Preparation of ecological balances

1. Product-related ecological balances

Ecological balances are tools for the evaluation of environmental impacts which develop during the life cycle of a product, i.e. from extraction of raw materials, during manufacture, use, recycling, re-use and final disposal of the product. Ecological balances are necessary for the recording, transparent preparation and evaluation of product-related impacts on environment. The product-related ecological balance is called as well "LCA" which is the abbreviation for "Life Cycle Assessment".

Ecological balances need not cover the whole life cycle of a product but may be restricted to certain life periods of the product concerned. These life periods are called modules or processes and will be subjected to separate examination. Depending on the field of interest and the interested parties the product-related ecological balances may have different effects. For instance, the buying patterns of consumers may be strongly influenced and, consequently, they form the basis for decision taking. Policy tries to create environmentally acceptable framework conditions on the basis of ecological balances, directives, decrees and laws. The manufacturers try to use the results of ecological balances as tools for their marketing strategy.

However, the ecological balance is as well a suitable tool for the improvement of the environmental properties of products and the production process itself. Therefore production companies and service providers should prepare their ecological balances in order to examine the effects of their production processes on the environment.

2. The strategy for the preparation of product-related ecological balances

All environmental effects of a product are summarized and evaluated in a product-related ecological balance covering the whole range from the exploitation, preparation and transport of raw materials, processing of the material, distribution and use of the product, its re-use or its recycling.

The strategy for the preparation of ecological balances is not yet standardized so that studies published until now can hardly be compared with each other.

The ISO (International Standardization Organization) has been effective since 1992 on an international level in order to establish international standards (ISO 14040 - 14043) on the strategy for the preparation of product-related ecological balances. In Germany the DIN-NAGUS (DIN standardization committee "Basic principles of environmental protection" takes all efforts for the establishment of German standards in compliance with ISO. The current state of standardization is summarized below.
3. **Construction of an ecological balance**

According to the principles laid down in ISO 14040 the ecological balance may be divided into four main components.

3.1 **Fixing the target and the scope of examination work**

Fixing the target and definition of the framework for examination are the prerequisites of examinations under the cover of the ecological balance.

The target describes the reason for the preparation of the ecological balance, the addressed target group and the possible modes of application. Among others, the description of the balance scope includes the fixing of the physical and time limits, the definition of a functional unit, the expression of assumptions taken and the designation of exclusion and elimination criteria.

Definition of the balance scope requires the intensive definition of the whole life cycle of the examined product. Apart from the physical and time limits useful criteria are normally required for the demarcation of the overall system. Specific attention must be attributed to the definition and the measurability of the functional unit. This functional unit serves as the profit-related and performance-related reference unit of the ecological balance (e.g. one pipe of one meter length with the same nominal diameter and the same material strength). The same functional unit should be used for the comparison of products or production methods.

Each published ecological balance must contain a critical statement delivered by independent internal and/or external experts or interested parties. The targets define who shall be the author and what shall be the message of such a statement. This critical statement shall subject the employed methods and the quality of the ecological balance to a thorough examination.

3.2 **Factual balance**

The factual balance is the heart of the ecological balance. The factual balance collects and quantifies all environmentally relevant data on the flow of mass and energy as the input and output variables.

The input variables definitely include all raw materials, auxiliary materials and utilities, thermal and electric energy plus fossil and regenerative primary sources of energy. The output variables include among others the products and secondary products and different kinds of emission (solid, liquid and gaseous). Secondary products are frequently used directly in the works for power generation. Consequently, they do not leave the balance scope and enter the energy balance as sources of energy.

Emissions may be either energy-related (e.g. CO₂, NOₓ, SO₂, N₂O etc.) or process-related as a result of the production process (e.g. waste water, oils, waste heat, noise, odors etc.). The energy-related emissions are released through provision, generation and utilization of energy and are gaseous in most cases.

The acquisition of non-material and non-energetic variables is a specific problem for the preparation of factual balances, such as the utilization of soil and nature in the biological production, in transportation, as dumping grounds and industrial estates, and the generation of noise and radioactive radiation.

The preparation of the factual balance requires much efforts in most cases. The quality of collected data may be most different so that it must be described. In production processes where not only the main product but also marketable by-products (secondary products) are
created the factual balance must include even the allocation of environmentally relevant variables to the individual products (allocation of mass and energy flows).

Data are collected on the basis of modules and sub-modules into which the life cycle of a product or an individual production company will be subdivided.

3.3 Valuation of effects

The valuation of effects serves to classify, group and characterize the factual balance data. The valuation of effects will be the more complete the more precise and detailed the factual balance is. Environmental influences are of global, regional or local importance and may be classified into the following three groups of effect categories. Further sub-classifications are possible.

(1) Utilization of resources:
   - Finite and regenerative energy resources
   - Finite and re-growing raw materials
   - Stressing of natural areas
   - Water
   - Air

(2) Ecological effects:
   - Greenhouse effect (global warming of the earth)
   - Ozonolysis in the stratosphere
   - Acidification of soil and water (e.g. through acid input from the air)
   - Eutrophication (e.g. through nutrient precipitation in soils and waters)
   - Environmental impacts caused by toxic substances
   - Biodiversity and species diversity.

(3) Effects on human health
   - Toxic substances with detrimental effects on human health
   - Effects injurious to health
   - Noise.

The effect categories in each ecological balance must be defined with regard to its target and its scope.

ISO CD 14.042 defines a few basic categories to be supplemented in each single case. The procedure for the valuation of effects should be as follows:

(1) The relevant effect categories shall be defined on the basis of the environmental processes and mechanisms and in compliance with the target definition.
(2) The input and output variables (e.g. mass and energy flows) determined in the factual balance shall be allocated to the defined effect categories.
(3) The effect categories shall be quantified and related to the functional unit.

The valuation of effects requires a high rate of transparency of the assumptions taken since a high number of subjective aspects may have influence on the selection of effect categories.
3.4 Evaluation

The evaluation is the final stage of the ecological balance.

On the one hand, data derived from the factual balance will be evaluated, such as the consumption of fossil sources of energy or the CO\textsubscript{2} release whereas data from effect valuation to be summarized in the form of effect categories will be evaluated on the other hand. Transparency and traceability of data and methods are the most essential prerequisite of a well evaluated and universally applicable ecological balance. If only factual balance studies are required, evaluation will be limited to the results of the factual balance (ISO FDIS 14.040).

The evaluation may be based either on the environmental effects of a single product or on the comparison between two or more products with equal performance values but made from different raw materials. These results shall be the basis for recommendations and decisions to be taken.

However, these decisions are no longer included in the ecological balance since further factors will be considered in this case, such as technical feasibility, economic and social aspects.

The evaluation phase is faced with the problem how to compare the different effect categories on a reference basis. Among others, the following question must be asked. Which phenomenon causes the most negative effect: The greenhouse effect, the acidification the or noise?

The evaluation will be strongly influenced by social, economic and environmental targets so that not only facts are considered but also current social values are reflected.

ISO FDIS 14.040 specifies a supplementary critical accompanying method (review) designed to ensure that:

(1) the methods used for the implementation of the product-related ecological balance are scientifically founded and practicable and in conformity with the national and international codes and standards;

(2) the used data are sufficient and appropriate with regard to the target of the product-related ecological balance;

(3) the known restrictions and the target of the product-related ecological balance have been duly considered;

(4) the report is transparent and correct in itself.

3.5 Use of ecological balances

Its use is not an integral part of the ecological balance. However, use of the ecological balance cannot be isolated from the ecological balance itself since the results of the ecological balance cannot be implemented without its use in practice. Use of ecological balances has effects on:

- Policy
  so that environmental framework conditions can be created through the issuance of directives, decrees and laws;
• Economy
  by means of strategic planning in response to changing market requirements;

• Research and development
  for the improvement of products and production methods;

• Public
  since ecological balances are an important tool for the activities of environmentalists' and consumers' associations;

• Consumers
  since each consumer may take the ecological aspects known from the ecological balances as the basis of its purchase decisions.

4. Problems when preparing the balance

4.1 Distribution - Allocation

In the event several products are created in the course of one production or one production process (e.g. manufacture of secondary products) the problem will be if and how the input and output variables of the factual balance can be distributed to the products and by-products.

The ISO standards 14.040 and 14.041 propose to distribute the input and output variables with their ecological effects to the products and secondary products (i.e. products inevitably created during the manufacture of the main product but also fit for recycling with regard to the aspects of material or energy). Waste materials originating from production and to be disposed of shall not be allocated any ecological effects. For example, allocation can be made on the basis of the following criteria:

• Mass;
• Volume;
• Energy content (calorific value);
• Market value.

The allocation procedure must be traceable and be documented in each case.

The consideration of secondary raw materials (recycling) in the balance forms a specific case of distribution. Re-use or further use and/or re-utilization or further utilization is the use of products with a history of at least one effective prior use before they are prepared as raw materials for another product. Normally this will not be a case of genuine recycling but rather a case of manufacture of a lower-quality product (down-recycling).

Different methodical approaches are currently under discussion. While one method generally cuts off the environmental effects of the preceding life cycles (cut-off method) so that it starts with the collection of materials for recycling, the environmental effects in other methods are distributed to several life cycles in a mode similar to a depreciation. In this case the selection of the allocation method will have a decisive influence on the result of the ecological balance.

4.2 Assessment of effects

As described in the section "Construction of an ecological balance" already, the assessment of effects examines the environmental effect of variables mentioned in the factual balance. The considered influences of global, regional and local importance are assessed on the
basis of the effect categories. This assessment is made through the creation of individual efficiency potentials. Each of the efficiency potentials \((W_P)\) will be determined as follows:

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W_P = \text{Emission factor} \times \text{emission volume}
\]

The emission factors reflect the intensity of the particular emission with regard to its impact on environment and under consideration of a specific effect, such as the greenhouse effect. Depending on the effect category, one and the same particular emission (e.g. \(\text{SO}_2\)) may have different efficiency potentials.

The assessment of effects will be made on the basis of the factual balance results which in the ideal case could cover all ecologically relevant data on the full product life cycle. Currently the most different methods are under development and employed in order to describe, classify and evaluate the impacts on environment. However, currently there is no uniform and generally accepted model for the evaluation of ecological aspects, and we assume such a model will hardly be available in the near future since the subjective approaches for evaluation are much too different. Possible effect categories for ecological balances are:

- Utilization of resources
- Global warming of the earth
- Ozonolysis in the stratosphere
- Acidification of soil and water
- Eutrophication
- Photochemical generation of oxidants
- Human toxicology / ecotoxicology
- Land use.

However, acquisition of all environmental effects for the preparation of an ecological balance would require huge efforts. Therefore, the number of effect categories should be restricted to the indispensable minimum such that the actually important environmental effects can be recorded. Below the effect categories are explained which are currently assessed as essential.

A) **Utilization of resources**

Non-renewable resources like mineral substances, metals, natural oil, natural gas and coal must be used as economically and efficiently as possible. Such resources in the form of materials should be used as long and as repeatedly as possible (recycling) although absolutely closed circuits are not possible. Such resources as sources of energy should be preserved as far as possible in order to ensure their long-term availability.

Renewable resources like wood, other kinds of biomass, wind and water power are not available unrestrictedly so that they should be used intensively. Cultivation of re-growing raw materials in artificial circuits (e.g. waste paper recycling) should be worth consideration under the aspect of resource utilization.

When considering the non-renewable resources the ratio of reserves to their rate of consumption may serve as the basis for the evaluation of an ecological balance. The smaller this ratio is, the more critical the particular material consumption should be considered.

B) **Greenhouse effect**

In the category of the greenhouse effect (global warming potential = GWP) the effect of those gases will be determined which contribute to the greenhouse effect caused by anthropogenic factors. Carbon dioxide (\(\text{CO}_2\)) with the comparison value of 1 shall be the reference variable for the determination of the greenhouse potentials of individual gases. The considered period
of time must be stated since the life cycle of gases in the atmosphere will be included in this calculation as well. The GWP is the sum of single GWP’s of the individual gases.

C) Acidification

Acidification is caused by such emissions like sulfur dioxide (SO$_2$), nitrogen oxides (NO$_x$) or ammonia (NH$_3$) released for instance during the combustion of fossil sources of energy, oxidized in the atmosphere and precipitated in the form of acids (sulfuric acid, nitric acid). Gaseous emissions are allocated an acidification potential with SO$_2$ being the reference variable.

**Literature**

