Approaches for Improving Performance of a National Power Sector: A Ghana Exploration

Abudu Abdul-Ganiyu

A thesis submitted in partial fulfilment of the requirements of Sheffield Hallam University and Business School Netherlands for the degree of Doctor of Business Administration

October 2020

Candidate Declaration

I hereby declare that:

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2. None of the material contained in the thesis has been used in any other submission for an academic award.
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Name	Abudu Abdul-Ganiyu
Award	DBA
Date of first Submission	October 2020
Faculty	Sheffield Business School and Business School Netherlands
Director of Studies	Dr Xiaohong Li

ABSTRACT

This research aims to explore approaches for improving the performance of a national power sector, focusing on Ghana. This research topic is particularly important because the power sector must perform well to satisfy a constantly rising demand for any nation, particularly for an African country, like Ghana.

A multilevel-concurrent triangulation design within the mixed-method paradigm forms the core of the methodology for this research. Three broad approaches have been explored. The first approach is efficiency modelling and evaluation based on Data Envelopment Analysis (DEA). The second applies international benchmarking (IB) to compare the performance of the power sector across a set of countries, including Ghana. Delphi approach is the third, which generates collective perspectives from experts in this sector in Ghana. The three approaches are integrated based on their findings and analysis to provide further insights for performance improvement of the sector.

The DEA approach identifies the relatively best and least performed decision-making units (DMUs) in the sector over the years to facilitate internal learning. The IB approach identifies the best performing country or countries based on key performance indicators (KPIs) and reveals the best practices implemented in these best performing countries. The independence of the power sector institutions, long-term planning, and effective management have been reasons for the sector's success among the benchmarking countries. The experts in Ghana confirmed that technical weaknesses have resulted in frequent interruptions in the power sector in Ghana, leading to high transmission and distribution (T&D) losses. The study also confirmed that the lack of investment and inefficient management of resources, and limited resources were the main problems in Ghana over the years. The integration of the findings of the three approaches provided significant insights for improving efficiency in the T&D subsectors, improving the regulatory and institutional framework, and improving performance of the general KPIs in the power sector.

The study contributes to the performance improvement of power sectors in developing nations as well as the performance management literature. The study concludes that different performance approaches can be implemented to improve the efficiency and effective management of the power sector. The study identifies relative efficiencies for

internal learning, effective management of power sector institutions, and the enforcement of power sector regulations as the ways forward.

ACKNOWLEDGMENT

I remain indebted to my Director of Studies, Dr Xiaohong Li at Sheffield Hallam University, for her support, encouragement, and scholarly guidance throughout this doctoral thesis. Throughout my period of study at the Sheffield Hallam University UK and Business School Netherlands, I have come into contact with many people who, in diverse ways, have contributed to making my studies a success. They include Professors, Lecturers, Administrators, and my colleagues' doctoral researchers. I shall remain grateful to all of them. I am hopeful that the findings and conclusions of my research which border on performance improvement with a focus on the power sector of Ghana, will make a positive contribution towards improving the performance of Ghana's power sector. Beyond Ghana, I also hope that power sectors of other developing countries can draw valuable insights from the findings and conclusions leading to the improvement of their national power sectors.

My wife has remained my pillar of support throughout this doctoral journey. I owe Adam Barbara Jemi a great deal of gratitude. I also thank my mother, Safia Mumuni, whose daily and night prayers have never been lost on me. May God grant her good health and long life to reap the fruits of her labor.

Finally, I am thankful to all the power sector institutions in Ghana, namely, the Ghana Grid Company (GRIDCo), the Electricity Company of Ghana (ECG), the Northern Electricity Distribution Company (NEDCo), the Volta River Authority (VRA), the Public Utilities and Regulatory Commission (PURC), the Energy Commission (EC), and the Ministry of Energy for granting me access to the secondary data required for the thesis. I am also thankful to all the power sector experts and others who were interviewed as part of the Delphi approach.

DEDICATION

In memoriam of my late father, Paul Braimah Abudu, my two late sisters, Sherifa Bunyansa Abudu and Nadrat-Naim Abudu. May their Souls continue to Rest in Perfect Peace.

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ACRONYMS

DEA	Data Envelopment Analysis
TWH	Terawatt hours
IB	International Benchmarking
SE4ALL	Sustainable Energy for All
PURC	Public Utilities and Regulatory Commission
BSC	Balance Score Card
EFQM	European Foundation for Quality Management
RADAR	Results, Approaches, Deploy, Assess and Refine.
SMART	Strategic Measurement and Reporting Technique
RPI	Retail Prices Index
CE	Cost Efficiency
TE	Technical Efficiency
AC	Alternating Current
AE	Allocative Efficiency
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
FACTS	Flexible AC Transmission Systems
WAMS	Wide Area Monitoring Systems
DMU	Decision Making Units
ECM	Efficiency Contribution Measure
T&D	Transmission and Distribution
CRS	Constant Returns to Scale
VRS	Variable Return to Scale
ERS	Efficiency Reference Set
MPSS	Most Productive Scale Size
KPIs	Key Performance Indicators
ANOVA	Analysis Of Variance
BSP	Bulk Supply Point
PDL	Percentage Distribution Losses
ECG	Electricity Corporation of Ghana

NEDCo	Northern Electricity Distribution Company
SD	Standard Deviation
CoV	Coefficient of Variation
OPEX	Operating Expenditure
TNTS	Total Number of Technical Staff
Kw	Kilowatt
PCA	Principal Component Analysis
Kwh	Kilowatt per Hour
Gwh	Gigawatt per Hour
T&T	Trinidad and Tobago
EPI	Environmental Performance Index
USD	United States Dollar
Kv	Kilovolt
BSPs	Bulk Supply Points
SHEP	Self Help Electrification Programme
NCRE	Non-Conventional Renewables
MP-MC	Mean of Price and Mean of Cost
NCEP	National Council for Energy Policy
EPE	Energy Research Company
SOEs	State Enterprise Organizations
IPPs	Independent Power Producers
BERA	Botswana Energy Regulatory Authority
BPC	Botswana Power Corporation
NEB	National Energy Board
GNPC	National Petroleum Commission
NED	Northern Electricity Department
PSRC	Power Sector Reform Committee
VRA	Volta River Authority
EC	Energy Commission
GRIDCo	Ghana Grid Company
CTEEP	Companhia de Transmissâo de Energia Elétrica Paulista
ACR	Regulated Contracting Environment
ACL	Free Contracting Environment
UK	United Kingdom

EDF	Électricité de France S.A.
SIC	Sistema Interconectado Central
SING	Sistema Interconectado Central
CNE	National Energy Commission
SEC	Superintendent of Prices of Electricity and Fuels
ANEEL	Brazilian Electricity Regulatory Agency
CDEC	Independent System Operator
PPAs	Power Purchase Agreements
T&TEC	Trinidad and Tobago Electricity Commission
IRP	Integrated Resource Plan
RAP	Receita Annual Permitida
VAD	Value Added Distribution
NRV	New Replacement Value
BPA	Bui Power Authority
CEOs	Chief Executive Officer
MDs	Managing Director
NITS	National Interconnected System
BSC	Balanced Score Card
EFQM	European Foundation for Quality Management
RADAR	Results, Approaches, Deploy, Assess and Refine
PM	Performance Management
USA	United States of America
SFA	Stochastic Frontier Approach
TFA	Thick Frontier Approach
FDH	Free Disposal Hull
CVM	Competing Values Model
FACTS	Flexible AC Transmission Systems
DMU	Decision Making Units
BCC	Banker, Charnes and Cooper
CRS	Constant Return to Scale
CCR	Charnes, Cooper & Rhodes
VRS	Variable Return to Scale
Km	Kilometer
O&M	Operations and Management

OPEC	Organization of Petroleum Exporting Countries
AMERI	African and Middle East Resource Investment
MDAs	Ministries Departments and Agencies
ONS	Operador Nacional do Sistema Elétrico

CHAPTER ONE

INTRODUCTION

1.1 Introduction

To ensure the availability of electrical power, continuous improvement of a power supply network performance is essential besides the efficient use and effective management of electrical power (Amin & Stringer, 2008; Mayakrishnan, 2011).

This chapter introduces this research which focuses on power supply network performance and explores approaches that can be implemented to improve the performance of a national power sector, particularly for developing countries, like Ghana. Power network institutions must implement strategies leading to the efficient electrical power supply with quality service delivery (Amin & Stringer, 2008; Eberhard & Godinho, 2017). Also, to improve the performance of a national power sector, approaches adopted must create a sound policy, institutional and regulatory framework.

Section 1.2 provides the research background to establish the rationale of this research by focusing on current global power sector challenges and highlighting ongoing efforts for power sector performance improvement. Section 1.3 presents the research aim and objectives. Section 1.4 explores the significance of the study. Section 1.5 defines the scope of the study. Section 1.6 outlines the structure of the study and concludes the chapter.

1.2 Study background and rationale

It has been well established that the growth of an economy requires a sustainable electrical power supply (Doe & Asamoah, 2014). Electrical power is also crucial to maintain everyday life, for example, performing household chores, using electronic appliances and lighting for reading at night, and other pleasurable activities (Doe & Asamoah, 2014; Lorde, Waithe & Francis, 2010). However, there are growing concerns about the continuous surge in electrical power demand and the security of power supply globally (IEA, 2016).

The International Energy Agency (IEA) predicted that global electricity demand would increase by 50% from 20,863 in 2016 to 30,000 Terawatt hours (TWH) in 2030 (IEA, 2016). Based on the predicted demand for 2030, the IEA further indicated that there would be a potential lack of power supply security in 2030 if the current constraints in power supply persist. Without significant investment in the power sector, future power supply security, reliability and sustainability could not be guaranteed (IEA, 2020). Lack of power supply security would hit developing countries harder than developed countries. This is by virtue of the lower percentage of the population of developing countries with access to electrical power (IEA, 2016).

The United Nations Sustainable Energy for All (SE4ALL) program, aiming to provide electricity to everyone in the world by 2030, has not made sufficient progress, particularly for Asian and African countries (SE4ALL, 2017). The SE4ALL report in 2017 listed twenty countries in Africa and Asia that would have as high as 80 per cent of their populations lacking access to electricity by 2030 if the current electrical power supply security does not improve. It has been predicted that without improvements in the performance of the electrical power supply chain, a $45 billion annual investment would be needed to satisfy the expected increase in demand by 2030 (IEA, 2016; SE4ALL Report, 2017).

A diversified power generation mix with a high percentage of input from non-conventional renewable (NCRE) sources is expected to be a means for many nations to overcome the issue of electrical power supply security. The NCREs are expected to constitute at least one-third of the global electricity generation mix by 2025 (IEA, 2009; IEA, 2016; IEA, 2020). However, a higher percentage of the NCREs in a power generation mix does not automatically overcome electrical power supply security challenges. Some challenges include equipment failure, fuel supply shortages, climate change, and inefficient power supply management (Khan et al., 2013; Kahbrobaee, 2014; IEA, 2020; World Bank, 2009; Eberhard & Godinho, 2017).

Efforts to overcome challenges of the power sector in the past prompted power sector reforms that swept across the developing world around the 1990s. The reforms were aimed at fundamentally changing the policy, institutional and regulatory frameworks of national power sectors to improve performance (World Bank, 2009; USAID, 2005; PACG, 2005; Farsi, Fetz, & Filippini, 2007). The reform process saw a sequence of what was described as the ‘standard model’ and the ‘standard model’ with further technical and economic regulations targeting efficiency improvement.

The ‘standard model’, also referred to as the ‘textbook model’, pursued commercialization and privatization of national power sector utilities after initially unbundling the former vertically integrated power sector. The ‘standard model’ was intended to ensure that the power sector institutions became commercially viable with decent investment returns by operating in a competitive wholesale market (PACG, 2005; World Bank, 2009; Eberhard & Godinho, 2017).

The second step to the standard model was the pursuit of economic and technical regulations to improve the internal processes of the utilities for delivering quality services. The first set of regulations were 'cost-of-service' regulations, aiming to prevent excessive market power of utilities to protect consumer economic interests (Khalfallah, 2016). The regulator audits operations of the utilities, ascertain the cost incurred and compensate them by applying different pricing. However, the major drawback of 'cost-of-service' regulations is the lack of incentives for the utilities to strive towards cost efficiency (Joskow, 2008). Incentive-based regulations emerged as an alternative to the ‘cost-of-service’ ones. It has a reward and penalty system in line with regulatory benchmarks for the utilities. Incentive-based regulations include price caps, revenue caps, menu of contracts, performance-based, and yardstick regulations (Farsi et al., 2007; Khalfallah, 2013). These incentive-based regulations aimed to ensure efficiency gain-sharing between the utilities and end-consumers (Pollitt, 2017; Jamasb & Pollitt, 2000; Eberhard & Godinho, 2017; Farsi et al., 2007; Khalfallah, 2013) towards ensuring continuous competitiveness of the power sector.

After three decades since the reform, the performance of the power sector in much of the developing world has not seen significant improvement, particularly in African countries. In much of the developing world, electrical power utilities are saddled with debts that have affected their ability to make required investments in strengthening their transmission and distribution (T&D) networks. T&D losses are averaging 50% in developing countries compared to benchmark losses of 10% for developed countries (World Bank, 2009; Jimenez et al., 2014). In most major cities of Sub-Saharan Africa, line interruptions and power cuts are the norm, with industries and other businesses continuing to reel under the high cost of electrical power. This situation has been exacerbated because the policy, institutional and regulatory environment governing the operations of electrical power utilities remain ineffective and inefficient (Eberhard & Godinho, 2017). The regulatory bodies are not independent, and political authorities interfere with their activities (World Bank, 2009; Eberhard & Godinho, 2017).

To overcome the power sector challenges, this study explores performance improvement approaches, which could be particularly relevant to the performance improvement of a national power sector. A number of approaches in the literature are reviewed in this study, and three approaches are selected to be explored. DEA efficiency modelling and evaluation identifies relevant input and output factors for both the T&D subsectors and generates relative efficiency performance of decision making units (DMUs) within the sector. The international benchmarking (IB) approach identifies best-performing countries and the best practices Ghana can adopt to improve the power sector’s performance. The Delphi approach provides the perspectives of experts in terms of critical themes relevant to the power sector and its performance. The integration of the applications of the three approaches generates specific best practices for Ghana's power sector's performance improvement across the policy, regulatory and institutional framework, and the power network. Power sectors of other developing countries can consider the research findings for performance improvement, in terms of efficiency improvement, best practices, and areas for change in managing the sector.

1.3 Aim and objectives

This research aims to explore approaches towards identifying best practices for improving the performance of a national power sector, with a focus on Ghana. Three approaches have been explored: DEA, IB, and Delphi. DEA and Delphi approaches are based on Ghana's power sector’s data and IB considers some of developing countries including Ghana.

The step-by-step objectives to achieve the research aim are:

1. Review different approaches for improving performance in the literature and the characteristics of the power sector to select performance improvement approaches for this study.
2. For the three selected approaches: DEA, IB and Delphi, review relevant literature to identify:
    - Input and output factors that can be used in the DEA efficiency modelling and evaluation;
    - Quantitative and qualitative indicators on which IB can be applied to reveal best practices to improve performance of the power sector at a national level;

- Factors about power sector policies, regulatory and institutional framework, and the power network relevant to a national power sector for applying the Delphi approach.

3. Gather data from units of the T&D subsectors in Ghana's power sector, the benchmarking countries, and Ghana's power sector experts.
4. Perform DEA to identify the most relatively efficient unit(s) and conduct a trend analysis, window analysis and sensitivity analysis.
5. Compare key quantitative performance indicators among the benchmarking countries to identify best-performing countries and reveal their best practices.
6. Identify elements for improvement across subsectors in the power sector based on the perspectives of the experts through Delphi.
7. Integrate the results from the three approaches to generate a collective process and outcomes for improving the performance of a national power sector with a focus on Ghana.

1.4 Scope of the study

This study explores approaches to identify best practices for improving the performance of a national power sector with a particular focus on Ghana. This study does not intend to explore all performance improvement approaches; but it focuses on efficiency improvement in the T&D subsectors, identified best practices internationally for performance improvement, and improvement in the policy, institutional and regulatory framework. The best practices are identified from Ghana’s peers, where economic conditions are similar to Ghana. This study uses the three approaches: DEA, IB, and Delphi, as the means towards improving the performance of a national power sector. The two selected approaches, DEA and Delphi, require data collection solely from Ghana, and the other one, IB, needs data collection from Ghana’s peer countries.

Some performance improvement approaches in the literature have been reviewed before selecting the three approaches with justification. To explore the applicability and usefulness of these three approaches to the performance improvement of the sector, the approaches have been applied to Ghana’ data and its peer countries. The assessment units for the DEA efficiency modelling and evaluation entail all T&D subsectors units in the power sector of Ghana over a number of years. The IB and the Delphi approaches are applied to all the three subsectors and its policy, regulatory and institutional framework. The data have been collected as far as available to the most recent year when the data collection took place.

1.5 Significance of the Study

The two dimensions of contribution to knowledge and practical implications are discussed in this section.

1.5.1 Contribution to knowledge

The study methodology considers the exploration of different approaches and their integration of findings associated with their application processes to identify best practices to improve the performance of a national power sector. This methodological process contributes to knowledge both within the power sector and the performance management sphere in the following ways:

1. The integration of the three approaches is advanced as this allows leveraging the advantages provided by the set of approaches. They complement each other.

2. The methodology of each approach and their integration can be used for performance improvement of power sectors of other countries.

3. Identified further research areas valuable to the power sector for its continuous performance improvement by implementing effective methods through further learning.

1.5.2 Contribution to industrial practice

This study contributes to the improvement of policymaking in the power sector with the improved understanding of the impact of power sector reforms and the provision of a means for improving the efficiency and practices for the sector. This study also contributes to the improvement of power sector regulations. The details of significance in these areas are specified below:

1. **Policymaking**

   Best practices identified through international comparison and expert perspectives on the power sector contribute to policy changes in the sector and changes in the sector's policy, institutional, and regulatory structures for a developing country like Ghana. Improved understanding of power sector reforms contributes to future policymaking effectiveness.

2. **Management of the power transmission and distribution subsectors**

   Power sector units within the T&D subsectors can adopt the efficiency models this study has developed. The model supports the effective evaluation of the efficiencies of the units in the two subsectors. This contributes to continuous improvement and facilitates internal learning.

3. **Determination of tariffs**

   Ghana's tariff adjustment formula indicates high operational losses in the power sector given the high value of the benchmark losses which is around 21%. The Public Utilities Regulatory Commission (PURC) could consider developing a model with multiple input and output factors, based on DEA, to evaluate the efficiency of the two subsectors and set efficiency benchmarks.

4. **Applicability of approaches to other sectors**

   Even though this study explores approaches for performance improvement of the power sector, the general processes of applying these approaches allow their applicability for performance improvement of other sectors. Other sectors can consider the research methodology based on the applications of the performance improvement approaches to improve performance.

1.6 Organization of thesis

Following this introductory chapter, chapter two reviews the relevant literature. The literature review includes a review of factors affecting the performance of the power sector, performance improvement models, and identifies the three performance improvement approaches for exploration by this study. Chapter three presents the methodology for the research based on a mixed-method-concurrent-triangulation design. The methodology chapter explains data collection methods and processes, and methods for analysing data collected for each of the three selected approaches and their integration.

Chapter four presents the results of the factor selection process and the results of the DEA efficiency modelling and evaluation using the data collected from the T&D subsectors of Ghana's power sector. Chapter five presents the results and analysis based on the IB. Chapter six presents the results and analysis for the Delphi approach based on the perspectives of Ghana's power sector experts. The integration of the results across the three approaches is provided in chapter seven. Chapter eight presents the conclusion.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

As found in the performance measurement and management literature, many approaches have been developed for performance improvement. This chapter reviews two critical performance measures to fulfil the research aim: efficiency and effectiveness and a set of performance improvement approaches. Also, the characteristics and factors affecting the performance of the national power sector are reviewed.

Section 2.2 presents the characteristics of a national power sector from the literature perspective, and section 2.3 explores the factors affecting the performance of a national power sector. Section 2.4 defines efficiency, effectiveness, and the relationships between the two. Section 2.5 explores various performance improvement approaches with comparison and justifications for the selected performance improvement approaches for this study. Section 2.6 summarises the chapter with highlighted key points.

2.2 Characteristics of a national power sector

The characteristics of a power sector can be represented in two aspects: model structures and sector regulatory framework. These aspects are reviewed below, with strengths and weaknesses discussed in the literature.

2.2.1 Power sector model structures

The power sector follows two broad organizational structures: vertically integrated and unbundled structures (Michaels, 2006; Chimbaka, 2016). Vertical integration is a business arrangement whereby different supply chain stages are owned and operated by the same firm. In the power sector, a Vertically Integrated Utility (VIU) is a state monopoly, typically responsible for managing all the functions, including generation, transmission, distribution, and retailing of power to end consumers. On the other hand, an unbundled structure has separately managed power generation, transmission, and distribution functions with different entities participating (Boulle, 2019; Eberhard & Godinho, 2017; Mulder & Shestalova, 2006; Michaels, 2006; Chimbaka, 2016).

Four primary forms of unbundling are discussed in the literature with their practical implementation. These are functional unbundling, accounting unbundling, legal unbundling, and ownership unbundling. Table 2.1 describes each unbundling type and its purpose.

Unbundling	Description	Purpose
Functional unbundling	Separating functional business units within a larger VIU	To enhance the efficiency of each functional unit whilst ensuring management control across the different functions
Accounting unbundling	Separated functional units with the same reporting and records system within a larger VIU	To ensure a standard of financial reporting and records whilst maintaining management's functional needs
Legal unbundling	Subsidiary companies of VIU are established, with each being responsible for a particular function	To give a measure of independence to the previous functions in terms of their strategic and operational decision-making whilst maintaining an oversight control from a VIU
Ownership unbundling	Companies of different functions are separate legal entities with full autonomy and independence	To function as fully independent utilities for any previous functions to be competitive

Table 2.1: Descriptions of each power sector unbundling model and purposes

In both functional and accounting unbundling, the business units are within the larger VIU. However, each has its necessary expertise, specialising in the business of a particular power sector function. Analysts describe them as not the truest unbundling types because they remain mere business units within a VIU (Boulle, 2019; Mulder & Shestalova, 2014; Shen & Yang, 2012). Even though in legal unbundling, the entities created are subsidiaries within a larger VIU, a certain degree of independence and autonomy enables them to make more strategic decisions that have a far-reaching impact on the specific business function. Ownership unbundling is the truest form of unbundling where all the utilities or entities are entirely independent and can function within a wholesale competitive power market (Boulle, 2019; Mulder & Shestalova, 2014; Shen & Yang, 2012).

The strengths of a vertically integrated structure are essentially the weaknesses of an unbundled structure and vice versa. Table 2.2 provides the strengths and weaknesses of both unbundled and vertically integrated structures.

	Vertically Integrated	Unbundled
Likely strengths	1. Effective and efficient coordination across the three functions 2. Leveraging organizational resources more efficiently through enterprise resources planning 3. Effective risk management within the integrated system and the advantage of a lower cost of capital 4. Conflicts and hold-ups are likely to be prevented 5. End-user tariffs tend to be lower due to low administrative cost	1. Transparency with effective and efficient regulatory functions 2. Insight into network cost management and implementation rules 3. Fair competition 4. Providing infrastructure for good corporate governance and strengthening accountability 5. Independent management and financing of the network 6. Strong resilience of the electricity sector and reduced risk of energy supply 7. Non-discriminative third-party access to the network
Weaknesses	1. Lack of competition and less innovation opportunities 2. Lack of motivation for service quality improvement 3. Information asymmetry and less regulatory effectiveness 4. Lacking infrastructure for effective corporate governance and accountability 5. Challenging to assign responsibility when faults occur, leading to ambiguous financing and investment decisions	1. Coordination and enforcement of regulations could be ineffective 2. Economies of scope and scale tend to be diminished to lead to high tariffs 3. A tendency to have standalone commercial companies and prone to the risk of takeovers 4. A tendency for conflicts and holds-up due to conflicts among utilities 5. High end-user tariffs due to high administrative costs among the different utilities

Table 2.2: Strengths and weaknesses of vertically integrated and unbundled structures

The nature of the power network implies that generators, transmitters, and distributors all need each other to function. In an unbundled structure, there is the tendency for one entity to hold a higher bargaining power than the other, and this may result in holding up operations of the others. However, hold-ups are unlikely to occur in a vertically integrated structure because the three functions are managed under one entity. In addition, a vertically integrated structure aims to ensure that the different components work in unison towards achieving the overall goal. If the functions were managed under separate entities, like in an unbundled structure, the potential for pursuing different operational and business goals could arise (Michaels, 2006; Chimbaka, 2016, Mulder & Shestalova, 2014). However, vertically integrated structures are fraught with political interferences. These constraints affect the ability of a regulator to monitor and enforce obligations required by a utility as contained in contracts towards other parties within the power sector. It also hampers the regulatory function of ensuring responsibilities towards power consumers, especially reliability and quality of power supply (Mulder & Shestalova, 2014; Eberhard & Godinho, 2017, Shen & Yang, 2012).

On the other hand, unbundling is likely to create access to information across separate functions easily. Due to transparency, unbundling gives fewer incentives for cross-subsidies and other distortions. Under unbundling, the VIU loses the possibility to strategically reallocate its internal costs, which provides the regulator with better insight into network management costs to implement more appropriate rules, such as efficiency targets. In unbundling, the inclusion of multiple actors allows for the diversification of power sources, thereby spreading energy supply risks (Mulder & Shestalova, 2014; Eberhard & Godinho, 2017, Shen & Yang, 2012).

2.2.2 Power sector regulatory framework

The regulatory framework within a national power sector is informed by three fundamental pillars of regulatory governance, regulatory substance, and regulatory impact. The three pillars are defined below:

- ***Regulatory governance*** is defined as 'the institutional and legal design of the regulatory system and the framework within which decisions are made' (Brown et al., 2006, p.19).
- ***Regulatory substance*** is defined as 'the content of the regulation, the actual decisions, whether explicit or implicit, made by the specified regulatory entity or other entities within the government, along with the rationale for the decisions' (Brown et al., 2006, p.20).
- ***Regulatory impact*** being a consequence of regulatory governance and regulatory substance (Kapika & Eberhard, 2013)

Regulatory governance provides rules, regulations, and processes to guide the operations of all utilities within the power sector. It sets out the governance relationships among the utilities, between utilities and regulators, and between the utilities and the consumers. It sets the parameters to guide these relationships to monitor compliance and appropriate sanctions applied where violations are observed (Brown et al.,2006). Kapika and Eberhard (2013) underscore the fact that the need to ensure that services are reliable, utilities are viable, and new investments from the public and private sectors are attracted to the power sector, makes regulatory governance integral to the power sector. They emphasize that these goals can be achieved if an institutional, regulatory and legal framework supports independent regulatory decision-making.

According to some experts, the fundamental challenge for regulatory governance regimes is to find a mechanism for restraining the degree of regulatory discretion (Eberhard, 2007). Levy and Spiller (1994;) identifies three complementary means for controlling arbitrary administrative action as: '(a) substantive restraints on the discretion of the regulator, (b) formal or informal constraints on changing the regulatory system, and (c) (set up) institutions that enforce the above formal-substantive or procedural constraints' (p.202). While agreeing with Levy and Spiller, Stern and Cubbin (2004) indicate that regulatory discretion cannot be eliminated, notwithstanding the laws put in place that attempts to eliminate it. However, whether regulatory discretion is curtailed or not, an independent regulator insulated with appropriate legislative powers remains a critical pathway towards improving regulatory governance (Stern & Cubbin, 2004; Brown et al.,2006; Kapika & Eberhard, 2010; Kapika & Eberhard, 2013).

Regulatory substance aims to ensure that reasonable electricity prices are dictated on the market, appropriate pricing methodologies implemented and enforced by the regulator, and appropriate market access and the licensing regime is in place. Competition through an unbundled power sector structure and the horizontal disintegration of vertically integrated monopolies may create an efficient and effective power sector. However, there are concerns for rent-seeking, especially in the transmission and distribution subsectors, which makes an effective regulatory system justifiable to the protection of consumer interests, without compromising access to electricity (Kapika & Eberhard, 2013; Kapika & Eberhard, 2010; Rodriguez Pardina & Schiro, 2018). Therefore, regulatory substance is minded about quality and reliability standards being implemented across the power sector value chain. Regulatory substance anticipates conflicts between consumers and the utilities and among the utilities and pursues conflict resolution mechanisms to prevent and manage conflicts (Kapika & Eberhard, 2013; Kapika & Eberhard, 2010). While consumers are concerned about the regular and sustainable supply of electricity to support their daily activities, regulatory substance requires that utilities conduct their operations to ensure the timely and sustainable supply of electricity in a cost-efficient manner.

Also, to ensure electricity supply security, which is a continuous flow of electricity to satisfy the significant proportion of the demand if not all, electricity needs to be priced in a market-driven way to provide a sufficient return to investors to be sustainable in supply (Amin & Stringer, 2008; Eberhard & Godinho, 2017). This is consistent with the views by Stern (2009), stating that 'the critical objective of economic regulation of infrastructure industries is to ensure the continuous supply, over the long-term, of unspecified infrastructure services of defined quality at the minimum necessary cost (and prices) to the population and industry of the country (p.15). Kapika and Eberhard (2010) assert that Stern's (2009) point of view on regulatory performance should be evaluated within the context of regulatory impact. Regulatory impact is the consequence of regulatory governance and regulatory substance and assesses the impact of both regulatory governance and regulatory substance on both consumers and utilities. Regulatory impact strikes a balance between the utilities and consumers and ensures that the interests of both are kept (Kapika & Eberhard, 2013).

2.2.3 Types of power sector economic regulations

Aside from the "standard model", a primary power sector reform tool in the past, regulations associated with the reforms intended to directly impact the performance improvement of the operations of electrical power utilities (Eberhard & Godinho, 2017; Khalfallah, 2013). The first set of regulations aimed to prevent the utilities from exercising excessive market power to protect consumers' economic interests. These regulations are termed 'cost-based regulations', also known as 'cost-of-service or 'cost-plus regulations' (Khalfallah, 2013). The regulators audit the utility operations and ascertain the cost incurred over the previous year. They also audit the projected cost for the following year and compensate the utility by setting fair prices. The major drawback of 'cost-of-service or 'cost-plus regulations' is the lack of incentives for the utilities to introduce measures towards cost efficiency. Regulatory objectives tend not to be ambitious enough.

On the other hand, incentive-based regulations have become popular, especially among developed countries, since the 1980s. Some developing countries have embraced incentive-based regulations since power sector reforms began in the 1980s. These regulations use rewards and penalties to induce the utilities to achieve desired goals of efficiency, leading to efficiency gain-sharing between utilities and consumers as against the 'cost plus regulations' where inefficiencies are passed on to the consumer (Farsi, Fetz

& Filippini, 2007; Khalfallah, 2013, Jamison, 2014). Some popular incentive-based regulations include price-cap, menu of contracts, performance-based, and yardstick regulations. Table 2.3 summarizes the features of these types of economic-based regulations.

Type of Economic Regulation	Description	Measurement Methods/Implementation
Price (Revenue) cap	This requires the regulator to set a maximum price that the firm can charge or a certain amount of revenue they are allowed to gain by that price	This method sets the maximum rate of regulated price increase covering the inflation rate in line with retail price index (RPI) offset a possible productivity growth
Menu of contracts	A firm can choose a suitable one from a set of profit-sharing contracts offered by the regulator in terms of projected expenditures, efficiency capability, and risk aversion	The price that a regulated firm can charge is linked partially to the actual costs observed ***ex-post*** as well as to a reference cost determined ***ex-ante***
Yardstick regulation	It is based on the performance of other similar utilities. The utility is benchmarked against other utilities in the industry	Frontier techniques such as Data Envelopment Analysis (DEA) and Corrected Ordinary Least Squares (COLS) are often used for the benchmarking analysis
Performance-based regulation	The regulator establishes a direct link to a utility between its performance and financial reward/ penalty.	The regulator sets a specific linkage **ex-ante** between the financial reward-penalty scheme and the targeted performance of a utility based on some critical power sector performance indicators, for example, SAIDI, SAIFI, CAIDI, and T&D losses.

Table 2.3: Features of economic regulation types

With a price (revenue) cap, the regulated utilities can gain more or less profits depending on whether their productivity has been improved or not (Farsi et al., 2007; Khalafallah, 2013). The X-factor can be set equal to the annual expected or target growth rate of the total factor productivity (TFP) in the entire sector. The X-factors can also be set equal to the yearly target change in productive efficiency for each company. The threshold level set by the regulator provides an incentive to companies to achieve a certain level of productivity to be profitable. The regulator can alter the price-cap based on a benchmarking analysis among companies to drive the productivity effort by companies (Farsi et al., 2007). In 'menu of contracts', the regulatory mechanism is applied in the total costs of a regulating firm with some controllable cost items. It can ensure that the company meets both productive and allocative efficiency objectives. It provides incentives to reduce costs to benefit the company (Khalafallah, 2013).

Yardstick regulations encourage competition among firms through performance comparison among regulated firms to achieve regulatory objectives. This measured performance becomes the basis for determining appropriate price caps for the different sets of utilities in the industry (Farsi et al., 2007; Khalafallah, 2013). With Performance-based regulation, targets are set along with key indicators considering the utilities' past performances. These are linked to the utility's projected controllable costs, which form the basis for determining regulated tariffs (Vogelsang, 2006). Khalafallah (2013) asserts that performance-based regulation is more incentivizing than other economic regulatory mechanisms as it defines a clear financial incentive by achieving specific performance goals. The company is clear with the rewards and penalties in line with its achieved performance level.

Despite the benefits of incentive-based regulations over cost plus regulations, they also have drawbacks. Drawn from Welke (2010) and Khalfallah (2013), some disadvantages of incentive-based regulations include:

- The need to minimize costs could result in the utility lowering service quality;
- Utilities may profile consumers to serve the class of consumers with the lowest risk and adequate returns;
- The price caps set by the regulator might be too high, leading to the elimination of consumer surplus;
- A utility may conceal and share inaccurate data.

Chile, Norway, the UK, Netherlands, USA, Australia, and Finland are among the countries that are popular in the successful implementation of incentive-based regulations, such as yardstick and performance-based regulations. For many developing countries, however, the absence of wholesale competitive and deregulated power markets has made incentive-based regulations challenging to be implemented (Farsi et al., 2007; Eberhard & Godinho, 2017).

2.3 Factors affecting a power sector performance

Besides the type of model structures and economic regulations, several technical factors affect the management and performance of generation, transmission, and distribution subsectors in a national power sector. The common factors are discussed in this section.

2.3.1 Power generation sources

As global electrical power demand continues to rise, there are concerns about the security, reliability and viability of current conventional, mostly from non-renewable (fossil fuel) sources, as they are rapidly depleted. Experts in this field believe that the fossil age may last for a few more decades (Owusu & Asumadu-Sarkodie, 2016). This explains the current energy transition debate that has dominated the global energy sector. This has prompted a lot of research into renewable sources, referred to as non-conventional, as the driver for power generation towards supply security and sustainability. Aside from the security of supply, reduction in carbon emissions and the greenhouse effect (GHE) is another driving force to make the transition towards cleaner sources of energy, for example, renewable sources (Benjamin, 2016; Fouquet, 2014; Sharma, 2017; Omer, 2009, Owusu & Asumadu-Sarkodie, 2016). There is a continuous commitment on the national and multilateral levels to make funds available for exploration into renewable (NCREs) energy. New technologies deliver carbon reduction, and waste reduction outcomes are increasingly bankable (Omer, 2009). Table 2.4 provides five common renewable sources for electricity and their potential.

Energy Source	Conversion	Potential
Hydro	Construction of dams to produce waterfalls that power turbines	A technical annual potential of 14,576 TWh
Wind	Harnesses kinetic energy from moving air. Wind turbines convert the energy of wind into electricity	Wind is inexhaustible and abundant
Solar	Uses solar irradiance to generate electricity using photovoltaic (PV) and concentrating solar power (CSP)	7,500 times the world's total annual primary energy consumption of 450 EJ
Geothermal	Heat is mined from geothermal reservoirs using wells and other means. Once drawn to the surface, fluids of various temperatures can be used to generate electricity	Geothermal gradient averages about 30 °C/km
Biomass	Combustion of a feedstock to generate electricity sustainably based on harvested biomass	A total terrestrial surface of about 3,500 EJ/year

Table 2. 4: Types of renewable power generation sources and potential

Hydroelectric energy is a renewable source and classified as a conventional energy source because it has been a significant energy source over the years. The world's leading country in hydropower generation is the United States, with a capacity of 71,000 MW daily. In South America, 73 per cent of the electricity used comes from hydropower compared to 44% in the developing world as a whole (World Energy Council, 2013). Also, wind energy is considered one of the most sustainable sources of electricity generation as it produces no toxic pollution or green house gases (GHGs). Wind is inexhaustible and abundant, making it a viable and large-scale alternative to fossil fuels. Wind energy has taken a commanding lead among renewable sources and exists everywhere globally, in some places with considerable energy density (Sharma, 2017; Owusu & Asumadu-Sarkodie, 2016).

Like wind, the sun is also a tremendous source for generating clean and sustainable electricity without toxic pollution or global warming emissions (Sharma & Rout, 2013). The issue is the stability of electricity generation and equipment required to produce at a high conversion rate. Solar energy technology is obtained from solar irradiance to generate electricity using photovoltaic (PV) and concentrating solar power (CSP) (Owusu & Asumadu-Sarkodie, 2016). The geothermal power plant, known as hydrothermal plant, is located near geologic "hot spots" where hot molten rock is close to the earth's crust and produces hot water or other regions of hot, dry rock which can be relied upon for electricity generation. There are areas of the earth's interior accessible by drilling and where the gradient is well above the average gradient (Owusu & Asumadu-Sarkodie, 2016). Geothermal plants differ in their technology to convert the resource to electricity and the type of cooling technology they adopt (water-cooled and air-cooled) (Sharma, 2017).

Biomass power plants share some similarities with fossil fuel power plants as both involve the combustion of a feedstock to generate electricity (Sharma, 2017). However, the feedstock of biomass plants is inexhaustible as against exhaustible fossil fuels. Harvesting biomass for producing electricity is diverse, including energy crops (like switchgrass, giant miscanthus, agricultural waste, forest products, urban waste, and manure) (Sharma, 2017; Owusu & Asumadu-Sarkodie, 2016). One advantage of biomass electricity is that fuel is often a by-product, residue, or waste product. Significantly, it is essential given that it does not create a competition between land for food and land for fuel (Urban & Mitchell, 2011 cited in Owusu & Asumadu-Sarkodie, 2016).

Energy source	Conversion	Potential
Coal	Coal is burnt to produce excessive heat for steam production to spin turbines for electricity generation	Coal is the most abundant fossil fuel, and supplies are expected to last longer than for other fossil fuels
Oil and natural gas	Oil or gas produces the heat needed for turning turbines for electricity generation.	Gas-fired power plants are the only fossil fuel technology set to grow in almost all regions, due to the low upfront investment cost for new plants, and the increasing availability of gas
Nuclear	Nuclear fission is used to generate heat which creates steam to spin turbines to generate electricity	One ton of Uranium-235 would provide as much energy as produced by 3 million tons of coal or 12 million barrels of oil

Table 2.5: Types of non-renewable power generation sources and potential

The non-renewable sources are mainly from fossil fuels formed over billions of years from the remains of living organisms. According to IEA (2018), traditional thermal sources, such as fossil fuel and nuclear, still accounts for 75% of the total electricity generation worldwide. Even though aggressive scenarios of developing other power generation sources exist, the IEA does not envision the global generation share of thermal sources falling below 50% before 2030. However, fossil energy sources require technologies to achieve zero emissions in the medium to long term. Some of the main approaches that will be used to reduce CO_2 emissions are increasing the efficiency of energy conversion, utilization, capturing and storing of CO_2 from fossil fuel combustion. Carbon Dioxide Capture and Storage (CCS) is a technology that can reduce the greenhouse gas problem and facilitate the continued use of fossil fuels (Laković et al., 2016). But it has its limitation both in the cost of the equipment and the capacity in the long run (Laković et al., 2016).

Coal, the most abundant fossil fuel, is a primary non-renewable source. Coal supply is expected to last longer than other fossil fuels, such as oil and gas. Coal-fired power offers cost advantages over gas-fired power as the natural gas price is usually higher and more volatile. Emissions of airborne pollutants may be lower as well. A disadvantage is the high initial investment cost compared to gas-fired power. Also, coal-fired power plants emit large amounts of CO_2 (Lekovic et al.,2016; OECD, 2010). The IEA predicts that natural gas will overtake coal in capacity supply by the mid-2020s amid the rapidly rising renewables share. Even though nuclear energy could also present a significant potential given the massive deposits that have been made around the world, concerns about the effects of atomic energy on climate change and global warming give the uncertainty of nuclear energy (Jacobson, 2019).

2.3.2 Technical factors affecting the performance of the transmission network

The following technical factors generally affect the performance of a power transmission network:

1. The length and type of transmission lines (Mehta & Mehta, 2005)
2. Flexible AC Transmission Systems (FACTS) (Frolov et al., 2013)
3. Wide Area Monitoring System (WAMS) (Eissa et al., 2015; ABB, 2007)
4. The number of transformers (Mehta, 2005; Nunoo & Mahama, 2013)
5. Superconductors (Mehta, 2005; Patrick & Fardo, 2009).

The length of a transmission line below 50km is categorized as short. In contrast, a transmission line between 50km and 100km is medium. A transmission line above 100km is categorized as long. The short, medium and long transmission lines will normally transmit electrical power at voltages of <20kv, >20kv and <100kv, and >100kv respectively (Mehta & Mehta, 2005). Mehta and Mehta (2005) indicate that longer transmission lines are difficult to manage and have a higher maintenance cost. The two main transmission lines are high-voltage alternating current (HVAC) transmission lines and high voltage direct current (HVDC) transmission lines. Alternating current refers to the flow of electric charge that changes direction periodically. On the other hand, direct current refers to a constant flow of electric charge in a single direction. HVDC lines offer significant advantages over HVAC lines due to the lower transmission losses. The losses on an HVDC line can be 25% lower than those on an HVAC line at a similar voltage (ABB, 2007).

The industry has discovered a family of electrical and electronic devices referred to as Flexible AC Transmission Systems (FACTS), which provide various benefits for increasing transmission efficiency and safety (Frolov et al., 2013). The most immediate benefits of FACTS devices come from their ability to allow existing AC lines to be heavily loaded without increasing the risk of disturbances on the system (ABB, 2007).

FACTS device	Types
Series Controllers	1. Thyristor Controlled Series Capacitor (TCSC) 2. Thyristor Controlled Phase Angle Regulations (TCPAR or TCPST) 3. Static Synchronous Series Compensator (SSSC)
Shunt Controllers	1. Static Var Compensator (SVC) 2. Static Synchronous Series Compensator (SSSC)
Combined Series Controller and Combine Series-Shunt Controllers	1. Interline Power Flow Controller (IPFC) 2. Unified Power Flow Controllers (UPFC)

Table 2. 6: Different FACTS devices and associated types

Also, several constraints in power transmission affect the reliability of the transmission grid and availability. These include thermal or current limits where electrical lines resist the flow of electricity and produce heat. If the current flow is too high for too long, the line heats up and loses strength. Again, voltage tends to drop between the sending and receiving ends of a transmission line, and this can cause damage to the properties of end consumers (ISSER, 2005). However, if operators can monitor grid conditions precisely and in real-time, most of the constraints observed on a transmission line can be managed appropriately to enhance the transmission network's effectiveness and efficiency for the entire transmission utility. Wide area monitoring systems (WAMS) remains the industry best practice (Eissa et al., 2015; ABB, 2007)

Transformers are used to control the voltage (step-up) by increasing or decreasing it when necessary. In power transmission, the power transformer is needed to perform both roles. Some percentage of power is lost during transmission over a long distance, as the current converts some of the power into heat through the transmission lines. The voltage must increase to ensure less power losses. The higher the voltage is, the lower the current must flow within the transmission line to deliver the same amount of power over a time period (Mehta, 2005; Nunoo & Mahama, 2013). This requires a step-up power transformer as soon as power is offloaded to the transmission utility by the power generator. However, the high voltage is stepped down to the required voltage at the distribution substation before distributing it to final consumers.

The conductor is one of the essential items for electrical power transmission. It retains as a high-cost item in the total cost of the equipment for a transmission utility (Mehta, 2005). The properties to consider in determining the suitability of electrical power conductors are:

- High electrical conductivity
- High tensile strength to withstand mechanical stresses
- Low cost so that it can be used for long distances
- Low specific gravity so that weight per unit volume is small

Materials commonly used in manufacturing conductors are aluminium, steel, and copper. These metals possess the necessary flexibility, current-carrying ability, and economical in cost to act as efficient conductors. Copper is a better conductor, with aluminium being 30% lighter than copper. When weight is a factor in selecting conductors, aluminium becomes preferred (Mehta, 2005; Patrick & Fardo, 2009).

2.3.3 Technical factors affecting the distribution network performance

The technical factors affecting the power transmission subsector also impact the distribution subsector. However, some other technical factors that uniquely impact a distribution network are the following:

- Type of construction
- The structure of the distribution grid
- The power distribution transformers

A distribution system includes either overhead construction, underground construction, or both. Poles made of wood, concrete, or steel are arranged to carry transformers and conductors overhead. In underground construction, cables, conduits, and manholes remain under the surface of streets and sidewalks. In many cases, however, many distribution utilities rely on overhead distribution systems against underground distribution lines. The choice between overhead and underground construction of a distribution system depends on many factors (Mehta, 2005). These factors include public safety, initial cost, and flexibility with each of them. Each type of distribution system has advantages and disadvantages. But due to the initial cost involved in constructing an underground distribution line, many distribution grids have tendered to use overhead distribution systems. Underground distribution systems are used sparingly, especially in cases where it is impossible to use an overhead distribution system or the law not permitting overhead distribution systems in very isolated circumstances (Mehta, 2005; ISSER, 2005).

The distribution power transformer transforms power to the necessary voltage required by the consumer. The distribution of alternating-current power depends on the use of transformers at many points along the route of the power distribution system. Effective and efficient power distribution hinges mainly on the quality of distribution power transformers. They constitute a large portion of a typical power distribution utility investment (ABB, 2013; Patrick & Fardo, 2009; Eduful1 & Mensah, 2010). Distribution power transformers are mostly step-down transformers. This is because power distribution voltages get stepped down from the primary distribution substation to the consumer's premises. But distribution transformers differ from power transformers. Power transformers are used for power transmission, whereas distribution transformers are used purposely for power distribution.

Power transformers are rated in MVA and typically vary roughly from 16 Megavolts per amps (MVA) to 63 MVA. Meanwhile, distribution transformers are rated in kVA and range between 50 to 1000KVA depending on the type of mount (ABB, 2013; Eduful1 & Mensah, 2010). Distribution transformers are either Poll Mounted (PMT) or Ground Mounted (GMT). The standard practice in Ghana is to limit PMT installation to a maximum capacity of 200 KVA. However, there is no capacity limit when it comes to the installation of GMT (Eduful & Mensah, 2010).

2.4 Efficiency and effectiveness performance measures

Managing organizational performance requires the two fundamental dimensions of measures: efficiency and effectiveness, as efficiency and effectiveness define the overall health of an organization (Bourne et al., 2002). These two performance dimensions require specific measures in a particular business context. This section explores the definitions of efficiency and effectiveness and their interrelationships. Measures associated with these two performance dimensions have also been reviewed.

2.4.1 Efficiency

Table 2.7 provides three definitions of efficiency, which have been frequently referred to by other studies.

Definitions	Comments
'The ratio of outputs to inputs' (Cooper et al., 2006, p. 1; Sherman & Zhu 2006, p.3).	Input and output-based measure. This definition explains the fundamental principle to measure efficiency in a ratio
'A comparison of actual performance with optimal performance located on the relevant frontier' (Lovell, 1993, p.33).	Output-based measure. The difficulty is in determining optimal performance – the frontier
'Efficiency is essentially a comparison between inputs used in a certain activity and produced outputs.' (Aubyn et al., 2009 p.5).	This is the same as the first definition with more detail.

Table 2.7: Definitions of efficiency with comments

The efficiency of a measurement unit is determined by its output-to-input ratio. The unit may vary in scale from a single operation to a process or multiple processes of several operations. The efficiency ratio of each measurement unit in the same industry can be compared to other units. The unit(s) with the highest value of efficiency is(are) frontier(s) (Sherman & Zhu, 2006). A unit becomes relatively efficient if using a specific amount of input results in attaining the highest possible output under the current conditions. In this case, both the input and output levels are points on the efficiency frontier among the units in the analysis (Aubyn et al., 2009; Mihaiu et al., 2010; Daraio & Simar, 2007). The reverse is where input levels are reduced to the lowest possible level at a specific output level on the frontier (Aubyn et al., 2009; Mihaiu et al., 2010; Daraio & Simar, 2007; Fried, Lovell & Shelton, 2008; Mouzas, 2006). Therefore, the efficiency of a firm can be determined by comparing observed output to the highest potential output obtainable from the input or comparing observed input to the lowest potential input required to produce the output under the prevailing conditions.

There are three main types of efficiency: technical efficiency, allocative efficiency, and cost efficiency. The definitions and associated specific features are presented in Table 2.8.

Type of efficiency	Definitions	Specific features
Technical efficiency	'Ratio between observed output and maximum output, under the assumption of fixed input, or as the ratio between the observed input and the minimum input under fixed output' (Porcelli, 2009, p.3). Bhagavath (2006) defines technical efficiency as the 'conversion of physical inputs (such as the services of employees and machines) into outputs relative to best practice' (p.61).	1. Focused on quantities 2. Compared to the maximum potential under a fixed input or output level
Allocative efficiency	'Allocative efficiency determines the gap between a firm (current profitability position) and the point of maximum profitability, given market prices of inputs and outputs' (Casero et al., 2009 p. 8).	1. Focused on profitability 2. Based on market prices of inputs and outputs 3. Aimed for the least cost inputs and optimum level of revenue from outputs
Cost efficiency	Product of technical and allocative efficiencies	1. Consider both quantity and price and their integrated impact 2. Optimization of both production levels at a given cost.

Table 2. 8: Types of efficiency and specific features

Technical efficiency is concerned about the quantity of inputs used relative to the quantity of outputs generated. An organization can therefore measure technical efficiency by using the ratio of its outputs and inputs and determining whether wastages are occurring or not based on a given technology. In relative terms, technical efficiency can be improved by benchmarking the industry best performing organization in terms of efficiency measured by this ratio (Fried et al., 2008). Unlike technical efficiency, allocative efficiency is measured by considering inputs prices and revenues of the outputs. An organization operating highly efficient technically, may still be inefficient allocatively because it is not using inputs in their best proportions given the current prices (Bhagavath, 2006; Cesaro et al., 2009).

Cost efficiency combines both technical and allocative efficiency and is generated based on the scores of both technical and allocative efficiencies (Bhagavath, 2006). An organization's cost efficiency is related to its production costs and its revenue and is observed at the point of both technical and allocative efficiency (Cesaro et al., 2009; Ouattara, 2012; Bhagavath, 2006). The objective for using cost efficiency is concerned with whether the firm's operations are profitable (Cesaro et al., 2009). Cost efficiency, therefore, is the product of technical efficiency and allocative efficiency (Bhagavath, 2006; Cesaro et al., 2009; Ouattara, 2012).

2.4.2 Effectiveness

According to Reimann (1975), the concept of organizational effectiveness remained the most elusive and controversial as far as organizational theory literature is concerned. Many studies have attributed organizational effectiveness to goal attainment (Reimann, 1975; Oghojafor et al., 2012). However, since organizational goals may differ from one organization to another, organizational effectiveness might mean differently to different people or organisations. Table 2.9 provides four definitions of organizational effectiveness.

Definition	Comments
'The extent to which an organization can achieve its goals' (Oghojafor et al., 2012, p. 86).	Whether these goals are internally and/or externally oriented remains unclear
'The ability of an organization to account successfully for its outputs and operations to its various internal and external constituencies' (Gartner & Ramnarayan, 1983, p.97).	It includes both internal and external elements, but it does not emphasize the importance of external impact on the effectiveness of an organization
'Ability of the organization, in either relative or absolute terms, to exploit its environment in the acquisition of scarce and valued resources' (Yuhtman & Seashore, 1967, p.898).	They are focused on acquiring resources and do not specify the ability to achieve the external stakeholders' needs
'The extent to which an organization as a social system, given certain resources and means, fulfils its objectives without incapacitating its means and resources and placing undue strain upon its members' (Georgopoulos & Tannenbaum, 1957, p.535).	They are inwards looking, except if the organization's objective might be linked to external stakeholders for effectiveness

Table 2.9: Definitions of organizational effectiveness

These definitions of organizational effectiveness reflect the different orientations. The definitions by Oghojafor et al. (2012) and Yuhtman & Seashore (1967) reflect the orientation that the effectiveness of an organization is about its ability to either achieve goals or manage resources (to achieve goals). Maintaining employee satisfaction and morale, minimizing conflict, and being efficient subscribes to the view provided by Georgopoulos and Tannenbaum (1957). Chiyem and Anayo (2018) claim that this perspective is appropriate when organizational performance is strongly influenced by specific processes such as cross-functional teamwork. The shortcoming of this orientation is the lack of satisfaction of clienteles or participants as it is internally focused (Eydi, 2015).

The underlying assumption of the definition by Gartner and Ramnarayan (1983) is that organizations depend on various groups for resources and ultimately for their survival. An organization, therefore, becomes effective if it can satisfy these stakeholders, or else it is at risk of them withdrawing their support, causing organizational ineffectiveness and failure (Connolly, Conlon, & Deutsch, 1980; Chiyem & Anayo (2018). But the challenge with this perspective also lies with the fact that it is difficult to determine a means by which all stakeholders' interests can be fulfilled and how this can be measured (Oghojafor et al.,2012).

2.4.3 Relationship between efficiency and effectiveness

The relationship between efficiency and effectiveness is associated with an organization's total health or overall performance (Bourne et al., 2002; Worthington & Dollery, 2000; Porcelli, 2009). The accounting framework explains that achieving a return on assets requires the involvement of both efficiency and effectiveness, as return reflects the market value of the outputs (Mouzas, 2006). Mouzas (2006) presents the concept of different performance outcomes as an interaction between effectiveness and efficiency levels (see Figure 2.1).

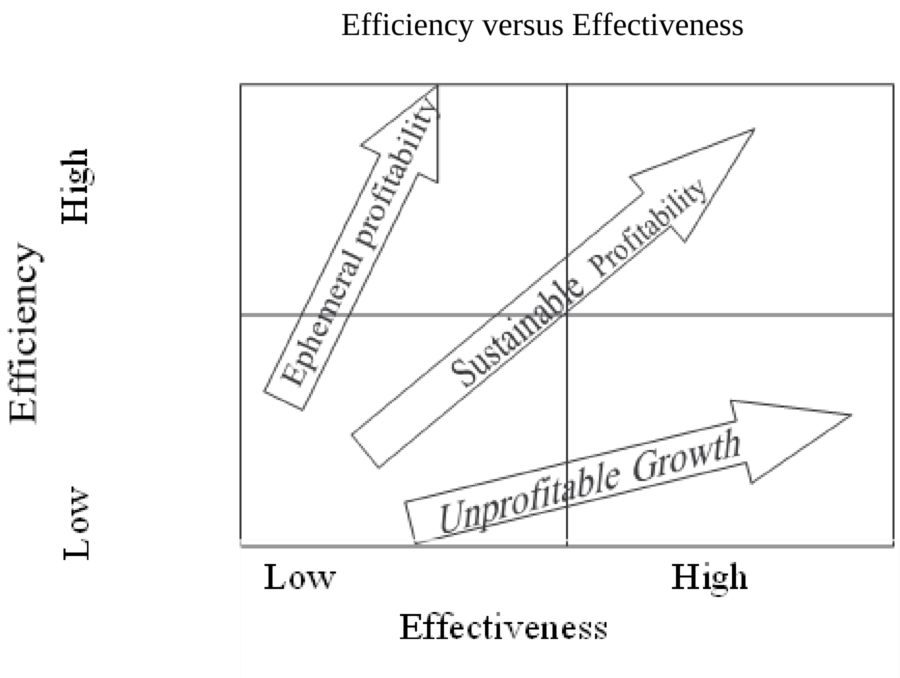

Figure 2.1: Relationship between efficiency and effectiveness levels to performance (Mouzas 2006, p. 4)

Mouzas (2006) explains that focusing on efficiency and neglecting effectiveness would result in ephemeral profitability. In contrast, focusing on effectiveness and neglecting efficiency may result in unprofitable growth as the opportunity cost of capital is higher than the revenue resulting in negative cash flow and unprofitable levels. An approach aiming at high efficiency and effectiveness requires organizations to stretch their endeavours with an integrative framework of organizational actions. The framework can enable organizations to create new sources of value inherent in business networks and create a superior sustainable profitability level (Mouzas, 2006).

Organizational overall performance can be measured by the integration of effectiveness and efficiency, using the product of the two measures (Bartuševičienė & Šakalytė, 2013). If the organization is inefficient but effective, it might survive at a high cost, not being sustainable. These organizations should consider assessing and improving the resource allocation and processes for producing goods and providing services. If efficient but ineffective, internal production and management costs are under control. However, there is not enough revenue to cover the cost, leading to failure in the long term. The companies with high effectiveness and high efficiency are well known as high-performance entities. They demonstrate excellence in their operational performance, strategic planning of resources and market growth, and a satisfied customer. Their outcomes are productive, cost under control, tasks distributed well and completed promptly with a significant number of satisfied customers (Bartuševičienė & Šakalytė, 2013). Table 2.8 summarizes the implications of different combinations of efficiency and effectiveness.

	Effective	**Ineffective**
Efficient	The company thrives. Succeeds at high productivity	Cost is under control, but no gain and fails to succeed. The company is bankrupting slowly
Inefficient	Succeeds temporarily at a high cost. The company exists but is not sustainable	An expensive failure. The company is bankrupting fas

Table 2.10: Implications of different combinations of effectiveness and efficiency

Porcelli (2009) provides a framework for measuring organizational performance using both dimensions of efficiency and effectiveness (see Figure 2.2):

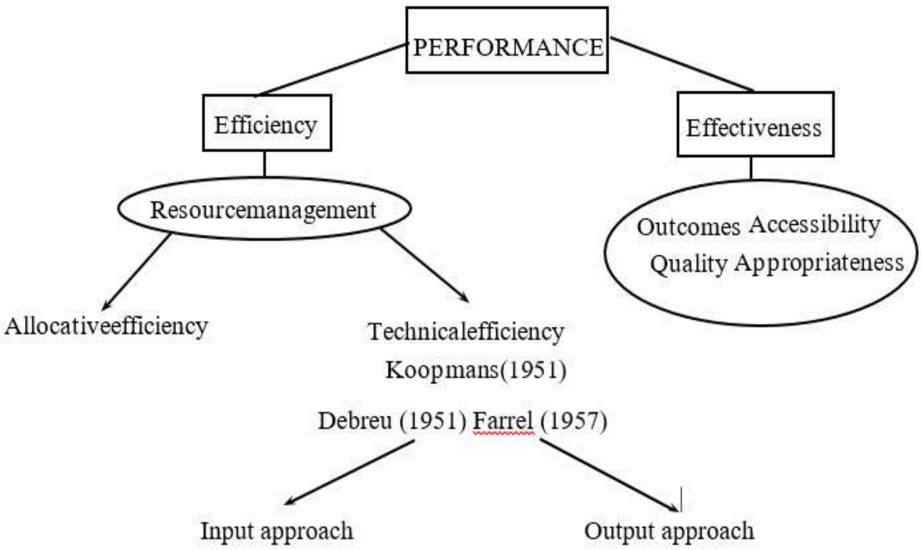

Figure 2.2: An efficiency and effectiveness performance framework (Porcelli, 2009, p. 3)

According to Porcelli (2009), efficiency measures internal resources performance, whilst effectiveness measures the accessibility of products and services to external customers and the quality level of products and services. Both measures need to be considered for the overall organizational performance. Efficiency leads to allocative efficiency and technical efficiency, which can be measured using either input or output approaches. Effectiveness involves the degree to which a system achieves programs and policy objectives in terms of outcomes, accessibility and quality (Porcelli, 2009).

2.5 Performance improvement models and approaches

There are several frequently used performance improvement models in the literature. They are the Balanced Scorecard (BSC), Performance Prism, EFQM Excellence Model, and Performance Pyramid (Kaplan & Norton, 1992; Neely et al., 2001; Looije-traa, 2015; Cross & Lynch, 1991). The literature provides other approaches for performance improvement, including parametric and non-parametric approaches (DEA), benchmarking, and the Delphi. This section reviews some of the performance improvement approaches.

2.5.1 Balanced scorecard

Kaplan and Norton (1992) noted that intangible assets played a critical role in value creation, and financial measures alone were far from enough to determine an organisation's performance. Firms were, therefore, wrong to neither measure nor integrate intangible assets into their management systems (Munzoni, 2007; Kennerley & Neely, 2003; Bourne et al., 2003; Kaplan & Norton, 1992, 2004; Kaplan, 2010). The BSC was proposed to respond to this difficulty. The BSC considers measuring performance from four perspectives: learning and growth, internal process, customer, and financial perspectives (Kaplan & Norton, 1992). The BSC integrates intangible assets into a firm's performance measurement in line with its strategy reduces the problems associated with using only financial measures (Hristov & Chirico, 2016; Awadallah & Allam, 2015).

Even though the BSC still measures financial metrics in one perspective, the measures in the non-financial perspective support the fulfilment of measures in the financial perspective. Through learning and growth, an organization can commit and improve itself to produce products and provide services based on the market's needs. Internal business processes are the critical internal operations that enable the organization to satisfy customer needs. Product or service lead time, quality, experience, and cost are essential customer considerations within the customer perspective. All the non-financial perspectives drive the improvement to give financial health to the organization and decent returns for its shareholders (Kaplan, 2010). Thousands of private, public, and not-for-profit organizations have implemented the BSC. The widespread use of the BSC is due to its multi-perspective nature and improvement based on learning and innovation (Martinson's et al., 1999; Awadallah & Allam,2015).

2.5.2 Performance prism

The Performance Prism (PP) addresses the critical questions of the links between measures and the performance of an organization across a range of issues. Neely, Adams, and Kennerly developed the PP in 2002. Aside from broadening the perspectives, the PP is generally viewed as a model that seeks to address the shortcomings of the BSC (Neely et al., 2001; Agbanu et al., 2016). Due to the broad nature of the stakeholder perspectives, the PP can be applied to both profits and not-for-profit organizations, unlike the BSC, which appears to focus on profits only. The five facets of the PP are stakeholder contribution, stakeholder satisfaction, strategies, processes, and capabilities (Neely et al., 2001).

Stakeholder Satisfaction: This involves asking two related questions of `Who are the stakeholders and what do they want and need?'. The PP provides a long list of stakeholders who impact the organization's success.

Strategy: Strategy constitutes how the organization goes about the combination of its resources to deliver services to its customers or the markets. Neely et al. (2001) indicate that an organization must have a strategy to provide value to some stakeholders. Therefore, it is essential to determine the needs and wants of stakeholders first to inform the appropriate strategies needed to fulfil them.

Processes: This facet of the PP asks, 'What are the processes we have to put in place to allow our strategies to be delivered?' processes entail the standard generic business processes underpinning a vast majority of organizations. These include: developing new products and services, generating demand, fulfilling demand, planning and managing the enterprise. These cross-functional processes should identify specific measures that allow management to address questions associated with each one.

Capabilities: Neely et al. (2001) stated that 'capabilities' is a concept least understood. Capabilities are the combination of people, practices, technology, and infrastructure. Capability draws these elements together to enable the organization's business processes for both now and the future. An organization should ask itself, `What are the capabilities we require to operate our processes?". By addressing this question, it becomes possible to identify measures that allow the organization to assess whether it has the required capabilities in place now and whether they are being sufficiently nurtured and protected.

Stakeholder contribution: this facet addresses the critical question of the organisational stakeholders. According to Neely et al. (2001), this facet recognizes that organizations have to deliver value to their stakeholders and enter into a relationship with their stakeholders, involving the stakeholders contributing to the organization. Using employees as an example, they want a safe and secure workplace and a decent salary. In return, the organization wants its employees to contribute to the business in terms of ideas, work effort, and loyalty to ensure organizational success.

The Performance Prism is relatively new, having been developed only in the year 2000, of which the notable applications and the initial successes were at DHL International in the UK (DHL UK) and also at the UK-based charity, London Youth, in which the PP helped its senior management to build a set of performance measures appropriate to their needs (Neely et al., 2001). However, PP faces some critical challenges, including giving little concentration to designing the system. Although the PP extends beyond traditional performance measurement, it offers little about how the performance measures are realized (Metawe & Gilman, 2005).

2.5.3 The EFQM excellence model

The European Foundation for Quality Management (EFQM) Excellence Model, also known as Self-assessment or EFQM, was developed in 1991 and revised in 1999 by EFQM (EFQM, 2012). EFQM excellence model is an essential means of identifying best-performing firms as they serve as important role models to others in promoting performance excellence across different fields (Eskildsen & Dahlgaard, 2000; Agbanu et al.,2016). The design of the EFQM excellence model sits on a tripod of Fundamental concepts, RADAR thinking, and Criteria.

Some broadly defined principles can help an organization achieve performance excellence irrespective of the industry and markets. Fundamental concepts are the foundation for achieving sustainable excellence in any organization. They are customer added value, creating a sustainable future, developing organizational capabilities, harnessing creativity and innovation, leading with vision, inspiration, and integrity, managing with agility, succeeding through people's talents, and sustaining outstanding results (Looije-traa, 2015; EFQM, 2012).

The EFQM explains that the framework or processes in which the organization can convert the fundamental concepts identified into achieving its goals is based on criteria that have an enabler criterion and results criterion. The EFQM identifies five elements of the enabler criterion as strong leadership, strategy, people, partnerships and processes, products, and services. Leaders shape the future, and they are also role models in terms of the values that the rest of the organization members must represent. Leaders also have flexibility in their approach, enabling an organization to anticipate and react promptly to ensure its ongoing success. EFQM explains that organizations must deploy a strategy that remains consistent with their vision and mission and should meet the needs of their stakeholders. The people must be at the centre of strategy where their necessary capabilities are developed to implement any designed strategy. Employees expect fair treatment, which inspires confidence in all aspects of their work. Another determinant of excellent performance is promoting and maintaining a healthy relationship with partners (suppliers, regulators, creditors, other service providers, etc.). These partners are critical regarding the feedback they can share with the organization to achieve performance excellence. Resources must be well bundled to accomplish the needed organizational results (EFQM, 2012).

The EFQM concludes that processes, products, and services which are the last elements of the enabler criterion, deal with the design and management of organizational processes in ways that lead to the delivery of products and services of increasing value to customers. On the other hand, the EFQM outlines elements of the results criterion as customer results, people results, and society results. Customer results focus on exceeding the needs and expectations of customers, while people results focus on the needs and expectations of the employees. Society results are about meeting the needs and expectations of the immediate and broader community in which an organization operates. Business results focus primarily on the shareholders and other critical stakeholders.

The EFQM describes the RADAR as "a simple but powerful tool for driving systematic improvement in all areas of the organization". The RADAR supports the criteria, and it provides a clear and systematic way of planning and implementing a strategy to achieve the needed results. RADAR stands for Results, Approaches, Deploy, Assess and Refine. The RADAR thinking enables the organization to determine the quantity and quality of the results it should be working towards along each of the results criteria. Once the results of any form suitable to the organization are determined, the next step is to plan and develop a set of sound approaches that can deliver the required results. The approaches must then be fully deployed to ensure implementation. Assessing what is achieved as the performance is ongoing is critical. This will indicate whether planned results are being achieved and refining approaches, if necessary, to ensure the needed impact is made.

2.5.4 Strategic measurement and reporting technique (SMART) performance pyramid

Cross and Lynch (1991) introduced the Strategic Measurement and Reporting Technique performance pyramid in 1991. The model represents an acknowledgement that traditional performance measurement systems were falling short of meeting the needs of managers in a much changing business environment. The system is designed to create a management control system of performance metrics to define and sustain organizational success. It has four objectives that affect its external effectiveness and internal efficiency (Looije-Traa, 2015; Khurram Khan, 2011).

The first level of the pyramid is defined as the overall corporate vision, which is further divided into individual business unit objectives. At the second level of the pyramid are short-term targets and long-term goals of growth and market position. The third level contains day-to-day operational measures. The last level includes four critical indicators of performance measures: quality, delivery, cycle time, and waste (Striteska & Spickova, 2012). The SMART performance pyramid is a model which measures stakeholder satisfaction, such as customer satisfaction. It also measures operational activities such as productivity and lead time. The main strength of the SMART performance pyramid are links between corporate objectives and operational performance indicators (Kurien, &Qureshi, 2011 cited in Sorooshian et al., 2016). Another strength of the SMART performance pyramid lies in its representation of the hierarchical view of business performance measurement. It distinguishes the differences between measures of interests of external parties and measures of interest within the business (Neely et al., 2000).

The SMART performance pyramid, however, faces several critical challenges. One is that it does not consider the concept of continuous improvements, and the other one is that it does not provide any mechanisms to identify key performance indicators (Meral & Mark, 2005). In addition, stakeholders other than customers and shareholders do not feature prominently in the pyramid (Agbanu et al.,2016; Meral & Mark, 2005)

2.5.5 Efficiency measurement based on Farrell approach

Farrell (1957) introduced production frontier functions as the basis of determining a production unit level of overall efficiency. Farrell decomposed the overall efficiency into its technical and allocative components using a simple graph with two input variables (Worthington, 2001; Murillo-Zamorano, 2004; Bhagavath, 2006). Figure 1 illustrates this scenario. Two inputs, x_1 and x_2 are utilized to produce a single output *y*, which can be expressed as $y = f(x_1, x_2)$. The assumption is that the two input factors increasing at a constant rate cause the output to increase at a constant rate. The isoquant *SS*' shows the combination of inputs needed to produce a given output level. The output values obtained based on any combination of inputs are represented by straight-line P. This permits the measurement of technical efficiency**.**

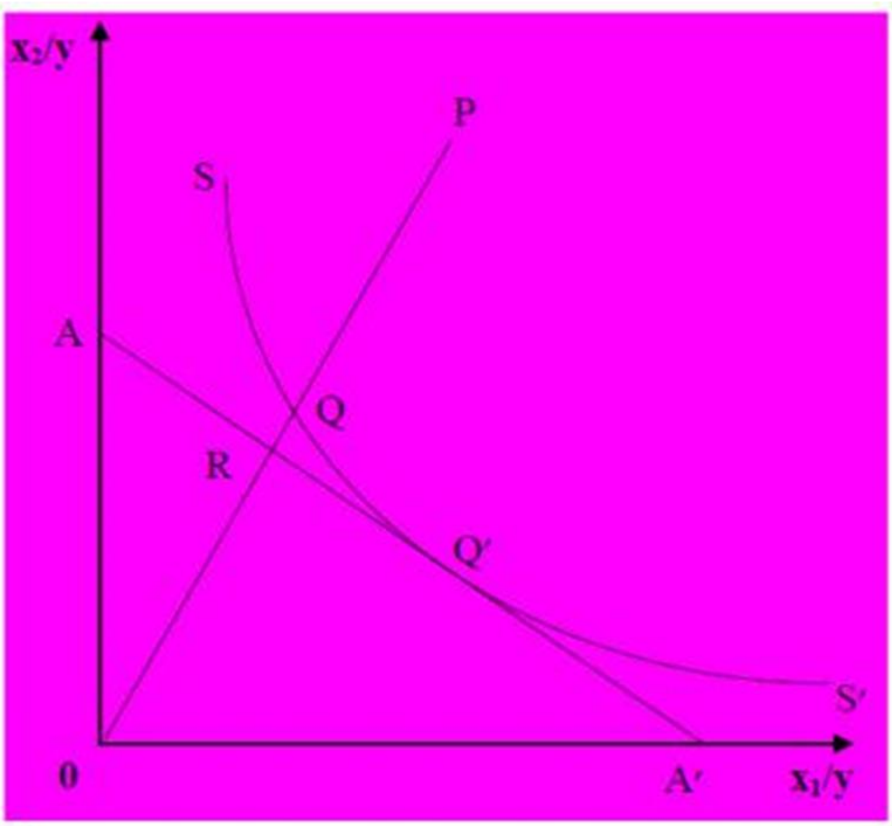

Figure 2.3: Technical, allocative, and productive efficiency (Worthington, 2001, page 4)

Given that an organization uses a quantity of combination of inputs to produce output quantity y, an organisation's ability to maximize output from a given set of inputs is technical efficiency**.** It measures the necessary proportion of x_1 and x_2 to produce *y*. The reduced combination quantity of x_1 and x_2 without reducing the output indicates improved overall technical efficiency. This may reduce the cost of producing *y* due to the reduction of the combination of two input quantities. Also, it estimates the proportion by which output *y* could be increased, holding x_1 and x_2 constant. Point *Q* from point Q' indicate the improvement in technical efficiency since it already lies on the efficient isoquant (note that *0Q*/*0Q* = 1)

The graph uses the line *AA*' to represent the input price ratio by showing the different combinations of inputs that can be purchased with a given cost outlay. With this, Allocative efficiency can also be obtained. Given the respective prices, an organization can use the ratio *OR*/*OQ* to estimate its ability to utilize inputs in optimal proportions. The distance *RQ* is the reduction in production costs that would occur if production occurred at *Q*' – the allocatively and technically efficient point, rather than *Q*, the technically efficient but allocatively inefficient point. Total economic or productive efficiency becomes the ratio *OR*/*OP*, and total inefficiency is 1 - *OR*/*OP*. The cost reduction possible is the distance *RP* obtained from moving from *P* (the observed point) to *Q*' (the cost-minimizing point).

Farrell acknowledged that if his model were allowed to stand in the manner that it has been illustrated using Figure 1, it would be assumed that the production function of a fully efficient firm is known. Meanwhile, this is not the case. This led Farrell (1957) to suggest that the limitation could be dealt with by using sample data to estimate the efficient isoquant through a non-parametric piecewise-linear isoquant or a parametric function, such as a Cobb-Douglas fitted to the data. Either way, no observed point should lie to the left or below the isoquant or the function. Subsequently, studies on efficiency measurement have tended to reflect the dimensions of the stochastic-parametric approaches and the DEA-non-parametric approach (Worthington, 2001).

2.5.6 Parametric approach to efficiency measurement

The parametric approach specifies a production function based on appropriate production technology. Variations existing between real-world organizations and the set production function are observed. Two types of factors influence the variations. One type of variation is due to factors not being within the organization's control, often referred to as statistical noise or randomness. The other types are factors within the organization's control (Worthington, 2001, 2001; Farsi et al., 2007).

The parametric technique can be further divided into three distinct approaches, which are the stochastic frontier approach (SFA), the Thick Frontier Approach (TFA), and the Distribution Free Approach (DFA). The efficiency frontier is constructed based on econometric modelling, usually in Cobb-Douglas (log-linear) production function (Worthington, 2001, 2001; Farsi et al., 2007). Therefore, the production function is defined by the explanatory variables (inputs, outputs, and other possible explanatory variables) and the two components of this regression´s composite error term (the random error) and the inefficiency term. SFA assumes two-sided distribution (usually normal with zero mean) of the error term and one-sided distribution of the non-negative inefficiency. DFA relaxes the composite error term of distributional assumptions. The core inefficiency is distinguished from random error by the assumption of core inefficiency being persistent over time, while random errors tend to average out over time (Worthington, 2001; Farsi et al., 2007; Murillo-Zamorano, 2004; Emrouznejad, 2000; Tahir et al., 2009; Asmare & Begashaw, 2018). TFA does not impose distributional restrictions on the composite error term but assumes that the inefficiency term is different in the observed decision-making units' highest (th

ick frontier) and lowest efficiency quartile. Random errors are present within these quartiles (Asmare & Begashaw, 2018).

2.5.7 DEA-non-parametric approach to efficiency measurement

Non-parametric approaches to efficiency measurement and evaluation are primarily based on mathematical programming in which the efficiency of a unit is determined relative to other units in the same organization or industry. Non-parametric approaches calculate relative efficiency. The efficiency frontier is considered a function of a set of observed variables without the imposition of a specific functional form of inputs and outputs (Emrouznejad, 2000; Worthington, 2001). There are two approaches under the non-parametric approach: Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH) methods. DEA is the most popular non-parametric approach. It is an analytical approach that compares relative efficiencies of a set of homogenous units operating within the same organization or organizations in the same industry (Emrouznejad, 2000; Worthington, 2001). These units in the DEA literature are referred to as Decision Making Units (DMUs). A DMU is an entity to be evaluated to convert inputs into outputs (Cooper et., 2001). DEA assumes that all firms face the same unspecified technology which defines their production possibilities. DEA identifies the optimal ways of performance rather than just generating average efficiency values. The objective of DEA is to determine which firms operate on their efficiency frontier and which firms do not (Yue, 1992). Also, DEA uses actual sample data to derive the efficiency frontier against which each firm in the sample can be evaluated. This means an explicit functional form for the production function does not have to be specified in advance (Cooper et al., 2001; Yue, 1992; Sherman & Zhu, 2006).

Sherman and Zhu (2006 pp.51-52) identify four primary features of DEA. They are:

1. DEA compares units considering all resources used and services provided and identifies the most efficient unit(s) or the best practice unit(s), and the relatively less efficient units;

2. DEA generates the amount of each type of cost and resource which could have been saved if each less efficient unit could have operated as efficiently as the frontier unit;

3. Specific changes in the less efficient units can be further identified to implement to achieve potential savings, estimated based on the DEA results;

4. Management receives information on the relative efficiency performance of units, which may help internal learning and decision-making.

DEA has the following strengths (Lovell, 1993):

1. No restriction in terms of the number of input and output factors;

2. No need for prices as a homogenizing element;

3. The optimal level of performance determined within the set of DMUs evaluated;

4. Unique ability to measure the efficiency of multiple-input and multiple-output of DMUs without assigning prior weights to the inputs and outputs;

5. No a priori parametric restrictions on the underlying technology;

6. The potential to impose axiomatic properties and estimate the frontier non-parametrically;

7. Easy computations;

8. Limited restrictive assumptions.

When DEA results are compared to the results of others such as the SFA, DFA and TFA, they tend to be highly consistent when both methods have been applied in a single study (Fried et al., 2008; Ahmed, 2015; Oh & Hildreth; 2016; Toma et al., 2017; Asmare & Begashaw, 2018).

The main challenge of DEA, however, is selecting the output and input factors. Output factors are generated through production and measured based on a production cycle. The input factors are the human and material resources used to transform other material resources into outputs (Norman & Stoker, 1991). Because DEA is a non-parametric approach, misspecification of the model can arise when the selection of input and output factors are inappropriate. The DEA modelling and its use for efficiency evaluation tend to lose its discriminatory power as the dimensionality of the production space increases. Also, inaccurate efficiency results arise when the real-time values for selected input and output factors are imprecise and vague (Saati & Imani, 2015; Hatami-Marbini et al., 2011, 2014; Emrouznejad, 2000; Tavani, 2011; Wagner & Shimshak, 2007; Nataraja & Johnson, 2011).

Some factor selection methods include efficiency contribution measure (ECM), principal component analysis (PCA-DEA), a regression-based test, and bootstrapping method via Monte Carlo simulations (Nataraja & Johnson, 2011). Another factor selection method is a correlation process known as "isotonicity" (Lovell, 1993; Bowlin, 1998; Yang, 2013; Meenakumari & Kamaraj, 2008).

1. ECM analyses the relevance of a factor based on its contribution to efficiency. Two DEA formulations are considered, one with the candidate variable and one without it. A binomial statistical test determines if the effect of this variable on the efficiency measure indicates that the candidate factor is essential to the production process (Nataraja & Johnson 2011).

2. The PCA-DEA uses statistical methods to reduce the dimensionality of the data set by expressing the variance structure of a matrix of data through a weighted linear combination of variables. Each principal component accounts for maximal variance while remaining uncorrelated with the primary main components (Nataraja & Johnson 2011).

3. In bootstrapping, test statistics are calculated, and a bootstrap estimation procedure is used to obtain the critical values that suggest which variables are more relevant (L. Simar & Wilson, 2001; Nataraja & Johnson, 2011).

4. In the regression-based test of Ruggiero, an initial measure of efficiency is obtained from a set of known production variables. Each candidate factor is regressed against the efficiency value to determine the relevant factors. The coefficient values should be positive for input factors, and for output factors, the coefficient values should be negative (Nataraja & Johnson, 2011).

5. There are two methods of eliminating irrelevant variables using the principle of "isotonicity". The first method is to regress each input against the other. A significant positive correlation between any two input factors means that one of the input factors has to be eliminated, leaving the other. The same understanding must hold for any two output factors (Lovell, 1993; Yang, 2013 Meenakumari & Kamaraj, 2008). The second method involves the regression of an input factor against an output factor. Where the correlation between them is positive and significant, both are considered in the sample of factors (Bowlin, 1998).

Nataraja and Johnson (2011) observed that the ECM has relatively long run times even though it performs well under most scenarios. The PCA-DEA has the shortest run time, works best with smaller sample sizes, and it is robust to the high correlations between input variables. However, the PCA-DEA turns out to show varying efficiency results depending on the choice of technology (CRS or VRS) and does not work well with higher-dimensional datasets. Nataraja and Johnson (2011) found that bootstrapping requires a long run time because of its heavy computational burden, and the number of bootstrap replications needed is unclear. They conclude that bootstrapping for variable selection is about the worst compared to the other three.

According to Nataraja and Johnson (2011), the regression-based test can be implemented easily, and it also performs better because it is less vulnerable to the curse of dimensionality. This method is also robust to the choice of technology (Constant Return to Scale or Variable Return to Scale). The major weakness of the Ruggiero regression-based test is highly correlated inputs and smaller sample sizes. However, 'Isotonicity' addresses the weakness of the Ruggiero-based test. In 'isotonicity, highly correlated inputs are not allowed, as much as highly correlated outputs are not allowed.

Also, to overcome the challenge of the imprecise and vague nature of input and output values that sometimes arises in real-world situations, Hatami-Marbini et al. (2011; 2014) provide a taxonomy and review of some Fuzzy DEA methods that have sought to deal with this challenge. They are the tolerance approach, the αlevel-based approach, the fuzzy ranking approach, and the possible approach.

- In the tolerance approach, the idea is to incorporate uncertainty into the DEA models by defining tolerance levels on constraint violations. This approach Fuzzifies the inequality or equality signs but does not directly treat fuzzy coefficients. The limitation of the tolerance approach is related to the design of a DEA model with a fuzzy objective function and fuzzy constraints, which may or may not be satisfied.
- In the αlevel-based approach, the main idea is to convert the FDEA model into a pair of parametric programs to find the lower and upper bounds of the α-level of the membership functions of the efficiency scores.
- In the Fuzzy ranking approach, the main idea is to find the fuzzy efficiency scores of the DMUs using fuzzy linear programs, which require ranking the fuzzy set.
- In the possibility approach, the fuzzy variable is associated with a possible distribution in the same manner that a random variable is associated with a probability distribution.
- In fuzzy possible approach, fuzzy coefficients can be viewed as fuzzy variables, and the constraints can be considered fuzzy events. Hence, the possibilities of fuzzy events (i.e., fuzzy constraints) can be determined using possibility theory.

2.5.8 Benchmarking

'Benchmarking is a tool for improvement, achieved through comparison with other organizations recognized as the best within the area' (Bhutta & Faizul, 1999 p. 225). Benchmarking also involves the process of identifying the highest standards of excellence for products, services, or processes among peers, to facilitate learning from the best performing peers to make improvements (Helgason, 1997). Helgason (1997) broadly identify steps involved in benchmarking as:

- Identify an organization that is better than what your organization does;
- Study how it achieves such results;
- Make plans for improving your performance;

- Implement the plans; and
- Monitor and evaluate the results.

Due to competitive pressures in the private sector, which have resulted in enterprises adopting measures for continuous improvement, benchmarking has long been a phenomenon in the private sector used to guide the process of planning, performance targeting, and implementation of processes leading to continuous improvement. Even though benchmarking as a performance improvement tool in the public sector has also been used, its application is less straightforward (Diewert & Nakamura, 1999; Helgason, 1997; Cole, 2011). Helgason (1997) explains a difference between the private and public sectors in terms of competitive pressures for improvement. While objectives of the private sector may be defined by consumers and competition, in the public sector, goals are determined mainly by democratic processes. Benchmarking is not just copying practices from other organizations, private or public. However, by comparing and identifying best practices from peers, an organization makes adjustments in its systems, supporting performance improvement.

The literature provides different benchmarking approaches across different types of organizations, of which one approach or the other can be applied depending on the objectives and the context (Cole, 2011). Bhutta & Faizul (1999) summarized seven types of benchmarking:

1. *The internal benchmarking* identifies best performing units within an organization by comparing the performance of all units.
2. *The performance benchmarking* identifies specific performance indicators. Such as financial, operational, functional, and compares the organization's performance against better-performed ones in the industry.
3. *Strategic benchmarking* involves the decision to change the strategic direction of an organization by comparing better-performed companies in the competition.
4. *The process benchmarking* identifies the defects in the methods and processes of one organization compared to best practices among peers.
5. *Competitive benchmarking* is performed against the very best in the competition, where performance and results are compared.

6. *Functional benchmarking* aims to improve a particular technology or process associated with an operation function.
7. *Generic benchmarking* involves comparing processes and technology to others irrespective of the company and the industry for improvement.

This list has not included the benchmarking across nations' international benchmarking (IB) (Prasad et al., 2009; Dominique et al.,2013). According to Dominique et al. (2013), as policy-makers search for signposts to guide the design and implementation of successful public policies, international benchmarking has become an attractive tool. Dominique et al. (2013) define international benchmarking as “the systematic measurement and comparison among countries against a selected set of indicators”.(p.505). International benchmarking has increased remarkably over the last couple of years due to global interdependency and the limitations of theoretical approaches to public policy making. International benchmarking provides empirical data of tried and tested policies, programmes and initiatives that may have been successful in some jurisdictions and provides lessons for other countries to emulate. Some international benchmarking programmes include the ‘World Bank Ease of Doing Business’ and the OECD’s PISA rankings which measure educational achievement (Dominique et al.,2013; Fagerberg, 2001).

IB can start with selecting Key Performance Indicators (KPIs) reflecting significant industry or sector elements for comparison. A framework to compare the performance of the industry or sector across the benchmarking countries is applied. Best practices among the peer countries are identified, enabling a less performing country along each benchmarking indicator to adapt and improve its performance (Prasad et al., 2009; Philips, 2014)

Dominique et al. (2013) provide the following broad features to consider in embarking on international benchmarking:

- Identification of ‘best in class’ performers
- Selection of the relevant qualitative and quantitative indicators to measure performance.
- Systematic measurement and comparison against the selected panel of indicators
- Implementation of actions for improving performance

- Monitoring and evaluation of results

2.5.9 Delphi approach

The Delphi approach assembles a panel of experts to explore a set of specific questions in relation to a research area. It aims to gain feedback and identify common ground to conclude (Donohoe et al., 2012). The Delphi approach is used to gain consensus utilising a series of questionnaires among the expertise feedback in critical areas for investigation. According to Habibi et al. (2014), the approach was designed to encourage debate and thoughts devoid of influence by other persons.

The method requires knowledgeable and expert contributors individually responding to questions and submitting the results to a central coordinator. This process repeats until the coordinator sees that a consensus has been formed (Grisham, 2009). The Delphi approach can be used in a wide range of areas, such as business, technology, science, education, and health, to generate forecasting. The number of experts included in the Delphi approach is usually small, and the results generated by the approach are qualitative (Lazar & Mirela, 2008). Habibi et al. (2014) assert that the Delphi approach should be the prerequisite in qualitative research mainly based on the individuals' judgments and opinions. Inferential statistical techniques such as mean tests will not be relevant or appropriate, but it focuses on the richness of answers from experts in the field.

The first primary task in a Delphi approach is to create the expert panel. However, determining who should constitute the expert panel and the size remains the most significant challenge. Depending on the study's objectives, a panel can be composed of any combination of stakeholders, subject experts, and facilitators (Lazar & Mirela, 2008; Habibi et al., 2014). Grime and Wright (2016) recommend between 5 and 20 experts depending on the subject matter. Regarding the background and knowledge of the expert panel members, purposive sampling is recommended. This identifies members with a deep and thorough understanding of the subject matter. The researcher defines the qualification of an expert in terms of the subject matter, and identifies persons who meet the qualification. Snowball sampling for instance, can be used after the first set of experts have been identified, leading to other experts to be included (Warner, 2014).

Lazar and Mirela (2008) identify the significant advantage of the Delphi approach as the fact that it helps prevent the halo effects of participants succumbing to the opinions of a dominant personality. However, the scientific nature of the method and the possibility of influence by the researcher and bias on the part of the experts are two main disadvantages of the approach. Some more advantages and disadvantages (Lanzar & Mirala, 2008) of the Delphi approach are provided below:

Advantages:

- Rapid consensus;
- Participants can reside anywhere in the world;
- Coverage of wide range of expertise;
- The anonymity of participants helps prevent the halo effects when participants succumb to the opinions of a dominant personality;
- Participants have the time to consider outcomes and solutions carefully.

Disadvantages:

- Results are dependent on the quality of the participants;
- The scientific nature of the method is sometimes questioned;
- The researcher can influence results;
- The top experts may be difficult to recruit.

2.6 Summary of reviewed models and justification for selected models

The table below summarises all the performance improvement models examined in section 2.5. The justification for the chosen three approaches has been provided in this subsection.

Performance improvement approach	Purpose
Balance scorecard	Focusing on the development of a balanced set of measures for organizational development
Performance prism	Providing broader perspectives that facilitate performance measurement and improvement for both profit and non-profit organizations
SMART performance pyramid	It provides a hierarchical structure for measuring organizational performance along with various levels of an organization and along with internal efficiency and external effectiveness
EFQM excellence/model	Serves as an important means by which best performing firms are identified to serve as important role models to others in the promotion of performance excellence across different fields
DEA and other related approaches	Serves as a tool for identifying performance frontiers for performance improvement among a set of homogenous units.
Benchmarking	Identifies best performing organizations within an industry or sector along with various performance indicators for others to emulate and improve their performance
Delphi approach	Thrives on achieving consensus among experts' perspectives as the basis of improving the performance

Table 2. 11: Summary of performance improvement models reviewed

Even though all the performance improvement approaches help improve the performance of an organization, the goal of this study, the study objectives, and the context inform the approaches chosen. Given that the study goal is to explore approaches towards identifying best practices for improving the performance of a national power sector, the performance improvement approaches chosen must provide some basis for comparing performance both within the national power sector and across different power sectors. This makes DEA, IB, and the Delphi approach more suitable for the study than popular ones such as the Balanced Score Card, Performance Prism, EFQM, and the SMART Performance Pyramid. The popular performance management models are more suitable for studying specific organizations and do not provide an explicit framework for comparing or benchmarking performance across organizations and different sectors. In addition, they do not explicitly offer standard Key Performance Indicators (KPIs) to form the basis for comparing performance across organizations. In the case of the DEA and IB, the indicators chosen are explicit and standard across the organizations and sectors. Furthermore, the popular performance management models are more of controlling tools meant for the continuous management of an organization aside from the evaluation of performance. This study required tools heavy on performance evaluation to critically identify weaknesses across the power sector that have to be overcome towards performance improvement. Because this is also sector-based instead of organization-specific, it is possible to integrate results and findings across the different sectors to improve the performance of the entire sector. The BSC and the other performance management models may not be integrated because they are meant for organizations specific.

In choosing the DEA non-parametric approach for the study's efficiency modelling and evaluation aspect, the study considers that non-parametric approaches offer ease and simplicity in evaluating efficiency using multiple input and output factors. This is why the DEA-non-parametric approach is more popular and widely used by both researchers and practitioners in efficiency studies than the parametric stochastic approaches (Farsi et al., 2007; Asmare & Begashaw, 2018). Given that the study's efficiency modelling and evaluation aspect is geared towards designing an approach to improve the efficiency performance of a power sector, the DEA approach came in handy. Also, in line with the study's objectives, benchmarking occurs at two levels. First, the efficiencies of units within each subsector are compared to identify best practices for improvement. Second, the comparison of Ghana's power sector performance to the performance of other similar developing countries to identify best practices for improvement. The second level justifies the use of international benchmarking (IB). Also, given that the study's overall goal is to improve the performance of a national power sector, the study considers the perspectives of experts within the sector valuable. Delphi's approach provides a means of exploring the perspectives and synthesizing them to identify significant insights that can be integrated with results from the other study approaches towards performance improvement of the power sector.

2.7 Summary

This chapter presented a review of the significant issues underpinning the study. The literature establishes efficiency and effectiveness as two defining elements for the total health of an organization. While efficiency is a measure that shows the best use of organizational resources to generate an optimum output level, effectiveness is much broader in scope and depends on the type of organization, the goals it sets for itself, how it goes about its internal processes, and the stakeholders it sets out to serve.

Factors affecting the performance of a national power sector have also been discussed. The literature provided the different types of structures existing in the sector and factors to consider towards determining a robust regulatory framework. Also, factors affecting power generation capacity, existing sources' potential, and the implications for supply security and reliability have been discussed. The factors affecting the performance of the transmission and distribution subsectors have also been provided. The types of structural and regulatory models that have been pursued mostly among developing countries over the years have been discussed, and their implications for performance improvement.

The review then focused on some models that have been employed by organizations and industries towards performance improvement. The strengths of these models have been examined; the review provides justifications for the three performance improvement approaches that have been selected for the study.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The study explores methodological aspects of the three chosen approaches for improving the performance of a national power sector. The first approach is Data Envelopment Analysis (DEA), The second approach is international benchmarking (IB). The third approach is Delphi. The methodology of applying the three approaches also extends to their integration, which is explained in this chapter.

Section 3.2 explores different research designs and the design chosen for this research with justifications. Section 3.3 explores the processes and outcomes of selected factors, performance indicators, and themes for DEA, IB, and Delphi, respectively. The data collected reflects the three approaches based on which the subsequent chapters present the analysis. Section 3.4 offers the data types, sources of data, and the data collection methods. Section 3.5 explains the data analysis methods. Section 3.6 explores the possible integration of the three methods. Section 3.7 summarizes this chapter.

3.2 Research approaches and design

Qualitative and quantitative research methodologies anchored on the constructionist (interpretive) and positivist paradigms, respectively, are discussed in section 3.2.1. Mixed-method research, a blend of quantitative and qualitative research methodologies, is explained in section 3.2.2. This research adopts a strand of mixed-method design, and the justification for choosing this strand is provided in section 3.2.3. Section 3.2.4 presents a flow chart that outlines the step-by-step process of conducting this research in an integrated form, including each of the three approaches and their integration.

3.2.1 Theoretical underpinnings of qualitative and quantitative research

Quantitative approaches follow positivist ontological and epistemological underpinnings. Reed (2006) described Positivism as ‘the situation in which individual sense-experience and theory-free observational data are regarded as the only firm foundations for scientific knowledge’ (p.40). Positivism is embedded in classical organizational theory, where classicalists believe that adopting rationality, orderly and scientific approaches to organizational management remains the surest way to higher organizational productivity and efficiency (McAuley, Duberley & Johnson, 2014).

Theorists and practitioners from the classical organizational school adopt a quantitative approach reflective of positivism to explore and establish causal relationships between factors in organizations to provide some basic laws on how organizations function. Researchers along this paradigm believe that logically deductive conclusions can be arrived at when scientific explanations are expressed in a standardized form (Hanson, 1969 cited in Lee, 1991). According to Lee (1991), when formal deductive logic and hypothetical deductive logic rules are employed, theoretical propositions emerging from the analyzed data must reflect four requirements: falsifiability, logical consistency, relative explanatory power, and survival. Lee (1991) explains:

- *Falsifiability* as the presence of inaccuracies in the empirical content of theoretical propositions that can be detected only through contradictory observations.
- *Logical consistency* requires propositions of a theory to be related to one another by the rules of formal logic or logically deducible from the same set of premises.
- *Relative explanatory power* ensures that a theory can explain or predict a subject matter and any competing theories.
- *Survival* refers to actual attempts aiming at its disconfirmation through controlled empirical tests.

Opposed to positivist ontology and epistemology is constructionism, where qualitative approaches form the basis upon which truth is established. A constructionist believes that the meanings and interpretations of organizational actors on happenings and developments in organizations play a crucial role in understanding and studying organizations. Constructionism emphasizes the need for understanding subjects in specific situations instead of being general. The understanding of subjects would emerge and evolve within specific localized environments (McAuley et al., 2014). Constructionism is aligned to the neo-classical organizational school, where a neo-classicalist adopts management strategies that ensure an intrinsic link between an individual and the associated organization. The individual and the organization are seen as one rather than separate entities. Happenings within organizations are interpreted within 'subjective' settings, such as organizations and cultures, and relay to understandings and meanings attached to others operating in different cultures and other organizations (McAuley et al., 2014). The constructionist-neo-classical school, in their study of organizations, adopt qualitative methods. Unlike a quantitative approach, which follows structured rules in conducting research (Lee, 1991; Reed, 2006), a qualitative approach does not follow a straitjacket. Instead, researchers along this paradigm have continued to develop dimensions that support different methodologies across various types of research. The three popular dimensions are:

- **Hermeneutics:** The art of interpreting and understanding relationships between a researcher, the subject of research, and the reader (McCauley, 2004). Hermeneutics facilitates the interpretation of human behaviour and has applications in social science research (Tice & Slavens 1983; Taylor 1979; Bernstein 1978, 1983)

- **Ethnography:** 'Doing ethnography, as anthropologists put it, is interpreting the behaviour of human subjects in their local settings' (Lee, 1991, p. 349). An anthropologist seeks to understand the meanings the local behaviours signify to the human subjects, the 'natives' themselves. In ethnography, one test for the validity of an interpretation is the extent to which the behaviour of the native does not strike the ethnographer as an absurdity, irrational, strange, surprising, or confusing. Thus, a good ethnographer will identify these meanings and understand the rational connection behind the actions that they observe and the meanings attached to them (Lee, 1991).

- **Grounded theory:** Grounded theory considers individual, group or organizational collective experiences over time to develop a pattern or theory that can be used in predicting future responses and outcomes (Goulding, 2009). Processes of grounded theory are grounded on the ability to gather and analyse data, and the results should lead to the generation of new theory. According to Charmaz (2003), validity in its strictest sense is not an issue in grounded theory. Instead, the criteria established by Straus and Glazer (1967, pp. 237-250) should be the basis for determining the quality of grounded theory:

  - '**Fit. H**ow do concepts closely fit with the incidents they represent, and how thoroughly the constant comparison of incidents to concepts has been done.

  - **'Relevance**. Participants' real concern evokes "grab" - capturing the attention and not just for academic interest.

  - **'Workability**. How the problem is being solved with many variations.

  - **'Modifiability**. How the existing theory could be altered when new relevant data is compared to existing data.

3.2.2 Theories of mixed-method research

Mixed methods research is grounded on the pragmatist paradigm, which emerged as the mediating force between the quantitative–positivist and qualitative-interpretivist paradigms. Proponents of this research design have claimed its validation because the mixed methods design has been increasingly adopted in research (Cameron, 2009). Tashakkori and Teddlie (2003) conclude that to understand any complex social phenomenon more thoroughly, it is essential to gather data across various sources and analyze them with mixed methods where applicable. Along with a growing interest in the mixed-methodology approach and its deployment, different typologies have emerged which seek to explain the varying contexts and processes in which the mixed methods has been applied (Cameron, 2009). Researchers within this paradigm develop their designs by ensuring that they adequately address their research questions without departing from its tenets (Johnson et al., 2013). Tashakkori and Teddlie (2009) distinguish a study employing two or more approaches at some stage without integrating them from the mixed methodology of integrating methods to achieve the research aim. They describe the former as quasi-mix methods.

Creswell and Plano Clark (2010) developed a four-type typology of mixed methodology research: triangulation, embedded, explanatory, and exploratory. The four typologies are presented in Table 3.1:

Design	Variants	Timing	Weighting	Mixing	Notation
Triangulation	• Convergence • Data transformation • Validating quantitative data • Multi-level	Quantitative and qualitative at the same time	Usually, equal	Merge the data during the analysis or interpretation stage	QUANT+ QUAL
Embedded	• Embedded experimental • Embedded experiential	Concurrent or sequential	Unequal	Embed one type of data within the other type of design.	QUANT (qual) Or QUAL (quant)
Explanatory	• Follow-up explanations • Participant selection	Quantitative followed by qualitative.	Dominated by quantitative, with involvement of qualitative	Connect the data between the two phases.	QUANT to Qual
Exploratory	• Instrument development • Taxonomy development	Qualitative followed by quantitative	Usually, qualitative	Connect the data between the two phases.	QUAL to quant

Table 3.1: Major types of mixed methodology designs (Creswell and Plano Clark, 2010, p. 145)

Each design type is associated with the dimensions of variants, timing, mix, and notation. Essentially, variants define the critical characteristics of a mixed-method research design, while timing is about using the qualitative and quantitative aspects, which should come first. The mix is about the research design stage in which qualitative and quantitative data are integrated. Four factors underpin the categorization and design of mixed-method research:

- First, the theoretical perspective concerns whether the study itself is based firmly or indirectly on a theory;
- The second is the priority of strategy, where the research relies more on either the quantitative or qualitative approach and whether the design prioritizes the use of both approaches equally;
- The third factor is the sequence of data collection; which type of data should be collected first? Or is there any sequence at all?
- The fourth factor is integration, which could occur at the data collection stage, the data analysis stage, and/or the data interpretation stage (Terrell, 2012).

Terrell (2012) presents six mixed-method designs based on these four factors (Tabel 3.2).

Type of Design		Primary focus	Priority of strategy	The sequence of data collection	Point of integration	Strengths of the design	Weaknesses of the design
Sequential	**Explanatory**	Explains quantitative results based on the other	Equal priority	Quantitative first, followed by qualitative	During interpretation	clear and distinct stages	Time-consuming
	Exploratory	Used to explore a theory	Can be equal or priority given to either	Qualitative before quantitative	During interpretation stage	clear and distinct stages	Time-consuming
	Transformative	Advocacy or pursuit of ideology	Priority is given to either or both	Either type of data can be collected first	During integration	Straight forward in implementation and reporting	Lack of enough literature on this type
Concurrent	**Triangulation**	For validation within a single study	Priority can be equal and can be given to either	Concurrent data collection	Can occur during analysis and interpretation stages	Shorter data collection time compared to sequential methods	Requires a great deal of expertise to implement
	Nested	Gaining a broader perspective.	The data collection approach is of priority	One type of data collection is embedded in the other	Data mixed at the analysis stage	Allowing for perspectives from both	Discrepancies can occur.
	Transformative	Guided by a theoretical perspective	It May be equal or given to either	Concurrent data collection phases	During the analysis or interpretation stage	Familiar to many researchers	Discrepancies could occur in the data transformation stage

Table 3. 2: Summary of mixed-method design types

The classifications by Terrell's (2012) and Creswell and Plano Clark's (2010) share overwhelming similarities. In sequential explanatory design, the focus is to explain key aspects of quantitative results using the qualitative approach. This is often conducted by first collecting and analyzing the quantitative data, followed by qualitative data collection such as follow-up interviews, and analysis (Terrell, 2012). Creswell and Plano Clark (2010) present two variants of the sequential explanatory model: the follow-up explanations model and the participant selection model. The follow-up explanations model is used when a researcher needs qualitative data to explain quantitative results. The participant selection model is used when a researcher needs quantitative information to identify and purposefully select participants for a follow-up qualitative study.

The sequential exploratory design has two common models: the instrument development model and the taxonomy development model. In the instrument development model, qualitative data is collected first to form the basis for instrument building to guide theory development in the study. The identified instrument will entail quantitative metrics and scales to be used to collect the quantitative data to test the theory. In the taxonomy development model, the initial qualitative data is collected to identify essential variables through a classification system so that quantitative data is collected afterwards to study the results in more detail (Creswell & Plano Clark, 2010). There is no implementation sequence in the case of sequential transformative design, unlike the exploratory and explanatory designs. Instead, it is guided by a particular theoretical orientation and advocacy (Hanson et al., 2005). Researchers choose methods that better serve their theoretical perspectives, and the findings are integrated during the interpretation stage (Terrell, 2012; Kroll & Neri, 2009).

Concurrent triangulation design remains the commonest design approach within the mixed-method paradigm (Creswell & Plano Clark, 2010). It involves the collection of both qualitative and quantitative data over the same period and integrating the data results at either the analysis stage or the interpretation stage. During interpretation, the researcher notes a case of convergence or the lack of it. The intent of researchers using this design approach is to achieve confirmation, corroboration, or cross-validation within a single study (Terrell, 2012; Kroll & Neri, 2009).

In concurrent nested methods, even though the two methods are implemented concurrently in a single study, one of the methods is embedded in the other. The research question answered by the embedded method is usually secondary connected to the general research question (Kroll & Neri, 2009). Researchers employ this design to gain a broader perspective as they employ the two methods in answering different research questions within the study.

In concurrent transformative design, both the qualitative and quantitative data are collected simultaneously, and the integration is done either at the analysis or interpretation stage. Like the sequential transformative, this design is also informed by a theoretical perspective (critical theory, advocacy, participatory research, or theoretical framework). The researcher, therefore, chooses methods that satisfy their theoretical perspectives (Terrell, 2012; Kroll & Neri, 2009).

3.2.3 The strand of mixed method design chosen for this research and justification

The design for this research follows a concurrent triangulation design (Creswell & Plano Clark, 2010; Terrell, 2012). The major strength of concurrent triangulation design is that it is easy to implement (Creswell & Plano Clark, 2010). This can be an effective research design as both data types are collected during a single time phase. The data collected using mixed methodologies are analyzed separately and independently, using the techniques traditionally associated with each data type before triangulating the findings. Creswell and Plano Clark (2010) identified the following four variants of the concurrent triangulation design.

- The convergence model involves collecting and analysing both quantitative and qualitative data separately on the same phenomenon and comparing and contrasting the different results during interpretation.

- The data transformation model involves the same data collection but separate quantitative and qualitative data. In this model, however, after the initial analysis, the researcher uses procedures to transform one data type into another by quantifying qualitative findings or qualifying quantitative results. This allows the data to be mixed during the analysis stage.

- The quantitative data model validates and expands on qualitative findings through a survey. In this model, the researcher collects both types of data within one survey instrument. But the qualitative data collected are only add-ons that help broaden understanding of the quantitative data that has been collected.

- A multilevel model in which quantitative and qualitative data are used to address different phases of a single study. The results of the analysis from each level are merged for interpretation.

The multilevel model within the concurrent triangulation design with some modification is adopted for this study. The three approaches are presented below:

- The design employed in the first approach (DEA) is quantitative. Efficiency needs to be quantified, and a quantitative research design is necessary to collect data leading to the determination and evaluation of efficiency. The data types, methods of data collection, and methods of evaluating the efficiency results are all informed by the principles of DEA.
- The IB approach uses analysis of variance (ANOVA) to compare the performance of the IB countries using selected performance indicators. However, using the sequential-explanatory design, qualitative information regarding each country's national power sector performance is used to validate and explain each country's performance on the quantitative indicators and identify best practices.
- Delphi approach is qualitative, where the perspectives of power sector experts in Ghana shared are collected and analysised to identify common themes for issues and improvement possibilities for the three power subsectors.

In order to achieve the research aim, the analyzed results based on the three approaches are integrated. The integration is generated based on the relevance and nature of the results from these approaches to provide further insights.

3.2.4 The research design process flowchart

The flow chart below provides the process with specific steps for conducting this research. This flow chart reflects a multilevel-concurrent-triangulation design. The methodological aspects involve objective setting, data collection, data analysis, and the integration of the data results. The first three aspects are carried out at the same time in a single phase. The last is to integrate the results from the three aspects across the three critical areas for performance improvement of the national power sector.

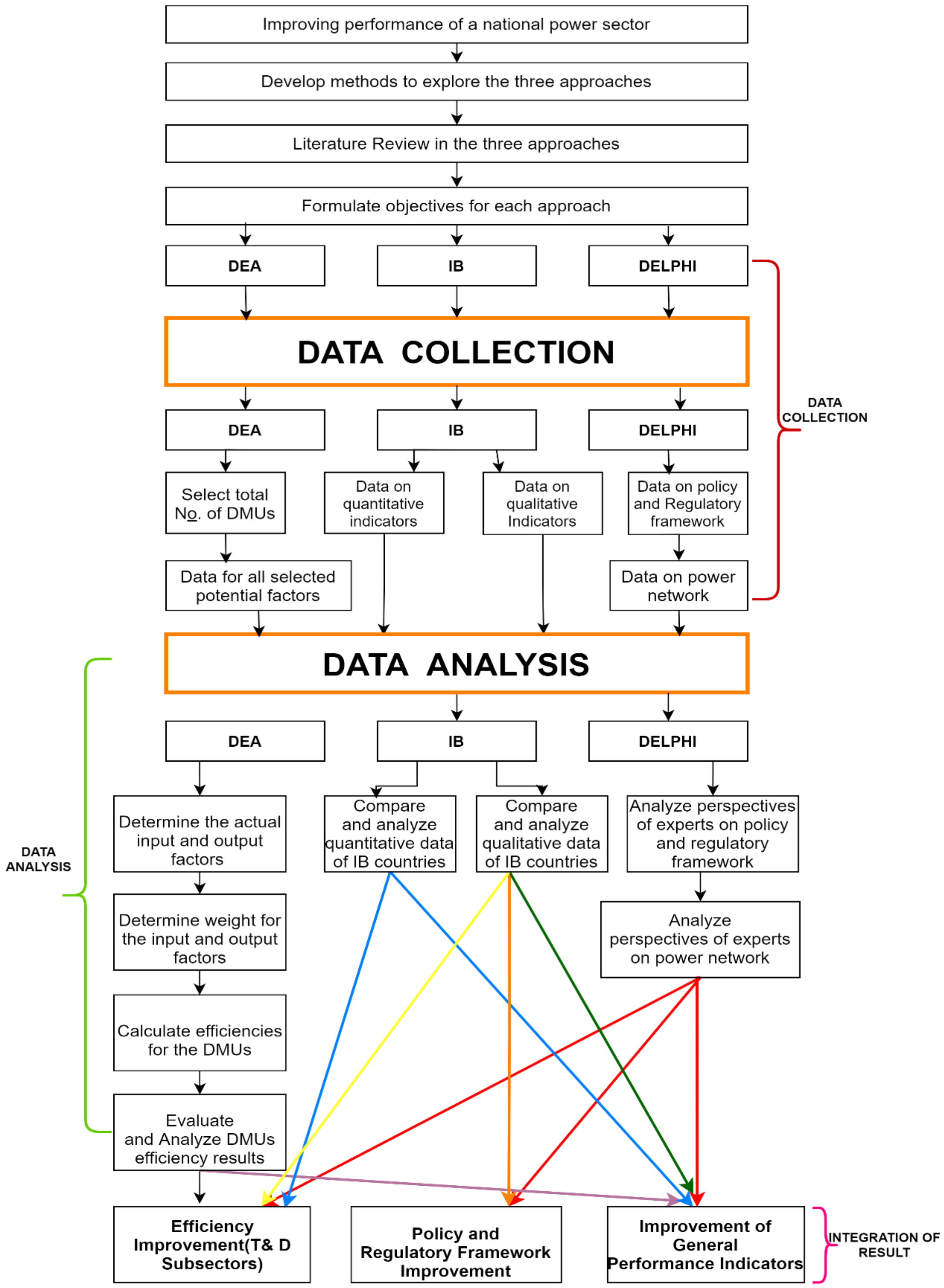

Figure 3. 1: A Flowchart of the research process

3.3 Factors and measures for power sector performance improvement

The study identified factors and associated measures across the three approaches: DEA efficiency modelling and evaluation in the T&D subsectors, international performance benchmarking, and Delphi's approach of power sector experts' perspectives.

3.3.1 Factors and measures for DEA

Based on the literature review, candidate input and output factors impacting the performance of the T&D subsectors have been identified, and these are used for the DEA efficiency modelling and evaluation in the two subsectors. The selection of these factors also considered data availability in the two subsectors. Table 3.3 provide the input and output factors for the transmission subsector.

Power Transmission Input Factors		
Factor	**Definition**	**Measurement**
Total Number of Technical Staff (TNTS) and hours worked	This is the total staff within a transmission area whose roles are directly linked to the transmission of power to a distributor: 3. Engineers 2. Technicians 1. Mechanics	Total number of staff multiplied by the number of hours worked over a defined period
Total Transmission Transformer Capacity (TTTC)	Power transformer capacity determines the ability of a transmission utility to wheel the needed power from a generation source to a bulk distribution point (BSP)	Capacities of all transformers within the transmission area in use are aggregated to get total capacity (in MVA)
Total Number of Power Transformers (TNPT)	The total number of transformers in active use within the transmission area.	The aggregate sum of transformers in use.
Total Length of the Transmission Lines (TLTL)	The length of the Transmission line within a transmission area	Measuring total length in km radially or around the ring system within the transmission area
Power Transmission Output Factors		
Total Amount of Power Transmitted (TAPT)	This is power transmitted to the distribution source over a defined period	This is measured in MW at the bulk supply points of distributors within a transmission area
Total Number of Bulk Customers Served (TNBS)	This includes all the Distributors and other individual bulk consumers of electricity	By counting entities that are connected to the transmission system directly
Total System Hours Lost (TSHL)	This is a power quality indicator that determines the availability of the transmission network	By aggregating the total hours lost due to unavailability of the transmission system
Percentage of Transmission Line Availability (PTSA)	The rate at which the transmission system was available over a year	By determining the rate of availability

Table 3.3: Input and output factors for the transmission subsector

The total number of technical staff is categorized into ranks. Engineers assume the highest rank of '3'; Mechanics assume the rank of '2' and Technicians assume the rank of '1'. The higher the rank, the higher the cost of hiring. This, therefore, gives room for differentiation for allocative efficiency evaluation. Transformers are centrally procured for all seven transmission areas (DMUs), which makes a transformer's unit capacity equal across all the transmission areas (DMUs). The total capacity of transformers as it stands can therefore remain a differentiation factor for allocative efficiency. Conductors used by the transmission areas are also centrally procured, which makes prices of conductors across all the areas equal; hence, there is no difference when it comes to cost per unit length of a transmission line among the transmission areas (DMUs). The revenue accruing from the total amount of power transmitted to various bulk supply points (BSP) is also assumed to be equal across all power transmission areas (DMUs) in Ghana. This constitutes negotiated service charges determined with generators and distributors on the one hand and the transmitter on the other hand. The two output factors in their current state ensure differentiation to evaluate allocative efficiency. The efficiencies calculated for the transmission areas (DMUs) are therefore representative of technical, allocative, and cost efficiencies. The table below shows the candidates' input and output factors for the power distribution subsector.

Factor	Definition	Measurement
Total Power Input (TPI)	Total power received across the various inputs' points in the distribution region.	This is measured by the amount of power transmitted to the distribution region or metering of various power input points to estimate the total power input into the region in MW
Total Power Transformer Capacity (TPTC)	The transformer capacity is in place to wheel power to consumers within the distribution region.	Total power transformer capacity is measured by aggregating the capacities of all transformers in KVA within the distribution region
Total Number of Distribution Transformers (TNDT)	A total number of transformers in the hold of the utility within a particular region.	By taking proper inventory of the number of transformers currently in use
Total Number of Technical Staff (TNTS) in hours over the defined period	This is the total number of all staff within a distribution region whose roles are linked to the distribution of electricity within the distribution region: 1. Maintenance staff 2. Billing staff 3. Customers Service staff	This is measured by aggregating staff numbers in the categories provided multiplied by the number of hours worked over the defined period
OPEX	This is a variable cost or expenditure incurred by a distribution utility as it carries out its functions over a year	OPEX is determined by totaling variable costs incurred related to operations within the year

Table 3.4: Input and output factors for the distribution subsector

Factor	Definition	Measurement
Total Amount of Power Distributed (TAPD)	This is the total amount of power that has been distributed to all points within the distribution region	This is measured by aggregating power that is supplied to consumers and the power used up by the utility itself at its sub-distribution stations (Measured in MW)
Percentage of Distribution System Availability (PDSA)	It provides in percentage rating the availability of the distribution system over a year	It is determined by considering the total outages in days over a year and expressing that as a percentage over the total number of days
Total Power Billed (TPB)	This is the total power that can be accounted for over a year after power has been consumed	It is measured by metering all power-consuming points within the distribution region (in KW)
Network Stability in Hours Duration (NSHD)	It is a power quality indicator that determines how stable the flow of power in the distribution network was	Stability is ascertained in hours or minutes duration
Percentage Distribution Loss (PDL)	Total system losses as a percentage of the power input.	It is measured by taking the difference between total power input and total power billed and expresses the result as a percentage of total power input.
Customer Population Served (CPS)	This is the total number of customers the distribution region continued to serve over a year	By taking the total number of customers connected to the distribution grid within the distribution region who have continued to make power purchases over the year

Table 3.5: Output factors for the power distribution sub-sector

The ‘Technical staff’ in the power distribution subsector of Ghana are categorized into three. These comprise ‘Maintenance’, ‘Customer service’, and ‘Billing’. Of these three categories, the distribution utilities (ECG and NEDCo) provide two rankings: ‘Senior Staff’ and ‘Junior staff’. ‘Senior staff’ are assigned a rank of “2” and ‘Junior staff’ are assigned a rank of “1”. Therefore, the rankings are used as the price differentiator for allocative efficiency across all distribution subsector DMUs. Total transformer capacity is derived from the rated capacities of each of the total number of transformers used in each of the Distribution DMUs. These transformers are centrally procured and for allocative efficiency, the price of a unit of transformer capacity, therefore, remains equal across all the DMUs, hence price of a unit of transformer capacity is not included as the number of transformers as well as their capacities provide differentiation for allocative efficiency.

Also, the study assumes that total power input into the DMUs should remain the same for allocative efficiency since the off-taker price of electricity between the two main distributors (ECG and NEDCo) and the generators is centrally negotiated and remains the same. Meaning, each power distributor buys electricity at the same price from the generators. Given that the price for a unit (1 KWh) of electricity supplied to an end-user is fixed across all the DMUs, there is no need to introduce a price differentiator for total power billed. Also, operating expenditure as an input factor for technical efficiency is expressed as a quantity output which makes each unit equivalent to one (Ghana cedi).

3.3.2 Performance indicators for international benchmarking

A significant power sector indicator usually compared across national power sectors is percentage transmission and distribution losses (% T&D losses). T&D losses encompass the total losses recorded by both transmission and distribution utilities in the country under consideration. It is computed through two dimensions. First, by determining the difference between the amount of power injected into the transmission and distribution grids and the amount of power delivered to the final consumer. Second, by determining the amount of power delivered to the final consumer and yet was not billed and cannot be indeed accounted for. The losses at both dimensions are added to constitute the total T&D losses (Division & Elizalde, 2012). When T&D losses are reduced, it frees more power that can be supplied to consumers who currently do not have access to power, especially among developing countries where there are considerable concerns for universal access to power. The factors used for the IB are based on the literature reviewed on benchmarking relating to the power sector. The table below provides base definitions of the indicators and their measures.

Name of indicator	Broad Definition	Measurement
Generation capacity/demand ratio	Measures to what extent installed/generation capacity meet demand	%
Cost of electricity generation	Measures the cost of producing 1 MWh or kWh of electricity Should include the cost of power generated internally and procured externally by the utility	$/MWh or Cents/KWh
SAIDI	Measures quality of power supply. Consumer dissatisfaction with service is often related to the high level of outages	Outage duration/ year
Average retail prices of electricity in USD cents for KWh	Measures utility's ability to revise tariffs and adjust tariff schemes to cover costs	Cent/kWh
Percentage of population with access to electricity	Measures the level of electrification across the country	Population with access to electricity/total population
Environmental Performance Index (EPI)	It measures the impact of state policies (including the energy sector) on the environment	Combination of weighted scores across various environmental indicators to create an index year on year.
Percentage T&D loss	Measures the total system losses within the power network	Power injected into the T&D network/power billed expressed as a % of power injected

Table 3.6: International performance benchmarking indicators

3.3.3 Themes for qualitative interviews in Delphi

Table 3.7 provides thematic areas explored using the Delphi approach involving the power sector experts in Ghana. These themes are derived from a review of the literature on factors affecting the performance of a national power sector. They cut across issues bordering on the policy, regulatory, and institutional framework and policy and managerial issues that specifically affect the generation, transmission and distribution subsectors.

Policy, regulatory and institutional framework	Generation	Transmission	Distribution
1. Policy and institutional structure 2. Weaknesses of the sector structure 3. Overcoming the structural weaknesses. 4. Respective mandates of the regulatory institutions 5. Private sector participation for all subsectors	1. Existing power generation resources 2. The nature of private sector participation 3. Challenges /Weaknesses 4. Overcoming the challenges /weaknesses 5. Generation mix and the NCRE potential	1. Nature of the transmission network 2. Challenges/ weaknesses 3. Overcoming the weaknesses 4. Reasons for high transmission losses and solutions 5. GRIDCO's weaknesses and overcoming them 6. Capacity of the transmission network to cater for increases in load over the next decade	1. Nature of Ghana's distribution network 2. Challenges /Weaknesses 3. Reasons for high distribution losses 4. Curtailing the distribution losses 5. Capacity of the network to cater for increases in load 6. Managing the two distribution utilities more effectively.

Table 3.7: Themes for the Delphi approach

3.3.4 Research data types, data sources, and data collection methods

The data needs for each performance improvement approach differ and peculiar to the approach. Table 3.8 presents the summary across the data types, source of data, and data collections methods.

Data types	Data sources	Data collection methods
Number of Decision-Making Units	ECG, NEDCo, and GRIDCo	The DMUs of the respective utilities used for the research are gotten through the existing organizational structures of the respective utilities (GRIDCO, ECG, and NEDCo).
Input and output factors and their data	ECG, NEDCo, and GRIDCO	The input and output factors are derived from the literature review. Data relating to the transmission subsector are collected from GRIDCO, while data relating to the distribution subsector are collected from ECG and NEDCo
Weights of selected input and output factors	ECG, NEDCo, and GRIDCO.	Five experts from the transmission and distribution subsectors were made to assign weights to each input and output factor. This is done based on the extent to which they perceived an input or output factor as relevant to the efficiency of a DMU.
International benchmarking indicators	Through published and unpublished works (online and offline sources)	Quantitative data values and the qualitative information for each benchmarking country are derived from national and international sources in the form of document analysis and data mining
Qualitative information across the power sector based on the perspectives of power sector experts	Power sector experts in Ghana	• This information is collected from a Delphi team of 20 experts; • The method for collecting this information is a face-to-face with each expert; • The nature of the questions centred on the themes (provided in table 3.7) outlined for this approach; • To keep track of all details of the interviews, proceedings are recorded by audio with the consent of each respondent; • The researcher engages each respondent for an average of forty-five minutes; (The interview guides used are provided as appendices V, VI,VII and VIII)

Table 3.8: Data types, data sources, and data collection methods

3.4 Methods of analysing data along the three approaches

Under the multilevel concurrent triangulation design, the analysis methods reflect the three approaches before the integration. The three analysis methods are presented below.

3.4.1 DEA efficiency modelling and evaluation

The analysis aspects of the DEA involve determination of the number of DMUs; selection of input and output factors; weights allocation to the relevant factors; efficiency evaluation; efficiency trend analysis; sensitivity analysis; and window analysis.

Selection of input and output factors

The study used the following steps to perform the selection of input and output factors for the DEA Efficiency evaluation for both the transmission and distribution subsectors:

1. Decide potential input and output factors for selection

   Following the rule by Norman and Stoker (1991) regarding considering as many relevant potential factors as possible, four candidates input factors and four candidates output factors were considered for the transmission subsector. A sample of 42 data points representing each input and output factor was used. For the power distribution subsector, five candidates input and five candidate output factors with 84 sample data points for each factor were used.

2. Generate correlation coefficients between input and output factors

   Each input factor was correlated against each output factor to generate correlation coefficients for each pair for transmission and distribution subsectors.

3. Perform significant test for the correlation coefficient

   A critical values table based on a p-value of 0.01 was used as the test of significance for the correlation coefficients in both subsectors. Where a significantly positive correlation is presented between any pair of input and output factors, both factors are selected for efficiency modeling and evaluation in line with the principle of ‘isotonicity’ (Lovell, 1993; Yang, 2013; Bowlin, 1998; Meenakumari & Kamaraj 2008).

4. To get good discriminatory power out of the CCR and BCC models, Boussofiane et al. (1991) stipulate that the lower bound on the number of DMUs should be the multiple of the number of inputs and the number of outputs. Golany and Roll

(1989) also establish a rule of thumb that units should be at least twice the number of inputs and outputs considered.

Based on the requirements of a number of factors in relation to the number of DMUs as provided in step 3, this study used two input factors and two output factors for the DEA efficiency modelling and evaluation in the power transmission subsector. For the distribution subsector, using Boussofiane et al. (1991), four input and two output factors were used.

Determination of the number of DMUs

Based on Boussofiane et al. (1991), 7 DMUs are selected for the efficiency modelling and evaluation in the transmission subsector, while 14 DMUs are chosen for the efficiency modelling and evaluation in the distribution subsector.

Assigning weights to selected factors

After the factor selection and determination of DMUs for both the transmission and distribution subsectors, the weight allocation needs to be determined for the factors. Weights range between 0 and 1 (Norman & Stoker, 1991). High weight for a factor means managers consider it to be more important in determining the efficiency of the DMU and vice-versa. To create standards and consistency across the DMUs, five experts from the transmission and distribution subsectors were made to assign weights to the selected input and output factors. All five experts have taken simple weight averages to represent weights for the selected input and output factors. The respective coefficient of variations (CoV) and standard deviations (SDs) are calculated and analyzed. The five experts used in determining weights of the selected input and output factors are the same experts whose perspectives were gathered for the Delphi approach. The demographic characteristics of the experts are provided in Appendix IX.

Constructing the DEA Model

This study employed the CCR (CRS) model on account of the following two reasons:

- the relative efficiencies of the transmission and distribution units are used
- the two subsectors are service organizations, with flexible optimal scale of operation for the transmission and distribution units.

Using the CCR (CRS) model, the overall efficiency of a DMU is set between 0 and 1. Assuming that there are n DMUs to be evaluated, each DMU consumes varying amounts of m different inputs to produce s different outputs. Specifically, DMU_j consumes X_{ij}

amounts of input i and produces Y*rj* amounts of output ***r***. The fractional formulation of the CCR model becomes:

Model 1

$$Maximize \;\; \theta_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$$

$$subject \;\; to \;\; \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$

$$u_r, v_i \geq 0 \quad for \;\; all \;\; r \;\; and \;\; i.$$

Where Ur and Vi are the weights of the input and output, Yro , Xio are rth output and ith input of DMUo.

This model can be re-written in a linear programming form as:

Model 2

$$Maximize \;\; \theta_o = \sum_{r=1}^{s} u_r y_{ro}$$

subject to:

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad j = 1, ...n$$

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$u_r, v_i \;\; \geq 0$$

The dual Linear Program becomes:

$$\theta^* = \min \theta$$

Subject to $\sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta x_{io}$ i = 1,2,….. m

$\sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{ro}$ r = 1,2,……s

$\lambda_j \geq 0$ j = 1,2……n θ unrestricted

The dual LP is seeking the efficiency rating, minimize *0,* subject to the constraint that the weighted sum of the inputs of the other service units is less than or equal to the inputs of the service unit being evaluated and that the weighted sum of the outputs of the other service units is greater than or equal to the output of the service unit being evaluated. The weights are the lambda values. Given that this is a linear model, once the input and output factors for both the transmission and distribution subsectors are known, the factors are fitted into the model.

Analyzing the DEA Efficiency Results

This study evaluated the transmission and distribution units (DMUs) using the CCR-DEA model on the Constant Return to Scale (CRS) assumption. The study generated overall relative efficiencies in the case of the power transmission subsector. However, in the case of the distribution subsector, relative technical, allocative, and cost efficiencies for each DMU were generated. An input orientation was used for the efficiency evaluation in both subsectors. A DEA software package known as **DEA Frontier** developed by Joe Zhu (2014) generates the efficiency results.

The steps used in presenting and analyzing the DEA efficiency results are outlined below:

1. Efficiency reference sets (ERS) for purposes of benchmarking

   A DEA software is applied to generate results for each of the two subsector's decision making units (DMUs) in terms of their relative efficiency.

2. Efficiency trend analysis

   A trend analysis is conducted to observe the change of the efficiency performance of each DMU over time to establish the consistency in these DMUs.

3. Sensitivity Analysis

   Data variation cuts across three dimensions; a) varying the quantity of one input or one output, b) a simultaneous variation of all data in equal proportion, and c) arbitrary changes in the data relating to both inputs and outputs. DEA sensitivity analysis explores these dimensions as well as ascertain the impact of each input and output factor on the DEA efficiency results. Each input or output factor is excluded from the model to explore the impact on relative efficiencies across DMUs (Noora et al.,2013). The results after excluding each factor are compared to the original result to ascertain the impact of each factor on the model result.

4. Window Analysis

   Window analysis is a method for detecting trends over time in efficiency scores postulated by Charnes et al. (1978). Windows might cover periods over which similar operating conditions or seasonal performance effects are identical. However, window analysis provides no evidence on the nature of any technical change (Emrouznejad, 2000). An essential advantage of the window analysis is that it effectively increases the number of units for evaluation, increasing the discriminatory power. Window analysis is carried out by tracking efficiency over time (Pjecevic, 2011). This is done by choosing a window length ***p*** and then evaluating ***nxp*** efficiencies for each DMU (the number of windows for the DMUs depends on the period considered). In window analysis, a DMUs performance can be compared using the efficiencies within its windows. In contrast, a DMUs performance can also be compared to the performance of another DMU using the efficiency performances between their respective windows.

   A window length of three (3) is considered for the power transmission subsector, resulting in six different windows for each DMU. But given that the total number of DMUs is seven (7), the total number of windows becomes 42. A window length of three (3) is considered for the power distribution subsector, resulting in 6 different windows for each DMU. But given that the total number of DMUs is fourteen (14), the total number of windows becomes 84.

3.4.2 Analysis of IB data

The analysis of variance (ANOVA) approach is employed towards analyzing the results of the quantitative benchmarking indicators. A One-way ANOVA and Post-hoc test approach are applied for the following reasons:

- The countries selected for benchmarking were treated as independent samples;
- The consistency with which a country performs on each indicator was important for this study;

- With the test static being the sample mean, ANOVA facilitated the test of the difference between the group means;

- However, since ANOVA only indicates the statistical difference between two or more groups without highlighting the specific groups causing the differences, a post-hoc test was used to compare Ghana to the rest of the countries selected along each indicator.

The following steps were used in the implementation of the one-way ANOVA and the posthoc test (Tukey-HSD and Games-Howell):

1. The means for each indicator over the six years for each country were first calculated;
2. A one-way analysis of variance (ANOVA) was run on the group means as the test statistic. Given that there are seven (7) quantitative indicators, there were seven one-way analysis of variance (ANOVA) runs;

3. For each one-way analysis of variance run, the P-value was used to determine whether the difference that existed between the means of the groups was statistically significant($P>0.05$ as statistically insignificant and $P<0.05$ as statistically significant);

4. However, since Ghana is the focus of this benchmarking exercise, where the researcher sought to establish Ghana's position on each indicator relative to each benchmarking country, where a significant difference existed between the group means, a homogeneity test was run using Levene's test. Where homogeneity existed in the variances of the group means for any indicator, a Tukey (HSD) approach was used to compare Ghana to each country along with the indicator. Where there was a lack of homogeneity between the variances of the group means, the Games-Howell post-hoc test was used;

5. The rest of the countries were categorized as best performing for each indicator that Ghana could adapt. A best practice country was one with a statistically significant difference in the post-hoc test based on the p-value when Ghana was compared to it.

Using a sequential-explanatory approach, qualitative information/data were explored for each country along themes related to the quantitative indicators to understand the respective performance of the benchmarking countries and identify practices that a developing country such as Ghana could adapt towards improving its power sector performance.

3.4.3 The Delphi approach

The approach to analyzing the results from the perspectives of power sector experts is along two dimensions. The first dimension is to identify all common themes that cut across all the subsectors (policy, regulatory and institutional framework; power generation; power transmission; and power distribution). The second dimension addresses the themes specific to the various subsectors. This enables the researcher to reach some particular conclusions representing the collective thoughts of the experts for each theme.

3.4.4 Methods for integration of the three approaches

Based on the results and analysis of the three approaches, the significant insights identified serves as the basis for integrating them to improve Ghana's power sector performance through the following ways:

1. The first one is the policy and regulatory framework improvement by integrating results of the IB and Delphi approaches;
2. Efficiency improvement relating to transmission and distribution (T&D) subsectors is done by integrating results of all the three approaches;
3. Improvement of the general power sector performance indicators is also done by integrating IB results with the results of the Delphi approach.

3.5 Summary

This chapter presents different research philosophies as well as different mixed-methodology types. The methodological process for conducting this research is described and justified. The design for this study follows a mixed-methods approach which reflects the philosophical paradigm of pragmatism. The variant of the mixed-method approach adopted for the research is a multilevel-concurrent triangulation design (Creswell &Plano Clark, 2010; Terrell, 2012). In line with the multilevel concurrent triangulation design, all three performance improvement approaches are carried out simultaneously over a single time phase. However, a sequential explanatory approach is adapted to identify best practices after quantifying the performance levels of benchmarking countries across the selected performance indicators.

The type of data for the DEA approach is quantitative, and the study relies on secondary sources (ECG, GRIDCo and NEDCo) to collect the data. The data on IB cuts across qualitative and quantitative. Online and offline sources derive these data through document analysis and data mining. The Delphi approach deals with qualitative data types that cut across specific qualitative themes. The study employs in-depth interviews to collect these types of data. The standard DEA approach informs the analysis of the DEA efficiency results. The chapter also identified ANOVA, and the post-hoc tests as the method of analyzing the quantitative data aspect of the IB. At the same time, content analysis and some power sector critical issues were used to analyze the qualitative data. The perspectives of power sector experts were analyzed along with some definite themes reflecting the three subsectors.

CHAPTER FOUR

DATA ENVELOPMENT ANALYSIS RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the efficiency evaluation and analysis of Ghana's transmission and distribution subsectors using Data Envelopment Analysis (DEA). Section 4.2 analyses the transmission subsector, and section 4.3 analyses the distribution subsector. The final section 4.4 summarizes the chapter and presents the benefits of applying DEA for efficiency performance improvement in general.

DEA has been applied to Ghana's power transmission and distribution subsectors and shares the same process for both. The DEA process includes input and output factor selection, factor weight determination and allocation, efficiency evaluation, efficiency trend analysis, sensitivity analysis, and window analysis. All these analyses are based on 2010 to 2017 data, except to illustrate how the DEA efficiency results are analyzed, as well as the sensitivity analysis, the most recent year's data have been used.

4.2 Results and analysis for the transmission subsector

This section includes six subsections. This follows the DEA analysis process stages explained in chapter 3, from factor selection, weights allocation to selected factors, efficiency evaluation, efficiency trend analysis, sensitivity analysis of the selected factors, and window analysis of the DMUs efficiency performance over the period.

4.2.1 Factor selection

Following the DEA factor selection principle of including as many relevant potential factors as possible (Norman & Stoker, 1991) and data availability, four potential input and four potential output factors are considered (see Table 4.1).

Potential Input Factors	Potential Output Factors
Total yearly hours of technical staff (Hours)	The total amount of power transmitted (MW)
Total transmission transformer capacity (MVA)	The total number of bulk suppliers (No.)
The number of transmission transformers (No.)	Percentage transmission line availability (%)
The total length of transmission lines (km)	Total system hours availability (Hours)

Table 4.1: Potential inputs and outputs factors for the transmission subsector

In order to determine the final selected factors, the statistical significances of correlation coefficients between each pair of these potential input and output factors are applied. The correlation coefficients are provided in Table 4.2.

Correlation Coefficients		**Output Factors**			
		Total Amount of Power Transmitted	**Total No. of Bulk Suppliers**	**Percentage Transmission Line Availability**	**Total System Hours Lost**
Input Factors	Total No of Tech Staff	-0.035	**0.717**	-0.350	-0.360
	Total Transformer Capacity	**0.810**	**0.830**	-0.270	-0.270
	Total No of Transformers	0.220	**0.830**	-0.370	-0.360
	Total Length of Transmission Lines	**0.770**	**0.440**	0.110	-0.001

Table 4. 2: Correlation coefficients of potential inputs and output factors for the transmission subsector

Note: Critical value ±0.393 gives a 99% significant confidence level of a sample size 42.

At the 99 per cent confidence level, the two output factors, 'percentage transmission line availability and 'total system hours lost', are excluded from the DEA modelling for the transmission subsector. These two output factors are apparently not impacted by the four potential input factors and might be affected by other downtime causes, such as shutting down a portion of the transmission line for non-regular repairs or maintenance and destruction to a transmission line due to unexpected causes. For the remaining two output factors, 'the total number of bulk suppliers' is significantly correlated with all four input factors, and 'total amount of power transmitted' is significantly correlated with two out of the four input factors.

In the process of power transmission, a certain level of step-up voltage is needed to feed power onto a transmission line and wheeled to the bulk supplier, where voltage is stepped-down to an acceptable level. The amount of power transmitted through a transmission line depends on the transformer's capacity. The longer a transmission line within a power transmission network, the higher the transformer capacity is required, assuming the stability of the network remains. The bulk suppliers include those who receive electricity from the transmitter and redistribute it to other consumers and those who consume electricity directly received from the transmitter beyond a certain minimum threshold.

The number of bulk suppliers determine the total demand and the rate of utilization of the transmission subsector assets, such as transmission lines and transformers. The higher the number of bulk suppliers connected to the transmission network, the higher the transformer capacity likely to be required and the longer the length of the transmission line likely to be in place. Based on the results of the correlation analysis, two input and two output factors have been selected for the DEA modelling to evaluate efficiency of the transmission subsector (see Table 4.3).

Input factors	Output factors
Total Transmission Transformer Capacity (X_1)	Total Amount of Power Transmitted (Y_1)
Total Length of Transmission Lines (X_2)	Total Number of Bulk Suppliers Served (Y_2)

Table 4. 3: Selected input and output factors for the transmission subsector

4.2.2 Weight allocations to the selected factors

A value between 0 and 1 has been allocated to each of the selected input and output factors to give the relative importance of the factor (Norman & Stoker, 1991). A higher value indicates more significance of the factor, and vice versa. Simple averages of the weights collected from five experts for each input and output factor are used along with the standard deviation (SD) and coefficient of variation (CoV). Table 4.4 presents weights given by each of the five experts and the averages of the five, SDs, and CoVs for the two input factors.

Input Factors	W1	W2	W3	W4	W5	Mean	SD	CoV
Total Transmission Transformer Capacity **(X_1)**	0.50	0.75	0.50	0.58	0.73	0.61	0.12	0.20
Total Length of Transmission Lines (**X_2**)	0.50	0.25	0.50	0.42	0.27	0.39	0.12	0.31

Table 4.4: Individual weights by experts and the simple mean, SD and CoV for the two selected input factors

Based on the averages, the experts considered 'total transmission transformer capacity' (X_1) twice as important as 'total length of transmission lines' (X_2) in determining the efficiency of the transmission subsector. Individually, three experts agreed that X_1 is a more critical input factor than X_2, whereas the other two experts weighted the two input factors equally. CoV is higher for 'Total length of transmission lines' than the 'Total transmission transformer capacity' indicating that the experts had a higher common agreement on the 'Total transmission transformer capacity' than the 'Total length of transmission lines. Table 4.5 presents weights given by each of the five experts and the averages of the five, SDs, and CoVs for the two output factors.

Output Factors	**W1**	**W2**	**W3**	**W4**	**W5**	**Mean**	**SD**	**CoV**
Total Amount of Power Transmitted **(Y_1)**	0.80	0.50	0.45	0.60	0.45	0.56	0.15	0.26
Total Number of Bulk Suppliers Served **Y_2**	0.20	0.50	0.55	0.40	0.55	0.44	0.15	0.33

Table 4.5: Individual weights by experts and the simple mean, SD and CoV for the two selected input factors

Based on the average values, the experts considered the ‘total amount of power transmitted’ (Y_1) to be slightly more important than the ‘total number of bulk suppliers served’ (Y_2) in determining efficiency in the power transmission subsector. Two experts weighted Y_1 higher while two other experts weighted Y_2 higher. However, Y_1 assumed the highest average because expert 1 assigned a much higher weight to $Y_{1,}$ creating a wider gap between the two factors. The weights assigned by the rest of the experts to the two output factors are almost equal. The weightings of expert 3 and expert 5 were the same, while expert 2 weighted the two output factors equally and expert 4 weighted them differently but quite close.

4.2.3 Evaluation

The most recent year data, 2017’s, were used to illustrate the DEA efficiency results for the study. The relative efficiency for each of the seven DMUs in the transmission subsector and their associated reference sets are generated and provided in Table 4.6. The reference set for each frontier DMU is itself and the reference sets for each less efficient DMUs consists of all the frontier units. The conditions are considered similar for all the DMUs in the transmission subsector. However, due to different operational practices, some DMUs are less efficient than others and the reference sets provide the relative efficiencies compared to the frontier units. DEA, however, does not identify practices taking place within each DMU or the best practices among the units. However, the results can facilitate the next step of internal learning among the DMUs.

DMU	Relative efficiency	References sets
DMU_2	1.000	1.000 DMU_1
DMU_2	0.785	0.217 DMU_1 0.267 DMU_3 0.374 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.725	0.272 DMU_1 0.233 DMU_3 0.029 DMU_6
DMU_5	0.436	0.034 DMU_1 0.262 DMU_3 0.087 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.649	0.082 DMU_1 0.162 DMU_3 0.093 DMU_6

Table 4. 6: DEA relative efficiencies of DMUs and associated reference set values of transmission subsector in 2017

The DEA results confirmed that DMU_1, $DMU_{3,}$ and DMU_6 were frontier units based on 2017's data out of the seven DMUs (see Table 4.6). The remaining four DMUs were less efficient. The relative efficiency figures reveal that DMU_5 was the least relatively efficient unit, less than half of the frontier units' efficiency level. The efficiencies of the other remaining DMUs were not more than three-quarters of the frontier units' efficiency level. The DEA methodology employed for this study has an input orientation, and this implies that a less efficient DMU needs to improve by reducing its total input relative to the current output produced. The proportions of reduction needed are provided in the reference set which is a combined input reduction, comparatively to the frontier units.

4.2.4 Time trends of the relative efficiencies of DMUs

The trends of the efficiency performance for the seven DMUs in the transmission subsector from 2010 to 2017 are presented in Table 4.7 and illustrated in Figure 4.1.

DMU	2010	2011	2012	2013	2014	2015	2016	2017
DMU_1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DMU_2	0.90	0.80	0.83	0.81	0.58	0.83	0.81	0.78
DMU_3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DMU_4	0.76	0.74	0.74	0.78	0.78	0.68	0.64	0.72
DMU_5	0.69	0.51	0.40	0.42	0.43	0.45	0.42	0.44
DMU_6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DMU_7	0.81	0.68	0.67	0.67	0.56	0.64	0.61	0.65

Table 4.7: Relative efficiencies of DMUs in transmission subsector from 2010 to 2017

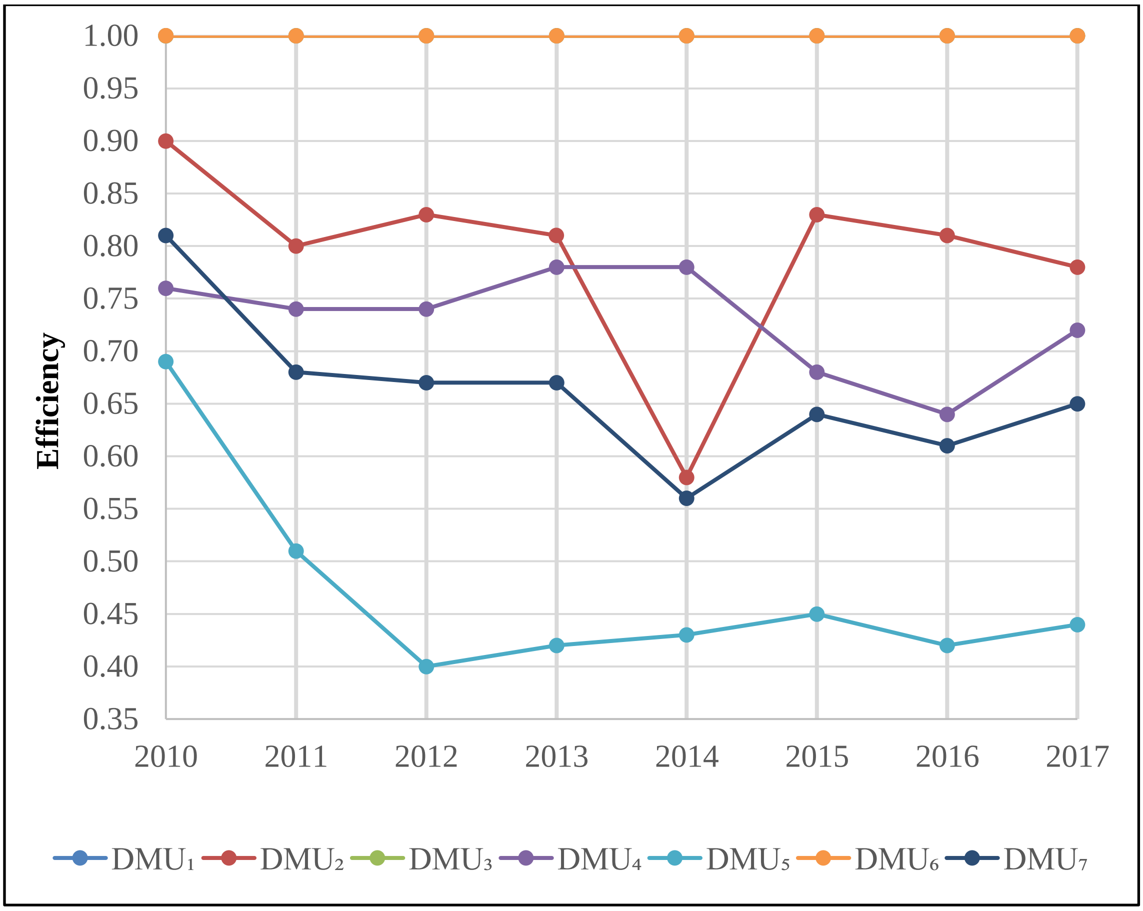

Figure 4.1: Efficiency trends for transmission subsector DMUs from 2010 to 2017

All the three frontier units remained frontiers over the eight years. The efficiency performance of these three units could either have stayed the same, have improved, or otherwise simultaneously. The remaining five DMUs remained relatively less efficient comparatively. The relative differences between these less efficient DMUs and the frontier units had been enlarged from 2010 to 2017, gradually overall, except for one sharp drop in 2014 for DMU_2 and DMU_7.

During Ghana's power crisis period from 2012 to 2015, the trend analysis confirms that efficiency performance differences between the frontiers and the less efficient DMUs were more dramatic. DMU_2 and DMU_7 recorded their lowest relative efficiency performance in 2014, DMU_5 in 2012, and DMU_4 in 2016. These figures indicate that the less efficient DMUs were hit harder during the power crisis period. Given that total power demanded and transmitted was low during the power crisis period, the 'total power transformer capacity and 'total transmission line length' would have also been underutilized. The increase of flexibility of the power sector to respond to either the crisis or increase in demand could be an interesting research topic to reduce the impact on the sector and its DMUs. However, this is outside of the scope of this study.

4.2.5 Sensitivity analysis

A sensitivity analysis explores the impact of the absence of either one of the input factors or one of the output factors on relative efficiencies of DMUs using the developed DEA model. This sensitivity analysis explores the implications of each factor on the relative efficiency performance of the DMUs in the power transmission subsector in order to determine the key factors. Once the key factors of input and output factors are determined, an efficiency goal can be set. The 2017 data are used for the sensitivity analysis. The sensitivity results of the input factors is provided in Table 4.8.

DMU	DEA sensitivity analysis results		
	Presence of X_1 and X_2	**Absence of X_1**	**Absence of X_2**
DMU_1	1.00	1.00	0.85
DMU_2	0.79	0.55	0.75
DMU_3	1.00	0.17	1.00
DMU_4	0.72	0.33	0.64
DMU_5	0.44	0.18	0.43
DMU_6	1.00	1.00	1.00
DMU_7	0.65	0.36	0.62

X_1: Total Transformer Capacity
X_2: Total Length of Transmission Lines

Table 4.8: Sensitivity analysis of input factors for the transmission subsector

Table 4.8 presents the relative efficiencies of the original DEA, which contain both input factors and DEA relative efficiencies when one of the two input factors is absent. For the three frontier DMUs, DMU_6 remains a frontier DMU for either of the input factors being absent. Without the inclusion of 'Total transformer capacity' , the efficiency of DMU_3 is dramatically reduced to 17% from 100%. Meanwhile, without the inclusion of 'Total length transmission lines', DMU_3 remained efficient. This indicates that 'Total transformer capacity' is the key factor for DMU_3. Without the inclusion of 'Total length of transmission lines', DMU_1 efficiency is slightly down to 85% from 100 %, but it remained efficient without the inclusion of 'Total transformer capacity'.

For non-frontier units, all the original efficiencies have been dramatically reduced, ranging from 24% to 39%, without the inclusion of ‘Total transformer apacity’. This indicates the importance of the input factor of ‘total transformer capacity’ to efficiency based on the developed model for the transmission subsector. For non-frontier DMUs, all the original efficiencies have been reduced slightly, without the inclusion of ‘Total length transmission lines’ . The changes range from 1% to 8%. The sensitivity analysis confirms that ‘total transformer capacity’ plays a more important role in determing the efficiency for the transmission subsector than ‘total length of transmission lines’.

The two input factors constitute the primary requirements that a transmission utility requires to function. A transmission network is constituted by connecting transmission lines within a large geographical area. But transformers of the required capacity are needed to wheel power from generation points to bulk supply points (BSP), which is more critical even though without the lines, electrical power of any capacity cannot be transmitted. In reality therefore, both input factors need to be present in order for electricity to be transmitted.

DMU	Presence of Y_1 and Y_2	absence of Y_1	absence of Y_2
DMU_1	1.00	1.00	0.61
DMU_2	0.79	0.45	0.56
DMU_3	1.00	1.00	0.31
DMU_4	0.72	0.68	0.24
DMU_5	0.44	0.30	0.25
DMU_6	1.00	0.29	1.00
DMU_7	0.65	0.44	0.39

Y_1: Total Amount of Power Transmitted

Y_2: Total Number of Bulk Suppliers Served

Table 4.9: Sensitivity analysis of output factors for transmission subsector

Table 4.9 presents the relative efficiencies for the original DEA containing both output factors and DEA relative efficiencies when one of the two output factors is absent. Without the inclusion of ‘total amount of power transmitted’, the efficiency of DMU_6 was dramatically reduced to 29%. Without the inclusion of ‘total number of bulk suppliers and consumers served’, the efficiencies of two frontier units, DMU_1 and DMU_3 reduced to 0.61 and 0.31, respectively.

For non-frontier units, without the inclusion of ‘total amount of power transmitted’, all the original efficiencies have been reduced, ranging from 14% to 34%. Without the inclusion of ‘total number of bulk suppliers and consumers served’, all the original efficiencies have been reduced from 19% to 48%. The developed model for the transmission subsector shows greater sensitivity to both output factors. However, the 'total number of bulk suppliers and consumers served' has a slightly higher impact than the 'total amount of power transmitted'.

Comparing the sensitivity analysis results to the weights assigned by the experts, it is observed that the average weight assigned to 'total amount of power transmitted' was higher than the weight assigned to 'total number of bulk suppliers and customers served'. Both output factors are critical for the efficient and effective functioning of a transmission utility. This is because the higher the number of bulk suppliers served, the higher the likelihood of demand for power to be needed and transmitted. This defines the rate of utilization of the transmission assets of both transformer capacity and the length of transmission lines.

4.2.6 Window analysis of relative efficiencies

For this study, a window length of three years is used, giving six window periods for each DMU and forty-two window periods for seven DMUs in the power transmission subsector. Forty-two window periods provide a sufficient basis to explore weak and strong performances emerging over the period. Table 4.10 provides the window analysis results, the Means, SDs, and CoVs for each window period.

DMUs	2010	2011	2012	2013	2014	2015	2016	2017	MEAN	SD	CoV
DMU_1	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	1.00				1.000	0	0
				1.000	1.000	1.000			1.000	0	0
					1.00	1.000	1.000		1.000	0	0
						1.000	1.000	1.000	1.000	0	0
DMU_2	0.900	0.800	0.823						0.843	0.042	4.980
		0.800	0.823	0.820					0.816	0.011	1.350
			0.8266	0.820	0.580				0.742	0.116	15.640
				0.820	0.580	0.823			0.742	0.116	15.640
					0.580	0.830	0.810		0.740	0.116	15.670
						0.830	0.810	0.790	0.809	0.018	2.220
DMU_3	1.000	1.000	1.000						1.00	0	0
		1.000	1.000	1.000					1.00	0	0
			1.000	1.000	1.000				1.00	0	0
				1.000	1.000	1.000			1.00	0	0
					1.000	1.000	1.000		1.00	0	0
DMU_4	0.760	0.74	0.740						0.747	0.008	1.070
		0.740	0.740	0.780					0.752	0.016	2.130
			0.740	0.780	0.780				0.764	0.015	1.960
				0.78	0.780	0.680			0.744	0.044	5.910
					0.780	0.680	0.640		0.699	0.057	8.160
						0.680	0.640	0.730	0.682	0.035	5.130
DMU_5	0.689	0.510	0.400						0.536	0.116	21.690
		0.510	0.400	0.420					0.446	0.049	10.990
			0.400	0.420	0.430				0.417	0.008	1.920
				0.420	0.430	0.450			0.431	0.013	3.010
					0.430	0.450	0.42		0.432	0.013	3.020
						0.450	0.42	0.44	0.435	0.013	2.990
DMU_6	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	1.000				1.000	0	0
				1.000	1.000	1.000			1.000	0	0
					1.000	1.000	1.000		1.000	0	0
						1.000	1.000	1.000	1.000	0	0
DMU_7	0.810	0.680	0.670						0.722	0.064	8.860
		0.680	0.670	0.670					0.676	0.002	0.300
			0.670	0.670	0.560				0.635	0.055	8.650
				0.670	0.560	0.640			0.623	0.049	7.870
					0.560	0.640	0.610		0.603	0.034	5.640
						0.640	0.610	0.650	0.634	0.015	2.370

Table 4.10: Window analysis for the transmission subsector from 2010 to 2017

Among the four less efficient DMUs, their lowest means for the window periods occurred at window periods 4, 5, and 6. These three window periods are within Ghana's power crisis period from 2012 to 2015. Within this period, the gap between the less efficient DMUs and the relatively efficient ones was wider, resulting in the lower means of the window periods. DMU_2 and DMU_4 experienced the highest instability and inconsistency from 2014 to 2016. They, however, recorded their lowest instability and inconsistency over two window periods spanning 2010-2013. The highest instability and inconsistency period for DMU_5 and DMU_7 is from 2010 to 2012. They recorded their lowest instability and inconsistency spanning three periods from 2012 to 2016.

While the highest pattern of instability and inconsistency for DMU_2 and DMU_4 was within the power crisis period, the lowest pattern of instability and inconsistency for DMU_5 and DMU_7 was rather within the crisis period. However, the mean efficiency values for DMU_5 and DMU_7 over the crisis period were lower than the mean efficiency values over the same period for DMU_2 and DMU_4. This means that DMU_5 and DMU_7 were more stable and consistent in generating lower efficiency values over the crisis period than DMU_2 and DMU_4, an indication that both DMUs were severely hit by the power crisis period.

4.3 Results and analysis for the distribution subsector

The application of DEA to the distribution subsector are provided in the subsections below.

4.3.1 Factor selection

Following the principles of including as many relevant potential factors as possible and data availability, five potential input and five potential output factors are considered (summarized in Table 4.11).

Potential input factors	Potential output factors
Total Transformer Capacity	Total Amount of Power Billed
Total Number of Distribution Transformers	Percentage Distribution System Availability
Average Operating Expenditure	Network Stability in Hours Duration
Total Number Technical Staff	Total Customer Population Served
Total Power Input	Percentage Distribution Losses

Table 4.11: Potential inputs and output factors for the distribution subsector

Correlation coefficients between each paire of the potential input and potential output factors are givein in Table 4.12.

Input/output correlation coefficients	**Total power billed**	**Percentage distribution system availability**	**Network stability in hours duration**	**Customer population served**	**Percentage Distribution loss**
Total transformer capacity	0.84	-0.25	-0.25	0.70	0.08
Total number distribution transformers	0.66	-0.37	-0.35	0.53	0.26
Average operating expenditure	0.42	-0.48	-0.49	0.63	-0.13
Total Number of Technical Staff	0.58	-0.19	-0.18	0.69	0.15
Total power input	**0.84**	**-0.09**	**-0.10**	**0.53**	**-0.09**

Table 4.12: Correlation coefficients of potential inputs and outputs factors for the distribution subsector

Note: Critical value of ±0.283, which gives significant confidence at 99% with a sample size of 84.

All the five input factors are resources contributing to the first four output factors positively in a logic sense. Among these four output factors, however, 'percentage distribution system availability' and 'network stability in hours duration' have negative correlations with all input factors and therefore they are excluded from the DEA model. The correlation coefficients for the remaining output factor - 'percentage distribution losses' are insignificant with all the potential input factors and therefore it is also excluded. Even though 'percentage distribution losses' has been excluded in the DEA modelling for the distribution subsector, this output factor is an important performance indicator. Factors, such as the age of the transformers, distance between distribution substations and load centers, obsolete nature(age) of distribution lines, rate of power theft (consumed and unaccounted for) and the technical mix of the staff, could impact on this output factor. The factor selection process however confirms that this output factor is not influenced by the current potential input factors.

At 99 percent confidence with the critical value of ± 0.283 for the sample size used, 'total power billed' and 'customer population served' are the two output factors selected and they are all significantly positively correlated with the all five input factors. 'total power input' should have direct implications on the 'total power billed' if power input within the distribution network has been adequately accounted for. It also impacts the number of 'customer power served'. This is because the total number of customers connected to the distribution grid and their demand will determine whether power input within a distribution region is sufficient. The required total transformer capacity has a direct relationship with the distribution utility serving the number of customers to meet the demand. The total technical staff are all full-time equivalent employees (otherwise working hours should be used) within the distribution region. Assuming they are qualified at a required level to fulfill their job roles, the total number of technical staff will also impact on the power distributed to end consumers. They comprise billing staff, maintenance staff, and customer service staff.

Operating expenditure is a variable cost for a distribution utility to performer the required functions and has a likely impact on the utility's ability to distribute power to consumers and bill the power consumed. The number of the distribution transformers could have been included; however, this is likely to make a similar impact as the transformer capacity. Either the total transformer capacity or the number of distribution transformers could be used as an input factor; but there is no need to include both of them. The transformer capacity with higher correlation coefficients is therefore selected.

The four input factors and two output factors selected are summarized in Table 4.13.

Selected Input Factors	Selected Output Factors
1. Total Power Input **(X_1)**	1. Total Amount of Power Billed **(Y_1)**
2. Total Transformer Capacity **(X_2)**	2. Customer Population Served **(Y_2)**
3. Total Number of Technical Staff **(X_3)**	
4. Operating Expenditure **(X_4)**	

Table 4. 13: Selected input and output factors for the distribution subsector

4.3.2 Weights allocation to selected factors

A value between 0 and 1 has been allocated to each of the selected input and output factors to give the relative importance of the factor. A higher value indicates more importance of the factor than others, and vice versa. Simple averages of the weights collected from five experts for each input and output factor are calculated along with the standard deviation (SD) and coefficient of variation (CoV). Table 4.14 presents weights given by each of the five experts and the averages, SDs, and CoVs.

Factor	W1	W2	W3	W4	W5	M	SD	CoV
Total Power Input **(X_1)**	0.40	0.35	0.30	0.32	0.25	0.31	0.06	0.18
Total Transformer Capacity **(X_2)**	0.20	0.20	0.25	0.25	0.20	0.24	0.04	0.15
Total Number of Technical Staff **(X_3)**	0.20	0.20	0.20	0.27	0.30	0.21	0.06	0.28
Operating Expenditure **(X_4)**	0.20	0.25	0.25	0.20	0.25	0.24	0.03	0.12

Table 4.14: Expert weights for selected input factors, along with means (M) standard deviation (SD) and coefficient of cariance (CoV) in the distribution subsector

Based on the averages provided in Table 4.14, the experts considered that ‘Total power input’ (X_1) was the most important input factor among the four input factors. Operating expenditure and the total transformer capacity are considered equally important, followed by the total number of technical staff. It is not surprising as the sector is dominated by equipment and the presence of technical staff is largely to maintain a technically functioning system. The CoV values are slightly high for ‘Total number of technical staff’ (X_3), indicating the five experts have different opinions on this input factor. However, the value of 28% indicates an agreement towards this factor. With the other three input factors the CoVs for the other three input factor indicate good agreements among the five experts with less than 20% controversy. Table 4.15 provides weights assigned to the output factors by the five experts in the power distribution subsector, along other measures.

Factor	W1	W2	W3	W4	W5	M	SD	CoV
Total Amount of Power Billed **(Y_1)**	0.55	0.57	0.50	0.55	0.43	0.52	0.057	0.109
Customer Population Served **(Y_2)**	0.45	0.43	0.50	0.45	0.57	0.48	0.057	0.118

Table 4.15: Expert weights for selected output factors, along with means (M), standard deviation (SD) and coefficient of variance (CoV) in the distribution subsector

The experts considered the ‘Total amount of power billed’ to be slightly more important than the ‘Customer population served’. It might be due to the fact that total power billed may influence the number of customers which can be served. The less than 20% CoV values indicate the relative good convergency among these five experts, even though the agreements have some variations.

4.3.3 Evaluation

The DEA evaluation process for the distribution subsector is illustrated using the 2017’s data, the most recent year of the data collection for the study. The relative efficiencies for each DMU in 2017 are provided with their associated reference sets. The reference sets for each less efficient DMU constitute its specific frontier DMUs. The distribution subsector conditions are similar among all DMUs but their internal operational practices may be different from the reference sets. But due to poor working practices, the less efficient DMUs are not as efficient as their reference sets.

The DEA modelling reveals that seven out of fourteen DMUs in the distribution subsector, are frontiers for all the three efficiency measures in 2017 (see table 4.16), based on the input and output factors used. This indicates that the frontier DMUs across all the three efficiency measures are operating at a higher level than the other remaining seven DMUs. The least efficient unit is DMU_{13} cross all te three efficiency measures, followed by DMU_4, of which both are nearly 20% below the frontier units for technical and allocative efficiencies, giving a much lower cost efficiency. The other five less efficient units are only marginally lower than the frontier DMUs. Overall, the DEA modelling identified three groups of efficiency level of the DMUs, which are frontier DMUs, almost frontier DMUs, and DMUs which need much improvement. A less efficient DMU needs to implement improvement approaches to reduce its total input to be commensurate with the output produced.

DMU	Technical efficiency	Technical efficiency reference sets	Allocative efficiency	Allocative efficiency reference sets	Cost efficiency
DMU_1	0.947	0.867 DMU_3 0.260 DMU_5	0.947	0.835 DMU_3 0.326 DMU_5	0.896
DMU_2	0.995	0.433 DMU_3 0.794 DMU_5 0.653 DMU_{12}	0.996	0.434 DMU_3 0.793 DMU_5	0.990
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	0.836	0.251 DMU_3 0.199 DMU_5	0.836	0.251 DMU_3 0.199 DMU_5 0.385 DMU_7 0.216 DMU_{14}	0.698
DMU_5	1.000	1.000 DMU_5	1.000	1.000 DMU_5	1.000
DMU_6	0.970	0.654 DMU_3 0.256 DMU_7 0.535 DMU_{14}	0.970	0.654 DMU_3 0.256 DMU_7 0.535 DMU_{14}	0.941
DMU_7	1.000	1.000 DMU_7	1.000	1.000 DMU_7	1.000
DMU_8	0.970	0.178 DMU_3 0.282 DMU_7 1.194 DMU_{14}	0.978	0.178 DMU_3 0.282 DMU_7 1.194 DMU_{14}	0.948
DMU_9	0.978	0.056 DMU_3 0.030 DMU_5 0.284 DMU_7 0.628 DMU_{11}	0.972	0.056 DMU_3 0.030 DMU_5 0.284 DMU_7 0.628 DMU_{11}	0.950
DMU_{10}	1.000	1.000 $DMUD_{10}$	1.000	1.000 DMU_{1O}	1.000
DMU_{11}	1.000	1.000 DMU_{11}	1.000	1.000 DMU_{11}	1.000
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.828	0.022 DMU_3 0.283 DMU_{10} 0.425 DMU_{11} 0.133 DMU_{14}	0.833	0.019 DMU_3 0.315 DMU_{10} 0.405 DMU_{11} 0.132 DMU_{14}	0.689
DMU_{14}	1.000	1.000 DMU_{14}	1.000	1.000 DMU_{14}	1.000

Table 4.16: Efficiency results of DMUs in distribution subsector for 2017

4.3.4 Time trends of the relative efficiencies of DMUs

The results of the three efficiency performance measures for the power distribution subsector from 2010 to 2017 are presented in table 4.17 along with the illustrative graphs in Figures 4.2 to 4.4.

DMU	EFF TYPE	2010	2011	2012	2013	2014	2015	2016	2017
DMU_1	Technical	1.00	1.00	1.00	1.00	0.99	1.00	0.87	0.95
	Allocative	1.00	1.00	1.00	1.00	0.99	1.00	0.87	0.95
	Cost	1.00	1.00	1.00	1.00	0.98	1.00	0.76	0.89
DMU_2	Technical	1.00	1.00	1.00	0.98	0.84	0.74	1.00	0.99
	Allocative	1.00	1.00	1.00	0.99	0.84	0.74	1.00	0.99
	Cost	1.00	1.00	1.00	0.97	0.71	0.55	1.00	0.99
DMU_3	Technical	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Allocative	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DMU_4	Technical	0.99	0.94	1.00	1.00	1.00	1.00	1.00	0.83
	Allocative	0.98	0.92	0.92	1.00	1.00	1.00	1.00	0.83
	Cost	0.97	0.87	0.92	1.00	1.00	1.00	1.00	0.69
DMU_5	Technical	1.00	1.00	0.93	1.00	0.96	0.88	1.00	1.00
	Allocative	1.00	0.94	0.94	0.96	0.93	0.88	1.00	1.00
	Cost	1.00	0.94	0.87	0.96	0.90	0.78	1.00	1.00
DMU_6	Technical	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
	Allocative	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97
	Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94
DMU_7	Technical	1.00	0.95	0.97	1.00	1.00	0.99	1.00	1.00
	Allocative	1.00	0.95	0.95	1.00	1.00	0.97	1.00	1.00
	Cost	1.00	0.91	0.93	1.00	1.00	0.97	1.00	1.00
DMU_8	Technical	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.98
	Allocative	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.98
	Cost	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.96
DMU_9	Technical	0.98	0.88	0.99	1.00	1.00	1.00	0.96	0.97
	Allocative	0.98	0.88	0.88	1.00	1.00	1.00	0.96	0.97
	Cost	0.95	0.78	0.87	1.00	1.00	1.00	0.92	0.95
DMU_{10}	Technical	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Allocative	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DMU_{11}	Technical	1.00	1.00	0.97	1.00	0.91	0.97	1.00	1.00
	Allocative	1.00	1.00	1.00	1.00	0.90	0.97	1.00	1.00
	Cost	1.00	1.00	0.97	1.00	0.82	0.95	1.00	1.00
DMU_{12}	Technical	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Allocative	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Cost	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
DMU_{13}	Technical	1.00	0.95	0.98	0.94	0.90	0.90	1.00	0.83
	Allocative	1.00	0.95	0.95	0.93	0.92	0.89	1.00	0.83
	Cost	1.00	0.90	0.93	0.88	0.83	0.80	1.00	0.69
DMU_{14}	Technical	1.00	0.96	1.00	0.93	1.00	1.00	1.00	1.00
	Allocative	1.00	0.98	0.98	0.93	1.00	1.00	1.00	1.00
	Cost	1.00	0.94	0.98	0.86	1.00	1.00	1.00	1.00

Table 4.17: Technical, allocative, and cost efficiencies for distribution subsector

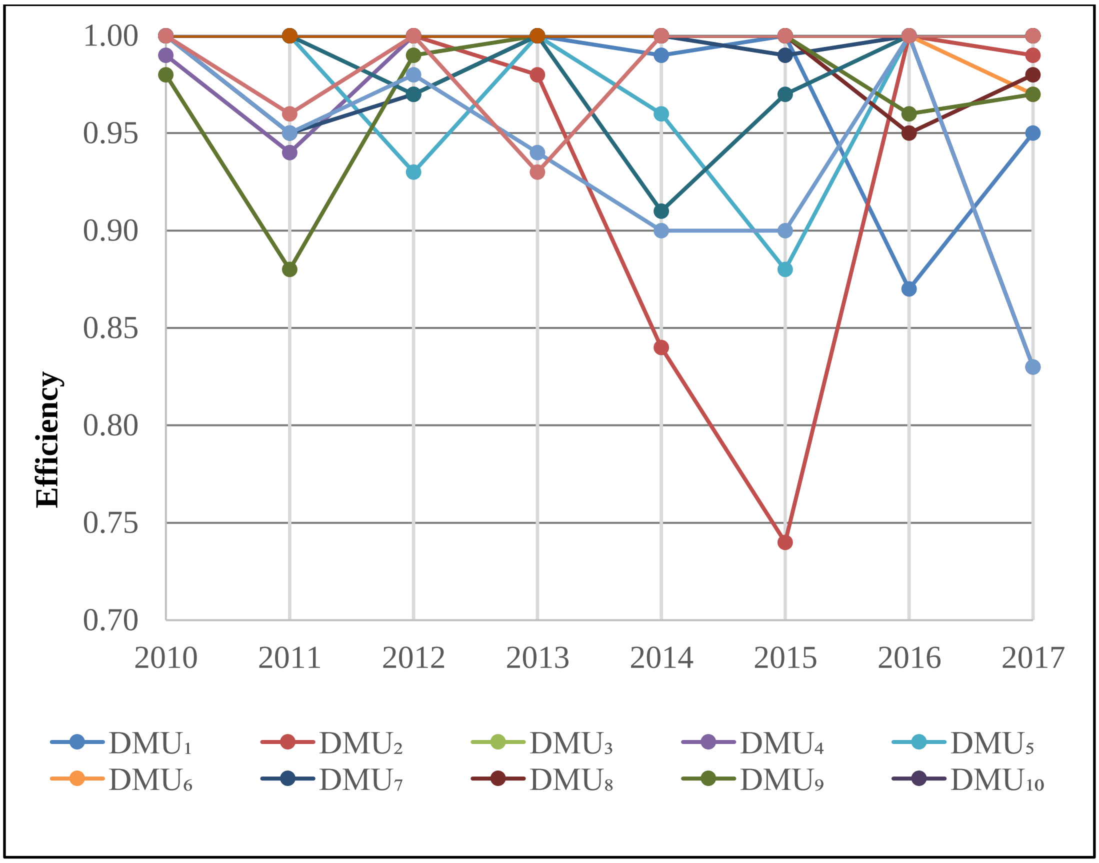

Figure 4.2: Technical efficiency trends of DMUs in distribution subsector from 2010 to 2017

Three DMUs remained consistent as frontier DMUs throughout the eight years. As technical efficiency measures physical inputs relative to the quantity of outputs produced (Fried et al., 2008; Cesaro et al., 2009), it indicates that these three DMUs had been consistently in the leading position in terms of efficient use of resources. Some DMUs had better years before 2017, for example DMU_{13} which had reached the frontier position twice for eight years. It stayed below the frontier line for most years of the period making it the relatively worst performed DMU. The rest of the DMUs remained on the frontier line for at least three or more times over eight years.

The majority of the DMUs experienced a drop in their technical efficiency levels in 2010 and 2011 and remained quite inconsistent throughout. The power crisis period (2012-2015) had a negative impact on the technical efficiency of the distribution subsector DMUs with most of the DMUs recording their lowest efficiency levels. The gaps between the frontier DMUs and the less efficient DMUs were wider over this period compared to other years. Clearly, DMU_2 recorded the sharpest drop within the power crisis period in 2015.

Three DMUs remained consistently as frontiers, including the crisis period. It implied that their relative efficient performance was even throughout the crisis period.

Allocative efficiency

The line chart below provides the allocative efficiency performance for each DMU from 2010-2017.

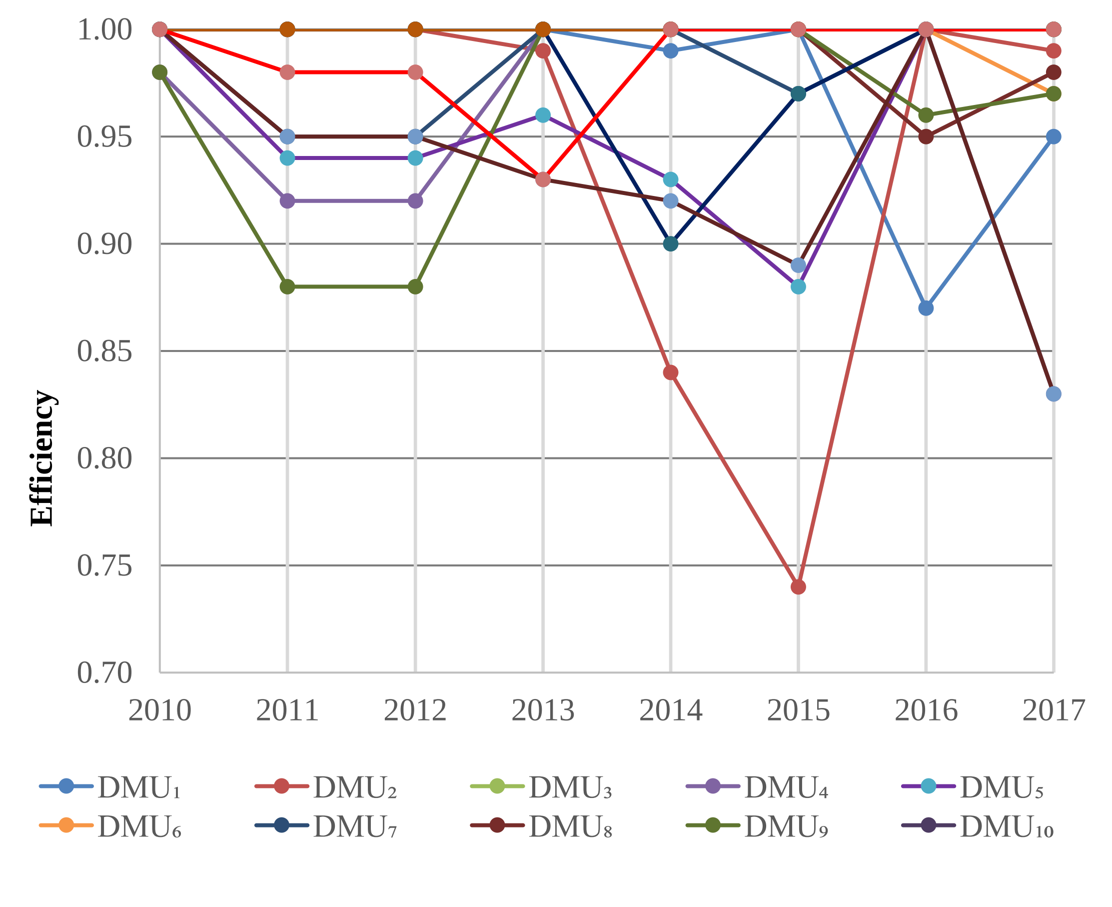

Figure 4. 3: Allocative efficiency trends of distribution subsector DMUs

The same DMUs remained as the frontiers for allocative efficiency throughout the eight years. To be allocatively efficient relatively, a firm must be able to combine inputs and outputs in optimal proportions in light of prevailing prices. This determines the gap between the firm's efficiency position at any point and the point of maximum profitability (Fried et al., 2008; Cesaro et al., 2009). For the power distribution subsector, it means that the input factors had to be combined by the DMUs to be mindful of the lowest cost prices of inputs and yet capable of producing the outputs that make them efficient. While the unit cost for the other input factors remains the same across all the fourteen DMUs, the differentiation factor however was a combination of the categories of the technical staff to ensure that depending on the senior and junior staff combination relative to their ranks (the higher the rank, the higher the salary), a DMU can produce an output that makes it allocatively efficient. The three DMUs that remained consistently as the frontiers used the categories of staff in their best proportions relative to the rest.

DMU_{13} was only on the allocative efficiency frontier line for two occasions. It stayed below the frontier line for the rest of the period making it the poorest performed DMU. The rest of the DMUs stayed on the frontier line for at least three times over eight years. It is observed that most of the DMUs experienced a drop in their allocative efficiencies from 2010 to 2011 and flattened between 2011 and 2012. They picked up their efficiencies only slightly between 2012 and 2013 and remained quite inconsistent after that. The power crisis period (2012-2015) also negatively impacted as most of the DMUs recorded their lowest efficiencies within the crisis period. The gap between the frontier DMUs and the less efficient DMUs was also wider over this period compared to other years. Figure 4.3 also shows clearly that DMU_2 recorded the sharpest drop within the power crisis period for 2014 and 2015.

Cost efficiency

The cost efficiency performance results for each of the fourteen DMUs from 2010 to 2017 are illustrated by Figure 4.4.

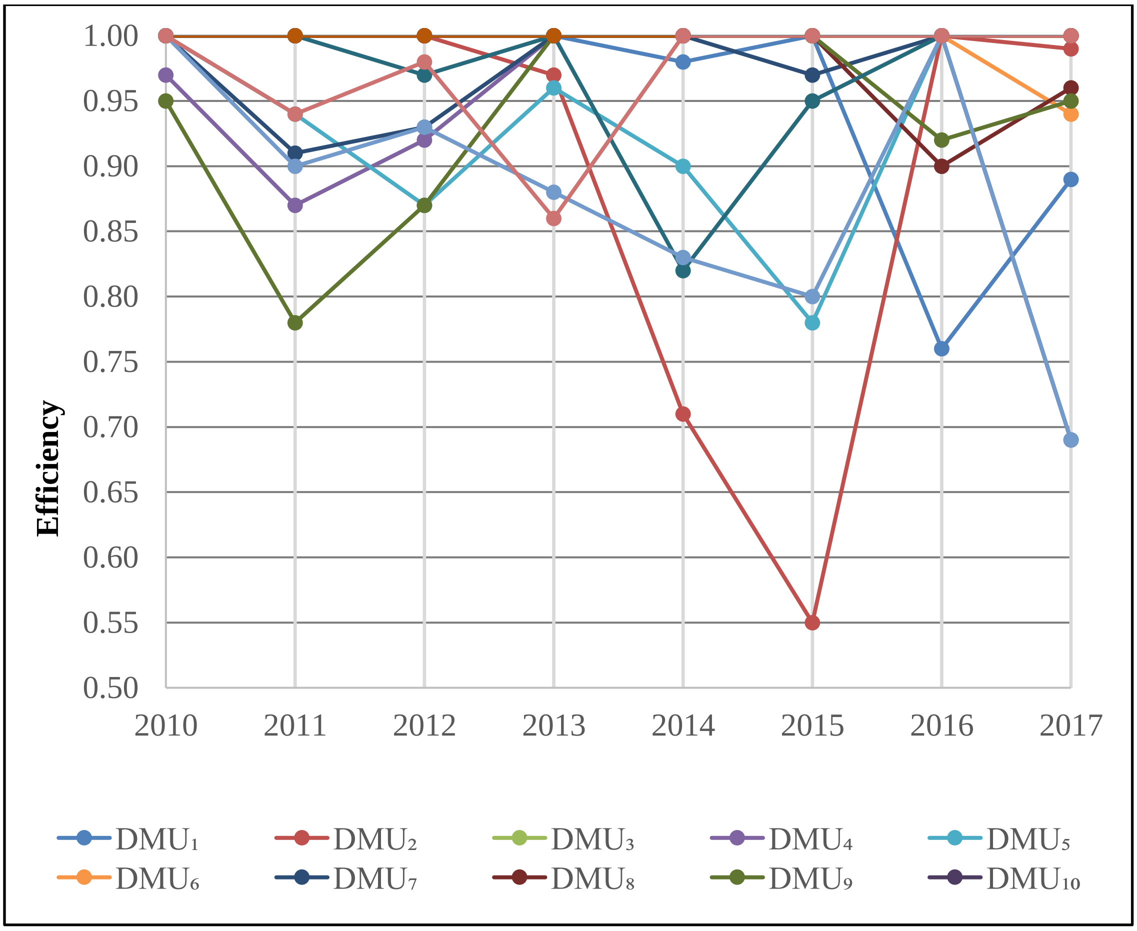

Figure 4.4: Cost efficiency trends of DMUs in distribution subsector from 2010 to 2017

An organization becomes cost efficient if the reduction in its production costs and/or the increase in its revenue could apply to operate at the point of both technical and allocative efficiency. Cost efficiency determines whether a firm is operating at an optimal level and whether its operations are profitable (Cesaro et al., 2009; Ouattara, 2012). The cost efficiency figure trends the same way as the technical and allocative efficiency figures.

The three consistently efficient DMUs also constitute the frontiers on the cost efficiency figure. However, DMUs that were only either technically or allocatively inefficient for any year are now found below the frontier line and those that were both technically and allocatively less efficient experienced a dramatic drop below the frontier line.

This has resulted in more drops below the frontier line compared to the drops experienced on the technical and allocative efficiency figures. The dramatic drops occurred between 2010 and 2011 and between 2013 and 2015.

4.3.5 Sensitivity analysis

Sensitivity analysis explores the impact of the absence of one of the input factors or one of the output factors on efficiency based on the developed DEA model. Once the key drivers (input and output factors) are determined, it helps managers to prioritize the quantity levels and cost associated with the inputs and the quantity of outputs that can be produced. The 2017 data are used for the sensitivity analysis because it was the most recent year. This subsection presents sensitivity analysis results for technical and allocative efficiencies of both input and output factors for the power distribution subsector

Technical efficiency

Given that there are four input factors, each input factor is removed from the model to regenerate a set of new technical efficiency results. Therefore, four different sets of results are produced and compared to the original results to ascertain the impact of each factor. The table below presents the sensitivity analysis for the input factors.

DMUs	Presents of X_1 X_2 X_3, X_4	Absence of X_1	Absence of X_2	Absence of X_3	Absence of X_4
DMU_1	0.95	0.95	0.82	0.95	0.95
DMU_2	0.99	0.99	0.99	0.76	0.89
DMU_3	1.00	1.00	1.00	1.00	1.00
DMU_4	0.84	0.79	0.84	0.65	0.84
DMU_5	1.00	1.00	1.00	1.00	1.00
DMU_6	0.97	0.86	0.97	0.80	0.97
DMU_7	1.00	1.00	1.00	1.00	1.00
DMU_8	0.98	0.67	0.98	0.92	0.98
DMU_9	0.97	0.89	0.95	0.95	0.97
DMU_{10}	1.00	1.00	1.00	1.00	0.85
DMU_{11}	1.00	1.00	1.00	1.00	1.00
DMU_{12}	1.00	1.00	1.00	1.00	1.00
DMU_{13}	0.83	0.83	0.73	0.83	0.73
DMU_{14}	1.00	1.00	1.00	1.00	1.00

X_1: Total Power Input
X_2: Total Transformer Capacity
X_3: Average Operating Expenditure
X_4: Total Number of Technical Staff

Table 4. 18: Sensitivity analysis results of input factors for technical efficiency in the distribution sub-sector

Without the inclusion of ‘total power input’, the relative efficiencies of four DMUs changed. For three of the DMUs, the drop wasn’t too dramatic. It was quite dramatic in the case of DMU_8, which is about 31%. All seven frontier DMUs remained efficient without its inclusion . Without the inclusion of total transformer capacity, three DMUs relative efficiencies dropped but were not dramatic. All frontier DMUs remained relatively efficient without its inclusion. Without the inclusion of ‘average operating expenditure’, the relative efficiencies of five DMUs dropped but were not dramatic. The highest drop was recorded by DMU_4, which is 19%. Without the inclusion of ‘total number of technical staff’, three DMUs relative efficiencies decreased, with DMU_{10}, which was a frontier DMU becoming entirely less efficient. It lost an efficiency value of 15%.

The sensitivity results confirm the impact of each of the input factors on the efficiency of the distribution subsector based on the efficiency model. Without power input into a distribution network, the network is functionless. But for power to run through distribution lines to homes and industrial premises for use, the needed transformer capacity (voltage) must be in place. A distribution utility incurs a huge variable cost as it remains in the constant business of serving customers' power needs, ensuring that distribution lines are constantly maintained and repaired where faults occur. Other cost areas involve billing customers, revenue collection, customer complaints, and general goods and services. OPEX is, therefore, a critical input factor for the effective operations of a distribution utility. The technical staff are those involved in the activities that directly relate to the supply of power to end consumers. From the sensitivity results, in the determination of technical efficiency, all four input factors are critically important. Each one makes about the same impact on the distribution subsector efficiency model.

For the sensitivity analysis results of the output factors, each output factor is removed to regenerate three sets of relative efficiency results. Each set is compared to the original efficiency results to ascertain the impact of each output factor on the technical efficiency model for the distribution subsector. Table 4.19 presents the results.

DMUs	Presence of Y_1 and Y_2	Absence of Y_1	Absence of Y_2
DMU_1	0.95	0.62	0.95
DMU_2	0.99	0.94	0.69
DMU_3	1.00	1.00	1.00
DMU_4	0.84	0.79	0.75
DMU_5	1.00	1.00	1.00
DMU_6	0.97	0.86	0.95
DMU_7	1.00	1.00	0.80
DMU_8	0.98	0.68	0.93
DMU_9	0.97	0.85	0.88
DMU_{10}	1.00	0.79	1.00
DMU_{11}	1.00	1.00	0.99
DMU_{12}	1.00	1.00	1.00
DMU_{13}	0.83	0.63	0.80
DMU_{14}	1.00	1.00	1.00

Y_1: Total amount of power billed
Y_2: Customer population served

Table 4.19: Sensitivity analysis results of output factors for technical efficiency

Without the inclusion of 'total amount of power billed', the technical efficiencies of eight DMUs dropped, with one of the frontiers DMUs not being relatively efficient anymore. The loss in efficiency value without the inclusion of 'total amount of power billed' ranged from 11% to 33%. Without the inclusion of 'customer population served' , the technical efficiencies of eight DMUs also dropped, with one frontier DMU not being relatively efficient anymore. The loss in efficiency without the inclusion of 'customer population served' ranges from 1% to 30%.

From the sensitivity analysis result, both output factors impact the distribution subsector efficiency model. However, 'total amount of power billed' makes the greatest impact. The 'customer population served' determines the rate of utilization of the distribution utility assets and how efficiently a distribution utility can serve the total number of customers within a distribution region.

Allocative efficiency

The sensitivity analysis results for the allocative efficiency for both the input and output factors are presented in Tables 4.20 and 4.21. Each input factor is removed from the model to regenerate new allocative efficiency results. Four different sets of results are regenerated for the input factors, while three different sets of results are regenerated for the output factors. Each regenerated set is compared to the original results to ascertain the impact of each input and output factor.

DMUs	Presence of X_1, X_2 X_3 and X_4	Absence of X_1	Absence of X_2	Absence of X_3	Absence of X_4
DMU_1	0.95	0.95	0.80	0.95	0.95
DMU_2	0.99	0.99	0.99	0.76	0.89
DMU_3	1.00	1.00	1.00	1.00	1.00
DMU_4	0.84	0.79	0.84	0.65	0.84
DMU_5	1.00	1.00	1.00	1.00	1.00
DMU_6	0.97	0.86	0.97	0.80	0.97
DMU_7	1.00	1.00	1.00	1.00	1.00
DMU_8	0.98	0.67	0.98	0.92	0.98
DMU_9	0.97	0.89	0.95	0.95	0.97
DMU_{10}	1.00	1.00	1.00	1.00	0.85
DMU_{11}	1.00	1.00	1.00	1.00	1.00
DMU_{12}	1.00	1.00	1.00	1.00	1.00
DMU_{13}	0.83	0.83	0.75	0.83	0.73
DMU_{14}	1.00	1.00	1.00	1.00	1.00

X_1: Total power input

X_2: Total transformer capacity

X_3: Average operating expenditure

X_4 : Total Number of Technical Staff

Table 4.20: Sensitivity analysis results of input factors for allocative efficiency

Without the inclusion of 'total power input', the relative efficiencies of four DMUs changed. For three of the DMUs, the drop wasn't too dramatic. It was quite dramatic in the case of DMU_8, which is about 31%. All seven frontier DMUs remained efficient without its inclusion. Without the inclusion of 'total transformer capacity' , three DMUs relative efficiencies dropped but were not dramatic. All frontier DMUs remained relatively efficient without the its inclusion. Individually, the drop experienced by DMU_1

for the allocative efficiency sensitivity analysis is slightly higher than the drop it experienced under technical efficiency. This shows that without the inclusion of 'total transformer capacity'**,** the allocative efficiency of DMU_1 was slightly more impacted than the impact on its technical efficiency. On the other hand, the drop experienced by DMU_{13} is lower compared to the drop it experienced under technical efficiency when the 'total transformer capacity' was excluded. This indicates the exclusion of total transformer capacity has a lower impact on it in terms of allocative efficiency than technical efficiency. Without the inclusion of 'average operating expenditure', the relative efficiencies of five DMUs dropped but were not dramatic. The highest drop was recorded by DMU_4 which is 19%. Without the inclusion of **'**total number of technical staff' , three DMUs relative efficiencies dropped, with DMU_{10}, which was a frontier DMU, becoming entirely inefficient. It lost an efficiency value of as much as 15%. Like technical efficiency, the distribution subsector efficiency model shows almost equal sensitivity to all the input factors. The sensitivity results for allocative efficiency output factors are provided in table 4.21

DMUs	**Presence of Y_1 and Y_2**	**Absence of Y_1**	**Absence of Y_2**
DMU_1	0.95	0.62	0.95
DMU_2	0.99	0.94	0.69
DMU_3	1.00	1.00	1.00
DMU_4	0.84	0.79	0.75
DMU_5	1.00	1.00	1.00
DMU_6	0.97	0.86	0.95
DMU_7	1.00	1.00	0.80
DMU_8	0.98	0.68	0.93
DMU_9	0.97	0.85	0.88
DMU_{10}	1.00	0.79	1.00
DMU_{11}	1.00	1.00	0.99
DMU_{12}	1.00	1.00	1.00
DMU_{13}	0.83	0.63	0.81
DMU_{14}	1.00	1.00	1.00

Y_1: Total Amount of Power Billed
Y_2: Customer Population Served

Table 4.21: Sensitivity analysis results of output factors for allocative efficiency

Without the inclusion of 'total amount of power billed', the allocative efficiencies of eight DMUs dropped with one of the frontiers DMUs not being relatively efficient anymore. The loss in efficiency value due to its exclusion ranged from 11% to 33%. With the exclusion of 'customer population served', the allocative efficiencies of eight DMUs also dropped, with one frontier DMU not being relatively efficient anymore. The loss in efficiency following its exclusion ranges from 1% to 30%. DMU_{13} allocative efficiency is slightly lower due to the exclusion of 'customer population served' compared to its technical efficiency when the same output factor was excluded.

In determining allocative efficiency, 'total amount of power billed' and 'customer population served' both have a significant impact on the distribution subsector efficiency model.

4.3.6 Window analysis

For this study, a window length of three years is considered, giving six different window periods for each DMU. This gives a total of eighty-four window periods to be analyzed across fourteen DMUs in the power distribution subsector. Eighty-four window periods are large enough to have both weak and robust performances emerging over the period for comparison.

DMUs	2010	2011	2012	2013	2014	2015	2016	2017	M	SD	CoV
DMU1	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	0.982				0.994	0.004	0.840
				1.000	0.982	1.000			0.994	0.004	0.840
					0.982	1.000	0.760		0.914	0.107	11.890
						1.000	0.760	0.890	0.886	0.099	11.050
DMU2	1.000	1.000	1.000						1.00	0	0
		1.000	1.000	0.970					0.989	0.017	1.590
			1.000	0.970	0.720				0.893	0.127	14.410
				0.970	0.720	0.550			0.742	0.172	23.200
					0.720	0.550	1.000		0.753	0.187	24.780
						0.550	1.000	0.990	0.847	0.219	24.910
DMU3	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	1.000				1.000	0	0
				1.000	1.000	1.000			1.000	0	0
					1.00	1.000	1.000		1.000	0	0
						1.000	1.000	1.000	1.000	0	0
DMU4	0.970	0.870	0.920						0.920	0.047	4.42
		0.870	0.920	1.000					0.930	0.058	5.78
			0.920	1.000	1.000				0.974	0.034	3.74
				1.000	1.000	1.000			1.000	0	0
					1.000	1.000	1.000		1.000	0	0
						1.00	1.000	0.699	0.899	0.146	15.74
DMU5	1.000	0.940	0.870						0.938	0.050	5.54
		0.940	0.870	0.960					0.926	0.030	4.21
			0.870	0.960	0.890				0.910	0.032	4.30
				0.960	0.890	0.780			0.879	0.074	8.68
					0.890	0.780	1.000		0.891	0.09	10.10
						0.780	1.000	1.000	0.926	0.104	11.20
DMU6	1.000	1.000	1.000						1.000	0	0
		1.00	1.000	1.000					1.000	0	0
			1.000	1.000	1.000				1.000	0	0
				1.00	1.000	1.000			1.000	0	0
					1.000	1.000	1.000		1.000	0	0
						1.000	1.000	0.942	0.980	0.027	2.75
DMU7	1.000	0.910	0.930						0.947	0.038	4.06
		0.910	0.930	1.000					0.947	0.038	4.06
			0.930	1.000	1.000				0.977	0.033	3.37
				1.000	1.000	0.97			0.989	0.015	1.52
					1.000	0.970	1.000		0.989	0.015	1.52
						0.97	1.000	1.000	0.989	0.015	1.52
DMU8	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	1.000				1.000	0	0
				1.000	1.000	1.000			1.000	0	0
					1.000	1.000	0.896		0.965	0.040	5.08
						1.000	0.896	0.968	0.951	0.043	4.48

DMUs	2010	2011	2012	2013	2014	2015	2016	2017	M	SD	CoV
DMU_{9}	0.950	0.780	0.870						0.870	0.069	7.98
		0.78	0.873	1.000					0.880	0.089	10.12
			0.873	1.000	1.000				0.960	0.059	6.21
				1.000	1.000	1.000			1.000	0.000	0.00
					1.000	1.000	0.920		0.97	0.036	3.68
						1.000	0.920	0.950	0.960	0.032	3.35
DMU_{10}	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	1.00				1.000	0	0
				1.000	1.000	1.00			1.000	0	0
					1.000	1.000	1.000		1.000	0	0
						1.000	1.000	1.000	1.000	0	0
DMU_{11}	1.000	1.000	0.960						0.988	0.017	1.67
		1	0.960	1.000					0.988	0.016	1.67
			0.960	1.000	0.820				0.928	0.078	8.44
				1.000	0.820	0.940			0.921	0.076	8.23
					0.820	0.940	1.000		0.921	0.076	8.23
						0.940	1.000	1.000	0.981	0.026	2.63
MU_{12}	1.000	1.000	1.000						1.000	0	0
		1.000	1.000	1.000					1.000	0	0
			1.000	1.000	1.000				1.000	0	0
				1.000	1.000	1.000			1.000	0	0
					1.000	1.000	1.000		1.000	0	0
						1.000	1.000	1.000	1.000	0	0
DMU_{13}	1.000	0.900	0.920						0.944	0.041	4.36
		0.900	0.920	0.880					0.903	0.019	2.20
			0.928	0.880	0.830				0.879	0.040	4.57
				0.880	0.830	0.790			0.835	0.034	4.06
					0.830	0.790	1.000		0.876	0.089	10.15
						0.790	1.000	0.690	0.829	0.128	15.50
DMU_{14}	1.000	0.941	0.980						0.974	0.024	2.50
		0.941	0.980	0.860					0.928	0.049	5.30
			0.980	0.860	1.000				0.947	0.061	6.42
				0.860	1.000	1.000			0.954	0.065	6.81
					1.000	1.000	1.000		1.000	0	0
						1.000	1.000	1.000	1.000	0	0

Table 4.22: Window analysis results of DEA cost efficiency

The means of the window periods reveal that window period six (2015, 2016, and 2017) recorded the highest number of worst window periods performance among the DMUs. This represents 42.85% of the total number of window periods. Window period six comprises of years 2015, 2016, and 2017. The performance of the DMUs involved may have been affected by the power crisis period of 2012 to 2015. It can also be observed that those window periods that fell within the years 2014, 2015, 2016, and 2017, window periods five and six, recorded the most inconsistent and unstable efficiency performance among the DMUs. This represents about 72% of the total window periods for the DMUs that didn’t remain consistently efficient throughout the eight years.

Meanwhile, the window periods that spanned 2010, 2011, 2012, and 2013, window periods one and two, were more likely to demonstrate more stability and consistency. Based on the analysis of the window periods, it can be concluded that the effects of the power crisis negatively impacted both the Mean efficiency performance and the consistency in how they performed identifying the practices that the full relatively efficient DMUs implemented over this period is critical for the other DMUs to also learn and keep their performance at an optimum level in times of a crisis.

4.7 Summary

The DEA approach offers its anytical powers to establish relative efficiencies among DMUs. This chapter has presented the process and results of the DEA approach to the transmission subsector and the distribution subsector of the Ghana’s power sector. The six steps of the DEA approach, including factor selection, weight allocation, DEA efficiency evaluation, trend analysis, window analysis, and sensitivity analysis, have been applied to these two power subsectors individually.

The results of the DEA approach includes the relative efficiencys of DMUs within each of the subsectors. The most relative efficient units, the frontier units, are more than one for each subsector. The trends of these DMUs in terms of their relative efficiency performance are relatively stable with some exceptions. It is either they have improved or stayed the same simutaniously, or it might be due to the fact that operations under the same environment have not changed for each of the DMUs and no internal learning among different DMUs had taken place, at least not sufficiently.

CHAPTER FIVE

RESULTS AND ANALYSIS OF INTERNATIONAL BENCHMARKING

5.1 Introduction

Short profiles of the benchmarking countries are presented in section 5.2. Section 5.3 compares the performance of the benchmarking countries across the quantititave performance indicators. With the assistance of the results on best performing countries on those quantititave indicators in section 5.3, section 5.4 performs qualitative benchmarking to identify the best practices. Section 5.5 summarizes this chapter and highlights the value of the IB approach for performance improvement.

5.2 Comparison of benchmarking countries in terms of development levels

The profiles of benchmarking countries in terms of its economic and social development levels are provided in Table 5.1, with the reference of the United Nations Development Programme (UNDP) Human Development Index (HDI) report (2015).

Country	Life expectancy at birth	Expected years of schooling	Mean years of schooling	GNI Per Capita (2015$)	HDI Value	Position based on HDI comparison
Ghana	62.8	11.1	6.9	4,614	0.590	6
South Africa	62.6	13.8	10.1	12,528	0.701	5
Botswana	67.3	12.6	9.2	16,237	0.717	4
Brazil	75.0	15.3	7.6	14,775	0.756	3
T & T	72.9	12.6	10.9	28,744	0.792	2
Chile	79.6	16.2	10.2	22,949	0.842	1

Table 5.1: Comparison among benchmarking countries (HDI 2015)

Chile has the highest HDI value among the six benchmarking countries. This indicates Chile has more significant social and economic progress over the years than the other benchmarking countries. However, GNI Per Capita rates Trinidad and Tobago the number one country among these six benchmarking countries.

Aside from life expectancy, of which Ghana came the second last, Ghana came the lowest for all the other indicators. The political and development histories of these benchmarking countries are similar. However, the other bencmarking countries have made better position economically and socially than Ghana, even though Ghana has made the most significant progress base on HDI. Predictably, in analysing the power sector quantitative indicators, the expectation is for the other countries to perform better than Ghana. They can be aspirators in the light of suitable best practices that Ghana can adapt. Other details regarding each country’s brief history and state of development are provided below.

Ghana

Ghana is a country in West Africa and covers an area of 238,535 km^2 (92,099 mi^2), spanning diverse geography and ecology from coastal savannahs to tropical rain forests. With over 31 million people, Ghana has the second highest population country in West Africa, after Nigeria. Ghana is an average natural resource enriched country possessing industrial minerals, hydrocarbons, and precious metals. It is an emerging designated digital economy with mixed economy hybridization and an emerging market. It has an economic plan target known as the "Ghana Vision 2020". This plan envisions Ghana as the first African country to become a developed country between 2020 and 2029 and an industrialized country between 2030 and 2039.

Brazil

Brazil is a sovereign country in South America, with a total land area of approximately 8,358,140 km^2. The largest and most populous country in South America, Brazil underwent more than a half-century of populist and military governments until 1985, when the military regime peacefully ceded power to civilian rulers. Brazil is the largest national economy in Latin America, the world's ninth-largest economy, and the eighth largest in purchasing power parity (PPP), according to 2018 estimates. Brazil has a mixed economy with abundant natural resources and has remained the world’s largest producer of coffee for the last 150 years. Brazil is classified as an emerging power.

Chile

Chile is a sovereign country in South America, with a total land area of approximately 743,812 sq km. Although Chile declared its independence in 1810, decisive victory over the Spanish was not achieved until 1818. After a series of elected governments, the Marxist government of Salvador Allende was overthrown in 1973 by a military coup led by Augusto Pinochet. He ruled until a freely elected president was inaugurated in 1990. Sound economic policies, maintained consistently since the 1980s, contributed to steady growth, reduced poverty rates by over half, and helped secure the country's commitment to democratic and representative government. Chile has increasingly assumed regional and international leadership roles befitting its status as a stable democratic nation. In January 2014, Chile took a non-permanent seat on the UN Security Council for the 2014-15 term.

Trinidad and Tobago

Trinidad and Tobago are a sovereign country in Central America/Caribbean, with a total land area of approximately 5,128 sq km. The islands were first colonized by the Spanish and came under British control in the early 19th century. The emancipation of the slaves hurt the islands' sugar industry in 1834. Manpower was replaced with the importation of contract labourers from India between 1845 and 1917, which boosted sugar production and the cocoa industry. The discovery of oil on Trinidad in 1910 added another important export. Independence was attained in 1962. The country is one of the most prosperous in the Caribbean thanks largely to petroleum and natural gas production and processing. Tourism, mostly in Tobago, is targeted for expansion and is growing.

Botswana

Botswana is a sovereign country in Africa, with a total land area of approximately 566,730 sq km. Formerly, the British protectorate of Bechuanaland, Botswana, adopted its new name upon independence in 1966. More than four decades of uninterrupted civilian leadership, progressive social policies, and significant capital investment have created one of the most stable economies in Africa. Mineral extraction, principally diamond mining, dominates economic activity, though tourism is a growing sector due to the country's conservation practices and extensive nature preserves. Botswana has one of the world's highest known HIV/AIDS infection rates, but it is also one of Africa's most progressive and comprehensive programs for dealing with the disease.

South Africa

South Africa is the southernmost country in Africa. With over 60 million people, it is the world's 23rd-most populous nation and covers an area of 1,221,037 square kilometres (471,445 square miles). South Africa is a multi-ethnic society encompassing various cultures, languages, and religions. Its pluralistic makeup is reflected in the constitution's recognition of 11 official languages, the fourth-highest number in the world.

During the 20th century, the black majority sought to claim more rights from the dominant white minority, which played a significant role in the country's recent history and politics. The National Party imposed apartheid in 1948, institutionalizing previous racial segregation. After a long and sometimes violent struggle by the African National Congress (ANC) and other anti-apartheid activists both inside and outside the country, the repeal of discriminatory laws began in the mid-1980s. Since 1994, all ethnic and linguistic groups have held political representation in the country's liberal democracy, which comprises a parliamentary republic and nine provinces.

South Africa has been classified by the World Bank as a newly industrialized country, with the third-largest economy in Africa, and the 35th-largest in the world. South Africa also has the most UNESCO World Heritage Sites in Africa. The country is an upper-middle power in international affairs; it maintains significant regional influence and members of the Commonwealth of Nations and G20. However, crime, poverty, and inequality remain widespread, with about a quarter of the population unemployed and living on less than US$1.25 a day.

5.3 International benchmarking of quantitative performance indicators

Two sets of quantitative performance indicators are presented for the quantitative IB analysis (see Table 5.2).

Operations related indicators	Cost and price-related indicators
Transmission and distribution losses (%)	The average unit cost of electricity generation (cents USD/kWh)
Population with access to electricity (%)	The average retail price of electricity (cents USD/Kwh)
Environmental Performance Index (EP1)	
System Average Interruption Duration Index (SAIDI)	
Power generation to demand ratio	

Table 5.2: Quantitative indicators for IB

This section compares the performance of the benchmarking countries for each quantitative indicator listed in table 5.2 through trend analysis. It intends to establish if significant differences exist among these countries through comparing variances (see the ANOVA results in Appendix III). The post-hoc results of the ANOVA establish the specific differences occurring between Ghana and each of the benchmarking countries across these indicators. This is to identify the best performing country in relation to each of these quantitative indicators that Ghana can adopt best practices from. The results and analysis of each indicator are presented under each of the subsections below.

5.3.1 Transmission and distribution losses

Country	2010	2011	2012	2013	2014	2015	Mean	SD	CoV
Botswana	7.90	12.10	11.00	9.30	7.10	13.60	10.17	2.51	0.247
Brazil	16.63	16.46	17.08	16.63	15.78	17.00	16.60	0.47	0.028
Chile	8.22	7.13	5.02	6.69	6.54	6.30	6.65	1.05	0.158
Ghana	26.75	28.05	26.1	26.75	28.9	28.5	27.51	1.13	0.041
South Africa	9.53	8.47	8.72	8.49	8.39	8.10	8.62	0.49	0.057
T & T	5.00	5.00	5.00	5.00	5.00	5.00	5.00	0.00	0.000

Table 5.3: T&D losses (%) of six benchmarking countries over 2010 to 2015

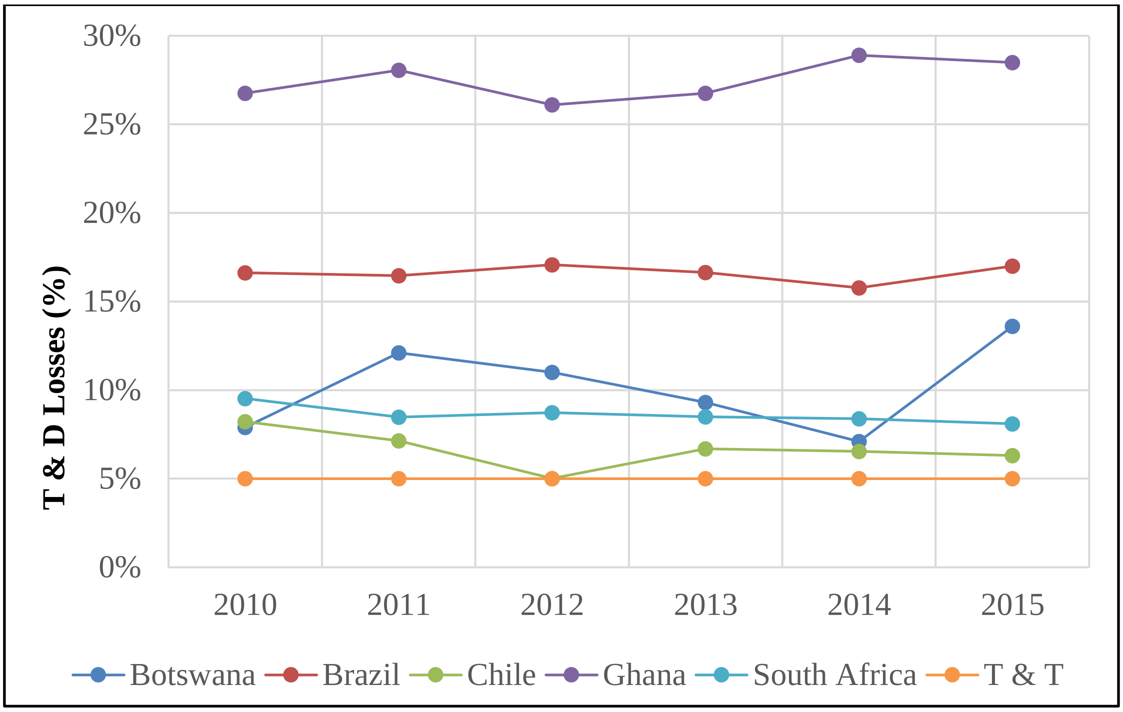

Figure 5. 1: Trends of T&D losses (%) of IB countries from 2010 to 2015

Trinidad and Tobago (T&T) had the lowest T&D losses across all the six years, qualified as the best performing country on this indicator. 2012 saw both T&T and Chile equally being the lowest in the T&D loss. Ghana had had the highest T&D losses, almost five times higher than those of T&T and nearly twice for the second highest country Brazil on this indicator. Chile and Botswana experienced high fluctuations over these six years, confirmed by their CoVs. T&T also had the lowest fluctuation on this indicator during these six years. With 5% T&D losses, T&T is really the country leading in this performance indicator among its peers.

5.3.2 Percentage of population with access to electricity

Country	2010	2011	2012	2013	2014	2015	M	SD	CoV (%)
Botswana	52.68	53.24	53.38	53.70	55.89	58.12	54.50	2.09	0.038
Brazil	98.98	99.33	99.52	99.58	99.65	99.71	99.46	0.27	0.003
Chile	99.38	99.59	100.00	99.60	100.00	99.71	99.71	0.25	0.002
Ghana	64.20	64.06	69.22	70.70	78.30	75.72	70.37	5.84	0.083
South Africa	82.90	84.70	85.30	85.40	86.00	85.50	84.97	1.09	0.013
T&T	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.000

Table 5.4: Percentage population with access to electricity (%)

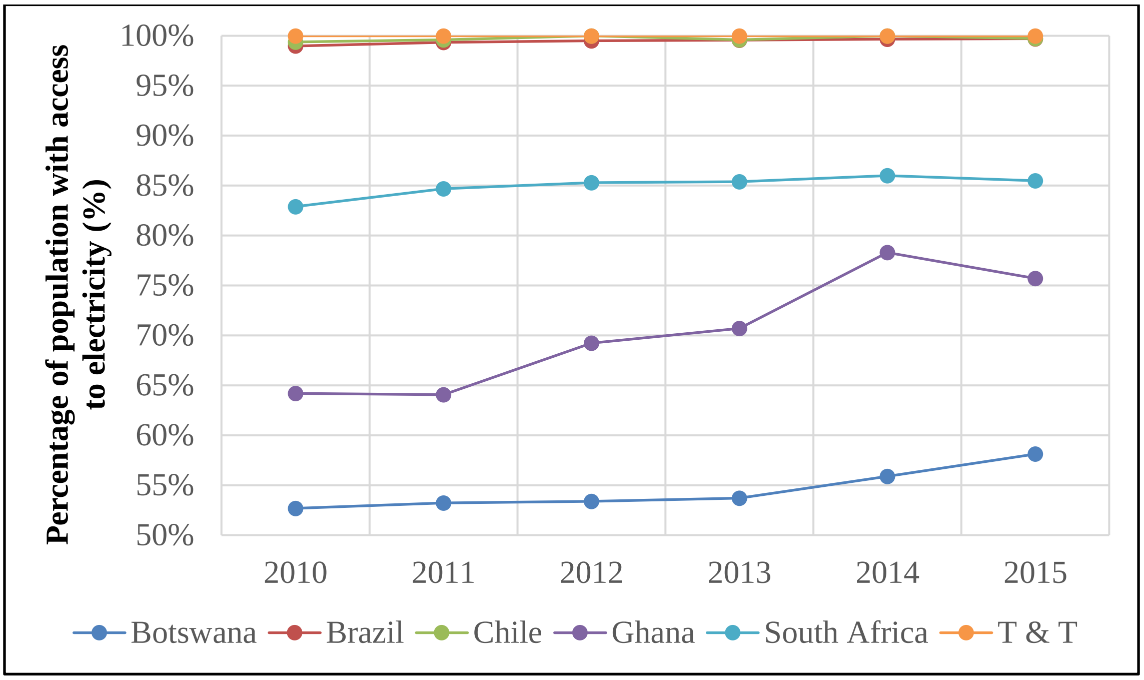

Figure 5.2: Percentage population with access to electricity (%)

Over the period of analysis, Ghana had been the second lowest in terms of percentage population with access to electricity among these six benchmarking countries, with Botswana the lowest. There was much room for improvement for all the African countries involved in the study. Ghana had only a rise of about eleven percent of its population with access to electricity between 2010 and 2015, representing the highest improvement among the three African countries.

Among all the benchmarking countries, T&T had remained consistently with the entire population having access to electricity over these six analysis years. Based on the ANOVA results, except for Botswana, significant differences exist between Ghana and each of the other benchmarking countries consistently over the six years.

5.3.3 Environmental Performance Index

The EPI is an overall score that measures a country's performance on how different activities, including the energy sector, impact on the environment. These indices use 2006 as the base year with the value of 100. The index indicates the change of the impact on environment of its social and economic activities. The larger in difference of this score to 100, the better the improvement has been made. Therefore, a low value of this index compared to the previous year indicates an improvement year on year. As all the figures are much less than 100, it indicates a dramatic improvement compared to 2006, the base year.

Country	2010	2011	2012	2013	2014	2015	Mean	SD	CoV (%)
Botswana	41.30	41.30	33.00	32.53	47.60	47.60	40.56	6.66	0.164
Brazil	63.40	63.40	53.74	50.67	52.97	52.97	56.19	5.68	0.101
Chile	73.30	73.30	52.89	52.89	69.93	69.93	65.37	9.79	0.150
Ghana	51.30	51.30	69.17	69.17	32.07	32.07	50.85	16.60	0.326
South Africa	50.80	50.80	53.51	53.46	53.51	53.51	52.60	1.39	0.026
T & T	54.20	54.20	53.24	52.28	52.28	52.28	53.08	0.94	0.018

Table 5.5: Environmental Performance Index (EPI)

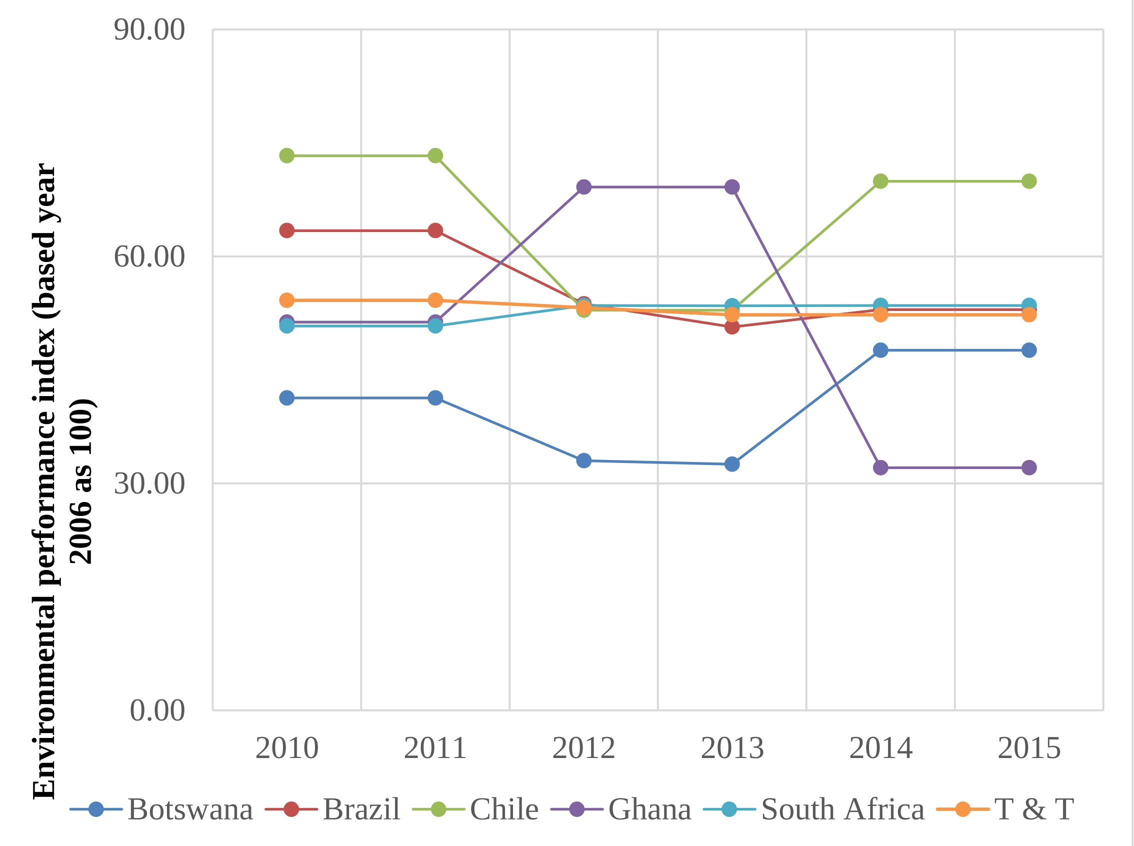

Figure 5.3: Environment Performance Index (EPI) with the base year 2006

Botswana has improved most on this index compared to its 2006's performance. Chile is the least improved country on this index, relative to its 2006 performance. These indices do not give the current relative positive among these countries, but relative progress compared to the country's 2006 performance.

There are two main factors contributing to a power sector's EPI changes: thermal sources in the power generation mix, and the thermal sources efficient level. Improvement on these two elements will generate a reduced EPI. In terms of improvement to its past in 2006, Ghana is the second most improved country on EPI but it does not indicate the absolute environmental performance level among the benchmarking countries.

5.3.4 Total duration of interruptions per year (SAIDI)

Country	2010	2011	2012	2013	2014	2015	Mean	SD	CoV(%)
Botswana	129.60	129.60	129.6	129.6	129.60	129.00	129.50	0.245	0.002
Brazil	18.42	18.61	18.78	18.49	18.03	18.62	18.49	0.26	0.014
Chile	6.70	6.20	6.99	5.96	6.31	6.09	6.38	0.39	0.062
Ghana	221.00	287.00	214.67	139.35	404.83	167.00	238.97	95.74	0.401
South Africa	52.60	45.80	41.90	37.00	36.20	38.60	42.02	6.28	0.149
T & T	9.38	8.10	7.73	6.63	5.44	5.13	7.07	1.64	0.232

Table 5. 6: Average duration of interruptions (SAIDI) (Hours)

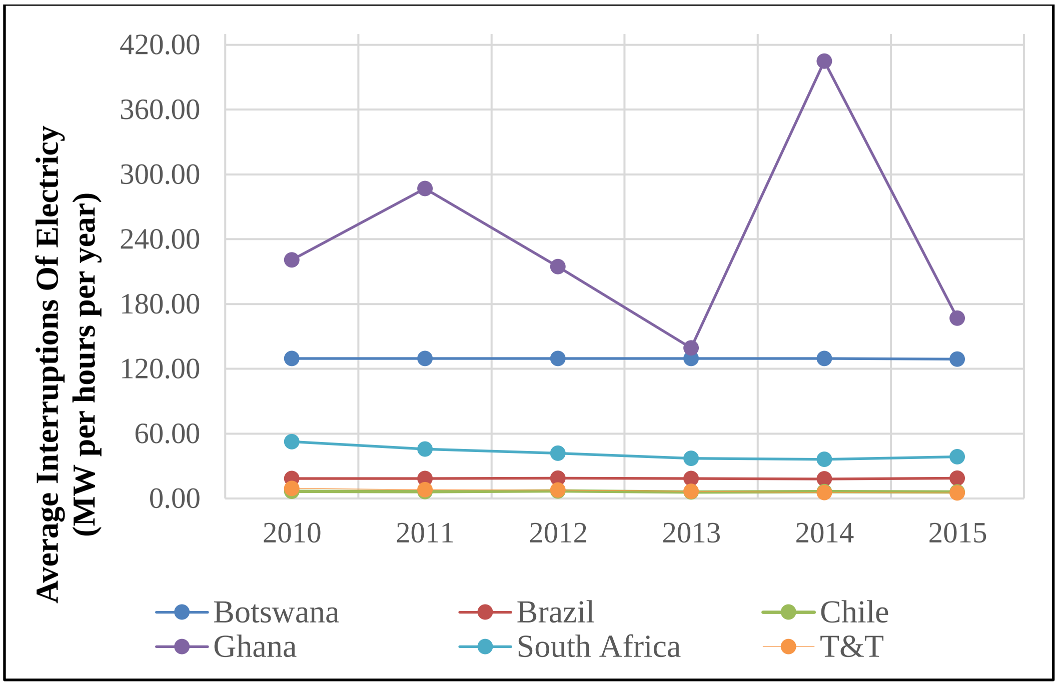

Figure 5. 4: Average duration of interruptions (SAIDI) (Hours)

There had been wide gaps between Ghana and each benchmarking country in terms of SAIDI. As the trend depicts, Ghana experienced a sharp rise between 2010 and 2011 and trended downwards to 2013 before rising again in 2014 and trending downwards to 2015. Compared to the other countries, Ghana's SAIDI was about 33 times of Trinidad and Tobago, which recorded the lowest SAIDI for each year. Ghana's SAIDI over the period is still about twice that of Botswana, the second-highest in terms of SAIDI.

5.3.5 Generation to demand ratio

This indicator gives a sense of the capacity of each country to meet existing and future demand for electricity. A ratio of the dependable capacity (excluding electricity imports) and peak demand for each country determines whether the capacity exceeds the demand, whether the capacity is less than the demand or the capacity and demand are equal. The data for this indicator are provided in table 5.7.

Country	2010	2011	2012	2013	2014	2015	Mean	SD	CoV (%)
Botswana	0.24	0.24	0.24	0.23	1.28	1.20	0.57	0.52	0.907
Brazil	1.56	1.68	1.66	1.76	1.87	1.71	1.71	0.10	0.061
Chile	1.63	1.70	1.78	1.77	1.92	1.98	1.80	0.13	0.074
Ghana	1.29	1.17	1.18	1.28	1.31	1.74	1.33	0.21	0.158
South Africa	1.14	1.14	1.15	1.18	1.21	1.24	1.18	0.04	0.035
T & T	1.39	1.88	1.79	1.79	1.79	1.79	1.74	0.17	0.101

Table 5. 7: Generation to demand ratio

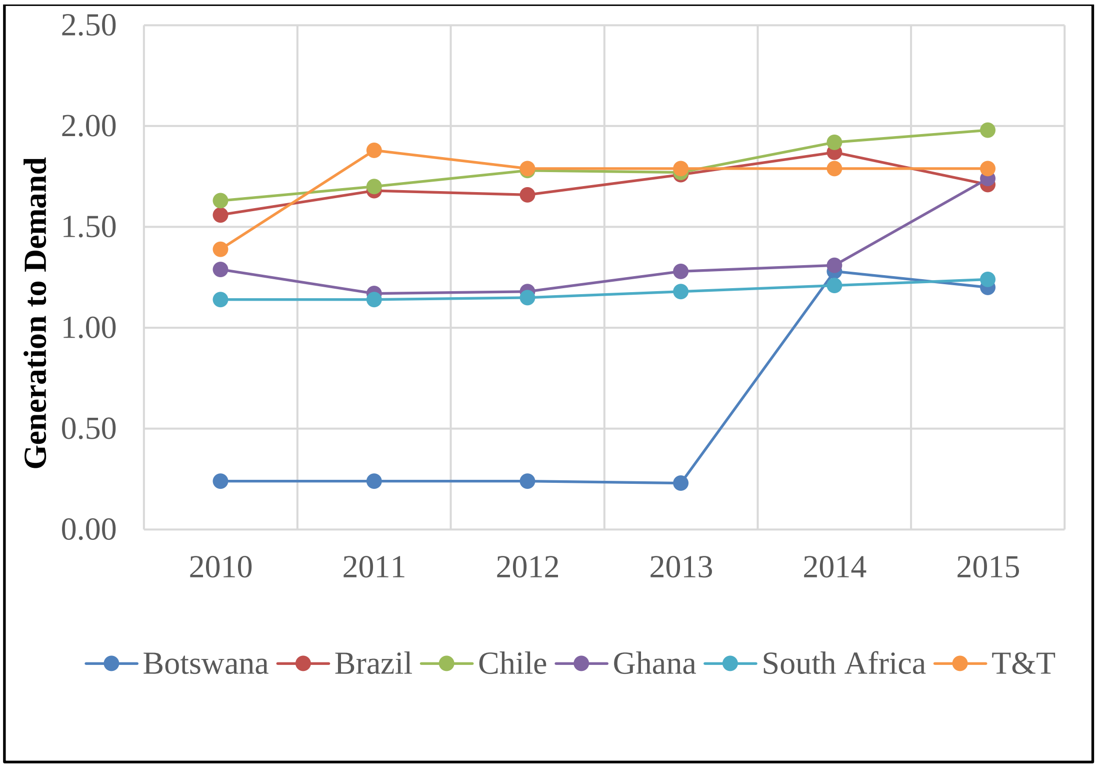

Figure 5.5: Generation to demand ratio

Aside from Botswana that registered an average ratio much below one, the rest of the benchmarking countries registered ratios well above one. Botswana's low generation to demand ratio is due to imports from South Africa to meet its domestic electricity demand. For a ratio above one, the capacity lack at any one point of time could be still happening as this is an aggregated dependable capacity. Generation plants at any point in time being idle is possible due to the lack of fuels to power the thermal generation plants.

5.3.6 Average unit cost of electricity generation and average retail prices of electricity

Since prices are often a function of cost, the interest in these two indicators is to establish whether retail prices (tariffs) for a unit (KWh) of electricity were above the cost of generating the same unit (kWh) of electricity in the respective countries for each of the six years. Table 5.8 provides the average unit cost of generating electricity using the levelized cost of electricity generation (LCOE) based on the fuel types in the generation mix and electricity import for each country.

Country	2010	2011	2012	2013	2014	2015	Mean	SD	CoV (%)
Botswana	11.16	11.17	10.17	10.51	11.05	10.92	10.83	0.37	0.034
Brazil	2.30	2.25	2.15	2.36	2.43	2.16	2.27	0.10	0.044
Chile	3.71	3.65	2.94	3.02	3.14	2.80	3.21	0.35	0.108
Ghana	3.80	4.13	3.21	3.24	3.39	3.02	3.47	0.38	0.109
South Africa	3.63	3.63	3.26	3.36	3.53	3.46	3.48	0.14	0.039
T & T	9.69	9.57	7.17	7.11	7.45	6.65	7.94	1.22	0.154

Table 5. 8: Levelized cost of electricity generation (USD cents per kWh)

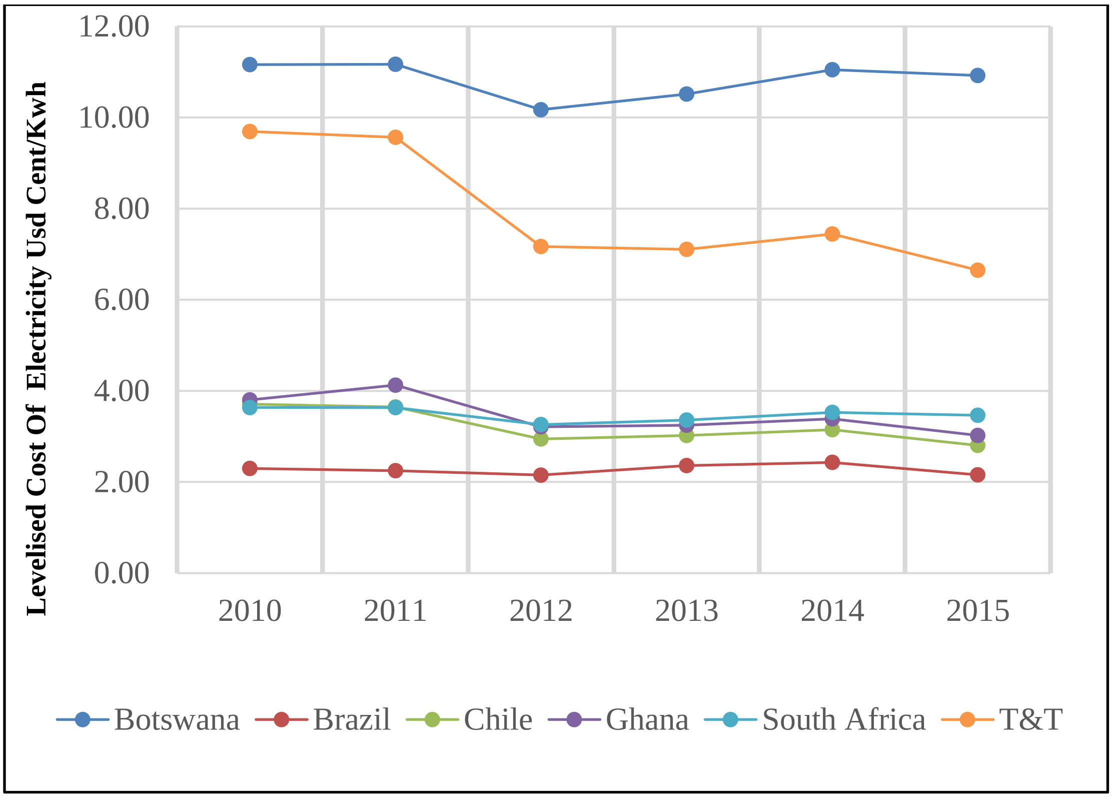

Figure 5. 6: Levelized cost of electricity generation (USD Cents/KWh)

The results of the average retail prices for the benchmarking countries are also shown in Table 5.9.

Country	2010	2011	2012	2013	2014	2015	Mean	SD	CoV(%)
Botswana	5.70	7.40	7.33	7.14	6.89	6.40	6.81	0.65	0.096
Brazil	19.73	15.99	22.36	15.42	14.75	15.83	17.35	3.01	0.174
Chile	10.15	11.60	11.75	10.70	11.15	10.35	10.95	0.66	0.060
Ghana	14.5	15.8	12.4	15.6	14.5	14.7	14.58	1.21	0.083
South Africa	4.22	5.12	5.85	5.82	5.99	4.93	5.32	0.69	0.129
T & T	4.96	4.94	4.93	4.92	4.95	4.97	4.95	0.02	0.003

Table 5. 9: Average retail prices of electricity (USD Cents/KWh)

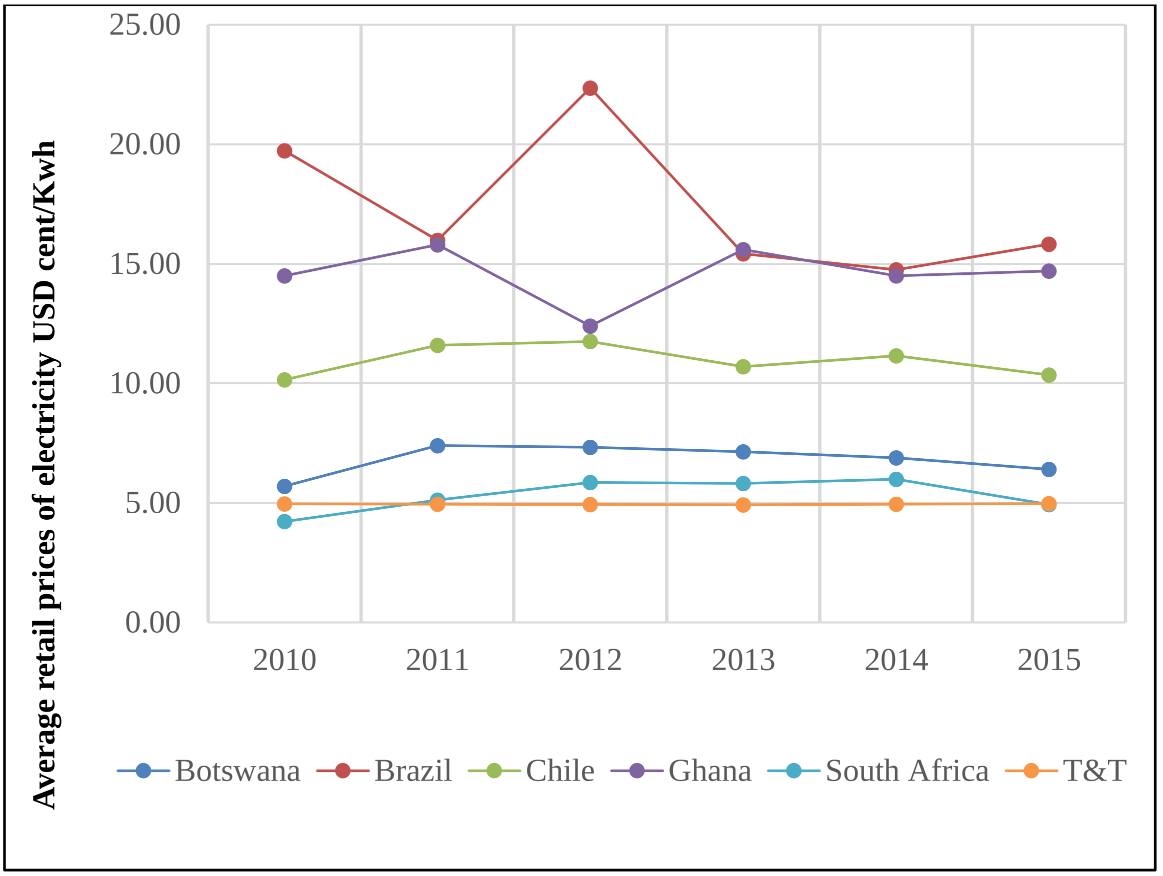

Figure 5.7: Average retail prices of electricity (USD Cents/KWh)

Brazil had the highest average retail price of electricity among the benchmarking countries. In contrast, the country with the lowest average retail price is T&T, which has registered steady stability throughout the period. Ghana experienced a rise between 2010 and 2011, was reduced from 2011 to 2012 and rose again in 2013. It saw a continuous marginal reduction between 2014 and 2015 compared to the 2013 figure. The results for Ghana indicate tariffs over the period have remained relatively stable. Table 5.10 provides the differences between the two average values for each benchmarking country. The differences in averages are also depicted in the bar chart (Figure 5.8)

Country	Average price – Average cost
Botswana	-4.02
Brazil	15.07
Chile	7.74
Ghana	11.12
South Africa	1.84
T & T	-2.99

Table 5. 10: Difference in average retail price-average cost of electricity generation

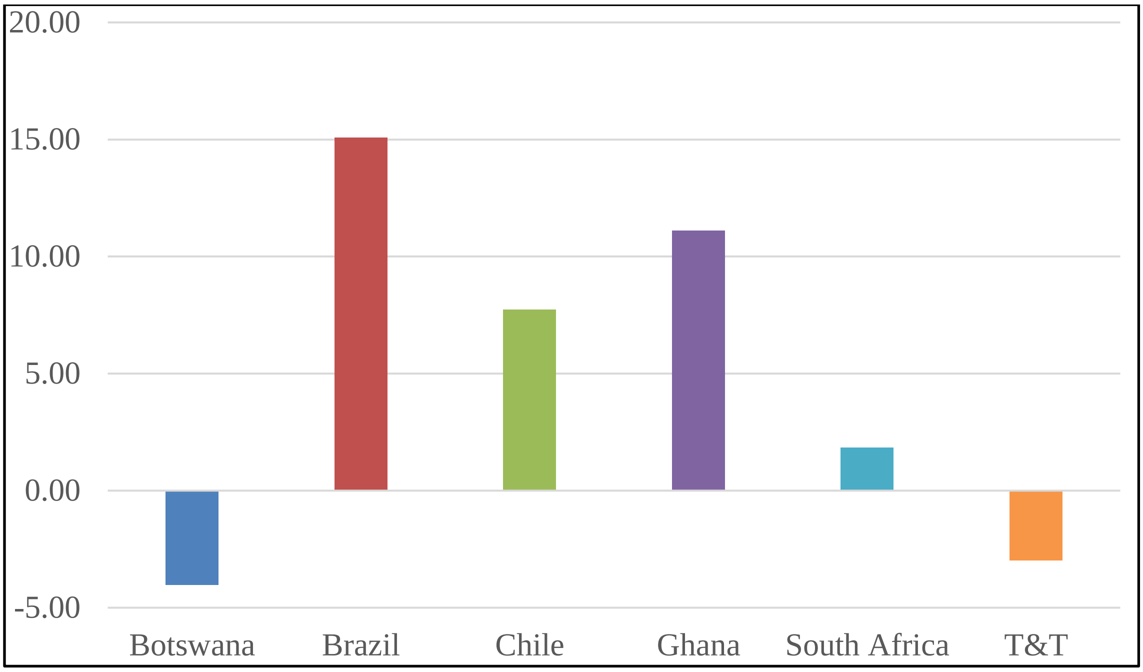

Figure 5.8: Difference in average retail prices and average cost of electricity generation

Botswana and T&T had their average retail prices lagging behind the average cost of electricity generation over these six investigation years. In countries where retail prices are lagging behind the cost of generation, electricity is heavily subsidized for consumers, both domestic and industrial. The implications are that state utilities would be heavily indebted if the state doesn't cover the cost of the subsidy. Also, the power sector would not be attractive to the private sector. Brazil and Chile had good positions in their markets with competitive retail electricity pricing relatively to their cost of electricity generation.

As the cost is only the cost of generation of electricity and there are other cost items before the total cost of electricity supply is obtained, for a country with marginal difference, for example, less than 15% , the overall revenue might not cover the total cost in the long run. That could be the situation for Ghana.

5.4 Identification and comparison of practices across the benchmarking countries

This section provides insights into each benchmarking country's power sector with the focus on its practices for performance improvement. The best practices are identified with the references of the results of the quantitative benchmarking indicators. The following dimensions of the power sector are explored and compared:

1. Policy landscape
2. Network structure
3. Regulatory framework
4. Reforms

5. Power network related issues

5.4.1 Policy landscape

Policy landscape includes the structure and process of policy-making and the roles and responsibilities of various policy-making institution.

Ghana	1. The ministry of energy provides the general policy direction on the energy sector management, which includes electrical power.
Botswana	1. The ministry of energy provides policy direction on the energy sector management, which includes electrical power. 2. The ministry of energy also provides general oversight over the Botswana Power Corporation (BPC).
Brazil	1. The ministry of mines and energy provides overall policy direction in the energy sector, including electrical power. 2. The National Council for Energy Policy (NCEP) serves as an advisory body to the government on managing the energy sector. 3. The NCEP formulates energy policies to promote the optimal use of energy resources. 4. The Energy Research Company (EPE) develops and maintains a ten-year energy expansion plan. 5. The EPE also supports the public auction process by developing generation and transmission grid planning studies.
Chile	1. Ministry of Energy is only responsible for central planning at the generation level.
South Africa	1. The Department of Energy in South Africa oversees policy-making and implementation in the energy sector, including electrical power. 2. Department for Public Enterprises represents the South African government interest in State Enterprise Organizations (SOEs) that includes power sector SOEs.
T&T	1. Ministry of Public Utilities and the Environment is responsible for policy direction in the power transmission and distribution subsectors. 2. Ministry of Energy and Energy Industries directs the policy on power generation and the management of T&T gas resources.

Table 5.11: The policy landscape of each of the benchmarking countries

Apart from Chile, which the ministry of energy is only involved generation planning, all the other benchmarking countries have their ministries of energy to be responsible for policy general policy direction across all the subsectors, generation, transmission and distribution. In Chile’s power sector, even though the ministry of energy exists, its policy-making role is only indicative in the sense that actual implementation lies with the private sector. Apart from sector ministries being responsible for the general policy direction, the rest of the benchmarking countries also play an active role in implementation. In the case of Brazil, however, even though the sector ministry is responsible for the overall policy direction, two very important bodies (NCEP and EPE) exist to provide technocratic advices to policy makers.

The disadvantage with leaving policy-making, especially in a critical area like the power sector, solely in the hands of ministries is that, as political establishments, policies in the sector could be politically driven and could lack technical expertise. The failings of the Brazilian and Chilean power sectors, which necessitated a series of reforms over the years, have been attributed to poor policymaking that was primarily driven by the political authorities (Pollitt, 2004; Losekann & de Oliviera, 2008). The failings of Ghana’s power sector have also been attributed to the overbearing control by the political authority. To avoid undesirable policies and actions by political authorities, Brazil’s elaborate power sector landscape has included the NCEP and EPE, which are products of power sector reforms. The NCEP formulates energy policies to promote the optimal use of energy resources and serves as the advisory think-tank to the government on energy (power) policy. On the other hand, the EPE develops and maintains a ten-year energy generation expansion plan that keeps Brazil up to date on its future energy requirements.

Based on the experiences of power sector reforms, Chile created a wholesale competitive power market and functioned out a policy landscape. The ministry of energy’s role is to create an enabling environment that could trigger a response from the private sector in a direction that would be desirable. For instance, the ministry is engaged in central planning in power generation while the projects are determined and developed by the generators (Gencos), primarily private sector-based. Policymaking in the power sector in Chile is therefore intended to stimulate the private sector's interest to invest in the sector and recoup returns appropriately and continuously. This requires policymaking to be fended off any unnecessary political expediency.

5.4.2 The structure of the power network

The structure of the power network is reflected by the type of the managerial and the degree of private sector participation. These are summarized in Table 5.12 for the benchmarking countries.

Country	Type of power network structure	Private sector participation
Ghana	Unbundled	Only in power generation
Botswana	Vertically integrated	None
Brazil	Unbundled	In all three subsectors
Chile	Unbundled	In all three subsectors
South Africa	Vertically integrated	None
T&T	Vertically integrated	Only in power generation

Table 5.12: Types of power sector structure among the benchmarking countries

Botswana, South Africa, and Trinidad and Tobago have vertically integrated power sectors. In a vertical structure, one utility is responsible for all three operations (generation, transmission, and distribution). Three main advantages exist in an integrated structure.

First, in a vertically integrated structure, there's the objective of ensuring that the different components work in unison towards achieving the overall goal. If the functions were managed under different entities, unlike an unbundled structure, the potential for pursuing other operational and business plans could arise. Secondly, employees can undertake two or more related roles, with organizational resources spread across the three functions, making administrative costs less expensive than an unbundled structure. Third, revenues accruing through power sales are all retained in one utility which ensures financial independence and viability of the utility compared to an unbundled structure. In an unbundled structure, generators depend on off-takers (distributors) while transmitters depend on distributors for their revenues. This can sometimes lead to a cycle of debts that endangers the power sector (Michaels, 2006; Chimbaka, 2016, Mulder & Shestalova, 2014).

As can be seen in Table 5.12, there's hardly private sector participation in vertically integrated structures except in a few cases where there are independent power producers (IPPs) who are often tied to power purchase agreements (PPA) by the state utility. The lack of competition, especially in transmission and distribution subsectors because of the lack of private sector participation, often leads to poor management and poor corporate governance structures in the power sector. The state utility is usually plagued with unnecessary governmental interferences and electricity subsidies, resulting in colossal indebtedness affecting the adequate electricity supply (Kapika & Eberhard 2013; Eberhard & Godinho, 2017). Brazil, Chile, and Ghana have adopted the unbundled structure based on the drawbacks of vertically integrated structures. This has been informed by lessons drawn from power sector reforms in the three countries. Unbundling leads to competitive pressures, transparency, and better regulatory benchmarking, improving efficiency and effectiveness. Most unbundled structures allow private sector participation (Besant-jones, 2007; Eberhard & Godinho, 2017; Pollitt, 2004). Unbundling also ensures the inclusion of multiple actors, which allows for the diversification of power sources, thereby spreading risks of energy supply (Mulder & Shestalova, 2014; Heim, Krieger & Liebensteiner, 2018, Eberhard & Godinho, 2017, Shen & Yang, 2012; Clark & Larson, 2020).

In Ghana's unbundled structure, private sector participation is limited to the power generation subsector, while the transmission and distribution subsectors are preserved as natural monopolies. The Ghanaian situation is still plagued with most of the drawbacks that confront a vertically integrated structure such as governmental interference, poor governance structures, and electricity subsidies that causes the indebtedness of the utilities. For instance, with the two quantitative indicators of cost of power generation and retail prices in section 5.2, the difference between cost of electricity generation and retail prices was very marginal. This indicates that if other cost elements such as transmission and distribution service charges were added, the current retail prices will appear heavily subsidized.

For Botswana and T&T, which are vertically integrated structures. In the case of Ghana, even though the difference between the two indicators over the period showed a net positive, this is only indicative given that actual retail prices are subsidized, and the utilities continue to record very high commercial losses. However, Chile and Brazil had retail prices way above the generation cost for all the years. This is because aside from ensuring that power sectors in the two countries are effectively regulated, the influence of the state is very minimal, making the business of power generation and trade profitable for both state and private sector utilities. This is typical of an unbundled structure with private sector participation across all the subsectors (Eberhard & Godinho 2017).

5.4.3 Regulatory framework

All the benchmarking countries have specific power sector regulators. Table 5.13 provides regulatory institutions in each benchmarking country and their specific responsibilities.

Country	Regulatory body	Main responsibilities
Ghana	EC	1. Sets standards for power quality. 2. Issues licenses to IPPs and gas companies.
Ghana	PURC	1. Reviews tariffs based on agreed benchmarks; 2. Monitors adherence to regulatory standards; 3. Receives and attends to customer complaints.
Botswana	BERA	1. Electricity sector regulation (technical and commercial) 2. Licensing of petroleum activities 3. Licensing of natural gas (coal bed methane); 4. Licensing of renewable, coal, and nuclear energy generation and supply.
Brazil	ANEEL	Set up and update both technical and commercial regulations in the power sector.
Brazil	ONS	1. Ensure the technical and operational robustness of the transmission network; 2. Ensure fair access to the transmission network.
Chile	CNE	Setting up and enforcing tariffs in the regulated market.
Chile	SEC	1. Handling of customer complaints and compensations; 2. Enforcement of service fines.
Chile	CDEC	In charge of the secure and economic operation of the generation-transmission system.
South Africa		1. Electricity sector regulation (economic); 2. Issues licenses for piped gas and petroleum operations.
T&T	RIC	Provides both technical and economic regulation over T&TEC and other institutions in the energy sector.

Table 5.13: Power sector regulators and responsibilities of the benchmarking countries

All the benchmarking countries have power sector regulators. The Botswana Energy Regulatory Authority (BERA) was established in 2017, making it the newest among the benchmarking countries for this study. Until 2017, the Ministry of Energy was responsible for regulating and supervising the Botswana Power Corporation (BPC) activities. This compromised the independence of the BPC as electricity prices were heavily subsidized, making it difficult for the BPC to balance its books against the backdrop of continuous electricity imports from South Africa.

Even though the regulatory framework across the benchmarking countries is quite similar, some slight variations are worth noting. For countries whose power sectors are vertically integrated structures, it can be observed that one regulator is responsible for regulating activities in the entire power sector (generation, transmission, and distribution). In those countries, a single state monopolistic utility is responsible for operations in the whole power sector with minimal involvement of IPPs in power generation. This is the case for Botswana (BPC), South Africa (Eskom), and T&T(T&TEC). Once a single state utility is mandated to undertake operations across the three functions in a vertically integrated structure, it makes sense that one state regulator should also be in place with expertise across the three subsectors to regulate the activities of the state utility. Or else, having two or more regulators responsible for regulating the power sector-related operations of one utility can easily create conflicts. Countries with an unbundled power sector structure have a more elaborate regulatory framework with specific regulators regulating different functions. There are separate institutions or one large institutions (public and private) conducting activities separately across the three subsectors in these countries. Again, this makes sense given that the power sectors of these countries are quite large, and with independent companies across the three subsectors (functions), separate regulatory bodies with expertise specific to the subsectors could be in place. This avoids conflicts and promotes efficiency.

5.4.4 Reforms of the power sector

Power sector reforms were a common feature in the half of the 20th century. While some nations have gone through the full scale of late reforms and have brought an end to it, for others their model of reforms has been partial. However, for some countries, power sector reforms remain an on-ongoing phenomenon that never ends (Jamasb &Pollitt, 2000; Eberhard, 2007). This subsection provides results on the nature of reforms across the benchmarking countries. It serves to appreciate the current state of the benchmarking countries in the wake of the reforms. Because the power sectors of Botswana and Trinidad and Tobago have not undergone any significant reforms over the years, this indicator focuses on Ghana, South Africa, Brazil, and Chile.

Ghana’s power sector pre-reforms era saw the establishment of the Ministry of Fuel and Power in 1978, which was in reaction to the global energy crisis of the late 1970s. Then followed the establishment of the National Energy Board (NEB) in 1982 (Opam, 1995). In Ghana, the establishment of the NEB was meant solely to oversee the further institutional development of Ghana’s energy sector. This led to the creation of the Ghana National Petroleum Commission (GNPC) to be responsible for managing the hydrocarbon resources of Ghana, the Electricity Corporation of Ghana (ECG), which was responsible for the distribution of electrical power to consumers in the south of Ghana, and the Northern Electricity Department (NED) which was responsible for the distribution of electricity to consumers in the north of Ghana (Opam, 1995).

In the case of South Africa, electrical power had long been used on a limited scale to power gold mines and railways. Notably, the significant action in South Africa's pre-reform era was introducing the electricity act of 1922, which led to the establishment of ESCOM. Two objectives could be informed from the establishment of ESCOM. First, the need for an umbilical nexus to be created between South Africa's coal and iron industries on the one hand and the power supply industry on the other hand. Second, the South African government intended to accelerate the production of electricity through available resources and ensure that electricity was available to everyone in South Africa (Eberhard, 2007).

With the two South American countries, power sector reforms started quite early in Chile, but the challenges in Brazil and Chile before the reforms were similar. The pre-reforms era in Brazil saw a rapid increase in power generation capacity by four times more in 1991 compared to 1950. However, in the early 1990s, the power sector in Brazil was in some dire straits, mainly due to mounting defaults arising out of poor billing, revenue collection, and the government energy expansion plan. This resulted in a cumulated debt reaching US$26 billion, causing a 70% increase in the average price of electricity. A high risk of electricity blackouts across the country ensued during the early 1990s (Mendonca & Dahl, 1999; Lima da Silva, 2007). On the other hand, Chile's power sector was characterized by high inflation, high fuel prices, and price controls on final prices. This led to significant losses and a lack of investment under public ownership. Successive governments brought upon by nationalization and the OPEC oil crisis was primarily responsible for the state of the power sector. According to Pollitt (2004), this signaled Chile's longest-running comprehensive power sector reforms in the post-World War II period.

The reform had impact on the power sector in those countries which experienced the reform. The four countries studied had different responses and policy mixes over the various power sector reform periods they have undergone so far. The detail is provided below.

Ghana

Under the dictates of the Bretton-woods, Ghana's power sector reforms began in the early 1990s with the setting up of the Power Sector Reform Committee (PSRC) to coordinate the formulation and implementation of the reform program. This followed the engagement of SYNEX in 1994, power sector consultants from Chile as part of the reform process (Opam, 1995; Kapika &Eberhard, 2010). Three broad recommendations emerged from the consultants:

1. Breaking up the vertically integrated state utilities into separate entities in readiness for an unbundled power sector structure;

2. Creating an environment to encourage independent power producers (IPPs) to enter the power market;

3. And establishing industrial regulators to be responsible for developing and implementing economic and technical regulations.

Ghana needed to unbundle the Volta River Authority (the main generator) by establishing a successor state-owned company responsible for power transmission based on the recommendations. At the same time, VRA maintains its original generation function. Also, the ECG (leading power distributor) needed to be unbundled horizontally in readiness for privatization. Here, five distributors were suggested to be formed out of ECG and NED to supply consumers with a load less than 5MW. In contrast, those consumers above this threshold would have an option to participate in the wholesale power market.

Even though Ghana is yet to carry through the entire recommendations of the power sector reforms, over the years, the impact of power sector reforms can be seen in the following areas:

1. Establishment of two primary regulators; Public Utilities Regulatory Commission (PURC) and the Energy Commission (EC);

2. The unbundling of the VRA which saw the establishment of the Ghana Grid Company (GRIDCO) as a separate entity responsible for power transmission;

3. Ghana's power market has remained open to Independent Power Producers (IPPs), bringing in more generation usually on Power Purchase Agreements basis;

4. The Electricity Corporation of Ghana (ECG) has also been converted into a public limited liability company called the Electricity Company of Ghana (ECG);

5. The Northern Electricity Department was also converted into public limited liability, now as the Northern Electricity Distribution Company (NEDCo), which remains a subsidiary of the VRA.

However, the unbundling of the ECG is yet to be done, and apart from the generation subsector where there are IPPs, there is no private sector participation in the transmission and distribution subsectors.

South Africa

Unlike Ghana, which responded to the wave of liberalism by attempting to liberalize its power market in a way, in South Africa, power sector reforms meant restructuring the vertical state monopoly to become more robust and agile. First came the era of "corporatization", in which several non-performing State Enterprise Organizations (SOEs) were lined-up either for privatization or restructuring. In the case of ESCOM, it was a restructuring effort that should lead eventually to commercialization (Koen, 2012). To support the restructuring efforts, two pieces of legislation were passed. That is the ESCOM Act of 1987, and the Electricity Act of 1987.

Unlike the 1922 Act, which indicated the need for electricity to be produced at no profit and no loss, the Escom Act of 1987 defined the utility's responsibility to provide electricity most cost-effectively. This led to establishing a new corporate body known as Escom replacing the former ESCOM. Also, the Electricity Act defined the structure, functions, and responsibilities of the Electricity Control Board and assigned the sole right of electricity supply within municipal boundaries to local government authorities. By 1992, the name ESCOM was changed to Eskom (replacing "C" with "K"). Eskom was to be controlled by the Electricity Council, whose composition was now more representative of stakeholders (Koen, 2012; Davidson et al., 2006).

Compared to Ghana, the impact of power sector reforms in South Africa has been no more than ensuring that the state continues to keep a stranglehold on the sector through Eskom. Eskom has maintained its vertical monopoly, only allowing minimal participation of IPPs and the municipalities responsible for power redistribution within their local areas. Even proposals to unbundle Eskom into subsidiaries, for each to carry out separate functions (generation, transmission, and distribution), remain an unchartered path.

Brazil

The nature of reforms intended in Ghana based on the recommendations and the few that have been implemented up to date mimics the power sector reforms in Brazil and Chile. There are two reform periods in the case of Brazil. That is the reforms of the 1990s and the 2004 reforms.

Following failings of the power sector in the early 1990s, reforms were mooted to redefine the role of the state in power sector policymaking and the state involvement in the operations of the power sector in general (Salcedo &Porter, 2013; Losekann & de Oliviera, 2008). The 1990s reforms also aimed to ensure that the power sector developed quickly and become attractive to private companies to stem the tide of indebtedness in the sector. While creating the environment for broader private sector participation, the reforms were also about putting in place an effective regulatory framework that could regulate the power sector towards addressing the needs of all stakeholders (Meisen & Hubert 2010; Lima da Silva, 2007).

Based on the broad intentions of the 1990s reforms, the following were instituted:

- The creation of a free and open market;
- The establishment of the Brazilian Electricity Regulatory Agency (ANEEL) to regulate the new private companies;
- The National Council for Energy Policy (NCEP) is responsible for advising the Brazilian Presidency on national policies regarding the power sector and the optimal use of Brazilian energy resources.

Despite the changes that the first reforms brought to the power sector in Brazil, electricity prices had risen to levels that potentially could create another power sector crisis. This was what occasioned the 2004 reforms. In the wake of the 2004 reforms, a new regulatory framework was introduced, which re-established the planning role of the State and drastically altered the wholesale market (Salcedo & Porter, 2013; Meissen & Hubert, 2010).

Following the recommendations of the 2004 reforms, the following have since been implemented:

- Establishment of the Energy Research Company (EPE) responsible for conducting studies and planning covering the power, oil and gas sectors and renewable energy potential;
- The EPE also supports the public auction process by developing generation and transmission grid planning studies;
- All energy trade is carried out by long terms contracts;

- Also, two trade environments were created in the wholesale market. The regulated contracting environment (ACR), where distribution companies buy energy in public auctions and the free contracting environment (ACL), where companies buy power through open contracting agreements.

Chile

Chile's power sector reforms drew experiences from the UK, France, and Belgium where the idea of separate generation and distribution utilities emerged which was modeled on cost (as UK Area Boards then paid the Central Electricity Generating Board), and a dispatch system based on marginal cost pricing (as perfected by the French company, EDF) and a system of trading power between generators to meet customer contracts (as existed in Belgium) (Pollitt, 2004).

In line with these broad goals, Chile's 1982 power sector reforms made the following proposals:

- Two main regional power markets were created: the SIC – covering the southern and central areas including Santiago – and the SING covering the northern part of the country;
- Within the two markets, generators were required to declare availability and plant marginal operating cost every hour;
- The marginal operating cost of the plants was to be used to set the basic marginal energy prices or spot price for generators to meet customer contracts;
- The revenue for the distribution companies was set based on the costs of a model company;
- Payment for existing transmission access was to be based on negotiated tariffs coupled with the compulsory right of access if capacity was available;
- New connections and lines were to be paid for by the generators, who were free to negotiate terms with transmission companies or build their own;
- The concept of two types of customers was established. That is the regulated and free market. The free customers were those with maximum demand above 2MW. Whereas regulated customers were customers whose individual demands were below 2MW;

- Free market customers were to contract directly with generators for the supply of power of their own;
- Regulated customers were to be served in the regulated market;
- Local distribution companies who could not contract directly with generators paid the regulated price of distribution plus a node price of energy which was based on the combination of the forecast short run marginal cost of energy, the capacity charge and the relevant transmission charge;
- The 1982 reforms created a regulatory and institutional framework that saw the establishment of the National Energy Commission (CNE) and the Superintendent of Prices of Electricity and Fuels (SEC).

These proposals were implemented, which saw a partial vertical disintegration of the sector and the formation of a wholesale power trading mechanism which led to the break-up of the incumbent integrated companies (Pollitt, 2004). It also saw the establishment of several regional power markets based on an Independent System Operator (the CDEC).

Despite the changes the 1982 reforms brought and the resultant impact on Chile's power sector, by the end of 1998, Chile was confronted with a power sector crisis. The crisis created droughts, technical failures, and delays in setting up combined-cycle natural gas plants (Gabriele, 2004). The short-term solution was provided by law in 1999, which resulted in electricity rationing. This law resulted in distributors compensating customers for energy losses during rationing and also established an obligation on generators to meet reasonable demands from distributors even in the absence of contracts. The long-term solution was provided by the "*Ley Corta*" (short law) (Pollit, 2004).

The 'Ley Corta' has significantly impacted Chile's power sector since coming into being in 2004. Some of these impacts are outlined below:

- A new transmission charging ensured Transelec could recover 100% of the toll revenue required to pay for its existing lines. This has provided an allocation of payment for transmission rights without disputes;
- The node price (paid by captive customers) doesn't vary by more than 5% from the free market price. This has resulted in significantly less risk for generators in supplying the captive market;

- The threshold level for free market customers to choose their supplier is changed from 2 MW to 0.5 MW. This has lifted most non-residential customers out of the captive market and significantly increased the competition for customers directly connected to the distribution system;

- There has been greater regulation of the access charges charged by distributors to competitive suppliers of customers connected to the distribution network. This has resolved most of the conflicts that surrounded third-party access charges;

- Also, a market for ancillary services has been introduced, allowing the trading of reactive power and voltage control services.

5.4.5 Power network related issues

This section discusses the following:

a) Current power generation resources

b) IPPs involvement in power generation

c) Future generation plans

d) Nature of the transmission and distribution network

e) Private sector participation in the transmission and distribution networks

f) Regulations in the transmission and distribution subsectors.

a) Current power generation resources

Table 5.14 provides the percentage of the total electricity generated from different sources for the benchmarking countries.

Country	Hydro (%)	Thermal (%)	Other (%)
Ghana	20	78	2 (NCRE)
Botswana	Non	Non	30 (coal) 70 (imports)
Brazil	77	15	8 (NCRE)
Chile	35	62	3 (NCRE)
South Africa	1.5	10	85 (Coal) 3.5 (imports)
T&T	0	100	0

Table 5.14: Power generation sources for IB countries

Apart from Botswana and T&T, all the other IB countries had used hydro, thermal, and NCRE for their electricity generation. T&T relies entirely on thermal generation sources, which enables it to meet its demands fully (see table 5.2 and Table 5,7). As an oil-producing country, T&T leverages its abundant associated gas to generate electricity that meets the needs of the entire population and its ammonia industry. Brazil and Chile relied on a mix of hydro and thermal to meet almost 100% of their total electrical power demand. Countries with significant portions of their national population not having access to electricity is indicative of their electricity generation resources not being fully exploited. It’s also because of a lack of an aggressive policy to connect the entire population to the national grid or build standalone power systems for communities that are not connected to the national grid.

Among the IB countries, Brazil has the highest percentage of hydro and the other NCREs in its generation mix. Chile and Ghana follow. While hydro and the NCRE sources, in the long run, are cheaper, in the medium to long term, the development cost can be very high, and for Ghana in particular this is the reason why the generation mix has shifted to thermal becoming the dominant source since Ghana started producing oil in 2010. Both South Africa and Botswana depend largely on coal as their electricity generation sources. South Africa and Botswana are among the countries with the highest coal deposits in Africa. Relying on coal gives the two countries a cheaper source for electricity generation (Ofetotse & Essah, 2012).

In line with the government of Ghana's policy of extending electricity to all towns and villages, a vigorous electrification program dubbed the Self-Help Electrification Programme (SHEP) had been pursued over the years. Under the program, communities contributed in the area of wooden poles. Ghana's government absorbed the rest of the cost by extending electricity to towns and villages across the country. On the other hand, Botswana continued depending on imports from South Africa while gradually expanding its coal potential for electricity generation. Botswana also adopted a policy of off-grid electricity access to mostly its rural population by developing potential sources such as solar and biomass. These initiatives contributed significantly to more people with access to electricity (REEP, 2014). T&T, Chile and Brazil, had consistently high levels of their populations having access to electricity throughout the years. Brazil has steadily relied on its hydro potential and potential in non-conventional renewables (NCRE) such as solar and wind. Much of Chile’s electricity is generated by private sector companies (Gencos), mainly through thermal sources.

But the competitive nature has ensured that almost the entire population has had access to electricity over the years. Ghana could develop its NCREs sources and extend electricity to the rest of the population, who are primarily rural-based on off-grid arrangements with more private sector involvement. This will attract funding and also ensure that electricity is cheaper.

b) IPPs involvement in power generation

Table 5.15 summarizes IPPs' share of power generation among the IB countries.

Country	Involvement of IPPs	IPPs' share (%)
Ghana	Y	60
Botswana	N	0
Brazil	Y	28
Chile	Y	62
South Africa	N	0
T&T	Y	40

Table 5.15: IPPs involvement and share of power generation among the IB countries

Both Botswana and South Africa did not involve IPPs in their electricity generation. The BPC and Eskom were responsible for managing all the electricity generation resources in Botswana and South Africa respectively. However, for the rest of the benchmarking countries, IPPs had a presence, ranging from 28% to 62%. IPP's primary source of power generation is thermal. They, therefore, turn to register more presence in countries where the main source of power generation is thermal. This is evident in Chile, Ghana, T&T, and Brazil. This is because the initial investment for a thermal generation plant is lower than hydro, NCREs, and coal.

While hydro and NCRE sources are also subject to climatic challenges, thermal sources are not confronted with such challenges. To ensure a quick investment return, IPPs turn to favor thermal sources. IPPs are also attracted into markets where off-taker prices are competitive. There are either competitive markets such as Brazil and Chile where electricity is traded directly on the market or on a Power Purchase Agreements (PPA) basis where other state utilities take power after being produced, which is the case for Ghana. The practice of electricity trade directly on the market or through tendering and auctioning serves the power sector better because it ensures that generation plants are efficient with a lower generation cost, which impacts lower electricity prices, enhancing the sector's competitiveness in general. In the case of PPAs, it puts the IPPs in too much comfort, which lowers efficiency standards. Most of such PPAs have "take or pay" clauses which further cripples the sector with mounting debts.

c) Future generation planning

Table 5.16 summarizes the future generation plans of the IB countries. It provides the focus of each country in terms of the sources it intends to target to augment its power generation capacity in the foreseeable future.

Country	Generation Plan	Generation Focus
Ghana	National Energy Policy	No clear focus
Botswana	Energy Resource plan	Coal and NCREs
Brazil	A ten-year energy expansion plan	NCREs-wind and solar thermal, coal, nuclear, and natural gas
South Africa	Integrated Resource Plan	Coal, Hydro, NCREs, and Shale gas
Chile	National Energy Strategy	NCRE, hydro, and thermal (natural and gas)
T&T	T&TEC Business Plan	Hydro

Table 5. 16: Future generation plans of the IB countries

A comprehensive plan for future power generation is essential for any country and no exception for all the IB countries. Ghana's energy policy had primarily intended to harness its renewable energy potential. However, due to the power crisis between 2012 and 2015 it abandoned its renewable energy policy and went for quick fixes. Ghana was later saddled with an excess generation capacity in the short term due to over-contracting of new plants, of which most of the capacity is emergency power. The contracts are on a "take or pay" basis of which Ghana continues paying for the power which is unable to be used, resulting in the piling of debts in the energy sector.

The rest of the benchmarking countries will target cheaper and available sources in the foreseeable future. Botswana and South Africa will continue to rely heavily on coal as their main electricity generation and supply sources over the next decade. However, their respective development plans and energy policies have made room to cater for NCRE sources to be part of their generation mixes. Botswana energy policy and its Master Energy Plan prioritize sources such as solar and biomass to cater to rural communities' needs and expand access to electricity, which currently stands at about 56%. In South Africa, the Integrated Resource Plan (IRP) projects demand in the range of 345- 416 TWh by 2030 with a peak demand of 61200 MW. This is considered in line with an average projected economic growth of 5.4%. The IRP anticipates installed generation capacity through the NCREs, resulting in the postponement of base-load capacity increases through nuclear to 2025 and beyond.

Brazil, Chile, and T&T take a long-term view so as far as power sector generation planning is concerned. The Energy Research Company, one of the products of the power sector reforms in Brazil, develops and maintains a ten-year energy expansion plan, which is updated annually. This makes the power sector in Brazil always looking ahead in ten years. The energy expansion plan considers economic and population growth trajectory, global trends, fuel availability, energy security, and other important variables (Pereira, 2014). Even though hydro will continue to lead the generation mix, the Energy Expansion Plan includes NCRE sources such as wind and solar as part of the anticipated generation mix. Coal, nuclear, and natural gas constitutes the thermal sources the plan is exploring (Meissen & Hubert, 2010; Perira, 2014). This will ensure universal access to electricity and meet Brazil's growing demand as it industrializes.

Chile has a National Energy Strategy that spans 18 years between 2012 and 2030. The strategy prioritizes the development of energy resources that assures Chile of sustainable economic growth while promoting health and environmental sustainability. Chile recognizes the potential it holds in the development of NCREs. To this end, the national energy strategy intends to tap into this potential to start with. Over the period, hydro will be targeted to contribute more to total power generation. But the strategy recognizes that hydro and other renewable sources are subject to climate patterns, and harnessing their full potential could be problematic. Therefore, the national energy strategy makes room for fossil fuel sources (natural gas and oil). T&TEC works with a five-year business plan at all times. The current business plan anticipates an introduction of hydro into the generation mix by the end of 2020. Currently, the only source of power generation in T&T is thermal.

Ghana needs a comprehensive generation plan similar to all the other benchmarking countries to avoid another power crisis. The plan must identify cheaper sources to continue to rely on building a more sustainable generation installed capacity. Even though there is excess capacity now by the current demand, which is based on the population with access to electricity, more than 20% of the national population does not have electricity. A comprehensive generation plan must target the extension of electricity to the entire population and consider economic growth projections and how that impacts demand. The plan must factor in a reserve margin of at least 30%.

d) Nature of the transmission and distribution networks

Ghana, Brazil, and South Africa operate interconnected power transmission systems, while Botswana, Chile, and T&Ts are not interconnected. The North-West of Botswana is currently not connected to the national grid but depends on imports from Namibia, Zimbabwe, and Zambia. In the case of Chile, its two main power systems, the SINC and SING are not interconnected. Also, T&TEC operates a connection system in Trinidad that is separate from the connection system in Tobago.

The two Islands are separated by 30 kilometers but are not interconnected electrically. An essential advantage of an interconnected system over one that is not interconnected lies in the fact that the peak load of the power stations can be exchanged. If the load curve of a power station shows a peak demand that is greater than the plant's rated capacity, then the excess load can be shared by other stations interconnected with it. However, the major disadvantage is that the generators of all the interconnected generating stations must operate at the same frequency and in a synchronized manner. This is because, during heavy load conditions, some generators can go out of step due to synchronization breakup, which can cause a significant blackout (WOE, 2019)

The table below provides the standard T&D voltages for the benchmarking countries. It can be seen that Ghana's average transmission voltage of 161kv is the second-lowest after T&T. The distribution voltage, which ranges between 230v and 440v however, compares favorably with distribution voltages of the other benchmarking countries. A low transmission or distribution voltage is one of the main reasons losses occur in a T&D network. This is because power is lost due to the heating of T&D lines over long distances. The losses turn to be more with a lower voltage because it will not be enough to overcome the resistance in power conductors to ensure the speedy flow of electricity.

As the quantitative benchmarking indicators provide, Ghana's average T&D losses of almost 27% are the highest among the benchmarking countries. The lower transmission voltage primarily causes the transmission losses component of the overall T&D losses. On the distribution loss component, much of it is commercial losses that are caused by electricity theft and poor billing. Even though Ghana's distribution voltage compares favorably to other countries, technical losses still occur, attributed to low and medium voltages and the obsoleteness of distribution lines. T&D losses can be reduced to the barest minimum if the transmission voltage is high (usually 300 kV and above), and low and medium voltage lines are replaced with high voltage lines. There ought also to be greater efficiency in billing and putting measures in place that avoid power theft (Mehta & Mehta, 2005; Nunoo & Mahama, 2013).

Country	Transmission voltage (Kv)	Distribution voltage (V)	Interconnected
Ghana	161	230-440	Y
Botswana	11-400	230-400	N
Brazil	230-750	127-220	Y
South Africa	132-765	230-400	Y
Chile	100-500	220	N
T&T	Standard 132	110-127	N

Table 5. 17: Summary of the nature of the T&D network in the IB countries

e) Private Sector participation in transmission and distribution subsectors

Apart from Brazil and Chile, the rest of the benchmarking countries have no private sector participation in their transmission and distribution subsectors. Even though Ghana has an unbundled power sector, apart from the power generation subsector with IPPs, the transmission and distribution subsectors are operated and managed by state monopolies. In South Africa, Eskom, a state monopoly, is the sole utility responsible for the transmission and distribution of power.

Similarly, the BPC and T&TEC are solely responsible for transmission and distribution operations in Botswana and Trinidad and Tobago, respectively. Brazil has roughly 65 transmission utilities. Apart from Electrobas, a state transmission utility, the rest are private sector transmission utilities. Electrobas controls about 57% of the total transmission assets while *Companhia de Transmissâo de Energia Elétrica Paulista* (CTEEP) controls about 30%. CTEEP is a private/public Company with 89.5 percent of its stock in private hands (Cote & Langevin, 2013; Salcedo & Porter, 2013). Regarding the power distribution subsector, Brazil has about 47 private power distribution companies out of 64. The private companies are responsible for 60 percent of total power distribution (Cote & Langevin, 2013). The private sector dominates Chile's power transmission subsector. Transelec and Transnet are the two major transmission utilities. Transelec, owned by a consortium, controls about 10,000 circuit kilometers of transmission lines representing approximately 50% of the total transmission assets. This is followed by Transnet, which is also owned by the private sector and controls about 25% of the total transmission assets. The power distribution subsector is equally dominated by the private sector, with Chilectra controlling about 40% of the total sales and CGE controlling 23% of the sales market. Other distributors are responsible for between 5% and 10% sales in the power distribution market (Transelec, 2017; Roy, 2016).

All the benchmarking countries have posted better results in their transmission and distribution subsectors than Ghana (the quantitative benchmarking results). The difference between the countries without private sector participation in their transmission and distribution subsectors and those with private sector participation lies in the average retail prices of electricity. Brazil and Chile have consistently registered retail prices well above the cost of power generation, which is typical of private sector-led power markets. This means that the transmission and distribution subsectors have continued to be profitable to the private sector (Cote & Langevin, 2013; Salcedo & Porter, 2013). Where electricity prices have lagged behind the cost of generation in markets controlled by the state, the utilities are likely to be saddled with debts. Governments' efforts at re-in fencing these debts are often not successful. This is particularly the case of Ghana.

f) Economic regulations in the transmission and distribution subsectors

The type of regulations employed in the respective countries has greatly been influenced by two main factors. That is whether the power sector is integrated or unbundled and whether there is private sector participation in the transmission and distribution subsectors or not. The countries whose power sectors are integrated operate economic and commercial regulations that are Cost-based. This is the case for Botswana, South Africa, and T&T among the benchmarking countries.

Also, the study observed that among countries with unbundled power sectors whose power sectors are operated and managed by state monopolies, their regulations are cost-based. This is the case in Ghana. Among the countries whose power sectors are unbundled with heavy involvement of the private sector in the generation, transmission, and distribution, their regulations are incentive-based. This is the case of Brazil and Chile. The table below presents the type of regulation for each country

Type Of Regulation	Countries
Cost-Based	Ghana, Botswana, South Africa, T&T
Incentive-Based	Brazil and Chile

Table 5. 18: Type of economic-based regulations cost-based regulations

Cost-based regulations involve compensating a firm based on the cost incurred in production and rendering of the service. The regulator audits the firm’s operations and investment costs and sets the allowed revenue for the next year. This revenue includes a reward in the form of a rate-of-return to compensate the firm’s capital assets (Khalfallah, 2013). This kind of regulation is not efficient when it comes to meeting regulatory objectives of enhanced efficiency and quality of service delivery. This is because there are no incentives to the regulated firm to reduce costs, and also the regulator is unable to accurately audit or observe the firm's incurred costs because of the information asymmetric advantage that the regulated firm possesses (Joskow, 2008; Jamison, 2007; Khalfallah, 2013). In the power sector, cost-based regulations involve: (1) the cost of power generated, (2) a transmission service charge, and (3) a distribution service charge. The revenue accruing from this goes to the integrated utility in the case of Eskom, T&TEC, and BPC. For an unbundled power sector, the revenues are collected and retained by the respective utilities within the chain.

Incentive-based regulations use rewards and penalties to induce the utilities to achieve desired goals of efficiency leading to efficiency gains sharing between utilities and consumers (Farsi, Fetz & Filippini, 2007; Joskow, 2007; Khalfallah, 2013, Jamison, 2007). Brazil uses a combination of revenue and price cap regulations for its transmission and distribution subsectors. Some benefits of revenue (price) cap regulations are incentives to improve efficiency, dampening the effects of cost information asymmetries, decreasing the incentive to over-invest in the capital, and providing simple and clear incentives for cost reduction (Joskow, 2008; Jamison, 2007; Khalfallah, 2013). Price and revenue caps are reflected in the auctioning processes for transmission and distribution concessions in Brazil's power sector.

Transmission Subsector (Revenue Cap)	Distribution Subsector (Price Cap)
1. Project requirements of the new transmission enterprises defined; 2. ANEEL carries out an international public auction of the transmission enterprises; 3. All licensed transmission companies (Trancos) can participate in the auction; 4. The Transco that offers the lowest annual revenue during the period of the concession (30 years) wins; 5. The winner is responsible for construction, operation, and maintenance of the concession during the period; 6. The revenue offered by the winner covers the firm's investment, operational and maintenance costs, and profit.	1. The procurement of new capacity is carried out through two public auctions every year; 2. The Discos bid for electricity to supply to their captive consumers; 3. The Discos are required to procure 100% of the electricity they produce through the auction process; 4. The winning Discos are required to sign separate bilateral contracts with their respective Gencos; 5. Any premium and pass on the cost which Discos may charge consumers on top of the wholesale auction price is regulated; 6. Discos procure electricity at a competitive price, to protect captive consumers and ensure efficiency in the wholesale market.

Table 5.19: A summary of the application of incentive-based regulations in the T&D subsectors in Brazil

While there's a revenue cap for the auctioning of the transmission concessions, there is a price cap in the auctioning processes to obtain the required electricity by the Discos for the captive markets. This is because a revenue cap is more appropriate than a price cap when costs do not vary appreciably with every unit of electricity involved. This is the case for the transmission of power (Jamison, 2007). In the auctioning process, revenue offered by the Transco is supposed to cover the firm's investment, as well as its operational costs, its maintenance costs, and, eventually, its profit. In Brazilian parlance, this is referred to as the Permitted Annual Revenue (Receita Annual Permitida – RAP). The Transcos are expected to benefit from the revenue cap situation by ensuring that revenues stay higher than the cost incurred.

To achieve this over the concession period (usually 30 years), Transcos must invest in building a robust and efficient transmission network that avoids network breakdown, network interruptions, and can satisfy all technical requirements set by the transmission subsector regulators. This reduces network maintenance and operations cost over time and therefore hands Transco a decent return on investment. There is an efficiency gainsharing here because Discos and other bulk customers connected to the transmission grid benefit from efficient and effective services from the Transco, and the Transco itself benefits from a higher profit by virtue of low operations and maintenance cost.

The auction process in the distribution subsector takes place only in the regulated market whereas industrial consumers with demands above 3 megawatts or who have voltage at the delivery point of greater than or equal to 69 kilovolts (kV) negotiate with power generation companies through long term contracts to acquire their power needs. Once the auction process for the distribution subsector ends, retail consumers are bound to purchase their power from specific distribution companies (Fiona et al, 2010). It can be observed in the auction process provided in the table (5.17) that in the distribution subsector, the type of incentive-based regulation used is a price cap. Price cap because any premium and passed-on cost which Discos may charge consumers on top of the wholesale auction price are regulated.

To benefit from a price cap, first, the Discos must procure electricity at a competitive price to ensure that any add-on will be within the price cap. In the second, adequate investment must be made towards ensuring a robust and efficient distribution network that continuously meets technical regulatory standards. This will reduce maintenance and operations costs. On the commercial side, billing and collection of bills ought to be effective and with good customer care. Once these are ensured, it will lead to efficiency gainsharing where consumers benefit from improved services and the Discos also receive a decent return on their investment over the concessionary period. A look at the cost of a kw/h of electricity and average retail prices of electricity as provided in tables 5.7 and 5.8 suggest that the business of power trade in Brazil is very profitable.

The challenge for the use of price and revenue caps is that efficiency for the firm could mean cost reduction at the expense of maintaining quality standards. So as long as this remains beneficial to the firm, that is what it will keep. The regulator can be handicapped because of the challenge of information asymmetry and also because the regulator may not be able to ascertain the efficiency of a firm (Joskow, 2008; Jamison, 2007; Khalfallah, 2013). Also, in the case of Brazil for instance, in the distribution subsector, competition is only limited to the auction process. Once the auction process ends, retail consumers are bound to purchase their power from specific distribution companies (Fiona et al, 2010). This can be a disincentive because consumers are bound to specific Discos, and there could be laxity in the services rendered by the Discos. Also, the fact that Discos are not allowed to compete with each other in the regulated market means that electricity prices are always likely to stay at the top end of the price band of the price cap.

In Chile, new regulated transmission investment is determined through a centralized process involving a holistic planning phase (the transmission 'trunk' study) and subsequent tendering process. Transmission tariffs are negotiated between transmission asset owners (Transco's) and the users (Gencos and Discos), a process that is supervised by CDEC. In terms of access to the transmission network, Trancos are required to provide connection to any generator that has complied with the regulations on the environment, technical, and construction standards. In terms of power trade and sales, the Chilean power market is structured along three markets. A spot market is where a Genco competes among themselves based on marginal cost. Here, whenever the plant is available, dispatch becomes ready irrespective of the contracts. When two or more plants are ready, the plant with the lowest marginal cost is dispatched and the next plant in that order to meet the demand at any point in time. The regulated market is where prices are paid by residential and other small consumers with less than 2 MW of consumption. The free market is constituted by consumers whose power demand exceeds 2 MW. The law allows them to negotiate energy contracts directly with Gencos.

Chile uses a form of incentive-based regulation in the regulated market that addresses some of the weaknesses that price(revenue) cap brings. This is known as yardstick competition. Yardstick competition is commonly seen as the most appropriate tool to address the challenges of price(revenue) cap regulations in a non-biased and non-discriminatory manner. The firm's performance is benchmarked with the performance of other firms in the industry or with efficient firms in other regions. This ensures that firms do not have control over their revenues, but instead whatever they achieve is indexed to the performance of their competitors (Khalfallah, 2013). The price paid (nodal price) for electricity by consumers in Chile considers three important factors. That is the spot market price for electricity, the transmission cost or charge, and an added value for the distribution service (VAD).

VAD price is determined from the optimization of a real Disco treated as a model company which is then benchmarked against all the other Discos. Based on the relative performance of the industry, the return for the Disco remains similar to the model company (Rudnick &Donoso, 2000).

Critical factors that underpin the determination of the VAD includes:

- Fixed costs for administration, invoicing and user service expenses, independent from consumption;
- Mean distribution losses in power and energy;
- Standard investment, maintenance, and operational costs per unit of power supplied;
- The annual investment costs are calculated considering the New Replacement Value (NRV), the facilities adapted to the demand, and a discount rate equal to a real 10% per year.
- These factors are calculated based on the specific standards distribution zones for the discos to ensure fairness and eventual fair pricing for consumers in the different zones.

5.5 Summary

This chapter compared the performance of the IB countries along some key power sector performance indicators and analyzed the practices that may account for each country's performance. In the process, best practices were identified, forming the basis for less performing countries such as Ghana to adopt the best practices towards improving their power sector performance. The table 5.20 provides the top three performing countries for each of the seven quantitative indicators.

Rank (Best to worst)	T&D Losses (%)	Population with access to electricity (%)	EPI	The average cost of generation (LCOE)	Average retail prices	SAIDI	Generation to demand ratio
1	T&T	T&T	Bostwana	Brazil	Brazil	T&T	Chile
2	Chile	Chile	Ghana	Chile	Ghana	Chile	T&T
3	South Africa	Brazil	Brazil	Ghana	Chile	Brazil	Ghana

Table 5. 20: Ranking of best performing countries for each quantitative indicator

Besides the average cost (LCOE) of electricity generation, average retail prices, and EPI, T&T is among the top three of the best performing countries across the other quantitative indicators. Brazil recorded the best ranking on average retail prices because electricity prices are well above the cost of electricity generation, and Ghana and Chile follow this.

All the benchmarking countries had medium and long-term policies towards augmenting their power generation capacity to serve as sustainable means of expanding electricity access and fulfilling the increasing demand. Sources such as hydro and NCREs are expected to contribute significantly to the generation mixes of the countries as compared to their current traditional sources. Even though the initial investment cost in hydro and the NCREs is high, the cost of generation, in the long run, is low, and this could translate into lower retail prices of electricity as well. Ghana, meanwhile continues to depend on thermal sources, which now register higher than hydro in its generation mix. To sustainably ensure that power generation is high and made readily accessible to a more significant percentage of Ghana's population in the long term, Ghana must continue to leverage its potential in hydro and develop new sources such as solar.

Ghana's performance was the worst for indicators such as T&D losses and interruptions in the transmission and distribution network compared to the other benchmarking countries. Ghana's transmission voltage was one of the lowest among the benchmarking countries. In other to improve Ghana's performance along those indicators, there is a need to increase the transmission voltage and replace gadgets and equipment that were obsolete to build a more robust network that reduces T&D losses and reduces interruptions in the power network. The nature of power sector reforms has also influenced to a large extent, the power sector structure, as well as the power sector policy framework, making the power sectors of Chile, Brazil, and Ghana more similar.

However, T&T and Botswana haven't undergone any significant reforms over the period. Reforms in Brazil, Chile, and Ghana have sought to establish the 'standard model'. Even though Ghana embraced reforms similar to Chile and Brazil, it has not followed through with all the recommendations of the reforms. These include the vertical disintegration of the ECG and creating space for the participation of the private sector in a wholesale competitive power market. This has resulted in a poor state of the utilities being overly indebted and causing inefficiencies in the sector.

Regarding economic regulations, while the power sectors in Chile and Brazil pursue incentive-based regulations, that of Ghana, South Africa, T&T, and Botswana pursue cost-based regulations. Incentive-based regulations have proven to be more impactful on the performance of utilities as against cost-based or cost-plus regulations. But incentive-based regulations are better suited in competitive power markets.

This approach can be used to improve the performance of the power sector through the following steps:

1. Identify the best performers for each benchmarking indicator;
2. Use the qualitative analysis to identify how such results are achieved;
3. Based on the analysis, best practices are identified across the benchmarking countries for each indicator;
4. Drawing on the best practices, develop a plan that includes breakdown elements of the best practices for improving the performance of the power sector;
5. Implement the set plan, but with the benefit of information from the benchmarking countries, avoid some of the pitfalls discovered;
6. Develop clear KPIs and milestones to serve as measures of success to serve as the basis for monitoring and evaluation;
7. The power sector can commit itself to continuous improvement by scanning the industry regularly to always find the best practices that it can always be adopted.

CHAPTER SIX

RESULTS AND ANALYSIS OF DELPHI METHOD

6.1 Introduction

This chapter presents the results and analysis of the Delphi approach applied to Ghana's power sector. A collective view of experts interviewed, and insights from other literature sources regarding actions needed to improve Ghana's power sector performance are integrated in discussions.

Section 6.2 presents the demographic characteristics of the experts used for the Delphi approach. Section 6.3 explores the policy-making structure, institutional and regulatory framework, and associated weaknesses. Section 6.4 investigates the impact of power sector reforms on the sector. Section 6.5 discusses private sector participation in the power sector. Sections 6.6 discusses challenges of power generation, transmission, and distribution, respectively. Section 6.7 summarizes the chapter and highlights the benefits of applying the Delphi approach for improving the performance of a power sector.

6.2 Demographic characteristics of experts used for the Delphi approach

The experts were drawn from the power sector of Ghana, with expertise reflecting the policy, regulatory, and institutional framework of Ghana and the three main functions of power generation, transmission, and distribution (see Appendix IX). The summary of the number of experts in the different areas is given in Table 6.1.

Areas of expertise	Number of experts	From
The policy, institutional structure, and regulatory framework	5	Public Utilities and Regulatory Commission (PURC), EC, ACEP and Ministry of Energy
Generation	5	GTS Engineering and Cenit Power
Transmission	5	GRIDCO
Distribution	5	ECG and NEDCo

Table 6. 1 Number of experts drawn from the different subsectors

Two experts were drawn from the Public Utilities and Regulatory Commission (PURC), and one expert each from each from the Energy Commission (EC), Ministry of Energy, and the African Centre for Energy (ACEP). For the generation subsector experts, three were drawn from GTS Engineering and two from Cenit Energy. Both GTS and Cenit are Independent Power Producers operating in Ghana. For the transmission subsector, all five were drawn from the Ghana Grid Company (GRIDCO), while for the distribution subsector, three were drawn from the Northern Distribution Company (NEDCo) and two drawn from the Electricity Company of Ghana.

Twelve out of the total of 20 experts interviewed, representing 60 per cent of the sample, had professional working experience in the power sector of Ghana of eleven years or over. Another 35 percent had between five- and ten years of professional experience in the sector, while just 5 per cent had professional experience below 5 years.

This indicates that experts included in the Delphi approach are rich in work experience in the sector and they should have more insightful information on the sector. However, their perspectives and suggestions reflect the practical side of the information of the power sector. The literature sources are used to explain, either confirming or adding debates, to these perspectives and actions suggested by the experts to reach conclusions towards improving Ghana's power sector.

6.3 Power sector structure, institutional and regulatory framework

This section presents the power sector structure. The weaknesses of regulatory institutions are discussed. The solutions are proffered based on the analysis of the perspectives of the experts. The section also explores the impact of reforms on the power sector, based on the experts' perspectives.

6.3.1 Ghana's power sector structure

The Ghana's power sector structure provides the Ministry of Energy, which has oversight responsibility for the sector and is responsible for the policymaking and direction required of the sector. The VRA and the Bui Power Authority (BPA) are the state institutions responsible for power generation, of which the presence of IPPs also adds to the current power generation capacity. Ghana Grid Company (GRIDCo) is solely responsible for power transmission. The distribution subsector consists of the Electricity Company of Ghana (ECG) and the Northern Electricity Distribution Company (NEDCo) (a subsidiary of the VRA) for southern and northern parts of Ghana's power distribution, respectively. The two regulatory bodies are the Energy Commission (EC) and Public Utilities Regulatory Commission (PURC), responsible for technical and commercial regulations. Figure 6.1 provides the graphic representation of the structure.

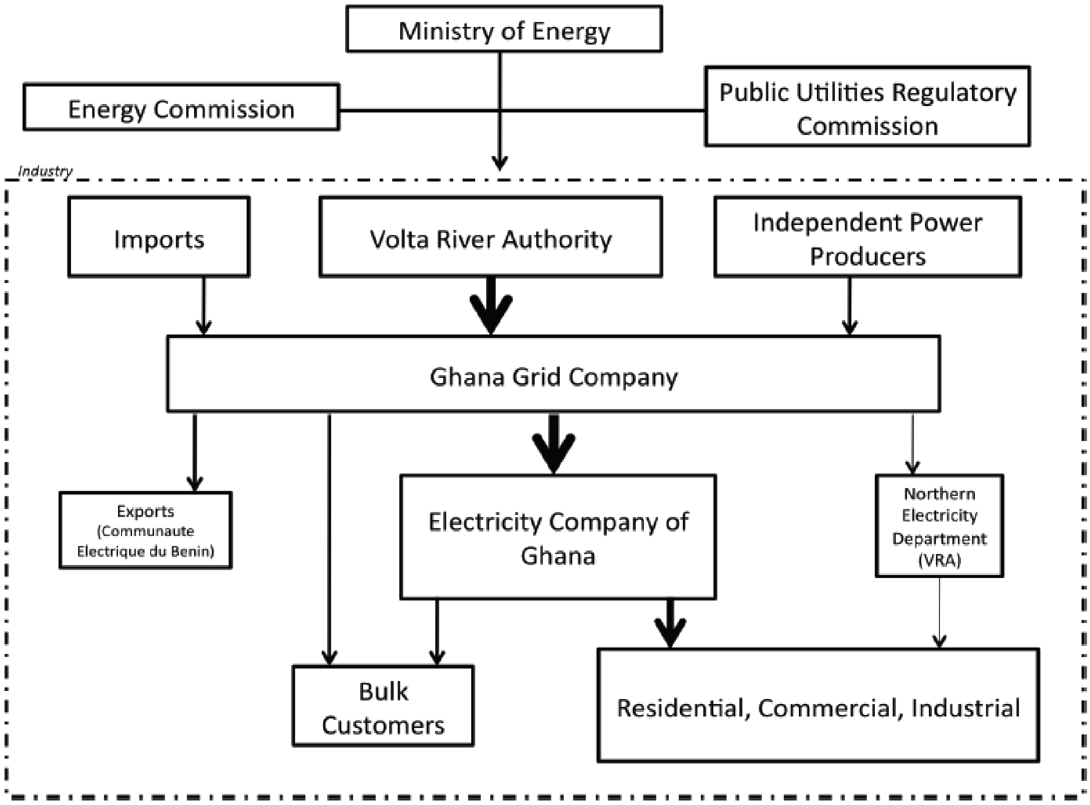

Figure 6. 1: Institutional structure of Ghana's power sector (Kapika & Eberhard, 2013; p.130)

6.3.2 Regulatory framework

Ghana's regulatory framework provides two institutions: the Energy Commission (EC) and the Public Utilities and Regulatory Commission (PURC), as provided in Figure 6.1.

The EC has the following mandates (Energy Commission, 2020):

- To serve as the Government's energy policy adviser by making national energy policy recommendations to the Minister of Energy.
- To formulate national policies for the development and utilization of indigenous energy resources, in particular, renewable energy: solar, wind, and biomass;
- Prepare, review and update periodically indicative national plans to ensure that all reasonable demands for energy are met;
- To prescribe by legislative instruments standards of performance and technical and operational rules of practice for the supply, distribution, sale of electricity and natural gas to consumers by public utilities;

- To enforce the provision of such legislative instruments uniformly throughout the country;
- To promote competition in the supply, marketing, and sale of renewable energy products and other forms of energy;
- To promote energy efficiency and productive uses of electricity, natural gas; and petroleum products.
- To license public utilities for the transmission, wholesale supply, distribution, and sale of electricity and natural gas; and
- To secure a comprehensive database for national decision making for the efficient development and utilization of energy resource

The PURC undertakes the following mandates:

- Provide guidelines for rates to be charged for the provision of utility services;
- Examine and approve utility rates;
- Protect the interest of consumers and providers of utility services;
- Monitor and enforce standards of performance for provision of utility services;
- Promote fair competition among public utilities;
- Receive, investigate and settle complaints relating to utility services;
- Advise any person or authority in respect of any public utility.

6.3.3 Challenges of the regulatory framework

Even though Ghana presents a regulatory framework that reflects the standard model similar to Brazil and Chile, the power sector experts enumerate its structural challenges in terms of regulatory governance and regulatory independence. Two main concerns on regulatory governance are identified.

First, conflicts between the two institutions sometimes arise in delivering their respective mandates. This is because even though the EC issues technical licenses to the Independent Power Producers (IPPs), gas companies, and set the transmission and distribution utilities standards, the PURC has the mandate to monitor the operations of these industry players.

All the experts agreed on role overlapping, especially when it comes to enforcing the licensing regime and applying sanctions.

Secondly, the challenge to do with regulatory governance lies in the fact that the political authority overbearingly controls Ghana's power sector policy-making structure and regulatory framework. This is typically seen in how board members and CEOs are appointed for the various power sector institutions, including the two regulatory institutions. The president of Ghana appoints both the board members and CEOs. This does not portend good regulatory governance because the CEOs rather become accountable to the president instead to the board. A non-performing CEO, unfortunately, cannot be dismissed by the board. The president could still remove a well performing CEO without consulting the board.

Given the regulatory governance challenge, lack of regulatory independence also arises on two fronts. First, policymaking in the power sector becomes politically driven instead of performance-driven because regulatory institutions are more or less under the government's stranglehold. Secondly, the two institutions lack adequate logistical and human resources to properly fulfil their respective mandates. For instance, both institutions do not have a presence in all of Ghana’s sixteen regions. They are also not adequately staffed, even in regions with a presence. This affects the effective and efficient delivery of their mandates.

6.3.4 Overcoming regulatory framework weaknesses

The experts proffer two solutions bordering on regulatory governance and regulatory independence to overcome the regulatory challenges. On regulatory governance, merger of the two regulatory bodies was suggested by some experts. However, some considers that it was necessary to maintain the two institutions’ independence but reducing some overlaps in roles and functions and deal with conflicts in different ways.

Given that Ghana operates an unbundled power sector structure, unbundled structures tend to have more elaborate regulatory frameworks compared to integrated structures. The regulatory institutions tend to be along technical and commercial regulations (Opam, 1995; Kapika &Eberhard, 2013). Having both the PURC and EC is one of the best practices under the unbundled power sector structure. The conflicts of the two institutions might lie beyond separate regulatory institutions. Other ways such as working collaboratively and sharing enough information might be the way forward.

On regulatory independence, the experts suggested the need for legislation that can insulate the regulatory institutions from governmental or political interferences. The experts suggested that the president should appoints board members, and the boards appoint MDs or CEOs. This would ensure regulatory independence and accountability to lead to performance improvement. Secondly, the two institutions must be well resourced in ways that reflect their respective mandates and program of activities annually.

6.4 Power sector reforms

Before the reforms, the power sector structure was an integrated structure with a state utility (VRA) being responsible for power generation and transmission, and two other state utilities responsible for power distribution. After the reforms, the generation subsector was unbundled into separate generation and transmission with the introduction of IPPs. The leading distributor (ECG) remained unbundled, and two regulators were introduced, the EC and PURC. The experts agreed that power sector reforms in Ghana brought both benefits and challenges. Table 6.2 summarizes both the benefits and challenges to the generation subsector.

Benefits	Challenges
1. With the introduction of IPPs, Ghana increased its generation capacity. 2. The introduction of IPPs enabled Ghana to sign power purchase agreements that resulted in increasing the country's generation capacity. 3. The liberalization of the generation subsector has created competition leading to improved efficiency among generation plants	1. The reforms had strengthened IPPs, but made State generators (VRA and BPA) weaker 2. Ghana's generation mix shifted to thermal as the dominant source by making other sources, such as NCREs untapped 3. The cost of power generation increased significantly over time, impacting retail prices 4. There is generally a lack of credible off-takers due to the indebtedness in the sector 5. There is a general lack of standardization of tariffs across plants since the introduction of the reforms

Table 6.2: Benefits and weaknesses of the reforms on the generation subsector

The reforms have benefited Ghana in terms of increasing the capacity of Ghana's power generation with the involvement of IPPs. For instance, from 2006 to 2016, Ghana increased its generation capacity from 1,730 MW to 3,759 MW, representing an 8.6% annual increase, with the IPPs contributing about 28% to the capacity (EC, 2016).

Notwithstanding IPPs' contribution to the stock of power generation, in the wake of the reforms, their presence had also posed some challenges to the generation subsector. The VRA buys fuels for the IPPs to produce electricity based on its balance sheet. There's a buy-back arrangement where the power produced is sold back to the VRA. This arrangement affects the competitive performance of the VRA since the IPPs themselves are competitors to the VRA. This point is reiterated in the voice of EP3 as '*almost every IPP is dependent on VRA to some extent and therefore run at the back of VRA, there is no true IPP'*. Apart from affecting VRA's competitive performance, anytime the VRA is saddled with a lack of fuel, it affects the IPPs too and reduces Ghana's generation capacity. What is required is to reform the sector to attract IPPs with the capacity to operate on their own without piggybacking on a state generator which is supposed to be a competitor (Amoako-Tuffour & Asamoah, 2015). In addition, the proliferation of IPPs in Ghana has resulted in a marked shift of Ghana's generation mix from hydro as the dominant source to thermal. This implied that Ghana had failed to exploit its potential in NCRE sources such as solar and wind (Amoako-Tuffour & Asamoah, 2015; Kumi, 2017). With thermal as the dominant source, the cost of generation is high, leading to the rise of end-user tariffs, which negatively impacts the economy.

Regarding the impact of the reforms on power transmission, three main developments are deduced based on the perspectives of the experts. They are the decoupling of transmission operations from power generation, establishing a separate Transco (GRIDCo), and GRIDCo being responsible for managing the National Interconnected System (NITS). The transmission subsector experts highlight both benefits and weaknesses. Decoupling of the two power subsectors led to an expansion of Ghana's transmission network. By setting up seven transmission centers since GRIDCo was established in 2008, enabling the connection of towns and villages across the country to the national grid, which increased Ghana's population access to electricity from 55% to 82% in 2018 (World Bank, Group, 2020). Also, given that IPPs now exist, Ghana's Grid Code provides that GRIDCo as the operator of the NITS should give unhindered access to all IPPs once they meet regulatory standards and reaches a connection agreement with GRIDCo (EC, 2018). This assures that IPPs have fair access to the transmission network once they set up and are ready to dispatch.

Even though decoupling the two subsectors has benefits to the power sector in terms of performance improvement, there are concerns about the additional cost leading to the rise of end-user tariffs. The overall intent of power sector reforms would have been defeated if decoupling hadn't happened. The idea of an unbundled power sector is to retain specific expertise in the three power subsectors and to ensure there is an independent and robust transmission network that serves as the anchor for the power sector (Eberhard & Godinho, 2017).

On the impact of the reforms on the power distribution subsector, the general position of the experts is that the recommendations of the committee on power sector reforms about the distribution subsector had not been implemented since they were made in the late1990s. The key recommendation was the horizontal unbundling or disintegration of the ECG in readiness for privatization, where five distributors were suggested to be formed out of ECG and together with NEDCo, to supply consumers with a load less than 5MW. In contrast, those consumers above this threshold would have an option to participate in the wholesale power market. Unfortunately, this hasn't been done more than two decades after the reforms. The power distribution subsector would have benefited from capital injection and enhanced operational performance leading to more competitive tariffs that benefit both consumers and the utilities.

6.5 Private sector participation in the power sector and public listing of state utilities

Private sector participation was only reflected in the form of Independent Power Producers (IPPs) in Ghana's power generation subsector (see Figure 6.1). The commonly agreed aspects by the experts are as follows:

- State monopolies control the transmission and distribution subsectors while the generation subsector has the involvement of IPPs. The IPPs have continued contributing significantly to the stock of Ghana's power generation capacity over the years.
- Regarding the absence of private sector participation in the other two subsectors, Ghana should open up its distribution subsector for private sector participation, but not the transmission subsector. This is because the power transmission network is a significant security asset of which the power sector is anchored, and for now, needs to be preserved as a state monopoly.
- Operatorship of the transmission network should therefore remain with the state monopoly (GRIDCo).

- The experts, however, emphasized the need for fair access to the network by all generators and off-takers depending on the connection agreements with GRIDCo and the regulatory standards being met.

On the power distribution subsector, the general agreements by experts are the following:

- ECG needed to be horizontally unbundled to create the space for concessionary arrangements in the subsector.
- While private sector involvement in the distribution subsector tends to invite more capital injection and reduce unnecessary state interferences, the experts argued that this can also lead to a more efficient distribution subsector.
- Consumers can expect improved and reliable power supply by adherence to efficiency by distribution companies (Discos) to remain competitive.
- Once incentives are in place to meet regulatory benchmarks, some anticipated benefits include reliable and uninterrupted power supply, competitive retail pricing of electricity, and the sharing of efficiency benefits.
- Because the management and organizational structures of NEDCo are still in their development stage, NEDCo should remain under the supervision and control of a bigger entity such as the VRA.

Regarding the listing of the Volta River Authority (VRA) - the state power generator and the Ghana Grid Company (GRIDCO) - the state power transmitter on the Ghana Stock Exchange (GSEs) as public entities as was mentioned in the 2017 budget statement and financial policy of the Government of Ghana, the experts viewed this as a step in the right direction. However, these were needed to be done in the foreseeable future. It was recommended that the state remained the single largest shareholder with a controlling stake in the case of GRIDCO, and the rest of the shareholding should be restricted to only Ghanaians. Accordingly, listing the VRA and GRIDCO on the stock exchange would ensure that the two agencies become more responsive as they play by the rules of the stock market. To make a successful listing and bring the benefits out of it, one expert stressed that inefficiency issues in the utilities must be first addressed. General government interference in the power sector needs to stop so that the right signals can be sent to the investing public.

6.6 Generation subsector

Table 6.3 provides Ghana's power generation installed capacity from 2010 to 2019 (EC, 2019).

Year	Hydro (MW)	Thermal (MW)	NCRE (MWp)	Total	% of Hydro	% of Thermal	% of NCRE
2010	1,180	985	-	2165	54.50	45.49	-
2011	1,180	990	-	2170	54.43	45.56	-
2012	1,180	1100	-	2280	51.75	48.24	-
2013	1,580	1248	2.5	2830.5	55.83	44.09	0.08
2014	1,580	1248	2.5	2830.5	55.83	44.09	0.08
2015	1,580	2053	22.6	3655.6	43.22	56.16	0.61
2016	1,580	2192	22.6	3794.6	41.63	57.77	0.59
2017	1,580	2785	22.6	4387.6	36.01	63.47	0.51
2018	1,580	3266	42.6	4888.6	32.32	66.80	0.87
2019	1,580	3549	42.6	5171.6	30.55	68.62	0.82

Table 6. 3: Power installed generation capacity of Ghana by source from 2010-2019

The hydro sources (Akosombo, Bui, and Kpone hydro dams) have served as the base load for Ghana over the years. But much of Ghana's power crisis has resulted from the dwindling fortunes of the hydro dams. Changes in climatic conditions have reduced inflows into the dams, reducing their capacity to produce electricity, much of which has occurred over the last decade. There has been a steady decline in the hydro component of the electricity mix from 54% in 2010, hydro declined to 30.55% in 2019. This challenge forced Ghana to diversify its power generation sources to include thermal. By 2015, thermal had overtaken hydro as the highest component of the generation mix. As can be seen from the table, the thermal component saw a sharp rise from 45.49% in 2010 to 68.62% in 2019. Ghana registered its first NCRE sources (mainly solar) as part of the generation mix in 2013. The effect of thermal registering the highest component of the generation mix is that it costs more to produce a kWh of electricity through thermal than through hydro. On the other hand, thermal plants have a low initial setup cost, and if fuels are available, they can run more smoothly and predictably than hydro. Thermal sources, therefore, provide a quick fix, especially for Ghana, still recovering from a power crisis.

Aside from the shift from hydro to thermal, which has contributed quite significantly to the cost of electricity generation in Ghana, the experts identified some more challenges confronting the power generation subsector which includes the following.

1. Irregular supply of fuels for thermal generation plants;
2. Inefficient operations of thermal generation plants;
3. Lack of a credible off-taker;
4. The increase VRA's debts;
5. Lack of investment in NCRE sources

Thermal plants in Ghana are faced with the challenge of not running at full capacity over the years due to the lack of availability of fuels. Under limited availability, the supplied fuels could be costly, which causes the high overall cost of power generation. For instance, gas supply in 2014 was limited to between 30 and 50 million standard cubic feet per day (mmscfd) as against the contractually agreed volume of 123 mmscfd from Nigeria to power Ghana's thermal plants. This caused the VRA (the state generator) to switch to more expensive crude oil (Eshun & Amoako-Tuffour, 2016; Ackah, et al., 2014). To solve the problem of limited fuel supply, the experts' common view is that, Ghana needed to put in place a gas commercialization plan that can harness Ghana's associated gas from the Jubilee field (Ghana's oil production site), and put in place the necessary infrastructure so that gas can be piped to the thermal plants sustainably for power generation. This will save Ghana of problems associated with the agreements for gas supply from Nigeria and further reduce the cost of electricity generation.

Also, the main concern for IPPs in Ghana's power generation subsector is the lack of credible off-takers. Since power cannot be stored once produced, there ought to be an assured and credible buyer when it is produced. The current off-takers are VRA (which act as a co-owner and off-taker), the ECG, NEDCo, and other licensed bulk customers. However, because VRA itself is also a competitor to the IPPs in the generation subsector, it is always unwilling to sign power purchase agreements (PPAs) with the IPPs. This is also because such PPAs affect VRA's financial viability as it must sell onwards to the distributors, which takes a considerable long time before such costs are recouped (Amoako-Tuffour & Asamoah, 2015).

The lack of credible off-takers affects the financial positions of the IPPs and does not enable them to improve their performance in further expanding their generation capacity to meet the production terms in the PPAs. Other IPPs are unlikely to consider the Ghanaian power generation market due to the lack of credible off-takers. The experts indicate that the off-taker challenge in the power sector can be addressed by ensuring the financial viability of the distributors. That ensures that end-user tariffs are competitive, and where the government introduces subsidies, the utilities should quickly receive full payment from the government. In addition, substantial financial resources can be unlocked if the distributors work towards improving their performance in order to reduce their technical and commercial losses.

Frequent shutdowns for repairs and maintenance of thermal plants causes their inefficiency. This significantly affects their throughputs and starves the generation subsector of the needed power to cater for the demand. In addition, most thermal plants in Ghana are set up in simple cycle modes instead of combined cycle modes. Simple-cycle plants only rely on gas turbines as the means of producing electricity. In contrast, combined-cycle plants use both gas and steam turbines, enabling them to produce 50% more electricity than simple-cycle plants. This implies that the thermal power plants in Ghana do not efficiently use their fuels. Two main solutions are proffered towards overcoming the inefficiency challenges of the generation plants. Firstly, the need to prioritize signing PPAs with IPPs whose plants are combined-cycle. Secondly, ensuring that simple-cycle plants that are capable of being converted into combined-cycle plants are converted. In addition, Ghana could also adopt a load dispatch policy that depends on the marginal cost of generation plants similar to Chile.

The VRA remains the hardest hit in Ghana's power sector financial challenges. VRA's debts as of 2017 stood at about 2.4 billion USD. Three main reasons account for the huge debts of VRA. First is the off-takers (ECG and NEDCo) not being credible, and the second is the power purchase agreements (PPAs) VRA enters. As an owner and off-taker, VRA caters for any shortfall arising out of electricity subsidies affecting the financial position of the VRA (Bokpe, 2016). For instance, in 2017, because of a tariff shortfall arising from the AMERI Plant Lease arrangement, the VRA incurred a cost of GH¢307.87 million (2016: GH¢281.69 million). This was supposed to be reimbursed by the Ghanaian Government but was never done (VRA, 2017). Because VRA's financial position is badly affected, it cannot invest further in developing more economic generation resources and increasing Ghana's installed capacity (Amoako-Tuffour & Asamoah, 2015). The third reason for VRA's debts is VRA's overhead and administrative cost. In VRA's annual report for 2017, the Authority acknowledged that it had reduced its administrative expenses by *'GH¢289.59 million (36.55%) from GH¢792.21 million in 2016 to GH¢502.62 million in 2017'*. This buttresses the point that the Authority recognizes administrative and overhead costs as part of the reasons for its huge indebtedness. To reduce the debts, the VRA needs to improve its cost efficiency and PPAs signed must ensure that the IPPs will not rely on the VRA for their fuels. This will save the VRA from using its limited resources to buy fuels for the IPPs.

Ghana's potential in the NCRE sources is huge. The solar potential is estimated at 35 EJ (exajoules), about 100 times the present power consumption. A wind speed of 9–9.9 m/s could sustain wind energy with an estimated gross potential of 2000 MW (Eshun & Amoako-Tuffour, 2016). The NCRE sources haven't played any significant role in the generation mix over the years. The following reasons account for Ghana's inability to exploit its potential in the NCREs:

- The initial setup cost is high.
- Investible funds are not readily available to exploit this potential.
- It takes longer time to build.
- The private sector does not find the NCREs attractive.
- It is unsustainable all year round.

Despite the initial cost of setting up and inconsistencies mainly due to weather patterns, in the medium to long-term, the experts believe that the NCREs remain a viable option Ghana has to pursue vigorously to diversify the generation mix. A policy on generation benefits can be developed to serve as a basis for convincing investors to go into the NCREs. The private sector can also be supported with subsidies to exploit Ghana's potential in renewable power generation. There are long-term benefits in reducing costs both in power generation and end-user tariffs. Developing the NCREs sector can also enable Ghana to create stand-alone off-grid plants that can cater for the needs of rural communities and some households. This will reduce pressure on the grid and make electricity readily available to electricity-intensive industries.

6.7 Transmission subsector

Ghana’s transmission network is divided into southern network and northern network. The southern network comprises four transmission areas: Akosombo, Volta, Takoradi, and Prestea. The northern network has three transmission areas: Kumasi, Techiman, and Tamale.

GRIDCo has the national transmission center (NTC), which is responsible for managing the transmission network and dispatching load and billing. Ghana’s transmission network follows specific rules and guidelines known as the GRID CODE. In the GRID CODE, the transmission voltage is specified and the level of power that a generator can be hooked onto the national grid. GRIDCOs primary transmission voltage in Ghana is 161kv. Meanwhile, GRIDCo transmits at other voltages of 59kv and 225k. A 330kv line is currently under construction to make the 330kv the standard transmission voltage in the foreseeable future.

The experts provided the following seven weaknesses confronting Ghana’s transmission subsector:

1. High transmission losses;
2. Low transmission voltage;
3. Differences in supplying to different capacities of distribution stations;
4. Encroachment of transmission pathways and destruction of transmission pylons;
5. Lack of standardization of transmission network assets;
6. Lack of enough generation reserve margin resulting in interruptions in the network;
7. Redundancies.

Even though Ghana is working towards replacing the current transmission voltage of 161kv with a transmission voltage of 330kv, this will not entirely address the weaknesses as in some countries, transmission voltages are as high as 500kv and 700kv, which makes the transmission system more robust. The main reason for the high transmission losses in Ghana is the low transmission voltage coupled with the fact that the transmission subsector has relied on legacy infrastructure dating back to more than 30 years. The infrastructure has become obsolete, and coupled with a low standard transmission voltage of 161kv, Ghana's transmission losses continue to hover between 5% and 6% as against an industry benchmark of 1.5% (PURC transmission benchmark is 3.5%).

Aside from the legacy infrastructure and the low transmission voltage, some other specific causes of the high transmission losses in Ghana are listed below:

- According to ET1, Ghana's power generation sources are primarily located in the south of Ghana. So, to supply load centres in the north, for instance, power has to be transmitted over long distances resulting in losses;
- ET2 indicates that during power transmission, some unavoidable heat is caused in the process. Because Ghana's transmission lines are obsolete and with inappropriate conductor sizes, the transmission losses tend to be high;
- Again, ET2 indicates that there is the phenomenon of radiation and electro-magnetic field which is produced around the conductors during power transmission. Its relationship with the atmosphere, therefore, results in the consumption of power, resulting in losses;
- All the transmission subsector expert admits that some of the transmission losses result from GRIDCo's own poor maintenance culture.

According to ET3*, 'because GRIDCo isn't so sound financially, the Ghana government relies on donors to acquire some machinery and equipment for power transmission, which sometimes results in the acquisition of sub-standard machinery and equipment'*. Donor support has helped address some of the challenges of the subsector. However, the difficulty lies in standardization and maintenance. There are differences in standards and specifications depending on which country is donating the transmission assets. This also means that the applications of different technologies primarily differentiate the maintenance regimes and protocols.

To overcome the technical challenges, the following solutions are proffered by the experts:

- There is a need to accelerate upgrading the transmission network infrastructure. That is ensuring that the 161kv lines are eliminated and replaced with the 330kv lines;

- There is the need to change all single circuit conductors to double circuits to make the network robust to reduce transmission losses;
- There is also the need for deployment of thermo vision equipment's that can be used to monitor hot spots at joints, with the view to eliminating them;
- To address the issue of technical capacity of staff, the experts recommended more funding in the area of training;
- To avoid redundancies that lead to interruptions in the transmission network, a ring system must be built across the entire transmission network;
- IPPs and the state power generators should be encouraged to build more generation plants closer to load centres across the country;
- Ghana should augment its generation capacity to make for a reserve margin of 30% to prevent network interruptions when generation plants are shut for maintenance.

It was gathered from the experts that GRIDCo is plagued with debts that are caused by debts owed by the two leading bulk distributors (ECG and NEDCo). Due to GRIDCo's financial challenges, it has not been unable to undertake some critical transmission subsector projects it has lined up over the last decade, which are expected to cost approximately 500 million USD. There are also human resource challenges at GRIDCo, which are also tied to financial difficulties. Funds are not available readily to support staff's continuous professional development towards enhancing their technical competence in a fast-paced and technologically driven industry. Keeping up the pace requires continuous capacity building. Another challenge lies with delays in the procurement process which sometimes results in the persistence of faults since necessary approvals must be sought before an item can be purchased to fix even minor faults. The experts also highlighted those managers within its engineering divisions aside from their technical expertise and competence mostly lack managerial expertise, which can hamper the growth of the business as a limited liability company.

To overcome the financial and management challenges, a summary of suggestions from the experts are provided below:

- GRIDCo must have a business orientation as a truly limited liability company that doesn't only prioritize rendering of transmission services but to do so profitably;

- As part of the business orientation, persons coming into management roles must be competent both technically and management wise;
- GRIDCo must prioritize the professional development of its staff by putting in place a dedicated budget to serve the purpose;
- Also, with a comprehensive professional development plan, GRIDCo can attract funding from the donor community to serve the purpose of capacity building of the staff.

6.8 Distribution subsector

Ghana's power distribution network is divided into two halves. The Northern Electricity Distribution Company (NEDCo) covers about 60% of the total landmass of Ghana and caters to electricity distribution in the northern part of Ghana. Even though the Electricity Company of Ghana (ECG) covers just about 40% of Ghana's landmass, it supplies electricity to about 65% of Ghana's population. NEDCo also has standing agreements that supply electricity consumers across the borders of Ghana and Togo, and Ghana and Burkina Faso to the north of Ghana. The northern and southern distribution networks face similar challenges.

6.8.2 Challenges of the distribution network

NEDCo	ECG
Low customer density in northern Ghana (impossible to construct HV and MV lines)	Poor revenue collection resulting in huge debts
Unaffordable prevailing tariffs for customers for electricity due to poverty levels	Lack of coordination between the Ministry of Energy and the ECG under the Self-Help Electrification Programme (SHEP)
Ancient distribution network	Huge operating debts due to unpaid bills
Outages and network unreliability	Outages and network unreliability
Huge distribution losses	Huge distribution losses

Table 6.4: Challenges of the power distribution subsector

Even though the NEDCo catchment area covers about 60% of Ghana's landmass, it caters to about 40% of electricity consumers primarily within the low-income bracket of Ghana. This unfortunate situation impacts both the technical and financial viability of the company. That is the inability of the company to construct high and medium voltage lines because of the low population density and the electricity consumers' inability to pay for electricity tariffs leading to substantial loss of revenue. Meanwhile, the distribution network has seen tremendous load increases over the years without a corresponding upgrading of the network, causing the network to overstretch, leading to high technical losses.

The lack of coordination between ECG and Ghana's Ministry of Energy under its self-help electrification program (SHEP) has caused the state distribution utility huge revenue losses in the southern sector. This is because electricity is mostly extended to rural areas without the ECG being in the known. By the time the ECG gets to know, a considerable amount of power would have been consumed before metering started to take place. Also, one of the ECG significant challenges which have caused its considerable debts to the VRA lies in the fact that most government Ministries Departments and Agencies (MDAs) consume electricity without paying for it. This constitutes about 80% of the debts of ECG. It is reported that as of 2015, for instance, the Government of Ghana owed ECG GH¢ 950 million (approximately USD 200 million) in subsidies and non-payment of bills by state institutions, including the MDAs (Bokpe, 2016). The private sector and individuals also owed ECG some GH¢ 610 million (Bokpe, 2016). These debts have made it difficult for the distribution companies and the other institutions they owe, including the VRA, to meet their obligations to their suppliers within the power sector value chain.

While the public utilities regulatory commission (PURC) sets a regulatory benchmark of 21%, which is high given that the World Bank sets a benchmark of 14% (World Bank, 2009), average distribution losses are around 24% in Ghana. The losses are in two parts, that is technical losses which are caused by overloaded networks and the use of equipment that are obsolete and substandard, and non-technical losses which has to do with the use of power without being accounted for, either due to faulty meters or the Discos inability to deploy strategies that collects all their revenue.

The experts underscored several critical points that have to be pursued to curtail losses in Ghana's power distribution sub-sector:

- Technical losses can be reduced drastically if the needed investments are made to replace obsolete equipment's, buy conductors of appropriate sizes, transformers of appropriate capacity, etc.;
- To reduce non-technical losses, the experts indicated that meters could be kept far away from customers and all post-paid meters should be replaced with prepaid ones;

- Having replaced post-paid meters with prepaid, it will also mean that the utilities would cut costs on meter readings. These cost savings can be rechannelled into regular monitoring of installed meters to prevent tempering;
- The utilities will also have to prioritize establishing more substations to bring the power source closer to consumers. This is another way of reducing technical losses.

6.9 Summary

On the power sector structure, the major challenge highlighted has been the interferences of political authorities on the management of power sector institutions. Interferences have affected the independence of the institutions and rendered them relatively ineffective. The power sector experts recommended the need for appointed board members to have the security of tenure and the mandate to appoint CEOs or MDs for the power sector institutions. Once the boards appoint CEOs or MDs, they become accountable to the respective boards, a good corporate governance practice.

Ghana has not yet realized the intended benefits of the power sector reforms. Even though the generation subsector was liberalized for the involvement of IPPs, the IPPs still depend on the VRA in particular for their fuels to generate electricity. This dramatically compromised the competition that the presence of IPPs was supposed to create. In the transmission subsector, the reforms led to the decoupling of power transmission from power generation. This was considered acceptable because the transmission subsector needed independence to ensure fairness among industry players in an unbundled power sector. Since the reforms were mooted in the distribution subsector, horizontally unbundle ECG into strategic business units has not been achieved. This is mainly due to the poor performance management of the distribution subsector.

Besides challenges in the power sector's institutional management, operations, and activities, there are also financial and technical challenges. Financial challenges are primarily due to uncompetitive end-user tariffs and high commercial losses. Technical challenges were inefficiency in generation plants, with many thermal plants running in simple cycle mode resulting in a high cost of electricity generation. Ghana's physical transmission and distribution networks are based on legacy infrastructure, which has turned obsolete. Increased demand over the years has deepened these problems further

CHAPTER SEVEN

INTEGRATION OF PERFORMANCE IMPROVEMENT APPROACHES

7.1 Introduction

This chapter explores the integration of the three performance improvement approaches presented in the previous chapters: Data Envelopment Analysis (DEA), international benchmarking (IB), and the Delphi approach. This aims to provide further insights for the performance improvement of the power sector. The implications of the integration are addressed in the following three aspects from section 7.2 to 7.4. The first is the policy-making structure, institutional and regulatory framework improvement. The second is efficiency improvement specifically for the transmission and distribution subsectors. The third concerns the improvement of selected power sector indicators. Section 7.5 summaries' the chapter.

7.2 Policy making structure, institutional and regulatory framework improvement

The potential improvement aspects and actions in relation to policy making structure and regulatory framework improvement have been looked through with both the IB and Delphi results, previously presented separately. Policy-making structure and regulatory framework are two related aspects and one impacts on the other. These two aspects are explored individually in subsections 7.2.1 and 7.2.2.

7.2.1 Policy making structure

The IB provided the prevailing policy making and institutional structure of all the benchmarking countries in a general manner. Delphi discussed the policy-making and institutional structure specifically for Ghana with much detail, without any inputs from other similar countries' practices. Having compared the practices in Ghana to those in other IB countries, the identifiable best practices and best practices from the experts' perspectives are compared to put forward the suggestions for the improvement of Ghana's policy-making structure and institutional.

A problem identified in the Delphi is the risk of primarily political bureaucracies by the sector ministry influencing and driving national policies in the power sector in Ghana. To overcome this risk, learning can be made from the experiences of power sector reforms in the best performing countries through the results of IB. IB revealed that Brazil had put other layers, such as the National Council for Energy Policy (NCEP), and the Energy Research Council (ERC) to ensure that policy-making in the power sector is insulated from unnecessary politicization as much as possible. The NCEP is clothed with the mandate to formulate energy policies and serves as the advisory body to the Brazilian government on the optimal use of its energy resources. The ERC, on the other hand, develops and maintains a ten-year energy expansion plan, which is updated annually to allow the power sector to plan consecutive ten years with the updates year on year (Salcedo & Porter, 2013; Pereira, 2014).

Ghana's ministry of energy provides the general policy direction and the oversight and coordination required for policy implementation with Energy Commission (EC) playing an advisory role besides its main function. The problem of using EC in Ghana, unlike NCEP and ERC in Brazil is that EC is a technical regulator and playing an advisory role to the ministry at the same time is inappropriate and unlikely to be effective. To avoid the risk of leaving power sector policy-making in the hands of political bureaucrats, Ghana could create a state agency that combines the roles of the NCEP and ERC in Brazil as the first step.

7.2.2 Regulatory framework

Differences in power sector regulatory frameworks of countries are primarily informed by the type of model structures that exist in the countries. Based on the results of the IB, the model structure in South Africa, Botswana, and Trinidad and Tobago are integrated models, while those of Ghana, Chile, and Brazil are unbundled models. Unlike integrated models, unbundled models retain technical and managerial expertise in distinct power subsectors: generation, transmission, and distribution (Eberhard & Godinho 2017; Pollitt, 2004). Unbundled structures are most likely to have more elaborated regulatory frameworks than integrated structures. That is represented by having two or more regulatory institutions which are responsible for regulating various aspects of the power sector.

The integrated structures in South Africa, Botswana and T&T have a regulatory institution responsible for regulating the state monopoly that manages and operates all three subsectors. In an integrated structure, it's expected that expertise across the three functions are retained in the state monopoly. This also requires a large regulator with expertise, both technical and managerial, across the three functions to be effective in its regulatory responsibilities. Brazil's unbundled structure has the Brazilian Electricity Regulatory Agency (ANEEL) and Operador Nacional do Sistema Elétrico (ONS). ANEEL provides regulations across the three subsectors and ONS provide the technical regulations required for the maintenance of the transmission network (Cote & Langevin 2013). Chile has the Economic Load Dispatch Center (CDEC), which is responsible for regulating the generation-transmission system. At the same time, the National Energy Commission (CNE) is responsible for setting regulated distribution charges and the Superintendent of Prices of Electricity and Fuels (SEC) ensures adherence to technical standards and commercial regulations (Rudnick, 2009).

The regulatory institutions in Brazil and Chile are backed by appropriate legislation that ensures that they are truly independent and insulated from interferences. Ghana has the Public Utilities and Regulatory Commission (PURC) responsible for commercial regulations and the Energy Commission (EC) responsible for technical regulations. The challenges confronting the regulatory institutions border on poor regulatory governance, lack of regulatory independence, resource constraints and blurring mandates on the two institutions. The analyses of both the IB and Delphi approaches on the regulatory framework improvement confirm that Ghana's regulatory framework has similarities to those in Brazil and Chile. Ghana should continue maintaining the two regulatory institutions (PURC and EC). However, regulatory governance can improve by insulating them from governmental interferences and making them more independent through appropriate legislation similar to both of Brazil and Chile. Regulations can be also improved significantly if resource constraints among the regulatory institutions could be overcome. To avoid conflicts, there should be more clarity in the mandates of the two institutions as well as enhanced collaboration as identified among the regulatory institutions in Brazil and Chile.

7.3 Implications for the improvement of T&D efficiency performance

Specific power sector regulations can have implications for the efficient performance of T&D units. Even though the structure of Ghana's power sector is similar to Brazil and Chile, while Brazil and Chile have kept wholesale competitive power markets with predominantly private sector presence across the three subsectors, in Ghana, private sector participation is registered only in the generation subsector. Over the years, incentive-based regulations have been implemented in Brazil and Chile to create the competitive business environment required for performance improvement of power sector utilities (Farsi, Fetz & Filippini, 2007; Khalfallah, 2013, Jamison, 2007).

Brazil implements revenue and price cap regulations in its transmission and distribution subsectors. In both the T&D subsectors, transmission and distribution concessions are auctioned. In the transmission subsector, the revenue offered by the winner is supposed to cover the firm's investment, as well as its operational costs, its maintenance costs, and, eventually, its profit. Regulators in Brazil refer to this as Permitted Annual Revenue

(Receita Annual Permitida – RAP) (Serrato, 2008). The power distribution market in Brazil is structured along two levels. That is the regulated market and the free market. The regulated market serves the captive consumers, whereas the free market serves the large industrial consumers and others whose power demand will typically exceed the threshold of 5MW. The auction process for distributed power takes place only in the regulated market. Within a distribution concession, any premium and passed-on cost distribution companies may charge consumers on top of the wholesale auction price for electricity is regulated, making it a price cap. Once the auction process for the distribution subsector ends, retail consumers are bound to purchase their power from specific distribution companies (Discos) (Fiona et al., 2010).

In Chile, new regulated transmission investment is determined through a centralized process involving a holistic planning phase (the transmission 'trunk' study) and subsequent tendering. Transmission tariffs are negotiated between transmission asset owners (Transcos) and the users (Gencos and Discos). Chile also has three power markets: spot, regulated, and free markets. The regulated prices are paid by residential and other small consumers with less than 2 MW of consumption. These regulations are based on yardstick competition (principle of a model company). In yardstick competition, the firm's performance is benchmarked with other firms in the industry or with efficient firms in other regions. Based on the principle of yardstick competition, the final nodal prices for regulated customers in Chile consider the spot market price for electricity, the transmission cost or charge, and an added value for the distribution service (VAD). The VAD price is determined by optimizing a real distribution company treated as a model company which is then benchmarked against all the other distribution companies.

Based on the policy-making structure and regulatory framework proposed, efficiency in the T&D subsectors in Ghana can be markedly improved by adopting either the Brazilian or the Chilean model. From the Delphi analysis, the power sector experts generally agreed that the transmission subsector should continue to be managed and operated by the state monopoly. By adopting the Brazilian model, therefore, there will be no auctioning for transmission concessions, but revenue cap regulation could be introduced to improve the operational efficiency of GRIDCo. However, based on the Delphi approach, the experts recommended the horizontal unbundling or disintegration of the ECG in line with the recommendations of the power sector reforms. By adopting the Brazilian model for Ghana's distribution subsector, after concessions are bided for, electricity pricing for the regulated market should follow a price cap regulation towards improving the operational efficiency of the distribution companies. Both GRIDCo and the new distribution companies (Discos) can adopt DEA as an internal learning tool to improve their decision-making units' efficiency (DMUs). Afterwards, the Chilean model, yardstick regulation, which thrives on the principle of a model company maybe be implemented in the T&D subsectors. The DEA methodology can be used to design a model Transco and a model Disco. Performance of the real Transco in Ghana can be benchmarked against the model Transco before determining real transmission service charges. Also, the performance of the real Discos in Ghana can be benchmarked against the model Disco before the nodal prices of electricity for the consumer market is determined. The nodal price for electricity will consider three important factors. That is the spot market price for electricity, the transmission cost or charge, and the added value for distribution service charge (VAD).

7.4 Improving specific weaknesses identified in Ghana’s power sector

The power sector needs to focus on overcoming the weaknesses identified in IB with the assistance of detailed exploration and suggestions by the experts in Delphi as well as the results of DEA analysis. For Ghana’s power sector, the weaknesses compared to other peer countries include a high percentage of transmission and distribution (T&D) loss, low percentage of the population with access to electricity, high system interruptions duration in hours (SAIDI), relatively low average power generation to demand ratio, the relatively high ratio of average unit cost of electricity generation over average retail prices of electricity. Results from all the three approaches are considered here for improving the performance for each indicator.

7.4.1 Reducing T&D loss and improving SAIDI

Ghana had the highest T&D loss relative to the other benchmarking countries. The experts all agreed that a high transmission voltage is a major contributory factor to curtailing losses and interruptions in a transmission line. Power is lost due to the heating of transmission lines over long distances. To prevent losses, a high transmission voltage is required to drive power at high speed (Mehta & Mehta, 2005; Nunoo & Mahama, 2013). Ghana’s standard transmission voltage of 161kv is low when compared to Brazil (490kv), Botswana (400kv), South Africa (400kv), and Chile (300kv). Other factors causing the high losses and interruptions are obsolete T&D lines, inappropriate conductors’ sizes, substations being far from load centers, and load theft, which is the major cause of commercial losses. To curtail T&D losses and create a more robust network that reduces interruptions, Ghana must replace the 161kv standard transmission voltage with one that is much higher (over 300kv).

7.4.2 Improving the percentage of population with access to electricity and generation to demand ratio

Ghana recorded the second lowest population with access to electricity and generation to demand ratio relative to all the benchmarking countries except for Botswana. About 80% of Brazil's power needs come from hydro and other non-conventional renewable energy (NCREs) sources. This caters to the electricity needs of almost 90% of the total Brazilian population with access to electricity. Ghana can tap into its hydropower potential across the country and develop its solar and wind power potential. Rural communities in Ghana can be targeted with the NCRE sources to reduce the burden on the national grid. Again, this poses a financial investment challenge.

Almost 100% of Trinidad and Tobago electricity is sourced from associated gas in its oil and gas industry. This source is cheap and has continued to support its ammonia industry, making it the largest exporter of ammonia in the world. Thermal (oil and gas) sources dominate hydro in Ghana's electrical power generation mix. Ghana can continue taking advantage of this source, as an oil and gas producer by generating more electrical power to increase access to electricity by the general population and improve the demand to generation ratio. This will also ensure that cheap electrical power is supplied to industry, especially as Ghana is on the verge of welcoming a bauxite and iron ore industry.

7.4.3 Cost of electricity generation and retail prices of electricity

To achieve business sustainability in the long run, retail electricity prices need to cover the total cost of power generation and distribution. A wholesale competitive power market requires the improved efficiency constantly to be profitable.

In the absence of competition, especially in the T&D subsectors, state utilities tend to pile huge debts due to retail prices lagging behind the total cost of electricity generation. Apart from Brazil and Chile, retail prices for other countries are either lagging behind the total cost of power generation or the difference between the generation cost and retail price is very marginal in the case of Ghana. Brazil and Chile are private sector-led with a regulatory framework that is robust and insulated from unnecessary interference. The surest way to overcome uncompetitive pricing is to create a power sector that is competitive. In such case, the practices for improving performance would drive the efficiency leading to competitive prices which can be offered to customers.

7.5 Summary

This chapter explore the integration of the results and analysis of the three performance approaches for improving the performance of the national power sector of Ghana. The integration of IB and Delphi approaches has focused on the policy-making structure and regulatory framework through the confirmation of experts' views and suggestions and the best practices of benchmarking countries. The integration of the three approaches have led to the identification of best practices for efficiency improvement and reducing T&D losses. The general power sector performance, which is based on the IB quantitative indicators, could be improved by integrating the qualitative analysis of the IB and the Delphi approaches.

With the consideration of the results of all the three approaches, the efficiency performance of the T&D subsectors in Ghana could have been enhanced dramatically and effectively. This could be done through identified internal strong and weak units, peer-country's best practices, as well as specific policy and regulatory framework changes. The integration of all the three approaches is certainly providing more opportunities for the sector moving towards a more efficient sector.

Figure 7.1 presents a framework which summaries the integration of the three performance improvement approaches applied in this study for effective performance improvement of a national power sector.

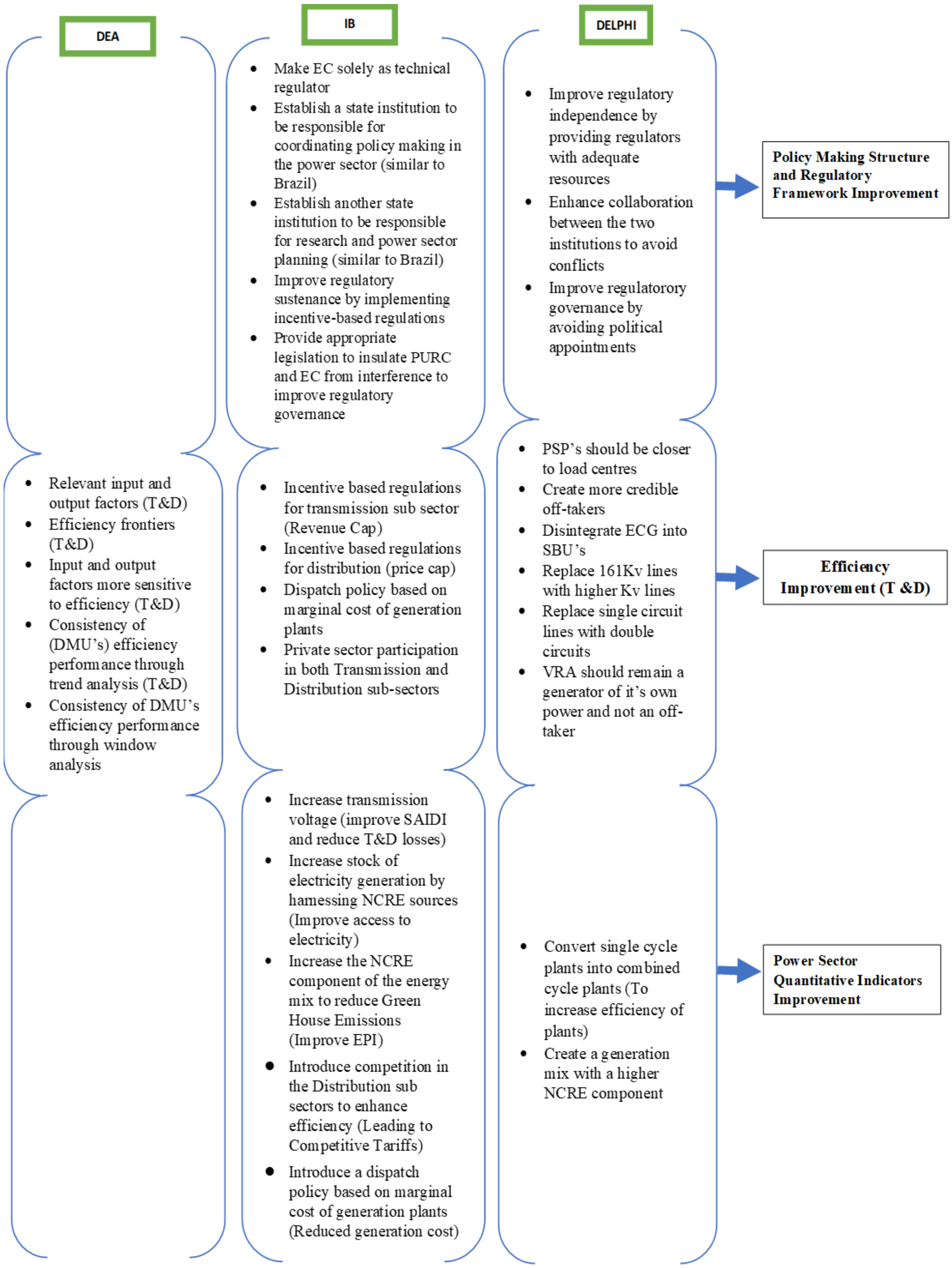

Figure 7.1: A framework for the integration of the performance improvement approaches for a national power sector

CHAPTER EIGHT

CONCLUSIONS

8.1 Introduction

This research has aimed to explore approaches to improving the performance of a national power sector, focusing on Ghana. This chapter summarizes the key findings of the study and provides conclusive discussions.

Section 8.2 summarizes the research design, and section 8.3 focuses on the key findings with the focus on their implications and applicability in a broad context. Section 8.4 presents the limitations of the research. Section 8.5 recommends further research areas.

8.2 Summary of research design

This study has adopted a multilevel-concurrent triangulation design within the mixed-method paradigm, of which the three broad approaches have been explored. Efficiency modelling and evaluation is the first approach. In particular, data envelopment analysis (DEA) was applied to the transmission and distribution subsectors in Ghana to provide relative efficiencies among decision-making units (DMUs) across several years, with selected input and output factors drawn from the literature and the factor selection method.

Identified relative efficiencies among DMUs in a sector or subsector can serve the purpose to reveal less efficient DMUs and facilitating learning and adaptation of practices internally to make improvements. The DEA modelling and evaluation consists of the following six steps after determining the DEA type to use: factor selection, weight allocation, efficiency evaluation, efficiency trend analysis, sensitivity analysis, and window analysis. This standard procedure has been applied to the subsectors of the Ghana's power sector.

International benchmarking (IB) is the second approach applied. By comparing the performance of Ghana and other similar countries across different indicators and different practices, best practices are identified. In particular, the IB approach has used the results of quantitative indicators to support the exploration and identification of qualitative best practices across the benchmarking countries. The identified best-performing countries based on the quantitative analysis conjunctionally with the qualitative analysis revealed best practices among the benchmarking countries. The integration of qualitative and quantitative benchmarking is a useful approach for identifying best practices for performance improvement.

The Delphi method is the third approach applied in the research. Collective perspectives of the Ghana's power sector experts have been gathered regarding the performance of the subsectors, practices, and the current policy and the institutional framework. The perspectives have been analyzed to reveal the agreed elements, such as challenges faced by the sector and subsectors, key issues associated, and suggestions for improvement to overcome the challenges.

The results from two or all three approaches are integrated at the final analysis stage of this research to explore the common themes from any two approaches and general areas for performance improvement from all the three approaches. This adds the confirmation and richness towards the improvement of the performance of Ghana's power sector. The explored common dimensions fall into the following general areas: policy, regulatory and institutional framework, efficiency improvement, and improvement of the general performance indicators.

8.3 Key findings and discussions

The major findings are threefold: an approach-based, Ghana's power sector performance specific, and suggestions for improvement of the performance of Ghana's power sector.

The findings for the approach-based are:

1. DEA is an effective approach to identify relative efficiencies among different decision or operation units for a power sector or subsector in a single year as well as the trends for their relative efficiencies over a number of years.

2. The IB approach, based on quantitative indicators, is a useful method to compare the performance of national power sectors to identify best-performing countries across a set of quantitative indicators. With the qualitative analysis of IB, best practices can be revealed across the benchmarking countries, which could be considered for the implementation to improve the performance of less performing countries, such as Ghana.

3. Delphi approach is an effective approach for analysing perspectives of the power sector experts across the key issues to identify challenges confronting the performance of a national power sector and subsectors. It is also useful to reveal the measures and suggestions that need to be implemented to overcome the challenges in order improve the national power sector performance.

4. The integration of the three-performance improvement approaches leads to identifying policy-making and regulatory framework improvement opportunities and actions through IB and Delphi approaches; improving efficiency performance through efficiency modelling and evaluation, IB and Delphi approach; improving the performance of the selected power sector performance indicators by integrating the IB and Delphi approaches**.**

The following presents major specific findings of the study on the power sector of Ghana:

1. There are more than single the most efficient DMUs for Ghana's power subsectors. The relative differences among these DMUs efficiency performance have been during the power crisis period.

2. Power sector institutions lacked independence, evidenced in the appointment systems of some principal officers and board members. In addition, the lack of security of tenure negatively affected planning and implementation of operational decisions to improve the sector's performance.

3. The failure in investing in renewable sources (hydro and non-conventional) for electricity generation in the sector has resulted in Ghana's generation mix shifting to thermal, leading to a rise in generation cost and end-user tariffs.

4. Even though Ghana's power sector was unbundled, the failure to introduce private sector participation in the distribution subsector has contributed to the poor performance of the sector.

5. Lack of investment in the infrastructure and technical personnel in the sector has saddled the power sector with obsolete infrastructure and inadequacy of technical expertise that continues to be one of the major challenges of the sector.

This study also identified and combined the following suggestions from the three approaches:

1. Promote internal learning among the transmission and distribution subsector DMUs to improve the efficiency of the less efficient DMUs, and thereby improve the overall efficiency of the transmission and distribution subsectors.

2. Amend the acts setting up the regulatory institutions to increase their level of independence and insulate them from any interference to improve regulatory

governance. The appointment of board members and CEOs should be non-political and must be driven by expertise and competence;

3. Introduce private sector participation into the distribution subsector by disintegrating the Electricity Company of Ghana (ECG) into strategic business units (SBUs) and introducing incentive-based regulations as a means to improve efficiency in the subsector;

4. Develop and implement a policy that comes with incentives to encourage the private sector to go into renewable (NCREs) energy generation;

5. Ensure competitive tariffs so that funds will be available to the utilities to support their expansion and investment plans;

DEA approach identified relative efficiencies among DMUs for both the transmission and distribution subsectors of Ghana’s power sector. Even though these results depended on the selected input and output factors used for the DEA modelling and evaluation, the results are valuable to identify the best and less performing DMUs in the subsectors where less efficient DMUs can learn from the relatively efficient ones or beyond. However, DEA does not identify best practices. Other approaches can be employed to facilitate this. DEA approaches are more than just presenting relative efficiencies among DMUs for a single year or over the years. It offers an analytical power through the sensitivity analysis on the impact of the absence of each input and output factor on the original efficiency results. This offers insights regarding whether an input or output factor is critical to the subsector in terms of the efficiency performance measures used.

Also, the relative efficiency trends can be revealed using both an efficiency trend analysis over the entire efficiency evaluation period or a window analysis to combine several years where appropriate to identify the effects of seasonal factors on the efficiency performance of DMUs.

In terms of the application of DEA to Ghana’s power sector, for both transmission and distribution subsectors, there was not just a single DMU that turned out as a frontier unit. Three DMUs remained the frontier units throughout the case of the transmission subsector. In contrast, at least seven DMUs out of fourteen were frontiers for the distribution subsector for all these investigation years. The power crisis period impacted the relative efficiency performance for DMUs in both the transmission and distribution subsectors. Less efficient DMUs fell far behind relatively.

For the transmission subsector, this could be attributed to the underutilization of transmission subsector assets such as the transformer capacity and the transmission lines due to a reduction in the power transmitted by this subsector over this period. In the case of the distribution subsector, this could be attributed to the lower power input into the distribution units as well as the underutilization of the subsector's assets, such as the transformer capacity.

The trend and window analysis reveals that the DMUs recorded their worst performance within the power crisis period, indicating that each DMU was affected individually negatively by the power crisis. The results also confirm the effectiveness of the DEA approach used to confirm the power sector crisis period. The efficiency modelling shows more sensitivity towards transformer capacity and the total number of bulk suppliers and bulk consumers served for the transmission subsector. This indicates that for efficiency evaluation in the transmission subsector, these two factors dominated this subsector's performance over the period. This implies that investment into right transformer capacity as well as developing more bulk suppliers and bulk customers could have given the more robust performance of the subsector.

For the distribution subsector, the efficiency modelling shows more sensitivity towards OPEX, the total amount of power billed, total power input, total transformer capacity, and a total number of technical Staff. This indicates that these factors dominated the distribution subsector's performance over the period for efficiency evaluation in the distribution subsector. Therefore, a more robust distribution subsector would depend on investments into effective billing mechanisms, the required amount of power being distributed to meet demand, transformer capacity, the technical staff, and OPEX to meet the cost of effectively managing a distribution utility.

By comparing the performance of the benchmarking countries along the set of quantitative indicators, IB analysis highlighted the best performer among the benchmarking countries on each indicator. With Ghana being the focus, the post-hoc test established the difference between Ghana and each country along all the indicators. The qualitative IB analysis reveals the best practices and Ghana could adopt to improve its power sector performance. The IB results showed that Ghana was the worst performer along all quantitative indicators except the percentage with access to electricity. For the percentage with access to electricity, Ghana performed just slightly better than Botswana.

The countries with lower annual T&D losses and lower system interruptions (SAIDI) were explained by their robust power network and higher standard transmission voltage in use by virtue of investment made in this area over the years. The countries with higher percentages of their national populations having access to electricity and meeting the power demand were associated with more effective and efficient planning and better leveraging on the power generation resources at their disposal. Ghana could develop its generation sources by creating a power sector generation plan that assesses its potential across the different power generation sources with the view of investing in sustainable and more cost-effective sources in the long run. Countries such as Brazil, Chile, and Ghana, two strong performers and one weak one, had pursued similar power sector reforms. The reforms affected the entire power sector in these three countries, reflecting the pursuit of the 'standard model'. However, Ghana's reforms had not brought intended results like other to countries.

Reforms changed the structure of the power sectors of the three countries from integrated to unbundled. An integrated structure has only one utility being mainly responsible for power generation, transmission, and distribution. An unbundled structure has separate utilities being responsible for managing the three subsectors (generation, transmission, and distribution). Reforms in the other benchmarking countries such as South Africa were only intended to restructure and strengthen their vertically integrated utilities.

The countries with an unbundled power sector structure have more private sector involvement across the three subsectors, except for Ghana. Ghana has private sector involvement only in the power generation subsector. Also, the countries with an unbundled structure and high level of private sector involvement across all subsectors achieved a breakeven where the average retail prices of electricity were above the cost of electricity generation. In countries without private sector involvement in transmission and distribution subsectors, regardless of the power sector structure, retail electricity prices tend to lag behind the cost of electricity generation. In those countries, once the national governments didn't offset the cost of subsidization, they accumulated debts in the sector. The power sector regulatory framework also depended on the power sector structure. For an integrated power sector, the existing regulatory framework was not as elaborate as those in the countries whose power sectors were unbundled with very high private sector involvement.

An integrated structure was likely to have one regulator responsible for the entire sector, while unbundled structures were likely to have separate regulators for the subsectors. The type of economic regulations also differed depending on the extent to which the private sector was involved. Countries with an integrated structure but limited private sector involvement pursued ‘cost-plus’ or ‘cost of service’ regulations while those with unbundled structures with high private sector involvement pursued incentive-based regulations.

Delphi's approach served as a valuable tool for pulling the experts’ collective views on various aspects of the power sector's challenges and how they could be overcome. The experts shared some views that were generally common across the different aspects. The two fundamental ones are the lack of institutional independence and overlapping mandates of the two regulatory institutions. Ghana could overcome the challenges by building strong legislation that insulates the regulatory institutions from political and governmental interferences. The utilities should also be preserved as corporate entities that observe good corporate governance practices, especially when appointing board members and CEOs. Because Ghana’s power sector structure follows the ‘standard model’ dictates, the two regulatory institutions (Energy Commission and Public Utilities and Regulatory Commission) can co-exist but require effective coordination and collaboration to improve regulatory governance.

Even though Ghana’s power sector reforms had made some positive impact on the power sector, the failure to horizontally unbundle the ECG into strategic business units towards the eventual involvement of the private sector has partly contributed to the lower performance of the power sector. The horizontal unbundling of the ECG could enhance the sector's competitiveness and attract private sector investment, leading to improved performance.

Ghana’s main generator (VRA) is saddled with huge debts, causing its inability to sustainably expand installed and generation capacity. This is due to the lack of credible off-takers in the power sector and the off-taker agreements which the VRA has been forced to sign over the years. Ghana’s policy of allowing IPPs to participate in the power generation subsector must be based on allowing only competitive IPPs and do not have to rely on the state generator (VRA) to do business. Also, the off-taker problems can be dealt with if the two main distributors can run effectively and efficiently by allowing ender-user tariffs to be competitive. Where subsidies are introduced, the state must be able to offset the cost of the subsidy.

To ensure the further financial viability of the VRA and the state transmitter (GRIDCo), Ghana could list both on the stock market so that they will be required to play by the rules of the market and accrue long-term capital to support their investment plans. Even though thermal sources are cheaper and easier to build, the shift from hydro as the dominant source to thermal has contributed to the current levels of relatively high tariffs in the power sector. Ghana's generation expansion plans must prioritize all hydro sources and other NCRE sources with the potential for power generation. These can contribute significantly to increasing electricity accessibility and bringing down end-user tariffs.

The integration of different performance approaches is a means of designing a process that can be implemented towards improving the performance of a national power sector more effectively. The integration of IB and Delphi approaches identified best practices that can be used to improve Ghana's policy, institutional structure, and regulatory framework. Also, applying the results from all three approaches, can improve the efficiency performance of the transmission and distribution subsectors in Ghana through learning and implementing best practices and overcoming challenges. The overall power sector performance can be improved by integrating the results from the quantitative and qualitative analysis of the IB and the Delphi approaches.

Brazil and Chile present the best examples regarding the policy and institutional structure for Ghana, giving the similarities among these three countries in terms of the structure of the power sector. Ghana's ministry of energy can continue providing oversight and coordination in the implementation of government policies to the power sector. However, in order not to leave policymaking in the hands of a political authority, Ghana needs to create an institution backed up by appropriate legislation to be responsible for advising the government on policymaking in the power sector and for the institution to be responsible for power generation planning and demand forecasting. This could be similar to the National Council for Energy Policy (NCEP) and Energy Research Council (ERC) in Brazil. Also, in terms of the regulatory framework challenges highlighted, Brazil and Chile's regulatory framework analyzed in the IB could offer best practices that Ghana could adopt.

The regulatory institutions are truly independent and derive their mandates from very robust legislations. But that is also because, in competitive power markets, the regulatory institutions must appear neutral to deliver their mandates effectively. The Energy Commission (EC) and Public Utilities Regulatory Commission (PURC) in Ghana must be insulated from governmental interference through legislations similar to the regulatory institutions in Chile and Brazil. Power sector regulations derived from the IB analysis, especially the ones in Chile and Brazil, if adopted and implemented, could affect both the technical and commercial aspects of the utilities, impacting on the efficiency performance of the T&D subsectors.

The results of the Delphi approach bordering on strengthening the T&D network are important areas of integration and the internal learning that must take place among the DMUs. Over the years, incentive-based regulations have been implemented in Brazil and Chile to create the competitive business environment required for performance improvement of power sector utilities. Incentive-based regulations use rewards and penalties to induce the utilities to achieve desired efficiency goals. Ghana could adopt price or revenue cap regulations as in the case of Brazil or yardstick regulation as in the case of Chile. The power sector utilities in Ghana will be required to commit to continuous improvement to meet the efficiency targets set by regulators. Once the efficiency goals are achieved, the gains should be shared between the utilities and consumers.

In terms of the general improvement in the performance of the general power sector indicators, the integration of the results of the three approaches identifies some important measures to be implemented. Ghana needs to replace its standard transmission voltage with a higher one to reduce T&D losses and system interruptions. Ghana must also replace its obsolete power sector infrastructure and build more substations to be closer to load centers as much as possible. These need financial investment and improved efficiency, and an effective medium to long-term plan is essential. With less power losses and interruptions in the network, a higher percentage of the national population can access electricity and meet the increased demand becomes possible. Ghana must leverage its potential in renewable energy (NCREs) sources and develop numerous dams with hydropower potential across the country. This would make Ghana's electrical power sufficient similar to Brazil, and at the same time reduce the cost of electricity generation. Rural communities in Ghana can be targeted with the NCRE sources to reduce the burden on the national grid.

Ghana can also improve efficiency in the generation subsector and further improve its score on EPI by targeting renewable sources, which will ensure that the energy sector does not adversely have a devastating impact on the environment. Also, a policy can be introduced whereby existing simple cycle plants will be required to convert to combined-cycle plants when possible. This can be the essential requirement for IPPs to enter the generation market. Ghana can also adopt a dispatch policy similar to Chile that depends on the marginal cost of generation plants. This will promote the efficient use and management of energy resources leading to less harm to the environment.

Apart from Brazil and Chile where retail prices were higher than the total cost of electricity generation, for the rest of the benchmarking countries, retail prices lagged behind the total cost and the difference was very marginal. Ghana can change the situation through developing a competitive power market to ensure the reduced state interference in the power market, especially when it comes to setting tariffs.

8.4 Limitations of the research

The limitations of this research are reflected in the dimensions of data availability, accessibility, and quality. Limitations could also be from the approaches selected for exploration. The limitations are discussed below, with justifications regarding how this research overcomes them to some degree.

8.4.1 Data availability and accessibility

Data availability and accessibility may restrict the level of exploration to any research, and there is no exception to this research. Data availability applies to all three approaches explored in this research. For the DEA approach, the factor selection requires the inclusion of many potential input and output factors as possible (cooper et al., 2000). However, the data availability restricts the number of potential input and output factors used in the DEA modelling. This research compensates this by identifying key input and output factors through the literature, and some of which were considered as potential input and output factors. The results of the DEA for the T&D subsectors, confirming the power sector crisis period, indicate the validity of the data used for this approach.

IB brought challenges including the indicators to be included due to the accessibility and availability of the data, identifying main practices across different countries, or even selected countries. None of the IB countries had a one-stop source where data on all the indicators could be collected. To overcome this limitation at some degree, various sources were consulted, both national and international, or sectional-based or published documents or governmental papers, as well as the use of data mining approaches.

A considerable long period was needed to collect interview data to apply the Delphi approach. Identifying experts, their expertise, and their availability brought enormous challenges. To overcome this, any chain effect of one interviewer leading to further engagement of experts was pursued. This is because some experts who were originally scheduled to be interviewed could not be interviewed by the schedule and alternative persons who fitted the profile and were willing to take part were interviewed.

8.4.2 Data quality

Data quality has several dimensions, including accuracy, timeliness, relevance, and reliability. The limitation of the data quality for this study is first, restricted in the timely dimension, as the quantitative data for the IB indicators were initially collected up to 2015. This is because the research started in 2015, and the data collected could only be up to the end of 2015, covering six years. However, the findings based on the IB approach remains relevant and beyond the year of the data period. For the other two approaches, efforts were made to extend the collection period up to 2017. It took a long time to collect these data due to the bureaucracies and protocols involved with collecting these kinds of data from state institutions.

Also, there is always the tendency to question the Delphi approach's scientific basis because of its subjective nature and the likelihood of bias. This may raise doubts about the quality of data collected. To overcome this, a total of twenty experts across different subsectors were consulted, which was a relatively large number based on the requirements of the Delphi approach. It is also worth noting that this is not a method to generate significant statistical results but looking for the richness of the content through the insights shared by the experts. The other limitation with the application of the Delphi approach is that the experts were all from Ghana’s power sector, which narrowed their perspectives to the peculiar situation of Ghana. If there was much time and resources, experts from other sectors could have been interviewed as well as from other countries to add an international perspective. However, as the study focuses on Ghana, Ghana’s experts' data need to be collected at first, even if an extended Delphi approach could have been pursued.

Overall, this study has explored all three approaches towards improving the performance of a national power sector by first recognizing that using one approach would have had its own inherent limitations, as indicated above for each approach. Secondly, the scope of such a study would have been narrowed to arrive at any useful conclusions for improving the performance of a national power sector. In that sense, the methodology for the study adopted the three approaches to ensure that the conclusions drawn cover the entire power sector to a large extent. By doing so, triangulating the results and the findings ensured that the strengths of another approach deal with the inadequacies of one approach, or confirmation of each other on some common aspects.

Since DEA is a linear programming model, there is always the flexibility of choice of input and output factors with increasing data availability so as long as they meet the requirements for inclusion (Lovell, 1993; Yang, 2013; Bowlin, 1998; Meenakumari & Kamaraj 2008). Irrespective of the number of data input and output factors available, the actual number to be included must obey the rule on the relationship between the number of DMUs and the number of input and output factors (Boussofiane et al., 1991).

On limitations of the IB, the significant insights provided by the qualitative data analysis validated the results of the quantitative analysis based on the best practices identified in the qualitative analysis. Also, the results from the other approaches have converged with the results of the Delphi approach. Perspectives shared by the experts were further backed up by some relevant literature on similar power sector related issues. The Delphi approach brought insiders' perspectives on Ghana's power sector, which is valuable regardless.

8.5 The way forward and further research areas

This research has achieved the aim of exploring approaches for improving national power sector performance. This research also generates the further research areas, which are relevant to this study but beyond its scope.

Research using DEA could be conducted for a comparative analysis of efficiency at subsector and sector levels across the benchmarking countries to broaden its horizon in comparison which is limited in the same country and sector or subsector. The selection of countries can follow the criterion used in selecting the international benchmarking countries for this study. It could also be done using a parametric efficiency model, such as the Stochastic Frontier Analysis (SFA), to generalize some different conditions across countries to focus on the efficiency improvement of operations. Parametric modelling may highlight the strengths and weaknesses of the sector and subsector in an international context.

DEA modelling and evaluation can be applied to the other power subsectors such as the power generation subsector when required data are available or accessible, as the current application of DEA was conducted was for the transmission and distribution subsectors. A planned DEA approach with the continuous data collection over a number of years can support continuous performance improvement of this sector. Less efficient units can attempt to emulate frontiers for improving their efficiency performance more effectively.

A further study can also explore different resources and possibilities of investing in Ghana's renewable energy sources. A long-term analysis of different energy sources in terms of their effectiveness, cost, and sustainability could add value to the sector's long-term development to meet the demand. More research is recommended to identify areas that can be leveraged effectively towards increasing the NCRE sources to contribute to the overall energy mix.

Performance improvement studies of other sectors, such as water, telecommunications and banking, can be carried out by employing multiple performance improvement approaches like this study. These sectors have similar structures as the power sector, and concerns for performance improvement and the underlying issues are the same. Integration of more than two approaches can add richness of the analysis and offer more options to be considered, leading to more robust recommendations for improving performance.

Putting forward further research areas is not for the purpose of exhausting all the research areas, but for achieving further continuous improvement across other sectors aside the power sector. A planned approach for collecting structured data will add invaluable value to facilitate the research in the performance improvement approaches and beyond.

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APPENDIX I

RELATIVE EFFICIENCIES OF TRANSMISSION SUBSECTOR DMUS AND THEIR REFERENCE SETS

2010

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.900	0.685 DMU_3 0.394 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.758	0.750 DMU_3 0.062 DMU_6
DMU_5	0.688	0.332 DMU_3 0.085 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.812	0.276 DMU_3 0.156 DMU_6

2011

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.802	0.773 DMU_3 0.284 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.738	0.779 DMU_3 0.026 DMU_6
DMU_5	0.514	0.347 DMU_3 0.066 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.679	0.306 DMU_3 0.118 DMU_6

2012

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.827	0.756 DMU_3 0.305 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.743	0.777 DMU_3 0.028 DMU_6
DMU_5	0.406	0.341 DMU_3 0.074 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.675	0.307 DMU_3 0.116 DMU_6

2013

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.819	0.761 DMU_3 0.298 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.776	0.764 DMU_3 0.045 DMU_6
DMU_5	0.417	0.335 DMU_3 0.081 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.674	0.307 DMU_3 0.116 DMU_6

2014

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.578	0.931 DMU_3 0.086 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.775	0.765 DMU_3 0.044 DMU_6
DMU_5	0.426	0.331 DMU_3 0.086 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.557	0.347 DMU_3 0.066 DMU_6

2015

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.828	0.755 DMU_3 0.306 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.682	0.763 DMU_3 0.046 DMU_6
DMU_5	0.450	0.320 DMU_3 0.101 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.638	0.320 DMU_3 0.101 DMU_6

2016

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.815	0.764 DMU_3 0.295 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.639	0.783 DMU_3 0.022 DMU_6
DMU_5	0.419	0.335 DMU_3 0.082 DMU_6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.614	0.328 DMU_3 0.090 DMU_6

2017

DMU	RELATIVE EFFICIENCY	REFERENCE SETS
DMU_1	1.000	1.000 DMU_1
DMU_2	0.785	0.217 DMU_1 0.267 DMU_3 0.374 DMU_6
DMU_3	1.000	1.000 DMU_3
DMU_4	0.726	0.272 DMU1 0.233 DMU3 0.029 DMU6
DMU_5	0.436	0.034 DMU1 0.262 DMU3 0.087 DMU6
DMU_6	1.000	1.000 DMU_6
DMU_7	0.649	0.082 DMU1 0.162 DMU3 0.093 DMU6

APPENDIX II

RELATIVE EFFICIENCIES OF DISTRIBUTION SUBSECTOR DMUS AND THEIR REFERENCE SETS

2010

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	1.000	1.000 DMU_1	1.000	1.000 DMU_1	1.000
DMU_2	1.000	1.000 DMU_2	1.000	1.000 DMU_2	1.000
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	0.987	0.257 DMU_1 0.022 DMU_6 0.696 DMU_8 0.003 DMU_{12} 0.117 DMU_{13}	0.981	0.250 DMU_1 0.030 DMU_6 0.706 DMU_8 0.001 DMU_{12} 0.096 DMU_{13}	0.969
DMU_5	1.000	1.000 DMU_5	1.000	1.000 DMU_5	1.000
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	1.000	1.000 DMU_7	1.000	1.000 DMU_7	1.000
DMU_8	1.000	1.000 DMU_8	1.000	1.000 DMU_8	1.000
DMU_9	0.975	0.595 DMU_8 0.295 DMU_{12} 0.125 DMU_{14}	0.975	0.595 DMU_8 0.295 DMU_{12} 0.125 DMU_{14}	0.951
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	1.000	1.000 DMU_{11}	1.000	1.000 DMU_{11}	1.000
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	1.000	1.000 DMU_{13}	1.000	1.000 DMU_{13}	1.000
DMU_{14}	1.000	1.000 DMU_{14}	1.000	1.000 DMU_{14}	1.000

2011

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	1.000	1.000 DMU_1	1.000	1.000 DMU_1	1.000
DMU_2	1.000	1.000 DMU_2	1.000	1.000 DMU_2	1.000
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	0.942	0.187 DMU_1 0.064 DMU_2 0.271 DMU_6 0.321 DMU_8 0.244 DMU_{12}	0.922	0.145 DMU_1 0.149 DMU_2 0.185 DMU_6 0.406 DMU_8 0.163 DMU_{12}	0.869
DMU_5	1.000	1.000 DMU_5	0.941	0.008 DMU_1 0.273 DMU_2 0.640 DMU_8	0.941
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	0.954	0.077 DMU_1 0.043 DMU_2 0.662 DMU_8	0.954	0.077 DMU_1 0.043 DMU_2 0.662 DMU_8	0.911
DMU_8	1.000	1.000 DMU_8	1.000	1.000 DMU_8	1.000
DMU_9	0.884	0.595 DMU_8 0.295 DMU_{12} 0.125 DMU_{14}	0.884	0.619 DMU_8 0.163 DMU_{12}	0.781
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	1.000	1.000 DMU_{11}	1.000	1.000 DMU_{11}	1.000
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.951	0.016 DMU_1 0.007 DMU_6 0.802 DMU_{10} 0.137 DMU_{12}	0.950	0.015 DMU_1 0.015 DMU_6 0.764 DMU_{10} 0.159 DMU_{12}	0.903
DMU_{14}	0.964	0.003 DMU_1 0.172 DMU_{10} 0.021 DMU_{11} 0.828 DMU_{12}	0.977	0.187 DMU_{10} 0.008 DMU_{11} 0.833 DMU_{12}	0.942

2012

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	1.000	1.000 DMU_1	1.000	1.000 DMU_1	1.000
DMU_2	1.000	1.000 DMU_2	1.000	1.000 DMU_2	1.000
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	1.000	1.000 DMU_4	0.922	0.145 DMU_1 0.149 DMU_2 0.185 DMU_6 0.406 DMU_8 0.163 DMU_{12}	0.922
DMU_5	0.927	0.094 DMU_1 0.233 DMU_4 0.389 DMU_6 0.008 DMU_{10}	0.941	0.008 DMU_1 0.273 DMU_2 0.640 DMU_8	0.873
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	0.975	0.429 DMU_4 0.193 DMU_6 0.063 DMU_8 0.124 DMU_{12}	0.954	0.077 DMU_1 0.043 DMU_2 0.662 DMU_8	0.930
DMU_8	1.000	1.000 DMU_8	1.000	1.000 DMU_8	1.000
DMU_9	0.988	0.355 DMU_4 0.115 DMU_6 0.561 DMU_{12}	0.884	0.619 DMU_8 0.163 DMU_{12}	0.874
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	0.965	0.003 DMU_1 0.024 DMU_4 0.409 DMU_{10} 0.460 DMU_{12}	1.000	1.000 DMU_{11}	0.965
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.977	0.008 DMU_3 0.009 DMU_6 0.720 DMU_{10} 0.436 DMU_{12}	0.950	0.015 DMU_1 0.015 DMU_6 0.764 DMU_{10} 0.159 DMU_{12}	0.928
DMU_{14}	1.000	1.000 DMU_{14}	0.980	0.187 DMU_{10} 0.008 DMU_{11} 0.833 DMU_{12}	0.980

2013

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	1.000	1.000 DMU_1	1.000	1.000 DMU_1	1.000
DMU_2	0.980	0.386 DMU_1 0.487 DMU_3 0.169 DMU_4 0.073 DMU_6	0.986	0.414 DMU_1 0.474 DMU_3 0.122 DMU_4 0.085 DMU_6	0.967
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	1.000	1.000 DMU_4	1.000	1.000 DMU_4	1.000
DMU_5	1.000	1.000 DMU_5	0.965	0.198 DMU_4 0.371 DMU_6 0.325 DMU_8	0.965
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	1.000	1.000 DMU_7	1.000	1.000 DMU_7	1.000
DMU_8	1.000	1.000 DMU_8	1.000	1.000 DMU_8	1.000
DMU_9	1.000	1.000 DMU_9	1.000	1.000 DMU_9	1.000
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	1.000	1.000 DMU_{11}	1.000	1.000 DMU_{11}	1.000
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.942	0.008 DMU_6 0.747 DMU_{10} 0.128 DMU_{11} 0.257 DMU_{12}	0.934	0.020 DMU_6 0.304 DMU_{10} 0.472 DMU_{11} 0.349 DMU_{12}	0.880
DMU_{14}	0.925	0.001 DMU_3 0.125 DMU_{11} 0.976 DMU_{12}	0.933	0.138 DMU_{11} 0.960 DMU_{12}	0.862

2014

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	0.992	1.007 DMU_3 0.018 DMU_4 2.344 DMU_{12}	0.990	0.996 DMU_3 0.038 DMU_4 2.314 DMU_{12}	0.982
DMU_2	0.844	0.921 DMU_3 0.050 DMU_4 0.468 DMU_{12}	0.839	0.899 DMU_3 0.087 DMU_4 0.419 DMU_{12}	0.708
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	1.000	1.000 DMU_4	1.000	1.000 DMU_4	1.000
DMU_5	0.955	0.365 DMU_4 0.385 DMU_6 0.035 DMU_8 0.206 DMU_{12}	0.937	0.334 DMU_4 0.341 DMU_6 0.179 DMU_8	0.895
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	1.000	1.000 DMU_7	1.000	1.000 DMU_7	1.000
DMU_8	1.000	1.000 DMU_8	1.000	1.000 DMU_8	1.000
DMU_9	1.000	1.000 DMU_9	1.000	1.000 DMU_9	1.000
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	0.907	0.007 DMU_6 0.341 DMU_{10} 0.744 DMU_{12}	0.903	0.010 DMU_6 0.325 DMU_{10} 0.754 DMU_{12}	0.819
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.898	0.002 DMU_3 0.881 DMU_{10} 0.366 DMU_{12}	0.924	0.020 DMU_6 0.304 DMU_{10} 0.472 DMU_{11} 0.349 DMU_{12}	0.830
DMU_{14}	1.000	1.000 DMU_{14}	1.000	1.000 DMU_{14}	1.000

2015

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	1.000	1.000 DMU_1	1.000	1.000 DMU_1	1.000
DMU_2	0.742	0.021 DMU_1 0.635 DMU_3 0.199 DMU_6 0.258 DMU_{12}	0.739	0.035 DMU_1 0.542 DMU_3 0.334 DMU_6 0.109 DMU_{12}	0.548
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	1.000	1.000 DMU_4	1.000	1.000 DMU_4	1.000
DMU_5	0.883	0.229 DMU_4 0.245 DMU_6 0.683 DMU_{10}	0.883	0.229 DMU_4 0.245 DMU_6 0.683 DMU_{10}	0.779
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	0.994	0.102 DMU_8 0.380 DMU_9 0.750 DMU_{10} 0.060 DMU_{12}	0.974	0.319 DMU8 0.068 DMU_9 0.755 DMU_{10} 0.077 DMU_{12}	0.968
DMU_8	1.000	1.000 DMU_8	1.000	1.000 DMU_8	1.000
DMU_9	1.000	1.000 DMU_9	1.000	1.000 DMU_9	1.000
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	0.974	0.415 DMU_{10} 0.782 DMU_{12}	0.971	0.411 DMU_{10} 0.789 DMU_{12}	0.945
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.896	0.011 DMU_6 0.981 DMU_{10}	0.890	0.025 DMU_6 0.949 DMU_{10}	0.797
DMU_{14}	1.000	1.000 DMU_{14}	1.000	1.000 DMU_{14}	1.000

2016

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	0.874	0.720 DMU_3 0.241 DMU_6 0.221 DMU_{13}	0.871	0.714 DMU_3 0.252 DMU_6 1.714 DMU_4	0.761
DMU_2	1.000	1.000 DMU_2	1.000	1.000 DMU_2	1.000
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	1.000	1.000 DMU_4	1.000	1.000 DMU_4	1.000
DMU_5	1.000	1.000 DMU_5	1.000	1.000 DMU_5	1.000
DMU_6	1.000	1.000 DMU_6	1.000	1.000 DMU_6	1.000
DMU_7	1.000	1.000 DMU_7	1.000	1.000 DMU_7	1.000
DMU_8	0.947	0.186 DMU_3 0.339 DMU_7 0.887 DMU_{12}	0.947	0.186 DMU_3 0.339 DMU_7 0.887 DMU_{12}	0.896
DMU_9	0.961	0.038 DMU_3 0.024 DMU_6 0.381 DMU_7 0.761 DMU_{12}	0.961	0.038 DMU_3 0.024 DMU_6 0.381 DMU_7 0.761 DMU_{12}	0.924
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	1.000	1.000 DMU_{11}	1.000	1.000 DMU_{11}	1.000
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	1.000	1.000 DMU_{13}	1.000	1.000 DMU_{13}	1.000
DMU_{14}	1.000	1.000 DMU_{14}	1.000	1.000 DMU_{14}	1.000

2017

DMU	Technical Efficiency	Technical Efficiency Reference Sets	Allocative Efficiency	Allocative Reference Sets	Cost Efficiency
DMU_1	0.947	0.867 DMU_3 0.260 DMU_5	0.947	0.835 DMU_3 0.326 DMU_5	0.897
DMU_2	0.996	0.433 DMU_3 0.794 DMU_5 0.653 DMU_{12}	0.996	0.434 DMU_3 0.793 DMU_5 0.654 DMU_{12}	0.991
DMU_3	1.000	1.000 DMU_3	1.000	1.000 DMU_3	1.000
DMU_4	0.837	0.251 DMU_3 0.199 DMU_5 0.385 DMU_7 0.216 DMU_{14}	0.837	0.251 DMU_3 0.199 DMU_5 0.385 DMU_7 0.216 DMU_{14}	0.700
DMU_5	1.000	1.000 DMU_5	1.000	1.000 DMU_5	1.000
DMU_6	0.971	0.654 DMU 3 0.256 DMU 7 0.535 DMU 14	0.971	0.654 DMU_3 0.256 DMU_7 0.535 DMU_{14}	0.942
DMU_7	1.000	1.000 DMU_7	1.000	1.000 DMU_7	1.000
DMU_8	0.978	0.178 DMU_3 0.282 DMU_7 1.194 DMU_{14}	0.978	0.178 DMU_3 0.282 DMU_7 1.194 DMU_{14}	0.957
DMU_9	0.973	0.056 DMU_3 0.030 DMU_5 0.284 DMU_7 0.628 DMU_{11}	0.973	0.056 DMU_3 0.030 DMU_5 0.284 DMU_7 0.628 DMU_{11}	0.946
DMU_{10}	1.000	1.000 DMU_{10}	1.000	1.000 DMU_{10}	1.000
DMU_{11}	1.000	1.000 DMU_{11}	1.000	1.000 DMU_{11}	1.000
DMU_{12}	1.000	1.000 DMU_{12}	1.000	1.000 DMU_{12}	1.000
DMU_{13}	0.828	0.022 DMU 3 0.283 DMU 10 0.425 DMU 11 0.133 DMU 14	0.833	0.019 DMU_3 0.315 DMU_{10} 0.405 DMU_{11} 0.132 DMU_{14}	0.690
DMU_{14}	1.000	1.000 DMU_{14}	1.000	1.000 DMU_{14}	1.000

APPENDIX III

RESULTS OF ANOVA FOR INTERNATIONAL BENCHMARKING INDICATORS

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	15.865	1.48816	0.000
	Brazil	-29.095	1.48816	0.000
	Chile	-29.34667	1.48816	0.000
	South Africa	-14.6	1.48816	0.000
	T & T	-29.63333	1.48816	0.000

Results of Tukey HSD post-hoc test for percentage of the population with access to electricity

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	7.77333	0.8124	0.000
	Brazil	-2.76333	0.8124	0.021
	Chile	3.63333	0.8124	0.001
	South Africa	9.26167	0.8124	0.000
	T & T	9.63267	0.8124	0.000

Results of Tukey HSD post-hoc test for average e retail prices of electricity

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	17.34167	0.71207	0.000
	Brazil	10.91167	0.71207	0.000
	Chile	20.85833	0.71207	0.000
	South Africa	18.89167	0.71207	0.000
	T & T	22.50833	0.71207	0.000

Results of Tukey HSD post-hoc test for percentage of T&D losses

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	10.29167	5.00341	0.336
	Brazil	-5.345	5.00341	0.89
	Chile	-14.52667	5.00341	0.068
	South Africa	-1.75167	5.00341	0.999
	T & T	-2.23333	5.00341	0.998

Results of Tukey HSD post-hoc test for Environmental Performance Index

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	-7.36621	0.35735	0.000
	Brazil	1.19158	0.35735	0.025
	Chile	0.25432	0.35735	0.979
	South Africa	-0.01407	0.35735	1.000
	T & T	-4.47264	0.35735	0.000

Results of Tukey HSD post-hoc test for levelized cost of electricity

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	109.475	22.61895	0.000
	Brazil	220.48333	22.61895	0.000
	Chile	232.6	22.61895	0.000
	South Africa	196.95833	22.61895	0.000
	T & T	231.90667	22.61895	0.000

Results of Tukey HSD post-hoc test for average outages of electricity

(I) Country Name	(J) Country Name	Mean Difference (I-J)	Std. Error	Sig.
Ghana	Botswana	0.75667	0.14397	0.000
	Brazil	-0.37833	0.14397	0.121
	Chile	-0.46833	0.14397	0.031
	South Africa	0.15167	0.14397	0.896
	T & T	-0.41	0.14397	0.077

Results of Tukey HSD post-hoc test for generation to demand ratio

APPENDIX IV

DATA SOURCES FOR INDICATORS

Country Name	Data Year	Source
Botswana	2010-2015	Botswana Power Corporation (2017) 2017 Annual Report
Brazil	2010-2015	Agora Energiewende & Instituto E+ Diálogos Energéticos (2019): Report on the Brazilian Power System
Chile	2010-2015	National Energy Commission (CNE), 2015 ENERGY STATISTICAL YEARBOOK CHILE
Ghana	2010-2015	Energy Commission of Ghana, NATIONAL ENERGY STATISTICS 2017 Revised Report
South Africa	2010-2015	Eskom Tariffs and Charges, Historical average prices and increase_v20200115_13h00
Trinidad and Tobago	2010-2015	Inter-American Development Bank (2016) Energy Dossier: Tobago & Trinidad

Data Sources for average retail prices indicator

<table>
<tr><th>Country Name</th><th>Data Year</th><th>Source</th></tr>
<tr><td>Botswana</td><td rowspan="6">2010-2015</td><td rowspan="6">World Bank Global Electrification Database from "Tracking SDG 7: The Energy Progress Report" led jointly by the custodian agencies: the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), the United Nations Statistics Division (UNSD), the World Bank and the World Health Organization (WHO).</td></tr>
<tr><td>Brazil</td></tr>
<tr><td>Chile</td></tr>
<tr><td>Ghana</td></tr>
<tr><td>South Africa</td></tr>
<tr><td>Trinidad and Tobago</td></tr>
</table>

Data sources for percentage of population with access to electricity

Country Name	Data Year	Source
Botswana	2010-2015	Botswana Power Corporation (2017) 2017 BPC Annual Report
Brazil	2010-2015	**Installed Capacity** Brazilian Energy Balance 2018 Year 2017 / Empresa de Pesquisa Energética – Rio de Janeiro: EPE, 2018
	2010	**Peak Demand** Ministério De Minas E Energia Secretaria De Energia Elétrica Departamento De Monitoramento Do Sistema Elétrico (2010)
	2011-2013	**Peak Demand** EPE 2016 Statistical Yearbook of electricity 2015 baseline year (2016)
	2014	**Peak Demand** Ministério De Minas E Energia Secretaria De Energia Elétrica Departamento De Monitoramento Do Sistema Elétrico (2014)
	2015	**Peak Demand** Ministério De Minas E Energia, EPE 2020 Statistical Yearbook of electricity 2019 baseline year
Chile	2010-2015	National Energy Commission (CNE), 2015 Energy Statistical Yearbook Chile
Ghana	2010-2015	Energy Commission of Ghana, National Energy Statistics 2017 Revised Report
South Africa	2010-2015	Eskom (2018) Eskom Integrated Report 2018
Trinidad and Tobago	2010-2015	Inter-American Development Bank (2016) Energy Dossier: Tobago & Trinidad

Data sources for generation to demand ratio

Country Name	Data Year	Source
Botswana	2010-2015	
Brazil	2010-2015	Terra; ANEEL (2020) Indicadores Coletivos de Continuidade (DEC e FEC)
Chile	2010-2011	CDEC SING (2016) Mejoramiento Continuo de los Procesos Vinculados a la Operación Económica y Segura del SING
	2012	Calidad y confiabilidad de los servicios eléctricos en América Latina / Alberto Levy, Juan José Carrasco. p. cm. — (Monografía del BID ; 809)
	2013-2015	División de Ingeniería en Electricidad- SEC (2018)
Ghana	2015	Energy Commission of Ghana, NATIONAL ENERGY STATISTICS 2017 Report MCC (2014) The Millennium Challenge Corporation (2014)
South Africa	2010-2015	Eskom (2018) Eskom Integrated Report 2018
Trinidad and Tobago	2010-2014	T&TECs (2014) Annual Performance Indicator Report Final 2014
	2015	T&TECs (2015) Annual Performance Indicator Report Final Revision

Data sources for average duration of power interruption

<table>
<tr><th>Country Name</th><th>Data Year</th><th>Source</th></tr>
<tr><td>Botswana</td><td rowspan="6">2010-2015</td><td rowspan="2">2010 & 2011 Source
Emerson, J., D. C. Esty, M.A. Levy, C.H. Kim, V. Mara, A. de Sherbinin, and T. Srebotnjak. 2010. 2010 Environmental Performance Index. New Haven: Yale Center for Environmental Law and Policy</td></tr>
<tr><td>Brazil</td></tr>
<tr><td>Chile</td><td rowspan="2">2012 & 2013 Source
Yale Center for Environmental Law and Policy, Yale University Center for International Earth Science Information Network, Columbia University EPI (2012)</td></tr>
<tr><td>Ghana</td></tr>
<tr><td>South Africa</td><td rowspan="2">2014 & 2015 Source
Hsu, A., J. Emerson, M. Levy, A. de Sherbinin, L. Johnson, O. Malik, J. Schwartz, and M. Jaiteh. (2014). The 2014 Environmental Performance Index. New Haven, CT: Yale Center for Environmental Law & Policy. Available: www.epi.yale.edu.</td></tr>
<tr><td>Trinidad and Tobago</td></tr>
</table>

Data sources for Environmental Performance Index

<table>
<tr><th>Country Name</th><th>Data Year</th><th>Source</th></tr>
<tr><td>Botswana</td><td rowspan="6">2010-2015</td><td rowspan="3">Wikipedia contributors. (2021, October 1). Cost of electricity by source. In Wikipedia, The Free Encyclopedia. Retrieved 09:32, October 7, 2021, from https://en.wikipedia.org/w/index.php?title=Cost_of_electricity_by_source&oldid=1047532885</td></tr>
<tr><td>Brazil</td></tr>
<tr><td>Chile</td></tr>
<tr><td>Ghana</td><td rowspan="3">IRENA (2020)

RENEWABLE POWER GENERATION COSTS IN 2019</td></tr>
<tr><td>South Africa</td></tr>
<tr><td>Trinidad and Tobago</td></tr>
</table>

Data Sources for Levelized cost of electricity

APPENDIX V

INTERVIEW GUIDE FOR THE POWER TRANSMISSION SECTOR

First of all, I would like to thank you for meeting me. My name is Abudu Abdul-Ganiyu, currently a doctoral candidate in Business Administration at Sheffield Business School, Sheffield Hallam University (UK) and Business School Netherlands. I am also a Senior Lecturer at Tamale Technical University. My doctoral thesis topic is "Approaches for Improving the Performance of a National Power Sector: An exploration for Ghana". My research intends to assess the perspectives of power sector experts across the generation, transmission, distribution and regulatory sectors. For the power transmission subsector, in particular, the aim is how the transmission utility can be efficient and effective to wheel the needed amount of power to various distribution areas, as Ghana's power consumption continues to increase.

You are one of the experts I have identified, and your input is extremely valuable to this research project and the future of Ghana's power sector. The interview should be no longer than an hour. I hope you do not mind for me to record our conversation as I can review them to ensure the contents, I will use for this research is accurate and complete to what I heard. I will also take notes to put down my thoughts and questions. Section "A" is concerned with yourself. Section "B" contains a set of the first line of open-ended questions. I may ask follow-up questions to each first line question if needed.

All responses shall be kept strictly confidential. Only coded contents will be used in my thesis without relating to each individual respondent. Your participation is greatly appreciated.

Are you willing to participate in this interview? Many thanks. Yes/NO

……………………….	………………………	……………………….
Interviewee	Witness	Date

Section A: (Demographic Information)

(1) Name of Respondent…………………………………..

(2) Name of Organization……………………………....

(3) Status or Rank…………………………………………..

(4) Sex of respondent (a) Male ☐ (b) Female ☐

(5) Age of respondent (a) Below 25 ☐ (b) 26-30 ☐

(c) 31- 35 ☐ ☐6-40 d) 41 -and above ☐

(6) Level of education (a) Diploma ☐ (b) HND ☐ (c) First Degree ☐

Masters ☐ (h) Doctorate ☐

(7) Number of years in service (a) 5 years or less ☐ (b) 6-10 ☐

(c)11-15 ☐ (c) Above 15 ☐

Section B: Interviewee questions

1 Can you provide an explanation or description of the nature of Ghana's power transmission network?
2 What constitutes the strengths of the current transmission network?
3 Are there any weaknesses of the current transmission network?
4 The decoupling of the power transmission from the power generation was one of the results of the power sector reforms in Ghana. Do you think whether this has benefited the nation? If year, what are benefits?
5 The Ghana Grid Company continues to record transmission losses in the neighbourhood of 5% currently. What do you think are the causes of these transmission losses?
6 What can be done to curtail these losses?
7 As a ten percent annual increase has been predicted in the power demand, do you think the current transmission network has the capacity to continue to meet the demand over the next ten years?
8 If no to question 7, what can be done to strengthen the transmission network to cater for the demand increases?
9 What do you think about the current state of Gridco? Are there any management and organizational challenges you consider requiring attention? What are they?
10 Can anything be done to make Gridco more effective and efficient as a transmission utility?

APPENDIX VI

INTERVIEW GUIDE FOR ACCESSING VIEWS OF POWER DISTRIBUTION EXPERTS

My name is Abudu Abdul-Ganiyu, currently a dual doctoral candidate in Business Administration at Sheffield Business School, Sheffield Hallam University (UK) and Business School Netherlands. I am also a Senior Lecturer at Tamale Technical University. My doctoral thesis topic is “Approaches for Improving the Performance of a National Power Sector: An exploration for Ghana”. I intend to assess the perspectives of power sector experts across the generation, transmission, distribution and regulatory sectors. For the power distribution sector, in particular, the aim is how the power distribution utilities can be managed to become efficient and effective in supplying power to all categories of power consumers connected to the national grid.

You are one of the experts I have identified, and your input is extremely valuable to this research project and the future of Ghana’s power sector. Section “A” is concerned with yourself. Section “B” contains a set of open-ended questions. You are required to write down your responses beneath question in much detail as you consider appropriate.

All responses shall be kept strictly confidential. Only coded contents will be used in my thesis without relating to each individual respondent. Your participation is greatly appreciated.

Are you willing to participate in this interview? Many thanks. Yes/NO

……………………….	………………………	……………………….
Interviewee	Witness	Date

Section A: (Demographic Information)

(1) Name of Respondent…………………………………..

(2) Name of Organization………………………………....

(3) Status or Rank…………………………………………..

(4) Sex of respondent (a) Male ☐ (b) Female ☐

(5) Age of respondent (a) Below 25 ☐ (b) 26-30 ☐ (c) 31- 35 ☐

(d) 36-40 ☐ d) 41 -and above ☐

(6) Level of education (a) Diploma ☐ (b) HND ☐ (c) First Degree ☐

Masters ☐ (h) Doctorate ☐

(7) Number of years in service (a) 5 years or less ☐ (b) 6-10 ☐

(c) 11-15 ☐ (c) Above 15 ☐

Section B: Interviewee questions

1. Can you provide a brief description of the nature of the power distribution network in Ghana?
2. What are the strengths of the current distribution network?
3. Are there any weaknesses of the distribution network?
4. What are the benefits of the long running power sector reforms in Ghana?
5. The ECG has recorded overall technical and non-technical losses around an average of 23% annually. What are the causes of this high percentage loss?
6. What can be done to reduce this loss?
7. Given an estimated increase of power demand by 10% annually, do you think the current distribution network has the capacity to continue to cater for any increases in load over the next ten years?
8. If not to question 7, what can be done to strengthen the distribution network to cater for the load increases?
9. What do you think about the current state of ECG/NEDCo? Are there some management and organizational challenges you think require attention?
10. What is your view about the financial viability of the ECG?
11. Do you support the attempts to bring in private sector participation in managing Ghana's power distribution network? Why?
12. Can anything be done to make the ECG/NEDCo more effective and efficient as a distribution utility?

APPENDIX VII

INTERVIEW GUIDE FOR ACCESSING THE VIEWS OF EXPERTS IN THE POWER POLICY AND REGULATORY SECTOR

My name is Abudu Abdul-Ganiyu, currently a dual doctoral researcher in Business administration at Sheffield Business School, Sheffield Hallam University (UK) and Business School Netherlands. I am also a Senior Lecturer at Tamale Technical University. My doctoral research topic is "Approaches for Improving the Performance of a National Power Sector: An exploration for Ghana". I intend to assess the perspectives of power sector experts across the generation, transmission, distribution and regulatory sectors. For the power policy and regulatory environment in particular, the aim is to collate views towards the best possible policy and regulatory environment Ghana can institute in managing the power sector in general. You are one of the experts I have identified whose perspectives would be of great significance towards achieving the goals of this research. Your help will be very valuable to this study.

Section "A" is concerned with yourself. Section "B" contains a set of open-ended questions, of which I may ask follow-up questions. All responses shall be kept strictly confidential. The coded contents will only be used in my study without relating to each respondent. Your participation in this study will be greatly appreciated.

Please, are you willing to participate in this interview? Yes/NO

……………………….	………………………	……………………….
Interviewee	Witness	Date

Section A: (Demographic Information)

(1) Name of Respondent…………………………………..

(2) Name of Organization……………………………....

(3) Status or Rank………………………………………..

(4) Sex of respondent (a) Male ☐ (b) Female ☐

(5) Age of respondent (a) Below 25 ☐ (b) 26-30 ☐ (c) 31- 35 ☐

(d) 36-40 ☐ d) 41 -and above ☐

(6) Level of education (a) Diploma ☐ (b) HND ☐ (c) First Degree ☐

Masters ☐ (h) Doctorate ☐

(7) Number of years in service (a) 5 years or less ☐ (b) 6-10 ☐

(c) 11-15 ☐ (c) Above 15 ☐

Section B: Interviewee questions

1. Can you please explain Ghana’s current power sector structure?
2. Are there any bottlenecks in the current structure you have explained?
3. Based on these bottlenecks, what structure will you propose?
4. Do you welcome private sector participation in the power sector? Why?
5. If yes to question 4, at what level (generation, transmission and distribution) should the private sector participation be considered?
6. Some have argued that private sector involvement will result in higher cost of electricity in Ghana which will lead to denying a significant number of the Ghanaian populace access to power. What view can you share on this?
7. Do you support the government intention of listing the VRA and Gridco on the stock market? Why?
8. Ghana’s current power sector structure is such that, apart from the power network institutions, the Energy Commission (EC) and the Public Utilities and Regulatory Commission (PURC) are existent to be responsible for technical and economic regulation respectively. What do you think about the respective mandates of these commissions? What can be done to strengthen them if needed?

APPENDIX VIII

INTERVIEW QUESTIONS FOR EXPERTS IN THE POWER GENERATION SECTOR

First of all, I would like to thank you for taking time to respond to these questions. My name is Abudu Abdul-Ganiyu, currently a dual doctoral candidate in Business Administration at Sheffield Business School, Sheffield Hallam University (UK) and Business School Netherlands. I am also a Senior Lecturer at the Tamale Technical University. My doctoral research topic is "Approaches for Improving the Performance of a National Power Sector: An exploration for Ghana' This aspect of the research intends to assess the perspectives of power sector experts across the generation, transmission, distribution, and regulatory sub-sectors. For the power generation sub-sector in particular, the aim is to explore how the management of power generation can be improved, to be more effective in order to meet Ghana's increasing power demand. You are one of the experts I have identified, and your input is extremely valuable to this research project and the future of Ghana's power sector.

Section "A" is concerned with yourself. Section "B" contains a set of open-ended questions, where you are required to write down your thoughts as much as you will want to express.

All responses shall be kept strictly confidential. Only coded contents will be used in my thesis without relating to any individual respondent. Your participation is greatly appreciated.

Are you willing to participate in this interview? Many thanks. Yes/NO. YES

……………………….	………………………	……………………….
Interviewee	Witness	Date

Section A: (Demographic Information)

(1) Name of Respondent:

(2) Name of Organization:

(3) Status or Rank:

(4) Sex of respondent (a) Male ☐ (b) Female ☐

(5) Age of respondent (a) Below 25 ☐ (b) 26-30 ☐ (c) 31- 35 ☐ (d) ☐ 36-40

d) 41 -and above ☐

(6) Level of education (a) Diploma ☐ (b) HND ☐ (c) First Degree ☐ Masters ☐ (h) Doctorate ☐

(7) Number of years in service (a) 5 years or less ☐ (b) 6-10 ☐

(c)11-15 ☐

(c) Above 15 ☐

Section B: Interviewee questions

1. Can you provide some examples of power generation sources both renewable and non-renewable in Ghana please?
2. In your view what are the critical challenges facing the power generation sector in Ghana?
3. What are your views towards the impact of the power sector reforms on the power generation sector?
4. Regarding the power generation sector, what can be done to address Ghana's capacity constraints in a short or longer term, such as the next two years, and over the next five years?
5. What views do you have to share about the current state of indebtedness of the Volta River Authority?
6. What is your view about the government decision to list the VRA on the Ghana Stock Exchange?
7. What is your view regarding the role of IPPs?
8. The power generation mix has seen an increase in the non-renewable component (thermal) over the years. What is your view on this?
9. What do you think the power generation sector or overall, the power sector can or should do, in order to exploit Ghana's potential in power generation through (the non-conventional) renewable sources, such as solar and wind?
10. In order to enhance the effectiveness and efficiency of the power generation sector, what organizational or management structure would you propose to change?

APPENDIX IX

DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

Respondent	Name Of Organization	Status/Rank	Sex	Age Bracket	Level Of Education	Number Of Years in Service
EPI	PURC	Head of Economic Regulation	Male	41 and above	Doctorate	Above 15
EP2	PURC	Monitoring& Evaluation	Male	36-40	Masters	6-10
EP3	EC	Operations	Male	36-40	Masters	11-15
EP4	ACEP	Executive Director	Male	36-40	Masters	6-10
EP5	Ministry of Energy	Deputy Director	Male	36-40	Masters	6-10
EG1	GTS Engineering	Shift Charge Engineer	Male	31-35	First Degree	6-10
EG2	Cenit Energy Limited	Technical Associate	Male	36-40	Masters	5 years or less
EG3	GTS Engineering	Operations Manager	Male	41 and above	HND	Above 15 years
EG4	Cenit Energy	Maintenance Engineer	Male	36-40	First Degree	11-15
EG5	GTS Engineering	Technical Manager	Male	31-35	First Degree	11-15
ET1	GRIDCO	Protection & Control Engineer	Male	31-35	First Degree	6-10
ET2	GRIDCO	Senior Electrical Engineer	Male	41 and above	First Degree	Above 15
ET3	GRIDCO	Electrical Engineer	Male	36-40	Masters	11-15
ET4	GRIDCO	Assistant Chief Technical Engineer	Male	41 and above	HND	Above 15 years
ET5	GRIDCO	Senior Technical Engineer	Male	41 and above	Masters	Above 15
ED1	NEDCO	Maintenance Engineer	Male	41 and above	Masters	Above 15
ED2	NEDCO	Engineering Operations	Male	36-40	Masters	6-10
ED3	NEDCO	Commercial Operations	Male	36-40	Masters	6-10
ED4	ECG	Technical Operations	Male	41 and above	Masters	Above 15
ED5	ECG	Technical Operations	Male	41 and above	Masters	Above 15