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Assessment of Energy Losses and Cost Implications in the Nigerian Distribution Network

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Abstract Energy shortages is the major challenge facing the industrial sector in Nigeria. This paper assessed the energy shortages due to technical losses in the Nigerian distribution network and the cost implications. The study was carried out based on network data collected over the period 2011-2015 from three electricity distribution companies (DisCos) drawn from the three major industrial cities of Nigeria. These data were simulated on the Electrical Transient Analysis program (ETAP) Version 12.6. The calculated energy losses for these cities for the said period are 108,959.87 MWH, 149,256 MWH and 72,743.08 MWH respectively. The corresponding revenue losses are ₦2,434,164,012, ₦3,538,754,758.8 and ₦1,699,751,530.1 respectively. The paper suggested remedial measures to reduce energy losses, mitigate losses arising from unannounced electricity cuts as well as achieve a more efficient and reliable electricity distribution network. The outcome of this research provides a data bank for policy makers and future researchers in the areas of electricity generation, transmission and distribution.

Keywords: *electricity failures, energy loss implication, energy shortages, Nigeria firms, power outages*

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1. Introduction

Energy is fundamental for socio-economic and industrial development. Energy stimulates productive activities in all sectors of a nation's economy including industry, commerce, agriculture and mining. Energy shortages have severe negative impact on both industrial and commercial growth. Ref. [1] investigated the relationship between energy consumption and the Nigerian economy from the period of 1970 to 2005 and found that energy consumption positively correlated with economic growth. Similarly, ref. [2] studied energy consumption and economic performance in Nigeria and found that the volume of energy consumption is a strong determinant of the nation's economic growth. Ref. [3] studied the relationship between energy consumption and economic growth for 11 countries in sub-Saharan Africa and found that energy consumption co-integrated with economic growth in Cameroon, Cote d'Ivoire, Gambia, Ghana, Senegal, Sudan and Zimbabwe thus proving that energy consumption has a significant positive long-run relationship on economic growth of those countries. Similarly, ref. [4] examined the impact of energy consumption on economic growth in Nigeria over the period 1980-2010 and found a long-run relationship between economic growth and energy consumption.

In their own work, ref. [5] employed a multiple regression model to ascertain the effect of electricity supply on economic development as well as the possible effect of electricity supply on industrial development in Nigeria during the period 1970-2010. Their findings show that electricity, gross fixed capital formation, industrial production variables and population positively correlated with the gross domestic product per capita in the country. In other words, energy shortages result in low economic activities. Figure 1 is a graphical representation of the effect of power outages on the Gross Domestic Product (GDP) of selected countries in Africa. As can be seen from the figure, the higher the economic cost of power outages in a nation, the higher the percentage of the nation's GDP that gets eroded.

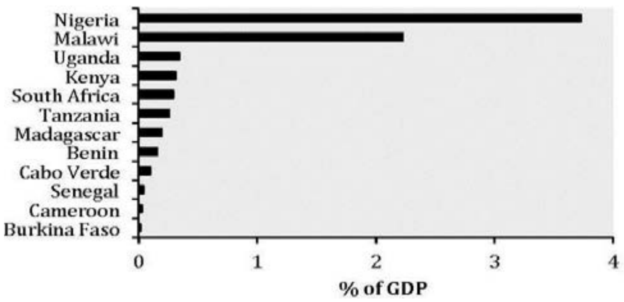

Figure 1. Economic Costs of Power Outages in selected African countries [7]

Energy shortages result from technical (load and no-load losses, line losses etc.) and non-technical losses (losses due to vandalism, illegal connections to transmission/distribution lines or energy theft, meter tampering etc.). In 2014 alone, about 12% of energy losses in the Nigeria distribution network was due to technical losses [6]. The established correlation between electricity supply and Gross Domestic Product makes it necessary, therefore, to ascertain energy losses due to technical losses and the cost implications in the Nigerian distribution network in view of perennial shortages in electricity supply to the nation's industrial sector.

The estimation of the quantity and cost of energy losses in the distribution systems due to vandalism and illegal connections to distribution lines, though these too are important factors of electricity losses is beyond the scope of this study.

Electricity Distribution companies (DisCos) in Nigeria are all privatized and are responsible for the expansion of the distribution network's MV and LV grid. The companies are generally owned by consortia among which are larger state governments. The 11 distribution companies were scheduled to handle over 5,000 MW and cover the areas: Abuja, Benin, Eko, Enugu, Ibadan, Ikeja, Jos, Kaduna, Kano, Port Harcourt and Yola. At the time of handing over to these core investor companies the concept of Aggregate Technical, Commercial and Collection (ATC&C) loss reduction was employed in the bidding process. What this means is that the investor that proposed the highest ATC&C loss reduction (in absolute percentage terms) over a five-year period was deemed to have won the bid. This concept was preferred over other sale evaluation methods in order to commit the distribution companies to pursuing loss reduction as a fundamental issue and a priority. Two years down the privatization line, however, these companies are faced with myriad operational challenges including lack of investment funds. Thanks to the Central Bank of Nigeria (CBN) which provided a 10-year intervention to the power sector to ensure provision of low cost, long-term debt financing to the DisCos. Recently, Kano DisCo acquired 62,000 energy meters courtesy of the CBN facility [8]. Some DisCos have opted to raise long term debt by way of debt securities issuance and listing and quotations of such securities on the market while a handful of other Discos are considering the adoption of off-balance sheet funding solutions to finance capital items such as metering, network expansion and embedded generation. To complement the distribution companies' effort towards energy efficiency improvement, the Federal Government in April 2015 adopted the Nigeria's National Renewable Energy and Energy Efficiency Policy which provides incentives for selling, manufacturing and importing energy-efficient products, while also promoting policies for renewable energy sources [9].

2. Methodology

Data and information on the sampled distribution networks were collected from three electricity distribution companies located in the three major Nigerian cities under review. The distribution companies are Eko Electricity Distribution Company (EKEDP) in Lagos city for data and diagram on the Agbara/Badagry distribution network, Kano Electricity Distribution Company (KEDCO) in Kano city for data and diagram on the Sabon Gari distribution network and the Port Harcourt Electricity Distribution Company (PHEDCO) in Port Harcourt city for data and diagram on the Port Harcourt distribution network. Data and information collected from each of the sampled distribution companies include: (i) Single line diagram of each injection substation and its associated feeders (See Figure 2 annexed). (ii) Monthly maximum loading on the feeders for the period 2011- 2015 (iii) Feeder route length (iv) Size of conductor used for feeders (v) Daily outages on each feeder for the period 2011-2015. These data were simulated on the Electrical Transient and Analysis Program (ETAP) version 12.6 software and the simulation results used in the computation of energy losses and the corresponding revenue losses in the respective distribution networks. The research findings are presented using appropriate statistical tables and charts.

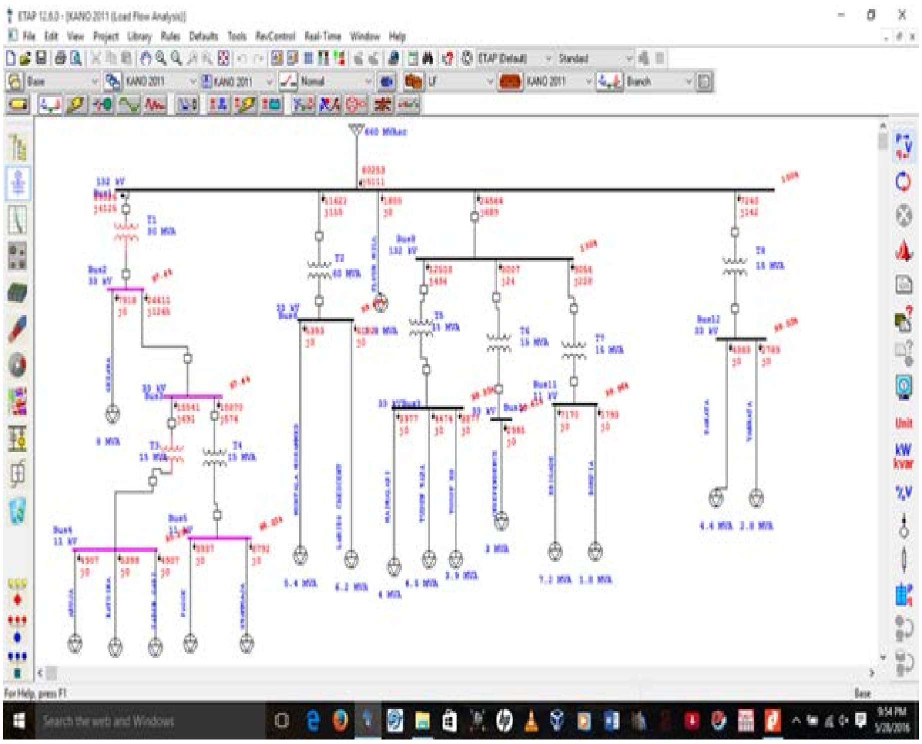

Figure 2. ETAP Single line representation of SabonGari distribution network

According to ref. [10], energy is the total amount of work done and power is how fast the work is done. In other words, power is energy per unit of time. Power is watts. Energy is watt-hours.

Given a typical network, therefore, the relationship between the energy input and the energy lost in the network respectively can be expressed as:

$$E_{in} = P_{in} \times t \quad (1)$$

$$E_{losses} = P_{losses} \times t \quad (2)$$

Where: E_{in} is the energy in Joules (J) delivered in the network, t is the time in Seconds (S) taken for energy transfer and E_{losses} is the energy lost in Joules (J) in the network.

Let C_e represent the electricity tariff or cost in Naira (₦) per unit of electrical energy lost, E_{loss} in Kilowatt-Hour (KWH), we can then express the total revenue lost, R_{lost} as follows:

$$R_{lost}(₦) = C_e(₦ / KWH) \times E_{losses}(KWH) \quad (3)$$

Table 1 - Table 3 show the calculated yearly energy losses and the losses in revenue due to energy losses in Beecham and Evans industrial feeders in Agbara/Badagry injection substations, Independence and Bompai industrial feeders in Sabon Gari/Dakata injection substations and Glass factory and Old Aba Road industrial feeders in Akanni/Trans-Amadi injection substations respectively for 2011-2015.

Table 1. Calculated Yearly Energy Losses and Losses in Revenue due to Energy Losses in Beecham and Evans Industrial Feeders in Agbara/Badagry Injection Substations for 2011-2015

Beecham 11KV Feeder			
Year	**Energy Loss (Kwh)**	**Tariff (₦/Kwh)**	**Loss in revenue (₦)**
2011	1,636,130	15.2	24,869,176
2012	3,143,240	23.10	72,608,844
2013	3,232,530	23.10	74,671,443
2014	3,358,580	23.10	77,583,198
2015	4,207,650	23.10	97,196,715
	Total		346,929,376
Evans 11KV Feeder			
Year	**Energy Loss (Kwh)**	**Tariff (₦/Kwh)**	**Loss in revenue (₦)**
2011	998,520	15.2	15,177,504
2012	2,128,320	23.10	49,164,192
2013	3,208,780	23.10	74,122,818
2014	3,527,400	23.10	81,482,940
2015	4,002,900	23.10	92,466,990
	Total		312,414,444

Table 2. Calculated Yearly Energy Losses and Losses in Revenue due to Energy Losses in Independence and Bompai Industrial Feeders in Sabon Gari/Dakata Injection Substations for 2011-2015

Independence 11KV Feeder			
Year	**Energy Loss (Kwh)**	**Tariff (₦/Kwh)**	**Loss of Revenue (₦)**
2011	2,190,400	15.2	33,294,080
2012	3,294,560	22.80	75,115,968
2013	3,577,570	23.94	85,647,025.8
2014	3,647,740	25.14	91,704,183.6
2015	4,101,459	26.39	108,237,503.01
	Total		393,998,760.41
Bompai 11KV Feeder			
Year	**Energy Loss (Kwh)**	**Tariff (₦/Kwh)**	**Loss of Revenue (₦)**
2011	754,530	15.2	11,468,856
2012	1,649,420	22.8	37,606,776
2013	2,115,880	23.94	50,654,167.2
2014	2,622,270	25.14	65,923,867.8
2015	2,909,110	26.39	76,771,412.9
	Total		242,425,079.9

Table 3. Calculated Yearly Energy Losses and Losses in Revenue due to Energy Losses in Glass factory and Old Aba Road Industrial Feeders in Akanni/Trans-Amadi Injection Substations for 2011-2015

Glass Factory 11KV Feeder			
Year	**Energy Loss (Kwh)**	**Tariff (₦/Kwh)**	**Loss of Revenue (₦)**
2011	754,530	15.2	11,468,856
2012	1,649,420	22.80	37,606,776
2013	2,115,880	23.48	49,680,862.4
2014	2,622,270	24.91	65,320,745.7
2015	2,909,110	25.66	74,647,762.6
	Total		238,725,002.7
Old Aba Road 11KV Feeder			
Year	**Energy Loss (Kwh)**	**Tariff (₦/Kwh)**	**Loss of Revenue (₦)**
2011	999,180	15.2	15,187,536
2012	1,618,500	22.80	36,901,800
2013	1,965,010	23.48	46,138,434.8
2014	2,149,640	24.91	53,547,532.4
2015	2,198,370	25.66	56,410,174.2
	Total		208,185,477.4

3. Results and Discussion

3.1. Energy Losses in the Distribution Network

Table 4 – Table 6 show the maximum energy losses in the respective sampled distribution network substations. During the period 2011-2015, the Agbara/Badagry substation in the Eko distribution network in Lagos showed a maximum energy loss of 108,959.87 MWH (Table 4).

Table 4. Maximum Energy Loss in Agbara/Badagry for 2011-2015

Feeder	Maximum Energy Loss (MWH) per Feeder					Total Energy Loss (MWH) 2011-2015
	2011	**2012**	**2013**	**2014**	**2015**	
Unilever	1,784.15	3,179.31	4,467.64	4,489.87	4,490.49	18,411.46
Evans	998.52	2,128.32	3,208.78	3,527.4	4,002.9	13,865.92
P&G	1,945.42	3,371.58	3,388.19	4,116.05	5,033.58	17,854.82
Beecham	1,636.13	3,143.24	3,232.53	3,358.58	4,207.65	15,578.13
Nestle	1,093.02	2,426.65	2,659.17	3,654.07	3,899.68	13,732.59
OPIC	2,060.2	3,135.84	3,611.95	4,503.56	5,308.46	18,620.01
Guinness	964.71	2,026.78	2,220.05	2,690.31	2,995.09	10,896.94
Total	10,482.15	19,411.72	22,788.31	26,339.84	29,937.85	108,959.87

Table 5. Maximum Energy Loss in Sabon Gari/Dakata for 2011-2015

Feeder	Maximum Energy Loss (MWH) per Feeder					Total Energy Loss (MWH) 2011-2015
	2011	2012	2013	2014	2015	
SabonGari	1,444.0	2,627.9	3,850.4	4,205.6	4,887.2	17,015.1
Bompai	754.53	1,649.4	2,115.9	2,622.3	2,909.1	10,051.2
Independence	2,190.4	3,294.6	3,577.6	3,647.7	4,101.5	16,811.7
Gezewa	2,357.2	4,503.2	4,862.6	4,959.4	5,002.1	21,684.5
Abuja	1,849.5	2,597	3,665.7	3,763.1	4,277.4	16,152.6
Flour Mill	2,765.1	3,889.3	3,997.7	4,087.3	4,242.2	18,981.5
Fagge	1,849.5	2,897	3,665.7	3,763.1	4,477.4	16,652.6
Murtala	1,093.0	2,426.7	2,659.2	3,654.1	3,899.7	13,732.6
Brigade	1,830.1	3,176.5	3,600.4	4,528.7	5,038.5	18,174.2
Total	16,133.33	27,061.6	31,995.2	35,231.3	38,835.1	**149,256**

Table 6. Maximum Energy Loss in Akanni/Trans-Amadi for 2011-2015

Feeder	Maximum Energy Loss (MWH) per Feeder					Total Energy Loss (MWH) 2011-2015
	2011	2012	2013	2014	2015	
Glass Factory	754.53	1,649.42	2,115.88	2,622.27	2,909.11	10,051.21
Rumuogba	915.09	1,617.12	1,929.01	2,132.49	2,218.76	8,812.47
Rumurolu	796.02	1,385.09	1,649.32	1,684.58	1,957.34	7,472.35
Water Works	915.09	1,617.12	1,929	2,132.49	2,237.49	8,831.19
Nda Bros	917.69	1,617.1	1,929.01	2,132.49	2,237.66	8,833.95
Famie	999.18	1,618.5	1,965.01	2,149.64	2,198.3	8,930.63
Rivoc	956.95	2,026.78	2,211.45	2,690.31	2,995.09	10,880.58
Old Aba Rd	999.18	1,618.5	1,965.01	2,149.64	2,198.37	8,930.7
Total	7,253.73	13,149.63	15,693.69	17,693.91	18,952.12	**72,743.08**

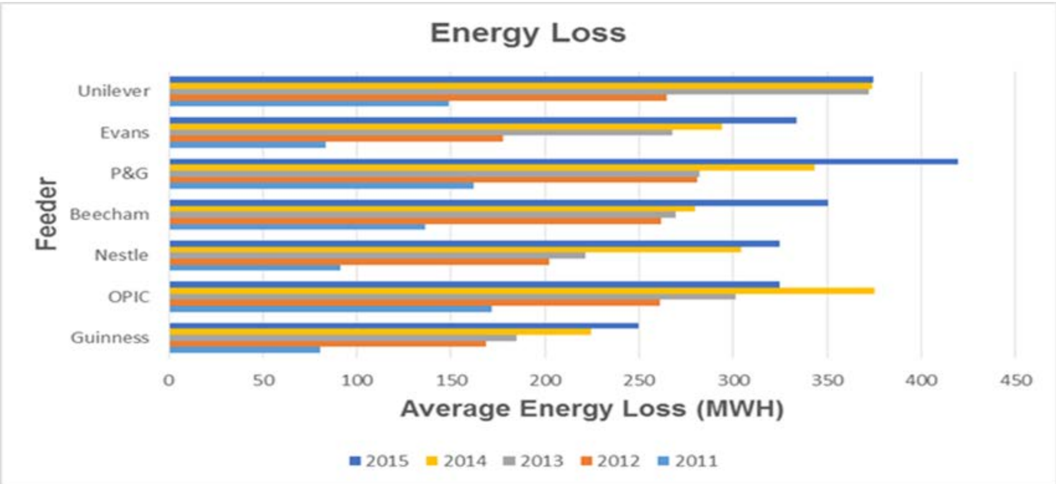

Figure 3. Average Energy Losses in Agbara/Badagry for 2011-2015

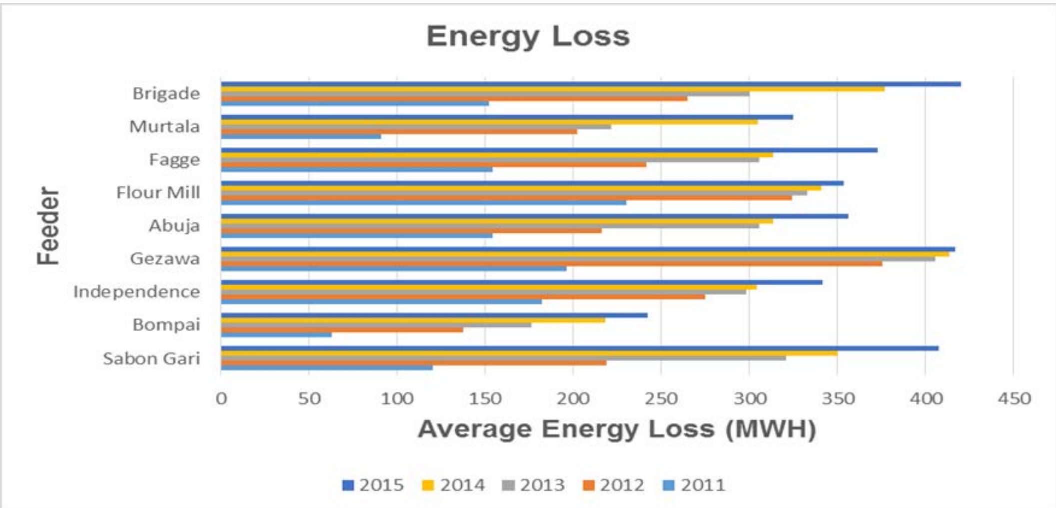

Figure 4. Average Energy Losses in Sabon Gari/Dakata for 2011-2015

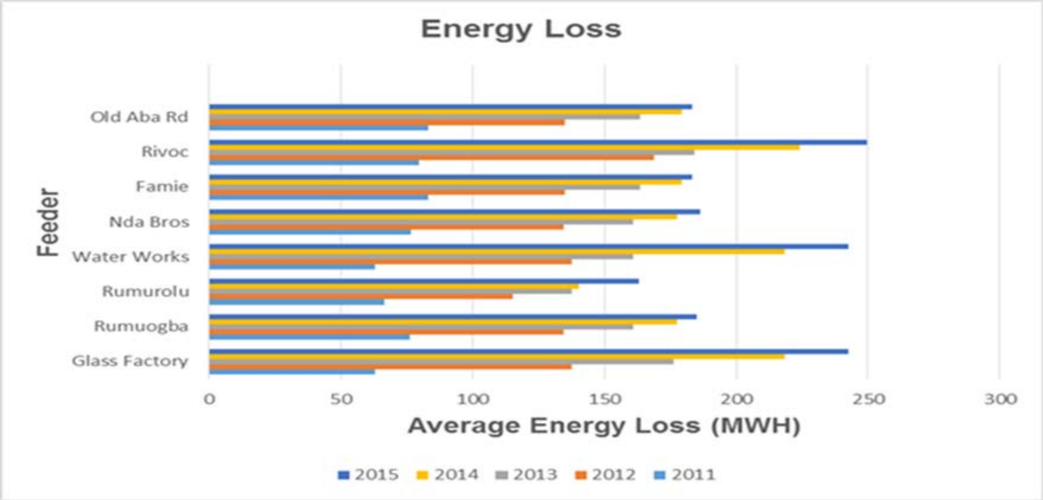

Figure 5. Average Energy Losses in Akanni/Trans-Amadi

It was observed also that the highest maximum energy loss during the period was reported on the Gezewa feeder in the Sabon Gari/Dakata injection substation in Kano distribution network. This high value of energy loss (21,684.5 MWH) reported on Gezawa feeder is attributable to the power losses on the feeder during the five (5) year period covered by the study. It is obvious from Tables 4 – 9 that the energy losses in each of the distribution networks increased yearly. This is attributable to yearly increases in power losses resulting from overloaded transformers, distribution lines and other system components [10,11]. Figure 3 – Figure 5 show the average energy losses in each of the distribution networks.

Recent researches [10,11,12] have shown that high power losses contribute to high energy losses in distribution networks. It is important therefore that utilities minimize power losses in the system in order to reduce the resultant energy losses. Other factors that contribute to increased energy losses in distribution systems are vandalism, illegal connection to transmission/distribution lines, poor workmanship, use of wrong sizes of conductors etc.

3.2. Loss of Revenue in the Distribution Networks

Table 7 - Table 9 show the maximum revenue losses in the industrial substations of the sampled distribution networks. During the five year period (2011-2015) covered by the study, the Agbara/Badagry substation in the Eko distribution network in Lagos showed a maximum revenue loss of ₦2,434,164,012 (Table 7). The Sabon Gari/Dakata substation in Kano distribution network showed a maximum revenue loss of ₦3,538,754,759 (Table 8) while the Akanni/Trans-Amadi substation reported maximum revenue loss of ₦1,699,751,530 (Table 9). It is obvious from the Tables that the revenue losses in each of the distribution networks increased yearly. This is due to yearly increases in energy losses as reported by each of the distribution companies investigated.

Table 7. Maximum Loss of Revenue in Agbara/Badagry per year

Feeder	Maximum Loss of Revenue (₦) per Feeder					Total Loss of Revenue (₦) 2011-2015
	2011	**2012**	**2013**	**2014**	**2015**	
Unilever	27,119,080	73,442,061	103,202,484	103,715,997	103,730,319	411,209,941
Evans	15,177,504	49,164,192	74,122,818	81,482,940	92,466,990	312,414,444
P&G	29,570,384	77,883,498	78,267,189	95,080,755	116,275,698	397,077,524
Beecham	24,869,176	72,608,844	74,671,443	77,583,198	97,196,715	346,929,376
Nestle	16,613,904	56,055,615	61,426,827	84,409,017	90,082,608	308,587,971
OPIC	31,315,040	72,437,904	83,436,045	104,032,236	122,625,426	413,846,651
Guinness	14,663,592	46,818,618	51,283,155	62,146,161	69,186,579	244,098,105
Total	159,328,680	448,410,732	526,409,961	608,450,304	691,564,335	**2,434,164,012**

Table 8. Maximum Loss of Revenue in Sabon Gari/Dakata per year

Feeder	Maximum Loss of Revenue (₦) per Feeder					Total Loss of Revenue (₦) 2011-2015
	2011	2012	2013	2014	2015	
Independence	33,294,080	75,115,968	85,647,026	91,704,184	108,237,503	393,998,760.4
Bompai	11,468,856	37,606,776	50,654,167	65,923,868	76,771,413	242,425,079.9
Flour Mill	42,029,976	88,675,128	95,704,220	102,753,465	111,951,658	441,114,446.8
Abuja	28,112,096	59,210,460	87,755,661	94,604,083	112,880,322	382,562,621.7
Gezawa	35,829,288	102,672,960	116,409,926	124,679,567	132,006,211	511,597,951.9
Brigade	27,817,216	72,423,744	86,194,534	113,851,769	132,965,751	433,253,014.1
SabonGari	21,948,952	59,916,120	92,178,815	105,728,030	128,972,416	408,744,333.5
Fagge	28,112,096	66,050,460	87,755,661	94,604,083	118,158,322	394,680,621.7
Murtala	16,613,904	55,327,620	63,660,530	91,863,320	102,912,555	330,377,928.8
Total	245,226,464	616,999,236	765,960,539	885,712,368	1,024,856,151	**3,538,754,759**

Table 9. Maximum Revenue Loss in Akanni/Trans-Amadi per year

Feeder	Maximum Loss of Revenue (₦) per Feeder					Total Loss of Revenue (₦)
	2011	2012	2013	2014	2015	2011-2015
Glass Factory	11,468,856	37,606,776	49,680,862	65,320,746	74,647,762.6	238,725,003
Rumuogba	13,909,368	36,870,336	45,293,155	53,120,326	56,933,381.6	206,126,566
Rumurolu	12,099,564.8	31,580,052	38,726,034	41,962,888	44,353,324.4	168,721,863
Water Works	13,909,368	36,870,336	45,293,155	53,120,326	57,413,993.4	206,607,178
Nda Bros	13,948,888	36,870,336	45,293,155	53,120,326	57,418,355.6	206,651,060
Famie	15,187,536	36,901,800	46,138,435	53,547,533	56,408,378	208,183,681
Rivoc	14,545,640	46,210,584	51,924,846	67,015,622	76,854,009	256,550,702
Old Aba Rd	15,187,536	36,901,800	46,138,435	53,547,532	56,410,174	208,185,477
Total	110,256,757	299,812,020	368,488,076	440,755,298	480,439,379	**1,699,751,530**

The Gezewa feeder in the Sabon Gari/Dakata injection substations in the Kano distribution network showed the highest energy loss (21,684.5 MWH) during the study period and so incurred the highest revenue loss of ₦511,597,951.9 when compared to the feeders in the Eko and Port Harcourt distribution networks that recorded lower energy loss values. Figure 6 – Figure 8 show the average revenue losses in each of the distribution networks.

Figure 6. Average Revenue Loss in Agbara/Badagry for 2011-2015

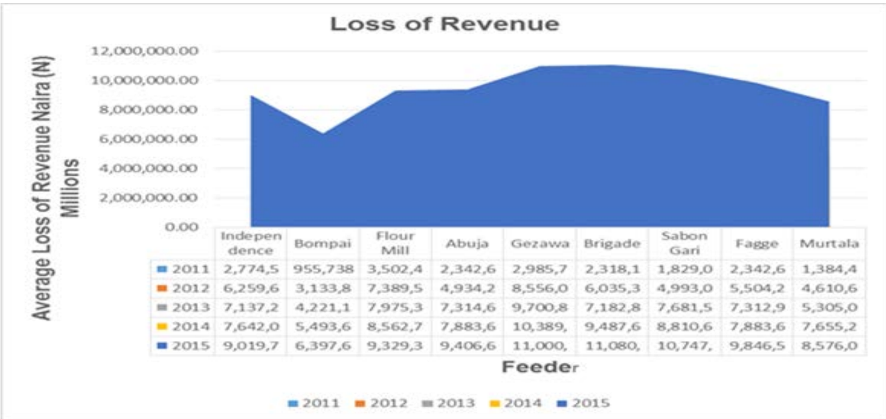

Figure 7. Average revenue loss in Sabon Gari/Dakata for 2011-2015

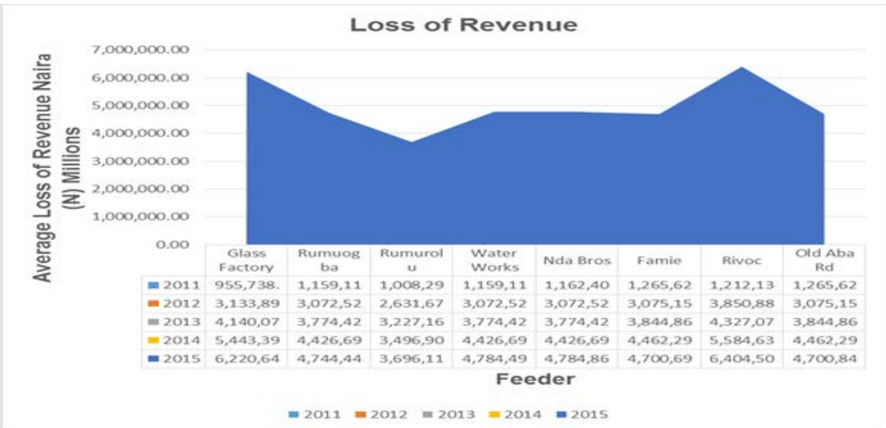

Figure 8. Average Loss of Revenue in Akanni/Trans-Amadi for 2011-2015

Table 10 shows the summary of the energy and revenue losses in the three distribution networks surveyed. These findings confirmed claims by earlier studies [10,13,14,15,16,17] that energy shortages result in loss of revenue and depletion of funds available to the distribution companies to invest in and render more satisfactory services to electricity consumers [18,19,20].

Table 10. Summary of Energy and Revenue Losses in the Lagos, Kano and Port Harcourt Distribution Networks

City	Energy Losses (MWH)	Revenue Losses (₦)
Lagos	108,959.9	2,434,164,012
Kano	149,256	3,538,754,758.8
Port Harcourt	72,743.1	1,699,751,530.1
Total	**330,959**	**7,672,670,300.9**

4. Conclusion

The calculated energy loss for the period 2011-2015 yielded 108,959.87 MWH for the Eko distribution network. This is while the Kano distribution network and the Port Harcourt distribution network reported 149,256 MWH and 72,743.08 MWH respectively. The calculated revenue loss for the same period showed ₦2,434,164,012 for the Eko distribution network, ₦3,538,754,758.8 for the Kano distribution network and ₦1,699,751,530.1 for the Port Harcourt distribution network. In other words, a total of ₦7,672,670,300.91 (Seven Billion, Six Hundred Seventy-two Million, Six Hundred Seventy Thousand, Three Hundred Naira, Ninety Kobo) only was lost as a result of a total energy loss of 330,958.95 MWH in the three distribution networks during the period covered by the research.

The paper recommends government legislation against vandalism and energy theft such that suspected vandals are prosecuted and convicts made to suffer stiff penalties. Such legislation should in addition compel Utilities make pre-paid meters available to every electricity consumers in order to checkmate power wastages and exploitation of unsuspecting customers by dubious staff of distribution companies (DisCos). The paper further recommends an immediate and comprehensive power generation planning programme that would determine the country's maximum load demand when the suppressed loads are added to the national grid. Government should emulate Ghana and Niger Republic and legislate an energy conservation and efficiency policy that would encourage consumers to use electricity gadgets and devices that do not consume much current. There should be intensive enlightenment programmes to educate the public and especially electricity users on how to use the energy economically and efficiently and on the need to safeguard electrical installations and equipment in their domains from being vandalised. The study findings would find application amongst energy policy makers and stakeholders in the energy industry.

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Competing Interests

The authors declare that no conflicting interests exist.

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