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RESEARCH ARTICLE

# Operational Performance Analysis of Generating Power Plant

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## ABSTRACT

**Human existence is heavily dependent on availability of electricity, and as such, poor performance of electric power systems in Nigeria often leads to unfavourable circumstances resulting from the failure of most electricity dependent systems. This study appraises the power generation system of a steam turbine power plant in Nigeria. Operational performance analysis was performed using productivity, profitability, and price recovery indices as measures of performance. Operational analyses revealed the average productivity, profitability, and price recovery indices of the power plant to be 1.05, 1.06, and 1.19, respectively, while their corresponding monetary contributions were ₦26,638,673,643.35; ₦39,854,453,032.67 and ₦13,215,779,389.32. On the long run, it was discovered that the performance indices and their monetary contributions were directly related. In conclusion, the necessity of performance analysis as a critical appraisal tool has been established. Carrying out similar actions across the power system value chain will ensure the optimum operation of the entire system.**

**Keywords:** Performance measures, Power generation system, Productivity, Profitability.

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## 1. Introduction

In Nigeria, it is largely accepted that the current state of electric power supply is one of the major causes of economic underdevelopment in the country [1], [2]. Government, and subsequently, private investors have attempted to find sustainable solutions to this problem with limited success. It is a common knowledge that large proportion of the private power-generating establishments in Nigeria are currently being owed very large amounts of money for power generated by the Nigerian Bulk Electricity Trader (NBET). As a result of this, many power generating establishments currently do not have adequate funds required for standard operations in meeting their operational demands. Its effect is that the growth of power plants is limited, as they may not be able to carry out major activities, such as overhauls/spares, fuel, expansions, etc. This thus necessitates that performance analyses need to be carried out on power enterprises so as to ensure that generated revenue and capital investments are strategically utilised in order to achieve optimal returns. The performance measure of a power plant, by way of its productivity, price recovery factor, profitability, efficiency, reliability, and other operating factors has definite socio-economic significance both on the company operating the plant and the nation at large [2]. Performance analysis/measurement is generally defined as regular measurement of outcomes and results, which generate reliable data on the effectiveness and efficiency of programs or actions [3]. Improvement of performance entails an optimization of the basic measures/elements of production/manufacturing's performance, which can be expressed in terms of quality, delivery speed, delivery reliability, price (cost), and flexibility [3]. The best approach for any particular organization to improve its performance will indeed differ from case to case [4]. Most performance measures can be used as objective functions for selecting work system control and design parameters [4]. Productivity models are available to measure productivity, both at micro-levels and at macro-levels. It is largely influenced by the organization's input costs and selling prices [4], meaning profitability could increase with decreasing productivity. It has been indicated that in production/manufacturing firms, performance measures might include efficiency, effectiveness, productivity, profitability, production count, rate of return, price recovery factor, capacity utilization, innovation, and vulnerability, as well as the quality of work and life, etc., [5]. Those containing information indicated by other measures include: 1) Productivity, 2) Profitability, and 3) Price recovery factor. A combination of these three, to a large

extent, is adequate to examine the behaviour of work systems under various scenarios. Productivity is conventionally defined as the ratio of total output to total input [5]–[9]. Findings indicated that productivity measurement is helpful in goal setting, cost reduction, resource allocation, motivation for improvement, forecasting output, national income, etc., [9]. A major drawback of partial productivity is that it focuses solely on one input factor to an extent that it somewhat undermines the effect of other inputs and as such cannot represent the overall status of the organisation [9]. Profitability is a measure of the ability of a business/production/manufacturing system to generate revenue in comparison to the expenses incurred. It is generally defined as a ratio between revenue and cost [9]. Thus, investigated include the confusing terminology within the field and frequently used terms like productivity, profitability, performance, efficiency and effectiveness [10].

$$Productivity = \frac{value\ of\ output\ (s)}{value\ of\ input\ (s)} \tag{1}$$

Partial Productivity Index compares the measured output to one factor of production input [11]. It can be expressed mathematically as:

$$Partial\ Productivity = \frac{Total\ Output\ (s)}{One\ Factor\ of\ Input} \tag{2}$$

The total productivity index compares the total output factor to a sum of all factors of input [12]. It is expressed mathematically as:

$$Total\ Productivity = \frac{Total\ Output\ (s)}{Total\ Input\ (s)} \tag{3}$$

This model is advantageous as it can be applied to any manufacturing organization or service company [13]. At 126 kWh per capita, Nigeria currently lags far behind other developing nations in terms of grid-based electricity consumption, and energy demand has been found to be higher than present possible supplies [14]. For instance, Ghana's per capita consumption (361 kWh) is 2.9 times higher than that of Nigeria, and South Africa's (3,926 kWh) is 31 times higher (NPBR, 2015). Due to available resources and technology, electricity generation in Nigeria has been largely through the combustion of natural gas, which constitutes (85% of installed capacity) or through hydroelectric methods (15% of installed capacity) [14]. Over the years, while power sector's development was very slow in Nigeria, and with deteriorated power generation, demand for power exponentially increased [15]. Different research has been conducted on the performance of business/production/manufacturing systems in recent times, with their outputs applied to diverse fields. However, a scarcity of studies regarding Nigerian power companies shows that this area is relatively under-researched as far as Nigeria is concerned. Overall Resource Effectiveness (ORE), by including the factors known as readiness, changeover efficiency, availability of material, and availability of manpower to address various kinds of losses associated with manufacturing systems, has been investigated [16]. Previous activities covered a study of the actual performance of a coal-based power plant at full and part loads [17]. Performance analysis of Egbin Power Plant in terms of efficiency and reliability in recent times led to some suggested measures of improvement [18]. Similar analysis has also been carried out on gas turbine power plants in Nigeria [19]. An approach based on data envelopment analysis (DEA) and the Malmquist Productivity Index (MPI), was developed to investigate the performance of power plants, with an empirical study conducted using eight thermal power plants in Taiwan [20]. Moreover, productivity change in Nigeria's power sector from 2004–2008 was analysed using the Malmquist index, with the input technological bias [21]. Nevertheless, none of these works focused on the productivity-related performance measures of individual Nigeria power plants, towards which this work was centered. Hence, the aim of this study was to determine the performance measurement indicators of profitability, productivity and price recovery factor for all the units of the power generating plant being studied, in determining how best to effectively utilise the available funds to achieve optimal output. Therefore, the objectives of this study include: 1. Gathering of all operational and cost data of the steam power plant under study. 2. Carrying out a performance analysis for all the units of the plant. 3. Appraising the overall performance of the plant and examining the performance mitigating factors and possible solutions. The justification for this work includes the fact that insufficient investments into the power sector is an issue which if not addressed will totally prevent any form of industrial growth in Nigeria. A good knowledge of the economic performance of the power sector will help shed light on the critical areas of investment that will ensure sustainable performance improvements and growth in the power sector. The scope of this study includes the economic performance analyses of a steam power plant in Nigeria in terms of its profitability, productivity, and price recovery factor. The reliability of the power system was not taken into consideration. Also, details associated with other power industry sub-sectors (transmission and distribution) were not taken into consideration.

### 1.1. *Definition of Relevant Terminologies*

The following terminologies, as given in the data table, are defined as follows:

(1) *Gross Generation*: This refers to the total amount of electric energy generated by a power plant over a specified time period. It is measured in Megawatt hour (MWh).
(2) *Auxiliary Power Consumption*: It can be defined as the electricity which is required to run the auxiliary equipment whose operation is essential for power generation in power plants. It is also measured in Megawatt hour (MWh).
(3) *Net Generation*: It is the difference between the gross generation and the auxiliary power consumption. It represents the actual amount of energy that is actually sent out to the national grid. It is measured in Megawatt hour (MWh).
(4) *Natural Gas Consumption*: This is the amount of fuel that is utilized to generate a specified amount

TABLE I: Template for the Summary of Operational Performance Data

| S/No | Year | Month | Gross generation [MWh] | Auxiliary consumption [MWh] | Net generation [MWh] | Natural gas consumption [kg] | Feedwater consumption [kg] |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

TABLE II: Template for the Summary of Operational Cost Data

| S/No | Year | Month | Unit generation cost [Naira/MWh] | Unit cost of natural gas [Naira/kg] | Unit cost of feedwater [Naira/kg] |
|---|---|---|---|---|---|
| | | | | | |

of energy over a defined period. It is measured in kilograms (kg).

(5) *Feed water Consumption*: This refers to the amount of demineralized water that is used to generate a specified amount of energy over a given period. It is measured in kilograms (kg).

## 2. Methodology

### 2.1. Introduction to the Power Plant

To achieve this, the power plant under study was visited for access to its generated data, as well as records of resource consumption.

### 2.2. Operations and Cost Data Collection

The relevant data required to carry out a holistic analysis of the performance parameters of the case study power plant was gathered through:

1. Access to plant daily generation report, which contained daily generation data, gas consumption data, and water consumption data.
2. Access to monthly reports, which showed the monthly generation information for each unit, gas consumption, and water consumption information
3. Access to the Company's Management Information System Data to obtain cost data for natural gas and energy generated.
4. Access to Nigerian Bulk Electricity Trader website to obtain energy generation cost information.
5. Access to NGC website to obtain natural gas costs.
6. Access to CBN website to obtain Naira-to-Dollar exchange rates for the period under review.

Table I represents the input and output resources which will be used to determine the performance indices of the system as defined in previous section.

The associated cost parameters for the selected inputs (natural gas and feed water) and outputs (net energy generation) which will be utilized in the computation of the performance indices of the plant were obtained from the establishments management information services department and are represented in the Table II.

### 2.3. Performance Analysis

The productivity evaluation model, as developed by [5], was used to determine the overall performance of the power plant. The Productivity, Profitability, and Price Recovery indices for each unit of the power plant were determined on a monthly basis over the selected period using the data represented.

These parameters were subsequently defined as follows;

$a_{ix}$ = unit price of output "i" in period "x"

$a_{i1}$ = unit price of output "i" in period "1" (or base period)

$O_{ix}$ = quantity of output "i" in period "x"

$O_{i1}$ = quantity of output "i" in period "1" (or base period)

$b_{kx}$ = unit price of input "k" in period "x"

$b_{k1}$ = unit price of input "k" in period "1" (or base period)

$I_{kx}$ = quantity of input "k" in period "x"

$I_{k1}$ = quantity of input "k" in period "1" (or base period)

$P_{.kx(M)}$ = Productivity index

$F_{.kx(M)}$ = Profitability index

$R_{.kx(M)}$ = Price recovery index

$P_{.kx(M)}$ = Relative productivity index

$F_{.kx(M)}$ = Relative profitability index

$R_{.kx(M)}$ = Relative price recovery index

$S(P_{.kx(M)})$ = Monetary loss or gain due to change in Productivity

$S(F_{.kx(M)})$ = Monetary loss or gain due to change in Profitability

$S(R_{.kx(M)})$ = Monetary loss or gain due to change in Price recovery factor

Likewise, these parameters will be defined as follows:

$$Absolute\ Productivity\ Index\ \left(P_{.kx(M)}\right) = \frac{\sum_{i=1}^{N} a_{i1} O_{ix}}{\sum_{k=1}^{M} b_{k1} I_{kx}} \quad (4)$$

$$Absolute\ Profitability\ Index\ \left(F_{.kx(M)}\right) = \frac{\sum_{i=1}^{N} a_{ix} O_{ix}}{\sum_{k=1}^{M} b_{kx} I_{kx}} \quad (5)$$

$$Absolute\ Price\ Recovery Index\ \left(R_{.kx(M)}\right) = \frac{\left(a_{ix} - a_{i1}\right) O_{ix}}{\sum_{k=1}^{M} \left(b_{kx} - b_{k1}\right) I_{k1}} \quad (6)$$

$$Relative\ Productivity\ Index = \frac{a_{i1} O_{ix}}{\sum_{k=1}^{M} b_{k1} I_{kx}} \Big/ \frac{a_{i1} O_{i1}}{\sum_{k=1}^{M} b_{k1} I_{k1}} \quad (7)$$

$$Relative\ Profitability\ Index = \frac{a_{ix} O_{ix}}{\sum_{k=1}^{M} b_{kx} I_{kx}} \Big/ \frac{a_{i1} O_{i1}}{\sum_{k=1}^{M} b_{k1} I_{k1}} \quad (8)$$

TABLE III: Template for the Summary of Performance Analysis Results

| S/No | Year | Month | Absolute | | | Relative | | | Monetary loss/Gain due to | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Productivity index | Profitability index | Price recovery index | Productivity index | Profitability index | Price recovery index | Productivity index | Profitability index | Price recovery index |
| | | | | | | | | | | | |

$$\text{Relative Price Recovery Index} = \frac{(a_{ix} - a_{i1})\, O_{ix}}{\sum_{k=1}^{M} I_{kx}\,(b_{kx} - b_{k1})} \Big/ \frac{a_{i1} O_{i1}}{\sum_{k=1}^{M} b_{k1} I_{k1}} \quad (9)$$

$$\text{Monetary Loss/Gain Due to Productivity Changes} = \left(\frac{a_{i1} O_{ix}}{a_{i1} O_{i1}} \sum_{k=1}^{M} b_{k1} I_{k1}\right) - \sum_{k=1}^{M} b_{k1} I_{kx} \quad (10)$$

$$\text{Monetary Loss/Gain Due to Profitability Changes} = \left(\frac{a_{ix} O_{ix}}{a_{i1} O_{i1}} \sum_{k=1}^{M} b_{k1} I_{k1}\right) - \sum_{k=1}^{M} b_{kx} I_{kx} \quad (11)$$

$$\text{Loss/Gain Due to Price Recovery} = \frac{((a_{ix} - a_{i1})\, O_{ix})}{a_{i1} O_{i1}} \left(\sum_{k=1}^{M} b_{k1} I_{k1}\right) - \sum_{K=1}^{M} (b_{kx} - b_{k1})\, I_{kx} \quad (12)$$

All these parameters are represented in Table III.

### 2.4. Comparison of Results

The results obtained from the performance analysis carried out using the two data analysis software were further compared using the Spearman rank correlation coefficient to find out if they are the same. This was used to establish the type of relationship between the calculated performances parameters from the two software types used. The results obtained were extensively discussed, and relevant charts were presented to facilitate understanding.

### 2.5. Appraisal of Overall Performance and Examining the Mitigating Factors

The following steps were taken to appraise the results that were obtained from the performance analyses of the power plant:

1. The values of the gross energy generated, auxiliary energy consumption and the net energy generated were plotted graphically against their corresponding time periods for the individual units so as to get an appreciation of the relationship between the auxiliary power consumption and the net energy generation. Also, the periods of outage for each unit were identified from the graphs plotted.
2. The peak periods of energy generation, as well as the least generation period, were identified for each unit. The trend of the auxiliary power consumption was also investigated.
3. The mean performance indices of productivity, profitability and price recovery factors were calculated so as to scrutinize the performance of each unit. Furthermore, a histogram showing the calculated mean performance indices of each unit was plotted so as to show the unit that had the best overall performance.
4. These processes were repeated for the overall plant performance data.
5. In addition, the average monetary contributions of each of the performance parameters were calculated so as to determine the impact of the various performance indices on the financials of the establishment.
6. Also, further investigation to establish the relationship between each performance index and its corresponding monetary contributions was carried out. This was done by calculating the Spearman's rank correlation coefficient for each index and its monetary contribution. In addition, scatter diagrams of the above parameters were plotted to further describe the relationship.

## 3. Results and Discussion

### 3.1. Introduction to the Power Plant

The power plant, classified as a thermal power plant and situated in the Southwestern part of Nigeria, commenced operations in the mid-eighties and is still currently running. It has an installed capacity of 1320 Megawatts (MW), consisting of six (6) units of 220 MW Maximum Capacity Rating (MCR) each.

### 3.2. Operation and Cost Data Collection

On following the steps described under the operations and cost data collection section above, the following results, as tabulated in Tables IV–VIII, were obtained.

#### 3.2.1. Operational Data

#### 3.2.2. Cost Data

The following were determined as the costs for the necessary inputs (natural gas and feed water) and outputs (net generation).

##### 3.2.2.1. Energy

The cost of power was obtained from the Multi-Year Tariff Order (MYTO 2015), which shows all the costs of energy per megawatt hour over the years.

##### 3.2.2.2. Natural Gas

The cost of natural gas was obtained from the organisations Management Information Section. The amount was given as $3300 per million standard cubic feet of gas, which

TABLE IV: Operational Performance Data for Unit 1

| S/No | Year | Month | Gross generation (MWh) | Auxiliary consumption (MWh) | Net generation (MWh) | Natural gas consumption (kg) | Feedwater consumption (kg) |
|---|---|---|---|---|---|---|---|
| 1 | 2014 | January | 49077 | 3936.2 | 45140.8 | 11642539 | 5851000 |
| 2 | | February | 92123 | 5120 | 87003 | 19746485 | 6633590 |
| 3 | | March | 86734 | 4948.4 | 81785.6 | 18745990 | 7148294.31 |
| 4 | | April | 72686 | 4553.9 | 68132.1 | 16200510 | 7952000 |
| 5 | | May | 65637 | 3961 | 58063.5 | 14265950 | 4338000 |
| 6 | | June | 105654 | 5623 | 100031 | 21773860 | 913000 |
| 7 | | July | 56656 | 3414.8 | 53241.2 | 12029010 | 3576000 |
| 8 | | August | 58774 | 4368.8 | 54405.2 | 12954800 | 3575000 |
| 9 | | September | 32226 | 2183.9 | 30042.1 | 6988370 | 1016000 |
| 10 | | October | 70213 | 4493.9 | 65719.1 | 1511800 | 1792000 |
| 11 | | November | 93324 | 5279 | 88045 | 19738726 | 5376500 |
| 12 | | December | 101161 | 5466.1 | 95694.9 | 21118464 | 8201000 |
| 13 | 2015 | January | 76668 | 4673.4 | 71994.6 | 16204164 | 1379230 |
| 14 | | February | 48537 | 3784.6 | 44752.4 | 10660102 | 4604150 |
| 15 | | March | 65871 | 4582.8 | 61288.2 | 14017237 | 1504000 |
| 16 | | April | 44756 | 4056.3 | 40699.7 | 10414432 | 2060000 |
| 17 | | May | 40652 | 2951.2 | 37700.8 | 9054940 | 3067279 |
| 18 | | June | 58721 | 3571.5 | 55149.5 | 12610325 | 4197000 |
| 19 | | July | 28803 | 1653.6 | 27149.4 | 6211101 | 2424000 |
| 20 | | August | Nil | Nil | Nil | Nil | Nil |
| 21 | | September | 34855.4 | 1776.3 | 33079.1 | 7041900 | 2776000 |
| 22 | | October | Nil | Nil | Nil | Nil | Nil |
| 23 | | November | Nil | Nil | Nil | Nil | Nil |
| 24 | | December | Nil | Nil | Nil | Nil | Nil |
| 25 | 2016 | January | Nil | Nil | Nil | Nil | Nil |
| 26 | | February | Nil | Nil | Nil | Nil | Nil |
| 27 | | March | Nil | Nil | Nil | Nil | Nil |
| 28 | | April | Nil | Nil | Nil | Nil | Nil |
| 29 | | May | Nil | Nil | Nil | Nil | Nil |
| 30 | | June | Nil | Nil | Nil | Nil | Nil |
| 31 | | July | Nil | Nil | Nil | Nil | Nil |
| 32 | | August | Nil | Nil | Nil | Nil | Nil |
| 33 | | September | Nil | Nil | Nil | Nil | Nil |
| 34 | | October | Nil | Nil | Nil | Nil | Nil |
| 35 | | November | Nil | Nil | Nil | Nil | Nil |
| 36 | | December | Nil | Nil | Nil | Nil | Nil |
| 37 | 2017 | January | Nil | Nil | Nil | Nil | Nil |
| 38 | | February | Nil | Nil | Nil | Nil | Nil |
| 39 | | March | Nil | Nil | Nil | Nil | Nil |
| 40 | | April | Nil | Nil | Nil | Nil | Nil |
| 41 | | May | Nil | Nil | Nil | Nil | Nil |
| 42 | | June | Nil | Nil | Nil | Nil | Nil |
| 43 | | July | Nil | Nil | Nil | Nil | Nil |
| 44 | | August | Nil | Nil | Nil | Nil | Nil |
| 45 | | September | Nil | Nil | Nil | Nil | Nil |
| 46 | | October | Nil | Nil | Nil | Nil | Nil |
| 47 | | November | Nil | Nil | Nil | Nil | Nil |
| 48 | | December | Nil | Nil | Nil | Nil | Nil |
| 49 | 2018 | January | 9146 | 826.5 | 8319.5 | 2097960 | 3152000 |
| 50 | | February | 41481 | 2794.2 | 38686.8 | 9106600 | 3693000 |
| 51 | | March | 51755 | 2954.1 | 48800.9 | 10656600 | 2524000 |
| 52 | | April | 82836 | 4477.9 | 77908.1 | 16540383 | 2826000 |
| 53 | | May | 37198 | 1951.5 | 35246.5 | 77536000 | 1899000 |
| 54 | | June | 90136 | 4578.4 | 85557.6 | 18823122 | 2261000 |

TABLE V: Operational Performance Data for all Units

| S/No | Year | Month | Gross generation (MWh) | Auxiliary consumption (MWh) | Net generation (MWh) | Natural gas consumption (kg) | Feedwater consumption (kg) |
|---|---|---|---|---|---|---|---|
| 1 | 2014 | January | 367825 | 345572.9 | 22252.5 | 80941117 | 17557488 |
| 2 | | February | 424552 | 23928 | 400624 | 91957885 | 28942040 |
| 3 | | March | 429907 | 27863.6 | 402043.4 | 93562040 | 23205694 |
| 4 | | April | 399041 | 26471.2 | 372569.8 | 88152800 | 13512000 |
| 5 | | May | 425627 | 27902.7 | 367688.6 | 92962820 | 15142060 |
| 6 | | June | 351998 | 23361.1 | 328636.9 | 74297699 | 14461237 |
| 7 | | July | 361352 | 23626.2 | 337725.8 | 76494010 | 11823000 |
| 8 | | August | 357384 | 24296.6 | 333087.4 | 76373490 | 12382000 |
| 9 | | September | 289844 | 20341.8 | 269502.2 | 61596553 | 9511000 |
| 10 | | October | 373616 | 21359.1 | 352256.9 | 79924149 | 14411000 |
| 11 | | November | 404245 | 25322.8 | 378922.2 | 86835162 | 20520500 |
| 12 | | December | 372276 | 23739.7 | 348536.3 | 79578376 | 24949000 |
| 13 | 2015 | January | 327109 | 23798.5 | 303310.5 | 70802677 | 18085732 |
| 14 | | February | 268631 | 20615.69 | 248015 | 58866054 | 14355150 |
| 15 | | March | 284072 | 21418.9 | 262653.3 | 60377279 | 7300725.57 |
| 16 | | April | 250103.3 | 22272.8 | 227830.5 | 58051096 | 9377400 |
| 17 | | May | 218400.8 | 17469.1 | 200931.7 | 48957654 | 22022915 |
| 18 | | June | 388380.3 | 26449.4 | 361930.9 | 84009742 | 25390600 |
| 19 | | July | 578225.6 | 31849 | 546376.6 | 120895196 | 28332000 |
| 20 | | August | 616780.7 | 31693.4 | 585087.3 | 127755508 | 34894000 |
| 21 | | September | 616797 | 32695.2 | 584101.8 | 127122755 | 30371000 |
| 22 | | October | 461944.12 | 25523.5 | 436420.62 | 95931670 | 32521545 |
| 23 | | November | 738808.4 | 35154.1 | 703654.3 | 152296686 | 40701000 |
| 24 | | December | 716196.6 | 34249.9 | 681946.7 | 147413569 | 32356000 |
| 25 | 2016 | January | 714042 | 34388.4 | 679653.6 | 148482483 | 28022512 |
| 26 | | February | 591799 | 29980.4 | 561818.6 | 124431280 | 31710000 |
| 27 | | March | 483856 | 26841.6 | 457014.4 | 102555538 | 34280000 |
| 28 | | April | 351958 | 21135.1 | 330822.9 | 75541755 | 36073300 |
| 29 | | May | 300191 | 19057.6 | 281133.4 | 65104793 | 35839000 |
| 30 | | June | 226067 | 15244 | 210823 | 50137900 | 29381000 |
| 31 | | July | 225292 | 16369.4 | 208922.6 | 50506615 | 20545000 |
| 32 | | August | 303452 | 19845.9 | 283606.1 | 63958543 | 22423754 |
| 33 | | September | 336023 | 20861 | 315162 | 72349794 | 30402000 |
| 34 | | October | 370154 | 21948.5 | 348205.5 | 80104077 | 27458000 |
| 35 | | November | 266131 | 17312.25 | 248818.75 | 57713946 | 16362340 |
| 36 | | December | 232275 | 15296.6 | 216978.4 | 49541077 | 9937000 |
| 37 | 2017 | January | 210996 | 14377 | 196619 | 45038675 | 22850000 |
| 38 | | February | 211781 | 14360.7 | 197420.3 | 45681642 | 22135000 |
| 39 | | March | 260842 | 17450.6 | 243391.4 | 56753107 | 17021931 |
| 40 | | April | 229182 | 15398.6 | 213783.4 | 49683532 | 16170000 |
| 41 | | May | 271990 | 18401.2 | 253588.8 | 60879184 | 22740665 |
| 42 | | June | 333133 | 18729.6 | 314403.4 | 70697885 | 22135000 |
| 43 | | July | 342079 | 19941.1 | 322137.9 | 71166429 | 37533000 |
| 44 | | August | 392554 | 21982.4 | 370571.6 | 81789111 | 30703013 |
| 45 | | September | 241763 | 14869.1 | 226893.9 | 49683817 | 35345000 |
| 46 | | October | 251131 | 16089 | 235041 | 53154437 | 31705000 |
| 47 | | November | 302115 | 18935.7 | 283179.3 | 62099787 | 3041600 |
| 48 | | December | 457556 | 25576.5 | 431979.5 | 95411213 | 31304000 |
| 49 | 2018 | January | 300827 | 19741.9 | 281085.1 | 61366464 | 43285437 |
| 50 | | February | 376085 | 22676 | 353409 | 78987220 | 28954000 |
| 51 | | March | 414177 | 25867.7 | 388309.3 | 86576343 | 30073000 |
| 52 | | April | 359790 | 22502.8 | 337287.2 | 74435591 | 30188000 |
| 53 | | May | 375963 | 23006.3 | 352956.7 | 79585553 | 29465000 |
| 54 | | June | 371318 | 21538.2 | 349779 | 79649377 | 30500000 |

TABLE VI: Cost Data for all Inputs and Outputs

| S/No | Year | Month | Unit generation cost (₦/MWh) | Unit cost of natural gas (₦/kg) | Unit cost of feedwater (₦/kg) |
|---|---|---|---|---|---|
| 1 | 2014 | January | 5555 | 22.58 | 0.86 |
| 2 | | February | 5555 | 22.58 | 0.86 |
| 3 | | March | 5555 | 22.58 | 0.86 |
| 4 | | April | 5555 | 22.58 | 0.86 |
| 5 | | May | 5555 | 22.58 | 0.86 |
| 6 | | June | 5555 | 22.58 | 0.86 |
| 7 | | July | 5555 | 22.58 | 0.86 |
| 8 | | August | 5555 | 22.58 | 0.86 |
| 9 | | September | 5555 | 22.58 | 0.86 |
| 10 | | October | 5555 | 22.59 | 0.86 |
| 11 | | November | 5555 | 23.93 | 0.86 |
| 12 | | December | 5555 | 24.36 | 0.86 |
| 13 | 2015 | January | 5555 | 24.36 | 0.86 |
| 14 | | February | 5555 | 28.71 | 0.86 |
| 15 | | March | 7638 | 28.57 | 0.86 |
| 16 | | April | 7638 | 28.57 | 0.86 |
| 17 | | May | 7638 | 28.57 | 0.86 |
| 18 | | June | 7638 | 28.57 | 0.86 |
| 19 | | July | 7638 | 28.57 | 0.86 |
| 20 | | August | 7638 | 28.57 | 0.86 |
| 21 | | September | 7638 | 28.57 | 0.86 |
| 22 | | October | 7638 | 28.57 | 0.86 |
| 23 | | November | 7638 | 28.57 | 0.86 |
| 24 | | December | 7638 | 28.57 | 0.86 |
| 25 | 2016 | January | 7638 | 28.57 | 0.86 |
| 26 | | February | 10082 | 28.57 | 0.86 |
| 27 | | March | 10082 | 28.57 | 0.86 |
| 28 | | April | 10082 | 28.57 | 0.86 |
| 29 | | May | 10082 | 28.57 | 0.86 |
| 30 | | June | 10082 | 41.03 | 0.86 |
| 31 | | July | 10082 | 45.39 | 0.86 |
| 32 | | August | 10082 | 44.37 | 0.86 |
| 33 | | September | 10082 | 44.26 | 0.86 |
| 34 | | October | 10082 | 44.23 | 0.86 |
| 35 | | November | 10082 | 44.23 | 0.86 |
| 36 | | December | 10082 | 44.23 | 0.86 |
| 37 | 2017 | January | 10086 | 44.26 | 0.86 |
| 38 | | February | 10086 | 44.29 | 0.86 |
| 39 | | March | 10086 | 44.42 | 0.86 |
| 40 | | April | 10086 | 44.35 | 0.86 |
| 41 | | May | 10086 | 44.28 | 0.86 |
| 42 | | June | 10086 | 44.36 | 0.86 |
| 43 | | July | 10086 | 44.32 | 0.86 |
| 44 | | August | 10086 | 44.35 | 0.86 |
| 45 | | September | 10086 | 44.33 | 0.86 |
| 46 | | October | 10086 | 44.34 | 0.86 |
| 47 | | November | 10086 | 44.37 | 0.86 |
| 48 | | December | 10086 | 44.37 | 0.86 |
| 49 | 2018 | January | 10086 | 44.33 | 0.86 |
| 50 | | February | 10086 | 44.36 | 0.86 |
| 51 | | March | 10086 | 44.32 | 0.86 |
| 52 | | April | 10086 | 44.33 | 0.86 |
| 53 | | May | 10086 | 44.36 | 0.86 |
| 54 | | June | 10086 | 44.33 | 0.86 |

TABLE VII: Performance Analysis for Unit 1

| S/No | Year | Month | Absolute profitability index (P.kx[M]) | Absolute productivity index (P.kx[M]) | Absolute price recovery index (R.kx[M]) | Relative productivity index | Relative profitability index | Relative price recovery index | Monetary loss/gain due to productivity changes | Monetary loss/gain due to profitability changes | Loss/gain due to price recovery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2014 | January | 0.9359 | 0.9359 | N/A | 1 | 1 | N/A | – | – | – |
| 2 | | February | 1.0702 | 1.0702 | N/A | 1.1435 | 1.1435 | N/A | 64,801,063.93 | 64,801,063.93 | – |
| 3 | | March | 1.0580 | 1.0580 | N/A | 1.1304 | 1.1304 | N/A | 55,983,200.26 | 55,983,200.26 | – |
| 4 | | April | 1.0156 | 1.0156 | N/A | 1.0852 | 1.0852 | N/A | 31,732,482.47 | 31,732,482.47 | – |
| 5 | | May | 0.9898 | 0.9898 | N/A | 1.0576 | 1.0576 | N/A | 18,763,573.19 | 18,763,573.19 | – |
| 6 | | June | 1.1284 | 1.1284 | N/A | 1.2056 | 1.2056 | N/A | 101,266,635.63 | 101,266,635.63 | – |
| 7 | | July | 1.0767 | 1.0767 | N/A | 1.1504 | 1.1504 | N/A | 41,307,607.11 | 41,307,607.11 | – |
| 8 | | August | 1.0224 | 1.0224 | N/A | 1.0924 | 1.0924 | N/A | 27,312,720.13 | 27,312,720.13 | – |
| 9 | | September | 1.0518 | 1.0518 | N/A | 1.1237 | 1.1237 | N/A | 19,635,192.81 | 19,635,192.81 | – |
| 10 | | October | 10.2281 | 10.2325 | 0.0000 | 10.9328 | 10.9282 | 0 | 354,379,478.48 | 354,364,360.48 | (15,118.00) |
| 11 | | November | 1.0254 | 1.0861 | 0.0000 | 1.1604 | 1.0956 | 0 | 72,241,854.44 | 45,594,574.34 | (26,647,280.10) |
| 12 | | December | 1.0193 | 1.0985 | 0.0000 | 1.1737 | 1.0891 | 0 | 84,062,107.96 | 46,471,242.04 | (37,590,865.92) |
| 13 | 2015 | January | 1.0101 | 1.0895 | 0.0000 | 1.1641 | 1.0793 | 0 | 60,227,328.48 | 31,383,916.56 | (28,843,411.92) |
| 14 | | February | 0.8019 | 1.0161 | 0.0000 | 1.0856 | 0.8568 | 0 | 20,950,480.63 | (44,395,944.63) | (65,346,425.26) |
| 15 | | March | 1.1652 | 1.0713 | 1.5205 | 1.1446 | 1.2449 | 1.6245 | 45,956,043.21 | 98,394,118.69 | 52,438,075.48 |
| 16 | | April | 1.0386 | 0.9542 | 1.3590 | 1.0196 | 1.1097 | 1.4520 | 4,632,029.05 | 32,829,709.55 | 28,197,680.50 |
| 17 | | May | 1.1019 | 1.0112 | 1.4479 | 1.0805 | 1.1773 | 1.5470 | 16,663,979.72 | 46,330,748.29 | 29,666,768.57 |
| 18 | | June | 1.1576 | 1.0624 | 1.5208 | 1.1352 | 1.2368 | 1.6249 | 38,973,626.77 | 86,176,983.97 | 47,203,357.20 |
| 19 | | July | 1.1550 | 1.0596 | 1.5200 | 1.1321 | 1.2341 | 1.6241 | 18,806,248.00 | 42,024,707.77 | 23,218,459.77 |
| 20 | | August | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 21 | | September | 1.2411 | 1.1385 | 1.6335 | 1.2165 | 1.3261 | 1.7453 | 34,938,135.88 | 66,377,086.18 | 31,438,950.30 |
| 22 | | October | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 23 | | November | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 24 | | December | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 25 | 2016 | January | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 26 | | February | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 27 | | March | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 28 | | April | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 29 | | May | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 30 | | June | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 31 | | July | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 32 | | August | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 33 | | September | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 34 | | October | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 35 | | November | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 36 | | December | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 37 | 2017 | January | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 38 | | February | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 39 | | March | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 40 | | April | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 41 | | May | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 42 | | June | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 43 | | July | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 44 | | August | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 45 | | September | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 46 | | October | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 47 | | November | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 48 | | December | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 49 | 2018 | January | 0.8767 | 0.9228 | 0.8261 | 0.9859 | 0.9367 | 0.8826 | (704,628.72) | (6,059,499.01) | (5,354,870.29) |
| 50 | | February | 0.9584 | 1.0292 | 0.8838 | 1.0997 | 1.0240 | 0.9443 | 20,811,499.67 | 9,757,480.61 | (11,054,019.06) |
| 51 | | March | 1.0374 | 1.1165 | 0.9544 | 1.1929 | 1.1084 | 1.0198 | 46,847,206.07 | 51,424,098.02 | 4,576,891.95 |
| 52 | | April | 1.0681 | 1.1513 | 0.9812 | 1.2301 | 1.1412 | 1.0484 | 86,489,180.06 | 103,898,890.30 | 17,409,710.24 |
| 53 | | May | 0.1033 | 0.1117 | 0.0946 | 0.1194 | 0.1104 | 0.1010 | (1,543,200,435.34) | (3,061,301,717.12) | (1,518,101,281.78) |
| 54 | | June | 1.0318 | 1.1131 | 0.9469 | 1.1893 | 1.1024 | 1.0117 | 80,832,266.91 | 85,624,608.23 | 4,792,341.32 |

converts to $0.145 per kg of natural gas (assuming a density of 0.05 pounds per cubic foot). This was subsequently converted to the local currency using the official Central Bank Exchange Rates.

#### *3.2.2.3. Feed Water*

The cost of feed water was obtained from the organisation's quality control department. In 2017, a study was carried out to determine the unit cost required to produce demineralised water. This was determined to be 0.86 per kilogram. This amount encompasses the cost of electricity, treatment, and demineralization of the water and is assumed to remain constant over the period of the study. The cost of feed water was assumed to be constant over the study period.

Table VI shows the costs of all the inputs and outputs over the study period.

### *3.3. Carrying out Performance Analyses*

The critical parameters utilized in the determination of the economic performance characteristics are Productivity, Profitability and Price Recovery Factor. These parameters will be calculated using the expressions defined in performance analysis section above. The computations were carried out using Microsoft Excel.

TABLE VIII: Overall Performance Analysis for all Units

| S/No | Year | Month | Absolute profitability index [P.kx[M]] | Absolute productivity index [P.kx[M]] | Absolute price recovery index [R.kx[M]] | Relative productivity index | Relative profitability index | Relative price recovery index | Monetary loss/gain due to productivity changes | Monetary loss/gain due to profitability changes | Monetary loss/gain due to price recovery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2014 | January | 0.0671 | 0.0671 | N/A | 1 | 1 | N/A | – | – | – |
| 2 | | February | 1.0591 | 1.0591 | N/A | 15.7883 | 15.7883 | N/A | 31,074,740,372.22 | 31,074,740,372.22 | – |
| 3 | | March | 1.0472 | 1.0472 | N/A | 15.6118 | 15.6118 | N/A | 31,160,993,621.07 | 31,160,993,621.07 | – |
| 4 | | April | 1.0337 | 1.0337 | N/A | 15.4102 | 15.4102 | N/A | 28,850,735,085.21 | 28,850,735,085.21 | – |
| 5 | | May | 0.9670 | 0.9670 | N/A | 14.4161 | 14.4161 | N/A | 28,336,506,349.09 | 28,336,506,349.09 | – |
| 6 | | June | 1.0802 | 1.0802 | N/A | 16.1026 | 16.1026 | N/A | 25,524,643,322.73 | 25,524,643,322.73 | – |
| 7 | | July | 1.0798 | 1.0798 | N/A | 16.0972 | 16.0972 | N/A | 26,229,979,619.51 | 26,229,979,619.51 | – |
| 8 | | August | 1.0664 | 1.0664 | N/A | 15.8967 | 15.8967 | N/A | 25,848,110,078.08 | 25,848,110,078.08 | – |
| 9 | | September | 1.0701 | 1.0701 | N/A | 15.9523 | 15.9523 | N/A | 20,918,693,853.08 | 20,918,693,853.08 | – |
| 10 | | October | 1.0764 | 1.0769 | 0.0000 | 16.0536 | 16.0466 | 0 | 27,353,635,071.85 | 27,352,835,830.36 | (799,241.49) |
| 11 | | November | 1.0044 | 1.0640 | 0.0000 | 15.8609 | 14.9736 | 0 | 29,400,508,090.70 | 29,283,280,622.00 | (117,227,468.70) |
| 12 | | December | 0.9878 | 1.0648 | 0.0000 | 15.8731 | 14.7259 | 0 | 27,044,273,659.94 | 26,902,624,150.66 | (141,649,509.28) |
| 13 | 2015 | January | 0.9682 | 1.0437 | 0.0000 | 15.5595 | 14.4328 | 0 | 23,503,141,524.02 | 23,377,112,758.96 | (126,028,765.06) |
| 14 | | February | 0.8093 | 1.0270 | 0.0000 | 15.3095 | 12.0644 | 0 | 19,196,807,882.37 | 18,835,958,971.35 | (360,848,911.02) |
| 15 | | March | 1.1588 | 1.0653 | 1.5128 | 15.8810 | 17.2745 | 22.5515 | 20,380,962,227.81 | 28,175,272,819.41 | 7,794,310,591.61 |
| 16 | | April | 1.0442 | 0.9596 | 1.3648 | 14.3054 | 15.5657 | 20.3455 | 17,547,993,607.41 | 24,274,912,465.41 | 6,726,918,858.00 |
| 17 | | May | 1.0826 | 0.9927 | 1.4272 | 14.7984 | 16.1384 | 21.2762 | 15,514,934,174.08 | 21,461,055,044.70 | 5,946,120,870.61 |
| 18 | | June | 1.1414 | 1.0478 | 1.4982 | 15.6203 | 17.0151 | 22.3338 | 28,053,052,706.97 | 38,788,595,642.80 | 10,735,542,935.83 |
| 19 | | July | 1.1998 | 1.1020 | 1.5716 | 16.4281 | 17.8856 | 23.4287 | 42,491,766,533.41 | 58,733,815,765.94 | 16,242,049,232.53 |
| 20 | | August | 1.2144 | 1.1151 | 1.5926 | 16.6230 | 18.1033 | 23.7414 | 45,536,885,813.12 | 62,939,895,308.77 | 17,403,009,495.65 |
| 21 | | September | 1.2196 | 1.1202 | 1.5978 | 16.6992 | 18.1813 | 23.8194 | 45,473,453,000.22 | 62,849,650,714.38 | 17,376,197,714.16 |
| 22 | | October | 1.2039 | 1.1049 | 1.5820 | 16.4716 | 17.9476 | 23.5836 | 33,946,284,749.32 | 46,923,487,200.89 | 12,977,202,451.57 |
| 23 | | November | 1.2253 | 1.1252 | 1.6067 | 16.7739 | 18.2668 | 23.9516 | 54,796,393,622.16 | 75,734,171,130.66 | 20,937,777,508.50 |
| 24 | | December | 1.2286 | 1.1286 | 1.6087 | 16.8252 | 18.3158 | 23.9816 | 53,116,204,909.46 | 73,409,162,916.47 | 20,292,958,007.01 |
| 25 | 2016 | January | 1.2168 | 1.1181 | 1.5917 | 16.6673 | 18.1395 | 23.7289 | 52,905,901,924.36 | 73,121,251,269.55 | 20,215,349,345.19 |
| 26 | | February | 1.5812 | 1.1001 | 3.4123 | 16.3997 | 23.5715 | 50.8691 | 43,687,782,809.12 | 80,857,357,518.98 | 37,169,574,709.86 |
| 27 | | March | 1.5569 | 1.0825 | 3.3679 | 16.1377 | 23.2093 | 50.2063 | 35,500,595,281.01 | 65,728,384,214.02 | 30,227,788,933.00 |
| 28 | | April | 1.5235 | 1.0581 | 3.3097 | 15.7741 | 22.7117 | 49.3396 | 25,658,990,821.85 | 47,532,426,448.46 | 21,873,435,626.61 |
| 29 | | May | 1.4990 | 1.0405 | 3.2635 | 15.5114 | 22.3461 | 48.6504 | 21,780,026,015.62 | 40,362,630,967.87 | 18,582,604,952.24 |
| 30 | | June | 1.0207 | 1.0119 | 1.0317 | 15.0844 | 15.2159 | 15.3805 | 16,301,063,858.95 | 29,603,631,103.04 | 13,302,567,244.08 |
| 31 | | July | 0.9118 | 1.0021 | 0.8210 | 14.9391 | 13.5923 | 12.2384 | 16,142,963,373.48 | 29,090,268,495.17 | 12,947,305,121.70 |
| 32 | | August | 1.0008 | 1.0765 | 0.9212 | 16.0480 | 14.9189 | 13.7333 | 22,022,211,998.98 | 39,768,010,764.92 | 17,745,798,765.94 |
| 33 | | September | 0.9842 | 1.0548 | 0.9096 | 15.7241 | 14.6725 | 13.5597 | 24,439,049,177.75 | 44,139,544,103.94 | 19,700,494,926.18 |
| 34 | | October | 0.9843 | 1.0556 | 0.9089 | 15.7366 | 14.6734 | 13.5499 | 27,002,851,741.04 | 48,767,612,224.12 | 21,764,760,483.08 |
| 35 | | November | 0.9773 | 1.0493 | 0.9015 | 15.6423 | 14.5696 | 13.4387 | 19,287,655,569.65 | 34,829,943,218.51 | 15,542,287,648.86 |
| 36 | | December | 0.9945 | 1.0693 | 0.9158 | 15.9408 | 14.8250 | 13.6523 | 16,840,996,261.71 | 30,411,447,075.33 | 13,570,450,813.62 |
| 37 | 2017 | January | 0.9851 | 1.0536 | 0.9124 | 15.7069 | 14.6856 | 13.6012 | 15,245,574,798.43 | 27,549,900,326.44 | 12,304,325,528.01 |
| 38 | | February | 0.9750 | 1.0439 | 0.9020 | 15.5622 | 14.5345 | 13.4458 | 15,298,027,888.88 | 27,641,167,796.23 | 12,343,139,907.35 |
| 39 | | March | 0.9681 | 1.0431 | 0.8897 | 15.5506 | 14.4326 | 13.2636 | 18,859,340,252.46 | 34,059,889,948.00 | 15,200,549,695.54 |
| 40 | | April | 0.9724 | 1.0456 | 0.8956 | 15.5874 | 14.4963 | 13.3506 | 16,567,838,377.90 | 29,926,372,953.35 | 13,358,534,575.45 |
| 41 | | May | 0.9420 | 1.0104 | 0.8698 | 15.0622 | 14.0423 | 12.9658 | 19,605,711,335.96 | 35,413,460,910.01 | 15,807,749,574.05 |
| 42 | | June | 1.0050 | 1.0812 | 0.9252 | 16.1174 | 14.9825 | 13.7918 | 24,420,638,543.69 | 44,117,429,969.49 | 19,696,791,425.81 |
| 43 | | July | 1.0197 | 1.0917 | 0.9434 | 16.2740 | 15.2008 | 14.0639 | 25,037,317,553.72 | 45,249,182,808.21 | 20,211,865,254.49 |
| 44 | | August | 1.0229 | 1.0989 | 0.9430 | 16.3823 | 15.2495 | 14.0577 | 28,814,170,143.50 | 52,064,131,806.11 | 23,249,961,662.61 |
| 45 | | September | 1.0249 | 1.0938 | 0.9514 | 16.3065 | 15.2785 | 14.1823 | 17,637,033,929.27 | 31,882,113,610.66 | 14,245,079,681.39 |
| 46 | | October | 0.9943 | 1.0637 | 0.9207 | 15.8567 | 14.8230 | 13.7260 | 18,236,466,526.30 | 32,955,830,085.62 | 14,719,363,559.31 |
| 47 | | November | 1.0356 | 1.1198 | 0.9482 | 16.6927 | 15.4380 | 14.1355 | 22,045,507,663.85 | 39,819,891,607.90 | 17,774,383,944.05 |
| 48 | | December | 1.0227 | 1.1001 | 0.9415 | 16.3996 | 15.2456 | 14.0347 | 33,591,310,551.14 | 60,690,649,174.99 | 27,099,338,623.85 |
| 49 | 2018 | January | 1.0281 | 1.0974 | 0.9542 | 16.3590 | 15.3260 | 14.2248 | 21,854,033,781.48 | 39,505,397,329.78 | 17,651,363,548.30 |
| 50 | | February | 1.0101 | 1.0856 | 0.9308 | 16.1831 | 15.0583 | 13.8759 | 27,457,690,402.57 | 49,608,599,877.19 | 22,150,909,474.62 |
| 51 | | March | 1.0139 | 1.0890 | 0.9348 | 16.2343 | 15.1142 | 13.9353 | 30,175,491,403.58 | 54,521,937,319.12 | 24,346,445,915.53 |
| 52 | | April | 1.0229 | 1.0978 | 0.9440 | 16.3654 | 15.2490 | 14.0721 | 26,224,343,953.69 | 47,387,663,036.26 | 21,163,319,082.57 |
| 53 | | May | 1.0012 | 1.0759 | 0.9226 | 16.0387 | 14.9249 | 13.7539 | 27,406,285,207.07 | 49,513,612,078.01 | 22,107,326,870.94 |
| 54 | | June | 0.9918 | 1.0648 | 0.9148 | 15.8740 | 14.7850 | 13.6380 | 27,140,805,720.06 | 49,034,492,079.12 | 21,893,686,359.06 |

### *3.3.1. Performance analysis for unit 1*

The month of January 2014 is the first month in the period under review. From Tables V and VI:

$a_{11}$ = price of output 1 (Net Generation/MWh) in period 1 (base period) = ₦5,555

$O_{11}$ = quantity of output 1 (Net Generation/MWh) in period 1 (base period) = 45140.8 MWh

$b_{11}$ = price of input 1 (natural gas) in period 1 (base period) = ₦22.58

$b_{21}$ = price of input 2 (feed water) in period 1 (base period) = ₦0.86

$I_{11}$ = quantity of input 1 (natural gas) in period 1 (base period) = 11642539 kg

$I_{21}$ = quantity of input 2 (feed water) in period 1 (base period) = 5851000 kg

Absolute Profitability Index (this was as defined in (5))

Hence, Profitability F = 0.936

Absolute Productivity Index (this was as defined in (4))

Hence, Productivity P = 0.936

Absolute Price Recovery Index (this was as defined in (6))

Hence, Price Recovery Index R = N/A

The same set of steps was repeated for the other parameters defined in (7) through 12 over the remaining months in the period under review using the operational information detailed in Table V, as well as the cost information detailed

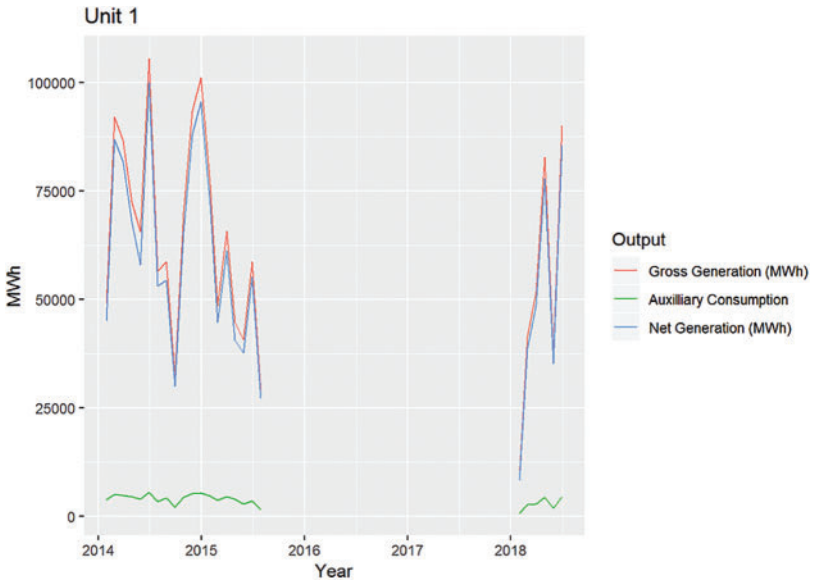


Fig. 1. Gross generation, auxiliary consumption and net generation for unit 1.

in Table VI. All computations were done using Microsoft Excel.

### *3.3.2. Performance Analyses for all Units*

Similar analyses were carried out for the remaining units. The overall results are presented in Table VIII below.

### *3.4. Comparison of Results*

The results obtained using the R Studio computer application and Microsoft excel were tested to ascertain their similarity using the Spearman's rank correlation coefficient between the two data sets. This was done on Microsoft excel and the correlation coefficients obtained showed that the results were the same.

### *3.5. Appraising the Overall Performance of the Plant*

From the results of the analyses carried out on the power plant using the performance measures of productivity, profitability, and price recovery factors, this section presents the interpretation of the calculated parameters for the individual units as well as for the power plant.

A major observation from the data for unit 1, as presented in (Table VII) was that the unit was out of service for an extended duration. Fig. 1 shows the trends of net energy generation in comparison with the gross generation and the auxiliary power consumption.

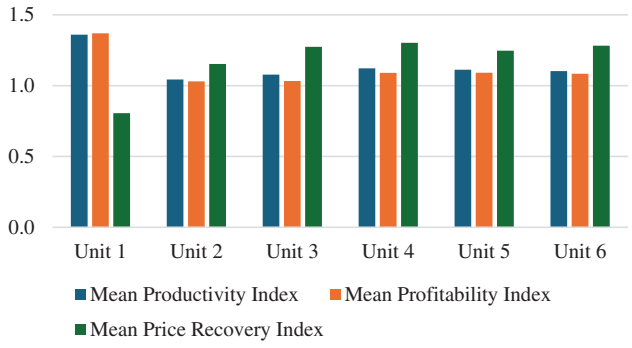


Fig. 2. Mean absolute performance indices for all units.

It can be seen that the particular unit had its peak generation in June 2014, while it recorded its lowest generation in January 2018. The auxiliary power consumption of the unit was relatively constant over the study duration. Also, from the data, it was observed that there was no generation between September 2015 and January 2018. The mean productivity, profitability, and price recovery indices were calculated to be 1.37, 1.36, and 0.81, respectively.

Similar analyses were carried out for the other units. (Fig. 2) shows a chart comparing the mean performance indices of all the units. It could be seen that while unit 1 experienced the highest mean productivity and mean profitability indices, it experienced the lowest mean price recovery index. In unit 2, with the lowest mean productivity and mean profitability indices, the second lowest mean price recovery index was experienced. With the second-lowest mean productivity and mean profitability indices in unit 3, it experienced the third-highest mean price recovery index. Moreover, with the second highest mean productivity and mean profitability indices in unit 4, the highest mean price recovery index was experienced. Also, as indicated for unit 5, with the third highest mean productivity and profitability indices, the third highest mean price recovery index was experienced. In addition, in the case of unit 6, with the third lowest mean productivity and mean profitability indices, the third highest mean price recovery index was experienced.

### *3.6. Overall Performance Analysis*

The overall plant performance data indicated that there was no significant period of complete downtime of the entire plant over the study period (Fig. 3). Altogether, the plant experienced its highest generation period between July 2015 and February 2016, which peaked in November 2015 with a net generation of 703,654.3 MWh. The trend of the auxiliary power consumption remained fairly constant throughout the period studied. The consumption of other resources such as natural gas and feedwater was also proportional to the amount of energy generated.

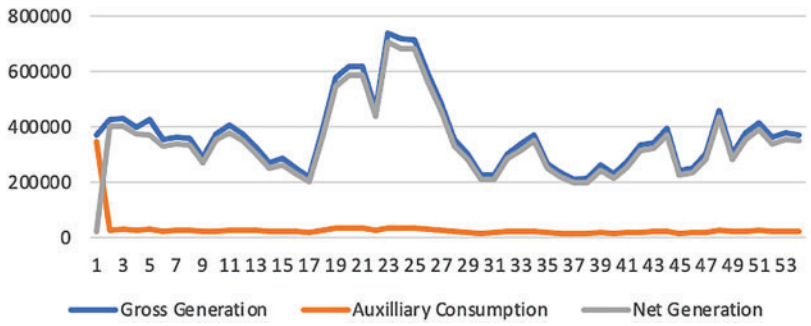


Fig. 3. Gross generation, auxiliary consumption and net generation for all units.

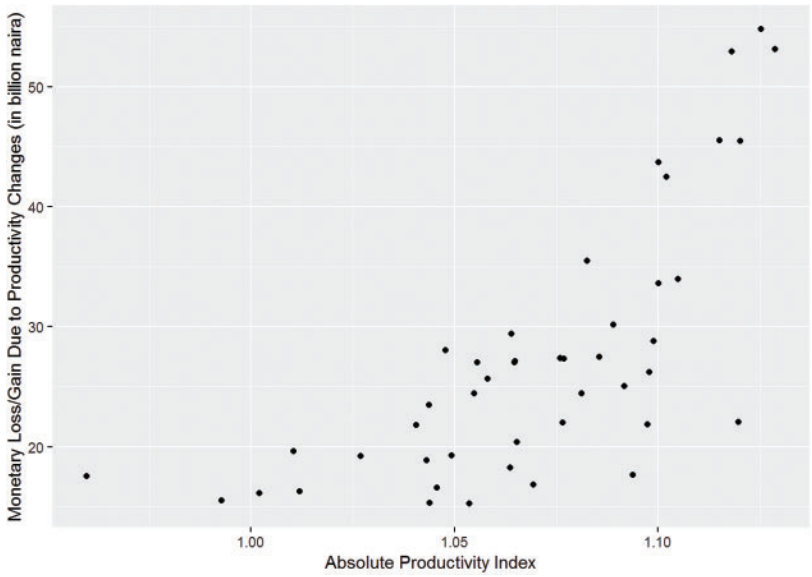


Fig. 4. Monetary loss/gain due to productivity against productivity index.

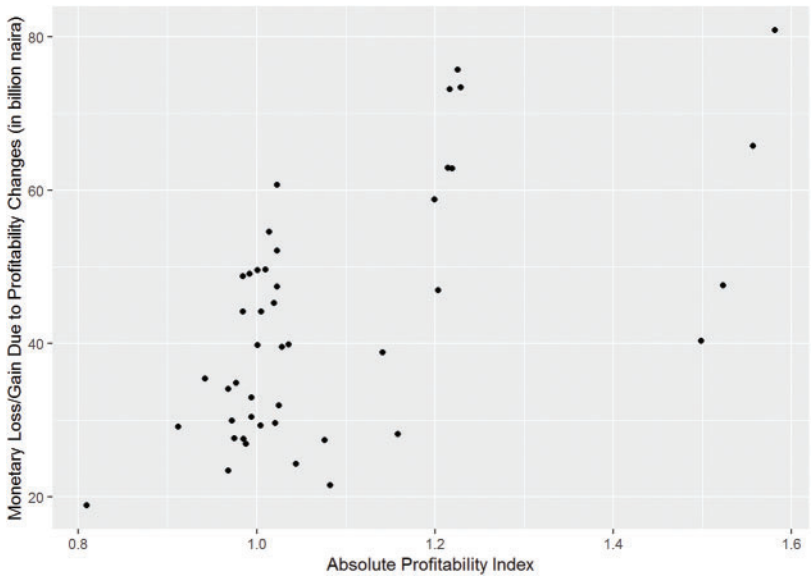


Fig. 5. Monetary loss/gain due to profitability against profitability index.

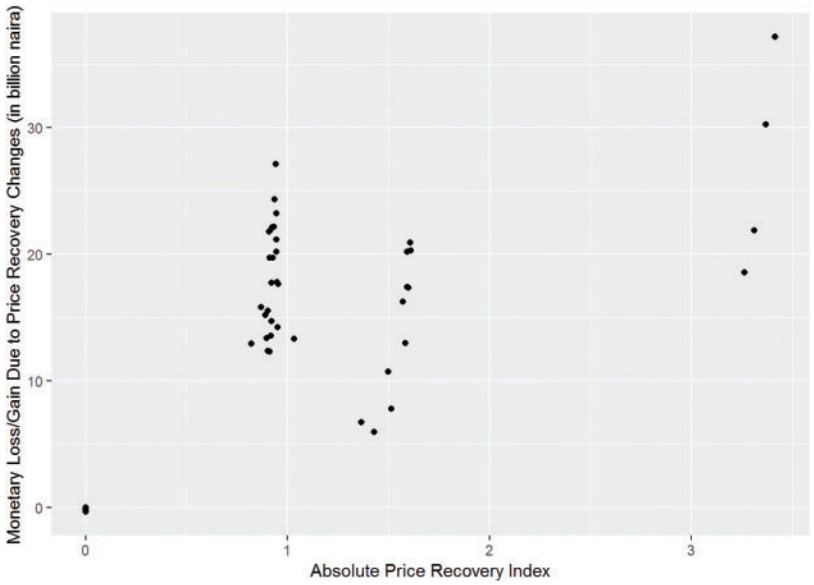


Fig. 6. Monetary loss/gain due to price recovery against price recovery index.

The mean productivity, profitability, and price recovery indices for the entire plant were calculated to be 1.05, 1.06, and 1.19, respectively. The average monetary contributions of the various performance parameters were also determined:

- Monetary gain due to productivity = ₦26,638,673,643.35
- Monetary gain due to profitability = ₦39,854,453,032.67
- Monetary gain due to price recovery = ₦13,215,779,389.32

A scatter diagram of the calculated monetary contributions against their respective performance indices was plotted for the overall plant performance. From the results, it was observed that there was a positive correlation between the monetary parameters and their respective performance indices. Correlation coefficients were calculated and are as follows:

- Correlation Coefficient of Productivity Index and its monetary contribution = 0.495
- Correlation Coefficient of Profitability Index and its monetary contribution = 0.630
- Correlation Coefficient of Price recovery Index and its monetary contribution = 0.613

The scatter diagrams are as given in Figs. 4–6.

From the analysis, it can be seen that the monetary contributions are related directly to the performance indices. As such, it is of paramount importance that these performance indices are kept as high as possible so as to ensure greater financial contribution. To achieve this, resources should be utilized efficiently and effectively so as to ensure minimal production cost per unit net generation output. The costs that have been identified include the cost of feedwater, natural gas, and average energy consumption, which play a significant role in determining the performance indices of the system.

## 4. Conclusions

Operational analysis of power and other systems is very critical to the growth and development of a society. It helps to identify the gaps in current operational practices and points out crucial areas of improvement.

In this work, the performance analysis was carried out on a steam turbine power plant based on the input and output resources and their respective costs. The analysis was a quantitative one which was carried out using R studio and Microsoft Excel. It utilized historical records obtained from the steam turbine power plant selected to study its performance.

The results showed the performance indices of productivity, profitability, price recovery factor and their respective monetary contributions to the performance of the system. Further analysis and comparison were carried out which established the type of relationship between these parameters.

Based on the outcome of this work, it is concluded that:

1. The data gathered covered a period of 54 months. It included information on the total generation, auxiliary energy consumption, net energy generation, feedwater consumption, and natural gas consumption, which were sufficient to carry out the required analyses.
2. The performance analysis was carried out for all the individual generating units of the plant as well as for the total output from the entire plant. The parameters determined included the productivity, profitability, price recovery indices, and their respective monetary contributions.
3. The overall performance parameters for the plant were evaluated based on the data analyzed. Critical issues observed include:

I. A significant number of the plant units experienced long-term downtime, while another faced intermittent failure, which raised concerns about the organization's maintenance culture.

II. The unusual amounts of consumption recorded at various points in unit 2 and unit 3 indicate that there may have been an error in the collation of the data, as such energy consumption was not realistic.
III. The performance indices recorded for the power plant were satisfactory.

## Conflict of Interest

The authors declare that there is no conflict of interest.

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