Eco-Efficiency Assessment - applied on different chelating agents

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Abstract

Chelating agents are used to improve the detergency power of cleaners and detergents. AkzoNobel (Amsterdam, the Netherlands) has conducted an Eco-Efficiency Assessment (EEA) of the alternative chelating agents GLDA (tetrasodium L-glutamic acid, N,N-diacetic acid); EDTA (ethylenediaminetetraacetic acid); NTA (nitrilotriacetic acid); and STPP (sodium tripolyphosphate). An EEA integrates and assesses the ecological and economic profiles of alternative systems delivering the same customer benefit. This paper gives an account of the main results of the environmental dimension of the chelate study and provides an in-depth description of the EEA methodology currently practiced within AkzoNobel. It is concluded that GLDA is the most environmentally benign chelating agent, and that the main reasons for this are that it is biodegradable, phosphorus free, and based on a renewable raw material.

Introduction

Chelating agents are widely used in detergents and cleaners to improve the detergency power. The chelating agents bind hard water ions (calcium and magnesium) firmly in complexes, thus softening the water, so that these ions cannot interfere with the cleaning action of the detergent and less detergent has to be used to achieve the necessary cleaning effect.

With the purpose of assessing different chelating agents from environmental and financial perspectives, an eco-efficiency assessment (EEA) was carried out (for European conditions). In this study GLDA was compared with its main alternatives, EDTA, NTA, and STPP. The chelating agents were compared on an *equal weight basis* in order to make the study independent of the exact amounts used in the many detergent recipes.

EEA METHODOLOGY

An EEA assesses the ecological impact and cost structure of competing products, processes, or services delivering the same customer benefit and identifies the best alternative. It includes all steps along the value chain. The general procedure for carrying out the EEA is presented in Figure 1 (modified from Rudenauer *et al*., 2005). The eco-efficiency methodology is based on a combination of a Life Cycle Assessment (LCA) according to ISO 14040+14044 and an assessment of the Life Cycle Costing (LCC). ISO standards on LCA methodology have been prepared for harmonization of LCA procedures and for credibility reasons. The grey-shaded steps in Figure 1 can be found in the LCA standards. The LCA is also complemented with an assessment of the alternatives' toxicity potential and risk potential. The eco-efficiency method used by AkzoNobel is also used by BASF and many more corporations and institutes.

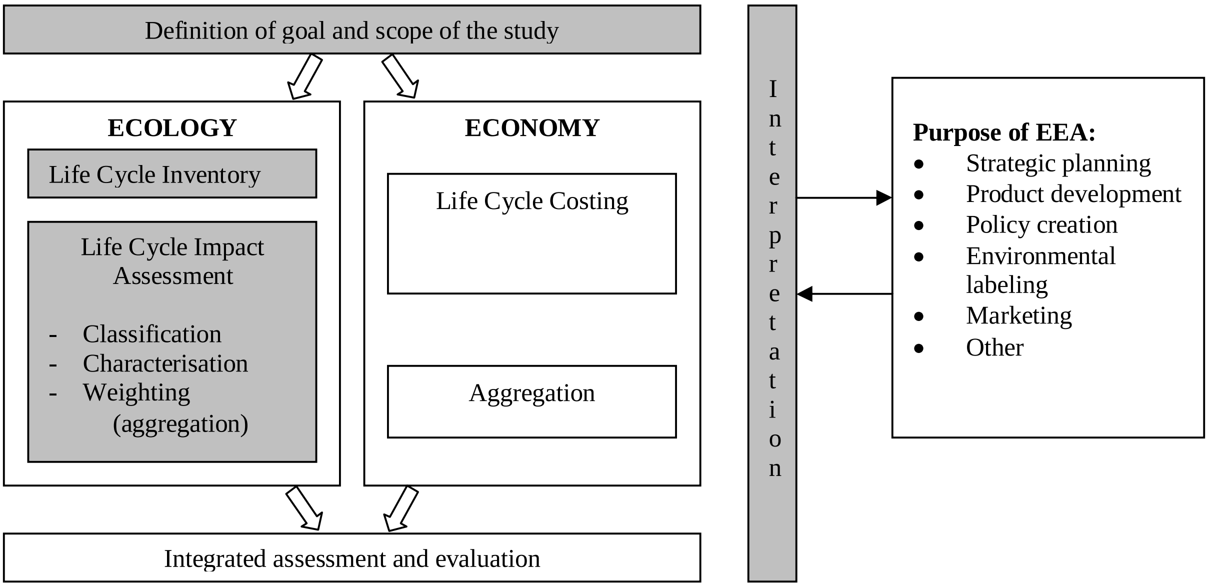


FIG. 1. *General procedures for eco-efficiency assessment (EEA).*

DEFINITION OF GOAL AND SCOPE

The goal definition states the purpose of the study and the intended use of the results. The scope definition includes a description of the product function to be studied. The function is quantified in terms of a functional unit, which is the reference to which all environmental impacts and costs are related to. Also included in the scope definition is a definition of the environmental and technical time perspective of the study, and of geographical and technical (against nature and other products' life cycles) system boundaries. This defines which processes to include in the EEA.

ECONOMY: LCC

The focus of LCC is adapted according to the goal and scope of the study (Rudenauer *et al*., 2005). The LCC is actor-specific, that is, all costs for a certain actor that are associated with a given alternative over the whole period of ownership or stewardship are taken into account. The actor to focus the LCC around is given by the goal and scope definition. Often the actor is the purchaser of a product, and the purpose of the LCC result is to communicate how future costs of the product will affect the economy of the purchaser (Bengtsson and Sjöborg, 2004). External costs are not covered by the LCC since by definition external costs are borne by society and reflect environmental aspects of the system under study (Rudenauer *et al*., 2005). These aspects are covered by the LCA steps.

ECOLOGY: LIFE CYCLE INVENTORY (LCI)

The LCI step involves quantification of inflows and outflows of material and energy over the defined system boundaries of the life cycle. It includes flows related to raw material extraction, processing of raw materials, manufacturing, use, maintenance, recycling/reuse, waste management, and transportation (Fig. 2). Each process requires material and/or energy inflow and produces different kinds of emissions and waste. The LCI results in a long list of different environmental interventions.

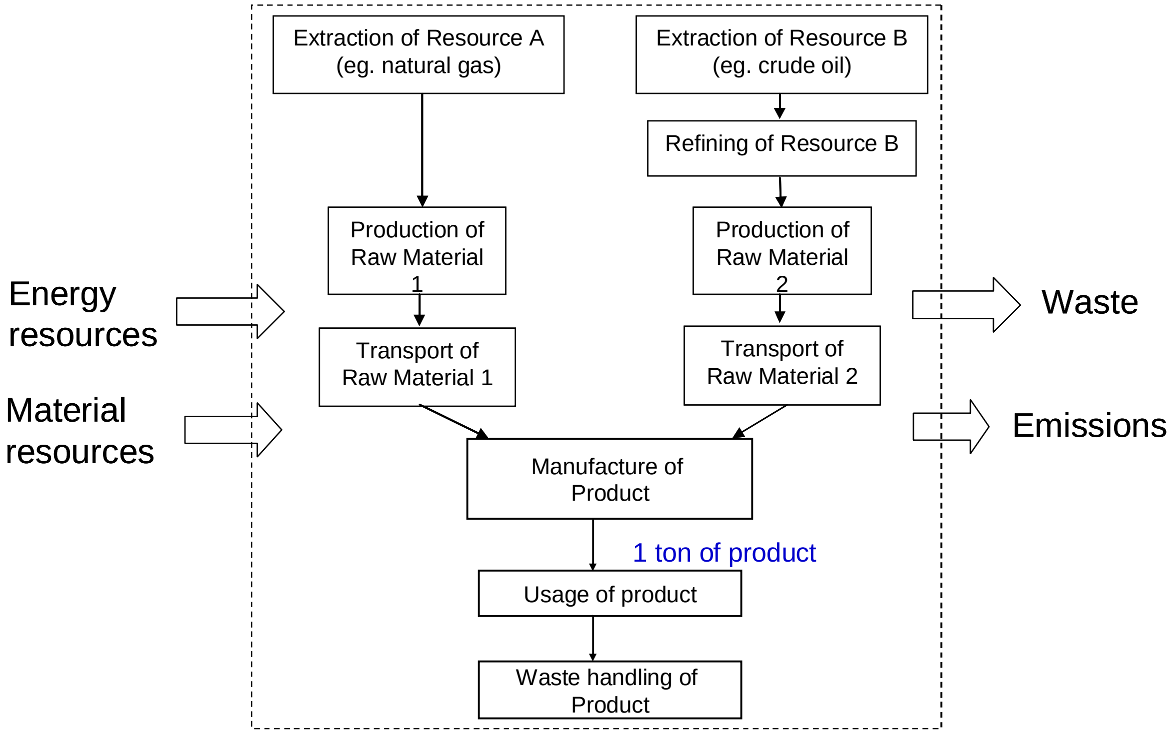


FIG. 2. *A product life cycle.*

ECOLOGY: LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The vast amount of data produced by the LCI and the complexity of the cause and effect of different environmental interventions make it hard to identify which data are important from an environmental point of view (Rydh *et al*., 2002). For interpretation and communication purposes, methods have been designed to aggregate the LCI data to fewer digits, representing either different impact categories (characterization) or the total environmental load of the system (weighting). In this way the environmental hot spots of the life cycle can more readily be identified. The LCIA encompasses three parts: classification, characterization, and weighting (Fig. 3).

In the classification phase, inventory data are sorted into environmental impact categories. The classification is based on scientific cause-effect relations, and hence one substance can be assigned to more than one environmental impact category. In the characterization process the inventory data are multiplied with a characterization factor that is specific for each data and environmental impact category. In this way, for each category, the potential environmental impact of all substances in the category is summed up and is represented by one index.

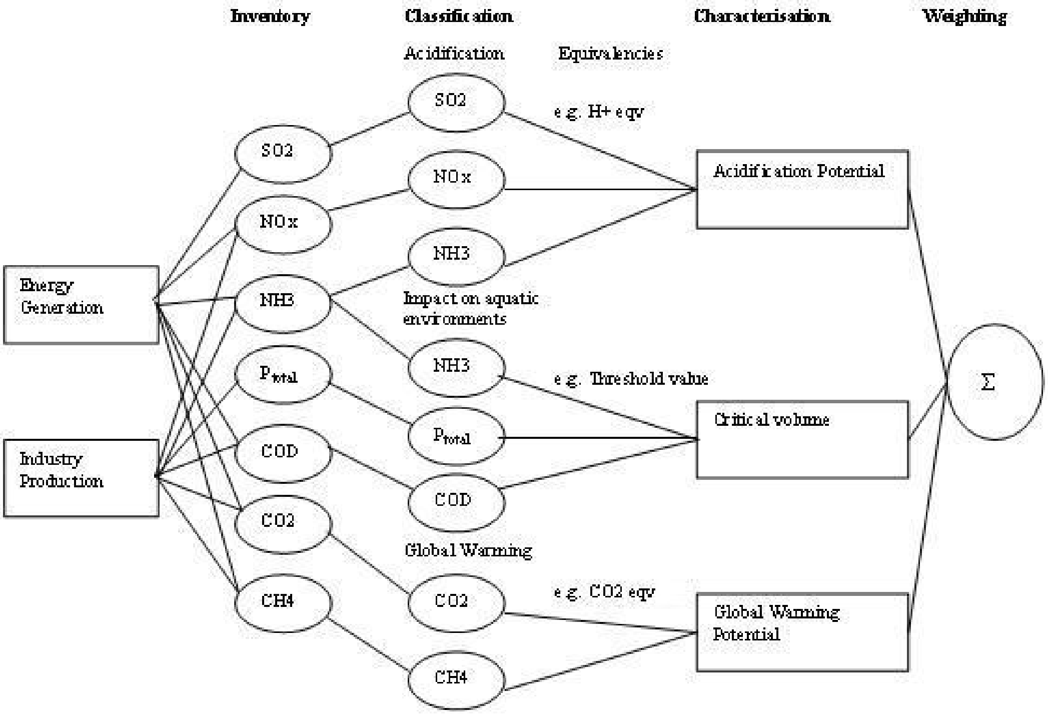


FIG. 3. *Phases included in Life Cycle Impact Assessment (LCIA)—the stepwise aggregation of information in Life Cycle Assessment (LCA). The inventory list is usually considerably more extensive, and more characterization/impact categories are normally included in the eco-efficiency assessment (EEA). Modified from Rydh* et al*. (2002).*

The impact categories that were considered in the EEA and were applied for different chelating agents are: primary energy consumption, resource depletion, area use, emissions, human toxicity, and risk. The impact category "emissions" is further subdivided into other impact categories (see Table 1).

In a further weighting process, the impact category results are aggregated into a single indication or statement of the total strain put on the environment. In the ISO standards the weighting is an optional step of the LCA, and no specific weighting methodology is recommended (ISO 14044, 2000). However, weighting is often a necessary step to simplify communication and decision making and is therefore widely used within industry. In the EEA method currently practiced by AkzoNobel, a weight that expresses the environmental importance of that impact category relative the other impact categories is assigned to each impact category.

These weighting factors are the geometric means of impact category-specific “relevance factors” and “societal factors.” For the European weighting, and the resulting weighting factors for the chelate study, see Table 1. To derive the relevance factor, the result of the alternative with the highest impact in that category is normalized against the total load of the same category in a specific region. This step yields the relative significance of the different impact category results. The societal factors, on the other hand, express the severity of each item relative to the other impact categories as perceived by a group of people (see Table 1). The societal factors are based on the opinions of people in the same region as were chosen for the derivation of the relevance factors. The societal factors have been presented by BASF and were derived through a public opinion poll (Kicherer, 2005). (For more information regarding the weighting methodology and the subsequent integration of ecological and economic data, presented below, see Saling *et al*. (2002) and Kicherer *et al*. (2007).

TABLE 1. Weighting factors for the chelate study[a]

Impact category	**Societal factor (*S*) [%]**	**Relevance factor (*R*) [%]**	**Total weighting factor (*T*) [%]** (geometric mean[b] of *S* & *R*)
Resource use	20	4	11
Primary energy use	20	5	13
Area use	10	0.3	2
Toxicity potential	20	20	20
Risk potential	10	10	10
Emissions	20	61	44
Water emissions[c]	35	95	78
Solid waste	15	—	—
Air	50	5	22
Global warming potential (GWP)	50	69	68
Photochemical ozone creation potential (POCP)	20	8	15
Ozone depletion potential (ODP)	20	—	
Acidification potential (AP)	10	23	17

[a]Totals may not agree because of rounding. The relevance factors and total weighting factors, as presented in the table, have been normalized so that they add up to 100%.
[b]The geometric mean of a data set $[a_1, a_2, ..., a_n]$ is given by $(a_1, a_2, ..., a_n)^{1/n}$. For example, in this table, $T = \sqrt{S*R}$.
[c]This impact category takes into account the eutrophication potential of substances emitted to water recipients.

In this way the weighting step combines all environmental loads and impact categories and makes it possible to assess the relative contribution of different data to the total strain. This facilitates effective communication and interpretation of the results and provides a better overview of a complex system. When performing an EEA the need for weighting is high, since otherwise each of the various environmental impacts would have to be compared with the cost side individually (Rudenauer *et al*., 2005).

INTEGRATED ASSESSMENT AND EVALUATION

The eco-efficiency method includes a weighting of environmental impact and costs, resulting in displaying the most eco-efficient alternative in a two-dimensional diagram (Fig. 4). The axes in the diagram are inverted so that the alternative that has the lowest sum of environmental and financial performance is found closer to the upper right corner. This alternative is termed the most eco-efficient alternative and is hence favored from an eco-efficiency perspective.

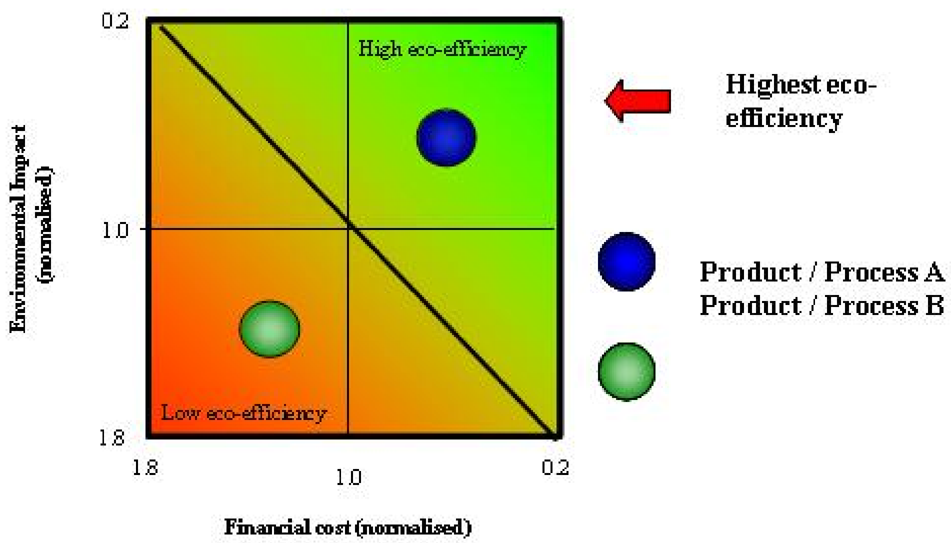


FIG. 4*. The eco-efficiency portfolio.*

INTERPRETATION

The purpose of the interpretation phase is to analyze the results of the study, evaluate and explain its limitations, and generate conclusions and recommendations (ISO 14044, 2000). The robustness of the results can be assessed with a sensitivity analysis of the effects that chosen methods and data have on the result of the study.

Results of EEA of different chelating agents. The impact category results for one ton of chelating agent are presented for the different alternatives in Table 2.

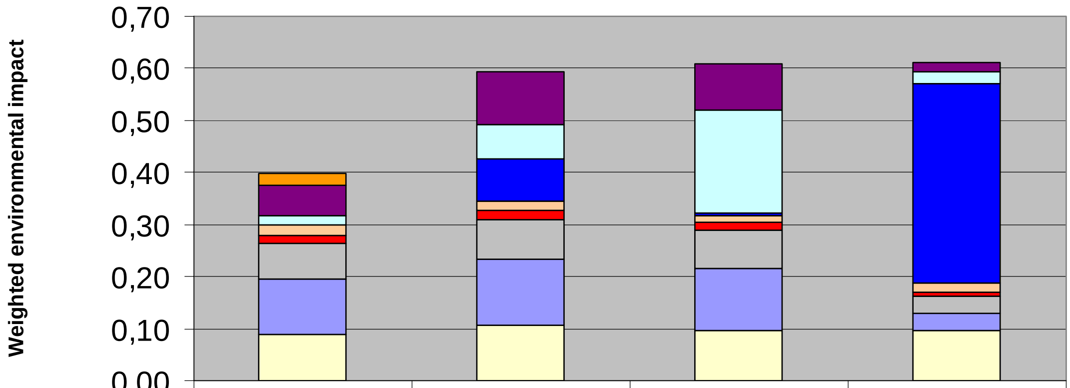
TABLE 2. Characterization/impact category results for 1 ton of the studied chelating agents[a]

	Alternatives			
Impact categories	**GLDA**	**EDTA**	**NTA**	**STPP**
Primary energy use [GJ]	57	74	68	12
Resource use [$yr^{-1/2}*10^{-3}$]	324	445	403	405
Area use [m^2*yr]	358	3	3	1
Toxicity potential [dimensionless]	0,09	0,34	1	0,11
Risk potential [dimensionless]	0,58	1	0,89	0,18
Global warming potential [ton CO_2 eqv.]	4,3	5,3	5,0	2,7
Photochemical ozone creation potential [kg C_2H_4 eqv.]	0,9	1,1	1,0	0,4
Ozone depletion potential [kg CFC-11 eqv.]	-	-	-	-
Acidification potential [kg SO_2 eqv.]	15	14	11	15
Waste [kg]	-	-	-	-
Water emissions [1000 m^3]	0,4	6	0,5	40

[a]Grey-shaded items constitute emissions. Abbreviations: GLDA, tetrasodium L-glutamic acid, N,N-diacetic acid; EDTA, ethylenediaminetetraacetic acid; NTA, nitrilotriacetic acid; STPP, sodium tripolyphosphate; CFC, chlorofluorocarbons.

From these results it is clear that a trade-off between different kinds of environmental impacts is needed in order to generate a priority list of the different chelating agents from a holistic environmental perspective. This trade-off is done via the weighting step. The weighting factors that were used to aggregate the impact category results in a single score, denoting the total environmental pressure of the different alternatives, are presented in Table 1 and represent European conditions.

The result of the weighting is illustrated in the bar chart and table in Figure 5. They show the weighted values for each impact category and alternative chelating agent; the top of the bars denotes the total and final environmental results that were integrated with economic data in the complete EEA.



	GLDA	EDTA	NTA	STPP
Area use	0,02	0,0002	0,0002	0,0001
Risk potential	0,06	0,10	0,09	0,02
Toxicity potential	0,02	0,07	0,20	0,02
Water emissions	0,0009	0,08	0,003	0,38
AP	0,02	0,02	0,01	0,02
POCP	0,01	0,02	0,02	0,006
GWP	0,07	0,08	0,07	0,04
Energy use	0,11	0,13	0,12	0,03
Resources use	0,09	0,11	0,10	0,10

FIG. 5. *Weighted values for the different impact categories and chelating agents. For abbreviations, see Tables 1 and 2.*

DISCUSSION

The result of this study indicates that GLDA scores best or second-best in all impact categories except “area use” and “acidification.” However, Table 1 and Figure 5 reveal the small relevance of “area use” in this assessment. Even though GLDA requires more land than its alternatives since it is based on renewable raw materials, the land use is small on an absolute basis and therefore not a key criterion in an environmental assessment of different chelating agents. In fact, in this study, emissions to water is the most important environmental aspect according to the applied weighting methodology, followed by toxicity, risk, and global warming potential.

CONCLUSIONS

GLDA performs well in all important aspects compared with the other alternatives, mainly because it is based on renewable raw materials and is readily biodegradable. Another advantage of GLDA is that (unlike STPP) it does not give rise to any phosphorus emissions to water and hence the eutrophication potential of GLDA is insignificant. With respect to the toxicity potential, GLDA scores much better than especially NTA, for which there is limited evidence of carcinogenic effects from exposure (= R40 label as defined in Annex III of European Union Directive 67/548/EEC). For these reasons it can be concluded that on an equal mass basis GLDA is the most environmentally benign chelating agent. A sensitivity analysis also showed that this result is robust with regard to the region (continent) that is chosen for the weighting.

For further reading:

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