Analysing scenarios for energy emissions reduction in South Africa

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Abstract
Global environmental pressure dictates that South Africa reduces its greenhouse gas (GHG) emissions, while national objectives focus on economic development. South Africa is faced with the dilemma of simultaneously alleviating poverty, reducing unemployment, growing the economy and responding to international pressure to reduce GHG emissions. As a result, policies that promote energy emissions reduction without being harmful to economic growth and national developmental priorities are needed. Environmental fiscal reform presents one such option. The impact of this is still unclear for South Africa, and this paper explores this issue. Energy balance data on energy consumption, energy emissions and input-output data for South Africa are used to assess the economic and environmental effects of environmental reform in the energy sector. Despite the high reduction in energy emissions, a tax on coal is not selected as the best alternative given the high negative impact on the economy. A tax on oil results in a low reduction in energy emissions, which limits its use as an environmental policy. The scenario using a petroleum products tax results in small decreases in economic growth but it has low energy emissions reduction, hence, this alternative is not selected as an option. Energy subsidy reform offers the second highest reduction in real energy emissions and a low decrease in economic growth, and this scenario is therefore recognised as the best option for carbon dioxide reduction in South Africa. The electricity tax offers moderate reductions in real energy emissions and a moderate decrease in economic growth, and therefore, it is deduced that the electricity tax option could be another option for carbon dioxide emissions reduction in South Africa.

Keywords: greenhouse gas, energy emissions, South Africa, policy reforms

1 Introduction

Since the first Earth Summit in 1992, climate change and greenhouse gas[1] (GHG) emissions reduction has occupied a permanent place on the international environmental agenda. The United Nations Framework Convention on Climate Change (UNFCCC) is a multilateral environmental agreement that has been signed and ratified by over 70 countries. South Africa is a signatory to the UNFCCC as well as the Kyoto Protocol, which is an agreement that commits all countries to stabilise their GHG emissions and share the burden. The Protocol came into effect in February 2005, and it commits Annex 1 countries to reduce their GHG emissions to 1990 levels by the year 2012. Under the Protocol, South Africa is classified as a non-Annex 1 country and as such does not have any commitments for emission reductions during the first commitment period of 2008-2012. However, this may change during the next commitment period.

South Africa has an energy intensive economy with a high reliance on fossil fuels largely due to an abundance of coal. The country has an above average energy intensity.[2] Ten other countries have higher commercial primary energy intensities than South Africa (Davidson, 2002). South Africa's gross national product (GDP) is the 26th highest in the world but its primary energy consumption ranks 16th (GCIS, 2001). South Africa also has one of the cheapest sources of energy, as this is viewed as a comparative advantage for economic development.

In 1994, the new South African government recognised a need to complement political liberation, global market access and international investments with poverty alleviation so that all South Africans benefit. In an attempt to alleviate poverty, economic growth and reduction in high levels of unemployment were identified as government's main priorities.

The Reconstruction and Development Programme (RDP) (1994) and the Growth Employment and Redistribution (GEAR) strategy (1996) provide the macro-economic framework for alleviating poverty and improving welfare. The RDP highlights the urgency for achieving rapid economic growth that contributes to development, particularly the eradication of poverty. GEAR as one of the principal strategies for the realisation of the policy objectives contained in the RDP, states that macro-economic stability should be promoted by reducing the budget deficit and the rate of inflation, growing the economy through increased exports and investments, and achieving redistribution by creating jobs from economic growth and labour market reforms.

Global environmental pressure dictates that South Africa eventually reduces its GHG emissions, while national objectives focus on economic development. South Africa is faced with the dilemma of simultaneously alleviating poverty, reducing unemployment, growing the economy and responding to international pressure to reduce GHG emissions. Policies that promote energy emissions reduction without being harmful to economic growth and national developmental priorities are needed. Environmental fiscal reform presents one such option. The impact of this is still unclear for South Africa and this paper explores this issue.

This paper examines the impact of alternative environmental fiscal policy reforms on economic and environmental indicators in South Africa. The paper uses the 2000 Input Output Table, data from the 2002 Energy Balance for South Africa and GHG emission factors from IPCC data. The next two sections briefly describe energy consumption and energy emissions in South Africa. This is followed by a discussion of the model and data used for analysis. The analysis section investigates alternative environmental fiscal reform policies. The last section concludes.

2 Energy in South Africa

2.1 Primary energy

Almost 95% of the primary energy mix in South Africa is made up of fossil fuels, with 77% of the total primary energy mix being made up of coal. Oil constitutes 13%, natural gas accounts for 1.5%, while biomass and renewable energy make up the remaining 5% of total primary energy.

Coal

Coal is the most dominant primary energy type produced and consumed. It is also one of the country's largest sources of foreign revenue. The bulk of this coal (approximately 91%) is consumed locally. Electric power generation and synthetic fuel industries consume approximately 85% of this coal (DME, 2002). Other coal consuming industries include the gold mining, cement and brick and tile sub sectors. The remaining 8% of locally consumed coal is used for household consumption.

Crude oil

South Africa's domestic production of oil is very limited at an estimated 25 000 barrels per day. The country imports oil primarily from the Middle East, with Saudi Arabia and Iran as its chief suppliers. Liquid fuel products refined locally from imported oil constitute approximately 62% of the total consumption. The country is one of the major oil refining nations in Africa (Energy White Paper, 1998).

Natural gas

Natural gas is used solely as a feedstock for production of synthetic fuels and coal gas as an industrial and domestic fuel. Natural gas consumed in South Africa is obtained from natural gas fields in Mozambique and Namibia.

2.2 Final demand energy

The basic final demand energy types consumed in South Africa include electricity, liquid fuels and petroleum products, coal, coke and peat, and biomass. Electricity and liquid fuels play a dominant role.

Electricity

South Africa generates two-thirds of Africa's electricity, approximately 90% of which is generated from coal. Total electricity generated is obtained from coal, liquid fuels, nuclear energy, hydroelectric and other renewable energy. The manufacturing sector is the largest consumer of electricity in South Africa, accounting for 44% of consumption. Mining and residential customers each account for 18% of demand, with another 9% going to commercial customers while transport and agriculture consume approximately 5.5% each. Residential consumption is experiencing the fastest growth due to the country's efforts directed towards rural electrification.

Liquid fuels and petroleum products

South Africa has a highly developed synthetic fuels industry, which takes advantage of the country's coal resources and offshore natural gas and condensate production. Approximately 36% of the liquid fuel demand in South Africa comes from synthetic fuels, and 64% is refined locally from imported oil. The transport sector is the largest consumer of petroleum products consuming 79% of the total amount of liquid fuels in the country, followed by agriculture and manufacturing, then by residential, non-energy,[3] mining and commerce.

Coal, coke and peat
Approximately 20% of total coal consumed in South Africa is used as a direct source of energy by the mining, industrial and residential sectors. Major steam-coal consuming sectors include the gold mining, cement and brick and tile industries, while the steel industry is the main consumer of domestic coking coal in South Africa, followed by mining and industrial consumption and the residential sector.

Biomass
Wood fuel constitutes 24% of total residential energy needs in South Africa (GCIS, 2002). This is the basic fuel that is consumed by approximately 3.2 million rural households, and it accounts for 65% of their energy needs which is mainly for heating and cooking purposes.

3 Energy emissions in South Africa

As a signatory to the UNFCCC, South Africa is obligated to produce a National Communications Report and GHG inventories. South Africa's most recent National Communications Report was submitted in 2000 and national GHG inventories have been developed for South Africa for 1990 and 1994. The National Climate Change Response Strategy for South Africa (2004) is the most updated domestic policy document that specifically focuses on the management of GHG emissions reduction in South Africa. GHG emissions are mentioned and discussed in other policy documents such as the National Environmental Management Act, Air Quality Act (2004), the Integrated Waste Management Strategy (2000), the 1998 Energy White Paper, the 2003 White Paper on the Promotion of Renewable Energy and Clean Energy Development, and the 2004 White Paper on the Renewable Energy Policy.

The country contributes about 1.6% to global GHG emissions, 42% to the total GHG emissions emitted in Africa, and it ranks amongst the top ten countries contributing to global warming (Davidson *et al.*, 2002). As one of the most industrialised countries in the region, South Africa is the single largest emitter of GHG emissions in Africa, primarily because of the overall size of the economy and its dependence on coal. On a global scale the country's contribution to GHG emissions is relatively small but, on a per capita basis, emission levels are well above the average for other middle-income developing countries. The South African economy is carbon intensive producing US$ 259 per ton of carbon dioxide emitted as compared with US$ 484 for Mexico and US$ 418 for Brazil, which are countries with similar levels of social and economic development (GCIS, 2001).

The energy sector is the single largest source of GHG emissions in South Africa, accounting for about 89% of the country's total emissions (DEAT, 2000). The national GHG inventory estimates that carbon dioxide is the most significant GHG in South Africa (DEAT, 2000). It accounts for more than 80% of the three GHGs in the national inventory. In 1990, the energy sector was responsible for 89.7% of total carbon dioxide emissions, and this increased to 91.1% in 1994. In 2000, it was estimated that the energy sector contributed 92.3% to total carbon dioxide emissions (DEAT, 2000; UNDP, 2002), attributed to an increase in electricity consumption brought about by the South African government's plan to provide electricity to all. In 2005, the Minister of Public Enterprises stated that electricity consumption in the past decade has increased at the same rate as economic growth. According to Davidson (2002), this trend is expected to continue as South Africa strives to meet its economic and developmental objectives. South Africa currently does not have any GHG emission standards, and there is no independent GHG emissions agency for certifying baseline emission levels and monitoring industries and activities.

4 Methodology and data

Changes in environmental fiscal policy affect households and firms through their consumption and production of goods and services. Like households, firms directly consume energy in the production of goods and services (direct inputs). In addition, these direct inputs may have energy inputs (indirect inputs). As a result, each good and service purchased by a household and firm will have direct and indirect energy inputs. In this paper, we have used an extended Input Output Table for 2000 (prepared by Statistics South Africa) to model policy changes through the economy to the production and household sectors.

Leontief (1936) was the first to develop this methodology which was applied to input-output analysis. In 1970, Leontief extended the original input-output approach to include environmental repercussions in the economic structure. The basis of extending the original input-output model lies in the fact that technical interdependence between pollution can be described in terms of structural coefficients similar to those used to trace the structural interdependence between all the regular branches of production and consumption (Leontief, 1970). Allan, *et al*, (2004) reformulated the environmental Leontief model to include additional pollution elimination column(s) for each sector indicating input-output coefficients for the pollution elimination sector. This extension to the environmental Leontief model allows for the empirical analyses of the environmental impacts of economic activities and of the resource requirement implied by the need to clean up and/or dispose of unwanted outputs (Allan, *et al*. 2004). Similar published analyses include Gay and Proops (1993) for the United Kingdom and Casler and Rafiqui (1993) for the United States of America.

An Input-Output Table contains information about sectors of an economy, mapping the flows of inputs from one sector to another or to final demand (that consumed by households or exported, etc.). The rows of a nominal IO Table can be written as:

$$P_i X_i = \sum_j P_i X_{ij} + P_i F_i \qquad (1)$$

Xi = output in sector I
Pi = price of sector I's output
Xij = sector j's requirements of intermediate inputs from sector I
Fi = final demand for sector I's output

We define the *input output coefficient* of sector i into sector j as

$$a_{ij} = \frac{X_{ij}}{X_j} \qquad (2)$$

These are assumed to be constant. In practice, we derive these from the nominal IO table

$$\frac{P_i X_{ij}}{P_j X_j} = \frac{P_i a_{ij}}{P_j} = a_{ij} \qquad (3)$$

We set all prices = 1 to get this result. This amounts to defining the units in which the quantity of each sector's output is measured. Adopting the convention of setting prices = 1 and mindful of the definition of Xij in equation 2, we can thus write

$$X_i = \sum_i a_{ij} X_j + F_i \qquad (4)$$

Or in matrix notation

$$X = AX + F \qquad (5)$$

A is the coefficient matrix. It has the property that every element is non-negative and the column sum of any column must be less than 1. The fact that the Leontief inverse is non-negative means that it is feasible to get a mathematical solution for any F. This may not be feasible economically, but we could use the estimate as a consistency check. Combining the output coefficients to produce an (I-A) *technology matrix* and inverting, the *Leontief inverse matrix,* $(I-A)^{-1}$ is produced, which gives the direct and indirect inter industry requirements for the economy:

$$X = (1 - A)^{-1} F \qquad (6)$$

As we show below, we can do this quite simply and easily on the computer (even in Excel). However, it is sometimes useful and enlightening to take a slower approach – the Neumann iteration method.

Equation 6 can be expanded to produce the following

$$(1 - A)^{-1} \cong 1 + A + A^2 + A^3 + ... + A^x \qquad (7)$$

$$X = (1 + A + A^2 + A^3 + ... + A^x)\,F = F + AF + A^2F + A^3 F + ... + A^xF \qquad (8)$$

This illustrates the material balance issue. Starting with the vector of final demands, we can work out the successive rounds of gross outputs necessary to achieve it. As we include further and further rounds, this converges on an 'equilibrium'.

This model is used for policy analysis as follows. The economy is considered to be in equilibrium as described by equation 6. Given demand, we obtain the corresponding supply. A base run for the model is computed using equation 6. This base run is then used to benchmark equilibrium. Once specified, the input-output model will generate production and pollution levels as an equilibrium solution. The parameters values obtained can be used to solve for alternative equilibria associated with a modified policy regime, in practice, a new demand. We will refer to these as counterfactual equilibria. Policy appraisal is then undertaken by contrasting benchmark and counterfactual equilibria. For example, if a tax t is applied and is passed on in its entirety to consumers, then the tax on goods consumed in final demand is td, the tax on the inputs to these goods is tAd, the tax on inputs to these is tA^2d and so on.

Combining, total tax is

$$tF + tAF + tA^2F + tA^3F + tA^4F + ... = t(I-A)^{-1}.F \qquad (9)$$

A number of adjustments had to be made to the input-output analyses for our purposes. Firstly, the input-output table was extended to decompose the energy components of a fuel sector, petroleum and coal products into its constituent parts, because we want to focus on the differential effects of policy changes of individual energy components. This has been done utilising the Energy Balance for 2002, published by the Department of Minerals and Energy in South Africa. Second, the IO Table is extended to include energy emissions. These were calculated broadly following IPCC Guidelines. Local emission factors were utilized where possible. In the absence of such factors, IPCC default factors were used. The resulting expanded energy and emissions matrix is used to find the effects (both direct and indirect) of a change in the policy on each sector of the economy.

5 Policy reforms and results

In this section, we consider the environmental and economy-wide impacts on households and firms of a number of different policy changes. The energy emissions input-output model indicates that carbon dioxide emissions are predominantly generated from the consumption of coal, crude oil, electricity and petroleum products. The first set of policies considers carbon dioxide taxes on coal, oil, electricity and petroleum products. Such market based energy emissions reduction policies provide incentives for greater efficiency in comparison to the command and control approach. These market based instruments encourage dynamic efficiency but differ with respect to uncertainty (IPCC, 2001a). Permits are quantity based instruments as the quantitative reduction in emissions is guaranteed, but the cost is uncertain and taxes are price based as the price is fixed and the quantity of emissions reduced is uncertain. Despite the political attraction of permits, these instruments are not favoured because they forgo the chance of raising revenue. The second set of policy reforms involves changes to the energy subsidy regime. Subsidy reform is another instrument that is increasingly being investigated as an option for reducing energy emissions. The Intergovernmental Panel on Climate Change (IPCC) (2001a) states that empirical and theoretical studies indicate that the removal of subsidies from fossil fuels or from electricity that relies on fossil fuels can be beneficial in reducing carbon dioxide emissions. The extent of the impact of reducing subsidies will depend on the specific characteristics of each country, the type of subsidy involved and the international co-ordination to implement similar measures.

Five target variables were developed to evaluate the interventions. These include gross domestic product, employment, household consumption, energy consumption and energy emissions reduction. Table 1 presents a summary of the results of policy reforms (rows) on target variables (columns). The table presents real changes in target variables as opposed to marginal changes.

According to Tables 1 and 2, the tax on coal offers the highest reduction in real energy emissions, but it has the highest decrease in economic growth. This scenario offers the highest real energy conservation and energy emissions reduction, but it also has the largest decrease in economic growth. This is due to the fact that coal is both a key contributor to economic growth through inter-industry linkages, as well as being an important contributor to GHG emissions. The coal tax generates the highest additional revenue, which suggests that there may be opportunities to reduce the negative economic effects by an appropriate recycling of the coal tax revenues.

The tax on oil offers the lowest reduction in energy emissions hence it is concluded that this is not the best option as a result of its lack of environmental effectiveness. This policy option is not iden-

Table 1: Ranked real decrease in target variables according to five scenarios

Scenario	*GDP*	*Employment*	*Household consumption*	*Primary energy consumption*	*Primary energy emission reduction*
Carbon dioxide tax on coal	1	1	1	1	1
Carbon dioxide tax on oil	5	5	5	3	3
Carbon dioxide tax on electricity	2	2	2	4	4
Carbon dioxide tax on petroleum products	4	4	4	5	5
Energy subsidy reform	3	3	3	2	2

Table 2: Target variables ranked according to worst negative economic and social impact and best positive environmental impact

Gross domestic product	Employment and household consumption	Energy consumption and energy emissions reduction
Carbon dioxide tax on oil	Carbon dioxide tax on oil	Carbon dioxide tax on coal
Carbon dioxide tax on petroleum products	Carbon dioxide tax on petroleum products	Energy subsidy reform
Energy subsidy reform	Energy subsidy reform	Carbon dioxide tax on electricity
Carbon dioxide tax on electricity	Carbon dioxide tax on electricity	Carbon dioxide tax on petroleum products
Carbon dioxide tax on coal	Carbon dioxide tax on coal	Carbon dioxide tax on oil

tified as a possible alternative despite it having the lowest reduction in economic growth. The tax on crude oil also generates the second lowest level of additional revenue, which indicates that this policy option would also be ineffective in generating revenue for environmental reform.

A tax on electricity offers the third lowest decrease in real energy emissions, and the second highest decrease in economic growth. Given the electricity intensive nature of the South African economy, this is expected. As with coal, electricity is a key contributor to economic growth through inter-industry linkages and one of the largest contributors to GHG emissions. The carbon dioxide tax on electricity generates moderate additional revenue which could be used to offset negative economic impacts. This policy is identified as a possible option given a comparatively moderate reduction in emissions and decrease in economy growth.

The tax on petroleum products offers the second lowest reduction in real energy emissions, and the second lowest decrease in economic growth. The petroleum products tax generates the second lowest level of additional revenue. As with the tax on crude oil, this policy is not selected as an option given the lack of effectiveness as an environmental and revenue generating instrument.

Energy subsidy reform offers the second highest real energy emissions reduction and the third highest decrease in economic growth. Energy subsidy reform generates the second highest level of revenue. This policy is identified as the best possible option given moderate reductions in energy emissions and a moderate decrease in economic growth. This policy option is also favoured because of its revenue generating ability.

It can be inferred from the analysis above that a coal tax will not be the best option for carbon dioxide emissions reduction in South Africa, if unaccompanied by alternative revenue recycling strategies that ameliorate the negative economic consequences. The tax on oil and petroleum products results in a low reduction in energy emissions, which limits the use as an effective environmental policy. Given that energy subsidy reform and a tax on electricity offers moderate reductions in real energy emissions and a moderate decrease in economic growth, these policy options are recognised as possible alternatives.

6 Conclusions

Energy balance data on energy consumption and input-output data for South Africa are used to assess the economic and environmental effects of changing environmental fiscal policies. The analysis is carried out using a 2000 base year. Policies that include a tax on coal have a stronger negative effect on the economy and, hence, a strong positive effect on GHG emissions reduction.

Energy subsidy reform offers the second highest reduction in real energy emissions and a moderate decrease in economic growth, and this scenario is recognised as another possible option for carbon dioxide reduction in South Africa. In real terms, the electricity tax offers a moderate reduction in real energy emissions and a decrease in economic growth. Therefore, it is deduced that the electricity tax option could be an option for carbon dioxide emissions reduction in South Africa.

Notes

1. Greenhouse gases include carbon dioxide, methane, carbon monoxide, nitrogen oxides, sulphur oxides and hydrocarbons, which are mainly produced from the combustion of fossil fuel.
2. Energy intensity refers to the amount of energy required to generate one unit of economic output. In South Africa, the amount of energy used for every unit of GDP generated in the economy is higher than the global average.
3. Non-energy use refers to products from oil and includes paraffin wax, bitumen, lubricants, solvents and white spirits.

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