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Forest Operations for Power Poles under Cradle-to-Gate Life Cycle Assessment Perspective

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ABSTRACT
Eucalyptus is obviously one of the most widely used tree species for electricity distribution in central Africa. Forest operations to obtain these electric poles are not without impact on the environment. With increasing focus on the environmental impacts of land use and materials, there is a growing need to produce accurate and verifiable life cycle data for forestry. This article therefore deals with the cradle-to-gate life-cycle assesment (LCA) of forest operations in order to obtain wooden utility poles used in the overhead power lines. It focuses on eucalyptus silviculture divided into four phases: nursery, forest growth, harvesting and transportation. West and Northwest Regions of Cameroon, where this tree species grows preferentially, were taken as the case study. Primary data on forest operations were collected both from the owners of nurseries and plantations and from the company in charge of the electricity distribution while emissions data were taken from literature. The environmental impact was analysed in terms of five impact categories. With regard to assessed impact categories, the following scores of 10.40 kg CO_2-eq for global warming, 0.15 kg SO_2-eq for acidification, 0.018 kg C_2H_4-eq for photochemical ozone formation, 0.19 kg 1,4-DB-eq for ecotoxicity, and 0.02 kg PO_4^{3-} for eutrophication have been recorded as values of a functional unit. Furthermore, activities related to the transportation have been identified as the most environmentally harmful with regard to global warming, acidification, photochemical ozone formation and eutrophication, while forest growth life stage recorded the highest values in ecotoxicity. The results suggested that fuel consumption in forest activities should be optimised in order to decrease effectively the environmental impacts and make these activities cleaner.

***Keywords* -** Cameroon, Environmental impact, Eucalyptus silviculture, Life cycle assessment, Wood utility pole.

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I. INTRODUCTION

Although the introduction of Eucalyptus in Cameroon dates from 1920 [1], Njoukam [2] specifies that it is from 1930 that Eucalyptus plantation programs established on significant surfaces started. The plantations were established by colonial government to contribute to the fiht against desert encroachment in the Northen part of Cameroon, to assist in the fiancial empowerment of the local populations of Western and Northwestern parts by putting at their disposal land for agricultural activities that generate revenue for their wellbeing and local development.

Later, their management objective was realigned to provide fuel wood, sawn timber, and above all, raw poles to the electricity supply company. In fact, thanks to the introduction in 1962 of wooden poles taken from the Eucalyptus saligna species on the electricity network, first on an experimental basis, and then as a progressive substitute for concrete poles installed by the colonial system, earthen spaces have been reserved more and more for the cultivation of eucalyptus trees.

Nowadays, a whole network of activities has developed around Eucalyptus woods. In the West and Northwest regions, forest reserves managed by the State, by cooperatives or by individuals as well as individual plantations, offer a large part of their space for the cultivation of this tree. The plantations play an important role in supplying raw poles to local and sub-regional market.

As a major operator in the energy sector in Cameroon, Eneo initiated the signing of major agreements with ANAFOR (the National Forestry Development Agency) and many City Councils across Cameroon at the end of 2018. These agreements are aimed at developing eucalyptus forests, for an estimated potential of 200,000 raw wood poles annually [3]. Thereby, Eucalyptus production is likely to increase. But, for recent decades, the burdens that a particular product may impose on human health and the physical environment are receiving increased consideration. Thus, since the use of renewable resources is one of the most important sustainability topics, and is directly related to the well-being of society, both in the short and long term; offsetting the negative effects of pollution on human health and climate, we are called upon to ask ourselves what impacts these forestry operations generate on the environment?

One of the ways of determining the environmental burdens of a product or an activity can be done using life cycle assessment (LCA) [4, 5, 6]. If a number of research has been done throughout the world [7, 8, 9, 10, 11, 12, 13, 14] and is still being carried out [15, 16] to understand environmental impact related to forest operations under LCA perspective, just few studies, conducted with that approach in developing countries context, have been recorded [17, 18], and none of them included the eucalyptus production.

The work presented herein is part of the general investigation (i.e. cradle-to-grave) that included the eucalyptus silviculture, pole shaping, pole treatment, pole in-service, and pole final disposal [19, 20]. Its purpose reports on the environmental impacts of silviculture resource management activities including tree nursery, forest growth, harvesting and transportation of eucalyptus, referred to as a forest resource cradle-to-gate LCA. It begins with the presentation of the methodology that sustains this cradle-to-gate LCA study. Results are then provided and discussed. It ends with a conclusion which recalls its achievements and specifies its limits.

II. MATERIALS AND METHODS

The current cradle-to-gate approach was adopted since the main activities required to obtain Eucalyptus tree used as a raw material for wooden utility poles, are limited to forest operations. In fact, in this contexte, a formal cradle-to-grave analysis would not be of practical value.

2.1 Goal and scope definition

According to the ISO standard for LCA [21], goal and scope definition is the LCA phase in which the aim of the study, and in relation to that, the breadth and depth of the study are established.

2.1.1 Goal definition

The goal of this study was to document the cradle-to-gate LCA of the forest operations leading to the production of raw eucalyptus wodeen poles from the western and northwestern Cameroonian highlands. Its output is intended for use by any company engaged in the production of raw wood poles to assess the environmental profile of its wooden electric poles. 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 context.

2.1.2 Scope definition

In defining the scope of this study, the following aspects are outlined.

2.1.2.1. Functional unit (FU)

Although in the context of forest operations, the FU is generally taken as a certain mass or volume of plant material [22, 23], we consider in this study a FU which is similar to that used in the LCA of electric poles. In fact, we are dealing with a part of the general investigation that included not only the Eucalyptus silviculture, but also pole shaping, pole treatment, pole in-service, and pole final disposal. Thus, as shown by Nimpa et al. [24], most LCA utility pole practitioners use a unitary FU defined as one x m pole processed and used in power distribution line with a lifetime of y years. So, one eucalyptus tree requiring twelve years of growth to mature was taken as a FU.

2.1.2.2. Description of the system under study

The boundary of the investigated system is illustrated in Fig. 1. The system consists of main activities carried out in the eucalyptus silviculture operations for raw poles. It has been assessed according four stages: (1) Nursery (nursery operations to grow eucalyptus tree seedlings); (2) Forest growth (Field preparation, fill planting of eucalyptus seedlings, and thinning of eucalyptus forest to grow eucalyptus trees), (3) Harvesting (harvest of eucalyptus saw logs), and Transportation (transport of raw poles to supplier or Eneo sites).

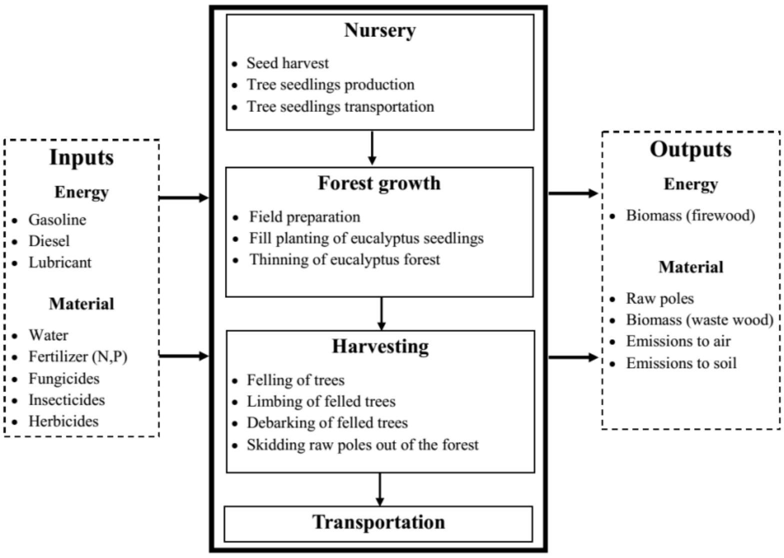


Fig. 1: Process flow of forest operations for eucalyptus power poles production in Cameroon

2.1.2.3 Selected impact categories and methodology of impact assessment.

According to Jawjit et al. [25] and Eshun et al. [18] impact categories presented below have been found relevant to fit the aim of such a study.

Global warming: Global warming is assessed in terms of greenhouse gases (carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)), which are the main pollutants contributing to the increasing temperature in the lower atmosphere. This raise of global temperature is expected to cause climatic disturbance, desertification, rising sea levels and spread of disease. Climate change is one of the major environmental effects of forest activity, and one of the most difficult to handle because of its broad scale. The combustion of fuels in the various silvicultural activities is one source of these gases. Global warming is calculated in this study as kilograms of CO_2 equivalents.

Acidification: This impact category is owing to the emission of acidifying substances. Sulphur dioxide (SO_2) and nitrogen oxides (NO_X) are the main pollutants emitted into the air. Once they are combined with other substances in the atmosphere, the whole turn into acids and reach the earth's surface as rain or fog. it causes ecosystem impairment of varying degree, depending upon the nature of the landscape ecosystems. The combustion of fuel is the main source of SO_2 and NO_X emissions. Acidification is calculated in this study as kilograms of SO_2 equivalents.

Photochemical oxidant: Ozone is protective in the stratosphere, but on the ground-level it is toxic to humans in high concentration. Photochemical ozone is formed by the reaction of volatile organic compounds and nitrogen oxides in the presence of heat and sunlight [26]. The impact category depends largely on the emission of CO, CH_4 and NO_X, and NMVOC (non-methane volatile organic compounds), which are considered to be tropospheric ozone precursors, are caused by combustion of fuel during forest operations. Photochemical oxidant formation is calculated in this study as kilograms of C_2H_4 (ethylene) equivalents.

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 nursery and forest operations. 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.

Eutrophication: Eutrophication occurs when there is an excess of nutrients (usually N or P) in a body of water. Fertilizers used in eucalyptus silviculture are the main agents responsible for nitrogen and phosphate emissions that enrich soils and waters with nutrients that can cause unwanted variation in species composition endangering the ecosystem. In marine ecosystems, for example, these substances encourage the rapid growth of algae which endanger the biodiversity of the environment by depriving the rest of plant organisms of CO_2 and light. As a result, the oxygen level in the environment drops, threatening the survival of flora and fauna. Eutrophication is expressed as kilograms of phosphate equivalent (kg eq-PO_4^{3-}).

2.2 Life cycle inventory (LCI)

The international standard for life cycle impact assessment [21] considers that LCI involves the collection and computation of data to quantify relevant inputs and outputs of a product or a system, including the use of resources and emissions to air, water and soil associated with the system. These data are derived from the activities related to system boundary as described in the scope definition (section 2.1.2.).

2.2.1. Data collection procedure

We collected primary data on nursery operations, forest management and harvesting operations using landowner surveys. Three nurseries (two in the Northwest Region and one in the West Region) and three eucalytus forests (one in the Northwest Region and two in the West Region) were surveyed. In order to interview those who were most likely to identify the real situation in the field, nurseries and euclyptus forests were identified with the assistance of the regional offices of the National Forestry Development Agency (ANAFOR) in Bafoussam and Bamenda Cities. These offices, in colaboration with Eneo the major operator in the energy sector in Cameroon, also facilitated the visits and interviews in West and Northwest Region. In order to undertake some comparative data, information was also gathered from farmers who subcontract raw poles supply to Eneo during a meting between Eneo and its subcontractor. After completing the surveys and doing the preliminary analyses of the data, a few hours workshop was conducted at each site to validate the observations and results with the respondents, the staff of ANAFOR and those of Eneo. The main resulting considerations are presented here below.

Nursery. Nursery activities range from collecting seeds to transporting mature seedlings to the transplanting site in the forest. In fact, seeds (seed-shells properly said) are collected directly from local stands of a species, from a number of trees to ensure a wide genetic base (the diversity of genes). This is done manually and only the gasoline used by motorcycles to travel to the plantations over a distance of about 20 km to collect these seeds is taken into consideration. Note that one kilogram of seed-shells contains about 300,000 seeds in powder form which will produce around 200,000 seedlings. All nursery activities are done manually. During sowing, except for the water irrigation, there are in some cases an initial inoculation with nitrogen fertilizer (approximately 65 g of urea), herbicide (0.1 l Roundup), insecticide (0.1 l of Dursban), and fungicide (25 g of copper oxychloride) for each seedbed expected to produice 500 young seedlings. This is necessary for good plant development since it increases plant disease resistance and help alleviate plant stress by enhancing the plant's water and nutrient uptake. Once the young seedlings are transplanted into the black polyetylene nursery bags, during the 4 to 5 months necessary for their growth (24-35cm high), urea can still be applied 260 g for 500 plants) as well as an insecticide (0.4 l of Dursban for 500 plants) and a fungicide (300 g of copper oxychloride for 500 plants). About 5,000 seedlings are transported from the nursery to the plantation in light duty vehicle (van) over a distance of about 50 km.

Forest growth. This phase bigins with site preparation. It consists of weeding which is done either by manual clearing or most of the time by herbicides spray as it is generally the case (Matthews et al., 2003) given the large areas of the plantations (use of about 4 l of Roundup per hectare). After weeding eucalyptus growth step begin with the planting of the seedlings from nurseries at a density of 2,500 seedlings per hectare (i.e 100/2 x 100/2). Input supplies are mainly consumed during the first 3 years. During this period, it is assumed a total of a spray application of 12 l of herbicide (Roundup: Glyphosate), 9 l of insecticide (Dursban: Chlorpyrifos), and 4 kg of Fungicide (copper oxychloride) per hectare. It is assumed as well a manual use of around 200 kg of fertilizer (diammonium phosphate: NP: 18 - 46). One hectare of cultivation under these conditions generates around 800 usable wooden poles.

Harvesting. Trees suitable for harvesting (those having at least 12 years) are first identified and marked. To fell and limb eucalyptus trees, the use of fuel-consuming chainsaws is required. Debarking of falled trees is done manually while skiding raw poles out of the forest is done by means of a crawler tractor which hangs an average of 30 poles and drags them over a distance of about 2 km. The remaining biomass generated in the forest site (leaves and branches) have not been taken into account in the analysis sine it has been assumed that they remain in the plantation contributing to improve the soil quality.

Transportation. A straw loader with front clamp (LandMaster 414) is used to load about 80 raw poles onto a 42-ton semi-trailer. Poles are then transported over an average distance estimated at 60 km to the Eneo pole yard or to private sites. Empty return journey of semi-trailers has not been considered.

Additional assuptions

The total amount of herbicide and insecticide applied ultimately reaches the environment through emissions to the ground.

Foliar washoff causes a loss of copper oxychloride (fungicide) sprayed on crops, leading to the contamination of the soil with copper (Cu). It occurs by particle detachment and transport of particles. Knowing that wash-off of fungicide deposits is influenced by drying time of the deposit,

rain intensity, and rain volume; we considered an average loss of 50% of the initiale sprayed quantity of copper oxychloride at the usual recommended dosage for crops [27, 28, 29].
A ratio of 1.5 l of fuel to fell and limb 25 trees is generally observed.

Other fuel and lubricants consumptions have been estimated based on Eneo's fuel and oil consumption monitoring sheets.
Approximately 42% of the nitrogen used ends up in the environment and 5% of phosphorus ends up in water.
Once compiled, the inventory data have been converted to a per FU and synthesized in Table 1.

Table 1: Activity data per FU from forest operations for eucalyptus power poles in Cameroon.

Activity stage	Unit	Value	Activity stage	Unit	Value
1-Nursery			**3-Harvesting**		
Input			*Input*		
Fertilizer (Urea) for seedlings growth	Kg	0.0033	Gasoline used by chainsaws	kg	0.2304
Herbicide (Roundup)	L	0.0002	Diesel used by Crawler tractor	kg	0.2263
Insecticide (Dursban)	L	0.0010	Lubricant used by Crawler tractor	kg	0.0054
Fungicide (Cupper oxychloride)	Kg	0.0035	*Output*		
Gasoline used for transport	Kg	0.8448	Gas (emissions from gasoline)	kg	-[a]
Output			Gas (emissions from diesel)	kg	-[a]
N (Urea)	Kg	0.0015	Gas (emissions from lubricant)	kg	-[a]
Glyphosate (from herbicide)	Kg	0.0005	**4-Transportation**		
Chlorpyrifos (from insecticide)	Kg	0.0024	*Input*		
Copper (from fongicide)	Kg	0.0006	Diesel used by Straw loader	kg	0.2101
Gas (emission from gasoline)	Kg	-[a]	Lubricant used by Straw loader	kg	0.0048
2-Forest growth			Diesel used by 42-ton semi-trailer	kg	2.2627
Input			Lube used by 42-ton semi-trailer	kg	0.0538
Herbicide (Roundup)	L	0.0064	*Output*	kg	
Fertilizer (NP:18-46)[b]	Kg	0.4000	Gas (emissions from diesel)	kg	-[a]
Insecticide (Dursban)	L	0.0036	Gas (emissions from lubricant)	kg	-[a]
Fungicide (Cupper oxychloride)	Kg	0.0080			
Output					
Glyphosate (from herbicide)	Kg	0.0144			
Chlorpyrifos (from insecticide)	Kg	0.0086			
Copper (from fongicide)	Kg	0.0014			
N (from Fertilizer NP)	Kg	0.0302			
P (from Fertilizer NP)	Kg	0.0092			
Gas (emissions from gasoline)	Kg	-[a]			

[a]values to be calculated using the emission factors (see Table 2) ; [b]diammonium phosphate

2.2.2. Emission inventory calculation

In the Cameroonian context, some emission inventory data were not available. Therefore, as suggested by Jawjit et al. [25] and later applied in developing countries' context by Eshun et al. [17], all emissions were calculated as a function of production activities and the emission factors using equation (1):

Emission = Activity x Emission Factor (1)

Emission factor are predefined values used to estimate emissions to the environment. They relate the quantity of substances emitted from a source to some common activity associated with those emissions. Knowing that five impact categories were took into account, 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 NO_X (smog) ; NO_X, NO_3, PO_4^{3-} (eutrophication), and Cu, $C_3H_8NO_5P$ (Glyphosate), $C_9H_{11}Cl_3NO_3PS$ (Chlorpiryfos) (Ecotoxicity). Emission factors used in relation (1) and summarized in Table 2 have been adapted from Eshun et al. [17]

2.2.3. Impact categories calculation

Equation (2) shows that the 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 (Guinée and Heijungs, 1995):

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

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 (ISO, 2006b). They have been summarized in Table 3.

Table 2: Emission factors used for the calculation of the emission in sylviculture operations in Cameroon

Activity area	**Compound emitted**	**Emission Factor**	**Unit**	**Reference**
Diesel use in harvesting and transportation operations	CO_2	3150.00	g/kg fuel	[30]
	CO	15.00	g/kg fuel	[31]
	N_2O	0.02	g/kg fuel	[30]
	CH_4	6.01	g/kg fuel	[30]
	NOx	50.00	g/kg fuel	[31]
	NMVOC	6.50	g/kg fuel	[31]
	SO_2	20.00	g/kg fuel	[31]
Gasoline use in nursery and harvsting operations	CO_2	3172.31	g/kg fuel	[31]
	CO	64.77	g/kg fuel	[31]
	N_2O	0.453	g/kg fuel	[31]
	CH_4	0.9	g/kg fuel	[31]
	NOx	9.76	g/kg fuel	[31]
	NMVOC	42.09	g/kg fuel	[31]
Lubricant use in harvesting and Transportation operations	CO_2	2946.66	g/kg fuel	[32]
	N_2O	0.02412	g/kg fuel	[32]
	CH_4	0.402	g/kg fuel	[32]
Nitrogen used	N_2O	0.03	kg N_2O-N/kg N	[31]
	NOx	0.025	kg NOx-N/kg N	[31]
	NO_3	0.35	kg NO_3-N/kg N	[31]
Phosphate used	PO_4^{3-}	0.2	kg PO_4^{3-}-P/kg P	[31]
Fongicide[c]	Copper	350	g/kg Fong.	[33]
Insecticide (Dursban)[c]	Chlorpyrifos	480	g/l Dursban	[33]
Herbicide (Roundup) [c]	Glyphosate	450	g/l Roundup	[33]

[c] Values specific to Cameroon

Table 3: Characterization factor applied to the forest operation

Impact category	Compound	Characterization factor	Reference
Global warming	Carbon dioxide (CO_2)	1kg = 1kg CO_2-eq	[31]
	Methane (CH_4)	1kg = 21kg CO_2-eq	[31]
	Nitrous oxide (N_2O)	1kg = 310kg CO_2-eq	[31]
Acidification	Sulfure dioxide (SO_2)	1kg = 1kg SO_2-eq	[34]
	Nitrogen oxide (NO_X)	1kg = 0.71kg SO_2-eq	[34]
Photochemical oxidant	Non-methane hydrocarbon (NMVOC)	1kg = 0.416kg C_2H_4-eq	[35]
	Carbon mono-oxide (CO)	1kg = 0.0276kg C_2H_4-eq	[35]
	Methane (CH4)	1kg = 0.006kg C_2H_4-eq	[35]
	Nitrogen oxide (NO_X)	1kg = 0.028kg C_2H_4-eq	[35]
Ecotoxicity	Copper (Cu)	1kg = 14.4kg 1,4-DB-eq	[36]
	Chlorpyrifos ($C_9H_{11}Cl_3NO_3PS$)	1kg = 14,5 kg 1,4-DB-eq	[36]
	Glyphosate ($C_3H_8NO_5P$)	1kg = 0,0149 kg 1,4-DB-eq	[36]
Eutrophication	Nitrate ($NO_{3)}$	1kg = 0,1 kg PO_4^{3-}-eq	[34]
	Oxyde d'azote NO_X	1kg = 0,13 kg PO_4^{3-}-eq	[34]
	Phosphate (PO_4^{3-})	1kg = 1 kg PO_4^{3-}-eq	[34]

III. RESULTS AND DISCUSSION

The impact indicator values at each of the four forest operation stages are reported below in respective sections. They are obtained from LCI and are presented below.

3.1. Environmental Emissions

The results of emission calculations have been expressed in kg of pollutant either emitted or generated from a product line of the forest operations per functional unit and summarized on Table 4.

This result shows that the production and combustion of fuels generate a range of air emissions and soil damages (Table 4). CO_2 appears as the largest emitter from each process stage. The impact categories are computed from these environmental emission values.

Table 4: Process emissions (kg/FU) for the life stages of forest operation for wood utility poles

Actif compound	Forest operation stage				Total
	Nursery	Forest growth	Harvesting	Transportation	
CO_2	0.267997	0.000000	1.459536	7.962313	9.689846
N_2O	0.000083	0.000907	0.000109	0.000051	0.001150
CH_4	0.000076	0.000000	0.001569	0.014886	0.016531
CO	0.005472	0.000000	0.018317	0.037093	0.060882
NMVOC	0.003556	0.000000	0.011168	0.016074	0.030798
NOx	0.000862	0.000756	0.013562	0.123643	0.138823
SO_2	0.000000	0.000000	0.004526	0.049457	0.053983
PO_4^{3-}	0.000000	0.001840	0.000000	0.000000	0.001840
NO_3	0.000523	0.10584	0.000000	0.000000	0.011107
$C_3H_8NO_5P$ (Glyphosate)	0.000450	0.014400	0.000000	0.000000	0.014850
$C_9H_{11}NO_3PSCl_3$ (Chlorpyrifos)	0.002400	0.008640	0.000000	0.000000	0.011040
Cu	0.000613	0.001400	0.000000	0.000000	0.002013

3.2. Environmental impact categories

The impact category values at each of the four forest operation stages, and a total for the gate-to-grave life cycle are summarized in Table 5.

Table 5: Forest operations' environmental impacts per FU and by life stage

Impact category	Unit	Forest operation stage				Cradle-to-gate
		Nursery	Forest growth	Harvesting	Transportation	
Global Warming	kg CO_2-eq	0.295360	0.281232	1.526293	8.290678	10.393563
Acidification	kg SO_2-eq	0.000612	0.000536	0.014155	0.137244	0.152547
Photochemical oxidant	kg C_2H_4-eq	0.001630	0.000021	0.005463	0.011143	0.018257
Ecotoxicity	kg 1,4-DB-eq	0.043627	0.145654	0.000000	0.000000	0.189281
Eutrophication	kg PO_4^{3-}-eq	0.000164	0.002997	0.001763	0.016074	0.020998

Global warming. Approximately 10.40 kg of greenhouse gas was emitted per FU of eucalyptus produced in Cameroun (Table 5). Harvesting and transportation operations were identified as the main life stages responsible for emissions that contribute to global warming. 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, Bolin and Smith [37] found in their pole production stage 44 lb CO_2-eq (around 20 kg CO_2-eq). This difference could be due to the fact that these authors introduced into their system boundaries considerations such as kiln drying, chemicals production for pole preservation, site preparation using a tractor…

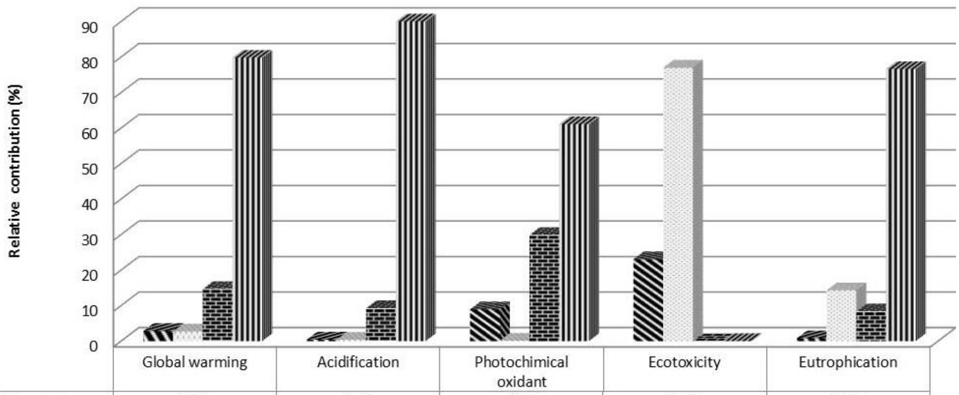
Acidification. The total per FU acidifying emissions from SO_2 and NOx were calculated to be 0.15 kg SO_2-equivalents (Table 5). As it has been the case to the global warming, transportation and harvesting operations were identified as the main life stages responsible for emissions that contribute to this impact category

Photochemical oxidant. This impact category is affected by hydrocarbon emissions associated to the incomplete combustion of fossil fuels. Therefore photochemical oxidant emissions are closely related to fuel use. In this impact category, the transportation operations subsystem remains the most important contributor and its contribution adds to 61% of the total. On the contrary, forest growth has the lowest impact due the non-use of fuel. The total emissions of tropospheric ozone precursor compounds have been determined to be about 0.0183 kg ethylene-eq/FU. Among the four main components of tropospheric ozone precursors – NMVOC, CO, CH4 and NOx – it has been found that NOx is the main contributor and accounts for 56% of the present impact category score in terms of C_2H_4-equivalent.

Ecotoxicity. The total emissions of ecotoxicity compounds are about 0.19 kg 1,4-DB-eq/FU. 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 nursery and forest growth stages are the main contributors with a respective contribution of 23% and 77%. Contrary to the other assessed impact categories, it is shown that only this impact category points out the forest growth life cycle stage as a significant impact bearer throughout the forest operations for wood pole.

Eutrophication. Eutrophying emissions from this study, about 0.021 kg PO_4^{3-}kg equivalent of eutrophying compounds, was found to be discharged per FU. Transportation is responsible for the largest proportion of this impact category.

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



	Global warming	Acidification	Photochimical oxidant	Ecotoxicity	Eutrophication
Nursery	2,84	0,40	8,93	23,05	0,78
Forest growth	2,71	0,35	0,12	76,95	14,27
Harvesting	14,68	9,28	29,92	0,00	8,40
Transportation	79,77	89,97	61,03	0,00	76,55

Fig. 2: Analysis of impact categorie contributions per forest operation stage

With the exception of ecotoxicity, the other impact categories related to forest operations for wood poles are largely due to transportation.

IV. CONCLUSION

The cradle-to-gate life-cycle assessment reported in this study is the first to profile forest operations for wood poles dedicated for power distribution lines in a sub-saharan African country. In addition, the study is presented as one of the ground works in the field of LCA for wood-based products in Cameroon.

According to the environmental results obtained, the following conclusions can be pointed out, knowing that as with all LCIs and LCAs, the conclusions are influenced and constrained by the assumptions made.

- LCI data for Cameroon with regard to forest operation were as to yet limitedly available. Thus, in spite of the fact that this study was based both on two over ten Cameroonian regions experience and on worldwide used primary emission data, it yielded good quality data to forest industry LCA research in third world.
- With regard to assessed impact categories, the following scores of 10.40 kg CO_2-eq for global warming, 0.15 kg SO_2-eq for acidification, 0.018 kg C_2H_4-eq for photochemical ozone formation, 0.19 kg 1,4-DB-eq, for ecotoxicity, and 0.02 kg PO_4^{3-} for eutrophication have been recorded as values of a functional unit in forest operations dedicated to the production of wood utility poles.
- Operations related to the transportation have been identified as the most environmentally harmful with regard to global warming, acidification, photochemical ozone formation, and eutrophication while forest growth life stages recorded the highest values in ecotocixity.
- The combustion of fuels has been found to be the most important source of pollution related to greenhouse gases, smog precursors, acidification and eutrophication compounds, with CO_2, and NOx being the most important pollutants.

The results for this study were also heavily influenced by the non-mechanization of forestry operations related to eucalyptus production in Cameroon context. This led to relatively low impact category values compared to results obtained in similar studies performed in other contexts.

Although we can say that this production activity is clean, it should still be noted that with vehicles in good conditions, with a lower rate of fuel consumed, these activities would be even cleaner.

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