Modeling Economy-Wide Impacts of Investments in Industrial Energy Efficiency: A South African Case Study

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ABSTRACT

While there is a significant body of literature on the microeconomic impacts of individual energy efficiency interventions in South Africa, little attention has been directed at the macroeconomic impacts of large scale programs. Promoting energy and economic efficiency is one of the main priorities in a recent White Paper on Energy Policy for South Africa. Several programs are outlined in the White Paper, which are beginning to take shape. The objective of this paper is to apply macroeconomic analytical tools to understand the economy-wide impacts of investment in industrial energy efficiency in a developing country context. Using South Africa as a case study, we develop an input-output framework for analyzing impacts on GDP and employment of investments in demand side efficiency improvements in industry. We examine a national industrial energy efficiency program that would set equipment standards resulting in maximum savings of 6% of industrial electricity use when fully implemented. The results show that the energy efficiency program will have a small but significant impact on job creation, with 20 000 to 70 000 job years created over the 20 year programme.

Introduction

Promoting energy and economic efficiency is one of the main priorities in a White Paper on Energy Policy for South Africa (DME 1998). While several programs are outlined in the White Paper, progress has been slow to date, partly because of the difficulty in overcoming many of the barriers to energy efficiency in South Africa (Spalding-Fecher 2003). One of the key challenges for decision makers and analysts in the energy sector is therefore how to link energy efficiency to the broader national policy goals of South Africa—and particularly job creation and economic growth (DTI 1996).

Research around the world on the costs and benefits of 'sustainable energy policy'—policies that promote investment in renewable energy, energy efficiency, and access to clean, affordable energy—show that these can lead to significant macro-economic benefits (Laitner et al. 1998; Bernow and et al. 1999; Krause 2000; Krause et al. 2002). Studies in six different European countries and the USA, for example, have demonstrated large job creation potential from more progressive energy policy (summarised in Renner 2000). In addition, one of the major themes of the Third Assessment Report from the Intergovernmental Panel on Climate Change is how investments in strategies to reduce emissions from fossil fuels and other sources of greenhouse gas emissions can accelerate development, rather than being an obstacle to it (Banuri and Weyant 2001; IPCC 2001)

There has been extensive research in South Africa on the local, microeconomic benefits of investments in energy efficiency (e.g. ERI 2000; Spalding-Fecher et al. 2002; Trikam 2002; Winkler et al. 2002). None of this research, however, has been able to follow through these impacts to the macroeconomic level—to understand how these policies and projects affect economic growth and job creation. One of the first papers to explore this linkage quantitatively in South Africa was Laitner (2001).

The objective of this paper is to apply macroeconomic analytical tools to understand the economy-wide impacts of investment in industrial energy efficiency in a developing country context. Using South Africa as a case study, we develop an input-output framework for analyzing impacts on GDP and employment of investments in demand-side efficiency improvements in the industrial sector. Section 2 introduces the modelling framework, followed by the key assumptions used in the analysis. This is followed by a discussion of the results, sensitivity analysis, and conclusions.

Methodology

Input-Output Analysis and Social Accounting Matrix

For the purposes of this paper, a simplified eight-sector input-output model of the South African economy has been used, based on data from a social accounting matrix (TIPS 2001; 2002), reflecting transactions in the national accounts for 1997 (see Table 1). That data contains a detailed representation for 45 business sectors in more than 100 accounting categories, but is aggregated for the purposes of this paper. Similar approaches have been used elsewhere by Geller et al. (1992) and Laitner et al. (1998), and for the South African context by Laitner (2001) and Jeftha (2003).

Table 1. Summarised Input-Output Table for South Africa, 1997 (Rand millions)

	Agri-culture (AG)	*Mining (MIN)*	*Manu-facture (MFG)*	*Elec-tricity (ELEC)*	*Trading (TRD)*	*Con-struction (CON)*	*Financial (FIN)*	*Services (SVC)*	*Inter-mediate Output*	*Final demand*	Total gross output
Agriculture	1 147	25	17 343	11	12	4	0	487	19 029	21 037	40 066
Mining	1	170	4 697	3 300	1	6	0	345	8 520	61 314	69 834
Manufacture	6 590	5 280	68 097	738	8 784	12 425	1 129	18 509	121 552	225 501	347 053
Electricity	307	4 778	8 417	7 283	1 340	249	217	4 379	26 970	8 641	35 611
Trade	3 135	2 694	24 158	773	14 826	3 593	1 372	12 527	63 078	74 658	137 736
Construction	169	541	0	986	1 952	9 509	150	2 053	15 360	37 116	52 476
Financial	293	0	5 581	595	3 799	738	9 099	7 572	27 677	9 744	37 421
Services	1 373	5 854	37 438	1 528	20 167	6 545	5 705	28 211	106 821	103 380	210 201
Total gross output	40 066	69 834	347 053	35 611	137 736	52 476	37 421	210 201	930398	9 323 699	

The eight key sectors are shown in the upper left quadrant of the table, which also shows total gross output (TGO) per sector in the columns, and the intermediate and final demands in the rows. From this matrix, the direct[1] requirements of each sector can be

[1] Direct in the sense that it indicates the express level of input for one unit of output, not yet taking into account indirect effects in other sectors of the economy.

calculated by dividing each cell by its respective TGO. Since we are considering the payments within the sector, we use the column totals for TGO. This gives the "A matrix", in which payments by sectors are recorded down columns, while receipts by sectors flow across the rows. A large value in the A matrix indicates a strong linkages between two sectors (Jeftha 2003).

The input-output model captures the levels of flow of revenue between different economic sectors (Robinson 1989). In response to a change in demand in a particular sector, both the indirect and direct effects are given. The direct effect of an increase of spending in the electricity sector, for example, is accompanied by indirect effects. The electricity sector demands services from other sectors, like construction. This leads to increased spending in that sector, and the feedbacks continue in a similar fashion. A more rigorous mathematical formulation of these relationships can be found in Jeftha (2003).

The Leontief inverse of the direct requirements $(I-A)^{-1}$ gives the output multipliers for each sector, which captures both the direct and indirect effects.[2] The introduction of measures such as industrial energy efficiency will have both direct and indirect effects on the economy. By accounting for these effects through the matrix, their overall impact on the economy can be examined (Jeftha 2003).

This output multiplier matrix can be interpreted (in the form $X = (I-A)^{-1} \times F$) as a series of linear equations from which we can derive how much of each sector output is required directly and indirectly to support a R1.00 increase in final demand of product from that sector. Each element shows the required production levels to meet the specified demands from different sectors in the economy. Furthermore, the individual entries can be summed down the column in Table 2 to give the overall effect of the increase in final demand. For example, in electricity, the output multiplier matrix indicates that R1.72 of economic activity are directly and indirectly needed to deliver R1.00 of electricity to a customer. Alternatively, a R1.00 investment expenditure in the sector has a total "multiplier effect" of R1.72. Of this, R1.28 is in the sector—the R1.00 itself, plus indirect effects feeding back into the sector, while the rest of the indirect effects are listed in the column.

The proportions of the output multiplier in the Leontief matrix are fixed and derive from the flows in the economy in a particular year, here 1997. They are static, but for the purposes of the analysis we assume that the revenue flows in the economy will not change significantly. While this is not realistic, to predict what changes *might* occur over a time horizon of 20 years is beyond the scope of this study. A further extension of the current paper would be to incorporate changes over time, using the methodology outlined by Jeftha (2003). Consumption is assumed to be fixed in its proportions over the period. Standard assumptions about production technology are that there are constant returns to scale and that the technical coefficients are fixed except in the exogenous shock of improved industrial energy efficiency.

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[2] This is because intermediate sales $(A \times X)$ plus final sales (F) add up to total sales (X).The linear algebra is that $A \times X + F = X$, or $A \times X - X = F$. The identity matrix I functions like the number 1 in ordinary algebra (I times any matrix reproduces that matrix). Therefore we can write $(I-A) \times X = F$, or $(I-A)^{-1} \times F = X$ (Van Seventer 2003).

Table 2. Output Multipliers or Leontief Inverse

	AG	*MINE*	*MFG*	*ELEC*	*TRD*	*CON*	FIN	SVC
Agriculture	1.0420	0.0071	0.0672	0.0046	0.0072	0.0219	0.0053	0.0107
Mining	0.0055	1.0132	0.0225	0.1195	0.0044	0.0089	0.0036	0.0077
Manufacture	0.2383	0.1245	1.2966	0.0763	0.1278	0.4108	0.0912	0.1518
Electricity	0.0220	0.0956	0.0492	1.2738	0.0249	0.0300	0.0209	0.0388
Trade	0.1190	0.0672	0.1248	0.0548	1.1513	0.1491	0.0819	0.0988
Construction	0.0095	0.0157	0.0070	0.0466	0.0238	1.2285	0.0119	0.0179
Financial	0.0248	0.0140	0.0434	0.0377	0.0565	0.0505	1.3395	0.0656
Services	0.0984	0.1347	0.1986	0.1070	0.2259	0.2655	0.2644	1.2078
Total	1.5595	1.4720	1.8092	1.7204	1.6218	2.1652	1.8187	1.5991

We further assume that for small changes in final demand, the inverse remains constant, i.e. the changes examined are small enough not to change the structure of the economy itself. Then the exogenous change requires the changes in outputs as embodied in the Leontief matrix (Van Seventer 2003). A change in final demand (dF) is multiplied by the Leontief matrix to give dX, hence the table is called the "output multiplier". Further basic macroeconomic assumptions for this approach are discussed in more detail in Laitner et al. (2001).

From SAM to Employment Multipliers

To move from a tool that assesses changes in economic output to one that allows us to analyse changes in employment, we need to understand the multiplier effect of economic output on employment. Obviously this will vary significantly across sectors, since different economic activities are more or less labor-intensive. In fact, even without a change in total economic output, a shift of output from a less labor-intensive to a more labor-intensive sector (e.g. from mining to services) could increase employment.

The A matrix and the output multipliers can be further manipulated to deduce new information (Jeftha 2003). To derive an *employment* multiplier, the total number of jobs in each of the eight sectors in the matrix (see Table 3) is divided by total gross output. The row vector of employment/output ratios is then multiplied by the Leontief inverse, which gives the change in total revenue in the sector concerned. From this, a matrix of employment multipliers is derived. The final row of Table 4 therefore shows the total impact (counting direct and indirect effects) on employment of expenditure of R1 million in each of the corresponding sectors.

Tracking Flows Through the Economy

The analysis is complicated, however, by the fact that spending on industrial energy efficiency will have both positive and negative impacts on spending elsewhere. The most obvious linkage is that investing energy energy efficient equipment today will reduce the industrial sector's expenditure on electricity in future years. In the year of the investment, this would decrease the profitability and output of the industrial sector. In future years, however, the energy savings from that investment will increase the industrial sector's profitability, and therefore output. In addition, the literature shows that increased energy efficiency is likely to have other positive spillover effects within the sector that will increase overall productivity (Ficket et al. 1990; Laitner et al. 1998; Hawken et al. 1999). In summary, the increase in gross output for the industrial sector (which comprises mining and manufacturing in our model) for a given year will be the energy savings and productivity gains, less the sum of equity investment, loan payments, and programme expenditures in that year. This means that in early years, when the program is getting started, the impact could be negative, because industry is investing heavily in more efficiency equipment and processes. Over time, however, as greater energy savings are achieved, we would expect a positive impact. The gross output of the electricity sector would decline by the same amount as the energy savings since it does not receive the electricity sales revenue from industry. If the electricity not used by industry can be exported, however, the impact on the power sector would be smaller, so this is a key assumption.

Table 3. Employment by Sector and Ratio to Total Gross Output

Sector	*Employees*
Agriculture	814 350
Mining	541 546
Manufacturing	1 119 973
Elec, gas, water	109 334
Construction	555 129
Trade*	1 581 703
Finance	680 156
Services	1 580 684

*Trade here includes the wholesale and retail sector and the transport and communication sector

Source: Employment data from Statistics South Africa (2001)

Table 4. Employment Multipliers (jobs per R million)

	AG	*MINE*	*MFG*	*ELEC*	*TRD*	*CON*	*FIN*	*SVC*
Agriculture	21.17	0.14	1.37	0.09	0.15	0.44	0.11	0.22
Mining	0.05	9.81	0.22	1.16	0.04	0.09	0.04	0.07
Manufacture	0.97	0.51	5.29	0.31	0.52	1.68	0.37	0.62
Electricity	0.05	0.23	0.12	3.04	0.06	0.07	0.05	0.09
Trade	1.10	0.62	1.15	0.50	10.61	1.37	0.75	0.91
Construction	0.09	0.15	0.06	0.43	0.22	11.36	0.11	0.17
Financial	0.63	0.36	1.11	0.96	1.44	1.29	34.13	1.67
Services	1.13	1.55	2.29	1.23	2.60	3.06	3.04	13.91
Total	**25.20**	**13.37**	**11.60**	**7.74**	**15.64**	**19.35**	**38.60**	**17.66**

A second important linkage is that the investment by the industrial sector would be income for the sectors that could provide energy efficiency services and equipment. In our model we have assumed that the energy efficiency services and equipment are provided by the construction sector. The important caveat, however, is that if more efficiency equipment must be imported, then this will not benefit the local economy. This is why the share of energy efficiency services and equipment that must be imported is a critical assumption (see sensitivity analysis). Similarly, if industry borrows money to pay for the energy efficiency improvements, then the interest payments are an additional expenditure for industry (which reduces gross output) but an income to the financial sector. Finally, the programme expenditures that are borne by industry are income to the services sector.

Once we understand the changes in output for each sector in a given year, we can use the employment multipliers to estimate changes in employment for each sector. Changes in employment, however, also depend on the productivity of labor. If labor productivity increases over the period, then fewer jobs would be created per million rands spent than suggested in Table 4. Our model allows for labor productivity to be changed and conducts sensitivity analysis of the results on this factor.

Assumptions

Industrial Energy Efficiency Programme Size and Savings

A number of reports suggest a large potential for cost-effective energy savings in Africa. According to the World Energy Assessment (UNDP et al. 2000), for example, possible savings in African industries range from 15-32% by 2020. Previous research in South Africa on major industries suggests that better compressed air management, lighting, boilers, and moving to variable speed drives, could save 20% of the energy use for those end-uses at paybacks of less than five years (Trikam 2002). Hence, we use a scenario based on a 6% improvement in total industrial electricity consumption to be conservative.

South Africa's industrial sector is aggregated into mining and manufacturing. The sector output is predominantly driven by GDP, with the exception of gold mining which is better represented by growth rate which, in South Africa's case, is negative. This is because gold reserves and ore quality are steadily depleting, and gold mining is becoming more energy-intensive as miners need to dig deeper for the precious commodity.

Ongoing research work at the Energy Research Institute, to be published later in 2003, uses the LEAP (Long-range Energy Alternatives Planning System) energy model to estimate total energy savings and costs based on a disaggregated analysis of industrial energy demand. The analysis realistically assumes a market potential of one half the lower technical potential of the energy efficiency measures to be implemented. The programme would comprise the following energy efficiency measures:

- thermal efficiency, such as improving the efficiency of the use and production of thermal heat;
- energy-efficient motors;
- compressed air management, such as repairing air leaks;
- variable speed drives;
- energy efficient lighting; and
- energy-efficient heating, ventilation and air-conditioning.

According to this analysis, an energy efficiency programme implemented over a twenty-year period, with a lead time of one year and beginning in 2003, will realise an annual saving of 6% in electrical energy per year when fully implemented. The programme will take four years to reach the 6% savings. Electricity use by industry (mining and manufacturing) in 2002 was 112 TWh. In the full energy model, this demand increases over time, so that an average annual savings of 9.5 TWh is equivalent to 6% of total consumption over the period.

Since we have a static model, we have simply applied the 6% savings to the current electricity consumption, with an average price of 12.6 c/kWh to estimate monetary savings and investment.

Typical payback periods and estimated fuel saving potential regarding the energy efficiency measures are shown in Table 5. The estimated fuel-saving potential refers to the savings that could be realised at the lower technical efficiency level for the energy efficiency measures. We assume that on average across a range of measures, the payback period will be three years, with only half the energy savings available in the year investment takes place. A reasonable range of payback periods would be from two to six years.

Table 5. Payback Periods and Fuel-Saving Potential

EE Measure:	*Assumed Payback Period (Years)*	*Technical Potential (%)*
Thermal efficiency	0.75	12.5
Energy-efficient motors	5	10.4
Compressed air management	1	55.6
Variable speed drives	4	15.2
Energy-efficient lighting	3	71.8
Energy-efficient heating, ventilation and air-conditioning	3	41.7

Source: Hughes et al. 2002

Structural Issues

Eskom not only supplies over 95% of South Africa's electricity needs, but over 50% of those of the African continent. While Eskom does export small amounts of electricity to neighbouring countries (4000 GWh in 2000 (DME 2002)), this is unlikely to grow significantly (ERI 2001), which means that there is limited potential to export the "saved electricity" at a profit. For share of local production of energy efficiency services and equipment, we use 50% as our base-case assumption, because, although some more efficiency equipment must be imported, many of the efficiency improvements come from more "low technology" housekeeping measures (ERI 2000).

Progress Ratio and Learning

The investment required to implement energy efficiency may decrease over time, as industry 'learns by doing'. International experience has demonstrated that costs are reduced through learning by experience (IEA and OECD 2000). Many factors combine to induce this learning, but together they can be represented by learning ratios and experience curves. Experience curves are can be represented mathematically by

$$\text{Price at year } t = P_0 \times X^{-E}$$

Where P_0 is the price at one unit of cumulative production or sales; X is cumulative production or sales in year t; and E is the positive experience parameter (IEA and OECD 2000: 10). Large values of E give a steeply decline experience curve; low ones a flat curve.

From the progress ratio can be derived,[3] given by PR = 2^{-E}. In this example, the progress ratio is 93%, or in other words, for every doubling of cumulative investment, costs reduce by 7%. Given this learning, the investment required would be reduced as shown in Table 6.

Table 6. Impact of Considering Progress Ratio on Investment

	Investment without learning (R million)	*Investment with learning (R million)*	*Percent (with / without)*
2004	313	313	100%
2005	626	577	92%
2006	626	556	89%
2007	626	542	87%
2008	313	268	86%

Other Key Assumptions

Labor productivity will continue to increase in the future, which means that using employment multipliers from 1997 is likely to overestimate the job creation for a given change in gross output. To take this into account, we assume that labor productivity will continue to grow at 6% per year, as it has in the non-agricultural sector in recent years (NPI 2001). For the financing of the investments, we assume that 50% is financed from debt at a 10% interest rate and loan period of five years. Programme costs are estimated at 5% of investment costs per year.

Analysis and Results

Figure 1 shows the results for GDP and employment for each year. Note that, although the GDP impacts of the programme are negative for almost half of the time period, the employment impacts are positive throughout. As discussed above, this is because output is being shifted from the capital-intensive power sector to the more labor-intensive construction, finance, and services sectors. Job creation is greatest in the early years of the programme, when the large investments in new equipment lead to increase economic activity in the construction, finance, and services sectors. Once the market is saturated and the maximum savings achieved, only a few hundred jobs are supported by the re-spending of the ongoing energy savings.

Figure 2 shows the effect of different payback period assumptions. the employment impacts of the energy efficiency investments for each year, depending on the payback period. The reason for the counterintuitive result that quicker paybacks lead to less job creation is that we have fixed maximum energy savings. Investment is estimated from maximum energy savings, payback period, and energy costs. This means that shorter payback periods means less investment is required to achieve the same savings, which means less job creation—even though the energy savings are most cost effective. The different between a two- and a six-year payback is 8000 job years at the peak of investment.

[3] $PR = \{P_o \times (2X)^{-E}\} / P_o \times X^{-E}\} = 2^{-E}$.

Figure 1. GDP and Employment Impacts by Year

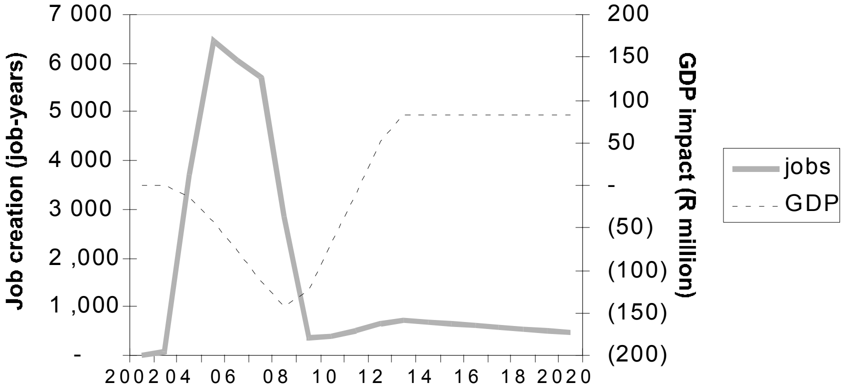


Figure 2. Impact of Payback Period Assumptions on Employment (Job-Years)

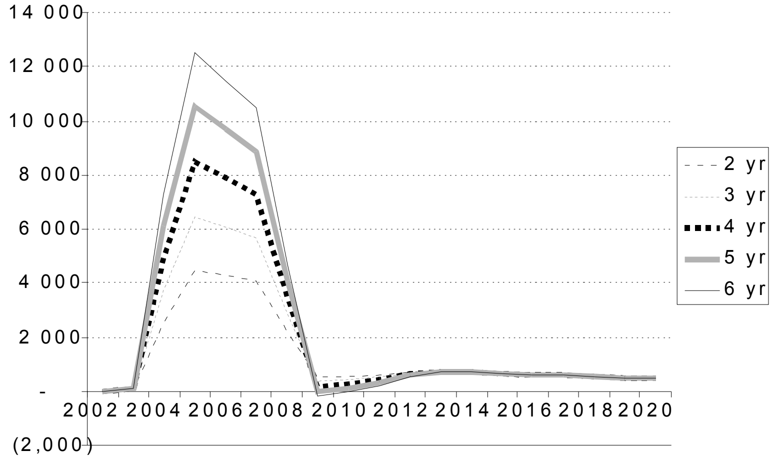
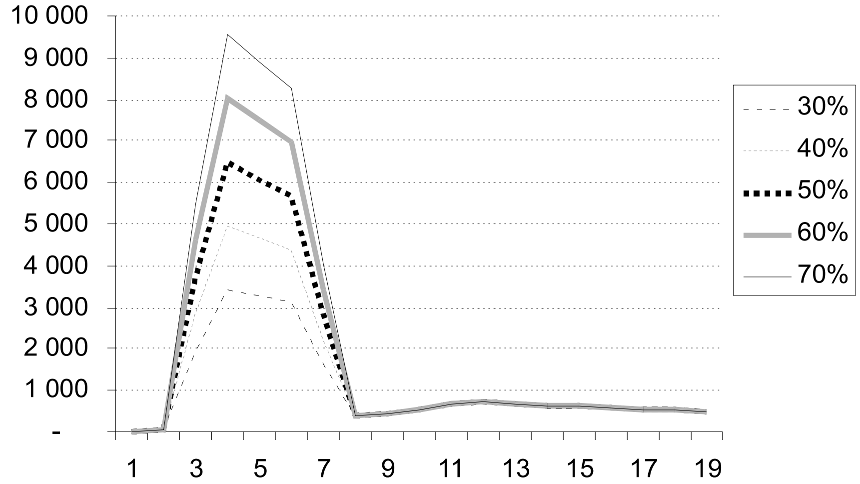


Figure 3 shows the sensitivity to local production, where moving from 30% to 70% local production increases job creation by 6 000 job years at the peak of investment.

Discussion and Conclusions

The results show that a modest investment in industrial energy efficiency will have a small but significant impact on job creation, with a range from 20 000 to 70 000 job years over 20 years. This is despite the fact that GDP impacts are negative in early years, but positive overall, because of the different labor intensities of key economic sectors. The results, however, are highly sensitive to key assumptions about the payback period of investments, local production of energy efficiency services and equipment, and the total saving that can be achieved. Even beyond refining the methodology further, additional research on these key assumptions would be useful to support policy makers. Additional issues that should be explored further include the non-energy productivity gains, which we have assumed are only 10% to be conservative, but could potentially be much greater.

Figure 3. Impact of Local Production Assumptions on Employment (Job-Years)



As discussed in the methodology section, the input-output approach itself does have limitations. Nor would greater disaggregation of the tables allow a more detailed understanding of sectoral impacts, but more importantly, we are not able to reflect potential structural changes in the economy. This limitation has been of major interest to the structuralist school of analysis (Taylor 1990), and needs further attention in this context. Particularly limiting in this case is the implicit assumption of full employment—the model does not account for the realities of unemployment in South Africa. This is clearly an area for further work. A further extension of the current paper would be to incorporate changes over time, using the methodology outlined by Jeftha (2003)

The main message from this analysis, however, is that an investment-led strategy for energy efficiency improvements can have significant socio-economic benefits, particularly in countries where job creation is a social and political priority. Extended this analysis to include end-use efficiency in other sectors and also the introduction of cleaner energy supply sources would provide a basis for understanding economy-wide impacts of a broader "sustainable energy" strategy in South Africa and in similar economies.

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