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Nigerian Power Sector: Comparative Analysis of Productivity

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Abstract: -Undoubtedly, power instability in the Nigerian Power Sector despite several mitigative measures by the government has created some chocks in the national socio-economic wheel of development. Unfortunately, the conceptual objective of the power reforms to remedy inadequate power generation capacity, inefficient usage of capacity, ineffective regulation and high technical losses is tardily being achieved. This research comparatively analyzed the rate of productivity change in Nigeria's power sector from 2005 – 2013. The analysis reveals that privatization improved the productivity index by 89%. It is expected that this work may assist the power policy makers and regulators to come up with abetter framework for the full realization of the noble goals envisaged in this reform act.

Keywords:- *Ineffective regulation, Productivity change, Productivity index, Power reform, Technical losses.*

I. INTRODUCTION

Electric power poverty is the lack of or limited access to electricity. Put differently, it occurs when supply of electric power falls below demand or expectations. Electric power poverty is a perennial social problem affecting most developing countries not just Nigeria alone. Statistics shows that 1.6 billion people (one quarter of the world population) have no access to electricity, 80% of them in South Asia and Sub-Saharan Africa (IEA, 2002). Four out of five people without electricity live in rural areas of the developing countries. Electric power poverty or crisis is a major barrier to growth and development in several areas of the world. This implies that many countries wishing to develop and become industrialized, must address their electric power challenges and ensure that adequate electricity is provided at affordable cost.

Electricity plays a very important role in the socio-economic and technological development of every nation. The electricity demand in Nigeria far outstrips the supply and the supply is epileptic in nature. The country is faced with acute electricity problems, which is hindering its development notwithstanding the availability of vast natural resources in the country. It is widely accepted that there is a strong correlation between socio-economic development and the availability of electricity. No doubt the epileptic performance of the power sector, in terms of matching supply with demand expectations, has led to a decline in the living standard of the population and hampered sustainable development in the country. Given the low levels of electricity generation and access in Sub-Saharan Africa, it is not surprising that per capita consumption of electricity averages just 457 kWh annually, with the average falling to 124 kWh if South Africa is excluded (World Bank, 2005). The wide energy gap and poverty in comparative regional terms is apparent in per capita electricity consumption in Nigeria being 140 KWh in 2004 compared to 1337 KWh in Egypt and 4560 KWh in South Africa as at 2003 (IwayemiA., 2008[a]). Nigeria's projected per capita consumption of 5000kWh in 2030 will be about 20% above the level that obtained in South Africa in 2003.

For the past three decades, inadequate quantity, quality and access to electricity services have been a routine feature in Nigeria. Although Nigeria is blessed with large amount of renewable energy resources like hydropower, solar, wind and biomass, extensive substitution of poor public electricity supply with high polluting self-generated power prevails. In fact, Nigeria's economy has been described as a *"diesel generator economy"* where businesses incur extremely high overhead cost in maintaining their power generators which cause unsafe health environment due to their carbon footprints. Conceptually, the power reforms are aimed at solving a myriad of problems, including limited access to infrastructure, low connection rates, inadequate power generation capacity, poor utilization capacity, and lack of capital for investment, ineffective regulation, high technical losses and vandalism as well as insufficient transmission and distribution facilities (Adenikinju, 1998).

II. OVERVIEW

To discuss the power sector in Nigeria in a realistic and practical context, some brief review is necessary to give an insight into the sector since independence. The history of electricity in Nigeria dates back to 1896 when electricity was first produced in Lagos, fifteen years after its introduction in Britain from which Nigeria obtained independence in 1960. The total capacity of generators used then was 60kW (Makoju J.O, 2007). The first attempt to nationally coordinate the supply and development of electricity occurred in 1950 with the establishment of a central body known as Electricity Corporation of Nigeria, ECN.

On1st April 1972, the operation of ECN and NDA were merged to form National Electric Power Authority (NEPA) a company with exclusive monopoly over electricity generation, transmission, distribution and sales throughout the country. Sincethe inception of NEPA which was renamed Power Holding Company of Nigeria (PHCN), the authority expanded annually in order to meet the ever-increasing demand. Unfortunately, majority of Nigerians still do not have access to electricity and supply to those connected is not regular. Nigeria also joined the trend, having deregulated its electricity industry through the enactment of the Electric Power Reform Act of 2005 (Isola W.A., 2011). The law paved the way for restructuring the power sector by the unbundling of PHCN into 18 companies: six generating companies, one transmission company, and 11 distribution companies and Independent Power Producers (IPPs). The incorporation of these enterprises under the National Integrated Power Project (NIPP) has been concluded. Ironically, though the electricity crisis has intensified,the present government has suspended the NIPP citing constitutional reasons associated with its financing from excess crude funds (Iwayemi A., 2008[a]).

Despite its long history, PHCN's developmentwas very slow and electricity generation in Nigeria deteriorated over the years. This was hardly expected given the country's enormous endowment in natural resources that facilitate and enhance electricity production. While the generation, transmission and distribution (GTD) deteriorated, the demand for electricity exponentially increases continuously. PHCN has been incapable of providing minimum acceptable international standards of electricity service reliability, accessibility and availability for the past three decades (Iwayemi A., 2008[b]). One method PHCN has used to beef up its actual power output from time to time has been the commissioning of new stations. Experience has shown that new power plants merely solve the problem in the short run. The technical problems that put out the older units no sooner than latter affect the new ones and they also go down (Adeola A., 2008). One of the objectives of this study is to compare the performance of the country's power generation stations over a period of time and make recommendations on how to improve their performance.

III. METHODOLOGY

Electric energy production in Nigeria over the last 40 years varied from gas–fired, oil–fired, hydroelectric power systems to coal-fired with hydroelectric power system and gas–fired system taking precedence (Garba B.& Sambo A.S. et al, 2009). Substantial expansion in quantity, quality and access to electricity is fundamental to rapid and sustained economic growth and poverty reduction.

The analysis of a network utility, such as an electricity industry, requires a fundamental rethinking on the way in which the sector is operated and regulated. The basic idea is to compare the productivity of Nigeria's power plants and to assess the impact of reform on Nigeria's power sector.

The policy implications of surveyed papers focus on the differences in efficiency and drivers of efficiency, the role of alternative regulatory frameworks in efficiency, and the comparative analysis of public and private companies. Kleit and Terrell observed that deregulating electricity generation increases efficiency while Barros and Peypoch state that regulation without competition decreases efficiency (Barros & Peypoch, 2008; Kleit & Terrell, 2000). Efficiency analysis in relation to electricity has been concentrated on distribution networks. Jamasb and Pollitt reviewed the frequency with which different input and output variables are used to model electricity distribution (Jamasb T.& Pollitt M., 2001).

Research on Nigeria power sector includes those on policies and issues, electricity generation, transmission and distribution, cost of infrastructure failure, energy poverty and investments in the power sector and analysis of power sector productivity(Iwayemi A., 2008; Garba B. et al, 2009; Adenikinju A., 2005; Agba M., 2011; Iwuamadi O.C. et al, 2012). None of these papers compared the annual productivity of Nigerian power plants and assessed the impact of the reformon the power sector using MATLAB®.

IV. MODEL DESCRIPTION AND ANALYSIS

The comparative analysis of productivity of a network utility, such as the Nigerian electricity industry requires a fundamental consideration of all factors of electricity production. This research analysis is with specific interest in electricity generation in Nigeria. Not restricting the survey to a sample of recent papers on energy production, it is observed that they adopt one of two complementary efficiency methodologies: Data Envelopment Analysis and the Stochastic Frontier Model. It is recognized in literature that both methods give similar ranking and that there is no universally agreed set of input and output variables for modeling of electricity units. This work employed the Cobb-Douglas Stochastic Frontier Model and Malmquist Index.

Cobb-Douglas Stochastic Frontier Model

If the electricity generation function is denoted by $G(L, K)$, then the partial derivative $\partial G/_{\partial L}$, is the rate at which electricity generation changes with respect to the amount of labor. Economists call it the marginal production with respect to labor or the marginal productivity of labor. Likewise, the partial derivative $\partial G/_{\partial K}$ is the rate of change of electricity generation with respect to capital and is called the marginal productivity of capital (Bao Hong, Tan, 2008).

In these terms, the assumptions made by Cobb and Douglas can be stated as follows:

1. If either labor or capital vanishes, then so will production.
2. The marginal productivity of labor is proportional to the amount of production per unit of labor.
3. The marginal productivity of capital is proportional to the amount of production per unit of capital.

Because the production per unit of labor is $G/_L$, assumption 2 says that $\partial G/_{\partial L} = \alpha[G/_L]$, for some constant α. If we keep K constant ($K = K_0$) then this partial differential equation becomes an ordinary differential equation:

$$dG/_{dL} = \alpha[G/_L] \quad (1.0)$$

This separable differential equation can be solved by re-arranging the terms and integrating both sides:

$$\int 1/_G\, dG = \alpha \int 1/_L\, dL \quad (1.1)$$

$$\ln(G) = \alpha \ln(cL) = \ln(cL)^\alpha \quad (1.2)$$

And finally,

$$P(L, K_0) = C_1(K_0)L^\alpha \quad (1.3)$$

Where $C_1(K_0)$ is the constant of integration and we write it as a function of K_0 since it could depend on the value of K_0.

Similarly, assumption 3 says that:

$$dG/_{dK} = \beta[G/_K] \quad (1.4)$$

Keeping L constant($L = L_0$), this differential equation can be solved to get:

$$G(L_0, K) = C_2(L_0)K^\beta \quad (1.5)$$

Finally, combining equations (1.3) and (1.5) gives:

$$G(L, K) = bL^\alpha K^\beta \quad (1.6)$$

Where b is a constant that is independent of both L and K.

Assumption 1 shows that α > 0 and β > 0.

Notice from *equation (1.6)* that if labor and capital is both increased by a factor m, then

$$G(mL, mK) = b(mL)^\alpha(mK)^\beta = m^{\alpha+\beta}\left(bL^\alpha K^\beta\right) = m^{\alpha+\beta}G(L, K) \quad (1.7)$$

If $\alpha + \beta = 1$, then $G(mL, mK) = mG(L, K)$, which means that production is also increased by a factor of *m* (Boa Hong, Tan; 2008).

Here the Cobb-Douglas stochastic production frontier function is as written in equation (1.6)

$G(L, K) = bL^\alpha K^\beta$

Where:

- $G = the\ total\ electricity\ generated\ in\ a\ period$
- $L = labor\ input\ (the\ total\ number\ of\ person\ hours\ worked\ in\ a\ period)$
- $K = capacity\ input\ (the\ installed\ capacity\ of\ equipments)$
- $b = total\ factor\ of\ productivity$

α *and* β are the output elasticities of labor and capital, respectively. These values are constants determined by available technology in a given period.

Output elasticity measures the responsiveness of output to a change in level of either labor or capital used in production (Iwuamadi et al, 2012).

V. MALMQUIST INDEX

This is a bilateral index that enables a productivity comparison between two different entities of similar category or between two different periods for the same entity. These entities could be economy, firms, processes, performances and so on. It is based on the concept of production function, that is, a function of

maximum possible production, with respect to a set of inputs pertaining to capital and labor (Malmquist S., 1953).
Here, we are comparing the productivity function between periods to assess the impact of power reform. Assume that the aggregate electricity generation function of a utility firm is given as $G(L, K)$. Then for firm A in period *t*, we have the aggregate production function as $G_t(L_{A_t}, K_{A_t})$ and for period *t+1*, we have $G_{t+1}(L_{A_{t+1}}, K_{A_{t+1}})$. L and K describe the labor input and the installed capacity respectively.
Substituting the inputs of period *t+1* into the generation function of *t* results to $G_t(L_{A_{t+1}}, K_{A_{t+1}})$ and the inputs of *t* into *t+1* to get $G_{t+1}(L_{A_t}, K_{A_t})$. The Malmquist index of period *t* with respect to period *t+1* is the geometric mean of $M_{A_t} = G_t(L_{A_t}, K_{A_t}) / G_t(L_{A_{t+1}}, K_{A_{t+1}})$ (1.8a)

and

$$M'_{A_t} = G_{t+1}(L_{A_t}, K_{A_t}) / G_{t+1}(L_{A_{t+1}}, K_{A_{t+1}}) \quad (1.8b)$$

Mathematically Malquist Index, *MI* for firm *A* between periods *t and t+1* is stated as:

$$MI_{A_{(t,t+1)}} = \sqrt[2]{(M_{A_t} \times M'_{A_t})} = \sqrt[2]{\left(\frac{G_t(L_{A_t}, K_{A_t})}{G_t(L_{A_{t+1}}, K_{A_{t+1}})}\right)\left(\frac{G_{t+1}(L_{A_t}, K_{A_t})}{G_{t+1}(L_{A_{t+1}}, K_{A_{t+1}})}\right)} \quad (1.8c)$$

VI. DATA SOURCE

This analysis made use of dataset on all the existing Nigerian electricity plants from 2005 to 2013 from several sources. The sources of the data are the Power Holding Company of Nigeria generation report, National Control Center PHCN Oshogbo, publications of Nigerian Ministry of Power and Steel. However data gaps are filled with other sources such as National Power Training Institute of Nigeria (NAPTIN) and publication of Iwuamadi et al, 2012.

VII. ESTIMATION OF MODELS

Let the power generation technology of Nigerian power stations in time *t*, be denoted as $\mathcal{G}_t$, which represents the transformation inputs $\{X^t \in R^m\}$ into the outputs $\{Y^t \in R^n\}$.

$$\mathcal{G}_t = \{(X^t, Y^t): X^t \text{ can produce } Y^t\}$$

$$\{(K_t, L_t) \in X^t\} \text{ where } K \text{ and } L \text{ are installed capacity and labor respectively}$$

$$\{(E_p, L_{av}, L_{max}) \in Y^t\} \text{ where } E_p, L_{av} \text{ and } L_{max} \text{ are electric energy produced, average load and maximum load respectively}$$

$$R^m \text{ and } R^n \text{ are all the inputs and outputs respectively}$$

Assuming constant return to scale of the input variables in consideration (Iwuamadi et al, 2012), an algorithm for human labor is given as:

$$L_t = \left|\left(\frac{K_t - K_{t-1}}{K_{t-1}}\right) L_{t-1} + L_{t-1}\right|_{t=2,3,4\ldots\ldots} \quad (1.9)$$

The output Cobb-Douglas stochastic production frontier function at time period *t* is defined as:

$$G_t(L_{A_t}, K_{A_t}) = P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t} \quad (1.10)$$

where $P_t = \beta_t / \alpha_t = Total\ factor\ productivity\ at\ period\ t$

$\beta_t = utilization\ factor$

$\alpha_t = capacity\ factor\ at\ t$

$(Iwuamadi\ et\ al, 2012)$

$$\{(K_t, L_t): K_t \geq 0, L_t \geq 0\} \quad (1.11)$$

To compare productivity over a period of time *t and t+1*, mixed period Cobb-Douglas stochastic production frontier functions is defined as:

$$G_t(L_{A_{t+1}}, K_{A_{t+1}}) = P_{t+1} * K_{A_{t+1}}^{\alpha_t} * L_{A_{t+1}}^{\beta_t} \quad (1.12a)$$

$$G_{t+1}(L_{A_t}, K_{A_t}) = P_t * K_{A_t}^{\alpha_{t+1}} * L_{A_t}^{\beta_{t+1}} \quad (1.12b)$$

Productivity change in firm *A*, between periods *t* and *t+1* can be measured relative to time period *t* as M_{A_t} or relative to time period *t+1* as M'_{A_t}, where

$$M_{A_t} = \frac{P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t}}{P_{t+1} * K_{A_{t+1}}^{\alpha_t} * L_{A_{t+1}}^{\beta_t}} \quad (1.13a)$$

$$M'_{A_t} = \frac{P_t * K_{A_t}^{\alpha_{t+1}} * L_{A_t}^{\beta_{t+1}}}{P_{t+1} * K_{A_{t+1}}^{\alpha_{t+1}} * L_{A_{t+1}}^{\beta_{t+1}}} \quad (1.13b)$$

The Malmquist productivity change index between *t* and *t+1* is defined as the geometric mean of M_{A_t} and M'_{A_t}. This is given as:

$$MI_{A_{(t,t+1)}} = \sqrt[2]{\left(\frac{P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t}}{P_{t+1} * K_{A_{t+1}}^{\alpha_t} * L_{A_{t+1}}^{\beta_t}}\right) \times \left(\frac{P_t * K_{A_t}^{\alpha_{t+1}} * L_{A_t}^{\beta_{t+1}}}{P_{t+1} * K_{A_{t+1}}^{\alpha_{t+1}} * L_{A_{t+1}}^{\beta_{t+1}}}\right)} \quad (1.14)$$

If this index exceeds unity, it indicates that there has been improvement in productivity between period *t* and *t+1*. Values less than unity suggest regression.
Equation (1.14) can be simplified further as:

$$MI_{A_{(t,t+1)}} = \left[\frac{P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t}}{P_{t+1} * K_{A_{t+1}}^{\alpha_{t+1}} * L_{A_{t+1}}^{\beta_{t+1}}}\right] \times \sqrt[2]{\left[\frac{P_t * K_{A_t}^{\alpha_{t+1}} * L_{A_t}^{\beta_{t+1}}}{P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t}}\right] \times \left[\frac{P_{t+1} * K_{A_{t+1}}^{\alpha_{t+1}} * L_{A_{t+1}}^{\beta_{t+1}}}{P_{t+1} * K_{A_{t+1}}^{\alpha_t} * L_{A_{t+1}}^{\beta_t}}\right]} \quad (1.15)$$

Where,

$$Technical\ Efficiency, TEFFC = \frac{P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t}}{P_{t+1} * K_{A_{t+1}}^{\alpha_{t+1}} * L_{A_{t+1}}^{\beta_{t+1}}}$$

Technological progress,

$$TECHC = \sqrt[2]{\left[\frac{P_t * K_{A_t}^{\alpha_{t+1}} * L_{A_t}^{\beta_{t+1}}}{P_t * K_{A_t}^{\alpha_t} * L_{A_t}^{\beta_t}}\right] \times \left[\frac{P_{t+1} * K_{A_{t+1}}^{\alpha_{t+1}} * L_{A_{t+1}}^{\beta_{t+1}}}{P_{t+1} * K_{A_{t+1}}^{\alpha_t} * L_{A_{t+1}}^{\beta_t}}\right]}$$

Equation (1.15) can be summarized as:

$$MALM = TEFFC \times TECHC \quad (1.16)$$

The Malmquist Index also referred to as Productivity Change Index is decomposed into two separate indexes measuring technical efficiency change (TEFFC) and technological change (TECHC). *TEFFC* measures the "catching up" to the frontier isoquant i.e. change in technical efficiency over the two periods. TEFFC is defined as the diffusion of best-practice technology in the management of activity (Ade I. et al, 2011). This is attributed to investment planning, technical experience and management and organization in power stations.
TECHC measures the shift in the frontier isoquant from one period to another i.e. change in technology over the two periods. As a consequence of innovation, technological changes occur, that is adoption of new technologies by best-practice power plant (Ade I. et al, 2011). This also reveals the effect of routine maintenance on the plants. If the value of either of these components is greater than the previous respective value, it suggests improvement but if otherwise it suggests the opposite.

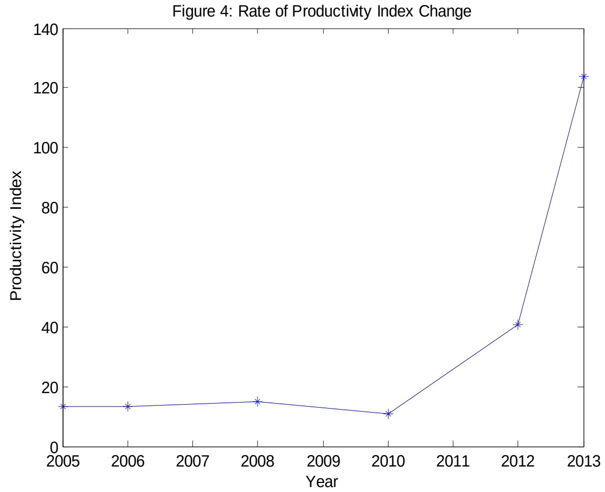
VIII. EFFICIENCY RESULT

Table 1: Table of the Productivity Change Index

YEAR	TEFFC	TECHC	Productivity Index
2005	1.0000	13.386	13.386
2006	1.1801	11.235	13.257
2008	1.9542	7.6215	14.894
2010	0.0983	108.45	10.658
2012	0.1712	285.25	40.787
2013	0.8329	148.75	123.89

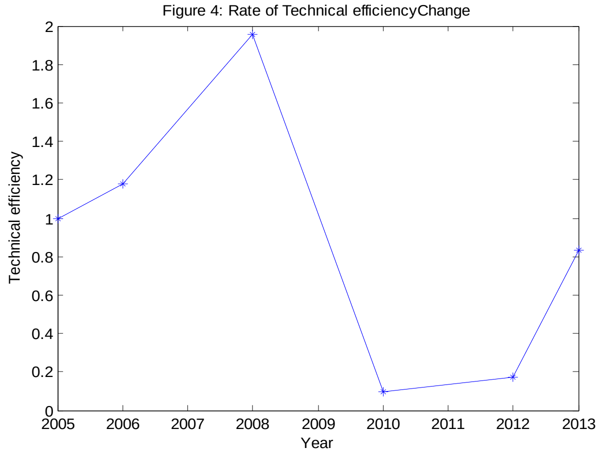
The Productivity Change Index result in Table 1 shows the annual productivity change of the period under review. The comparative analysis is sequential and orderly as are the years under review. The Productivity Change Index shown in Table 1 had 0.97% fall from 2005 to 2006 and 39.75% fall from 2008 to 2010. The unavailability of power plants due to insufficient gas supply in 2009 cost the power sector about 2000MW (Omachonu J. & Chiejine A., 2009).

Figure 4: Rate of Productivity Index Change



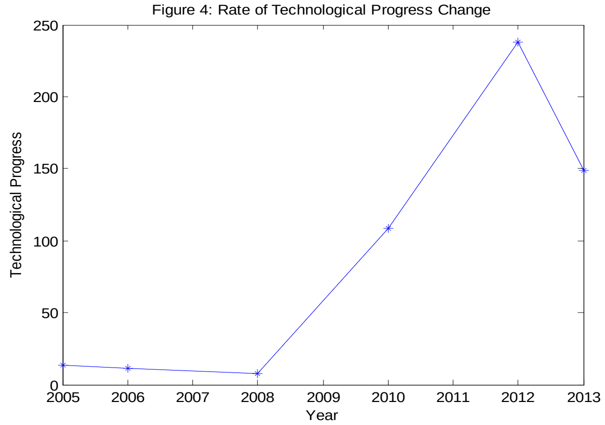
The sector experienced an average index increase in productivity of 11% from 2006 to 2008 and a rapid rise of 73.9% and 67.1% from 2010 to 2012 and 2012 to 2013 respectively.

Figure 4: Rate of Technical efficiencyChange



The trend of TEFFC shows a rapid fall of over 100% from 2008 to 2010. This reveals how inefficiently and ineffectively managed the power stations are in terms of downtime. It was observed that some plants were under utilized for their normal hours of operation all year round. At different times some of the plants were inevitably idle for such reasons as undergoing routine maintenance/inspection and fault development. However, the transmission network is likely to have more downtime than the plants and is likely to be called upon to generate for less time than it is actually available just as in 2009. In 2009, the power sector lost 450MW due to vandalisation of Okoloma Gas Station which supplies gas to Afam Power Station (Omachonu J. & Chiejine A., 2009). TEFFC has since then risen by 88.2% which is attributed to the rehabilitation of existing generating units, expansion of transmission capacity and the procurement of power from independent operators.

Figure 4: Rate of Technological Progress Change



The trend of TECHC graph is epileptic as it shows about 19.14% and 47.42% fall from 2005 to 2006 and 2006 to 2008 respectively. This reveals the constant deteriorating trend of power plants either as a result of insufficient routine maintenance/inspection and fault development. Due to the commissioning and installation of new generating plants at Ajaokuta 1, Agip 1(Okpai), Afam VI, Omoku and Egbin AES the sector experienced an appreciable rise in TECHC of 93% and 63% from 2008 to 2010 and 2010 to 2012 respectively. TECHC fell in 2013 owing to the rift between the Federal Government and the Labor Union during the final privatization process.

IX. CONCLUSION

The conceptual objective of the power reforms to remedy inadequate power generation capacity, inefficient usage of capacity, ineffective regulation and high technical losses is gradually being achieved.

The analysis reveals the eroding technical efficiency and technological setback in the power system. A number of reasons could be adduced to be responsible for this shortfall in power sector performance. These include: low plant availability due to breakdown, overdue overhaul of units, obsolete technology relative to advancement in the field, instability of the national grid system, ageing of plant components, disruption in gas supply, among others.

Measures to improve the performance indices of the sector is not just by privatization but includes: training of Operational and Maintenance (O&M) personnel regularly, improvement in O&M practices, proper Performance Evaluation of all power stations, organizing regular management meetings and improvement in the general housekeeping of the power plants. Another measure is the elimination or minimization of concerns about security of gas supply associated with resource control agitation in the Niger-Delta region. Credible and decisive effort to eliminate tension is more urgent than ever before. There should be an immense drive to harness other sources of electric energy not just limiting to and expanding on the same energy source. The country is blessed with a large amount of renewable energy resources like hydropower, solar, wind and biomass which will not only boost quantity and quality of electricity but also its reliability.

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