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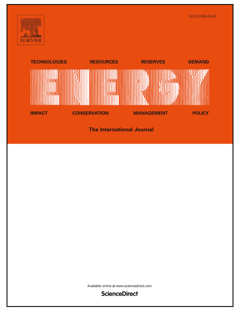

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Inter-fuel substitution possibilities in South Africa: A translog production function approach

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Abstract

This study applies the translog production function to investigate technical change and energy substitution possibilities among petroleum, coal and electricity over the period 1980-2012. Ridge regression technique is introduced to correct for multicollinearity in the data. The study documents several findings: first, electricity and coal are found to be the major drivers of South African output and also have a faster technological progress over petroleum. Second, all energy inputs were found to be substitutes; therefore removing all price ceilings and subsidies on petroleum will decrease the demand for petroleum in effect protecting South African economy from external petroleum price shocks while reducing CO2 emissions. This will also increase the demand for electricity from renewable sources; however the success of this substitution will depend on policies geared towards large scale electricity production to meet demand. Third and finally, this study points to evidence that, even though coal dominates as the main energy source of South Africa, enhancement in research and development of renewable energy technologies could present opportunities for electricity as a potential replacer of coal; and as such, accelerating the CO2 mitigation effort of the South African government.

Key words: Inter-fuel substitution, South Africa, output elasticity

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1 Introduction

South Africa being the second largest economy in Africa has embarked on heavy industrialization Vis a Vis high energy usage. Almost all economic sectors in South Africa including transport, mining, electricity, communication, production, agriculture, fishery, health, education and tourism relies heavily on energy to function. Besides the energy sectors immense contribution to the gross domestic product (GDP), food security, employment, trade, regional and sub-regional development are other contributions enjoyed from the energy sector. Even though the energy sector has become the bedrock of South Africa's development, it has become the most strenuous sector with regards to solving climate change, environmental pollution and energy security issues due to the reliance on coal and oil and the search for an alternate cleaner energy source. According to IEA,[1] coal and oil's contribution to the global primary energy consumption accounted for 29.9 % and 33% in 2013 respectively with coal generating 41% of electricity globally. Energy consumption in emerging economies like South Africa has been on the increase in recent years. South Africa's total energy consumption rose from 2.72828 quadrillion Btu in 1980 to 5. 77122 quadrillion Btu in 2008 with its attendant CO2 emissions almost doubling from 44.46181million metric tons in 1980 to 78.98331 million metric tons in 2008 due to higher percentage of coal and oil in its energy mix (seen in fig 1). South Africa is the largest CO2 emitter in Africa and the 14th largest in the world (source IEA estimate 2011). The rapid development growth of South Africa has resulted in an increasing trend of demand for energy and factor inputs see Fig 2.

Currently, the energy mix of South Africa is dominated by coal. South Africa's energy consumption mix is made up of 72% coal due to its availability and the fact that the country has only a little amount of proven crude oil reserve. About 62% of coal is used for electricity generation with coal powered plants dotted all over the country with installed capacity of 45,710 megawatts (source Eskom February 2013 and IHS world market energy [2]). Beside electricity generation, about 23% of coal is used by the petrochemical sector and about 8% in other industries.

Petroleum which is predominantly used in the transport sector accounts for about 22% of South Africa's energy consumption mix and 75% used in the transport sector. Petroleum is imported in crude form and refined domestically for domestic use. South Africa has the second largest refinery in Africa with a total refinery capacity of 485,000 barrels per day and crude oil imported largely from Saudi Arabia and other countries like Nigeria, Angola and Ghana are refined for its domestic consumption.

South Africa's electricity generation mix is made up of 90% coal, 5% nuclear and 5% hydro with very small amount generated from wind energy. Electricity is largely consumed by the industrial sector accounting for about 45% of the total consumption with the manufacturing, commercial mining and residential sectors accounting for 20%, 20%, 10% and 5% respectively.

The dominance of coal and petroleum in the energy consumption mix of South Africa is a major concern not to only the South African economy but to the world at large. South Africa being at the 14th position in terms of CO_2 emission should raise “eye brows” since its contribution to global warming and climate change is significant enough to be neglected on the global scale. Looking at the cursory plot of our data (see Fig 2), there is a clear indication that as the economy grows, the demand for energy inputs will increase which implies that CO_2 emissions will further increase; and as such, creating worsening environmental pollution which is already having a toll on the economy. Governments and other environmental activist groups are calling for the use of cleaner energy sources with numerous policies put in place to control the emission menace (see Table 1).

However the effectiveness and the realization of these goals will largely depend on the substitutability possibilities among the various energy inputs. Substitutability among different energy types and other factors of production will to a large extent determine the effect of output growth and changes in fuel prices on the demand for energy. These energy and factor substitutability studies have attracted a lot of interest due to risks of global warming and climate change in recent years with a number of research studies focusing on these areas. Even though there have been a number of publications on inter-fuel substitution, most of these studies target the highly industrialized and developed countries. One must not neglect the importance of directing attention to emerging economies like South Africa which is at its fastest stage of development.

Conducting this study for South Africa will present very important contribution especially in terms of the country’s energy economy. First the dominance of petroleum and coal in South Africa’s energy consumption mix should be a major concern and looking at the demand trend of energy and factor inputs, there is clear indication that the demand for these inputs will further increase as the economy grows over time. The results of this study could be used to facilitate future forecast that will match the demand and supply of energy inputs that is base not only on total energy consumption, but a categorization into renewables, petroleum and coal. This should not be taken for granted since reliable demand models must take into account the elasticities of substitution among various energy sources. Second, with the knowledge of which energy types are close substitutes, estimation of their technical progress over time will provide valuable insights on which energy sources should South Africa prioritize for the development of cleaner energy and also to be sure of the success of any energy reform policy geared towards the promotion of cleaner energy and the control of CO_2 emissions. Third the construction of energy – oriented computable general equilibrium (CGE) for South Africa could be based on the estimate from this paper since this varies from the normal CGE model where the former takes into account different energy and factor input forms to come out with a reliable CES which could be used to assess the impact of other energy-related policies (e.g. taxes and subsidies, price hikes and price regulations) on the economy. Finally, although there has been research works related to energy substitution on emerging economies like China which can be sighted in the work of Ma et al. [3] and Wesseh et al.[4], to the best of my knowledge, there has been no related publication directly on inter- fuel substitution with estimation of their differences in technical progress on

South Africa. Moreover, unlike the above two studies which utilized data on total electricity consumption, the present study has considered only renewable electric power data. This means that any substitution possibility would imply direct substitution of renewable energy for non-renewable energy. This will make it easier for policy makers to ascertain whether committing resources into cleaner energy development will be feasible. Hence, the present study brings valuable insight to the empirical literature and will help in filling the literature gap that exists for South Africa.

The remaining of our work is structured as follow: the second section contains a brief literature review. The third section contains the description of data set and how it was processed. The fourth part contains description and expansion of the model framework. The fifth section contains the empirical result and discussion and the sixth and the finale section contains the conclusion of the paper and policy discussion.

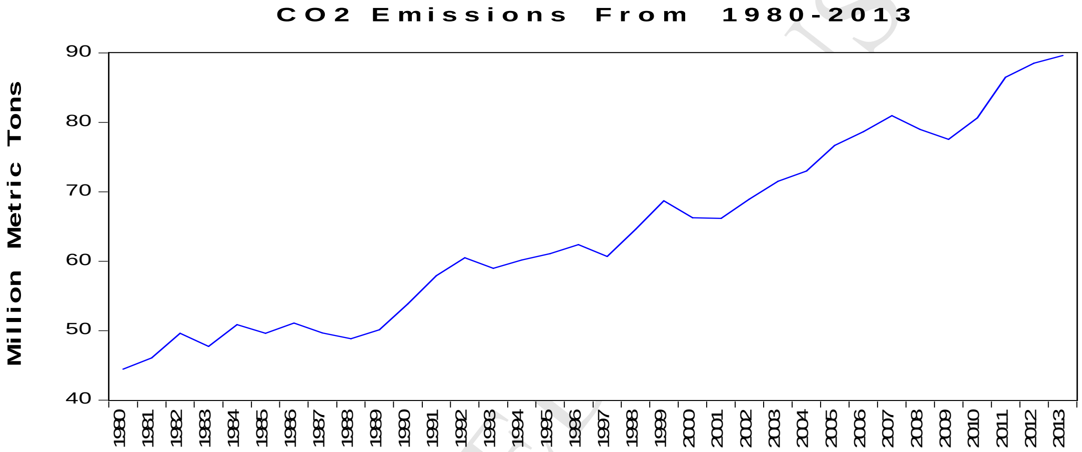


Fig 1. CO_2 emissions from energy use in South Africa (Million Metric Tons) Source US IEA database

2 Literature Review

After the seminal research work byBerndt and wood[5], energy and factor substitutability has been a consistent topic among energy research works with different empirical methods and different data sets employed to estimate the substitutability among energy and factor inputs however the most popular method used in estimation is the transcendental logarithmic (trans-log) cost function due to its preference for flexibility, tractable methodology, understandable and satisfaction of desired properties of production and cost function.Berndt and wood's [5] findings of complementarity relationship between energy and capital in the US manufacturing sector has received a wide range of support from other research works and notable among them are;Anderson R.[6], Fuss[7], Danny et al[8] andPrywes[9] however their findings was refuted by other researchers who suggest there exists substitutability relation between energy and capital inputs. Notable among them who supports the existence of substitutability relationship among energy and capital are; Pindyck [10], Thompson and Taylor [11], Koetse et al [12], Christopoulos[13], Griffen[14], Lin and Wesseh Jr,[15] Lin and Xie[16], Wesseh Jr and Zoumara[17] and Truong.[18] All these works adopted the translog production function. In fact this capital and energy substitutability hypothesis has not got a one-sided result with all findings having a mix results. To delve further into this capital energy hypothesis, Chakir and Thomas [19], Serletis and Timilsina [20], Bjorne and Jenson[21]adopted different methods to estimate the relationship among energy and factor inputs but concluded with mix result which implies a mix relationship among energy and factor inputs in general. In an attempt to delve into the mix result from different works on capital and energy substitutability, Stern[22] carried out a review work on 47 different studies and concluded that, the mixed result from different studies is due to the level of aggregation (e.g. regional, national sectorial), data used (i.e. time series, panel, cross section, pooled data), methodology used and the economic situation of the country of study however Smyth et al also criticized his result siting out datedness of his literature since most of his studies he reviewed used data prior to 1970s and only one-third of the studies he examined used data after 1990.In fact there have been limited inter-factor and inter-energy substitution studies on developing countries. The very few that exists includes; Wesseh Jr and Zoumara[17], Wesseh Jr. et al[4] and Serletis et al[23]. Serletis[23]analyzed substitution possibilities of energy and factor inputs in six high income countries, five middle income countries and four low income countries in their transport and industrial sector and concluded that there is a higher inter-fuel substitution possibilities in high income countries compared to middle and low income countries which is consistent with Stern's conclusion. This implies, inter-fuel substitution depends not on the level of economic development of a country but the structure of the economy. Literatures related to inter-factor and inter –fuel substitution with emphasis on their relative differences in their technical progress is very few particularly on emerging economies like South Africa. Ma et al[3] attempted analyzing the inter-factor substitutability possibilities in China and concluded with suggested possibilities of capital for energy on regional level and labor for energy on national level with capital having higher substitutability possibilities than labor. Smyth et al[24] also estimated the substitutability among capital stock, energy and labor in Chinese steel sector and concluded with substitutability possibilities between capital and energy and also labor and energy.

With the literature presented above, there is clear evidence that though South Africa relies heavily on coal for its power production with its high emissions potentials, littles or no attention has been given to South Africa in term of energy and factor inputs substitutability research. Carrying out this study will be very relevant to policy makers in formulating constructive and achievable energy policies to promote cleaner energy use and control emissions.

Table 1: Some policies put in place by government to promote the use and development of cleaner energy sources in South Africa (Source :) [25]

Year	Policy
1977	National building regulation and building standard Act 103 (NRBS): Empowering the ministry of trade and industry to regulate building Standards to conform to energy sustainability and efficiency form.
1998	Income tax Act 12i: Tax rebate for companies promoting and engaging in the improvement of energy efficiency.
2000	National Environmental Act 32 (NEMA): Promoting and development of energy generation in a non-harmful environment.
2003	White paper on renewable energy: Setting target for the production of Production of 10,000GWh of energy from renewable energy resources Mainly from wind, solar, biomass, and small scale hydro by 2013.
2005	Introduction of one-off capital subsidies for projects aims at producing Energy from energy technologies which includes: landfill gas extraction, Mini hydroelectric schemes, commercial and domestic water heaters and Sugar-cane bagasseh (generating power from sugar cane fiber)
2008	National Energy Act 34: Promoting efficient and economic use of energy Generated from non-depleting energy resources this includes ;(wind, Biomass, solar, tidal, hydro, geothermal and biological waste).

3 Description of Dataset and transformation

Dataset in this study is a yearly time series data of critical observations on Petroleum consumption, coal consumption, electricity consumption, labor, capital formation and GDP in South Africa from 1980 to 2012. For the avoidance of spurious results of our analysis, all datasets were taking through several transformations with all variables transformed into logarithmic form however, some variables were found not be stationary. We therefore transformed the data to a stationary one by taking first order differencing to satisfy the box-cox transformation requirement.

3.1 Output

Output in this study is represented by GDP of the South African economy from 1980-2012. To eliminate the impact of inflation, the GDP in constant terms was chosen and the calculation was based on constant price (2000=100). This study has employed a pure production approach where output is a function of capital, labor and energy in effect, this model incorporates wages, returns, investment and depreciation in the GDP calculation .GDP data was taking from World development indicators databank.

3.2 Capital formation

Getting data on capital at WDI databank [26] website has been difficult so we adopted calculation of capital stock employed by Goldsmith [27] for the first time in 1951 and we employed the perpetual inventory method (PIM) with calculations based on constant price (2000=100). The perpetual inventory method is given as follows:

$$K_t = K_{t-1}(1-\delta) + I_t \tag{1}$$

Where K_t is the current capital stock, K_{t-1} is capital stock of the previous year, δ is the capital depreciation rate, and I_t is the capital investment in the current year. Based on World Bank's total wealth estimate and per capita wealth estimate for 124 countries including South Africa, we computed initial capital stock using the following equations.

$$K_0 = I_0 / (g + \delta) \tag{2}$$

Where K_0 represents initial capital stock, I_0 represents the initial capital investment, δ represents the capital depreciation rate and g represents average growth rate of capital investment over the period of the study.

3.3 Consumption of petroleum and electricity

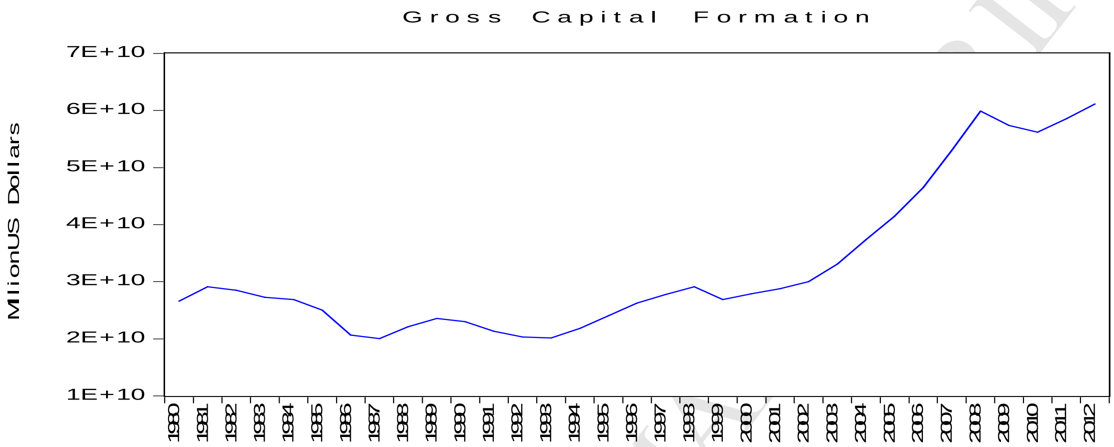
Data on electricity consumption and petroleum consumption in this study was taken from US Energy Information Administration (IEA) data base. All energy inputs are expressed in British thermal unit (BTU). It is the amount of energy needed to increase the temperature of one pound of water by one degree F. It's the standard measurement for stating the amount of energy that a fuel has as well as the amount of output of any heat generating device. Electricity consumption in this study represents only electricity from renewable sources. This was also taken from IEA database.

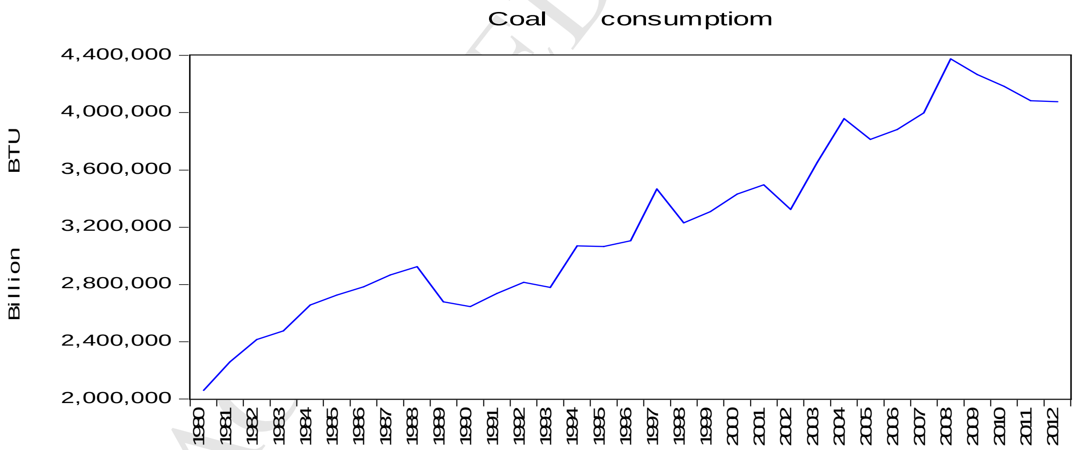
3.4 Coal consumption

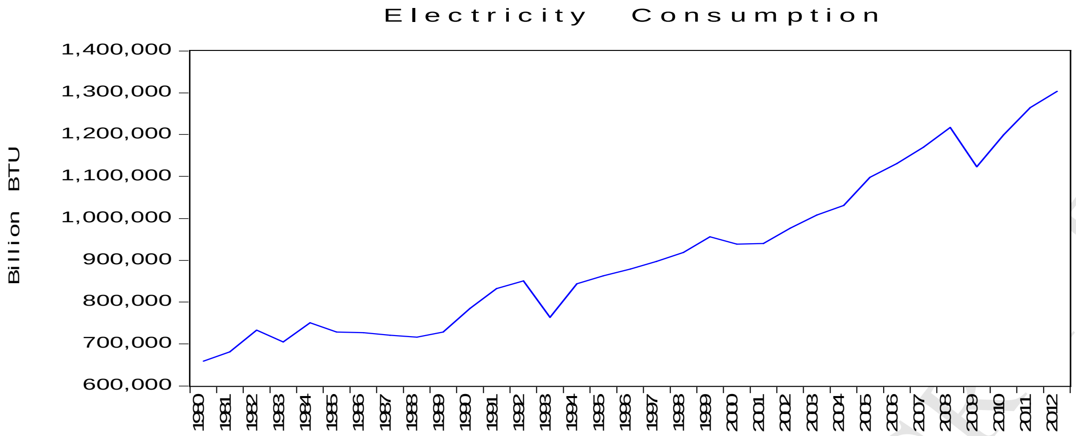
Data on coal consumption was taken from US Energy Information Administration Database and digest of South African energy statistics from 1980-2012. All coal data was converted into British Thermal Unit (BTU) as a standard unit for representing energy inputs.

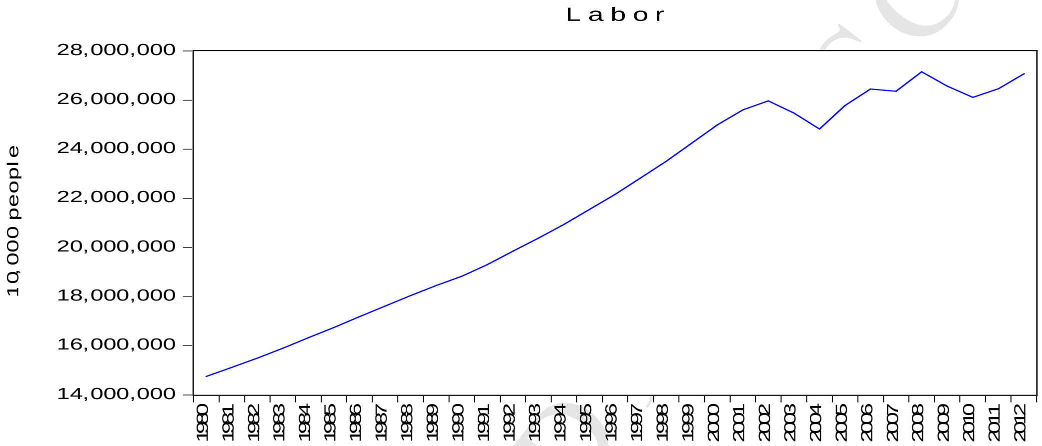
3.5 Labor

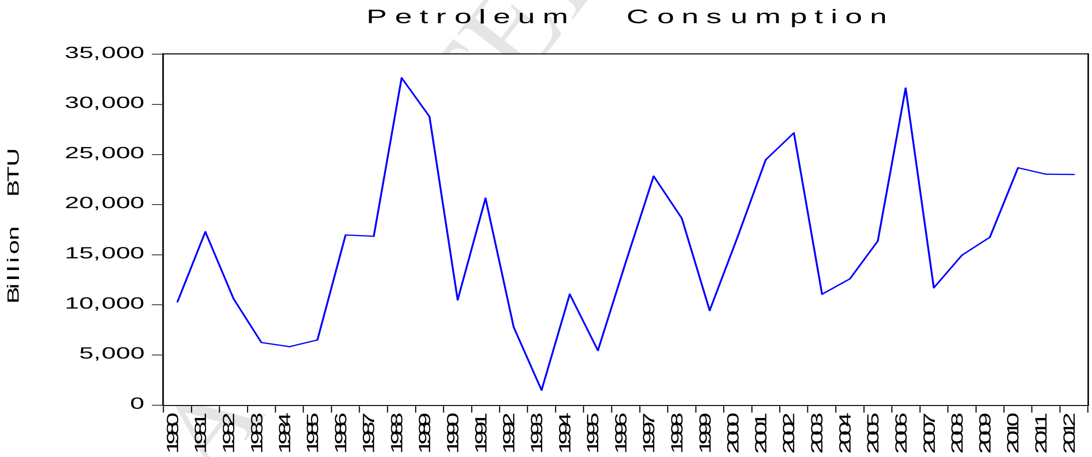
Data on labor was adopted from World development indicators databank however we did some transformation of the data to get the near accurate labor data. In our study we calculated employment ratio to population ratio multiplied it by the active population to represent labor over the period of the study.






Electricity Consumption
Billion BTU
1,400,000
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


Labor
10,000 people
28,000,000
26,000,000
24,000,000
22,000,000
20,000,000
18,000,000
16,000,000
14,000,000
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


Petroleum Consumption
Billion BTU
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

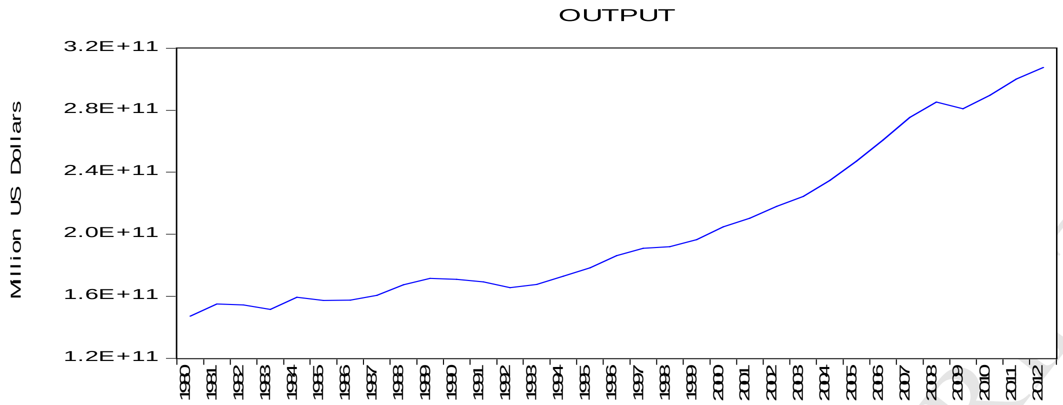


Fig 2. Plot of variable 1980-2012

4 Research method and estimation procedure

Adopting the approach used by Smyth et al [24], we employed the log linear trans-log production function to investigate substitutability among energy inputs namely; coal, electricity and petroleum. This method was chosen instead of trans-log cost function to avoid including data of prices of the inputs which are not available over our sample period.As a second order Taylor series [28], the trans-log production function can be used to investigate the interaction of input factors in production function. This can be expressed as follows:

4.1

$$\text{In}Y_t = \text{In}_{a_0} + \sum_i a_i \text{In}X_{it} + \frac{1}{2}\sum_i \sum_j a_{ij}\text{In}X_{it}\text{In}X_{jt} \quad (3)$$

Where Y_t denotes output at time t, a_0 shows the state of technical knowledge X_{it} and X_{jt} represents inputs I and j respectively at time t a_i and a_{ij} are technologically determined parameters. Here it is assumed that there exists a twice differentiable aggregate trans-log production function relating gross output to coal, capital, labor, petroleum, and electricity inputs in South Africa. As sighted in Pavelescu[29], imposition of assumptions like perfect competition or perfect substitution among inputs can be avoided when using functional forms. Trans-log production function is usually the preferred choice for most researchers due to the presence of quadratic terms which allows for nonlinear relationships between the output and inputs and due to its flexibility compared to other forms. With our inputs, we can specify the trans-log production function for South Africa as follows:

$$\ln Y_t = a_0 + a_K \ln K_t + a_L \ln L_t + a_C \ln C_t + a_P \ln P_t + a_E \ln E_t + a_{CK} \ln C_t \ln K_t + a_{CL} \ln C_t \ln L_t + a_{CP} \ln C_t \ln P_t$$
$$+ a_{CE} \ln C_t \ln E_t + a_{PK} \ln P_t \ln K_t + a_{PL} \ln P_t \ln L_t + a_{PE} \ln P_t \ln E_t + a_{EK} \ln E_t \ln K_t + a_{EL} \ln E_t \ln L_t$$
$$+ a_{EC} \ln E_t \ln C_t + a_{EP} \ln E_t \ln P_t + a_{CC} (\ln C_t)^2 + a_{PP} (\ln P_t)^2 + a_{EE} (\ln E_t)^2$$

In the expression above, Y_t represents the output of South African economy while K_t, $C_{t,}$ $L_{t,}$ $P_{t,}$ and E_t are capital, coal, labor, petroleum and electricity inputs in the South African economy respectively while t is the time index.
Classifying the South African economic region as a linear homogeneous production function, the output elasticity (η_{it}) of the ith input from equation (3) can be calculated as follows:

$$\eta_{it} = \frac{\partial \ln Y_t}{\partial \ln X_{it}} = a_i + \sum_j a_{ij} \ln X_{jt} > 0 \quad (5)$$

Hence, the output elasticity for capital stock becomes:

$$\eta_{Kt} = \frac{d \ln Y_t}{d \ln K_t} = a_K + a_{KC} \ln C_t + a_{KL} \ln L_t + a_{KP} \ln P_t + a_{KE} \ln E_t + 2a_{KK} \ln K_t > 0 \quad (6)$$

The output elasticity of coal becomes:

$$\eta_{Ct} = \frac{d \ln Y_t}{d \ln C_t} = a_C + a_{CK} \ln K_t + a_{CL} \ln L_t + a_{CP} \ln P_t + a_{CE} \ln E_t + 2a_{CC} \ln C_t > 0 \quad (7)$$

The output elasticity of Labor becomes:

$$\eta_{Lt} = \frac{d \ln Y_t}{d \ln L_t} = a_L = a_{LK} \ln K_t + a_{LC} \ln C_t + a_{LP} \ln P_t + a_{LE} \ln E_t + 2a_{LL} \ln L_t > 0 \quad (8)$$

The output elasticity for petroleum becomes:

$$\eta_{Pt} = \frac{d \ln Y_t}{d \ln P_t} = a_P + a_{PK} \ln K_t + a_{PC} \ln C_t + a_{PL} \ln L_t + a_{PE} \ln E_t + 2a_{PP} \ln P_t > 0 \quad (9)$$

The output elasticity of electricity becomes:

$$\eta_{Et} = \frac{d \ln Y_t}{d \ln E_t} = a_E + a_{EK} \ln K_t + a_{EC} \ln C_t + a_{EL} \ln L_t + a_{EP} \ln P_t + 2a_{EE} \ln E_t > 0 \quad (10)$$

We expect the output elasticity to vary across the samples because they are function of energy consumption per period. Elasticity between two factor inputs and two energy inputs can be calculated as:

$$\sigma_{ij} = \frac{\%\Delta(X_{it\wedge} / X_{jt})}{\%\Delta(P_{jt} / P_{it})} \tag{11}$$

Assuming the firms in South African economy are cost minimization entities, Eq (11) can be written as:

$$\sigma_{ij} = \frac{\%\Delta(X_{it} / X_{jt})}{\%\Delta(MP_{jt} / MP_{it})} = \left(\frac{d(X_{it} / X_{jt})}{d(MP_{jt} / MP_{it})}\right)\left(\frac{(MP_{jt} / MP_{it})}{(X_{it} / X_{jt})}\right) \tag{12}$$

From Eq (12), the final formula for the computation of substitution elasticities between input i and j in this study becomes:

$$\sigma_{ij} = \left[1 + \frac{-a_{ij} + (\eta_i / \eta_j)a_{jj}}{-\eta_i + \eta_j}\right]^{-1} \tag{13}$$

Because of the number of variables, this paper is investigating only inter fuel substitution restricting the variable to Coal, Petroleum and Electricityhence, the substitution elasticity among these variables in South Africa can be written as:

$$\sigma_{CP} = \left[1 + \frac{-a_{CP} + (\eta_C / \eta_P)a_{PP}}{-\eta_C + \eta_P}\right]^{-1} \tag{14}$$

$$\sigma_{CE} = \left[1 + \frac{-a_{CE} + (\eta_C / \eta_E)a_{EE}}{-\eta_C + \eta_E}\right]^{-1} \tag{15}$$

$$\sigma_{PE} = \left[1 + \frac{-a_{PE} + (\eta_P / \eta_E)a_{EE}}{-\eta_P + \eta_E}\right]^{-1} \tag{16}$$

In the equation above, $\sigma_{CP,}\sigma_{CE,}\sigma_{PE}$ represents inter-fuel substitution between Coal-Petroleum, Coal-Electricity and Petroleum- Electricity respectively.

4.2 Estimation procedure

Looking at the cursory representation of our inputs, we expect some likelihood of the existence of multicolinearity in our model due to the presence of interactions and square terms in the model.This is a statistical happening where two or more predictor variables in a multiple regression model are highly correlated. This phenomenon can change the coefficient estimate of a result of a small change in the model or the data.To reduce the number of parameters to be estimated in the model, we adopted the model framework proposed by Smyth et al[24]. The trans-log aspect of capital and labor and the substitution elasticities between these factors and energy inputs were not estimated to enable us concentrate only on the inter-fuel elasticities of substitution.To be able to contain the problem of multicollinearity, we adopted the ridge regression[34] technique proposed by Hoel and Kennard[30] for our computation. This ridge technique is obtained calculating $\left(X'X + k\mathrm{I}\right)\hat{\beta} = h$ to give $\hat{\beta} = (X'X + kl)^{-1}h;$ where h=X'X, k is the ridge parameter which satisfies $k \geq 0$ and I is the identity matrix. Generally, there is the highest value of k for any problem however there is the need to observe the ridge solution for a range of admissible values of k. Positive and small value of k improves the condition of the problem and lowers the estimates of the variance.While biased, the reduced variance of ridge estimate often results in a smaller mean square error whencompared to least-squares estimates.Hoerl[30] gave the name ridge regression to his procedure because of similarity of its mathematics to methods he used earlier,i.e. 'Ridge analysis', for graphically depicting the characteristics of second order responds surface equation in many predictor variables. In the econometric literature, several methods of obtaining the optimal value of the ridge parameter have been proposed. This paper uses the ridge trace plot method which is the most used in the literature. Coefficients are estimated with various levels of k from zero to one. The $\hat{\beta}_i$ coefficients are then plotted with respect to the values of k and the optimal value is chosen at the point where the $\hat{\beta}_i$ coefficients seems stabilize. After the computation of the output elasticities of the various pair of energy inputs and their elasticities of substitution, we calculated the technical progress of vaious energy input pairs using the functions as follows:

$$RD_{ij} = (a_i / \eta_i) - (a_j / \eta_j)$$

In the above equation, RD_{ij} represents the difference between technical progress of inputs i and j a_i and a_j are estimated coefficients from Eq (4) while η_i and η_j shows the output state of technical knowledge. If RD_{ij} is positive it shows a direct indication that the state of technical progress for input i is faster than input j. Negative RD_{ij} however means that the state of technical progress for input j is faster than input i while when RD_{ij} become zero it implies there is equality in technical progress for both inputs.

5. Estimated results and discussion.

To begin investigating our estimations, we subjected the log variables to a unit root test which became necessary after 4 out of the 5 log variable were found not to be stationary as can be seen in Table 3. We further tried to compute the Pearson's correlation coefficient for each of our predictor variables to enable us measure the linear independence between the two pair of variables giving the value between + and -1inclusive. Though this method has been refuted by some Authors (eg.Ahlgren et al)[31] with the explanation it is too sensitive to zeros, Bensman[32] and White[33] have strongly defended the method with the argument that the differences resulting from the use of different similarity measure can be neglected in research. Also, pearson's correlation coefficient involves the use of multivariate statistics which allows for negative value which can be sited in the cosine of Salton and McGill[33]. Result of our correlation estimate can be seen in Table.2.This result indicates some evidence of multi-collinearity among our variable which has compel us to employ the ridge regression method to attempt solving the problem of multicollinearity.From the estimation and investigating of multi-collinearity, we present the ridge trace plot (Fig 3) and adopted 0.4 as our ridge parameter since it is at this value that the coefficient becomes stabilized. Our ridge regression estimate (Table 3) actually reflects the situation in South Africa's energy economy with all parameters having the expected signs except petroleum which has negative sign. The result in Table 4 shows that 16 out of the 20 parameters estimated coefficient were significant which suggest a reasonable specification. In addition, diagnostic tests performed on the model showed that, about 72% of the independent variables as indicated by adjusted R^2 value and the Durbin-Watson statistic value closer to 2 which suggests that the model did not suffer from serial correlation. Our argument is based on the major parameters which are the major drivers of the South African economy to deem the model specification being appropriate. The ridge regression estimate table clearly shows that, all parameter are major contributors to South Africa's output (GDP) except petroleum. In fact, this result is a true reflection of South Africa's energy economy. South Africa does not have crude oil deposit and relies on imported petroleum which worsens its balance of payment deficits without contributing directly to the output (GDP) of the economy with coal, labor, electricity and capital playing the major role in its output growth. This result must not be interpreted to mean petroleum is not important in South Africa's economy but rather the importation of petroleum exerts pressure on the GDP growth of the economy.

Table 2 Stationarity Test

Variables	Level	First difference
Capital	-0.11	-3.26
Coal	-1.95	-6.19
Electricity	-374	
Labor	-1.4	-3.44
Petroleum	-0.11	-7.23

Table 3.correlation analysis

Variables	DLCAP	DLCOAL	DLELEC	DLLABOR	DLPET
DLCAP	1.000000 -----				
DLCOAL	0.126793 0.4892	1.000000 -----			
DLELEC	0.230700 0.2040	0.196134 0.2820	1.000000 -----		
DLLABOR	-0.124528 0.4971	-0.038203 0.8356	0.074897 0.6837	1.000000 -----	
DLPET	0.093064 0.6124	0.223977 0.2178	0.268624 0.1371	0.136592 0.4560	1.000000 -----

Fig 3 Ridge trace plot

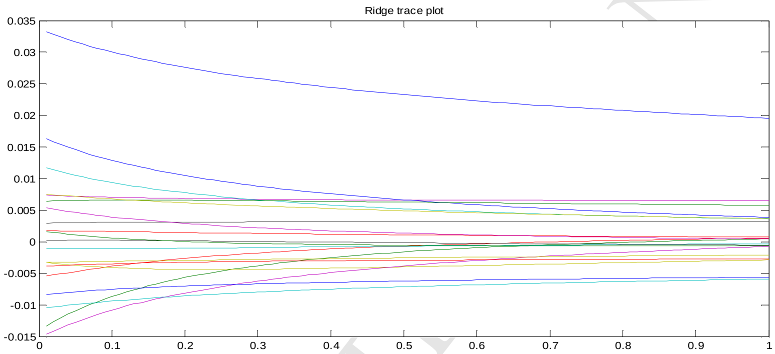


Table 4. Ridge coefficient estimates

Variables	Coefficient	Probability values
InK	0.0244	0.042
InC	0.0025	0.018
InE	0.0012	0.009
InL	0.0008	0.014
InP	-0.0067	0.228
InC*InK	0.0042	0.006
InC*InE	0.0030	0.025
InC*InL	0.0076	0.032
InC*InP	-0.0004	0.338
InE*InK	0.0012	0.023
InE*InL	0.0058	0.004
InL*InK	0.0049	0.038
InP*InK	-0.0027	0.446
InP*InE	-0.0032	0.244
InP*InL	-0.0064	0.322
InK^2	0.0064	0.004
InC^2	0.0030	0.025
InE^2	0.0075	0.048
InL^2	0.0017	0.034
InP^2	-0.0053	0.442
Ridge K	0.4	
Coefficient of determination	0.687	
F-statistics	72.6842	

Table 5 Model diagnostics

R^2	0.72
Durbin- Watson	1.56

Since the focus of this paper is to investigate the inter-fuel substitution possibilities in South Africa's energy economy, our estimate of elasticities of substitution has been limited to inter-fuel substitution possibilities among Coal, Electricity and Petroleum use in South Africa. Table 4 presents the results of the output elasticity for coal, electricity and petroleum in South Africa. Our result clearly shows that apart from petroleum, the other two energy inputs have positive elasticity with coal having the highest degree output elasticity value. This is a clear indication that, as the economy grows the demand for this energy inputs will increase over time with petroleum having adverse effect on output in effect there, is the need to look for a suitable substitute among these three energy inputs for a cleaner environment. With the results from table

4, we tried to estimate the output elasticity of substitution for these energy inputs. Our computations indicated all the three pair of energy inputs to be substitutes (see Table 5) which implies the degree of responsiveness for a unit change of one input will have a proportionate change in the other pair of input. From table 5, petroleum-electricity, coal-petroleum, and coal-electricity pairs are positive with petroleum-electricity and coal petroleum having the highest degree of substitution. Even though the degree of substitution between coal and electricity is less, it is much of importance since it indicates the possibility of renewable electricity replacing coal in the near future if more resources are allocated for research and development of renewable energy technologies. The substitutability relation between petroleum and electricity in our study is consistent with the findings in Smyth et al[24] on Chinese iron and steel industry which implies the removal of petroleum subsidies and increasing petroleum taxes to reflect the actual cost of petroleum products will decrease the demand for petroleum and increase the use of electricity which is a cleaner energy and protect South Africa's energy economy from external oil price shocks and speed up its CO2 mitigation efforts however the sustainability of this analysis will largely depend on the availability and willingness to use electric cars since petroleum is mainly use in the transportation sector and also the switch of industries from the use of petroleum to electricity since it comes with a cost. Petroleum and coal have the highest degree of substitutability in our computation and this indicate petroleum-coal are close substitutes which is also consistent with the findings of Seletis et al[23] in analyzing inter-fuel substitution possibilities in six high income countries, five middle income countries and four low income countries but substituting coal for petroleum or otherwise is just like substituting 'Coca cola for Pepsi cola' because both petroleum and coal are high CO2 emitters however should policy makers adopt clean coal technologies e.g. emission capture and save method, then there is a possibility of substituting coal for petroleum in the industrial sector. Shifting our focus to the substitution between electricity and coal, there is a great opportunity for South Africa to shift from the use of coal to electricity. This result is of a great importance to the South African's energy economy since its total electricity generation is made up of 90% of coal with the other 10% generated from renewable energy sources. In this study, the electricity we used represents only the 10% of electricity generated from the renewable sources with the 90% representing coal. From our computation, electricity is a close substitute to coal which implies the existence of great opportunity for South Africa to generate its electricity from renewable sources however the technological progress of these input pairs will determine the possibility of replacing coal with electricity in the future. Should South Africa increase its amount of electricity from renewable sources, there is still the need to factor in the cost of generating electricity from both sources or has to subsidize a large percentage of the cost of electricity from renewables.

Table 6 Output elasticity of energy inputs in South Africa's economy

Year	ηC_t	ηE_t	ηP_t
1980	NA	NA	NA
1981	0.003739	0.009120	-0.010882
1982	0.001945	0.008786	-0.013595
1983	0.001841	0.008997	-0.013637
1984	0.002535	0.008840	-0.012360
1985	0.002556	0.008940	-0.011656
1986	0.003138	0.008684	-0.008787
1987	0.002570	0.008927	-0.012109
1988	0.003971	0.009037	-0.010446
1989	0.002778	0.008587	-0.012659
1990	0.001222	0.008514	-0.015082
1991	0.003230	0.008664	-0.009937
1992	0.001242	0.008821	-0.014991
1993	0.000592	0.009154	-0.017064
1994	0.005594	0.008926	-0.006445
1995	0.002205	0.008909	-0.014568
1996	0.004330	0.008948	-0.009540
1997	0.003575	0.009205	-0.010970
1998	0.002654	0.008636	-0.012902
1999	0.001511	0.008731	-0.014031
2000	0.003652	0.009086	-0.010572
2001	0.003308	0.008928	-0.011122
2002	0.002918	0.008560	-0.011876
2003	0.001592	0.008889	-0.014872
2004	0.002979	0.008865	-0.011807
2005	0.003548	0.008727	-0.011716
2006	0.004033	0.008947	-0.010506
2007	0.001724	0.008817	-0.015330
2008	0.003553	0.009163	-0.011817
2009	0.002337	0.008703	-0.011392
2010	0.002713	0.008305	-0.010786
2011	0.002726	0.008583	-0.012270

2012	0.002854	0.008786	-0.012267
Average	**0.002786**	**0.008837**	**-0.01212**

Table 7. Substitution elasticity of energy input in South Africa

Year	σCE	σCP	σPE
1980	NA	NA	NA
1981	0.337779	1.003037	0.994082
1982	0.414246	1.003866	1.013650
1983	0.410617	1.004685	1.012271
1984	-0.066168	1.003065	0.943075
1985	-0.072992	1.003004	0.983138
1986	0.744638	1.001931	0.995714
1987	-0.099382	1.003231	0.972917
1988	0.492426	1.002794	0.994913
1989	-0.063737	1.003179	0.942795
1990	0.773836	1.004928	1.005751
1991	0.554958	1.002036	0.993294
1992	0.739677	1.004648	1.006531
1993	0.861886	1.088626	1.003294
1994	0.906664	1.001870	0.997413
1995	0.510338	1.004058	1.011774
1996	0.687580	1.002251	0.995195
1997	0.276380	1.002607	0.991527
1998	0.008979	1.002698	2.981327
1999	0.605156	1.003016	1.010929
2000	0.415527	1.002407	0.992507
2001	0.209438	1.002412	0.989644
2002	-0.049692	1.002273	0.978488
2003	0.663002	1.003884	1.008912
2004	-0.063582	1.002528	0.981067
2005	0.105213	1.002213	0.985754
2006	0.496802	1.002155	0.992130
2007	0.694855	1.003430	1.009213
2008	0.030240	1.002390	0.984779
2009	-0.052639	1.002133	0.975958
2010	0.237868	1.001664	0.984526
2011	-0.089794	1.002027	0.949545
2012	-0.102467	1.002125	0.960701
Average	**0.328677**	**1.005537**	**1.051338**

After the analyzing the possibilities of substitution of various input pairs, we also made an attempt to assess the relative difference in technical progress of all input pairs considered over time. In this attempt, we employed the aggregate trans-log production function of the South African economy and combined them with the output elasticities and estimated coefficients from Eq 4. The function we used in this calculation can be given as

$$RD_{ij} = (a_i / \eta_i) - (a_j / \eta_j) \tag{19}$$

In the above equation, RD_{ij} represents the difference between technical progress of inputs i and j a_i and a_j are estimated coefficients from Eq (4) while η_i and η_j shows the output state of technical knowledge. If RD_{ij} is positive it shows a direct indication that the state of technical progress for input i is faster than input j. Negative RD_{ij} however means that the state of technical progress for input j is faster than input i while when RD_{ij} become zero it implies there is equality in technical progress for both inputs. The result of this analysis is presented in Fig 4.

From fig 4 there is a clear evidence of the technological progress of coal faster than petroleum and electricity almost equal to petroleum however, all input pairs appear to be converging which implies that any of the inputs could dominate as the main energy source of South Africa with enhancement of research and development of their technology. This result implies that, South Africa could allocate more resources into research and development into renewable electricity technology to replace coal as their major source of energy in the near future. This will mean fueling the South African economy in a clean environment and mitigating CO2 emissions as well.

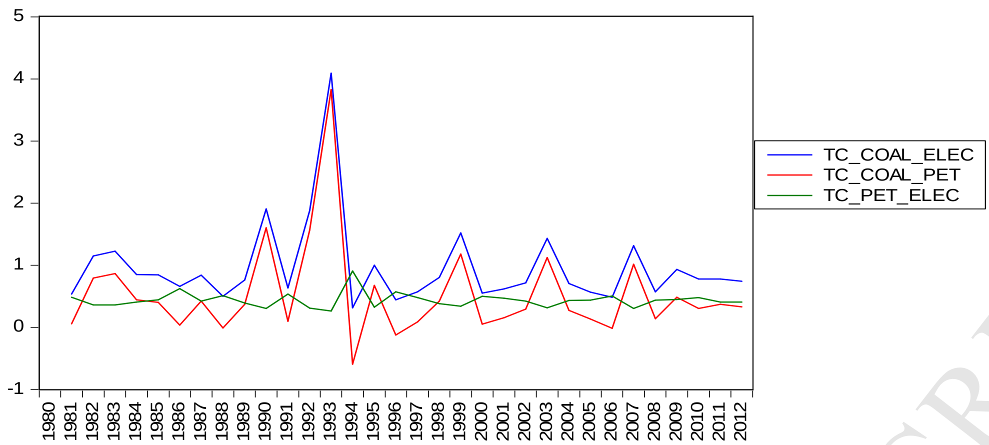


Fig 4 Difference in technical progress among energy inputs in South Africa

6. Conclusion and policy suggestions

The focus of this study is to investigate technical change and inter-fuel substitution possibilities in the South African Energy economy among Coal, petroleum and electricity. Other factor input like labor and fix capital formation were included to compute the production model for South Africa since they are important variable in South Africa's production economy. We employed the trans-log production function however; we introduced the ridge regression technique to try to solve the problem of multicollinearity in our data. These technics were applied to a yearly energy and factor inputs over the period 1980-2012. Our estimations and analysis brought out several findings. First, we found electricity and coal to be the main drivers of South African energy economy which implies that as the economy grows the demand for these energy inputs will increase over time. Second, all the energy inputs in our study i.e. petroleum, electricity and coal are close substitutes which implies that any of these energy inputs can be substituted for the other in effect removing subsidies and price ceilings on one input to reflect the right cost of it will increase the demand for the other favored input e.g. removing the price ceiling and subsidies on petroleum products will increase the demand for electricity and vice versa. Third our investigation found the rate of technological progress of coal to be faster than electricity and petroleum however, the rate of technological progress of all the input pairs appears to be converging which implies an improvement in the technology of any of these energy inputs could make it the main energy source of South Africa. Eg improvement in the technology of renewable electricity, could make it a potential energy source in effect, protecting the economy from external oil price shocks and mitigating of CO2 emissions on both national and global front which is in fulfilment of article 4.1of United Nations framework on climate change and South Africa's emission reduction target of 34% by 2020 and 42% by 2025. In fact South Africa has targeted increasing its renewable energy production to 3.2GW by 2020 which is also in line with policy recommendations from this study however all these policies cannot be implemented at the expense of the growth of the economy.

In the first place, all energy inputs employed in this study were found to be substitutes however the focus of this paper is finding a cleaner energy source for development in a cleaner environment therefore our interest is more in the possibility of substituting renewable electricity for petroleum and coal. With electricity being a substitute for petroleum, South African policy makers can formulate policies to remove all petroleum price ceilings and subsidies to reflect the actual price of petroleum products which will in turn decrease the demand for petroleum and increase the demand for electricity especially in the industrial sector in effect protecting South African economy from external oil price shocks and reduction of CO2 emissions however with the transport sector, there is the need to change consumers taste for petroleum cars to electric cars through price subsidies for electric cars and installation of sufficient charging stations.

Second, electricity generation from renewable sources turns to be expensive which will need governments support in terms of developing electricity infrastructure, giving production cost subsidies and duty waiver policies on the importation of machinery and other renewable energy installation equipment to help in reducing production cost of electricity from renewable sources.

Third, the switch from the use of petroleum to electricity especially in the industrial sector will come with a cost since there is the need for new technology and installations to enable the industries adjust to the new energy use which will also need governments policies to 'cushion' the industries from high cost of production to avoid this cost being passed on to the final consumers of their products.

Forth, our study concluded that, with the enhancement of research and development in the technology of renewable electricity, there is the possibility of renewable electricity replacing coal as the main energy source of South Africa which will help accelerate the CO2 mitigation agenda.

The contribution of this study to South Africa's energy economy is immersing however there is a limitation that has to be pointed out. In fact this study fail to forecast how long it will take the South African economy to switch from coal to renewable electricity however it is deemed to be a new door to further research into this area.

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Labor	-1.4	-3.44
Petroleum	-0.11	-7.23

Table 3.correlation analysis

Variables	DLCAP	DLCOAL	DLELEC	DLLABOR	DLPET
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DLCOAL	0.126793	1.000000			
	0.4892	-----			
DLELEC	0.230700	0.196134	1.000000		
	0.2040	0.2820	-----		
DLLABOR	-0.124528	-0.038203	0.074897	1.000000	
	0.4971	0.8356	0.6837	-----	
DLPET	0.093064	0.223977	0.268624	0.136592	1.000000
	0.6124	0.2178	0.1371	0.4560	-----

Table 4. Ridge coefficient estimates

Variables	Coefficient	Probability values
lnK	0.0244	0.042
lnC	0.0025	0.018
lnE	0.0012	0.009
lnL	0.0008	0.014
lnP	-0.0067	0.228
lnC*lnK	0.0042	0.006
lnC*lnE	0.0030	0.025
lnC*lnL	0.0076	0.032
lnC*lnP	-0.0004	0.338
lnE*lnK	0.0012	0.023
lnE*lnL	0.0058	0.004
lnL*lnK	0.0049	0.038
lnP*lnK	-0.0027	0.446
lnP*lnE	-0.0032	0.244
lnP*lnL	-0.0064	0.322
lnK^2	0.0064	0.004
lnC^2	0.0030	0.025
lnE^2	0.0075	0.048
lnL^2	0.0017	0.034
lnP^2	-0.0053	0.442
Ridge K	0.4	
Coefficient of determination	0.687	
F-statistics	72.6842	

Table 5 Model diagnostics

R^2	0.72
Durbin- Watson	1.56

Table 6 Output elasticity of energy inputs in South Africa's economy

Year	ηC_t	ηE_t	ηP_t
1980	NA	NA	NA
1981	0.003739	0.009120	-0.010882
1982	0.001945	0.008786	-0.013595
1983	0.001841	0.008997	-0.013637
1984	0.002535	0.008840	-0.012360
1985	0.002556	0.008940	-0.011656
1986	0.003138	0.008684	-0.008787
1987	0.002570	0.008927	-0.012109
1988	0.003971	0.009037	-0.010446
1989	0.002778	0.008587	-0.012659
1990	0.001222	0.008514	-0.015082
1991	0.003230	0.008664	-0.009937
1992	0.001242	0.008821	-0.014991
1993	0.000592	0.009154	-0.017064
1994	0.005594	0.008926	-0.006445
1995	0.002205	0.008909	-0.014568
1996	0.004330	0.008948	-0.009540
1997	0.003575	0.009205	-0.010970
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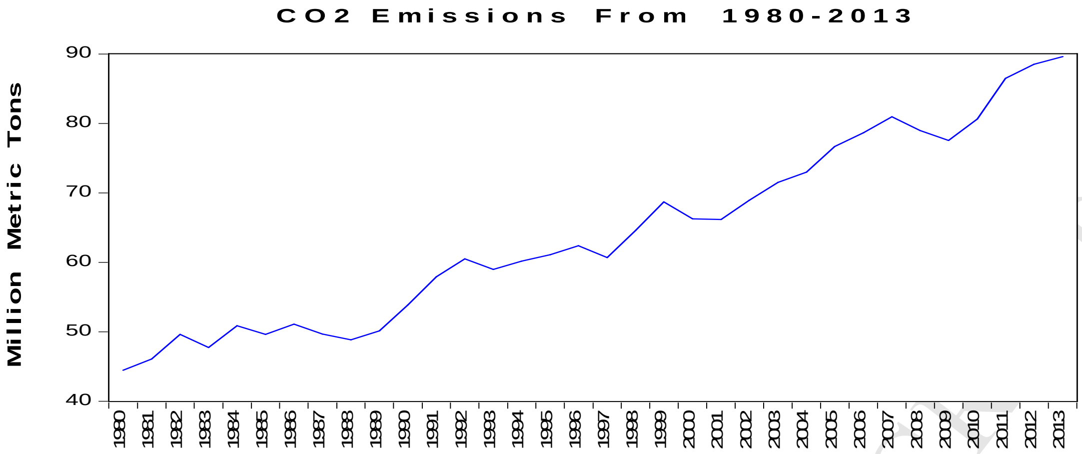
1999	0.001511	0.008731	-0.014031
2000	0.003652	0.009086	-0.010572
2001	0.003308	0.008928	-0.011122
2002	0.002918	0.008560	-0.011876
2003	0.001592	0.008889	-0.014872
2004	0.002979	0.008865	-0.011807
2005	0.003548	0.008727	-0.011716
2006	0.004033	0.008947	-0.010506
2007	0.001724	0.008817	-0.015330
2008	0.003553	0.009163	-0.011817
2009	0.002337	0.008703	-0.011392
2010	0.002713	0.008305	-0.010786
2011	0.002726	0.008583	-0.012270
2012	0.002854	0.008786	-0.012267
Average	**0.002786**	**0.008837**	**-0.01212**

Table 7. Substitution elasticity of energy input in South Africa

Year	σCE	σCP	σPE
1980	NA	NA	NA
1981	0.337779	1.003037	0.994082
1982	0.414246	1.003866	1.013650
1983	0.410617	1.004685	1.012271
1984	-0.066168	1.003065	0.943075
1985	-0.072992	1.003004	0.983138
1986	0.744638	1.001931	0.995714
1987	-0.099382	1.003231	0.972917
1988	0.492426	1.002794	0.994913
1989	-0.063737	1.003179	0.942795
1990	0.773836	1.004928	1.005751
1991	0.554958	1.002036	0.993294
1992	0.739677	1.004648	1.006531
1993	0.861886	1.088626	1.003294
1994	0.906664	1.001870	0.997413
1995	0.510338	1.004058	1.011774
1996	0.687580	1.002251	0.995195
1997	0.276380	1.002607	0.991527
1998	0.008979	1.002698	2.981327
1999	0.605156	1.003016	1.010929
2000	0.415527	1.002407	0.992507
2001	0.209438	1.002412	0.989644
2002	-0.049692	1.002273	0.978488
2003	0.663002	1.003884	1.008912
2004	-0.063582	1.002528	0.981067
2005	0.105213	1.002213	0.985754
2006	0.496802	1.002155	0.992130
2007	0.694855	1.003430	1.009213
2008	0.030240	1.002390	0.984779
2009	-0.052639	1.002133	0.975958
2010	0.237868	1.001664	0.984526
2011	-0.089794	1.002027	0.949545
2012	-0.102467	1.002125	0.960701
Average	**0.328677**	**1.005537**	**1.051338**

Table 1: Some policies put in place by government to promote the use and development of cleaner energy sources in South Africa (Source :) [25]

Year	Policy
1977	National building regulation and building standard Act 103 (NRBS): Empowering the ministry of trade and industry to regulate building Standards to conform to energy sustainability and efficiency form.
1998	Income tax Act 12i: Tax rebate for companies promoting and engaging in the improvement of energy efficiency.
2000	National Environmental Act 32 (NEMA): Promoting and development of energy generation in a non-harmful environment.
2003	White paper on renewable energy: Setting target for the production of Production of 10,000GWh of energy from renewable energy resources Mainly from wind, solar, biomass, and small scale hydro by 2013.
2005	Introduction of one-off capital subsidies for projects aims at producing Energy from energy technologies which includes: landfill gas extraction, Mini hydroelectric schemes, commercial and domestic water heaters and Sugar-cane bagasseh (generating power from sugar cane fiber)
2008	National Energy Act 34: Promoting efficient and economic use of energy Generated from non-depleting energy resources this includes ;(wind, Biomass, solar, tidal, hydro, geothermal and biological waste).


CO2 Emissions From 1980-2013
Million Metric Tons
90
80
70
60
50
40
1980
1981
1982
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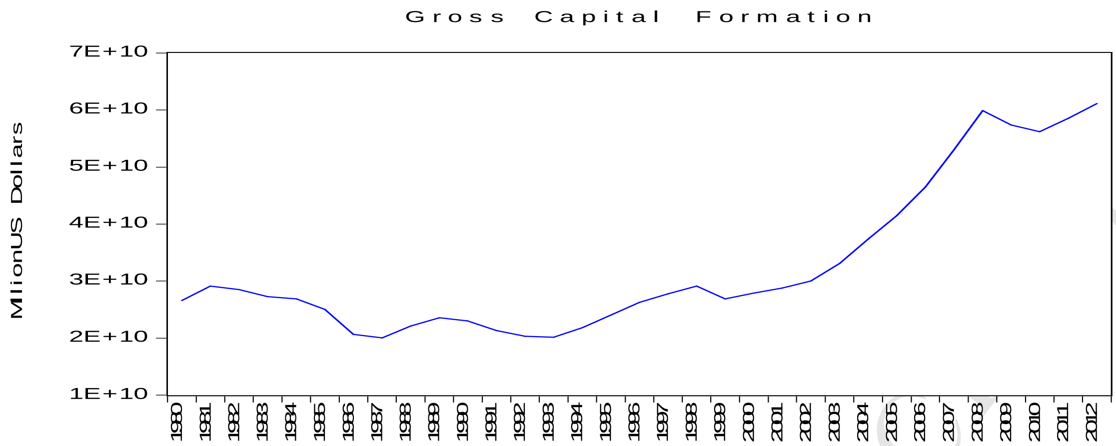
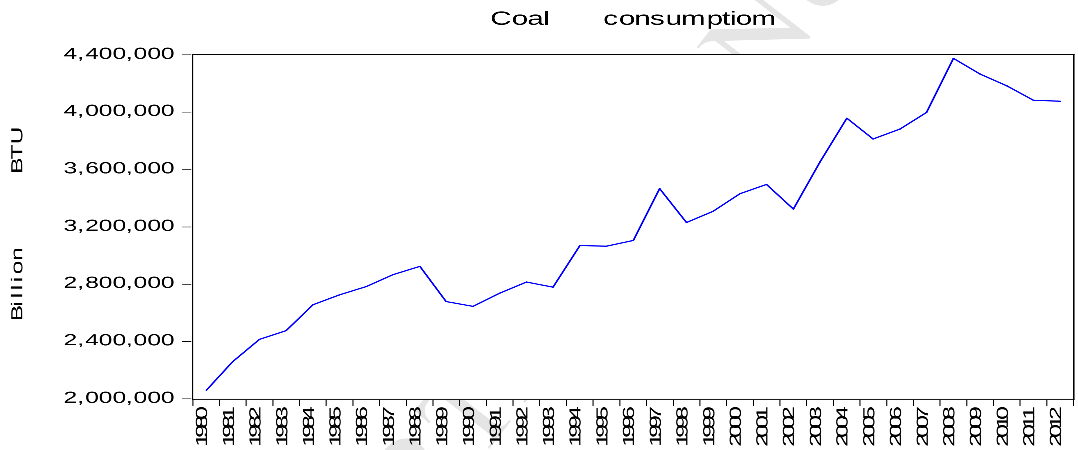
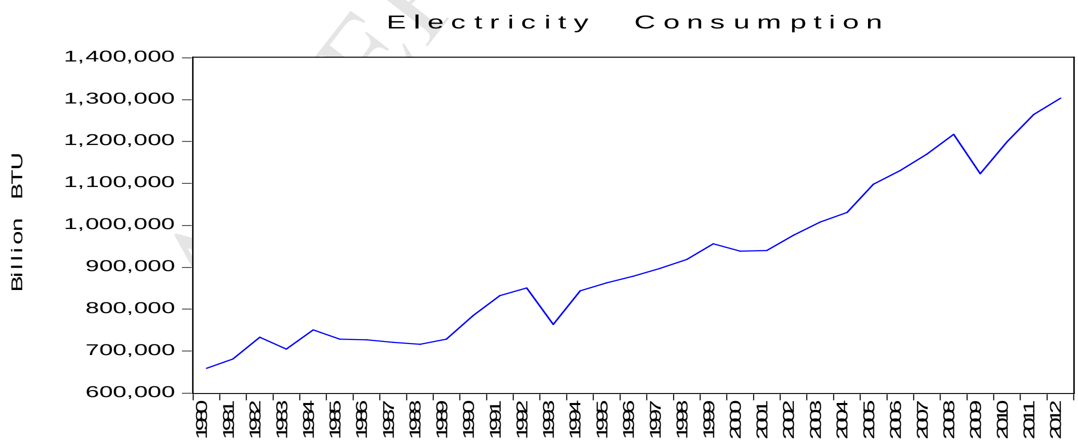

Gross Capital Formation
MlionUS Dollars
7E+10
6E+10
5E+10
4E+10
3E+10
2E+10
1E+10
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


Coal consumptiom
Billion BTU
4,400,000
4,000,000
3,600,000
3,200,000
2,800,000
2,400,000
2,000,000
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


Electricity Consumption
Billion BTU
1,400,000
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

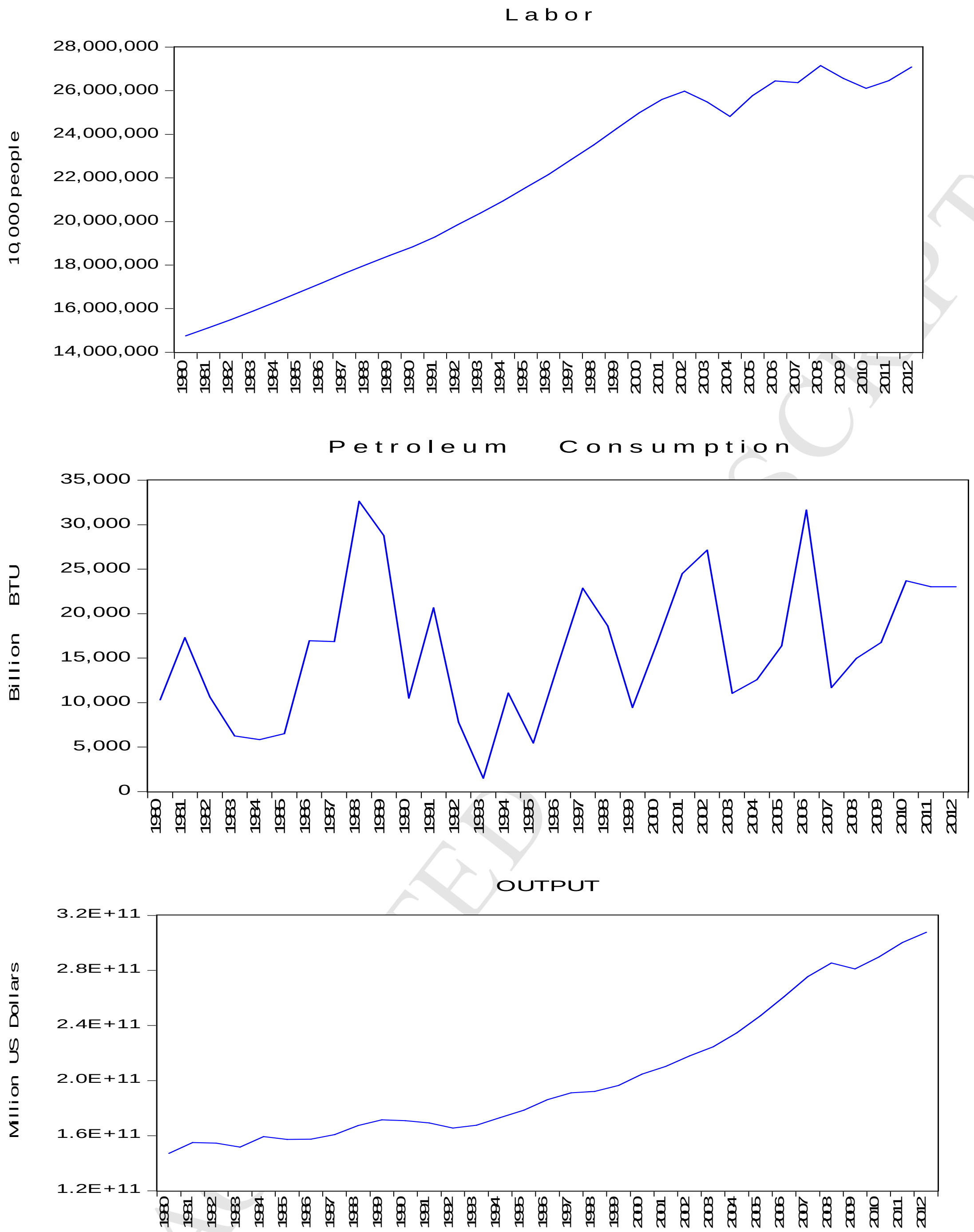
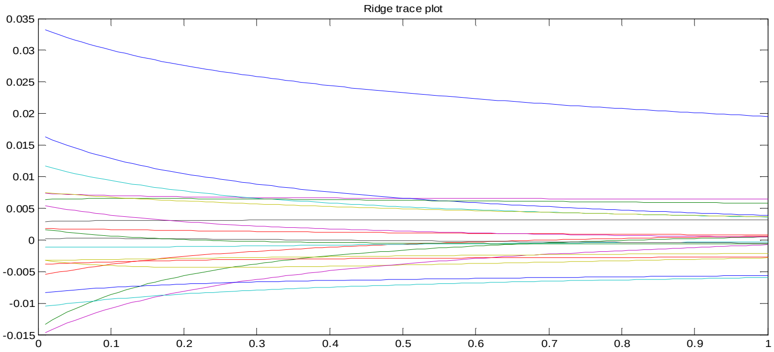
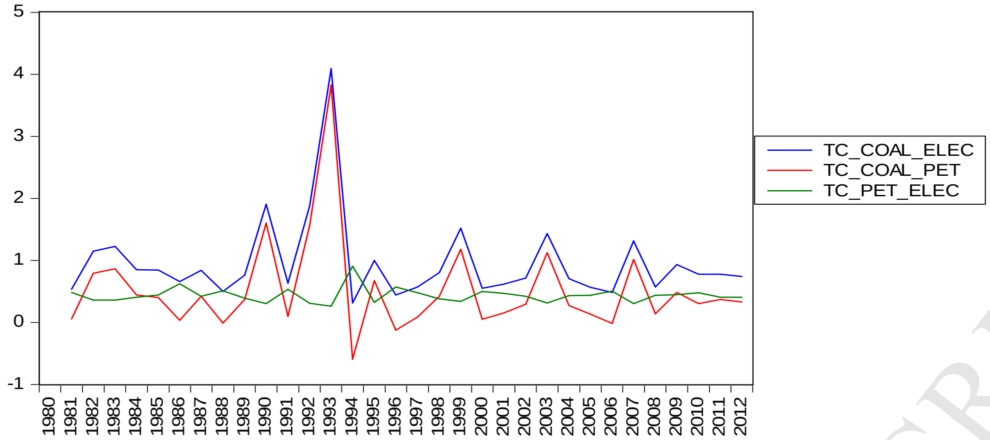


Fig 2. Plot of variable 1980-2012


Ridge trace plot
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


5
4
3
2
1
0
-1
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
TC_COAL_ELEC
TC_COAL_PET
TC_PET_ELEC

- We investigate inter-fuel substitution in South Africa
- All energy inputs employed were found to be substitutes
- There is possibility of substituting electricity for other energy inputs