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Environmental Profile of CBA (Copper-Boron-Azole)-Treated Wooden Utility Poles: A Developing Country Case

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Abstract: *Wood poles are popular and are used worldwide in the power supply industries because of their high strength per unit weight, low installation and maintenance costs, and local availability. However, the environmental sustainability which is another required criterion to appreciate the whole quality of wood utility poles has until now not received attention from the developing countries' research community. To overcome this lack of interest, this study investigates the gate-to-grave life cycle environmental impacts, related to CBA-treated wooden utility poles used for electricity distribution in a developing country for primary environmental characterization of wood pole related operations. The gate-to-grave LCA covered four life stages of wood utility pole: shaping, treatment, in-service, and final disposal. Five impact categories have been assessed based on an extensive primary data search through a detailed life cycle inventory. Cameroon was taken as the case study and life stage operation data were taken from the national utility company while inputs and outputs emissions data were taken from literature. Impact category scores were expressed per functional unit which was taken as one 9 m eucalypt saligna pole processed and used in power distribution line with a lifetime of 30 years. The results showed that the following scores of 65.60 kg CO_2-eq for global warming, 0.76 kg SO_2-eq for acidification, 0.08 kg C_2H_4-eq for photochemical ozone formation, 2.00 kg 1,4-DB-eq for ecotoxicity, and 60.67 kg for solid waste have been recorded as environmental profile characterization values of a wood utility pole. Furthermore, activities related to the wood pole treatment have been identified as the most environmentally harmful with regard to global warming, acidification, and photochemical ozone formation, while in-service and final disposal life stages recorded the highest values in ecotoxicity and solid waste respectively. In spite of the fact that this study was based both on Cameroonian experience and on worldwide used primary emission data, it yielded good quality data unique for power pole LCA research in third world.*
Keywords*: Cameroon, Environmental profile, Gate-to-grave, Life cycle assessment, Wood utility pole.*

1. Introduction

Wood utility poles are designed to be used in the electricity supply and telecommunications lines. Their function is to support the overhead lines and the conductors. Wood poles are popular throughout the world because of their high strength per unit weight, low cost, excellent insulating characteristic, excellent durability (if they are well treated), and especially their local availability.

Since the early' 60s, wooden pole structural systems have been adopted by the national power utility company in Cameroon as an economical and frugal method for supporting overhead power distribution lines. Consequently, steel and concrete poles used in the first Cameroonian overhead power lines by the ''Compagnie Coloniale de Distribution de l'Énergie Électrique'' in the year 1929 [1] are less and less visible in the electrical network, and currently represent 7% of all networked poles while the number of in-service treated wood poles is estimated at 1.024 million [2].

Regardless of the pole material used in the electric network, it negatively affects the environment during its lifespan as it is the case for any product. These environmental impacts however differ from one material to another [3].

One of the ways of determining the environmental burdens of a product is the assessment of its environmental profile. The assessment of the environmental profile of a product can be done using life cycle assessment (LCA) [4, 5, 6]. LCA study is usually carried out to determine the potential impacts that a product generates across its life cycle [7, 8, 9]. Furthermore, as shown by Plouffe et al. [10] LCA is one of the tools most commonly used to develop products which are economical and environmentally friendly.

Since the first utility poles LCA study, carried out by Erlandsson et al. [11], there have been a number of LCA studies of utility poles, but none of these studies included the developing countries [12]. So, because LCA approach is widely spread in the world and is still in its beginning in Africa [13], and because of the potential for different LCA results from different areas, a utility pole LCA specific to developing countries has been found imperative in order to develop local sustainable indicators in wood pole production, use, and end-of-use.

By taking Cameroon as an experimental case, this study was conducted based on the following three specific questions: (i) which environmental emissions can be associated with the wood utility pole industry in the context of developing countries? ii) What kind of environmental impacts can be recorded across the wood pole' life cycle? (iii) In which wood utility pole life-cycle stage do these impacts account the biggest?

The goal of the study was then to document the gate-to-grave LCA of eucalypt wooden utility poles used in the Cameroonian power distribution lines in order to gain a solid understanding of the environmental issues associated with the processes of using wood poles, and to provide wood utility pole related LCA data in a context of developing countries. The outputs of this study were mainly intended for use by Cameroonian policy and electric utility decision-makers. Researchers and LCA practitioners were equally concerned since this study could serve as a benchmark to the wood utility pole-related LCA studies of other third world countries.

The paper begins with the description of the methodology that sustains this LCA study. LCA results according to our three specific research questions are then provided and discussed. The paper is concluded with the presentation of limitations, and how this research can be taken forward to make the paper richer.

2. Materials And Methods

Life cycle assessment (LCA) is a standardized [14] and well established method to assess, and improve our understanding of possible impacts associated with the manufacturing of a product. In fact, LCA establishes a link between energy and material flow related with the life cycle of a product and the associated potential environmental burdens [15]. As such, it allows, for a given product, to highlight the stages of its life cycle which have high environmental burden.

2.1 Goal and scope

2.1.1 Goal

This gate-to-grave LCA study has been initiated to assess the environmental impacts of eucalypt wooden utility poles used in the Cameroonian low and medium voltage power transmission lines. Therefore the intended applications of the study were (i) to gain a solid understanding of the environmental issues associated with the operations performed by electric utility on wood poles during their life cycle stages, and (ii) to provide data from developing countries to wood utility pole related LCA field of study. The outputs of the study are mainly intended for use by Cameroonian investors, policy and electric utility decision-makers in order to assist and facilitate a better environmental management and communication with third parties. Researchers and LCA practitioners are equally concerned since the study can serve as benchmark to other wood utility pole related LCA studies conducted in developing countries.

2.1.2. Functional unit

The choice of functional unit (FU) is fundamental in LCA study since FU provides a reference to which the inputs and outputs are referred [14]. In power pole related LCA studies, three types of FU are often used: (i) a mass or volume based FU defined by a certain mass or volume of primary raw material used in poles manufacture, (ii) a unitary FU defined by a unitary pole, and (iii) a grid-based FU defined by a certain number of poles in a delimited network region for a specific period of time [12]. In an extensive literature search, Nimpa et al. [12] showed that, by far most LCA utility pole practitioners' use a unitary FU since this indicates the numerical representation of the functions provided by the wood pole, which can be used in comparison with alternative materials delivering the same function. So, in this study, the functional unit considered was a unitary FU and defined as: one 9 m eucalypt pole processed and used in power distribution line with a lifetime of 30 years.

2.1.3. Description of the system under study

This paper focuses on eucalypt wood pole since this is the main raw material for the manufacture of wooden utility poles in Cameroon. High-quality power poles are obtained from eucalypt wood [16]. Eucalypt, a fast growing specie, is highly productive and is easily adaptable to low-fertility soils. Eucalypt wooden poles used in the Cameroonian power distribution lines originate from tropical moist agroforestry plantations in Western and North-western regions of Cameroon. The received tree trunks at the electric utility park gate are mature and apparently flawless. The processing of these tree trunks in order to be used as utility poles meets the technical specifications of UPDEA (French acronym of union of producers, transporters and distributors of electric power in Africa) standards [17]. While utility poles can range anywhere from 8 meters to 15 meters, depending on their final use, an approximate median size pole that is used in this LCA as the representative pole is a 9 m long pole since most in-service poles are around 9 m tall. Because they are embedded in the soil, exertions due to tensile strength of the cables and the effects of wind, networked poles are either implanted as single or doubled poles which work permanently in bending. A study carried out by Njankouo et al. [16] on technological enhancement of the eucalypt wood showed that the mechanical properties of eucalypt wooden poles respond well to these movements. So, as observed on the field, wood poles are very robust and allow for overhead wires to be attached in a variety of ways. Once processed, networked eucalypt poles can remain in service for about 30 years if they are inspected and maintained properly [18].

The eucalypt power pole operations have been assessed from gate (tree trunks received at the park gate) to grave (discarded poles disposal) perspective. Thus, the prior forest operations which yield eucalypt timbers and their transportation up to utility pole park gate have been excluded from the assessment since the aim of the study was to track environmental impacts generated by eucalypt power pole operations under responsibility of utility pole company. Correspondingly, the production of chemical wood preservatives as well as their transportation up to the main Cameroonian commercial harbor (located in Douala the economical capital of the country) has also been excluded from the system boundaries. These exclusions are in accordance with the requirements of performing an environmental profile of a product [19]. These requirements propose, among others, to take into account only the product life cycle stages which are directly under the responsibility of the producing company.

The proposed operation system of eucalypt power poles has been divided into four main phases:

2.1.3.1. Phase 1: poles shaping

The shaping stage is the set of operations that transform eucalypt tree trunks already pealed into raw poles ready for treatment. It takes place at the wooden pole park. This stage begins with the pole mover which offloads trucks coming from the forests carrying tree trunks. Offloaded poles are sprawled on previously arranged pole rack raised from the ground. Fuel-fired chainsaws are used to cut the ends of the tree trunks and surface defects for the purpose of giving them the convenient dimensions. The poles are then marked with paint and their structural stability is ensured by fittings in forms of S attached to the bottom of the poles and a strip which is strapped round the head of the pole. The pole mover sorts poles and stores them by category under shelters for drying in the open air. The fate of pieces of wood of 0.20 m to 1.30 m obtained after the dimensional standard of raw poles is not included within the boundaries of the system. However, smaller dimensions of wood and sawdust are modeled as non-treated solid waste.

2.1.3.2. Phase 2: poles treatment

The wood poles treatment stage takes place in the factory of the utility pole company (treating facility), located at about 10 km to the wood park. The handling of poles, similar to what is observed at the wood pole park, consists of offloading trailers coming from the shaping site and classifying them. Then, untreated wood poles are loaded onto small rails or trams cars (bogies) that are pushed into the cylinder (pressure tank) using forklift trucks. Once in pressure tanks, tanalith solution (CBA) is applied to the wood poles through a pressure treating process. This batch process involves applying a vacuum to the wood to remove trapped air, and then introducing the CBA solution under high pressure. The vacuum step facilitates the pressurized penetration and incorporation of the CBA solution into the cellular structure of the wood pole. In current formulation, CBA (tanalith E 3485) solution has a relative mass of 1.3, and is a water-based formulation containing copper carbonate hydroxide (22.5% w/w) i.e. 12.9% copper, boric acid (5% w/w) i.e. 0.65% boron, tebuconazole (0.5% w/w), and monoethyleneamine (30% w/w) an amine derivative associated to copper to prevent heavy metal leaching. Copper, tebuconazole, and boric acid act as both insecticide and fungicide. Each impregnation poles cycle in the pressure tank lasts approximately 240 minutes and two pressure tanks can treat a maximum of 120 poles per cycle. After one cycle of treatment, the charges are removed from the pressure tank and treated poles are classified in shelters for drying prior to transportation to the 15 stores of the national utility pole company.

2.1.3.3. Phase 3: poles in-service

The wood poles in-service life stage begins with the transportation of these poles from the company stores to their networking site. This stage is made up of a ten-year inspection program. These inspections are to verify the structure of the poles in order to assess their state of biological decay. Once poles have been spent about 30 years in network, most of them which have become defective are removed from the network and brought to the wood park. The different activities carried out to fulfill these requirements are the main actions undertaken during this phase of pole life cycle.

2.1.3.4. Phase 4: poles disposal

The concluding step in the life cycle of a wood utility pole is disposal at the end of its operating life at the national utility company wood park. Damaged parts of these decommissioned poles are cut off and kept for disposal on open air; the parts in good state are reclaimed for other purposes (out of the scope of this study). Once in the open air, the chemicals in the preservatives eventually leach into the soil and ground water; releases during these processes are considered through leaching models. These externalities are very significant and are addressed in this study.

In addition to these four considered stages, ancillary activities such as haulage, and transportation of workers were also taken into account and computed within the system boundaries. Since transportation has not been considered as a wood pole life stage, emissions derived from transportation have been included to the concerned stages as described above. The investigated system is illustrated in Fig. 1.

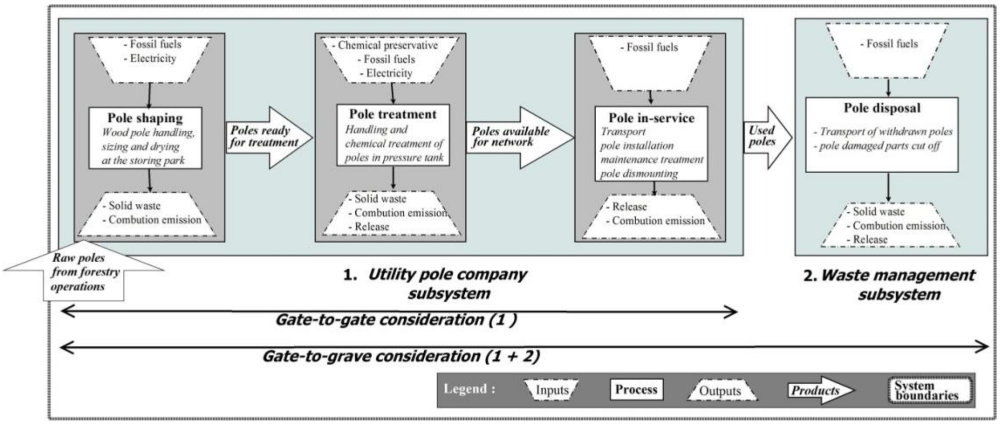


Fig. 1: Flow diagram with the stages necessary to describe wooden utility poles LCA.

2.1.4. Selected impact categories and methodology of impact assessment.

Choosing LCA methodologies and impacts of interest are strongly connected to the goals of the study. Moreover, it is well known that the list of selected impact categories has to comply with internationally accepted practice [20]. But, as stated by Eshun et al., [21] most life cycle impact assessment (LCIA) approaches in LCA developed for western countries and their specific environmental problems have become the “standard list” of impact categories included in most LCAs. Consequently, the methodologies for characterizing those potential impacts are based on how these problems manifest themselves in those developed countries. In addition, their “standard problem list” and the characterization methodologies for different impact categories may not be necessarily relevant to developing countries’ environmental conditions and particularly not for the timber and power utility poles sectors in Cameroon. For these reasons, the decision to assess an impact category in this study has been based on the proposals both formulated by the preceding cited author [21], and by Nimpa et al. [12] who conducted an extensive power utility poles literature review and pointed out the most relevant and assessed impact categories in utility pole related LCA studies. So, impact categories cited below have been found relevant to fit the aim of our study and are briefly and qualitatively described according to Jawjit et al. [22].

2.1.4.1. Global warming (GW)

Global warming is the effect of increasing temperature in the lower atmosphere. The lower atmosphere is normally heated by incoming radiation from the outer atmosphere (from the sun). A part of the radiation is normally reflected by the soil surface but the content of carbon dioxide (CO_2) and other “greenhouse” gases (e.g. methane (CH_4), nitrous oxide (N_2O), etc.) in the atmosphere absorb the Infra Red-radiation. This results to the greenhouse effect. Greenhouse gases, which are the main pollutants contributing to the global warming problem, are expressed as GWP (global warming potentials). The combustion of fuels in the various poles processes is one source of these gases. Global warming is calculated in this study as kilograms of CO_2 equivalents.

2.1.4.2. Acidification (A)

Acidification is an impact category mainly owing to the emission of acidifying substances, which causes important effects in the soil, groundwater, ecosystems and materials. Sulphur dioxide (SO_2) and nitrogen oxides (NOx) emitted into the air are spread in the atmosphere which, when combined with other substances in the atmosphere, turn into acids. These compounds reach the earth’s surface as rain or fog. The combustion of fuel in activities related to wood pole life cycle is the main source of SO_2 and NOx emissions. Acidification is calculated in this study as kilograms of SO_2 equivalents.

2.1.4.3. Photochemical oxidant (PO)

Photochemical ozone formation is caused by the degradation of volatile organic compounds (VOC) in the presence of light and nitrogen oxide (NO_x): “smog” (as a local impact) and “tropospheric ozone”,(as a regional impact). The amount of ozone formed depends mainly on the amount of nitrogen oxides and organic compounds in the atmosphere. The emission of VOCs, CO, CH_4 and NOx, which are considered to be tropospheric ozone precursors are caused by combustion of fuel during the pole shaping and treating process, and transportation of wood poles. Photochemical oxidant formation is calculated in this study as kilograms of C_2H_4 equivalents.

2.1.4.4. Ecotoxicity

The ecotoxicity impact category refers to the impact of toxic substances on various ecosystems and includes ecologically toxic constituents released to the soil during the wood pole life cycle stages. The main considered substances in this study are heavy metals, such as copper. Ecological toxicity is calculated in this study as kilograms of 1,4-DB (1,4-dichlorobenzeen) equivalents.

2.1.4.5. Solid waste (SW)

This impact category expresses the quantity of waste generated over the wood pole life cycle. The calculation of this impact category has been done considering both treated and untreated waste. Treated waste consists of waste oil filters, waste fuel filters, waste air filters, waste batteries, waste tires, florescent light bulbs, oily rags, oily absorbent pads, contaminated soil and residual mud from tanks. Untreated waste consists of wood waste off-cut (low dimension of sawn wood and the remains of unusable decommissioned poles). Solid waste is calculated in this study as kilograms of generated solid waste.

Considered LCIA methodology is documented below in the life cycle inventory (LCI) section.

2.2 LCI

LCI involves the collection and computation of data to quantify relevant inputs and outputs of a product system, including the use of resources and emissions to air, water and soil associated with the system [14]. These data are derived from the activities related to system boundary as described in the scope (section 2.1.3.). In addition, knowing that wood density changes as a function of moisture content and because poles are measured and the class and length are determined when they are green (prior to drying and treatment), the LCI calculations were done assuming the green basis wood density.

2.2.1. Data collection procedure

The main activities performed in the utility pole company subsystem and waste management subsystem have been presented in Fig. 1. LCI for these activities focused on the material use, energy use, and emissions of pollutants.

Various transportation related to the poles life cycle (from wood park to pole factory, from pole factory to utility yard, from utility yard to onsite installation, removal return to yard, and within a single life stage,) have been assumed as follows: 42-ton semi-trailers carry the poles from the park to the factory (10 km), delivering poles in 15 company stores (5400 km aggregate), carrying chemical preservative products from its delivery place to the factory (about 270 km), 28-ton trucks carry some solid waste from the factory to the treatment site (about 270 km). Empty return journey of semi-trailers and trucks have not been considered since in this stage they often carry other company materials without direct relation to the wood poles life cycle. A light truck and trailer for transporting six to eight wooden poles from each company store to the landscape site at a distance of 32 km was assumed.

Emission estimates for various transports were based on fuel use quantity per traveling distance (l/km). Traveling distances were established through interviews with wood pole plant managers and truck drivers. The calculation of fuel consumption applied to the LCI of the transport stage was made with 70 liters of diesel per 100 km, and 13 liters of gasoline per 100 km. Lubricants have been estimated based on utility pole company reports.

The pole initial preservative retention rate, which refers to the amount of chemical preservative that remains in the wood after the treatment process is complete, is 8.05 kg active ingredients per cubic meter of wood, i.e. 1kg/m^3 copper, as outlined by the national electric utility company through its wood poles processing plant. Quantification of copper in the runoff from CBA-treated wood poles have been estimated based on studies done by Thaler and Humar [23] at the rate of 6% of the impregnated copper leached from treated wood pole within the first three weeks after the treatment. In addition, the impregnated wood pole lost 15% of its infused copper within the following six months (178 days) of exposure, and only lost an additional 2% in the subsequent five months (158 days). Afterwards, copper leaching became insignificant. Based on a 30-year service life, approximately 36% of the initial copper retention is released to the ground over the pole service life.

At the end of service life stage, poles may have recycling value as treated wood, such as for use as fence posts or landscaping or as fuel to produce process heat. In this study, it is considered that national utility company simply dispose of the decayed underground parts of used poles (about 10% of the pole length + one meter) as solid waste in landfill. So, offcut pole disposition, as modeled in this LCI, is based on the assumption that CBA not leached during pole life will gradually be released from poles to the ground.

In addition, knowing that discarded poles are maintained as unmanaged piles of wood residuals that are not intentionally composted, released gases resulting from this process have been estimated considering that discarded wood landfilled or abandoned in nature has the potential of releasing carbon into the atmosphere as methane and carbon dioxide, as assessed by Micales and Skog [24].

Since dimensions and classes of the wood poles are variables, collected data have been calculated on the basis of a set of wood poles with the individual characteristic of 9 m height with an average volume of 0.28 m^3 and an average weight of 255 kg. These categories of poles represent 44.19% of wood poles annually manufactured by the national electric power utility company [25]. So, data related to the above described activities have been firstly compiled with regard to 5610 wood poles representing the average monthly pole production of the year 2013 in order to facilitate the data collection. Once compiled, the inventory data have been converted to a per pole functional unit in the same way as Bolin and Smith [3]. Collected operation data have been synthesized in Table 1.

Table 1: Activity data per FU for the calculation of emissions from eucalypt power poles in Cameroon.

Life stage	Units	Value	Life stage	Units	Value
Shaping			**Disposal**		
Input			Input		
Diesel	kg	1.8131	Diesel	kg	2.8364
Gasoline	kg	0.0820	Gasoline	kg	0.0831
Lubricant	kg	0.0110	Lubricant	kg	0.1746
Electricity	kWh	0.1878	Wood disposed as waste	kg	53.833
Output			Output		
Wood off cut	kg	6.3751	Waste wood	kg	53.833
Solid waste to be treated	kg	0.0820	Solid waste to be treated	kg	0.0627
Treatment			Leaching from waste wood	kg	0.0378
Input			**Various transportation**		
Raw pole	kg	255	Raw poles' transport		
Raw pole	m^3	0.28	Diesel	kg	0.0706
Copper infused in pole	kg	0.28	Lubricant	kg	0.0047
Diesel	kg	1.4918	Wood preservative' transport		
Lubricant	kg	0.0123	Diesel	kg	0.0758
Electricity	kWh	0.5686	Lubricant	kg	0.0048
Output			Workers' transport		
Solid waste	kg	0.2751	Gasoline	kg	0.6067
Copper released	kg	0.0168	Lubricant	kg	0.0083
In-service			Treated poles' transport		
Input			Diesel	kg	7.1632
Diesel	kg	0.1774	Lubricant	kg	0.4730
Gasoline	kg	0.0002	Transportation of solid waste to be treated		
Lubricant	kg	0.0118			
Output			Diesel	kg	0.0137
Solid waste	kg	0.0482	Lubricant	kg	0.0009
Copper released	kg	0.0840			

2.2.2. Emission inventory calculation

Emission inventory data are calculated using emission factors which are predefined values that are used to estimate emissions to the environment. Emission factors relate the quantity of substances emitted from a source to some common activity associated with those emissions. In the Cameroonian context, there were no available emission inventory data. Therefore, as suggested by Jawjit [22] and later applied in developing countries' context by Eshun et al [26], all emissions were calculated as a function of production activities and the emission factors using the following Equation (1):

$$\text{Emission} = \text{Activity x Emission Factor} \quad (1)$$

As presented in section 2.1.4., we took into account five impact categories. The emissions related to these impacts include CO_2, CH_4 and N_2O (global warming), SO_2 and NOx (acidification), non-methane (NM)VOCs, CO, CH_4, and NOx (smog). Data related to the production of waste were directly acquired from utility pole company reports. With regard to emissions derived from performed activities, emission factors used in Equation 1 and summarized in Table 2 have been adapted from Eshun et al [26]. In Eshun et al. study, information was taken from different sources (literature data, on-field data and simulations) and was considered to be the best available data which fit the developing countries status. As far as ecotoxicity is concerned, the copper emission has been modeled as presented above in section 2.2.1.

Table 2: Emission factors used for the calculation of the emission in power pole sytems in Cameroon

Activity area	Compound emitted	Emission factor	Unit	Reference
Diesel used for pole shaping, treatment, in-service, disposal, and transportation	CO_2	3150.00	g/kg fuel	[27]
	CO	15.00	g/kg fuel	[28]
	N_2O	0.02	g/kg fuel	[27]
	CH_4	6.01	g/kg fuel	[27]
	NOx	50.00	g/kg fuel	[28]
	NMVOC	6.50	g/kg fuel	[28]
	SO_2	20.00	g/kg fuel	[28]
Electricity[a] used in pole park and pole treatment factory	CO_2	0.239547303	kg/kWh	[29]
	N_2O	0.000007167	kg/kWh	[29]
	CH_4	0.000001238	kg/kWh	[29]
Gasoline used for workers transportation	CO_2	3172.31	g/kg fuel	[28]
	CO	64.77	g/kg fuel	[28]
	N_2O	0.453	g/kg fuel	[28]
	CH_4	0.9	g/kg fuel	[28]
	NOx	9.76	g/kg fuel	[28]
	NMVOC	42.09	g/kg fuel	[28]
Lubricant used in heavy duty vehicles and light duty vehicles	CO_2	2946.66	g/kg fuel	[30]
	N_2O	0.02412	g/kg fuel	[30]
	CH_4	0.402	g/kg fuel	[30]
Released gases from disposed poles	CO_2	0.024	g/g of wood	[24]
	CH_4	0.013	g/g of wood	[24]
[a]Related emission factors are specific to Cameroon				

2.2.3. Impact categories calculation

Results for category indicators or potential environmental impacts are usually calculated by accumulating the products of the individual emission inventory data multiplied by its characterization factors for the given impact category as shown in Equation 2 [31]:

$$I_j = \sum_i E_i \, CF_{j,i} \qquad (2)$$

Where I_j is the j impact indicator, E_i the amount of the emitted compound i (emission) and $CF_{j,i}$ the j characterization factor of the compound i.

Characterization factors represent the potential of a single emission or resource consumption to contribute to a given impact category [20]. The characterization factors used in the calculation of considered impact indicators have been summarized in Table 3.

Table 3: Characterization factor applied to the wood utility pole sector of Cameroon

Impact category	Scale	Compound	Characterization factor	Reference
Global warming	Global	Carbon dioxide (CO_2)	1kg = 1kg CO_2-eq	[28]
		Methane (CH_4)	1kg = 21kg CO_2-eq	[28]
		Nitrous oxide (N_2O)	1kg = 310kg CO_2-eq	[28]
Acidification	Regional	Sulfure dioxide (SO_2)	1kg = 1kg SO_2-eq	[32]
		Nitrogen oxide (NO_X)	1kg = 0.71kg SO_2-eq	[32]
Photochemical smog	Local	Non-methane hydrocarbon (NMVOC)	1kg = 0.416kg C_2H_4-eq	[33]
		Carbon mono-oxide (CO)	1kg = 0.0276kg C_2H_4-eq	[33]
		Methane (CH4)	1kg = 0.006kg C_2H_4-eq	[33]
		Nitrogen oxide (NO_X)	1kg = 0.028kg C_2H_4-eq	[33]
Ecotoxicity	Local	Copper (Cu)	1kg = 14.4kg 1,4-DB-eq	[34]
Solid waste	Local	Quantity of solid waste generated	Kg of solide waste produced	[35]

3. Results And Discussion

To assess and discuss the processes that result to environmental impact from CBA-treated eucalypt utility poles, impact indicator values are added for the entire life cycle stages. The impact indicator values at each of the four life cycle stages and a total for the gate-to-grave life cycle of CBA-treated eucalypt pole are reported below in respective sections. But before that, the environmental emissions resulted from LCI is presented.

3.1. Environmental Emissions

This study took into account emissions contributing to global warming, acidification, smog, ecotoxicity and solid waste. The results of emission calculations as presented above in section 2.2.2. have been expressed in kg of pollutant either emitted or generated from a product line of the wooden utility pole per functional unit and summarized on Table 4.

Table 4: Process emissions (kg/FU) for the life stages of wood utility pole in the Cameroonian context

Compound	Shaping	Treatment	In-Service	Disposal	Total
CO_2	8.2347923	29.0828101	0.5946054	11.0516606	48.9638683
N_2O	0.0003516	0.0001905	0.0000039	0.0000989	0.0006450
CH_4	0.0119514	0.0526705	0.0010716	0.7171087	0.7828021
CO	0.0728656	0.1309636	0.0026785	0.0481421	0.2546497
NMVOC	0.0412330	0.0567509	0.0011642	0.0220283	0.1211764
NOx	0.1009121	0.4365452	0.0088760	0.1433234	0.6896567
SO_2	0.0376761	0.1746181	0.0035494	0.0570045	0.2728481
Cu	0.0000000	0.0168000	0.0840000	0.0378311	0.1386311
Solid waste	6.4570707	0.2751783	0.0482769	53.8960933	60.6766191

According to the results, life stage operations together with the production and combustion of fuels generate a range of air emissions and soil damages (Table 4). CO_2 is the largest emitter from each process stage. In addition, to the total air emissions released for eucalypt pole gate-to-grave life cycle (51.08 kg/FU) more than half (58.6%) was generated in the treatment-related processes.

It can also be useful to examine those emissions attributed only to the on-site activities related to gate-to-grave eucalypt power pole. Output data for site-generated emissions are provided in Table 5. Emissions generated by the direct production, use and disposal of eucalypt power pole through each unit process and the combustion emissions of the various fuels used (diesel, gasoline, and lubricant) were included. Not included are those emissions released by transportation. This allows pointing out transport as one of the main hot spots owing to its major contribution to almost all the environmental emissions under study. In fact, by comparing total air emissions from Table 4 with that of Table 5 (15.03 kg), it is noticeable that around 70% of total air emissions are due to the various transportations involved in eucalypt gate-to-grave-related activities. This particular state of affairs has important consequences on impact indicator as it is shown hereunder.

Table 5: Considered on-site process emissions (kg/FU)

Compound	Shaping	Treatment	In-Service	Disposal	Total
CO_2	6.0489150	4.8717594	0.0743257	2.9522227	13.9472228
N_2O	0.0000750	0.0000342	0.0000005	0.0000573	0.0001671
CH_4	0.0109753	0.0089715	0.0001339	0.7023870	0.7224678
CO	0.0325081	0.0223774	0.0003348	0.0131152	0.0683355
NMVOC	0.0152367	0.0096969	0.0001455	0.0071977	0.0322769
NOx	0.0914563	0.0745914	0.0011095	0.0214541	0.1886113
SO_2	0.0362624	0.0298366	0.0004437	0.0081600	0.0747026
Cu	0.0000000	0.0168000	0.0840000	0.0378311	0.1386311
Solid waste	6.3750000	0.1834522	0.0000000	53.8333333	60.3917855

In consideration of other LCA studies performed in developing countries (Jawjit et al., 2006; Eshun et al., 2010, 2011a, 2011b, 2013) it can be argued that all of the data used in the present study to quantify the emissions and environmental impact was considered to be the best data available. However, the calculated emissions were subject to uncertainty. But, a sensitivity or uncertainty analyses to assess the sensitivity of the calculated emissions, including uncertainties in the assumptions and method used have not been carried out in this study. The characterization factors used, such as global warming potentials, acidifying and ecotoxicity potentials also were subject to uncertainties because these values were not developed on Cameroon-based data, although global warming potentials are commonly used and accepted as characterization factor for greenhouse gases [28]. Despite these limitations the estimated emission presented above and environmental impact presented here below may be the best available data at the present time and, therefore, they served the purpose of this study.

3.2. Environmental impacts

In the scenario where transports are taken into consideration, the impact indicator values at each of the four life cycle stages, and a total for the gate-to-grave life cycle of CBA-treated utility poles, are summarized in Table 6.

Table 6: CBA-treated utility poles' environmental impacts per FU and by life cycle stage

Impact categories	Units	Life cycle stage				CBA pole
		Shaping	Treatment	In-Service	Disposal	gate-to-grave
Global Warming	kg CO_2-eq	8.59476	30.2479	0.61833	26.14161	65.60265
Acidification	kg SO_2-eq	0.10932	0.48456	0.00985	0.158764	0.762504
Photochemical oxidant	kg C_2H_4-eq	0.02177	0.03934	0.00080	0.018647	0.080565
Ecotoxicity	kg 1,4-DB-eq	0.00000	0.24192	1.2096	0.544768	1.996288
Solid waste	kg	6.45707	0.27517	0.04827	53.89609	60.67661

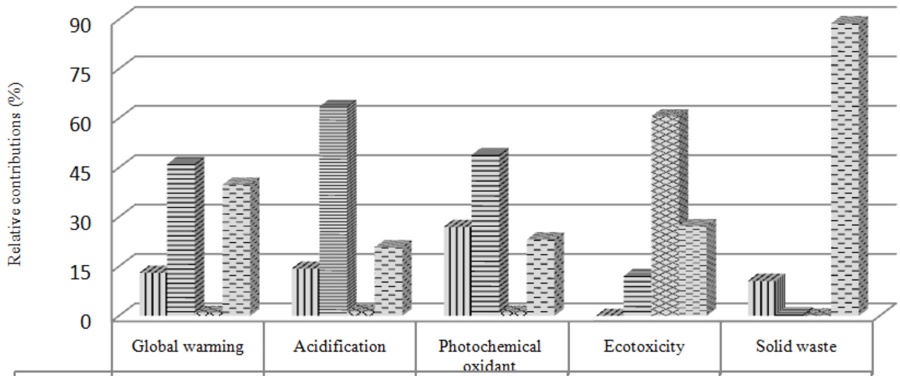
Since the magnitude of all the above underlined impact categories were expressed in different units and therefore cannot be directly reported in a single figure, a simple approach to see what processes have the greatest impact can be accomplished by inspecting the relative contributions as shown in Fig. 2

3.2.1. Global warming

In this eucalypt power pole LCA, namely in the scenario where transports are taken into consideration, treatment and final disposal operations were identified as the main life stages responsible for emissions that contribute to global warming, followed by shaping operations as illustrated in Fig. 2. CO_2 emissions dominate the contributions to global warming (98.4%), followed by CH_4 (1.5%). The N_2O contribution is unimportant to be worth considering. The gate-to-grave global warming due to utility pole related operations has been estimated to 65.60 kg CO_2-eq per pole. Despite the differences of study conditions, namely the countries, the tree species, the management practices, the aims, the allocation procedures, the assumptions, and the system boundaries; this value can be considered in a range with those of other utility pole LCAs.

In fact, Kunninger et al. [36] reported for copper chromium florine (CCF) and copper chromium boron (CCB) treated wood poles in Switzerland's context values of 29.5 kg CO_2-eq per 11m pole and 33.5 kg CO_2-eq per 11m pole respectively. More recently, Bolin and Smith [3] in USA's context reported for pentachlorophenol treated wood pole a value of 73.6 kg CO_2-eq per 13.7m pole. However, it should be noted that these two above cited studies were conducted in cradle-to-grave perspective while the present excluded cradle stage or forestry operations which certainly would have increased the total value of global warming.

In the on-site emission scenario (Table 5), shaping operations contribute the most to total global warming followed by treatment and disposal operations. Whatever be the considered scenario, one can note that, the contribution of the in-service life stage operations to the global warming is the least compared with the other life stage contributions.



	Global warming	Acidification	Photochemical oxidant	Ecotoxicity	Solid waste
Shaping	13	14	27	0	11
Treatment	46	64	49	12	0
In-Service	1	1	1	61	0
Disposal	40	21	23	27	89

Fig. 2:Analysis of contributions per life stage in impact categories under study

3.2.2. Acidification

The total per pole acidifying emissions from SO_2 and NOx were calculated to be 0.762 kg SO_2-equivalents (Table 6). As it has been the case to the global warming, treatment and final disposal operations were identified as the main life stages responsible for emissions that contribute to this impact category, adding up to 78%. Shaping operations make up almost the remaining 21% (Fig. 2). The in-service life stage exhibits only a very small contribution (1%) since there is a small NOx emission from fuel use. NOx emissions are the main acidifying emissions in all life stage operations under study and represent more than 71% of total emissions.

3.2.3. Photochemical oxidant formation

Photochemical oxidant emissions are closely related to fuel use due to the fact that this impact category is affected by hydrocarbon emissions associated to the incomplete combustion of fossil fuels. In this impact category, the treatment operations subsystem is the most important contributor and its contribution adds to 49% of the total, followed by shaping and final disposal operations (Fig. 2). On the contrary, in-service has the lowest impact due to the lower fuel use and can, in fact, be considered negligible with respect to this environmental problem (Table 1). The total emissions of tropospheric ozone precursor compounds have been determined to be about 0.0805 kg ethylene-eq/pole (Table 6). Among the four main components of tropospheric ozone precursors – NMVOC, CO, CH_4 and NOx – it has been found that NMVOC is the main contributor and accounts for almost half of the present impact category score in terms of C_2H_4-equivalent although it ranged at the last position while considering the emission values (Table 4).

3.2.4. Ecotoxicity

The total emissions of ecotoxicity compounds are about 2 kg 1,4-DB-eq/pole (Table 6). In general, this impact category assesses the toxicity derived from chemicals (mainly metals) at terrestrial, marine and freshwater levels. In the case of the terrestrial ecotoxicity, as it has been considered in this study, both in-service and final disposal stages are the main contributors with a respective contribution of 61% and 27%. Contrary to the other assessed impact categories, it is shown that only this impact category points out the in-service life cycle stage as a significant impact bearer throughout the CBA-treated wood pole life cycle. Since the issue of assessing leaching from treated timber is a very complex subject, Aston [37] urged a certain degree of caution when drawing conclusions from leaching studies. So it should be noticed that the present ecotoxicity result must be taken with caution since it is based on a developed country leaching scenario which has been conducted with different pole species, in different climatic conditions [23], and which could not be suitable to both eucalypt specie and local climatic conditions.

3.2.5. Solid waste

The results of solid waste generation from eucalypt pole life cycle were derived directly from Utility park and factory data. The gate-to-grave solid waste generated was equal to 60.67 kg/pole. It has been found that almost all the solid waste have been generated in the final disposal stage (89%), and both treatment and in-service life stages were not really impacted by solid waste. In addition it has been shown that waste wood stands as the main contributor to this impact category (Table 1). By considering landfill as the only final disposal scenario of waste wood, this study went against conclusion drawn by Erlandsson [38] who considered landfill as a much worse alternative for dealing with used treated pole given that there is bound energy in the pole which is lost when sent to the landfill. At this level, it is important to remind that in our final disposal scenario not the entire removed poles were disposed of in landfills, but only damaged portions. Portions in good state were recycled as fence posts or landscaping; however related activities have been considered out of the system boundary under study. In consideration of other utility pole-related LCA studies, the final disposition of wood poles, have been identified as a recurrent issue since there were a great variety of chemical preservatives used to protect wood poles against biological decay [12]. Different scenarios to manage the end-of-use of treated wood poles have been implemented knowing that used poles can be disposed in landfill as waste, incinerated as fuel to produce process heat, or recycled as fence posts or landscaping. The chosen options in this study were consistent with what is observed on the field regardless of the country’s legislation.

4. Conclusion

The life-cycle assessment reported in this study is the first to profile wooden utility poles for power distribution lines in a developing country. In addition, the study is presented as one of the ground works in the field of LCA for wood-based products in Cameroon. Two main objectives were proposed in this study: provide data from developing countries to wood utility pole related LCA field of study; assess the environmental impacts of eucalypt wooden utility pole as a decision making indicator in the ecodesign process and communication with third parties. So, this CBA-treated wood poles study has been conducted in gate-to-grave perspective and the emission sources of environmental pressure intrinsic of the wood utility pole industry in Cameroon have been identified for five environmental problems: global warming, acidification, photochemical ozone formation, ecotoxicity, and production of waste. According to the environmental results obtained, the following conclusions can be pointed out.

- LCI data for developing countries with regard to wood utility pole industry were as to yet limitedly available. Thus, in spite of the fact that this study was based both on Cameroonian experience and on worldwide used primary emission data, it yielded good quality data unique to power pole LCA research in third world.

- With regard to assessed impact categories and considered life cycle stages, the following scores of 65.60 kg CO_2-eq for global warming, 0.76 kg SO_2-eq for acidification, 0.08 kg C_2H_4-eq for photochemical ozone formation, 2.00 kg 1,4-DB-eq, for ecotoxicity, and 60,67 kg for solid waste have been recorded as values of environmental profile characterization of a wood utility pole.
- It has been found that enormous amounts of wood wastes are generated and sent to landfills in the final disposal life stage due to the waste management policy adopted by the national electric utility company.
- Operations related to the wood pole treatment have been identified as the most environmentally harmful with regard to global warming, acidification, and photochemical ozone formation, while in-service and final disposal life stages recorded the highest values in ecotocixity and solid waste respectively.
- The combustion of fuels, both in on-site activities and in pole transportation between life stages, has been found to be the most important source of pollution related to greenhouse gases, smog precursors and acidification compounds, with CO_2, NMVOC, and NOx being the most important pollutants, respectively.
- Ecotoxicity has been assessed as releasing copper from CBA-treated poles; but the related findings were based on European databases which use different wood species and where climatic conditions are different. So it has been recommended that results obtained should be taken with caution.

This LCA study suffers from a number of limitations. In particular, due to its aim (assessing only environmental burdens associated with operations under the main national electric utility control), we have limited ourselves to the gate-to-grave life stages by excluding an important life stage which allows a complete wood pole environmental profile: eucalypt forestry operations. To overcome this limitation, we plan to extend the scope of this study, not only to assess the real environmental profile of CBA-treated utility poles with regard to all the existing life stages, but also to take into account, in a comparative point of view, the two other pole materials, steel and concrete, which are traditionally used in developing countries; hoping that one could reach meaningful conclusions in favor or against using one sort of pole material. In addition, data quality analyses as recommended by ISO 14044 and which involved gravity analysis, uncertainty analysis and sensitivity analysis have not been performed in this study. Knowing that addressing data quality, namely uncertainty, is among the greatest of the grand challenges, not only for utility poles LCA, but for other LCA, this issue will be considered with interest in our scope extending future utility pole-related LCA studies.

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