Applying indicator systems and valuation methods in eco-balancing: case study from the beer production process

Jorge Marx-Gómez and Claus Rautenstrauch

Otto-von-Guericke-University Magdeburg, Institute for Technical and Business Information Systems, P.O. Box 4120, 39016 Magdeburg, Germany
E-mail: gomez@iti.cs.uni-magdeburg.de

Abstract: In this study the authors summarise the development of an indicator system for impact assessment and balance valuation and the application of this system to an existing inventory (actual balance) of the Hasseröder Brewery Ltd. The actual balance represents the results of a previously conducted project during which a complex material flow network of the beer production process was elaborated and refurbished with specified data. The collected and registered balance items reflect the ecologically relevant material and energy flows of the enterprise's divisions. Building upon these results the distinct impacts have been estimated and analysed in order to investigate and assess the raw materials and energy flows involved in the beer production process with regard to their respective ecological hazards. Development, implementation and application of the evaluation method have been carried out utilising the software tool Umberto, which had already been employed in the generation of the material flow network. The study first outlines the fundamental characteristics of eco-balances and indicator systems and refers to the features covered by the software tool Umberto. Following this, the course of investigation concerning the establishment of an impact assessment and a balance valuation are explained and the methodologies are applied to the existing case of the brewery. In conclusion, an interpretation of the eco-balance is carried out that eventually shapes the delineation of alternatives for actions for the brewery.

Keywords: Eco-balance; material flow networks; impact assessment; balance valuation.

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Biographical notes: Dr. Ing Jorge Marx- Gómez studied computer science and business engineering at the Technische Fachhochschule Berlin. He is now lecturer and researcher at the Otto-von-Guericke-Universität Magdeburg where he also obtained a PhD degree in business information systems. His research interests include material flow management systems, recycling program planning, disassembly planning and control, simulation and neuro-fuzzy-systems.

Prof. Dr. Claus Rautenstrauch studied computer science and business administration at the University of Dortmund where he also received a Dr. rer. pol. in business administration. In 1995 he received his habilitation for his work in on integration of recycling and production planning at the

Westfälische Wilhelms-Universität Münster. After one year in industry and another year as visiting professor at the University of Konstanz he became a full professor of business information systems at the Otto-von-Guericke-Universität Magdeburg. His current research areas are material flow management systems, environmental reporting, disassembly planning, application service providing and distance learning. Furthermore he is speaker of the working group on industrial environmental management information systems of the German computer society.

1 Introduction

1.1 Research questions and scientific rationale

The Hasseröder Brewery Ltd. is a one-product-enterprise which exclusively manufactures beer of the brand 'Hasseröder Premium Pils'. The company's objective is to responsively contribute to reducing, or to avoiding environmental pollution that may arise from its industrial activity. The preparation of an eco-balance marks the initial step for a comprehensive inventory and evaluation of the environmentally relevant activities and serves as the groundwork for introducing an environmental management system as well as for certification in accordance with the EMAS-regulation.

The results obtained in a previous project 'Material flow based eco-balancing and evaluation of a beer production process – case study' convey the basis for this examination. In the course of the previous project allocation difficulties between the project materials and the elements already implemented in Umberto arose when advancing the impact balance. The indicator systems implemented in Umberto may be applied to the existing actual balance, however they do not lead to reasonable findings [1].

The current case study adapts the methods developed by the German Federal Agency for the Environment Berlin (UBA) as indicator system in accordance with the specific input and output figures of the Hasseröder brewery and expands the system with an additional effect category in order to achieve adequate results for the remaining phases of the eco-balance (impact assessment/balance valuation and interpretation).

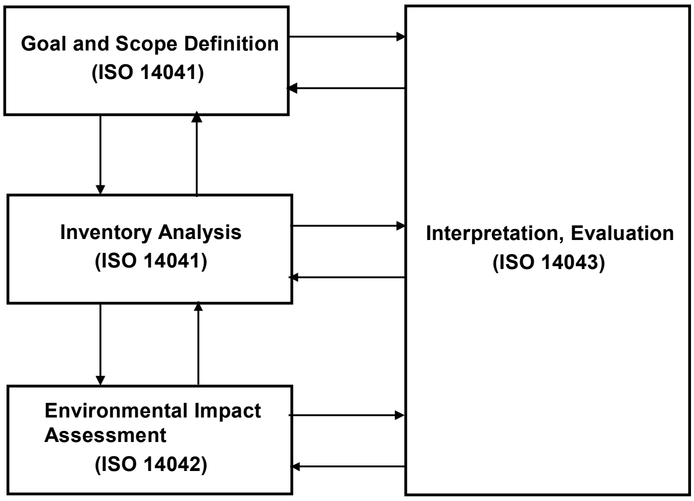
1.2 Eco-balancing

Eco-balancing is a method for documenting the environmental aspects and potential environmental effects associated with a product or production process [2] through:

- compiling an actual balance of relevant input and output flows of a production system
- evaluating the potential environmental effects associated with these inputs and outputs
- interpreting the results of the actual balance and effects with regard to the objective of the study.

Figure 1 shows the four stages of an eco-balance [1].

Figure 1 Process scheme of an eco-balance



The data collections and calculation procedures contained in the actual balance quantify the relevant input and output flows of a system. The I/O-flows encompass the supply of resources, the emissions into air, water and soil as well as those products and by-products originating form the production process. Thus, the actual balance records all material and energy flows compiled within the perimeters of an input/output balance. Depending on the goal and scope of the eco-balance to be examined, the obtained data provide potential interpretations [3].

An impact balance describes the aggregated flow factors registered in the actual balance with regard to their potential impact on the natural environment. While it does not attempt to exactly record real impacts of particular material and energy flows, it quantitatively attributes potential impacts to the material and energy flows of the actual balance [4].

While conducting the balance valuation, the distinct results of the actual balance are subject to an assessment logic that helps connect them to each other in a meaningful and transparent way. The assessment logic has a crucial influence on the total result of the eco-balance. Here, the significance e.g. of the greenhouse effect in relation to the introduction of nutrients into soil and surface water is determined.

To evaluate the potential impact of the collected data on the environment, the impacts are assessed and interpreted. The interpretation is executed separately from the actual balance, because it is reasonable to consider shifts in the comprehension of environmental impact potentials of substances [5]. Incorporated in the impact assessment are findings from ecological impact analysis, e.g. impact threshold values and hazardous potential of the substances. The interpretation considers those priorities in the community concerning environmental policy that can be expressed in threshold values and environmental quality objectives, among others.

The interpretation summarises the results of the actual and impact balances with regard to the previously determined goal and scope of the eco-balance (DIN EN ISO 14040). The final stage of the eco-balance may include a sensitivity analysis and a consistency test, the identification of environmental impacts as well as conclusions and the deduction of recommendations. It gives better understanding of the obtained data. Only the combination of tangible information and judgements as to value can provide the basis for establishing an environmental program comprising measures and concrete objectives.

1.3 Indicator systems within Umberto 3.1

Establishment of the eco-balance for the Hasseröder Brewery Ltd. in Wernigerode involved utilisation of the software tool Umberto. Umberto provides for a clear-cut separation of actual, impact and valuation levels. Moreover, the software contains a particular evaluation component, the Valuation System Editor (VSE), which serves to supply individual valuation and indicator systems. Additionally, the VSE offers the user specific functions for impact assessment and balance valuation. Another advantage of Umberto is represented in the fact that it does not require a particular approach for impact assessment and balance valuation because the VSE already covers a variety of indicator systems [6]:

- indicator system accordant to the UBA-method
- indicator system accordant to the Eco-Indicators 95 method and
- indicator system in accordance to the method of ecological scarcity (Swiss Ecopoints).

Indicators are valuation terms that, applied to the data of an actual balance, represent an assessment conforming to a predetermined pattern. The indicators are connected to raw materials, coefficients and parameters in material flow networks. An interconnected number of indicator definitions compose an indicator system. Indicator systems can acquire any level of complexity: from plain operational coefficients (e.g. CO_2-emissions per product unit) to valuations which are reviewed separately over several hierarchical levels or aggregated according to fixed weight factors. The data of the actual balance to be considered can be readily determined. Various mathematical functions and logical operations are available [7]. Indicators can be combined in an indicator system in a way that yields statements about the entire actual balance or the ecologically relevant parts.

The interconnection of one or several indicators may be generated over different levels and follows a thoroughly defined scheme. Indicator systems are universally defined and independent of individual inventories. For application the indicator system is selected and subsequently related to the inventory (actual balance). Elements and materials are linked in correspondence to the balance [8]. In Umberto this allocation occurs automatically under the premise of identical paraphrasing of the materials. In case of incompatibilities manual association by the user is possible. The results of these indicator systems can be derived numerically or as diagrams.

2 Valuation according to the UBA approach

The impact assessment and balance valuation of the extended actual balance of the Hasseröder brewery employed the approach of the Federal Agency for the Environment (UBA). This method, published in 1995 by the UBA, is based on a procedure which has been developed and implemented by the ifeu-Institut Heidelberg. The following reasons make the application of this method favourable:

- the method portrays no highly aggregated factors. All temporary results are subject to interpretation
- input/output flows and emissions are linked to impact categories prior to weighing the distinctive categories through valuation [9]
- the method of the UBA executes a thorough distinction between impact assessment and balance valuation.

The phase of impact assessment and balance valuation is divided into the following steps:

- *classification*: linking of actual balance data and impact categories
- *characterisation*: modelling and aggregation of the actual balance data within the impact categories
- *valuation*: weighing and summarising the results across all impact categories in order to achieve comparability and possibly aggregation.

2.1 Impact assessment

The impact assessment is executed to consolidate the information contained in the actual balance for preparation of the subsequent balance valuation (inventory analysis). In order to achieve this the documented material flows are described with regard to their potential environmental impacts. Substances with comparable impacts are aggregated. This procedure strives for a comprehensive impact assessment of all input and output flows.

In the first step of the impact balance, the classification, all material and energy flows that have been confirmed in the actual balance (e.g. resource consumption, emissions and the amounts of waste) are linked to impact categories according to their environmental impact potential, respectively.

The impact potentials are calculated in the second step. Within the categories suitable rates are determined which enable impact related aggregation. They describe the potentials in a quantitative form [5].

The UBA has suggested and implemented a discrimination of environmental impacts along the following impact categories:

1. consumption of raw materials
2. greenhouse effect
3. ozone depletion
4. impediments to human health
5. direct damage to organisms and eco-systems

6 generation of photo-oxidants

7 acidification of soil and surface water

8 introduction of nutrients into soil and surface water

9 consumption of space

10 noise incrimination.

The individual impact categories differ in spatial respect (global, regional and local impacts) as well as with regard to the specification of the identification of substances (aggregated parameters, single item registers). The execution of impact related aggregations of material flows depends on the respective impact categories. The beer production process of the Hasseröder brewery delivers the following potentials:

Table 1 Selected impact related aggregation regulations

Impact category (reference substance)	*Standard calculation formula*	*Result*
Consumption of raw materials - fossil energy - non-renewable raw materials - water of disparate origin	Crude oil equivalent factor	797550,165 kg 38,85 m^3 516478,92 m^3
Greenhouse effect (CO_2)	$\sum_{i=1}^{n} GWP(100)_i \cdot \text{Emissions}_i$ into air [kg]	44455338,42 kg CO_2
Ozone depletion (R11)	$\sum_{i=1}^{n} ODP_i \cdot \text{Emissions}_i$ into air [kg]	0 kg
Generation of photo-oxidants (Ethene)	$\sum_{i=1}^{n} POCP_i \cdot \text{Emissions}_i$ into air [kg]	2737,67 kg Ethene
Acidification (SO_2)	$\sum_{i=1}^{n} AP_i \cdot \text{Emissions}_i$ into air [kg]	19219,94 kg SO_2
Eutrophication (PO_4)	$\sum_{i=1}^{n} EP_i \cdot \text{Emissions}_i$ into air [kg]	8757,88 kg PO_4

The abbreviations in Table 1 are explained below:

- GWP(100)i Global Warming Potential of the Emission i for time range of 100 years
- ODPi Ozone Depletion Potential of the Emission i
- POCPi Photochemical Ozone Creation Potential of the Emission i
- APi Acidification Potential of the Emission i
- EPi Eutrophication Potential of the Emission i

2.2 Balance valuation (inventory analysis)

In the balance valuation (inventory analysis) the results of the impact assessment and the actual balance, especially the individual impact areas, are weighed with regard to their relative significance to each other and with respect to the ultimate results. The UBA-method proceeds verbally-argumentatively along several steps. First the results of the impact assessment are set in relation to the respective stress situation (specific contribution). In the second step the respective ecological significance of the distinguished impact categories is determined. The overall importance is obtained from the particular contribution and the ecological significance in a concluding step [9,10]. The elements to be evaluated are weighed with respect to two factors:

- by the specific contribution as a normative criterion, which is utilised to weigh the investigated impact categories concerning the relative influence of the analysed object
- by the ecological significance as criterion for valuation and prioritisation, which helps establish a hierarchy of the scope of the environmental impacts imposed by the impact categories [10].

Consumption of water represents the maximum value and is set equivalent to '1'. In a brewery water is utilised in many processes. All other impact categories acquire values ranging from 'low' (< 0,2) to 'medium' (< 0,6). Figure 2 depicts the relative contributions of the production process in the brewery. Diagram strings with a similar shade of grey belong to the same impact category. The brewery performs no recognisable contribution to ozone depletion. In relation to the maximum value, in this case the consumption of water as raw material, the other contributions of the impact categories could be regarded as of secondary significance. Emission of lead into water and emission of ammonia and hydrogen fluoride are not detectable. According to the actual balance, dust is emitted in such small amounts that it ranges below 1%. In comparison the brewery contributes most to the categories:

- consumption of raw materials: usage of water
- nutrification of soil and water
- occupation of waste disposal sites.

The final step of the UBA valuation method comprises the verbally argumentative overall evaluation by enumerating the different impact categories via the specific contribution and the ecological significance. This step is limited to an appreciation of the impact categories and their relation to each other, hence further calculation of the results of the impact balance is renounced. For the individual impact categories in the brewery a comprehensive evaluation, depicted in Figure 3, has been generated. It should be noted that all categories have attained an overall significance ranging only between low and medium.

The diagram should be read as follows: diagram strings extending over five columns have a very high overall significance. This would indicate the need for immediate action on the part of the brewery.

Figure 2 Contributions from the production process (relative proportions related to the highest contribution of the production process, maximum = 100 %)

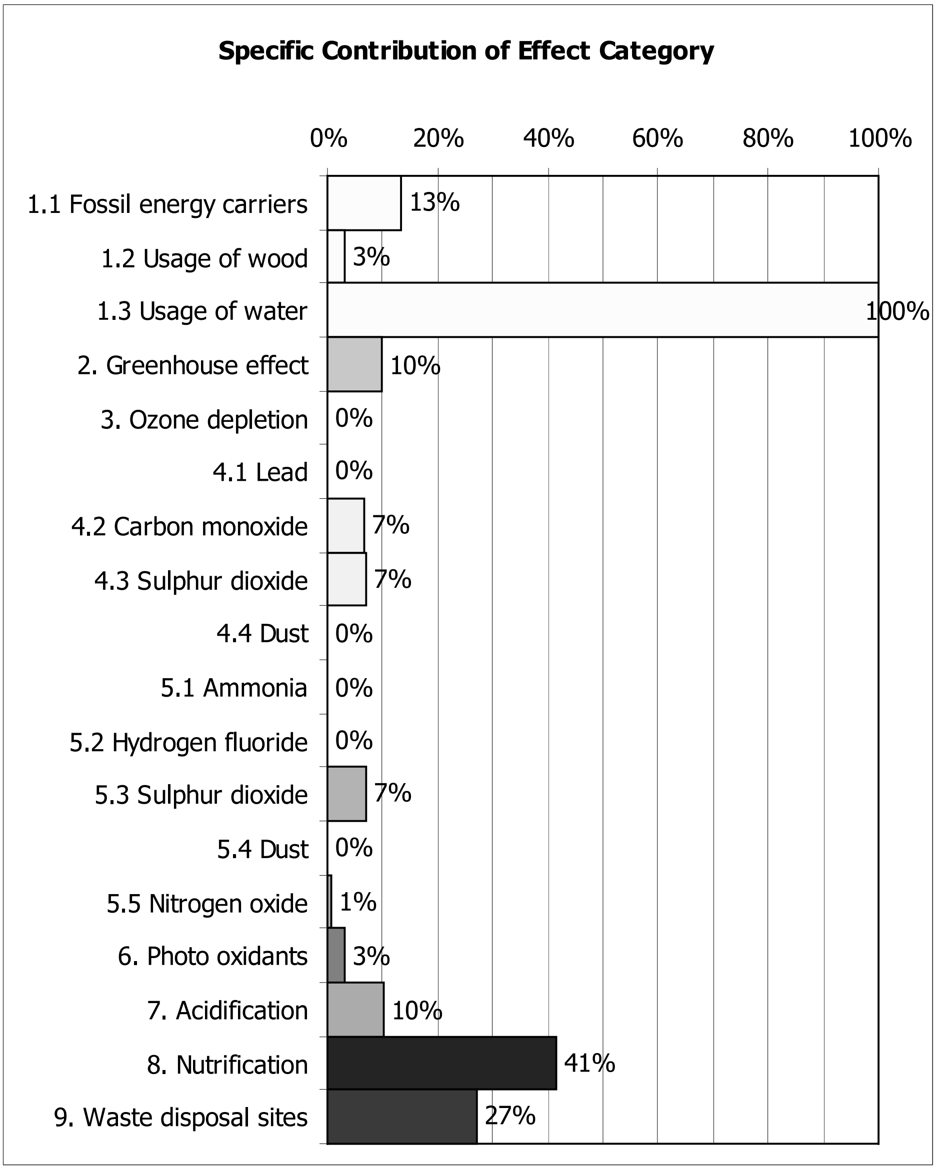
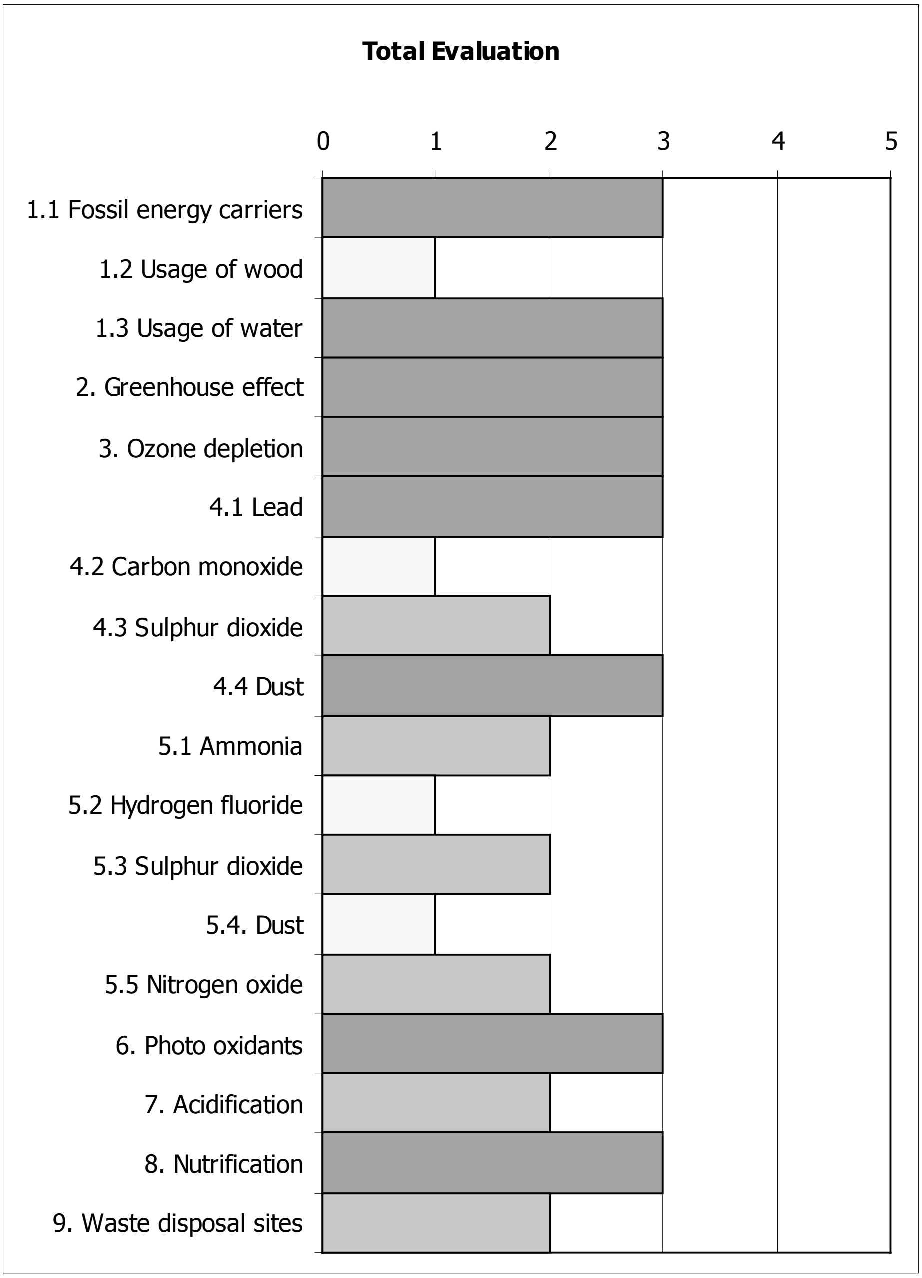


Figure 3 Comprehensive evaluation of the impact categories



First those impact categories are determined that represent a *very high* to *high* overall significance, because these environmental impacts presumably require immediate action. This is e.g. the case, if an impact category with a *very high* ecological significance is related to a low to medium or *very high* specific contribution. The impact categories which describe a particular environmental problem are considered crucial points that should consequently be optimised. Concerning the production process in the brewery no impact category attains a *high* or *very high* significance. Accordingly, no urgent need for action can be deducted.

Next, environmental problems with a *medium* overall significance are reviewed. With respect to sustainability criteria these topics possess a potential need for action. The impact categories with a *medium* overall significance are the consumption of raw materials (fossil energy carriers and use of water), the greenhouse effect, the toxigenicity (dust, generation of photo-oxidants) and the introduction of nutrients into soil and surface water.

Impact categories with a *low* to *medium* overall significance range at the bottom of the hierarchy. This notion applies to impact categories with a *low/low to medium* ecological significance related to a *low/low to medium* specific contribution. These are represented by the categories consumption of raw materials (wood), toxigenicity (carbon monoxide and sulphur dioxide), acidification of soil and water, occupation of waste disposal sites and eco-toxigenicity (sulphur dioxide, dust and nitrogen oxide).

Some categories possess a comparatively low significance, however it should be noted that under certain circumstances a multitude of substances with low specific contributions give rise to substantial environmental problems due to the sum of the individual contributions. In this case, the structure of the provocative agents should additionally be examined (UBA, 1999).

2.3 Extending the UBA method

The UBA method for impact assessment and balance valuation was originally developed for life cycle analysis (LCA), through which all ecologically relevant material and energy flows ‘from cradle to grave’ are investigated. The complete production process in the Hasseröder Brewery Ltd. can be regarded as part of such an analysis, because the brewery is a one-product company. Impact assessments in general require that the material and energy flows obtained in the input/output balances are taken from the natural environment and returned to it.

Since this investigation focuses alone on the production process of beer, particular prior and subsequent chains are not considered. Some material and energy flows that neither originate in the natural environment nor return to it are included in the process balance. The I/O balance of an energy provider who supplies private households with e.g. methane as energy carrier (natural gas) will contain also methane as output. However to deduct a contribution to the greenhouse effect is not appropriate, because the methane is not returned to the natural environment [11].

Up until now most material and energy flows could be associated with one of the previously outlined impact categories. Yet this applies not to all materials like the majority of auxiliary and processing substances (AaPS). This leads to twisted conceptions since these substances appear only in the anthroposphere. The substances and their by-products are already considered indirectly in the actual balance. Actually, almost all cleansing and disinfectant agents contribute to pollution of sewerage which eventually leads to enhanced CSB-rates. The indicator value CSB is employed to evaluate the environmental category nutrification of soil and surface water. The following section introduces the risk for hazards and damages as an additional impact category and suggests an evaluation of these factors.

2.3.1 Impact category risks and hazards

Certain products that are employed in a company unfold a direct impact in case of emergencies. They contribute to potential hazards and risks when these substances are stored and used. Consequently, an expansion of the UBA method to include the impact factors risks and hazards is suggested, while pursuing the approach of the initial UBA method.

2.3.2 Classification

Similar to the impact category consumption of raw materials different sub-categories are generated for classification. They are oriented along the properties and the purpose of the substances.

- cleansing and disinfectant agents (CIP): substances which are used for cleaning and disinfecting pipe and tank systems
- filtration aids: substances which are inevitable to produce filtered beer from mash
- lubricants: substances like lubricants for conveyors, conveyor belts to sort bottles, for packaging and unpacking devices
- other auxiliary and processing substances (AaPS): substances which do not fit into one of the other categories.

2.3.3 Characterisation

For evaluation purposes the different criteria are examined in respect of the endangerment of soil and water, the flammability, the industrial safety, the emissions and the environmental performance in case of emergencies.

To facilitate the inclusion of quantitative as well as of qualitative aspects so-called evaluation coefficients (EC) for the individual parameters of the substances are introduced (see Table 2). The increase of the evaluation coefficients is not linear, because greater hazards are rated inversely proportional higher. The hazard potential is assessed on the basis of the amount of substances stored and employed in the production, respectively. The evaluation coefficient is zero for those parameters which are not available or non-existent.

The hazard potential (HP) of a substance can be quantitatively determined through multiplying the amount utilised m_i by the evaluation coefficient. The total sum of the hazard potentials of the individual substances yields the overall risk potential of a particular group of substances, e.g. the cleansing and disinfectant agents employed in a company (UBA, 1995). The formula for an assessment of the *hazard potential* reads:

$$HP = \sum_{i=1}^{n} \left\{ m_i \cdot \left[EC(WEG) + EC(P) + EC(FG) + EC(RS) + EC(E) \right] \right\} \quad \text{[kg]}$$

Table 2 Evaluation coefficients for substance parameters

Water Endangerment Grade (WEG)		*EC(WEG)*
0	In general not water endangering	0
1	Less water endangering	1
2	Water endangering	3
3	Highly water endangering	6
Poison (P)		EC(P)
Xi	Irritating	1
C	Caustic	2
Xn	Less poisonous	3
T	Poisonous	6
T+	Very poisonous	7
Flammability Grade (FG)		EC(FG)
EZ	Inflammable	2
F	Less inflammable	3
F+	Highly inflammable	4
O	Fire enforcing	5
E	Explosive	7
Number of R-Sets (RS)		EC(RS)
1		2
2-3		3
4-5		5
Environmental Compatibility (E)		EC(E)
N	Environmentally harmful	3

For our case, the Hasseröder Brewery Ltd., the hazard potential of the groups of substances mentioned above are listed in Table 3:

Table 3 Hazard potentials of the substances employed

Group of Substances	*Hazard Potential*
Cleansing/Disinfectant Agents (CIP)	7625374,87 kg
Auxiliary Filtration Agents	840646,76 kg
Conveyor Lubricants	180210,24 kg
other AaPS	135392,37 kg

2.3.4 Valuation

In compliance with the UBA method the specific contribution and the ecological significance of the categories have to be assessed. Estimation of the specific contribution of the individual sub-categories requires an appreciation of the overall potentials for the frame of reference. Due to the fact that in the course of this case study appropriate data were not available an alternative valuation is suggested which does not comply with the UBA method, however it allows for an approximation.

In order to obtain an adequate valuation a greatest possible risk potential can be contrived. It is calculated through multiplication of the stored amount of a substance by the greatest valuation coefficient for each substance parameter. Afterwards these products are added. The formula for an assessment of the greatest hazard potential reads:

$$HP_{\max} = \sum_{i=1}^{n} \left\{ m_i \cdot \left[EC(WEG)_{\max} + EC(P)_{\max} + EC(FG)_{\max} + EC(RS)_{\max} + EC(E)_{\max} \right] \right\} \text{ [kg]}$$

In the next step the hazard potential is weighed using the greatest possible hazard potential. This operation yields a value between 0 and 1.

$$\text{WHP} = \frac{\text{Hazard Potential}}{\text{max. Hazard Potential}}$$

The contended comprehensive valuation can be deducted by ranking the risk potentials according to their significance (see Table 4).

Table 4 Ordinal scale for valuation

Risk Potential	*if WHP:*
low significance	< 0,2
low to medium significance	0,2 to 0,4
medium significance	0,4 to 0,6
high significance	0,6 to 0,8
very high significance	0,8 to 1

This evaluation technique allows for a first approximated estimation of the risk that arises from particular products within the anthropogenic system (see Table 5).

Table 5 Evaluation of auxiliary and processing substances

Group of Substances	*Hazard Potential*	*Valuation*	
Cleansing/Disinfection Agents (CIP)	7625374,87 kg	0,1960	low
Auxiliary Filtration Agents	840646,76 kg	0,1941	low
Conveyor Lubricants	180210,24 kg	0,2857	low to medium
other AaPS	135392,37 kg	0,0357	low

The assessment of the auxiliary and processing substances at the Hasseröder brewery yielded a low to medium hazard potential and risk for disturbances.

3 Summary and conclusion

This case study accomplished the two remaining phases of the eco-balance for the Hasseröder Brewery Ltd., i.e. the impact assessment/balance valuation and the interpretation of the eco-balance. The previous study yielded that allocation problems between project materials and the elements of the implemented indicator systems arise when carrying out the impact balance. Hence, not all of the recorded material flows could be investigated in terms of an impact assessment and a balance valuation [12]. Different methods for carrying out the impact assessment were analysed and compared to solve the problem [13,14]. Eventually, the method of the German Federal Agency for the Environment (UBA) was selected and expanded.

During the process of analysing and expanding the UBA method it was stated that a variety of materials covered by this method could be evaluated, but that no correlating data were obtained in the actual balance: another allocation problem. For this reason the material flow network for assessment of the actual balance in Umberto was extended with further important parameters; at the same time additional data were allocated in the brewery. The actual balance was calculated again because some of the data, e.g. concerning emissions into air, had changed and new data were recorded. The current balance was then used to generate the impact balance. In the course of the impact assessment differentiated potentials were identified which enable the brewery to recognise its environmental problems.

In particular, aggregations yielded fossil energy carriers associated with crude oil resource equivalents, climate sensitive substances associated with CO_2-equivalents, generation of photo-oxidants associated with ethene-equivalents, nutrification associated with phosphate-equivalents and acidification associated with SO_2-equivalents. For the category ozone depletion no climate sensitive gas could be aggregated so that an ozone depletion potential was not recorded. The raw materials were divided into fossil energy carriers, wood and water. However, since a survey of equivalents was not possible for all impact categories, aggregation of the categories impediments to human health and direct damages to organisms and the eco-system were abandoned.

During the phases of impact assessment and balance valuation the information provided by the actual balances was summarised anew. This in turn provided new findings and assessments. The different contributions of the material flows to the impact categories were determined through an analysis of equivalents and, if possible, aggregated.

For some impact categories commonly accepted formulas for calculation are available. The categories toxicity and eco-toxicity still lack such models. This made an interpretation of the individual substances inevitable. Further impact categories of ecological significance, e.g. the diversity of biological species and annoyances caused by odours had to be renounced in the present method of assessment.

The outcome of the eco-balance of the Hasseröder Brewery Ltd. in Wernigerode that has been evaluated shows no significant environmental problems. None of the analysed impact categories possessed a great or very great significance that would have implied immediate need for action. Nor does the brewery contribute to ozone depletion. A medium significance was established for the categories

- fossil energy carriers
- usage of water
- greenhouse effect
- generation of photo-oxidants and
- nutrification of soil and water.

The material flows in these categories can be influenced by the brewery in a satisfactory way. From an ecological point of view it could be advisable to intensify energy generation through biological gas, since the contribution to the category consumption of fossil energy carriers would be diminished. On the other hand this would possibly lead to an increase of the greenhouse effect.

The following categories are of minor significance:

- occupation of waste sites
- acidification of soil and water
- sulphur dioxide emissions in the categories eco-toxicity and toxicity.

These categories possess only low to medium overall significance.

Simulation of the material flow network will enable the brewery to assess in advance which ecological impacts potentially arise from changes in the production process. A necessary condition would be to further maintain the material flow network in the brewery.

In concluding the valuation of the eco-balance for the Hasseröder Brewery Ltd. in Wernigerode no distressing deficiencies were detected. The eco-balance did not imply the need to take immediate action on the part of the brewery.

With regard to sustainability water consumption and nutrification of soil and water should be reduced. It would be desirable to further expand the valuation method employed in the future in order to provide for an assessment of noise and odour emissions.

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