

## Estimating the Efficiency of Sustainable Development by South African Mining Companies

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**KEYWORDS** Data Envelopment Analysis. Energy and Water Usage. Greenhouse Gas Emissions

**ABSTRACT** The purpose of the study was to develop a model, using data envelopment analysis (DEA), in order to estimate the relative efficiency of nine South African listed mining companies in their efforts to convert environmental impact into economic and social gains for shareholders and other stakeholders. The environmental impact factors were used as input variables, that is, greenhouse gas emissions, water usage and energy usage, and the gains for shareholders and other stakeholders were used as output variables, that is, number of employees, taxes, donations, dividends and reinvestments. The study found substantial differences between the relative efficiency of gold-mining companies and the efficiency of all the other mining companies, where gold-mining companies were the most inefficient to convert their environmental impact into economic and social gains. The practical implication is that gold-mining companies should use the coal- and platinum-mining companies indicated in this study as a benchmark for best practice in sustainable development. Further research is recommended, that is, since more companies are willing to report on their environmental impact, a similar study should be conducted to include more mining companies from different sectors. This will allow a greater discrimination between the companies due to the larger quantity of data and a better comparison can be made between mining companies in the different mining sectors.

### INTRODUCTION

Sustainable development focuses on the use of resources to meet human needs and preserving the environment, so that these needs can also be met by future generations (Adams 2006). The World Commission on Environment and Development's report in 1987 initiated the debate about sustainability and identifies three dimensions of sustainable development, namely environmental, economic and social sustainability (WCED 1987). To meet the needs of future generations, these three dimensions need to be integrated to address the balance between dimensions of sustainability. Sustainable development relies on economic development (Shi 2002), and although economists evaluate economic development differently, its benefit, harm and other consequences should be taken into account (Ciegis and Kareivaiti 2009). Sustainability is an evolving concept, which makes it difficult to put the already adequately defined definition into practice by scientists and managers (Anderson and Mårell 2007). The importance of the

topic is that it emphasises the relationship between environmental impact with social and economic development that will provide a new perspective to the managers of mining companies.

In the past, many authors (see Table 1) challenged the idea that the reduction of environmental harm leads to an improvement in economic performance. These studies used different indicators to estimate economic performance, as exhibited in Table 1.

**Table 1: Economic performance indicators used by previous studies**

| <i>Author(s)</i>          | <i>Economic Performance Indicator</i>                            |
|---------------------------|--|
| Jaggi and Freedman (1992) | Net income, return on equity/ assets, cashflow to equity/ assets |
| Hart and Ahuja (1996)     | Return on sales/ equity/ assets                                  |
| Bhat (1999)               | Market value of shares   |
| King and Lenox (2001)     | Market value versus replacement value of shares                  |
| Rivera (2001)             | Revenue  |
| Orlitzky et al. (2003)    | Corporate financial performance                                  |
| Ambec and Lanoie (2008)   | Profit, that is, cost and revenue                                |

The above-mentioned studies all have two aspects in common, firstly, the economic performance indicators all emphasise the creation of shareholders' value and the interests of other stakeholders are not measured. Secondly, these studies all measured the strength of a linear association between environmental performance with economic performance by using correlation analysis. The gap that this study attempts to fill is to use not only economic, but also social performance indicators that emphasise the creation of value for shareholders as well as other stakeholders. Furthermore, an alternative approach, other than the mentioned linear association, may provide other insights with regard to the interaction of the sustainability dimensions.

The research question is what is the relative efficiency of South African mining companies to convert environmental impact into economic and social gain? In other words, what is the relative efficiency of sustainable development of South African mining companies? The purpose of the study was to develop a data envelopment analysis (DEA) model where environmental impact indicators are used as input variables and both economic and social performance indicators are used as output variables. This is to determine the efficiency of how mining companies convert their environmental impact into economic and social gains for both shareholders and other stakeholders. Since this model was applied to nine mining companies that operated in four different sectors, a comparison between the mining companies in the different sectors could also be made. The study found that the gold-mining companies were the most inefficient in converting environmental impact into economic and social gains for shareholders and other stakeholders. The practical implication is that gold-mining companies should use the coal- and platinum-mining companies indicated in this study as a benchmark for best practice in sustainable development.

### **Sustainable Development**

Besides a legislative approach, a strategic approach is needed to solve the environmental, economic and social problem (Sendroui and Roman 1999). Changes in production and consumption need to be made for sustainability to be effective. Governments, communities and businesses all see the importance of protecting

the environment for future generations and have responded to the challenge of sustainability. With the emphasis on mining, Petterson (2007) indicated the "dark face" of mining as today's extraction of minerals, which is non-renewable, will reduce the availability of those minerals tomorrow, and furthermore, aspects such as pollution and environmental impacts may lead to community and political unrest. At the other end of the scale, that is, the "lighter face" of mining, Petterson (2007) mentioned benefits such as "the development of water supplies, school, church, medical facilities and buildings, health programmes such as malaria mitigation, sport facilities, scholarships, and work-related skills training and development."

The interaction between the three dimensions of sustainability is also known as triple bottom line accounting and a growing number of companies are publishing triple bottom line and sustainability reports (Brown and Fraser 2006). Many companies are reporting according to the Sustainable Reporting Guidelines (GRI 2002), which are voluntary guidelines that companies use to report on the three above-mentioned sustainability dimensions. The Global Reporting Initiative (GRI) is voluntary guidelines that companies use to report on the environment. The aim of the GRI is to enhance the quality of sustainability reporting (Ambe 2007).

### **Data Envelopment Analysis (DEA)**

Data Envelopment Analysis (DEA) is a non-parametric linear programming technique that measures the relative efficiency of a comparative ratio of outputs to inputs for each company (Ray 2004; Avkiran 1999). Unless managers are concerned that variables should be restricted because they are over-represented or under-represented, common practice allows the optimisation model to determine the weight for each variable (Avkiran 1999). DEA is a relative efficiency measure that accommodates multiple inputs, multiple outputs and other factors in a single model (Halkos and Salamouris 2004). The main usefulness of DEA is its ability to identify inefficient companies, to generate potential improvement for them and indicate efficient companies that should be used as a benchmark by the inefficient ones (Avkiran 1999).

The fundamental assumption of DEA is that

if company A is capable to produce  $Y(A)$  units of output with  $X(A)$  inputs, then other producers should also be able to do the same if they were operated efficiently. The core of the exercise is to find the “best” virtual producer for each real producer and then compare the producer to its best virtual producer in order to determine its efficiency. The best virtual producer is found by means of linear programming (Anderson 1996). DEA effectively estimates the frontier by finding a set of linear segments that envelop the observed data. DEA can determine efficiencies from an input-orientated (input minimisation) or output-orientated (output maximisation) point of view (Coelli et al. 2005). Furthermore, analysts choose between using constant return to scale (CRS) or variable return to scale (VRS). The first implies a proportionate rise in outputs when inputs are increased, in other words, a firm’s efficiency is not influenced by the scale of operations (Avkiran 1999). This is a significant assumption, since CRS may only be valid over a limited range and its use should be justified (Anderson 1996). “VRS implies a disproportionate rise or fall in outputs when inputs are increased” (Avkiran 1999), in other words, if a firm grows in size, its efficiency will not stay constant, but it will either rise or fall. The successful application of the assessment of comparative efficiency of companies depends on the selection of appropriate input variables and output variables (Min et al. 2009), which can be related to each other (Ray 2004) and should not be opposed to each other, but rather complementary (Li and Liang 2010).

#### Data Envelopment Analysis (DEA) Model

The following summarises the DEA model that was specified, with the following input variables: Greenhouse gas emissions in tons ( $x_1$ ), water usage in  $m^3$  ( $x_2$ ) and energy usage in giga joules ( $x_3$ ). The following output variables were specified: Number of employees ( $y_1$ ), taxes ( $y_2$ ), donations ( $y_3$ ), dividends ( $y_4$ ) and reinvestments ( $y_5$ ).

The three environmental impact indicators, namely greenhouse gas emissions, water usage and energy usage, were used as the input variables in the DEA model, because mining companies use these three indicators in their sustainability reports for benchmarking. Greenhouse

gas emissions consist mainly of carbon dioxide ( $CO_2$ ) and other gases such as methane ( $CH_4$ ), nitrous oxide ( $N_2O$ ), hafnium carbide (HFCs), perfluorinated compounds (PFCs), sulphur hexafluoride ( $SF_6$ ) and other  $CO_2$  equivalents. The water usage is the quantity that is indicated “for primary activity only.” Energy usage includes the following: electricity purchased from the national utility ESKOM; and energy from processes and fossil fuels consumed.

The aim of the DEA model is to determine how efficient the mining companies are in converting the above-mentioned environmental impact indicators (inputs) into economic and social gains (outputs). Therefore, five variables were selected that are to the benefit of various stakeholders. The first is the number of employees. This includes full-time employees from all operations plus contractors working on a temporary and full-time basis on the mine. The second is the gross payment of taxes to the government. The broader community is the beneficiary in this regard. Donations, where selected parts of the community are the beneficiary, is the third output variable. The fourth and the fifth output variables are mainly to the benefit of shareholders, namely dividends and reinvestments.

## METHOD

### Sample and Data

A convenience sample of nine South African mining companies was selected for the study and their annual financial information (2005 to 2009) was used. The reason why only nine mining companies were selected was due to the limited environmental data available and due to the limited number of mining companies that reported on environmental-related issues prior to 2005. The nine companies operate in the following sectors of the mining industry; three in the gold-mining sector (AngloGold Ashanti, Goldfields and Harmony), four in the platinum-mining sector (AngloPlat, ImpalaPlat, Lonmin and Northam), one in the coal-mining sector (Anglo Coal) and one is a diversified natural resources company (BHP Billiton). Documentary data from internal company sources, such as annual reports and sustainability reports, were used to acquire the information needed for this study.

### DEA Methodology

The software package of Zhu (2004) is purpose-built to solve the DEA problem and was used in this paper to generate estimates of the annual input-orientated and output-orientated technical efficiencies for each company over a five-year period. Technical efficiency estimates how well inputs are converted into outputs (Avkiran 1999). The less restricted VRC approach was used. The DEA formula is as follows (Zhu 2004):

*Input-orientated*

$$\begin{aligned} \min \theta - \epsilon \left( \sum_{i=1}^m S_i^- + \sum_{r=1}^s S_r^+ \right) \\ \text{subject to} \\ \sum_{j=1}^n \lambda_j X_{ij} + S_i^- = \theta X_{io} & \quad i=1,2,\dots, m; \\ \sum_{j=1}^n \lambda_j Y_{rj} - S_r^+ = Y_{ro} & \quad r=1,2,\dots, s; \\ \sum_{j=1}^n \lambda_j = 1 \\ \lambda_j \geq 0 & \quad j=1,2,\dots, n. \end{aligned}$$

*Output-orientated*

$$\begin{aligned} \min \phi - \epsilon \left( \sum_{i=1}^m S_i^- + \sum_{r=1}^s S_r^+ \right) \\ \text{subject to} \\ \sum_{j=1}^n \lambda_j X_{ij} + S_i^- = \theta X_{io} & \quad i=1,2,\dots, m; \\ \sum_{j=1}^n \lambda_j Y_{rj} - S_r^+ = \phi Y_{ro} & \quad r=1,2,\dots, s; \\ \sum_{j=1}^n \lambda_j = 1 \\ \lambda_j \geq 0 & \quad j=1,2,\dots, n. \end{aligned}$$

The input-orientated formula and the output-orientated formula calculate input minimisation and the output maximisation, respectively (where  $\theta$  indicates the efficiency score). Each observation,  $DMU_j$  ( $j = 1, \dots, n$ ), uses  $m$  inputs  $X_{ij}$  ( $i = 1, 2, \dots, m$ ) to produce  $s$  outputs  $Y_{rj}$  ( $r = 1, 2, \dots, s$ ), and where  $DMU_o$  represents one of the  $n$   $DMU$ s under evaluation, and  $X_{io}$  and  $Y_{ro}$  are the  $i$ th input and  $r$ th output for  $DMU_o$ , respectively. In order to consider any slacks, the presence of the non-Archimedean  $\epsilon$  effectively allows the minimisation over  $\theta$  to pre-empt the optimisation involving the slacks,  $s_i^-$  and  $s_r^+$ . [For a more detailed discussion on the DEA methodology, see Ray (2004), Zhu (2004) and Coelli et al. (2005)].

### EMPIRICAL RESULTS

Table 2 exhibits the relative technical efficiency of the nine mining companies that can be classified in four different sectors. The annual input-orientated and output-orientated techni-

cal efficiencies of each mining company are given from 2005 to 2009. These are estimates to indicate the efficiency of each company to convert the inputs (greenhouse gas emissions, water and energy) into outputs (number of employees, taxes, donations, dividends and reinvestments).

### DISCUSSION

Table 2 shows the average input-orientated technical efficiency of Platinum-mining company One is 0.992, implying that this company should reduce its input by 0.8% without reducing its outputs. Alternatively, the output-orientated technical efficiency of 1.006 implies that this company should increase its outputs by 0.6% without increasing its inputs.

Only the coal-mining company (One) was fully efficient (100 percent) for the whole period. The platinum-mining companies are the second most efficient with an average input-orientated estimate for the four companies (One to Four) of 96% and an output-orientated estimate of 104.9%. These companies were 13 out of the 20 times fully efficient. The single diversified company (One) is third with input- and output-orientated estimates of 92.9% and 103.9%, respectively. Diversified company One was also three of the five years fully efficient. The three gold-mining companies have the lowest efficiency estimates and none of them was fully efficient in any year. The average input-orientated estimate for these three companies is 77.5% and the average output-orientated estimate is 120.9%. The efficiency of the platinum-mining companies is ranked in overall second, third, fourth and sixth places, where the efficiencies of the gold-mining companies are ranked in the seventh, eighth and ninth places. It is also important to note that the efficiency estimates of the gold-mining companies are significantly worse than all the other mining companies.

It is not possible to compare these findings to other studies such as Ambec and Lanoie (2008), Orlitzky et al. (2003), King and Lenox (2001) and Rivera (2001), because, although the same topics were investigated, the aims were different and therefore the measuring methods were different. These other studies used the linear association method and could only indicate for example to mining-sectors whether it does / does not pay to be green for that sector. The problem is that the efficiency of an individual company

**Table 2: Input and output-orientated relative technical efficiency of different mining sectors**

| <i>Platinum</i>   |               |       | <i>Gold</i>       |               |       | <i>Diversified</i> |               |       | <i>Coal</i>       |               |       |
|-------------------|---------------|-------|-------------------|---------------|-------|--------------------|---------------|-------|-------------------|---------------|-------|
| <i>Efficiency</i> |               |       | <i>Efficiency</i> |               |       | <i>Efficiency</i>  |               |       | <i>Efficiency</i> |               |       |
| <i>Input</i>      | <i>Output</i> |       | <i>Input</i>      | <i>Output</i> |       | <i>Input</i>       | <i>Output</i> |       | <i>Input</i>      | <i>Output</i> |       |
| One 2005          | 0.962         | 1.031 | One 2005          | 0.815         | 1.196 | One 2005           | 0.763         | 1.164 | One 2005          | 1.000         | 1.000 |
| 2006              | 1.000         | 1.000 | 2006              | 0.731         | 1.316 | 2006               | 1.000         | 1.000 | 2006              | 1.000         | 1.000 |
| 2007              | 1.000         | 1.000 | 2007              | 0.778         | 1.218 | 2007               | 0.881         | 1.031 | 2007              | 1.000         | 1.000 |
| 2008              | 1.000         | 1.000 | 2008              | 0.799         | 1.165 | 2008               | 1.000         | 1.000 | 2008              | 1.000         | 1.000 |
| 2009              | 1.000         | 1.000 | 2009              | 0.794         | 1.140 | 2009               | 1.000         | 1.000 | 2009              | 1.000         | 1.000 |
| Average           | 0.992         | 1.006 | Average           | 0.783         | 1.207 | Average            | 0.929         | 1.039 | Average           | 1.000         | 1.000 |
| Two 2005          | 0.652         | 1.399 | Two 2005          | 0.658         | 1.358 |                    |               |       |                   |               |       |
| 2006              | 0.825         | 1.222 | 2006              | 0.637         | 1.344 |                    |               |       |                   |               |       |
| 2007              | 1.000         | 1.000 | 2007              | 0.605         | 1.400 |                    |               |       |                   |               |       |
| 2008              | 1.000         | 1.000 | 2008              | 0.698         | 1.257 |                    |               |       |                   |               |       |
| 2009              | 1.000         | 1.000 | 2009              | 0.953         | 1.038 |                    |               |       |                   |               |       |
| Average           | 0.895         | 1.124 | Average           | 0.710         | 1.279 |                    |               |       |                   |               |       |
| Three 2005        | 1.000         | 1.002 | Three 2005        | 0.883         | 1.091 |                    |               |       |                   |               |       |
| 2006              | 0.865         | 1.155 | 2006              | 0.856         | 1.117 |                    |               |       |                   |               |       |
| 2007              | 0.966         | 1.038 | 2007              | 0.757         | 1.221 |                    |               |       |                   |               |       |
| 2008              | 1.000         | 1.000 | 2008              | 0.835         | 1.136 |                    |               |       |                   |               |       |
| 2009              | 1.000         | 1.000 | 2009              | 0.823         | 1.134 |                    |               |       |                   |               |       |
| Average           | 0.966         | 1.039 | Average           | 0.831         | 1.140 |                    |               |       |                   |               |       |
| Four 2005         | 1.000         | 1.000 |                   |               |       |                    |               |       |                   |               |       |
| 2006              | 1.000         | 1.000 |                   |               |       |                    |               |       |                   |               |       |
| 2007              | 0.925         | 1.132 |                   |               |       |                    |               |       |                   |               |       |
| 2008              | 1.000         | 1.000 |                   |               |       |                    |               |       |                   |               |       |
| 2009              | 1.000         | 1.000 |                   |               |       |                    |               |       |                   |               |       |
| Average           | 0.985         | 1.026 | Total             |               |       |                    |               |       |                   |               |       |
| Total             | 0.960         | 1.049 | Average           | 0.775         | 1.209 |                    |               |       |                   |               |       |
| Average           |               |       |                   |               |       |                    |               |       |                   |               |       |

and sectors are not revealed, as being done in this study.

## CONCLUSION

The purpose of the study was to develop a DEA model to estimate the relative efficiency of South African mining companies in converting environmental impact into economic and social performance. To estimate the efficiency of sustainable development, the environmental impact indicators were used as input variables and both economic and social indicators are used as output variables. The limitation of the study is that only a limited number of companies were included, because of the fact that not all the companies submitted sustainability reports according to GRI guidelines. Clear trends could be identified with regard to four platinum- and three gold-mining companies. Since only one diversified and only one coal mining-company were included, no trend could be identified.

The study found that all the individual coal-, diversified- and platinum-mining companies were most of the time fully efficient, whereas all

the gold-mining companies were never fully efficient. The six most efficient companies are the coal-, diversified- and four platinum-mining companies and the most inefficient companies are the three gold-mining companies. It was also noted that the efficiency scores of the gold-mining companies are much worse than the efficiency scores of all the other companies. Therefore, the relative environmental impacts of gold-mining companies are much more than the impacts of all the other companies to generate gains for shareholders and other stakeholders. The practical implication is that gold-mining companies should use the coal- and platinum-mining companies indicated in this study as a benchmark for best practice in sustainable development. Furthermore, from an input-orientated view, managers, investors, business partners and the government can become aware of the fact that it seems that gold-mining companies harm the environment to a greater extent than other mining companies to create jobs, to support the community by taxes and donations, and create value to their shareholders by means of dividends and reinvestments. From an output-orientated view, these share-

holders and other stakeholders' gains should be increased relative to the environmental impact factors.

## RECOMMENDATIONS

The value of the study is that this is the first effort to develop a DEA model to estimate the efficiency of mining companies in converting environmental performance impact indicators into economic and social gains for both shareholders and other stakeholders. As more and more companies report on their environmental impact, a similar study should be conducted to include more mining companies from different sectors. This will allow a greater discrimination between the companies, due to the larger quantity of data and more clear differences regarding the mining companies in the various sectors.

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