Industrial Efficiency as an Economic Development Strategy for South Africa

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ABSTRACT

South Africa is a developing country that currently has no obligation to reduce greenhouse gas (GHG) emissions under agreements such as the Kyoto Protocol. Moreover, with an unemployment rate of 30% or more, the focus of most South Africa development policies is to increase job creation and overall industrial profitability. At the same time, however, research suggests that industrial energy efficiency measures offer the potential to increase profitability and jobs while reducing GHG emissions and influence other sustainable development goals. This paper draws on recent work in South Africa to show how certain energy efficiency measures meet national development goals and incidentally reduce GHG emissions. The implication is that certain GHG mitigation measures could support national economic development goals. These measures are both described and evaluated using a multicriteria analysis (MCA) framework with appropriate macroeconomic interactions and feedback. This framework can provide solutions that meet multiple policy and development goals.

Introduction

We begin with a short description of the South African energy sector. Next we describe the goals and targets which government hopes to meet by energy policy. We focus our attention on industrial energy efficiency measures and describe their attributes, such as their cost and potential for saving energy. In particular, the economy-wide effects of job creation and any changes in fuel consumption associated these measures are computed. (We also consider the same effects for building a new power station.) We then integrate these attributes into an energy systems model to ensure consistency. The model is programmed to solve for various goals and targets. We develop scenarios based on certain starting assumptions, including various weightings of the said goals, and observe the effect and role of industrial energy efficiency measures.

Background

The South African Energy Sector

The South African economy is energy-intensive, using a large amount of energy for every rand[1] of value added (Hughes et al. 2002). South African energy is dominated by coal, which contributes 70% of primary energy, so that the economy is therefore also carbon dioxide-intensive. Local coal is cheap and this results in low energy costs, particularly for electricity, which is the cheapest in the world. South Africa has little oil and most of its crude is imported. South Africa obtains useful amounts of energy from biomass and nuclear power, with smaller

[1] One rand was equal to approximately US$6 in 2004.

amounts from hydropower, natural gas, solar and wind. Much of the primary energy is transformed into final energy, such as electricity and liquid fuels. The country's final energy demand in 2005 is estimated to be 2400 PJ (excluding marine bunkers and non-energy fuel use), consisting of electricity (24%), coal (24%), liquid fuels (26%), biomass (15%) and with natural gas and other renewables less than 1% (ERC 2005).

Approximately 28% of South Africa's liquid fuel needs are produced from natural gas (5%) and coal, with relatively expensive, crude derived oil, providing the balance.

The low cost of energy has helped provide a competitive advantage, and encouraged the growth of energy-intensive industry, such as aluminum smelting and mining. The use of this low-cost energy is inefficient, and there are significant opportunities to save energy cost effectively via energy efficiency measures (Trikam 2002; Howells et. al. 2002; ERI 2000a). Further, these measures will not necessarily change the economy's energy-intensive structure (Trikam 2002), but rather move it towards better practice and closer to its efficient frontier (Laitner 2004). Several studies have documented reasons for the non-realization of these energy savings (DME 2004b). Recently the South African Department of Minerals and Energy (DME) developed an energy efficiency strategy in order to help realize policy goals. While the DME has supported energy efficiency initiatives (DME 1998), there has been very limited active policy.

Energy Efficiency Targets and Policy Goals

We summarize the goals which the South African government hopes to help meet by the deployment of energy efficiency measures. The government's target is a reduction in energy demand by 14% in the next eight years relative to a reference scenario (DME 2004b). We also list the effects which we model in this analysis[2].

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[2] This represents the fist attempt of such an analysis for all fuels in the industrial sector of South Africa. Previous attempts were limited to considering only electrical energy consumption (Howells 2004b).

Table 1. Goals to be Met by Energy Efficiency

Goals	Attributes modeled in this analysis and corresponding goal
Social sustainability **Goal 1: Improve the health of the nation** Energy efficiency reduces the atmospheric emission of harmful substances such as oxides of sulphur, oxides of nitrogen, and smoke. Such substances are known to have an adverse effect on health and are frequently a primary cause of common respiratory ailments. **Goal 2: Job creation**. Spin-off effects of energy efficiency implementation. Improvements in commercial economic performance, and uplifting the energy efficiency sector itself, will inevitably lead to nationwide employment opportunities. **Goal 3: Alleviate energy poverty** Energy efficient homes not only improve occupant health and wellbeing, but also enable the adequate provision of energy services to the community at an affordable cost.	**Goal 1**: Tons of sulphur dioxide, nitrogen oxides and total suspended particulates **Goal 2**: Thousands of jobs created **Goal 3**: NA
Environmental sustainability **Goal 4: Reduce environmental pollution** Energy efficiency will reduce the local environmental impacts of its production and use **Goal 5: Reduce CO_2 emissions** Energy efficiency is one of the most cost-effective methods of reducing GHG emissions, and thereby combating climate change. Addressing climate change opens the door to utilising novel financing mechanisms, such as the CDM, to reduce CO_2 emissions.	**Goal 4**: As per "Goal 1" **Goal 5:** Tons of CO_2 emitted
Economic sustainability **Goal 6: Improve industrial competitiveness** It has been demonstrated that one of the most cost-effective ways of maximizing commercial profitability is the adoption of appropriate energy efficiency measures. Nationwide, this will improve South Africa's export performance and improve the value that her economy derives from indigenous energy resources. **Goal 7: Enhance energy security** Energy conservation will reduce the necessary volume of imported primary energy sources, crude oil in particular. This will enhance the robustness of South Africa's energy security and will increase the country's resilience against external energy supply disruptions and price fluctuations. **Goal 8: Defer the necessity for additional power generation capacity** It is estimated that the country's existing power generation capacity will be insufficient to meet the rising national maximum demand by 2007-2012. Energy efficiency is integral to Eskom's Demand Side Management programme insofar as it contributes 34% towards the 2015 demand reduction target of 7.3GW.	**Goal 6**: Cost of energy supply in millions of rands **Goal 7:** Level of energy imports in rand and per unit of energy **Goal 8:** Power station investment timing

Source: DME 2004b

Methodology

Next we explain the methodology that we use to identify the role of energy efficiency measures to meeting the policy goals described. We begin by describing the use to which energy is put, specific efficiency measures to be considered and then the attributes assumed for this study. We then go on to describe the MARKAL energy-systems model that we employ and finally the scenarios that we adopt.

Industrial Energy Efficiency Measures

Energy is used in industrial equipment to supply a service, such as high temperature heat, motive power, lighting as well as others (see Figure 1). The services for which the energy is used are called the end-use services and the energy used for these supplies the end-use demand for energy. Energy efficiency measures considered here are those that supply the same quantity of service using less energy – reducing the end-use demand. Although these measures may cost more than their business-as-usual equivalent, these costs are often recouped over time from savings in the energy bill. The time taken to recoup the cost of the initial outlay is referred to below as the payback period.

In order to determine the potential savings that may accrue to any energy efficiency measures it is necessary first to determine the demand for energy end-use. Typically coal is used either for thermal purposes (boilers and furnaces), and oil for a mix of thermal and motive (ERI 2001). The apportionment of electricity is more complex, and we estimate an end-use demand for electricity by industry (Howells 2004). We combine these end-use splits with a detailed industry-by-industry sector energy forecast (NER 2004; Howells 2004b) in order to determine a forecast for the end-use of energy for the industrial sector as a whole. With assumptions about the savings potential of each energy efficiency measure by end-use, it is possible to estimate the total potential savings. The specific measures we consider are described by Howells and Laitner (2003) and Trikam (2002). We distinguish between measures that have a (hypothetically) high (80%) local and low (20%) local content in order to later derive policy implications (as per Hughes et. al. 2002 and Howells and Laitner 2003) and assume cost difference between these (as per Howells 2004). For the measures we consider, their payback, proportion of fuel saved and assumed cost-ratio (CR) of high local to high foreign content are listed below:

1. Variable speed drives: These drives reduce unnecessary power consumption in electrical motors with varying loads (ERI 2000b). Typical paybacks are 3.6 years, conservatively 2.2% of industrial electricity can be saved and the CR is 1.4.
2. Efficient motors (ERI 2000b): These motors are available at higher cost. Efficient motors can reduce power consumption, but may require modifications because running speeds are generally higher than for inefficient motors. Typical paybacks are 7 years, conservatively 2.3 % of industrial electricity can be saved and the CR is 1.4.
3. Compressed air management (ERI 2000c): This measure is easily achieved and often results in significant savings at low cost. Typical paybacks are 0.9 years, conservatively 3.2 % of industrial electricity can be saved and the CR is 0.9.
4. Efficient lighting (ERI 2000b): These measures take advantage of natural lighting, more efficient light bulbs and appropriate task lighting. Typical paybacks are 3.6 years, conservatively 1.9% of industrial electricity can be saved and the CR is 1.2.
5. Heating, ventilation and cooling (ERI 2000d): These measures are for maintaining good air quality and temperature and can commonly be improved through better maintenance and the installation of appropriate equipment. Typical paybacks are 2.2 years, conservatively 0.6 % of industrial electricity can be saved and the CR is 1.1.
6. Thermal saving (ERI 2000e): Thermal saving refers to more efficient use and production of heat. For steam systems in particular we consider condensate recovery and improved maintenance. Typical paybacks are 0.8 years, conservatively 1.4 % of industrial electricity, 10% oil and 15% coal can be saved and the CR is 1.2.

Were these energy efficiency measures to be taken up on a larger scale, they would affect dynamics of the energy system and attributes of the economy as a whole.[3] As less energy is used, less fuel is combusted and emissions decrease. Reduced demand for fuels such as electricity will delay the need to build new power stations and the associated costs. We account for these in an energy-systems model described below. Lowering the cost of supplying energy services will allow industry to allocate funds previously used for energy purchases. As resulting expenditure changes occur through the economy we expect to see direct and indirect changes in levels of activity. This will affect, among many other things, employment and fuel purchases.

We now describe how we quantify these effects using an input-output approach. Our aim is to quantify changes in employment per unit of energy saved by energy efficiency measure. As well as fuel use changes associated or rebound effects. We also quantify the effects associated with the investments required to construct a new power station.

Using an input-output analysis, we capture the level of flow of revenue between different economic sectors (Robinson 1989). We are interested in the response by sectors in the economy to a change in purchase or – in economic terms – "demand" patterns. (Specifically, we use the Leontief inverse of the direct requirements, which is derived from the national social accounting matrix (SAM) (TIPS 2001) to give the output "multipliers" for each sector.) The multiplier gives the overall changes in demand by each sector in the economy that result from direct increases or decreases in demand from a sector.

In the case of an energy efficiency measure, industry will pay for the implementation of the measure. We assume that 50% of this expenditure is financed internally and the rest from debt, to be repaid over five years. Depending on the local content of the measure, the money is spent locally and recycles, or leaves the economy (Spalding-Flecher et al. 2001). After the measure is implemented, industry in turn receives savings, and reallocates this spending, we assume, as per its usual pattern of expenditure.[4] In the case of the power station, we assume the investment to be 60% debt financed (NER 2004) repaid over the economic life of the plant. We also only consider the cost of the capital requirements for the new power plant, as this will be the only "change" to be accounted for from the current SAM.[5] For each change in purchases, whether as a loan from the financial sector, expenditure on construction for a new measure or power plant, or re-allocated funds from energy savings, we determine the direct and indirect effects that result for each economic sector. We can thus derive the changes in requirements for labor and energy costs.

Job creation effects related to energy efficiency investments have been described generally (Jeftha 2003; Laitner et al 1998; Geller et al. 1992), and specifically for South Africa (Laitner 2001; Hughes et al. 2002; Spalding-Fletcher et al. 2003; Howells 2004c). We adopt and adapt a demand input-output analysis, as per Howells (2004c), and determine economy-wide

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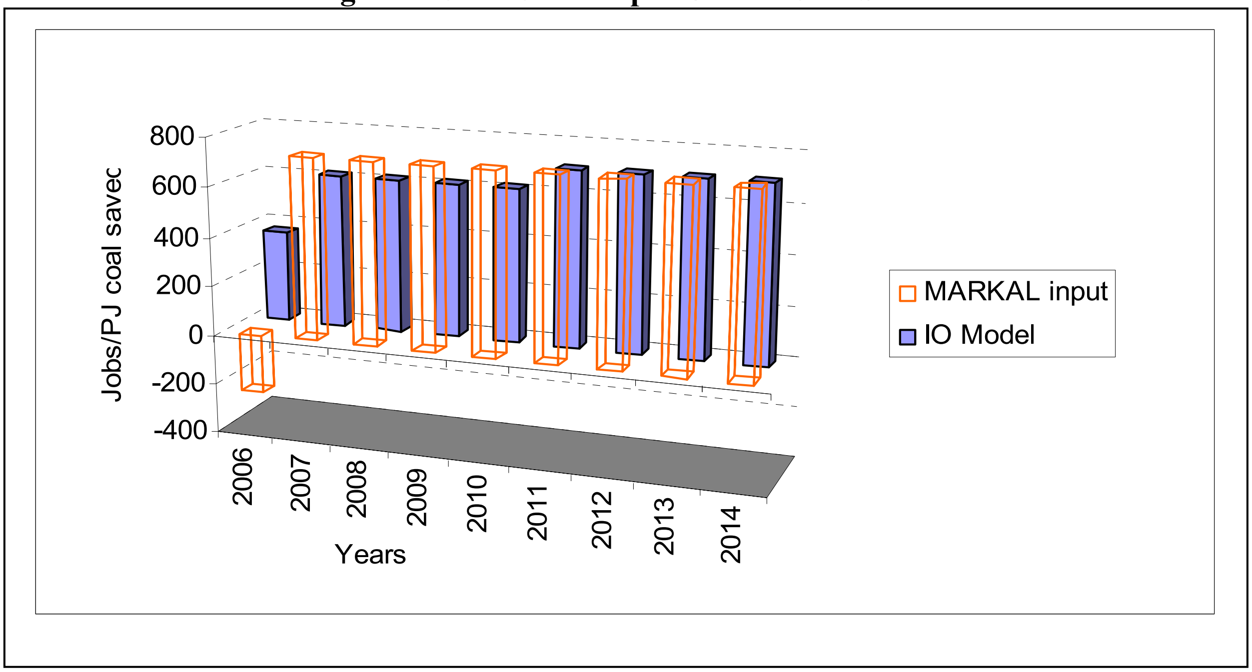
[3] Recall that the aim is not to affect the structure of the economy, and move away from energy-intensive industry, but rather to move it toward better practice by the adoption of energy efficiency options. It is the low cost of energy that gives much of South African industry a competitive edge.

[4] This assumption is inherent in the approach that we are taking. Further study could focus on what the marginal expenditure should in fact be.

[5] South Africa has had a significant reserve margin over the past fifteen years, reaching more than 30% at times. The current electricity price largely does not reflect the capital costs of new plant. By investing in energy efficiency options, the timing for investment in new plant can be delayed, along with the increased electricity costs which will follow. New base-load (probably coal) capacity is required in about 2011 and we assume that fuel and other costs will in real terms remain unchanged (NER 2004).

expenditure changes on labor due to the changes in purchasing per unit of energy saved for an energy efficiency measure, and per unit of capacity invested in for a new power station. We go further to simplify this for entry into the energy systems model, described later, into economy-wide job creation during an "investment year" and during the life of the measure. Figure 1 shows the increase in jobs that result from an energy efficiency measure investment in 2006 which reduces coal consumption.

Figure 1. Jobs Created per Unit of Coal Saved

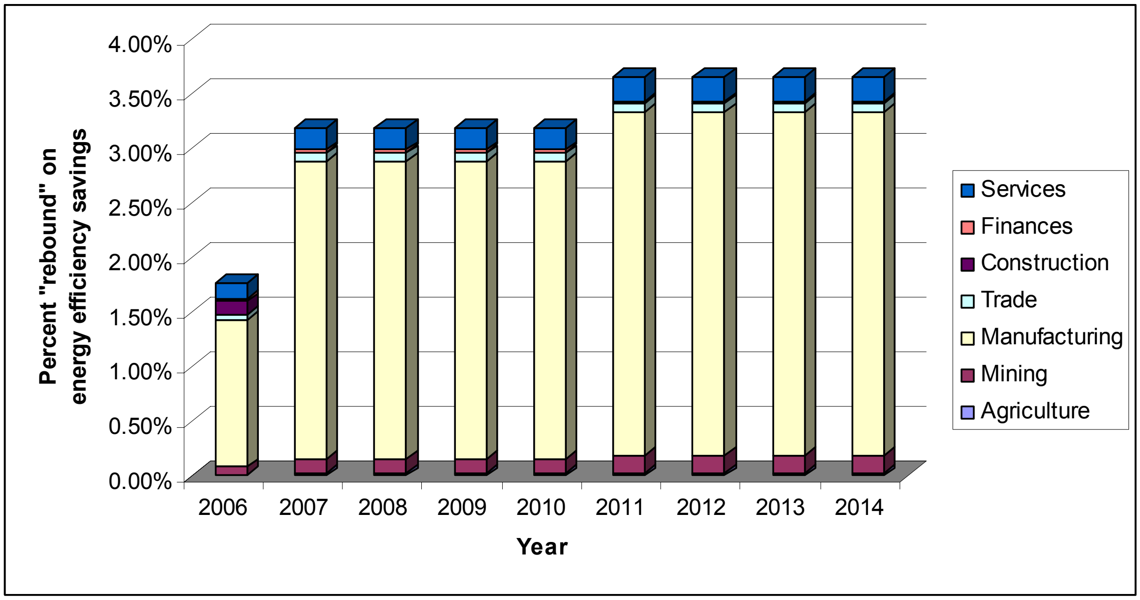


Note: This is for thermal energy efficiency saving with both a low payback and high local content. Using the IO model approach, this figure accounts for both the loss in revenue to coal mining and the effective gain in revenue from the money saved to industry.

While Figure 1 shows effects of a large discrete quantity of savings, and the jobs that result, it is likely that the savings will accrue gradually over time as more of the energy efficiency measures penetrate the market. Concurrent investment, saving and debt repayment will result in a smoother composite shaped graph.

The rebound effect is a term applied to an increased demand for energy service (and therefore energy) that results after the cost of the service is reduced due to the adoption of an energy efficiency measure. Using the input-output approach it is possible to determine the change in spending on fuel as a result of direct spending changes (Howells 2004c) – we derive sector-specific fuel multipliers. In Figure 2, we show increased consumption from the rebound effect by different economic sector for electricity. The rebound effect is expressed as the percentage increase in electricity consumption of the savings. As with deriving the job creation attributes (though not shown in Figure 2) we simplify the representation for input into the energy systems model.

Figure 2. Rebound Effect per Unit of Electricity Saved



Increased energy consumption due to the rebound effect will result in projected energy savings being offset by small levels of increased consumption. This will in turn lead to small increases in emissions and costs over those projected. The principal is equivalent to the notion of price elasticity, where the effect is a change in levels of consumption due to a change in the price. In the case of energy efficiency, the price of the service is reduced and energy consumption increased. In the case of new power station investments, the price of electricity increases, and demand decreases. We develop fuel multipliers both for changes of consumption in each sector and each fuel.

The Energy Systems Model: MARKAL

In order to consistently account for the attributes of the energy system and the role that energy interventions play in that system, we use the MARKAL (short for market allocation) energy model (ETSAP 2005). We do, however, deviate from the standard formulation of this model to incorporate rebound effects as well as to allow it to solve for multiple-criteria in order to meet development "goals". Normally MARKAL's single goal is to minimize the cost of the system modeled.

We calibrate the model using detailed sector-by-sector demand projections (Howells 2004b) and identify a limited set of power investments based on recent electricity sector planning (NER 2004). Based on this, we assume that open-cycle gas peaking plant and coal-fired power station investments will be used to meet increasing electricity demand. Other energy supply investments are considered to increase as per "business as usual", oil demand is met by increasing crude refining capacity, and coal by local coal mining increases.

In order to calculate the attributes of the system, coefficients gathered from various sources are used to relate energy use with the attribute considered. Gaseous emissions per unit of fuel consumed are taken from IPCC (1996), van Horen (1996), water emissions data from van Horen (1996), particulate emissions from Howells and de Villiers (1999), and indicators for the "difficulty of implementation" from Howells and Laitner (2003). Job creation and the effects of other sector growth are calculated using the input output approach discussed earlier. We assume that fuel significant fuel switching is limited over the scenario period (DME 2004).

The goal programming variation of MARKAL (GP-MARKAL) which we employ (we also use "standard" MARKAL) is described in Goldstein et al. (2003). Goal programming, in its various incarnations, is a subset of multicriteria analysis (MCA). The technique attempts to bring the solution as close as possible to the various goals of the analyst (Lee 1972). In GP-MARKAL, "importance" of meeting individual goals are weighted relative to each other. The form of goal programming employed is "non-preemptive". We run the model so that the goal is to maximize (or minimize depending on the goal) the model attributes that constitute policy benefits to be derived from deploying energy efficiency. Similar analyses have been carried out to assess economic and environmental development and have been discussed both internationally (see, for example, Huang et al. 1995; Greening and Bernow 2004; Pohekar and Ramachandran 2004) and for South Africa (Howells and Solomon 2002; Howells and Laitner 2003). This analysis differs from the latter for South Africa as it considers multiple objectives in a dynamic model, previous studies consider either only single objectives subject to constraints in a dynamic model or compared the effects of discreet investments. We also include detailed rebound effects.

Sector specific rebound effects are included by adopting a non-standard (Howells 2004c) model structure (see Sato et al. (2000) for an example of a standard structure). While changes in energy demands (and the resulting changes in attributes) have been accounted for in variations of MARKAL (such as MARKAL-MACRO and MARKAL-MICRO (Loulou et al. 2004)) this represents novel use of fuel demand multipliers in response to changes in the energy sector within the MARKAL reference energy system.

Scenarios

We develop five scenarios. The first is a *reference* scenario which is used to measure the success of the multi-objective scenarios.[6] This scenario assumes that there is limited uptake of energy efficiency. Next is the *least cost* scenario which determines the lowest cost configuration of the energy efficiency measures. We develop this further and increase the importance of the ease by which the energy efficiency measures are adopted and dub this the *industry goals* scenario. We develop a scenario which reflects current *government goals,* which emphasizes job creation. Finally we consider a scenario which weights heavily the need for GHG mitigation at the expense of other economic imperatives. We term this the *extreme green* scenario. All scenarios are run for the period 2005 to 2020.

From these scenarios we wish to investigate the role and effect of energy efficiency interventions. In particular we are interested in GHG emission levels.

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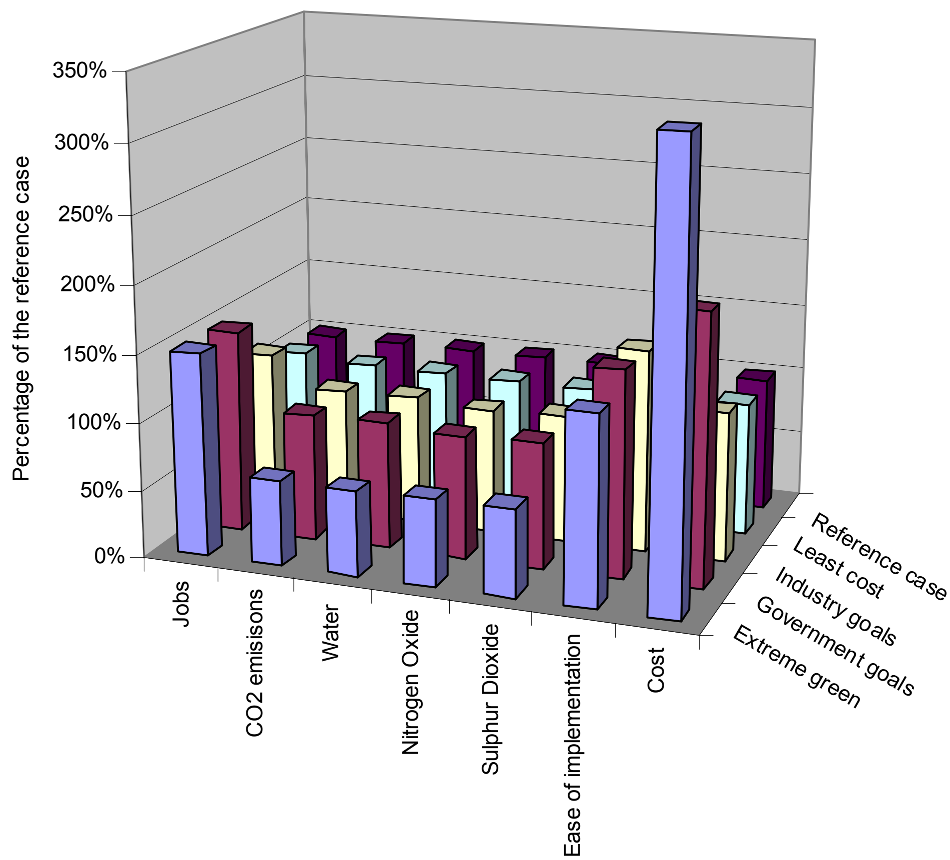
[6] The solution space we investigate with the other four scenarios is between the inefficient frontier represented by the reference scenario and the more efficient frontier were the DME's economy wide energy efficiency goals. These scenarios are adapted from (DME 2004b and Howells and Laitner 2003).

Results

By comparing the results of the scenario runs to the reference case, we quantify the effects of energy efficiency investments. These are shown in Figure 3. In all cases CO_2 emissions are mitigated, though it is not a goal in any but the extreme green scenario.

Figure 3. Attributes of the System Relative to the Reference Scenario



Interestingly, both the government goals and the extreme green scenario show significant increases in jobs. In the case of the extreme green scenario this is, however, achieved at a cost to the economy, approximately one third more than government goals. The government goals scenario achieves this at a lower cost by investing in high local content and relatively low cost energy efficiency measures, such as compressed air saving, while importing technology that would be more expensive to produce locally. Industry goals also shows a marked increase in job creation, and this is done at still lower cost to the economy and extends the investment style of government goals at the further expense of increases local manufacture. An aspect of this is that the need to build a new power station is delayed and the associated electricity price increases.

In all cases there is an increase in investment in energy efficiency technologies over the reference case.

Conclusions

This paper reports the development and application of a model that optimizes the energy system of a developing country to meet goals of development. The modeling technique chosen is a partial equilibrium, energy systems model that accounts for various attributes of the energy and economic system of South Africa. Also integrated into this model are aspects of an economic input-output model. We use the GP-MARKAL framework, which allows us to minimize several attributes of the system and these are reported as "development goals". We examine a limited set of potential interventions to a business as usual energy future, their effect on the energy-economy and the role that they may play in different development scenarios. This analysis allows the specific investments required and their effects to be identified.

A key finding is that certain energy investments both drive development and co-incidentally reduce emissions. Were these investments to be implemented for GHG reduction reasons they would, in effect, drive development. Clearly there is a role for technology transfer and a play-off exists between increased local content and potentially increasing costs.

This conclusion has a potentially profound effect in terms of the international climate change debate. Anecdotal arguments for clean development are moved to arguments that are quantifiable. The implication is that developing countries (in the short-to-medium term) can focus their attention on meeting urgent development imperatives and tend to a climate friendly future.

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