GRADUATE SCHOOL OF NATURAL RESOURCES LAW, POLICY AND MANAGEMENT (GSNRLPM)

CENTRE FOR ENERGY, PETROLEUM AND MINERAL LAW AND POLICY

Measuring Energy Efficiency in Electricity Production: A Data Envelopment Analysis (DEA) Approach for the OECD Countries

A PROJECT REPORT SUBMITTED TO THE GSNRLPM IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (MSc) IN ENERGY STUDIES WITH SPECIALISATION IN ENERGY AND THE ENVIRONMENT AT THE UNIVERSITY OF DUNDEE, SCOTLAND- UNITED KINGDOM

AUGUST, 2016

DECLARATION

I LINDAH NALUBANGA declare that this Project Report is my original work and it is a result of my own effort and experience as a student at the Graduate School of Natural Resources Law, Policy and Management and has never been submitted to any University or Institution of higher learning for acquisition of similar awards. The information that has been used in this report is recognized.

APPROVAL

This Project Report has been submitted with approval of my Academic Supervisor at the Graduate School of Natural Resources Law, Policy and Management- University of Dundee.

Academic Supervisor: Dr. Rafael MACATANGAY

DEDICATION

This project report is dedicated to the friendship and memory of Mr. and Mrs. Nelson Asirike. They are my parents whose support, encouragement and love have sustained me through my life. Mrs. Janet Asirike Walusaga you're amazing and I thank you for instilling in me the importance of honesty and hard work. My nieces and nephew may you also be motivated to reach greater heights.

ACKNOWLEDGMENT

I owe my deepest gratitude to the Almighty God for the gift life, wisdom, knowledge and understanding throughout this long journey. I am also most grateful to the staff of the Centre for Energy, Petroleum, Mineral Law and Policy (CEPMLP) for the support given to me. Special thanks to my academic supervisor Dr. Rafael MACATANGAY for his encouragement, guidance and meticulous corrections availed to me throughout my academic period.

I also owe thanks to the Government of Uganda, in particular the Office of the Auditor General and the Ministry of Energy and Mineral Development for providing me with the financial and moral support to enable me complete this program.

To my loving parents, sisters and brothers, you made success possible and rewarding. Thanks for the financial and moral support. I am grateful

I would also take this opportunity to thank my dearest friends and CEPLMP classmates; for the valuable company, friendship and encouragement. You made everything possible. May the good Lord reward and bless you all. I will always remain indebted to you all. I thank you.

ACADEMIC YEAR: 2015/16

NAME: LINDAH NALUBANGA

STUDENT ID: 150019524

MODULE CODE: CP50051

MODULE TITLE: PROJECT REPORT

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ACRONYMS

CO_2	Carbon dioxide
DEA	Data Envelopment Analysis
DMU	Decision Making Units
GCC	Gulf Cooperation Council
GEP	Gross Electricity Production
EMS	Efficiency Measurement System
EU	European union
IEA	International Energy Agency
OECD	Organisation for Cooperation and Development
TWh	Terawatt hours
SBM- MCMC	Slack Based Model
UK	United Kingdom
USA	United States of America

ABSTRACT

As energy trends change, energy efficiency has been a great concern to many countries. This concern has been very vibrant in countries that share a common development goal such as Organisation for Cooperation and Development (OECD) member countries. This so due to the reported benefits associated with energy efficiency such as a solution to the climate change problems, improved security of energy supply, and reduced exposure to price volatility, sustainable development among others. Moreover while assessing energy efficiency, electricity production is considered as one of the key areas to evaluate due to the fact that it determines the energy mix of a country. In this context, this study examines the efficiency of OECD countries in electricity production. It considers primary energy sources as inputs; electricity produced and carbon dioxide emissions as desired and undesired outputs respectively. Data Enveloping Analysis (DEA) technique is used to measure the efficiency basing on the charnes, cooper, and Rhodes (CCR) input oriented model. In this context, technical efficiency scores of 26 OECDs Countries is estimated. The results show that OECD countries' efficiency levels in electricity production are high and there no significant change over the three periods of 2005, 2010 and 2015.Countries from OECD Europe are the most efficient. On the other hand, Canada, Austria, Slovak republic and United States of America are the most inefficient in electricity production. While the non-OECD countries of china and Russia are efficient. The results suggest countries that can be benchmarked. Also, the results indicate several policy implications with regard to energy security and energy demand side management and supply.

WORD COUNT: 9,436 excluding references and appendix

CHAPTER ONE

1.0 INTRODUCTION

Energy is a necessary driver of both economic and social development, and the measures put in place for energy efficiency aid in boosting development. This is done through the increase in services gained from the consumption of every unit of energy OECD)/International Energy Agency (IEA), 2014a**).**

Lately, the notion "Energy efficiency" has gained a lot of attention due to the vast advantages associated with the concept. This has been exemplified in scholarly literature: some scholars have consented to the notion as a key step to solving global warming and climate change both in the developing and developed world (ALSAHLAWI, 2013; Martínez, 2016). Besides environmental-related advantages of energy efficiency, it is a cost effective way of reducing carbon emissions while at the same time improving security of energy supply and industrial competitiveness (Zhou et al, 2012).In fact the IEA refers to the above as multiple benefits and includes others such as energy delivery, macro-economic impacts, resource management, employment and poverty alleviation among others (OECD/IEA, 2014b)

However the definition of Energy efficiency has not been obvious as it seems. Bhattacharyya, (2011) emphasises the breadth of this term and confirms that it can best be defined according to the user and the focus of the analysis keeping in mind the original concept of the ratio of useful output processed to energy input into a process. While other scholars define this notion to reflect minimal use of energy while providing the same service/output (Cavalcanti and Barbosa, 2012; Blomberg et al. 2012; Backlund et al. 2012; Cui and Li, 2015)

Additionally, the IEA defines energy efficiency in line with the scholars above as a way of handling and limiting the growth of energy consumption. Accordingly, ''something is more energy-efficient if it delivers more services for the same energy input, or the same services for less energy input.’’ (IEA, 2016).

Further, reflecting on the vast advantages of energy efficiency as a whole, countries have focused on coming up with ways of measuring energy efficiency. However there is no agreement on the best method to use although some policy makers have been using economic indicators such as energy intensity, technical and physical indicators related to energy consumption and saving to measure efficiency (Bhattacharyya, 2011).

Recently the Data Enveloping Analysis (DEA) has been used in energy studies as a measure of energy efficiency as a whole (Azadeh et al. 2007; Zhou et al. 2012; ALSAHLAWI, 2013; Dogan and Tugcu, 2015). This method has been considered superior due to its ability to generate better energy index than the energy production ratio. This is so because the technical efficiency index reflects the ability to obtain maximum output from given inputs or to reduce the input level without sacrificing output (Martínez, 2016). Moreover, DEA has been typical of comparing economy-wide energy efficiency performance amongst countries and regions as compared to the recommended common practice of Index decomposition analysis (IDA) which is limited to a specific entity such as a country or a sector that consumes energy. This limits the idea of benchmarking (Zhou and Ang, 2008).

Therefore, just like the studies above, this study will also adopt the DEA approach aiming at analysing efficiency in electricity production of the periods 2005, 2010 and 2015 in 26 OECD countries.

Assessing energy efficiency in electricity generation is key because it influences the energy mix of a country and spills over to the energy policies of a country. Moreover, the process of electricity generation involves consumption of resources subject to other factors. In order to acquire electricity, primary energy sources are utilised (such as Coal, Natural Gas, Nuclear and Oil) yet the outputs are both good and bad (Gómez-Calvet et al., 2014).

Further, OECD countries provide a suitable example to analyse due to the changing trends in their energy use. For stance statistics show that OECD countries have reduced their consumption of primary energy sources particularly from fossil fuels. Electricity production has also reduced on average although it takes up the biggest share of primary energy sources. Carbon dioxide emissions have also reduced. (British Petroleum, 2015; OECD/IEA, 2016a).

This trend is expected to reflect improvement in energy efficiency of the OECD countries and other benefits such as energy security and positivity towards climate change mitigation. On that note, there is need for comparison of the individual OECD countries so that countries can benchmark with each other.

Therefore, the objective of this paper is to obtain a rank, index, or benchmark that will enable comparison between the OECD countries. The research questions will be;

i. What are the efficiency scores of OECD countries in electricity production?
ii. What specific countries can the inefficient countries benchmark from?

Moreover, this ranking/benchmark will not only be based on primary energy consumption and electricity produced but also incorporate the environmental issue in electricity production that is, CO_2 emission as an undesired output. However key to note is that this paper does not give a complete view of the OECD electricity industry.

The rest of the paper is organised as follows: Chapter 2 reviews the literature and describes the innovation. Chapter 3 presents the data and methodology: Chapter 4 discusses the results: chapter 5 is the conclusion, policy implications and limitations and chapter 6 presents the references

CHAPTER TWO

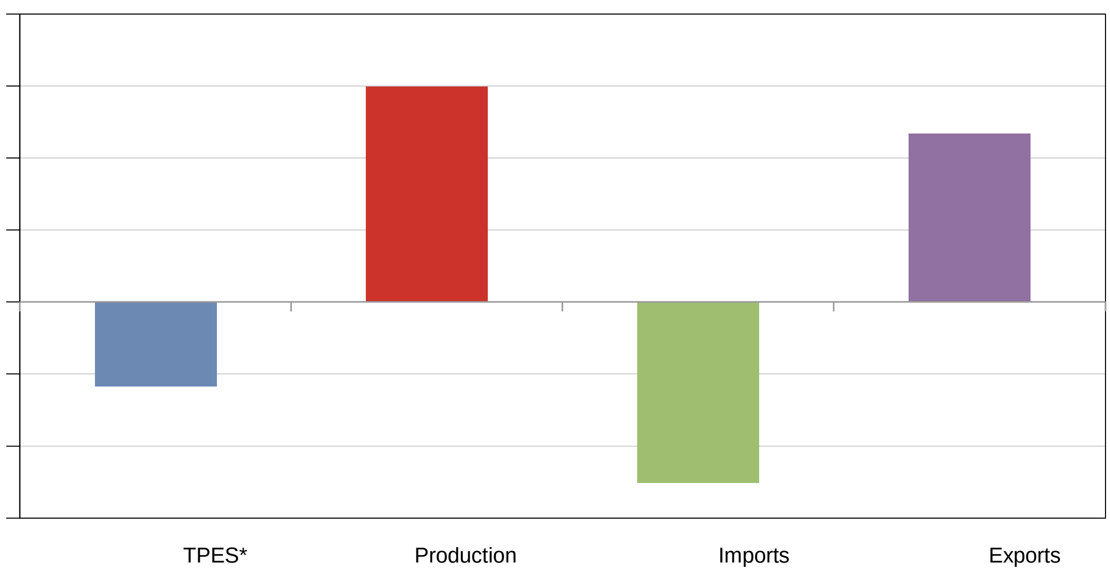
2.0 LITERATURE REVIEW

2.1 Electricity production of OECD countries

Electricity is known as a secondary source of energy produced from primary sources. These primary sources among others include oil; coal; nuclear; natural gas; and renewable sources such as wind, solar, and hydro power (Gómez-Calvet et la., 2014). Depending on the country's energy approach, selection is made from the primary source to form an energy mix.

Reflecting on the total primary energy supply (TPES) of the OECD countries, over 4000 Mtoe were produced in 2014. ''Also exports were the highest ever recorded (1695 Mtoe), while imports went down by 2.5% below the 2013 level.'' The 2014 increase in production was due to substantial increases in United States' oil and Natural Gas, Canada's oil, Australia's coal. The TPES has tentatively reduced by slightly over 1% in the period 2013-2014 as shown in figure 1 (IEA, 2015a).

Figure 1: OECD energy supply: 2013-2014 changes



Source: IEA, 2015

Nonetheless, there has been an increase in the gross electricity production (GEP) right from 144TWh in 1973 to 23,391 TWh in 2013 globally. This has presented an average annual growth rate of 3.4%. However in disaggregation, generally there has been a reduction in the GEP in the OECDs as compared to the non-OECDs. As of 2014, a reduction of 0.8% as compared to 2013 level was reported, brought about by a reduction in the utilisation of fossil fuels during electricity production. In the same year 10,773TWh (Including generation from pumped storage plants) were realised (IEA, 2015b).

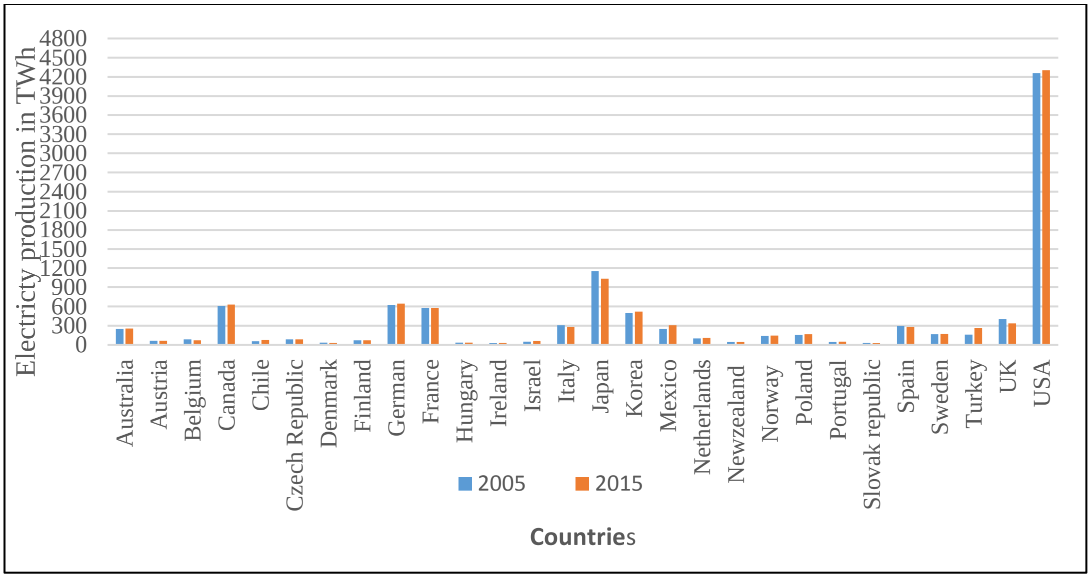
In comparison, the non-OECDs' GEP has increased at an average annual rate of 5.2% in the last 40 years (1973-2014). Also, their GEP in 2013 as the only available year with comprehensive data stood at 12,533 TWh with the biggest percentage coming from fossil fuels in that year (Ibid).

Still taking comparison of 2005 and 2015, the electricity generation has reduced in OECD from 58% in 2005 to 45% in 2015 while it has increased from 42% to 55.1% in non OECDs (BP Statistics, 2016).

In contrast, some countries have individually increased their electricity production while other have reduced as shown in figure 2 below for the periods of 2005 and 2015. USA, Japan, France, Canada, German and Korea have been the biggest producers of electricity in both periods. At the same time Canada, USA, Korea and German's generation has increased and so other countries like Mexico and Turkey. Given the undesirable output of CO_2 produced during electricity production; and also the biggest share of fossil fuels in these countries electricity generations; then the issue of energy efficiency should be a concern.

However, a significant decrease is observed in Japan, UK, Italy, Belgium and Slovak republic, Turkey which is an emerging economy.

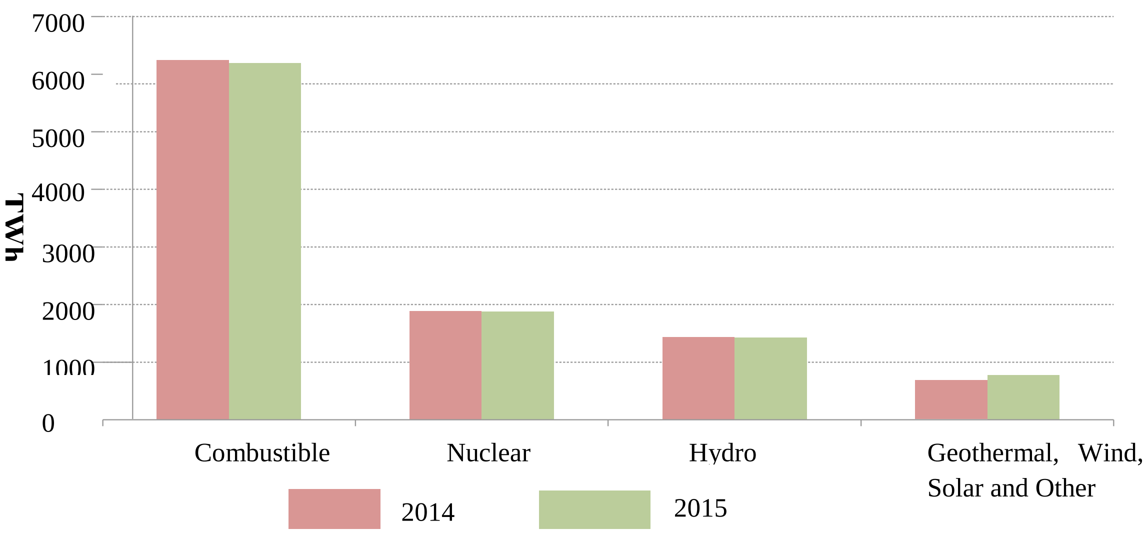
Figure 2: Electricity production in OECD countries



Source: Author's computation from BP statistics

Further, in electricity generation, combustible fuels (coal, natural gas and oil) form the biggest percentage of inputs followed by nuclear, hydro and other renewables respectively (geothermal, wind and solar) as shown in the figure below.(OECD/IEA, 2016b) .

Figure 3: Total OECD electricity productions by fuel



From the graph above, it is key to note that combustible fuels have reduced while the renewables (Geothermal, Wind, solar and others) have increased in OECD countries

2.2 Energy efficiency and OECD Countries

For sustainable development, Energy efficiency is very vital given its underlying advantages of energy security, reduced energy importation and reduced CO_2 emissions (Selvakkumaran and Limmeechokchai, 2013). Therefore, improving energy efficiency would imply a reduction in the overall energy use other factors kept constant, and this would in turn aid in obtaining the same output but using less inputs therefore utilising less of the natural resources (Camioto, et al., 2015).

Just like most countries, Energy efficiency has been an important issue in the OECD countries given their high level of energy use. It is even more important due to the high corruption in energy policies relating to energy efficiency as proved by Fredriksson et al., (2004).

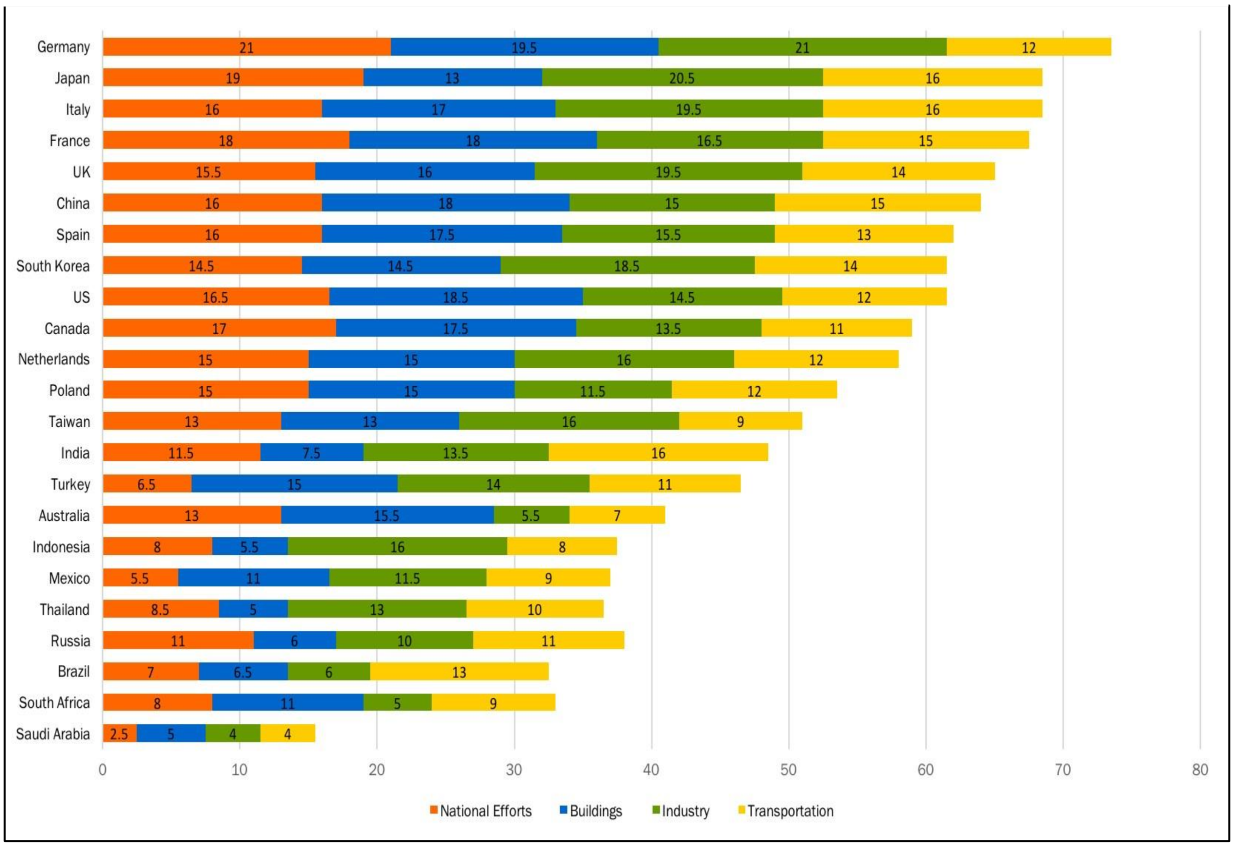
Considering the two key advantages of energy efficiency mentioned in paragraph 1 of this section, and one of them being improved energy security. Chester, (2010) reports the difficulty in defining energy security. However, she wraps up this notion as a focus on the supply of primary energy sources without disruption and also introduces the significance of electricity in this notion. On the same note she elaborates the definition in line with market behaviours and economic issues related to it such as economic welfare due to price disruption.

Further, studies have proved that the OECDs have scored very low in energy security, except for Denmark, Japan, and the UK (Sovacool and Brown, 2010); however, Japan's case of energy security became worse following the Fukushima nuclear disaster (Elliot, 2012). This has been heightened by the increased demand for energy sources by emerging Non-OECD countries such as India and China implying increased competition for the scarce energy resources (IEA, 2015b). Moreover, policy makers rely on energy independence as a measure of energy security without keen consideration of the vulnerability of supply and also possible substitutability of fuel (Cohen et al., 2011).

On the other hand, the projected energy-related CO_2 emissions in OECD 2012 to 2040 indicate an average increase by 0.3%/year quite lower than the non-OECD which stands at 1.5%/year. However in specifics, for Mexico and Chile, combined anticipated energy-related emissions will grow on average by1.1%/year while in other OECDs it will be less than 1%. In fact in 2040 the OECD Europe and American regions are anticipated to have reduced their CO_2 emissions from 13% to 10% and 20% to 16% respectively (OECD/EIA, 2016). The question would then be how energy efficiency can contribute to this success perhaps?

Nonetheless, the American Council for an Energy-Efficient Economy in their *third* edition International Energy Efficiency Scorecard assesses the energy efficiency of 23 top world energy-consuming countries that take up 75% of the world's energy. Taking in different parameters in this context, the most energy-efficient countries in the top 10 sampled apart from china are part of the OECD as shown in the figure 4 below.

Figure 4: Efficiency scores of OECDs



Source: American Council for Energy Efficient Economy (2016)

This analysis is in agreement with Apergis, et al. (2015)'s conclusion on the EU countries under the OECD regarding energy efficiency. However to differ slightly, they called for general concern on the declining energy efficiency on the entire OECD as a whole especially in the labour-intensive countries. Also, when utilising the energy intensity as a proxy of energy efficiency the European Union and Japan still perform better since 2012 (IEA,2014a).

Nonetheless, recognising their high energy use, the OECDs have spearheaded policies towards energy efficiency (Takana, 2011). In addition, they have realised the importance of developing and formulating well-grounded indicators for measuring energy efficiency for better policy formulation while expressing the difficulty in coming up with such indicators. (Takana, 2008; OECD/IEA, 2014a). These indicators include thermal energy efficiency of equipment; Absolute amount of energy consumption; Energy consumption intensity; and the diffusion rate of energy-efficient facilities.

i. **Thermal energy efficiency of equipment:** This is expressed as a ratio of energy output to energy input for both the end-use and energy conservation technologies.

ii. **Absolute amount of energy consumption – heat value:** In this case the complete amount of energy is sometimes used as the measure of energy efficiency performance.

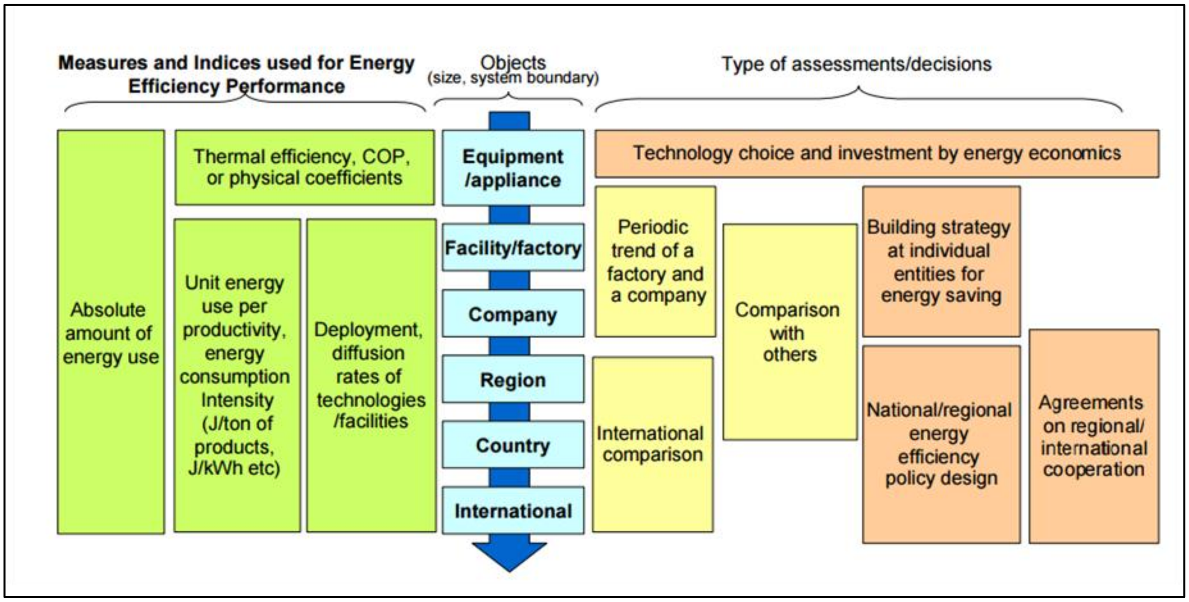
iii. **Energy consumption intensity (unit of energy consumption, specific energy consumption):** The ratio of energy consumed to the physical output value(or some economic value)

iv. **Diffusion rates of energy efficient facilities/types of equipment:** This entails measuring the rate at which an identified efficient technology is being deployed.

However of the four indicators, the Energy consumption intensity is preferred due to its ability to assess broad objects like countries whilst it is related to the operational process and the choice of technology. It is also not influenced by price fluctuations.

Takana, (2008) further gives a conceptual model incorporating boundaries on how this can be applied as shown in figure 5below.

Figure 5: Conceptual model of measuring Energy Efficiency



Source: Tanaka and OECD, 2008

The model spells out the size/systems boundaries in which energy efficiency can be applied and this allows for international comparison. Tanaka (2008), further cites the USA Energy Policy, the Dutch bench mark covenant, Japan Conservation law and UK climate change agreement among others as some of the energy related policies that incorporate this concept. However the applicability of the four measures has not been very common in scholarly literature as will be seen later although to the extent energy consumption intensity has been applied. The other three have been more common in domestic assessments and not international comparison.

2.3 Empirical Literature

The scholarly literature on energy efficiency has been evolving over time at an industrial and regional/international level. As seen in the previous chapter, OECDs tried to come up with measures but these have hardly been used especially at a macro-level. Instead other methods such as DEA have evolved. This section therefore dwells more on the studies that have used DEA and relates to a few that have not used DEA. One of the superiority of DEA is its capability to handle multiple inputs and outputs while measuring relative efficiency as also detailed in chapter 3.

Also although, few studies have focused on energy efficiency and to be specific efficiency in electricity production in the OECD countries using DEA, many others have used it in analysing macro-economy efficiency.

On that note Mukherjee (2008) used the production theoretic view to examine the energy use efficiency of US manufacturing sectors using time series data for a period of 1970-2001. In these works, capital, labour, energy, material and services were utilised as inputs while the quantity index of gross output for the sector was the single output. Using DEA as the primary measure of efficiency he formulated four models and concluded that the food, chemicals, petroleum and stone sectors were more efficient in comparison to the overall manufacturing sector. There was evident wastage in input utilisation in the manufacturing sectors and yet there was still potential for improvement to get to the frontier.

On the other hand, Martinez (2015) used the same inputs as Mukherjee(2008) besides services with a single output gross value of manufacturing to estimate and analyse energy efficiency in German and Colombian manufacturing industries from 1998 to 2005. This paper took two stage analysis. At the first stage DEA was applied as the measure of the energy efficiency index and Germany was found to be more efficient than Colombia. Also a regression panel analysis was performed to confirm the selected determinates of differences in energy efficiency. They reported a positive association of energy efficiency with labour productivity, size of the enterprise and electricity.

Shi and Wang (2010), on the other hand, examined the industrial energy efficiency of 28 administrative regions in China and 3 other areas from 2000-2006. They used the traditional DEA and extension of DEA model that incorporates the undesirable output CO_2 as an input. Their aim was to establish the efficiency scores and find the potential energy saving areas. They found that the Eastern area was more efficient than other regions. Yet the central posed as the area with more saving potential.

Further, Wu et al. (2012), in analysing the industrial efficiency of 28 provinces in china, also used DEA and hinged on both static and dynamic performance indexes. A period of 1997-2008 was considered. Using the inputs of capital stock, labour and energy to produce a desirable output (Industrial Value added), they also introduced an undesirable output (CO_2) emission in the modelling. The overall results showed an improvement in performance over the years basically due to technological improvement keeping other factors constant. The Eastern region was the most efficient and all the provinces had potential to improve energy efficiency if they reduced annual energy consumption by 18.4%.

Zhou and Ang (2008) proposed a DEA-type linear programming model for measuring economy-wide energy efficiency performance from 1997 to 2001. They considered 21 OECD countries using capital stock and labour as non-energy input while introducing coal, oil, gas and other energy as the energy inputs. GDP and CO_2 were considered as the desirable and undesirable outputs respectively. This study pioneered the inclusion of $C0_2$ as an undesirable output. They observed a small change in the overall efficiency of OECD countries

On the same note, Apergis et al. (2015), applied a more efficient DEA model that is the SBM-Undesirable and MCMC generalised mixed models to analyse the energy efficient levels of 20 OECDs for the period 1985-2011.They considered labour, renewables and non-renewable energy consumption and capital as inputs while income and CO_2 were considered as good and bad output respectively. Their findings were somehow in line with Zhou and Ang (2008) concerning the overall average decrease in the energy efficiency of OECDs though an increase in the scores. They called for policies that focus on provision of renewable technologies.

Alsahlawi (2013) on the other hand measured energy efficiency in the Gulf Cooperation Council (GCC) countries that is United Arabs Emirates, Saudi Arabia, Qatar, Oman, Kuwait and Bahrain using DEA. Data from 2001, 2003, 2005 and 2007 was used to perform the DEA considering capital, labour force and energy consumption as inputs while GDP as an output. In his works, he introduced three OECD countries as benchmarks of the most efficient countries basing on Zhou and Ang (2008)'s submission that is to say; Australia, Norway, and Switzerland. Before formulating the two modules, a causality test and other time series properties were performed on GDP and energy consumption. The efficiency conclusions were consistent for Kuwait, Bahrain and Oman and UAE in both models while different for Saudi Arabia and Qatar. Nonetheless compared to the benchmarked OECD countries all the GCC were inefficient.

Whereas the above literature has been entirely concentrated on the overall energy efficiency at industrial, sectorial and economy-wide, scholars have also explored energy efficiency in electricity production.

Towards the 1990s work on efficiency and productivity performance of the electricity industry especially on utilities was a great deal. Emphasis was more on generation than any other stage of the value chain due to the high costs involved in generation (Abbott, 2005). Abbott quotes Kendrick (1961) for having made the first attempt to measure efficiency and productivity in the electricity industry. Kendrick improved his work by 1983 and assigned weights to electricity produced as output with capital and labour as inputs in estimating electricity utilities of the US.

Similarly, Graus et al. (2007) pioneered the benchmarking concept in measuring energy efficiency in electricity production using the methodology proposed by Phylipsen et al. (1998). Efficiency of fossil –fired power generation was compared for China, Germany, India, Japan, France, Australia, South Korea, United Kingdom, Ireland, USA and aggregated Nordic countries of Norway, Denmark, Finland and Sweden. Using coal, Natural gas and oil as inputs while electricity produced was considered as the output, they concluded that Nordic countries, Japan, UK, and Ireland performed best while Australia, China and India were the worst in performance. Taylor et al. (2008) carried out a similar analysis on OECD economies while Graus et al. (2009) differed slightly by comparing past and future energy efficiency fossil power generation in 27 European Union Countries. Key in this study is the changes in energy intensity.

On the same note, Verdolini and Hascic (2012) looked at 28 OECD countries in comparing energy efficiency of electricity production. Different from Graus et al. (2007), Taylor et al.(2008) and Graus et al (2009) is the assessment of determinants of fuel efficiency; attention to technological change and availability; and establishing the relationship between fuel efficiency and carbon intensity.

Whereas the previous literature in the last three paragraphs is basically on measuring energy efficiency in electricity production using energy intensity, DEA has also been used by researchers to measure efficiency in this regard. Fare et al. (1990) studied productivity growth of electric utilities in Illinois for a period 1975-1981.They used DEA and computed a Malmquist productivity index. Looking at coal-fired plants, labour, capital, and average heat content were considered as inputs while electricity generated as output. A conclusion of no substantial change in the production growth was arrived at for the period 1976-1977 due to technological regression in the same period.

Applying APH –DEA approach and later a Malmquist productivity index in evaluating 13 largest electricity production firms in the OECD, Kasap and Kiriş (2013) established an overall technical efficiency of 0.82%. Also the total installed capacity and people employed were used as inputs while electricity produced (TWh) and sales revenues (in billions of euros) were considered as outputs.

Further, Xie, et al. (2013) used Slack Based DEA to examine the environmental total factor productivity index of 26 OECD electric power industries and the Brazil, Russia, India and China (BRICs). They later applied a Tobit regression model to establish the causal factors. In their model, labour, installed capacity and fuel and nuclear inputs were used as inputs while the outputs were both a desired and undesired that is electricity generated and CO_2 respectively. They concluded that the economic situation and price changes affect environmental efficiency and therefore a need for technological shift and research and development. Key to note in this study is the objective of environmental efficiency.

On the other hand, Gómez-Calvet et el. (2014) applied the directional distance function and slack based DEA models to evaluate the energy efficiency in electricity and heat generation of the EU25. They considered primary energy sources, capital and labour as their inputs while electricity was the desired output. They were so innovative that on top of the undesirable common output CO_2, they include radioactivity produced in nuclear generation. Grouping EU into EU 15 and 25, their results expose huge efficiency differentials in EU15, a notion they pride to have been expressed by other scholars.

Further, Dogan and Tugcu (2015) estimated the technical and super efficiency scores of the G-20 countries in electricity production for periods 1990, 1995, 2000, 2005 and 2011 using DEA.
Coal sources, hydroelectric sources, natural gas sources, oil sources and renewable energy sources without hydroelectric as inputs with a single output electricity generated was used. The results indicated on average china, Russia, Brazil and Korea to be efficient while France, India USA and EU turned out inefficient.

From the literature, it is clear that generally measuring energy efficiency has been considered both from a micro and macro perspective and DEA as a methodology is greatly being used. Key to acknowledge is the gradual incorporation of the undesirable outputs in the current works although not at a high scale as also observed by Shi and Wang (2010). This paper takes the line of thinking of Dogan and Tugcu (2015) and aspects of Gómez-Calvet et al. (2014). It will estimate efficiency scores for 2005, 2010 and 2015 for the OECD. This particular analysis has never been done on OECD countries to the best of my knowledge .Therefore by inclusion of CO_2 as an undesirable output and using Oil, Natural Gas, and coal, nuclear, hydroelectric as inputs while electricity produced as a desirable output will contribute to knowledge in empirical literature. Moreover Shi and Wang (2010)'s concern of studies failing to minimise energy consumption in addition to the undesirable outputs will be addressed. Somewhat close to this study relating to the OECDs are the works of Zhou and Ang (2008). However, their basis was on the entire energy efficiency and not electricity production and besides the years they studied were from 1997-2001. The works of Verdolini and Hascic (2012) that would relate to this study did not use DEA and concentrated on fossil related sources.

CHAPTER THREE

3.0 DATA AND METHODOLOGY

Given that the study is focused on OECD countries, it would be my wish to include all OECDs however out of the 32 countries in the OECD, the study will use data on 26 OECD countries due to data limitations of; Belgium, Estonia, Iceland, Israel, Latvia and Luxembourg which will not be included in the analysis. For example Belgium's data was aggregated with Luxembourg in 2005 although disaggregate in the other two years of 2010 and 2015 thus hindering its use in the analysis. On the other hand, reliable data was not available for the other 5 countries. The exclusion of other OECD countries was also experienced by Dogan and Tugcu,(2015) and Apergis et la., (2015).

However, the rest of the 26 OECDs including; Australia, Austria, Chile, Belgium, Canada, Czech Republic, Denmark, Finland, France, Hungary, Ireland, Italy, Japan, Korea, Mexico, German Netherlands, New Zealand, Norway, Poland, Portugal, Slovak republic, Spain, Sweden, Turkey, UK, USA will be considered.

In addition three other non-OECD countries are introduced in the sample for comparison purposes that is Russia, India, and China. These countries have been ranked among the best energy efficient non-OECD countries by the American Council for an Energy Efficient Economy (2016) and so Dogan and Tugcu. (2015). Moreover these particular countries' primary energy demands have gone up. Alsahlawi, (2013) further exemplifies the inclusion of countries not considered in the original sample for comparison purposes.

Furthermore, as acknowledged by Gómez-Calvet et al. (2014), studies that control environmental matters while measuring energy efficiency are still evolving. In addition, they note that energy consumption as a variable is treated either as an input or output depending on the objective of the study. However the expected procedure is to treat it as an input in studies that include an environmental factor or output such as CO_2 while the reverse is true to studies that focus entirely on economic related issues.

Further, before clarity is made on the inputs and outputs, emphasis is drawn back to chapter 2 that electricity is a secondary type of energy and can be generated using different primary energy sources such as coal, hydroelectric, natural gas, nuclear, oil or renewable energy. Moreover during the production both a desirable and undesirable outputs are realised ceteris paribus.

The variables used in this study include oil sources, Natural Gas sources, coal sources, Nuclear and hydroelectric as inputs all measured in million tonnes of oil equivalent. Renewables energies were not included due to problems with data availability for all the countries. Electricity generated is the desired output measured in terawatt hours while Carbon dioxide emissions is the undesirable output measured in million tonnes.

The consideration of primary energy sources as an inputs has been used in studies such as Zhou and Ang (2008); Gómez-Calvet et al.(2014); Dogan and Tugcu (2015).The first two studies incorporate also economic variables while the previous does not. Also, all these studies consider electricity produced as a desirable output and CO_2 as undesirable output besides Dogan and Tugcu who considers only electricity produced and ignores CO_2 emissions. Dogan and Tugcu's choice of variables would be okay inconsideration of Gómez-Calvet et al's submission that choosing the inputs to use depends on the objective of the study. However, still they would have considered CO_2 emissions in their study. Also Zofio and Prieto (2001) and Kasap and Kiriş (2013) considered this particular undesirable output in their studies.

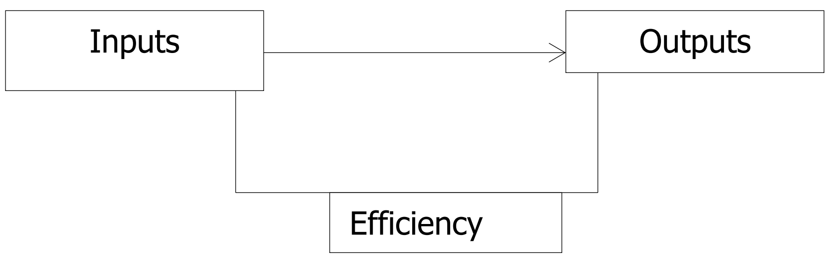
Differing from Gómez-Calvet et al. (2014) who aggregated the total primary energy consumption to form the inputs, in this study I disaggregate them as Zhou and Ang (2008) and Dogan and Tugcu(2015).

As reported by Dyson et al (2001), the number of Decision Making Units (DMUs) in this case the OECD countries should at least be 2m $\times$ s where $m \times s$ is the number of input times the number of outputs in order to get reasonable results. This selection confirms to their submission.

Data of all the inputs and outputs is sourced from the British Petroleum (BP) statistical review world energy outlook for 2005, 2011 and 2015 on all the variables. The same years will form the scope of the study. Analysing the scores in periods say every after 5 years in this case enables to establish the trend of efficiency performance of the DMUs in different times and hence able to conclude on efficiency as illustrated by Dogan and Tugcu. (2015).

3.1 Methodology

In this paper DEA is used to establish the efficiency score. To understand the entire concept of DEA, it is paramount to comprehend the production process. The production process entails the use of resources while obtaining products. In this regard, the resources can be referred to as the inputs while the products are the outputs (Ortega and Gavilan, 2013). Therefore production can simply mean transforming inputs in to outputs which can be either desirable or undesirable outputs. As highlighted by Dogan and Tugcu (2015), it is vital to determine how the inputs are being utilised while generating outputs and efficiency is one of the key measures in that regard. An illustration is presented below



None the less, measuring energy efficiency has been simpler because the norm has been to compare the measures of energy intensity or just considering the energy inputs/output ratio. However this traditional method of energy intensity only considers a single factor productivity, since it is measured simply by the ratio of output to energy (Boyd and Pang, 2000)

Similarly measuring a component that entails measuring productivity is not easy as compared to the above methodology for it entails drawing a frontier and establishing the efficiency performance index. Herein after compare them and establish which one is best performing .The DEA approach in establishing the frontier has been preferred by many scholars as evidenced in the literature under chapter 2.3.

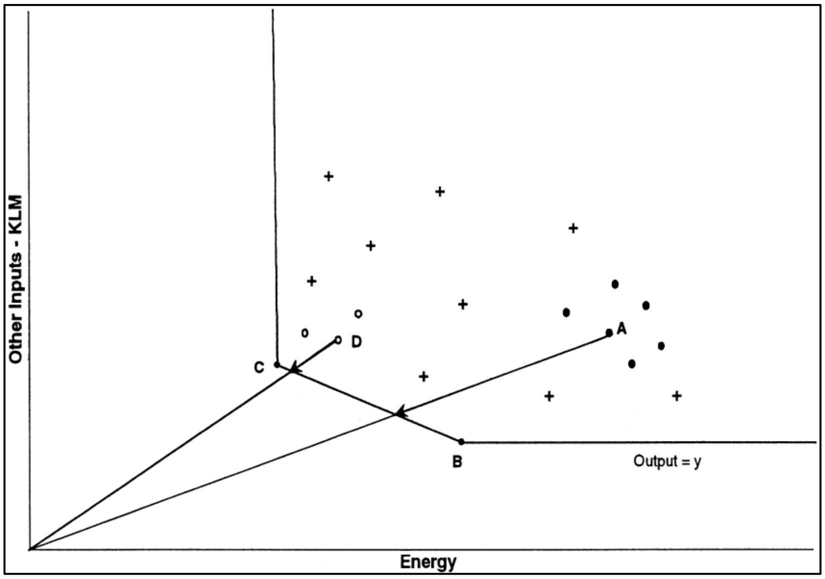
DEA is a non -parametric methodology (**that is no need to make any assumption about the population distribution**) involving mathematical linear programming used to assess a set of comparable DMUs. This methodology was first developed in 1978 by Charnes, cooper, and Rhodes (CCR) while measuring efficiency of individual DMUs that used multiple inputs and outputs (Shi and Wan, 2010). The methodology has its superior advantages of handling multiple inputs and outputs; non requirement of a functional form assumption involving the inputs and outputs; comparisons of DMUs; and lastly scaling is not an issue implying that inputs and outputs can have completely different units (Sherman and Zhu, 2006)

Sherman and Zhu (2006) further identifies four great use of DEA in day to day managerial decisions as follows:

i. DEA makes comparisons among DMUs allowing for all resources and services utilised, while identifying the most efficient/best practice DMUs and the inefficient units in which real efficiency improvement is possible.
ii. DEA computes the specific saving potential that an inefficient DMU can achieve so as to become efficient as the most efficient/best practice DMU.
iii. DEA identifies specific changes in the inefficient DMUs making the efficient DMUs to also improve to the most efficient DMU performance.
iv. Upon analysing the efficiency scores, managers are better informed and can make informed decision regarding productivity improvements and transfer systems.

However, from a simpler understanding, the idea is to construct a frontier for the DMUs and those that happen to be on the frontier are regarded efficient in their resource utilization while those that are not on the frontier are inefficient keeping other factors constant. Therefore inefficient DMUs can benchmark from the efficient ones. Boyd and Pang (2000) makes a clear demonstration of this concept as shown in figure 6

Figure 6: Illustration of the concept of DEA



Consider the diagram above for illustration purposes. Typically the figure represents a combination of inputs producing the same output. countries denoted by points C and B are considered to be technically efficient .The implication is that since they lie on the isoquant then they cannot reduce their inputs(Oil sources, Natural Gas Sources, Natural gas sources, Oil sources, nuclear, hydroelectric) and remain at the assumed output(Energy production) level Y. But countries denoted A and D are inefficient .These countries can still get to the frontier by reducing their inputs by the amount indicated by the arrow and still remain in the input set say L(Y).For stance A's low productivity may be due to increased energy use according to the diagram .

Not forgetting that one of the underlying assumptions is feasibility. Implying that if say two input–output combinations are feasible productions, then any mixture of the two is also a feasible production.

Practically there are two orientations in DEA that is Input oriented and Output oriented. The later examines if the DMU in question can reduce its input while maintaining the present levels of output. On the other hand, the former examines if the DMU in question can increase its output while maintaining the input at the present levels (Zhu, 2014). In this paper an Input oriented approach will be considered taking into account Constants Returns to Scale (CRS). In this context, Fare and Grosskopf. (2000) submits that a production function exhibits CRS if equal changes in output requires equal changes in input .CRS assumption is typical while analysing country level studies and this has been tested and proved in the studies of Barla and Perelman(2005) and Gómez-Calvet et al. (2014). The CCR input oriented model that is used in this paper was first used by Fare et al., (1989) and also used by Yang and Pollitt (2007) : Zhou and Ang (2008): Dogan and Tugcu. (2015) among others. Therefore the essence of DEA is to assign weights to inputs and outputs

Sherman and Zhu (2006) presents the CCR input oriented model as follows;

We assume that we have n DMUs (in this case countries).Each $DMU_j(j = 1, \dots, n)$. The DMUs use different inputs $x_{ij}(\ i = 1, \dots, m)$ to produce different outputs $y_{rj}(\ r = 1, \dots, m)$

$$min\ \theta_0$$

$$subject\ to$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \ \theta_0 x_{i0}, i = 1, \dots, m \qquad (a)$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq \ \theta_0 x y_{r0}, r = 1, \dots, s \quad (b)$$

$$\lambda_j \geq 0 \ \ j = 1, \dots, n \qquad (c)$$

In order to obtain the efficiency rating, we minimise θ_0 which is the efficiency score of DMU_0, subject to the constraints (a) that the weighted sums of the inputs of other DMUs being evaluated are less or equal to the inputs of the DMU being evaluated. (b) that the weighted sum of the output of the other DMUs is greater than or equal to the DMU under evaluation. λ represents the weights. In this envelopment model, the DMU is efficient if it scores 1 or 100%.The inefficient DMU will score less than 1 or 100%

Also the assumption of strong disposability is held in this model which means that in case inputs are increased or held the same, then output will not reduce. To put it in another way, an increase in the input does not ‘congest’ the output (Fare and Grosskopf, 2000).

However, as pointed out in quite many literature, the concern is how to treat the undesirable outputs in the standard DEA model (Färe et la., 1989;Seiford and Zhu, 2002 and Gómez-Calvet et al., 2014).They all first consent that in the production process both a desired(good) and undesired(bad) outputs can be the end result. Moreover all the scholars above agree in their literature that the renowned CCR model also known as the standard DEA model does not allow for the decrease in output but rather the decrease of only inputs. Moreover all outputs under this model are assumed to be desirable. The question then put forth is should both the desired and undesired outputs be treated the same? In this case electricity generated as a desired output while CO_2 is the undesired output. Seiford and Zhu, (2002) bases on other scholar's submission and summarises the possible ways to deal with the undesired outputs while using the traditional DEA that bases on the CCR model.

i. To merely pay no attention to the undesirable outputs:
ii. The undesirable output can be handled in a non-linear DEA model:
iii. Treat the undesirable as an output under weak disposability:
iv. Consider the undesirable as an input.
v. .Apply a monotone decreasing transformation.

In this paper I apply possible ways **1** and **4**. Similar ideas were applied by Seiford and Zhu (2002) and Mukherjee (2008) while modelling undesirable factors in efficiency evaluation and measuring energy use efficiency in US manufacturing respectively.

Possible ways 1: This entails running model 1 as explained above and simply ignoring the CO_2 emissions for this case and consider only electricity generation as an output. Kasapand Kiriş (2013) and Dogan and Tugcu (2015) ignored CO_2 but got results that were consistent with other scholars.

On the other hand, Yang and Pollitt (2007) dwells on Tyteca (1997)'s works and introduce the model under possible way 4.The implication is to treat CO_2 as an input instead of undesirable output hence it is also minimised which is not the case in model 1

Therefore, minimise the ratios of the weighted sum of inputs and undesirable outputs over the desired outputs. The underlying reasoning is that the undesirable output should be reduced too.CO_2 is a negative externality therefore it imposes damages to the environment thus the need for its reduction while generating electricity. This is also in conformity with International Panel on Climate Change's submission regarding CO_2 emissions and electricity production (Inter Governmental Panel on Climate Change, 2014).

Therefore in this model, let us assume N similar DMUs each is using M inputs to produce both $p\ and\ S$ ie desired and undesired outputs respectively. Vectors y_j^d and y_j^u are the desired and undesired outputs for DMU_j.Let the output matrix be $Y \in R_+$ containing non negative elements. The output matrix Y can be decomposed as $Y = \begin{bmatrix} Y^d \\ Y^u \end{bmatrix}$, where $P \times N$ matrix Y^d is for desirable output and $S \times N$ matrix Y^U is for undesirable.

x_j are the inputs used by DMU_j and $X \in R^{M \times N}$

Using $F_J(X, Y,^d Y^u)$ to represent efficiency measurement for DMU_k then with the assumption of strong disposability on the undesirable output the equation becomes

$$F_J(X, Y,^d Y^u) = \min\theta$$

$$s.t.$$

$$y_j^d \le Y^d \lambda$$

$$\theta y_j^u \ge Y^u \lambda$$

$$\theta x_j \ge X\lambda$$

$$\lambda \ge 0, j = 1, \dots, K$$

$$\lambda \in R_+ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..2$$

λ is interpreted as in model 1 and so are the efficient scores.

Possible way 4 of treating the undesirable as an input has been explored for example in the works Seiford and Zhu (2002).This will be regarded as my preferred model as compared to ignoring the existence of the undesirable output altogether. Although putting in mind the concerns reported by Kuosmanen, (2005). Moreover his concerns are based on to Färe and Grosskopf (2003, 2004)'s submission in favour of using possible way 3.However Kuosmanen, (2005) goes on to prove that possible way 3 still has some weaknesses. From this observation, this subject matter of how to treat undesirable output is inconclusive and therefore I will refer to 1 and 4.

Table 1 below shows the specific models that will be run while considering the possible ways of dealing with the undesirable outputs. The underlying equation is the same but the second equation is also minimising the undesirable output.

Table 1: Summary table of models

Model	Inputs	Outputs	Type of RS	Comment
Model 1	Oil, Natural Gas, coal, nuclear, hydroelectric	Electricity generated	CRS	Do nothing to the undesirable output
Model 2	Oil, Natural Gas, coal, nuclear, hydroelectric, CO_2	Electricity generated	CRS	Consider it as an input

Key to note is that all inputs are modelled under strong disposability and so the output.

Model 2 is the preferred model because in reality it does not make sense to ignore the undesired output.

There are different DEA software technologies. These are classified under commercial and non-commercial DEA tools. Barr, (2004) evaluates these DEA software/tools basing on set criteria including; available models, key DEA futures and capabilities, platform and interoperability, user interface, reporting, documenting among other. The best commercial DEA software he identifies include; DEA-Solver-Pro, Frontier Analyst, OnFront and Warwick DEA. The non-commercial software include DEA Excel Solver, DEAP, Efficiency Measurement System (EMS) AND pioneer 2. In this paper OnFront 2.02 developed by Färe and Groskopf (2000) will be used due its vast advantages put forth by Burr in line with the evaluation criteria and its preference to be used by Economists and researchers as noted by him. EMS will be used for confirmatory purposes to establish if both software give the same on model 2. Also DEA Excel Solver is used to confirm the results of the two software for model 2 in period 2005.One period is considered due to the limited time available to exam all periods given that the exercise is time demanding. However, this is a crucial aspect in verifying results while implementing an empirical methodology.

CHAPTER FOUR

4.0 FINDINGS

Using the inputs and outputs presented in 3.1, the energy efficiency scores of the different countries were obtained using both Onfront and EMS software. EMS was used for verification purposes as a norm in empirical studies and this was tested for the preferred model i.e. Model 2 which is going to be the basis of the discussion. Also DEA solver was used to confirm the results of 2005 model 2 only due to limited time. The results are in the same rage for Onfront and EMS, however they differ slightly wusing DEA solver for some DMUs, this could be due to the fact the assumptions of CRS and strong disposability are not held in the basic DEA solver.

Further, the full ranking of countries and their performance in different years is presented in table 2 for both model 1 and 2. However, as mentioned in the previous paragraph, the discussion is going to dwell on model 2 but for comparison purposes results of model 1 is also presented.

Key to note is that both models present slightly different results in absolute although taking averages the scores appear the same. Zhou and Ang (2008) and Mukherjee (2008) also had differences in their results as they carried out similar analysis. The slight differences are notable for countries of Canada, Germany, Turkey and USA, the rest of the DMUs remained with same scores. This actually suggests that modelling an undesirable output as an input under the assumption of strong disposability may present the same results as the model that ignores the undesirable output completely. Although empirically it is okay as observed by other scholars and also illustrated by Seiford and Zhu (2002) and Yang and Pollitt (2007) probably more superior models can prove this. The results are presented in table 2 below;

Table 2: DEA Results for Models 1 and 2

S/No	Countries	Model 1				Model 2			
		CRS			Average	CRS			Average
		2005	2010	2015		2005	2010	2015	
1	Australia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Austria	0.82	0.97	0.81	0.87	0.82	0.97	0.81	0.87
3	Canada	0.79	0.83	0.78	0.80	0.80	0.83	0.78	0.80
4	Chile	0.89	1.00	1.00	0.96	0.89	1.00	1.00	0.96
5	Czech Republic	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6	Denmark	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Finland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8	France	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9	Hungary	1.00	1.00	0.99	0.99	1.00	1.00	0.99	1.00
10	Germany	0.95	0.94	1.00	0.96	0.97	0.94	1.00	0.97
11	Ireland	0.93	1.00	0.96	0.96	0.93	1.00	0.96	0.96
12	Italy	1.00	0.97	1.00	0.99	1.00	0.97	1.00	0.99
13	Japan	1.00	0.99	1.00	1.00	1.00	0.99	1.00	1.00
14	Korea	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
15	Mexico	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
16	Netherlands	1.00	1.00	0.80	0.93	1.00	1.00	0.80	0.93
17	New Zealand	0.98	1.00	0.93	0.97	0.98	1.00	0.93	0.97
18	Norway	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
19	Poland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	Portugal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
21	Slovak republic	1.00	0.85	0.82	0.89	1.00	0.85	0.82	0.89
22	Spain	1.00	1.00	0.97	0.99	1.00	1.00	0.97	0.99
23	Sweden	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
24	Turkey	0.89	1.00	1.00	0.96	0.91	1.00	1.00	0.97
25	UK	0.81	1.00	1.00	0.94	0.81	1.00	1.00	0.94
26	USA	0.87	0.87	0.93	0.89	0.89	0.87	0.93	0.90
Average OECD		0.96	0.98	0.96	0.97	0.96	0.98	0.96	0.97

27	china	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
28	India	1.00	0.94	1.00	0.98	1.00	0.94	1.00	0.98
29	Russia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Average Non OECD		1.00	0.98	1.00	0.99	1.00	0.98	1.00	0.99

Source: Author's computation using onfront software

From the table above and taking reference from model 2, it is clear that on average the OECD countries have an efficient score of 0.97.This implies that OECDs are inefficient and using 0.03 or 3% excess of their inputs following Sherman and Zhu, (2006)'s illustration of interpreting DEA results. Also their efficiency improved from 2005 to 2010 and then declined on average from 2010 to 2015 by 0.01. Similarly, the average score is still in line with Zhou and Ang (2008)'s findings in their model 1 which is somehow close to this one in OECD countries.

However, in specifics some countries have been improving in terms of efficiency in electricity production while others have been declining over the three periods. At the same time others have been efficient throughout the three periods. Australia, Czech Republic, Denmark, Finland, France, Korea, Mexico, Norway, Poland and Portugal, are efficient throughout. Implying that 13 OECDs out of the 26 are efficient in all the three periods. Although Japan and Hungary are efficient on average but not in 2010.

In all the three periods Canada performed the worst and taking averages Canada still performed the worst followed by Austria, Slovac Republic, USA, Netherlands, United Kingdom, Ireland, Chile, Germany , New Zealand , Turkey, Italy, Spain. Although these countries were inefficient basing on averages, it is key to note that USA and United Kingdom's efficiency improved from 2010 to 2015 while the rest reduced in the same period of comparison.

Basing on Sherman and Zhu (2006)'s illustration of interpreting DEA results, the efficiency scores of 0.8 or 80% of Canada indicate that Canada is using 0.2 or 20% excess inputs compared to other DMUs/countries that score 1 or 100.Thereforeit is possible for Canada to become efficient and hence get to the frontier if it reduces its inputs by 0.2 or 20% while maintaining the same level of output.   Similarly for the case of Austria, its efficiency score is 0.87 or 87% implying that Austria is using 0.13 or 13% excess inputs. Therefore it is possible for it to get to the frontier if it reduces its inputs by 0.13 as it maintains its current output. This applies to the rest of the DMUs/Countries that did not score 1. This kind of illustration was also used by Coelli, (1996) and Färe and Groskopf (2000).

However as clarified by Ortega and Gavilan (2013) these efficiency scores/measures have to be understood in the relative terms. This is so because a firm may appear efficient when analysed under a particular group however if it's compared with another set, this may not be the case. This is practically observed under the works of Gómez-Calvet et al.(2014) in measuring the Energy efficiency in the European Union, looking at their scores of 2005 for Austria and Spain, both countries were efficient while they are inefficient in this model as they are compared with other OECD countries.

Similarly, it is observed that the OECD countries have experienced little change in their overall performance. At the same time there are differences in the performance across the countries, as also observed by Zhou and Ang (2008) and Apergis et la. (2015).This could be due the differences in capacity utilisation throughout the year as well as the technical progress (Mukherjee, 2008).

Further, the energy efficiency of OECDs in the EU[1] in this regard has been higher than other OECD countries on average. This can be explained   by the established of a common energy efficiency legislation or if I may say the 2012 EU Energy efficiency directive that requires member countries to reach a 20% energy efficiency by 2020.Special emphasis is to be put on primary energy consumption or energy intensities domestically depending on the preference of the country (EU, 2016).
Also some EU countries including Germany, Denmark, Netherlands, Sweden and Norway have since legislated new taxes on the use of fossil fuels and CO_2 emissions in order to improve energy efficiency. Geller et la., (2006) .This has been reflected in the reduced use

[1] Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Turkey and United Kingdom.

of fossil fuels as a primary source of energy and the reduced CO_2 in these particular countries.

Also the OECD America[2] has averagely performed poorer as compared to the OECD Asia/Oceania[3].USA's inefficiency could be right from the lack of concrete energy efficiency policies as put by Hayes and Herndon(2013).Moreover electricity efficiency in the USA has also been hindered by complex behavioural features of markets and people(Sakai, 2013).

On the other hand, Japan has always valued energy efficiency since the 1970s due to the fact that it is not energy self-reliant. This has been emphasised in their several energy policies that emphasise secure energy pathways; efficient technology in the power industries: research and development among others (Geller et la., 2006).This notion was strengthened further after the Great East Japan Earthquake of 2011 that disrupted their energy mix in electricity production and also led to the increased use of fossil fuels (IEA, 2014b).

Further, these results differ slightly from Apergis et la. (2015)'s submission that capital intensive countries performed better than the labour intensive countries. In this case USA, Germany, UK, Netherlands and Canada are all capital intensive countries but they did not perform well on average. This may suggest that technology may not have a great impact on efficiency levels but other factors like input mix may do so. Moreover these countries have moved from the industrial to the service sector (IEA, 2014a)

On the other hand the Non-OECD countries indeed performed well as also observed in literature review apart from India. These countries are not as capital intensive as the countries in the previous paragraph moreover they are associated with high consumption of primary energy sources and CO_2 emissions. Their efficiency can be explained by the pressure that has been put on these countries especially china and India to change of their

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[2] USA, Canada, Mexico and Chile

[3] New Zealand, Australia and Japan.

primary energy mix from fossils to more less carbon sources and also use of Best Environmental Practices. This is further evidenced in their improved energy intensities (Zemin, 2008; Zhou et al., 2010; IEA, 2014a; Hussy et al.2014**)**.

Also, considering the current period of the sample i.e. 2015.The number of times each (efficient) DMU in this case country is used as a reference (including itself) is presented in Appendix 1. This presents the particular efficient DMU that can be used as a benchmark by an inefficient DMU basing on the computed λ variables or computed weights (Ozcan, 2014).For stance, Canada to become efficient it has to adopt a mixture of the actual techniques of Italy, Norway, Sweden, and Russia while reducing its output and maintain its inputs. The values of the λ will determine the best of the benchmarked. The economic implication is to revisit the primary mix.

On that note, Column 3 of the appendix shows the actual number of times a DMU has been used as a reference while column 4 shows the actual DMUs that should benchmark from the efficient one. Denmark is the most benchmarked DMU with a frequency of 6 including itself. The specific countries that benchmark from Denmark include; Hungary, Ireland, Netherlands, New Zealand, and Spain. Similarly other countries that are highly benchmarked include France with 5 references including itself, Norway, Sweden, UK and Russia. The countries with reference point 0 imply they cannot be benchmarked.

CHAPTER FIVE

5.0 CONCLUSION, POLICY IMPLICATION AND LIMITATIONS

This study has measured and analysed energy efficiency of 26 OECD member countries in terms of primary energy consumption use and electricity production and CO_2 emissions. Three periods are assessed that is 2005, 2010 and 2015.

As observed by Gómez-Calvet et al. (2014), studies that attempt to evaluate energy efficiency in electricity production at country levels are still modest. Yet this particular component in the energy sector is very important while designing energy related policies. Electricity production determines the primary energy mix. Also in the production process both positive (electricity) and negative (CO_2) externalities result as outputs yet many inputs are utilised

DEA technique follows to be the best tool to use in the case of multiple inputs and outputs. Therefore the technical input oriented CCR model was used. It was modified according to Yang and Pollitt (2007) to incorporate the undesirable output.

Two models are run using Onfront software and there is small difference in the results. Also Model 2 as a preferred model is run using EMS software to confirm if both software give the same results. It turns out that results are the same. DEA excel solver is applied on the 2005 period and results slightly differ.

The results show that OECD efficiency levels in electricity production are high and there has not been a significant change in the three periods. Similarly, 13 out of the 26 OECDs have been efficient in all the three period on average. Of all the OECDs Canada and Austria are the most inefficient countries. On the other hand EU-OECDs turn out to be more efficient than other OECD regions. On the same note the non-OECD countries are also efficient besides India. Also Denmark and France are the most benchmarked countries.

The results generally are to some extent in line with other scholars. Further comparing with the scope of other OECD related studies, i.e. periods before 2005, majority of the OECDs have improved while others like USA have declined. This situation calls for the inefficient countries to benchmark from the efficient ones and improve. This is so given that the non-OECD countries of China, Russia and India who have been proved to be one of the biggest consumers of primary energy sources are efficient. This indeed puts a threat on the energy security of OECDs and also their environmental commitments.

Given that the inefficient OECDs are using many inputs to generate electricity, then they have to identify where there is waste. This is in addition to strengthening domestic policies on energy demand management and supply. Also this study suggests that the emission levels do not guarantee inefficiency (example china is the biggest emitter but efficient). Therefore a more solid reason for inefficient countries to check their domestic policies governing the end energy use including; appliance usage; transport; buildings among others before determining their generation. Also since this study has not empirically established the relationship between CO_2 and efficiency scores, then there is still need for OECDs to move from carbon intensive fuels like oil, gas and coal to non-fossil like renewables and nuclear.

Further, in line with Apergis et la. (2015) submission; improving energy efficiency would ease the heavy investment in energy infrastructure; minimise the exposure to price volatility of energy sources; improve affordability of energy by low income earners; decrease the pollution at both local and international level and lastly improve the social welfare.

Also, this study is an economy wide study using data that is aggregated. In this context, Mukherjee (2008) notes that carrying out these studies at industrial levels would give a better understanding of the issues raised in the analysis; although Zhou and Ang (2008) states the concern of data availability as a limitation to such studies.

Further, acknowledging Gómez-Calvet et al.(2014)'s submission that inclusion of variables depend on the objective of the study in this case assessing how OECDs are efficient in electricity production using their primary energy sources; Other studies can include economic variable which is vital for my micro analysis. But with caution that a country's economic conditions had a small impact on the electricity generation sector but the regulatory and model selection impacted more on the level of efficiency (Xie, et al., 2013).Also more comprehensive methods that can run superior models like fuzzy DEA can be explored using similar data.

CHAPTER SIX:

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APPENDICES

Appendix 1 Specific benchmarking results

S/No	DMUs/Countries	Reference Count	Benchmarking DMUs
1	Australia	1	Australia
2	Austria	0	Italy, Norway, Portugal, Turkey
3	Canada	0	Italy, Norway, Sweden, Russia
4	Chile	1	Chile
5	Czech Republic	4	Czech Republic
6	Denmark	6	Denmark
7	Finland	2	Finland
8	France	5	France
9	Hungary	0	Czech Republic, Denmark, UK
10	Germany	2	Germany
11	Ireland	0	Czech Republic, Denmark, France, UK
12	Italy	6	Italy
13	Japan	1	Japan
14	Korea	1	Korea
15	Mexico	1	Mexico
16	Netherlands	0	Denmark
17	New Zealand	0	Denmark, Italy, Norway, Portugal
18	Norway	4	Norway

19	Poland	1	Poland
20	Portugal	3	Portugal
21	Slovak republic	0	Czech Republic, France, Sweden, Russia
22	Spain	0	Denmark, Finland, France, Italy, Sweden
23	Sweden	4	Sweden
24	Turkey	2	Sweden
25	UK	4	UK
26	United States of America	0	France, Germany, Italy, UK, Russia
27	china	1	china
28	India	1	India
29	Russia	4	Russia

Source: Source: Author’s computation using Onfront software