# A Technical Framework for Industrial Greenhouse Gas Mitigation in Developing Countries

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**ABSTRACT**

Industrial energy efficiency measures offer the potential to reduce greenhouse gas (GHG) emissions, affect job creation and influence other sustainable development goals. At the same time, it affects industry in terms of implementation difficulties and profitability. In this paper we develop a hypothetical case study to show how certain industrial electrical energy efficiency measures can meet national development goals and incidentally reduce GHG emissions. The implication is thus that certain GHG mitigation measures could support national development. These measures are evaluated in scenarios, and then weighted in terms of their overall desirability. A multicriteria analysis (MCA) framework is used for the case study, which is limited to industry in South African. The analysis, though hypothetical, is based on several studies that provide the data used in the framework.

South Africa is a developing country that currently has no obligation to reduce GHG emissions under agreements such as the Kyoto Protocol. Moreover, the role of emissions trading mechanisms as an effective incentive for developing countries to reduce GHG emissions is unclear. It is therefore sensible to investigate mitigation options that would promote development and reduce GHG emissions, and then to evaluate these options in terms of national development or government policy goals and the key effects of their implementation within industry.

For governments of developing countries, benefits such as job creation may be more important than GHG mitigation. However, the strong correlation between GHG mitigation measures such as the efficient use of industrial energy and benefits such as job creation warrants further study and is described in this paper. The method presented in this paper uses an MCA framework to examine GHG mitigation, and shows that the framework can provide solutions that meet multiple policy- and development goals.

A special aspect of the framework is that it can use data from studies with varying levels of accuracy, and then combine the data into a consistent decision making format.

## Introduction

### Problem Statement

South Africa is a developing country that currently has no obligations to reduce GHG emission levels under agreements such as the Kyoto Protocol. Moreover, the role of emissions trading mechanisms as an effective incentive for developing countries to reduce emission levels is unclear.

In developing countries such as South Africa, the issue of GHG mitigation is generally viewed with suspicion: Economic development often increases emission levels, so strategies to reduce these levels are viewed as impeding development and thus as contrary to government policy. It is therefore sensible to investigate mitigation strategies to show that they can encourage development. The goal of this paper is thus to show, using a multicriteria analysis framework, that GHG mitigation can encourage economic development.

GHG emission levels can be reduced through application of industrial electrical energy efficiency measures. These measures relate GHG mitigation to economic development because they affect sustainable development goals such as job creation, and also affect industry in terms of implementation difficulties and profitability.

Strategies such as fuel switching, use of renewable energy, more efficient methods of energy transformation and supply, and improved manufacturing processes can also reduce emission levels. In this paper we restrict our study to electrical energy efficiency measures because these have been identified as a key priority in national planning (Trikam et al. 2003).

To explore the relationship between GHG mitigation and economic development, we develop a hypothetical case study. In it we show how certain energy efficiency measures can meet national development goals and simultaneously reduce GHG emissions. These measures are evaluated in three scenarios, *viz.*

1. A **base case** in which government development goals such as job creation are emphasised; this scenario also accounts for aspects such as profitability and ease of use, although these are given a lower priority,
2. A **profit-driven case** in which profitability and ease of implementation are favoured above development goals such as job creation, and
3. An **environmental interest case**, in which aspects such as water conservation are the focus.

Each scenario involves at least one objective. For example, in the base case listed above, job creation competes against profitability and ease of use. A shortcoming of most standard economic analyses and models is that they tend to focus on a single objective - either to minimize cost, or to maximize profit, welfare, or consumer utility (Laitner and Hogan, 2000; and Hobbes and Meier, 2000). Although the need for multicriteria decision models increases as climate change issues grow more complex, current policy tools do not always have the capacity to solve for multiple objectives. In contrast to these tools, we use the multicriteria decision analysis (MCA) framework[1] in this paper to investigate the scenarios listed above, and show how this framework can be adapted to do a goal-programming analysis of emission reductions.

## Method of Solution

We wish to compare the effect of 11 different energy efficiency measures. The measures are assessed according to 10 guidelines, or attributes, and the effects of each measure are compared according to a set of criteria. These criteria are then grouped to form the three scenarios that are evaluated and from which conclusions are drawn. The scenarios are imposed on the data in the framework by assigning the attributes present- and future impact scores that reflect the characteristics of each scenario. For example, in the profit-

[1] Hobbes and Meier (2000) provide an in-depth review of a variety of multicriteria decision tools that would also be useful in policy analysis.

driven case, the attributes *profitability* and *ease of use* are emphasised by giving them higher present impact scores than in the base case where job creation is emphasised.

The attribute values used in the model may be expressed in different units, such as South African Rand[2] per kilowatt-hour (*R/kWh*) or kilograms per cubic meter ($kgm^{-3}$). To avoid disparity when comparing the values, they are first normalised by scaling each set of attribute values according to the range of values for that attribute.

To cater for uncertainty in the attribute values, each normalised value is randomised. The premise behind the randomisation is that the attribute values for each measure may be unreliable. The effect of errors in the values is simulated by applying random adjustments to each impact score and attribute value. This is done over multiple runs of the model, and the results of each run are then averaged. In this way the average values of the impact scores and attribute values can be determined, as well as a confidence range for each value. This confidence range gives an estimated value for the potential errors in the input data, and hence an overall measure of confidence in the results (Cartwright, T.J., 1993). Once the results are obtained, if the final score of a candidate solution is standardised and randomised to within a 95% confidence interval and it lies unambiguously above that of another solution, we can conclude that the first solution is better than the second. If the confidence ranges of the two alternatives overlap, no such conclusion may be made (Cartwright, T.J., 1993).

An important adaptation of this method is that the magnitude of the randomisation applied is specific to each attribute. This adaptation is an important difference to existing assessment techniques because it allows for data from different studies that have different levels of accuracy to be combined in one study.

## The Multicriteria Framework

The multicriteria framework that is used in this paper consists of entities, attributes and data. The entities comprise the energy efficiency measures, the attributes are the guidelines for the assessment, and the data consists of attribute values and impact scores. In this section, we describe these aspects in more detail.

### Measures Considered

The measures that we consider are limited to industrial electrical energy efficiency. The reasons for choosing these measures are firstly, that the measures represent ‘big hits’ in terms of the potential GHG savings accruable to the suppliers of energy within South Africa. Secondly, the measures produce complex effects observable in more than one field of study. Previous attempts have not been able to capture these effects well. Finally, the measures have been identified as targets in current national planning (Trikam et al. 2003).

The following technologies, approaches and mechanisms were adopted (bracketed abbreviations in ***bold italics*** refer to labels used in the results table):

1. **Variable Speed Drives (*VSD1 & VSD2*) -** These drives reduce unnecessary power consumption in electrical motors with varying loads.

[2] One South African Rand is currently worth approximately eight U.S. dollars.

2. **Efficient Motors** (***Motors1 & Motors2***) – 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.
3. **Compressed air management** (***CA***) - This measure is easily achieved and often results in significant savings at low cost.
4. **Efficient lighting** (***Lighting1 & Lighting2***) - These measures take advantage of natural lighting, more efficient light bulbs and appropriate task lighting.
5. **Heating, Ventilation and Cooling** (***HVAC1 & HVAC2***) - These measures are for maintaining good air quality and temperature and can commonly be improved through better maintenance and the installation of appropriate equipment.
6. **Thermal saving** (***Thermal1 & Thermal2***) – Thermal saving refers to more efficient use and production of heat.

Certain components of these measures could be produced locally or imported. In the above list the suffixes '1' and '2' indicate, respectively, measures with 80% and 20% local content. Compressed air management is assumed to have 100% local content because of the way in which this measure is implemented. These cases may have important effects in terms of job creation and technology transfer, and are evaluated in the analysis.

The above list is not exhaustive; these options are used in the MCA framework to serve as an example that shows how multiple objectives can be met while GHG emissions are mitigated. From the example, we thus infer that selected GHG emission reduction measures can encourage national development.

**Criteria for Policy Setting**

The manner in which GHG mitigation is handled reflects the positions and priorities of the parties concerned. Each priority determines a set of criteria by which the mitigation options should be assessed. A set of development criteria which could be affected by energy efficiency measures was established for the South African Department of Minerals and Energy in (Hughes et al 2002), where it was proposed that a list of measures appropriate to electrical industrial efficiency would include (bracketed ***bold*** abbreviations are used in the table of results):

- Greenhouse gas mitigation (***GHG***)
- Resource (fuel saving/system ***efficiency***)
- Water saving (**Water**)
- Mitigation of local environmental loading (Specifically:
  - Sulphur Dioxide $SO_2$,
  - Nitrogen Oxides $N_2O$ and
  - Total Suspended Particulates ***TSP***).
- Technology and technology transfer (***Technology***)
- Job creation (***Jobs***)

Further important criteria concern the capacity to implement potential GHG mitigation measures. Selected criteria include Profitability (***Profitability***) and Ease of implementation (***Ease***) (Howells & Solomon 2002).

The importance of each criterion varies according to priority. The priorities in turn depend on the party involved, such as a government department and its associated objectives. The importance of the criteria are reflected in the present- and future impact scores assigned to each one.

GHG mitigation has traditionally not been viewed as a priority in developing countries. The MCA framework now makes it possible to evaluate this aspect in relation to existing development priorities.

**Data Used for this Study**

Data for the study was gathered from previous work and also from specific modelling for this paper. The three categories of data required for the analysis are attribute data, uncertainty data, and the weighting of the development criteria. The attribute data captures the contribution that each energy efficiency measure makes to the specific objective or criteria, uncertainty data reflects a confidence interval about the attribute data, and the development criteria weightings reflect specific policy concerns.

**Attribute data.** Attribute values for each measure are expressed as the unit contributions to each development objective or criterion, and are summarised in Table 1. The *job creation* values in the table account for both 20% and 80% local content (excluding compressed air which has 100% percent local content). These levels affect job creation potential and were extracted from an input-output economic model (Laitner 2002). This model was run for an eleven year period from 2003 to 2013. Parameters for the modelling are documented in (Hughes et al 2002), and the model was adapted from (Laitner 2002). The attribute data gathered from this study includes the profitability of the various measures considered. Foreign content (100%-local content) is used as an indicator of *technology* transfer.

An energy model of South Africa (Howells et al 2002) was developed with the LEAP 2000 energy modelling/accounting software and re-run for this study in order to establish changes in local environmental loadings for the period 2003 to 2013. The mitigation levels of $CO_2$ equivalent for the following attributes were determined for each measure:

- Greenhouse gases[3] (***GHG***): Carbon dioxide ($CO_2$) , Methane ($CH_4$) and Nitrous Oxide ($N_2O$),
- Local pollutants: Sulphur Dioxide (***SO₂***), Nitrogen Oxides (***NOₓ***) and Total Suspended Particulate (***TSP***)
- Power station water effluent (***water***)

The values calculated for the above attributes are taken from a program over eleven years with consistent assumptions for the input-output economic model.

Several local industrial case studies such as (Kenny et al 2001 a; Kenny et al 2001 b; Kenny et al 2001 c and Van Es 2002) have evaluated 'ease of implementation' for selected measures within local industry. These studies further quantify profitability and ease of implementation for electrical for electrical energy efficiency measures, and the values derived in these studies are used in this paper.

[3] GHG emissions were combined into a single indicator, namely carbon dioxide equivalent, using the respective global warming potential of the individual species.

‘Balance of trade’ attribute data was considered negligible, as the fuel savings (mainly coal consumption in the power sector) are expected to affect only longer term trade significantly (van Hooren 1999).

**Uncertainty data.** Key to the approach of this paper is the notion that individual estimates of attributes have different uncertainties. This is often the case in developing country analyses, where data is available only from *ad hoc* studies. The different uncertainties make direct comparison difficult, unless, as in this paper, an approach that accounts for the uncertainty is adopted. It is thus necessary to establish error ranges for the attributes, and the derivation of these error ranges is discussed below. Only then can we compare the energy efficiency measures evaluated in the MCA framework. The uncertainty values used are summarised in Table 1. These hypothetical values are used in the scenarios discussed below. A sensitivity analysis that uses increased levels of uncertainty is included in order to account for the possible effects of data with large uncertainty on the final results.

The following assumptions were made for the scenarios:

- Estimates of emissions- and water consumption levels are considered accurate to 5%. The estimates are consistent with assumptions that are typical of large-scale local planning programs.
- Estimates of job creation potential were derived by using a large array of assumptions. The relationships between these assumptions are expected to change in proportion to South African economic and labour characteristics. The estimates are thus assigned an uncertainty of 30%.
- Profitability values are derived from limited case studies of (well-managed) local industry. The uncertainty associated with these figures is thus assumed to be 20%.
- Ease of implementation may, as with the previous assumption, depend on the measure and circumstance of the plant considered. An uncertainty of 20% is assumed.
- Technology transfer is estimated by the foreign content in the measure. This does not distinguish between ‘advantageous’ and ‘neutral’ transfer. A high degree of uncertainty (60%) is thus associated with indicator.

**Importance and weighting.** The importance of each development criterion relative to the development priorities of government is often not explicitly quantified. It is thus captured via hypothetical scenarios. In practice these scenarios should be determined by debate amongst policy makers. Values of the estimated importance are based on current government spending (Treasury 2003) that can be linked with previously listed objectives. These levels of government spending are determined by factors such as societal needs and political considerations.

Of the two sets of weightings proposed below, one is for the present (period one) where environmental concerns are relatively low, and the other is for the longer term (period two) where environmental effects are considered more important. However, given the current planning priorities of the South African government, it is not likely that future priorities will be considered as important as those of the present. We thus assume that, in deriving the optimal solution, future development criteria are only 20% as important as current development criteria. The weights are set accordingly. The attribute values for the energy efficiency measures considered are presented in Table 1.

## Table 1. Attribute Data for the Multi-Criteria Analysis

| | GHG mitigation | Job years (and technology transfer: 100%-local content) | | Water saving | Fuel saving | $SO_2$ mitigation | TSP mitigation | $NO_X$ mitigation | Ease of implementation[4] | Profitability (Payback) |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit | Thousand tons | 80% | 20% | M Liter | PJ | Thousand tons | Thousand tons | Thousand tons | index | years |
| Compressed Air | 22,829 | 7,500 | - | 229 | 247 | 224 | 6.9 | 89.2 | 1 | 1 |
| HVAC (1/2) | 547 | 270 | 60 | 5.5 | 5.9 | 5.4 | 0.2 | 2.1 | 2 | 1 |
| Lighting | 9,639 | 3,200 | 900 | 96.7 | 104 | 95 | 2.9 | 27.7 | 3 | 3 |
| Motors | 14,393 | 7,600 | -1,300 | 149.9 | 162 | 147.2 | 4.5 | 58.4 | 3 | 5 |
| Thermal saving | 13,478 | 4,400 | 3,200 | 135.2 | 146 | 132.8 | 4.1 | 52.7 | 1 | 0.5 |
| VSDs | 3,794 | 3,700 | -1,500 | 38.1 | 41.2 | 37.4 | 1.2 | 14.8 | 3 | 4 |
| Uncertainty | 5% | 30% | 60% | 5% | 5% | 5% | 5% | 5% | 20% | 20% |
| Near term weighting | 0.0 | 0.0 | 0.0 | 6.3 | 1.6 | 3 0.0 | 1 0.8 | 0 0.5 | 0.0 | 0.0 |
| Medium term weighting | 6.0 | 0.0 | 0.0 | 2.6 | 3.2 | 6 0.0 | 3 0.6 | 0 0.9 | 0.0 | 0.0 |

## Scenarios

**The base case.** In the base case, job creation is treated as the most important criterion, and the weights of the remaining attributes are positioned relative to it. To derive the attribute weights for the base case, the following assumptions were made:

- The relative weightings of emissions are calculated by using low-end externality costs for power station emissions (van Hooren 1999). The externality data is derived primarily from health impacts, which inform local environment strategy (DEAT 2003). However, GHG emissions were assumed to be zero during period one and to become as important as $SO_2$ emissions during period two. The importance of other emissions doubles relative to the future because clear links are established between sustainability and growth, and also because of increased influence from a larger, middle-class "green" lobby.
- Profitability was considered to be as important as job creation in the longer term because the industrial lobby gathers momentum. Initially it is taken to be only half as important.
- The importance of GHG mitigation increases significantly as a result of the annex one agreements to which South Africa is now committed.

[4] In order to give desirable attributes higher values than less desirable attributes, the reciprocal of these values (as well as payback) is included in the model.

- Ease of implementation increases in importance with increasing industrial lobby, which resists direct government involvement in production. Initially it is assumed to be half as important as job creation.
- The scarce water resources of South Africa are further prioritised by government in terms of reducing consumption, thereby doubling its importance.
- Technology transfer increases in importance from the first to the second period, as the relationship between development and transfer becomes better described, and the need for technological edge is maintained.

Allocation of funds in the South African budget of 2002 gives the spending on various departments within government (Treasury 2003). The values give no more than an indication of the relative importance of these departments in decision making. It is noteworthy how unimportant atmospheric pollution is relative to other criteria.

**Other scenarios: profit-driven and environmental interest.** These scenarios are permutations of the base case and represent a departure from current government policy. The Profit-driven scenario reduces the importance of job creation by 75%, and at its expense doubles the importance of profitability and ease of implementation. In the Environmental interest scenario the importance of profitability and ease of implementation is reduced by 80%, while environmental concerns such as emissions savings are amplified to between 1000% and 2000% of their original values[5]. Job creation is reduced to 25% of its importance in the base case.

A sensitivity analysis was also performed by increasing the uncertainty of the attribute data.

## Results

A Monte-Carlo simulation was run in a custom application, and results for the scenarios are given in Figure 1. For each measure there are two scores, indicating a range of confidence for the measure. This confidence interval is affected by aspects such as the uncertainty associated with the input data. It also allows the better mitigation options to be identified from amongst the group, since options with higher scores are better at fulfilling the policy reflected in the criterion weighting structure.

### Base Case

In this case, jobs, profitability and ease of use were given the largest significance weightings for the present and future scenarios. Three groups of candidates emerge, *viz.* those with preference scores of more than 2, those with scores between 1 and 2 and those with scores of less than 1. Amongst the last group, there appear to be three sub-groups.

The first group contains the three potential winners, CA, Thermal1 and Thermal2. These are unambiguously better than all of the other candidates, but cannot be distinguished from each other because their confidence intervals overlap. The members of this group seem to be set apart from their peers on the basis of their scores for profitability and ease of use.

[5] Recall that in the base case, environmental emissions savings have lower importance relative to job creation.

Motors1 is the only candidate in the second group. Although this candidate has a high score for job creation, it has poor scores for profitability and ease of use compared to the members of the first group. Thus it is easily distinguished from them on the basis of these discriminants.

The third group consists of the sub-groups {HVAC2, Lighting1, Lighting2}, {Motors2, VSD1} and {HVAC1, VSD2}. Amongst the first sub-group, Lighting1 does not fare significantly better than its peers despite having a larger job creation score. In this case it appears that the distinguishing features of the candidates are profitability and ease of use. In the case of {Motors2, VSD1}, job creation appears to be a very strong feature, since although Motors2 has significantly higher scores on most other attributes, VSD1 still manages to performs as well as Motors2 on the basis of its score for this attribute.

Given the policy associated with this case, we see that the attributes *profitability* and *ease of use* appear to be the distinguishing criteria for all of the groups, with job creation playing a secondary role. This does not contradict the weighting structure of the case.

**Environmental Interest**

Here water consumption, followed by efficiency and then TSP were given the highest combined weightings in order to reflect an "environmentally friendly" disposition in this scenario. For this case, CA emerges as the clear winner. Thermal1 and Thermal2, followed by Motors1 are the next best options.

In terms of confidence intervals, all four of these options are distinguishable from each other, and it further appears that the candidates may be grouped together as {CA}, {Thermal2, Thermal1, Motors1, Motors2}, {Lighting2, Lighting1} and {VSD2, VSD1, HVAC2, HVAC1}. Somewhat surprisingly, technology, ease, profitability and jobs seem to be the discriminants amongst the second group, accounting for the order of preference given that the scores for the other attributes are identical for each pairing. In the third group, technology also plays a strong role. In the fourth group technology and jobs seem to play a role in distinguishing this group from the others. Technology appears to be the stronger factor, often appearing to compensate the final scores for differences in the jobs created by each candidate.

In relation to the policy reflected in the weighting structure of this scenario, the attributes are not as clearly demarcated as in the base case, *i.e.* there is not a clear correspondence between the policy and the candidate groupings in that more attributes than favoured by the policy play a role in classifying the candidates.

**Figure 1. Results of the Multi-Criteria Analysis, Showing (from Top to Bottom) Confidence Intervals for the Base, Environmental Interest and Profit-Driven Case and a Large Uncertainty Analysis**


## Profit-Driven Scenario

In this case, ease of use and profitability were given preference over the other attributes in terms of weighting. Thermal1 and Thermal2 appear to be the best candidates in this scenario, with Thermal2 a clear winner. Amongst the top three candidates, the technology score appears to result in the observed ordering more strongly than jobs created; Thermal1 and Thermal2 are equal on all the other scores, yet Thermal2 is better than Thermal1 on the basis of its technology score.

# Implications for the Energy Efficiency Policy

With the exception of the base case, each of the scenarios investigated produced a clear winner. Thus a framework is in place for decision making in accordance with different policies. The study further illustrates how uncertainty can be handled, and allows accurate characterisation of current- and future scenarios. In addition, government can assign weightings that are appropriate and consistent with national prerogatives. Insight is also given to the relative importance of various non-environmental criteria which are likely to provide incentives for GHG mitigation measures. This illustrates the need for such an approach to GHG mitigation as well as its lack of importance in terms of stand-alone policy. Within each scenario, different groups of candidates emerged according to their preference scores. In each group, certain attributes were found to play a role in distinguishing the members of that group from the rest of the available options. In this regard, the base case is set apart from the other three cases, since in this case there was no clear winner but a set of three potential candidates and also because the distinguishing attributes agreed with the policy imposed on the weighting structure. In the other cases, attributes other than determined by the policy were found to define the groupings.

In terms of future work, it would be of interest to assess the role of the uncertainty value in the final preference scores in a more definite fashion, *i.e.* it would be interesting to determine whether there is a point after which the results remain the same irrespective of the uncertainty settings, and at the other extreme if there is a point after which the results become unstable (completely different preference orderings with each run). It would also be interesting to account for more than one policy at a time. The technique, as applied in this paper, will simply find an optimal solution to the problem. There is no direct means of filtering out less suitable candidates by means of constraints, such as stipulating that $NO_x$ emission levels should be below a certain limit, or of tailoring the solutions by means of criteria, such as stipulating that in addition to meeting the constraints, the final solution is to be such that the employment score is maximised. These aspects can be addressed by means of other optimisation techniques, and it would be of interest to investigate how these may be incorporated into the existing framework presented in this paper.

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