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The Direct Assessment and Captive Costs Methods for Estimating the Economic Costs of Power Outages among Selected Industries in Nigeria

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***ABSTRACT*:** *Due to frequent power outages, the typical Nigerian firm incurs huge costs arising from damaged equipment, lost output, spoiled materials, idle workers and restart costs. This paper developed mathematical models for the computation of the economic costs due to power outages in selected electricity intensive industries from the major industrial areas of Nigeria. This became necessary to optimize investment and operating decisions for adequate power outage mitigation measures.*

Keywords: *Electricity, Impact, Industries, Outages, Power outages costs*

I. INTRODUCTION

Provision of infrastructural services such as electricity, in most developing countries, is the sole responsibility of government. Confronted with ever dwindling revenue, however, most governments are unable to provide and maintain these infrastructures resulting in shortages in the supply of these services [1]. An electric power outage has many socio-economic consequences [2]. Preventing power outages therefore is important in order to avoid its adverse effects on both the economy and the social life of the people [3]. Understanding the impact of a power outage is vital to devising measures to curtail it. The magnitude of the cost of a power outage depends on several factors such as the duration of the outage, the time of day the outage occurred, the season of an outage, the frequency of an outage, the severity of the outage, the type of customer (whether industrial, service, residential or agricultural) and the character of the outage (whether the outage was anticipated or not) [3, 4, 5]. Among these factors, however, are two that have the greatest monetary significance. These are: the duration of the power outage and the character of the outage [6]. Frequent power outages in Nigeria arising from government inability to provide uninterruptible power supply has imposed a huge cost on the average firm operating in the country resulting from damaged equipment, lost output, spoiled materials, idle workers and cost of operation restarts. It is imperative, therefore, to quantify these costs in order to successfully optimize investment and operating decisions for adequate power outages mitigation and more efficient power sector.

II. METHODS OF EVALUATING POWER OUTAGES COSTS

Several methods have been evolved for the assessment of the customer costs of electric power outages [3, 5, 7]. See Table 1. The major categories commonly in use today include:

***Indirect Analytical methods*.** The indirect analytical method, also known as the Ratio of Gross Economic Output to Energy Consumption technique [8, 9], uses objective data such as electricity tariffs, gross national product of a country and the country's annual electricity consumption to ascertain the interruption costs otherwise referred to as the Customer Damage Functions (CDF). Some of the big advantages of this method of evaluating power outage costs are: its objectivity in using publicly declared, easy to access data like electricity prices and turnovers, straightforwardness and cheapness in estimating the value of outage costs. The method, however has some big disadvantages as well. For instance, many direct costs are usually not sufficiently captured and all indirect costs are virtually overlooked. Its results are also too broad and are therefore not very useful to the utilities for planning purposes [3, 7].

Case studies

Case studies are usually carried out after the occurrence of large and significant blackouts as in the case of the 1977 New York City blackout and covers both direct and indirect costs of power interruption [8, 9]. The direct costs of an outage often include loss of sales, loss of food, etc. while the indirect costs are comprised of emergency costs and losses resulting from some civil disorders that took place following the outage. Case studies have the unique advantage of dealing with more accurate data due to the fact that the study gets conducted soon after a real interruption. The major disadvantages of the method are the frequency of the large blackout events and the difficulty to draw an analogy between the large scale and the small scale blackouts [3, 9]. Previous studies show that the indirect costs are usually higher than the direct costs despite being very cumbersome to ascertain [3, 10]. Also, the study findings from case studies suffer great limitations imposed by geographic constraints as well as the characteristics and duration of the specific outage being studied [8].

Customer Surveys methods

Customer surveys methods employ the technique of asking questions in order to determine the costs of power outages and therefore require active mutual communication e.g. one-to-one interviews, telephone calls, and sending and receiving e-mails. Questions are often asked about the time of day when the outage occurred (whether during working hours or outside working hours), the duration of the outage, and the season of the year (whether summer or winter) [9]. The customer surveys methods are the most suitable for calculating outage costs because it affords sufficient and more accurate outage cost data for planning purposes [3, 11]. The methods have the disadvantages, however, of being very costly due to the fact that customer response rates to survey are usually low such that to get more accurate data, the questionnaire must be done to as many customers as possible. Besides, it requires much time and effort to design the survey, retrieve and analyse the respondent data [8].

Variations of the customer surveys methods include: The preparatory action method (PAM), that directly evaluates outage costs in terms of costs of mitigation measures required to avoid outage, the direct worth (DW) technique that evaluates the outage costs in terms of avoiding the impact of the outages [11] and the price proportional method that involves both the willingness to pay (WTP) and willingness to accept (WTA) techniques [3, 12]. In WTP, the survey asks the customers how much they are willing to pay for uninterruptible electricity supply. But in WTA, the survey seeks to understand how much the customers are willing to accept as compensation in case of an interruption in service supply [13]. Studies, however, show a pattern among the respondents to demand more compensation while unwilling to pay the amount of money that would otherwise be needed to provide them with the desired service for the same outage scenario. This causes much disparity between WTP and WTA results such that it is often advised that WTP and WTA results be never used in isolation while making outage cost evaluations.

Proxy methods

Proxy methods make use of an observable customer behaviour in order to estimate the cost of an outage. These power outage cost assessment approaches, consider that an industrial customer would rather prefer to rely on back-up generation until such a time when the marginal cost of additional back-up power would equal the expected marginal cost of an outage event [14]. Such choice by the consumer thus becomes an evidence of 'revealed preference' towards avoiding an outage [15, 16]. Proxy methods are widely known not to reveal much detail about consumer preferences and sometimes provide only an upper or lower limit on outage cost estimates. In order to obtain an outage cost, proxy methods also make numerous assumptions, and usually does not consider such helpful cost assessment factors like the duration of an outage, time or season of the outage, type of customer, etc. [8].

Power outage cost researches in Nigeria applied mostly the customer surveys methods and dates back to the 1960s when [17] used the production function approach (a variation of the customer survey method) to study power outage costs in the industrial and commercial sectors in Nigeria during 1965 and 1966. The problems with this study was that [17] used aggregated data for the manufacturing sector and thus omitted subsector effects of the power outages; besides, the study focused only on output loss for unsupplied electricity and ignored other equally vital costs such as raw material and equipment spoilage and the cost of auto-generation [1].

Another researcher, [18] adopted the self-assessment technique to study the cost of power outages on the household sector and focused on the high-income area of Lagos Island, Ikoyi, Victoria Island, Yaba and Surulere areas of Lagos state in Nigeria. He ended up with high cost estimates having concentrated his study only on the high-income area of the household sector in Lagos.

Yet [19] used the self-assessment survey to measure the adaptive costs to the business sectors in coping with infrastructural deficiencies in Nigeria. Their study shows that most firms in Nigeria adapt to the unreliability of publicly provided electricity by investing in backups. The problem with this study is the self-assessment approach used which suffers from the limitation of subjectivity.

Table 1: Previous studies on Cost of Power Outages

S/N	Study	Country	Sector	Methodology
1.	Ukpong (1973)	Nigeria	Industrial	Proxy method
2.	Ontario Hydro (1980)	Canada	Industrial	Survey
3.	Bental and Ravid (1982)	USA and Israel	Industrial	Proxy method
4.	Billinton, Wacker and Wojczynski (1982)	Canada	Industrial	Survey
5.	Billinton, Wacker and Wojczynski (1982)	Canada	Residential	Survey
6.	Iyanda (1982)	Nigeria	Residential	Survey
7.	Bernstein and Heganazy (1988)	Egypt	Industrial	Proxy method
8.	Doane, Hartman and Woo (1988)	Canada	Residential	Survey
9.	Lee and Anas (1992)	Nigeria	Industrial	Survey
10.	Caves, Herriges and Windle (1992)	USA	Industrial	Proxy method
11.	Uchendu (1993)	Nigeria	Industrial	Survey
12.	Matsukawa and Fuji (1994)	Japan	Services	Proxy method
13.	Beenstock, Goldin and Haitovsky (1997)	Israel	Business & Public	Proxy method
14.	Adenikinju (2005)	Nigeria	Manufacturing	Survey

Later, [20] considered the different types of outage costs e.g. material and equipment loss, value of unproduced output lost, etc. through a survey of various sectors covering the industrial and commercial firms in Lagos state. However, the study like [19] adopted the self-assessment survey approach widely known for subjectivity and possible exaggeration of figures by the respondents. Besides, the study was conducted within the Lagos metropolis only, thereby making generalisation of the results to other industrial areas of the country almost impossible.

Reference [21] estimated the adaptive costs of electricity failure on the Nigerian economy without due consideration of the short-term losses incurred by consumers such as raw material and equipment spoilage and lost output [1]. Their research was therefore not sufficiently comprehensive and generalizable.

Lastly, [1] adopted both the revealed preference approach [14, 15, 22] which allowed him to freely estimate the firms' willingness to pay for a reliable supply of electricity and the production approach which enable him estimate the potential losses to the firm from power outages. His approaches have the dual benefits of making inference of the mitigated costs arising from the installation of private generators possible thereby providing a basis for why firms still invest in their own electricity generation plants, high marginal cost of private generation notwithstanding. The approaches also allowed the losses due to power outages to be characterized based on firm size, location and sector of operations. A major drawback of his study is that it focussed on firms located along Lagos–Ibadan, Kano–Kaduna and Anambra–Imo axes [1] thereby capturing but marginally the industrial nerve-centres of the nation. The outcome of the study can therefore be hardly used to generalise to other parts of Nigeria.

III. THE METHODOLOGY FOR THIS STUDY

The afore-stated literature highlight some of the attempts to estimate the cost of electric power outages in Nigeria. This paper as an addition to these efforts, however, adopted the direct assessment and captive costs methodology in estimating the economic costs of the power outages among Nigerian industries – an approach different than any previously used by any researcher known to the authors of this paper. For instance, unlike any of the previous studies, this paper used a methodology which combines the full benefits of the direct and the

captive costs assessment methods and survey techniques. This makes it possible to ascertain both the direct cost of power outages to the respective industries and the costs incurred by each industry as it invests in backup facilities to mitigate power outages. Unlike previous attempts to evaluate costs of outages also, the study covered Lagos, Kano and Port Harcourt which, statistically speaking, are the most populous as well as the three most industrialised cities of the country. With stratified sampling design employed in the work, therefore, it is very possible to generalise the results of the research to all subsectors of industries in Nigeria irrespective of their sizes, business specialties and locations.

Two models were derived for this study. The first is the total direct cost model for the evaluation of power outages incurred by each of the industries selected for study. See Fig. 1. This model is expressed mathematically as:

$$T_{dc} = C_{dm} + C_{po} + C_{lb} + C_{de} + C_{er} + C_{rs} \quad \text{.....(1)}$$

The summation of the total direct cost for all the industries gives:

$$\sum_{i=1}^{N} T_{dci} =$$

$$\sum_{i=1}^{N} C_{dmi} + C_{poi} + C_{lbi} + C_{dei} + C_{eri} + C_{rsi} + ... + C_{dmN} + C_{poN} + C_{lbN} + C_{deN} + C_{erN} + C_{rsN}$$

.....(2)

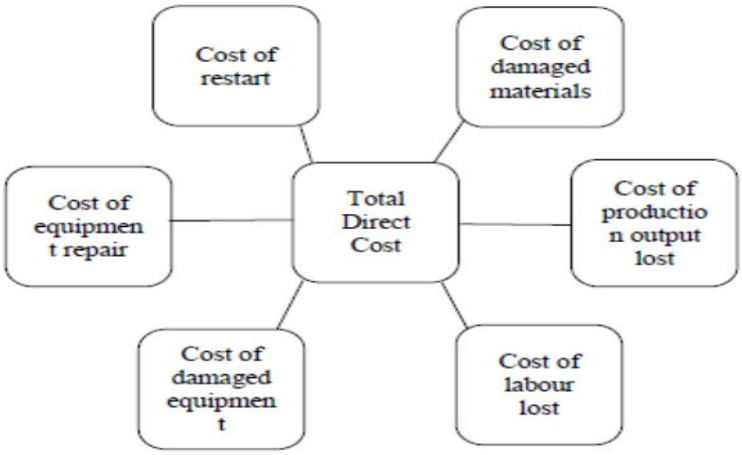

Fig. 1: Total direct costs due to power outage

Where,

T_{dc} = Total direct cost incurred by each industrial consumer

C_{dm} = Cost of damaged materials

C_{po} = Cost of production output lost

C_{lb} = Cost of labour lost

C_{de} = Cost of damaged equipment

C_{er} = Cost of equipment repair

C_{rs} = Cost of restart

N = Total number of industries selected for the study

The cost per unit of electricity in Kilowatt-hour lost ($/KwH) is expressed as:

$$C_{el} = T_{dc} / E_{ls} \quad \text{..........}(3)$$

Where,

E_{ls} = Total units of electricity, in Kilowatt-hour, lost due to power outages

The second model is that of the total captive (indirect) cost derived from the cost of backup facilities put in place by each of the industrial consumer to mitigate power outage. Total captive cost or cost of backup facilities for each industry expressed mathematically,

$$T_{bc} = [(C_{bc} \text{ x } D_{fb}) + C_{bm} + C_{fc}] / E_{bp} \quad \text{..........}(4)$$

Therefore the summation of the total captive cost for all the industries gives:

$$\sum_{i=1}^{N} T_{bci} = \sum_{i=1}^{N} [(C_{bci} \text{ x } D_{fbi}) + C_{bmi} + C_{fci}] / E_{bpi} + \dots + [(C_{bcN} \text{ x } D_{fbN}) + C_{bmN} + C_{fcN}] / E_{bpN} \quad \text{..........}(5)$$

Where,

C_{bc} = Purchase or capital cost of backup plant

D_{fb} = Depreciation factor of backup plant (assumed per annum)

C_{bm} = Annual maintenance cost of backup plant

C_{fc} = Annual cost of fueling backup plant

N = Total number of industries selected for the study

E_{bp} = Total units of electrical energy, in Kilowatt-hour, generated by backup plant per annum. Adding (2) and (5) yields:

Total cost in $ due to power outages,

$$T_{cpoi} = \sum_{i=1}^{N} T_{dci} + \sum_{i=1}^{N} T_{bci} \quad \text{..........}(6)$$

IV. CONCLUSION

This paper successfully developed mathematical models for the computation of economic costs arising from power outages in selected electricity intensive industries in Nigeria. The direct costs and the captive (backup) costs assessment techniques are useful in estimating the costs directly incurred by the firm and the mitigation costs arising from the use of backup facilities in the event of a power outage. By including all the essential components e.g. the cost of damaged materials, production output lost, labour lost, damaged equipment, equipment repair, restart as well as purchase cost of backup plant, annual maintenance cost of backup plant and annual cost of fueling backup plant, etc. the paper covered almost holistically the industrial costs due to power outages. The results, therefore, are reliable for the purposes of industrial energy planning.

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