Integration of Life Cycle Assessments in the decision-making process for environmental protection measures and remedial action at active and abandoned mining sites

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Abstract. Life-Cycle Assessments (LCA) have increasingly been used to evaluate the environmental performance of industrial processes and products and have been employed as a basis in decision making processes in the public and industrial sector. In contrast, assessment methodologies for environmental protection measures and remediation measures with respect to their consumption of natural resources are generally poorly developed. In this paper a methodology for LCA of environmental protection measures and remedial actions is suggested, using the remediation/reclamation of mining sites as an example.

Introduction

During the United Nations UNECD conference in Rio de Janeiro, Brasil, in 1992, the protocol "Agenda 21" (UN 1992) was ratified by more than 170 countries. Since then, in the frame of "sustainable development" environmental Life-Cycle Assessments (LCA), which provide a framework for identifying and evaluating environmental burdens associated with the life cycles of materials and services in a "cradle-to-grave" approach, have been increasingly employed as a basis for decision making processes in the public and industrial sector. In contrast to industrial processes, assessment methodologies for environmental protection measures and reclamation/remediation measures with respect to their consumption of natural resources are generally poorly developed.

In the presentation a methodology for LCA of environmental protection measures and remedial actions is outlined. In this context, the term environmental protection measures encompasses

- end-of-pipe technologies (e.g. water-treatment, exhaust-gas purification, waste management and recycling),
- reclamation/remediation measures at contaminated sites, and
- radiation protection measures.

In general terms, environmental protection measures aim at issues such as (i) reduction/prevention of existing contamination of air, soil, ground and surface water bodies, etc. and/or (ii) prevention of contemporary and future emissions, via air, soil and water pathways, and thus to minimise present and future exposition of natural species and humans to hazardous substances or radiation.

In contrast to their environmental benefits, environmental protection measures themselves usually utilise and consume natural resources such as energy, raw materials, soil/land and are also accompanied by emission of gases (e.g. CO_2 and greenhouse gases, or ozone), waste water and/or noise and odorous substances, which in our opinion suggests the use of LCA for such measures, too.

General approach to LCA

As environmental awareness increases, the environmental performance of products and processes has become a key issue in the industrial and public sector. One tool for the assessment of the environmental compliance and the improvement of the environmental performance of products or industrial systems is the LCA. LCA as defined by ISO 14040 (ISO 1997) comprises a compilation of input and output flows of materials, energy, wastes etc. and associated potential environmental detriments of a product or a service throughout its life cycle.

In general, a four-part approach to LCA – in compliance with ISO 14040ff. (ISO 1997, 1998, 2000a,b) – is widely accepted today (cf. Fig. 1):

1. Goal and scope definition (i.e. description of the product, process, or activity; definition of boundaries and environmental effects that have to be considered)
2. Life Cycle Inventory (LCI), i.e. quantification of energy/material inputs and environmental releases (e.g. solid wastes, waste water discharge, air emissions) associated with each stage of the life cycle (cf. Fig. 2);
3. Life Cycle Impact Assessment (LCIA), i.e. assessment of the impacts of the material, energy and waste streams identified in the LCI on human health and the environment (cf. Fig. 3); and
4. Interpretation of the results of LCI and LCIA and evaluation of opportunities to reduce energy/material inputs and/or environmental impacts.

One of the key aspects of the LCA is the valuation step in which the results from LCI and LCIA are compiled and weights or relative values are assigned to the different impact categories to make them comparable and to allow a transparent ranking of the options considered. For this purpose, various qualitative and quantitative assessment methodologies have been developed (e.g. verbal argumentation, outranking, monetarization, Ecopoints, UBA/ifeu, CML, SETAC, Eco-indicator, CAU, e.g. IFEU 1995; Barnthouse et al. 1998; Bengtsson 2000; US EPA 2001; MVROM 2001; Ciroth et al. 2003).

Application of LCA to environmental protection measures in the mining industry

The extraction of metallic ores, lignite, coal or other natural resources and the associated milling processes may have environmental impacts on various scales, ranging from local to global. Potential effects to be considered in LCA of mining activities comprise e.g. the consumption of natural resources (including the extracted ore or energy resource), land use, emission of greenhouse gases, dispersion

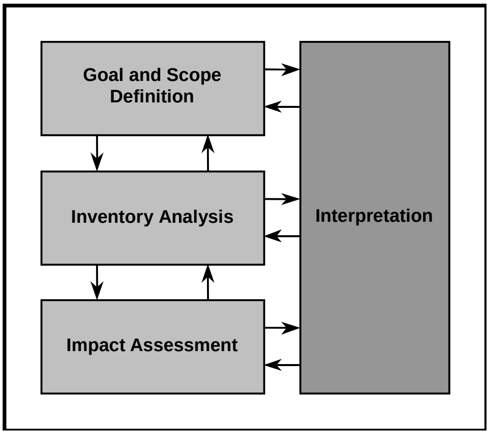

Fig. 1. Phases of an LCA.

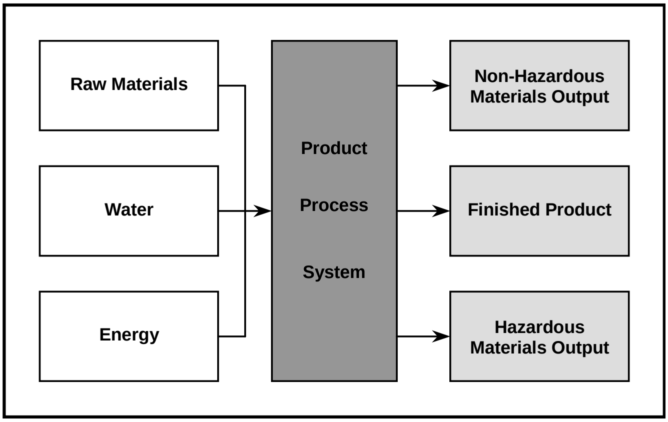

Fig. 2. Generic flow diagram of input and outputs for a process or system.

Resource Depletion	**Acidification**
Land Use	**Eutrophication**
Global Warming	**Salinisation**
Ozone Depletion	**Hazardous Wastes**
Photochemical Smog	**Odorous Substances**
Human Toxicity	**Noise**
Terrestrial Toxicity	**Detriments on Ecosystems**
Aquatic Toxicity	**Detriments on Landscapes**
Radioactivity	**Letality/Human Health**

Fig. 3. Commonly used life cycle impact categories.

of dust, disposal of tailings and waste rock, generation of acid mine drainage, waste water discharges, etc. Environmental protection measures at active mining at milling sites like end-of-pipe-technologies (water treatment plants, tailings management technologies), measures for reduction of energy consumption and air emissions, or recycling techniques (e.g. of lubricating oils) can be addressed as part of the whole production process, i.e. their environmental performance can be evaluated during environmental LCA of the whole process as in other industrial sectors.

However, remedial actions at contaminated and abandoned industrial sites in general are usually not addressed by LCA. Therefore the following part of the presentation focuses on the application of LCA to reclamation measures during the close-out of mining activities and the remediation of abandoned mining sites.

In general, the clean-up of contaminated sites requires appropriate and efficient methodologies for the decision-making about priorities and extent of remedial measures that aim at two usually conflicting goals to (i) protect people and the environment by reducing detrimental impacts to the extent feasible, and (ii) to minimize the expenditure of money and other resources. Extensive mining of polymetallic sulfide ores, uranium ores, or coal/lignite often requires considerable clean-up efforts to protect the environment and the public. This can be seen e.g. from various projects in the context of the UMTRA (Uranium Mill Tailings Remedial Action) and CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act; commonly known as 'Superfund') programmes in the United States (e.g. King 1995) or the estimated financial liabilities associated with mine tailings and waste rock in Canada (e.g. BCMEM 1998).

Abandoned mining and milling sites can represent complex environmental situations, where health risks and environmental detriments may result from various sources, such as the discharge of contaminated mine waters into ground and surface water bodies as well as mining-related hazards like slope failure of waste dumps, failure of tailings dams, collapse of underground workings, etc.. Furthermore, at uranium mining and milling sites, or at sites, where former mining activities were associated with naturally occurring radioactive materials (e.g. extraction of heavy minerals, zircon, REE, tin, etc.), radiological risks (e.g. from radon exhalation, dispersion of radioactive dust from mine wastes, contaminated surface and ground waters) may have to be taken into account.

The clean-up of contaminated mining and milling sites must therefore take into consideration a variety of different contaminants and risks to humans and the environment arising for various exposure pathways. In general, the following factors have to be included in the site assessment and the evaluation of remediation options:

- health damage for humans due to carcinogenic and/or toxic substances (e.g. arsenic, heavy metals) and in some cases radiological risks (external irradiation; incorporation of radioactive substances);
- environmental detriments like damage to ecosystems, such as lakes and rivers, due to the discharge of contaminated mine waters;
- damage to resources due to contamination of groundwater and surface water bodies;
- direct physical risks (e.g. the danger of dam failures) and risks ensuing from the clean-up activities themselves (e.g. working or traffic accidents).

The decision making on appropriate remediation measures at contaminated (mining) sites is generally based on the legal framework and the existing regulatory guidelines (e.g. with respect to surface water contamination, radiation doses for the public, etc.), the reasonably achievable reduction of environmental contamination and remaining risks, and the financial efforts associated with the remediation options/measures in the short- and long-term, taking into account the potential land use and the socio-economic environment. Usually costs and benefits of the remediation measures are focal points in the decision making process and the selection of concrete (technical) measures. In some cases (e.g. if radiation protection is an issue) the risks to workers may be included in the assessment. However, to the authors knowledge, the overall environmental performance of remediation alternatives is mostly not included in the decision-making process, although their consumption of natural resources and the associated emissions and wastes may be rather different. This aspect will be illustrated in the following examples.

One of the major environmental problem at mining sites is the generation of contaminated acid or neutral mine drainage, which may require long term efforts for water treatment. In many cases various active and passive water treatment technologies are available to achieve the required treatment goals. Usually the treatment alternative with the lowest costs is chosen, omitting an assessment of the overall environmental compliance with respect to materials/energy inputs and waste/emission outputs. Active treatment technologies show large differences e.g. with respect to their energy consumption (e.g. membrane vs. neutralisation/precipitation processes), the amount of treatment chemicals required, and/or the amount, toxicity and emission behaviour of the residues (e.g. High density sludge vs. conventional lime neutralisation). Passive treatment methods ("wetlands", SAPS) are characterised by low energy and material consumption but often utilise large areas and can be associated with gaseous (CO_2, CH_4) or odorous emissions.

The remediation of waste rock dumps and tailings ponds may require the reshaping/recontouring of dumps, the relocation of waste material, and/or the construction of engineered covers e.g. to avoid/reduce acid mine drainage generation and the amount of seepage water, to minimise emission of dusts/radon, or to allow further land use. Potential environmental burdens associated with such measures are fuel consumption of and emission from trucks/loaders used for transport of mine wastes or cover material, consumption of land used as disposal areas for mine waste, or the excavation of soils and clay for cover construction at other locations.

The consumption of natural resources by remediation measures including those during the close-out or at abandoned (large scale) mining sites and their associated emissions as illustrated above should in our opinion be integrated in the decision making process. In this context the use and inclusion of LCA for remediation measures is suggested to derive optimized concepts for the reclamation of abandoned sites. Based on experience with risk based cost-benefit analyses for the decision-making on remediation measures at large scale uranium mining and milling sites (cf. Goldammer et al. 1999, Deissmann and Kistinger 2004), a monetarization approach in the valuation step is suggested to make the different risks and impacts resulting from the site before/after remediation as well as from the remedial action comparable. Furthermore this approach allows the comparison to the financial expenditures for the measures in the short- (e.g. application of engineered covers on waste rock or tailings; backfilling of mine waste in open pits) and long-term (e.g. costs for monitoring, maintenance, seepage collection and – if required – water treatment). This monetarization approach utilises different methodologies for the various impact categories. E.g. the risks for human life and health during, before and after remediation are expressed as a ‘mean effective loss of life expectancy’ (MEL), which is converted into an equivalent monetary value according to ICRP (ICRP 1991). The monetary equivalent of emissions can be derived by applying the ExternE methodology (EC 1995). Damage to ecosystems, in particular surface water systems, and resources can be expressed in monetary terms, based on the societal willingness and ability to pay for the prevention or mitigation of ecological damage. Uncertainties in the basic data and assumptions made can be taken into account, e.g. by using probabilistic simulation techniques (Monte Carlo simulations).

Concluding Remarks

Reclamation measures at contaminated (mining) sites aim at issues such as (i) reduction of existing environmental contamination and/or (ii) prevention of contemporary and future emissions, to minimise present and future exposition of natural species and humans to hazardous substances or radiation. In contrast to their environmental benefits, these measures themselves usually utilise and consume natural resources (e.g. energy, raw materials, water, soil/land) and are accompanied by emissions (e.g. greenhouse gases, waste water, dust, noise, etc.). In our opinion this aspects suggest the use of LCA for such measures, too, to evaluate not only regulatory compliance (e.g. with respect to ground and surface water quality, air quality, radiation protection guidelines etc.) and costs but also the environmental performance of the remediation measures and their sustainability. In this context, the use of a monetarization approach of risks and impacts in the valuation step of the LCIA is suggested, to make the different impact indicators comparable. The proposed methodology should serve as a basis for rational and transparent decisions about clean-up measures in order to implement optimized remediation concepts, based on a holistic approach that considers aspects of costs, benefits, risks, and consumption of natural resources, including the effects resulting from the remedial action itself.

References

Barnthouse L, Fava J, Humphreys K, Hunt R, Laibson L, Noesen S, Norris G, Owens J, Todd J, Vigon B, Weitz K, Young J (1998) Life cycle impact assessment: the state-of-the-art. SETAC, 145 p

Bengtsson M (2000) Environmental valuation and Life Cycle Assessment. Chalmers University, Göteborg

BCMEM - British Columbia Ministry of Energy and Mines (1998) Policy for metal leaching and acid rock drainage at mine sites in British Columbia.

Ciroth A., Fleischer G, Gerner K, Kunst H (2003) A new approach for a modular valuation of LCAs. Int. J. LCA 8: 273-282

Deissmann G, Kistinger S (2004) Application of risk-based cost-benefit analyses for decision-making in environmental restoration of uranium mining and milling sites. Proceedings International Workshop on Environmental Contamination from Uranium Production Facilities and Remedation Measures. ITN Portugal

EC - European Commission (1995) ExternE, Externalities of Energy. Vol. 2: Methodology.

Goldammer W, Nüsser A, Bütow E, Lühr, HP (1999) Integrated assessment of radiological and non-radiological risks at contaminated sites. Mathematische Geologie 3: 53-72

ICRP International Commission on Radiological Protection (1991): 1990 Recommendations of the International Commission on Radiological Protection. Annals of the ICRP, 21

IFEU - Institut für Energie und Umweltforschung (1995) Bilanzbewertung in produktbezogenen Ökobilanzen. Evaluation von Bewertungsmethoden, Perspektiven. UBA Texte 23/95

ISO International Organization of Standardization (1997) Environmental Management - Life Cycle Assessment - Principles and Framework (ISO 14040)

ISO International Organization of Standardization (1998) Environmental Management - Life Cycle Assessment - Goal and Scope Definition (ISO 14041)

ISO International Organization of Standardization (2000a) Environmental Management - Life Cycle Assessment - Life Cycle Impact Assessment (ISO 14042)

ISO International Organization of Standardization (2000b) Environmental Management - Life Cycle Assessment - Life Cycle Interpretation (ISO 14043)

King VV (1995) Environmental considerations of active and abandoned mine lands – Lessons learned from Summitville, Colorado. U.S. Geological Survey Bulletin 2220: 1-38

MVROM - Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (2001) The Eco-indicator 99. A damage orientated method for Life Cycle Impact Assessment - Methodology Report

UN- United Nations (1992) United Nations Conference on Environment and Development (Rio de Janeiro, 3-14 June 1992) - Documents - Agenda 21

U.S. Environmental Protection Agency (2001) LCAccess - LCA 101: 1-41