

**Submission for
NSF Protocol P352
Validation and Verification of Eco-efficiency
Analyses, Part A.**

**BASF's Eco-Efficiency Analysis Methodology
November 2012**



Submitted by:

BASF Corporation
Product Stewardship
100 Park Avenue, Florham Park, NJ, 07932

Prepared by:

Bruce Uhlman, Senior Sustainability Specialist
Tom Laginess, Senior Sustainability Specialist
David Green, Senior Sustainability Specialist
Daniel Steinmetz, Manager Product Stewardship
Peter Saling, Head of Eco-Efficiency Analysis, SEEBALANCE®

Table of Contents

1.	Purpose and Intent of this Submission	1
2.	Content of this Submission	1
3.	BASF’s EEA Methodology	1
3.1.	Overview	1
3.2.	Preconditions:	2
3.3.	Work Flow	2
4.	Study Goals, Decision Criteria, and Target Audience	2
4.1.	Study Goals.....	2
4.2.	Context.....	2
5.	Functional Unit, Alternatives and System Boundaries	3
5.1.	Functional Unit	3
5.2.	Alternatives.....	4
5.3.	System Boundaries	4
6.	Environmental Burden Metrics.....	4
6.1.	Overview	4
6.2.	Cumulative Energy Demand (Energy Consumption)	5
6.3.	Abiotic Depletion Potential (Raw Material Consumption).....	5
6.4.	Air Emissions.....	6
6.5.	Water Emissions	7
6.6.	Solid Waste Emissions.....	7
6.7.	Land Use	8
6.8.	Toxicity Potential	8
6.9.	Risk Potential	11
6.10.	Other Environmental Burden:	12
6.11.	De Minimis Levels:.....	12
7.	Economic Metrics	12
7.1.	Statement of Intent	12
7.2.	Economic Metrics.....	13
7.3.	Time and Regional Value of Money:	13
7.4.	Cost Dimension Importance.....	13
8.	Weighting, Normalization and Factors.....	13
8.1.	Overview	13
8.2.	Weighting Factors.....	14
8.3.	Normalization	15
8.4.	Relevance Factors.....	15
8.5.	Societal Weighting Factors	16
8.6.	Calculation Factor	17
8.7.	Economic Relevance Factors.....	17
8.8.	BIP (GDP) Relevance	17

9. Study Outputs, Final Report and Presentation.....	18
9.1. Final Report and Final Presentation of Results.....	18
9.2. Representations of Results	18
9.3. Bar Charts.....	19
9.4. Environmental Footprint	19
9.5. Eco-Efficiency Analysis Portfolio	19
10. Life Cycle Inventory Data – Eco-Profiles.....	19
10.1. Overview.....	19
10.2. Identifying Required Eco-Profiles	20
10.3. Elements of BASF’s Eco-Profiles:.....	20
10.4. Selecting Eco-Profiles for Use in Study	21
10.5. Time horizon:	21
10.6. Creating New Eco-Profiles.....	22
10.7. Calculating Eco-Profiles.....	22
10.8. Eco-Profile Reporting Requirements.....	22
11. Use of Relative Inputs	23
11.1. Absolute vs. Relative Inputs.....	23
11.2. Selective Use of Relative Inputs	23
11.3. Reporting Requirements	23
12. Data Quality Objectives	23
12.1. Data Quality Statement	23
12.2. Sensitivity and Uncertainty Considerations.....	24
12.3. Reporting Requirements	24
13. Statements of Limitations and of Validation of EEA Study Results.....	25
13.1. Limitations	25
13.2. Validation.....	25
14. BASF EEA Mastersheet.xls.....	25
14.1. Overview.....	25
14.2. Elements.....	25
15. References	27

1. Purpose and Intent of this Submission

- 1.1. The purpose of this submission is to establish BASF Corporation's methodology for performing Eco-efficiency Analyses for the intent of having it validated under the requirements of NSF Protocol P352, Part A: Validation of an Eco-Efficiency Analysis Methodology.
- 1.2. It is the intent of BASF Corporation to use the same validated eco-efficiency model to conduct several individual eco-efficiency studies and have those studies submitted to NSF for verification under NSF Protocol P352, Part B: Verification of Eco-Efficiency Analysis Studies.

2. Content of this Submission

- 2.1. This submission specifies the minimum content of an Eco-Efficiency Analysis (EEA) conducted in accordance with BASF Corporation's EEA (BASF EEA) methodology, and includes the environmental and economic parameters considered, the weighting and normalization procedures to quantify the environmental burden (environmental footprint) and economic costs (life cycle costing), as well as the process by which the data are evaluated for appropriateness and quality, followed by the options for presenting results and conclusions.
- 2.2. As required under NSF P352 Part A, BASF is submitting both a written document describing the elements of the BASF EEA methodology, and a computerized model that incorporates these elements into a working system. Enclosed with this document is BASF_EEA_Mastersheet.xls that is the computerized model programmed in Microsoft[®] Excel.

3. BASF's EEA Methodology

- 3.1. *Overview:* The process for performing a BASF EEA has been previously published^(1,2) and it involves measuring the life cycle environmental impacts and life cycle costs for product alternatives for a defined level of output. In other words, a BASF EEA evaluates both the economic and environmental impacts that products and processes have over the course of their life cycle. The methodology was created by BASF, in partnership with an external consultant, and has since been further developed. BASF EEA follows the ISO 14040⁽³⁾ and 14044 standards for the environmental assessment evaluation and ISO 14045⁽⁴⁾ for eco-efficiency assessment. In addition to these standards, BASF EEA also includes additional enhancements that allow for the expedient review and decision-making at all business levels. Since its inception in 1996, BASF has completed over 500 analyses on a wide variety of products and processes. At a minimum, BASF EEA evaluates the environmental impact of the production, use, and disposal of a product or process in the areas of energy and resource consumption, emissions (air, water, and solid waste), toxicity and risk potential, and land use. The EEA also evaluates the life cycle costs associated with the product or process by calculating the total costs related to, at a minimum, materials, labor, manufacturing, waste disposal, and energy. While NSF Protocol P352 allows applicants the flexibility to implement eco-efficiency analysis studies based upon specific

requirements, the overall procedure for the BASF EEA methodology is shown in Figure 1.

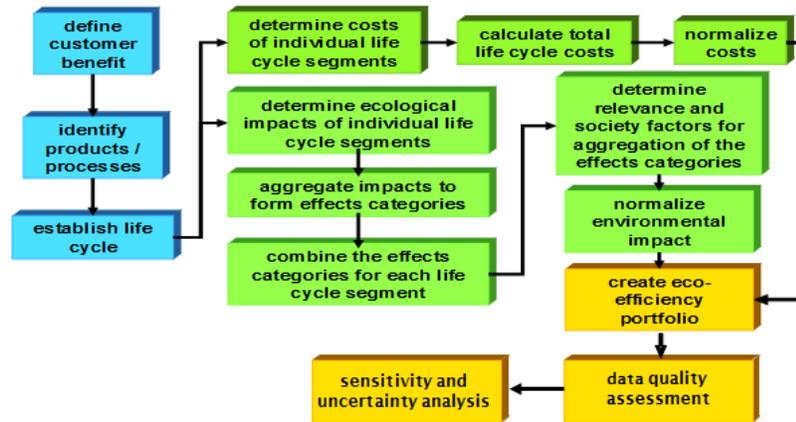


Figure 1: Generalized process flow diagram of EEA Methodology

- 3.2. *Preconditions:* The basic preconditions in BASF EEA are as follows: 1) products or processes studied have to meet the same defined functional unit (a.k.a customer benefit), 2) the entire life cycle is considered, 3) data gathering and constructing the system boundaries are consistent with the functional unit and 4) both an environmental and an economic assessment are carried out.
- 3.3. *Work Flow:* A BASF EEA is worked out by following specific and defined ways of calculations: 1) calculation of total cost from the customer viewpoint, 2) preparation of a specific life cycle analysis for all investigated products or processes according to the rules of ISO standards 14040 and 14044 3) determination of impacts on the health, safety, and risks to people, 4) assessing impacts on biodiversity through land use and land transformation over the whole life cycle, 5) calculation of relevance and calculation factors for specific weighting, 6) weighting of life cycle analysis factors with societal factors, 7) determination of relative importance of ecology versus economy 8) creation of an eco-efficiency portfolio, and 9) analyses of appropriateness, data quality, and sensitivities.

4. Study Goals, Decision Criteria, and Target Audience

- 4.1. *Study Goals:* The starting point for a BASF EEA is to determine the specific goals for that study, which provides the context to define the target audience, alternatives for the study and its system boundaries. Also, the criteria for decision making is defined based upon consideration of economies, markets, and innovations.
- 4.2. *Context:* Development of the study goals and context for decision criteria includes defining the following, which are shown conceptually in Figure 2:
- 4.2.1. *Study Drivers*, e.g. R&D decisions, capital investment, market differentiation, process optimization, quantify benefits of the sustainable changes made to products, regulatory issues, response to green-washing claims, etc.
- 4.2.2. *Geography*, e.g. global, national/regional, or local.

- 4.2.3. *Scenario and Horizon*, e.g. 3 years, 10 years, 40 years, other timeframe.
- 4.2.4. *Engagement*, e.g. customers, regulators, consumers, academics, non-governmental organizations, internal use, etc.
- 4.2.5. *Life Cycle*, e.g. full life cycle, supply chain, production etc.
- 4.2.6. *Product and Market*, e.g. one product/one market, few products/one market, one product/few markets, all products/all markets etc.
- 4.2.7. *Economy*, e.g. developed, emerging, or under development
- 4.2.8. *Innovation*, e.g. incremental, gap closure, step change

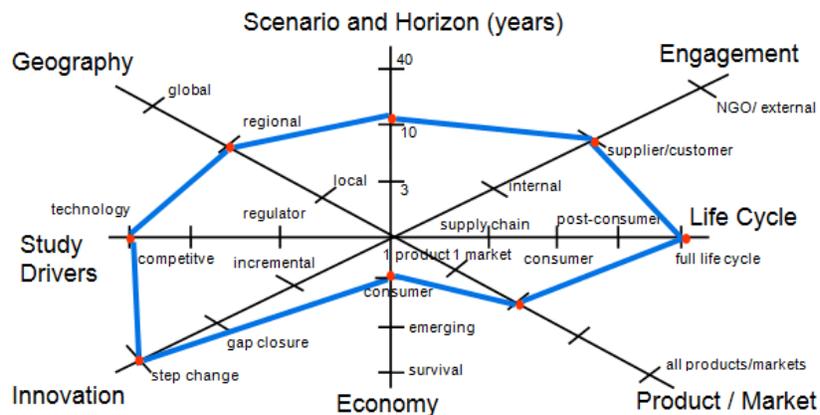


Figure 2: Conceptual diagram showing study goals, target audience and broader context for decision criteria within the BASF EEA methodology

The definition of the study goals and the context also helps to identify the various points along the value chain (in the life cycle), where sustainability issues are the most prominent. Where this occurs, they should be included in the choice of system boundaries. To this end, initial research should be conducted to capture the economic and environmental aspects of the processes or products under consideration. This can range from desk research to additional consultation with specific institutions or data providers, or even extended to a wider involvement and discussion with various stakeholders. The range selected depends on both the complexity of the study and the requirements of the customer. The results of the analysis will also be used to make decisions on the specific data sources to be used within the study.

5. Functional Unit, Alternatives and System Boundaries

- 5.1. *Functional Unit*: The term functional unit is defined in the International Standard ISO 14040 as the “quantified performance of a product system for use as a reference unit in a life cycle assessment.” For BASF EEA the term Customer Benefit (CB) is used as the defined level of output and basis of comparison rather than the term functional unit, however the CB is identical to the functional unit defined in ISO 14040. The CB will be defined specific to each BASF EEA and will take into consideration the elements

described in Section 4 and incorporate a life cycle perspective in accordance with ISO 14040 ff. For example, as discussed in Section 4, engagement, geography, market, scenario and horizon, economy, life cycle, and level of innovation should all be considered when selecting the CB. Justification will be provided as to the reasons for selecting a particular CB.

- 5.2. *Alternatives*: These represent the products or processes that will be compared in the BASF EEA, and for each EEA a minimum of two alternatives will be included. The alternatives will be defined specific to each BASF EEA and will take into account the CB, system boundaries and consideration of the elements described in Section 4. Each alternative must be analyzed against the same customer benefit and justification will be provided as to the reasons for selecting particular alternatives.
- 5.3. *System Boundaries*: The scope of any BASF EEA is defined by its system boundaries, which define the specific elements of raw material extraction, acquisition, transportation, production, use, and disposal that are considered as part of the analysis. BASF EEA considers the entire life cycle but then concentrates on the specific stages in a life cycle where the alternatives under consideration differ. It is important to note that the same life cycle stages must be included when analyzing each alternative. The system boundaries will be defined specific to each BASF EEA and will take into account the CB, alternatives and consideration of the elements described in Section 4 above as well as ISO 14040 ff. Justification will be provided as to the reasons for selecting particular system boundaries. An example of three system boundaries is shown conceptually in Figure 3.

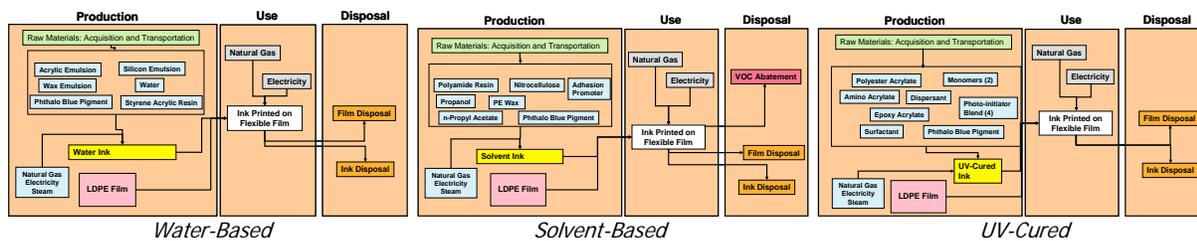


Figure 3: Conceptual diagrams of system boundaries for three technologies

Process steps for the life cycles that are deemed to be the same, or sufficiently similar, for all alternatives under consideration do not have to be included in the analysis. For example, if the study is comparing three different manufacturing processes for the identical chemical X, then the use and the disposal phases do not have to be taken into account. Expert opinion is used when deciding if process steps can be excluded from the analysis. The written Final Report and/or Final Presentation shall clearly state those process steps that were not included in the analysis and consideration should be given in the data quality assessment as to the impact of exclusion.

6. Environmental Burden Metrics

- 6.1. *Overview*: For BASF EEA environmental burden is characterized using eleven categories, at a minimum, including: primary energy consumption (expressed as cumulative energy demand (CED)), raw material consumption (expressed as abiotic depletion potential), global

warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), photochemical ozone creation potential (POCP), water emissions, solid waste emissions, toxicity potential, risk potential, and land use. These are shown in Figure 4.

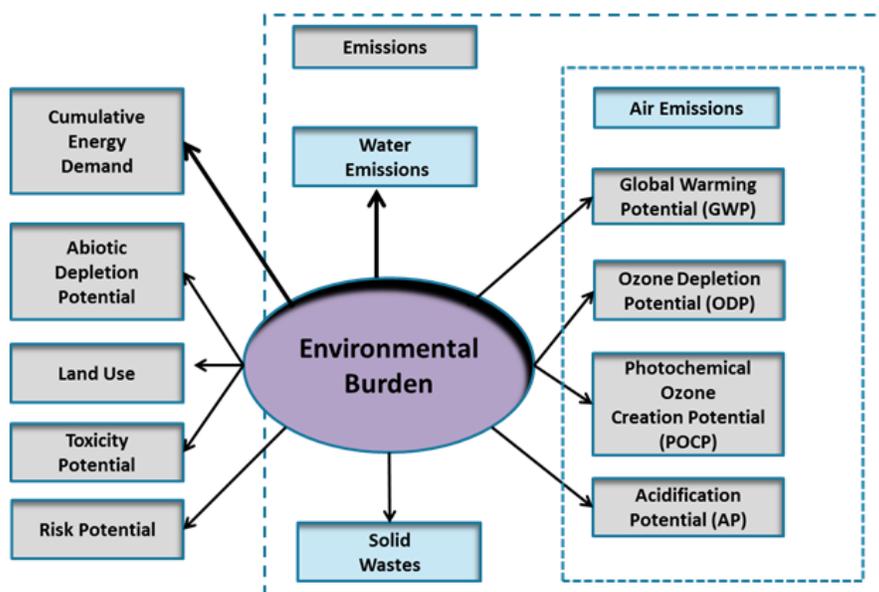


Figure 4: Environmental Burden Metrics for BASF EEA Methodology

- 6.2. *Cumulative Energy Demand (Energy Consumption)*: includes the cumulative energy utilized during production, use, and disposal as well as the energy content remaining in the products. All forms of energy are converted back to their primary energy sources, measured in MJ/CB, and include: crude oil, natural gas, anthracite, lignite, uranium ore, water power, biomass and others. This captures conversion losses from electricity and steam generation. The energies from biomass feedstocks are included; however, not included is the sun energy that is needed to produce the biomass. The individual energy values are summed to obtain the total primary energy consumption.
- 6.3. *Abiotic Depletion Potential (Raw Material or Resource Consumption)*: includes the amount of key abiotic raw materials consumed. Resources (raw materials) are defined as the basic building blocks needed to create a product. At a minimum, BASF EEA will consider the following raw materials: coal, oil, gas, lignite, uranium, sodium chloride, sulfur, phosphorus, iron, lime, bauxite, sand, copper and titanium. These materials are selected as the resources to be considered because they are the basic starting blocks for a wide range of polymers and products (i.e. coal as a raw material for electricity generation and oil as a pre-chain material for plastics). Additional resources are included as deemed necessary, with justification provided. The characterization model used is a function of natural reserves of the resources (elements or fossil fuels) combined with their current rates of extraction. The characterization factor is the abiotic depletion potential (ADP). This factor is derived for each extraction of elements or fossil material and is a relative measure with the depletion of the element "silver" as a reference. Applying this method the LCI results, extraction of elements and fossil

fuels (in kg), are multiplied with the characterization factor (in kg of silver equivalents/kg extraction) to obtain the indicator result (in kg silver equivalents).

6.3.1. Raw material consumption values are weighted with a factor that reflects the demand and exploitable reserves of the raw materials, according to the statistical calculations of the U.S. Geological Survey and other sources, so that the lower the reserves of a raw material and the higher the worldwide rate of consumption, the scarcer that material is and, therefore, the higher the weighting factor it is assigned. See Section 8 for a full discussion of weighting factors applied to raw material/resource consumption. The U.S. Geological Society statistical calculations used in this section are independent of the Land Use environmental burden metric.

6.3.2. Renewable resources, which are assumed to be sustainably managed and theoretically unlimited in terms of availability. Therefore, they are assigned a weighting factor equal to zero. Renewable resources are however considered in the other environmental burden metrics but not in that of raw material / resource consumption. In cases when renewable raw materials are not sustainably managed (e.g., rainforest logging), the appropriate resource factor is applied.

6.3.3. The data sources for the demand and exploitable reserves, which are used in calculating the weighting factors, are provided in the Mik-values worksheet of the enclosed BASF_EEA_Mastersheet.xls. These sources provide data for how long a particular raw material will remain in production assuming today's economical methods for extraction and assuming that consumption remains constant. Mik-values are updated on a periodic basis.

6.4. *Air Emissions:* Air emissions are calculated in terms of mass of emissions generated per CB (kg/CB) over the entire life cycle. BASF EEA will consider at a minimum, but not be limited to, the following chemicals: CO₂, SO_x, NO_x, CH₄, non-methane volatile organic compounds (NM-VOC), halogenated hydrocarbons (hal. HC), NH₃, N₂O, and HCl. These emissions are grouped together and the environmental burden is reported under the following air emission categories:

- Global warming potential (GWP) - CO₂, CH₄, HC, N₂O, (reported as CO₂-equivalents)
- Photochemical ozone creation potential (POCP) - NM-VOC, CH₄, (reported as ethylene equivalents)
- Ozone depletion potential (ODP) – HC, (reported as CFC-11 equivalents)
- Acidification potential (AP) - SO_x, NO_x, NH₃, HCl, (reported as SO₂-equivalents)

6.4.1. The amount of air emissions are weighted with a factor reflecting their potency regarding the global warming, acidification, smog creation, and ozone depletion potentials, as shown in the Mik-values worksheet of the enclosed BASF_EEA_Mastersheet.xls. For example, air emissions for each major greenhouse gas were adjusted for the 100-year GWP as defined by the Intergovernmental Panel on Climate Change (IPCC)⁽⁵⁾. See Section 8 for additional discussion of weighting factors applied to air emissions.

6.4.2. BASF EEA predominately focuses on anthropogenic emissions, basically those emissions resulting from human activity. Biogenic emissions, namely CO₂ emissions resulting from natural biological processes, are generally not included as biogenic emissions and are generally part of a closed carbon loop and balanced when considered over the entire life cycle.

6.4.3. Whenever significant inputs to the analysis are in the form of biomass, provisions will be made to account for land use change emissions of CO₂-equivalents. If land use change emissions are not included, it will be clearly stated as an assumption.

6.5. *Water Emissions:* Water emissions are assessed through a critical volumes approach, which considers both the total amount of emissions to water, as well as the ecological impact of the chemicals being emitted. The individual critical volumes are then summed for a particular life cycle stage in order to obtain an overall impact (L/CB). At a minimum BASF EEA will consider the following chemicals for water emissions: COD, BOD, N-total, NH₄ as N, PO₄ as P, adsorbable organically bound halogens (AOX), heavy metals, hydrocarbons (to include detergents and oils), sulfate, and chlorine.

6.5.1. For BASF EEA, critical volumes (CV) are calculated as the ratio of the amount of chemical emitted to the Maximum Emission Concentration (MEC) threshold limits, which are listed in the annex to the German waste water ordinance. The methodology considers total water discharge, which includes water emissions to both waste water treatment systems and discharges to surface waters. The greater the water hazard posed by a substance, the lower its discharge concentration limit. For example, an emission of 200 mg NH₄-N with an MEC threshold value 10 mg/L results in a critical volume of 20 L (CV = 200 mg/10 mg/L). Threshold limits are provided in the Mik-values worksheet of the enclosed BASF_EEA_Mastersheet.xls. There are no provisions to regionalize or localize the MEC values used in the calculation as it is likely these values are similar across geography, as they are common wastewater constituents with well-established toxicity, and doing so would not be expected to significantly improve the accuracy of the results in relation to the high level of effort that would be required to localize the MEC values.

6.6. *Solid Waste Emissions:* In BASF EEA the solid waste emissions account for all materials disposed of in a landfill; therefore, materials that are recycled or reused are not counted as solid waste. Wastes are categorized as municipal, hazardous, construction, mining and radioactive with a weighting factor applied to each type to account for potential impact. Examples of these waste categories are:

- Municipal: household trash
- Hazardous: RCRA (Resource Conservation and Recovery Act) definition of hazardous waste
- Construction: non-hazardous waste materials generated during building or demolition activities

- Mining: non-hazardous earth or overburden generated during raw material extraction activities
- Radioactive

The impacts are then summed to obtain an overall impact amount in kg of municipal waste/CB. The weighting factors are 1, 5, 0.2, 0.04, and 300,000 for each waste category, respectively, and are subjective values based on disposal costs and are intended to reflect the degree of potential environmental impact.

- 6.7. *Land Use*: This indicator is an assessment of generalized impacts on biodiversity through land occupation and land transformation and is quantified as m²a/CB (square meter years per customer benefit), according to the scheme developed by Köllner and Scholz⁽⁶⁾.

The method uses generic characterization factors for quantifying damages to ecosystems as a result of land occupation and land transformation, termed the Ecosystem Damage Potential (EDP). Based on an extensive meta-analysis of biologists' field research, the EDP factors were derived from data on the diversity of plant species, threatened plant species, moss and mollusks. Another feature of this method is that land occupation and transformation are assessed, using an actual or calculated restoration time period. This means that the land use damage is the most significant for land use types that are difficult to restore and need extremely long time periods to recover (e.g., over one thousand years for primary forest and peat bog).

The land use results are calculated based on the total amount of land used (m²a/CB) in each of a total of thirteen categories for occupation with corresponding EDP weighting factors to reflect the potential impact for these land uses. The transformation of the land has fifteen categories for which the land can be transformed from and transformed to based on the original nature of the land. The specific land use classes considered for both land occupation and land transformation along with their corresponding EDP weighting factors are provided in the Mik-values worksheet of the enclosed BASF_EEA_Mastersheet.xls.

- 6.8. *Toxicity Potential*: For BASF EEA the toxicity potential is assessed not only for the final products, but for the entire pre-chain of chemicals used to manufacture the products as well. The quantities of each substance to be included in the analysis must be inventoried in order to calculate toxicity potential. The result is an assessment of life cycle toxicity potential that includes not only the final products but also the reactants needed in its manufacture. In addition, the toxicity potential is also quantified for the use and disposal stages of the life cycle. The general framework for performing the analysis of toxicity potential is described by Landsliedel and Saling⁽⁷⁾ and is based upon the Hazardous Materials Regulations (R-phrases) outlined in Directive 67/546/EEC. This method was chosen because in order to score the toxicity of a substance, the consideration of all possible effects is needed. The R-phrase system is widely used in Europe for the classification of a substance's various toxic effects. With the introduction of the Globally Harmonized System (GHS) for classification of hazards, the scheme adapts to the new classification by mapping the R-phrases to the categories of the new system.

6.8.1. For BASF's Eco-efficiency analysis, the toxicity potential assessment focuses on human toxicity potential. Physical hazards (i.e. flammable, explosive, etc.) are considered in our risk potential assessment. Ecological toxicity potential is taken into account in the water emissions assessment and in special cases when application to the land and potential run-off or discharges to water bodies are of potential concern, then additional modeling of ecological toxicity can be adapted into the Eco-efficiency study. Developed models such as the USETox™ model can be utilized to characterize ecotoxic impacts.

The scoring system for human toxicity potential presented in Table 1 is based on six groups of toxic properties described by R-phrases. Each group is given a score, ranging from 100 – 1,000 based on the severity of the toxic effects. A substance is assigned to one of these groups by its toxic properties, also described by R-phrases. If there is only one R-phrase for the substance, it will be assigned to the appropriate group; however, if there are additional R-phrases the substance will be up-graded (i.e. +1). However, weak effects or local effects (group 1 and group 2 respectively) and the same effect caused by an additional exposure route (e.g. oral and dermal) will not lead to an up-grade. In general, there is only one upgrade for a substance, irrespective of how many additional R-phrases are present. Scoring for toxicity based on R-phrases shall be done according to the following scheme:

Group	Description	Toxic Effects given by R-Phrases	Score
1	Weak effects	R36, R38, R66, R67	100
2	Local effects	R21, R22, R34, R35, R37, R41, R42, R43, R62, R65	300
3	Acutely toxic Irreversible effects Reproductive toxicity suspected	R20, R24, R25	400
4	Severe irreversible effects Reproductive toxicity	R23, R27, R28, R29, R31, R33, R39, R48, R60, R63, R64, R68	550
5	Carcinogenic	R26, R32, R40, R45, R46, R49, R61	750
6		Only by combination	1000
+ 1	Up-grade by additional effects	Additional "strong" effects (all effects except those of group 1 & 2 and additional exposure routes)	

Table 1: Scoring system for toxic properties described by R-phrases

Where R-phrases are not specifically identified for a chemical but a material safety data sheet exists, health effect information obtained from the data sheet can be used to estimate the appropriate R-phrases. For data sheets which follow the OSHA recommendations for hazardous communications, relevant information can be found in the following sections: hazard identification, toxicological information or regulatory information. However, in some cases limited or no toxicological information may exist for a substance. In these cases, valuable toxicological data can be obtained from related substances, structure-activity relationships and even data from the results of inadequate or preliminary tests. The estimation of possible toxic effects of substances utilizing any of these data sources, requires expert judgment and consultation with toxicologists.

6.8.2. The toxicity is evaluated not only for the final product, but also for the entire pre-chain, i.e. the chemicals needed to make the products, going all the way back to the basic raw materials that are extracted from the earth. Toxicity scoring for the pre-chain will be based on R-phrases and include an additional factor to account for the amount used in the pre-chain. The quantities of each substance to be included in the analysis must be inventoried in order to calculate toxicity potential. In addition to consideration of the production phase of the life cycle, the toxicity potential is also quantified for the use and disposal stages as well. Figure 5 shows an example of scoring the production and pre-chain for 2-nitrochlorobenzene.

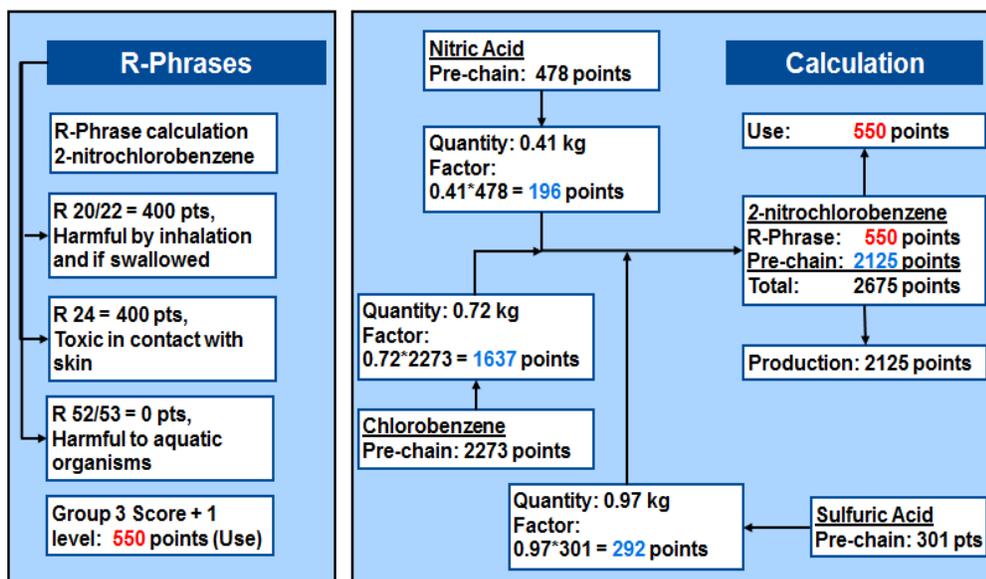


Figure 5: Toxicity scoring system for 2-nitrochlorobenzene

6.8.3. As already discussed, the toxicity potential is quantified for the production, use, and disposal stages of the life cycle. From the standpoint of the final consumer the use phase is the most important so it is weighted at 70% of the total score while the production phase is weighted at 20% and disposal at 10%. These weighting factors, the sum of which equals 100%, were selected based on potential for exposure at each classification level. For instance, workers in the production phase are protected by way of personal protective equipment (PPE), OSHA regulations, etc., while consumers (i.e. use phase) are the least protected, thereby resulting in the highest weighting of 70%.

6.8.4. The toxicity potential can be modified based on weighting factors assigned to both the production phase and use phase of the life cycle. For the production phase a weighting factor based on the safety standards with which the manufacturing facility complies (e.g. the minimum required by regulations, or higher self-imposed or industry imposed standards) is applied. These production phase weighting factors are shown in Figure 6. High safety standards in a production facility may help mitigate any potential exposure operators may have to hazardous chemicals during any potential process upset or accident. Conversely,

poor or low safety standards at a chemical or manufacturing plant will not help in minimizing the potential health hazards to operators associated with the substances being handled at a facility. Safety levels identified are high, medium and low. Weighting factors range from 1.0 for processes with low safety standards, 0.1 for medium and 0.01 for plants with high safety standards. Thus the potential health risk for processes manufactured under a high safety standard will be less than the same material manufactured with a process incorporating low safety standards.

Safety Standard	Factor
low	1.00
medium	0.10
high	0.01

Figure 6: Production Phase Factors – Safety Standards

Similarly, weighting factors are also applied to the use phase of the life cycle. BASF EEA considers three exposure elements 1) system conditions 2) vapor pressure and 3) nanoparticles and these are shown in Figure 7.

System Conditions	Factor	Vapor Pressure	Factor	Nanoparticles	Factor
Closed system	0.01	low (< 1 mm Hg)	0.01	not persistent	1.00
Partially open system	0.10	medium (1 - 3 mm Hg)	0.10	absorbed and reactive	3.16
Open system	1.00	high (> 3 mm Hg)	1.00	persistent	10.00

Figure 7: Use Phase Exposure Factors

The determination of the exposure element/weighting factor to be utilized for a given study is dependent on expert/reviewer opinion. Specific to system conditions, a “closed” system is defined as a system where no external release or exposure to the surroundings is possible, e.g. a completely closed reactor. An “open” system is defined as one in which continuous exposure is possible, i.e. an open storage tank. A “partially closed” system falls between an open and closed system and can be considered to be a closed system that is occasionally opened in order to perform a given task.

With regard to nanoparticles, the BASF EEA has adopted the scientific definition of a nanoparticle, i.e. a particle having one or more dimensions of the order of 100 nm or less. The weighting factors associated with various forms of nanoparticles were derived by a panel of toxicology experts. A non-persistent substance was deemed to have the same weighting as a substance with a high vapor pressure. A substance that remains in the body (i.e. bioaccumulative) was estimated by the toxicology community to be ten times worse than one that is non-persistent. Finally, the weighting factor for a nanoparticle that is absorbed and reactive has been calculated as the geometric mean of the non-persistent and persistent weighting factors (i.e. 1 and 10).

- 6.9. *Risk Potential (Occupational Illnesses and Accidents)*: The risk category in BASF EEA, includes physical hazards during the production, use and disposal phases and

also considers the risk of explosions, flammability, storage accidents, worker illnesses and injury rates, malfunctions in product filling/packaging, transportation accidents and any other risks deemed relevant to the study. The risk potential is established using quantitative government and industry data (e.g. working accidents and occupational disease using industry related data) as well as expert judgment. The risk assessments generally follow the following steps: a) definition of the possible hazards of all alternatives; b) itemizing the possible hazards into production, use and recycling modules; c) determination of the extent of the hazard and the probability of its occurrence and comparison of alternatives.

This is not a quantitative risk analysis but rather a semi-quantitative assessment based on potential risks. The Risk Potential category does not include an evaluation of human health toxicity concerns, because they are examined in another section of the EEA.

6.10. *Other Environmental Burden:* The BASF EEA may include additional environmental burden categories at the Study Director's discretion. In situations where additional environmental burden categories are used, the category will be defined along with necessary weighting and normalization factors for the category, the data sources for the category and reporting requirements.

6.11. *De Minimis Levels:* Materials or processes can be excluded from consideration in the six key environmental burden metrics if they are viewed as being at de minimis levels (i.e. below minimum levels). Thus, eco-profiles or toxicity potential scores are not required for de minimis materials. The cutoff criteria for raw materials and energy consumption is < 1.0% while the cutoff criteria for toxicity potential is consistent with the OSHA Hazard Communication Standard requirements for development of Material Safety Data Sheets (MSDSs). In this case, the de minimis level is 1.0% unless the listed toxic/hazardous chemical is an OSHA-defined carcinogen. The de minimis level for OSHA-defined carcinogens is 0.1 %.

Consideration is also given to the cumulative percentage of de minimis components not being considered for specific materials or unit operations. If the cumulative de minimis quantity not included in an impact assessment of a material or process is greater than 3%, then the project team will evaluate the significance and what potential impact this may have on the study results. As this will be done on a case by case basis, the decision of the project team and justification on what, if any, course of action was taken shall be clearly communicated in the final report.

7. Economic Metrics

7.1. *Statement of Intent:* It is the intent of the BASF EEA methodology to assess the economics of products or processes over their life cycle and to determine an overall total cost of ownership for the identified customer benefit (\$/CB). The approaches for calculating costs vary from study to study. When chemical products of manufacture are being compared, the sale price paid by the customer is used followed by any subsequent costs incurred by its use and disposal. When different production methods are compared, the relevant costs included are normally further itemized along the various life cycle stages and include for example, operating costs, maintenance costs, the purchase and installation of capital equipment, depreciation, and waste disposal

costs. The costs incurred are summed and combined in appropriate units (e.g. dollar or EURO) without additional weighting of individual financial amounts. Regardless of the method used, the BASF EEA methodology will incorporate

- the real costs that occur in the process of creating and delivering the product to the consumer;
- the subsequent costs which may occur in the future (due to tax policy changes, for example); and
- costs having an ecological aspect, such as the costs involved to treat wastewater generated during the manufacturing process.

7.2. *Economic Metrics:* The exact metrics chosen for a study depend upon the scope of the study, the identified customer benefit, the alternatives considered, system boundaries and consideration of the elements described in Section 4. Economic metrics included in BASF EEA, each of which must be consistently applied to each alternative, cover all relevant costs and, at times, revenue and, at a minimum, include consideration of the following:

- Raw material;
- Labor;
- Energy (electric, steam, natural gas, and other fuels);
- Capital investment;
- Maintenance;
- EH&S programs and regulatory costs;
- Illness & injury costs (medical, legal, lost time);
- Property protection & warehousing costs;
- Waste costs (hazardous, non-hazardous);
- Transportation;
- Training costs; and,
- Others, as applicable (e.g. taxes, levies).

7.3. *Time and Regional Value of Money:* Cost analysis in BASF EEA can be calculated as either a point in time or over a period of time that takes into account the time value of money. If the analysis is performed to account for the time value of money, then a Net Present Value, or similar metric, shall be calculated; with the time frame of the cash flow and assumed discount rate specified. The regional currency of the costs calculation shall be specified (e.g. US dollars (\$), Euros (€)) and exchange rates shall be applied when necessary.

7.4. *Cost Dimension Importance:* In a BASF EEA, the cost dimension and environmental dimension are weighted equally.

8. Weighting, Normalization and Factors

8.1. *Overview:* BASF's EEA methodology assesses environmental burdens and economic costs independently, while incorporating weighting factors, then normalizes both to

obtain an environmental fingerprint and then aggregates to develop a relative environmental impact using relevance and societal weighting factors. The method used by BASF is based on a suggestion by the VNCI⁸ and the UBA⁹. The application of these factors is shown in Figure 8. The advantages of taking this approach is as follows:

- Both a society-related and a scientific weighting system are used, and changes in society's attitude can be incorporated;
- Study specific relevance factors are calculated for each analysis;
- Relevance factors ensure that relatively high environmental burdens are more heavily weighted than relatively low ones; and
- A high relevance factor identifies critical environmental burdens.

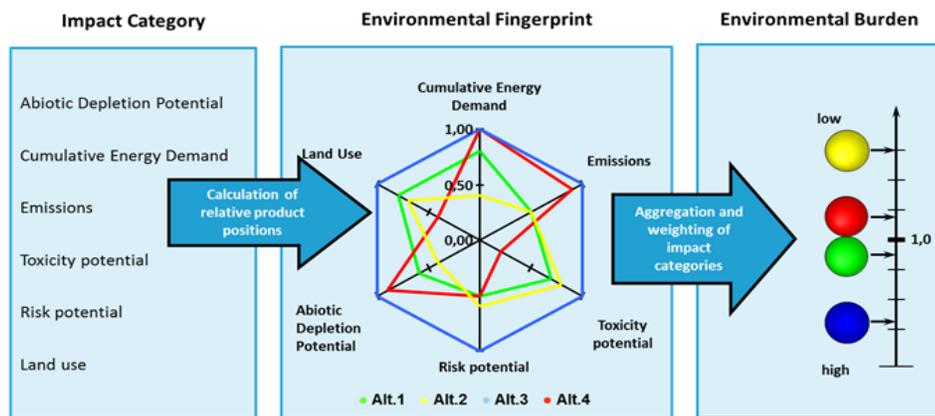


Figure 8: Application of Weighting Factors, Normalization and Aggregation in BASF EEA

8.2. *Weighting Factors (Characterization Factors)*: As described in Sections 6 and 7 above, weighting factors or characterization factors are applied to some environmental burden metrics to calculate equivalencies (e.g. CO₂-equivalents/CB) or to scale environmental burdens (e.g. abiotic resource consumption (kg silver equivalents/CB)). Not all environmental burden metrics have weighting factors applied (e.g. Cumulative Energy Consumption) and no weighting factors are applied to economic metrics. The following is a summary of the weighting factors used in BASF EEA:

- Economic Metrics – No weighting/characterization factors applied.
- Cumulative Energy Consumption (Primary Energy Consumption) – No weighting/characterization factors applied.
- Abiotic Resource Consumption (Resource Consumption) – Weighting based on reserves and demand.
- Air Emissions – Weighting to calculate equivalent emissions as follows:
 - Global Warming Potential (GWP): CO₂-equivalents
 - Photochemical Ozone Creation Potential (POCP): Ethylene-equivalents
 - Ozone Depletion Potential (ODP): CFC-11 equivalents
 - Acidification Potential (AP): SO₂-equivalents

- Water Emissions – Critical Volumes based on Maximum Emissions Concentration
- Solid Waste Emissions – Weighting based on category of waste
- Land Use – Weighting based on types of land use and transformation
- Toxicity Potential – Weighting based on individual materials and life cycle stage
- Risk Potential (Occupational Illnesses and Accidents)– Weighting based on risk element life cycle stage

8.2.1. Weighting factors are shown in the Mik-values worksheet of the enclosed BASF_EEA_Mastersheet.xls. The weighting factors are reviewed regularly to determine if changes are needed. This review period should not exceed three years. Changes to the weighting factors should be noted in the “Up-dates EEA” worksheet. The most recent review and updating was completed in 2012.

8.3. *Normalization:* For each environmental burden metric the results are normalized in order to generate the Environmental Fingerprint plot (Figure 8), and then the normalized results for the six environmental burden metrics are aggregated into a single relative environmental impact score and represented in the EEA Portfolio. Normalization is done by dividing the amount for an environmental burden metric for each alternative by the alternative with the highest value for that burden. An example of normalization is shown in Table 2.

Alternative	Primary Energy Consumption	Normalized Value
auto 1	880958 MJ/CB	1.00
auto 2	834248 MJ/CB	0.95
auto 3	806222 MJ/CB	0.92
auto 4	862274 MJ/CB	0.98
auto 4 diesel	560306 MJ/CB	0.64

Table 2: Example of normalizing primary energy consumption for five different automobile alternatives

8.3.1. The normalized environmental burden metrics are shown on the “Evaluation” worksheet of the enclosed BASF_EEA_Mastersheet.xls and are represented in the Environmental Fingerprint plot.

8.4. *Relevance Factors:* The relevance factor reflects the extent to which a given environmental or social burden, e.g. emissions, energy consumption or working accidents contributes to the total corresponding burden in a given geographic region. Relevance factors are used when aggregating the six environmental burden metrics into a single relative environmental impact score. They indicate how important the individual environmental burden metric is for a particular eco-efficiency analysis. These factors are “scientific weighting factors” because they are not influenced by a definition but are calculated. The greater the contribution of an impact to the total category of the same impact (in North America, for example), the higher the relevance factor. The

relevance factor for each environmental burden metric is calculated as follows:

$$\text{relevance factor} = \frac{\text{environmental burden metric}}{\text{total burden in region}}$$

8.4.1. BASF EEA has relevance data for the United States, Canada, Mexico, Germany, Europe, Great Britain, Morocco, Japan, China and Brazil. The appropriate regional factor to utilize is based on the system boundaries for the study. The relevance factors are to be obtained from credible, publically available sources, with their references cited in the EEA_Relevance worksheet of the Mastersheet.

8.4.2. The relevance factors are to be updated every five years or as deemed necessary. Specific values, and sources, are shown in the “Relevance” worksheet of the enclosed BASF_EEA_Mastersheet.xls. For the United States, the values are obtained primarily from various government agencies such as the Department of the Interior, the Environmental Protection Agency (EPA) and the Department of Energy (DOE). Changes to the relevance factors should be noted in the “Up-dates EEA” worksheet. The most recent updating for North America was completed in 2012.

8.5. *Societal Weighting Factors*: These factors are used when aggregating the six environmental burden metrics into a single relative environmental impact score. The purpose is to weight the individual burden metrics by a factor that accounts for the society’s opinion on the importance of that metric, relative to the other burden metrics. An example of a societal weighting factor scheme is shown in Figure 9. For these weighting factors, societal views of the individual ecological impact categories were determined jointly by TNS Infratest and BASF through surveys, public opinion polling, expert interviews, etc., and recorded in a weighting scheme.

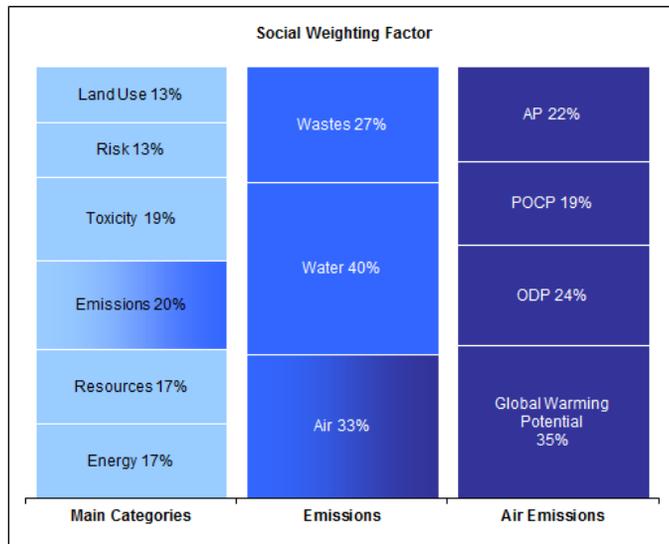


Figure 9: Example of societal weighting factors in BASF EEA

8.5.1. BASF EEA has societal weighting factors data for the United States, Germany, Europe, Great Britain, Morocco, Japan, China and Brazil, and the appropriate factors are selected based on the system boundaries for the study.

8.5.2. The societal weighting factors are to be updated regularly, as deemed necessary, but not for a period to exceed five years. Specific values, and sources, are shown in the "EEA_Results" worksheet of the enclosed BASF_EEA_Mastersheet.xls. Changes to the societal weighting factors should be noted in the "Up-dates EEA" worksheet. The most recent updating for several regions, including the United States was done in 2010.

8.6. *Calculation Factor*: The relevance and the societal weighting factors are combined into an effective calculation factor for each burden metric. Using the calculation factor, the environmental burden metrics are combined and ultimately plotted as a single point in a coordinate system. The calculation factor is determined for each environmental burden metric and is calculated as the geometric mean of the relevance factor and societal weighting factor according to the following formula:

$$\text{Calculation Factor}_{Env\ Metric} = \sqrt{\text{relevance factor}_{Env\ Metric} \times \text{societal weighting factor}_{Env\ Metric}}$$

8.6.1. The calculation factor is the final factor applied prior to calculating the relative environmental impact that is plotted as part of the Eco-Efficiency Analysis Portfolio.

8.7. *Economic Relevance Factors*: In a similar fashion that the environmental relevance factors are calculated, the total costs of a system can be related to the total sales of the manufacturing industry in the field under study. This, as in the case of the calculation of relevance factors for total environmental impact, will give a relevance factor that reflects total costs. For BASF EEA this factor reflects to what extent the alternatives studied contribute to the gross domestic product of a country.

8.7.1. BASF EEA has economic relevance data for the United States, Germany, Europe, Great Britain, Morocco, Japan, China and Brazil, and the appropriate factors are selected based on the system boundaries for the study.

8.7.2. The economic relevance factors are to be updated regularly as deemed necessary, but not for a period to exceed five years. Specific values, and sources, are shown in the "EEA_Relevance" worksheet of the enclosed BASF_EEA_Mastersheet.xls. Changes to the relevance factors should be noted in the "Up-dates EEA" worksheet. The most recent updates for North America was completed in 2012.

8.8. *BIP (Bruttoinhaltsprodukt) Relevance (GDP Relevance)*: While economics and environmental burden are weighted equally at the start of a study, a BASF EEA compares the ratio of the final weighted total environmental burden to the final weighted total cost (E/C ratio) to determine if the economic or the environmental impacts were more relevant or influential for a particular study. With this system, where, for example, economic factors have a higher relevance than environmental

factors, analyses can take a greater account of the total costs axis. This E/C ratio is called the BIP (or GDP) Relevance and utilized when developing the EEA Portfolio.

8.8.1. No updates to the BIP Relevance (GDP Relevance) are necessary as this is a value calculated from other relevance factors which are already updated periodically. The BIP relevance (GDP relevance) result is shown on the "Relevance" worksheet of the BASF_EEA_Mastersheet.xls.

9. Study Outputs, Final Report and Presentation

9.1. *Final Report and Final Presentation of Results:* BASF EEA methods, parameters, results and conclusions can be summarized in a written Final Report and/or Final Presentation. At a minimum, the Final Report and/or Final Presentation shall include a discussion of the following:

- Introduction and study goals;
- Customer Benefit, alternatives and system boundaries;
- Input parameters and assumptions;
- Method of Economic costs evaluation;
- Method of Environmental burden evaluation;
- Eco-efficiency analysis results and discussion;
- Data quality assessment;
- Sensitivity/uncertainty analysis, and
- Limitations of EEA study results
- References.

9.2. *Representations of Results:* Results of a BASF EEA are represented as bar charts for total costs and each of the eleven environmental burden metrics as well as an Environmental (Ecological) Fingerprint plot and an Eco-Efficiency Analysis Portfolio. Figure 10 provides examples of these outputs from a BASF EEA.

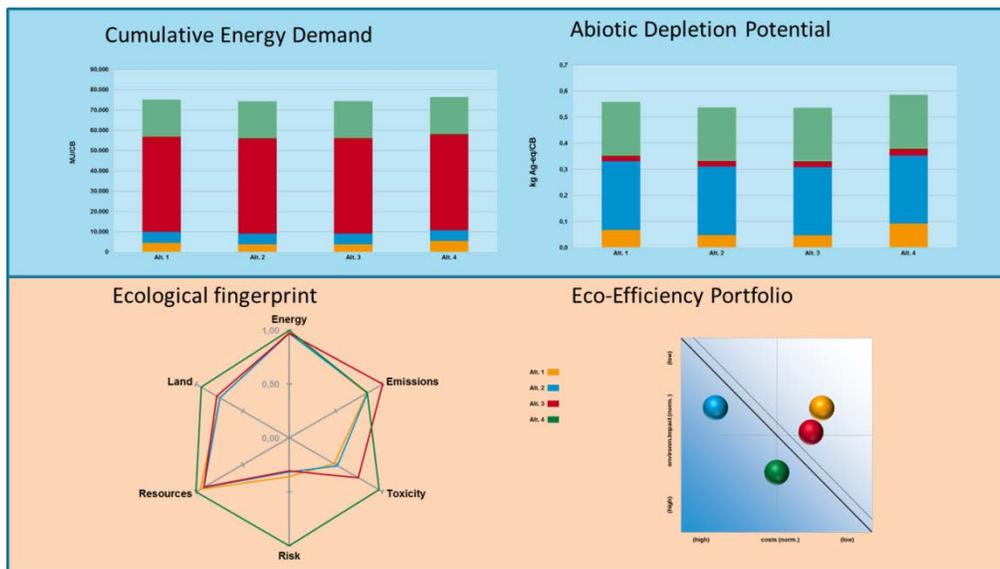


Figure 10: Examples of results presented in a BASF EEA

The BASF EEA methodology allows results to be graphically depicted and discussed, and may assist in decision processes for implementing the most eco-efficient alternative. This contributes to more sustainable development, and supports acceptance of applicable investment and purchasing decisions. The basis for subsequent decisions may be backed with appropriate data, and the effectiveness of the particular measures may be reviewed and documented.

- 9.3. *Bar Charts*: At a minimum, each BASF EEA shall include bar charts that show the results of the analysis for the economic and each of the environmental burden metrics. At a minimum, the bar charts should be generated based on weighted results, but not results that have been normalized or have had the relevance, societal or BIP factors applied. If deemed appropriate, bar charts based on normalized, relevance, societal and/or BIP factors can be added in addition to the weighted charts.
- 9.4. *Environmental (Ecological) Fingerprint*: After weighting and normalization procedures have been carried out for the environmental burden metrics, the appropriate computed values are collected in a specific plot, the Environmental Fingerprint, as shown previously in Figure 8. This diagram shows the environmental advantages and disadvantages of the considered alternatives in a relative comparison with each other. The alternative that lies furthest out and has the value of 1.00 is the least favorable (highest burden) alternative in the category in review. The closer to the origin (0.00 coordinate) an alternative lies, the more favorable (less environmental burden) it is. The axes coordinates are calculated mutually independent of one another, so an alternative that, for example, does well in energy consumption can perform worse with regards to emissions. The environmental fingerprint makes it possible to identify environmental impact drivers and give clues as to the areas in which, with the help of the calculation factors, improvements should be achieved in order that the overall system may be optimized from an environmental perspective.
- 9.5. *Eco-Efficiency Analysis Portfolio*: The BASF Eco-Efficiency portfolio was developed to graphically depict both economic and environmental results on a single 2x2 matrix (see Figure 10). The normalized values from the Environmental Fingerprint are aggregated into a single relative environmental impact through the use of the relevance, societal and BIP (GDP) factors and plotted against total costs. Because environmental impact and cost are equally important, the most eco-efficient alternative is the alternative with the largest perpendicular distance above the diagonal line. Alternatives whose summed economic and environmental ratings are identical or within a specified sensitivity (normally 5%) are considered to be equally eco-efficient.

10. Life Cycle Inventory Data – Eco-Profiles

- 10.1. *Overview*: BASF manages its life cycle inventory (LCI) data in a manner consistent with ISO 14040 ff. LCI data is one of the types of information critical to performing a BASF EEA, the other being the model parameters. LCI is essentially an inventory of input/output data with respect to the product or process under consideration. Input/output data, pertaining to the environmental burden metrics,

namely: abiotic resource depletion, energy consumption, emissions and land use/transformation are collected and stored in a standard format (BASF Eco-profiles). For BASF EEA the term “Eco-Profile” is used in place of life cycle inventory. The general process of selecting Eco-Profiles for use in BASF EEA, shown schematically in Figure 11, involves using existing Eco-Profiles or creating a new one and using a specific Eco-Profile or an analogous one. General descriptions of *existing*, *new*, *specific* and *analogous* Eco-Profiles are provided in Section 10.4. All Eco-Profiles used in a BASF EEA should be provided in the “Eco-profiles” worksheet, and can be seen, as an example, in the enclosed BASF_EEA_Mastersheet.xls. See Section 10.8 for BASF EEA reporting requirements in regards to development and use of Eco-Profiles.

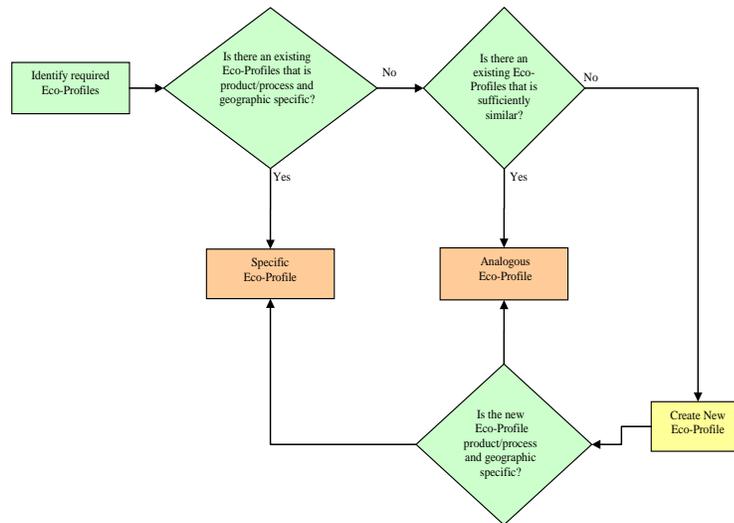


Figure 11: Process flow for selecting Eco-Profiles.

10.2. *Identifying Required Eco-Profiles:* The goals of the study, the defined customer benefit, alternatives and system boundaries (as discussed in Section 4 above) are considered when identifying what specific Eco-Profiles are necessary for a given BASF EEA. Because the process of completing a BASF EEA is often iterative, as data is collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the necessary Eco-Profiles, and; therefore, there should be an ongoing evaluation of the appropriateness and quality of the Eco-Profiles throughout the BASF EEA study.

10.3. *Elements of BASF's Eco-Profiles:* The basic BASF Eco-Profile shall contain, at a minimum, all of the elements that comprise the environmental burden metrics, except for toxicity and risk that are described in Sections 6.8 and 6.9, respectively. As shown in Figure 12, the Eco-Profile is organized by the categories of energy, resources, air emissions, water emissions, solid waste and land use and transformation with the corresponding units for each category. The Material category allows for the addition of other raw materials that may be required due to the specific nature of the study. Data from the Eco-Profile are used to calculate the environmental burdens for the analysis. In some cases, one element may impact more than one environmental metric. Methane (CH₄), for example, is a chemical that impacts both the GWP and POCP burdens.

Energy	unit	Air Emissions		Land use NEW: Ecosystem Damage Potential (EDP)		
Coal	MJ	CO2	mg	1	Occupation, urban	m2a
Oil	MJ	SOX	mg	2	Occupation, industrial area	m2a
Natural Gas	MJ	NOX	mg	3	Occupation, traffic area	m2a
Hydro	MJ	CH4	mg	4	Occupation, mineral extraction site	m2a
Nuclear	MJ	NM-VOCs	mg	5	Occupation, dump site	m2a
Lignite	MJ	halog. HC	mg	6	Occupation, arable	m2a
Other	MJ	NH3	mg	7	Occupation, arable, monotone-intensive	m2a
Biomass	MJ	N2O	mg	8	Occupation, arable, non-irrigated, organic	m2a
CED (cumulative energy demand)	MJ	HCl	mg	9	Occupation, permanent crop	m2a
Resources		Water Emissions		10	Occupation, pasture and meadow	m2a
Water	kg	COD	mg	11	Occupation, forest	m2a
Coal	kg	BOD	mg	12	Occupation, shrub land, sclerophyllous	m2a
Oil	kg	N-total	mg N	13	Occupation, water areas	m2a
Gas	kg	NH4 as N	mg N			
Lignite	kg	PO4 as P	mg P	1	Transformation, from urban	m2
Uranium	kg	AOX	mg	2	Transformation, from industrial area	m2
NaCl	kg	HM	mg	3	Transformation, from traffic area	m2
Sulfur	kg	HC	mg	4	Transformation, from mineral extraction site	m2
Phosphorus	kg	Sulfate	mg	5	Transformation, from dump site	m2
Iron	kg	Chloride	mg	6	Transformation, from arable	m2
Lime	kg	Solid Wastes		7	Transformation, from arable, monotone-intensive	m2
Bauxite	kg	Municipal Waste	kg	8	Transformation, from arable, non-irrigated, organic	m2
Sand	kg	Special Waste	kg	9	Transformation, from permanent crop	m2
Copper	kg	Construction Waste	kg	10	Transformation, from pasture and meadow	m2
Titanium	kg	Mining Waste	kg	11	Transformation, from forest	m2
				12	Transformation, from shrub land, sclerophyllous	m2
				13	Transformation, from water areas	m2
				14	Transformation, from tropical rain forest	m2
				15	Transformation, from unknown	m2

Figure 12: BASF Eco-Profile elements.

10.4. *Selecting Eco-Profiles for Use in Study:* The process of selecting Eco-Profiles for use in BASF EEA is based on expert judgment. Once the required Eco-Profiles for a particular study are identified, then existing Eco-Profiles are used or new ones are created. Furthermore, the Eco-Profiles used in the study will be either specific or analogous. An *existing* Eco-Profile is one that was previously calculated by BASF or was obtained from a reputable external source (e.g. customer, supplier, US Life Cycle Inventory database, scientific literature) A *new* Eco-Profile is created by BASF especially for a given EEA. A *specific* Eco-Profiles means the input/output data match very closely the product or process under consideration. An *analogous* Eco-Profiles means that the input/output data is sufficiently similar the product or process under consideration. The following decision criteria for evaluating the suitability of Eco-Profiles for use in a BASF EEA shall be considered:

- Scope of study: Selected Eco-Profiles should align with the goals of the study, the defined CB, alternatives and system boundaries (as discussed in Section 4 above).
- Product/process specificity: In general, eco-Profiles for a specific product/process are preferred, over analogous Eco-Profiles that may be based on industry averages. If product/process specific Eco-Profiles are not pre-existing, then an analogous Eco-Profile can be used.
- Geographic specificity: Eco-Profiles created within the geographic context of the study are preferred, in general, to Eco-Profiles for regions outside the study context. An exception to this rule is if an international Eco-Profile is deemed superior to the domestic Eco-Profile.

10.5. *Time horizon:* In general, Eco-Profiles created within three years of the date of the EEA are preferred over older Eco-Profiles.

- 10.6. *Creating New Eco-Profiles:* The BASF procedure for creating Eco-Profiles involves the compilation and quantification of material and energy inputs and outputs for each unit process within the system boundaries throughout its life cycle. For a BASF EEA, these inputs include the use of energy, raw materials and land use/transformation, with outputs including releases to air, water and land (solid waste). In addition, BASF EEA considers toxicity and risk potential as “outputs”. The sources of data can include existing ecological studies, questionnaires completed by production plants, scientific publications, analogies and expert judgments. The procedures used for data collection vary depending on the scope, unit process or intended application of the study as defined in Section 4 above. As acknowledged in ISO 14040 ff, data collection for development of an Eco-Profile can be a resource-intensive process and practical constraints on the scope of data collection are considered in the BASF EEA process.
- 10.7. *Calculating Eco-Profiles:* BASF utilizes the Boustead Model (ver. 5.0.11) as its primary means for calculating Eco-Profiles. Boustead is a commercially available software (website: <http://www.boustead-consulting.co.uk/>) that is both a database and a LCI modeling tool. This tool is a life cycle analysis industry standard and was developed by Boustead Consulting Ltd. which has over 35 years of experience in LCA consulting. Calculations done in Boustead are based on a unit operation process that allows it to analyze highly complex linear and non-linear systems without resorting to approximations or simplifications which may otherwise introduce inaccuracies. A unit operation is a process which produces a single product, see Figure 13. Each of these unit operations will take its inputs from other upstream unit operations and its output product will act as a feed for further downstream operations. In general, a unit operation will be independent of the upstream operations that are feeding it and the downstream operations that are taking its products and, therefore, any unit operation can be analyzed without reference to the other unit operations within the system.

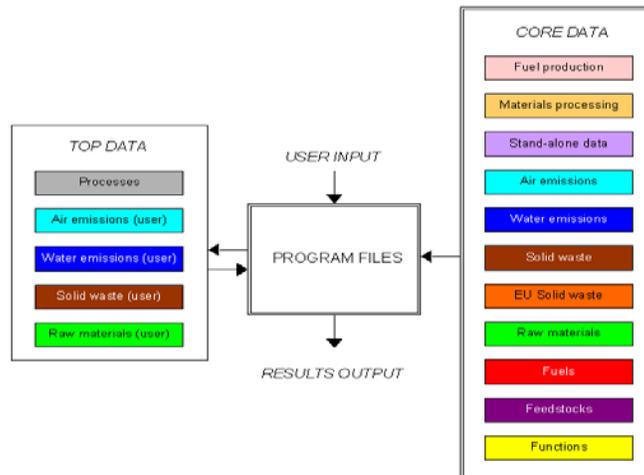


Figure 13: Structure of Boustead Model showing how Eco-Profiles are calculated.
 Source: <http://www.boustead-consulting.co.uk/products.htm>

- 10.8. *Eco-Profile Reporting Requirements:* The presentation and/or final report of BASF EEA results should include a description of the Eco-Profiles used in the study and assessment of the appropriateness of the Eco-Profiles as related to the goals of the study, the defined Customer Benefit (CB), alternatives and system boundaries (as

discussed in Section 4 above). Evidence of sufficiency and/or expert judgments used should be articulated in a transparent manner. In addition, the presentation or report shall contain a data quality assessment in regards to the Eco-Profiles which identifies critical uncertainties, or sensitivities, that have significant impacts on study results. It is not necessary to describe every Eco-Profile that was potentially available for use in the study, as this may be extremely resource-intensive and is, therefore, not consistent with ISO 14040 ff.

11. Use of Relative Inputs

- 11.1. *Absolute vs. Relative Inputs:* The BASF EEA methodology allows for analysis based on both absolute inputs and relative inputs. When there is a high degree of similarity in the analysis between inputs into the model (e.g. composition, energy, assumptions related to production, use and disposal of the alternatives), performing the analysis utilizing relative inputs often provides a higher degree of resolution to the results and does not affect results or conclusions. Relative inputs mean the data in the EEA, such as raw material usage and energy inputs, are based on differences in the amounts rather than the absolute amount. For BASF EEA, relative amounts are calculated by subtracting the usage of the alternative with the lowest amount from the other alternatives. For example, if all three alternatives use a catalyst in the amounts of 5, 4 and 2 kg/CB the relative inputs would be 3, 2 and 0 kg/CB.
- 11.2. *Selective Use of Relative Inputs:* Selective use of relative inputs is acceptable in that they may be used for some economic and environmental metrics in a study but not necessarily for every metric. Selective use of relative inputs is consistent with ISO 14040 ff as it provides a means for greater clarity of results. For example, life cycle impacts of automobiles is often dominated by gasoline consumption during the vehicles service life and by selecting relative inputs only for gasoline usage it provides better resolution in regards to the impact of the other metrics (e.g. materials, energy, supply chain logistics).
- 11.3. *Reporting Requirements:* The presentation and/or final report of BASF EEA results shall include a description of relative inputs used within the model and the appropriateness of using them as it relates to the goals of the study, the defined CB, alternatives and system boundaries (as discussed in Section 4 above). In addition, the presentation or report shall contain a data quality assessment in regards to the use of relative data which identifies critical uncertainties, or sensitivities, that have significant impacts on study results.

12. Data Quality Objectives

- 12.1. *Data Quality Statement:* Because the process of developing a BASF EEA is often iterative, as data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the inputs/outputs. The BASF EEA methodology calls for an ongoing consideration of the appropriateness, accuracy and preciseness of input data throughout the study.

12.2. *Sensitivity and Uncertainty Considerations:* A BASF EEA shall include an assessment of both sensitivity and uncertainty in regards to study inputs and outputs. The scope of this assessment should be based upon the study as defined in Section 4, and shall include an evaluation of the quality of the input/output data in relation to the Relevance and Calculation factors for the study. These factors are specific to each EEA, as they are calculated values, and they are summarized in two graphs provided in the “Relevance” worksheet. Examples of these graphs are shown in Figure 14.

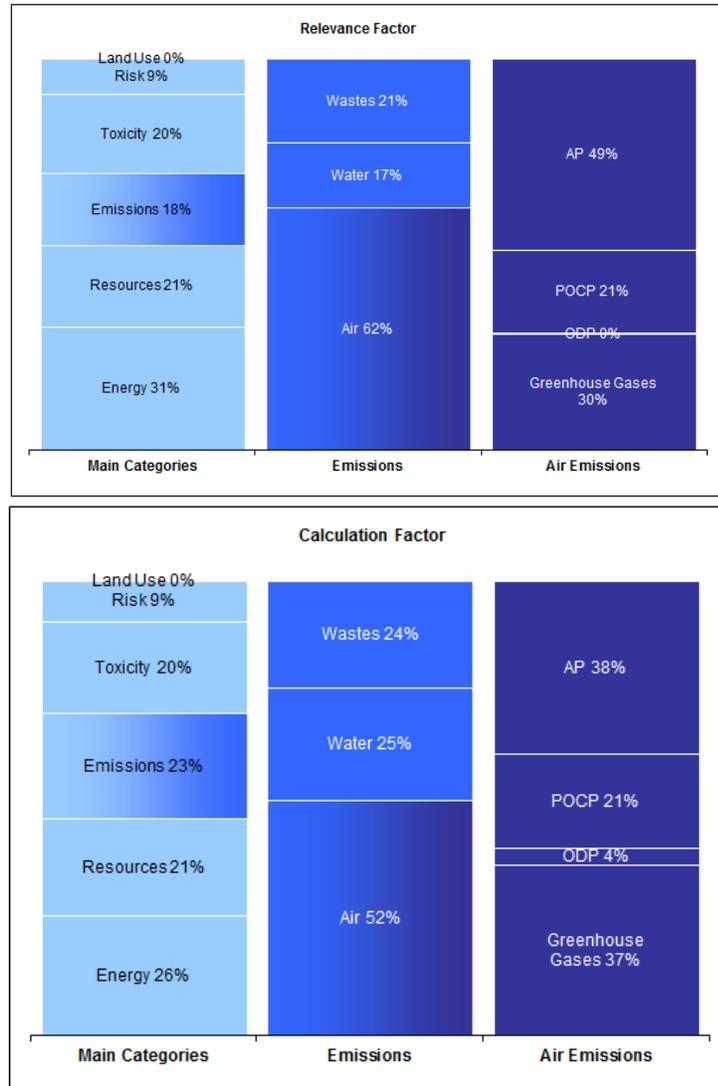


Figure 14: Examples of graphs of relevance and calculations factors in BASF EEA

12.3. *Reporting Requirements:* Findings from the data quality assessment, which identifies critical uncertainties, or sensitivities, that have significant impacts on study results, shall be included in the written Final Report and/or Final Presentation.

13. Statements of Limitations and of Validation of EEA Study Results

- 13.1. *Limitations:* At a minimum, each report or presentation of study results will carry the following statement regarding limitation of study results:

"These Eco-efficiency analysis results and its conclusions are based on the specific comparison of the production, use, and disposal, for the described customer benefit, alternatives and system boundaries. Transfer of these results and conclusions to other production methods or products is expressly prohibited. In particular, partial results may not be communicated so as to alter the meaning, nor may arbitrary generalizations be made regarding the results and conclusions."

- 13.2. *Validation:* The report or presentation should include, at a minimum, the following statement if, and only if, the study was performed in complete accordance with BASF EEA methodology validated under the requirements of NSF P352:

- 13.3. "This Eco-Efficiency analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352. More information on BASF's methodology and the NSF validation can be obtained at <http://www.nsf.org/ecoefficiency>". Slight modifications to this statement are allowed, if required.

14. BASF EEA Mastersheet.xls

- 14.1. *Overview:* BASF has developed a computerized model that incorporates all elements and formulas for calculating a BASF EEA into a working system computerized model programmed in Microsoft® Excel. This system is the BASF Mastersheet.xls spreadsheet

- 14.2. *Elements:* Table 3 describes the function of each worksheet contained within BASF's Matersheet.xls and Figure 11 is a process flow diagram that shows how information is processed within the spreadsheet. Note: The BASF_EEA_Matersheet.xls contains worksheets for conducting Socio-Eco-Efficiency (SEE) studies, which are not part of this application and, therefore, those worksheets are listed as Not Applicable.

Worksheet Name	Contents	Comments
Input Parameters	Study specific parameters are input on this page, including alternatives, formulation information, material and energy usage. Cost, tox and risk data are NOT entered here.	The formats and inputs to this page will vary for each specific EEA.
General data	Establishes the modules for the study. This worksheet is populated with data from the Input Parameters worksheet.	This provides raw material and energy usage per Customer Benefit (CB) from which all environmental impact calculations are performed. Data on this page are in units of material per CB (Usage/CB).
Costs	Cost calculations are done on this page, and linked to Diagrams worksheet.	The formats and inputs to this page will vary for each specific EEA.
Eco-profiles	Life cycle inventory (LCI) data are entered into this sheet and form the basis from which environmental impacts are calculated.	LCI data from Eco-profiles represents Environmental Impact per unit of material. (Impact/Usage)
RiskPot	Risk calculation is done here, based on data from Eco-profiles and other risk information	
ToxPot	Toxicity calculation is done here, according to BASF EEA methodology, based on external toxicity data.	
Evaluation	Results for EEA are provided on this page, including: final environmental scores, weighting factors, environmental fingerprint, eco-efficiency portfolio and scenario analysis.	
Relevance	Data for calculation of relevance factors and weighting factors	
Diagrams	This worksheet contains bar charts of the EEA results	Includes both cost and environmental impact diagrams
CarbonFootprint	Worksheet that completes Carbon Footprint Assessment for alternatives.	Allows for stand-alone determination of carbon footprint for alternatives
Alt.1 thru 10 BASF EEA Mastersheet allows for the comparison of ten different alternatives, so there are ten Alt. worksheets.	Total impact per module is summed based on data in Eco-profiles and then totaled for all modules to obtain total environmental burden.	
Mik-values	Weighting factors for air emission, water emission, solid waste emission, raw material consumption, and land use.	Weighting factor values are used in the Evaluation worksheet.
Up-dates	Running log of updates to EEA model.	Most recent updates are in English.
Boustead	Provides a summary of LCI module numbers. Boustead is name of program that BASF uses for its LCI data.	Data on this page are not used at all in the EEA calculation.
Captions for Diagrams	English and German Headers/Legends for EEA Diagrams	Language selection in General Data worksheet
Heating Values	Lower and Higher Heating Values of Gas, Liquid and Solid Fuels	Not used in EEA Mastersheet. For general information.

Table 3: Worksheets include in BASF EEA Mastersheet Excel file

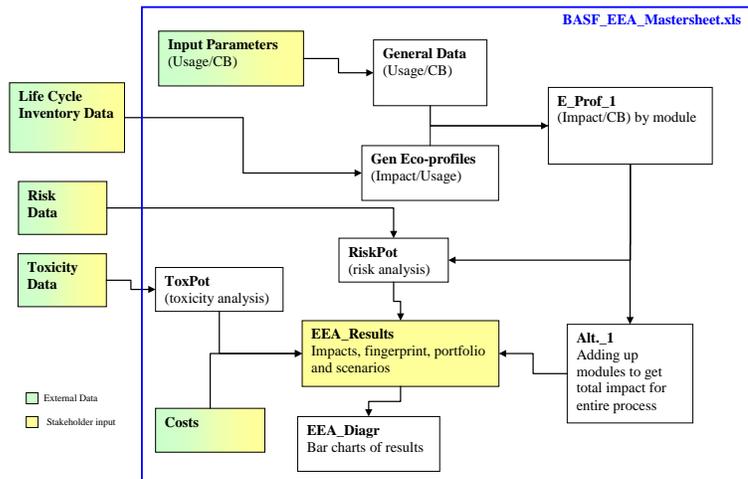


Figure 11: Process flow diagram for BASF EEA analysis using BASF's Mastersheet.xls.

15. References

- ¹ Saling, P., A. Kicherer, B. Dittrich-Kraemer, R. Wittlinger, W. Zombik, I. Schmidt, W. Schrott, and S. Schmidt. 2002. Eco-efficiency Analysis by BASF: The Method. *Int. J. Life Cycle Assess.*, 7 (4): 203.
- ² Shonnard, D.; Kicherer, A; and Saling, P. Industrial Applications Using BASF Eco-Efficiency Analysis: Perspectives on Green Engineering Principles. *Environ. Sci. Technol.* 2003, 37, 5340-5348.
- ³ ISO, International Organization for Standardization. Environmental Management-Life Cycle Assessment-Principles and Framework; ISO 14040:2006; ISO 14044:2006. ISO, Geneva, Switzerland, www.iso.org (2006)
- ⁴ ISO, International Organization for Standardization. Environmental Management- Eco-efficiency assessment of product systems -- Principles, requirements and guidelines; ISO 14045. ISO, Geneva, Switzerland, www.iso.org (2012)
- ⁵ Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- ⁶ Koellner, T., and R. Scholz, "Assessment of Land Use Impacts on the Natural Environment," *International Journal of Sustainable Development* 12 (1), pp. 16-23 (Jan 2007)
- ⁷ Landsiedel, R.; Saling, P. "Assessment of Toxicological Risks for Life Cycle Assessment and Eco-Efficiency Analysis," *International Journal of Lifecycle Assessment*. 7 (5), pp. 261-268 (2002).
- ⁸ Vereniging van de Nederlandse Chemische Industrie (Dutch Chemical Industry) (VNCI) <http://www.vnci.nl/vnci/de-vnci.aspx>
- ⁹ Umweltbundesamt (German Environmental Protection Agency) <http://www.umweltbundesamt.de/>