Measuring Eco-efficiency by a LCC/LCA Ratio
An evaluation of the Applicability in Environmental Decision-making Situations

A case study at Akzo Nobel

Master of Science Thesis in the Master Degree Programme, International Project Management

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Abstract

The corporate world has an immense impact on the environment and plays an important role in the holistic context of sustainable development. This is one of the focal motives for the development of the concept, eco-efficiency. Eco-efficiency was developed by the world business council for sustainable development (WBCSD) in the beginning of the 1990's as a model for managing the work of corporate organisations in a manner, consistent with sustainable development. Eco-efficiency is defined as a business concept that creates an increased value to a product or service with less environmental impact.

The purpose of this dissertation is to study and determine the eco-efficiency of an industrial process used for incineration of process water, in a case study at Akzo Nobel in Stenungsund. The outcome of the case study is intended to be a foundation for a decision-making situation considering discharge of emissions contributing to oxygen deficiency in water. The study also aims to evaluate the method used for measuring eco-efficiency. The method applied for calculating the eco-efficiency in this thesis is developed by Steen (2004) and is intended to function as an interpretation tool for eco-efficiency. The method makes use of the established life cycle concepts LCA and LCC by applying life cycle data in a ratio of the value of the process and the environmental impact caused by the process.

In the case study the present process conditions are scrutinized and compared to a different scenario representing the nominal capacity of the process system. The results from the case study indicate that the present process conditions have a considerably higher eco-efficiency than the nominal scenario. Therefore an increased incineration of process water with consideration to eutrophication is an alternative, which should be carefully considered. The central conclusions that have arisen from this dissertation is that it is of great importance to consider the underlying factors and surrounding environment when analysing eco-efficiency in decision-making situations. This is something, which has been very apparent in the context of weighting the impacts of different environmental indicators and the choice of system boundaries. A final conclusion considering the use of eco-efficiency in decision-making situations is that the concept and ultimately the method of measuring have proven themselves useful in comparative analyses. However, since the concept, eco-efficiency is fairly young and not yet established, it is probably wise to present the results together with environmental and economic indicators separately in a descriptive manner.

Preface

This report is the result of a master thesis for the joint MSc Programme International Project Management at Chalmers University of Technology and Northumbria University in Newcastle upon Tyne.

The master thesis has been carried out on behalf of the CPM project, Environment and Economy at the department of Environmental systems Analysis. The examiner for the project; Bengt Steen, the department of Environmental systems Analysis at Chalmers.

I would like to thank Sara Tollin and Klas Hallberg at Akzo Nobel in Stenungsund for their continuous support and help with technical data for the case study. Further, I would like to thank Bengt Steen for supervision of this master thesis and finally Fredrik Lyrstedt for interesting discussions and great exchange of ideas along the project.

Göteborg, October 2005

Guy Skantze

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Introduction

Environmental issues have become increasingly important in modern societies around the globe. In the north these issues arose in the early 1970's (Meadows et al, 1992) when the availability of natural resources and the increasing population of the world were first debated in a larger context. In order to better being able to control and manage environmental issues and the world health the term sustainable development was introduced in the World Conservation Strategy (IUCN, 1980). Sustainable development is defined by the United Nations and the Bruntland Commission in their opening work for the Earth Summit in Rio de Janeiro 1992 (WCED, 1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The concept sustainable development is commonly described as being composed by three pillars of sustainability (Lehni, 2000). These pillars are: economic growth, ecological balance and social progress. In order to obtain a sustainable development all three pillars must be considered and taken into account (WCED, 1987).

Companies and business organisations play important roles in the striving to obtain a sustainable development. In order for a corporate organisation to act in a sustainable manner it is important to find ways of approaching the three different pillars of sustainability. There is no panacea for reaching a sustainable development but there are different concepts and tools that are very useful when working towards a sustainable development. This dissertation focuses on the concept eco-efficiency and the tools available to measure and interpret eco-efficiency.

Eco-efficiency can be described as creating more value with less impact (Lehni, 2000) and is defined as: product or service value / environmental influence. The concept eco-efficiency was founded by the World Business Council for Sustainable Development (WBCSD) in 1991, as a tool for improving and monitoring sustainability in corporate organisations. The WBCSD states that corporate organisations need to focus on three main areas to successfully embrace the concept and offer eco-efficient products and services. These areas are: Reducing the impact on nature, reducing the consumption of resources and increasing the service or product value. Environmental work can lead to efficient ways of cutting costs in an approach very much similar to lean design and lean manufacturing systems (Gordon, 2001). A well developed and decentralized environmental work throughout the organisation could also lead to good publicity for the company, which is something that is particularly important in the complex business environment of today.

The aim of this dissertation is to measure the eco-efficiency of an industrial process used for incineration of process water in a case study at Akzo Nobel in Stenungsund and evaluate the method of measuring in a sensitivity analysis.

This master thesis is the result of a case study on behalf of CPM (Competence Centre for environmental assessment of product and material systems), the University of Chalmers, Gothenburg and the University of Northumbria, Newcastle.

Purpose

The purpose of this dissertation is to examine and measure the eco-efficiency of an industrial process used for incineration of process water, in a case study at Akzo Nobel in Stenungsund. Furthermore, the study aims to evaluate the method (Steen et al, 2004) of measuring and monitoring eco-efficiency as well as examining the applicability and communication possibilities of the eco-efficiency result as a foundation for decision-making processes.

Scope

The case study is performed from a company perspective and the results are intended to be used in a decision-making situation considering an industrial process used for incineration of process water. The study involves two different scenarios representing varying process conditions. These scenarios are scrutinized in a comparative analysis in order to obtain probing factors for optimal utilization of the process.

Method

This thesis has been carried out to enhance knowledge about a model developed for calculating eco-efficiency and to examine how the model applies to decision-making situations concerning environmental and economic issues in corporate organisations. In order to develop a theoretical foundation for the thesis, secondary data on the concept of eco-efficiency has been gathered and interpreted in the theoretical frame of reference. In addition to the theoretical studies, empirical studies have been carried out in a case study at Akzo Nobel in Stenungsund. The results from the case study together with the theoretical data has formed the basis for the analysis and discussion where the authors experience is combined with reasonable theories on the concept of eco-efficiency.

Delimitations

This study focuses on eco-efficiency as a measurement for describing the relationship between economy and environment. There are other models for explaining such connections, however, this study is attempting to examine a specific model developed for interpreting eco-efficiency.

Theoretical Frame of Reference

The theoretical frame of reference provides a background to the concept of eco-efficiency by describing its objectives, purpose and fundamental elements. Furthermore, the chapter describes how to measure and report eco-efficiency together with its communication possibilities.

Eco-efficiency

In this chapter the concept and purpose of eco-efficiency is described. Further, information of the functions and applications of eco-efficiency is provided together with interpretation keys for measuring the eco-efficiency of products and processes.

Objectives and Purpose

Eco-efficiency can be viewed as a tool for becoming more sustainable and environmentally proficient. However, eco-efficiency does not by itself lead to a sustainable development. It should be viewed as a business concept that creates more value with less impact. The WBCSD defines eco-efficiency as "being achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity". Sustainable development is usually described as a combination of economics, ecology and social progress. The concept of eco-efficiency more or less excludes the latter and concentrates on the economical value and the environmental impact of a product or process. Even though eco-efficiency is a business concept that mainly focuses on reducing environmental impacts and increasing revenues it can also be stated that the concept aims for an improved quality of life which is an important part of sustainability. Eco-efficiency is commonly divided into three different objectives (Lehni, 2000). The first is to reduce the consumption of resources by minimizing the energy use, materials, water and land, improve recycling and product durability. The second objective is to reduce the impact on nature. This aim can be accomplished by continuously trying to reduce air emissions, water discharges, waste disposal and the dispersal of toxic substances. By using renewable raw materials the impact on nature is further decreased. The third and last objective is to increase product or service value. This can be linked to value management that concentrate on a products or service value by improving the functionality, flexibility and modularity and thereby providing more benefits to the customer. The focus is set on what the customer actually need and provides the opportunity to produce products with less material and resources and yet the same functionalities. Many organisations that embrace the eco-efficiency concept will also start thinking about implementing an environmental management system (EMS) that is integrated with their existing business management systems (Lehni, 2000). This is probably something that is especially applicable for small and medium sized companies.

There are a number of important opportunities for companies related to the concept of eco-efficiency. According to the WBCSD (Lehni, 2000) there are four major areas that provide opportunities.

- The first opportunity consist of reengineering the production chain or the product process by reducing the material consumption, reduce pollution, avoid risks and thereby save cost and raise larger profit margins.
- Secondly there is a great opportunity in collaborating with other organisations and companies. One of the most successful themes of collaboration is to re-valorise the by products of the organisation.
- The third opportunity consists of redesigning the product, process or service. This is something, which can be related to the concepts of Eco-design and Value management.
- Fourth, some organisations conduct a total reform work and do not only redesign their products or processes, but also recreate their demand and supply chains.

All in all one can definitely conclude that many organisations provide products and services that are produced in resource and energy intensive production chains. By implementing eco-efficiency in an organisation this can efficiently be minimized and controlled. Eco-efficiency is relatively young and it is not yet a fully established business concept. An essential part of eco-efficiency is to be able to measure and monitor its progress in a particular organisation. This part has intentionally been left rather open, this because different branches behave differently and also because there are a number of different interpretation keys available. As stated before eco-efficiency is not only applicable in large multinational organisations but also in small and medium sized companies. Eco-efficiency is relevant throughout an entire organisation (Desimone, 2000) and applies to marketing and product development as well as manufacturing and distribution. Desimone et al (2000) describes five different categories essential for becoming more eco-efficient:

1. **Benefits from reducing the current costs of poor environmental performance**
2. **Benefits from reducing potential future costs of poor environmental performance**
3. **Reduced costs of capital**
4. **Benefits from increased market share and improved or protected market opportunities**
5. **Benefits from enhanced image**

According to Desimone et al (2000) eco-efficiency is the best model to achieve the above five benefits because “it is a management philosophy that links with other business ideas such as total quality management and strategic collaboration. It contributes to the sense of purpose and shared values that are central to achieving business excellence.” It is difficult to demonstrate the different benefits of implementing eco-efficiency into an organisation. Environmental investments can sometimes take years before they become visible and it is not unusual that the benefits appear in intangible assets such as improved company image.

The WBCSD has outlined seven important opportunities in order to successfully work eco-efficiently:

1. **Reduced material intensity**
2. **Reduced energy intensity**
3. **Reduced dispersion of toxic substances**
4. **Enhanced recyclability**
5. **Maximized use of renewables**
6. **Extended product life**
7. **Increased service intensity**

These seven elements can be efficiently accomplished by harnessing the three objectives below:

- **Reducing the consumption of resources**. This is accomplished by minimizing the use of energy (electricity and fuels), materials water and land, improving the possibilities to recycle, extend the life time of the product or process by producing more durable product, and by closing material loops.

- **Reducing the impact on nature**. The impact on nature can be efficiently reduced by minimizing air emissions, water discharges, waste disposal and dispersal of toxic substances, and harnessing the sustainable use of renewable resources.

- **Increasing service or products value**. This can be achieved by developing the product functionality, flexibility, modularity and thereby providing increased benefits to the customers, providing additional services such as maintenance or exchange services, and concentrating on the functional needs that the customers actually wants (similar to value management).

Measuring

Measuring and monitoring corporate progress with various indicators is an important part of any business (Holliday et al, 2002). In order to obtain a more eco-efficient and ultimately a more sustainable business it is of great importance to be able to measure the economic and environmental progress of an organisation. Eco-efficiency unites the fundamental components necessary for economic and environmental prosperity. However, without relevant and meaningful indicators the concept is merely empty words. There are a number of reasons for why companies and organisations measure their eco-efficiency performance. These reasons can be issues like tracking and documenting performance and progress, identification and prioritisation of opportunities for improvement, and identifying cost savings and similar benefits linked to eco-efficiency. Indicators for eco-efficiency can also serve as magnificent tools for investment decisions and understanding why different processes or products performance is limited in certain aspects (Verfaille & Bidwell, 2000). Furthermore it is often stated that eco-efficiency can be a great means for communicating corporate progress to various stakeholders such as investors, consumers and customers. Another important possibility, which the eco-efficiency indicators provide, is benchmarking. Benchmarking is something that has become increasingly important in today's continuously changing business environment. However, comparisons and benchmarking between businesses and business units should be executed with great carefulness (NRTEE, 1999). Different businesses and business units might be working under fundamentally different economic, environmental, political and natural resource prerequisites. Different industrial processes are inherently different which is why greatly different achievable eco-efficiencies might be a fact.

Jollands (2004) states that since economic activities enforce significant impacts on the environment, it is reasonable to consider that economy-environment interactions form an important part of the eco-efficiency concept. The efficiency outcome of the interaction between economy and environment is meant to reflect the concept of sustainable development and the part which business plays in sustainability. Jollands argues that the focus on sustainable development in eco-efficiency context often is implicit. The fact that eco-efficiency brings together economy and environment has led the WBCSD (Desimone, 2000) to define eco-efficiency as:

$$\frac{\text{Product or service value}}{\text{Environmental influence}}$$

This is a fundamental equation that can be used with a number of different indicators. It is of great importance that the reporting is practical and straightforward. Furthermore, the indicators must be accurate and relevant in a scientific manner. Verfaillie & Bidwell (2000) present eight principles, which should be included in eco-efficiency indicators. Indicators should:

1. **Be relevant and meaningful with respect to protecting the environment and human health and/or improving the quality of life**. –The main objective with eco-efficiency is to enhance an organisations environmental performance relative to the value of the organisations product or services.
2. **Inform decision making to improve the performance of the organisation**. **–**One of the purposes with eco-efficiency is to facilitate for management to decide on important business decisions.
3. **Recognize the inherent diversity of business**. **–**It is important for any organisation to recognize its key factors/indicators considering environmental and economic performance; this is something that can be different in different organisations.
4. **Support benchmarking and monitoring over time**. –In order for the indicators to support monitoring and benchmarking it is important that they are generally applicable and reproducible, this ensure that users receive correct information.
5. **Be clearly defined, measurable, transparent and verifiable**. **–**The boundaries and systems of the indicators should be easily accessible and defined for decision makers.
6. **Be understandable and meaningful to identified stakeholders**. **–**In order for the indicators to be of optimal use for all involved stakeholders it is of great importance that they are easy understandable and also that its limitations are made clear.

7. **Be based on an overall evaluation of a company's operations, products and services, especially focusing on all those areas that are of direct management control**. –The indicators should be relevant to the nature of business in which the organisation operates, this facilitates the comparability and makes sure that the indicators are of importance in a sustainable context.
8. **Recognize relevant and meaningful issues related to upstream (e.g. suppliers) and downstream (e.g. product use) aspects of a company's activities**. –Production of raw materials and the recyclability of products are areas that are of a holistic (cradle-to-gate) interest when it comes to measuring eco-efficiency.

These principles are generally applicable on all fields of business involving the concept of eco-efficiency. The eco-efficiency indicators can also be applied on different level within a business organisation; this is described in figure 1.

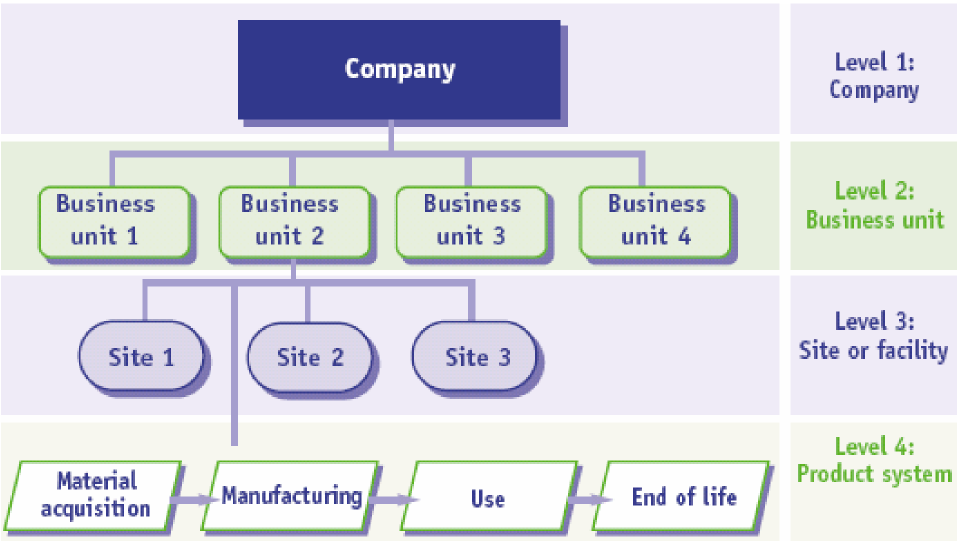


Figure 1. Different organisation levels of eco-efficiency indicators (NRTEE, 1999).

In order for an eco-efficiency measurement to be effective and reflect the real conditions it is important that the eco-efficiency indicators apply well to the following four areas (Sturm et al, 2004):

I. **Understandability.** It is important that the environmental data about a process or product is presented together with technical and economic data to obtain a holistic perspective. This makes it more important to present the environmental data in a way, which is easy to understand for the users.

II. **Relevance.** The information should provide relevant data, which should give the users a possibility to understand how, their activities change over time.

III. **Reliability.** The data must be unbiased and impartial to be of any use for both external and internal users. The reliability would be further strengthened with a standardisation of the data reporting.

IV. **Comparability.** The data must be useful in the sense that it is easily comparable when measuring and evaluating a business process over a period of time.

Calculating Eco-efficiency

This section describes how eco-efficiency can be calculated according to Steen et al (2004). The two fundamental parts of eco-efficiency, product value and environmental influence are characterized as life cycle cost (LCC) and environmental damage cost (EDC), hence the basic eco-efficiency equation is:

$$\frac{LCC}{EDC}$$

However, in order to create a calculation model that facilitates the interpretation of eco-efficiency the equation is standardized as the algorithm:

$$1 - \frac{EDC}{LCC}$$

The standardization results in an eco-efficiency of 100 % when the EDC is negligible compared to the LCC. Furthermore, the eco-efficiency is less than zero when the EDC exceeds the LCC and more than 100 % in cases when the EDC is negative i.e. creates a surplus value to a system.

Environmental Damage Costs (EDC)

The environmental damage cost for a product or a system is derived from the cost of six different environmental indicators. The environmental indicators are:

- Greenhouse gases
- Acidifying gases
- Ozone depleting gases
- Gases contributing to creation of ground level ozone
- Emissions contributing to oxygen deficiency in water
- Consumption of non-renewable energy reserves

The amounts of emission from each environmental indicator are derived from a LCA for the process or product. LCA is short for Life Cycle Assessment and is commonly described as following a product from its cradle to its grave (Baumann & Tillman, 2004). The cradle is referred to the beginning of the product life cycle and involves extraction and refining of raw materials and the grave is referred to as the disposal phase of the life cycle. In between the cradle and the grave is the usage phase of the product life cycle. An LCA can be described as an inventory of the emissions produced and the resources used during a product life cycle.

Each environmental indicator is expressed in a representative unit for the specific indicator and is the sum of all emissions within the indicator range. For example, the representative unit for greenhouse gases is carbon dioxide equivalents; hence all greenhouse gases emitted by the process are translated into CO_2 equivalents. In order to present the EDC for each indicator the amount of each indicator unit is multiplied by its environmental load unit, ELU (see EPS below) to yield the total EDC for the specific indicator. The ELU is developed to facilitate the weighting of environmental impacts.

Environmental Priority strategies (EPS)

Environmental priority strategies in product design (EPS) was initially developed for the Volvo Car Corporation by the Swedish Environmental Research Institute, IVL (Steen, 1999a) as the EPS enviro-accounting method. The method was intended to assist designers and design engineers in decision situations. The EPS system has been revised a number of times within different projects. The Centre for Environmental Impacts Assessment for Products and material Systems, CPM (Steen, 1999a) later modified the method to apply to five safe guard subjects and the willingness-to-pay for these safeguard subjects. The five safeguard subjects, human health, biological diversity, ecosystem production capacity (e.g. crops, wood, fish, meat), abiotic resources (e.g. fossil fuels, metals), and cultural and recreational values (e.g. aesthetics, landscape scenery) are based on the United Nations, UN Rio declaration from 1992. The EPS-system can be described by a number of principles in agreement with ISO 14040 (Steen, 1999a). These four principles, the top-down principle, the index principle, the uncertainty principle, and the default principle are described below.

I. **The top-down principle**. The EPS method is a complex system that is built upon a monetary basis. This means that some information will be difficult or impossible to obtain. More important factors are given priority and less important factors is dealt with when and if information is available. The top-down principle results in that issues close to decisions are prioritised before issues related to fundamental information.

II. **The index principle**. The EPS method is developed as a tool to assist in environmental decision-making situations. In order to obtain a holistic view of a product or process life cycle it is of great importance to have prepared and weighted impact indices. The indices contain the aggregated environmental impact from production, processing and waste management of materials. The environmental information, which is obtained from LCA, is combined with a characterisation factor and a weighting factor to produce an environmental index. The sum of the different indices generated from various activities is presented as an Environmental Load Unit (ELU) of the product life cycle. The ELU facilitates comparisons in decision-making situations considering choice of materials and processes in a holistic approach.

III. **The default principle**. Choosing a standard way of using the EPS system provides a way of again facilitating various decision-making situations. The default principle has three main advantages. The first is that a default method is in line with the typical product development process where initial guidance on which materials and processes that is needed is critical. Further on, a default method approach facilitates communication of the environmental policy to designers and design engineers. Finally, the decision making process can proceed faster than it would have done when performing a complete LCA.

IV. The uncertainty principle. Environmental impact assessment involves a large number of uncertainties such as the effects of various local and global emissions and the use of emission factors when there is lack of environmental data from a process. It is important to deal with issues of such kind in a adequate manner. A way of dealing with uncertainties is to describe environmental impacts as potential effects (Steen, 1999a). This approach is used in the ISO 140 40 and specifies a difference between a life cycle impact assessment and the actual impacts on the environment.

When calculating an Environmental Load Unit, ELU the weighting part of the index principle is based on the above mentioned safeguard subjects. Each safeguard subject has different subcategories, which the ELU is depending on. An example of an ELU calculation for carbon dioxide is described in table 1 below.

Table 1. Calculation of ELU for carbon dioxide.

	Charactarisation		**Weghting**	
Safeguard subjects	Global frequency x (or intensity)	(Contribution of 1kg to global emissions)x	Value of unit effect =	Sum
Human health	*(Affected persons/year)*	*1/(kg/year)*	*(Euro/person*year)*	*(ELU/kg CO2)*
Reduced life expectancy	5,40E+09	1,26E-16	85 000	5,78E-02
Severe morbidity	2,50E+09	1,26E-16	100 000	3,53E-02
Morbidity	2,50E+09	1,26E-16	10 000	6,55E-03
Severe nuisance			10 000	
Nuisance			100	
Ecosytem production	*(kg lost produce/year)*	*1/(kg/year)*	*Euro/kg produce)*	*(ELU/kg CO2)*
Reduced fish or meat prod.		1,26E-16	1	
Reduced crop prod.	6,00E+11	1,26E-16	0,15	1,13E-05
Reduced wood prod.	-3,20E-12	1,26E-16	0,04	-1,09E-04
Reduced water prod.			0,03	
Biodiversity	*(% of 1 NEX)*	*1/(kg/year)*	*Euro/NEX)*	*(ELU/kg CO2)*
Extinction of species	100	1,26E-16	1,10E+11	1,39E-03
Cultural values	*(not yet defined)*			
Abiotic resources	*(not applicable*			
	for emissions)		0,0674	
			Sum	1,01E-01

Life Cycle Costing (LCC)

Life cycle costing (LCC) is an analytical tool belonging to the group of life cycle approaches (Huppes, 2005a). LCC is commonly adopted in decision-making situations concerning design, development, and purchase of products, processes, or activities, and the corporate, public and policies connected to them. LCC brings together the two terms life cycle and costing and consists of a number of stages designed on the goals and scope of the situation to which it is applied.

Life cycle cost is defined as all the costs related to the life cycle of a product or process that are directly enclosed by the different participants in the product or process life cycle (supplier, producer, user/consumer) with interrelating insertion of externalities that are assumed to be internalised in the near future of decision making (Rebitzer et al 2005). Life cycle costing, LCC is the assessment of life cycle cost applied to various products or processes. Life cycle costs are commonly divided into internal and external costs. Internal costs are characterized as being paid by a directly involved stakeholder (a producer, transporters or a consumer) and related to production, use, or end-of-life expenses and therefore connected to a business cost and liability. Internal costs involve all costs and revenues within a business system and are often divided into cots inside or outside an organisation. External costs involve the monetary impacts of environmental and societal activities not directly economically related to the firm, consumer or government that is producing, using or handling the product or process. These costs are referred to as externalities and are often debated in lifecycle contexts.

LCC is commonly divided into three different types of lifecycle perspective (Huppes, 2005a)

- **Business LCC** or conventional LCC is applied for internal, business related, cost assessment and controlling. The cost assessment can also apply to revenues of products as well. The product analysed is typically complex, has along lifetime and high LCC costs. Typical functional unit is set to 1 unit of product. The cost assessment is typically used in different decision-making situations considering optimisation or purchase.
- **Environmental LCC**. The product analysed is typically less complex than in a business LCC. In environmental LCC assessment the analysis is generally more strictly related to a functional unit (such as m^3) as is given in ISO 14040 (Steen, 1999a). These assessments are not executed in order to examining controlling or tendering possibilities but rather to investigate environmental and economic impacts caused by a product or process. The methods for cost calculation are often simpler than for business LCC studies and commonly use price as a foundation for costs.
- **Societal LCC** is often described as an LCC dealing with internal costs from more than one perspective. A typical example for when societal LCC studies are used is assessments of the societal impact from an industrial site on the nearby neighbourhood.

In this study the LCC calculations are much similar to an environmental LCC assessment since the purpose of the study is to examine the environmental and economic impacts of an industrial process in an eco-efficiency study. According to SETAC (Huppes, 2005b) there are five stages that are the most aggregated and should be consistently applied in environmental LCC assessments:

1. Research and development
2. Production of materials/components
3. Manufacturing
4. Use and maintenance
5. End of –life management

It should also be noted that specific activities or processes could be related to different stages at the same time, i.e. raw material and fuel production.

Akzo Nobel Case Study

This Chapter describes the case study at Akzo Nobel in Stenungsund. The organisation and its strategy for environmental work are briefly described together with information about the industrial process, which the actual case deals with.

Akzo Nobel

Akzo Nobel is a multinational organisation with its head office in Arnhem, Netherlands. The business group consists of a number of companies producing healthcare products, coatings and chemicals to customers around the globe. The Akzo Nobel Business Group presented a turnover of 115 billion SEK in 2004 and employs 62 000 people in more than 80 countries (Akzo Nobel, 2005). Akzo Nobel's business strategy is to create above-average economic value over the business cycle. They strive to be an organisation in which talented, ambitious people are proud to work. Furthermore, the company continuously invest in building sustainable leading business positions. This is something that is in line with the company's desire to be respected in the societies in which they operate.

Site Stenungsund Akzo Nobel

Akzo Nobel in Stenungsund employs approximately 450 people and has continuous production all year around. The yearly production operating time is 8400 hours (MKB, 2004). The site has two production units, which are described below.

- Ethylene amine plant: Ethylene oxide/glycol plant and the Amine plant. The production process in the Ethylene amine plants is continuous and typical products are ethene oxide, glycol, ethanol amines, ethylene amines and amine derivates.
- Surfactants plant: Einulsifying plant / special tenside plant. The production process is divided into short production series with batches of different products and typical products are non-ion-, anion-, cat ion tensides and amphoteres.

The different production units are comprised as three production units, which deliver process water to the refuse incinerator. These three production units are called:

- Amine
- EMU
- STF

Global Environmental Work at Akzo Nobel

Akzo Nobel works continuously with extensive environmental improvements throughout their entire organisation. The environmental work is consistently divided into four major areas, energy efficiency; emissions to air; water and waste management (Akzo Nobel, 2005). The energy consumption per unit of product is considered greatly important in the ambition to achieve an environmentally responsible production. Emissions to air have a strong relation to global warming and the generation of ground level ozone. This is a global environmental concern, which Akzo Nobel continuously works with and aims to reduce their environmental impact. Fresh water availability is a major environmental concern in many areas of the world today. Akzo Nobel consumes 180 billion m^3 of fresh water every year. The major part of this is surface water that is used as cooling water and is discharged without any chemical pollution. A major environmental concern considering water discharges is eutrophication as a result of discharge of COD from wastewater. Akzo Nobel has set a goal of reducing their COD discharge 30 % by 2010. Waste reduction is another important part of the company's environmental strategy. They actively work with finding new uses for waste products by recycling and reusing. Furthermore, Akzo Nobel consistently tries to replace end-of-pipe solutions by reengineering their production processes and thereby produce fewer waste products. Their long-term goal considering waste products is a 30 % reduction by 2010.

An important part of the environmental work at Akzo Nobel is led by the department of Sustainable Development. The sustainable development group work as internal consultants with various projects for the entire Akzo Nobel organisation and has its base in Stenungsund, Sweden. Typical tasks which the department of Sustainable Development work with are (Sustainable Development, 2005):

- Perform environmental and eco-efficiency studies of products from a life cycle perspective
- Assist customers regarding product stewardship and sustainability issues
- Manage the EU Life Environment Project DANTES

In the strive towards a more sustainable production Akzo Nobel together with ABB, Stora Enso and The university of Chalmers has started the network Dantes. Dantes is financed by the European Union and functions as a network where the involved organisations exchange knowledge and information. Dantes provide the members with the opportunity to learn from each other and create new systems; techniques and tools for measuring environmental progress (Dantes, 2005) visit www.dantes.info for further information.

The Environmental Issue

The Akzo Nobel Surface Chemistry Site in Stenungsund has recently received a new environmental permit, which allows the organisation to increase their production at the site in Stenungsund. In the terms for the new environmental permit it is stated that an investigation of the possibilities to decrease the discharge of COD to 10 metric tons per year in the industrial outlet (AMV, 2002). The consequence of a decreased discharge of COD in the industrial outlet is that an increased amount of process water must be incinerated in the refuse incinerator. COD is short for chemical oxygen demand and is a generic term for organic compounds which demand oxygen to break down (biologically or non-biologically) in water (Petersson, 2002). Measuring the level of COD in water is a common approach to measure the quality of the water.

The environmental dilemma arises when different environmental impacts are weighted against each other. Large discharge volumes of COD can result in eutrophication of adjacent water recipients. This is a problem that can be solved by incinerating highly concentrated process water. However, an increased incineration also results in increased volumes of air pollutants such as greenhouse gases and gases contributing to ground level ozone. Furthermore, an increased incineration also results in an increased consumption of non-renewable resources. The purpose of this investigation is to determine how the eco-efficiency of the refuse incinerator changes with varying process conditions. The result of the eco-efficiency analysis will hopefully provide probing factors for a decision-making situation considering if it is beneficial in a sustainability sense to increase the incineration of process water or if the incineration should be reduced.

Description of the refuse incinerator

Polluted process water and ventilation gases from the different process plants need to be purified before discharge into adjacent water recipients. This purification process is accomplished by incineration of process water and ventilation gases at a temperature of approximately 950˚ C during more than 2 seconds in excess of oxygen (Kindstrand, 2004). The nominal capacity of the refuse incinerator is 6.5 tons/h. A principal flow chart of the refuse incinerator is given in figure 2 below. The main units of the refuse incinerator plant are:

- Two parallel evaporation plants for evaporation of process water (vaporization occur to 90% and the concentrate 10% is injected into the afterburner).
- Afterburner.
- Steam boiler.
- Dust separator.
- Cooling system for waste gas flue.
- Waste gas fan connected to a 50 m high chimney.
- Filter stations and pressure regulation for fuel gas together with HP- and LP-ventilation gases.
- Antifoam system.

The refuse incineration plant is adapted for fully automatic operation controlled with 3 fully automatic burner control systems with 3 PLC systems. In addition to this the refuse incineration plant is connected to a catalytic purification plant for CO_2-ventilation gas where organic compounds are oxidised to CO_2 and water.

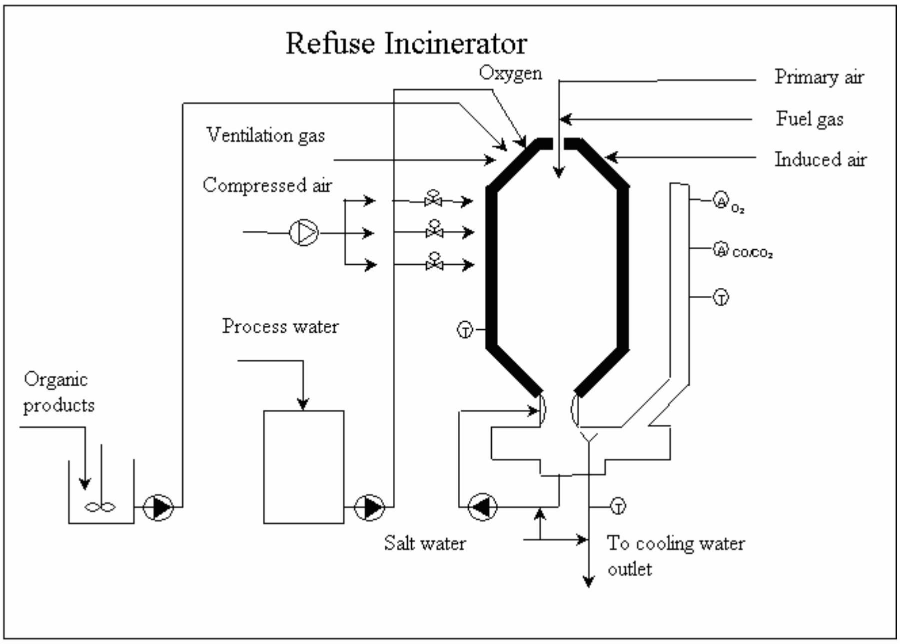


Figure 2. Principal flow chart of refuse incinerator (MKB, 2004).

Goal and Scope description of the analysis of the process system

In order to perform eco-efficiency calculations for further evaluation of the system it is of great importance to specify the fundamental prerequisites of the system. The goal and scope description of the analysis of the process system is developed with guidance from ISO standard 14040 for LCA (Steen, 1999a).

The functions of the process system

The main purpose of the process system is to eliminate toxic substances in the industrial outlet and to reduce the amount of organic substances (COD) to adjacent water recipients via the industrial outlet. A positive side effect of the system is the opportunity to recover heat and produce steam for use within the site.

The functional unit

The functional unit for this case is: m^3 of incinerated process water during one year. This functional unit is chosen to facilitate the investigation considering whether or not it is eco-efficient to reduce the amount of organic substances in the industrial outlet.

The process system to be studied

The process system stretches from the different production sites to the waste management units, including basin for breakdown of organic compounds, cistern for assembling of process water and the refuse incinerator. An overview of the process system is described in figure 3.

The process system boundaries

The process system boundaries reach from the outlet of industrial process water from the three production units to the outlet of the two different end-of-pipe units, the basin for breakdown of organic compounds and the refuse incinerator. More contaminated water containing toxic substances or high concentrations of COD are sent to the refuse incinerator for incineration. Less contaminated process water is sent to the basin where the organic compounds partially break down. Whether the non-toxic process water is sent to the basin or the refuse incinerator is determined by the concentration of COD in the process water. Furthermore the fuel gas feed from external site and the electricity use of the refuse incinerator is included within the system boundaries. The process system boundaries are described in figure 3.

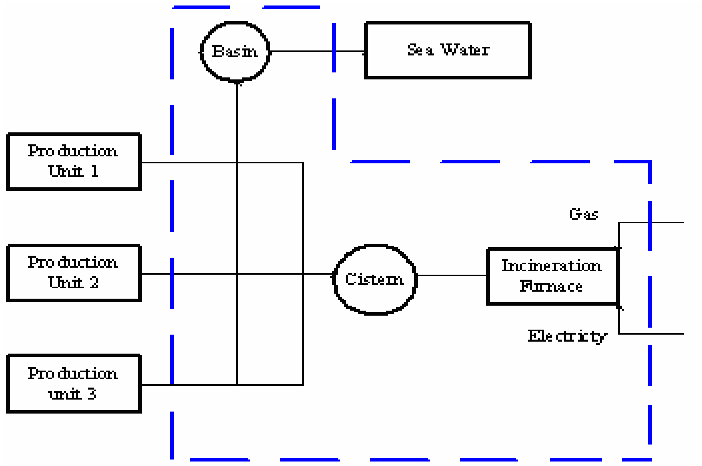


Figure 3. Process system and boundaries.

Allocation procedures

The refuse incinerator has a steam production unit that evaporates process water with the use of exhaust gases to produce steam for use within the site in different production plants. This steam is an essential part of different chemical processes around the site. Before the new refuse incinerator was installed a freestanding steam boiler was used to produce steam within the site. With the present refuse incinerator, the use of this steam boiler has been significantly decreased and the emissions and resource use caused by the steam boiler are subtracted from the refuse incinerator, to determine which emissions or resource use that solely belong to the COD incineration process.

Data requirements

The data that is required to calculate the eco-efficiency of the refuse incinerator is described in the chapter "theoretical frame of reference". The data needed for calculating the eco-efficiency is environmental damage costs (EDC) and life cycle costs (LCC). The environmental damage costs are derived from LCA data for the production of fuel gas and the production of electricity together with emission data from the refuse incinerator and data from the EPS system. The LCA data covers the life cycle of the product from extraction of raw materials to production and incineration. The life cycle cost data is derived from the technical specifications of the refuse incinerator together with the specified prices for variable costs.

Limitations

The refuse incinerator has recently been put into use and has during the first months in use been optimised. The fact that the refuse incinerator has been in use for a rather short time has resulted in relatively uncertain measurements and to a certain extent fairly rough assumptions. This does not affect the result and comparative analysis of the process system between the two scenarios since the same assumptions are made in both scenarios.

Scenario descriptions

The case study is divided into two different scenarios with varying process conditions. The first scenario reflects the process conditions of today whereas the second scenario represents the nominal capacity of the refuse incinerator. The two scenarios provide representative circumstances for the research question of the case study, which is to determine if it is justifiable in a sustainability sense to incinerate larger volumes of process water in order to reduce the amount of COD discharge to adjacent water recipients.

Description of scenario 1

Scenario 1 is based on the process conditions from 2004 when the new refuse incinerator initially was taken into use. The amount of water delivered to the refuse incinerator during 2004 represents the routines for handling of process water from the different production units, which is in use 2005. The process water delivered to the refuse incinerator, from the three different production sites, Amine, EMU and STF was totally 31 744 m^3 during 2004. The amount of purified water discharged via the basin for breakdown of organic material through the industrial outlet to seawater was totally 76000 m^3 during 2004. The concentration of COD in the industrial outlet is calculated on the foundation of the amount of COD 2004, 11000 kg divided by the water discharged via the industrial outlet 76000 m^3 to result in 0.15 kg / m^3. The combustion efficiency of the refuse incinerator is 70 %. This means that for each MJ of fuel gas that is combusted 0.7 MJ of steam is produced. The amount of fuel gas needed to incinerate 1 m^3 of process water is 110 kg. The electricity used for incineration of 1 m^3 of process water is 33 kWh. The technical in data for the process is summarised in the table 2 below.

Table 2. Technical in data for scenario 1.

Technical in data for scenario 1		**Unit**
Combustion efficiency	70	%
fuel gas/process water	110	kg/m3
process water to incineration	31744	m3
water discharged via ind. outlet	76000	m3
electricity/process water	33	kWh/m3

Description of scenario 2

Scenario 2 is based on the process conditions specified as the nominal capacity of the refuse incinerator. The process water delivered to the refuse incinerator, from the three different production sites, Amine, EMU and STF is calculated on the nominal feed capacity of the refuse incinerator, 6.7 m^3/h. The incinerated process water is totally 56280 m^3 during one year. The amount of purified water discharged via the basin for breakdown of organic material through the industrial outlet to seawater is calculated on the basis of the total water from the production units and discharge during 2004, 107744 m^3. The total amount of water discharged via the industrial outlet is 51464 m^3 (107744-56280). The increased volume of process water in scenario 2 is assumed to originate from the EMU and STF production plants since these are the plants from which an increased amount of process water would have come from in a nominal case i.e. a full utilization of the refuse incinerator. This is water with a relatively low concentration of COD, which in the present scenario is delivered to the basin for partial breakdown of organic material and thereafter discharged to adjacent water recipient. The concentration of COD in the industrial outlet is calculated on the foundation of the amount of COD 2004, 11000 kg divided by the water discharged via the industrial outlet 76000 m^3 to result in 0.15 kg / m^3. The combustion efficiency of the refuse incinerator is 70 %. This means that for each MJ of fuel gas that is combusted 0.7 MJ of steam is produced. The amount of fuel gas needed to incinerate 1 m^3 of process water is 110 kg. The electricity used for incineration of 1 m^3 of process water is 33 kWh. The technical in data for scenario 2 is presented in table 3 below.

Table 3. Technical in data for scenario 2.

Technical in data for scenario 2		**Unit**
Combustion efficiency	70	%
fuel gas/process water	110	kg/m3
process water to incineration	56280	m3
water discharged via ind. outlet	51464	m3
electricity/process water	33	kWh/m3

Results

In this chapter the results from the two different scenarios in the case study at Akzo Nobel are presented and explained. The chapter representing the both scenarios is divided into life cycle costs and environmental damage costs.

Results from scenario 1

Scenario 1 represents the present process conditions of the refuse incinerator. The environmental data are obtained from automatic sampling systems at the site and the economic data are calculated on a basis from a specified operational prescription of the refuse incinerator.

Life cycle costs

The life cycle costs (LCC) are composed of fixed and variable costs for the refuse incinerator. The LCC are viewed as the willingness to pay (WTP) for the service or process and are thereby representing the value of the process system. In this case the life cycle costs are viewed as the WTP for a reduced or absent eutrophication in adjacent water recipients. The variable costs are composed by fuel costs, electricity costs and etcetera. The fixed costs are composed by the costs for investment, staff, maintenance, depreciation and other fixed costs and are calculated on a depreciation time of 15 years.

Environmental damage costs

The calculation of the environmental damage costs for the different environmental indicators is built upon the environmental impacts from usage of electricity and fuel gas in the refuse incinerator. The EDC for the electricity is calculated on Swedish average electricity (Spine, 2001) and the EDC for the incineration is calculated on fuel gas from Borealis (Borealis, 2005). The amount of emissions and the damage cost for each indicator is presented in table 4 below.

Table 4. Environmental damage costs for scenario 1.

Environmental Damage Costs			
Indicator	**Unit**	**Value**	**SEK**
Greenhouse gases	kg CO2 equivalents	1766922.81	1784238.621
Acidifying gases	kg SO2 equivalents	6416.77	196189.6475
Ozone depleting gases	kg CFC-11-equivalents	0.00	0.00
Gases contributing to creation of ground level ozone	kg ethene-equivalents	250.72	3516.4415
Emissions contributing to oxygen deficiency in water	kg O2-equivalents	4009.42	37.4935
Consumption of non-renewable energy reserves	EUR	2207032.49	20635753.78
		EDC	22 619 735.99

An example of how the EDC for greenhouse gases are calculated is given here: The amount of greenhouse gases produced by the system, 1766922.81 kg is first multiplied by the environmental load unit (ELU) for the equivalent unit for greenhouse gases, carbon dioxide equivalents, 0.108 ELU/kg. The ELU is equivalent to EURO, which is why the result is multiplied by the currency, 9.35 SEK/EUR (Dagens Industri, 2005) to result in the EDC for greenhouse gases, 1784238 SEK.

EDC for greenhouse gases $= 1766922.81 \times 0.108 \times 9.35 = 1784238$

As illustrations of what the different environmental damage cost indicators are composed by the amount of emissions and their damage costs are described below for the indicators non-renewable resources, greenhouse gases and emissions contributing to oxygen deficiency in water.

Table 5. The EDC for non-renewable indicators in scenario 1.

Non renewable resources	kg (el. use)	kg (combustion)	EUR
Coal	8.0661504	6418.82	320.06
Iron	0.00	437.98	420.90
Uranium	6.49E+00	5.73	14547.67
Oil	1.27E+02	1606246.40	812824.82
Natural gas	3.25E+00	1140891.57	1254984.30
Copper	0.00	595.51	123866.71
Aluminium	0.00	154.97	68.03
Manganese	0.00	0.00	0.00
		Sum	2207032.49

In table 5 the environmental damage costs for the consumption of non-renewable resources is presented. A description of how the EDC for oil is calculated is given here to illustrate how the different damage costs are compiled: The amount of oil needed to produce 1kWh (Spine, 2001) of Swedish average electricity, 1.21E-04 kg is multiplied by the electricity use needed to incinerate 1 m^3 of process water, 33 kWh to give the amount of oil (from electricity) needed to incinerate 1 m^3 of process water and the total volume of incinerated process water during the year, 31744 m^3 to give, 1.27E+02 kg. The amount of oil needed to produce 1 kg of fuel gas, 0.46 kg is multiplied by the amount of fuel gas needed to incinerate 1 m^3 of process water, 110 kg to give the amount of oil (from fuel gas) needed to incinerate 1 m^3 of process water and the total volume of incinerated process water during the year, 31744 m^3 to give, 1606246.40 kg. The total amount of oil needed, (1.27E+02 + 1606246.40) kg is finally multiplied by the environmental load unit for oil, 0.506 EUR/kg to give the EDC for oil, 812824.82 EUR, which is slightly more than a third of the total damage costs for the non-renewable resources indicator.

In table 6 the emissions contributing to oxygen deficiency in water (COD) are presented. As can be seen the major part of the emissions come from discharge.

Table 6. The amount of emissions contributing to oxygen deficiency in water for scenario 1.

Eutrophication potential (EP) EP emission	kg O2-ekv (electricity use)	kg O2-ekv (discharge)	kg O2-ekv (fuel combustion)	kg O2-ekv.tot
Ptot	0.00	0.00	12.22	12.22
NH4	0.00	0.00	8.87	8.87
NOX	7.51E+02	0.00	0.00	751.04
N	2.60E+01	0.00	131.43	157.41
COD	0.00	3000.00	79.88	3079.88
			EP	4009.42

As can be seen in table 4 the two most significant environmental indicators in this case study are greenhouse gases and non-renewable resources. In table 7 the emissions contributing to global warming and their source are presented.

Table 7. The amount of emissions contributing to global warming from scenario 1.

Global Warming Potential (GWP) GWP gas	kg CO2-ekv (electricity)	kg CO2-ekv (fuel incineration)	kg CO2-ekv (fuel production)	kg CO2-ekv (total)
CO2	2.89E+04	1871.69	1736037.98	1766822.11
CH4	0.00	59.90	69085.16	69145.06
N2O	0.00	0.00	100.70	100.70
			GWP	1766922.81

The eco-efficiency from scenario 1 is calculated to –90.23 %.

Results from scenario 2

Life cycle costs

The life cycle costs (LCC) are composed of fixed and variable costs for the refuse incinerator. The LCC are viewed as the willingness to pay (WTP) for the service or process and are thereby representing the value of the process system. In this case the life cycle costs are viewed as the WTP for a reduced or absent eutrophication in adjacent water recipients. The variable costs are composed by fuel costs, electricity costs and etcetera. The fixed costs are composed by the costs for investment, staff, maintenance, depreciation and other fixed costs and are calculated on a depreciation time of 15 years.

Environmental Damage Costs

The calculation of the environmental damage costs for the different environmental indicators is built upon the environmental impacts from usage of electricity and fuel gas in the refuse incinerator. The EDC for the electricity is calculated on Swedish average electricity (Spine, 2001) and the EDC for the incineration is calculated on fuel gas from Borealis (Borealis, 2005). The total environmental damage costs has in scenario 2 increased from nearly 26 million SEK in scenario 1 to 40 million SEK during one year. The amount of emissions and the damage cost for each indicator is presented in table 8 below.

Table 8. Environmental damage costs for scenario 2.

Environmental Damage Costs **Indicator**	**Unit**	**Value**	**SEK**
Greenhouse gases	kg CO2 equivalents	3132636.59	3163336.41
Acidifying gases	kg SO2 equivalents	11376.51	347831.27
Ozone depleting gases	kg CFC-11-equivalents	0.00	0.00
Gases contributing to creation of ground level ozone	kg ethene-equivalents	444.52	6234.30
Emissions contributing to oxygen deficiency in water	kg O2-equivalents	3821.12	35.71
Consumption of non-renewable energy reserves	EUR	3912921.77	36585818.55
		EDC	40103256.24

As can be seen in table 9 the consumption of non-renewable resources has compared to scenario 1 increased significantly from 2200 tons to slightly more than 4000 tons in this scenario representing the nominal process conditions.

Table 9. The EDC for non-renewable indicators in scenario 2.

Non-renewable resources	kg (el. use)	kg (fuel combustion)	EUR
Coal	14.30	11380.15	567.44
Iron	0.00	776.52	746.23
Uranium	1.15E+01	10.16	25792.05
Oil	2.25E+02	2847768.00	1441084.32
Natural gas	5.76E+00	2022724.84	2225003.66
Copper	0.00	1055.81	219607,44
Aluminium	0.00	274.76	120.62
Manganese	0.00	0.00	0.00
		Sum	3912921.77

Even though the discharge of COD decreases from 3000 kg to 2031 kg (Table 10) the total amount of emissions contributing to oxygen deficiency remain nearly unchanged compared to scenario 1. This is depending on the increased amount of nitrogen based air pollutants.

Table 10. The amount of emissions contributing to oxygen deficiency in water for scenario 2.

Eutrophication potential (EP) EP emission	kg O2-ekv (electricity use)	kg O2-ekv (discharge)	kg O2-ekv (fuel combustion)	kg O2-ekv.tot
Ptot	0.00	0.00	21.67	21.67
NH4	0.00	0.00	15.72	15.72
NOX	1.33E+03	0.00	0.00	1331.54
N	4.61E+01	0.00	233.02	279.09
COD	0.00	2031.47	141.63	2173.10
			EP	3821.12

The greenhouse gases increases from 1766922.81 kg in scenario 1 to nearly the double amount 3132636.59 kg in scenario 2. The greenhouse gases emitted from scenario 2 are presented in table11 below.

Table 11. The amount of emissions contributing to global warming from scenario 2.

Global Warming Potential (GWP) GWP gas	kg CO2-ekv (electricity)	kg CO2-ekv (fuel incineration)	kg CO2-ekv (fuel production)	Kg CO2-ekv (total)
CO2	5.13E+04	3318.38	3077879.84	3132458.04
CH4	0.00	106.20	122483.39	122589.59
N2O	0.00	0.00	178.54	178.54
			GWP	3132636.59

As a result from the significantly increased environmental damage costs the eco-efficiency has decreased from –90.23% in scenario 1 to –198.20 % in scenario 2.

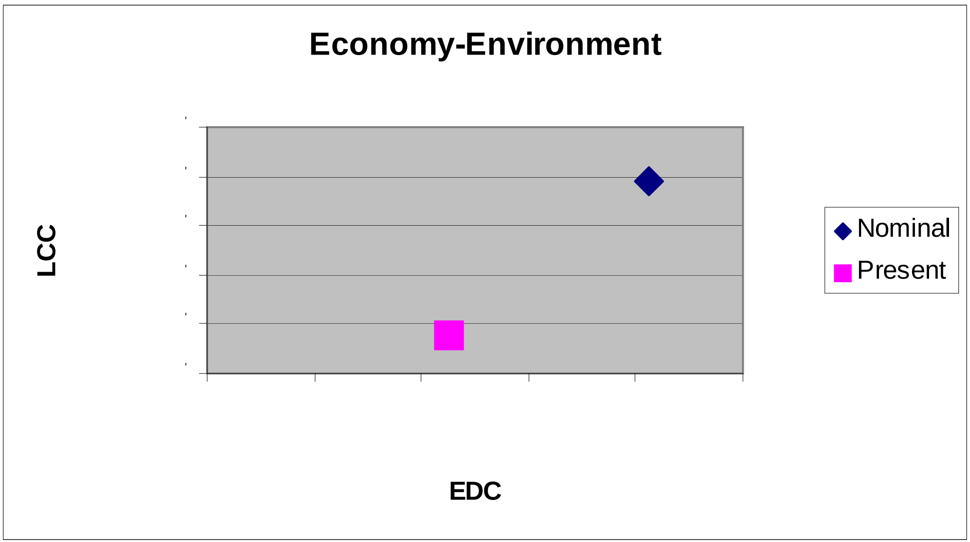
Analysis

In the analysis the results are examined with respect to the difference between the two scenarios representing different process conditions. This is achieved by performing a sensitivity analysis on various characteristics. The characteristics, which are scrutinized in this analysis, are weighting factors, heat recovery, and type of fuel.

Increased incineration of process water

In scenario 2 a significantly increased incineration of process water reduces the outlet of COD to adjacent water recipients via the industrial outlet from ~11 tons per year to ~7 tons per year. The process conditions in this scenario are set to the maximum level of which the refuse incinerator can operate i.e. nominal conditions. The eco-efficiency in scenario 1, representing the present process conditions is calculated to –90.23 %, which is 107.97 % more than in the second scenario, representing the nominal process conditions. The reduced result in eco-efficiency for scenario 2 is depending on various factors. An increased incineration leads to a small reduction in damage cost for the indicator considering emissions contributing to oxygen deficiency in water. However, the most significant environmental indicators in this specific case are greenhouse gases and non-renewable resources. The EDC for the consumption of non-renewable resources and the greenhouse gases in scenario 2 has nearly duplicated compared to scenario1. In chart 1 below the relation of the life cycle costs and the environmental damage costs are described. It can clearly be established that the present case have significantly lower life cycle costs as well as environmental damage costs compared to the nominal case.

Chart 1. The relation between LCC and EDC for scenario 1 and 2.



Weighting factors

In this case COD has a rather low EDC compared to other indicators. However, the EDC for COD might be different if the ELU for COD was weighted in a different manner. The weighting in the EPS default method is based on a global average considering oxygen free sea bottoms. An important aspect is the type of characterisation factor used for the weighting of an environmental indicator. In the EPS default method the characterisation factor for COD is chosen as NEX (Steen, 1999b) i.e. normalised extinction of species, in this case fish. An alternative approach to choosing the characterisation factor for weighting of the environmental impacts of emissions contributing to oxygen deficiency in water could be a recreational standpoint (Steen, 2005) i.e. what the average citizen in the adjacent municipality is willing to pay for a water recipient with good recreational possibilities. The two different alternatives can be explained as a global average considering eutrophication and a site-specific evaluation of the local effects of COD discharge.

Heat recovery

The refuse incinerator has a unit that produce steam by heating water with exhaust gases and thereby recover heat from the process system which otherwise would have been wasted. Because the new refuse incinerator produce steam, the steam production of the usual steam boilers can be decreased. The new refuse incinerator process system thereby eliminates parts of the previous steam production and thus the environmental damage costs which otherwise would have been the result of a maintained use of the steam boiler unit in addition to the refuse incinerator. This effect also reduces the total use of fossil fuels within the site and thereby saves the company from using parts of the previous amounts of fuel oil as a combustion fuel in the steam boiler. Therefore the organisation also saves money. Sanne (2000) argues that when systems achieve a higher efficiency, one can no longer regard the increased efficiency as unequivocally good unless the savings are used wisely. Higher efficiency results in increased or enhanced processes or services with less input. However, economists have long stated that more cost efficient products or processes are likely to increase the utility of processes and services and thereby the environmentally beneficial effects are counterbalanced. This effect is referred to as the “rebound effect”. What this means is that if a company saves money and prevent environmental impacts the environmental impacts will arise in another situation where the money are used.

The importance of fuel type

A possible future scenario is that the fuel gas, which is used as a fuel for the refuse incinerator no longer, is available. This would lead to a scenario where the fuel gas is replaced with fuel oil. Therefore a comparison between fuel gas and fuel oil is performed here. The damage costs for greenhouse gases are more than twice as high for incineration with fuel oil compared to incineration with fuel gas. In such a case the differences between the two scenarios, which are compared in this study, could have been even more significant.

The amounts of greenhouse gases from incineration with fuel gas (the present scenario) as a combustion fuel are presented in table 12.

Table 12. The amount of greenhouse gases from scenario 1 using fuel gas for combustion.

Global Warming Potential (GWP) GWP gas	kg CO2-ekv (electricity)	kg CO2-ekv (fuel incineration)	kg CO2-ekv (fuel production)	kg CO2-ekv (total)
CO2	2.89E+04	1871.69	1736037.98	1766822.11
CH4	0	59.90	69085.16	69145.06
N2O	0	0.00	100.70	100.70
			GWP	1766922.81

The amounts of greenhouse gases from incineration with fuel oil as a combustion fuel are presented in table 13 below.

Table 13. The amount of greenhouse gases from scenario 1 using fuel oil for combustion.

Global Warming Potential (GWP) GWP gas	kg CO2-ekv (electricity)	kg CO2-ekv (fuel incineration)	kg CO2-ekv (fuel production)	kg CO2-ekv (total)
CO2	2.89E+04	2803850.62	351406.08	3184169.13
CH4	0	20714.46	64892.61	85607.08
N2O	0	0.00	0.00	0.00
			GWP	3184169.13

Discussion

In the context of sustainable development and the corporate world eco-efficiency is becoming increasingly important. Economic growth, which certainly is one of the major driving forces for corporate organisations, has an obvious effect on the environment in the sense that all economic activity causes an environmental impact (Meadows, 2005). The business society therefore plays an important part in the striving towards a sustainable development. The concept of eco-efficiency harnesses the fundamental requirements for a sustainable business society and is indeed an excellent approach to adopt for any environmentally conscious organisation. Working with the main characteristics of eco-efficiency, reducing the consumption of renewable resources, reducing the impact on nature and increasing the service or products value developed is without a doubt a good approach in order to become a more sustainable organisation. However, the question of how and when to measure the eco-efficiency is still an issue that requires further reflection in companies around the world.

According to Sturm et al (2004) it is important that an eco-efficiency measurement applies to the following four characteristics: Understandability, relevance, reliability, and comparability. In this model developed by Steen (2004) the equation $1 - \frac{EDC}{LCC}$ is used for calculating the eco-efficiency. The model clearly describes the relationship between technical and economic data together with the environmental data, which enhances the understandability and facilitates the interpretation of the results. The environmental and economic data, which is derived from life cycle assessments, provide relevant information from established sources and is therefore greatly relevant. This together with the economic quantification of the environmental impact with the use of the established EPS-system provides reliability to the calculation, which clearly is valuable considering communication issues. The environmental indicators used in the model are essential indicators in the striving towards a more sustainable development and it is therefore important that they are measurable. All of the indicators can be found in LCA reports and they are often continuously measured which facilitates comparing business systems and processes over a period of time.

The main purpose of the process is not only to reduce the amount of organic substances to adjacent water recipient but also more importantly to prevent dispersion of directly toxic substances such as nonyl phenol to adjacent water recipient. It this therefore important to recognise that when studying the process system with regard to COD and eutrophication certain main aspects to the system are left outside the system boundaries. This leads to a quandary where the value of the process in total must be viewed as elimination of toxic substances and prevention of eutrophication, and the value of the process system analysed is prevention of eutrophication. An increased discharge of process water via the industrial outlet, compared to the present process conditions, would result in increased dispersion of toxic substances, which could have an enormous environmental impact on the adjacent water recipient. A reduction of the incineration of process water with respect to toxic substances is therefore not desirable.

The cost of COD discharge for the company is practically nothing. However, an increased discharge of COD could lead to fines for the company. As stated in the goal and scope description of the analysis of the process system the functional unit of the process system is m^3 of incinerated process water during one year. It is therefore again important to acknowledge that because the value of the process system is defined with respect to incineration of COD the eco-efficiency does not reflect the total conditions of the process system. Hence, the eco-efficiency of the process system could be fundamentally different in a situation, which also describes the possible dispersion of toxic substances.

An intermediate goal of the dissertation is to analyse the purpose of the case study at Akzo Nobel, which is to determine if the eco-efficiency increases or decreases with an increased incineration of process water. The underlying scope of this purpose is to describe the relationship between greenhouse gases (GWP), the consumption of non-renewable resources and emissions contributing to oxygen deficiency in water (COD) caused by the incineration furnace. The relationship between GWP, consumption of non-renewable resources and COD has a number of limitations, which the eco-efficiency model itself probably cannot answer. The difficulty consists of weighting the environmental consequences of COD discharge in the adjacent water recipient. The environmental load unit (ELU) for COD is very small compared to the ELU for CO_2, which is the equivalency unit for greenhouse gases.

The ELU for COD from the EPS is based on calculations from a global perspective of oxygen deficiency and eutrophication. However, oxygen deficiency is to a great extent a local environmental problem that causes impacts on the adjacent natural recipients. An alternative approach would therefore be to develop a local ELU for COD. This is something that would require a thorough environmental study of the local conditions considering oxygen deficiency on the sea bottom of the adjacent water recipient, Askeröfjorden. In this case it would probably be desirable to investigate which amount of COD discharge that is acceptable per year in Askeröfjorden. Furthermore, the ELU values are calculated on the willingness to pay (WTP) among the inhabitants of the OECD countries for a reduced emission of each environmental indicator. A local ELU for COD would therefore also require a local perspective concerning the WTP for a reduced or absent eutrophication in Askeröfjorden. It must also be noted that the characterisation factor used when calculating the ELU for COD is normalised extinction of species (NEX) for fish. In a local perspective the extinction of fish is more of a recreational problem (Steen, 2005) since a local decrease in fish population will not affect the fish population in the Skagerrak and the Kattegatt. Therefore a possible approach would be to choose a characterisation factor for COD which better reflects a local recreational perspective.

Furthermore, it is of great importance to recognise that the eco-efficiency of the process system is very dependent on the conditions of the natural surroundings of the process system. The result from this study indicates that a decreased level of incineration with regard to COD will increase the eco-efficiency. However, a decreased incineration and thereby an increased discharge of COD could lead to oxygen deficiency in the adjacent water recipient. This will lead to a new weighting of the ELU for COD that better represents the new local conditions and ultimately the eco-efficiency will decrease.

Furthermore, the communication possibilities of the eco-efficiency calculations must be considered. An eco-efficiency with a negative percentage ratio can probably entail certain difficulties in a communication context, involving people who are uninitiated to the concept of eco-efficiency. Future studies considering the communication possibilities and the context of analysing the difference between different scenarios involving decision-making situations, is therefore needed.

The value of the process in the model developed by Steen (2004) is represented by the willingness to pay for the process and is derived from LCC data. However, predicaments related to the phenomena rebound effect (Sanne, 2000) can inflict a re-evaluation of the process value by an additional ‘value added’ to the LCC. This has been evident in a work by Lyrstedt (2005) where eco-efficiency measurements of electric motors at ABB, by using the model developed by Steen have proved the importance of considering ‘value added’.

Conclusions

An important part of the purpose for this dissertation is to evaluate if the eco-efficiency measurement is sufficient as a foundation for decision-making. One of the major conclusions, which can be distinguished from this study, is that it is important to interpret the underlying causes for the eco-efficiency result rather than being satisfied with just the one number that the eco-efficiency percentage provides. It is of great relevance to understand the relationship between the value of the process system and the environmental impact, which the process system causes.

The purpose of the case study is to investigate how the eco-efficiency changes between two different scenarios representing varying process conditions. The result from the comparative analysis provides a foundation for a decision-making situation considering which alternative is the most eco-efficient and thereby more justifiable in sustainability sense. The results from the two different scenarios in the case study show a significant decrease in eco-efficiency in the nominal scenario compared to the present process conditions. This gives an indication that an increased incineration of process water, with respect to emissions contributing to oxygen deficiency, not is to recommend in order to obtain a more environmentally sustainable process.

In a context where different processes or services are compared towards each other it is the difference between the cases that is of interest and that provides the information of how to act in a decision-making situation. It can also be concluded that the eco-efficiency in a case like the one at Akzo Nobel, which investigates a process system from a certain angle, does not reflect the eco-efficiency of the process system in total. This is something, which is important to pay regard to when interpreting the results of comparative eco-efficiency analyses.

Another central erudition, which has arisen from this study, is the importance of considering the surrounding environment when calculating the environmental damage costs for a process system. This is something, which has been evident in the case of weighting the environmental consequences and costs of an increased discharge of emissions contributing to oxygen deficiency in adjacent water recipients. This confirms the importance of what the WBCSD refer to as business specific indicators. There are different conditions in different process systems and these needs to be dealt with in a business specific approach where the surrounding environment is taken into account.

A general conclusion from this particular dissertation is that the eco-efficiency measurement is a good tool that facilitates a decision-making situation in site or facility evaluations. However, it must also be stated that eco-efficiency not is an unambiguous concept and therefore eco-efficiency measurements might not be the single means for a decision but rather a good tool together with other studies or indicators. Future studies considering the applicability and uses in similar case studies are therefore desirable to strengthen the existing knowledge in this area.

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