Chapter 5: Environmental Matrix Evaluation for Corporate Decision Purposes

5.1 Process industry activities causing environmental impacts

The main activities, of the process industry, center around processes manufacturing products (see Figure 5.1 for the process- and product life cycles). In each one of the phases, of the product and process life cycle, there are specific activities that have cross boundaries with nature and that can consequently cause environmental impacts. The activities together with the nature constituents form the cause of an environmental impact (see cause indicators in Chapter 4).

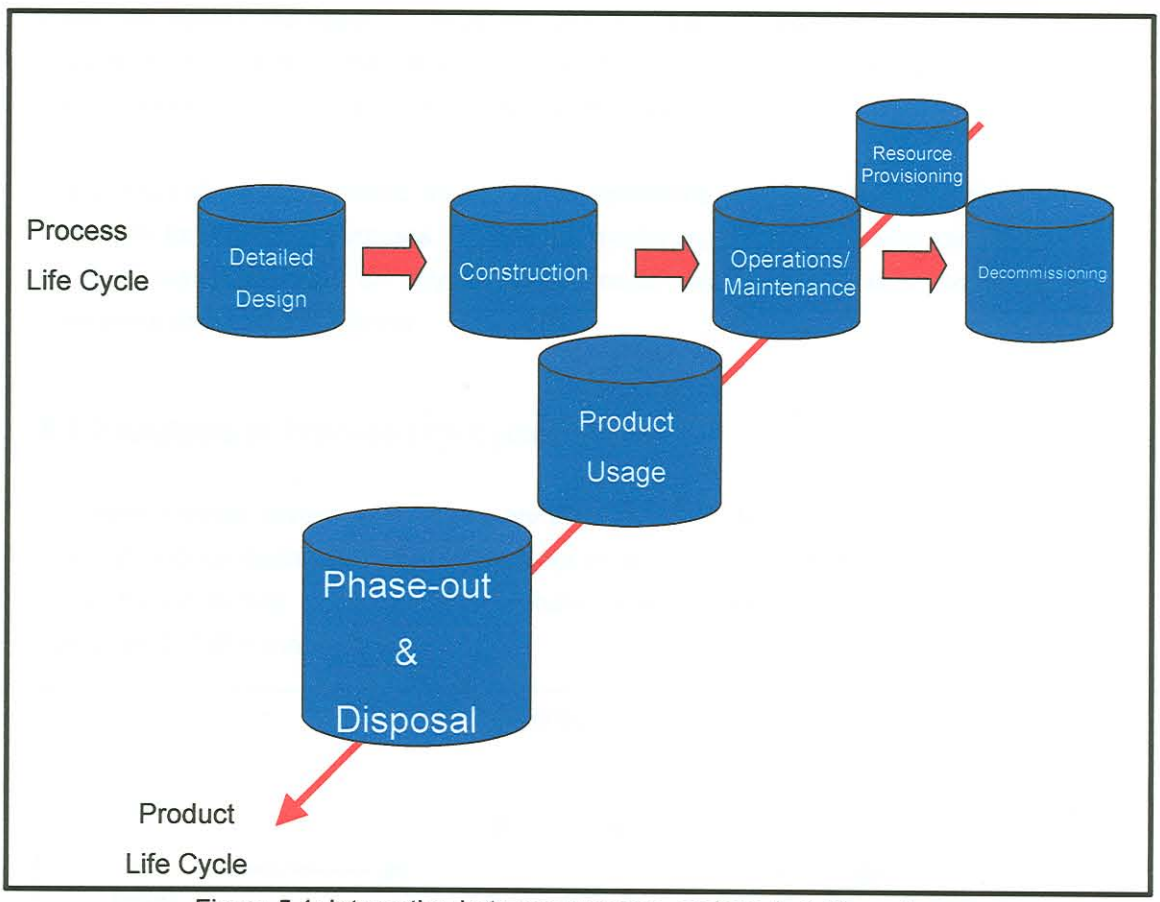

Figure 5.1: Interaction between process- and product life cycle

Environmental impacts in each one of the phases have an associated intensity as well as probability of occurrence. The three critical phases in the process life cycle with regards to possible environmental impacts and future liabilities have been identified in Chapter 3 as: Construction, Operations and Decommissioning Phases. The reason for this is that impacts associated with the process design phase have a low intensity and it is believed that the design phase should be proactively used to minimize future liabilities by applying Design for Environment principles. Sharratt & Choong (2002) agree that to a large extent environmental

impacts of a process is determined by its design, *"decisions taken during process design include not only decisions that affect on-site environmental performance, but also, through the selection of feedstocks, suppliers, energy sources and transport systems, the indirect environmental impacts are determined."*

5.1.1 Products of the Process Industry

The process a project implements produces products, therefore the product life cycle must also be taken into consideration when evaluating the environmental impacts resulting from the project. The principles of "Product Stewardship" also known as "Extended Product Responsibility" force companies to consider the environmental footprint of their products. Producer Responsibility Laws are also gaining prominence (United States' Environmental Protection Agency webpage). Companies have the greatest responsibility to reduce the environmental impacts of their products since they possess the greatest ability to do so (United States' Environmental Protection Agency webpage).

The product life cycle is viewed as part of the operations phase in order to minimize the complexity for evaluation purposes. The environmental impacts of the project can therefore be evaluated by focussing on only the three process development phases: Construction, Operations and Decommissioning.

5.1.2 Analysis of Process Life Cycle Phases

The three process development phases are analysed by applying the IDEFØ methodology. The methodology applies "box and arrow" graphics to show the inputs to a process/function; output from it as well as the enabling mechanisms and controls (KBSI, 2002). The basic syntax for IDEFØ is shown in Figure 5.2.

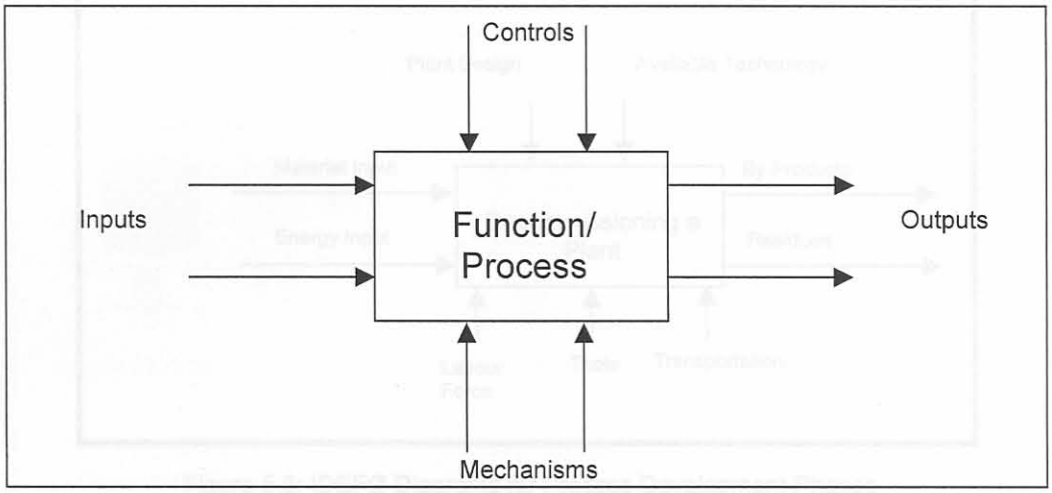

Figure 5.2: Basic Syntax of IDEFØ

Source: KBSI, 2002

The diagrams for the three phases, which are based on the IDEFØ methodology, are shown in Figure 5.3.

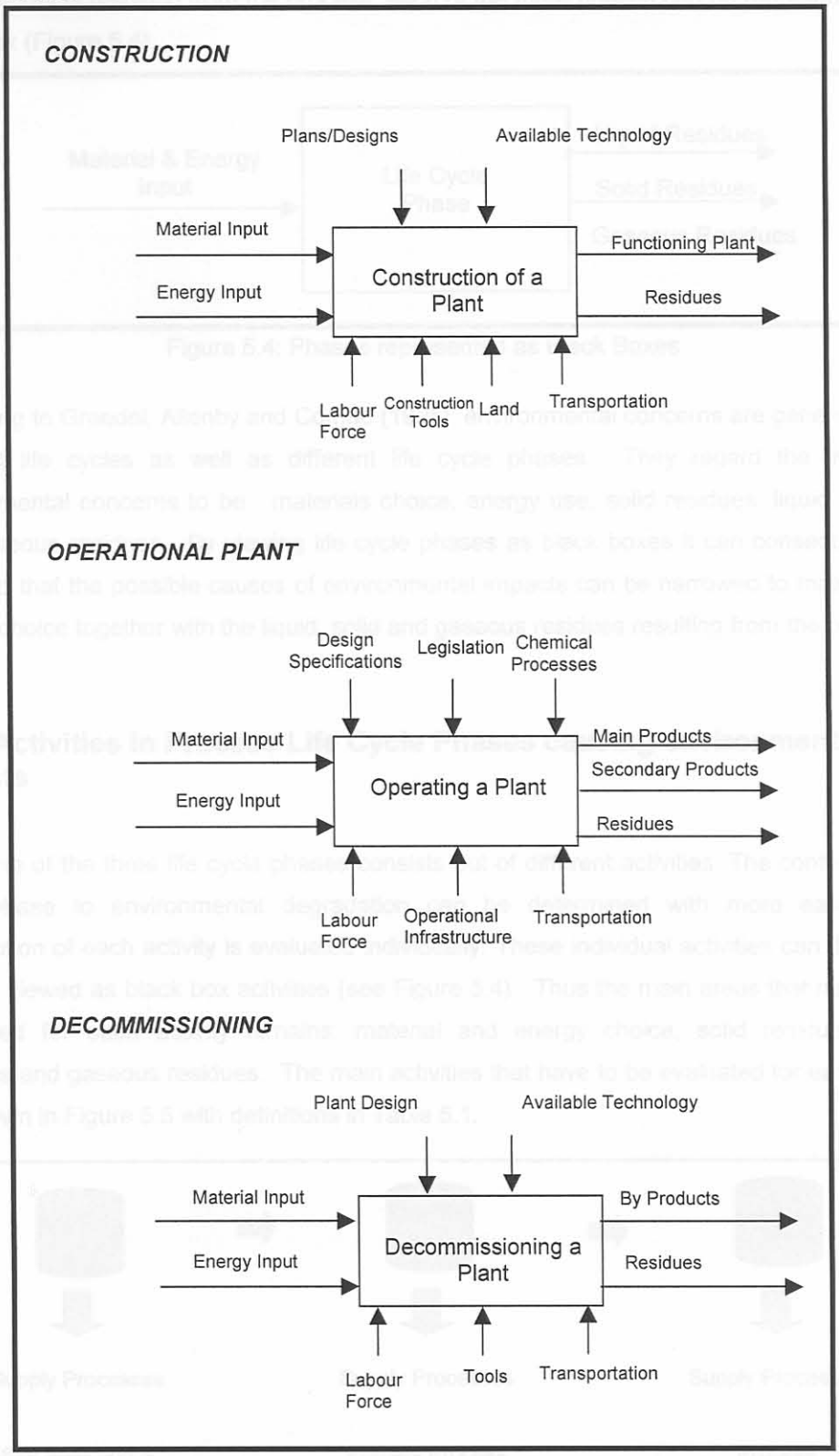

Figure 5.3: IDEFØ Diagrams for Process Development Phases

If a black box is drawn around the process, the controlling and enabling mechanisms, as well as the products resulting from the process, each of the three phases can be represented as a black box (Figure 5.4).

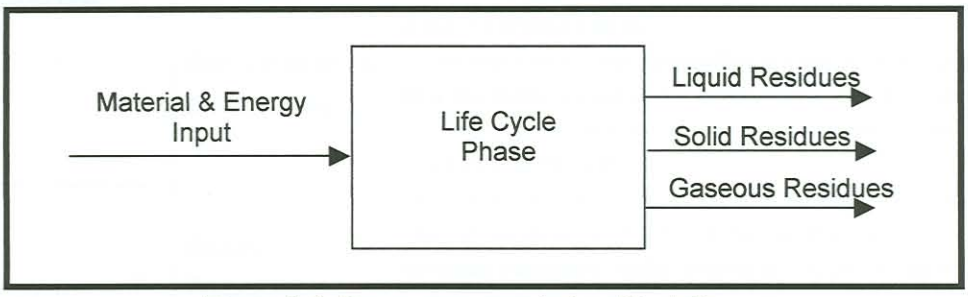

Figure 5.4: Phases represented as Black Boxes

According to Graedel, Allenby and Comrie (1995), environmental concerns are generic across different life cycles as well as different life cycle phases. They regard the five main environmental concerns to be: materials choice, energy use, solid residues, liquid residues and gaseous residues. By viewing life cycle phases as black boxes it can consequently be deduced that the possible causes of environmental impacts can be narrowed to material and energy choice together with the liquid, solid and gaseous residues resulting from the phases.

5.1.3 Activities in Process Life Cycle Phases causing environmental impacts

Each one of the three life cycle phases consists out of different activities. The contribution of each phase to environmental degradation can be determined with more ease if the contribution of each activity is evaluated individually. These individual activities can, however, also be viewed as black box activities (see Figure 5.4). Thus the main areas that need to be evaluated for each activity remains: material and energy choice, solid residues, liquid residues and gaseous residues. The main activities that have to be evaluated for each phase are shown in Figure 5.5 with definitions in Table 5.1.

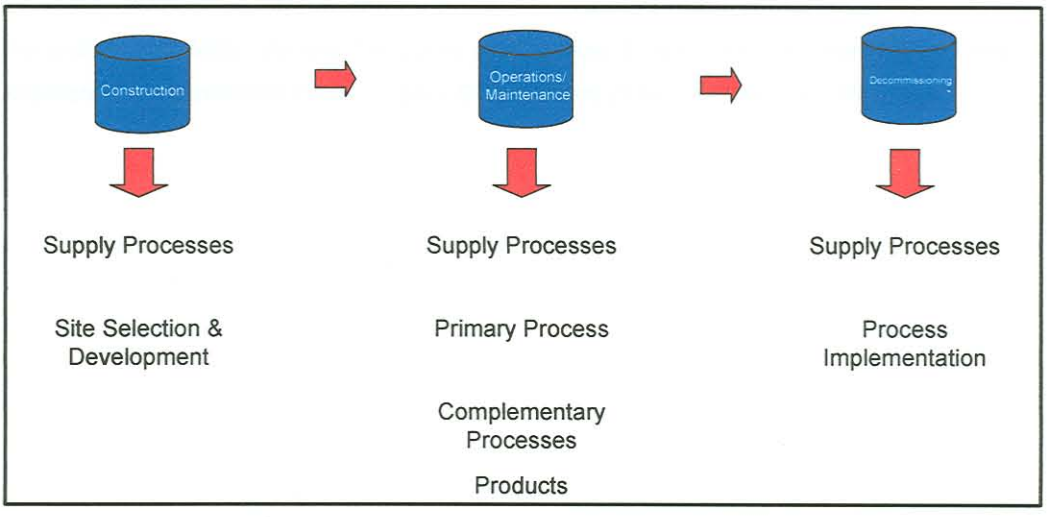

Figure 5.5: Main activities in each phase

Phase	Activity	Definition
Construction	Supply Processes	All processes involve with the supply of all material, energy and any other consumables required for the completion of the construction phase of a process's life cycle.
	Site Selection & Development	All processes involve with the selection of a specific site or location for a new facility; as well as the selection of construction materials and methods as well as all processes involve in the final construction of the facility.
Operation	Supply Processes	All processes involve with the supply of all material, energy and any other consumables required for normal operation i.e. raw material extraction, transport to facility, process to prepare raw material for process; packaging of raw material; packaging material sourced for finished product. (Pre Gate focus)
	Primary Process	All steps essential to manufacture product/All value adding steps that leads to the final product excluding supply and complementary processes.
	Complementary Process	All support processes excluding supply processes; i.e. transport and storage of product; waste management. (Post Gate focus)
	Products	A post gate focus that looks at the possible environmental impacts of product use and product end-of life (recycling; re-use or disposal)
Decommissioning	Supply Processes	All processes involve with the supply of all material, energy and any other consumables required for the completion of the decommissioning process.
	Process Implementation	All steps essential to disassembly the plant and recycle equipment as well as all processes needed to restore the original landside.

Table 5.1: Definitions of main activities

5.2 Environmental Matrix Evaluation

5.2.1 Purpose of the Matrix

The corporate decision-making tool that is developed and proposed in this dissertation is based on the Design for Environment (DfE) Matrix evaluation approach that was introduced by Allenby in 1992 (as cited in Allenby 2000). The tool is to be applied proactively in the Idea Generation, Pre-feasibility and Feasibility phases and thus before the Environmental Impact Assessment is performed in the Detailed Development phase (see Figure 5.6).

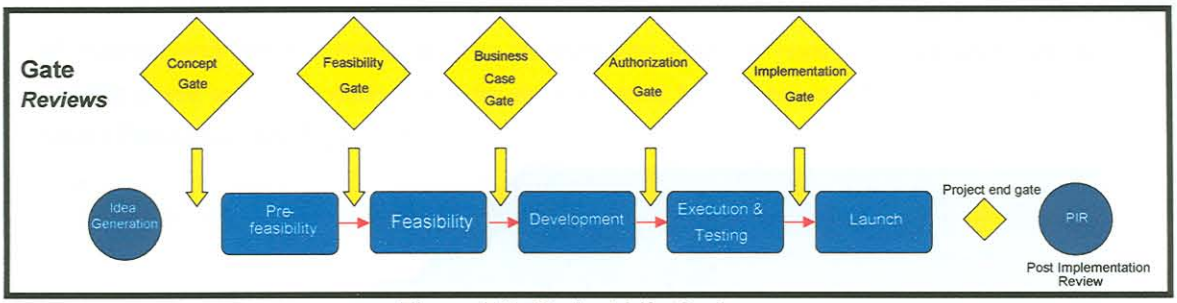

Figure 5.6: Project Life Cycle

The environmental matrix tool that is proposed in this document aims to assist designers and enforce DfE principles as the phases in which it is applied correspond with the design phase of the process (Figure 3.13) The matrix can be viewed as a bridge between the decision makers and the designers as illustrated in Figure 5.7.

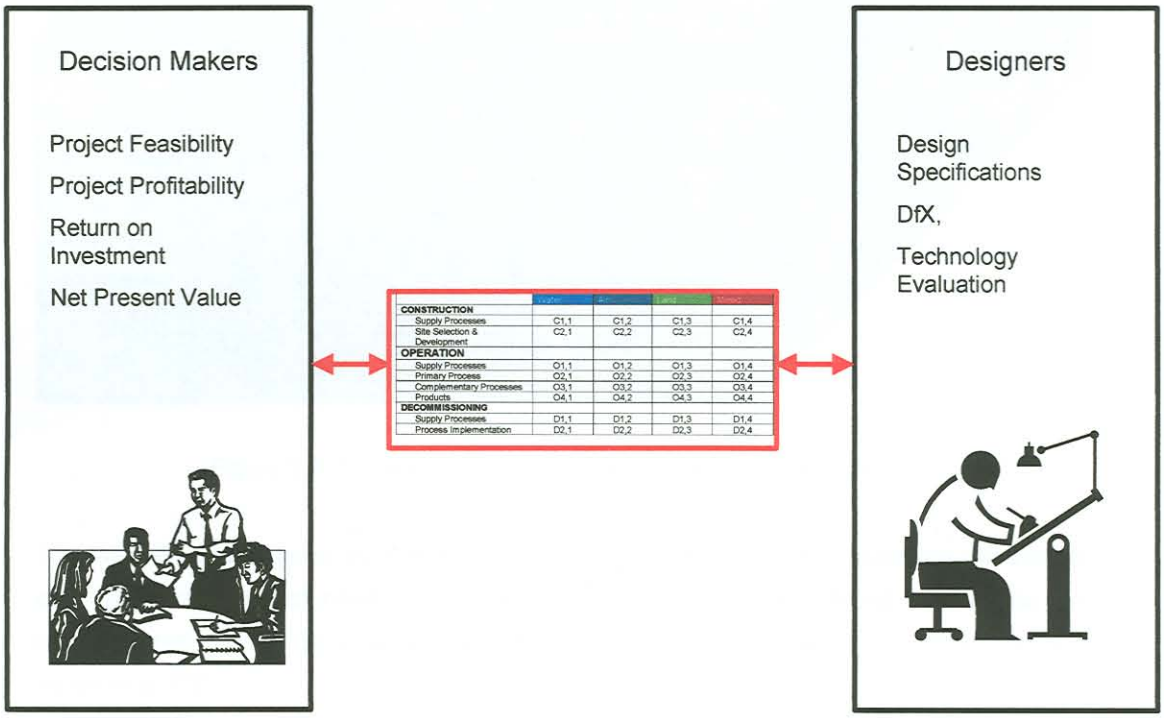

Figure 5.7: The "bridge" between designers and decision makers

5.2.2 Structure of the Matrix

In order to determine the possible environmental impacts associated with a process industry project, the contribution of the individual activities (performed in different phases) to the cause indicators (identified in Chapter 4) need to be evaluated. To ensure efficient evaluation of possible environmental impacts resulting from project activities, the influence of material and energy choice, and liquid, solid and gaseous residues of each activity on the four environmental factors identified in Chapter 4 must be assessed.

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The ideal matrix will consequently be a three-dimensional matrix that can evaluate the impact of material and energy choice, and liquid, solid and gaseous residues associated with a specific phase activity on each one of the environmental factors, namely Water, Air, Land and Mined Resources (see Figure 5.8).

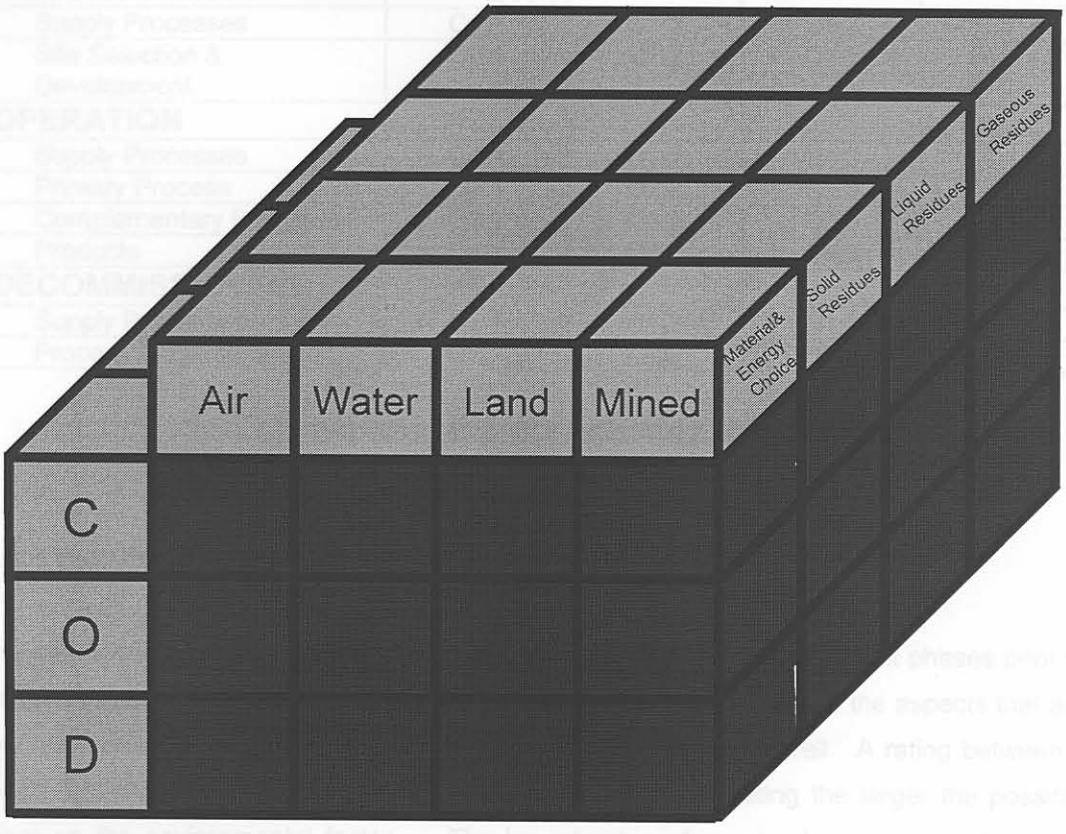

Figure 5.8: Three-dimensional Environmental Evaluation Matrix

The main disadvantage of such a matrix is that on a phase only level there are already 48 cells of interaction that need to be evaluated. If the matrix is adapted to evaluate the environmental impacts on an activity level the number of cells that needs to be evaluated will increase to 128.

An alternative approach is to evaluate the impacts of the activities of each phase on the four environmental factors and to ensure that the scoring guidelines for each cell (interaction) incorporates the possible impacts resulting from material and energy choice, solid residues, liquid residues and gaseous residues. The matrix is then reduced to a two dimensional matrix with 32 cells of interaction that need to be evaluated (Figure 5.9)

	Water	Air	Land	Mined
CONSTRUCTION				
Supply Processes	C1,1	C1,2	C1,3	C1,4
Site Selection & Development	C2,1	C2,2	C2,3	C2,4
OPERATION				
Supply Processes	O1,1	O1,2	O1,3	O1,4
Primary Process	O2,1	O2,2	O2,3	O2,4
Complementary Processes	O3,1	O3,2	O3,3	O3,4
Products	O4,1	O4,2	O4,3	O4,4
DECOMMISSIONING				
Supply Processes	D1,1	D1,2	D1,3	D1,4
Process Implementation	D2,1	D2,2	D2,3	D2,4

Figure 5.9: Two dimensional Environmental Evaluation Matrix

5.2.3 Scoring Method

The matrix shown in Figure 5.9 is used for evaluation purposes in the project phases prior to Gates 1 to 3. Although the same matrix is used in each project phases, the aspects that are evaluated change and therefore the scoring guidelines change as well. A rating between 1 and 5 is assigned for each cell of interaction; the higher the rating the larger the possible effect on the environmental factor. The lowest value of one is chosen as any industrial operation has an effect on the environment to some extent; it is only the intensity of that effect that differs, *"all economic activity contributes to the net entropy through the continuous dissipation of free energy and matter"* (Rees, 1988).

A rating is assigned by completing the scoring guidelines. For gates 1 and 2 the scoring method follows the approach introduced by Graedel & Allenby (1995) and refined by Graedel (1998). The scoring guidelines for Gate 1 and 2 are a set of YES/NO questions. At Gate 1 only one question is asked and examples of worst-case scenarios are listed.

At gate 2 a set of questions must be completed for each cell of interaction in order to rate the possible impact. Only planned impacts, i.e. impacts that will occur on a continuous basis after implementation are therefore known to the designers, are evaluated at gate 2. Gate 3 considers planned as well as unplanned impacts, e.g. accidental spills, and a risk factor for each question is determined from a scoring grid (Figure 5.10). A value of High, Medium or Low is assigned to the probability of occurrence, as well as the intensity of impact. The risk factor for each cell (interaction) is determined by adding the risk factors of each question in the cell's question set (see section 5.3 and refer to Appendix G). The highest possible rating for gates 1 and 2, is thus 160, and for gate 3 800.

		Intensity of occurrence		
		High	Medium	Low
Probability of occurrence	High	5	4	2
	Medium	4	3	1
	Low	2	1	1

Figure 5.10: Scoring Grid to determine risk factor

5.3 Scoring Guidelines

Scoring guidelines for each element are provided for gates 1 to 3. The questions asked in the scoring guidelines should focus on the following aspects namely:

- Design – questions to verify that an optimal environmental friendly design, that meets the specifications, has been achieved. These questions must ensure that all alternatives have been investigated. Design incorporates the design of the process, maintenance as well as planned maintenance shutdowns.
- Planned Impacts – question that address the quantity and intensity of direct and indirect impacts as well as ways to minimize these impacts.
- Unplanned impacts – under this aspect questions addressing accidental releases are included.

All three of these aspects are not applicable to all activities. The level of detail in the questions addressing these aspects varies between the gates. The questions compiled from the environmental checklists (Table 5.3, Table 5.5 and Table 5.7) together with the questions developed by Graedel and Allenby (1995), Graedel (1998) and Yarwood & Eagan (1998), served as a basis for the questions used in the scoring guidelines. A complete set of scoring guidelines and protocols are attached in Appendix G.

5.3.1 Construction Phase

The construction phase has two main activities: Supply Processes and Site Selection and Development. Table 5.2 shows which aspects the scoring guidelines should address for each interaction between the activities and the environmental factors.

	Water	Air	Land	Mined
Supply Processes	• Design • Planned Impacts	• Design • Planned Impacts	• Design • Planned Impacts	• Design • Planned Impacts
Site Selection & Development	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design

Table 5.2: Aspects scoring guidelines should focus on for Construction phase

Table 5.3 shows the questions of concern for the Construction Phase, which are compiled from the various environmental checklists that have been studied (see Appendix F).

CONSTRUCTION PHASE			
Water	**Air**	**Land**	**Mined**
• Will the river flows be altered due to construction? • Will the construction alter the existing drainage patterns of the site or area? • What type of emissions will be discharged into water system? • Will the construction result or contribute towards an increase in water temperature? • Will the quality and/or quantity of groundwater be threatened at any time? • Does the construction endanger a wetland or inland floodplain? • How much surface water will be withdrawn during construction?	• Will the construction result in fugitive dust and particulates? • Will the construction increase ambient noise levels and/or expose people or wildlife to excessive noise? • Will the construction cause vibrations? • Objectionable odors? • What type of emissions to air would result from the construction? Hazardous or greenhouse gasses?	• Landslides and landsubsidence ? • Will the construction result in erosion of soil due to increase winds or removal of vegetation? / Could erosion occur as a result of clearing or construction? • Will the construction result in substantial loss of topsoil? • Will the construction have an impact on land classified as farmland or substantially alter existing or proposed land use of an area? • How will construction debris be disposed off? • Will the construction substantially degrade the existing visual character or quality of the site and its surroundings? • Will the construction have a substantial adverse effect on biodiversity?	• What kinds of energy will be used to meet the energy needs of the construction phase?

Table 5.3: Questions of concern for Construction Phase

5.3.2 Operation Phase

Four activities have been identified for the operation phase. Table 5.4 shows which aspects the scoring guidelines should address for each interaction between the activities and the environmental factors during this phase.

	Water	Air	Land	Mined
Supply Processes	• Design • Planned Impacts	• Design • Planned Impacts	• Design • Planned Impacts	• Design • Planned Impacts
Primary Processes	• Design • Unplanned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts	• Design • Unplanned Impacts
Complementary Processes	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts
Product	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts

Table 5.4: Aspects scoring guidelines should focus on for Operation phase

Waste or residues (Solid and Liquid) generated by the primary process are addressed under the complementary processes as waste management processes. Table 5.5 shows the questions of concern for the Operation Phase, which are again compiled from the various environmental checklists that have been studied (see Appendix F).

OPERATION PHASE			
Water	**Air**	**Land**	**Mined**
• What type of emissions will be discharged into water system? • Will water or emissions be discharged into the ground water? • Will the operational process result in an increase in water temperature? • Is there a probability that waste streams will be	• Will the operational process increase ambient noise levels and/or expose people or wildlife to excessive noise? • Will the operational process cause: o Vibrations? o Objectionable odors? o Emissions of a hazardous air pollutant	• Will the operational process result in excessive magnetic fields and/or radiation? • Will the process generate significant solid waste? If yes, what impact will this waste have on the existing landfill capacity? • Will the operational process have a	• Will the operational process result in extensive use of existing mineral resources (mining, oil, gas, etc)? • What kinds of energy will be used to meet the energy needs of the process? • Will the process result on the loss of availability of a known mineral

stored in underground tanks (thus making ground water vulnerable to contamination) or that waste material could enter ground waters? • How much water will be needed for the operational process? (Determine additional burden on water resources)	and/or greenhouse gas? • Do any proposed air emissions require new air control systems or upgrading of existing systems?	substantial adverse effect on biodiversity?	resource or locally-important mineral resource?

Table 5.5: Questions of concern for Operation Phase

5.3.3 Decommissioning Phase

The Decommissioning Phase consist of two activities and Table 5.6 shows which aspects the scoring guidelines should address for each interaction between the activities and the environmental factors.

	Water	Air	Land	Mined
Supply Processes	• Design • Planned Impacts	• Design • Planned Impacts	• Design • Planned Impacts	• Design • Planned Impacts
Process Implementation	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design • Unplanned Impacts • Planned Impacts	• Design

Table 5.6: Aspects scoring guidelines should focus on for Decommissioning phase

Table 5.7 shows the questions of concern for the Decommissioning Phase, which are also compiled from the various environmental checklists that have been studied (see Appendix F).

DECOMMISSIONING PHASE			
Water	**Air**	**Land**	**Mined**
• What type of emissions will be discharged into water system? • Can the decommissioning result or contribute towards an increase in water temperature? • Will the quality and/or quantity of groundwater be threatened at any time?	• Will the decommissioning increase ambient noise levels and/or expose people or wildlife to excessive noise? • Will the operational process cause: o Vibrations? o Objectionable odours? • Will the decommissioning result in fugitive dust and particulates?	• Will the decommissioning result in erosion of soil due to increase winds or removal of vegetation?	• What kinds of energy and material will be used to meet the specific needs of the decommissioning phase?

Table 5.7: Questions of concern for Decommissioning Phase

5.4 Interpretation of Results

The completed matrix shows a rating for the impact of each phase on every environmental factor, as well as a rating for the total impact on each of the environmental factors. Figure 5.11 illustrates an example of completing the Environmental Evaluation Matrix.

Gate 1:

	Water	Air	Land	Mined
CONSTRUCTION (10)	***6***	***2***	***2***	***6***
Supply Processes	5	1	1	5
Site Selection & Development	1	1	1	1
OPERATION (20)	***12***	***12***	***8***	***4***
Supply Processes	5	1	1	1
Primary Process	1	5	1	1
Complementary Processes	5	5	1	1
Products	1	1	5	1
DECOMMISSIONING (10)	***2***	***6***	***6***	***2***
Supply Processes	1	1	1	1
Process Implementation	1	5	5	1
(40)	**20**	**20**	**16**	**12**

Gate 2:

	Water	Air	Land	Mined
CONSTRUCTION (10)	***7***	***5***	***5***	***7***
Supply Processes	5	2	3	5
Site Selection & Development	2	3	2	2
OPERATION (20)	***15***	***14***	***12***	***9***
Supply Processes	5	2	3	2
Primary Process	4	5	2	2
Complementary Processes	5	5	2	2
Products	1	2	5	3
DECOMMISSIONING (10)	***5***	***8***	***7***	***3***
Supply Processes	2	3	2	1
Process Implementation	3	5	5	2
(40)	**27**	**27**	**24**	**19**

Gate 3:

	Water	Air	Land	Mined
CONSTRUCTION (50)	***21***	***18***	***12***	***33***
Supply Processes	15	8	8	25
Site Selection & Development	6	10	4	8
OPERATION (100)	***57***	***58***	***41***	***26***
Supply Processes	25	8	6	10
Primary Process	15	15	8	3
Complementary Processes	12	18	14	8
Products	5	17	13	5
DECOMMISSIONING (50)	***16***	***32***	***34***	***20***
Supply Processes	5	7	9	11
Process Implementation	11	25	25	9
(200)	**94**	**108**	**87**	**79**

Figure 5.11: Example of a completed matrix at each gate

The matrix determines whether the interaction between a specific activity and specific resource can be viewed as a possible area of environmental concern. Possible areas of environmental concern are referred to as hotspots. Environmental hotspots and potential liabilities are identified based on the rating of the matrix element during a specific gate review:

- Gate 1: Hotspots are elements with a rating of 5
- Gate 2: Hotspots are elements with a rating of 3 or higher
- Gate 3: Hotspots are elements with a rating of 9 or higher

The information about hotspots must be communicated to the decision-making process and it must therefore be incorporated into this process. Methods to utilize the information in the decision-making process are discussed in Chapter 7. The hotspot information must also be communicated to the next project phase as points to consider or reconsider during the design. Thereby, it is ensured that process designers adequately address potential environmental liabilities, and gate reviewers consider the implications before proceeding with the project.

5.5 Conclusion

A Environmental matrix Evaluation tool is introduced to bridge the gap between the designers and decision-makers. The tool is based on Design for Environment (DfE) principles. The potential impact that can result from the interaction between various identified activities in each critical phase (Chapter 3) with the environmental factors (Chapter 4) has been evaluated. Scoring guidelines are provided for each interaction to guide the user during the evaluation process. The tool is best applicable before Gates 1 to 3 in the staged project management framework.

A completed matrix provides identifies potential areas of environmental concern, also called "hotspots". This information must be communicated to the designers in order for the matrix to fully support DfE, but the information must also be integrated into the decision-making process. Various methodologies to ensure the integration will be discussed further (see Chapter 7). A practical case study in the South African process industry will determine the useability of the Environmental Evaluation Matrix for designers, and establish whether the tool will contribute to existing project management frameworks.