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Production and characterization of ecological fire starter from sawdust and vegetable oil

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A R T I C L E I N F O

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A B S T R A C T

The objective of this article aims to reduce indoor air pollution through the use of ecological fire starter (EFS) made from sawdust and vegetable oils. In the Far North region of Cameroon, plastic waste is used to ignite and stoke solid fuels fires, exposing mainly women and children who are responsible for cooking to health risks from indoor air pollution. Thus, the survey conducted among the population of the region shows that 96% of urban households use plastics waste made with LDPE, HDPE, PET, PS, PP and EVA as fire starter for solid fuels. In the region, 5544 tons of plastic used by households could emit approximately 15,314 tons of CO_2 eq per year. The region has a manufacturing capacity of 1000 tons of EFS while its need is 894 tons in 2022. The lower heating value of the EFS varies between 31.914 ± 0.810 and 25.127 ± 0.026 MJ/kg, and have many ecological health and economic advantages. A household needs about 10 g of EFS to ignite solid fuel per day, with an annual expenditure ranging from 5.5 and US$ 7 to purchase EFS. Therefore, it is important to promote EFS through developing countries and look for another way to recover plastic waste.

1. Introduction

In recent decades, environmental pollution by plastic has become increasingly alarming [1–5]. It is noted that between 1950 and 2017, about 7000 million of 9200 million tons of cumulative plastic manufactured, became waste [6]. Today, 40% of plastics manufactured are in the form of packaging; South Korea uses it the most, with 100kg/capita/year, followed by the United States (80 kg/capita/year), and African countries come last with 5 kg/capita/year [7]. Plastics waste are omnipresent and their complete decomposition takes between 100 and 500 years [4]. The African continent had the highest rate of non-compliant waste disposal at 88.5% [8]. Cameroon imported and consumed over 1,391,089 tons of plastics between the years 1990 and 2017 [2]. Thus, in Cameroon, [9] [1] of October 24, 2012, in its article 3, paragraph 2, provides for measures to limit the manufacture and import of plastic, rather to promote the recycling, reuse and other forms of recovery of waste from plastic.

Currently, recycling rate of plastic waste worldwide is less than 10% [6]. The issues surrounding urban waste management in

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[1] MINEPDED: Ministry of Environment, Nature Protection and Sustainable Development; MINCOMMERCE: Ministry of Commerce.

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general and plastics in particular are among the most complex because of their effects on human health. For example, in many developing countries, due to cooking energy shortages and high costs, women in mostly poor households are often forced to use plastic containers and old shoes as cooking fuel or to stoke solid fuel fire [10]. During plastic waste gasification, pyrolysis and open air combustion, some pollutants such as particulate matter, carbon monoxide, carbon dioxide are emitted in atmospheres [11,12]. These particulate matters and gases emitted by polluting fuels, heating and cooking appliances with open fire or not connected to a chimney and inefficient, are harmful to human [13–17].

The Indoor Air Pollution (IAP) due to burning plastics causes chest irritation, headaches, rashes, cancers, loss of coordination, and nausea [1,18]. In 2017, more than 3.6 million ton of CO_2 eq were generated from 2.7 million tons of plastic waste [3], and by 2050, plastic production and incineration could emit 2.8 billion tons of CO_2 eq [19]. Certainly, the open burning of plastic, as well as the unregulated incineration and recycling of waste, affects local communities [20]. Indoor air quality is a determinant of human health and well-being [1,21,22]. Today, the air pollution causes more than 4.3 million premature deaths per year through the world [16,23]. Each year, IAP causes about 13,000 deaths in Cameroon [24]. In addition, environment unhealthiness has an economic impact resulting in public health costs that amount to the global economy over US$ 5 trillion each year [16], and according to Ref. [25]; 12% of people worldwide spend more than 10% of their income on health care. But people with very low incomes lack insurance and experience health stress [26].

Cameroon in general and the Far North region in particular is not spared from these situations. In fact, people in urban areas are proving difficulties in ignition solid fuel fire. This situation combined with impoverishment forces them to use plastic waste, card-boards, and old shoes for energy purposes. Therefore, there is an urgent need to find an affordable and ecological fire starter (EFS) which is closely related to the objective of United Nations sustainable development goals 7 and circular economy. It is with this in mind that this work will focus on the characterization of NEFS and the manufacture of EFS based on wood sawdust and vegetable oils.

2. Materials and methods

2.1. Description of the study area

The study was carried out in the Far North region of Cameroon, which by projection of the general census of populations and habitats of 2005, estimates in 2022 of 5,059,084 inhabitants (i.e. 1,151,148 inhabitants in urban areas and 3,907,936 inhabitants in rural areas). In addition, there are 128,086 Nigerian refugees who have fled the abuses of the terrorist sect Boko Haram [27], for a total of 5,187,170 inhabitants. Based on 4.7 persons per household in urban areas [28], in 2022 there would be more than 244,925 households in urban areas in the Far North region of Cameroon.

2.2. Data collection

The chosen methodology combines survey tools on the characterization of the different fire starters of solid fuels. Thus, questionnaires were administered to 450 households in five major quarters (Domayo, Dougoï, Doualaré, Pitoaré and Palar) in the city of Maroua, the regional capital of the Far North of Cameroon. The questionnaires are oriented on the different fire starters used whether it is ecological or not and quantify them, determine the time taken for the ignition of solid fuels. The survey was conducted from January 2021 to May 2022. Then, present the process of manufacturing of the EFS based on sawdust (Sd) and the three types of vegetable oils: refined palm oil (RPO), refined cottonseed oil (RCO) and peanut oil (PO) in order to determine the followings properties: the lower heating value, the burning time, the wood fuel ignition, the flame height and as well as its economic profitability.

2.3. Estimation of CO_2 eq emissions from plastic waste burning

As part of this work, after quantifying the plastic used in the ignition of wood fuel, we have determined the Lower heating value (LHV) and the total energy contained in these plastics. According to Ref. [29]; the emission factor for the combustion of plastic is 75 tCO_2 eq/TJ. Thus, the CO_2 eq which would be emitted in the indoor environment is given by equation (1) according to Ref. [30].

$$CO_2 \text{ emitted} = Qt_{\text{Plastic burnt}} * CO_{2\,\text{plastic emission factor}} \tag{1}$$

With, Qt (t): quantity of plastic burnt

2.4. Characteristics of EFS

2.4.1. Manufacturing process of EFS

The EFS manufacturing process begins with the collection and sieving of sawdust through a 5 mm mesh sieve. Thus, the sifted sawdust is mixed with a vegetable oil after a gentle heating (250 °C) until a total homogenization. This step is followed by compaction with mechanical or manual press and soaking in a gelatinous solution of arabic gum with 20%, before being dried. The ratio of 35:75; 45:65; 55:45 and 65:35 of vegetable oils to wood sawdust was used to determine some physical and energetic properties of EFS. The EFS manufacturing process is illustrated by Fig. 1.

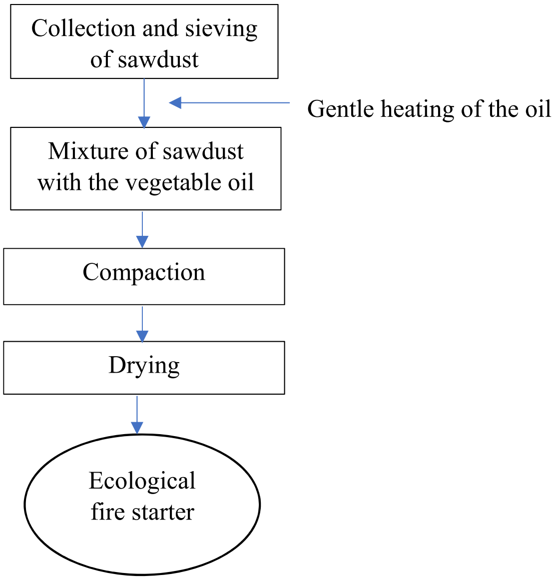

Fig. 1. Manufacturing process of EFS.

2.4.2. Proximate analysis

2.4.2.1. Lower heating value (LHV). The LHV of plastic packaging and various EFS were determined by the calorimeter bomb method according to American Standard Testing Methods (ASTM) D5865-10a (2010). The calorimeter bomb brand SPAN Automation, Model: SABC-01 was used in this work. The sample to be burned is weighed on a precision electronic scale (0.0001g) and is introduced into the bomb. The ignition wire (10 or 13 cm long) is attached to two electrodes of the bomb so that it touches the compacted sample in the crucible. Then, the bomb is hermetically sealed and filled with oxygen to 30 atm. The bomb is introduced into a thermostatic bath of distilled water. Awaiting about 5 to 10 min for the ambient temperature of the calorimeter water to be stabilized before starting the combustion of the sample. At the end of the combustion, the length of the remaining wire and sample were measured. Thus, the true values are introduced into the system in order to automatically generate the value of the calorific value of the fuel. For each sample, the test was repeated 4 times.

2.4.2.2. Determination of durability. The impact resistance index (IRI) is determined as described by Ref. [31]; by dropping each EFS from a height of 2 m onto a steel floor until it became fractured. The number of drops and number of pieces of the broken EFS were recorded. For each type of EFS, three sets of test measurements were performed. The IRI determination is illustrated by equation (2).

$$IRI = \frac{Average\ of\ number\ drops}{Average\ number\ of\ pieces} * 100 \quad (2)$$

2.4.2.3. Determination of wood fuel ignition time by EFS. For the burning time, 1; 2; 3; 3.5 and 4 g of EFS were measured. In addition, ignition tests for solid fuels (fuelwood, charcoal briquettes and charcoal) were carried out in triplicate sets of measurement, and using a stop watch as performed by Ref. [32]. Thus, it is important to determine the amount of EFS to be used for solid fuel ignition and derive the requirement for the region.

2.4.2.4. Determination of EFS flame height. The flame height is important characteristic to be determined. It is defined as the distance from the burner to the position on the centerline where the fuel and oxidizer are the stoichiometric proportion [33,34]. In this work, as the small burning, we graduated an iron bar and placed it next to a burning EFS in order to measure the flame height. The measurements were made in triplicate for each type of EFS.

2.4.2.5. Evaluation of the economic profitability of EFS. To evaluate the manufacturing cost of EFS, the availability and accessibility of raw materials (wood sawdust, vegetable oil and binder) in the region were assessed. Thus, a survey was conducted among the carpenters of the "Comice market" in Maroua town (for sawdust), and the traders (for oils and binders). The manufacturing cost of EFS is given by equations (3) to 5).

$$TCp = (QF * Pf) + (QO * Po) + (Qc * Pc) + Ci \quad (3)$$

With

TCp: total cost of production; Qf: quantity of fuel used to manufacture the fire starter; Pf: unit cost of fuel; QO: quantity of vegetable oil; Po: unit price of vegetable oil.

$$Ci = a.I \text{ with} \tag{4}$$

$$a = i(1+i)^n / ((1+i)^n - 1) \tag{5}$$

With:
a: is depreciation; i: is the annual interest rate; n: is the lifetime of the equipment; I: total investment.

2.5. Data analysis

The analysis of the various data collected in the field and those from practices, was done thanks to excel 2019, SPSS 24 and LXSTAT 2007 software. Indeed, after having stripped these data, they were introduced into these software, in order to have the appearance of graphs, tables and curves that are necessary for the interpretation of the results.

3. Results and discussion

3.1. Types of materials usually used to ignite wood fuel fire

In the urban areas of the Far North region of Cameroon, due to the lack of the agricultural residues (cotton stalks, sorghum stalks and maize stalks) and wood twigs to ignite the solid fuel fire, households resort to the use of the fuels shown in Fig. 2.

Fig. 2 shows that 90% of respondents use plastic packaging waste, 4% use wood twigs, 3% use others (old slippers, water and juice bottles, old plastics buckets, old nylon bags, etc.) kerosene is used by 2% and finally cardboard/paper is used by 1%. In view of all these fire starters, there is only 4% of urban households use the ecological fire starters which are twigs of wood. Thus, it can be said that 96% of respondents use NEFS. The quantity of fire starters to be used depends on the solid fuels. Table 1 illustrates the quantification of NEFS per cooking.

Results with the same superscript letters in the same column are not significantly different according to the statistical analysis of ANOVA (Fisher test, $P < 0.05$). Table 1 shows that by cooking meals, the quantity of NEFS depends of the type solid fuel. The charcoal needs more NEFS to be ignited compared to firewood. In the region, the number of meal preparation varies per household and per day as illustrated in Fig. 3.

Fig. 3 shows that the majority of respondents (54.43%) prepare the meal 3 times per day, followed by those who do it 2 times (34.18%) and finally 11.39% do once by preparing a large quantity of meals that may be sufficient for both lunch and dinner.

Thus, based on the average use of plastic waste per household, its total consumption is more than 5544 tons per year for lighting or stoking solid fuel fires in Far North region of Cameroon. According to Ref. [30]; plastic combustion emits 75 tCO_2/TJ. The most used plastic to ignite the fire of wood fuel fire in the Far North region of Cameroon, are composited of low-density polyethylene (LDPE) and high-density polyethylene (HDPE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), ethylene vinyl acetate (EVA). The plastic burning emits bad odors. As [35] says, some people don't know the effects of inhaling plastic-polluted air, or even other people do, but turn a blind eye to it as if nothing had happened. The smoke from burning of these plastics materials emit fine particles, carbon monoxide, carbon dioxide, which affects human health [23,36,37]. The effects of inhaling air polluted by burning plastics include nausea, coughing, dyspnea, eye irritation and others [23]. In addition, children and women are more exposed when they go to garbage to look for plastics wastes, could be injured by sharp objects, inhale of foul odors, and often get their fingers burned during ignition of wood fuel by plastic burning. Table 2 illustrates different the amount and ignition of solid fuel by different NEFS.

The results in this Table 2 show that the ignition time varies between 8 and 20 min. This explain the length of exposure of users by inhaling the smoke released during the ignition of solid fuels fire by plastics. The ignition time depends on the type of fuel and the

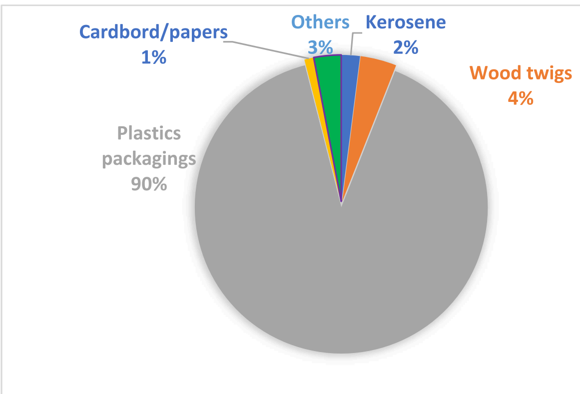

Fig. 2. Non/ecological fire starter utilization rate.

Table 1
Amount of NEFS to ignite wood fuel fire.

Type of fuel	Type of NEFS			
	Plastics packaging (g)	Slippers (g)	Nylon bag (g)	Kerosene (Liter)
Charcoal	$35^a \pm 5$	$50^a \pm 10$	$40^a \pm 5$	$0.035^a \pm 0.005$
Firewood	$25^b \pm 5$	$40^b \pm 5$	$30^b \pm 5$	$0.025^b \pm 0.005$

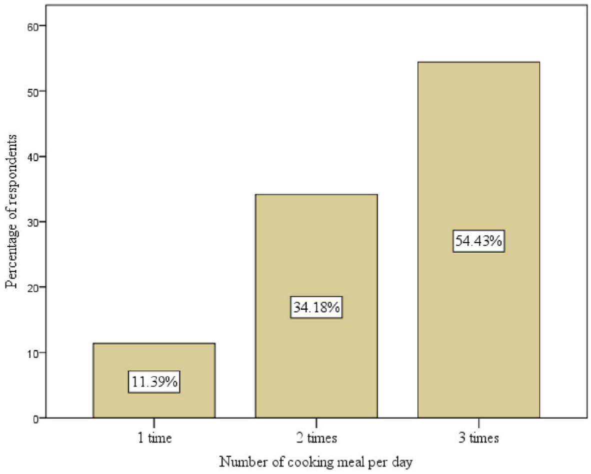

Fig. 3. Number of times meal preparation per day.

Table 2
Ignition time of wood fuel by NEFS.

Types of NEFS	Firewood		Wood charcoal	
	Amount of NEFS needed (g) or liter	Ignition time (minutes)	Amount of NEFS needed (g) or liter	Ignition time (minutes)
Plastics packaging	25 ± 5	12.33 ± 2.51	35 ± 5	14.33 ± 2.51
Slippers	40 ± 5	14.66 ± 4.50	50 ± 10	15.66 ± 4.04
Nylon bag	30 ± 5	13.66 ± 3.51	40 ± 5	15.33 ± 2.51
Kerosene	0.025 ± 0.005	09.00 ± 1.00	0.035 ± 0.005	10.00 ± 2.00

environment conditions [38] and on mass of fuel [34].

3.2. Estimation of the amount of CO_2 eq emitted by the combustion of plastic

The amount of CO_2 eq emitted during the ignition of fuels by plastic packaging is none other than the amount of energy contained by the emission factor of 75 tCO_2 eq/TJ [29]. Thus, Table 3 illustrates the different the quantity, LHV and total Energy of plastic waste burning.

Table 3 shows that the households of the Far North region of Cameroon consume about 5544 tons per year of plastic to ignite the wood fuel fire. The LHV of plastics waste depend of the type of plastics. Thus, among the plastics studied in this work, bucket composite of PP contains more LHV with 47.197 ± 0.171 MJ/kg, followed by old nylon bags of PS and plastics packaging (HDPE) with 40.751 ± 0.051 MJ/kg and 35.966 ± 0.183 MJ/kg, respectively. Slippers (composite of EVA) contains the less LHV with 17.725 ± 0.270 MJ/kg.

Table 3
LHV and total energy resulting from different NEFS.

Types of raw materials (Composite)	Quantity (t/year)	LHV (MJ/kg)	Quantity of energy (TJ)
Plastics packaging (HDPE)	4230	35.966 ± 0.183	152
Plastics packaging (LDPE)	1200	41,083 ± 0,017	49
Water and juice bottle (PET)	44	22.654 ± 0.136	1
Bucket (PP)	5	47.197 ± 0.171	0.23
Slippers (EVA)	20	17.725 ± 0.270	0.355
Nylon bags (PS)	45	40.751 ± 0.051	1.83
Total	5544	N/A	204.185

All these NEFS contain 204.185 TJ. Thus, according to equation (1), the multiplication of the total energy (204.185 TJ) by emission factor (75 tCO_2 eq/TJ) for plastics [29,30] about 15,314 tCO_2 eq can be emitted from burning plastics used by households to ignite the wood fuel fire in Far North region of Cameroon. This explains the exposure of users by inhaling the smoke released by the combustion of the latter. Then, a good way of valorization of these plastic materials would be oriented towards the manufacture of pavers [39]. Or, in order to overcome the depletion of fossil fuel, liquid fuel can be produced from gasification or pyrolysis of plastic waste [40,41]; Bin Bai et al., 2020; Yan Yang et al., 2021). Plastic waste made with LDPE were used by Ref. [42] as co-pyrolysis to increase the carbonization yield of rice husks.

3.3. Characteristics of EFS

In this work, the EFS are compacted with a manual press. These EFS have a cubic shape, the length of one side is 4 cm and 1 cm height, and this gives a volume of 16 cm^3. Fig. 4 illustrates EFS made with wood sawdust (55%) and vegetable oils (45%) (see Fig. 5).

Fig. 4 shows the EFS taking a cubic shape. A piece of EFS weighs 10 g and must be divided into 4 to be used. This shape is the best one for handling, transport and storage [43]. Table 4 illustrates the densities and durability of EFS.

Table 4 shows that there is a significant difference between the LHV of the different EFS, the RCO is the best one, followed by RPO, and PO comes, but their density and durability are not significantly different according to ANOVA analysis ($P < 0.05$). The soaking of EFS in a gelatinous solution of gum Arabic (wt. 20%) allows it not to crush easily. The photos 4 and Table 5 illustrate respectively the burning test, and variation of burning time and height as function of oil ratio.

This Table shows that the burning time of an EFS depends on the weight and decrease with the proportion of vegetable oil that composes it. The density and the speed of the wind can affect this time, but in this work, these parameters were not varied. To ignite the wood fuel fire, it requires an average of 3.5 ± 0.5g per cook for household. However, the amount needed to ignite the solid fuel fire depends on the moisture content. According to Ref. [44]; 6.5 g of the fire starters' composite of wood fiber with wax were sufficient. The height of flame increase with the proportion oil. The higher the oil content, the greater the flame height. This would explain the decrease of time burning of EFS when increasing oil proportion. However, there is not significantly difference between the flames heights of different oil used at the same ratio in EFS. The greater the height of the flame of EFS, the faster the solid fuel will be ignited. In fact, it accelerates the oxidation reaction, allowing the fire to generate more and more heat to the point of igniting the remaining fuel. The flame height is correlated with the fuel mass [34], it increase with increasing of the rate of air flow [33]. EFS made from natural raw materials has many benefits to the environment and human health according to Ref. [45]. EFS gives off very little smoke and does not give off odors that can block breathing as does the burning of plastics.

3.4. Estimation of region's requirement and economic profitability of the EFS

Based on the test done, a household requires of 3.5 g of EFS/cooking (i.e.10 g/day). Thus, by multiplying the number of households (244,925) by the daily consumption (0.01 kg of EFS) and by the number of days in a year (365 days) gives a total requirement of 894 tons of EFS per year. This amount will depend on the number of households that depend on plastics, cardboards, kerosene to ignite the solid fuel fire. According to the evaluation conducted among the carpenters of "Maroua Comice" market, 1.51 ± 0.02 ton of sawdust are produced each day (i.e. 550 ± 1.25 tons per year). Thus, the region capacity to manufacture EFS considering the ratio of wood sawdust at 55% (i.e. 55 kg) to mixt with 45% (i.e. 45 kg) of vegetable oil, is 1000 tons per year. The region will have sufficient amount of EFS to cover the potential household demand. The EFS manufacturing unit would require an investment of US$ 1,005,395 to manufacture 894 tons, which results in a cost per kilogram of US$ 1.13. Then, the selling price of one kg of EFS could be set at US$ 1.5. Table 6 illustrates the economic and financial performance analysis of the EFS manufacturing unit for the Far North region of Cameroon.

Fig. 4. Ecological fire starters.

Fig. 5. Burning test of EFS.

Table 4
Energetic and physical properties of EFS.

Type of EFS	LHV (MJ/kg)	Density (g/cm^3)	Durability (%)
RCO + Sd	$27.806^{a} \pm 0.131$	$1.6^{a} \pm 0.04$	$100^{a} \pm 0.00$
RPO + Sd	$27.704^{b} \pm 0.173$	$1.6^{a} \pm 0.02$	$100^{a} \pm 0.00$
PO + Sd	$27.605^{c} \pm 0.072$	$1.6^{a} \pm 0.03$	$100^{a} \pm 0.00$

Table 5
Variation of the burning time and height flame of the EFS.

Oil ratio in EFS (wt. %)	Burning time of 3.5g of EFS (Minutes)			Flame height of 3.5g of EFS burning (cm)		
	RCO + Sd	RPO + Sd	PO + Sd	RCO + Sd	RPO + Sd	PO + Sd
35	$8.65^{a} \pm 0.67$	$8.64^{a} \pm 0.65$	$8.65^{a} \pm 0.63$	$5^{a} \pm 0.50$	$5^{a} \pm 0.50$	$5^{a} \pm 0.50$
45	$8.57^{b} \pm 0.62$	$8.60^{b} \pm 0.61$	$8.61^{b} \pm 0.60$	$6^{ab} \pm 0.40$	$6^{b} \pm 0.40$	$6^{b} \pm 0.40$
55	$8.53^{c} \pm 0.54$	$8.54^{c} \pm 0.55$	$8.55^{c} \pm 0.52$	$7^{c} \pm 0.50$	$7^{c} \pm 0.50$	$7^{c} \pm 0.50$
65	$8.45^{d} \pm 0.52$	$8.44^{d} \pm 0.53$	$8.44^{d} \pm 0.52$	$8^{d} \pm 0.50$	$8^{d} \pm 0.50$	$8^{d} \pm 0.50$

Table 6
Economic and financial performance analysis.

Designation	Year 1	Year 2	Year 3	Year 4
Economic performance analysis				
Added value (AV) (US$)	649,376	948,773	1,028,013	1,107,252
Value Added rate (AV/CA)	0.373390269	0.616636132	0.625218904	0.64128095
Gross operating surplus (US$)	403,48	702,878	782,117	861,357
Financial performance analysis				
Self-financing capacity (US$) (1)	403,48	702,878	782,117	861,357
Discount factor,10% rate (2)	0.909	0.826	0.751	0.683
Discounted cash-flow (US$) (3) = (1)*(2)	366,763	580,577	587,37	588,307
Discounted cumulative cash flows (US$)	366,763	947,341	1,534,711	2,123,017

According to the financial performance analysis in Table 6, the installation of manufacturing unit of the EFS will be profitable from the third year as its discounted cumulative cash flows is higher than the investment amount. A household will only spend between US$ 5.5 and 7 to buy the EFS that they would use for a year. This amount of money to spend on the purchase of EFS is less than what a household might spend on a simple medical consultation which is more than US$ 8, when a family member becomes ill. Having an EFS would also prevent the risk of injury, bites by sharp materials and any others contaminations when collecting plastic waste in trash cans to ignite fires in households.

4. Conclusion

The aim of this work was to characterize NEFS used for solid fuels in the Far North region of Cameroon and to propose an ecological alternative. Therefore, it emerges from this study that 96% of urban populations use NEFS to ignite and to stoke the solid fuel fire. Thus, more than 5544 tons of plastics waste are used each year and their burning would emit 15,314 tCO_2 eq. The burning of these plastics mainly exposes the women and children who are responsible for cooking. Therefore, the manufacturing of EFS from wood sawdust and vegetable oils is an effective solution to this problem of IAP that endangers human health and well-being. It is urgent to invest in the manufacturing unit of EFS in order to reduce the exposure of populations to the various harmful effects of inhaling smoke from the burning of plastics. Moreover, the EFS manufacturing is circular economy when recovering the wood sawdust into EFS which will be economically profitable. To this end, it is important to conduct extensive awareness campaigns on the dangers of the use of plastic waste as solid fuel fire starter and to promote the use of EFS. Through these practices, the environment will be cleaned up and lives will be saved anywhere the need arises in the world.

Author contribution statement

Ezéchiel Kodji: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tize Koda Joel: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Marcel Hamda Souloukngа; Djoulde Darman Roger: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e18253.

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