MEASURING THE ELASTICITY OF ELECTRICITY DEMAND IN SOUTH AFRICA: IMPLICATIONS FOR FUTURE DEMAND AND SUPPLY

A thesis submitted in partial fulfilment of the requirements for the degree of

MASTER OF COMMERCE (FINANCIAL MARKETS)

of

RHODES UNIVERSITY

by

Sebastian Kosiorek

December 2017

Supervisor: Prof Gavin Keeton

Co-supervisor: Prof Ferdi Botha

ABSTRACT

A key economic issue for government is the ability to effectively match electricity supply to electricity demand, because of the substantial economic losses in the case of where there is too little supply, or the waste of scarce resources where there is too much supply. In the case of South Africa, this issue, the importance of which was highlighted by the power shortages and associated "rolling blackouts" experience in 2008, has led to the creation of the Integrated Resource Plan (IRP) as a means to decide how energy policy will be developed. Recently, however, the IRP 2010 and its subsequent 2013 and 2016 (draft) updates have been criticised as being too optimistic in regards to their projections of economic growth and electricity demand, making the recommendations in these documents to be flawed. Using monthly data from January 1990 to May 2017, together with Autoregressive Distributed Lag (ARDL) bounds testing for cointegration, this paper measures changes in the elasticity of electricity demand as a result of the massive price hikes over the past decade. Thereafter, the implications of changed electricity as well as possibly lower Gross Domestic Product (GDP) growth in the future for forecasts of possible future demand for electricity are examined. From these revised forecasts, it is possible to make appropriate recommendations in regards to electricity supply policy for South Africa including what possible energy mix is needed as well as the requirements for creating new supply to meet possible future demand. It is concluded that future electricity demand is likely to be much lower than forecast in the IRP 2010 and IRP 2013 documents. The degree of uncertainty in electricity demand growth suggests that large-scale increases in supply capacity taking years to construct, such as coal or nuclear, should be avoided. Small, incremental increases in supply that are able to come on stream swiftly, such as gas, solar and wind power, are likely to be more appropriate for meeting South Africa's future needs.

DECLARATION

Except where explicitly stated otherwise and acknowledged, this thesis is wholly my own work and has not been submitted to any other University, Technikon or College for degree purposes.

TABLE OF CONTENTS

Contents

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

1.1. Research Context

The electricity sector has long been considered an essential part of the efficient workings of a modern economy. Electricity supply is unusual as it is often viewed as a "'natural monopoly" (Posner, 1968). A natural monopoly is the result of the relationship between demand and the technology of supply. If all demand in the market can be satisfied at the lowest cost by one firm instead of two or more, the market is said to be a natural monopoly (Depoorter, 1999). The electricity market is also unusual in that demand for electricity fluctuates during the day and seasonally. Electricity generation capacity needs to be adequate to meet "peak" demand, but a proportion of supply lies idle when demand is lower unless there is an incentive for consumers to make use of it during these periods and smooth consumption, such as through lower pricing (Depoorter, 1999).

The supply side of the market has been further impacted by technological changes as options such as renewable energy in recent years have become more viable, allowing for a departure from the more traditional usage of fossil fuels and to relatively small-scale production units rather than large-scale mega-plants.

The demand side of the electricity market is also unusual in that the demand for electricity is usually viewed in the classical sense as inelastic. That is, it is needed by most consumers and has few real substitutes so its demand is not seriously impacted by changes in its price (Anderson *et al.*, 1997). However, Kirschen (2003) notes that demand for electricity is not perfectly inelastic. Kirschen (2003) finds that electricity, like any other commodity, will be bought by consumers until price equals marginal utility. A change in price can therefore have an effect on demand, if not in the short run, then in the long run. In the case of a price increase, there will be little immediate effect on the amount demanded for day-to-day activities due to consumers having preset needs. But the increase in price will have an effect on long-run behaviour. In the long run, it has been found that a price increase can cause a negative reaction in consumers, bringing about changes in demand to differing degrees (Kirschen *et al.*, 2000). The demand for electricity is therefore elastic in the long term.

Substantial price changes over time would lead to consumers acting in a rational manner and changing their consumption patterns. Electricity demand will rise in periods where prices are lowered and fall when prices increase (Faria and Vale, 2011). Moreover changing behaviour in this manner has been found by Spees and Lave (2007)to occur only when consumers are given such information in advance. Thus, while the elasticity of electricity demand might be higher in the long run, it is still fairly inelastic in the short run when consumers who did not expect the price increases to occur have already planned their usage for the time period.

'Price elasticity of demand' is only one piece of the puzzle determining changes in consumer demand over time. A second important factor is 'income elasticity of demand' (Gately and Huntington, 2002). In this case, the key aspect that determines the elasticity of demand for a product is consumer income, where higher/lower income and changes in said income impact on demand. In the case of the economic climate shifting, such as that of a recession, the effect would be lower income for consumers and in turn a lower demand for electricity. The key role that price elasticity plays is in determining how large an impact the decline in income will have on demand. The extent of the decline is the income elasticity of demand. Gately and Huntington (2002) make note that these two elasticities – price and income - may vary widely over time and must both to be taken into account for effective forecasting of future demand.

Fan and Hyndman (2011) noted that estimating elasticity of electricity demand accurately requires consideration of a number of issues. In the case of Australia, they note that accurate estimation of electricity elasticity requires detailed information on other inputs that are substitutes for the use of electricity. Estimates must also account of large variations in the cost of electricity between sectors and regions (e.g. discounts for bulk buyers) and requires knowledge of the mix of sectors and disaggregation of data. Fan and Hyndman (2011) found that it is best to make use of data at a higher frequency such as quarterly data. They found using historical data that South Australia's price elasticity ranged between -0.365 to -0.428. This indicates only a relatively moderate response to changes in price. Price elasticity varied during the day and was most responsive at the expected peak period when prices are highest (Fan and Hyndman, 2011).

Bentzen and Engsted (1993) note that the oil crisis of 1993/1994 caused a great amount of attention to be given to projecting future energy demand. The problem however was the estimation of the elasticities of oil demand, both price and income, due to the nature of the variables as non-stationary. They found that using an error-correction model would be best. For the two decades preceding the oil crisis, as well as at the time of the crisis itself, oil consumption had been steadily growing in line with economic growth. Oil consumption however, significantly slowed during and after the 1973/74 oil crisis. Due to this, it appeared likely that a structural break in demand would have occurred as a result of the abrupt change in the oil price at that time. However, contrary to expectations, Bentzen and Engsted (1993) found that the data examined showed there had not been a structural break with short and long run income elasticities of 0.666 and 1.213 and own-price elasticities of -0.135 and -0.465 respectively.

Bentzen and Engsted (1993) note also that forecasting future energy demand is extremely difficult. A change in any one of the variables, such as oil price growing at a lower rate that was expected, means the forecast will underestimate future energy consumption.

All these factors are important when looking at South Africa's Integrated Resource Plan (IRP), first published in 2011 as a blueprint for the 2010-2030 period, and intended as a means to adequately address South Africa's energy needs. The documents and forecasts are supposed to be updated every two years to take into account changes in the economic climate and suggest the best future course of action (Department of Energy (DoE), 2011). Thus, the steadily deteriorating economic performance of South Africa has been noted in the 2010, 2013 and 2016 (draft) documents. The assumptions made still seem unduly optimistic, however, especially with regard to likely future GDP growth and also the elasticity of future electricity demand relative to that growth. As a result, the demand projections, and therefore the perceived needed future supply, appear far more than what one would reasonably expect.

An example of this excessive optimism is that while the original 2010 IRP document projected GDP growth to be 4.6% per annum over the next 20 years for the time period of the plan 2010-2030, the 2013 plan increased the expected GDP growth to 5.4% per annum in line with the National Development Plan, even though South Africa's actual growth performance had deteriorated in the interim. In addition, the original IRP 2010 projected capacity requirement to be 52 248 MW by 2030, with a total annual demand total of 454 TWh in 2030 (DoE, 2011). The updated IRP 2013 found that instead total annual demand in 2030 could be lowered to a range of 345-416 TWh and that 6 600 MW less capacity would be required for reliable electricity generation (DoE, 2013).

The lower than expected growth performance of the South African economy from 2010-17, and the reality that electricity demand today is now lower than it was in 2008, bring into doubt whether the demand expectations of the IRP documents are still plausible and, hence, whether the suggested supply needs set out by the IRPs are still appropriate.

1.2. Goals of the Research

The goal of the research is to critically evaluate the electricity demand and supply projections contained in the IRPs of 2010, 2013 and 2016 (draft). To achieve this, sub-goals are:

- Calculating possible changes in the elasticity of electricity demand as a result of the dramatic price increases in electricity that have occurred over the last decade.
- Assessing the impact of identified elasticity changes as well as possibly slower future GDP growth on the electricity demand projections contained in the IRPs.
- Assessing the impact of identified changes in demand projections for required future supply.

1.3. Methods, Procedures and Techniques

Elasticity of electricity demand for South Africa will be calculated, making use of the econometric methods found within the literature. Of specific interest will be calculating the long-term income and price elasticity of demand, making use of variables such as energy consumption, real energy prices and real income as a means to estimate said elasticities (Bentzen and Engsted, 1993).

South Africa's price and income elasticities of demand will be calculated making use of accepted techniques found in the literature, including the Autoregressive Distributed Lag model to identify the importance for electricity demand in SA due to changes in overall GDP growth, structural changes in the sectoral composition of GDP and price changes over the past decade.

The results of this analysis will be applied to the various scenarios put forward in the IRP documents, to check whether the demand projections of these documents are reasonable against the backdrop of possible future growth and elasticity scenarios. Alternative forecasts will be done with GDP estimates that are more in line with expectations of what actual GDP may really be in the next few years. These forecasts will be compared with those in the IRP. In this way the sensitivity of future demand projections to both changes in growth forecast and price elasticity of demand will be assessed.

The forecast of possible electricity demand in 2030 will be used to assess the implications for South Africa's future supply needs and the appropriateness of the supply solutions set out in the IRP documents. The final portion of this paper will critique current policy proposals as well as make suggestions regarding future electricity demand and supply in line with the findings of the paper.

1.4. Ethical considerations

As the analysis uses only publicly available data approval by the Rhodes University Economics Department Ethics Committee was not required. The only ethical considerations are those facing all researchers, of objectivity and lack of bias. Ethical principles in this regard will be rigidly observed.

Chapter 2: Theory and Literature Review

2.1. Introduction

The nature of electricity and how it links to the day-to-day lives of consumers as well as the growth of an economy makes it one of the most important public commodities on the market. This in turn has led to much research into both the demand and supply side of the electricity market as a means to understand and project future demand needs and base economic policy around this. The goal of this chapter is to review the literature regarding the macroeconomic theory in relation to the nature of the electricity market, as well as the determinants of both demand and supply.

This includes looking at the theory behind what is known as a 'natural monopoly', as well as the determinants of elasticity of demand and how these both apply to the electricity market and aid in projecting both future demand and supply, and also finding examples in the literature of these theories in practice. In addition, the link between both economic growth and electricity consumption will be explored.

2.2. Theory of natural monopolies

Posner (1968) defines a monopoly as market where there is only one seller of a product/service with no close substitute. A natural monopoly refers not just to the number of sellers in the market but also the relationship between demand and the technology of supply. If all demand in said market can be satisfied at the lowest cost by one, firm instead of two or more, then the market is a natural monopoly, regardless of the actual number of firms (Posner, 1968).

In the case where there are more firms within such a market, these firms will quickly be driven either outside of the market as production costs exceed profits, or will be taken over through mergers (Posner, 1968). Entrants are thus not attracted normally to these markets, and even in the absence of predatory measures by the monopolists, will fail to survive within the market (Depoorter, 1999). In the case of natural monopolies, the concept of competition is not a viable regulatory mechanism and thus direct controls are necessary for the market to perform efficiently (Posner, 1968). These regulated industries are essential to modern society, being public goods needed to function, which is why there has been heavy regulation and/or state ownership of these industries. Mosca (2008) notes that the idea of natural monopolies came into existence hand in hand with the concept of 'perfect competition' as they arose from the natural play of market forces.

Industries such as electricity, water and telephones, all face relatively high fixed cost structures, where the costs necessary to produce even a small amount are very high, but, after the initial investment, the average cost per unit declines rapidly (Depoorter, 1999). Competition in these industries is considered socially undesirable due to the unnecessary costs imposed on society, specifically needless duplication of expensive capital equipment (Depoorter, 1999). Regulation and control over these monopolies has in recent times come under scrutiny, due to both the costs and logic behind the 'natural monopolies'. There has been an increasing case of 'public utilities' becoming privatized and deregulated, with varying degrees of success. DiLorenzo (1996) states that the idea of a natural monopoly is more akin to a myth than economic fact and that the claimed problems of duplication and the power of economies of scale are in fact not ‘natural’ but usually rather due to the intervention of government in the market.

Using the electricity market as an example, DiLorenzo (1996) finds that historically the electric utilities market has had decades-long competition within the US and that the idea of competition disappearing in these markets is improbable. Primaeux Jr (1986) found that where there was direct competition in the different cities in the US, it had persisted over the long term (over 80 years). Competition was strong in both price and service, and consumers gained substantial benefits in comparison to cities where monopolies were in place instead.

Unlike what classic theory would imply, Primaeux Jr (1986) suggests that firm costs are actually lower where there are two or more firms operating in an industry, and there is no excess capacity being generated, with supply meeting demand, and therefore no waste of resources. Price wars that do occur between firms are not as damaging as theory would suggest. Primaeux Jr (1986) concludes that the benefits gained from allowing competition heavily outweigh any dissatisfaction caused by duplicated power lines in the electricity industry. Primaeux Jr (1986) in addition finds that electricity utility executives within monopolised industries admitted consumers would benefit from competition, but had personal preference for monopolistic markets.

Demsetz (1968) also found that rivalry within utility industries would be a much more effective way of keeping markets free from imperfections Demsetz (1968) concludes that intervention is not as necessary as economic theory has implied in the past.

In recent times there has been a change in the view of policymakers regarding to natural monopolies. The initial fears of adverse economic consequences, due to a lack of effective regulation of natural monopolies, have instead been replaced by the question of whether the cost of regulation is more than the cost of the potential imperfect market (Joskow, 2005). Deregulation as noted previously, is becoming more prevalent, and rather than focus on the control of price and entry into these industries, a new type of regulatory mechanism has been put in place, one which focuses on company performance (Joskow, 2005).

Künneke (1999) questions whether the electricity market still has the characteristics of a natural monopoly, given the changing economic characteristics of electricity networks. Liberalization and growth has caused competition within electricity networks that has weakened the natural monopoly characteristics of electricity markets (Künneke,1999). Three major developments that have led to this outcome. The first, is the development of small-scale, decentralized electricity production. This has allowed consumers to internalize positive network externalities to a point where it is possible to sell excess electricity in a liberalized market. The second, is the evolution of 'parallel lines', that is the parallel development that can occur in liberalized markets that can lead to toward intra- and inter-market competition. The last, is that of controlled electricity transport and distribution, which Künneke (1999) allows for multi-functionality with other networks and meeting changing technical and economic needs which are not met by the public grid.

Künneke (1999) concludes that more research is still required to fully understand the electricity market, but that the reforms that taken place in it in recent years cannot be ignored. He draws parallels to the telecommunications sector as an indicator of how the market may evolve in the future, as a liberalized sector with numerous private players.

2.3. Demand Side of Electricity

2.3.1. Theory of Elasticity of Demand

One of the most well used instruments in terms of understanding consumer behaviour in macroeconomics is the 'elasticity of price demand' (Anderson *et al.*, 1997). Elasticity of demand is one of the core means of understanding and predicting the behaviour of consumers in response to changes in price. Specifically, elasticity of demand shows how sensitive consumers are to changes in the price of goods. Put simply, as prices rise one would expect that consumer demand would decline, but the extent of this decline is described by the price 'elasticity' of a product. Anderson *et al.* (1997) illustrate the idea with a simple example: in the case where a one percent increase in the price of a product has caused demand for the product to fall by one percent, the price elasticity of the good in question would be 1. This suggests that for most goods, the elasticity hovers somewhere around 1.0. However, there are outliers where goods can be more elastic, or conversely more inelastic, due to their properties/importance to consumers. Traditionally, a good that is needed for day-to-day operations, or has few to no substitutes, would be inelastic, while a luxury good, or a good with substitutes, would be price elastic (Anderson *et al.*, 1997).

An example of an inelastic good can be seen in electricity, due to its importance to everyday life and the existence of no close substitute. As an example, one can look at a manufacturing plant. In the short term the work schedule is hard to change, and thus the consumption of electricity in the short term is normally fixed at a predetermined amount as per the plant schedule. But in the long term it is possible to change schedules and reduce consumption if the electricity price rises unexpectedly.

The case of elasticity and how it impacts on energy demand is thus of great importance to economists, with the need to model both short run and long run elasticity being a key concern when forecasting energy demand into the future. Bentzen and Engsted (1993) note the importance of this, and look to the case of OECD countries in the two decades preceding the oil crisis of 1973/74 where energy consumption had been steadily growing until the crisis. Energy consumption thereafter slowed down, due to what could be attributed to both a slowdown in economic growth and the increasing costs in energy. Understanding both these impacts is important for understanding energy demand (Bentzen and Engsted, 1993).

However, it must be noted that the effects of elasticity in the market are not limited to price elasticity. The impact on demand of changes in income must also be taken into account. Just as price effects consumer demand, so does consumer income. Similar to price elasticity of demand, income elasticity of demand determines the way that consumers will respond due to a shift in the market. However, unlike price, this change is not in the control of producers (Gately and Huntington, 2002). Income elasticity refers to the change in demand for a good by consumers due to an increase or decrease in their income. Like price elasticity, income elasticity can fluctuate widely (Gately and Huntington, 2002). Gately and Huntington (2002) find that these two differing elasticity can vary widely, and both must be taken into account in attempts to predict future consumer behaviour.

2.3.2. Examples of Price Elasticity and Income Elasticity

2.3.2.1. Denmark

The problem regarding the estimation of elasticity, particularly long-run elasticity, is that not only is the required data not always readily available, but the variables to determine said elasticity are normally non-stationary and have multicollinearity (Bentzen and Engsted, 1993). The often-used solution of first differencing can be used when looking at short-run effects, but the long run variation in the data is removed, meaning that long-run elasticity cannot be modelled with such data. Instead, Bentzen and Engsted (1993) make use of both cointegration and error-correction models to model the data of Denmark. Using a long period of data, from 1948-90, they are able to successfully estimate both the short and long run elasticity of energy demand in Denmark. They go further to test the case of whether the 1973/74 oil crisis caused a structural break in Denmark's energy demand, as well as forecasting future energy demand. The results were surprising in regards to energy demand, as, unexpectedly the oil crisis was found to have not caused a structural break to occur in Denmark's energy demand, even though the price of energy rose dramatically (Bentzen and Engsted, 1993). After calculating elasticity, it becomes possible to forecast future energy consumption. Bentzen and Engsted (1993) plot different scenarios for Denmark, using different rates of economic growth and energy mixes and compare these scenarios of future demand to other models. They note that the plausibility of such forecasts rests on their assumption. In the case of Denmark, GDP growth rate of 1.9% was used, which makes the resultant projections unrealistic.

2.3.2.2. Australia

Fan and Hyndman's (2011) findings in regards to price elasticity of demand in Australia suggests there are various difficulties when attempting to accurately calculate price elasticity. The case of Australia was of interest as most sectors of South Australia were, until recently, insulated from volatile electricity prices and normally paid a flat rate for electricity consumed. Economy activity, demography and weather were therefore the main drivers of state-wide demand. They note that when estimating elasticity, information on substitutes for electricity is difficult to acquire, and an increasingly large amount of data creates a more complex model. Instead, Fan and Hyndman (2011) chose to make use of a model that used a limited number of variables including population, state output, price and climate.

They note that the second major issue when estimating elasticity, especially when doing so for a country, is that price elasticity can vary widely across different sectors (residential/industrial/commercial) and regions in an economy. This in turn means that knowledge of the mix of sectors and a disaggregation of the data is needed for an accurate estimation. Finally, specifically in the case of Australia, the usage of a nonlinear structure of tariff schedules made it much more difficult to quantify price elasticity (Fan and Hyndman, 2011). They also note that the price of electricity sometimes changes within a calendar year, so it is best to make use of higher frequency such as quarterly data to more accurately model the relationship between demand and its driving factors.

Narayan and Smyth (2005) found that the case of Australia was of interest due to the radical overhaul in the electricity sector since the beginning of the 1990s. They argue that measuring price and income elasticities are necessary when making decisions for public policy. To do this they decided to make use of aggregate Australian data, which differs from other studies, such as the work of Fan and Hyndman (2011). Making use of the price of electricity, natural gas, income and temperature, the study made use of an autoregressive distributed lag framework with a bounds test to determine long-run elasticities in Australia. Though different to previous studies in terms of method used, Narayan and Smyth's (2005) results were found to be robust in the case of finite sample sizes. Estimates of both short and long run elasticities through this model were consistent with other studies and other countries, but normally in the lower spectrum of what has previously been found. In general, due to the lower short-run elasticities, it was found that responses to environmental policy initiatives, such as carbon emission policy, would not have the major impact expected by those supporting the usage of said policies.

2.3.2.3. Barbados

A similar study by Mitchell (2006) on income and price elasticity of oil demand in Barbados made use of both the error correction model of both Engle and Granger as well as the Johansen version of the model. The study looked at the responsiveness of energy demand to a change in oil price and whether an increase would be effective in reducing Barbados' energy consumption (Mitchell, 2006). This was of major concern due to the increasing prices of oil at the time and the ever-increasing cost of Barbados' energy import bill (Mitchell, 2006). Similarly to Bentzen and Engsted (1993), Mitchell (2006) used a long period of data (1960-2005) and cointegration was used to find the relationship between the variables which would otherwise be lost with other econometric methods.

Mitchell (2006) found that the price elasticity of demand for petroleum energy ranged between -0.16 to -0.28, while the income elasticity of demand ranged between 0.57 and 0.42. This meant that, in the long run, a 100% increase in the price of petroleum could cause the demand for petroleum to reduce by 20%, while a 100% increase in income would increase consumption by roughly 50%. In the short run, however, it was found that there was no significant relationship between energy demand and price (Mitchell, 2006). Only income had any tangible effect on energy demand in the short run. Even in this case and demand for petroleum energy itself was found to be inelastic in the short run while fairly elastic in the long run, as expected. Mitchell (2006) found that a full pass through of the increased prices would lead to energy consumption reductions as well as lowering the effect of the energy import bill. There would, however, be a negative impact on potential economic growth, meaning that any policies increasing energy prices would require care so as to not damage the economy as a whole.

2.3.2.4. South Africa

Ziramba (2008) similarly looked at the case of residential electricity in South Africa with the ARDL model. The main aim was to test for what are the main determinants of electricity consumption in South Africa, making use of real GDP per capita, real per capita residential electricity consumption and real residential electricity tariff (price) for the years 1978-2005 (Ziramba, 2008). In regards to income, the sign was positive as expected with a long run elasticity of 0.31, but price elasticities were insignificant but with the correct sign (Ziramba, 2008). Ziramba (2008) found that residential electricity demand has price and income elasticity of -0.011 and 0.33 respectively, meaning that both are relatively inelastic. Ziramba (2008) concludes that, in the case of South Africa, the effect of a price increase alone cannot significantly decrease electricity consumption, nor would a significant increase in income lead to a significant increase in electricity consumption.

2.3.2.4. Organisation for Economic Co-operation and Development (OECD) Countries and non-OECD countries

Gately and Huntington (2002) find that the effects of price elasticity and income elasticity are not symmetrical in terms of how they affect the long-term demand response of consumers. The specifics of the asymmetrical effects are that an increase in income which leads to an increase in energy demand would conversely not decrease by the same amount in the case of a reduction in income of the same amount (Gately and Huntington, 2002). Similarly, in the case of a price increase, the demand decreasing effect would not be entirely reversed by a reduction in price of the same amount.

Gately and Huntington (2002) found that for all regional groups studied (OECD and non-OECD countries) there was generally an asymmetric demand response to price and/or income. They note that most research does not take into account the asymmetrical relationship. Ignoring this asymmetry lead to bias on estimated elasticities. Incorrectly specifying a demand equation as perfectly reversible, when in fact it is not, would bias downward any estimated income elasticities (Gately and Huntington, 2002).

For most countries, demand in fact responded more strongly to increases in price than to decreases in price (Gately and Huntington, 2002). This was against expectations that this would hold true only for developing non-OECD countries and instead is the same for richer OECD countries. They conclude that there is no perfect price-reversibility and that not taking this into account can lead to a downward bias on estimations. In the case of income, demand responded more strongly to increases than to decreases, but only for some countries such as non-OECD oil exporters (Gately and Huntington, 2002).

2.3.3. Impact of Technology

In regards to the role that technological innovation plays in the elasticity of demand for energy, Herring and Roy (2007) delve into the debate of whether such innovation into improved efficiency actually leads to lower energy consumption, as well as reduced environmental impact. The belief is that as efficiency improves, this leads to lowered consumption of energy, so that it is possible to achieve the same output with less energy than in the past. They answer this question with a firm 'no', due to the existence of 'rebound' effects and 'take-back effects'. These effects lower the implicit price of energy consumption, leading instead to greater energy consumption.

Herring and Roy (2007) identify three different types of rebound effects that occur: direct, indirect and economy wide. The first of these, the direct rebound effect, is brought about by consumer desire to make use of more of any product or service due to its lower price, the price elasticity of the product in other words. Priced efficiency gains and non-priced induced gains must be distinguished as they have differing potential effects, the former being caused by factor substitution which can cost an economy while the latter is caused by technological improvements.

The second of these rebound effects is the indirect effect, that is, due to lower energy prices more income is available to spend on other goods and services, which in turn can also involve consuming energy (Herring and Roy, 2007). An example given by Herring and Roy (2007) is that, money saved through the usage of a central heating system may instead be used for an overseas holiday, causing an increase of spending on aircraft fuel consumption. In the case of producers, efficiency improvements can lead to a change in demand for other factors of production. This decrease in costs in one sector can lead to a shift in the rest of the economy. For example, a decrease in the steel price leads to lower cost of cars, which in turn leads to a larger amount of cars being bought and finally higher demand for gasoline (Herring and Roy, 2007).

The final rebound effect, and the one with the greatest effect, is the economy-wide effects, where long term changes in the economy are caused by technological innovation, changes in consumer preference and/or social institutions (Herring and Roy, 2007). The lowered cost of energy services has a great effect on the direction and speed of innovation and consumption in the economy. In this case new products/services would be created to exploit markets created by lowered costs which in turn leads to an overall increase in energy consumption (Herring and Roy, 2007). In the case of energy utilities, they have focused on efficiency improvements to lower the cost of their product to increase profit via selling more at a low margin rather than little at a large margin. This has in turn led to a continued and ever growing market for electricity and new electronic goods (Herring and Roy, 2007).

2.3.2. Determinants of Demand

As a product that is needed for day-to-day activities or operations, the traditional view is that the demand for electricity is fairly inelastic as regardless of price, there will always be a need for a set amount of electricity. Kirschen (2003) points out that treating electricity as a commodity that is bought and traded means that in the traditional view consumers would act in a rational way and only buy electricity until cost equals marginal utility gain. Paying a flat rate per kilowatt per hour, consumers are not affected by changes in the daily spot price, as their demand is determined by their day-to-day activity/operations (Kirschen, 2003).

Spees and Lave (2007) note that customer response is a neglected means of solving the problems of the electricity industry. Industry has focused mainly on the supply side of the market due to the persistent belief that electricity demand is very inelastic. Fluctuations in demand during the day, due to seasonal/hourly/daily fluctuations of demand, are taken for granted by suppliers and require extra generating capacity to meet demand during these peak periods (Spees and Lave, 2007).

The view that demand is inelastic has been challenged in recent times. Evidence suggests that demand of is not necessarily as inelastic as believed. Rather, demand has shown to be fairly elastic when the price of electricity has been increased to the point of negatively affecting consumers' activities and forcing a change in behaviour, though to differing degrees (Kirschen *et al.*, 2000). In the short term, the degree of elasticity is found to be low due to only some consumers having the ability to change/reschedule their operations in response to changes in sport prices during the day (Kirschen *et al.*, 2000).

The example of highly variables prices in different time periods leads logically to customers adjusting their energy usage to take advantage of lower prices and increasing consumption in these periods, while reducing consumption in periods of high pricing (Faria and Vale, 2011). The idea of customers responding to stimuli such as high prices at certain periods in the day are known as demand responses management (Faria and Vale (2011). Specifically, this example would be a price-based response, where consumers respond to price adjustments meant to impact their consumption. However, the response by consumers in this case is entirely voluntary and assumes that the consumers will make a logical decision regarding efficient consumption (Faira and Vale, 2011).

The elasticity of demand for consumers is, however, much lower in the short run than in the long run due to consumers ability to react to increasing prices. In the long run the consumer has time to make decisions, such as buying energy efficient appliances which save costs in the long run (Spees and Lave, 2007). Responsiveness in this case is much higher when there is an incentive for consumers to react, such as buying said appliances. However, in the short run the only option available to a consumer is to forego consumption (Spees and Lave, 2007).

Manipulation of price is not necessarily the only option available to producers as a means to change consumer behaviour. There is also the possibility of us incentives-based system (Faria and Vale, 2011). Such incentives come together with rates charged to consumers and at times can also impose penalties on consumers that enter a program that imposes contractual obligations in return for the rates/incentives provided.

A key reason as to why there is a desire to change the behaviour of consumers must be explained. As a commodity, the supply and demand of electricity must be well balanced at all times. Too much supply leads to wastage, while supply that cannot match demand leads to power outages which can have far reaching consequences for an economy. In this case, control over behaviour is an attempt by producers to flatten the 'load curve' of supply and demand, that is to lessen consumption in peak periods and rather level out demand over time (Kirschen *et al.*, 2000). The fluctuations of seasonal and daily demand are the causes of this natural constraint on production, as are the costs and technological constraints related to efficiently storing electricity (Lijesen, 2007). The key issue to take from this in the end is that while demand fluctuates throughout the day, the supply of electricity cannot easily fluctuate to stay

1:1 to demand, instead staying as a static supply that a producer must continually generate (Lijesen, 2007). Due to the nature of electricity transmission, an imbalance between supply and demand for even a moment can lead to the stability of the entire electricity grid to be in jeopardy, which in turn disrupts the delivery of electricity for all suppliers and consumers on the grid, causing blackouts (Borenstein, 2002).

2.4. Supply Side of Electricity

2.4.1. Determinants of Supply

Theory regarding the supply side of the electricity market focuses specifically on the supply of electricity and production, rather than how consumers will react and attempts to change consumer behaviour. Instead the market as a whole can potentially be restructured to work more efficiently than the traditional setup, which, due to the unique nature of electricity, can have wide-spreading consequences. The tendency for natural monopolies to form in the market, which in most cases is controlled by the government as a public utility for the good of the people (Varian, 2014), was discussed in Section 2.2.

2.4.2. The Case of Renewable Energy

Renewable energy has been the lauded alternative to commonly used fossil fuels, with benefits such as clean energy that doesn't damage the environment, and being an inexhaustible source of energy, due to how the energy is generated. However, with these positives comes the negative conception of cost in regards to renewable energy, specifically that the cost of setting up and maintaining renewable energy generators are too high compared to their cheaper, but more damaging, fossil fuel counterparts.

A key point of difference between these two types of energies is that, unlike fossil fuels, renewable energy is inexhaustible. The work of Hotelling (1931) highlights the problem in regards to 'exhaustible resources' such as oil, noting that the classical view of economics that production will continue at a steady rate indefinitely is incompatible with 'exhaustible resources'. For example, when looking at the production of a mine, Hotelling (1931) lists a number of questions that need to be answered regarding its production, such as: how much of its proceeds are return on capital and how much is income, what is the value of the mine when all its contents are known and what is the uncertainty of the estimate, what should production be so as to profit quickly now or profit more but further in the future, and, if the mine is publicly owned, what would be the way to gain the greatest general good. These questions form the basis of Hotelling's (1931) view that the economics of exhaustible resources are impossible to map with a simple static model and why calculations are difficult in determining the workings of, in this case, a mine.

In addition, though renewable energy in theory is an attractive prospect, it faces large barriers to entry as a viable energy system, especially if one were to try to replace an already existing system such as coal. This is exemplified in the work of Beard and Ujjayant (2009) where the cost of network externalities in a Hotelling model show the difficulty in changing to such a system. The foremost issue in this case was not whether the new renewable system is viable but rather the barriers faced when adopting a renewable energy system (Beard and Ujjayant, 2009). One such barrier is the fact that consumers benefit from more consumers consuming the same type of energy (fossil fuels in this case) causing the adoption of new types of energy to be difficult until there is a sizable amount of users (Beard and Ujjayant, 2009).

The case of a renewable energy and fossil fuels can be traced back to the decision made when both systems were immature in which case the choice was dependant on network externalities and asymmetrical information (Beard and Ujjayant, 2009). An example by Beard and Ujjayant (2009) is that of automotive clubs, which led to the petrochemical economy to grow as it did. The clubs and gas station network were significant factors that led to the adoption of the internal combustion engine as the main type of transportation in the early twentieth century.

The key point made of this example is that network externalities lead to a technological lock that in turn leads to path dependencies. This fact can potentially be much more important than the price of renewable energy in explaining the ongoing difficulty in markets in switching from a fossil fuel based system. Hotelling's rule regarding scarcity and the increasing costs of fossil fuels due to supply diminishing still holds true, but this does not stop the externalities of the existing system from being an effective barrier to the adoption of renewable energy. They find that this lock into fossil fuels is much more important than price effects conclude that any new technology will face difficulties unless it exploits network externalities in consumption, otherwise becoming an inefficient option to the pre-existing system.

2.4.3. Examples of Renewable Energy

The idea behind renewable energy as a resource is attractive but as noted, has both its own advantages and disadvantages compared to continued reliance on the current energy systems that South Africa makes use of, specifically coal. With this in mind, implementing renewable energy faces a major hurdle due to lacking the positive network externalities of an already existing energy system. However there is also another challenge to renewable energy. Nuclear energy is seen as another alternative to renewable energy and in recent times has become a point of major interest in regards to the future of South Africa's energy policies.

This does not mean renewable energy is not a valid option for South Africa. Successful implementation however is of utmost importance of a new system. For this reason it is useful to look at countries that have successfully transitioned to renewable energy as a viable system.

2.4.3.1. Denmark

The case of Denmark is interesting, as it is a country that heavily relied on one source of energy, oil, before being forced to change due to the oil crisis of 1973 (Lund, 2010). As a result of the crisis it was forced to change its energy infrastructure, moving away from oil and into other energy types, including renewable energy. Denmark has been very successful in this endeavour, to the point of being more than able to self-supply its energy demands (Lund, 2010). Renewable energy as a source of electricity supply went from 0 in 1972 to 17 per cent by 2008, with wind power being a strong contributor. Though oil and gas still play a role, the renewable component of supply is likely to increase in the future (Lund, 2010).

Lund (2010) finds that there are three key components to the implementation of renewable energy strategies that were key to their successful implementation in Denmark. These three major technological changes are: energy savings on the demand side, efficiency improvements in energy production, and replacement of fossil fuels by various sources of renewable energy (Lund, 2010). Interestingly, due to the nature of conservation and efficiency improvements, this has also led to the primary fuel consumption in Denmark to also stay relatively consistent for more than 30 years, even with a growth of over 70% in GDP over the period (Lund, 2007).

2.4.3.2. Germany

Germany is another success story in the implementation of renewable energy systems, specifically in regards to wind power, which accounts for around 39% of installed wind power in the world (Wüstenhagen and Bilharz, 2006). Similarly to Denmark, the move to sustainable electricity/power was due to the 1973 oil crisis (Wüstenhagen and Bilharz, 2006). This caused a move to both nuclear and wind energy, with both becoming large parts of the modern German power supply, though in recent times the public perception of nuclear as an energy choice has lowered in the eyes of the public, particularly the young (Wüstenhagen and Bilharz, 2006). The success of renewable energy in Germany is surprising, as the focus of government research and development has been mostly nuclear (Wüstenhagen and Bilharz, 2006). A key point to how the system works in Germany is through the feed-in system, where tariffs are placed on renewable energy at a lower rate than those of fossil fuel type energy, which allowed for the early growth of the renewable energy sector to occur. To aid in sharing the burdens of the feed-in system, a nationwide settlement system was also developed to aid the utilities which allowed local grid operators to transfer the costs of the renewable energy law on tariffs to the next higher grid level. Due to the high voltage line level in Germany, this allowed the costs to be balanced out across the country (Wüstenhagen and Bilharz, 2006).

Wüstenhagen and Bilharz (2006) find that Germany's success in renewable electricity has been due to effective public policy, the critical mass of interest groups in favour of renewable energy, and a critical mass of politicians that aided in implementing renewable energy policies. In the view of Wüstenhagen and Bilharz (2006), if all three of these factors are sufficiently fulfilled in a country, then it is possible to effectively use the lessons learned from the German system in the designing of renewable energy policies and markets. These include the role of parliament in aiding the implementation of renewable energy policies, careful burden-sharing in customer demand and market liberalisation (Wüstenhagen and Bilharz, 2006).

Wüstenhagen and Bilharz (2006) warn, however, that the actual adoption of the legislation was near-accidental and there was significant changes that occurred in both 1998 and 2002 when it was unknown if the system would function smoothly.

2.5. Connection between Economic Growth and Electricity Consumption

Electricity supply has in the past been found to be a large contributor to GDP growth. Most recently, this traditional view of the relationship has been noted by the World Bank as one of the key reasons that GDP growth in South Africa has been so severely constrained (Mbatha, and Tshandu, 2015). An example of the importance of the supply of electricity has for economic growth was found by Ferguson *et al.* (2000), where the correlations between electricity usage and economic development was positively correlated for over 100 countries. The conclusion from this study implies that in general the rule that electricity consumption begets economic development holds true. However, even with these findings the relationship between economic growth and adequate electricity supply has been a much researched topic, especially in regards to the policy implications for developing countries whose situations vary greatly in comparison to the developed world (Altinay and Karagol, 2005). The answer has been much more ambiguous than might have been expected, suggesting the relationship between electricity and growth needs to be established on a case-by-case basis, rather than as a steel-clad rule.

2.5.1. Examples of the Economic-Growth Relationship

Due to the importance of the possible relationship between economic growth and the belief that a lack of electricity can lead to constrained growth, there is no lack of research on the subject.

2.5.1.1. Korea

Korea was found to have a bilateral relationship between economic growth and electricity supply (Yoo, 2005). This is to say, that an increase in supply can lead to an increase in growth and vice versa and where there is a constraint on electricity supply this leads to economic growth being restricted. Yoo (2005) notes that the unique circumstances of Korea must be taken into account. The reason that such a relationship exists, can be attributed to Korea's economic structure, as well as the historical pattern of its economic development.

2.5.1.2. Bangladesh

Bangladesh is the opposite of Korea, showing how different the aforementioned relationship can be. Mozumder and Marathe (2007) find, the case of Bangladesh is a stark contrast to that of Korea, with its infrastructure being one of the least developed in the world and with an inability to reliably produce electricity leading to frequent load shedding in the country. The relationship between economic growth and electricity consumption in this case was only one way, that is that an increase in GDP led to an increase in electricity consumption, but the reverse was not found to hold (Mozumder and Marathe, 2007). From this Mozumder and Marathe (2007) find that in the case of Bangladesh policies of energy conservation will have little effect on the economic development of Bangladesh and that a well-designed energy conservation policy could benefit the country. Specifically this would mean that increased energy efficiency can lead to a reduction in energy-related pollution and emissions leading to both a better economy and environment (Mozumder and Marathe, 2007). For countries in a similar position to those of Bangladesh that lack infrastructure and development, it can be assumed that similar results could be found. This could lead to similar policy recommendations, that policies that lead to electricity conservation will not adversely affect economic growth, but will instead aid in both development and cut social costs regarding energy-related pollution.

2.5.1.3. Turkey

Turkey is a country that is still developing, but is in a much more advanced state than. Altinary and Karagol (2005) found that Turkey have faced ever increasing electricity consumption needs as it grew, and cases when it failed to meet its needs led to damaging repercussions. This is highlighted especially in the 1980s and 1990s, where the lack of electricity to meet demand was accompanied by economic crisis (Altinay and Karagol, 2005). Altinay and Karagol (2005) find using economic data between 1950 and 2000 that there was indeed unidirectional casualty with regards to the electricity consumption and economic growth relationship, running from consumption to growth. This means that electricity consumption for Turkey can be an indicator of growth and that the supply of electricity in Turkey is vital to continued economic growth, limiting policy space with regards to constraining electricity supply (Altinay and Karagol, 2005).

2.5.1.4. South Africa

A recent study by Khobai *et al.* (2017) attempted to determine what the relationship between electricity consumption and economic growth is in South Africa. Notably this is the first study of its kind in South Africa, making it of particular interest to this study. Making use of data between the period 1985 to 2014, the study looked at economic growth, electricity supply, trade openness, electricity prices, capital and labour (Khobai *et al.*, 2017). Making use of ARDL and VECM, Khobai *et al.* (2017) found that in the short run there was no causality going from economic growth to electricity supply, or from electricity supply to economic growth, meaning that electricity conservation policies would be possible without negatively affecting South Africa's growth. In the long run, however, a bidirectional relationship was found between these variables, meaning that different policies would be needed for different time frames (Khobai *et al.*, 2017). This means that in the long run it would not be possible to make use of electricity conservation policies, as this would negatively affect South Africa's economic growth. This finding requires that secure, reliable, efficient, clean and sustainable energy be pursued (Khobai *et al.*, 2017).

2.6. Conclusion

This chapter provided an overview regarding the theory of the determinants of demand and supply within the electricity market. The unique nature of the electricity market as a natural monopoly, controlled by the state in the classical view, was shown to be slowly falling away, leading to a market more controlled by private suppliers, though this is not the case in South Africa.

Regarding the demand side of electricity, electricity demand being inelastic has been found to hold only in the short run, due to the inability of consumers to change their consumption. However demand elasticity has been found to be more elastic in the long run. This means that consumer behaviour can be influenced through different pricing methods. However demand can also be affected by the incomes of consumers as well. Income elasticity of demand must also be taken into account when projecting future demand. It is determined by the income of consumers, which means that in times of good economic growth, there likely to be increased electricity consumption. The extent of this rise relative to GDP increases depends on the increases in price and income in relation to one another.

The supply side of the market, as a natural monopoly, means that there would normally only be a single government-controlled supplier at certain fixed costs. However it is possible to move to a less regulated and privatized market. Renewable energy has become a much more attractive option in terms of supply, due to improvements in technology, as well as the fact that fossil fuels are not an infinite resource. Successful examples of switching to renewables, such as in Denmark, show the possibility of countries such as South Africa being able to successfully switch to a more renewable energy-focused energy mix.

Chapter Three: The South African Perspective

3.1. Introduction

The key question that this thesis is planning on answering, is what the suspected changes in the income elasticity in electricity demand in South Africa in recent years mean for future demand and, therefore, supply. To do this, the current state of electricity demand and supply must be looked at, as well as current and past expectations, and whether or not past scenarios had played out as anticipated.

To achieve this, this chapter will look at the Integrated Research Plans for South Africa. These are the focus on which South Africa's energy policy is based and feature prominently in the decision making process of government. Reviewing these Plans as well as related documents allows a clear analysis of whether the current proposed course of action is appropriate, and whether current expectations are plausible or improbable in the current economic climate.

3.2. The Integrated Resource Plan

The Integrated Resource Plan (IRP) is designed as a means to determine long term electricity demand, as well as plan how this demand will be met in terms of the amount generated, the type of generation, timing and total costs (DoE, 2010). Due to its long term nature, being set between 2010-2030, the plan itself was to be changed and updated as necessary to accommodate changing circumstances within South Africa's economic landscape (DoE, 2011). Changes were expected to be done every two years, to allow the plan to keep up with emerging technologies and developments. In addition, there was to be public consultation to make sure that various groups would be happy with the proposed energy mix, as well as adding additional input for additional scenarios and policy options (DoE, 2011). Other goals included were economic development, funding, as well as environmental and social policy formulation.

Three IRPs have so far been produced to keep up with developments, namely, the 2010, 2013 and the 2016 (draft) IRP documents. Each update added to the 2010 plan by adjusting for new technologies and expectations. Each of these documents will be reviewed in order as to see how the plan has changed and whether or not the expectations set forward are still plausible.

3.3. Demand

3.3.1. IRP 2010

The first plan drawn up with both input from government as well as the public aimed at achieving a balance between an affordable price for electricity as a way to support South Africa as a globally competitive economy, as well as to create a more sustainable and efficient economy as a means to aid in economic growth (DoE, 2011).

The total projected demand in the IRP 2010 was forecast to rise to 454 TWh by 2030. Peak demand, using the "policy-adjusted" IRP rises from38 885 MW in 2010, increasing each year by 10000-20000 MW, with peak demand forecast to be 67 809 MW by 2030 (DoE, 2011). To meet this and have an adequate reserve margin, the projected amount of new generation capacity required would be 52 248 MW.

The projection of future demand was based on GDP growth of 4.6% per annum over the 20 years that the plan would be in effect. Moreover, it was expected that there would be a gradual reduction in electricity intensity due to both increased efficiency as well as diversification in both the secondary and tertiary sectors of the economy (DoE, 2011). The primary sector, however, would still be energy intensive due to the focus on extraction of natural resources and manufacturing..

During the consultation process, concerns were raised that the demand forecast was on the higher side of the forecasting spectrum, with a resultant risk that there would be an oversupply of capacity if demand ended being lower than anticipated. It was noted that there was a lack of importance given to the price elasticity of demand, and it was decided that additional research in the future should into future iterations, as existing research was not adequate (DoE, 2011).

Energy efficiency demand side management (EEDSM) was seen to have greater potential than assumed in the demand forecasts, but were ultimately dismissed in favour of conservative EEDSM assumption to ensure security of future supply. Universal access and its potential was also not made use of, as the current system of prepaid metering was expected to continue (DoE, 2011).

The main driver of the demand forecasts was the assumptions regarding economic growth and its link to electricity consumption. As there exists a strong correlation between GDP growth and electricity sales growth, a large part of the forecast was based on this relationship (DoE, 2010). In regards to GDP growth, the AsgiSA target of 6% GDP growth by 2014 was used as the base for the high GDP growth forecast (DoE, 2010). This goal was assumed to be achievable only by 2016 because of the global economic recession at the time. Even this revised goal may be considered rather optimistic because it was based upon GDP growth of close to 6% per annum, a rate that had been previously achieved only from 2005-2007. Thus, the forecast was that growth for the majority of the period would be 6% per annum, until it gradually declined to 5.3% by 2035, making the annual average growth rate for the period 2010-2035 5.5% per annum in the high GDP growth forecast (DoE, 2010).

The moderate GDP growth forecast was similar to the average historical GDP growth of the years preceding 2010, being seen as the potential growth if the targets set by AsgiSA were not met. The average annual GDP growth forecast in this case was 4.5% between 2010 and 2035. This forecast was closer to the potential growth of the South Africa economy as believed by the South African Reserve Bank as well as many other institutions for the medium term (DoE, 2010).

The low GDP forecast was 1% lower than the moderate GDP forecast, approximately 3.5% for the period between 2010-2035 (DoE, 2010). Ashe growth for the past years was in a narrow cone of plus/minus 1%, this difference was cited as very realistic/appropriate for long term planning (DoE, 2010).

The second of the two assumptions, electricity intensity, is by the IRP 2010's definition "a measure of the ratio of electricity energy consumption relative to gross domestic product" and could be expressed at both basic prices and market prices (DoE, 2010). The expected trend for South Africa, like other developing countries, would be that the tertiary sector, which is not an energy intensive sector, would in future grow at a faster rate than the primary or secondary sectors (DoE, 2010). In addition, high electricity price increases would also cause consumers to substitute to other energy sources, or force an increase in energy intensity, which would bring a reduction in energy intensity in the economy.

The expectation of a decline in energy intensity was also used as an indicator for how much energy efficiency has improved, to the point that there was an expectation that energy efficiency would improve by 35% by 2035 (DoE, 2010).

Notably, the price elasticity of demand was not included in forecasting models, though price increases have two effects on electricity demand: income effects that impact on GDP growth and substitution effects which lead to a direct impact on electricity demand (DoE, 2010).

Instead, there was a belief that these effects were already captured in the IRP 2010 through assumptions made on GDP growth for the former, and future electricity intensity for the latter (DoE, 2010).

3.3.2. IRP 2013

The 2013 update was created as per the guidelines set out in the first IRP, as a regular update to the original plan due to the shifting conditions in South Africa. These changes have made the economic landscape quite different from what the original 2010 IRP assumed, with special mention being made of the electricity demand outlook having changed greatly from what was previously expected (DoE, 2013).

The key changes in this new outlook regarding demand were:

- Demand in 2030 was projected to be in the range of 345-416 TWh instead of 454 TWh.
- Peak demand was reduced from 67 800 MW to 61 200 MW in the Upper range forecast.
- This meant that 6 600 MW less capacity would be required for reliable generating capacity.

The economic growth used for these projections follows the growth suggested by the National Development Plan of an average of 5.4% per year until 2030. This was also in line with a planned shift in economic development away from energy intensive sectors which would allow the growth rate to have less of an impact on electricity demand from 2030 onwards forward (DoE, 2013). The 2013 IRP however did warn that electricity demand in the future might to reach the levels forecast (especially within the next five years), risking potential oversupply of generation capacity through overbuilding (DoE, 2013).

Other points of uncertainty within the IRP were found to be the additional variables within energy supply, especially the possible potential of shale gas and other gas developments in the region (DoE, 2013). Other variables included the global agenda in regards to stopping climate change, uncertainty surrounding the cost of nuclear capacity, and future fuel costs/availability, specifically in regards to coal and gas.

The fixed capacity plan of the 2010 IRP was found to be too stringent in its approach when faced with such uncertainties. Instead it was suggested that a more flexible approach should be taken with the 2013 IRP as a means to take into account different outcomes and changing assumptions/scenarios and looking at determinants which are required when making key investment decisions (DoE, 2013).

In terms of expected demand, it was found that actual electricity demand was lower in the past three years than forecast by the IRP 2010 (DoE, 2013). The underlying trend was found to indicate a lower growth in electricity demand than what was expected in past planning assumptions. In comparison, economic activity was not far off from what was forecast The IRP 2013 therefore attributes the lower than expected electricity demand to multiple factors. The first of these is the Eskom buyback program which encouraged a reduction in energy consumption by some industrial consumers in 2011 and 2012, with a hypothesized amount of 4 TWh being saved each year due to this mechanism (DoE, 2013). In addition, constraints caused by the supply situation and suppressed demand on both industrial and domestic consumers are believed to have reduced energy demand as well.

The constant price increases over the past five years were found also to have significantly changed consumer demand, highlighting the importance of price elasticity of demand forecasting, which had been given little attention in the IRP 2010. The adjustment showed that price increases are a major factor in terms of demand contraction, especially in the case of energy intensive consumers, with the possibility that some of these consumers relocated smelting operations to countries with cheaper electricity prices (DoE, 2013). While quantifying this impact on future demand was thought to be impossible, the impact was instead reflected as a progressive decrease in electricity intensity in GDP for the IRP 2013.

Energy efficiency improvement, which was also in due part to price increases, was found to also add to lower demand and the continued decline in electricity intensity over the past three years had exceeded expectations (DoE, 2013).

The IRP 2013 update reiterates the point that historically there has been a strong correlation between economic growth and demand for electricity in South Africa, with a special mention being made of both the manufacturing and mining sectors. It admits that this relationship has changed over time and electricity intensity has decreased (DoE, 2013). Due to economic growth being a determinant of electricity demand, the IRP 2013 developed 4 different future scenarios of what economic growth might be for the next fifty years as a framework to consider what impact different economic growth scenarios may have on electricity demand (DoE, 2013).

Growth in expected annual electricity consumption by 2030 varied greatly, from 319 301 GWh in the worst case, to 474 990 GWh in the best case scenario. In comparison to the Council for Scientific and Industrial Research (CSIR) moderate estimation made for the IRP 2010, in the best case scenario electricity demand would be much higher (over 100 000 GWh), while in the worst case scenario it was lower by 60 000 GWh (DoE, 2013).

In general, the update considers a significant decline in energy intensity to have occurred in the South African economy, driven by significant changes in the structure of the economy, with a movement away from energy intensive sectors to less energy intensive sectors (DoE, 2013). In addition, price elasticity of demand was key to changes in energy consumption patterns. Higher electricity prices and continued improvements of technology will continue reducing the energy intensity of production processes and appliances. Expectations in the update are that even without intervention, the market itself will drive further energy efficiency in the next 30 years (DoE, 2013).

3.3.3. IRP 2016

The latest update to the IRP once more has shifted due to the changes since the 2013 IRP update. While the 2010-2030 IRP is still the official government plan, the IRP 2016 update has found a number of important assumptions have changed since the last update (DoE, 2016).

- The electricity landscape has changed considerably in the past three years, this is most notable in both electricity demand as well as the relationship between electricity demand and economic growth.
- There have been new developments both locally and globally in technology and fuel options that can be taken advantage of.
- There has been a change in the scenarios for carbon mitigation strategies as well as the impact this has on electricity supply up to 2050.
- The affordability of electricity and how this impacts both supply and demand has changed.

The actual update itself has not been completed. Both assumptions and the Base Case have been completed, however alternative scenarios have yet to be completed (DoE, 2016).

When looking at supply and demand, it is necessary to look at the source of the decision making process for the IRP 2016. This includes a 2016 CSIR document which was used as the basis for estimating potential future demand for 2016-2030 period.

In order to project future demand for electricity, CSIR (2016) updated previous work in the 2010 and 2013 IRP, with updated data on the electricity usage in the different electricity sectors being and used as inputs (CSIR, 2016).

In regards to potential drivers of electricity consumption, CSIR made use of Gross Domestic Product (GDP), final Consumption Expenditure of Households, index for Manufacturing production volumes, Index for Mining production volumes, population, number of households and average household size and gold ore milled/treated (CSIR, 2016).

Notably, CSIR had to make adjustments for changes in electricity intensity for 2016 because historical data for intensity was found to be inadequate in previous IRP forecasts (CSIR, 2016). This was due to a need to contrast the expansion of the electricity intensive sectors of the economy with the growth of the less energy intensive sectors in making up total economic growth.

Four scenarios were forecasted. The differences between these scenarios were within the economic variables used, specifically expected GDP, expected final consumption expenditure on households and the relevant manufacturing and mining indexes, while variables such as population and percentage losses were kept the same (CSIR, 2016).A key difference in the two High scenarios was that though GDP growth remained the same, the growth was in less energy intensive sectors (tertiary economic sector) (CSIR, 2016).

The demand forecasts ranged from 297 459 GWh in 2030 in the Low scenario to a high of 389 904 GWh in the High scenario.

3.4. Supply

Each of the IRP documents provided detailed scenarios of the supply options available to meet forecast future demand as well as reduce Carbon Dioxide (CO_2) emissions. Because this research project is focused on calculating elasticity of electricity demand and its implications for future demand, details of the supply options are not immediately relevant. A summary of the differences in the supply options in the 2 IRPs forms part of Section 3.5.

3.5. IRP Comparison

As the review of each IRP has shown, the documents have gradually shifted in the way it means to accomplish its mandate. In particular, this shift is shown by the acknowledgement in the IRP

2013 of how it is necessary to have flexible planning as a means to account for the unpredictable nature of what future electricity demand may be.

3.5.1. Demand Comparison

Making use of the IRP 2010, 2013 and the draft 2016, it is possible to see just how demand and supply projections have changed since the IRP's initial creation in 2010 Peak demand forecast have been revised steadily downwards from the IRP 2010's revised base case, IRP 2013 Green Shoots/Base Case and the Draft IRP 2016 Update Base Case. Specifically, the original IRP began with a much higher forecast of peak demand that grew quickly. The document itself admitted that its forecast of expected peak demand of 67 809 MW in 2030 was on the higher end of the spectrum (DoE, 2011). The belief originally was that security of supply should not be imperilled and that it was preferable to have more supply than to have a shortage. While this may have been sensible at the time (following the trauma of the 2008 blackouts) the IRPs that followed moved away from this view. The original IRP now seems very optimistic in regards to how demand would grow in the future, even though it accepted that there would be a move to a much less electricity intensive economy (DoE, 2011).

The IRP 2013 Base Case readjusts potential peak demand quite sharply from the IRP 2010, with starting point of actual demand for 2010-12 being much lower than what was originally forecast (National Energy Regulator of South Africa (NERSA), 2012). The large difference between expectations and reality in regards to peak electricity demand, shows the complex and unpredictable nature of forecasting electricity demand. This had an effect on policymakers when it came to working on the IRP 2013.

The evidence of a trend of lower energy consumption is particularly evident is the projections done in the 2013 IRP. Forecast peak demand in 2014 drops from 43 436 MW in the 2010 IRP to 38 924 MW. A key point raised is the changed relations between GDP and electricity demand. The 2013 IRP notes that GDP growth for 2010 and 2011 were only marginally lower than had been forecast in the 2010 IRP but electricity demand was much lower than expected, pointing to a change in the electricity intensity of growth (DoE, 2013).

This more pessimistic view of lower demand permeates the IRP 2013 projections. The difference in peak demand between the two IRPs is 7 300 MW, the 2030 peak being 60 509 MW in the 2013 IRP compared with 67 809 MW in the 2010 IRP.

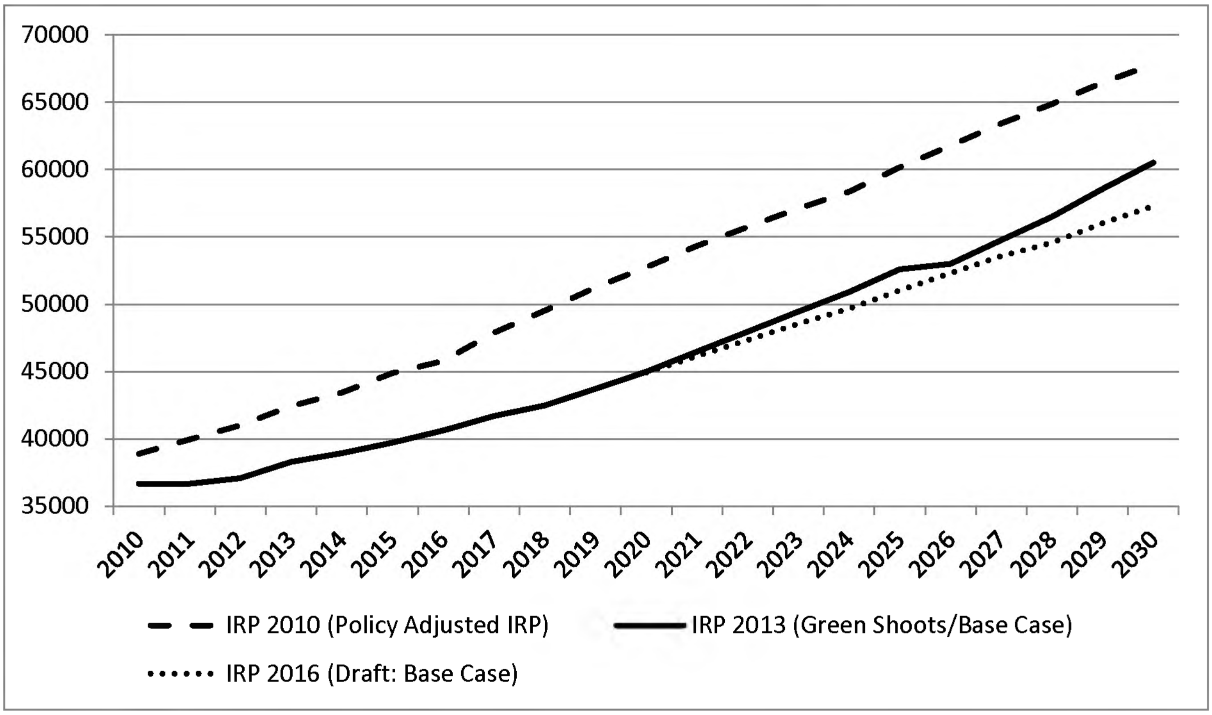
The 2016 update further reduces its forecast of peak demand in 2030 to 57 274 MW, lower than the 2013 IRP by 3 400 MW. Figure 1 shows that while forecast peak demand in the IRP 2016 is lower than the IRP 2013, the extent of the downward revision is not to the same extreme as between the 2010 and 2013 IRPs.

The expected peak demand between updates has been steadily reduced. Reasons for this were noted in the 2013 IRP and are repeated here because of their likely continued impact on future demand (DoE, 2013):

- Buyback programmes by Eskom which incentivised lowered demand.
- constrained supply which had led to demand to be suppressed for both industrial and household consumers.
- Electricity price increases which led to large adjustments in consumer demand causing consumers to lower consumption and/or move to cheaper alternatives in other countries.
- Improved energy efficiency due to price increases.

To this can be added the reality that GDP growth from 2012-2017 has been much lower than was expected. Poor growth is now expected by government to persist until at least 2020 (National Treasury, 2017).

Figure 1: IRP 2010/2013/2016 Peak Demand Comparison (MW)

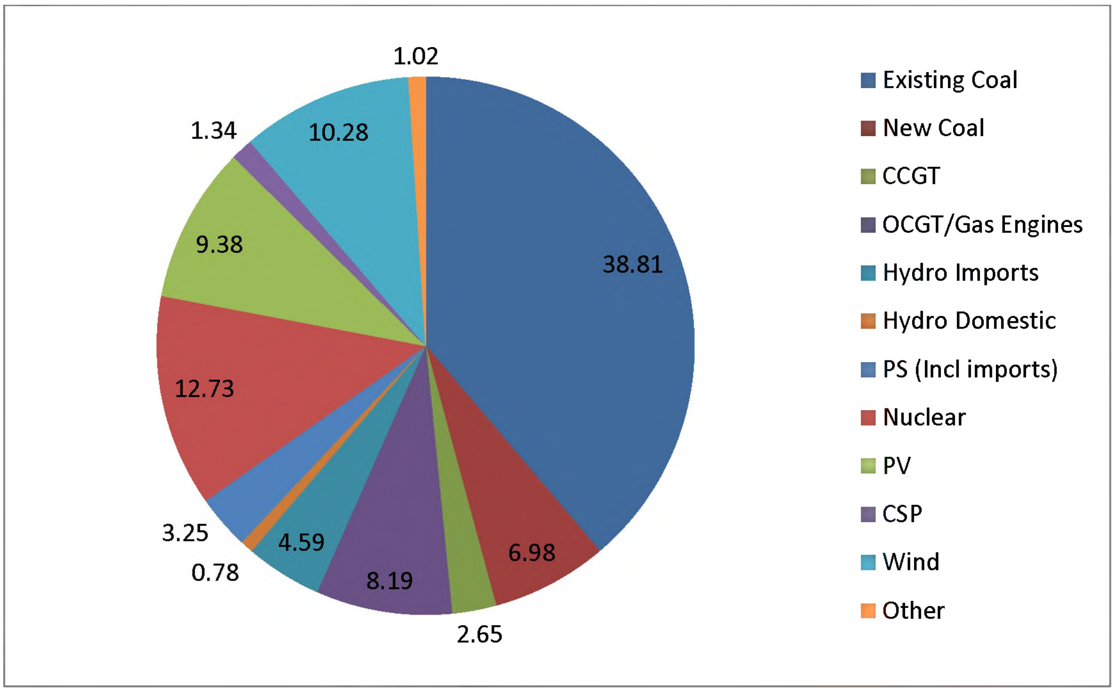


Source: DoE (2011, 2013 & 2016)

3.5.2. Supply Comparison

Projections of supply have similarly shifted from what initially proposed, due both to demand projections not being met as well as technological improvements over the years. A prime example of this is the proposal regarding nuclear power, with the need for of nuclear reactors being pushed out further into the future in each IRP. However, although total supply has fallen in tandem with the lowered expected demand forecasts, there is also another important change in the supply sections of the IRPs. This change is in the nature of the technologies used to achieve security of supply, with the technology that is most effective in reaching said goals continuously shifting. Thus it is necessary to compare how the means to reach the end goal of security of supply have changed between the plans.

Figure 2: IRP 2010 Total Supply Distribution by 2030 (% of total)



Source: DoE (2011)

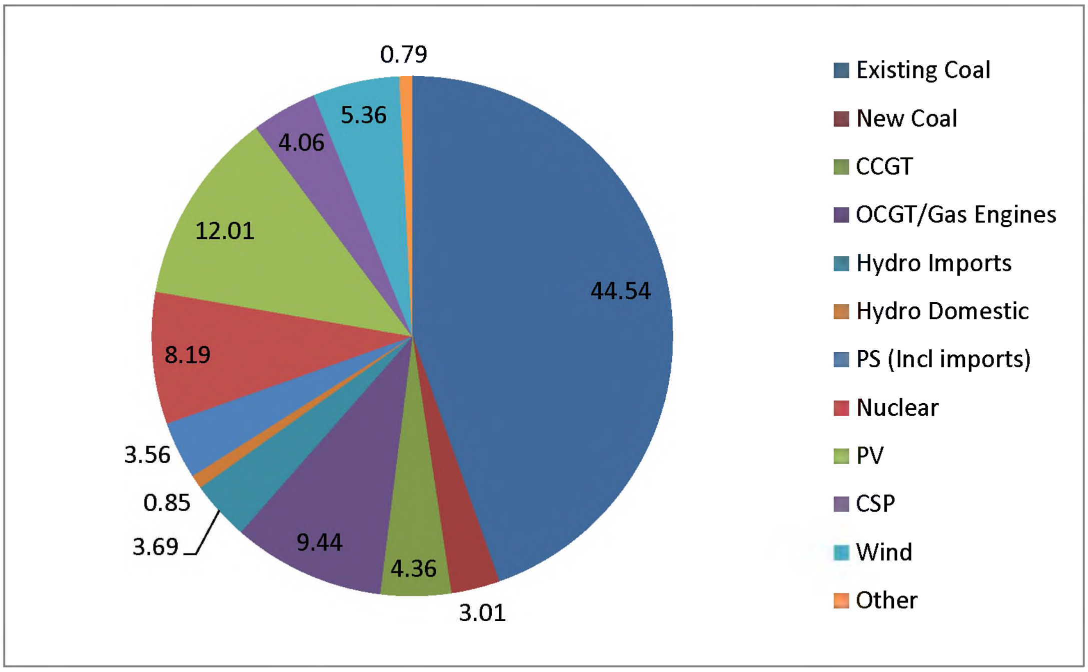
The IRP 2010 estimated total supply of 89 532 MW by 2030, with the largest share (38.8%) of this supply being provided by existing coal plants. New coal plants would contribute only 6 250 MW (6.98%) of total supply for 2030. A major focus for new supply was placed on hydro imports, photovoltaic energy, open cycle gas turbines and nuclear power. Nuclear power would provide the largest share of electricity outside of coal plants with a contribution of 11 400 MW (12.7%) by 2030. Renewable energy technologies such as wind would supply 9 200 MW (10.3%), photovoltaic energy 8 400 MW (9.4%) and hydro imports 4 109 MW (4.6%).

Key features of supply in the IRP 2010 therefore were the move to make more use of renewable technologies, as well as a belief that due to large increases in demand nuclear would be necessary. Renewable energy as a whole made up the second largest portion of the energy mix (26.37% of total supply). The proposed usage of a variety of technologies shows that the early planning was unsure which of these technologies would be the most effective and thus instead opted for using a variety of energy types.

This energy mix changes somewhat in the IRP 2013 (Figure 2), due both to the new technologies and the lower than expected demand. Total supply by 2030 for the IRP 2013 if forecast to be 81 350 MW, far lower than the 89 532 MW of the IRP 2010. Noticeably existing coal increases while new coal decreases, due to coal plants that came online between 2010-2013. A larger portion of the overall energy mix is also provided by existing coal because of the lower needed total supply in the IRP 2013.

In addition, nuclear is reduced to 6 600 MW from its original 11 100 MW. Wind energy is also reduced by more than half, from 9 200 MW to 4 360 MW. The share of total supply made up of wind falls from 10.4% in the IRP 2010 to 5.4% in IRP 2013. However, while Wind energy becomes less popular as a renewable energy choice, photovoltaic energy increases from 8 400 MW to 9 770 MW, making it the single biggest portion of the energy mix (12.0%) outside of coal (47.6%). This is in line with the belief that the full nuclear fleet/decision can be delayed while renewable energy, specifically solar energy in this case, have gained traction in the newer IRP updates.

Figure 3: IRP 2013 Total Supply Distribution by 2030 (% of total)



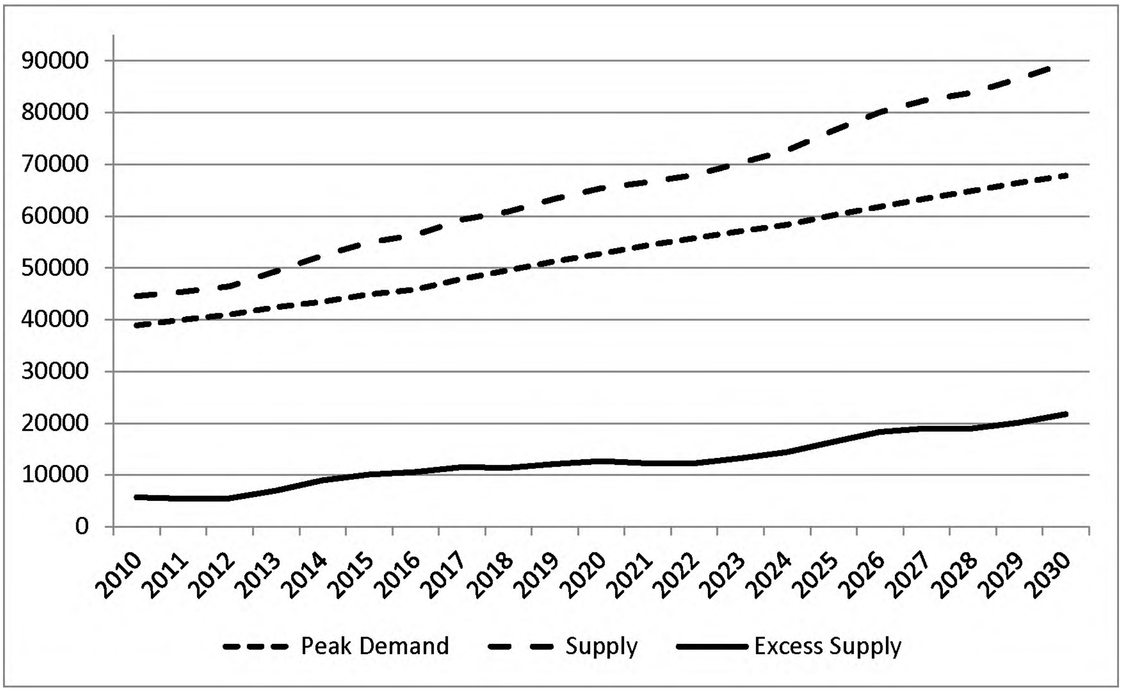
Source: DoE (2013)

In the case of the IRP 2016, however, there is however an interesting paradox in the case of the nuclear decision. It is stated that due to the time needed in building the reactors there is a need to already to finalize decisions in regards to suppliers and builders even though it will only be necessary to build the reactors themselves to secure supply much further into the future. This seems to go against the idea set forth in the 2013 IRP, where it is argued that flexible planning is necessary due to the fact that demand has not met previous expectations and how new technology gives rise to opportunities that would be better used. The plan in the 2016 draft in regards to nuclear would 'lock' South Africa into a decision that may in the future turn out to be unnecessary due to the uncertainty of future electricity demand.

3.5.3. Excess capacity

When comparing forecast peak demand and envisaged supply there is a cause for concern, as Figure 4 illustrates for the IRP 2010.

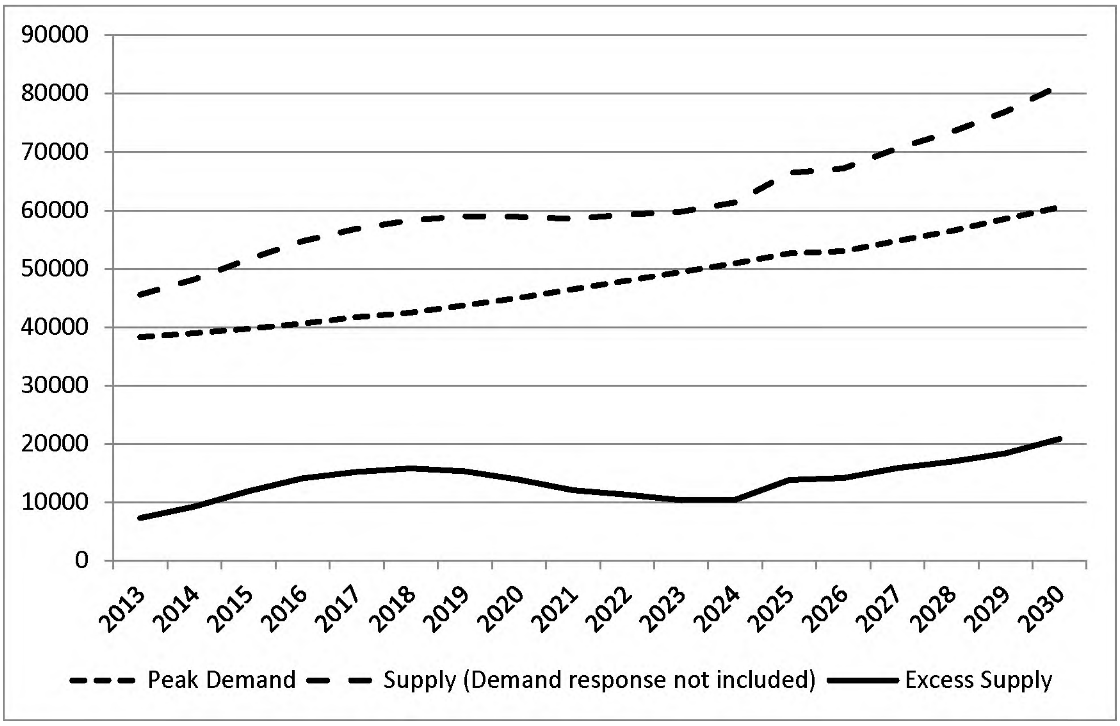
Figure 4: IRP 2010 Demand/Supply/Excess Supply Comparison (MW)



Source: DoE (2011)

The difference between supply and peak demand is quite large, even from the original start point of 2010 where there is an excess of 5 650 MW or roughly 13% of total supply. This is concerning due to the nature of electricity and the inability to store electricity. Excess capacity rises to 21 723 MW, or 24.26% of total supply, by 2030. This means that a quarter of generating capacity is unnecessary. The IRP 2013 (Figure 5) allows for a similar amount of excess capacity even though overall supply and demand are much lower than in the IRP 2010.

Figure 5: IRP 2013 Demand/Supply/Excess Supply Comparison (MW)



Source: DoE (2013)

In the IRP 2013, the start point is excess capacity of 7 280 MW or 16% of total supply. The excess supply for the IRP 2030 is 20 841 MW which is 26% of total supply. This planned excess supply, would seem to be against the mandate of being flexible in decision making The conclusion that one can draw is that both the 2010 and 2013 IRP are too rapidly bringing online additional supply when peak demand is not growing near the rate it would have to be to justify the current supply plans in both the IRP 2010 and 2013. While some excess capacity is needed to allow for maintenance and unplanned breakdowns of plant, excess capacity of such a magnitude represents a waste of scarce investment resources. It can be argued that caution is justified in case demand grows more rapidly than forecast. It will be shown in the Chapters that follow that forecasts of demand are much more likely to be overoptimistic. The supply plans of the 2013 and 2016 IRPs, if implemented, could lead to massive unneeded overcapacity – possibly as much as 50% (Figure 9).

3.6. Conclusion

This chapter focused on how the IRPs differed in regards to supply and demand, showing how they adjusted to South Africa's changing economic landscape and questioned whether these changes were correct. In conclusion, it was found that though the IRPs gradually lowered expectations of demand, the final completed IRP (2013) was still too optimistic in its projections for demand and growth in South Africa when looking at the current estimated growth rates. Rather it was found that a cautionary stance should be taken for energy policy and locking in future projects was against the recommendations of the IRP 2013 which found that flexible planning was necessary for South Africa's energy policy.

Chapter 4: Data and Econometric Method

4.1. Introduction

The methods and procedures used to obtain the findings of this research, as well as the data used, are described in this Chapter. The method of research is quantitative, and the paradigm is positivist.

Section 4.2 describes the data used and the sources from which it was obtained. Section 4.3 explains the autoregressive distributive lag method used to measure the short- and long-run elasticities of electricity demand and whether there is any evidence of structural change. Section 4.4 describes the tests used to determine whether there was a structural break in electricity demand, the tests for stationarity used to determine the order of integration of the variables used, and the test for cointegration used to determine whether the variables are co-integrated, as well as the relationship between the variables. Section 4.5 concludes.

4.2. Data and data sources

Three data sources were required to model electricity demand. Due to the constraints in finding the exact data, it was required that proxies be made use of for some of the data. The validity of using these proxies are justified below.

The first was the dependent variable, electricity demand. For this, monthly data of electricity generated were obtained from the South African Reserve Bank Online database. As electricity production at power stations is adjusted by Eskom in line with fluctuations in peak daily and seasonal demand, this set of data is used as a proxy for electricity demand in South Africa. This is possible to use as a proxy due to the fact that electricity supply continually adjusts at all times to meet demand, making it near-equal to demand at all times.

Not all electricity generated is for South African consumption, as South Africa exports some electricity to neighbouring countries. An alternative monthly data series of "electricity generated for South African consumption" published by Statistics South Africa was also considered. However, this series is only available on a seasonally adjusted basis from January 1998. Data from the two possible time series were compared (Figure A.1 in Appendix A). The two series were very similar from January 1998 to March 2017. The advantage of the South African Reserve Bank series for electricity generated is that seasonally adjusted data are available from January 1990. Consequently, it was decided to use the Reserve Bank series as the preferred measure of electricity demand.

In line with Bentzen and Engsted (1993), Mitchell (2006) and Gately and Huntington (2003) the independent variables for the analysis are South Africa's real GDP and real electricity prices.

Data for real GDP are available from the South African Reserve Bank Online database. However, GDP data are available only quarterly, whereas electricity demand and prices are available monthly. Because of the value of having data of the highest possible frequency in econometric analysis, it was decided to use the monthly Coincident Indicator of the South African Reserve Bank as a proxy for real GDP. The Coincident Indicator was obtained from the South African Reserve Bank's Online database.

The suitability of the Coincident Indicator as a proxy for GDP was tested by graphically comparing it with quarterly GDP. The Coincident Indicator was converted into quarterly frequency by taking the average monthly index for each quarter. The comparison with real GDP is shown in Figure A.2 in Appendix A. While the coincident indicator appears to be more volatile than real GDP, the advantage of it being available monthly justified its use as the preferred measure of changes in economic activity in South Africa and therefore one of the determinants of changes in electricity demand.

Because not all components of GDP are equally electricity-intensive, it was decided to also include in the model the two sectors which are identified by Eskom (2009, 2017) as being the largest users of electricity, namely manufacturing and mining. The contribution of these two sectors to real GDP is available from the South African Reserve Bank Online database, but these data are in quarterly frequency. Statistics South Africa publishes seasonally adjusted monthly manufacturing and mining production indices. These were also obtained from the South African Reserve Bank Online database. These indices were converted to quarterly averages and compared with their respective GDP counterparts. The results are shown in Figures A.3 and A.4 in Appendix A. The manufacturing and mining production indices data are very similar to their GDP counterparts. Accordingly, it was decided to use these production indices as the preferred data series because of the advantage of their data being available on a monthly basis.

For the third data set of real electricity prices, two possible monthly time series were available, namely the Consumer Price Index (CPI) for electricity and Producer Price Index (PPI) for electricity. Although there is little difference between these variables over time (see Figure A.5 in Appendix A) the Real Consumer Price Index (CPI) for electricity was preferred because the model looks at electricity demand rather than production. The CPI for electricity data set was provided to the author by Statistics South Africa. However, the CPI for the electricity sub-index of the CPI is available only from January 1999. Prior to this date the available sub-index is "electricity and other fuels". Figure A.6 in Appendix A shows that there is little difference between changes in these measures. This is unsurprising as electricity comprises 98.7% of the electricity and other fuels sub-index (StatsSA, 2016). Accordingly, a price index for electricity was constructed using the CPI for electricity from January 1999 and CPI for electricity and other fuels prior to this date. In addition, as electricity prices in real terms are needed to accurately estimate the relationship between price and electricity generated (Bentzen and Engsted, 1993; Mitchell, 2006), the price index for electricity was converted into real terms by deflating the series with headline CPI. In this way a real electricity price index was constructed for use in the model.

4.3. Model Specification

This section focuses on the econometric model and method used. Following the literature on electricity demand and its relationship with both the price of electricity and GDP (Bentzen and Engsted,1993; Khobai *et al.*,2017) - represented by the constructed real consumer price for electricity index and the coincident indicator - the long-run relationship between electricity demand, electricity price and GDP in linear logarithmic form is given by the following equation:

$$D_t = a_0 + a_1 CI_t + a_2 REP_t + \varepsilon_t \qquad (1)$$

where D_t represents electricity demand, CI_t represents the Coincident Indicator and REP_t represents the real consumer price index for electricity.

The model can be expanded further by disaggregating GDP into two of its components that are the most energy intensive, namely manufacturing and mining. Changes in these sections of the economy are likely to impact most on electricity demand. Unfortunately, it is not possible to generate a monthly index for GDP excluding manufacturing and mining as the monthly data are indexes. The model can be written as:

$$D_t = a_0 + a_1 MAN_t + a_2 MIN_t + a_3 P_t + \varepsilon_t \qquad (2)$$

where MAN_t is the Manufacturing Indicator and MIN_t represents the Mining Indicator.

4.4. Method

In estimating the price and income elasticity of demand for electricity, the work of Narayan and Smyth (2005) and Ziramba (2008) are useful guides for the appropriate techniques and procedures needed to correctly estimate said elasticities (see section 4.4.3).

4.4.1. Structural Breakpoint Test

The sharp increases in the real price of electricity from mid-2008 and the flattening out of electricity demand thereafter (Figure 6 below) strongly suggest that there may have been a structural break in the data during this period, which may have potentially changed the relationship between the variables. The first step thus is to check for a structural break in the data from July 2008 when real electricity prices started to rise exponentially. To test for the possibility of a structural break, the Chow Breakpoint test will be applied for both the CI model (Model 1) and the manufacturing/mining model (Model 2).

4.4.2. Stationarity tests

The second step is the application of stationarity tests. Although we expect that the data are non-stationary, it is required that we confirm this through the proper econometric methods. Thus it is necessary to test whether the data are stationary or not and whether the data are integrated of order one (or I(1)) or integrated of order zero (or I(0)). The Augmented Dickey-Fuller (ADF) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests will be used to determine the order of integration of the variables and thereby avoid the results of this study being spurious.

4.4.3. Cointegration Methodology

The study will use an autoregressive distributed lag (ARDL) framework with the bounds testing procedure created by Pesaran *et al.* (2001). Similar to both Narayan and Smyth (2005) and Ziramba (2008), this method is used due to the models' use of finite data, as well as the robustness of the test's results. In addition, this method also has advantages over the more commonly used Engle-Granger method, as the short-run dynamics are not pushed into the residual term. Thus, they have better statistical properties and are not being biased in the case of small samples (Pattichis, 1999).

Another important advantage that the bounds test has is that it is possible to make estimations even if explanatory variables are endogenous, while also being able to correct for residual serial correlation (Ziramba, 2008). In addition, the ARDL framework does not need the variables to all be integrated of the same order, as is the case with the Johansen or Engle-Granger methods.

It allows the usage of both I(0) and I(1) variables, but not variables of a higher order (Pesaran *et al.*, 2001)

The empirical model (Model 1) is as follows for the CI:

$$\Delta \ln D_t = b_0 + \sum_{i=0}^{m} b_{1i} \Delta \ln D_{t-i} + \sum_{i=0}^{m} b_{2i} \Delta \ln CI_{t-i} + \sum_{i=0}^{m} b_{3i} \Delta \ln REP_{t-i} + b_4 D_{t-1} + b_5 CI_{t-1} + b_6 REP_{t-1} + \upsilon_t \quad (3)$$

and the second empirical model for the Manufacturing Indicator and Mining Indicator variables (Model 2) is:

$$\Delta \ln D_t = b_0 + \sum_{i=0}^{m} b_{1i} \Delta \ln D_{t-i} + \sum_{i=0}^{m} b_{2i} \Delta \ln MAN_{t-i} + \sum_{i=0}^{m} b_{3i} \Delta \ln MIN_{t-i} + \sum_{i=0}^{m} b_{4i} \Delta \ln REP_{t-i} + b_5 D_{t-1} + b_6 MAN_{t-1} + b_7 MIN_{t-1} + b_8 REP_{t-1} + \upsilon_t \quad (4)$$

where Δ is a first difference operator, b_0 is the intercept, variables b_{1i} to b_{3i} and b_4 to b_6 are short and long run elasticities and $\upsilon_t$is the error term.

The long run relationship can be tested using the modified F-statistics, where the null hypothesis as set out by Pesaran *et al.* (2001) is of no cointegration ($\rho = b_4 = b_5 = b_6$) against the alternative hypothesis of cointegration ($\rho \neq b_4 \neq b_5 \neq b_6 \neq 0$).

Pesaran *et al.*'s (2001) testing procedure makes use of two critical bounds, a lower and upper bound, and where the modified F-statistic is greater than the upper bound, the null hypothesis is rejected. In the case of being lower than the lower bound, the null hypothesis is not rejected and in the case of the statistic being in between the bounds, the results are inconclusive with regards to cointegration.

Where there is a long run relationship, the unrestricted error correction model (UECM) is estimated, which for the CI model (Model 1) is shown as follows:

$$\Delta \ln D_t = b_0 + \sum_{i=0}^{m} b_{1i} \Delta \ln D_{t-i} + \sum_{i=0}^{m} b_{2i} \Delta \ln CI_{t-i} + \sum_{i=0}^{m} b_{3i} \Delta \ln REP_{t-i} + \lambda EC_{t-1} + u_t (5)$$

And for the Manufacturing Indicator and Mining Indicator model (Model 2):

$$\Delta \ln D_t = C_0 + \sum_{i=0}^{m} b_{1i} \Delta \ln D_{t-i} + \sum_{i=0}^{m} b_{2i} \Delta \ln MAN_{t-i} + \sum_{i=0}^{m} b_{3i} \Delta \ln MIN_{t-i} + \sum_{i=0}^{m} b_{4i} \Delta \ln REP_{t-i} + \lambda EC_{t-1} + u_t \quad (6)$$

where λEC_{t-1} is the error correction term which measures the speed of adjustment towards equilibrium, which must be negative, between 0 and -1 andstatistically significant. Equations

3 and 4 are thereafter examined by testing for both serial correlation and normality in the residuals.

4.5. Conclusion

This chapter has identified the data as well as the required tests and method to be used to determine the short and long run elasticities of demand for electricity in South Africa. Data requirements were identified from the literature and the data itself was acquired from sources in the public domain. The methods identified to be used are: graphical analysis, breakpoint test, unit root test and ARDL bounds testing which were all found to be suitable to use for the data acquired for this paper. The test results and summaries of these results are shown in the following chapters.

Chapter 5: Results

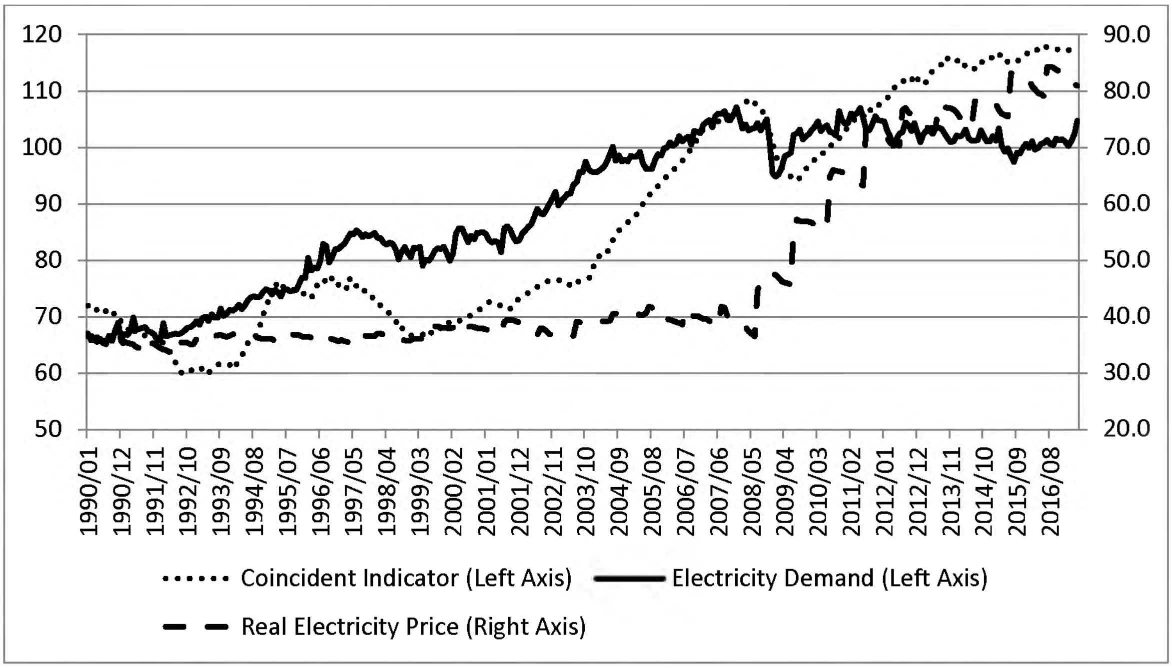
5.1. Introduction

A graphical analysis of the data used, Chow Breakpoint findings, unit root test results, as well as the ARDL results are discussed in this chapter.

Section 5.2 provides a graphical analysis of the data and suggests what this might mean in regards to the actual econometric analyses. Section 5.3provides the empirical results as well as interpretation of the ARDL bounds test results, to determine what these mean for forecasting South Africa's future electricity demand. Section 5.4 provides an explanation for some unexpected results of the ARDL bounds test and Section 5.5 concludes this chapter.

5.2. Graphical analysis of the data

Figure 6: Electricity Demand, Overall Economic Growth and Electricity Prices



Source: SARB Online Database, real electricity price calculated by the author from StatsSA data

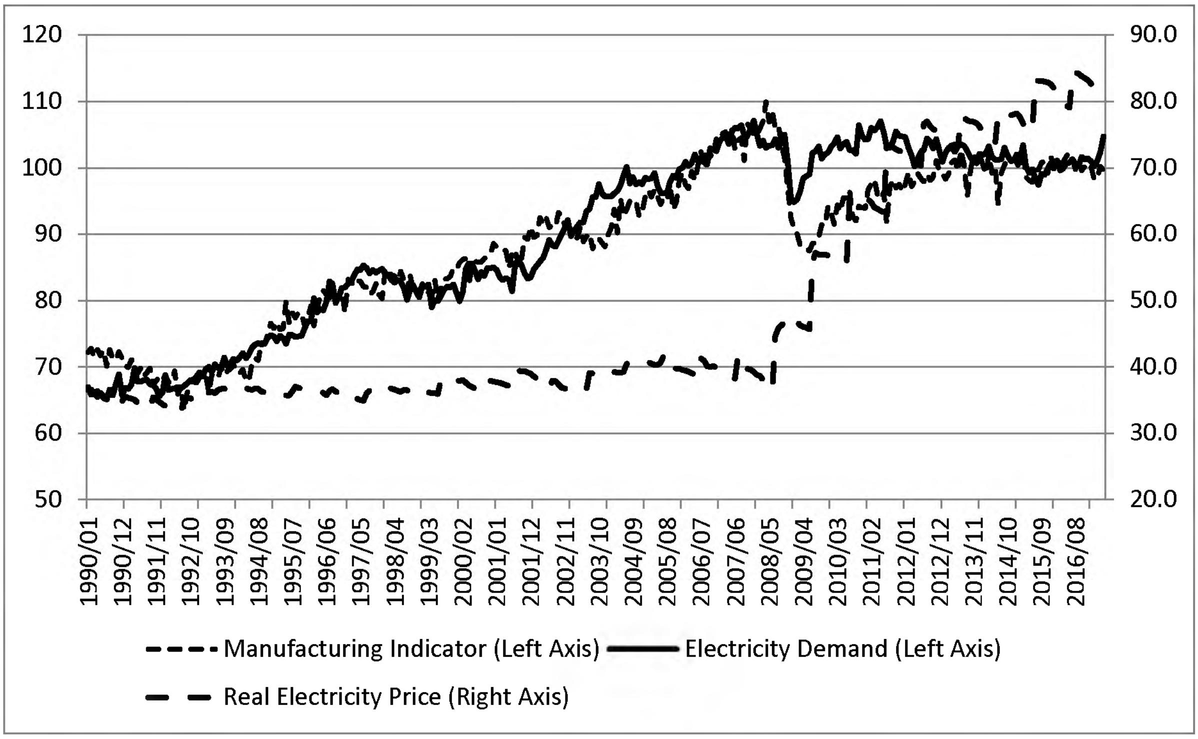
The first comparison shown in Figure 6 looks at the coincident indicator in comparison to both electricity demand and the real electricity price. After initially falling and then rising only modestly from 1990 to June 2008, the real price of electricity jumped dramatically from July 2008. The real price of electricity in June 2008 was exactly the same as in January 1990. But from July 2008 to May 2017 the real price of electricity rose 125.4%. In nominal terms the price of electricity rose 264% during the same period. While the rate of annual price increases since 2012 has slowed, prices continue to increase in real terms, which is a very different situation from anything that was experienced pre-2008.

Looking at electricity demand and the coincident indicator shows the expected relationship, where an increase in the coincident indicator is accompanied by an increase in electricity demand. The relationship is far from perfect – for example the coincident indicator slows in 1993 but electricity demand continues rising. The effect of the global financial crisis is seen clearly in the fall in the coincident indicator in 2008. Electricity demand also fell in 2008, along with falling domestic economic activity. The coincident indicator then starts to rise again and so does electricity demand, but from the end of 2009 electricity demand stops growing even though the coincident indicator continues rising. The likely explanation for this visual change in the relationship between the two variables is the dramatic increase in real electricity prices. A structural change in the relationship between electricity demand and economic growth appears to have occurred.

To put this change in perspective, from January 1990 to June 2008 the coincident indicator rose by 50.7% and electricity demand rose 54.3%. From July 2008 to May 2017 the coincident indicator rose 9.1% while electricity demand fell by 3.0%. Not only has the rate of growth of the coincident indicator fallen but the relationship between changes in the coincident indicator and electricity demand also changed. From a long-term relationship in which changes in the coincident indicator and electricity demand were almost the same (an elasticity of almost 1), the relationship since July 2008 has actually been slightly negative.

The question then is why is electricity demand stagnant after July 2008 while the coincident indicator continues to grow? There are two possible explanations. Firstly, the sharp increases in the real price of electricity have caused all consumers to reduce their usage. In other words, the income elasticity of electricity demand has fallen across the board. The second explanation is that the rise in the price of electricity impacted especially on those sectors that are the largest users of electricity and the flat overall demand for electricity is therefore related to the slow growth performance of specific sectors, especially manufacturing and mining.

Figure 7: Electricity demand, Manufacturing Production and Real Electricity Prices



Source: SARB Online Database, real electricity price calculated by the author from StatsSA data

Figure 7 plots manufacturing production instead of the coincident indicator against electricity demand and the real price of electricity. It shows a much closer relationship with electricity demand than Figure 6. Prior to July 2008 the relationship between growth in the manufacturing sector and electricity demand appears to be very close. Specifically, manufacturing grew together with electricity demand prior to 2008. This is the same relationship as between the coincident indicator and electricity demand, which is unsurprising as manufacturing is one of the larger sectors in the economy. Over this period, the real price of electricity was unchanged, which benefited electricity-intensive manufacturing.

In 2008 however, this all changed due to the sharp rise in electricity prices. During the global financial crisis there were sharp falls in both manufacturing production and electricity demand, but the fall in manufacturing was even more pronounced. Thereafter, electricity demand recovered more rapidly than did manufacturing and the recovery in both then levelled off.

To put these changes in perspective, from January 1990 to June 2008 manufacturing rose 50.1% (the same as the increase in the coincident indicator) while electricity demand rose 54.3%. From July 2008 to May 2017, manufacturing production fell 7.0% and electricity demand fell 3.0%. The relationship between manufacturing production and electricity demand therefore remained positive, albeit less elastic. Unlike the relationship between electricity demand and the coincident indicator, which became negative when the overall economy grew slowly, both electricity demand and manufacturing fell simultaneously. The reason for this appears to be the extreme rise in real electricity prices in the same period.

Figure 8: Electricity demand, Mining Production and Real Electricity Prices

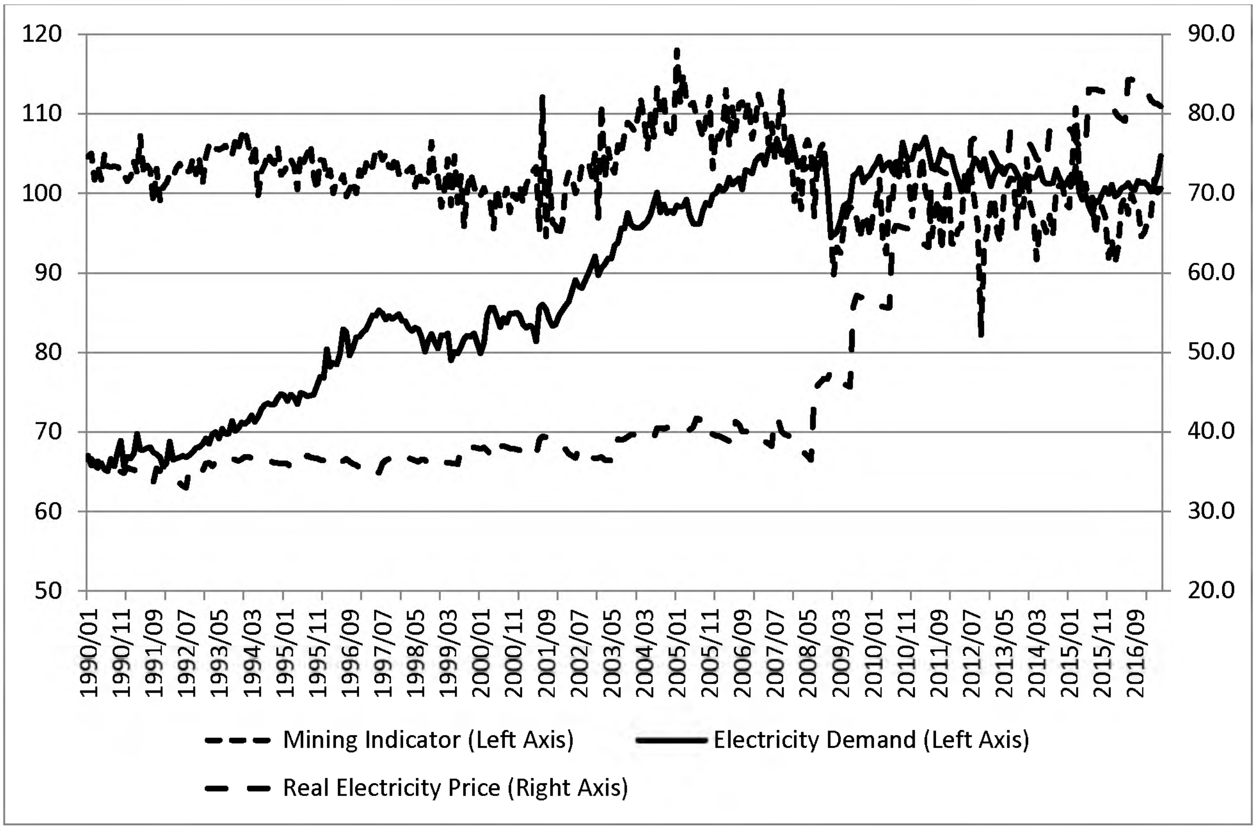


Figure 8 shows mining production alongside electricity demand and the real price of electricity. It shows that even prior to the 2008 global financial crisis, mining production in South Africa was largely unchanged, so the rise in electricity demand over this period was unrelated to changes in mining output. Mining production rose from 2002, but then fell prior to the financial crisis for reasons unrelated to electricity prices (gold production fell, (Gold in South Africa, 2005)). Post-2008, mining production recovered slightly and then held stable at the new level, despite the sharp real electricity price rise in the same period.

From January 1990 to June 2008 mining production rose just 0.7% compared to a rise in overall electricity demand of 54.3%. From July 2008 to May 2017, mining production fell 5.7% and electricity demand fell 3.0%. While the relationship in both periods is positive as expected it is so small as to be almost meaningless. The fall in mining production post-2008 may, however, have contributed to the surprising fall in electricity demand even though the coincident indicator rose (see Section 5.4 below).

As a whole, these results strongly suggest that there has been a structural change in electricity demand from mid-2008 and changes in manufacturing and mining may have played a role in bringing about this change. The slowdown in energy-intensive manufacturing and mining was caused by a number of factors that are beyond the scope of this study, but rising electricity prices were probably also important. Since 2008, both electricity demand and manufacturing have fallen. It is therefore likely that there was a structural change in the economy at this point and that much higher real electricity prices played a role in bringing about this change. The increased cost of electricity meant that energy-intensive projects that were previously profitable were no longer viable. This can be seen, for example, in the shutdown of the Alusaf aluminium smelters due to their lowered profitability (Mining Technology, 2014). In addition, the higher real electricity prices forced manufacturers to adapt to the increasingly expensive environment. Thus, the IRP 2013 noted that there had been increased use of technology that improved energy efficiency (DoE, 2013). In addition, the IRPs all noted a move away from energy-intensive sectors and increased focus on sectors of the economy that required less electricity.

The less significant role of manufacturing and mining is illustrated in the above graphs. There seems to have been a shift that changed the relationship between electricity demand and economic growth, with the higher real price of electricity aiding in making the energy-intensive sectors to be much less attractive business ventures.

5.3. Empirical Results

5.3.1. Test for Structural Break

The results for the Chow Breakpoint test shown in Table 1 areas expected. As the null hypothesis of no structural change was rejected in each case, for both models there was found to be a structural break at the expected date: July 2008. This implies that the relationship between electricity demand and the explanatory variables did indeed change in July 2008, and in turn requires testing of both the pre-break and post-break samples for stationarity.

This effectively splits both models: Model 1 becomes Model 1a (pre-July 2008) and Model 1b (post-July 2008), and Model 2 becomes Model 2a (pre-July 2008) and Model 2b (post-July 2008).

Table 1: Chow Breakpoint Test

	F-Statistic	P-value	Break
D| CI, REP	89.95121	0.0000	Yes
D| CI, MAN, MIN	76.84808	0.0000	Yes

Source: Eviews 9

5.3.2. Unit Root Test

The results of the ADF test (Table 2) were as expected, with variables being integrated of either order zero or order one. This is in line with what is needed to make use of the ARDL framework. However, the KPSS test (Table 3) is shown to have mixed results compared to the ADF tests. Specifically, it is found that the Coincident Indicator pre-break and Real Electricity Price post-break are of order two. This is in conflict with the results of the ADF test. However, the KPSS test has a weakness in that it has a high rate of incorrectly rejecting the null. Thus, when looking at both of the tests together, it is possible to safely conclude that the variables for all the models are likely integrated of order zero or one and can be used for Bounds cointegration testing.

Table 2: Unit Root Test (ADF)

Variable	Level Constant	1st Difference Constant	Order
Log(Electricity Demand) (1990M01-2008M06)	-0.5844	-13.6367*	I(1)
Log(Coincident Indicator) (1990M01-2008M06)	0.0231	4.3609*	I(1)
Log(Real Electricity Price) (1990M01-2008M06)	-1.9980	-3.3213**	I(1)
Log(Mining) (1990M01-2008M06)	-3.4192**	-11.6574*	I(0)
Log(Manufacturing) (1990M01-2008M06)	0.6822	-16.02046*	I(1)
Log(Electricity Demand) (2008M07-2017M05)	-3.0630**	-9.5413*	I(0)
Log(Coincident Indicator) (2008M07-2017M05)	-0.9893	-3.5091*	I(1)
Log(Real Electricity Price) (2008M07-2017M05)	-11.9064*	-1.8891**	I(0)
Log(Mining)(2008M07-2017M05)	-6.0229*	-12.5369*	I(0)
Log(Manufacturing)(2008M07-2017M05)	-3.1350**	-12.6906*	I(0)

Note: *,** and *** represent significance at the 1%, 5% and 10% levels respectively

The null hypothesis is that the variable has a unit root

Source: Eviews 9

Table 3: Unit Root Test (KPSS)

Variable	Level Constant	1st Difference Constant	Order
Log(Electricity Demand) (1990M01-2008M06)	1.8689*	0.0803	I(1)
Log(Coincident Indicator) (1990M01-2008M06)	1.3730*	0.4878***	I(2) or higher
Log(Real Electricity Price) (1990M01-2008M06)	1.5519*	0.1032	I(1)
Log(Mining) (1990M01-2008M06)	0.5627**	0.1099	I(1)
Log(Manufacturing) (1990M01-2008M06)	1.8545*	0.2049	I(1)
Log(Electricity Demand) (2008M07-2017M05)	0.2826	0.097	I(0)
Log(Coincident Indicator) (2008M07-2017M05)	0.9954	0.1906	I(0)
Log(Real Electricity Price) (2008M07-2017M05)	1.0146*	0.5692***	I(2) or higher)
Log(Mining)(2008M07-2017M05)	0.0456	0.3439	I(0)
Log(Manufacturing)(2008M07-2017M05)	0.7353***	0.2103	I(1)

Note: *,** and *** represent significance at the 1%, 5% and 10% levels respectively

The null hypothesis is that the variable is stationary

Source: Eviews 9

5.3.3. ARDL Bounds Test

From the ARDL bounds test, surprisingly we find cointegration in only one of the models, as shown in Table 4. In Model 1a, Model 2a and Model 2b, the pre-break coincident indicator model and both pre- and post-break mining/manufacturing indicator models respectively, there is no long-run relationship between the variables as the F-statistic in not significant, meaning that the bounds test has found that there is no significant long-run relationship between the variables. This means that the variables, according to the data, in these models are not related to each other in the long-run.

The only model that has followed expectations is Model 1b, which looks at how overall economic growth (CI) and the real electricity price (REP) affect overall electricity demand in the post-July 2008 period. It is the only one of the models that has a long-run relationship between the variables. In regards to the diagnostics for Model 1b, there was no significant normality or autocorrelation, meaning the results from the model would not be spurious.

It was expected from the graphical analysis that all the models would show long-run relationships between the variables, except possibly for mining output. The results of the ARDL bounds test show that basing future electricity demand projections on expected growth in manufacturing or mining would be statistically baseless.

Table 4: ARDL Cointegration Test

	ARDL	Bounds test F-Statistic
D| CI, REP (1990M01-2008M06)	(5,1,0)	3.2113
D| REP, MAN, MIN (1990M01-2008M06)	(11,1,0,1)	2.1171
D| CI, REP (2008M07-2017M05)	(2,4,6)	7.4577*
D| REP, MAN, MIN (2008M07-2017M05)	(12,9,0,7)	1.7958

Note: * represents the 1% significance level.
Source: Eviews 9

Table 5: Diagnostic Check

D| CI, CPI (1990M01-2008M06)

LM Test	p-value	JB	p-value	Ramsey RESET	p-value
0.0835	0.9200	0.2376	0.8880	0.4185	0.5193

Note: LM test and JB represent the tests for serial correlation and normality
Source: Eviews 9

5.3.4. ARDL Results

The results are surprising and are opposite to the expectations of the study and the graphical analysis. While there is cointegration in the post-2008 crisis period for Model 1b, the actual long-run relationship between electricity demand and real electricity prices and CI is not significant. The CI coefficient is insignificant, and the magnitude suggests that when there is a 1% increase in economic growth, there would be a tiny increase in electricity demand with an elasticity of 0.0021%.

In the case of real electricity prices (REP),however, the sign is the opposite of what is expected. Instead the results imply that a 1% higher price leads to higher electricity demand with an elasticity of 0.0478%. This result can be explained by looking at figure B.2 in appendix B for the relation between electricity prices and electricity demand post the 2008 crisis. In the graph, post-2008 price continued to rise while demand remained stable, being unaffected by price. Graphically this implies that electricity demand is not affected by electricity price and will continue to rise regardless of changes in price, leading to the ARDL results to appear as they are.

Table 6: ARDL Results

D| CI, REP (2008M07-2017M05)		
Var	Coeff	T-statistic
C	1.7712	5.2566*
lnD(-1)	0.7599	7.5342
lnD(-2)	-0.1262	-1.3503
lnCI	0.7467	3.0576*
lnCI(-1)	-0.7695	-1.9632**
lnCI(-2)	0.3117	0.7975
lnCI(-3)	0.2069	0.5555
lnCI(-4)	-0.4966	-2.1053**
lnREP	-0.0058	-0.1734
lnREP(-1)	-0.0260	-0.6264
lnREP(-2)	0.0372	0.8903
lnREP(-3)	0.0182	0.4368
lnREP(-4)	-0.0909	-2.2105**
lnREP(-5)	-0.0176	-0.4152
lnREP(-6)	0.0673	2.1941**

Note: *,** and *** represent significance at the 1%, 5% and 10% levels respectively

Symmetric Long-Run Coefficients

Var	Coeff	T-statistic
CI_t	0.0021	-0.0229
REP_t	0.0478	-1.2864
C	4.8352	15.5161*

Error Correction Coefficients

Var	Coeff	T-statistic
EC	-0.3663	-5.5501*

Note: * represents significance at the 1% level.

Source: Eviews 9

5.4. Possible explanations for absence of cointegration

The reduced significance of the coincident indicator as a determinant of electricity demand post-2008 is impacted by the fact that while overall GDP has continued to grow since 2008, the same is not true in the case of the electricity-intensive sectors of GDP, mining and manufacturing. An understanding of the impact of these differential sectoral performances can be gleaned by comparing the distribution of electricity in the economy as revealed by Eskom.

The Eskom Annual Report for 2009 (Eskom, 2009) reveals that for the year 2008, manufacturing (known as industry in the report) accounted for 28.6% of total electricity consumption, and mining 15%. This means that the rest of the economy accounted for 56.4% of total electricity consumption in 2008. The more recent 2017 Eskom Annual Report (Eskom, 2017) reveals that manufacturing has fallen to 23% of total electricity consumption and mining to 14%. The rest of the economy therefore accounted for 63% of consumption in 2017. If we look back further to 1990, manufacturing accounted for 25.1%, mining 24.5% and the rest of the economy only accounted for 50.4% of total electricity consumption, quite different from the current day (Eskom, 1990).

Comparing how electricity demand grew over these years compared to actual output or GDP shows an interesting relationship between electricity consumption and sectoral output. Note, however, that monthly data are not available for the rest of the economy ('other') and so annualised quarterly data from the South African Reserve Bank (SARB Online database) was used to measure 'other GDP growth'. This and growth in the different sectors could then be compared to their sectoral growth in electricity consumption.

It is also possible that the usage of proxy data, that is electricity supply for electricity demand, may help explain the lack of co-integration between "electricity demand" and price and income.

In regards to manufacturing, from 1990 to 2008 electricity consumption grew by 77% and output grew by 44.9%, showing a strong connection that higher output lead to much higher electricity consumption. The relationship was not as strong for 2008 to 2017, when electricity consumption fell by 20.4% but output fell by only 4.6%. This shows that manufacturing has become more efficient in regards to electricity consumption. Lower electricity demand by the manufacturing sector after 2008 is therefore the result of both falling manufacturing output and more efficient electricity usage.

From the graphical analysis, changes in mining output are expected to be much less important for electricity consumption than was the case for manufacturing. From 1990 to 2008, mining output fell by 1.1% and electricity consumption by mining fell by 4.9%. This reduction in electricity consumption by mining continued between 2008 and 2017, with output falling by 2.8% and electricity consumption by 7.6%.

In regards to the rest of the economy, 'other' output increased by 87.6% from 1990 to 2008 and electricity consumption by this section of the economy increased by 73.8%. For 2008 to

2017, ‘other’ output increased by 18.6% and electricity consumption once again increased, this time by 10.3%.

In summary, from 1990-2008 total output in South Africa grew 50.7%. Manufacturing grew 44.9%, mining fell 1.1% and ‘other’ grew 87.6%. Overall electricity consumption grew 54.3%. Electricity consumption for manufacturing grew 77%, it fell 4.9% for mining and it rose 73.8% for ‘other'. From 2008-2017 total economic output rose 9.1%, manufacturing output fell 4.6%, mining production fell 2.8% and ‘other’ rose 18.6%. Total electricity demand fell 3%, electricity demand for manufacturing fell 20.4%, electricity demand for mining fell 7.6% and electricity demand for ‘other’ GDP increased 10.3%. The resultant changes in income elasticity over the periods are shown in Table 7.

Table 7: Elasticity of Income Demand

Elasticity	1990-2008	2008-2017
Mining	4.28	2.69
Manufacturing	1.71	4.46
Other	0.84	0.55
Total	1.11	-0.10

Source: Eviews 9

Overall electricity demand (the dependent variable in Models 1 and 2) therefore disguises structural changes that were occurring in the sectors that make up that demand. Electricity demand was falling post-2008 in manufacturing and mining but rising for ‘other’. Electricity demand was being negatively impacted by falling manufacturing and mining output, but also by more efficient usage in all 3 sectors of economic activity.

It is therefore not surprising that the ARDL results were mainly insignificant. The single dependent variable in all four models disguises changes in its structural makeup. But the dependent variable could not be changed to electricity demand for the individual sectors in order to conduct more detailed analyses, as these data are not available monthly.

5.5. Conclusion

This chapter focused on the econometric models and tests traditionally used to determine price and income elasticity. Making use of graphical analysis, breakpoint tests, unit root tests and the ARDL bounds tests, it was possible to determine whether the data was usable as a means to determine the income and price elasticity of electricity as well as estimate what each respectively was for the case of South Africa.

In the majority of models there was found to be a lack of cointegration which was concluded to be due to a lack of appropriate data being available. The results of these tests and the implications of these findings are presented in the following chapter.

Chapter 6: Conclusion

6.1. Introduction

This section concludes the research. This includes summarising the results of the econometric models, forecasting potential future electricity demand and finally giving possible energy policy recommendations from these findings.

6.2. Econometric results

The econometric results in general were not in line with expectations. The results were mainly insignificant, implying that contrary to the *a priori* expectations electricity demand is not affected by either GDP growth or the real electricity price. The effect of the structural break is a likely cause of the unexpected findings. However, there is a notable issue impacting upon the econometric results. The reason the results were not in line with expectations, outside of the structural break, is likely due to a missing variable in the models. The missing variable is the part of the economy other than mining and manufacturing, but data on this section of the economy is not available in a monthly form and thus was unable to be used in the model. Moreover, the dependent variable, overall electricity demand, is the sum of sectoral demands that were behaving very differently.

What the results are showing is that the rising real price of electricity (price elasticity of demand) was not sufficient to prevent electricity demand from rising in the rest of the economy outside manufacturing and mining. What the real price hikes did was impact negatively on both output and electricity demand from the most electricity-intensive parts of the economy, namely manufacturing and mining. The rest of the economy continued to grow and electricity demand from this sector of the economy increased. However, the much higher real price of electricity meant that electricity demand from even this growing sector of the economy increased at a much slower pace than what would have been expected pre-2008.This is shown by a fall in the elasticity of electricity demand relative to increase in output from the 'other' sectors of the economy from 0.84 in 1990-2008 to 0.55 from 2008-2017 (see Table 7).

The models' results however are in conflict with those of Khobai *et al.* (2017). Specifically, that study found that there was a long-run relationship between overall electricity consumption and economic growth, while the results in this study find that the relationship is positive but insignificant. This is likely due to the fact that the samples make use of different periods, 1985-2014 for Khobai *et al.* (2017), while the data in this study were for the time period 1990-2017.

In addition, Khobai *et al.* (2017) made use of additional variables such as labour, which were not used in this study. However, there was another key difference between the method used in this study and that of Khobai *et al.* (2017). Specifically, Khobai *et al.* (2017) did not test or account for a possible break in the data, which may have been a key reason as to why the results differ.

It must however be noted that the measures of demand and price elasticity are also not entirely identical to that of Khobai *et al.* (2017), notably making use of proxy data for electricity demand. The usage of different data, including the aforementioned usage of labour by Khobai *et al.* (2017) as well as the usage of a breakpoint test may explain why these results differ.

These results are important in assessing the IRP documents' forecasts of future electricity demand for South Africa. They allow an assessment of the assumptions made in the IRP calculations in regards to what possible electricity demand will be in 2030 and how these assumptions have been possibly affected by recent economic events and the change in the relationship between economic growth and electricity demand.

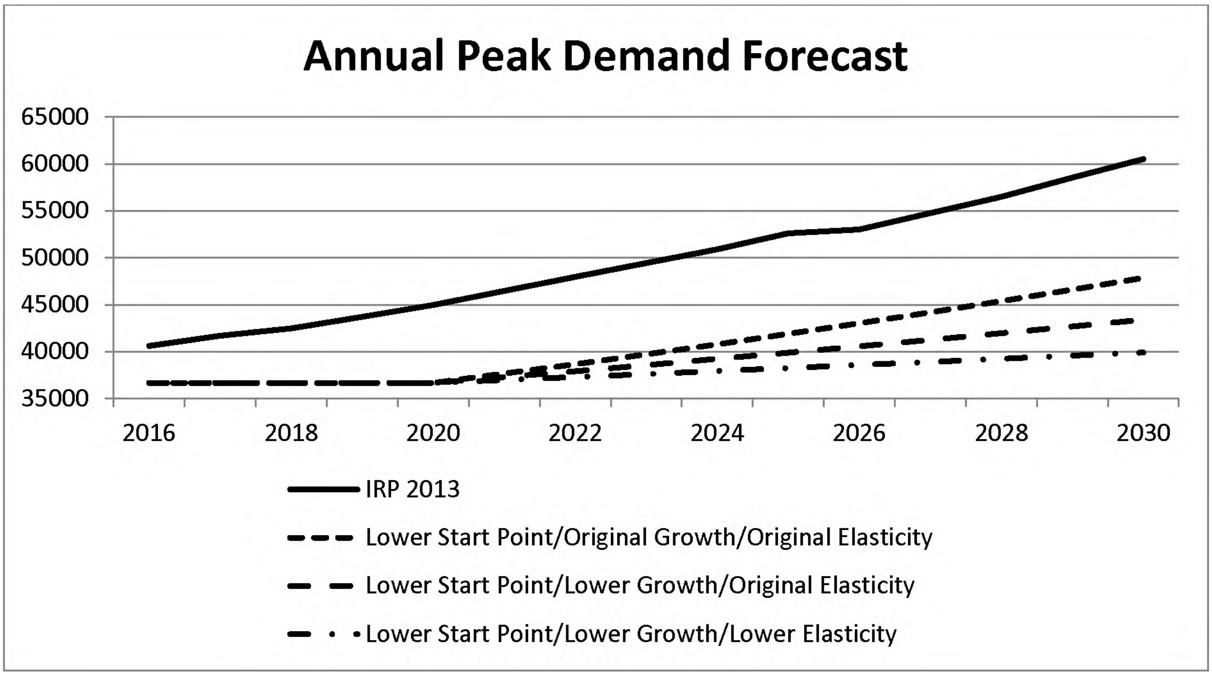
6.3. Forecasting future demand

A key finding from the research is that electricity demand has slowed, coupled with a change in the consumption habits of the different sectors of the economy. The IRP 2013 already acknowledged that electricity demand would not grow to the extent that the original 2010 IRP expected and lowered future electricity demand expectations accordingly (DoE, 2013). While the econometric results were mainly not significant, it is possible to forecast what potential electricity demand may be in the future still with this information in mind.

Projections of future demand until 2030 in the 2010, 2013 and draft 2016 IRPs were shown in Figure 1. Demand was projected to rise by 2020 to 52 719 MW, 44 977MW and to 44 916 MW in the 2010, 2013 and draft 2016 IRPs respectively. By 2030 the projections were 67 809 MW, 60 509 MW and 57 274 MW for the 2010, 2013 and draft 2016 IRPs respectively. The reason for the progressively lower forecasts in the later IRPs is largely the recognition that electricity demand has not grown since 2010. Given government's projections that total GDP growth in 2017 will be about 0.7% and this will rise to just 1.1% in 2018, 1.5% in 2019 and 1.9% in 2020 (National Treasury, 2017) and given the reduced elasticity of electricity demand shown in the previous Chapter, it can now be concluded that electricity demand in 2020 is unlikely to exceed that in 2010.

This means that the starting point of demand projections from 2020 will be 30.45% lower than in the 2010 IRP,18.48% lower than the 2013 IRP and 18.37% lower than the draft 2016 IRPs. This fact alone reduces projected electricity demand in 2030 by the same percentages. However, on the basis of the findings of this study, it is necessary also to challenge the projected future GDP growth assumptions and the electricity demand elasticities used in the IRPs. This is done for the 2013 IRP projections in Figure 9.

Figure 9: Annual Peak Demand Forecasts 2020-2030 (MW)



The first of these forecasts is the original annual peak demand forecast for the 'grassroots' case from the IRP 2013. This base case is exactly as it is published within the IRP 2013, taking note that the GDP growth forecast in this case was 5.4% and electricity demand growth was 2.7% meaning that the elasticity for electricity demand was 0.5 for the base case, neither extremely elastic or inelastic. In this case, the forecast predicts that the peak annual demand for electricity by 2030 will be 60 509 MW.

The second forecast takes into account that the initial starting point at 2020 will be much lower than predicted, that the peak demand for electricity in 2020 will be the equivalent of peak demand for electricity in 2010. With this starting point, the same GDP growth and elasticity are assumed. Peak electricity demand by 2030 in this case is now only 47 856 MW.

The third forecast makes use of the lower starting point but also takes into account possible lower GDP growth. As noted, GDP growth is unlikely to be as high as originally set out by the

IRP and so a lower annual growth figure is used, in this case 3.4% per annum. With the lower growth in the economy and a lower starting point, peak electricity demand by 2030 is lowered further to 43 395 MW.

The final forecast takes into account another possible factor along with the lower GDP growth. The possible break in the relationship and restructuring in the economy would have an effect on the elasticity of demand for electricity. Due to efficiency or a focus to less electricity intensive industries, the elasticity of future demand for electricity is lowered to 0.25[1]. This new forecast has annual peak demand at 39 902 MW by 2030.

This final forecast is 28.28% lower than the original 2013 IRP GDP/elasticity forecast. It is 36% lower than the 2010 IRP forecast for 2030.Not only is it lower, but such a drastic change since the last IRP update also shows that electricity demand projections for a long period such as ten years are extremely uncertain. Planning must thus be flexible to account for potential demand changes in the industry.

6.4. Policy recommendations

This research has shown that forecasting electricity demand, especially into the distant future, is not something easily done, due to the constantly changing economic and technological landscape. This in turn means that plans cannot be simply set for the long term, as the assumptions and expectations that provided the basis for these plans can be quickly overturned.

Instead it is necessary to be flexible in planning energy policy for South Africa. In general, the results of this study signify that accurately forecasting electricity demand into the future is not a simple endeavour. The income elasticity of overall electricity demand has fallen. But forecasting future electricity demand requires not only forecasting future GDP but also the composition of that growth in terms of manufacturing and mining. Using historical trends of electricity demand will almost certainly lead to large amounts of excess capacity and wasted resources. Because increases in future demand are very difficult to determine, a more flexible approach to securing supply for South Africa as a means to avoid wastage and needless expenditure is needed.

[1]Table 7 showed the elasticity of total GDP from 2008-2017 to be –0.1 and the ARDL model showed an elasticity of just 0.0021. Elasticity of demand for 'other" GDP was 0.55. Future elasticity will depend upon price changes, but importantly also the composition of GDP growth, especially whether manufacturing and mining output stop falling. If mining and manufacturing, which make up almost 40% of electricity demand, stop falling and future electricity demand growth occurs mainly in the 'other' category of demand, an elasticity as low as 0.25 seems possible.

Even without going into other considerations such as commitments regarding future CO_2 emissions, but rather focusing on just the economic factors of energy policy, requires that planning for future demand be a regular exercise. Rather than committing to long-term plans or capacity builds that may in the future end up being unnecessary, a focus should be given to technologies that are both quick to bring online and increase electricity supply incrementally rather than force large step-changes in supply, which potentially lead to an oversupply of electricity and a waste of scarce capital resources. Small, incremental increases in supply that are able to come on stream swiftly, such as gas, solar and wind power, are likely to be more appropriate for meeting South Africa's future electricity needs.

REFERENCES

Altinay, G. and Karagol, E., 2005. Electricity consumption and economic growth: evidence from Turkey. *Energy Economics*, 27(6), pp.849-856.

Anderson, P.L., McLellan, R.D., Overton, J.P. and Wolfram, G.L., 1997. Price elasticity of demand. *McKinac Center for Public Policy*. [Online]. Available: http://scholar.harvard.edu/files/alada/files/price_elasticity_of_demand_handout.pdf (Accessed 13 October 2017).

Beard, R. and Ujjayant, C., 2009. *Hotelling with network externalities*. [Online]. Available: https://ideas.repec.org/p/hal/journl/hal-00497186.html (Accessed 20 May 2017).

Bentzen, J. and Engsted, T., 1993. Short-and long-run elasticities in energy demand: a cointegration approach. *Energy economics*, 15(1), pp.9-16.

Borenstein, S., 2002. The trouble with electricity markets: understanding California's restructuring disaster. *The Journal of Economic Perspectives*, 16(1), pp.191-211.

Council for Scientific and Industrial Research, 2016. Forecasts for electricity demand in South Africa (2014-2050) using the CSIR regression model. Council for Scientific and Industrial Research. [Online]. Available: http://www.energy.gov.za/IRP/2016/IRP-AnnexureB-Demand-forecasts-report.pdf

Demsetz, H., 1968. Why regulate utilities? *The Journal of Law and Economics*, 11(1), pp.55-65.

Department of Energy, 2010. Electricity Regulations on the Integrated Resource Plan 2010-2030. *Government Gazette*, 551(34263), 1-71.

Department of Energy, 2011. Integrated Resource Plan 2010-2030 (Final Revision). [Online]. Available:www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (Accessed 15 August 2017).

Department of Energy., 2013. Integrated Resource Plan For Electricity (IRP) 2010-2030 Update Report 2013. [Online]. Available: http://www.doe-irp.co.za/content/IRP2010_updatea.pdf (Accessed 20 August 2017).

Department of Energy, 2016. Integrated Resource Plan For Electricity (IRP) 2010-2030 Update Report 2016. [Online]. Available: http://www.gpwonline.co.za/Gazettes/Gazettes/40445_25-11_NationalGovernment.pdf (Accessed 20 August 2017).

Depoorter, B.W., 1999. Regulation of natural monopoly. *Encyclopedia of Law and Economics, Part V-Regulation of contracts*.

DiLorenzo, T.J., 1996. The myth of natural monopoly. *The Review of Austrian Economics*, 9(2), pp.43-58.

Eskom, 1990. Eskom Annual Report 1990. [Online]. Available: http://www.eskom.co.za/sites/heritage/Annual%20Reports/1990%20Annual%20Report.pdf(Accessed 20 November 2017).

Eskom, 2009. Eskom Annual Report 2009. [Online]. Available: http://www.financialresults.co.za/eskom_ar2009/ar_2009/index_annual_report.htm (Accessed 8 November 2017).

Eskom, 2017. Eskom Integrated Report Presentation 2017. [Online]. Available: http://www.eskom.co.za/IR2017/Documents/ResultsPresentation2017.pdf (Accessed 8 November 2017).

Fan, S. and Hyndman, R.J., 2011. The price elasticity of electricity demand in South Australia. *Energy Policy*, 39(6), pp.3709-3719.

Faria, P. and Vale, Z., 2011. Demand response in electrical energy supply: An optimal real time pricing approach. *Energy*, 36(8), pp.5374-5384.

Ferguson, R., Wilkinson, W. and Hill, R., 2000. Electricity use and economic development. *Energy policy*, 28(13), pp.923-934.

Gately, D. and Huntington, H.G., 2002. The asymmetric effects of changes in price and income on energy and oil demand. *The Energy Journal*, pp.19-55.

Gold in South Africa, 2005. Chapter 2: reserves to doré: the gold mining industry. [Online]. Available: http://www.goldinsouthafrica.com/pdfs/Chapter_2.pdf (Accessed 4 December 2017).

Herring, H. and Roy, R., 2007. Technological innovation, energy efficient design and the rebound effect. *Technovation*, *27*(4), pp.194-203.

Hotelling, H., 1931. The economics of exhaustible resources. *Journal of political Economy*, 39(2), pp.137-175.

Khobai, H., Mugano, G. and le Roux, P., 2017. The causal relationship between electricity supply and economic growth in South Africa. *Studies in Economics and Econometrics*, *41*(2), pp.69-86.

Kirschen, D.S., Strbac, G., Cumperayot, P. and de Paiva Mendes, D., 2000. Factoring the elasticity of demand in electricity prices. *IEEE Transactions on Power Systems*, 15(2), pp.612-617.

Kirschen, D.S., 2003. Demand-side view of electricity markets. *Power Systems, IEEE Transactions on*, 18(2), 520-527.

Künneke, R.W., 1999. Electricity networks: how 'natural' is the monopoly?. *Utilities Policy*, 8(2), pp.99-108.

Lijesen, M.G., 2007. The real-time price elasticity of electricity. *Energy economics*, 29(2), 249-258.

Lund, H., 2007. Renewable energy strategies for sustainable development. *Energy*, 32(6), pp.912-919.

Lund, H., 2010. The implementation of renewable energy systems. Lessons learned from the Danish case. *Energy*, 35(10), pp.4003-4009.

Mozumder, P. and Marathe, A., 2007. Causality relationship between electricity consumption and GDP in Bangladesh. *Energy policy*, 35(1), pp.395-402.

Mosca, M., 2008. On the origins of the concept of natural monopoly: Economies of scale and competition∗. *The European Journal of the History of Economic Thought*, 15(2), pp.317-353.

Mitchell, T., 2006. A co-integration analysis of the price and income elasticity of energy demand. *Research Department, Central Bank of Barbados*.

Mbatha, A. and Tshandu, P., 2015. South Africa power crisis has 'severe' GDP effects, World Bank says. [Online]. *Moneyweb*. Available: http://www.moneyweb.co.za/news/south-africa/south-africa-power-crisis-has-severe-gdp-effects-world-bank-says/ (Accessed 13 July 2017).

Mining Technology, 2014. BHP Billiton to close South African Bayside aluminium smelter. [Online]. Available: http://www.mining-technology.com/news/newsbhp-billiton-to-close-south-african-bayside-aluminum-smelter-4162463 (Accessed 20 October 2017).

Narayan, P.K. and Smyth, R., 2005. The residential demand for electricity in Australia: an application of the bounds testing approach to cointegration. *Energy policy*, 33(4), pp.467-474.

National Energy Regulator of South Africa, 2012. Electricity supply statistics for South Africa 2012. [Online]. Available: http://www.nersa.org.za/Admin/Document/Editor/file/News%20and%20Publications/Publications/Current%20Issues/Electricity%20Supply%20Statistics/Electricity%20Supply%20Statistics%20for%20South%20Africa%202012.pdf (Accessed 20 October 2017).

National Treasury of South Africa, 2017. Medium Term Budget Policy Statement 2017. [Online]. Available: http://www.treasury.gov.za/documents/MTBPS/2017/mtbps/FullMTBPS.pdf (Accessed 29 November 2017).

Pattichis, C.A., 1999. Price and income elasticities of disaggregated import demand: results from UECMs and an application. *Applied Economics,* 31, 1061–1071.

Pesaran, M.H., Shin, Y. and Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, 16(3), pp.289-326.

Posner, R.A., 1968. Natural monopoly and its regulation. *Stanford Law. Review*, 21, p.548

Primeaux Jr, W.J., 1986. *Direct electric utility competition: The natural monopoly myth*. New York.

South African Reserve Bank (SARB), 2017. Release of Selected Monthly Data Economic indicators (seasonally adjusted). [Online]. Available: https://wwwrs.resbank.co.za/webindicators/MonthlyIndicators.aspx?DataType=MRDEI. [Assessed 13 March 2017].

Spees, K. and Lave, L.B., 2007. Demand response and electricity market efficiency. *The Electricity Journal*, 20(3), pp.69-85.

Statistics South Africa, 2017. Consumer Price Index (CPI) 2016 Weights. [Online]. Available: http://www.statssa.gov.za/publications/P01415/P014152016.pdf [Assessed 13 March 2017].

Varian, H. R., 2014.*Intermediate Microeconomics: A Modern Approach*, 9th Edition. New York: W.W. Norton & Company.

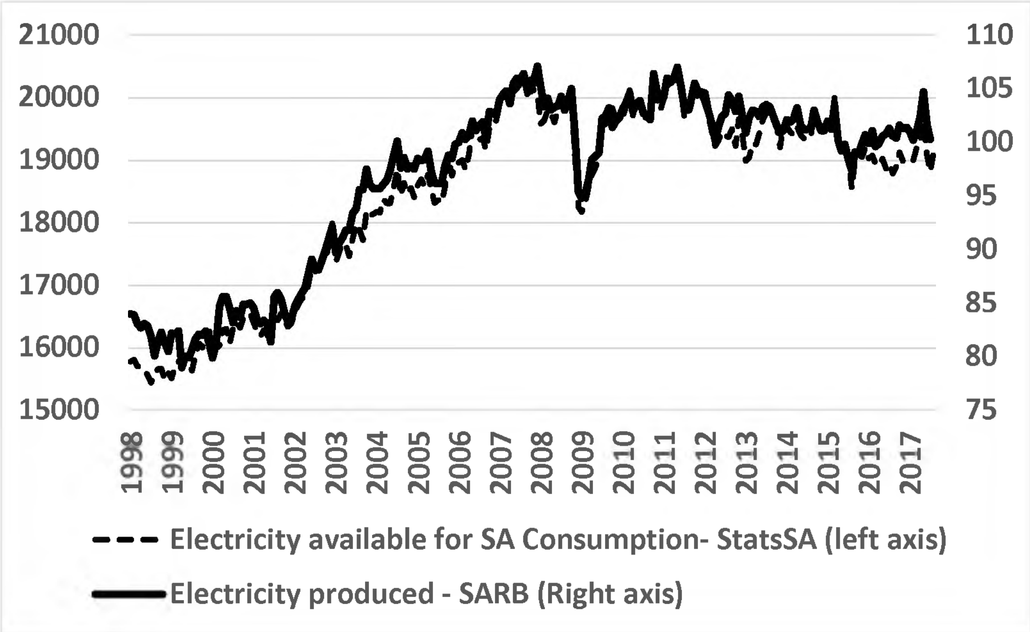
Wüstenhagen, R. and Bilharz, M., 2006. Green energy market development in Germany: effective public policy and emerging customer demand. *Energy policy*, 34(13), pp.1681-1696.

Yoo, S.H., 2005. Electricity consumption and economic growth: evidence from Korea. *Energy Policy*, 33(12), pp.1627-1632.

Ziramba, E., 2008. The demand for residential electricity in South Africa. *Energy Policy*, 36(9), pp.3460-3466.

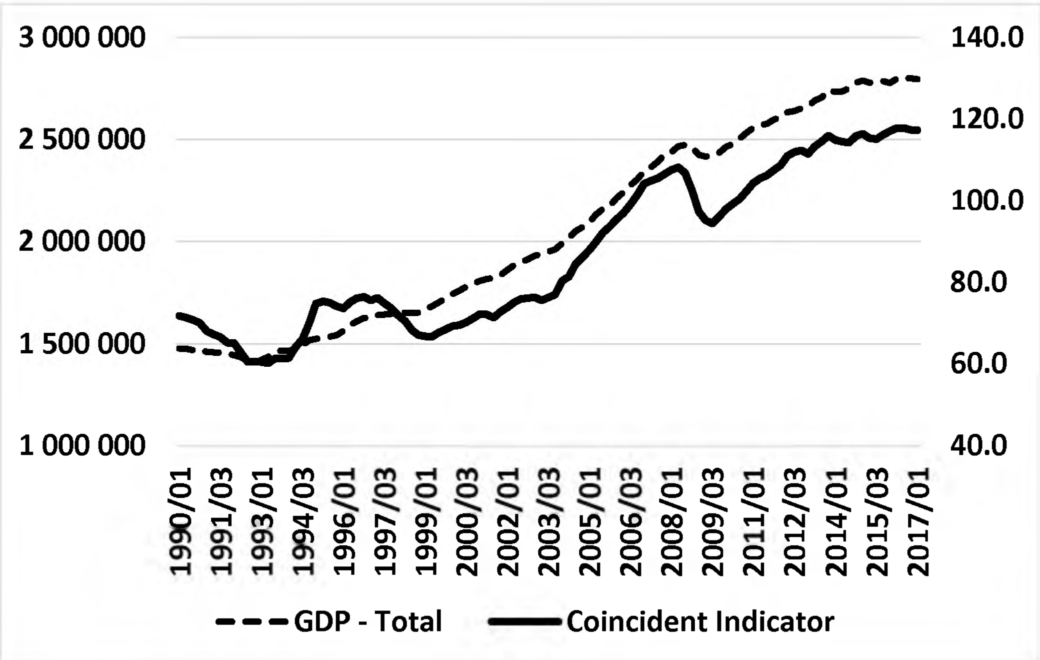
APPENDIX A

Figure A.1: South Africa - Electricity available for SA consumption (StatsSA) versus Electricity produced (SA Reserve Bank) (monthly – seasonally adjusted)



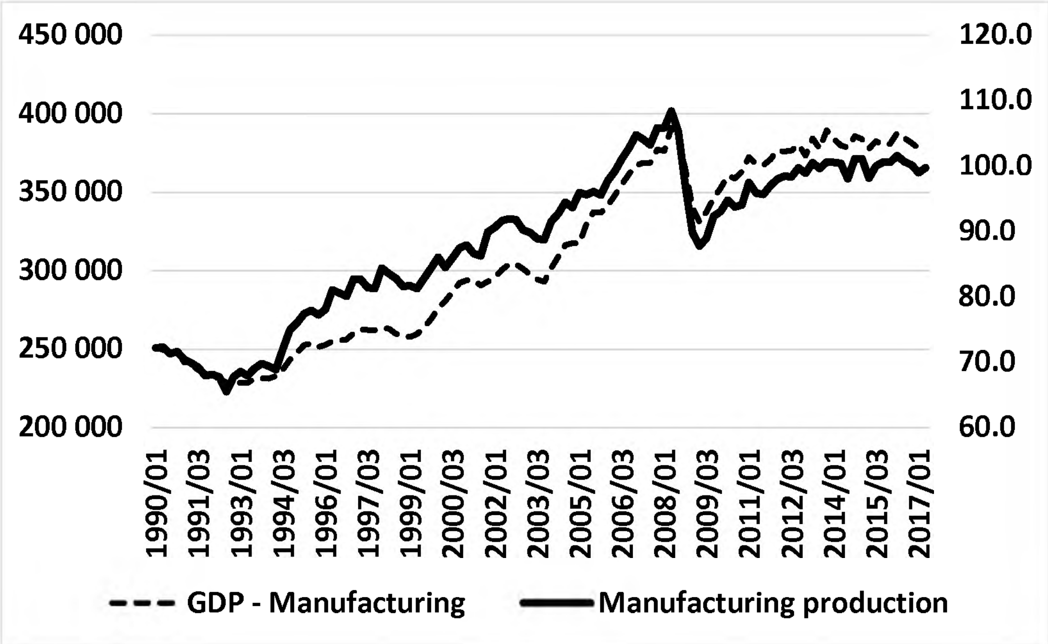
Source: StatsSA Online database and SA Reserve Bank Online database

Figure A.2: South Africa - Coincident Indicator versus real GDP (quarterly, seasonally adjusted annualised)



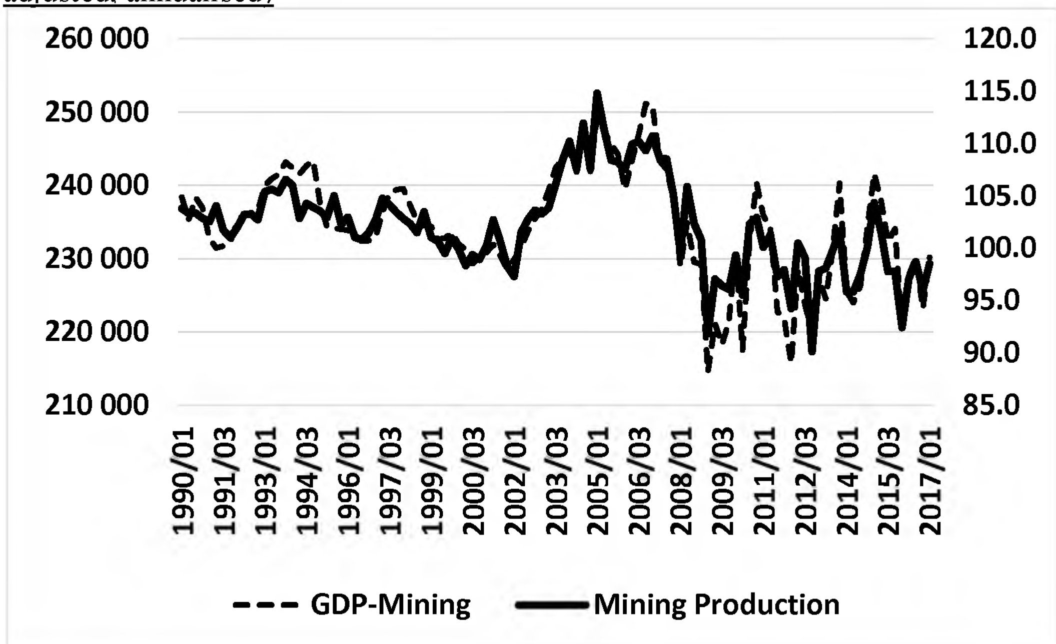
Source: SA Reserve Bank Online database

Figure A.3: South Africa – Manufacturing Production versus Manufacturing GDP (quarterly, seasonally adjusted, annualised)



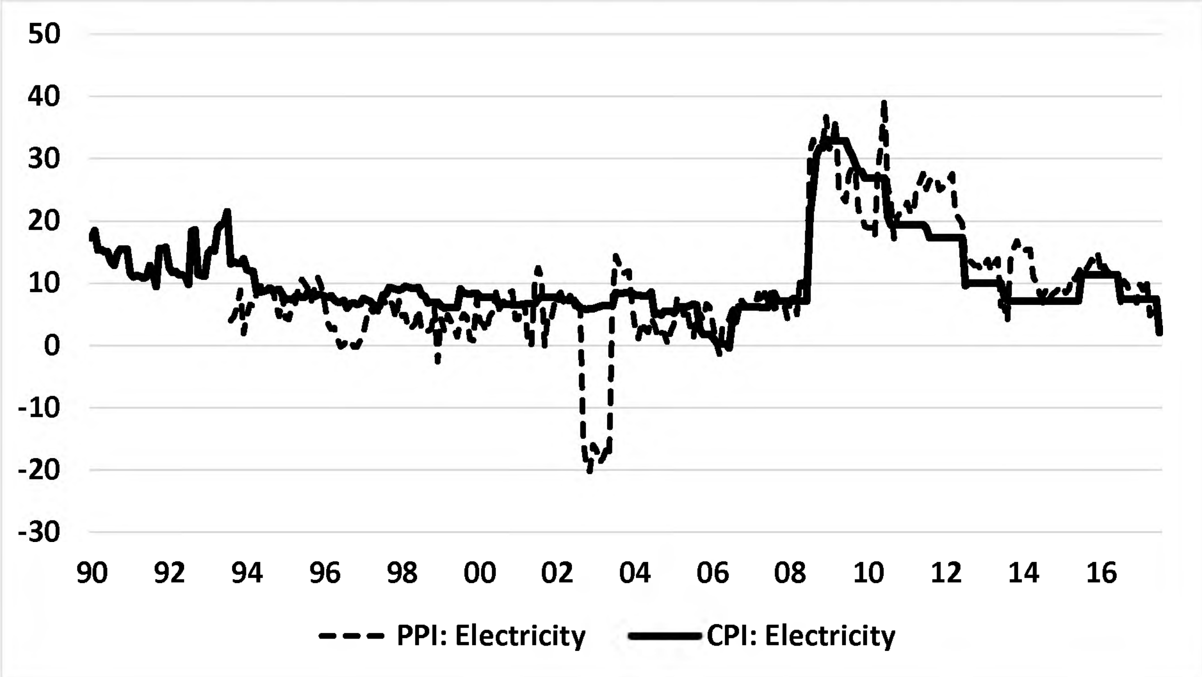
Source: SA Reserve Bank Online database

Figure A.4: South Africa - Mining Production versus Mining GDP (quarterly, seasonally adjusted, annualised)



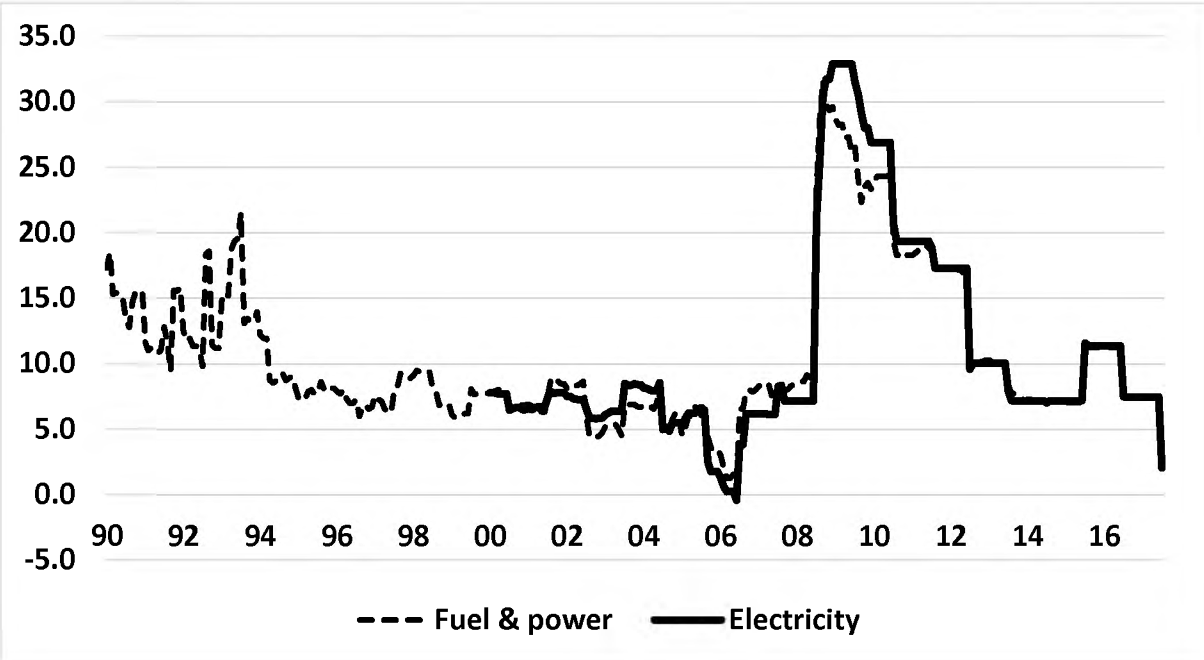
Source: SA Reserve Bank Online database

Figure A.5: South Africa – CPI and PPI electricity (% change from previous year)



Source:StatsSA Online Database and data provided direct to author

Figure A.6: South Africa – CPI Fuel & Power versus CPI Electricity (% change from previous year)



Source:StatsSA, data provided direct to author.

APPENDIX B

Figure B.1: CUSUM Test Diagram

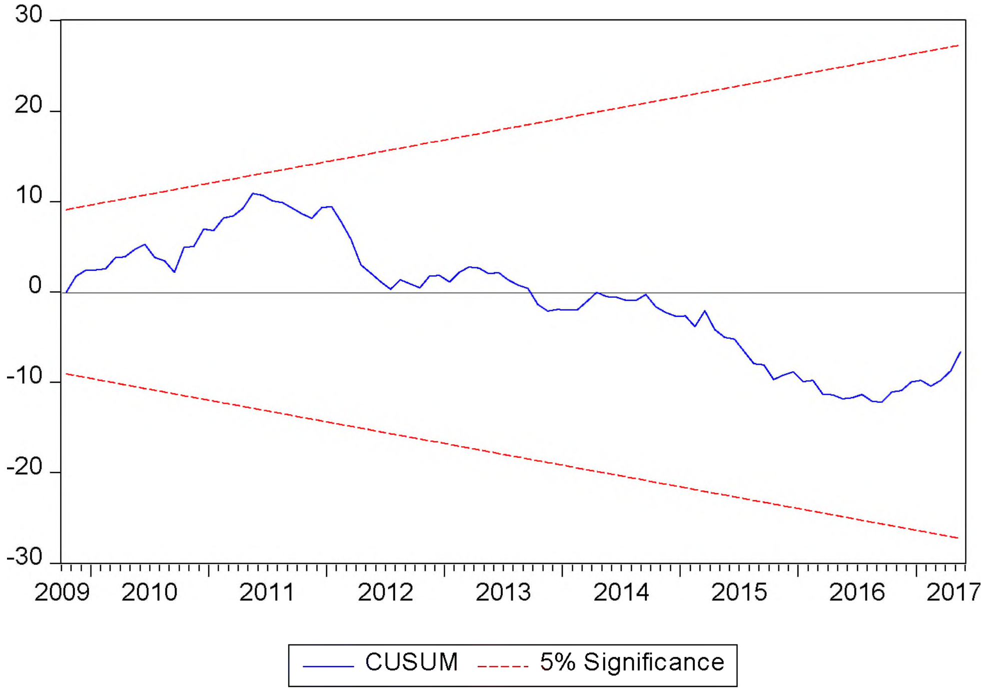


Figure. B.2: Electricity Demand/Price post-2008

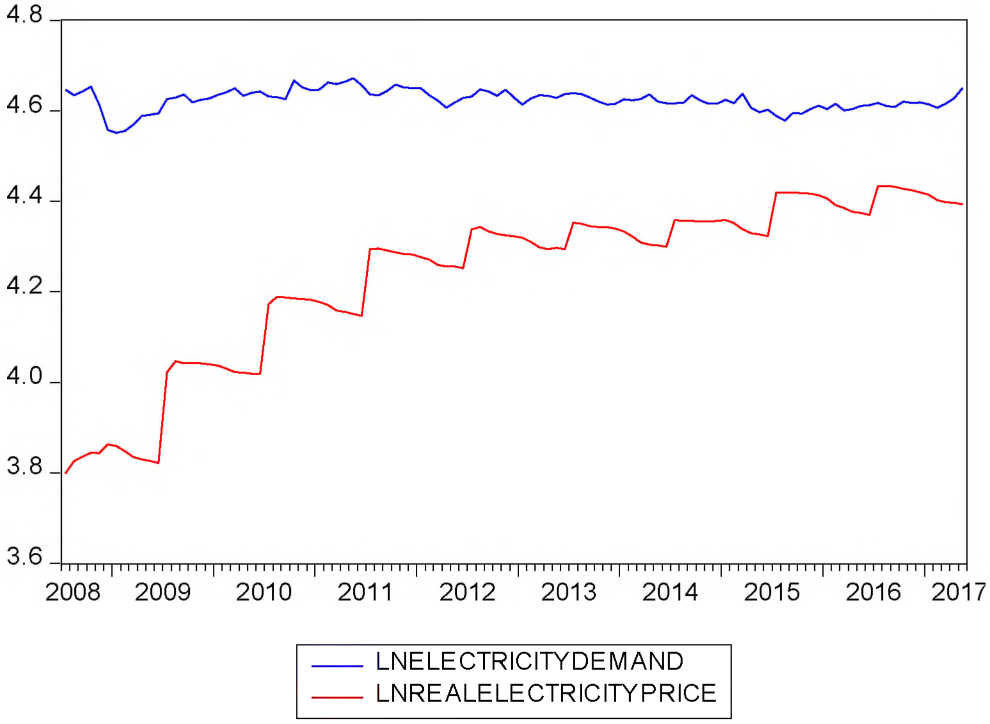


Figure B.3: Electricity Demand/Economic Growth post-2008