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A SUSTAINABILITY COST ACCOUNTING METHODOLOGY FOR TECHNOLOGY MANAGEMENT IN THE PROCESS INDUSTRY

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ABSTRACT

Decision-makers in the South African process industry have communicated the need to express all aspects of sustainable development into monetary terms for internal decisions. Especially where new technology developments are undertaken, the region-specific positive and negative impacts should be reflected in the financial evaluations of the related projects. A framework of criteria is introduced to incorporate all aspects of sustainable development of operational initiatives, such as technology management, into the assessment process during project Life Cycle Management (LCM) as a strategic competence. The criteria consider the two life cycles that are fundamental to managers in this process industry sector during project LCM: the asset life cycle that is required to manufacture products, and the product life cycle from which income is derived. The economic criteria of the framework are centred on the internal financial feasibility of a project, whereas environmental criteria are concerned with the external impacts of the asset and product life cycles. The social criteria include both internal and external aspects that are influenced by operational initiatives. A Sustainability Cost Accounting (SCA) methodology is introduced to translate the framework criteria (where possible) into monetary indicators. Existing methodologies from developed countries are adapted for the economic and environmental criteria. In these cases price indexes and discounting is used to obtain monetary values throughout the life of the implemented project. The monetary conversions of the social criteria are region-specific and consider the expenditures for and contributions of the technology to society over its life cycle. A case study in the South African context (to manufacture Gas-To-Liquid diesel) is used as basis to demonstrate the SCA methodology.

INTRODUCTION

Business (including industry), as one of the three pillars of society (the other two being government and civil society) (Wartick and Wood, 1998), has a responsibility towards the whole of society to actively engage in the sustainability arena, and the long-term survival strategy for a company must allow the incorporation of sustainability into decision-making practices (Holliday *et al.*, 2002). The pressure is therefore mounting for businesses to align operational processes with the three objectives of sustainable development (Keeble *et al.*, 2003), namely: economic, environmental and social sustainability.

In South Africa, companies are also moving towards a more sustainable approach for internal decision-making processes (Van der Walt, 2003). However, the South African legislation mainly focuses on environmental issues (Sampson, 2001), and enforcement and compliance to governmental legislation is weak and environmental management is often of low importance to industry (Brent *et al.*, 2002). In terms of social sustainability, legislation dealing with social aspects has been tabled, but unlike environmental legislation it does not currently affect South African businesses in a direct manner (Labuschagne, 2003). Compared to developed countries, the South African manufacturing sector is typically lagging with respect to incorporating social aspects of sustainability at several levels within the organisation.

Nevertheless, as the markets of large South African companies expand, and they become multinational companies, more strict legislation and enforcement is faced. The global sustainability pressures, through international trade barriers and the promotion of parent companies, consequently drive South African companies to change management practices and production methods (Sampson, 2001). Assessing potential liabilities and sustainability risks of newly developed technologies is therefore fundamental to the technology management process in these South African companies.

Identification of measurable indicators to assess the sustainability of technologies

The identification of suitable indicators to measure the impacts of an operational activity, e.g. a newly developed technology, on the three main sustainability dimensions is dependent on the preferences of the specific assessors and decision-makers of sustainability performances in industry. Two approaches are currently under debate (Labuschagne *et al.*, 2005). On the one hand all impacts could be translated into financial terms, which is often understandable in terms of reasonable objectivity by decision-makers. On the other hand, it is difficult, if not impossible, to place an economic value on all environmental and social impacts, and a qualitative (and quantitative) route with decision analysis techniques, e.g. Multi-Criteria Decision Analysis (MCDA), could be used for comprehensiveness.

The former approach has been dealt with extensively, especially with respect to environmental sustainability. For example, an "account of sustainability" has been proposed, which attempts to calculate the additional costs that would be borne by an organisation in order for a newly developed technology to leave no detrimental effects (on the natural environment) at the end of an accounting period (Gray, 1992). Such approaches have been formalised into what is now known as full cost accounting (FCA) (Milne, 1991; Atkinson, 2000; Bebbington *et al.*, 2001; Mathews and Lockhart, 2001; Carter *et al.*, 2001) and total cost assessment (TCA) (AIChE, 2000) procedures. However, the social aspects of sustainability in these and similar studies are ill represented (World Bank, 2003).

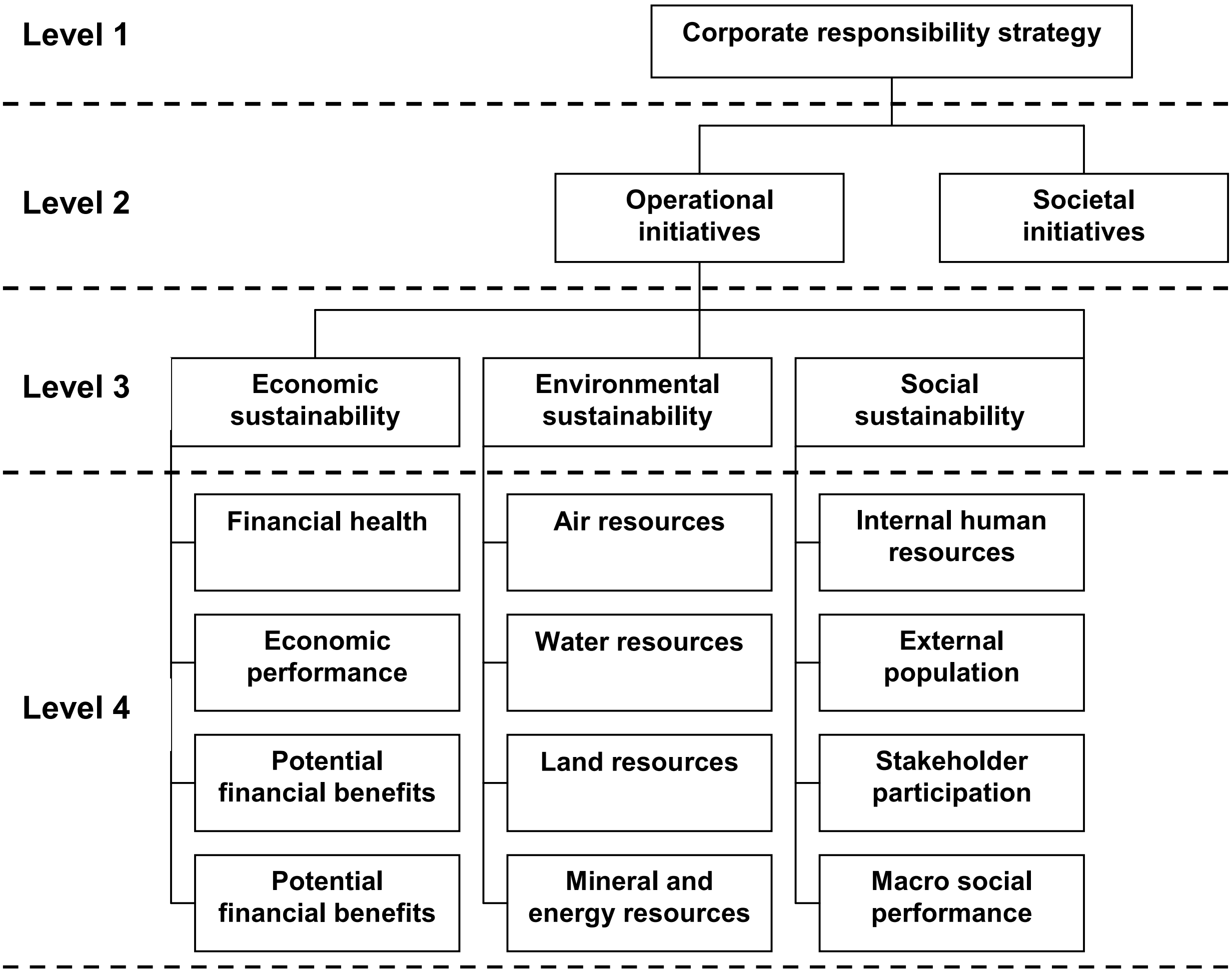

Figure 1. A proposed sustainability assessment framework (Labuschagne *et al.*, 2005)

Based on these established FCA and TCA procedures, this paper introduces a Sustainability Cost Accounting (SCA) procedure to assess the environmental and social impacts of a new technology in the process industry in monetary terms, and therefore the overall sustainability performances of a technology with respect to the "triple bottom-line" (Elkington, 1997). Thereby, sustainability weaknesses and associated improvement possibilities of the assessed technology can be identified. Although the SCA procedure has been developed specifically for technology management purposes in the South African process industry, it can be applied to other regions and industry sectors.

The SCA procedure is based on a framework of appropriate criteria to assess the sustainability performances of industry activities (Labuschagne *et al.*, 2005). The framework is shown in Figure 1 and is divided into different levels to address the separate aspects of corporate responsibility strategy in terms of sustainability. The sub-criteria (level 4) in the framework to evaluate the performances of an operational initiative, e.g. a deployed technology, in terms of the three main dimensions of sustainable development are described in Tables 1 to 3.

Table 1. Definitions of the criteria included in the economic dimension of the sustainability assessment framework (see Figure 1)

Category/Criteria	Definition
Economic sustainability	**The economic dimension concerns the economic health and viability of a developed technology. It has an internal focus that evaluates the organization's short and long-term financial stability and survival capabilities through the introduction of the technology.**
Financial Health	Financial Health entails those aspects assessing the internal financial stability of a company (and an introduced technology) and includes traditional measures such as profitability, liquidity and solvability.
Economic Performance	Economic Performance assesses the company's value (due to an introduced technology) as perceived by shareholders, top management and government and includes measures such as share profitability, contribution to Gross Domestic Product as well as market share indicators.
Potential Financial Benefits	Potential Financial Benefits assess financial benefits other than profits, e.g. national and/or international subsidies based on the environmental, social and/or technological improvements due to an introduced technology.
Trading Opportunities	Trading Opportunities assess the vulnerability of the organization's trade network as well as the risks it is exposed to by the network it is embedded in (due to an introduced technology), by considering the number of national and/or international organizations in the trade network.

Table 2. Definitions of the criteria included in the environmental dimension of the sustainability assessment framework (see Figure 1)

Category/Criteria	Definition
Environmental Sustainability	**The environmental dimension concerns an organization's impacts on the environment due to an introduced technology. It has an external focus and addresses impacts on air, water, land and mined abiotic resources.**
Air Resources	Air Resources assess a technology's contribution to regional air quality effects (e.g. visibility, smell, noise levels, etc.) as well as to global effects such as global warming and stratospheric ozone depletion.
Water Resources	Water Resources assess the availability of clean and safe water by focusing on a technology's impacts on the quantity and quality of water.
Land Resources	Land Resources assess a technology's impacts on the quantity and quality of land resources, including aspects such as biodiversity, erosion, transformation and rehabilitation ability, etc.
Mined Abiotic Resources	Mined Abiotic Resrouces assess a technology's contribution to the depletion of non-renewable mineral and energy resources.

Table 3. Definitions of the criteria included in the social dimension of the sustainability assessment framework (see Figure 1)

Category/Criteria	Definition
Social Sustainability	**The social dimension concerns the technology's impact on the social systems in which it operates, as well as the organization's relationships with its various stakeholders during the development, operation and decommissioning of a technology.**
Internal Human Resources	Internal Human Resources focuses on the social responsibility of the company towards its workforce and includes all aspects of employment (e.g. employment practices, work conditions, workforce development, etc.)
External Population	External population focuses on the impact of the technology on a society, e.g. impact on availability of services; community cohesion, economic welfare, etc.
Stakeholder Participation	Stakeholder participation focuses on the relationships between the company and ALL its stakeholders (internally and externally) by assessing the standard of information sharing and the degree of stakeholder influence on decision-making.
Macro Social Performance	Macro Social Performance focuses on the contribution of an organization (and its technology) to the environmental and financial performance of a region or nation (e.g. contribution to exports).

THE SUSTAINABILITY COST ACCOUNTING (SCA) PROCEDURE

The monetary valuation of sustainability is similar to the methodology of cost-benefit analysis (CBA) in order to internalise, at corporate decision-making level, the externalities associated with an assessed technology, e.g. human health impacts on a macro-scale. Thereby, the Sustainability Cost Accounting (SCA) procedure enables trade-offs between costs (external impacts or deterioration in society and the natural environment) and benefits (internal and external contributions). However, the differences in the allocation of imposed costs and created benefits makes trade-offs problematic from a theoretical perspective in that trade-offs adhere to the concept of weak sustainability (Rennings and Wiggering, 1997; Atkinson, 2000). Although a company might contribute more than the damages it causes, these contributions do not necessarily compensate for the damage costs. Therefore, trade-offs between the sub-criteria at level 4 of Figure 1 might be unjustified, and it is recommended that decision-makers undertake caution when comparing the SCA indicator results and subsequently interpreting the overall sustainability of an assessed technology (Van Erck, 2003).

Nevertheless, whether addressing environmental or social aspects, sustainability cost accounting adheres to four steps of an economic CBA that have been distinguished (Blignaut, 1995; Van Pelt, 1993a):

1. Making an inventory of (positive and negative) impacts on the environment and society as well as on the economic situation of the company.
2. Determination of the monetary value of the impacts.
3. Discounting long-term effects.
4. Assessing risk and uncertainty in case probabilities can be assigned to the likelihood that an event (industrial accident) will occur, or little is known about future impacts and no probabilities can be assigned.

The fourth step is specific with respect to the evaluated technology and the industry sector. For this reason it is not explicitly addressed in the generalised SCA procedure.

Inventory of impacts

In this step, all costs and benefits that are imposed by a company (as a by-product of its economic activity) on third parties are identified. The benefits consider improvements to sustainability, which include the wealth created by a company (through an introduced technology), or the expenditures of a company from which society and the natural environment benefits. The negative impacts concern damage costs, which are the costs associated with the impacts of a technology on the environment and society for which a company is not held (financially) responsible. These externalities have also been referred to as "societal costs" (EPA, 1995a).

Determining the monetary values of impacts

Different techniques are available to evaluate externalities, with definite possibilities and limitations to apply them for the SCA procedure. However, the techniques have been differentiated between (Van Pelt, 1993a; Van Erck, 2003):

- "Cost approaches", which assess actual costs or hypothetical expenditures aimed at reducing or eliminating impacts; the two methods that are most often used to establish a range of values for environmental externalities are the damage-cost and the cost-of-control approaches, and
- "Benefit approaches", which analyse how changes in environmental and social quality affect income or wealth generation in society; one technique that is used is to calculate opportunity costs to preserve an asset (instead of appraising a certain function), e.g. relocating an industrial plant to secure an ecological sensitive area.

For the SCA procedure published externality cost values from developed countries, based on these two approaches, are adopted for South Africa. Two methods are applied to convert the published data for the South African situation in 2002 with respect to environmental impacts (Van Erck, 2003):

- The damage costs to human health that are proposed in international studies are dominated by the valuation of mortality (Spadaro and Rabl, 2002). The single most important parameter is the "value of a statistical life". Assuming these valuations vary in direct proportion to income, an adjustment is made to the USA and European values to reflect, for example, South African income levels (see Table 4).
- The differences in price levels between countries are used to adapt damage costs of buildings and crops affected by pollutants, and to convert damage costs associated with land use. It is assumed that the relative value of these assets and the price levels in a country thereof reflect the restoration costs. The differences in price levels are shown in Table 5.

The costs of global environmental impacts associated with a company's emissions do not only affect the area or region where the company is located; the economical estimates of the scale of damages from these pollutants account for global costs and no adjustment of these values are therefore required for South Africa.

Table 4. GDP/capita ratios (for 2002) of South Africa compared to developed countries or regions (Nationmaster, 2003)

Country or Region	GDP/capita (US$)	Ratio
South Africa	9.44	1.0
United States of America	35.94	3.8
European Union	24.83	2.6

Table 5. Price index of South Africa compared to developed countries or regions (EIU, 2004)

Country or Region	Price Index[a]	Difference[b]
United States of America	87.3	62 %
European Union	78.7	56 %
South Africa	49.0	-

[a] The Economist Intelligence Unit (2004) calculates the costs of living for mayor cities worldwide. The costs of living are determined by considering the costs of a number of goods and services. The price indexes of fourteen different USA cities and 19 cities in the European Union have been compared to price levels in the cities of Johannesburg and Pretoria in South Africa.

[b] Difference between Price Indexes of developed country or region compared to South Africa.

Certain published damage costs are problematic altogether and have not been used in the SCA procedure. For example, macro socio-economic indicators based on the willingness to pay approach (AIChe, 2000; Blignaut, 1995; Van Pelt, 1993a) have been shown to be unsuitable in the South African context (Brent and Hietkamp, 2003).

With respect to social impacts, the actual costs are country-specific and must therefore be determined on a case-by-case basis.

Discounting long-term effects

The discounting of long-term costs and benefits is one of the most widely criticised elements of particularly environmental CBAs (Van Pelt, 1993b). The primary reason is that future environmental costs and benefits have a small impact on the Net Present Value (NPV) of developed technologies. This is advantageous to operational initiatives with long-term environmental impacts and associated costs.

The SCA methodology applies marginal costs of environmental impacts that have been proposed in literature. The discount rates in the published studies apply for different economic regimes and have to be adjusted in order to be applicable for South Africa. In general, the discount rates that are used in literature are relatively low, e.g. a discount rate of 2% has been proposed (Hartridge and Pearce, 2001). These low rates of discount are used because growing scarcity of environmental assets will push selling prices upwards and therefore contribute to increasing margins between cost and benefits, which mitigates the impact of discounting. In contrast, for poorer countries, a discount rate of between 5 and 8 % has been suggested (Van Pelt, 1993b), given the low growth rates and low marginal returns. For a country, such as South Africa, with mixture of first- and third-world conditions, a discount rate of 4 % is adopted for the purposes of this paper. However, it has been shown that small changes in discount rate can change the results of the SCA assessment substantially (Van Erck, 2003), which should be considered during the interpretation of the results, e.g. through sensitivity analyses. This is addressed in the cases study example of the paper.

THE SUSTAINABILITY COST ACCOUNTING (SCA) INDICATORS

Practicable Sustainability Cost Accounting (SCA) indicators have been proposed (Van Erck, 2003), based on the theoretical requirements of the SCA procedure and the framework to evaluate a developed technology in terms of sustainable development. The indicators have been developed for the criteria at level 4 of the framework (see Figure 1) and are summarised in Tables 6 to 8. The tables provide the costs (of impacts) in the South African currency (for the year 2002), i.e. the Rand (R), for direct use in the South African industry.

Table 6. The economic indicators that are used in the SCA procedure

Main criteria	Sub-criteria	Indicator	Comments
Financial health	Financial health	Profit after tax	Estimate figures from annual (financial) reports
Potential financial benefits	Potential financial benefits	Financial benefits other than tax reductions directly related to an operational initiative	Estimate figures from annual (financial) reports

Table 7. The environmental indicators that are used in the SCA procedure

Main criteria	Sub-criteria	Indicator	References	Cost (2002)	Comments
Air	Regional pollution	Impacts on human health (in R_{2002}/kg) due to: SO_2 NO_x Heavy metals PM_{10} Photochemical ozone	(EPA, 1995b) (Rabl and Eyre, 1998) (European Commission, 1997)	See Table 9	Based on a population density of 80 inhabitants/km^2
		Impacts on buildings (in R_{2002}/kg) due to: SO_2	(European Commission, 1997)	R 2.03 per kg of pollutant	Based on a population density of 80 inhabitants/km^2
		Impacts on crops (in R_{2002}/kg) due to: Photochemical ozone		See Table 9	Based on a population density of 80 inhabitants/km^2
	Global pollution	Impacts (in R_{2002}/kg) due to Greenhouse Gases (equivalent CO_2)	(European Commission, 1997) (Spadaro and Rabl, 2002) (Van Erck, 2003)	R 0.22 per kilogram of CO_2 equivalent	Damage costs are based on the lower global estimates of the European Commission
Water	Water use	Difference between opportunity costs and water price	(Van Horen, 1996) (Nieuwoudt, 2002)	R 1.99/m^3	Estimate based on difference between opportunity costs (Van Horen) and water price (medium estimate from Nieuwoudt)
	Water pollution		(AIChe, 2002)	Negligible	Based on willingness to pay and is considered negligible
Land	Land use	Opportunity costs for the total area affected	(Constanza *et al.*, 1997)	See Table 10	Based on the specific land type that is affected
	Land pollution	Remedy costs	(AIChe, 2002)	Negligible	Based on willingness to pay and is considered negligible
Mined abiotic resources	Minerals and energy resources	Cost of economic depreciation of non-renewable resources	(El Serafy, 1996) (Van Erck, 2003)	Calculated user costs of specific natural resources	Discount rate of 4% for South African setting

Table 8. The social indicators that are used in the SCA procedure

Main criteria	Sub-criteria	Indicator	Comments
Internal human resources	Employment stability	Expenses on: Wages U.I.F. Life insurance Medical aid	Adopt expenditures from annual financial reports. Based on expected number of employees required to manufacture a product or provide a service
	Health and safety	Cost (to a company) of medical mortality/morbidity	Damage costs of mortality and morbidity of employees resulting from their manufacturing or service provision activity for a newly developed technology
	Capacity development	Investments in training, education and R&D	Adopt expenditures from annual (financial) reports
External population	Human capital	Investments in medical and educational facilities directly attributable to an introduced technology	Adopt expenditures from annual reports or project specific publications
	Community capital	Real estate price changes in the area where a technology is introduced	Base estimates on real estate prices provided by local real estate agents and total real estate value provided by municipalities
Stakeholder participation	Stakeholder participation	Expenses on Environmental Impact Assessments	Company-specific information
Macro-social performance	Socio-economic performance	Tax on profits Tax on wages Other taxes	Adopt expenditures from annual financial reports. Based on expected profit and number of employees related to a manufactured product or provided service
	Socio-environmental performance	Expenditure on monitoring	Expected investment in regional pollution monitoring due to the introduced technology

Table 9. Damage costs of selected regional air pollutants

Pollutant	Impact	Costs (€/kg)[a]	Reference	Converted costs (Rand/kg)[b]
PM_{10} (primary)	Mortality and morbidity	15.40	(Spadaro and Rabl, 1999)	63.80
SO_x (primary)	Mortality and morbidity	0.30	(Spadaro and Rabl, 1999)	1.24
SO_x (via sulphates)	Mortality and morbidity	9.95	(Spadaro and Rabl, 1999)	41.20
NO_x (primary)	Mortality and morbidity	Negligible	(Spadaro and Rabl, 1999)	—
NO_x (via nitrates)	Mortality and morbidity	15.70	(Spadaro and Rabl, 1999)	65.00
NO_x (via O_3)	Mortality and morbidity	1.15	(Rabl and Eyre, 1998)	4.76
NO_x (via O_3)	Crops	0.35	(Rabl and Eyre, 1998)	2.37
VOC (via O_3)	Mortality and morbidity	0.73	(Rabl and Eyre, 1998)	3.04
VOC (via O_3)	Crops	0.20	(Rabl and Eyre, 1998)	1.32
CO (primary)	Cancer	0.02	(Spadaro & Rabl, 1999)	0.08
As	Cancer	171.00	(HEAST, 1995)	708.00
Cd	Cancer	20.90	(HEAST, 1995)	87.00
Cr (VI)	Cancer	140.00	(HEAST, 1995)	580.00
Ni	Cancer	2.87	(HEAST, 1995)	11.90

a The damage costs assume an average population density of 80 persons/km^2, in 1995 prices.

b The damage costs converted to South African circumstances, in 2002 price.

Table 10. Damage costs per hectare of selected land use types (Constanza *et al.*, 1997)

Type of land affecteda	Value per hectare (US$/ha/year), 1997 prices
Forests	302.00
Grass/rangelands	232.00
Wetlands[b]	14785.00
Lakes/rivers[b]	8498.00
Cropland	92.00
Urban	0.00
Other	0.00

a The values of these specific land types are extremely regionally bound.

b The high damage costs of these affected land types are due to the scarcity of these natural assets in the specific regions where the study was conducted.

Attributes of the SCA procedure in terms of the value of company means and assets

By applying the monetary appraisal to determine a technology's sustainability performance, only those impacts on criteria that are convertible in monetary terms are taken into consideration. These impacts can be divided into two categories:

- The first category results from some of the money flows from and to a company. These money flows are all part of the company's turnover and some contribute to the sustainability of the company or its operational initiative, such as the profit.
- The second category results from impacts on assets the company does not (directly) pay for. The most important of these (macro) effects are the so-called externalities, such as damage costs from pollution.

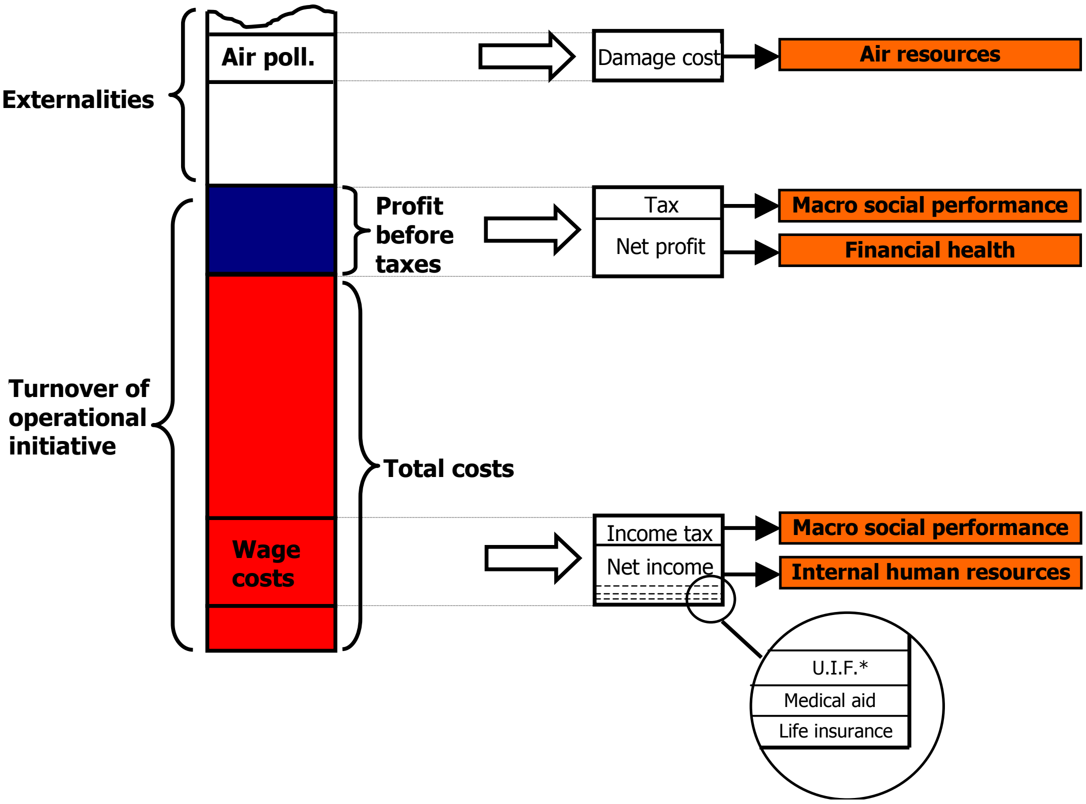

Figure 2. Example of the mechanism used for Sustainable Cost Accounting

Figure 2 illustrates how these different impacts can be linked to corporate financial evaluations. In Figure 2 the bar on the left represents the total value of means and assets, which a company has control over. Some of these means are allocated in such a way that it contributes to the sustainability of the company. On the other hand, some of the impacts on assets decline the company's (and evaluated technology's) sustainability.

An example of allocation of means that contribute to the company's sustainability is the profit from its operations. As shown in the figure the profit contributes to different aspects of sustainability. The taxes paid over profit are contributions to the government's budget, which is used to benefit society. These fall under "macro social performance" as part of social sustainability in the framework (see Figure 1). The profit after taxes contributes to the financial health of the operational activity (e.g. a technology) and contributes therefore to the economic sustainability of the company.

Another example is the expenditure on wages that are part of the company's costs. These expenditures contribute to the social sustainability of the company's activity. Figure 2 illustrates how different parts of these expenditures are divided in terms of sustainability. As are shown, costs do not necessarily have a negative impact on the result of the SCA of the operational initiative; if these costs are expenses society benefits from these costs are credited in other aspects of the total sustainability assessment.

The bar in Figure 2 represents a value, but gives no indication whether a part of this value has a positive or a negative impact on the company's sustainability. By the translation of parts of this value to the different operational sustainability sub-criteria (level 4 of Figure 1) that distinction is made.

CASE STUDY EXAMPLE

A hypothetical (technology) case study in the process industry of South Africa is used in order to demonstrate the proposed Sustainability Cost Accounting (SCA) procedure. The case study increases the understanding of the possible practical obstacles of the methodology. Furthermore, it reveals how positive and negative impacts (of a specific technology in the process industry) on sustainability relate to each other. The case study indicates what the major impacts are (of a specific technology in a specific location) and how these impacts are expected to change if certain system conditions changed.

Three of the key premises to apply the SCA procedure to the case study are:

- The assessment merely focuses on the environmental, social and economic sustainability of a specific operational initiative (or technology); therefore, all Corporate Social Responsible (CSR) projects, which are not associated with the specific technology, are excluded.
- The assessment is exclusively based on the monetary indicators that have been proposed for the SCA procedure. Therefore not all of the criteria (of a comprehensive sustainable development framework) receive due consideration. The implications of this limitation are addressed.
- An assessed technology is inextricably bound to its location in that the associated regional or local impacts (of the technology) are site-specific.

All the cost figures are reported in the South African Rand currency (at 2002 price levels), which, at the beginning of 2005, traded at a level of approximately 6 Rand to 1 US$, or 8 Rand to 1 €.

Scope of the hypothetical case study

Location of the case study. The case study aims to assess the overall sustainability of the known Gas-to-Liquid (GTL) technology, which converts natural gas to liquid fuels (Sasol, 2002). The assessment is based on a full-scale production plant in the town of Secunda in central South Africa. Secunda exists solely due to the construction of a Coal-to-Liquid (CTL) manufacturing plant. The operation of the (hypothetical) plant is assumed to be similar to the current facility in Secunda. However, no process-specific data are used from the existing plant. Rather, published data are used, e.g. reported life cycle inventories (Marano and Ciferno, 2001).

The choice for the setting is important for the SCA procedure as site-specific data, e.g. real estate prices, land prices and population density, affect the outcome of the procedure. The primary advantage of using the Secunda site for the case study is its isolated setting, which makes it simpler to recognise and attribute different impacts to the operational activity, especially with respect to environmental and social impacts. Impacts are often difficult to attribute to one operational activity alone if a plant is located in an established industrial area. In the case of Secunda, the region consisted of agricultural land, primarily maize and livestock, before the coal-based plant was constructed. Even now, no major industries have emerged in the close vicinity of the main petrochemical facility. Furthermore, a Strategic Environmental Assessment (SEA) of the facility in Secunda is available in the public domain, which provides more detailed information on environmental and social impacts around this specific site (CSIR, 2000). Especially patterns of pollutants, information about water use and land use are valuable.

Boundaries of the case study. All impacts on sustainability resulting from a deployed technology can be attributed to two distinct life cycles: the life cycle of the technology itself, as well as the life cycle of the product (or service) that arises from the implemented technology (Labuschagne and Brent, 2005). Figure 3 illustrates the integration of these two life cycles for a technology in the process industry. In the figure the process life cycle is presented by one axis that focuses on the physical structure of the plant (or technology). The other axis represents the product life cycle.

A SCA evaluation of the sustainability of a technology must therefore clearly establish (in a transparent manner), which life cycle phases are included or excluded in the evaluation.

Determining the aspects that are considered in an evaluation could have an important influence on the outcomes of a technology assessment study.

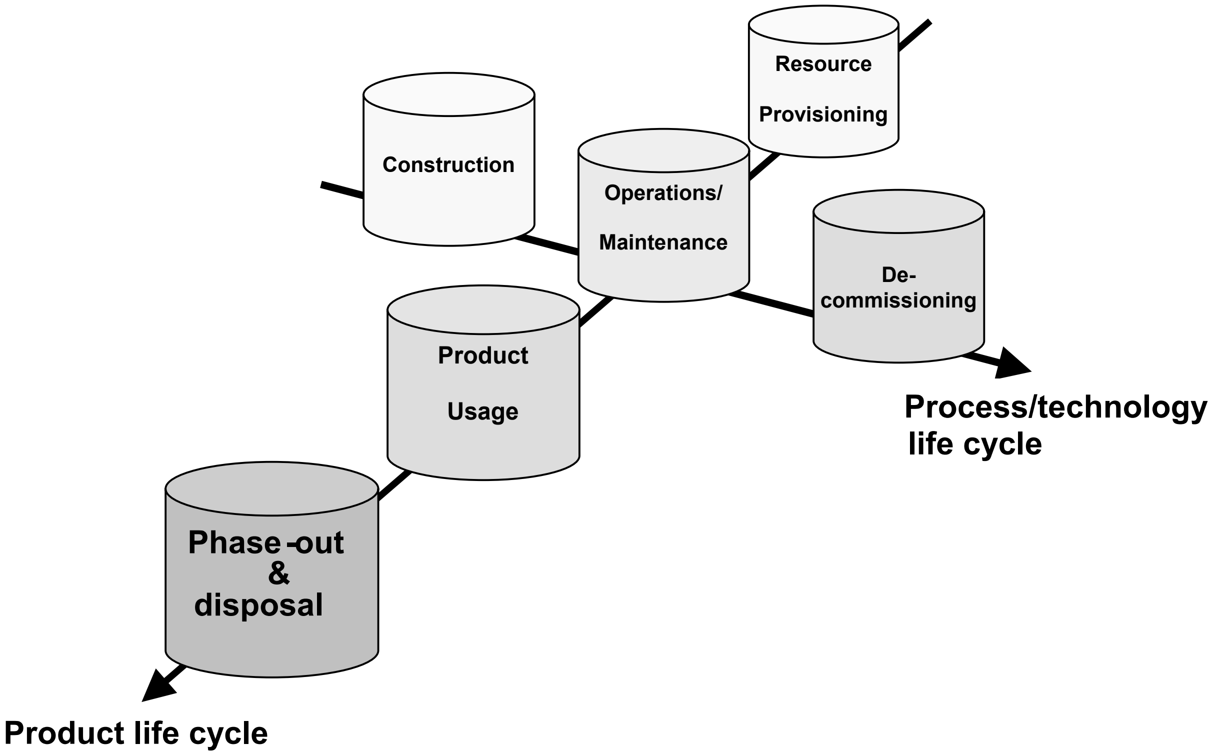

Figure 3. The different life cycle phases of an introduced technology (in the process industry) that must be considered

The choice of the Secunda site is not ideal for (natural gas) GTL manufacturing when transport to and from the facility is taken into account. Because of its limited natural gas resources, the South African process industry is forced to obtain its primary feedstock elsewhere. In the case of Secunda, the natural gas is obtained by means of a pipeline from Mozambique (Sasol, 2002). This is considered an inevitable limiting condition and therefore forms part of the context in which the technology is deployed.

Apart from the impacts associated with obtaining the natural gas feedstock, impacts resulting from the electricity requirement of the evaluated GTL facility are also included, since these impacts were expected to be significant. All other supporting industries of the operational activity are excluded from the boundaries, since these are considered to be minor in comparison to the evaluated impacts (Marano and Ciferno, 2001). Also, the life cycle of the manufactured product is not been considered in order to simplify the assessment case study. Thereby, the case study focuses on the sustainability of the manufacturing GTL technology only and not on the manufactured product.

Furthermore, the flows of materials that result from the construction, use and decommissioning of production capital (in the process life cycle) are not considered in the assessment. This capital consists of the physical structure of the plant, and supplies and services facilitating operations other than raw materials for the production process. Calculations made in the ExternE project (European Commission, 1997) show that the environmental impacts associated with material inputs to fossil power plants are two to three orders of magnitude lower than those from the power generation stage. Similar numbers are assumed for a GTL plant.

The functional unit of the case study. In order to account and compare the impacts associated with the inventory results of the case study, it is necessary to select one functional unit to use when reporting the results. The functional unit that is used for the assessment is "a barrel of fuel produced on an annual basis". The choice of a barrel, rather than a metric unit such as a tonne, is that the unit is generally used in industry and no conversion is needed when adopting data from literature.

Economic sustainability of the GTL technology

The economic sustainability of a GTL operation is based on the financial figures of the specific technology. The indicators that are taken into account with the SCA procedure are the operational activity's profit after tax, and the additional financial benefits.

The profitability of the GTL technology is based on financial data of the current coal-conversion operation in Secunda (Sasol, 2002). Therefore, the estimated marginal production profitability of the GTL conversion (from natural gas) is assumed to be at least comparable with the current operations (with coal as feedstock), i.e. a company (in a developing country) would not consider converting to a new feedstock if it was not the more economical feasible option.

The assessment only focuses on the fuels produced (and not on other chemical products) and therefore it is necessary to determine what part of the profit made by the Secunda operations can be attributed to the fuel production. To do so the annual turnover in terms of fuel sales and the profit margin on these fuels is established, based on the regulated wholesale fuel price in South Africa (DME, 2003). The profit after tax or attributable earnings of the GTL fuel, which is currently produced at Secunda, is 115.50 R/bbl based on 2002 prices (Van Erck, 2003). The profitability of manufacturing GTL fuel from natural gas would therefore be at least this amount. The profitability of these types of operations includes all additional financial benefits, e.g. subsidies from government, and these are not reported on separately for the case study.

Environmental sustainability of the GTL technology

Two steps are required to process the relevant data to assess the environmental impacts associated with the GTL technology. Firstly, an inventory has to be made that catalogues and quantifies all materials and energy used and the environmental releases arising from all stages in the life cycle system. This is the Life Cycle Inventory (LCI) as defined by the ISO standard 14041 (ISO, 2005). The second step is to analyse how these uses and releases affect actual and potential environmental and human health areas of concern. This is referred to as the Life Cycle Impact Assessment (LCIA) according to the ISO standard 14042 (ISO, 2005). The LCIA step is incorporated in the environmental indicators of the SCA procedure.

Three aspects need to be considered when evaluating the environmental sustainability of the GTL technology (Van Erck 2003):

- Distances; for the Secunda setting the pipeline connecting the plant with the gas fields of Temane in Mozambique is 865 km in length.
- Size of the manufacturing facility; the capacity of the hypothetical plant is assumed to be equal to the current coal-based facility (118 000 bpd), and is similar to the capacities of the plants discussed in literature with respect to LCIs (Marano and Ciferno, 2001).
- Influence of population density; the health impacts associated with regional pollution directly relate to the population density in the close and remote vicinity of the manufacturing plant. For the case study, cost data from other studies (Spadaro and Rabl, 2002) and site-specific dispersion patterns of regional air pollutants (CSIR, 2000) are used to determine the distance from the plant in which the population is affected by the normal operation of the plant. Thereby, the areas around Secunda that are (significantly) affected by primary and secondary air pollutants are determined. Thereafter, actual damage costs (or SCA indicators) can be calculated based on the representative affected population densities. Based on numerical integration it is estimated that 27 % of the total primary pollutants are detected within a 30-kilometre radius of the source, in which all of the major towns around Secunda are located with a population density of 242 inhabitants/km^2 (Van Erck, 2003). The remaining 73 % affects an average population density equal to that of the area in a 500-kilometre radius from the plant (54 inhabitants/km^2) (Van Erck, 2003). The outer boundary is therefore set at 500 km. These areas are shown in Figure 4.

Impacts on air resources. The Life Cycle Inventory (LCI) of the air emissions (Marano and Ciferno, 2001) of the full life cycle is shown in Table 11 (Van Erck, 2003). With respect to the impacts on a global level, the only damage costs caused by emissions of N_2O and CH_4 are attributable to the contributions to greenhouse effects and these pollutants are not reported separately. Rather, the CO_2 equivalent totals are added (Guinée *et al.*, 2001). By multiplying the adjusted damage costs (or indicators) of the SCA procedure with the amount of air pollutants emitted the total damage cost are calculated (see Table 11) (Van Erck, 2003).

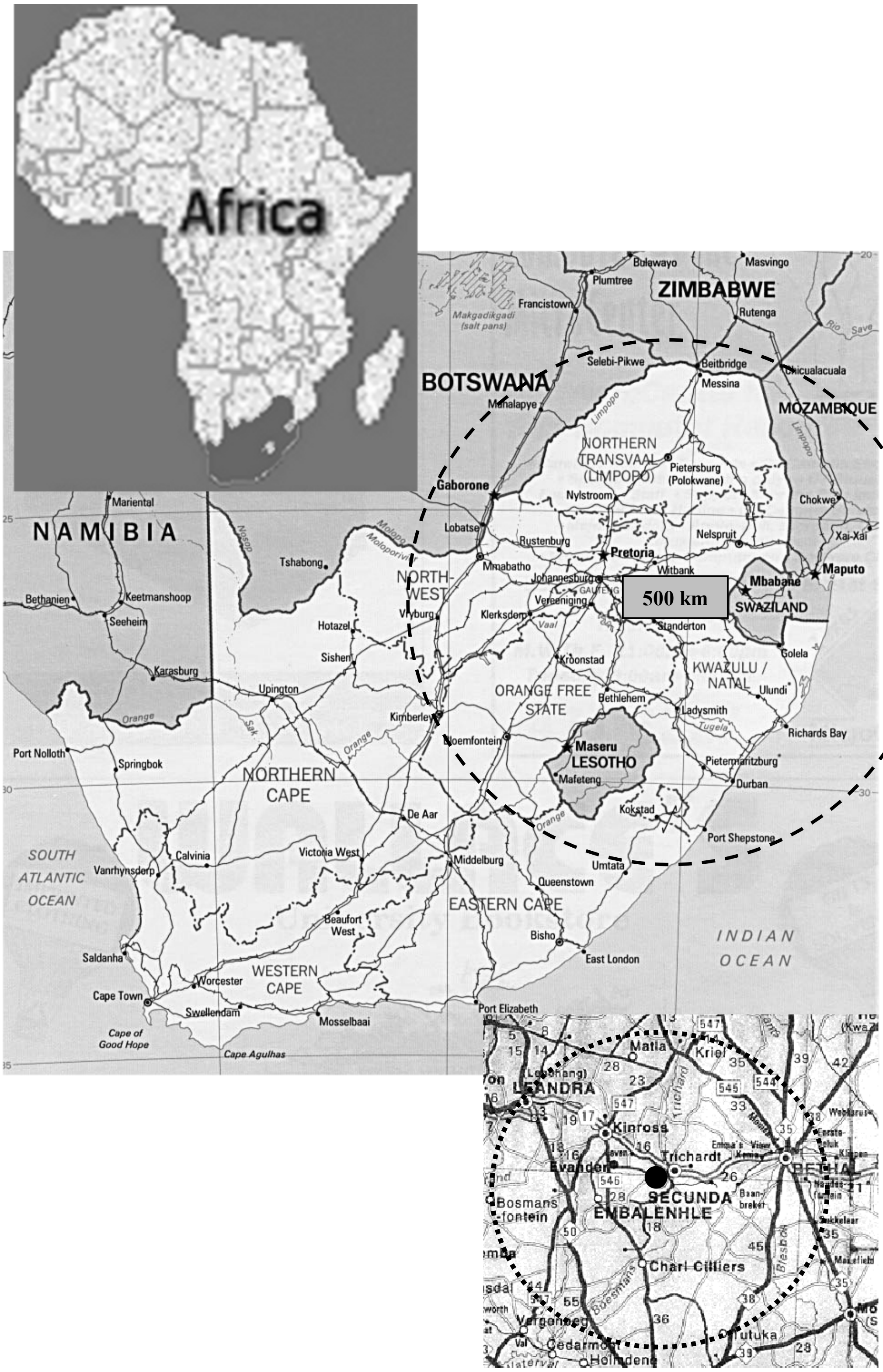

Figure 4. Close (30 km) and remote (500 km) areas affected by regional pollutants of the Secunda manufacturing facility

Table 11. Damage costs of considered air pollution impacts per barrel of GTL produced

		Emissions (g/bbl)	**Damage** (R/kg)	**Total damage cost** (R/bbl)
Global	CO_2 equivalent	194948	0.221	43.2
Regional (health)	SO_x (primary)	13.9[a]	1.63	0.02
	SO_x (secondary)	13.9[a]	27.8	0.39
	NO_x (secondary)	703	43.9	30.8
	NO_x (via O_3)	703	3.21	2.3
	CO	118	0.109	0.013
	VOC	876	2.1	1.80
	PM	15.1	84	1.26
Regional (buildings)	SO_2	13.9	1.37	0.02
Regional (crops)	NO_2	13.9	1.60	1.12
	VOC	703	0.89	0.62
Total				**81.6**

[a] Amounts of SO_x are assumed the same for both primary and secondary impacts. The emitted primary pollutants are partially converted into secondary pollutants. The damage costs for both pollutants are calculated based on an average conversion velocity, whereby a certain amount maintains its original form and deposits as primary pollutant and the rest reacts into secondary pollutants. The damage costs of these secondary pollutants are expressed per amount of emitted primary pollutant.

Impacts of water use. Water is mainly used for cooling processes (during GTL fuel manufacturing) and because of the relative high temperatures in South Africa it can be expected that water consumption is high. It has been assumed that the water consumption of a GTL plant in the South African setting is 30% higher than the quantities proposed in literature (Marano and Ciferno, 2001). The water consumption of the GTL plant (for this case study) is thereby 2256 litres per barrel of fuel manufactured.

Studies indicate that there is a scarcity of water in the region of Secunda and the amount of water that is extracted from the catchment already exceeds the natural supply of the water reserve (CSIR, 2002; Basson *et al.*, 1997). Therefore, the damage costs as a result of water use do apply and the opportunity costs, as indicated in the SCA procedure (benefit approach), are used to assess the damage cost for the total water consumption (Van Erck, 2003).

The total opportunity costs of the water consumed are estimated to be 5.44 R/bbl. After subtracting the current price paid for the consumption of this water, the externality costs resulting from water use are 4.49 R/bbl.

Impacts of land use. The land use of the case study results from the constructed pipeline and the manufacturing plant itself. The impact at the gas extraction site is minor, since the surface is scarcely affected.

The 865-kilometre subsoil pipeline from Mozambique to the plant in Secunda will be overgrown with natural cover after construction. The impacts associated with land use are therefore considered minimal. The area of the current plant itself, i.e. 2100 hectares (Sasol, 2002), is considerable. For the case study it is assumed that this land area would be similar for a GTL process with natural gas as a feedstock.

The land types affected as a result of the GTL conversion are predominantly grass and rangeland (66%) and cropland (34%) (CSIR, 2000). The assumption is made that the division of the land use reported in the SEA reflects the division of land use for the Secunda GTL operation (of the case study). Multiplying these percentages of the total area affected with the damage costs and converting to 2002 South African prices, the damage costs as a result of land use amount to 0.08 R/bbl of GTL fuel produced (Van Erck, 2003).

Impacts of the use of mined abiotic resources. The damage costs for the case study reflect the depletion of the gas fields in Mozambique. The current estimates state that the combined Temane and Pande gas reserves (in Mozambique) have a capacity of 3.2 trillion cubic feet (Sasol, 2002). With a production capacity of 118.000 bbl, the Secunda plant would need 1.21 billion cubic feet of natural gas per day. At this rate of depletion, the life span of the reserves would be 8.3 years.

The discount rate is set at 4 % and the user costs (of the SCA procedure) are 69% of the profit made from selling the natural gas (Van Erck, 2003). Based on the current natural gas sales to many industrial customers in South Africa, the total user costs amount to 56.00 R/bbl.

Social sustainability of the GTL technology

For the GTL case study the social indicators of the SCA procedure are mainly based on the current operations in Secunda as a benchmark (Sasol, 2002). Expenditures that contribute to the social sustainability are often reported for the whole company. Examples are expenditure on taxes, wages, training and education, and research and development.

Impacts on internal human resources. The total expenditure on wages, including contributions to the Unemployment Insurance Fund (UIF), life insurance and medical aid, was 1 205.2 million Rand after tax (in 2002) for the 5 872 employees of the Secunda operations. Only 66%

of the sales of the products were obtained from fuels and therefore it is assumed that 795.4 million Rand was spent on workforce compensation to produce fuels. The workforce that is not accounted for (in the life cycle system) is employed in the upstream processes (or supply chain). It is assumed that this number will be small in relation, since the extraction of natural gas is not a labour-intensive process.

For the production of fuel at the Secunda operations, 49.4 million Rand was assigned for the training and education of employees in 2002, including student bursaries (for tertiary education). It is assumed that training includes the aspects of health and safety. Specific losses for the company due to the incapacity of employees resulting from health and safety incidences have been excluded from the case study.

The expenditure on research and development, on behalf of the Secunda operations, was estimated to be 202 million Rand of which 66% is attributable to the production of fuels, i.e. 133 million Rand.

Based on a production capacity of 118000 bbl/day, the total expenditure on employment stability is 18.50 R/bbl and on capacity development 3.90 R/bbl. Consequently, the total expenditure on internal human resources (for the GTL technology) is estimated to be 22.40 R/bbl of fuel produced.

Impacts on the external population. The sub-criteria of external population include impacts on “human capital” and “community capital”.

Contributions to human capital are only directly attributable to an operational activity where a government stipulates that an operational initiative may only continue if it contributes (financially) on local medical or educational facilities. In Mozambique, 5.5 million Rand is invested on the renovation of public schools during the construction of the natural gas pipeline (Sasol, 2003), which amount to 0.13 R/bbl of fuel produced. The investment in the schools represents the first planned social development project, as an additional financial burden to the natural gas project.

With respect to community capital, a similar amount to the investment in schools is spent on productive capital, e.g. the supply of water, and other community capital, e.g. recreation facilities, in Mozambique. The precise impacts on community capital, which are caused by the fuel manufacturing operations, are difficult to determine. An attempt is made, however, to quantify the impacts of the Secunda operation on the real estate value in the affected area. The local municipality and real estate agents determine these real estate values.

As previously stated, the only major industrial activity within the close vicinity of Secunda, other than the coalmines that supply the manufacturing process with coal, is the CTL process itself. The hypothetical case study assumes that the industrial activity would remain similar if natural gas was used as feedstock. It is obvious that the development of the plant formed an incentive for other economic activities to emerge in the area in order to address the population needs. However, apart from this industrial activity, the setting does not have significant economic advantages or disadvantages over neighbouring areas. The possible differences in secondary or supporting economic activities can be related to the difference in welfare level resulting from the main economic activity, i.e. the Secunda operations. Therefore, a difference is expected between the economic activity (and house prices) in the Secunda area and the average house prices in the neighbouring areas, i.e. it is assumed that no tangible causes other than the operational initiative of the GTL technology influence the local house prices. Subsequently, the approach that is followed, attempts to correlate the variations in the house prices with the distances from the plant. The objective is to compare similar settings with varying distances from the plant.

The average real estate price for a 3-bedroom house is the basis on which the analysis is performed. It is assumed that the price differences between these residences indicate the price differences of all real estate in the area. Based on an interview with a local real estate agent it is estimated that the real estate values in the towns of Bethal and Leandra (see Figures 4 and 5) reflect the standard house prices in the area outside the circle of influence of the Secunda operations. Based on this estimation, the impacts on house prices are confined to a radius of 25 kilometres or less. The base price of a standard 3-bedroom property is set at 250 000 Rand. In relation to this base price, the cost of a standard 3-bedroom house in Secunda and the towns of Trichardt and Kinross are compared, together with the distances from the plant (see Figure 5) (Van Erck, 2003).

A standard 3-bedroom house in Secunda is more expensive than the base price. This indicates that real estate is appreciated better close to the plant due to the travelling preference of many employees, regardless of local nuisance levels, e.g. pollution and visual aesthetics. Although Trichardt and Kinross are further from the plant, the nuisance levels are smaller and the trade-off between these two influences results in higher real estate prices.

It must be emphasised that the price curve (of Figure 5) is crude and it would be erroneous to expect that a high accuracy of the valuation of this non-transparent impact be achieved using this method. However, the figures provide an order of magnitude of the impact of the operational initiative on real estate prices. By using the difference in real estate prices, and the total real estate value in the area affected, the total impact on community capital is estimated. Based on the total values and the impact on these values (in %), the difference in value attributable to the industrial activity is calculated (see Table 12). The total (positive) impact on the real estate value is estimated at 552 million Rand.

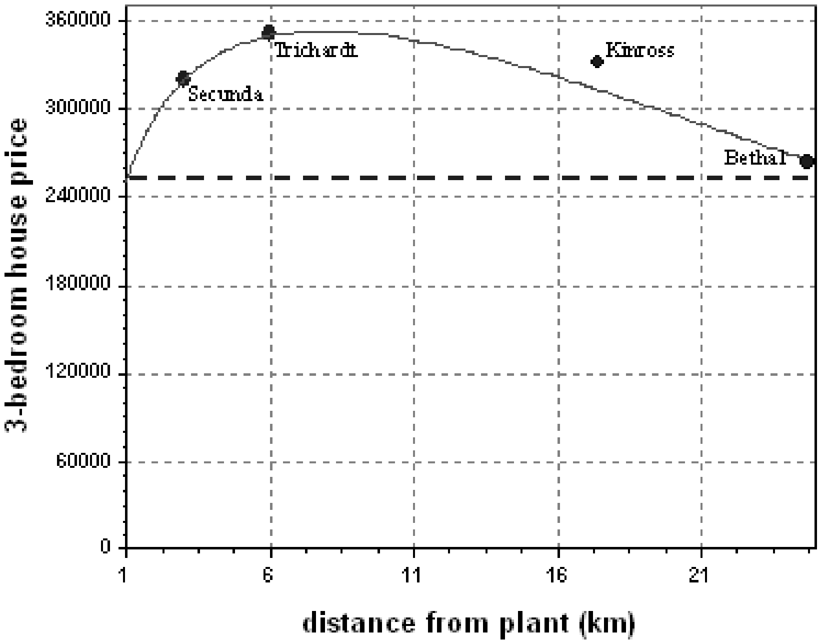

Figure 5. House prices in the vicinity of the Secunda plant

Table 12. Real estate values in the case study area affected by the Secunda operations

Town	Number of real estate units	Total value	Ratio of house price to base price	Normalised total value	Difference in value
Secunda	8128	855 570 721	1,28	668 414 626	187 156 095
Embalenhe	31480	633 172 912	1,40	452 266 366	180 906 546
Evander	2299	359 396 000	1,36	264 261 765	95 134 235
Kinross	3420	175 399 300	1,20	146 166 083	29 233 217
Trichardt	920	209 775800	1,40	149 839 857	59 935 943
Total					**552 366 036**

The method that is used to convert this impact to a barrel of fuel is based on the potential earnings made on the increase in real estate value. The mortgage rate in South Africa in 2002 was 15%. The discount rate for these investments is assumed to be 6%. The annual net earnings from mortgages on the total extra added value therefore would be 9% of 552 million Rand. This is approximately 50 million Rand per year or 1.15 R/bbl of fuel produced.

Stakeholder participation. The total expenditures of the Secunda operations on stakeholder participation (as defined by the SCA procedure indicators) are estimated to be 50 million Rand annually (Sasol, 2002). This is equivalent to 0.77 R/bbl (Van Erck, 2003).

Macro-social performance. The impacts categorized under macro-social performance are subdivided in socio-environmental and socio-economic performances.

With respect to socio-environmental performance, seven stations are operated in the vicinity of the Secunda plant to monitor the ambient air quality. In addition to those, five stations are operated to monitor the water quality in the surface waters surrounding the plant. Furthermore, the company is involved in a joint undertaking with the national government to improve monitoring in areas throughout the country that are either ecologically sensitive or exposed to significant amounts of pollutants (Sasol, 2002; CSIR, 2000). It is estimated that the expenditures on these monitoring activities annually amount to 2 million Rand. This is equivalent to approximately 0.05 R/bbl of fuel produced (Van Erck, 2003).

The socio-economic performance of the operational initiative is measured by its tax contribution to the government. Three types of taxes are transferred from a South African company to the government:

- Tax on profits; the amount attributable to the production of fuels based on the total sales of fuels and the average tax percentage that was paid in 2002. The total tax, which the Secunda operation paid on profit was 2619.8 million Rand and according to the distribution of sales 1729 million Rand is attributable to the sales of fuels. This is equivalent to 40.10 R/bbl.
- Tax on wages; the amount attributable to the production of fuels is based on the number of employees working at the Secunda facility. Based on the ratio of sales between fuels and other products from Secunda the amount of tax on wages attributable to the production of fuels in 2002 was 261.5 million Rand. This is equivalent to 4.40 R/bbl.
- Other taxes, e.g. property taxes; attributed similar to the tax on profits, which amounts to 0.90 R/bbl.

The total contribution to socio-economic performance is therefore 45.50 R/bbl.

Overall sustainability performance of the GTL technology

Results of the SCA assessment. The overall results of the SCA procedure, as applied to assess the sustainability performance of the GTL conversion technology in the Secunda setting, are summarised in Table 13.

Table 13. SCA results of the GTL conversion technology assessment

(Sub) criteria	Score (R_{2002}/bbl)	Significance[a]	Comments
Economic dimension	**115.10**		
Financial health	115.10	High	The following has not been taken into account: contributions to corporate head office, auxiliaries and research and development activities that occur off-site
Environmental dimension	**- 142.17**		
Air resources Regional impacts Global impacts	- 81.60 - 38.30 - 43.30	High	Low estimate of the ExternE accounting framework (European Commission, 1997)
Water resources Water use	- 4.49 -4.49	Low	Based on published estimates (Van Horen, 1996)
Land resources Land use	- 0.08 -0.08	Low	Only land use of the plant taken into account
Mined abiotic resources	-56.00	High	4 % discount rate, based on local proven reserves
Social dimension	**70.05**		
Internal human resources Employment stability Capacity development	22.35 18.50 3.85	High	
External population Human capital Community capital	1.41 0.13 1.28	Low	
Stakeholder participation	0.77	Low	
Macro social performance Socio-environmental Social-economic	45.55 0.05 45.50	High	See the comments on ‘financial health’

[a] A score value (for a criterion) that contributes less than 5% to the overall score of a sustainable development dimension, is not considered significant.

The internal financial health of the technology is the only criterion, which is evaluated in terms of the economic dimension of sustainable development. The results indicate an overall positive contribution of the technology to this dimension. In contrast, the technology has serious negative impacts on the external natural environment beyond the geographical boundaries of the technology. The largest impacts of the life cycle system are attributable to atmospheric emissions and the use of non-renewable resources, i.e. natural gas as a feedstock to the GTL process, and coal for the generation of the required electricity. Water use is of lower significance, although important in the South African context. In total, the negative impacts on the environmental dimension outweigh the positive contribution of the technology to the (internal) economic dimension. However, the technology does have a positive affect on the social dimension, with the largest contributions due to the wages (for direct employees) and socio-economic benefits (due to the taxes that are paid by the company to society). The impacts on the other social sub-criteria are minimal.

The assessment considers the deployment of a technology in a specific setting. Site-specific variables strongly determine the outcome. Therefore, when concluding on this data prudence is called for when linking results to the application of the technology in general.

DISCUSSION OF THE SCA PROCEDURE

The sustainability performance assessment framework

Significant limitations in the sustainability performance assessment are recognised in the choice of the methodology. Due to the application of a monetary appraisal procedure, some of the criteria (in the comprehensive sustainability performance assessment framework) are ignored in the analyses (Van Erck, 2003).

Difficulties occur especially with the limited capacity, which the monetary appraisal approach has to recognise (and therefore distinguish between) qualitative differences in impacts. An example is the problem to appraise the criterion “financial health” in terms of solvency and liquidity, instead of merely by the company’s profitability. Furthermore, the monetary appraisal is inadequate to correct for inefficient market mechanisms. An efficient market mechanism regulates the value of scarce and ample assets by price levels. If price levels do not reflect the true value of an asset, e.g. if there are not sufficient feasible alternatives to choose from, or price levels do not exist for certain assets, the SCA procedure will not correct for these shortcomings. For example, expenditures on research and development activities are appraised equal to expenditures on wages, whereas similar benefits are not necessarily realised within a company.

The uncertainty of data that is used in the case study

The uncertainty of the SCA results may be more problematic than the usefulness of the outcome of an assessment. A prerequisite for incorporating the outcome of a SCA assessment in decision-making is that the results should be sufficiently accurate. If there is significant uncertainty about the results of the sustainability criteria that are measured, integrating the

SCA outcome with other decision-making aspects will become increasingly difficult. As long as there is a clear understanding about what is excluded in the assessment the results may be useful. Therefore, the uncertainty of results is a more significant drawback of the procedure than the limitation to recognise qualitative differences or account for all relevant sub-criteria of the sustainability performance assessment framework.

The inaccuracy of data that is adopted from literature, the conversion methods applied and specifications in the Secunda setting all cause a margin of error in the end results of the SCA procedure. Based on these uncertainties, an attempt has been made to quantify this margin of error (Van Erck 2003). Apart from the appraisal of "community capital", an assessment of the margin of error for the economic and social indicators was not considered necessary, i.e. the data obtained from company publications are believed to be accurate. Also, the "community capital" criterion has a small influence on the overall sustainability performance evaluation, and the uncertainty of the data is not regarded as significant to the outcome of the case study (see Table 13).

The discount rate, which is applied to calculate long-term environmental impacts, is chosen arbitrarily. The consequence of manipulating the discount rate for long-term environmental damage costs has been illustrated (Degenhardt, 1998). A lower discount rate implies higher current damage costs, because the present values of future losses are weighted higher. For example, whereas a damage of $100 in 100 years would amount to $5 (by using a discount rate of 3%) in the present day, the damage would amount to $37 (at present) by using a 1% discount rate. In other words, by applying higher discount rates, a lower present value of future damages will result. Although the SCA results do depend on the chosen discount rate, it must be emphasised that the overall outcomes and conclusions would not be influenced significantly for this case study.

CONCLUSIONS AND RECOMMENDATIONS

A Sustainable Cost Accounting (SCA) procedure is introduced in this paper, whereby the external (macro) impacts of an introduced technology can be converted into monetary terms for internal decision-making at company level. The procedure is based on existing full cost accounting (FCA) and total cost assessment (TCA) methods, but due consideration is given to social as well as environmental impacts, which differs from the current approaches. Through the common denominator, the externalities can be incorporated with a typical internal (financial) evaluation of the performance of a technology. Thereby, the overall sustainability of a technology is ensured, i.e. the "triple bottom-line" approach. The SCA procedure identifies which criteria of a comprehensive sustainable development framework are practicable from the perspective of a monetary methodology. Monetary indicators are subsequently proposed for the economic, environmental and social dimensions of sustainable development. The economic indicators are based on established evaluation methods. The environmental indicators apply costs (of externalities) that have been proposed for other regions in the world. The conversion methodology of these values for other regions (specifically South Africa) is discussed. With respect to the social indicators, new valuation procedures are proposed.

The indicators and the SCA procedure are demonstrated and assessed in the context of the South African petrochemical industry, i.e. the Gas-to-Liquid (GTL) conversion of natural gas into liquid fuel at the location of Secunda in central South Africa.

The SCA procedure shows certain limitations. Firstly, the concept of sustainability cannot be expressed in monetary terms in a comprehensive manner. Thereby, not all of the criteria that are considered relevant to assess sustainability performances can be measured. Secondly, although the SCA procedure is generally applicable, the values used by the different indicators have to be evaluated on a case-by-case basis and reported in a transparent manner. Also, the uncertainty of the data that is obtained, and on which the SCA assessment is based, may strongly influence the usability of a sustainability performance assessment's results, e.g. future damage costs will change with the fluctuations of the markets. However, this does not mean that the SCA procedure is incapable of improving the understanding of a technology's sustainable performance, i.e. the criteria that are measured are all considered relevant for the assessment of a technology's sustainability.

Apart from the implications that the limitations of the approach impose, the interpretation of the scores of the different dimensions of sustainable development is challenging. Assessing a technology's sustainability performance by allowing trade-offs between the contributions and damages should be seriously considered before it is applied. Ultimately, the trade-offs between the different dimensions would be the responsibility of the specific decision-makers, and therefore reflect the preferences of the decision-makers.

This does not imply that the results are unsuited to assist a company to improve the sustainability performance of a deployed technology. The results of each sustainability dimension can function as a benchmark to measure subsequent sustainable performances against, or to identify improvement possibilities for a developed technology. It is, however, unjustifiable to label different activities as more and less sustainable merely based on such results.

Recommendations

In general it is observed that the results of the SCA procedure are disputable and this limits the possibility to use them in decision-making or technology management. The approach, however, does show potential and some aspects need further attention to improve the usefulness of such a SCA procedure. Therefore, two recommendations are suggested to establish the usefulness of this approach and to possibly extend parts of it:

- In most cases the monetary route uses only one or two indicators to measure the sub-criteria, where some are considered impossible to appraise. It is therefore proposed to combine the monetary assessment methodology together with qualitative indicators for an overall sustainability performance assessment. Such an approach should be tested with further case studies.
- As discussed, the uncertainty of data is considered the main problem for using the outcome of the SCA in decision-making. Damage cost estimates must therefore be refined, especially if the procedure is applied in developing countries such as South Africa.

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