ORIGINAL RESEARCH ARTICLE

Composite electricity distribution poles for Kenya: a predictive, systematic and meta- analytic review

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ABSTRACT

Increasing levels of global forest denudation have led to increased global warming due to rising levels of greenhouse gases in the atmosphere. This is further exacerbated by the need for poles for power distribution among other uses. A need, therefore, exists to venture into alternative poles that are environmentally friendly and address the effects of deforestation. The paper addresses this emerging issue by suggesting the adoption of composite poles for power distribution in Kenya. Composite poles are those whose outer materials are ultraviolet stabilized, recyclable, and resistant to corrosion and attacks such as from insects and rodents. The outer material also has minimum water porosity. The inner material, on the other hand, is made of both fiber and Polyurethane material. The fibres are organic and can be of industrial or biological materials such as fiberglass, carbon fibre, or plant fibre, among others. This paper analyses the composition, available technologies, socio-economic benefits as well as risks to be mitigated by the adoption of composite poles in Kenya. Analysis of the total cost per pole installed for various pole types was done. Data collection methods involved interviewing Kenya Power and Lighting Company (KPLC) staff, the observation made at the Limuru factory, and the use of existing documentation by KPLC and the Kenya Bureau of Standards (KEBS). The paper reviewed studies done by KPLC and standards developed thereof by KEBS. Further key attributes of various pole technologies were compared and a comparison of composite poles with wood and concrete poles was carried out. In addition, the technical features of poles were compared. Data collected was analysed and the results were presented in tabular forms. The cost analyses of the various poles and a summary of the failure of wooden poles in various regions throughout Kenya were also covered. The study has demonstrated based on a life-term analysis, that composite poles would save up to 40% of the total costs incurred for projects that are replacing wooden and concrete poles over 80 years. This translates to about KES 51, 868, 363 per composite lifetime or about KES 648, 354 per year (USD 5,533.60 /a) in addition to the added benefits of easier and quicker installations, low operation costs, and longevity. Further still, Composites poles would significantly impact the amount of money charged to connect new clients to the Grid electricity. The study concludes by indicating that a need exists for further analysis of the cost elements using Net Present Value (NPV) approaches.

Keywords: Composite poles, fibre reinforced poles, concrete poles, ultra-violet, polyurethane.

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1.0 Introduction

Over the years, the use of concrete and wooden poles has dominated power distribution networks throughout the world and more so in Kenya. As a mitigation measure for deforestation, there have been technological changes through the use of composite poles, which are geared towards addressing the limitations of concrete and wooden poles. Concrete poles last longer but have the challenge of breaking when mishandled and have a heavy weight, resulting in a higher logistical cost. Wooden poles are cheaper but have a shorter lifespan due to rotting, termite and rodent infestation (Bolin & Smith, 2011). This results in higher operating costs, especially in swampy areas, mountainous areas, and off-grid areas. In order to overcome these challenges, the need to venture into alternative poles such as composite poles that are environmentally and economically friendly becomes more of a necessity than just an alternative.

1.1 Utilisation of various poles types for power distribution

Composite poles have a long history, with indications of the first one being installed on the Hawaiian island of Maui in the early 1960s. Made of Fibre Reinforced Polymer (FRP), composite poles are 25% less dense than wood, 90% less dense than steel, and 30% less dense than concrete. These make them comparatively more lightweight, stronger, and with lower conductivity properties (Table 1). (Pidaparti & Kalaga, 2017).

Table 1: Characteristics of various materials used to make power distribution poles

Property	Steel	Concrete	Wood	Composite
Density (pcf)	490	150	60	45
Mod. of Elasticity E (ksi)	29,000	5,000 to 6,000	1800 to 1900	20, 000 - 22,000 ***
Expected Service Life (years)	60 *	50	45 **	70 to 100
Coefficient of Thermal Conductivity (BTU/hr/ ft/ in/ °F)	25 to 40	10	0.8 to 1.2	5

Source: (Pidaparti & Kalaga, 2017)

*Where: *- Galvanized, ** - Treated and *** - depending on manufacturing process.*

Globally, the use of composite poles is increasing. In 1996, a 21.34-meter composite pole was developed, while in 2009, a 38.1-meter fibreglass composite pole was erected (Zhang *et al.,* 2010). Currently, research work has led to the fabrication of the Iso-truss transmission structures using lattice framework technology that demonstrates a practical application of the composite poles. Other areas of application of composites include cross-arms that add under-build distribution circuits to existing high-voltage transmission lines (Pidaparti & Kalaga, 2017). In Canada, Great Lakes Power has installed approximately 300 composite poles for H-Frame construction in its 230 kV transmission, while BC Hydro has installed 90 composite poles on lines at various voltages. In the USA, Ameren installed hundreds of composite poles system-wide to replace wooden poles damaged by a variety of causes. BTES, a company in Tennessee,

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USA, has installed 144 FRP poles on two transmission projects. Further, other utilities like TVA, SCE, Allegheny Power, and DVP are considering using FRP on their transmission lines (Pidaparti & Kalaga, 2017).

Based on global considerations, it is noted that the main hindrance to composite poles is the price per unit. The fibre-reinforced poles cost nearly twice the cost of wooden poles when considering the distribution networks (Pidaparti & Kalaga, 2017). The price differential, however, between FRP and wooden poles diminishes significantly when large transmission-sized poles are used. Due to this upfront initial cost element and not due to total life cycle costs, many utility companies tend not to deploy composite poles.

Globally, the market potential for distribution poles is about $9.3 billion for the USA. Of these, about 3.6 million distribution poles (mostly wood) have to be replaced each year. In addition, about 2.4 million have to be added annually. Unfortunately, the current manufacturing capabilities for composites are about 20,000 poles per month (Pidaparti & Kalaga, 2017). Scotland added 220 MW to the grid by installing 140 composite poles in just 5 days, reducing the installation costs, time, and need for access roads in the rugged Scottish terrain (Bolin & Smith, 2011). Information from *Electfarr Line Construction* (United States of America), a utility pole provider, shows that each wooden utility pole takes about 2-3 hours to install without any additional obstacles. In other words, installing three poles would take one day, so it would take more than 46 days to install 140 wooden poles.

In Kenya, the use of composite poles is still in its nascent stages. In 2014, the Kenyan Standard that details the technical specifications for the use of composite poles for telephone and grid electricity poles were developed. The specification was specifically for solid composite poles for overhead power lines, pole-mounted substations, street, and public lighting, line switchgear, and equipment. (Arbeli, 2016).

1.2 Technical specifications for composite poles in Kenya

The Kenyan technical specification for composite pole technology is anchored in the Kenya Standard KS 2513:2014 for Composite Poles for Telephone, Power, and Lighting Purposes (Nyakundi, 2021). The specification applies to these types of poles: (a) composite poles and (b) composite poles with Earth. Generally, the specification requires composite poles to have three components: the pole outer material; fibre; and polyurethane.

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Table 2: Description of various composite pole sections

Composite pole section	Material and description
Pole outer material	This material should be ultraviolet (UV) stabilized and recyclable. It should be resistant to attacks like those of termites, rodents, and boring insects. It should also be resistant to corrosion and have a minimum water porosity.
Fibre	Fiber must be industrial, biological, and/or organic in nature, such as fiberglass, carbon fiber, plant fiber, and organic materials.The tender response by local manufacturers showed they are using plant fibre like bamboo
Polyurethane (PUR)	Should be flexible and recyclable. It should maintain the flexural properties throughout the entire working life. Local manufacturers use PUR as a resin, which reinforces fibres.

Source: Kenya Power & Lighting Company. Document no. -KP1/13D/4/1/TSP/03/019-1

Local standards require the above technology to produce poles that are uniform in diameter and suitable for direct embedment into the ground without special foundations. The manufacturing materials selected should produce high-density, low-porosity, and lightweight recyclable poles.

The high-density polyethylene (HDPE) material in composite poles plays a key role in their durability by ensuring that the mechanical and chemical integrity of the pole remains intact. These poles can withstand harsh environmental conditions, rough handling, and any physical damage such as attacks from termites, woodpeckers, rodents, and impact from vehicles, among others. The tensile strength of these poles may also be enhanced by varying their material composition, making them withstand high tensile loads as in the case of steel but with minimal weight (high strength to weight ratio) (Gong *et al.,* 2013).

An existing document (KEBS, 2014) from the Kenya Bureau of Standards (KEBS) outlines the Kenya Standard KS 2513:2014, developed in 2014, which specifies the characteristics of solid composite poles, their design, raw materials, and construction methods and testing.

1.3 Materials and construction

1.3.1 The Composite Poles were designed, manufactured and tested to KS 2513:2914 and the requirements of this specification. The earthing details were to be as per this specification based on AS 4065-1992 and KS 04-503

1.3.2 The poles were to be round, with uniform diameter, and suitable for direct embedment into the ground without special foundations as per KS 2513:2014.

1.3.3 The poles were to be so designed and manufactured that their strength in transverse direction would be sufficient to take the load due to wind on conductors, fittings and the pole.

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1.3.4 Materials for composite pole manufacture were to be selected as to produce high density, low porosity and light weight recyclable poles, comprising of outer material, fibre and polyurethane.
1.3.5 The finished pole was to have a smooth and even external surface, free from kinks and swells.
1.3.6 Composite Poles to be used for street lighting were to have an embedded PPR conduit of diameter 23mm.
1.3.7 The earthing conductor was to be soft drawn copper conductors suitable for grounding electrical systems where high conductivity and flexibility are required.

Source: Kenya Power & Lighting Company. Document no. -KP1/13D/4/1/TSP/03/019-1)

Thus, from an enabling environment (regulations, policies, and standards), the use of composite tools in Kenya should, in tandem with the global trends, be increasing, but this has not been the case. This paper thus attempts to investigate the composite poles scenario and advise if such a direction will be beneficial to developing countries like Kenya.

1.4 Study justification and research gap

The Kenyan government has, in the last 8 years since 2014, allocated over KES 156 billion towards revamping the Kenyan electricity grid (Energy, 2022). This has mainly focused on the replacement of the distribution and transmission poles made of wood or concrete. This has meant a corresponding increase in costs, which has to be passed on to the new consumer in terms of connection fees, depending on whether one is getting connected to a single-phase or three-phase system. To help keep the connection fee low, a KES 2.7 billion subsidy was effected to theoretically keep the fees at KES 34,980 for a single-phase and KES 49,080 for three phases. However, the increased replacement of wooden poles (4 times within 80 years) and concrete poles (2 to 3 times within 80 years) means that replacement costs will erode any benefits acquired by the connection subsidy. (Energy, 2022).

Consequently, a need exists to explore the potential that the replacement of wooden and concrete poles with composite poles would have on the dynamics of connection fees. This study thus sought to address this gap by using analysis of field data acquired from KPLC as well as from secondary literature to make a case for the utilisation of composite poles within the Kenyan transmission and distribution grids. In verity, the study sought to address the research gap concerning the determination of the veracity and feasibility of composite poles in Kenya.

2.0 Materials and methods

2.1 Data collection

Interviewing of KPLC staff, observations made at the Limuru factory, and use of existing documentation by Kenya Power and Lighting Company (KPLC) and Kenya Bureau of Standards (KEBS) were the methods used to collect data. Existing data from Rural Electrification and Renewable Energy Corporation (REREC) shows that in 2015, Eco-poles Industries Kenya Limited (EIKL) offered KPLC 100 (no.) 10m long composite poles free of cost to test the technology. The poles were tested at the factory and passed the quality and functional tests. They were then

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installed at Westlands and Rudi and their performance was monitored for six months. The Monitoring and evaluation (M & E) result recommended their use based on a more detailed initial lifecycle-based cost-benefit analysis, and the prevailing policy.

2.2 Data analysis

Data collected was analysed and results were presented in tabular and graphical form. The cost incurred in erecting poles was compared for the different pole materials. Moreover, at constant diameters and heights of 225 millimeters and 10 meters, respectively, the weight of the various poles was compared for each material.

3.0 Results

3.1 Case study description

In one scenario, according to a study by the Ministry of Energy (MoE) in 2020, a total of 41 projects that would replace the wooden poles due to termite infestation were analysed region-wise across the country. The Rift Valley region, which is an undulating terrain requiring special efforts during replacements, took a huge share of these projects, as shown in Table 3 below.

Table 3: Region wise allocation of Poles replacement projects

Region	No of projects replaced	% Total
Rift Valley	15	36.60%
Nyanza	6	14.60%
North Eastern	6	14.60%
Coast	4	9.80%
Western	4	9,8%
Central	3	7.30%
Eastern	3	7.30%

Source: (Energy, 2020).

From the study, it was noted that majority of the projects (about 40) were replaced between 2014 and 2020 while one project was replaced in 2008.

3.2 Life time replacement of the poles in the case study

When comparing composite poles with wooden or concrete poles, the lifetime of the poles significantly affects the cost. Generally, a wooden pole lasts a maximum of 20 years while, based on life cycle assessment and Brazilian standard ABNT NBR 8451:1998, a reinforced concrete pole has a minimum lifetime of 30 to 35 years (de Simone Souza *et al.,* 2017). For the composite pole, it is expected to last 80 years. For purposes of the calculations, the minimum lifetime period is taken, to ensure that an operation period for the poles is guaranteed. Based on these lifetimes, the actual cost of the wooden and concrete poles' replacement was determined as illustrated in Table 4.

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Table 4: Determination of the lifetime Poles replacement costs (Energy 2020)

NO.	YEAR	AMOUNT (KES)	REPLACEMENT TYPE	Number of poles	Number of lifetime replacement	Approximate costs (KES)
1	2019	622,177.36	Wooden	47	4	2,488,709.44
2	2019	27,860.04	Wooden	3	4	111,440.16
3	2017	25,359.32	Wooden	2	4	101,437.28
4	2017	223,443.50	Wooden	17	4	893,774.00
5	2019	11,600.00	Wooden	1	4	46,400.00
6	2017	153,734.74	Wooden	12	4	614,938.96
7	2017	257,978.50	Wooden	20	4	1,031,914.00
8	2020	542,991.65	Wooden	41	4	2,171,966.60
9	2017	40,933.20	Wooden	4	4	163,732.80
10	2014	1,228,980.72	Wooden	92	4	4,915,922.88
11	2017	689,835.74	Wooden	52	4	2,759,342.96
12	2018	1,050,391.19	Wooden	79	4	4,201,564.76
13	2017	647,395.38	Wooden	49	4	2,589,581.52
14	2014	345,466.06	Wooden	26	4	1,381,864.24
15	2020	406,190.11	Wooden	31	4	1,624,760.44
16	2017	3,662,560.84	Wooden	274	4	14,650,243.36
17	2015	294,561.10	Wooden	23	4	1,178,244.40
18	2008	1,110,543.48	Wooden	84	4	4,442,173.92
19	2014	1,695,992.95	Wooden	127	4	6,783,971.80
20	2020	2,198,206.57	Wooden	165	4	8,792,826.28
21	2014	194,780.24	Wooden	15	4	779,120.96
22	2017	104,901.12	Wooden	8	4	419,604.48
23	2020	152,120.08	Wooden	12	4	608,480.32
24	2014	524,462.91	Wooden	40	4	2,097,851.64
25	2014	51,572.06	Wooden	4	4	206,288.24
26	2018	125,368.62	Wooden	10	4	501,474.48
27	2019	2,157,822.15	Wooden	162	4	8,631,288.60
28	2017	756,819.31	Wooden	57	4	3,027,277.24
29	2019	15,199.74	Wooden	2	4	60,798.96
30	2017	272,070.36	Wooden	21	4	1,088,281.44
31	2017	1,274,498.88	Wooden	96	4	5,097,995.52
32	2017	501,016.56	Wooden	38	4	2,004,066.24
33	2018	65,746.58	Wooden	5	4	262,986.32
34	2020	178,300.80	Wooden	14	4	713,203.20
35	2019	171,181.00	Wooden	13	4	684,724.00
36	2017	1,909,349.30	Concrete replacement	77	2.67	5,091,598.13
37	2019	404,880.00	Wooden	31	4	1,619,520.00

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NO.	YEAR	AMOUNT (KES)	REPLACEMENT TYPE	Number of poles	Number of lifetime replacement	Approximate costs (KES)
38	2017	817,628.00	Wooden	62	4	3,270,512.00
39	2019	159,104.00	Wooden	12	4	636,416.00
40	2019	10,863,568.00	Concrete replacement	436	2.67	28,969,514.67
41	2020	738,774.05	Wooden	56	4	2,955,096.20

From the foregoing Table 4, the actual installation costs under a business-as-usual scenario (no technology change, but continuing with the current pole technology) is capped at KES 129, 670, 908.44 million, as compared to the current one-time wooden and concrete pole replacement costs of KES 36, 675, 366.

3.3 Cost Analysis

Table *5* below illustrates analysis of the total cost per pole installed for various types of poles transported at a distance of 30 km.

Table 5: Cost analysis of the total cost per pole installed for various pole types for a 30km-distance

	Cost breakdown (KES)					
Pole description	Cost of Pole	Transport	Hole digging	Erection	Dressing	Total Poles costs
Wooden poles – 10M	9,740	330	1,500	1,000	800	13,370
Concrete poles – 10M	15,335	1500	1,500	5,800	800	24,935
Composite poles Ø225 - 10M	30,700	100	1,500	500	800	33,600
Composite poles Ø225 with Bamboo pole	27,200	100	1,500	500	800	30,100
Composite poles Ø180- 10M	27,500	100	1,500	500	800	30,400
Composite poles Ø180 with free bamboo	25,000	100	1,500	500	800	27,900

Based on Table 5, a lifetime cost analysis was done to assess whether using composite poles over 80 years would compare to using wooden and concrete poles over the same duration (the latter two with replacements). The results (Table 6) demonstrate that (assuming a fixed cost for the 3 types of posts over 80 years), composite poles will save ~40% (KES 51, 868, 363) of the KES 130, 749, 440 used over the time period.

Table 6: Lifetime Cost analysis of different poles types in 80 years

	Wooden pole replacement	Concrete poles replacement	Composite poles replacement
Number of poles as per Case study	1,807	513	0
Replacement rate of the poles	4	2.67	0
Number of poles over the 80 year lifetime**	7,228	1,368	2,320 ***
Life time of pole before replacement	20	30	80

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Average cost (KES) / pole (including transport, erection, dressing and hole digging) over 80 years	13,370	24,935	33,600
Total costs (over an 80-year period) in KES	96,638,360	34,111,080	77,952,000
Total project replacement cost vs composites in KES		130,749,440****	77,952,000

*** - The number of poles over the maximum lifetime of the longest surviving pole i.e. Composite pole is taken as 80 years and thus number of poles will vary depending on the replacement rate over the 80 year period*

**** - The figure 2,320 is obtained by adding all the current existing wooden poles (1,807) and concrete poles (513). The comparative analysis is thus done by considering that if all existing poles (wooden and concrete) were replaced by composite poles over an 80-year period, what would be the impact.*
***** - The observed variation between the total approximate costs in Table 4 of KES 129,670,908.44 and the total lifetime costs of KES 130,749,440 in Table 6 are attributable to the rounding off errors. In addition, the costs in Table 4 is calculated based on costs, while that of Table 6 is based on rounded off poles figures.*

3.4 Comparison of technical features and key attributes for various pole materials
Referring to the study done by KPLC to compare various technical pole features where 225mm diameters of the respective pole materials were used, it can be observed from Table 7 that the cost of erection when using wooden and concrete poles is higher (KES 1,000 and 5,800 respectively) compared to composite poles, which is KES 500.

Table 7: Comparison of key attributes of various types of pole technologies

Composite pole		Concrete pole		Wooden pole	
√	Lightweight		Lightweight		Lightweight
√	Non toxic	√	Non toxic		Non toxic
√	No corrosion		No corrosion	√	No corrosion
√	Sustainable		Sustainable		Sustainable
√	Long lifecycle	√	Long lifecycle		Long lifecycle
√	Low carbon footprint		Low carbon footprint		Low carbon footprint
√	Recyclable		Recyclable		Recyclable
√	UV resistant	√	UV resistant		UV resistant
√	Rain and salt resistant		Rain and salt resistant		Rain and salt resistant
√	Pest and rodent resistant	√	Pest and rodent resistant		Pest and rodent resistant
√	Flexible		Flexible		Flexible
√	No deforestation	√	No deforestation		No deforestation
√	Reusability		Reusability		Reusability

According to table 2, composite poles are the lightest (180 kilograms), which explains why the cost of transporting composite poles was the lowest; that is, more of these poles could be transported per trip, reducing the number of trips made and thus the overall cost, which includes but is not limited to fuel and labor costs (Table 8).

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Table 8: Technical features of the ø225 composite pole technology compared with other pole technologies

S/no	Property	Composite pole	Wood	Concrete
1	Weight	180 kg	600-650kg	860-900 kg
2	Transport	100 per truck	50-60 per truck	30 per truck
3	Installation / Connection	Requires 4 people to install (2 to 3 times) faster	Requires 8-10 people to install	Requires 14 people to install or additional costs be incurred in the use of a crane

4.0 Conclusion

Conclusively, we can deduce that the composite pole is the most viable pole type to use for power distribution. It is durable and can last for over 50 years because of its excellent chemical and mechanical properties. The analysis of the various sites indicates that in the long term, when considered with regard to life-term, composite poles provide better value for money as compared to concrete and wooden poles. Significant among the 41 project sites considered is the fact that, at the end of the 80 years, a switch to composite poles would save close to 40% of the previously planned expenditure.

The other additional socio-economic advantages that this switch to composite poles would bring include:

i. Transfer of technology and know-how.
ii. Use of locally produced raw materials and a market for dried, semi-processed, and value-added fibre producing plants like bamboo lead to new jobs and growth in the local economy.
iii. development of cottage industries for bamboo and other fibre-producing plants, with countless products along commodity value chains.
iv. Bamboo and other fibre-producing plants are renewable and environmentally friendly resources with greater potential, growing three times faster than eucalyptus and
v. Local partnerships through cooperation with local companies in expertise, quality, ethical standards, and joint action.

The risks to be mitigated by adoption of composite poles in areas with challenges under this section include but are not limited to: delays in project implementation; public protests due to delayed projects; additional budget due to replacement of wooden poles; accidents; including electrocution resulting from falling wooden poles; and power outages due to faulty wooden poles.

5.0 Recommendations for further research

This study has demonstrated that the use of composite poles over their lifetime far outweighs

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the costs and advantages that wooden and concrete poles would have. However, future studies should consider: (a) time value of money in the costs so assessed. This requires a Net Present Value (NPV) methodology in doing the cost analyses and (b) making a predicted approach based on energy demand and growth projections of the electricity grid to determine how this impacts the number of poles required over a time horizon of 80 years.

6.0 Acknowledgements

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6.2 Presentation of the study, findings, and a portion of the work

These preliminary findings were presented in abstract communication and poster presentation at the 16th JKUAT scientific, technological and industrialization conference held at Jomo Kenyattata Univesity of agriculture and techolnology , Kenya, from 24 to 25, March 2022. This paper's abstract may be found at: https://drive.google.com/file/d/1pCiWvu_euU7VfS-_Q4krXYViWSeFelml/view from the 16th JKUAT and 1st Hybrid Scientific Confrence.

6.3 General

REREC Supply Chain Department for sharing tendering details, the KPLC team for sharing details of field study/experimentation/Analysis and tender specifications for composite poles,

6.4 Specific

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6.5 Declaration of interest

All authors declare that they have no conflict of interest. The author(s) of this article are responsible for the content, editing decisions, manuscript composition, viewpoints expressed, and acceptance of the final content, and consent to publish if any errors remain.

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