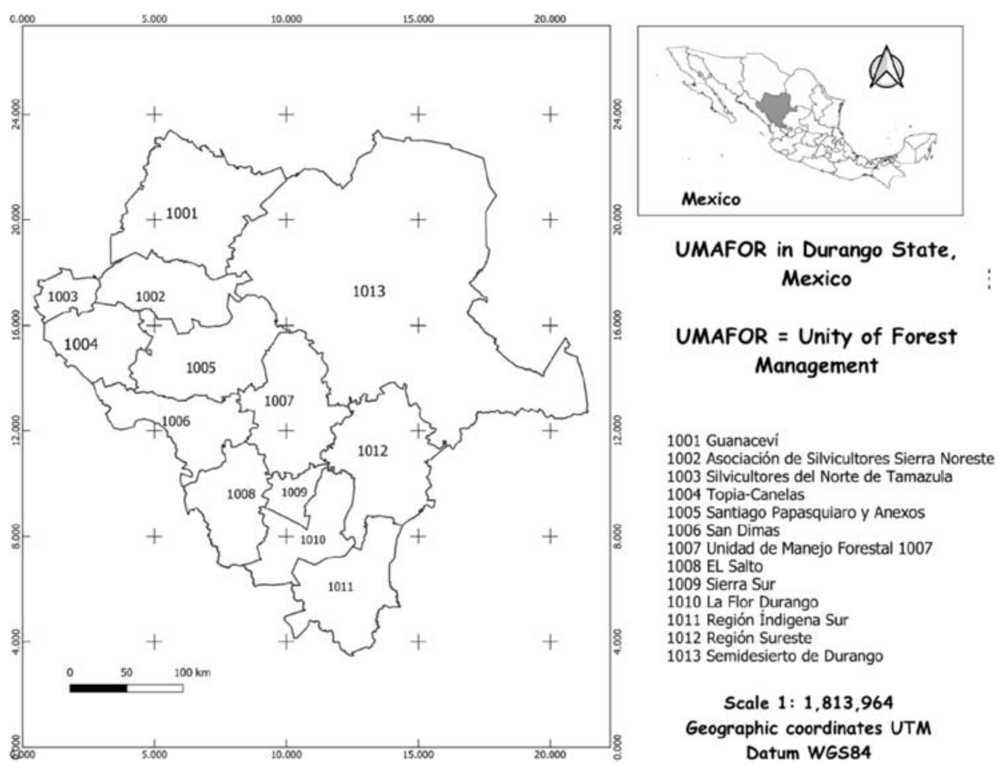

Figure 3. Geographical division by municipalities in the state of Durango, Mexico. Graphics elaborated by the authors.

(quantities estimated as transported by animals, vehicles, or manual handling) during 12 months. The questionnaire was applied in each community to 50 heads of households selected at random, of whom 75% were women and 25% were men with an average age of 41 years. Firewood was weighed in the quantities reported in the survey for a standardization of the units according to [15]. The firewood used was weighed for seven days (at the beginning and end of that period, T) according to the methodology proposed by [16] with the following equation to determine the consumption per day per person:

$$CL = \frac{Pi - Pf}{P * T} \quad (1)$$

where, CL: fuelwood consumption (kg); Pi: initial weight of firewood (kg); Pf: final weight of firewood (kg); P: number of people living in the household; T: number of days between Pi and Pf, in this case $T=7$.

Once the consumption of firewood per day was obtained, the result was multiplied by 365 to estimate the annual consumption.

Quantification of CO_2 emissions

The Greenhouse Inventory Software® was used to determine CO_2 emissions from firewood consumption. This software was designed in a series of steps based on the instructions of the 1996 Intergovernmental Panel on Climate Change Methodology [17], which includes the following formula:

$$EL = fC * fO * fCO_2 * CTL \quad (2)$$

where, EL: CO_2 emissions from the use of firewood (Mg CO_2 a^{-1}); fC=carbon content in wood (0.5); fO=percentage of oxidation of wood during combustion (87%); fCO_2=coal-to-CO_2 conversion factor (44/12); CTL=total fuelwood consumption in Megagrams per year (Mg a^{-1}).

The result obtained by equation 2 shows the total consumption of firewood in Megagrams per year (Mg a^{-1}). However it is required that the result is expressed in kt a^{-1}; therefore, the figure of firewood consumption to be entered into the IPCC-1996 software must be adjusted with equation 3 [18].

$$EL = \frac{fC * fO * fCO_2 * CTL}{1000} \quad (3)$$

With this, the estimation of CO_2 emissions from rural municipalities that burn wood in the state of Durango was obtained.

RESULTS AND DISCUSSION

Determination of firewood consumption at Forest Management Units (UMAFOR) and at the municipal scale

Firewood is used to cook most of the food consumed in homes, especially those that require long cooking times (preparation of tortillas, bean cooking, barbecue, etc.). The gas is mainly used to prepare food that does not require a lot of time on the fire. Firewood is the main source of fuel in rural communities because of the general culture of improving the taste of food, the ease of extraction and transport. The results of the estimation of the average amount of firewood by the direct and indirect methods was 3.5 kg a day per inhabitant for Durango, 76% of the interviewees mentioned using the three-stone stove to cook with firewood.

Quantification of CO_2 emissions in the UMAFOR and municipalities of Durango

According to the results, the annual balance of CO_2 released by firewood consumption in rural communities in Durango was 268.05 kt of CO_2. The contribution of each of the UMAFOR and the municipalities is presented in Tables 1 and 2. The UMAFOR and the municipalities that are located in the semi-arid part of the state (UMAFOR 1012, UMAFOR 1013, and the municipalities of Victoria de Durango, Gómez Palacio and Lerdo) are the ones that concentrate the greatest contributions to the CO_2 emitted by the consumption of firewood. This is due to the fact that those municipalities include the largest number of rural communities.

The sociodemographic profile of the semi-desert region in Durango presents environmental problems such as desertification, erosion, absence of official decrees to

Table 1. CO_2 emission from the use of firewood in Forest Management Units (UMAFOR) in kilotons per year (kt a^{-1}).

UMAFOR	No. of communities with more than 100 and less than 2,500 inhabitants	CO_2 emission in kt $year^{-1}$	%
1001 Guanaceví	44	7.55	2.81
1002 Tepehuanes	10	1.16	0.43
1003 Tamazula Norte	14	2.1	0.78
1004 Topia-Canelas	51	9.44	3.52
1005 Santiago Papasquiaro	78	11.73	4.37
1006 San Dimas	39	5.83	2.17
1007 Durango	92	20.9	7.79
1008 El Salto	52	8.98	3.35
1009 Sierra del Sur	13	4.07	1.51
1010 La Flor	34	7.5	2.79
1011 Mezquital	58	8.04	2.99
1012 Región Sureste	137	52.92	22.35
1013 Semidesierto de Durango	400	127.82	47.68
Total	1,022	268.04	100%

Table 2. CO_2 emission from the use of firewood at the municipal scale in kilotons per year (kt a^{-1}).

Municipality	No. of communities with more than 100 and less than 2,500 inhabitants	CO_2 emission in kt $year^{-1}$	%
Canatlán	35	11.9	4.43
Canelas	9	1.26	0.47
Coneto de Comonfort	10	2.72	1.01
Cuencamé	28	12.08	4.50
Durango	105	35.65	13.30
El Oro	20	2.57	0.95
General Simón Bolivar	22	6.67	2.48
Gómez Palacio	90	34.78	12.97
Guadalupe Victoria	10	7.07	2.63
Guanaceví	20	2.88	1.07
Hidalgo	10	2.44	0.91
Indé	17	2.65	0.98
Lerdo	43	19.98	7.45
Mapimí	18	3.41	1.27
Mezquital	68	9.52	3.55
Nazas	15	5.31	1.98
Nombre de Dios	27	8.17	3.04
Nuevo Ideal	14	3.25	1.21
Ocampo	41	9.08	3.38
Otáez	18	2.49	0.92
Pánuco de Coronado	15	4.66	1.73
Peñón Blanco	10	3.15	1.17
Poanas	14	8.97	3.34
Pueblo Nuevo	57	10.26	3.82
Rodeo	25	4.74	1.76
San Bernardo	10	1.42	0.52
San Dimas	41	6.07	2.26
San Juan de Guadalupe	15	2.94	1.09
San Juan del Río	26	5.17	1.92
San Luis del Cordero	3	1.29	0.48
San Pedro del Gallo	6	0.93	0.34
Santa Clara	5	1.78	0.66
Santiago Papasquiaro	53	9.08	3.38
Súchil	9	1.56	0.58
Tamazula	56	8.18	3.05
Tepehuanes	13	1.43	0.53
Tlahualilo	19	6.03	2.24
Topia	18	3.3	1.23
Vicente Guerrero	8	3.21	1.19
Total	1,022	268.04	100%

determine Protected Natural Areas and accentuated effects of climate change. These effects are accentuated by the excessive use of the scarce remaining forest resources, which intensifies the loss of biodiversity. Since there is a lot of pressure from the inhabitants on these areas, who generally have subsistence economies originated in the ways they obtain their food, household heating, and their productive micro-enterprises which involve the use of firewood [19].

Some studies (20) argue that as household incomes improve, solid biofuels are replaced by gas. In the semi-arid areas of Durango there is a deforestation crisis mainly due to families with incomes from subsistence activities who cannot easily afford the price of gas, or if they have the means, they usually combine firewood with the use of gas to compensate for the expenses.

Overall, in the homes of rural communities in Durango, the traditional three-stone stove is used for cooking, which coincides with what has been reported by [21]. This practice results in incomplete combustion that, in addition to generating other GHGs, is inefficient and causes environmental pollution problems and health problems in people [22]. It was observed that only 3.2% of the interviewees use proper wood stoves, which are designed with a closed combustion chamber, and have a chimney to keep away the gases produced by the household firewood combustion, this is, generated by the members of the household family [23].

CO_2 constitutes 49% to 57% of the total GHGs emitted, while the remainder is a contribution of other gases (CO, CH_4 and CN) according to [24]. If the goal is an effective reduction of the CO_2 emitted by firewood consumption, not only in Durango, but in all areas of the world where it is used, it is strictly necessary that developed eco-technologies do emit lower CO_2 rates than those emitted by traditional firewood burning, and those emission rates from the use of traditional fuels [24]. If a combination is made, of firewood with energy-saving stoves using of natural gas, it would be possible to obtain a decrease in the CO_2 released into the atmosphere according to [25].

In this regard, [6] recorded an inventory of greenhouse gases for Mexico using the IPCC-1996 methodology in the period between 1993 and 2002. Their results on firewood use, CO_2 emitted to atmosphere were 17 611 Gt per year, equivalent to 17 million 611 thousand Mg per year. If the emissions of the state of Durango in Mg of CO_2 are compared with those at the national scale, those represent 1.52%; and Mexico contributes with 2.13% of the global CO_2 emissions to the atmosphere.

CONCLUSIONS

Firewood consumption in the communities of Durango is important as a source of CO_2 emissions. If we add forest fires to this, and the agronomic and pasture burnings for livestock, the emission of vehicles and the CO_2 from industry, a total calculation would allow a better understanding of the environmental problems in Durango. Monitoring the air quality is necessary to implement solutions towards preventing air pollution in this state.

In Durango, as in all of Mexico and Latin American countries, there is still much to be quantified about CO_2 emissions and other GHGs, since it is yet a recent issue. Actions must be planned and implemented to address the damage, not only to natural resources but also to public health, with the highest emphasis on the contribution of this state to the inventories in process of the global warming.

Firewood is a fuel that has remained in force as a source of energy since the discovery of fire by humans. Projected scenarios show that this validity will continue in the near future. For this reason, it becomes necessary to couple that use with eco-technologies that help supporting firewood efficient consumption. Regarding the specific CO_2 emissions into the atmosphere, based on the data obtained in this research, Mexico is still far below within the figures of CO_2 released into the atmosphere, compared to other places in the world like the United States of America and China.

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