Eco-Efficiency Analysis

Chelating Agents for Automatic Dishwashing: ADW Household Tabs

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Objectives and Use of the Eco-Efficiency Study

- This eco-efficiency analysis compared various chelating agents for household automatic dishwashing applications.
- The study used the methodology of the eco-efficiency analysis, developed by BASF as a life-cycle tool to show and assess different parts of the life-cycle of the chemical reactions and related materials which are required to achieve the desired product. It is one method amongst others that are able to assess environmental data over the whole life cycle.
- The ecological calculations of the single results in each category are following the ISO-rules 14040 et seq. in the main points. The quantitative weighting step to obtain the ecological fingerprint and the portfolio are not covered with the ISO-rules. The eco-efficiency analysis has more features than are mentioned in the ISO rules.
- The methodology has been approved by the German TÜV. This methodology was used by the "Öko-Institut - Institute for applied ecology" in Freiburg Germany in different APME-studies. Öko-Institut uses a quite similar methodology with a different weighting system ("Ecograde"). The Wuppertal Institute accepts the method: “Basically, the large number of indicators used in the eco-efficiency analysis of BASF make relatively reliable statements possible …“. The method was initially developed by BASF and Roland Berger Consulting, Munich.

TÜV Berlin
ID:5711150561

Validated Eco-Efficiency Analysis method

Customer Benefit

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Customer benefit

Production and use of 100 20 g tabs for household automatic dishwashing application

(*) tabs formulations show same performance

Alternative Systems

STPP tabs

MGDA tabs

GLDA tabs

Customer Benefit and Alternatives

- The eco-efficiency analysis compares three different formulations for consumer ADW tabs, based on three different chelating agents:
    - Sodium tripolyphosphate (STPP)
    - Alanine, N,N-bis(carboxymethyl)-, trisodium salt (MGDA)
    - Glutamic acid, N,N-bis(carboxymethyl)-tetrasodium salt (GLDA)

- The weight of each tab is fixed (20 g) and reflects the common weight of commercially available ADW tabs
- Equal weight amounts of STPP, GLDA and MGDA show, respectively, increasing chelating capacity
- Since the chelating agents have different chelating capacity, where necessary, further ingredients are added to the tabs and considered in the analysis to achieve tabs with equal performance and equal weight

Alternatives

- The three chelating agents have been chosen as possible alternatives for the analysis based on following criteria:
  - market relevance
  - consumer safety
  - performance

- In the ADW formulations the chelating agents are used as powders, their active content is considered according to the technical information and safety data sheet available: STPP 100%, MGDA 86% and GLDA 74%
- The three formulations showed in table below have been tested within BASF application labs and show comparable performance. These formulations can be considered as representative for common ADW formulations:
  - MGDA, GLDA, STPP, sodium citrate and sodium sulfate are used in different amounts in the three alternative tabs, therefore these ingredients are considered in the analysis
  - Sodium carbonate, surfactants, polymers and further ingredients are used in equal amounts in the tabs, therefore these ingredients are NOT considered in the analysis

Alternatives
Tabs Composition (% weight)

	MGDA Tabs	STPP Tabs	GLDA Tabs
MGDA	17,4%	-	-
GLDA	-	-	26,2%
STPP	-	50,0%	-
Sodium citrate	23,3%	-	23,3%
Sodium sulfate	9,3%	-	0,5%
Sodium carbonate	20%	20%	20%
Surfactants, polymers, bleaching	30%	30%	30%

In the ADW formulations the chelating agents are used as powders, their active content is considered according to the technical information and safety data sheet available: STPP 100%, MGDA 86% and GLDA 74%

Costs

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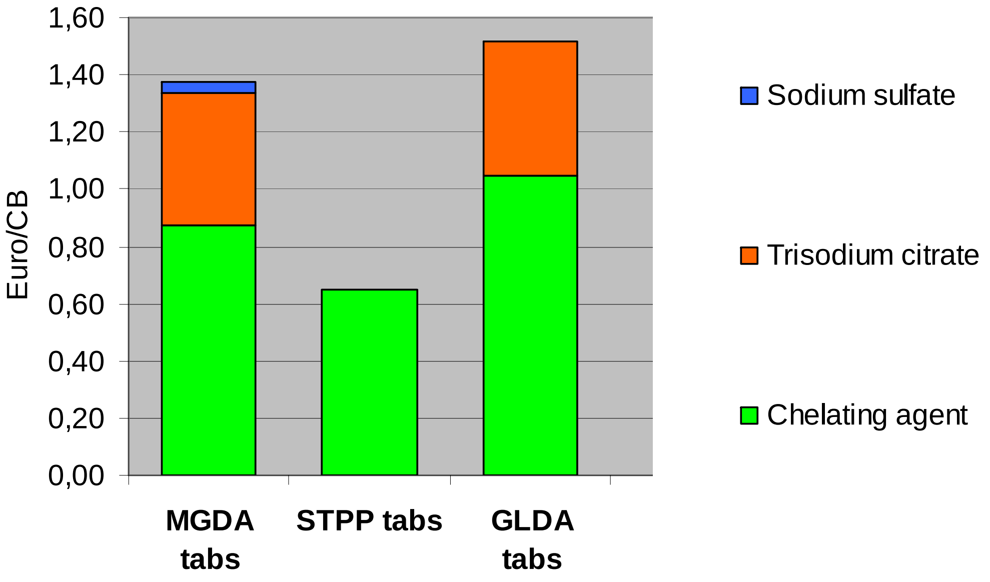
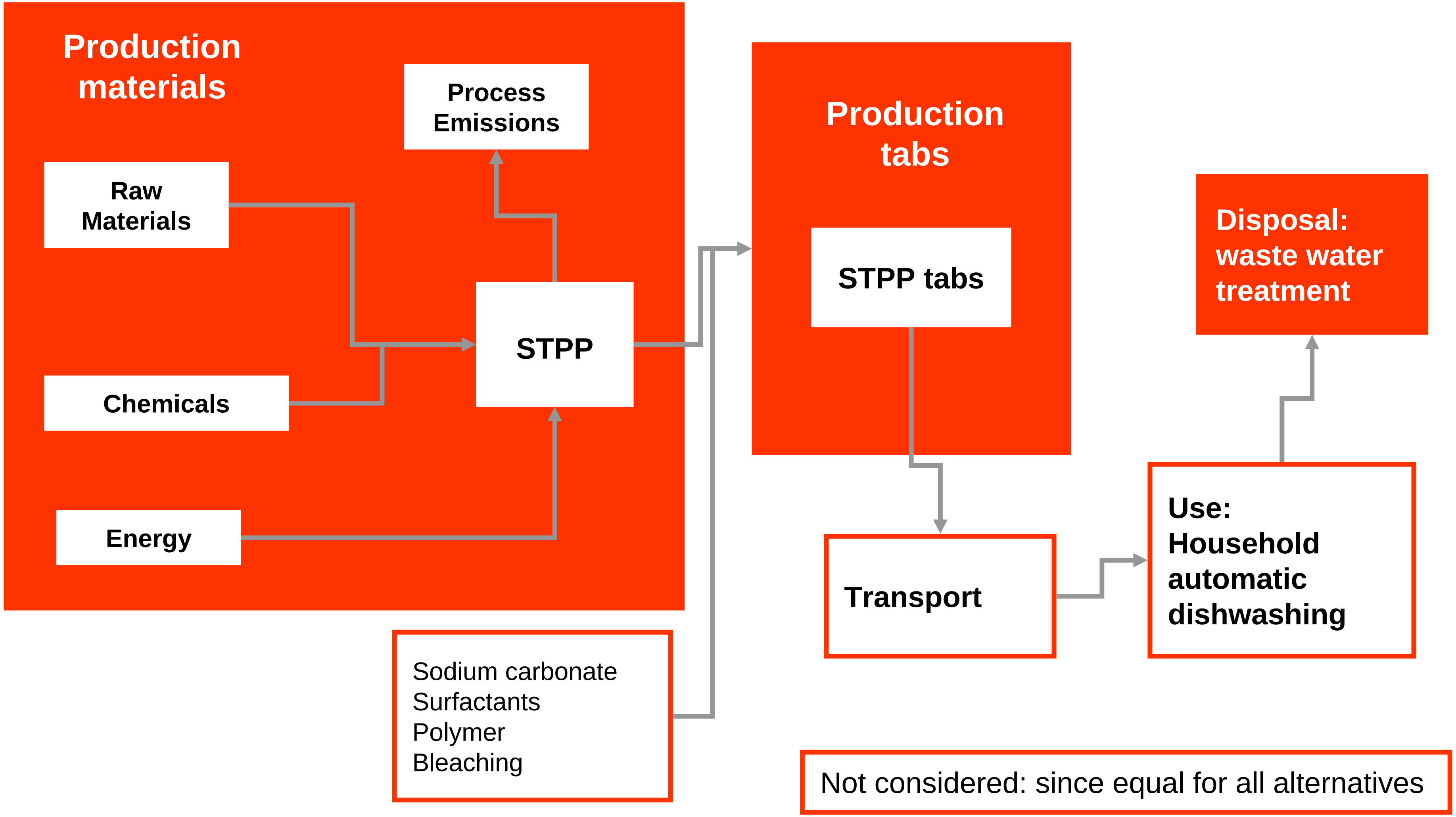
- The costs for formulators are evaluated, not the costs of tabs for end consumers, since the latter costs do not necessarily represent ingredients' costs
- Costs of alternatives are calculated based on estimated market price of ingredients (status 2007): chelating agents, sodium sulfate and sodium citrate
- Costs for further ingredients, production of tabs, packaging and transport of tabs, dishwashing, water treatment are not considered and assumed equal for all alternatives



System Boundaries
STPP tabs



Production materials

Process Emissions

Raw Materials

STPP

Chemicals

Energy

Production tabs

STPP tabs

Disposal: waste water treatment

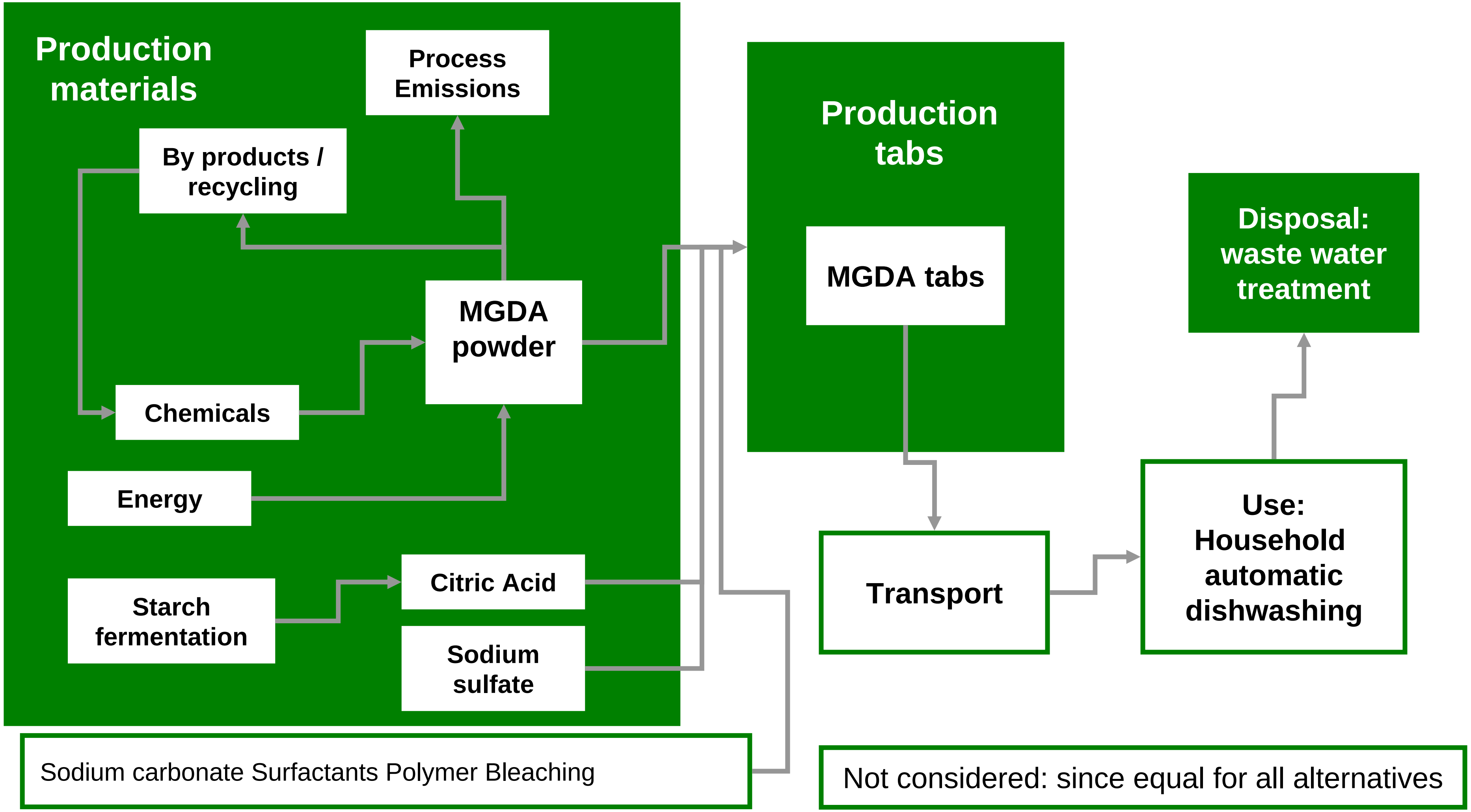
Transport

Use: Household automatic dishwashing

Sodium carbonate
Surfactants
Polymer
Bleaching

Not considered: since equal for all alternatives

System Boundaries
MGDA tabs



Production materials

Process Emissions

By products / recycling

MGDA powder

Chemicals

Energy

Citric Acid

Starch fermentation

Sodium sulfate

Production tabs

MGDA tabs

Disposal: waste water treatment

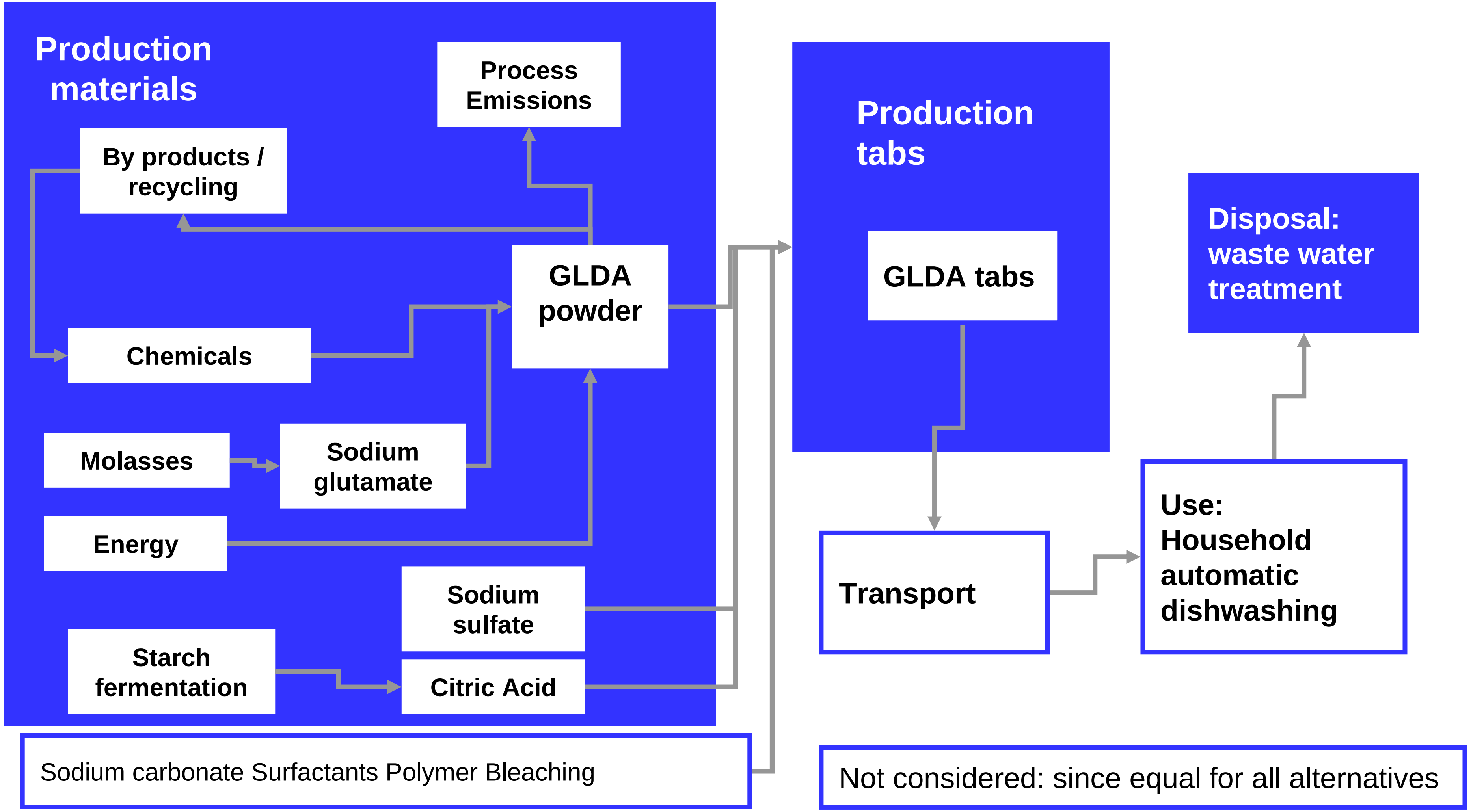
Transport

Use: Household automatic dishwashing

Sodium carbonate Surfactants Polymer Bleaching

Not considered: since equal for all alternatives

System Boundaries
GLDA tabs



Production materials

Process Emissions

By products / recycling

GLDA powder

Chemicals

Molasses

Sodium glutamate

Energy

Sodium sulfate

Starch fermentation

Citric Acid

Sodium carbonate Surfactants Polymer Bleaching

Production tabs

GLDA tabs

Disposal: waste water treatment

Transport

Use: Household automatic dishwashing

Not considered: since equal for all alternatives

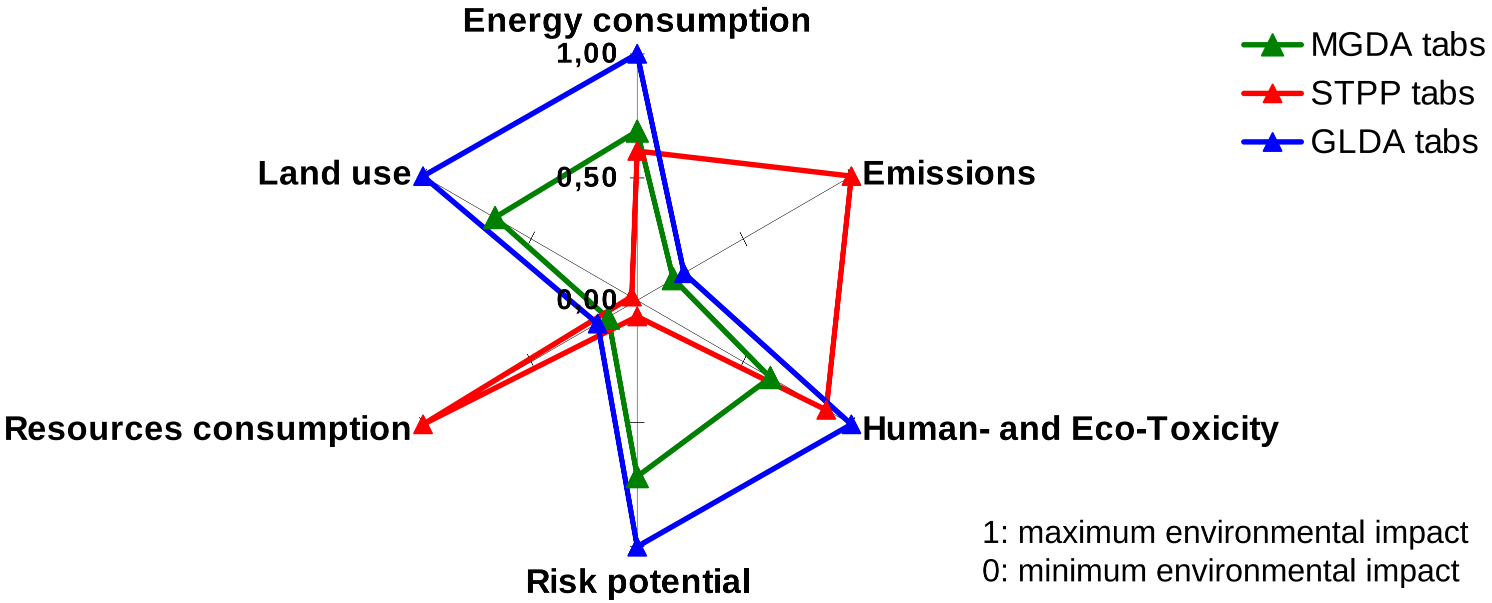
System Boundaries
Waste Water Treatment

- The emissions to water compartment after waste water treatment are calculated based on average data of German waste water facilities:
  - COD elimination 95%
    - Exception

      COD elimination for MGDA and GLDA: 100%

      since these substances are readily biodegradable
  - BOD elimination 99%
  - P elimination 90%
  - N elimination 80%

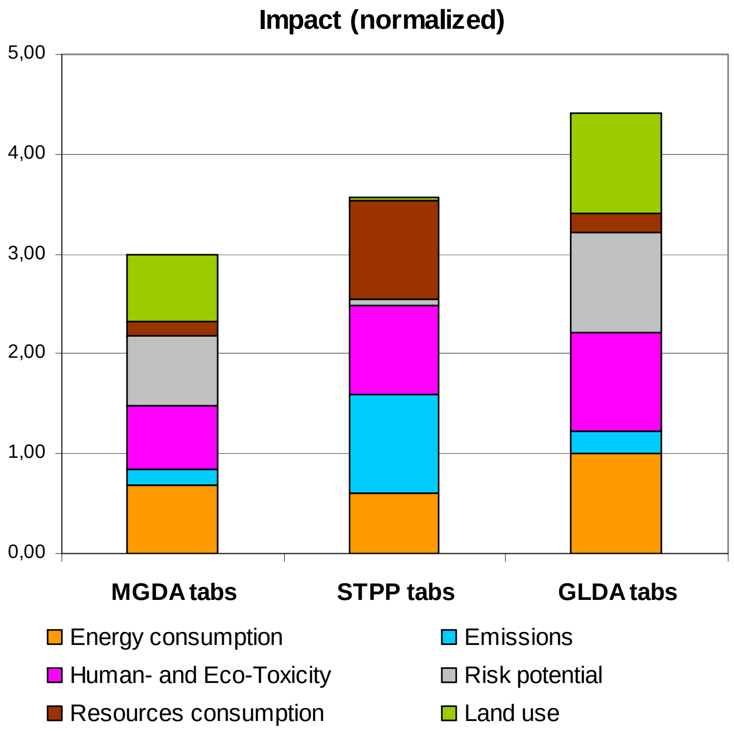
Environmental Impact
Ecological Fingerprint

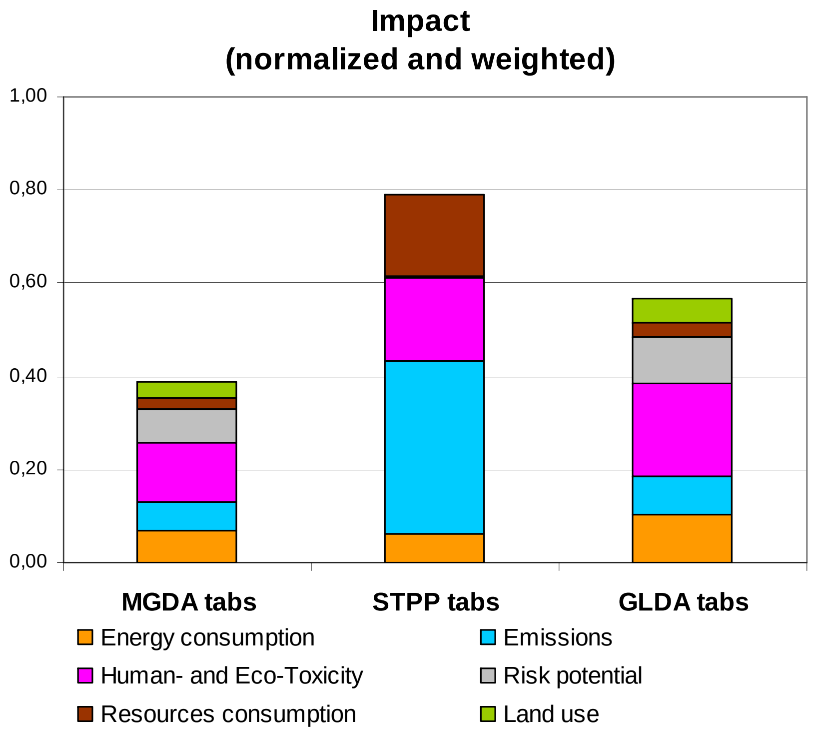


1: maximum environmental impact
0: minimum environmental impact

- STPP tabs have highest impact in the categories emissions and resource consumption, they have the lowest impact in land use and risk potential
- GLDA tabs have the highest impact in energy consumption, land use and risk potential
- MGDA tabs have the lowest impact in the categories emissions, resource consumption and in human and eco-toxicology

Environmental Impact





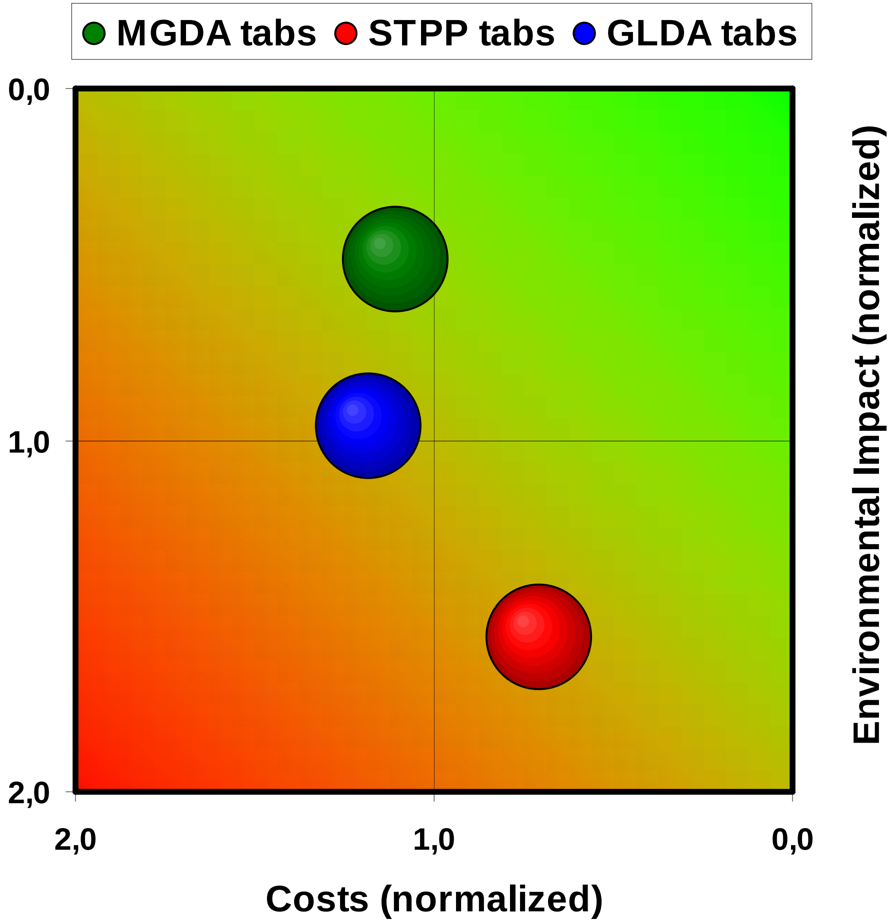
- After the environmental impacts in each single category have been calculated (ecological fingerprint, left), each score is weighted according to weighting factors resulting from data in the analysis and societal weighting factors (right)

Weighting Factors

- The societal weighing factors are published in: P. Saling, A. Kicherer et al, Int. J. LCA **7** (4), 203-218, (2002)
- The resulting weighting factors in the analysis are listen in the table below:

Impact Category	Societal factor	Total weighting Factor
Resources consumption	20%	17%
Energy consumption	20%	10%
Emissions	20%	37%
Air	50%	18%
Water	35%	71%
Waste	15%	11%
GWP	50%	53%
ODP	20%	2%
POCP	20%	21%
AP	10%	25%
Human- and Eco-Toxicity	20%	20%
Risk potential	10%	10%
Land use	10%	10%

Eco-Efficiency Portfolio



- The results demonstrate that the new aminocarboxylates tabs have less impact on the environment when compared to phosphate.

Environmental Impacts

- The following tables show the environmental impact of the three alternatives tabs formulations in each single category.
- The environmental impact is calculated for the complete life cycle, as described within the system boundaries given above. For understanding the contribution to each impact category along the life cycle of single life cycle steps, the life cycle is divided into the following single steps:

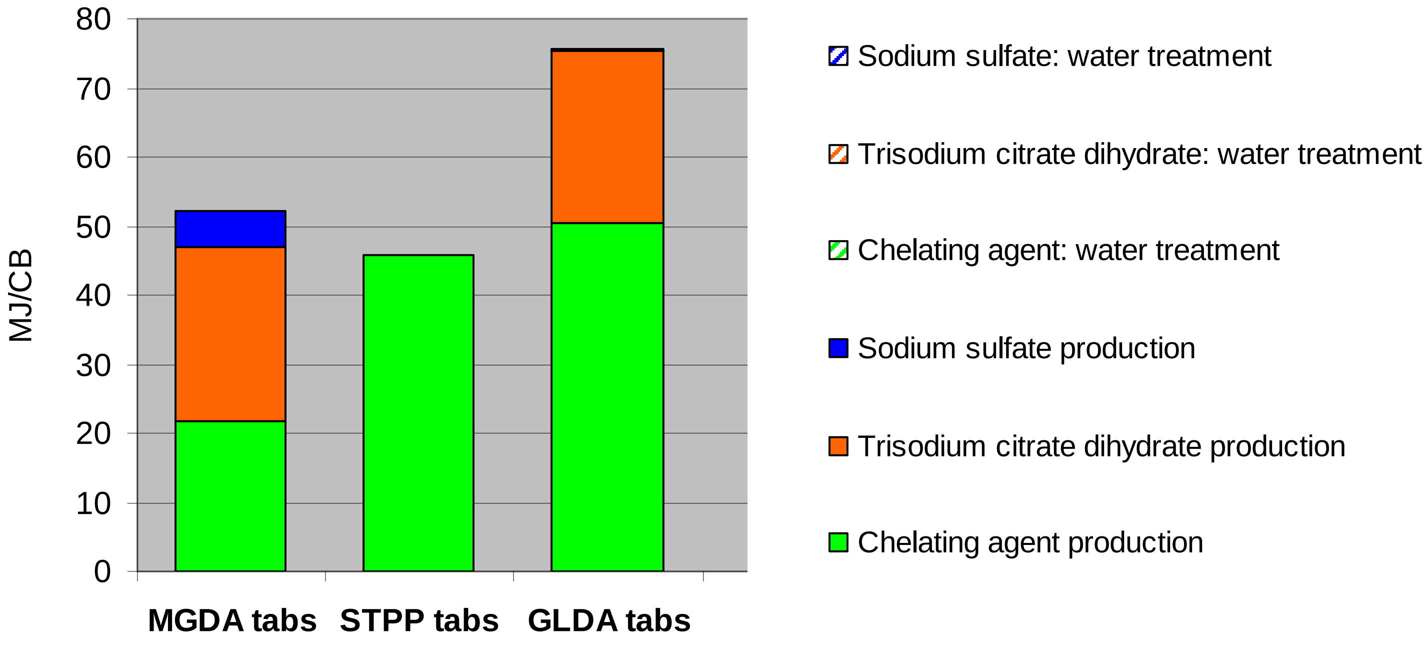
- Chelating agent production:
- Trisodium citrate dihydrate production:
- Sodium sulfate production:

describe the impact of production of the given ingredient from raw materials supply, including all precursors steps, to energy supply and generation

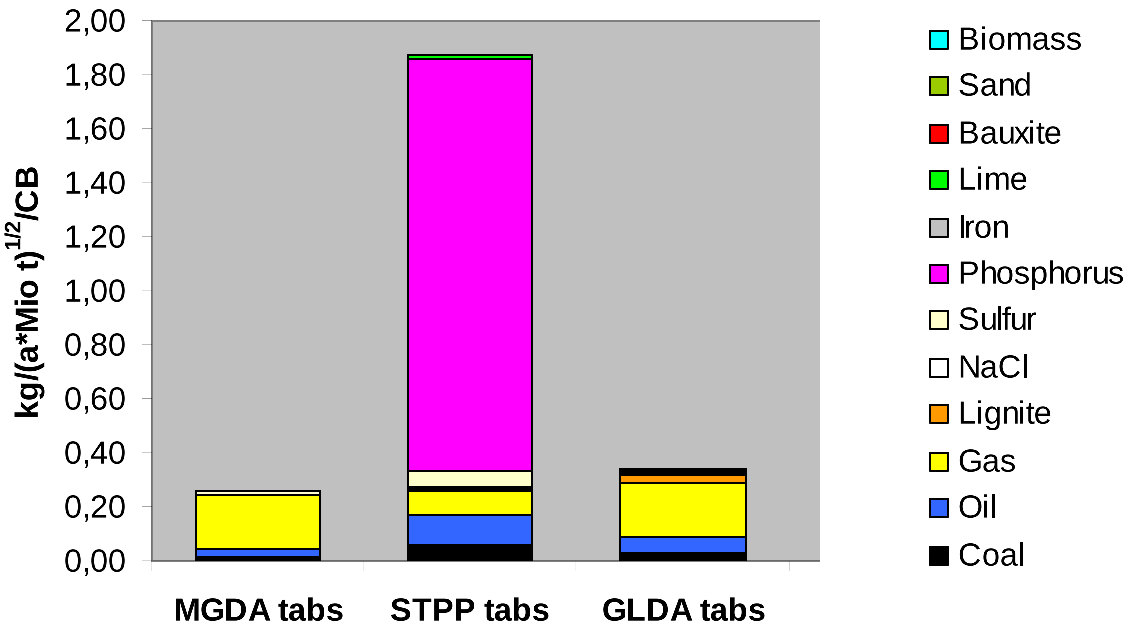
- Chelating agent, water treatment:
- Trisodium citrate dihydrate, water treatment:
- Sodium sulfate production, water treatment:

describe the emissions into environment arising from each ingredient after water treatment in water treatment facilities facilities

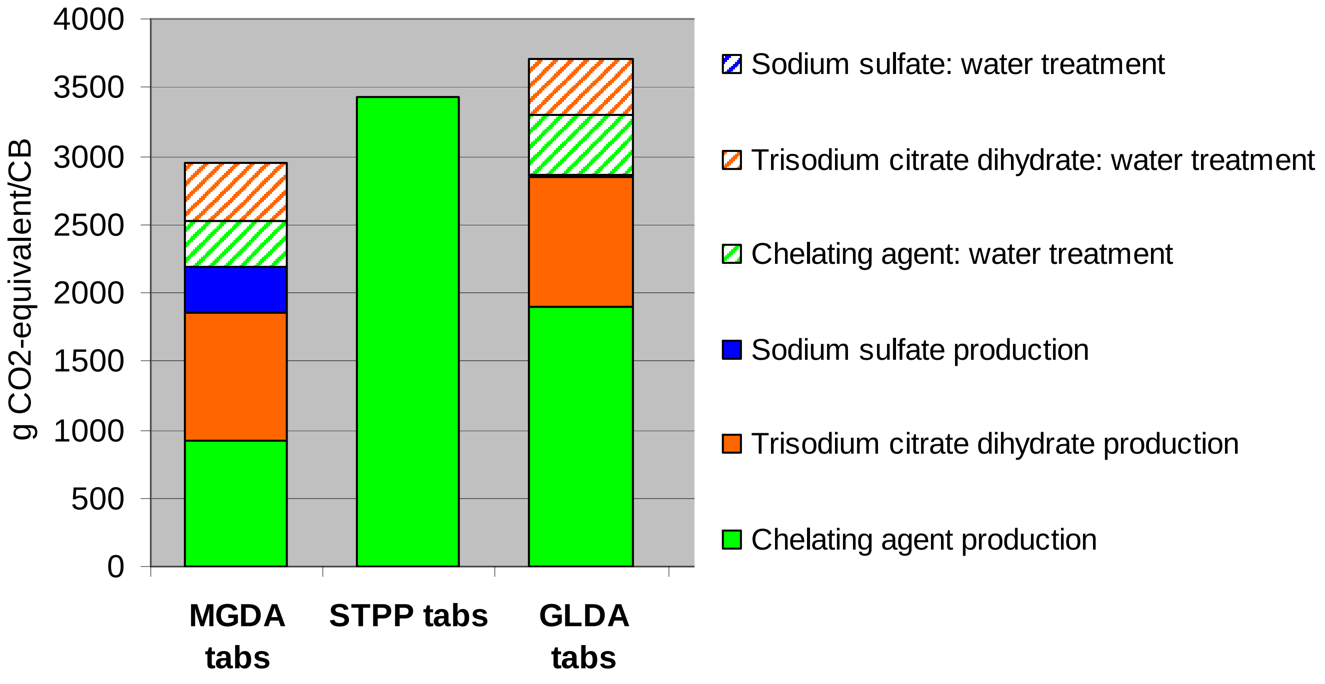
Environmental Impacts: Energy Consumption



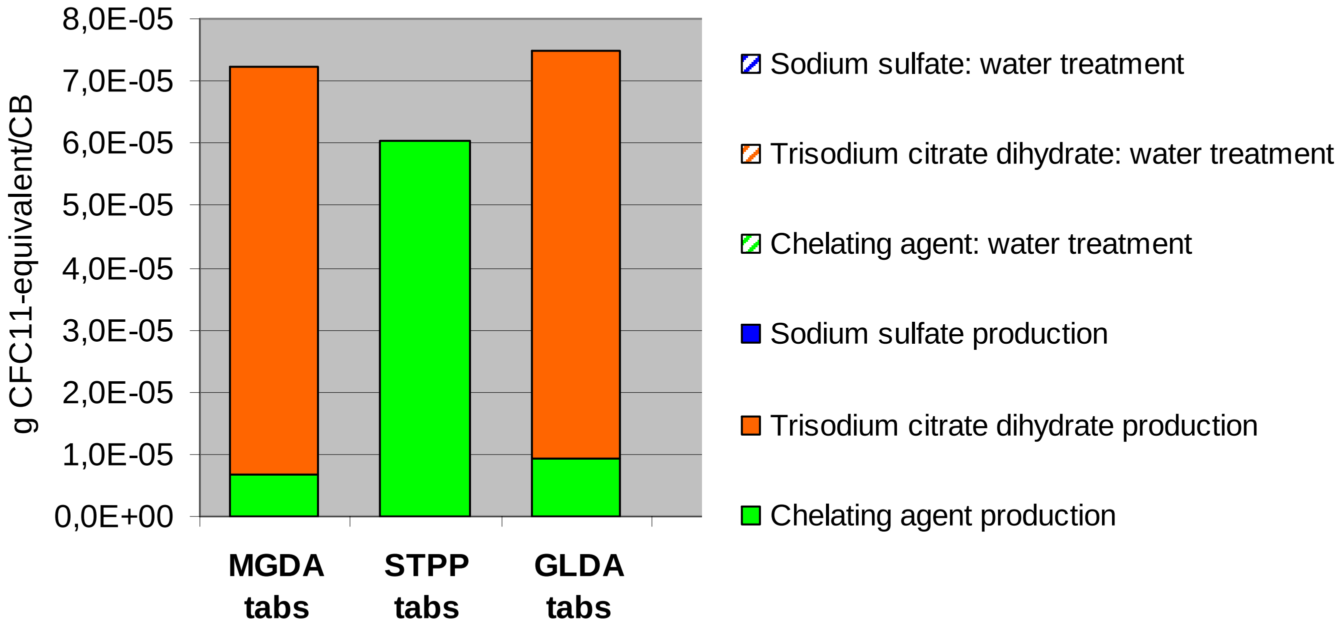
Environmental Categories
Resources Consumption



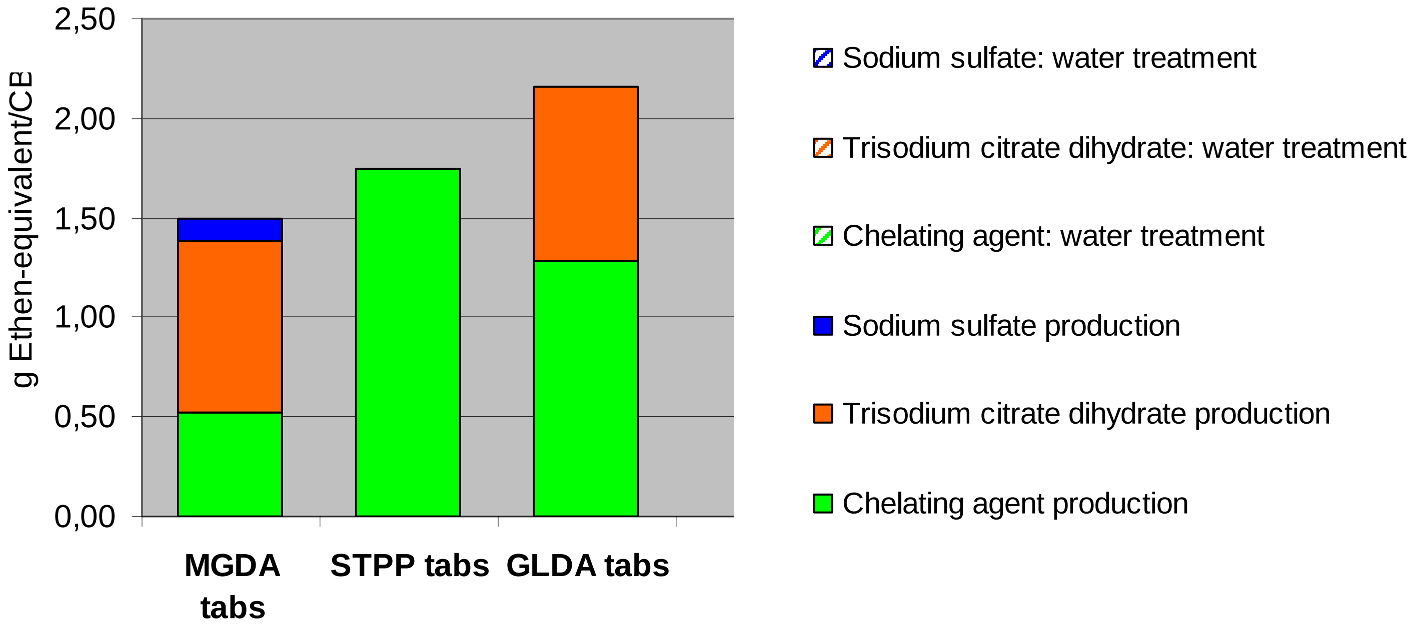
Environmental Categories
Global Warming Potential
(CH_4, CO_2, N_2O, chlorofluorocarbons)



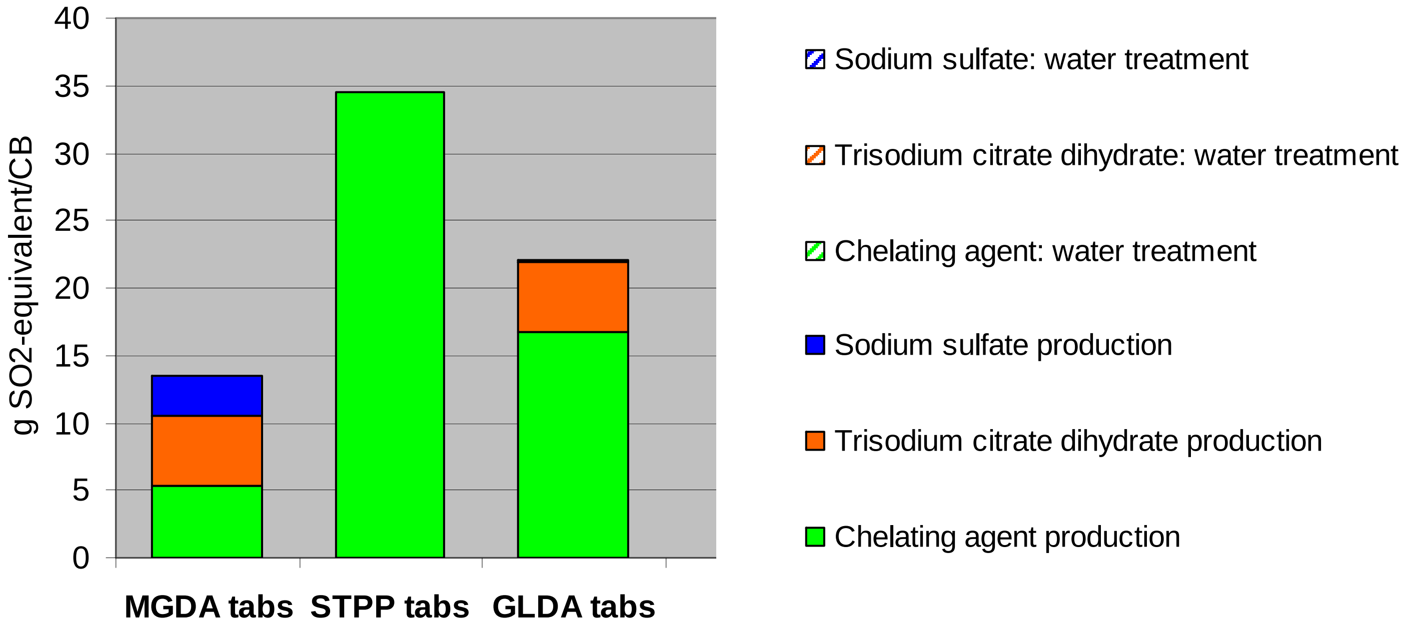
Environmental Categories Ozone Depleting Potential (chlorofluorocarbons)



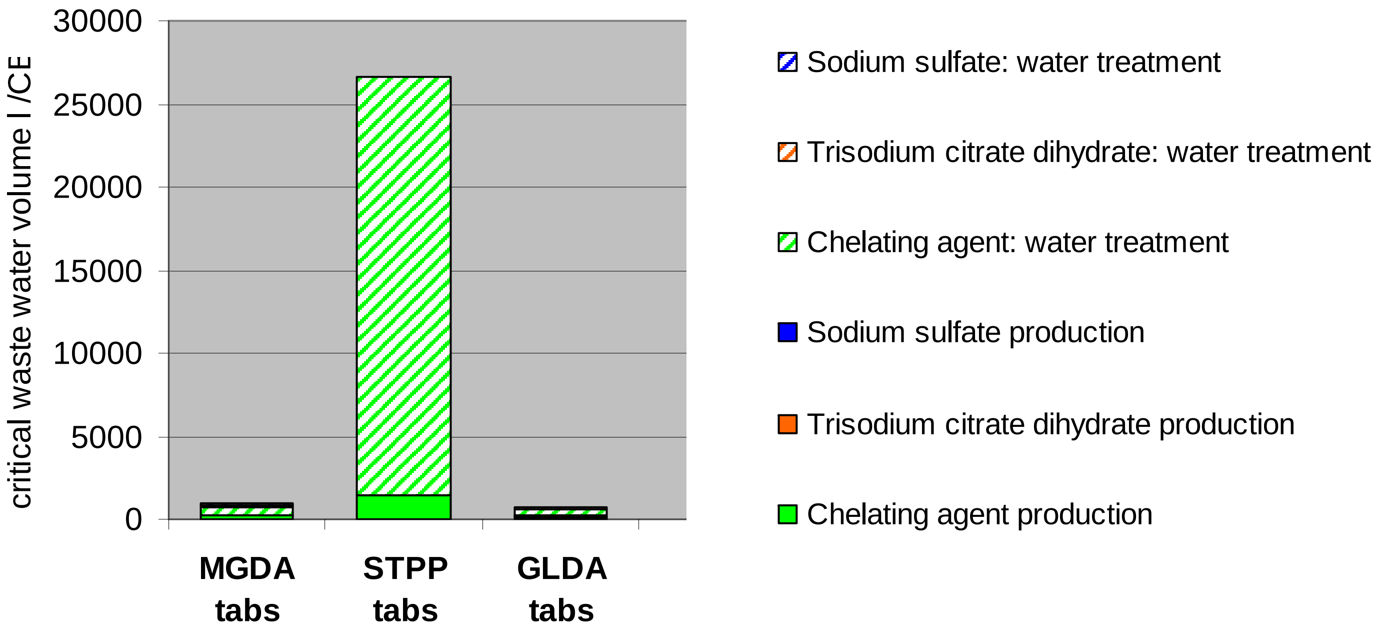
Environmental Categories
POCP (photochemical ozone creation potential: low VOC, CH_4)



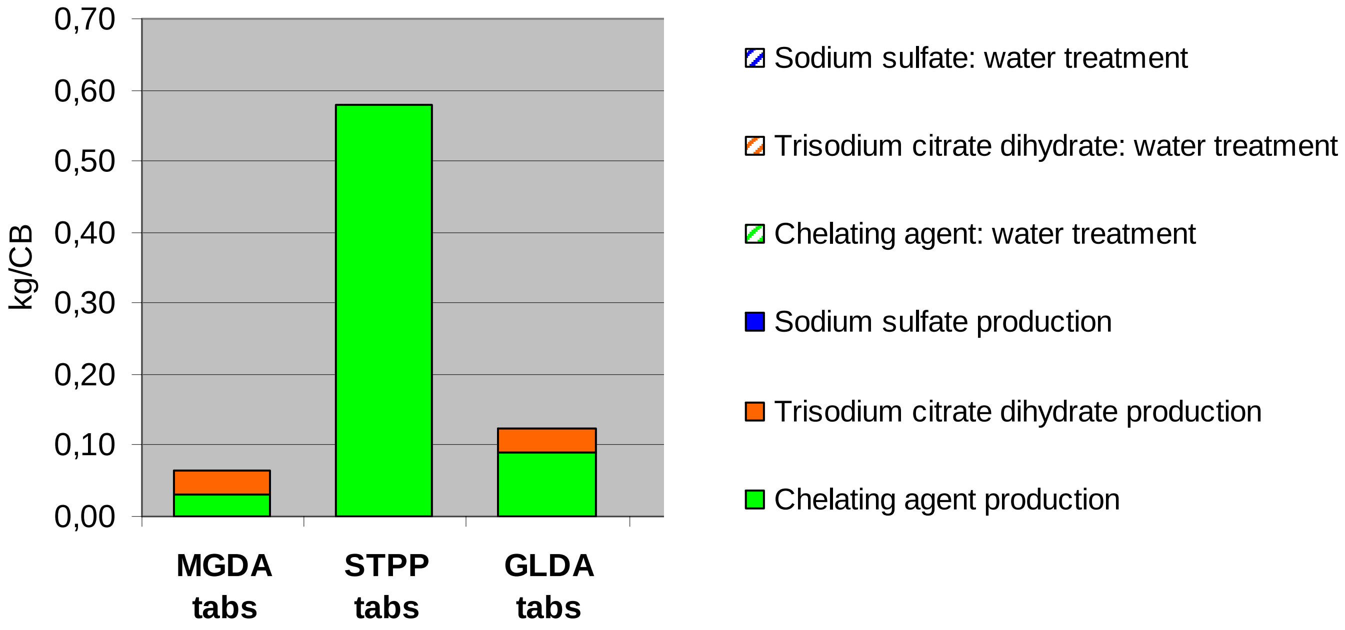
Environmental Categories
Acidification Potential (SO_x, NO_x, NH_3, HCl)



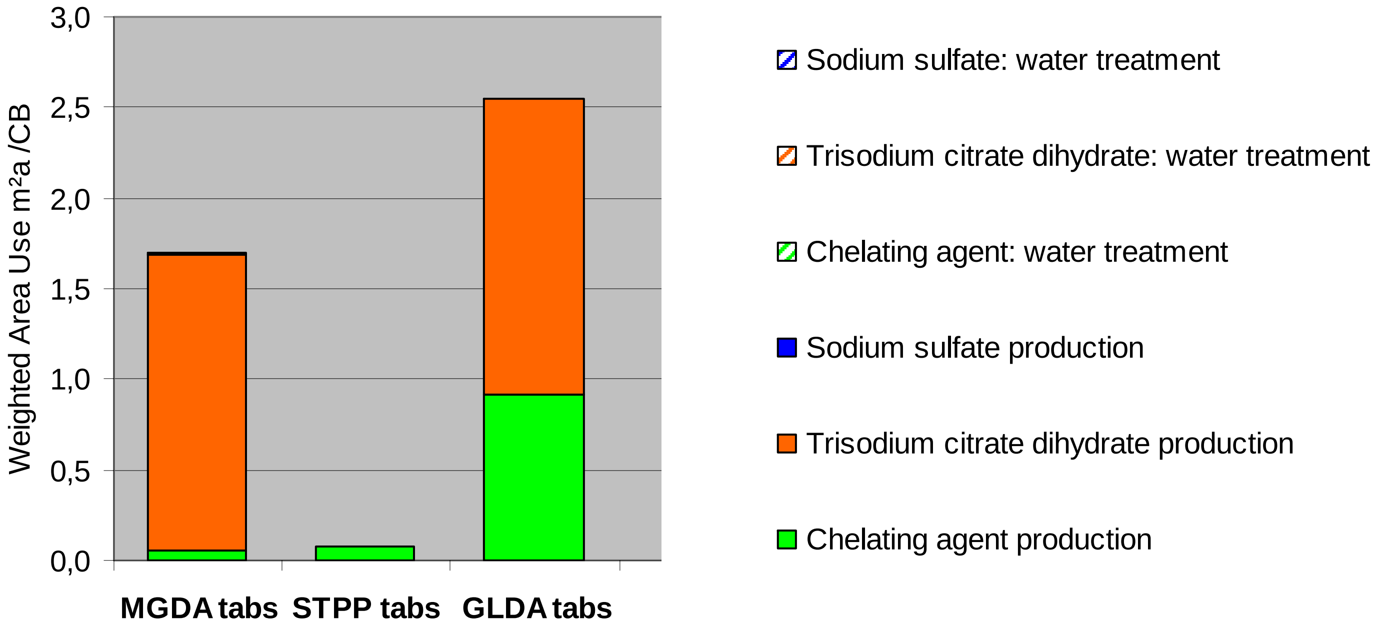
Environmental Categories
Water Emissions



Environmental Categories
Wastes



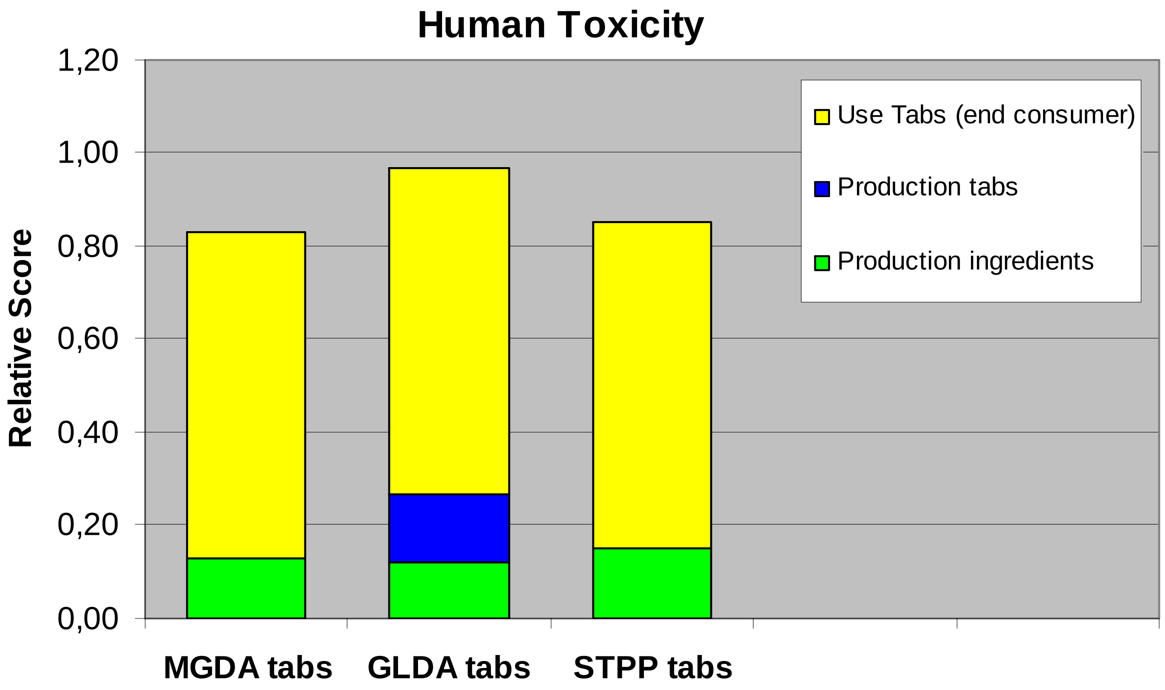
Environmental Categories
Land Use



Environmental Categories
Toxicity and Eco-Toxicity

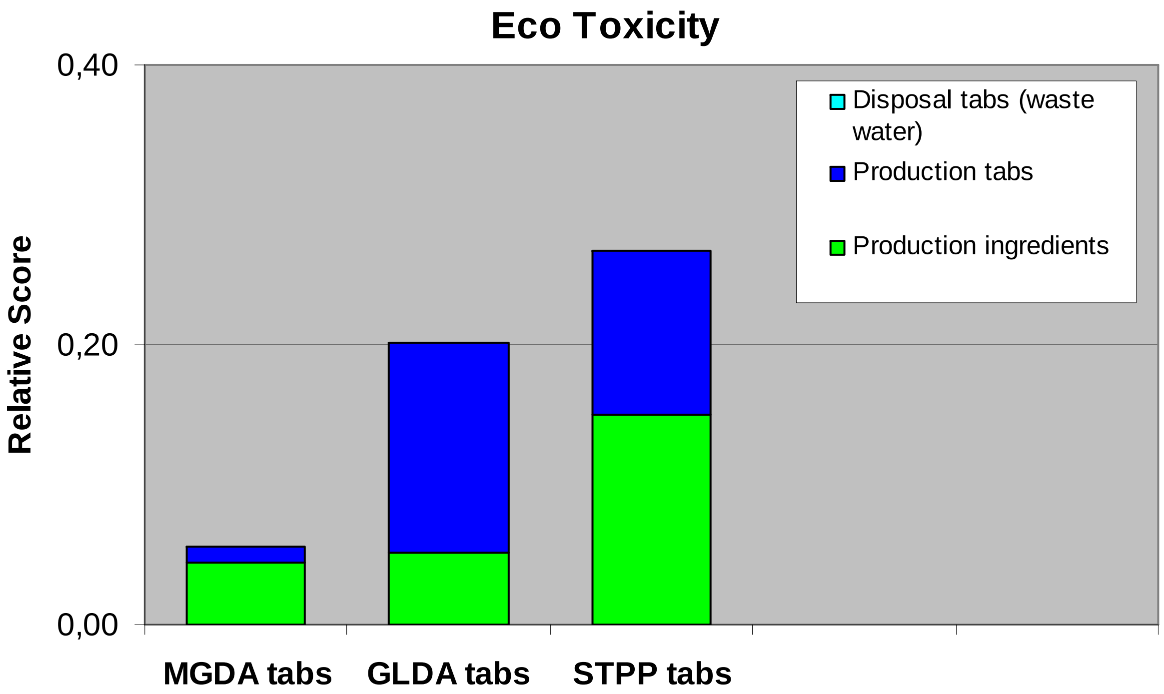
- Human toxicity is a standard category for eco-efficiency analysis. The evaluation is based upon risk phrases of products and of their pre-chain, as published in the safety data sheets (R. Landsiedel, P. Saling, Int. J. LCA **7** (5), 261-268, (2002))
- Eco-toxicity is a standard assessment for SEEBALANCE analysis. The method used for the determination of the eco-toxicity potential follows the basic rules of the European Union Risk Ranking System (EURAM).
- The evaluation is based on water solubility, water/octanol partition coefficient, bio-degradability and toxicity towards water organisms, plants, bacteria. These data are usually available in the safety data sheets (P. Saling, R. Maisch, M. Silvani and N. König, Int J LCA **10** (5) 364 – 371 (2005))
- For both categories, the materials are evaluated separately in two phases of their life cycle: production of materials and use
- For this analysis, eco-toxicity was taken into account: human toxicity contributes for 70% to the final toxicity score, eco-toxicity for 30%

Environmental Categories
Toxicity



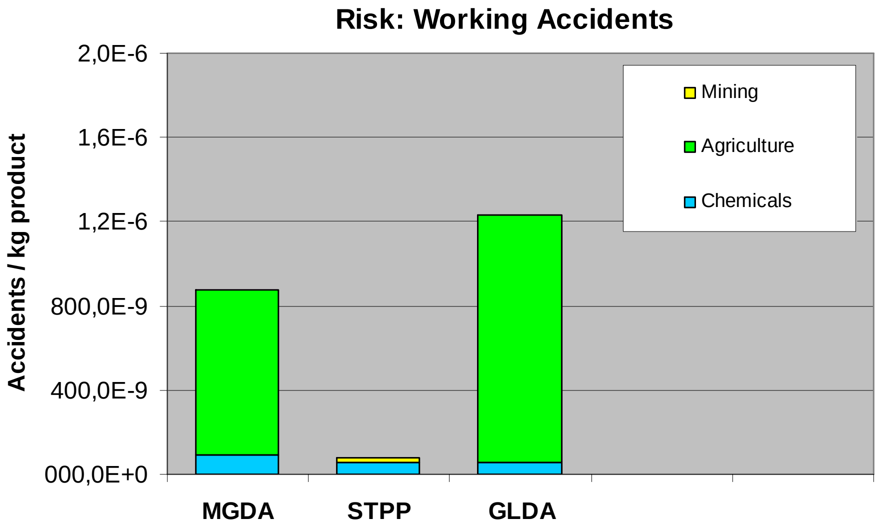
- ADW tabs have all the same risk labelling, independently from the chelating agent used
- Among these three chelating agents GLDA powder is the only one with a risk phrase R36/38 (safety data sheet)

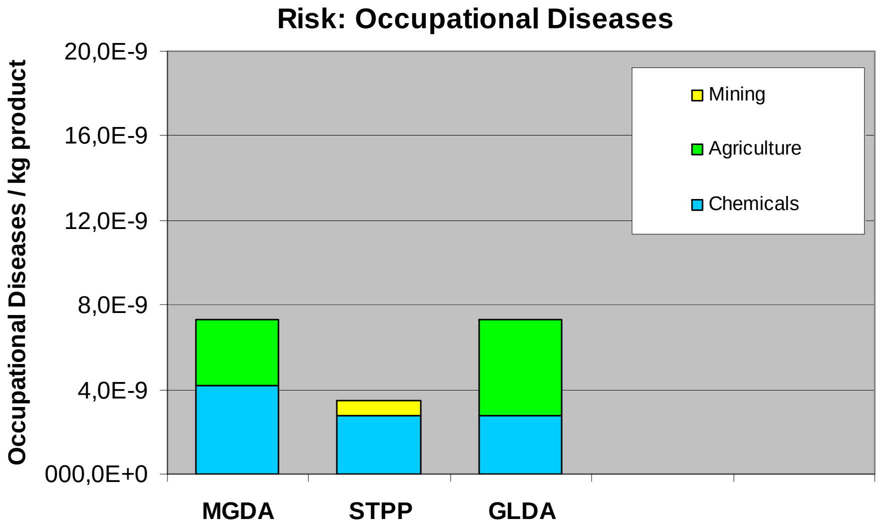
Environmental Categories
Eco-Toxicity



- Main differences for the eco-toxicity score calculated from data available:
  - MGDA: chronic toxicity >100 mg/l
  - GLDA: acute toxicity >100 mg/l
  - STPP: PNEC 0,227 mg/l

Environmental Categories
Risk (working accidents and occupational diseases)





- Main differences for the risk score arise from statistical higher amount of working accidents and occupational diseases connected to agriculture (molasses and starch pre-chain) compared to chemical industry

Appendix (A)

Literature

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Chemical Processes

- MGDA Synthesis
  - BASF internal communications
  - Ullmann's Encyclopedia of Industrial Chemistry

- GLDA Synthesis
  - DE 4211713
  - Ullmann's Encyclopedia of Industrial Chemistry
  - Estimated based on BASF knowledge of similar processes

- Sodium Glutamate, Sodium Citrate
  - Ullmann's Encyclopedia of Industrial Chemistry, 2005
  - BASF internal communications

- For MGDA and GLDA powders a drying step by spray drying is assumed

Life Cycle Inventories

- MGDA
  - BASF data
- GLDA
  - Estimated based on public literature and similar BASF processes
- Sodium Glutamate, Sodium Citrate, Sodium Sulfate
  - Estimated based on public literature
- STPP

For Life Cycle Inventory of STPP three sources are available

1) EMPA St.Gallen (Ökoinventare für die Produktion von Waschmittel-Inhaltsstoffen) 1999

2) SimaPro Database (Ecoinvent data 2005)

3) WRC Report (PHOSPHATES AND ALTERNATIVE DETERGENT BUILDERS – FINAL REPORT) 2002

Data from EMPA St.Gallen were used since they are the best case for STPP

Appendix (B)

Methodology

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The Eco-Efficiency Portfolio According to BASF

Reference:
P. Saling, A. Kicherer et al, Int. J. LCA **7** (4), 203-218, (2002)
A. Kicherer, S. Schaltegger, H. Tschochohei, B. Ferreira Pozo Int J LCA **12** (7) 537 – 543 (2007)

- BASF has developed the eco-efficiency portfolio to allow a clear illustration of eco-efficiency.
- The overall cost calculation and the calculation of the ecology fingerprint constitute independent calculations of the economic and environmental considerations of a complete system with different alternatives. Since ecology and economy are equally important in a sustainability study, a system can compensate for weaknesses in one area by good performance in the other. Alternatives whose sums of ecological and economic performance are equal are considered to be equally eco-efficient.
- The values obtained from the ecology fingerprint are multiplied by weighting factors (description of fingerprint and weighting factors can be found on subsequent pages) and added up in order to determine the environmental impact of each alternative. The various environmental impact values are normalized by the mean environmental impact and plotted on the eco-efficiency portfolio.

The Ecology Fingerprint According to BASF

- The impact categories are normalized (and, in the case of emissions and material consumption, also weighted) and plotted on the ecology fingerprint. This plot shows the ecological advantages and disadvantages of the alternatives relative to one another. The alternative with a value of one is the least favorable alternative in that category; the closer an alternative is to zero, the better its performance.
- The axes are independent of each other so that an alternative which is, for example, favorable in terms of energy consumption may be less favorable in terms of emissions.
- Using the ecology fingerprint, it is possible to find the areas in which improvements are necessary in order to optimize the whole system effectively.

Determination of Energy Consumption

The impact category energy consumption is based on the consumption of primary energy over the whole life cycle. The sum of fossil fuels before production and of the renewable energy before harvest or use is shown. Thus conversion losses from the generation of electricity and steam are taken into account. In the case of BASF processes, company-specific data is used. In the case of non-BASF processes, the UCPTE data set [1] is used. However, consideration of specific scenarios for the production of electricity and steam are possible, e.g. for site comparisons.

The energy consumption figures are assigned to the individual types of energy carriers. The consumption of the various forms of primary energy is taken into account in the consumption of raw materials.
In the category of “energy consumption”, there is no further conversion to specific impact categories. The energy consumption values are normalized so that the least favorable alternative assigned a value of 1; the other alternatives are arranged on an axis ranging from 0 to 1. The performance in all other environmental impact categories are compared in this manner.

In order to calculate the total energy requirement the lower calorific value of the primary energy equivalent is used. The following forms of energy are taken into account: coal, oil, gas, lignite, nuclear energy, hydraulic power, biomass and others.

[1] West European Electricity Coordination System
(UNION POUR LA COORDINATION DE LA PRODUCTION ET DU TRANSPORT DE L`ÉLÉCTRICITÉ)

Determination of Material Consumption

The mass of raw materials necessary for each alternative is determined. The individual materials are then weighted according by a factor incorporating the life span and the fractional consumption of that material [2].

In the case of renewable raw materials, sustainable farming is assumed. Therefore, the resource that has been removed has been replenished in the period under consideration. This means an endless life span and thus a weighting factor of zero. Of course, in the case of renewable raw materials from non-sustainable farming (e.g. rainforest clearance), an appropriate (non-zero) weighting factor is used for the calculation.

High energy consumption can be correlated with low materials consumption if renewable raw materials such as wood or hydraulic power are used. What therefore appears to be double counting of raw material and energy consumption does not occur with these two categories.

[2] U.S. Geological Survey, Mineral Commodity Summaries, 1997; Römpp Chemie Lexikon, Thieme, Stuttgart; Institut für Weltwirtschaft, Kiel; D. Hargreaves et al, World Index of Resources and population, Dartmouth Publishing, 1994; World Resources, Guide to the Global Environment, Oxford 1996; Deutsches Institut für Wirtschaftsforschung, Berlin

Determination of Air Emissions

Air emissions of different gases are recorded separately and added up over the whole life cycle. In most processes, the emission of carbon dioxide is the largest air emission. This emission is typically followed (in terms of quantity) by emissions of sulfur and nitrogen oxides as well as N_2O and hydrocarbons. All emissions occurring during the life cycle are considered, for example for the generation and use of electricity as a source of energy. As a rule, these impact the manufacturing process through the consumption of sources of primary energy.

The effect of these air emissions in the environment varies depending on the type of gas. In order to take account of this, the various emission quantities are linked to scientifically determined assessment factors [3]. Using this method, the emissions of 21 kg of carbon dioxide have the same greenhouse effect as 1 kg of methane. These so-called impact categories are used for each emission. Some emissions, for example the emission of methane, play a role in several impact categories. The impact categories that are taken into consideration in the eco-efficiency analysis are the global warming potential, photochemical ozone creation potential (summer smog), acidification potential (acid rain) and ozone depletion potential.

[3] UBA Texts 23/95

Procedure for Assessing Water Emissions

The assessment of water pollution is carried out by means of the "critical volume" model. For selected pollutants that enter the water, the theoretical water volume affected by the emission up to the statutory limit value (critical load) is determined. The volumes calculated for each pollutant are added up to yield the "critical volume".

The factors for calculating the critical volume are shown in the table. The requirements that are made on sewage at the entry point into surface water, listed in the appendices to the German Waste Water Regulation (AbwV), are the basis for the factors.

These limit values are generally based on the relevance of the emitted substance for the environment; in some cases, technical issues were taken into account in establishing the statute. In spite of this restriction, BASF uses this method for several reasons:

- existence of complete database for most of the emissions
- recognition of the Waste Water Regulation and broad acceptance of the associated limit values

parameter	*Appendix to Waste Water Regulation (AbwV)*	requirement on waste water (mg/l)	factors for calculating ‚critical volumes' (l/mg)
COD	*Nr. 1*	75	1/75
BOD_5	*Nr. 1*	15	1/15
N-total	*Nr. 1*	13	1/13
NH_4-N	*Nr. 1*	10	1/10
P-total	*Nr. 1*	1	1
AOX	*Nr. 9*	1	1
heavy metals	*Nr. 9*	∅ 1	1
HC	*Nr. 45*	2	½

COD: chemical oxygen demand; BOD_5: biochemical oxygen demand;. N-total: total nitrogen. NH_4-N: ammonium-nitrogen; P-total: total phosphorus; AOX: adsorbable organic halides; heavy metals: sum of copper, nickel, lead, mercury etc; HC: sum of hydrocarbons.

Determination of Solid Waste

The results of the material balance on solid waste emissions are summarized into four waste categories: municipal waste, chemical (special) waste, construction waste and mining waste. Due to lack of other assessment criteria, the average costs (normalized) for the treatment or disposal of each type of waste are used as weighting factors to form the overall impact potential. Production residues that are incinerated are considered in the overall calculation by including the incineration energy and the emissions that occur during incineration.

Assessment of the Area Use

Area is not consumed like a raw material but, depending on the type, scope and intensity of the use, is changed so radically that it is impaired or even destroyed in its ability to perform tits natural function. Apart from the direct loss of fertile soil, there are a series of subsequent effects, for example cutting into ecosystems, loss of living space for flora and fauna, etc.

Area necessary to fulfill the customer benefit is considered for each alternative. The area requirement is assessed by weighting according to principal type of use and in relation to the relevance of the area requirement. Since virtually all the countryside in Europe is cultivated, the origins of the areas are not important. For special questions (e.g. conversion of rainforest to plantations), there is no difficulty in extending the consideration of the area requirement in this direction.

The life cycle consists of construction, operation and demolition and is put in relation to the overall capacity of the system. In the case of non-renewable resources, the recultivation time is taken into account.

	area type		assessment factor
0	natural	unaffected ecosystems	0
I	close to nature	forestry use, forest areas and bio-agriculture close to nature	1
II	semi-natural	semi-natural agricultural use, green area	1.5
III	remote from nature	agricultural use and arable cropping remote from nature	2.3
IV	sealed	sealed and impaired area, industrial area	5.1
V	sealed & separating	traffic areas that split up ecosystems (roads, railwys and waterways)	7.6

Assessment of the Area Use: Examples

	amount	area II	area III	area IV	area V
materials		m2a	m2a	m2a	m2a
platinum post-enrichment	100 kg	-24990.00	21680.00	2647.42	665.28
aluminum 0% recycled	100 kg	-49.59	45.39	3.43	0.91
polypropylene	100 kg	-20.56	18.63	1.84	0.09
cement	100 kg	-0.84	0.69	0.09	0.07
energy					
unleaded gasoline post-refinery	t	-97.77	86.05	11.26	0.48
electricity- West Germany mix	GJ	-9667.00	9374.00	260.77	32.45

	alternative 1			alternative 2		
	numerical value	factor	numerical value	numerical value	factor	numerical value
area II	4	1.5	6	2	1.5	3
area III	10	2.3	23	5	2.3	11.5
area IV	0.6	5.1	3.1	0.6	5.1	3.1
area V	0.1	7.6	0.8	1.2	7.6	9.1
sum			32.9			26.7

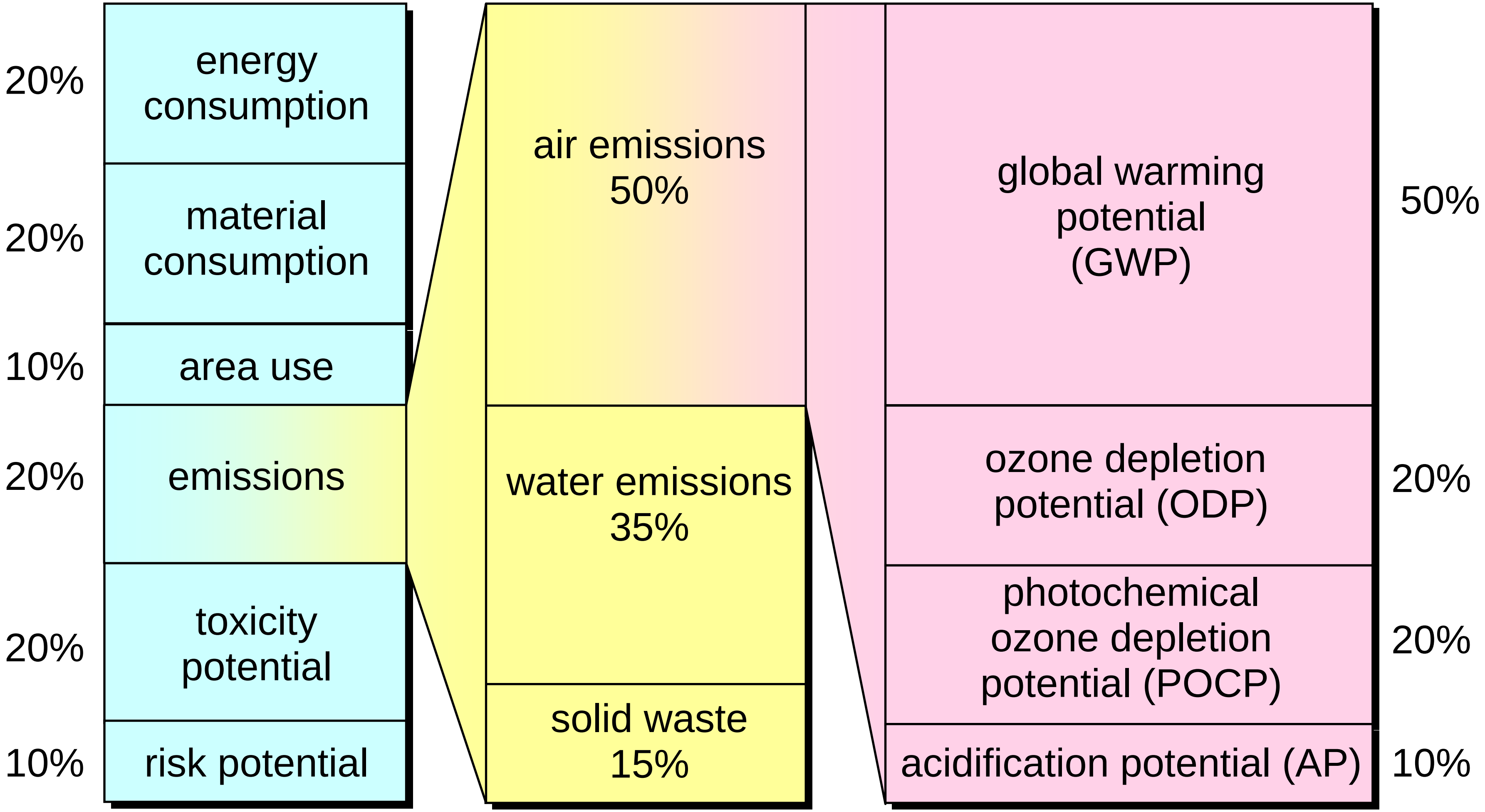
The numerical values are weighted and added up.
Then the normalization is carried out as well as the determination of the relevance.

Determination of the Overall Environmental Impact

The values obtained in the material balance and impact estimate (greenhouse potential, ozone depletion potential, photochemical ozone formation potential, acidification potential, water emissions, solid waste, energy consumption, raw material consumption and area requirement) are aggregated with weighting factors to yield an overall environmental impact value. The weighting factors consist of the following:

- a *societal factor:*
  What value does society attach to the reduction of the individual potentials?
- a *relevance factor*:
  What is the fractional contribution of the specific emission (or consumption) to the overall countrywide emissions?

Determination of Environmental Impact: Societal Weighting Factors



20%	energy consumption	
20%	material consumption	
10%	area use	
20%	emissions	
20%	toxicity potential	
10%	risk potential	

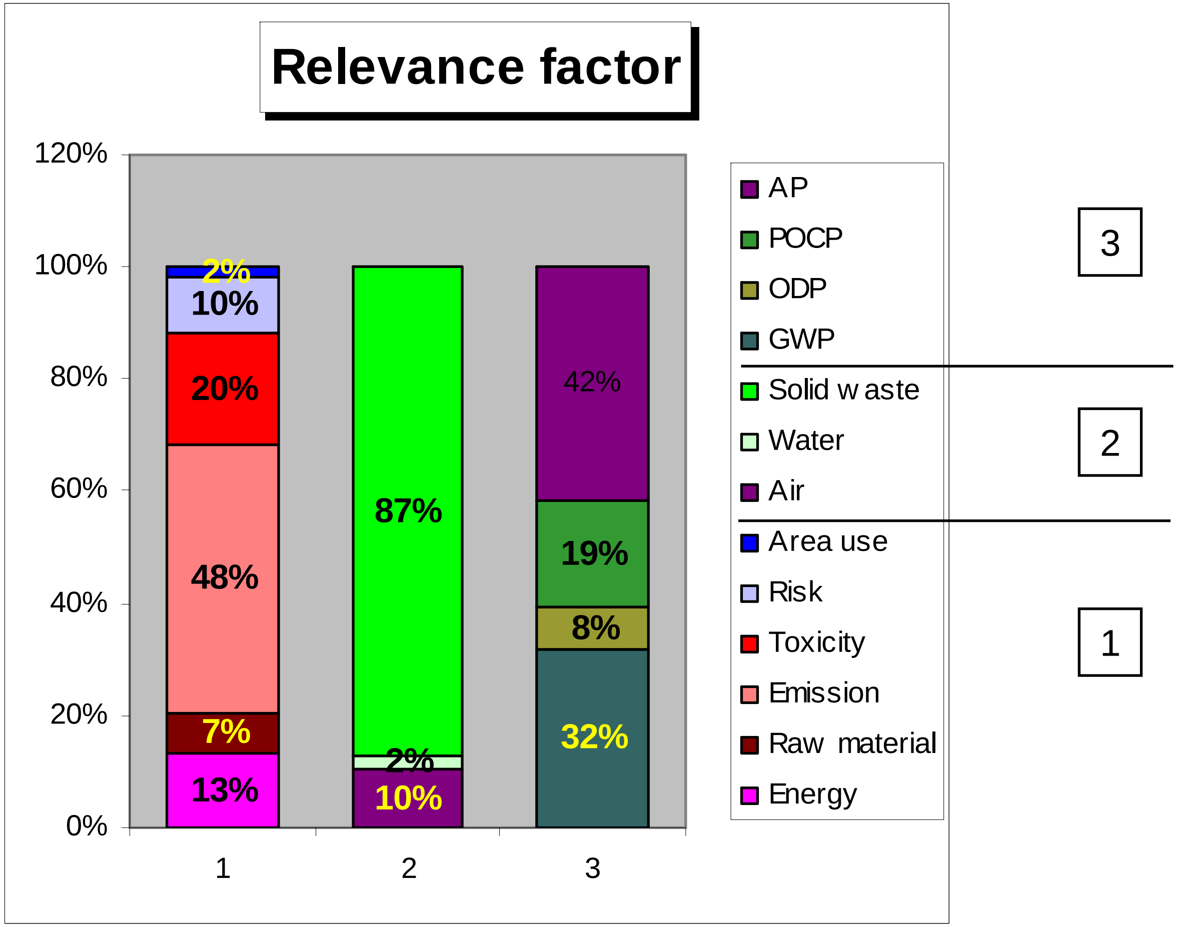
Emissions:

- air emissions 50%
- water emissions 35%
- solid waste 15%

Air emissions:

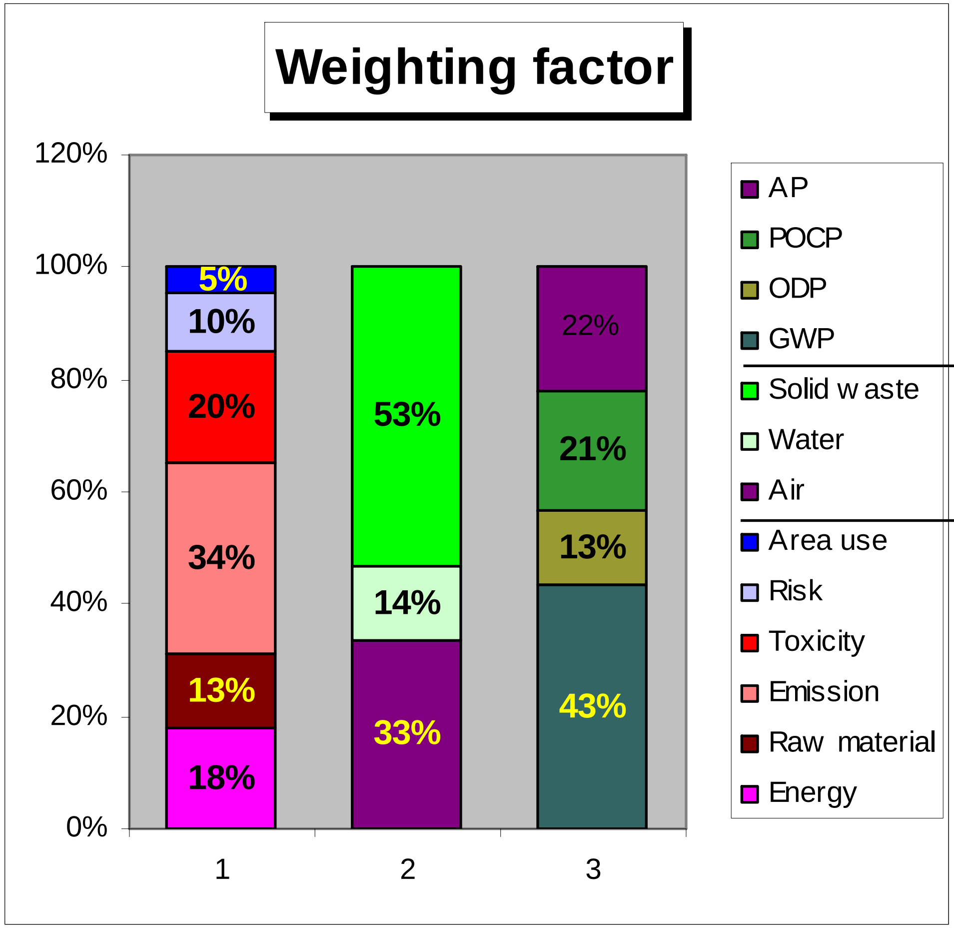
global warming potential (GWP)	50%
ozone depletion potential (ODP)	20%
photochemical ozone depletion potential (POCP)	20%
acidification potential (AP)	10%

Relevance Factors



BIP relevance factor
0.37

Weighting Factors



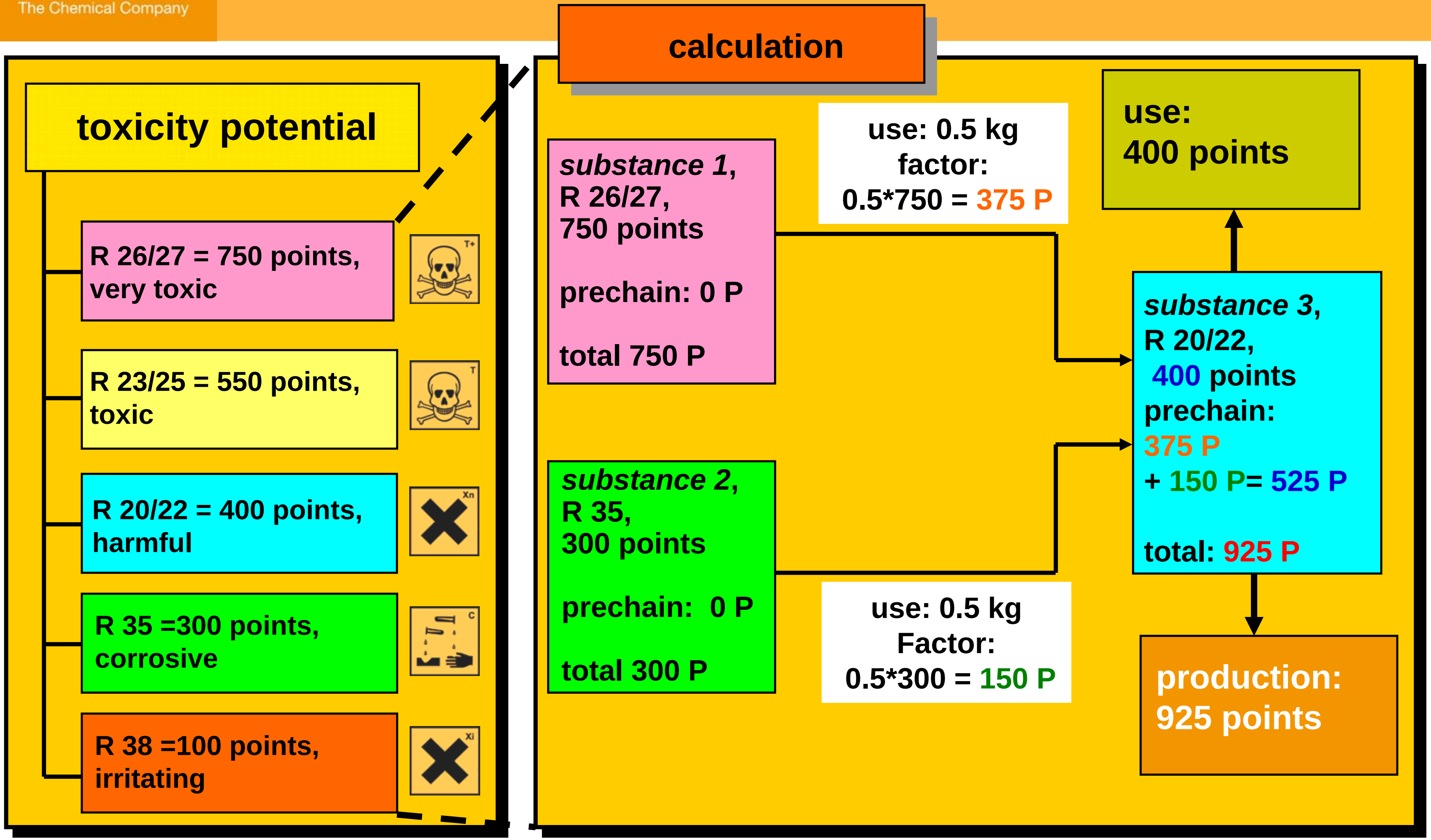
Weighting factors are derived from relevance factors and societal factors.

Determination of the Toxicity Potential

Reference: R. Landsiedel, P. Saling, Int. J. LCA **7** (5), 261-268, (2002)

- The toxicity potential is determined using an assessment method developed by BASF based on the R-phrases of the Hazardous Substances Regulation Act (GefStoffV). In cooperation with toxicologists numerical values ranging between 0 and 1000 were assigned to each R-phrase (or combinations thereof) according to their risk potential. For example, the classification R 26/27 (very toxic) is worth 750 points and the considerably less critical category R 35 (corrosive), 300 points (see example on next page). These R-phrase-based values are determined for all intermediate and final products that are used during the life cycle of each alternative, taking into account likelihood of human exposure.
- The calculated index figures are multiplied by the amounts of substances used and and added up to yield the overall toxicity potential over the life cycle.
- In the production category, only the actual R-phrases of a substance are considered. In contrast, in the production phase, the R-phrases of the pre-chain are evaluated as well as of the substance being produced.
- The results of these assessments are expressed in dimensionless toxicity units which can be compared with one another by normalizing and weighting the various life span phases.
- Only potential toxicity values are calculated. In order to be able to assess an actual risk to humans, additional calculations on the exposure of humans, uptake of the substance, etc., are needed.

Determination of the Toxicity Potential: Example



toxicity potential

- R 26/27 = 750 points, very toxic
- R 23/25 = 550 points, toxic
- R 20/22 = 400 points, harmful
- R 35 =300 points, corrosive
- R 38 =100 points, irritating

calculation

substance 1, R 26/27, 750 points

prechain: 0 P

total 750 P

use: 0.5 kg
factor:
0.5*750 = 375 P

substance 2, R 35, 300 points

prechain: 0 P

total 300 P

use: 0.5 kg
Factor:
0.5*300 = 150 P

substance 3, R 20/22, 400 points
prechain:
375 P
+ 150 P= 525 P

total: 925 P

use:
400 points

production:
925 points

Determination of the Risk Potential

- Statistical data on accidents in various industries or in various occupations are included. The focus is always on the severity of potential damage that an operation can cause, multiplied by its probability (see: P. Saling, C. Gensch, D. Kölsch, G. Kreisel, D. Kralisch, A. Diehlmann, D. Preuße, M. Meurer, I. Schmidt: Entwicklung der Nachhaltigkeitsbewertung SEEBALANCE® im BMBF-Projekt ‚Nachhaltige Aromatenchemie', in Karlsruher Schriften zur Geographie und Geoökologie, Band 22, 2007
- The risk potential in the eco-efficiency analysis is established using expert judgement. For example safety data on various types of reactions in the chemical industry may be included.
- In the risk potential category, different types the damage can be considered. For example, possible damage due to physical reactions (explosion or fire hazards and transportation risks), impurities in the product, incorrect handling, incorrect storage, etc may be included.
- The criteria of the risk potential are variable and may be different in each study, because they are adapted to the circumstances and special features of the particular alternatives. The number of risk categories may vary.
- All aspects of the complete life cycle are included in the assessment.
- Risk potentials are calculated values. In order to be able to estimate a risk actually occurring to a human, additional calculations and estimates are required.

Appendix (C)

Glossary

Glossary of Abbreviations and Technical Terms I

AOX: abbr. for adsorbable organic halogen, a category of water emissions

AP: abbr. for acidification potential or acid rain. In this impact category, the effects of air emissions that lower the local pH values of soils and can thus e.g. cause forest death are taken into account.

BOD: abbr. for biological oxygen demand. This is a method for determining wastewater loads.

CB: abbr. for customer benefit. All impacts (costs, environment) are specific to this customer benefit which all alternatives being evaluated have to fulfill.

CH_4: abbr. for methane.

Cl^-: abbr. for chloride.

COD: abbr. for chemical oxygen demand. This is a method for determining wastewater. loads.

CO_2: abbr. for carbon dioxide.

critical volume: operand for assessing the extent to which wastewater is polluted by mathematically diluting the wastewater with fresh water until the allowed limit value is reached. This volume of fresh water that has been added is referred to as the critical volume.

municipal waste: waste that may be deposited on a normal household landfill.

emissions: emissions are categorized as emissions into air, water and soil. These broad groupings are further subdivided into more specific categories.

Glossary of Abbreviations and Technical Terms II

energy unit: energy is expressed in megajoules (MJ). 1 **MJ** is equivalent to 3.6 kilowatt hours (**kWh**).

feedstock: the energy content that is bound in the materials used and can be used e.g. in incineration processes.

GWP: abbr. for global warming potential, the greenhouse effect. This impact category takes into account the effects of air emissions that lead to global warming of the earth’s surface.

hal. HC: abbr. for halogenated hydrocarbons.

halogenated NM VOC: abbr. for halogenated non-methane volatile hydrocarbons.

HC: abbr. for various hydrocarbons or hydrocarbon emissions into water.

HCl: abbr. for hydrogen chloride.

HM: abbr. for heavy metals.

impact potential: name of an operand that mathematically takes into account the impact of an emission on a defined compartment of the environment.

material consumption: in this category, the consumption of raw materials is considered along with worldwide consumption and remaining reserves. Thus, a raw material with smaller reserves or greater worlwide consumption rates is more critically weighted.

Glossary of Abbreviations and Technical Terms III

NH_3: abbr. for ammonia emissions.

NH_4^+: abbr. for emissions of ammonium into water.

NM VOC: abbr. for non-methane volatile organic compound.

N_2O: abbr. for N_2O emissions.

NO_x: abbr. for various nitrogen oxides.

normalization: in the eco-efficiency analysis, the worst performance in each ecological category is normalized to a value of one. Thus alternatives with better performance in that category will lie between zero and one on the ecological fingerprint.

ODP: abbr. for ozone depletion potential, damage to the ozone layer. This impact category takes into account the effects of air emissions that lead to the destruction of the ozone layer of the upper layers of air and thus to an increase in UV radiation.

PO_4^{3-}: abbr. for emissions of phosphate into water.

POCP: abbr. for photochemical ozone creation potential. This effect category takes into account the effects of local emissions that lead to an increase in ozone close to the ground and thus contribute to what is known as summer smog.

Glossary of Abbreviations and Technical Terms IV

risk potential: impact category assessing the effects of risk factors over the complete life cycle. Risks such as transportation risks, dangers of explosion, dangers of accidents, etc. may be included

SO_x: abbr. for various sulfur dioxides.

SO_4^{2-}: abbr. for emissions of sulfates into water.

special waste: waste that has to be deposited on a special landfill.

system boundary: determines what aspects are considered in the study.

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Glossary of abbreviations and technical terms V

Time span: The period for which a raw material is still available and can be used. The current use of the raw material in relation to what is currently known to be the amount that is still available and can be used industrially is the basis for the assessment.

Total N: Collective term for all water pollutants that contain nitrogen and that cannot be included in one of the other categories.

Toxicity potential: In this category, the effect of the substances involved is assessed with regard to their effect on human health. It relates solely to possible material effects in the whole life span. Further data have to be used to assess a direct risk.

The symbols have the following meanings: T+: very toxic; T: toxic; Xn: harmful; C: corrosive; Xi: irritating.