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Domestic Energy Consumption and Its Contribution to Greenhouse Gas Emissions: Insights from Koulikoro Urban Community, Sudano-Sahelian Zone of Mali in West Africa

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ABSTRACT: The objective of this study is to estimate the carbon dioxide (CO_2) released by domestic energy (firewood and charcoal) in the urban commune of Koulikoro, Mali. This study employed questionnaire survey to identify the type of energies used, their costs, the quantity consumed, and the difficulties of access to these energies and their impact on natural resources in Koulikoro. The consumption of each family per neighbourhood was extrapolated to its total population to determine the carbon emitted and the carbon dioxide released. Thus, the carbon dioxide emitted in tonnes per neighbourhood was determined. The findings revealed three types of energy in the urban commune of Koulikoro, mainly firewood 72%, charcoal 25% and Gas 3%. The use of these energy sources depends on accessibility and availability. The increase in consumption per district is a function of the number of people. Daily used charcoal was estimated at 2 kg day^{-1} and 7 kg day^{-1} for firewood. Overall, average firewood using was highest in largest household size and it was 62% higher than in small size category which recorded the lowest. Annual amount of charcoal used was 676 kg year^{-1} and 2294 kg year^{-1} for firewood. However, annual amount of fuelwood per person was higher in small size category and 178% greater than in largest household group than other household size. Carbon consumption per capita per year was greater in small household group estimate to be 477 kg pns-^{1} year-^{1}. Thus, the urban commune of Koulikoro has a significant carbon dioxide emission and firewood emits more CO_2 than charcoal.

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The Republic of Mali, a continental country with a surface area of 1,241,238 km² and a population of more than 18 million inhabitants in 2020 (Soumaré *et al.*, 2020 Dolo *et al*. 2022), is one of the largest states in West Africa and is crossed by two major rivers (the Niger and the Senegal). The climate is characterised by three seasons (a dry season, a rainy season and a cold season) with a drying Saharan wind called the

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harmattan and average temperatures ranging from 24^0C in January to 35^0C in May. Mali is divided into three climatic zones: the desert north, which covers two-thirds of the country; the southern Sahara, where rainfall does not exceed an annual average of 130 mm; and the central Sahel, which has a relatively dry climate, with an annual average rainfall of between 200 mm and 500 mm and whose vegetation cover varies from steppe in its northern part to savannah in its southern part, and finally the Sudan-South, which is covered by a wooded savannah in the north and forests in the south, is watered by rainfall averaging 1,400 mm per year (Diallo *et al*. 1994; Tarawali and Hiernaux 2002; Ibrahima *et al*. 2020). In Mali, the work of the Projet Inventaire des Ressources Boisuses provided insight into the country's forest capital. It indicated that forest formations cover about 36,026,705 ha. The wood capital was evaluated at 520,781,060 m^3 (PIRL, 1992). The energy sector alone has an annual turnover of CFA 10-14 billion. The share of the forestry sector in the national gross domestic product is estimated at 5% in 1992 (Whiteman and Lebedys, 2006). Domestic energy remains an issue of concern in the world, especially in developing countries where the majority of the population uses firewood, charcoal to meet their energy needs for cooking. It is the main source of domestic energy with more than 95% of all types of domestic energy used (Thomson, 1981; Diallo *et al*., 1994; Neumann *et al*., 1998; Heubach *et al*., 2011; Houessou *et al*., 2012; Zhou *et al*., 2013; Ouédraogo *et al*., 2014; Ibrahima *et al*., 2020; Callo-Concha *et al*., 2022).

In recent decades, Mali has experienced a strong degradation of woody forest resources due to a very important and increasing abusive exploitation over time and this is due to population growth. According to the FAO, between 1990 and 2010 Mali lost about 79,100 ha of forest, or 0.56% per year. Despite their ecological, socio-economic and cultural importance, our forests are subject to degradation, the main causes of which are both climatic and anthropogenic (Gonzalez, 2001; Herrmann *et al*., 2013; Spiekermann *et al*., 2015 Ibrahim *et al*., 2018). In addition, they will have serious consequences on climate change through greenhouse gas emissions which will increase firewood crisis (Benjaminsen, 1997). Carbon dioxide (CO_2) is a naturally occurring gas in the atmosphere, accounting for 0.04% of the atmospheric mass. Despite its relatively low content in the atmosphere, carbon dioxide has the ability to absorb infrared radiation emitted by the Earth system and contributes significantly to the natural greenhouse effect (second only to water vapour), which is an essential mechanism for life on Earth (Wilson *et al*., 2009; D'Alessandro *et al*., 2010). Indeed, a terrestrial atmosphere deprived of the greenhouse effect would imply a surface temperature of -18^0C, water would only be present as ice and no life would be possible. The greenhouse effect then keeps the Earth's average surface temperature at around 15^0C. All green plants photosynthesise by absorbing CO_2 and transforming it into different organic compounds that constitute plant material such as wood, bark or leaves (Sagan *et al*., 1972; Schneider, 1989; Kweku *et al*., 2017). This contributes to the reduction of CO_2 in the atmosphere. The amount of carbon trapped in terrestrial ecosystems is about 3 times higher than that in the atmosphere (Moumouni *et al*., 2018). The Intergovernmental Panel on Climate Change and other scientific committees estimate that up to 25% of CO_2 absorption from the atmosphere is by forests (Moumouni *et al*., 2018; Yamagata *et al*., 2018; Romanovskaya *et al*., 2020; Spampinato *et al*., 2019). However, the ever-increasing injection of carbon dioxide of anthropogenic origin (deforestation, abusive or uncontrolled logging, etc.) implies an increase in its atmospheric concentration, thus disturbing the Earth's global radiative balance (Yamagata *et al*., 2018). It is within this framework of study that we carried out our 4-month internship within the DREF- Koulikoro, the theme of which you will have the scope is entitled: Estimation of greenhouse gases through the use of domestic energy in Mali: (case of CO_2) in the urban commune of Koulikoro. This work was carried out by means of a survey with a quota for each of the 10 neighbourhoods in the rural commune of Koulikoro (Katibougou, Koulikoro Ba, Koulikoro centre, Plateau I, Plateaux II, Plateaux III, Kolèbougou, Bakarybougou, Souban and Kayo), i.e. a total of 529 families surveyed. The objective of this study is to quantify the CO_2 released per household during the cooking of food using domestic energy (coal and wood).

MATERIALS AND METHODS

The study area: The Commune Urbaine de Koulikoro is located about 60 kilometres east of Bamako. It stretches for 14 kilometres along the Niger River, wedged for the most part between it and the rocky hills of Mount Mandingue (Benkahla *et al*., 2003; Traore *et al*., 2023). The city of Koulikoro is at the crossroads of rail, road and waterways. The Commune of Koulikoro was created by territorial decree $N^0$439/D I - 3 of 09 April 1958, which fixed its limits by decree $N^0$441/D I - 3 of 09 April 1958. The initial boundaries were changed with the successive adoption of Law N°66-38/ANRM of 03 August 1066, Law $N^0$96-059 of 04 November 1996, on the creation of communes as well as Decree $N^0$1-057/P-RM of 16 August 2001 on the approval of the Master Plan for the development and urban planning of the city of Koulikoro and its surroundings (Diop *et al*., 2015; OCHA, 2019). It covers an area of and is limited: to the North by the villages of Tanabougou and Tiètiguila (Commune Rurale de Meguétan); to the South by the Niger River; to the East by the village of Shô (Commune Rurale de Méguétan); to the West by the villages of Massala and Djindjila (Commune Rurale de Méguétan) Koulikoro was founded in 1800 by a descendant of Tianzé DIARRA named Dioba DIARRA. It was around 1860 that the SINGARE and FOFANA families arrived from Kaarta to settle. Koulikoro was the centre of a tiny Bambara kingdom of Ségou called (Méguétan). The average raisnfall is 850 mm per year. The average annual temperature is 39^0C in the hot season and 21^0C in the cool season. The main soil types found in the area are tropical ferruginous soils with a silty to sandy-silty texture on the surface and silty at depth (Diarra *et al*., 2021; Traore *et al*., 2023).

Identification and determination of the quantity of the most consumed energy sources: Sampling: For the realization of activity (a), the type of sampling adopted was that of stratified sampling with two degrees (Duc Nguyen *et al*., 2020; Iliyasu and Etikan, 2021). We considered the neighborhoods (10) of the urban commune of Koulikoro as the first stage and the families of each neighborhood as the second stage with 4201 families in total. In this survey, the interviewed household per neighborhoods was calculated at 11% rate using the following formular:

$$n = \frac{N}{1+N(e)^2} \qquad (1)$$

Where n is the sample size, N is the population size, and e is the precision level (Glenn, 1968; Naing, 2003).

Data collection: Data collection was based on a survey in which the population data per neighbourhood was provided by the TDRL (Tutorial on Woody Resources) carried out from June-November 2020. We surveyed family heads in the Urban Common of Koulikoro (UCK) through a questionnaire survey on the identification of the energies used, their costs, the quantity consumed, the difficulties of accessing these energies and their impact on the environment. During this study, 661 households were selected as the survey sample (Table 1). The analysis of the table shows that the starting point for each neighbourhood was the home of the head of the neighbourhood for each of the ten neighbourhoods surveyed; the distance respected was that for every two households, the third was surveyed; this procedure was applied at the four cardinal points of the neighbourhood (Table 1).

*Carbon dioxide emission assessment of the most used energy source***:** For this work, the weights of wood energy (firewood and charcoal) were determined. These activities were carried out in the market of three districts (Koulikoro-Ba, Koulikoro-Centre and Kolèbougou) in a random way and the choice was motivated by the results of the survey on the place of supply of the respondents in energy wood, added to the data collected from the DREF-Koulikoro. The amount of fuelwood sold were directly weighted with an electronic scale and recorded using a paper sheet (Figure 2).

Table 1. Distribution of the number of households surveyed in Koulikoro urban community

Neighborhoods	Survey statistics	
	Household size	**Surveyed household**
Bakarybougou	205	59
Katibougou	150	53
Kayo	514	71
Kolèbougou	146	53
Koulikoro-ba	546	72
Koulikoro-centre	617	73
Plateau I	321	66
Plateau II	652	73
Plateau III	348	67
Souban	702	74
Total	4201	661

Fig 2: Quantification session of wood units in supply markets

Data processing and analysis: Since the amount of fuelwood consumed by households cannot be provided accurately, the number of pieces for the different types of daily fuelwood sources were counted and weighed to determine the amount consumed. The number of-pieces used per energy source was divided by the-number of households to find the average amount of the type of wood energy source used per day in each-neighborhood (10). To find out the total amount of wood energy source type consumed in each neighborhood, the amount of wood energy type per day for each household was divided by the number of members in each household to find out the amount consumed per person.

$$DAFW\ (kg\ day^{-1}) = \frac{nHh}{NHH} \quad (1)$$

Where DAFW = Average amount of fuelwood used per day in the study area, nHh = daily amount of fuelwood used by each household and NHH = total number of surveyed households.

This daily amount was multiplied by the number of days per year (360 days) and multiplied by the total member of each household to obtain average annual consumption of fuelwood.

$$ACFW\ (kg\ year^{-1}) = DAFW \times 360 \times NHH \quad (2)$$

Where ACFW = average annual consumption of fuelwood, DAFW = Average amount of fuelwood used per day in the study area and NHH = total number of surveyed households.

Then, the unit price of firewood and charcoal was collected from the various markets most frequented by households. However, the quantity consumed and the expenditure on paraffin was obtained from the survey of respondents and no estimate of the amount was made for paraffin. Based on the market price of the energy sources per unit and the ratio of households using the energy sources in each neighborhood, the average price of the energy type was calculated. The monthly and annual quantity for each reported energy source type used by households was multiplied by the common price per unit of the energy type to obtain the expenditure of each household by energy source type. However, the quantity consumed and expenditure on gas was obtained from the respondent survey and no estimate of the amount was made for this type of household energy source.

The consumption of the household per neighbourhood was calculated to obtain the carbon exploited and the CO_2 emitted considering the amount of fuelwood energy type of sources described up-on. To go from wood amount to carbon quantities, the following relationships are used:

1 m^3 of wood harvested = 1tonne of CO_2 (4);
1 tonne of dry matter (TMS) = 0.5 tonnes of carbon (5);
1 tonne of carbon = 3.667 tonnes of CO_2 (6);

The amount of charcoal was converted to CO_2 by using factor according to the Greenhouse gas emissions conversation guide (Gunkel, 2009).

All data were entered into Excel Office 2016 and SPHINXPro.5.8 software. For the processing and analysis of numerical (quantitative) data we used Excel Office 2016 and SPHINXPro.5.8 for non-numerical (qualitative) data. R software was used for ANOVA. Then all data was verified for normal distribution of residuals and homogeneity of variances. Data not meeting the assumptions of ANOVA were transformed. Whenever F-Tests indicated significant treatment effects ($p \leq 0.05$) means were separated using the Least Significant Difference ($LSD_{0.05}$).

RESULTS AND DISCUSSIONS

Determination of the quantity of the most consumed energy sources Socio-demographic characteristics of respondents: The majority of the Koulikoro urban community is made up of children (52%), followed by women (25%) and men (23%). Which imply that this population is at increasing demographic stage. The consumption people are greater than the worker force. Children are 126% greater than men and 108% greater than women (Figure 3).

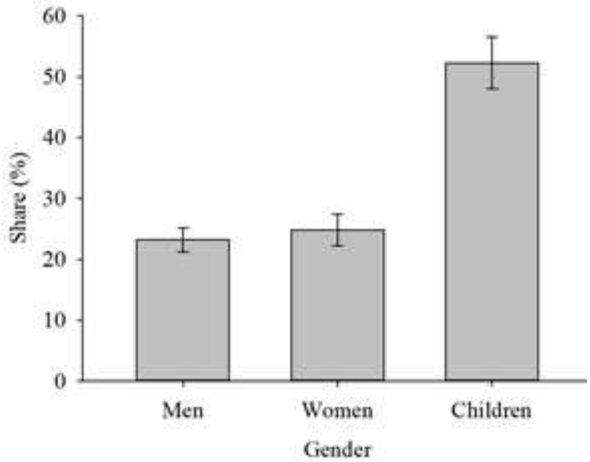

Fig 3: Demographic statistics of the population of the neighbourhoods surveyed. Error bars represent +/- one standard error of the mean

*Respondent education statute***:** Figure 4 shows us the level of education of the people surveyed. Analysis of the figure shows a very high rate at primary level with more than 29%, followed by secondary, Koranic, higher and literate with respectively (22.31%, 14.93%, 4.35%, and 1.32). However, the uneducated presents 27.03%.

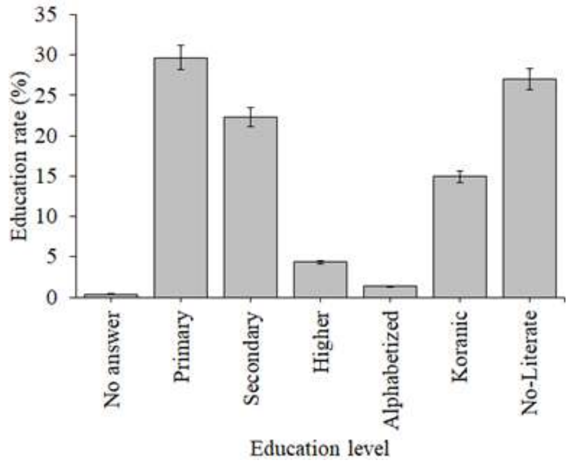

Fig 4: educational level of the respondents. Error bars represent +/- one standard error of the mean

Identifying domestic energy sources: Koulikoro urban municipality have a domestic energy base on fuelwood as energy sources. The used energy sources are firewood (72%), charcoal (25%) and gas (3%). This finding is consistent with result from Nigeria (Vihi *et al*., 2022). Where after studied the Analysis of Household Fuelwood Consumption as Domestic Cooking Energy Source and the Implications on the Environment: A Case of Vandeikya Local Government Area of Benue State, Nigeria concluded that firewood was 70% used by surveyed population and only 3% for charcoal. Main domestic energy source is firewood which has a higher used and 182% greater than charcoal using and over 2000% greater than gas. It followed by charcoal 7% using greater than lowest gas (Figure 5). This widespread use of firewood is due to the poverty of the population and the proximity of the Tienfala classified forest, which serves as a supply reserve (Bazile, 1997). Although charcoal is used quickly and cleanly, it is used less in the study area because mean by becoming increasingly rare and expensive on the market. This can also be explained by the degradation of the sources of supply, which are increasingly poor in large trees. As a result, small trees are being used as fuelwood, increasing the rate of use of this energy source. The rural firewood initiative development of Malian government could contributed to this fact (Hautdidier *et al*., 2004).

Amount of used fuelwood: Daily used charcoal was estimated at 2 kg day^{-1} and 7 kg day^{-1} for firewood. This amount of firewood is higher than the value obtained in Ghana (Amoah *et al*., 2015) and less than the results from (Kandel *et al*., 2016) who got the daily firewood consumption value of 8.4 kg day^{-1}. On average firewood using was highest in largest household size and it was 62% higher than in small size category which recorded the lowest (Figure 6). The monthly (Figure 7) and annual fuelwood utilization follow the same trend. This higher fuelwood consumption in large household group size could be due to fact that these household categories spend more time by cooking than small household (Gioda *et al*., 2022). Study by Kumar and Kumar (2015) in India, found that found that fuelwood consumption decreased as family size increased. Annual amount of charcoal used was 676 kg year^{-1} and 2294 kg year^{-1} for firewood in Koulikoro urban community (Figure 8) higher than the finding of Gioda *et al*. (2022) who obtained 1297 kg year^{-1}. However, this amount of firewood is less than the finding from Nepal where an annual average firewood consumption of was estimated to be 3060 kg per household.

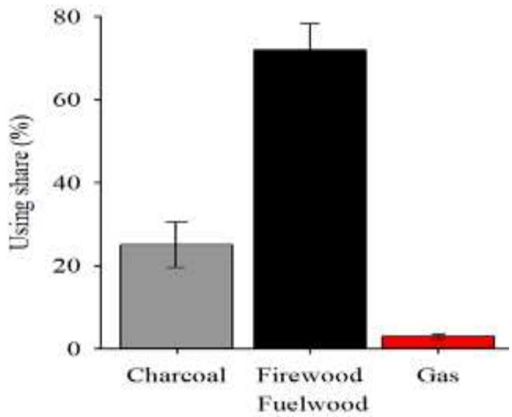

Fig 5: Identification of domestic energy sources used in the urban commune of Koulikoro in Mali. Error bars represent +/- one standard error of the mean

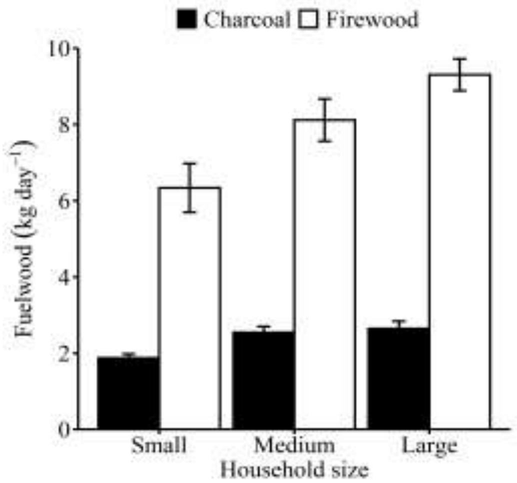

Fig 6: Average daily amount of firewood and charcoal consumed per household size in the urban commune of Koulikoro in Mali. Error bars represent +/- one standard error of the mean

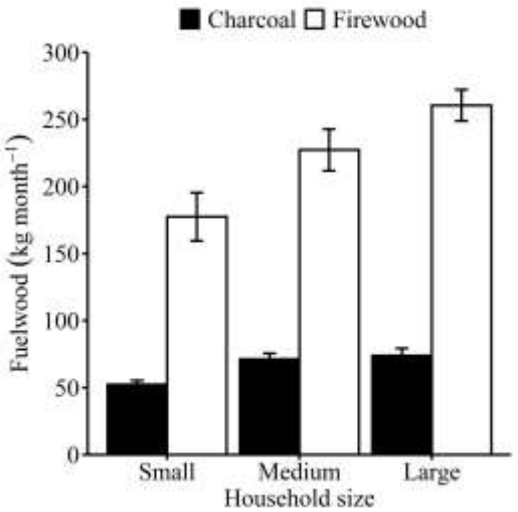

Fig 7: Average monthly amount of firewood and charcoal consumed per household size in the urban commune of Koulikoro in Mali. Error bars represent +/- one standard error of the mean

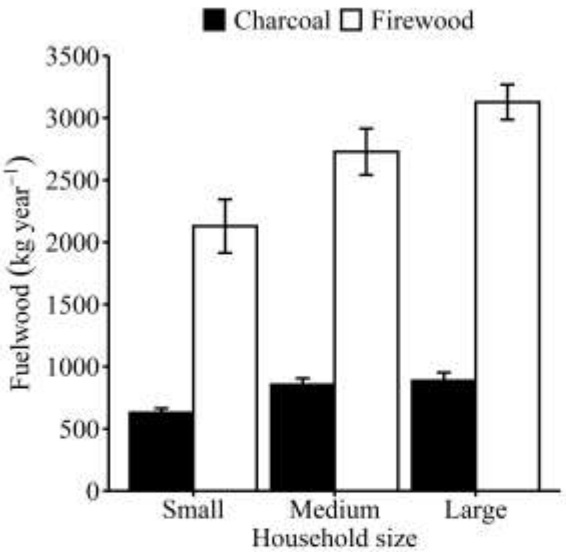

Fig 8: Average annual amount of firewood and charcoal consumed per household size in the urban commune of Koulikoro in Mali. Error bars represent +/- one standard error of the mean

In contrary of daily fuelwood using, annual amount of fuelwood per person was higher in small size category than other household size. Firewood using in small household group size was 178% greater than in largest household group size which recorded the lowest (Figure 9). This can be explained by the fact that there is generally only one kitchen in small households, whereas there are many kitchens in large households in the study area. It can also be linked to the state of health of household members, especially in large households. The majority of households treat themselves with traditional medicines, which require the use of energy. Annual amount per person (pns) of firewood used was 438 kg pens^{-1} year^{-1} and 141 kg pns^{-1} for charcoal in Koulikoro urban community. The same scenario of firewood consumption per person was observed in Nepal (Ram and Bahadur, 2020).

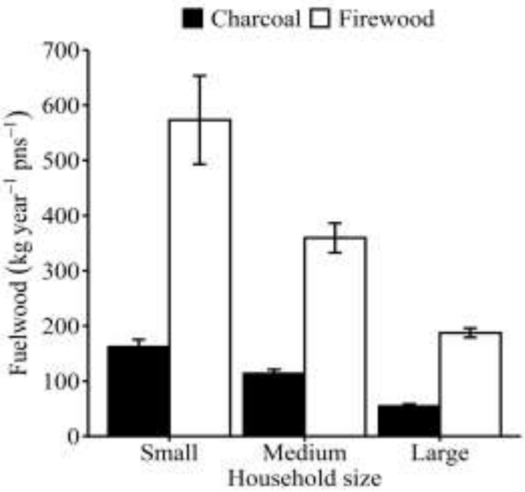

Fig 9: Average annual amount of firewood and charcoal consumed per person and household size in the urban commune of Koulikoro in Mali. Error bars represent +/- one standard error of the mean

However, spenditure in firewood was highest in large household group size and it was 2 times higher than in small household category size which recorded the lowest (Figure 10). Annual spenditure of household in domestic fuelwood was 84672 FCFA kg year^{-1}. This finding is contrary to those from Vihi *et al*. (2022) who reported that about 44% and 37% of respondents from his study area obtains their fuelwood at no cost from forest and their own farm. This different maybe due to the urbanization level of our study area.

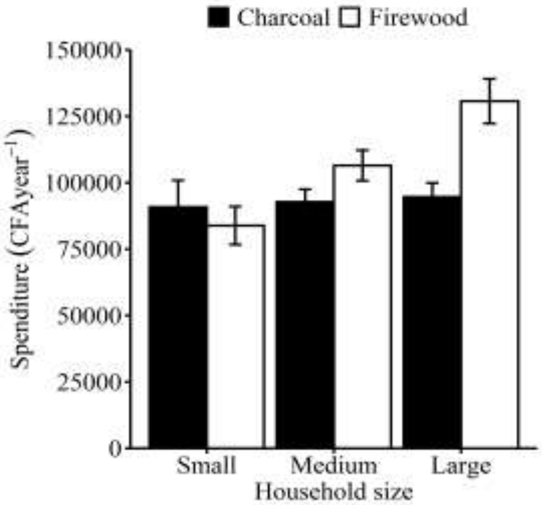

Fig 10: Average annual spenditure in fuelwood per household size in the urban commune of Koulikoro in Mali. Error bars represent +/- one standard error of the mean

Determination of carbon dioxide emissions: The most utilization of fuelwood carbon is made by large household group size with 704 ± 740 kg of carbon per year. Daily household carbon using is ranged from 2 kg day^{-1} for large household against 1 kg day^{-1} for lowest consuming household small. However, carbon consumption per capita per year was greater in small household group size (477 kg pns^{-1} $year^{-1}$) and was 3 time higher than in large household group size (Table 2). Similarly, average annual emission of CO_2 per capita follow the same trend (Table 3).

Table 2: Estimated amount of average carbon exploited by household through the use of fuelwood as a domestic energy source in the urban commune of Koulikoro

Household categories	Average carbon (Kg)		
	Daily	Annual	Person $year^{-1}$
Large	2 ± 2^{a}	704 ± 740^{a}	43 ± 43^{c}
Medium	2 ± 2^{a}	653 ± 665^{a}	86 ± 94^{b}
Small	1 ± 1^{b}	494 ± 440^{b}	130 ± 151^{a}
P	<0.001	<0.05	<0.001

Notes. Number in bracket is the standard deviation of means and the different lower-case letters after bracket shows significant difference ($p < 0.05$).

In overall, annual CO_2 emission was estimated to be 317 kg CO_2 $year^{-1}$. Daily household CO_2 emission range from 7-4 kg CO_2. This result is consistent with the founding from Bangladesh (ADOR *et al.*, 2020) where the daily household CO2 was estimated to be 6.4 kg CO_2 day^{-1}. However, this finding is less than the value of 14.26 kg CO_2 day-1 obtained in Nepal (Ram and Bahadur, 2020). This difference might be associated to the difference of firewood species type and the using rate of different fuelwood sources in the study areas.

Table 3: Estimated amount of average carbon dioxide emitted by household through the use of fuelwood as a domestic energy source in the urban commune of Koulikoro

Household categories	Average carbon dioxide (Kg)		
	Daily	Annual	Person $year^{-1}$
Large	7 ± 7^{a}	2581 ± 2713^{a}	157 ± 159c
Medium	6 ± 6^{a}	2394 ± 2440^{a}	317 ± 343^{b}
Small	4 ± 4^{b}	1813 ± 612^{b}	477 ± 553^{a}
P	<0.001	<0.05	<0.001

Notes. Number in bracket is the standard deviation of means and the different lower-case letters after bracket shows significant difference ($p < 0.05$).

Conflict of interest: The authors declare no conflict of interest.

Conclusion: In conclusion, this research has made it possible for us to distinguish between numerous domestic energy sources that Koulikoro's urban commune uses: firewood, charcoal, and, sporadically, gas. The high incidence of fuelwood consumption among households can be attributed to the lack of efficient access to alternate energy sources, such gas. The majority of Koulikoro's urban districts still use fuelwood for cooking, despite being aware of the negative environmental effects of doing so. To address this, before an eco-friendly energy source becomes accessible, better stoves should be marketed. In order to monitor firewood consumption responsibly in the Koulikoro district, the local Water and Forests extension agency may find this finding useful. It will also help households understand their part in it.

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