Service Life Prediction and Durability of Wooden Utility Poles in Cameroon: a Factor-Based Approach

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Abstract

The durability of wooden electric poles is a critical concern in Cameroon, where they are extensively used for electricity distribution. However, for nearly two decades, their premature degradation has gradually led the government to consider replacing them with concrete poles, a solution that is both costly and environmentally unfriendly. The aim of this study is to propose an approach for predicting and enhancing the service life of wooden poles, particularly eucalyptus poles, which are widely used in the country. The factor method, employed as the methodological framework, is based on identifying and weighing factors and sub-factors that influence the longevity or degradation of wooden poles throughout their life cycle. This method identifies six categories of factors and 19 sub-factors or variables, each with two or three weighted characteristics, as per ISO 15686 standards. The results show that a desired service life can be achieved by considering a combination of these variables, with the service life ranging from 8 months to 86 years. Furthermore, they recommend concentrating efforts on the optimal management of the conditions that influence the durability of wooden poles to avoid costly and unsustainable replacements.

Keywords: utility poles, durability, factor method, service life prediction, reference service life

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1. Introduction

The durability of power distribution lines is a crucial issue for industrial and technological development worldwide. It is even more important in developing countries, where these lines are mostly overhead, supported by utility poles whose reliability is essential to ensure access to energy.

Although various materials are used for manufacturing utility poles (Werner and Richter, 2007), wooden poles remain the preferred choice in Sub-Saharan Africa (UPDEA, 1993), particularly in Cameroon, due to their relatively low cost (Ngog, 1993), favorable mechanical properties for power line construction (Njankouo et al., 2000), and the availability of locally sourced materials, such as eucalyptus, a species widely cultivated in Cameroon (ANAFOR, 2013).

However, despite these advantages, the number of failures and premature collapses of wooden poles has been steadily increasing for nearly two decades. In 2022, the Minister in charge of Energy reported that 60% of the 1.3 million wooden poles in use nationwide required replacement (Bangda, 2022). In response to the issue of their short service life, the Cameroonian government has initiated a plan to replace these wooden poles with concrete ones through the Electricity Sector Recovery Support Program (PARSEC), funded by the African Development Bank (AfDB), and launched on December 2, 2024 (ARMP, 2024). The first phase of the program involved replacing 10,000 wooden poles with concrete poles at a cost of 9.5 billion XAF (15,626,423.84 USD).

While the government's decision may help address the social issue of continuous electricity access, it seems to lack a holistic approach that, within the context of sustainable development, ensures that one social issue is not resolved by creating others, particularly economic and environmental ones. Indeed, it has been shown that the supply and implementation cost per kilometer of wooden poles is five times lower than that of concrete poles, with a ratio per kilometer of 1:5 (Ngog, 1993). Furthermore, throughout their life cycle, a wooden pole contributes 73 kg of CO_2-equivalents to global warming, compared to 1,446.96 kg of CO_2-equivalents for a concrete pole, a ratio of approximately 1:20 (Bolin and Smith, 2011).

Building on the expertise developed in other regions, where the average lifespan of wooden poles, under optimal maintenance conditions, can reach 70 to 100 years (Stewart, 1996; Nelson, 1999), we can reasonably conclude that a sustainable solution to the unreliability of wooden poles in service in Cameroon (and Sub-Saharan Africa) should not involve replacing them with concrete poles. Instead, the focus should be on addressing the root causes of their rapid degradation in the electricity network and preventing these factors to ensure an optimal service life.

Ensuring this optimal service life involves the use of techniques for predicting the lifespan of construction products. One such technique is the factor method, which is commonly used to predict the longevity of materials based on various parameters that influence their degradation (Brischke et al., 2006; Souza et al., 2018; Marques et al., 2018; Rajender et al., 2024). This method relies on identifying key factors, such as climatic conditions, the mechanical properties of the material, and the characteristics of the service environment, all of which can impact a product's lifespan (ISO 15686-1, 2000).

Taking advantage of the control over the life cycle of wooden poles used in Cameroon (Njankouo et al., 2017; Nimpa et al., 2021; Voufo et al., 2022), this study aims to demonstrate that a desired service life can be achieved by adopting a combined approach that considers the factors related to the technologies and processes involved in the production of wooden poles, the environment in which they are used, and the way in which the poles are employed.

To achieve this, a local assessment of the service life prediction for wooden poles is presented. The factor method is then explained and applied to predict the service life of wooden poles, considering the phases of their life cycle. The results obtained are presented, followed by the conclusion of the study.

2. Local assessment of the predicted service life of wooden poles

The company responsible for electrical power distribution (ENEO) maintains a reception form for wooden poles, which outlines the key characteristics required to ensure their quality. These characteristics include: (i) the type of forest from which the tree is harvested; (ii) the maximum thickness of the sapwood, which must not exceed a quarter of the radius of the tree's cross-section; (iii) the diseases the pole must be free of; (iv) the straightness of the pole; and (v) the dimensions of the pole's circumference and height. Furthermore, ENEO specifies that, in accordance with the guidelines from ARCH TIMBER PROTECTION, the supplier of chemical preservatives for wooden poles, the service life of the poles is determined by the user based on the chosen specifications (Tchouakeu, 2008). Table 1 presents the specifications currently in use at ENEO's Wooden Pole Planning and Production Unit.

Table 1. Predicted service life of wooden poles

Desired service life	Specifications		
	Concentration of the solution	Maximum moisture content	Retention of active ingredients
20 – 25 ans	4,5 %	28 %	8,8 Kg/m3
25 – 30 ans	5 %	28 %	10,5 Kg/m3

This approach has also been observed at CAMITEX, a local company that supplies wooden poles. It is apparent that the service life of wooden poles only takes into account a few specifications related to the shaping and treatment phases, without considering the durability factors in other stages of the poles' life cycle. However, it is increasingly clear to many Cameroonians that wooden poles often fail to meet the minimum service life requirement of 20 years (i.e., once installed in electrical distribution networks), underscoring the need for a more comprehensive predictive approach based on life cycle thinking.

3. Proposal for a New Model

The proposed service life prediction model is based on the factor method. In the following sections, we will outline the specifics of this method and subsequently apply it to predict the service life of wooden poles in

Cameroon.

3.1. Methodological basis of the proposed model

The proposed model is based on the factor method, which follows a deterministic approach. ISO 15686-1 (2011), "Service Life Planning", provides guidelines for predicting the service life of a structure through calculations. It defines the factor categories considered in the model and offers guidance on the weighting criteria for these factors, which total seven: (i) Factor A: quality of components; (ii) Factor B: design level; (iii) Factor C: work execution level; (iv) Factor D: indoor environment; (v) Factor E: outdoor environment; (vi) Factor F: In-use conditions; and (vii) Factor G: maintenance level.

In accordance with these seven factors, which ISO 15686-1 considers exhaustive, it is clear, as noted by Ciantar and Hadfield (2004) and De Saxce et al. (2012), that the durability of any product is jointly influenced by: (i) the technologies and production processes used, (ii) the environment in which the product is used, and (iii) the manner in which the product is used. This classification divides factors A to G into three groups: those directly related to the technologies and production processes of wooden poles (inherent quality characteristics); those related to the environment of use (deterioration of wooden poles due to climatic, edaphic, biological, and anthropic factors); and those related to the mode of use (deterioration of wooden poles due to usage conditions). Table 2 provides further details on these factors.

Table 2. Key Factors in Wooden Pole Service Life Prediction

Factor type	Factors		Example of parameters to consider
Factors related to quality characteristics	A	Quality of components (wood)	Eucalyptus Silviculture Monitoring
	B	Design level	Shaping and treatment processes
	C	Work execution level	Technical staff competence
Usage environment	D	Indoor environment	*Non applicable*
	E	Outdoor environment	Micro-environmental and macro-environmental conditions
Usage conditions	F	In-use conditions	Mechanical shock, vandalism, overloads from other equipment
	G	maintenance level	Quality and frequency of maintenance, accessibility for maintenance

The factor method predicts the service life of components subjected to specific conditions, based on a reference service life (RSL) that is adjusted by several modifying factors. In other words, it is based on two key concepts (Bourke, 1999; Hovde, 2004): (i) the RSL, defined as the expected lifespan under normal usage and maintenance conditions; and (ii) the modifying factors, which either increase or decrease the RSL depending on whether these factors are favorable.

According to ISO 15686-1, the factor method (Equation 1) specifies that the estimated service life (ESL) is the product of the RSL and the seven factors (A to G) outlined in Table 2.

$$ESL = RSL \times A \times B \times C \times D \times E \times F \times G \qquad (1)$$

Factors A to G may depend on independent variables or sub-factors that influence the service life. ISO 15686-1 recommends that the RSL be determined through aging tests, followed by comparison with expert field data. In this study, the RSL was chosen in agreement with local producers of wooden poles. The criteria for selecting these producers are related to the economic and strategic importance of wooden poles, as well as to the chemical treatment applied to these poles and the environmental conditions at the installation sites.

Once the RSL is determined, it must be adjusted based on the values of the factors, depending on the differences between the reference and study cases.

a) If the reference case is identical to the study case, meaning the factors are the same as the conditions defining the reference case, then the ESL equals the RSL.

b) If not, the standard specifies that the quantification of the modifying factors takes a value of 0.8 for less favorable conditions and 1.2 for more favorable conditions, and takes a value of 1.0 whenever the factor cannot be applied.

The lack of a universally agreed guide or standard for estimating these seven factors has led to potential variations in the ESL, depending on the user. As a result, many criticisms have been raised against this method (Bourke, 1999; Moser, 2004; Hovde, 2004; Gaspar, 2009).

Despite these criticisms, the factor method remains the most widely accepted due to its clarity, ease of use, and high operability. In fact, it is now considered not just a method, but a comprehensive framework for predicting the service life of buildings and construction products (Galbusera et al., 2015). Moreover, this method is considered to strike the right balance between accuracy, speed, low cost, and ease of application, which likely explains why it is the only method widely accepted internationally (Emídio et al., 2014).

3.2. Application of the Factor Method to Predict the Service Life of Wooden Poles

The application of the factor method is viable in this study, as wooden poles are considered construction materials, and this method is widely used to predict the service life of buildings and construction products, as highlighted by Emídio et al. (2014).

For this approach, it is necessary to establish the RSL. In this study, the RSL for wooden poles is set at 20 years, which is the minimum duration recommended by experts from the company responsible for electricity distribution in Cameroon (Tchouakeu, 2008). This duration is consistent with the value cited by Otuko et al. (2024), who report that in Uganda, a country within the African Union, this is the service life guarantee provided by suppliers. Additionally, it is crucial not only to identify the factors that influence the poles' service life but also to assign appropriate weightings to these factors.

3.2.1. Identification of Factors Influencing the Service Life of Wooden Poles

The mechanisms of performance or degradation influencing the service life of wooden poles result from the interaction of three systems: the wooden poles themselves, anthropogenic degradation agents, and natural degradation agents. These agents impact not only the service life phase of the poles but also the preceding phases (forestry, shaping, and treatment). While the degradation of the poles is an inevitable consequence of the aging process, various factors, such as the wood's maturity or the lack of maintenance during service, for example, can either delay or accelerate this process.

The impact of each of the seven factors (Table 2) on the poles' durability is detailed below.

Quality of components

The quality of components factor, specifically the wood used for the poles, largely depends on the silvicultural characteristics of eucalyptus, such as species, growing environment, and tree maturity. Effective management of the eucalyptus silvicultural process, from nursery to harvesting, is crucial to ensure wood quality. This encompasses seed selection, plantation maintenance, thinning, and adherence to the recommended harvesting age. Environmental factors, such as humidity and soil quality, also contribute to the variability of wood properties (Stape et al., 2010). Logging operations, including felling and sawing, must be performed with precision to prevent the loss of healthy wood and the accumulation of water at the cut ends. The ANAFOR and ENEO support this approach by advising plantation owners and providing training on identifying trees suitable for pole production. Specific practices, such as controlling the ratio of heartwood to sapwood and detecting defects, ensure quality. Genetic improvement, particularly through the use of disease-resistant clones with high density (Costa et al., 2013) and low shear stress (Rockwood, 1984), is also recommended to further enhance wood quality

Design level

The design level refers to the method of storing the poles after felling, which includes the shaping and treatment phases. The logs are received and processed to maintain the structural integrity of the poles, then air-dried until they reach a moisture content of 28%, a critical threshold for the treatment process (Pirasteh et al., 2014). The treatment begins with surface cleaning to ensure proper impregnation. The concentration of the treatment solution and the process must ensure adequate biocide retention to guarantee durability. Quality control of impregnation, using coring and chemical analysis, is essential to verify the depth and quantity of preservative within the wood. The UPDEA 001 standard (1993) and relevant literature emphasize the importance of adhering to local best practices, such as the appropriate time for impregnation and respecting post-treatment chemical reactions to prevent the leaching of the preservative, which would negatively affect service life (Morrell, 2012). Furthermore, hardwoods like eucalyptus require higher preservative retention than softwoods due to the amount of lignin (Preston and Jin, 2005). Finally, physical protection at the base of the poles, which are often most vulnerable to fungal attacks, such as coating or the use of geotextiles, can extend their service life by reducing moisture and exposure to soil degradation agents (Morrell, 2012).

Work execution level

Factor C pertains to the competence of the personnel involved in the production, installation, and maintenance of wooden poles, and must be monitored throughout their entire life cycle. Qualified forestry workers follow the established technical guidelines for eucalyptus, while those responsible for shaping and treatment adhere strictly to procedural instructions. Similarly, handling personnel are trained to recognize the risks associated with impacts that could compromise the mechanical properties of the poles. Network installation personnel also follow procedures tailored to specific ecological zones to ensure proper placement. Existing literature highlights that workforce qualification and supervision during the manufacturing process, along with increased focus on training and safety, play a significant role in enhancing pole quality (Hertig and Davies, 2008).

Indoor Environment

This factor, which refers to the characteristics of an environment sheltered and protected from the elements, is not considered here, as wooden poles are consistently exposed to outdoor conditions. Therefore, factor D is not relevant to this study.

Outdoor Environment

Factor E concerns the impact of environmental conditions on the durability of wooden poles, particularly during their service life. Key degradation agents—such as temperature, humidity, precipitation, wind, and edaphic factors—vary across ecological zones like dry savannah, wet savannah, and dense forest. Considering these factors when positioning the poles in the electrical grid allows for better management of their exposure to degradation agents. Humidity, present in both the air and the soil, accelerates wood degradation, particularly in tropical areas, where fungi and termites cause considerable damage. High humidity and frequent rainfall also promote the leaching of preservative chemicals, leading to a reduction in the poles' strength. Poles protected by natural barriers or placed in shaded areas are less affected by solar radiation, while some regions are more susceptible to wind damage.

In-use conditions

This factor refers to the usage of wooden poles during their service life, which is often improper, particularly in densely populated urban areas. The poles are subjected to excessive loads from unplanned equipment, which causes surface damage and facilitates water infiltration. Vandalism, vehicle collisions, and nearby fires are also anthropogenic factors that adversely impact the service life of wooden poles.

Maintenance Level

Factor G addresses the maintenance of wooden poles in service, particularly in the critical deterioration zone around the base, which is located 20 cm above and 50 cm below the groundline. Curative methods, such as support braces, internal cavity treatments, and antiseptic bandages, are used to prevent decay at the base, as untreated damage typically leads to the replacement of the poles in over 90% of cases (Rahman and Chattopadhyay, 2007). Protecting the base is crucial for extending the service life of the poles (Gustavsen and Rolfseng, 2005)

From these six factors, independent variables or sub-factors that affect the service life of wooden poles were identified. The inventory, prevalence, and relevance of these sub-factors were established following interviews with independent nurserymen, eucalyptus plantation owners, forestry experts from ANAFOR, pole suppliers to the ENEO company, specialists from the Wooden Pole Sub-Directorate and HSE (Health, Safety, and Environment) of ENEO, wooden pole producers from CAMITEX, and experts from the electricity sector regulatory agency (ARSEL).

3.2.2. Assignment of Values to Each Factor

After identifying and classifying the independent variables or sub-factors affecting the durability of wooden poles according to the multiplicative factors used in the factor method, it is essential to assign a weight value to each sub-factor, as shown in Table 3.

Table 3. Factors and Sub-factors Influencing the Durability of Wooden Poles

Factors	Variables	Characteristics	Assigned values
A (K_1)	Genetic enhancement of young eucalyptus plants (K_{11})	Yes	1,2
		No	1
	Adherence to eucalyptus silvicultural techniques (K_{12})	High	1,2
		Medium	1
		Low	0,8
	Compliance with the minimum cutting age for trees (K_{13})	Yes	1
		No	0,8
	Felling, pruning, and logging procedures (K_{14})	Good	1
		Bad	0,8
B (K_2)	Execution of shaping operations (K_{21})	Correct	1
		Incorrect	0,8
	Drying procedure and moisture control (K_{22})	Correct	1
		Incorrect	0,8
	Quality of preservative, adherence to solution concentration and impregnation rate (K_{23})	Correct	1
		Incorrect	0,8
	Verification of treatment quality (K_{24})	Yes	1
		No	0,8
	Higher-than-usual retention rate of active substances (K_{25})	Yes	1,2
		No	1
	Additional physical protection at the pole base (K_{26})	Present	1,2
		Absent	1
C (K_3)	Employee qualification level (qualified and experienced, qualified, unqualified and inexperienced) (K_{31})	High	1,2
		Medium	1
		Low	0,8
D	Not applicable	-	1
E (K_4)	Precipitation and air/soil humidity levels (K_{41})	Hig	0,8
		Low	1
	Presence of wood-damaging insects (K_{42})	Suitable area	0,8
		Unsuitable area	1
	Wind strength/intensity (K_{43})	High	0,8
		Low	1
	Exposure to solar radiation (K_{44})	Directly exposed	0,8
		Partially exposed	1
		Not exposed	1,2
F (K_5)	Compliant use with design conditions (K_{51})	Compliant	1
		Non-compliant	0,8
	Extent of vandalism to poles in service (K_{52})	High	0,8
		Low	1
G (K_6)	Frequency of maintenance activities (K_{61})	Every 3 years	1,2
		Every 6 years	1
		None	0,8
	Curative treatment of poles in operation (K_{62})	Yes	1,2
		No	1

Table 3 highlights that each factor is influenced by several sub-factors or variables that affect the service life of wooden poles. This allows us to reformulate the factor method, as suggested by Teply (2003), who recommends that the value of each factor be the product of its sub-factors. A mathematical model of this problem results in the table presented in Annex IV.1, where the factors are denoted by Ki and the sub-factors by K_{ij}. The equation (1) predicting the estimated service life of the wooden pole then takes the following form:

$$\boldsymbol{ESL} = \boldsymbol{RSL}\ \mathbf{x} \prod_{i=1}^{6}\left(\prod_{j=1}^{n_i} \boldsymbol{K_{ij}}\right) \qquad (2)$$

Where:

K_{ij} represents the sub-factors of each factor K_i;

ni is the number of sub-factors associated with each K_i.

In the model, we considered 6 factors instead of 7, as factor D is not applicable to wooden poles. Thus, the ESL becomes a function of 19 sub-factors, as shown in Table 3. Since each sub-factor Kij has either two or three possible values, determining all possible ESL values becomes a combinatorial problem, which, through combinatorial analysis, results in 2,654,208 possible ESL values.

Since it is not feasible to manually determine all possible ESL values, a numerical simulation was implemented. To optimize computer memory usage, redundancies in the estimated service life values were excluded. This means that the program does not store any duplicate ESL values in memory. Additionally, the program allows for displaying all the Kij values that contributed to a specific ESL.

3.3. Analysis of the Obtained Estimated Service Life Values

From the 2,654,208 possible values, the redundancy filter retained 134 unique ESL values, which are distributed non-uniformly across a wide range of durations, from 0.7 years (8 months) to 86 years. Figure 1 provides an excerpt of the results generated and exported to Microsoft Excel.

K_{11}	K_{12}	K_{13}	K_{14}	K_{21}	K_{22}	K_{23}	K_{24}	K_{25}	K_{26}	K_{31}	K_{41}	K_{42}	K_{43}	K_{44}	K_{51}	K_{52}	K_{61}
1,2	1,2	1	0,8	0,8	0,8	0,8	0,8	1,2	1,2	1,2	0,8	0,8	0,8	1,2	1	0,8	1,2
1,2	1	1	1	1	1	1	1	1	1	1	0,8	0,8	0,8	1,2	1	0,8	1
1,2	1	1	1	0,8	0,8	0,8	0,8	1,2	1,2	1,2	0,8	0,8	0,8	1,2	1	0,8	1,2
1	1	1	1	1	1	1	1	1	1	1	0,8	0,8	1	1,2	1	0,8	1
1,2	1	1	1	1	1	1	0,8	1,2	1,2	1,2	0,8	0,8	0,8	0,8	0,8	0,8	1,2
1	1	1	1	1	1	1	1	1	1	1	0,8	0,8	1	1	1	1	1
1,2	1	1	1	0,8	0,8	0,8	0,8	1,2	1,2	1	0,8	1	1	1,2	1	0,8	1,2
1,2	1	1	1	0,8	0,8	0,8	0,8	1,2	1,2	1	0,8	1	1	1	1	1	1,2
1,2	1	1	1	1	1	1	1	1	1	1	0,8	0,8	0,8	1,2	1	0,8	1,2
1,2	1,2	1	0,8	0,8	0,8	0,8	0,8	1,2	1,2	1,2	0,8	0,8	0,8	1,2	1	1	1,2
1	1	1	1	1	1	1	1	1	1	1	0,8	0,8	0,8	1	1	1	1,2
1,2	1	1	1	1	1	0,8	0,8	1,2	1,2	1,2	0,8	0,8	0,8	1,2	0,8	0,8	1,2
1	1	1	1	1	1	1	1	1	1	1	0,8	0,8	1	1	1	1	1,2
1,2	1	1	1	0,8	0,8	0,8	0,8	1,2	1,2	1	0,8	1	1	1,2	1	0,8	1,2

Figure 1. Overview of selected ESL values based on K_{ij} combinations

3.3.1. Validation of the extreme service life values obtained

A potential concern arising from the simulation results is whether the extreme values of 8 months and 86 years are reasonable as potential service lives for eucalyptus wood poles used as supports for overhead power lines.

For the lower bound of the ESL range, this simulation, based on Cameroonian conditions, shows that under the combined effects of the factors and sub-factors, a wooden pole in service could potentially have a service life of less than one year. Table 4 presents some combinations of factors that can lead to such a short service life.

Table 4. Criteria responsible for a very short service life of wooden poles

Factors		**A**				**B**						**C**	**E**				**F**		**G**		***ESL (Yr)***
Variables (sub-factors)		**K_{11}**	**K_{12}**	**K_{13}**	**K_{14}**	**K_{21}**	**K_{22}**	**K_{23}**	**K_{24}**	**K_{25}**	**K_{26}**	**K_{31}**	**K_{41}**	**K_{42}**	**K_{43}**	**K_{44}**	**K_{51}**	**K_{52}**	**K_{61}**	**K_{62}**	
		Genetic enhancement of young eucalyptus plants	Adherence to eucalyptus silvicultural techniques	Compliance with the minimum cutting f...	Felling, pruning, and logging procedures	Execution of shaping operations	Drying procedure and moisture control	Quality of preservative, adherence to solution concentration and impregnation	Verification of treatment quality	Higher-than-usual retention rate of active substances	Additional physical protection at the pole	Employee qualification level	Precipitation and air/soil humidity levels	Presence of wood-damaging insects	Wind strength/intensity	Exposure to solar radiation	Compliant use with design conditions	Extent of vandalism to poles in service	Frequency of maintenance activities	Curative treatment of poles in operation	
Case 1	Caract.	N	F	N	B	In	In	In	N	N	A	F	H	Fz	H	Di	N	H	Nn	N	***0,704***
	Value	***1***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***1***	***1***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***1***	
Case 2	Caract.	Y	L	N	B	In	In	In	N	N	A	L	H	Fz	H	Di	N	H	Nn	N	***0,844***
	Value	***1,2***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***1***	***1***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***1***	
Case 3	Caract.	N	M	N	B	In	In	In	N	N	A	L	H	Fz	H	Di	N	H	Nn	N	***0,880***
	Value	***1***	***1***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***1***	***1***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***0,8***	***1***	

Legend : Caract.= Caractéristic ; N=No ; Y=Yes ; L=Low ; M=Medium ; B=Bad ; In=Incorrect ; A=Absent ; H=High ; Di=Direct ; Nn=None ; Fz=Favorable zone

Table 4 illustrates that the unfavorable combination of at least 15 out of the 19 factors influencing the durability of wooden poles can result in a very precarious service life for eucalyptus poles. These unfavorable factors do not apply solely to one phase of the poles' life cycle, but extend across both pre-service phases (such as forestry, shaping, and treatment) and the time the poles are in service. Field observations support the likelihood of a very short service life for wooden poles. Indeed, a scenario may arise where a tree, whose growth deviates from the prescribed silvicultural techniques, is felled before reaching maturity, and is neither shaped nor treated according to best practices. This tree may then be placed into service in an area where, in addition to climatic and edaphic conditions favoring its degradation, it faces additional stress from anthropogenic activities.

Regarding the upper bound of the ESL range, a service life of 86 years for a pole seems unlikely in the Cameroonian context, where implementing combinations of sub-factors conducive to such a long service life has proven difficult so far. However, the literature provides examples in which the average service life of wooden poles, under optimal maintenance conditions, ranges from 70 to 100 years (Stewart, 1996; Nelson, 1999). Table 5. presents a combination of factors that contribute to a very long service life for wooden poles in service.

Table 5. Factors contributing to the extended service life of wooden poles

Factors	A				B						C	E				F		G		*ESL (Yr)*
	K_{11}	K_{12}	K_{13}	K_{14}	K_{21}	K_{22}	K_{23}	K_{24}	K_{25}	K_{26}	K_{31}	K_{41}	K_{42}	K_{43}	K_{44}	K_{51}	K_{52}	K_{61}	K_{62}	
Variables (sub-factors)	Genetic enhancement of young eucalyptus plants	Adherence to eucalyptus silvicultural techniques	Compliance with the minimum cutting age	Felling, pruning, and logging procedures	Execution of shaping operations	Drying procedure and moisture control	Quality of preservative, adherence to solution concentration and impregnation	Verification of treatment quality	Higher-than-usual retention rate of active substances	Additional physical protection at the pole	Employee qualification level	Precipitation and air/soil humidity levels	Presence of wood-damaging insects	Wind strength/intensity	Exposure to solar radiation	Compliant use with design conditions	Extent of vandalism to poles in service	Frequency of maintenance activities	Curative treatment of poles in operation	
Caractéristic	Y	H	O	G	C	C	C	Y	Y	P	H	F	Unz	L	Ne	Co	L	E3	Y	***85,99***
Value	***1,2***	***1,2***	***1***	***1***	***1***	***1***	***1***	***1***	***1,2***	***1,2***	***1,2***	***1***	***1***	***1***	***1,2***	***1***	***1***	***1,2***	***1,2***	

Legend : Y=Yes ; H=High ; G=Good ; C=Correct ; P=Présent ; Znp= Unfavorable zone ; L=Low ;
Ne= Not exposed ; Co= Compliant ; E3=Every 3 years

This table illustrates that if the currently prescribed recommendations (with a weighting of 1) are followed, and furthermore, improvement activities (with a weighting of 1.2) are implemented throughout the life cycle of the wooden poles - particularly genetic improvement, which could enhance the natural durability class of eucalyptus; strict adherence to technical guidelines; frequent inspections of poles in service; and, if necessary, curative treatments - the maximum estimated service life in this simulation, as supported by the literature, becomes reasonable. Achieving or obtaining this service life in the Cameroonian context is therefore feasible.

3.3.2. Analysis of the Combination of Factors Leading to an ESL of 20 Years

The primary companies responsible for shaping and treating eucalyptus wood poles used in Cameroon propose a minimum service life of 20 years. Table 6 presents several combinations of factors that could ensure these wooden poles achieve the expected minimum service life.

Table 6. Factors Contributing to the Reference Service Life of Wooden Poles in Cameroon

Factors		A				B						C	E				F		G		*ESL (Yr)*
Variables (sub-factors)		K_{11}	K_{12}	K_{13}	K_{14}	K_{21}	K_{22}	K_{23}	K_{24}	K_{25}	K_{26}	K_{31}	K_{41}	K_{42}	K_{43}	K_{44}	K_{51}	K_{52}	K_{61}	K_{62}	
		Genetic enhancement of young eucalyptus plants	Adherence to eucalyptus silvicultural techniques	Compliance with the minimum cutting f...	Felling, pruning, and logging procedures	Execution of shaping operations	Drying procedure and moisture control	Quality of preservative, adherence to solution concentration and impregnation	Verification of treatment quality	Higher-than-usual retention rate of active substances	Additional physical protection at the pole	Employee qualification level	Precipitation and air/soil humidity levels	Presence of wood-damaging insects	Wind strength/intensity	Exposure to solar radiation	Compliant use with design conditions	Extent of vandalism to poles in service	Frequency of maintenance activities	Curative treatment of poles in operation	
Case 1	Caract.	N	M	Y	G	C	C	C	Y	N	A	M	L	Unz	L	Pe	Co	L	E6	N	***20***
	Value	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	***1***	
Case 2	Caract.	Y	M	Y	G	C	C	C	N	Y	P	H	H	Unz	L	Ne	Co	H	Nn	N	***20,38***
	Value	***1,2***	***1***	***1***	***1***	***1***	***1***	***1***	***0,8***	***1,2***	***1,2***	***1,2***	***0,8***	***1***	***1***	***1,2***	***1***	***0,8***	***0,8***	***1***	

Légend : Caract.=Caractéristic ; N=No ; M=Medium ; Y=Yes ; G=Good ; C=Correct ; A=Absent ; L=Low ; Unz=Unfavorable zone ; Pe=Partially exposed ; Co=Compliant ; E6=Every 6 years ; H=High ; Nn=None ; P=Present ; Ne=Not exposed

If the activities in the wooden pole supply chain for overhead power lines are conducted by highly skilled actors who strictly adhere to the currently recommended practices during the production and commissioning of wooden poles (weighting 1 in Table 6), it would indeed be possible for the poles to have a service life of 20 years in the overhead electricity distribution lines in Cameroon (Case 1). Moreover, this same service life could be achieved even in the presence of unfavorable factors, such as the failure to verify the quality of treatment, poles exposed to high levels of air and soil humidity, high levels of vandalism, and the absence of regular inspection campaigns. However, this would only be feasible if, in return, compensatory actions are taken to extend the poles' service life, including genetic improvement of seeds, chemical treatments with higher biocide retention rates than typically recommended, and additional physical protection at the base of the poles before installation.

Nevertheless, field observations generally suggest that the wooden poles currently produced in Cameroon fail to meet the durability expectations set by producers. This failure is not due to a lack of knowledge of the quality criteria for wooden poles, but rather to non-compliance with these criteria. The criteria, which are defined in a fragmented manner (silvicultural, shaping, treatment, and service life criteria), are not considered holistically due to the absence of a coordinating body within the wooden pole supply chain.

In any case, while field observations raise doubts about the 20-year service life recommended by wooden pole producers, it remains evident that some wooden poles in service in certain regions of Cameroon manage to meet and even exceed this service life. Should we understand these increasingly rare and exceptional performances as the result of a unique combination of favorable circumstances for the expected service life of the poles? Or perhaps, on rare occasions, some quality criteria for the poles are actually respected? Regardless, such an important industrial activity, responsible for distributing electrical energy across an entire country with major economic implications, should be managed with significant expertise by all involved parties. Therefore, the durability of wooden poles can only be guaranteed if efforts to ensure compliance with the quality criteria for inputs and outputs throughout the wooden pole life cycle are well coordinated

4. Conclusion

This study underscores the critical importance of adopting a sustainable and comprehensive approach to the durability of wooden utility poles in Cameroon, with particular emphasis on eucalyptus poles. While the Cameroonian government's decision to replace deteriorating wooden poles with concrete alternatives may offer a temporary solution, it fails to address the broader, long-term implications concerning sustainability, cost, and environmental impact. The findings of this study indicate that the premature failure of wooden poles is predominantly the result of a complex interplay of environmental, biological, and mechanical factors. Consequently, the degradation of these poles can be mitigated by effectively managing these influencing variables throughout the poles' entire life cycle.

Through the application of the factor method, this study identifies critical factors and sub-factors that significantly affect the service life of wooden poles. The analysis reveals that an appropriate management strategy could substantially extend their operational lifespan, thereby reducing the need for costly and ecologically detrimental replacements. It is evident that a targeted approach, which enhances production processes, optimizes installation conditions, and accounts for environmental factors, can markedly improve the durability of wooden poles. The study further demonstrates that the potential service life of wooden poles can range from as little as 8 months to up to 86 years, illustrating the substantial variability that exists based on the effective management of these influencing factors.

Additionally, the study highlights the urgent need for a context-specific and holistic solution that addresses the unique challenges posed by the Cameroonian environment. These challenges include, but are not limited to, climatic and edaphic factors, as well as the intrinsic biological properties of eucalyptus wood. While concrete poles may be perceived as a more durable option, the substantial environmental cost associated with their production, disposal, and long-term maintenance renders them a less sustainable solution when considered over the life cycle.

In conclusion, the results of this study suggest that a detailed understanding of the factors influencing the service life of wooden poles is paramount to identifying a more economically viable, socially equitable, and environmentally sustainable solution to the issue of pole durability. Future research and policy initiatives should focus on enhancing the management of these identified sub-factors, particularly through the adoption of improved maintenance practices, optimized material utilization, and context-specific construction techniques. By embracing this comprehensive approach, Cameroon can achieve a more sustainable, cost-effective, and resilient energy distribution network that will benefit both its citizens and the broader environment in the long term.

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